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Perspective

Wireless Semiconductors and Applications - Worldwide

Market Analysis

Mobile Momentum Propels Semiconductor Sales in the Wireless World

Abstract: *This document presents the Dataquest forecast for the wireless communications semiconductor market. A detailed semiconductor forecast for mobile communications, including the digital cellular, analog cellular, pager, and mobile infrastructure subsegments, is included.*
By Dale Ford

The Wireless Communications Semiconductor Market

The wireless communications applications semiconductor market more than doubled in size between 1993 and 1998, driven by torrid growth in the mobile communications sector. Strong pricing pressure is damping the forecast growth for wireless communications semiconductors to a 9 percent compound annual growth rate (CAGR) between 1997 and 2002. As shown in Figures 1 and 2 and Tables 1 and 2, worldwide wireless communications factory revenue is projected to grow to nearly $197 billion by 2002, which will push the related semiconductor market to more than $38.6 billion in the same time frame. The dominant force driving this growth is mobile communications equipment. In 1993, the mobile communications semiconductor market of $2.7 billion accounted for 21.5 percent of the total wireless communications market. By 2002, the mobile communications semiconductor market is forecast to reach nearly $16.7 billion, a growth of 623 percent from 1993, and account for more than 43 percent of the total wireless communications semiconductor market. Strong growth is forecast for local wireless communications and other wireless communications semiconductors. However, these market segments will remain one-fourth to one-fifth the size of the mobile communications semiconductor market in 2002.

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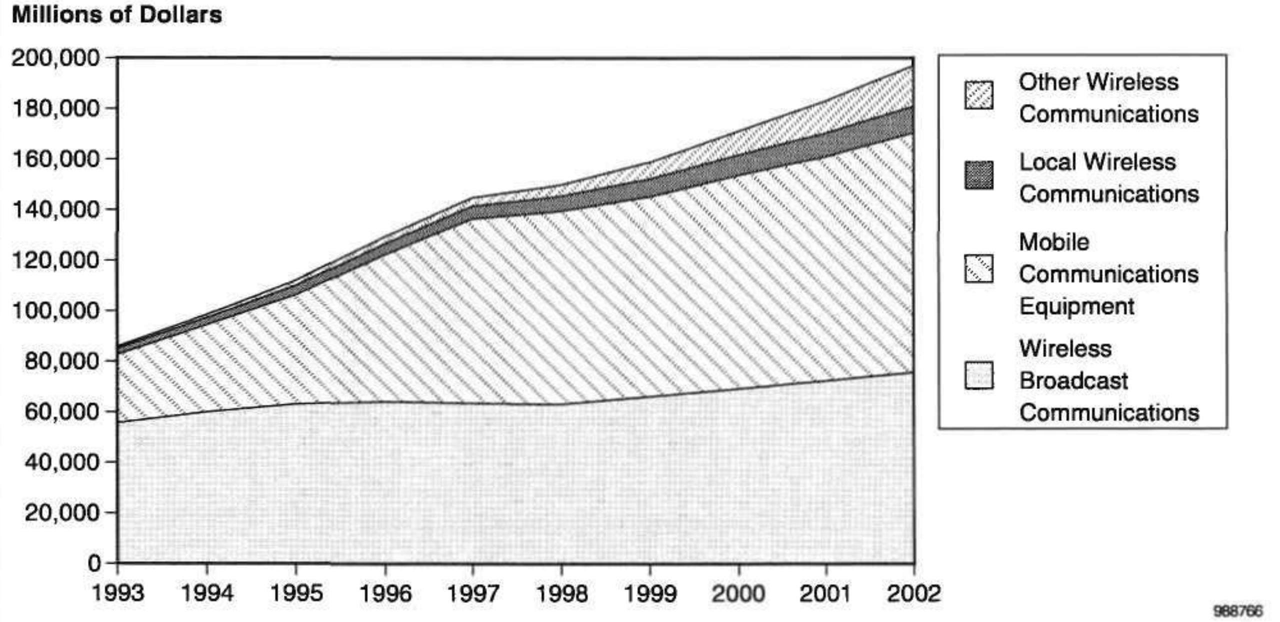
Within the mobile communications semiconductor market, digital cellular/personal communication services (PCS) products and the related mobile communications infrastructure will represent 89 percent of the semiconductor market in 2002. The impact of third-generation cellular products in this forecast period will be minimal and will represent a potential accelerator for market growth beyond 2002. Although small in comparison, the nascent two-way pager market represents the highest growth opportunity, with a forecast 103.7 percent CAGR through 2002. The analog cellular handset semiconductor market, the largest segment in mobile communications in 1993, is forecast to decline gradually to $82 million in 2002, less than 0.5 percent of the total mobile communications semiconductor segment.

Growth in the local wireless communications semiconductor market is forecast to remain in double digits, with a 10 percent CAGR through 2002. Leading this segment are digital cordless systems such as Digital European Cordless Telephone (DECT) and 900-MHz digital spread spectrum (DSS) handsets. In the space of 10 years, this semiconductor market segment will grow to more than $2 billion. Emerging markets in wireless local loop (WLL) and wireless broadband access systems such as local multipoint distribution service (LMDS) will provide an added boost to the local wireless communications segment. It is important to note that this semiconductor forecast does not include the potential impact of home wireless networks and Bluetooth-enabled products beyond cellular and paging products. Developments in these market areas are still in the very early stages, but they hold the potential to become a major force in the wireless communications semiconductor industry.

By comparison, the wireless broadcast communications semiconductor industry will experience very modest levels of growth. Also, a much lower percentage of the semiconductor content in these systems is related to the wireless communications function. The semiconductor forecast published in this document accounts for all the semiconductors in these systems, including chips involved in video display, graphics processing, and so on. The direct opportunity for companies developing wireless semiconductor products is much more limited in this market segment.

Opportunities for semiconductor companies in other wireless communications markets such as Global Positioning System (GPS), contactless chip cards, radio frequency identification (RFID) tags, and so on merit attention based on the 39.6 percent growth forecast for this area. GPS systems, not including GPS functionality associated with cellular/PCS handsets, are forecast to drive a semiconductor market of nearly $2.7 billion in 2002. This includes GPS applications in automotive navigation, tracking systems, survey and mapping products, and marine, aviation, and military uses. Products specifically not included in this forecast are Infrared Data Association (IrDA)-based communications, PC-TV products, radar detectors, broadcast radio and TV infrastructure, and proprietary or classified military communications equipment.

Figure 1
Worldwide Wireless Communications Factory Revenue*



*Does not include revenue from Bluetooth-enabled products beyond cellular/PCS handsets and pagers, home wireless networks, IrDA-based communications, PC-TV products, radar detectors, broadcast radio and television infrastructure, and military/civil aerospace equipment
Source: Dataquest (December 1998)

Table 1
Worldwide Wireless Communications Factory Revenue Forecast* (Millions of Dollars)

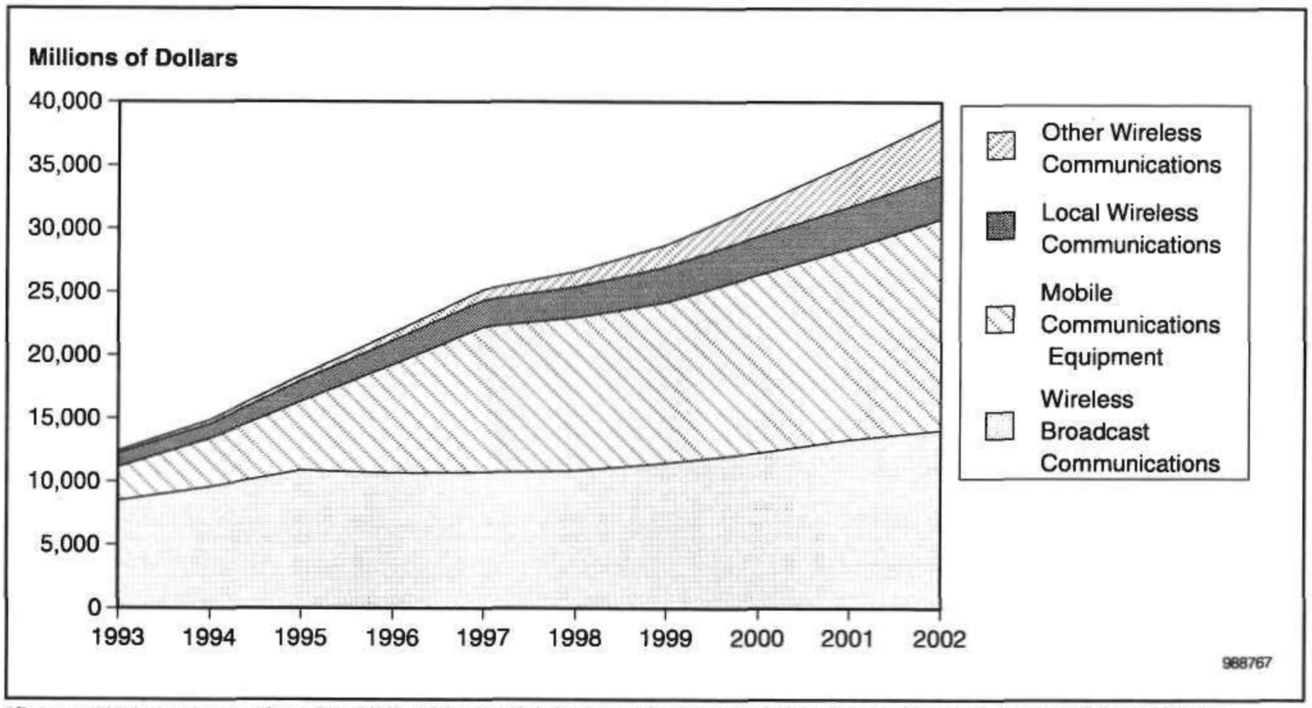
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Mobile Communications Equipment	**26,844**	**34,469**	**43,180**	**58,092**	**72,800**	**76,416**	**78,920**	**84,385**	**88,450**	**94,560**	**5.4**
Analog Cellular Handsets	7,587	10,721	11,203	9,232	5,803	3,587	2,336	1,602	1,067	507	-38.6
Digital Cellular/PCS Handsets	1,483	3,506	7,826	17,330	29,005	31,551	33,638	37,002	39,293	43,309	8.3
One-Way Pagers	1,769	2,465	2,965	3,299	3,133	3,151	3,153	2,944	2,647	2,375	-5.4
Two-Way Pagers	-	0	4	3	30	70	150	308	494	798	93.4
Mobile Communications Infrastructure	9,730	11,083	14,071	20,456	26,746	29,888	31,801	34,966	37,569	40,455	8.6
Other Mobile Communications	6,274	6,694	7,110	7,772	8,084	8,168	7,843	7,564	7,380	7,117	-2.5
Local Wireless Communications	**2,422**	**2,732**	**3,662**	**4,315**	**5,132**	**5,921**	**7,050**	**8,119**	**9,385**	**10,502**	**15.4**
Analog Cordless Handsets/Base Stations	2,285	2,390	2,472	2,312	2,302	2,093	1,857	1,609	1,295	1,065	-14.3
Digital Cordless Handsets/Base Stations	37	110	767	1,399	1,736	2,367	2,868	3,290	3,580	3,717	16.4
Wireless LAN	-	8	15	36	40	45	49	57	59	71	12.1
Wireless Local Loop	100	225	408	568	1,054	1,316	1,776	2,163	2,700	3,200	24.9
Wireless Broadband Access (e.g., LMDS)	-	-	-	-	-	100	500	1,000	1,750	2,450	NM
Wireless Broadcast Communications	**55,743**	**60,009**	**63,115**	**64,176**	**63,596**	**63,107**	**66,262**	**69,239**	**72,461**	**75,729**	**3.6**
Satellite/Terrestrial/MMDS Set-Top Box	0	411	1,362	2,362	2,219	2,338	2,872	3,623	3,967	4,310	14.2
Color TV	24,343	25,689	26,503	27,466	26,762	27,103	28,396	29,518	29,921	30,329	2.5
VCR	11,010	11,331	10,742	10,282	9,974	8,943	8,606	8,016	7,618	7,290	0
DTV	-	-	-	-	-	45	93	311	2,035	3,885	NM
Broadcast Radio/Tuners/Etc.	13,588	14,934	16,486	15,897	16,456	16,215	17,301	18,438	19,486	20,403	4.4
Auto Stereo	4,851	4,945	4,842	4,323	4,171	4,127	4,168	4,283	4,333	4,388	1.0
Other Wireless Broadcast	1,950	2,700	3,180	3,845	4,014	4,337	4,827	5,050	5,100	5,125	5.0

Table 1 (Continued)
Worldwide Wireless Communications Factory Revenue Forecast* (Millions of Dollars)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Other Wireless Communications	**759**	**1,296**	**2,006**	**2,783**	**3,270**	**4,411**	**6,628**	**9,307**	**12,698**	**16,072**	**37.5**
Global Positioning Systems (GPS)	534	1,040	1,710	2,429	2,753	3,710	5,577	7,719	10,715	13,600	37.6
Contactless Chip Card	0	0	4	8	56	98	288	628	790	1,006	77.9
Wireless Not Elsewhere Counted	225	256	291	346	460	604	762	960	1,193	1,465	26.1
Total Wireless Communications	**85,768**	**98,507**	**111,962**	**129,366**	**144,799**	**149,854**	**158,861**	**171,051**	**182,994**	**196,863**	**6.3**

*Does not include revenue from Bluetooth-enabled products beyond cellular/PCS handsets and pagers, home wireless networks, IrDA-based communications, PC-TV products, radar detectors, broadcast radio and television infrastructure, and military/civil aerospace equipment
NM = Not meaningful
Source: Dataquest (December 1998)

Figure 2
Worldwide Wireless Communications Semiconductor Application Market Forecast*, 1993 to 2002 (Millions of Dollars)



*Does not include revenue from Bluetooth-enabled products beyond cellular/PCS handsets and pagers, home wireless networks, IrDA-based communications, PC-TV products, radar detectors, broadcast radio and television infrastructure, and military/civil aerospace equipment
Source: Dataquest (December 1998)

Table 2
Worldwide Wireless Communications Semiconductor Application Market Forecast*, 1993 to 2002 (Millions of Dollars)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Mobile Communications Equipment	**2,677**	**3,812**	**5,433**	**8,548**	**11,458**	**12,111**	**12,715**	**14,073**	**15,116**	**16,682**	7.8
Analog Cellular Handsets	717	1,072	1,268	1,170	797	506	342	242	162	82	-36.5
Digital Cellular/PCS Handsets	372	872	1,943	4,480	7,235	7,877	8,444	9,541	10,378	11,679	10.1
One-Way Pagers	289	403	496	574	545	548	571	590	582	575	1.1
Two-Way Pagers	-	0	1	1	8	21	48	100	162	267	103.7
Mobile Communications Infrastructure	632	743	943	1,452	1,952	2,212	2,385	2,692	2,930	3,196	10.4
Other Mobile Communications	665	723	782	870	922	947	925	908	900	882	-0.9
Local Wireless Communications	**1,064**	**1,179**	**1,645**	**1,901**	**2,147**	**2,461**	**2,797**	**3,050**	**3,275**	**3,461**	10.0
Analog Cordless Handsets/Base Stations	1,037	1,098	1,238	1,150	1,182	1,132	1,086	970	815	715	-9.6
Digital Cordless Handsets/Base Stations	17	55	360	678	840	1,166	1,459	1,725	1,949	2,068	19.7
Wireless LAN	-	3	6	16	19	22	25	29	32	38	14.9
Wireless Local Loop	10	23	41	57	105	132	178	216	270	320	24.9
Wireless Broadband Access (e.g., LMDS)	-	-	-	-	-	10	50	110	210	319	NM
Wireless Broadcast Communications	**8,467**	**9,562**	**10,875**	**10,687**	**10,727**	**10,843**	**11,477**	**12,296**	**13,332**	**14,098**	5.6
Satellite/Terrestrial/MMDS Set-Top Box	0	229	567	981	1,004	1,080	1,195	1,456	1,573	1,682	10.9
Color TV	3,346	3,379	3,424	3,607	3,621	3,923	4,242	4,527	4,728	4,907	6.3
VCR	2,233	2,459	2,456	2,460	2,430	2,245	2,142	1,966	1,862	1,766	-6.2
DTV	-	-	-	-	-	4	10	47	496	925	NM
Broadcast Radio/Tuners/Etc.	2,048	2,581	3,490	2,610	2,596	2,437	2,624	2,940	3,249	3,349	5.2
Auto Stereo	665	676	668	702	723	759	810	864	903	929	5.1
Other Wireless Broadcast	176	238	270	327	353	395	454	495	520	538	8.8

Table 2 (Continued)
Worldwide Wireless Communications Semiconductor Application Market Forecast*, 1993 to 2002 (Millions of Dollars)

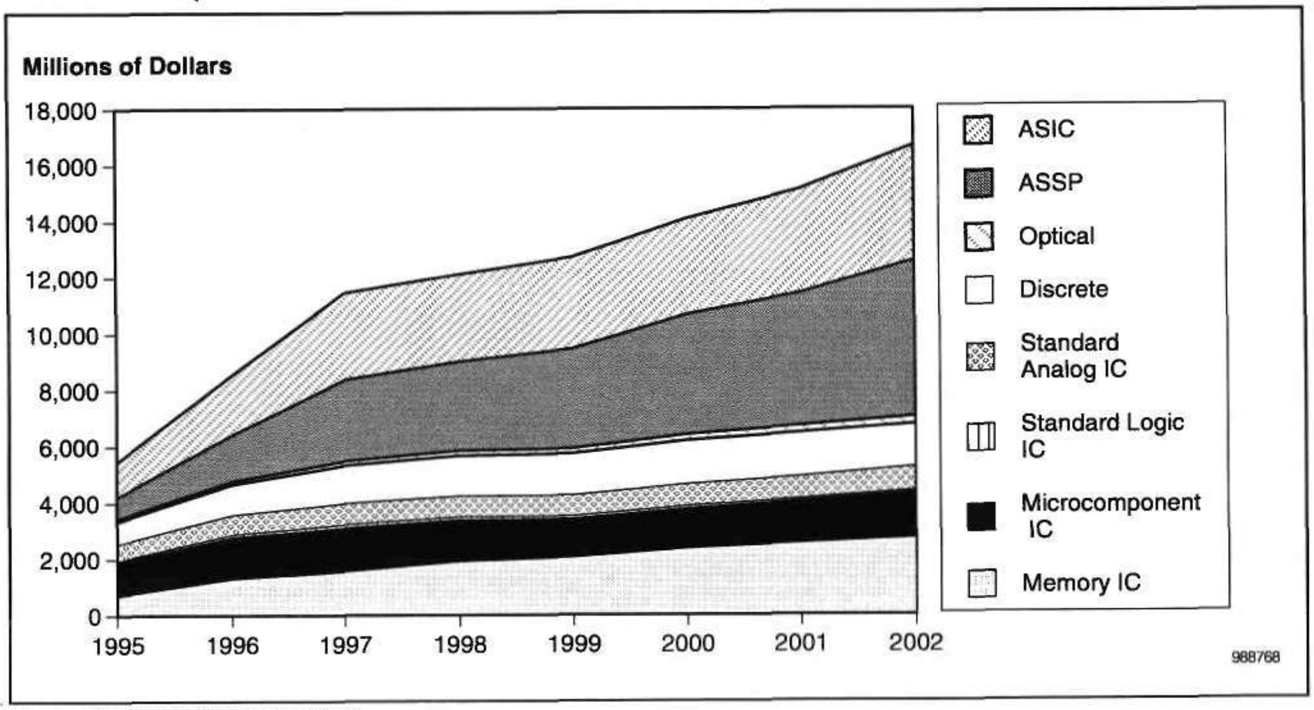
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Other Wireless Communications	**207**	**299**	**427**	**607**	**835**	**1,179**	**1,724**	**2,516**	**3,441**	**4,422**	**39.6**
Global Positioning Systems (GPS)	63	132	230	361	471	658	970	1,412	2,034	2,686	41.7
Contactless Chip Card	0	0	2	3	23	51	137	300	378	437	80.4
Wireless Not Elsewhere Counted	144	168	196	242	342	470	617	804	1,029	1,299	30.6
Total Wireless Communications	**12,415**	**14,852**	**18,380**	**21,743**	**25,166**	**26,595**	**28,714**	**31,935**	**35,164**	**38,662**	**9.0**

*Does not include revenue from Bluetooth-enabled products beyond cellular/PCS handsets and pagers, home wireless networks, IrDA-based communications, PC-TV products, radar detectors, broadcast radio and television infrastructure, and military/civil aerospace equipment
NM = Not meaningful
Source: Dataquest (December 1998)

Mobile Communications Boosts ASIC, ASSP, and Memory Markets

Within the mobile communications semiconductor market, suppliers of application-specific IC (ASIC) and application-specific standard product (ASSP) chips will find a nearly $10 billion opportunity in 2002. Also, nonvolatile memory, dominated by flash technology products, consumed in mobile communications electronics will grow to nearly $1.8 billion in 2002. These market opportunities are shown in Figure 3 and Table 3. Detailed semiconductor forecasts for the major mobile communications market segments are shown in Tables 4 through 7.

Figure 3
Worldwide Mobile Communications Semiconductor Application Market Forecast, 1995 to 2002 (Millions of Dollars)



Source: Dataquest (December 1998)

Table 3
Worldwide Mobile Communications Semiconductor Application Market Forecast, 1995 to 2002 (Millions of Dollars)

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Semiconductor Market	**5,438**	**8,542**	**11,458**	**12,112**	**12,716**	**14,073**	**15,113**	**16,682**	**7.8**
General-Purpose Standard Products	3,424	4,774	5,483	5,851	5,922	6,411	6,713	7,053	5.2
Memory IC	698	1,301	1,554	1,917	2,051	2,352	2,539	2,731	11.9
DRAM	53	76	98	112	122	137	123	134	6.6
SRAM	224	327	515	647	736	806	787	753	7.9
Nonvolatile Memory	403	875	913	1,123	1,150	1,361	1,576	1,787	14.4
Other Memory IC	17	23	29	35	42	48	54	57	14.7
Microcomponent IC	1,190	1,492	1,566	1,478	1,374	1,428	1,510	1,616	0.6
Microprocessor	102	134	166	220	266	295	330	356	16.5
Microcontroller	692	793	745	564	348	288	240	245	-19.9
Digital Signal Processor	396	565	655	694	760	845	940	1,015	9.1
Standard Logic IC	56	84	110	97	93	93	68	73	-7.8
Standard Analog IC	593	697	759	745	743	775	795	839	2.0
Discrete	798	1,084	1,337	1,434	1,481	1,551	1,556	1,516	2.5
Optical Semiconductor	89	117	157	181	180	213	245	277	12.0
ASSP	782	1,637	2,894	3,166	3,541	4,252	4,713	5,535	13.9
ASIC	1,232	2,131	3,082	3,095	3,254	3,409	3,688	4,093	5.8

Source: Dataquest (December 1998)

Table 4
Worldwide Analog Cellular Handset Semiconductor Market Forecast, 1995 to 2002 (Millions of Dollars)

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Unit Shipments (K)	**29,613**	**29,835**	**25,241**	**18,362**	**14,148**	**11,395**	**8,550**	**4,520**	**-29.1**
Total Semiconductor Market	**1,268**	**1,170**	**797**	**506**	**342**	**242**	**162**	**82**	**-36.5**
General-Purpose Standard Products	558	480	311	186	111	64	36	18	-43.3
Memory IC	89	59	28	13	7	2	0	0	-61.2
DRAM	-	-	-	-	-	-	-	-	NM
SRAM	-	-	-	-	-	-	-	-	NM
Nonvolatile Memory	89	59	28	12	6	2	-	-	-100.0
Other Memory IC	-	-	-	0	0	0	0	0	NM
Microcomponent IC	190	176	120	71	34	12	2	1	-63.1
Microprocessor	-	-	-	-	-	-	-	-	NM
Microcontroller	190	176	120	71	34	12	2	1	-63.1
Digital Signal Processor	-	-	-	-	-	-	-	-	NM
Standard Logic IC	6	6	2	1	-	-	-	-	-100.0
Standard Analog IC	190	176	120	76	51	36	24	12	-36.5
Discrete	63	47	28	15	10	7	4	2	-40.2
Optical Semiconductor	19	18	14	10	9	7	5	3	-28.8
ASSP	252	257	201	153	128	117	98	54	-23.1
ASIC	458	433	285	167	103	61	29	10	-49.0

NM = Not meaningful
Source: Dataquest (December 1998)

Table 5
Worldwide Digital Cellular/PCS Handset Semiconductor Market Forecast, 1995 to 2002 (Millions of Dollars)

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Unit Shipments (K)	**17,791**	**48,789**	**98,600**	**135,350**	**171,510**	**218,205**	**263,875**	**312,950**	**26.0**
Total Semiconductor Market	**1,943**	**4,480**	**7,235**	**7,877**	**8,444**	**9,541**	**10,378**	**11,679**	**10.1**
General-Purpose Standard Products	1,096	2,020	2,569	2,899	2,964	3,339	3,580	3,761	7.9
Memory IC	369	918	1,158	1,505	1,647	1,918	2,138	2,301	14.7
DRAM	-	-	1	5	8	12	17	21	78.0
SRAM	127	194	381	504	585	641	639	591	9.2
Nonvolatile Memory	242	725	776	993	1,046	1,254	1,467	1,673	16.6
Other Memory IC	-	-	-	3	8	12	15	16	NM
Microcomponent IC	292	403	362	236	68	48	62	70	-28.0
Microprocessor	-	-	4	21	34	43	62	70	80.9
Microcontroller	219	302	322	213	34	5	1	-	-100.0
Digital Signal Processor	73	101	36	2	-	-	-	-	-100.0
Standard Logic IC	16	31	51	55	51	48	21	23	-14.3
Standard Analog IC	155	237	362	394	422	477	519	584	10.1
Discrete	253	403	579	630	676	716	675	584	0.2
Optical Semiconductor	12	27	58	79	101	134	166	199	28.0
ASSP	303	1,066	2,243	2,458	2,778	3,339	3,684	4,415	14.5
ASIC	544	1,393	2,424	2,521	2,702	2,862	3,113	3,504	7.6

NM = Not meaningful
Source: Dataquest (December 1998)

Table 6
Worldwide Pager Semiconductor Market Forecast, 1995 to 2002 (Millions of Dollars)

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Unit Shipments (K)	39,479	44,201	43,746	45,083	48,053	50,824	52,875	56,707	5.3
Total Semiconductor Market	501	569	552	570	620	689	743	842	8.8
General-Purpose Standard Products	496	546	474	444	434	407	386	387	-4.0
Memory IC	50	68	72	74	81	90	97	109	8.8
DRAM	-	-	-	-	-	-	-	-	NM
SRAM	38	55	58	61	67	75	82	94	10.1
Nonvolatile Memory	13	14	14	13	14	14	14	15	2.4
Other Memory IC	-	-	-	-	-	-	-	-	NM
Microcomponent IC	216	228	199	188	186	172	163	168	-3.2
Microprocessor	-	-	-	-	-	-	-	-	NM
Microcontroller	216	228	199	188	186	172	163	168	-3.2
Digital Signal Processor	-	-	-	-	-	-	-	-	NM
Standard Logic IC	-	-	-	-	-	-	-	-	NM
Standard Analog IC	140	154	127	114	105	90	74	59	-14.2
Discrete	90	97	77	68	62	55	52	51	-8.1
Optical Semiconductor	-	-	-	-	-	-	-	-	NM
ASSP	5	23	77	125	186	283	356	455	42.6
ASIC	-	-	-	-	-	-	-	-	NM

NM = Not meaningful
Source: Dataquest (December 1998)

Table 7
Worldwide Mobile Communications Infrastructure Semiconductor Market Forecast, 1995 to 2002 (Millions of Dollars)

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Semiconductor Market	**943**	**1,452**	**1,952**	**2,212**	**2,385**	**2,692**	**2,930**	**3,196**	10.4
General-Purpose Standard Products	726	1,118	1,484	1,659	1,765	1,965	2,081	2,269	8.9
Memory IC	104	160	195	221	215	242	205	224	2.8
DRAM	38	58	78	88	95	108	88	96	4.2
SRAM	28	44	39	44	48	54	29	32	-3.9
Nonvolatile Memory	28	44	59	66	48	54	59	64	1.8
Other Memory IC	9	15	20	22	24	27	29	32	10.4
Microcomponent IC	321	494	683	774	882	996	1,084	1,183	11.6
Microprocessor	47	73	98	133	167	188	205	224	18.0
Microcontroller	28	44	59	44	48	54	29	32	-11.4
Digital Signal Processor	245	378	527	597	668	754	850	927	11.9
Standard Logic IC	19	29	39	22	24	27	29	32	-3.9
Standard Analog IC	28	44	59	66	72	81	88	96	10.4
Discrete	236	363	469	531	549	592	645	703	8.5
Optical Semiconductor	19	29	39	44	24	27	29	32	-3.9
ASSP	104	160	234	288	310	377	440	479	15.4
ASIC	113	174	234	265	310	350	410	447	13.8

Source: Dataquest (December 1998)

Dataquest Perspective

The wireless communications semiconductor market has been one of the few bright spots in an otherwise challenging semiconductor market during recent years. The exciting growth in this segment has continued even in the face of severe price pressure. The forecast for continued strong growth in wireless communications continues to attract aggressive competitors both large and small. The relatively large number of semiconductor companies competing in this segment will find that the continuing price, performance, and integration trends will result in a reduced number of competitors sharing the prize. Only the fittest and most focused will survive.

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Perspective

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Market Analysis

LMDS and MMDS Compete for the Last Mile, or Do They?

Abstract: *Wireless broadband access is emerging as a promising means for allowing small and medium-size companies without access to optical connections to have access to bandwidth. Local multipoint distribution service is the front runner for providing these services. Dataquest estimates that the market for wireless broadband access equipment will grow to $3.4 billion and the related semiconductor demand will grow to $476 million by 2003.*
By Stan Bruederle

Creating Competition for the Last Mile

One or two service providers with little competition dominate telecommunications and television services in most countries. The local phone company provides phone service, and the local cable company provides television programming. Efforts to create competition for these services have largely failed because of the high cost of duplicating the infrastructure required to deliver these services to businesses and homes in local service areas. The U.S. Federal Communications Commission (FCC) and similar organizations in other countries of the world have attempted to develop competing services by a variety of means, without much success.

Recently, the FCC has created other competitive communications channels that have the potential to provide a variety of services to consumer and business customers in direct competition with the local telephone companies and cable operators. Its sister Canadian agency, Industry Canada, has done the same, hoping to create an environment in which prices and services will be enhanced because of the competitive forces at work between existing providers and new wireless providers.

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(For Cross-Technology, file in the Semiconductor Application Markets binder)

The major advantage of broadband wireless services is the ability to install infrastructure at a reasonable cost. Estimates of the cost to install a broadband connection to a building are estimated to be about $2,500 for local multipoint distribution service (LMDS), substantially less than other alternatives. A multipoint multichannel distribution service (MMDS) installation is estimated to cost less than $1,000, given the broader coverage (25 to 35 miles) of an MMDS base station. Suppliers of both technologies are proposing to offer broadband access for well under $1,000 per month. This makes it possible for a new competitor to establish broadband connections to small and medium-size businesses at a low cost and to begin providing services relatively quickly.

The FCC auctioned licenses for MMDS frequencies in the 2.5-GHz band in 1996. Variations of MMDS-type services have been available since the 1970s. The Wireless Communications Association International estimates that 5 million people in 90 countries and more than 1 million people in 250 systems in the United States use wireless cable services today. Initially, MMDS was designed for delivery of television broadcasts to areas not supported by cable or broadcast television networks. Recently, the focus of MMDS providers has begun to shift to digital services offering broadband access for small business and consumers. Unfortunately, companies in the United States that provide MMDS services do not have the resources to upgrade their networks to digital equipment. As a result, many service providers and their suppliers are in difficult financial circumstances. LMDS services have just begun to emerge in the last five years. For the purposes of this Perspective, LMDS is defined as point-to-multipoint communications services offered on the millimeter microwave frequency bands. The bands currently being used for these services are the 24-GHz, 28-to-31-GHz, and 38-GHz bands. New entrants into the LMDS market are well financed and have targeted the broadband wireless access market with the objective of providing fiber-quality data services to small and medium-size companies that do not have access to fiber connections. Dataquest estimates that 95 percent of small and medium-size businesses do not have access to fiber connections. Because of this trend toward digital services, the FCC has taken steps to create an environment for accelerating the availability of wireless broadband data communications.

What Are MMDS and LMDS Networks?

LMDS and MMDS networks are distribution systems designed to provide one- and two-way broadband service to consumers and businesses. Digital MMDS provides 33 6-MHz channels that can provide up to 27-Mbps data rates to users using quadrature phase-shift keying (QPSK) and quadrature amplitude modulation (QAM) modulation techniques on frequency-division multiple access (FDMA) and time-division multiple access (TDMA) access technologies. LMDS provides raw bandwidth in the millimeter microwave bands. QPSK and QAM modulation techniques are also used with FDMA, TDMA, and code-division multiple access (CDMA) access technologies. The March 1998 LMDS auctions in the United States and the spectrum allocations in other countries are the single greatest allocation of spectrum for providing broadband services.

LMDS and MMDS networks provide a one- or two-way connection to sources of voice, video, or data to customers located within two to three miles (for LMDS) or 25 to 35 miles (for MMDS) of a base station. Service providers are shifting toward providing broadband digital access rather than simply competing with the cable providers for delivery of television programming.

Since LMDS/MMDS networks serve customers in fixed locations, service providers can choose to locate their service where customers are concentrated. As a result, the most attractive customers are likely to be business customers that require high data rate connections. Also, LMDS and MMDS offer operators the opportunity to expand their networks incrementally, as customer demand requires.

LMDS and MMDS service providers and customer-premise connections are similar. Both are capable of two-way wireless communications. This became true for MMDS in September 1998 when the FCC authorized two-way wireless communications in the MMDS bands. Figure 1 shows a simplified base station and customer premise setup.

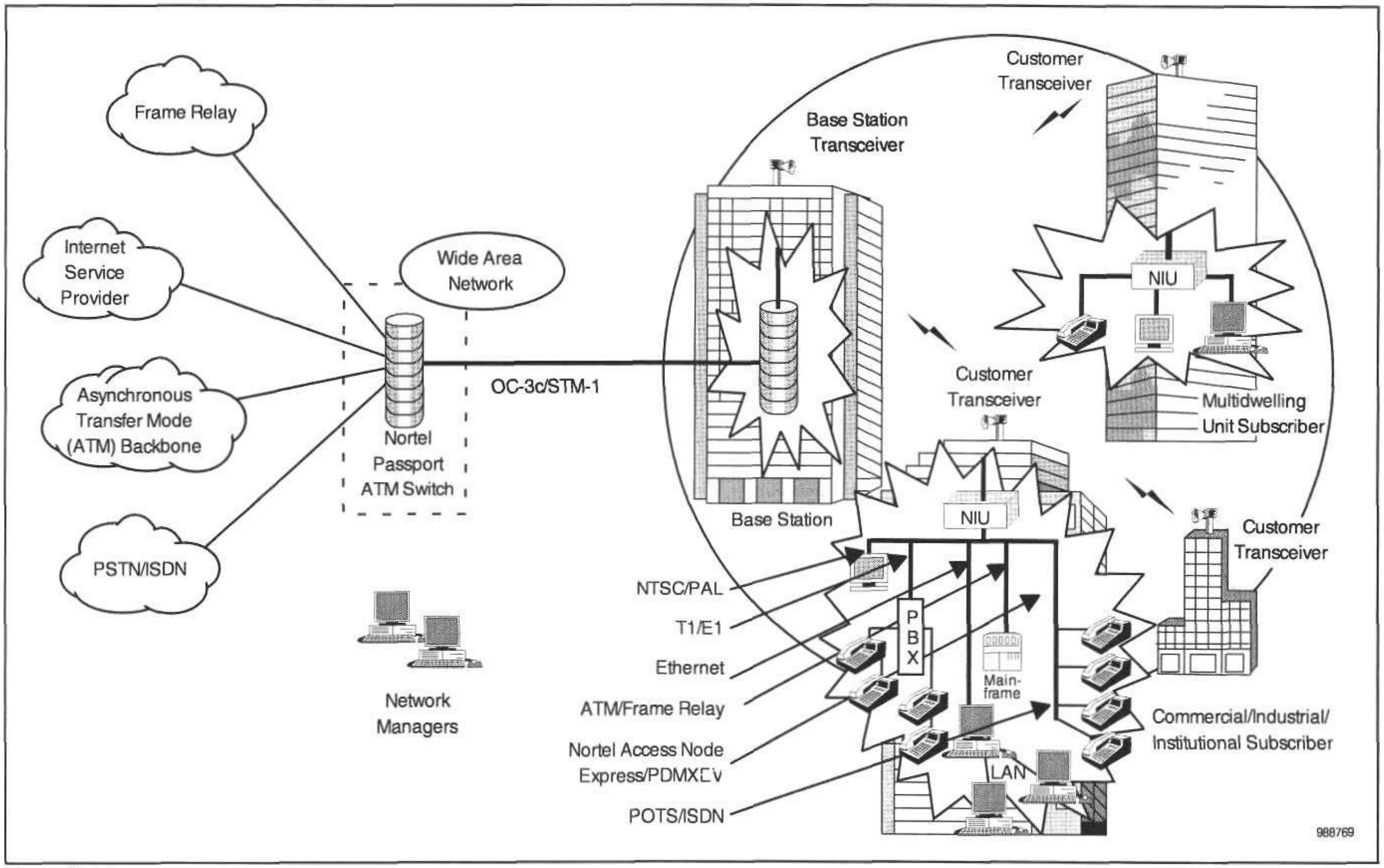
Industry Structure

MMDS and LMDS are both point-to-multipoint services but are very different in the following two ways:

- MMDS has evolved as a means of providing "wireless cable" services to people that do not have access to cable television services through the cable network. MMDS services are provided through the 2.5-GHz allocations auctioned by the FCC in 1996.
- LMDS has been developed as a broadband wireless access service, which WinStar calls Wireless Fiber, by the FCC as a competitive alternative to the high-speed data communications services offered by telephone companies and cable network service providers. Block A bandwidth of 1150 MHz and block B bandwidth of 150 MHz are available to service providers that acquired licenses in the February-to-March 1998 LMDS auction.

During the last few years point-to-multipoint technology has moved from analog to the digital domain as customer demand for analog TV services has dwindled in favor of satellite broadcast TV services and digital cable TV offerings. Customers that at one time depended on MMDS for their cable services now have much better TV access through the satellite service offerings. This and other factors have driven MMDS service providers to move toward digital TV and two-way data services to compete with offerings by cable TV service providers and to take advantage of the demand for high-speed data in homes and businesses.

Figure 1
MMDS/LMDS System Diagram



Source: Nortel

MMDS: An Industry in Transition

MMDS appeared to be a promising opportunity a few years ago when Bell Atlantic, BellSouth, Pacific Telesis, and NYNEX got behind the technology as a means of offering broadband services to homes in competition with the cable companies. Its potential has not been achieved, because the regional Bell operating companies (RBOCs) have backed off from their strong push into these services. Other than the RBOCs, most of those in this business are relatively small, undercapitalized companies that do not have the financial wherewithal to invest in the acquisition of more expensive digital technology. A scan of the financial reports of service providers and supporting equipment manufacturers provides a picture of declining revenue and growing losses at a time when a significant investment in new digital infrastructure is required. The following examples of selected companies provide an indication of the challenges of the transition the MMDS industry is currently going through:

- Heartland Wireless, the largest MMDS operator in the United States, announced in its third quarter financial report that it is filing for Chapter 11 protection after experiencing losses of $134 million in 1997 and $198 million for the first three quarters of 1998.
- American Telecasting Inc., another of the largest MMDS providers, announced that its accountant has indicated that ATI must undertake a financial restructuring in order to avoid a statement questioning the company's viability as a going concern in the accountant's audit report.
- California Amplifier, a supplier of MMDS and direct broadcast satellite reception equipment, reported revenue for the nine months ended November 28, 1998, to be $27.1 million, a decline of 30 percent from the same period in 1997. The company experienced losses of $1.5 million for the 1998 period.
- EMCEE Broadcast Products, a manufacturer of MMDS transmission equipment, reported revenue for the six months ended September 30 of $4.4 million, an increase of 10 percent over the same period in 1997. The company has experienced revenue declines for the last three years. The trend is for flat revenue for fiscal 1999.

The suppliers of MMDS equipment have experienced declining revenue. As a result, these companies are not able to offer services competitive with those being offered by the cable and satellite operators. Some companies have begun to offer wide-bandwidth data services. However, this is an emerging business opportunity that will not produce immediate revenue growth. Before September 1998, MMDS required a second medium for the return path. In September, the FCC agreed to allow MMDS channels to be used for both forward and return communications. This makes it possible for MMDS service providers to service the broadband needs and businesses that require them. It appears that business levels will continue to decline for some time in the MMDS market, causing continued decline in revenue for suppliers of MMDS hardware.

LMDS: Where the Current Action Is

LMDS is a different story. In the United States, the FCC auctioned off 1.3 GHz of spectrum in the 28- and 31-GHz region in March 1998. Also, companies have acquired broadband spectrum in the 24- and 38-GHz regions to provide the same types of point-to-multipoint services made possible by LMDS. A number of companies have the financial resources to buy licenses to provide nationwide services. The companies of interest in the 24 to 38-GHz spectrum are Teligent, Advanced Radio Telecom, and WinStar. Two new entrants, WNP Communications and NEXTBAND Communications, bought licenses in the LMDS auction that provide them with nationwide coverage and will be entering the market within the next two years. WNP and NEXTBAND spent $187 million and $135 million, respectively, to acquire broadband spectrum in the 28-to-31-MHz regions. Teligent, WinStar, and ART have the financial resources and the plans in place and are building out their networks now with the expectation of establishing services within the next year. WNP and NEXTBAND have not created specific plans but are expected to begin providing services in the next two years. An additional 102 bidders bought licenses for $214 million. Their challenge will be to acquire the financing for building out their networks in the next few years.

Another major rollout of LMDS is taking place in Canada, starting with the government's allocation of spectrum to three companies in 1996. These companies were given the direction to create a nationwide broadband wireless access network. The key companies in the Canadian LMDS rollout are WIC Connexus and Maxlink. These systems are rolling out much more slowly than the Canadian government would like. As a result, the government is planning to allocate 24-GHz and 38-GHz spectrum to get more competition into building out the Canadian system. The service companies are blaming the equipment vendors. Part of the problem is that their current equipment does not provide bandwidth-on-demand. They have now decided to go ahead with current equipment and upgrade later.

The third visible installation of an LMDS network is being carried out in Korea, where Korea Telecom has begun to roll out its network. This is the first deployment of LMDS technology in the world by an existing telecommunications service provider.

Other countries that have allocated spectrum for LMDS services include Russia, Western European countries, the United Kingdom, Venezuela, Argentina, Romania, and the Philippines.

The market opportunity for wireless broadband access is in LMDS. In Canada, which is rolling out its network in 1998 and 1999, WIC Connexus and Maxlink (the two major players) announced that they would be spending $500 million and $400 million, respectively, over the next four years to build out their networks. Maxlink claims that it will spend $2 billion on its network before it is completed. Newbridge received the bulk of these companies' business. In the United States, Advanced Radio Telecom completed financing agreements with Lucent Technologies and others that provide the company with up to $300 million to build out its network. Lucent will receive the purchase order for the equipment to build ART's network. The first $35 million will be used to finance the first three networks in Seattle, Washington; Portland, Oregon; and Phoenix, Arizona.

ART plans to provide services to the 100 largest markets in the United States over the next five years, implying an investment of more than $1 billion over the period. P-Com is a key supplier of millimeter-wave radios to ART and is expected to become Lucent's partner in the buildout of ART's point-to-multipoint network. Teligent has raised $100 million from Nippon Telephone and Telegraph, $125 million from its initial public offering in the fourth quarter of 1997, a $300 million debt financing, and a $780 million vendor financing commitment from Nortel, its equipment partner. Teligent has targeted a launch in 10 markets in 1998, 20 more markets in 1999, and an additional 20 to 50 markets in 2000 and 2001, for a total of 50 to 80 markets by the end of 2001. This would indicate a hardware investment of $800 million to $1 billion over the four-year period. WinStar Communications is the third major player in the buildout of a national fixed wireless network. The company is scheduled to complete a 40-market buildout by the end of 1999. WinStar recently announced a partnership with Lucent Technologies that involves an equipment financing arrangement of up to $2 billion in $500 million tranches. In addition to its existing 38-GHz spectrum, WinStar recently purchased LMDS licenses for $43 million during the U.S. auction. WinStar also purchased spectrum in New York from CellularVision USA for $32.5 million.

Tallying this up shows five North American companies investing more than $6 billion over the next five years in building out millimeter-wave point-to-point networks to serve small and medium-size businesses that do not currently have access to broadband fiber connections. Also, at least two more companies will join the pack as soon as they develop their business plans and secure the funding they need to build out their networks. To some extent, the hardware suppliers for these buildouts are already in place because of the financing established between the operators and their hardware suppliers. This is further detailed in Table 1.

Table 1
Network Operators and Their Equipment Suppliers

Operator	Equipment Supplier	Details
WIC Connexus	Newbridge	$500 million investment over four years. Major share went to Newbridge.
	Alcatel (radio equipment)	
Maxlink	Newbridge	$400 million investment over four years. Major share went to Newbridge. Maxlink plans to spend $2 billion over five years on its network.
	Alcatel (radio equipment)	
Teligent	Nortel	Nortel provided $780 million purchase loans. Other financing sources have provided another $500 million plus.
ART	Lucent	Lucent provided $25 million credit facility and $200 million purchase loans conditional on ART's ability to raise other capital.
	Possibly P-Com for radio equipment	
WinStar	Lucent	Lucent has established an equipment financing arrangement of $2 billion available in $500 million tranches.
	Nortel	
	Possibly P-Com for radio equipment	
Korea Telecom	Newbridge	Details are not available.

Source: Dataquest (December 1998)

There will be more players entering this market over the next few years. More than 100 companies bought spectrum in the March FCC auction. The companies shown in the table have marshaled the resources to create networks in the major population areas in the country. The smaller players will have the opportunity to provide services in less populated areas. One of their major challenges will be to acquire the resources to build out their networks and provide the services to their customers.

LMDS Networks: The Semiconductor Opportunity

A point-to-multipoint network is similar to a cellular network (see Figure 1). The base station consists of base station transceiver systems and a base station controller. Customer-premise equipment includes radio equipment and a network interface unit (NIU) that provides the connection to the customer's internal communications network.

Base Station Equipment

LMDS base stations provide conversion from the fiber network to the wireless network. Base station equipment is similar to its cellular counterpart, with some significant differences. LMDS equipment is fixed and thus does not have to deal with handoffs, roaming, and other issues related to mobile terminals. On the other hand, LMDS systems must be able to handle voice, data, video, and multimedia content with varying bandwidth demands. These types of demands will not exist for mobile communications until third-generation networks are deployed five or more years from now. The capability to process broadband content demands that equipment have much more robust digital signal processing capability than is currently required in cellular equipment.

An LMDS base station consists of the following:

- Network interface for fiber terminations
- Modulation and demodulation functions
- Microwave transmission and receiving equipment

Some base station architectures include switching equipment and the accompanying network management, which makes it possible to connect users in the LMDS without using the external fiber network.

The base station network interface converts the radio frequency signals sent to and received from the base station radio equipment into network compatible data (asynchronous transfer mode—ATM—is becoming the standard). These signals are sent to and received from the optical network. The network interface includes fiber-optic modules, related serialization and deserialization functions, digital signal processing coding and decoding functions, modulation/demodulation functions, compression and decompression functions, and data conversion functions.

LMDS radio frequency equipment sends and receives 24-GHz-to-38-GHz radio signals between the base station and the customer-premise equipment. Transceivers consist of transceivers and digital processing equipment that link the customer sites to the network. Radio equipment can be broadband multicarrier or single carrier per transceiver. Transceivers convert the 24-to-38-GHz signals to and from VHF intermediate frequency levels (in the 500-MHz-to-2-GHz range). These signals are sent to and received from the network interface equipment. The transmitted power of an LMDS transmitter is in the range of 1W, which can be shared among several carriers.

LMDS base station equipment is designed to operate with between four to 24 sectors and provide efficient coverage of a wide range of customers in accordance with their bandwidth needs. There is one transceiver for each sector.

Customer-Premise Equipment

Customer-premise equipment includes transceivers and a NIU.

The LMDS transceiver is generally located outdoors and is integrated with the antenna, which is about 12 inches in diameter. This makes a compact, relatively unobtrusive installation, an attractive feature of LMDS systems. The power output of a customer-premise equipment transmitter is in the range of 100mW. The transceiver upconverts and downconverts signals sent to and received from the in-building NIU.

The NIU provides the interface between the radio and the customer-premise network, which could be a LAN, a PBX, servers, or other equipment installed on the customer's premises. The functions in the NIU include data conversion, modulation and demodulation, encryption and decryption, embedded control, and customer-premise network interface functions.

Semiconductor Opportunities

LMDS transceiver equipment will make extensive use of gallium arsenide (GaAs) technology. Polymorphic high-electron-mobility transistor (PHEMT) and heterostructure bipolar transistor (HBT) technologies are well suited to the millimeter-wave sections of the radios, while metal semiconductor field-effect transistor (MESFET) technology is well suited to the intermediate frequency sections of the radios. The availability of this technology is critical to offering low-cost millimeter-wave integrated circuits.

The network interface units in the base station and the customer-premise equipment represent opportunities for high-performance digital signal processing products, embedded 32-bit microprocessors, memory (flash will be attractive for remote uploading of system updates), application-specific ICs (ASICs) and application-specific standard products (ASSPs), and mixed-signal products for data conversion and physical layer interface functions.

Dataquest estimates that the worldwide demand for LMDS base station and customer-premise equipment will approach $3.4 billion per year within the next five years, representing a $476 million annual opportunity for semiconductor manufacturers and an $85 million annual opportunity for suppliers of GaAs technology. Table 2 provides Dataquest's current forecast for LMDS equipment and semiconductor consumption.

Table 2
Forecast of LMDS Equipment Demand and Semiconductor Consumption (Millions of Dollars)

	1999	2000	2001	2002	2003
LMDS Equipment	500	1,000	1,750	2,450	3,400
Semiconductor Content Ratio (%)	10	11	12	13	14
Semiconductor Consumption	50	110	210	319	476

Source: Dataquest (December 1998)

Dataquest Perspective

The growth opportunity for broadband wireless access for the next five years is in LMDS. The early market development will be led by U.S. companies Teligent, WinStar, and ART with existing operations on the 24-GHz and 38-GHz spectrum, followed by the buildout of Canada's planned nationwide network by WIC Connexus and Maxlink, and Korea Telecom's buildout of its Korean network. The next buildout wave will come from the winners of the U.S. LMDS auction, WNP Communications and NEXTBAND Communications, which had to rewrite their business plans when they acquired more spectrum than they had expected. These companies will start their networks in the next two years. The last wave will be the smaller bidders of the U.S. LMDS auction and other countries that have allocated spectrum for LMDS. This may evolve over the next five to 10 years. Dataquest's forecast is based on the assumption that the operators will execute their network buildout plans as they have stated. The U.S. and Canadian first-wave companies have organized the resources, although they need to accomplish these objectives through their vendor purchase loans and other means as discussed earlier. The winners of the U.S. LMDS auction have yet to announce their vendors. We assume that any arrangements for these companies will include purchase loans similar to the arrangements made by WinStar. Teligent, and ART. There are a number of equipment vendors with the resources to provide this support, including Ericsson, Alcatel, Bosch Telecom, Siemens, and Newbridge Networks.

The target customers for semiconductor companies wanting to participate in the LMDS market emerge quite clearly from the analysis of the buildout process. The key turnkey systems suppliers are Newbridge Networks, Lucent Technologies, and Nortel, in that order. Alcatel and P-Com will apparently participate as subsystem suppliers to the operators, as subcontractors to the major equipment company suppliers, or as subsystem suppliers to the service providers. Smaller players could be left out of the early major buys for LMDS infrastructure but may have an opportunity to participate in the sales of customer-premise equipment as the operators sign up customers for their services.

Several large LMDS players have not been mentioned to date. Two of them are Ericsson and Bosch Telecommunications. It is likely that these companies will be contenders for the buildouts of WNP and NEXTBAND. It is quite likely that the larger new entrants will negotiate purchase loans from their equipment vendors as most of the other players have.

The following two key issues remain to be considered in this analysis:

- What will the 102 bidders in the LMDS auction do to roll out their business? They are not likely to get the benefits of financial support from the large equipment producers. They will have to carve their own niche opportunities in the areas in which they have bought spectrum. Two of the winners, Central Texas Communications, in Texas, and Liberty Cellular, in Kansas, have announced plans to establish LMDS services in their regions using Newbridge and Nortel equipment, respectively.
- How will the RBOCs play in this market? They did not play a role in the auction because they were allowed to bid only on the B block spectrum. They will be able to buy licenses from the other winners three years after the auction. The slow rollout of WNP and NEXTEL is working in favor of the RBOCs, because the new entrants may not be that well established in the market when the RBOCs are able to make their move. This may be a motivation for the RBOCs to enter the LMDS market in 2001. By then, Teligent, WinStar, and ART will have established the validity of the market opportunity, and the RBOCs will have a better idea of the risks associated with these markets.

The downside to this opportunity is the acceptance of LMDS services as an alternative to other means of broadband access. This could affect hardware demand in two to three years if customer demand does not materialize as expected. With major players willing to make billion-dollar investment loans, there are some big bets on the table. Small and medium-size businesses must be willing and able to install broadband access systems in their facilities, and they must find the wireless solutions a good technical and economic choice.

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Perspective

Wireless Semiconductors and Applications - Worldwide

Market Analysis

Third Quarter Wireless Update: The Churn Continues

Abstract: *Manufacturers of wireless infrastructure and subscriber equipment and semiconductor products experienced another quarter of mixed results. Revenue changes ranged from significant decline to strong growth. As a result of the wide range in performance some companies' positions in the industry have changed. This Perspective analyzes the quarterly performance of selected companies that serve the wireless communications market.*
By Stan Bruederle

Introduction

This Perspective looks at the performance of major players in the wireless communications with visible financial performance and analyzes the implications of their performance for the wireless market.

The third quarter saw continued industry dynamics as companies' positions within regions and their product positions determined market positions and growth patterns. System companies' revenue grew in the range of 15 to 20 percent, with Motorola and Ericsson experiencing weaker results because of their weak performance in their subscriber unit businesses. Nokia was the star performer with its 94 percent growth in handset shipments and 42 percent growth in infrastructure shipments.

Independent suppliers of power amplifiers (Spectrian and Powerwave) continued to be affected by the economic crisis in Asia, and their continuing efforts to transfer the business to the United States and other growing markets.

Semiconductor companies experienced widely varying results ranging from negative 28 percent growth at VLSI Technology, which is closely tied to

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Ericsson, to 243 percent growth at RF Micro Devices, which has the rapidly growing Nokia as its major customer (see Table 1).

Table 1
Third Calendar Quarter Financial Results for Selected Wireless Companies

	Revenue ($B)	Change (%)	Cost of Goods Sold ($B)	Change (%)	R&D ($B)	Change (%)	Net Income ($B)	Change (%)	Inventory ($B)	Change (%)
Ericsson	5.49	6.78	3.09	2.00	0.87	17.33	0.40	6.76	3.50	9.66
Lucent Technologies	8.04	15.93	4.26	9.86	0.97	16.52	0.55	48.51	3.08	5.30
Motorola	7.15	-2.74	5.16	3.39	0.73	5.32	-0.04	NA	4.29	4.74
Nokia	3.91	62.29	2.36	54.53	0.31	63.73	0.54	69.53	1.56	0.50
Nortel	4.14	18.38	2.35	14.83	0.62	16.67	-.30	NA	2.02	1.00
QUALCOMM	0.93	53.97	0.62	47.73	0.10	46.14	0.04	32.54	0.39	71.67
Powerwave Technologies	16.45*	-52.08	10.70*	-47.98	2.94*	-11.98	0.12*	-97.45	10.35*	17.08
Spectrian	26.87*	-44.30	20.63*	-40.16	6.55*	58.21	-3.20*	NA	19.86*	29.30
Alpha Industries	26.63*	3.68	16.76*	-6.58	2.89*	19.42	4.22*	80.34	9.59	20.78
Anadigics	22.04*	-17.55	21.76*	58.95	4.33*	-0.94	-4.96*	NA	11.98*	-39.13
Celeritek	10.83*	-19.96	8.19*	-7.16	1.36*	7.09	-0.49*	NA	11.04*	3.76
RF Micro Devices	31.42*	243.01	21.69*	349.07	3.22*	53.60	2.36*	188.60	26.90*	8.16
Texas Instruments	2.11	-15.48	1.31	-13.83	0.29	5.82	0.16	-90.42	0.57	-23.18
TriQuint	29.11*	65.68	17.93*	75.08	4.57*	71.16	2.86*	118.32	20.08*	63.38
VLSI Technology	130.8*	-27.78	80.49*	-19.70	26.47*	6.6	-3.56*	NA	45.49*	-12.32

*Figures followed by an asterisk are given in millions of dollars rather than billions of dollars
NA = Not applicable or not available
Source: Company quarterly financial reports, Dataquest (November 1998)

Equipment Companies Generally Experience Growth

Ericsson

Ericsson experienced 16 percent growth in its infrastructure business over the same quarter of 1997. Its handset business did not fare as well, experiencing a 2 percent decline compared with the same period one year earlier, in spite of stated unit shipment growth of greater that 50 percent. Ericsson is suffering from missing the most recent market window. As a result, the company has slipped from its position as the No. 1 supplier of cellular/PCS handsets in terms of revenue. The third quarter represents a downward trend against the results of the nine-month period ending at the same point. New handsets to be introduced in early 1999 are expected to rejuvenate Ericsson's performance. However, when these products are introduced, Motorola will have its new product families on the market while Nokia will continue to press its strong position as well.

Ericsson continues to experience positive results in its infrastructure business, with particularly strong results in China. The company is strongly pushing its W-CDMA thrust for the next-generation worldwide standard. Ericsson included the following announcements in its report:

- Handset sales were $1.38 million for the quarter. This result places Ericsson in the position of No. 3 supplier of cellular handsets, behind Nokia and Motorola.
- Sales in the Americas declined by 7 percent. Ericsson's largest markets are China, the United States, the United Kingdom, Brazil, and Italy.

Lucent Technologies

Lucent Technologies reported $8 billion in revenue for the third calendar quarter, an increase of 15.9 percent compared with the same quarter of 1997. Its wired, wireless, and optical infrastructure business grew 22.4 percent. The company terminated its joint venture with Philips Consumer Communications, thus ending its association with the wireless handset business.

Motorola

Motorola reported revenue of $7.2 billion for the third quarter, a decrease of 3 percent from revenue of $7.4 billion for the same period of 1997. The company experienced losses of $42 million for the period compared with a profit of $266 million in its third quarter of 1997. The Cellular Products Segment experienced 9 percent revenue growth to $3 billion for the period, while orders declined by 2 percent. Infrastructure business was up strongly, while the subscriber business declined as weakness in analog subscriber business offset growth in the digital phone business. Motorola's paging group experienced a 30 percent decline in revenue because of weakness in the Asian market. Orders declined as well. Motorola made the following announcements in its quarterly report and analyst reports:

- The nonsilicon components business was sold to CTS Corporation. This business includes ceramics, quartz oscillators, piezoelectric, and saw technology.
- The pending launch of Iridium positions Motorola to begin to profit from its investment and support of the satellite network. With the emergence of worldwide terrestrial solutions there is a question regarding the appeal of satellite phone networks.
- Motorola achieved $1.75 billion in handset revenue in the third quarter.

Nokia

Nokia continues to be the star performer in mobile communications. The company reported revenue of $3.9 billion (calculated at an exchange rate of Fmk 5.156 to U.S.$1) for the third calendar quarter, an increase of 62 percent compared with the same quarter of 1997. Infrastructure revenue grew 42 percent, while subscriber revenue grew a stellar 94 percent. Nokia announced the following in its report:

- Nokia shipped 1 million phones in one week in the quarter.
- Its subscriber revenue of $2.5 billion for the quarter makes it the leader in supplying cellular/PCS phones ahead of Ericsson and Motorola.

Northern Telecom

Nortel revenue was $4.1 billion for the third quarter, an increase of 18.4 percent over the same quarter in 1997. Wireless revenue grew 17 percent to $883 million in the September quarter. Nortel announced the following in its report:

- Nortel exited the subscriber business when Matra Nortel Communications (50 percent owned by Nortel) sold its 50 percent ownership in Matra Ericsson Telecommunications to Ericsson.

QUALCOMM

QUALCOMM reported revenue of $926 million for the third calendar quarter of 1998, an increase of 54 percent over the same quarter of 1997. Subscriber unit shipments for the 12 months ending with this quarter doubled over the year-earlier period. QUALCOMM shipped its 7 millionth phone this quarter, indicating that 1 million phones were shipped during the quarter, down slightly from 1.3 million phones in the prior quarter. QUALCOMM made the following announcements during the period:

- The company introduced the pdQ digital smart phone, combining PalmPilot personal digital assistant (PDA) capabilities with a code-division multiple access (CDMA) phone.
- QUALCOMM demonstrated its High Data Rate (HDR) technology, which supports Internet access at rates of up to 1.5 Mbps.
- The company began production of Q phones in its new manufacturing facility in São Paulo, Brazil.
- QUALCOMM exceeded 25 million mobile station modem chips to date, an increase of 15 million from one year ago.
- The company exceeded 2 million cell station modems shipped worldwide.
- QUALCOMM delivered samples of the Mobile Station Modem 3000, which can support data rates of 86 Kbps.
- The company shipped samples of the CSM2000, which supports eight forward and reverse link channels, significantly reducing the cost per channel and power requirements.

- Direct sales of wireless infrastructure equipment to operators made up the majority of infrastructure shipments.
- QUALCOMM launched the first open architecture network in the United States, linking the company's base station controller with another company's switch.

Independents Deal with the Asian Financial Crisis

Powerwave Technologies

Powerwave reported revenue of $16.5 million for its third quarter, a decline of 52 percent from the year-ago quarter. The company attributed the decline to delays in orders from OEM and system operator customers, as well as the ongoing Asian financial crisis. Revenue from multicarrier linear amplifiers (MCLAs) represented 79 percent of revenue, and personal communications services (PCS) products accounted for 15 percent of revenue. The balance of revenue was from Land Mobile Radio customers. The company made the following additional announcements for the period:

- Revenue from companies outside of Korea made up 63 percent of total revenue, compared with 14 percent one year earlier. Sales to North American customers increased from $4.36 million, or 12.7 percent of sales, in the third quarter of 1997 to $7.7 million, or 53.1 percent of sales in the third quarter of 1998.
- BellSouth and Metawave Communications each accounted for more than 10 percent of revenue in the third quarter representing about 40 percent of quarterly North American revenue.
- Powerwave announced that it will acquire Hewlett-Packard's RF power amplifier business, which makes single-carrier power amplifiers, a complementary business to Powerwave's MCLA business. The purchase price was about $57 million.

Spectrian

Spectrian reported third quarter revenue of $26.9 million, a decline of 44.3 percent from the year-ago revenue figure. During the past year, Spectrian has begun to contract the manufacture of higher-volume printed circuit boards. During the past six months, the company has begun to contract the manufacture of single-carrier power amplifiers to an offshore manufacturer. During the past six months, 98 percent of Spectrian's business has come from four customers, Northern Telecom (66 percent), QUALCOMM (11 percent), Nortel Matra (11 percent), and LG Information & Communications (10 percent).

The company expects its business to continue at the current levels for the next few quarters.

Semiconductor Companies RF Micro Devices and TriQuint Have a Great Quarter

Alpha Industries

Alpha Industries experienced 80 percent third quarter profit growth to $4.2 million on a 3.7 percent increase in sales to $28.6 million. The company has chosen to focus its resources on the wireless semiconductor industry for future growth. The company made the following announcements for the quarter:

- One customer represented 25 percent of the company's business for the six months ending with the third quarter of 1998 compared with 21 percent for the same period of 1997.
- Alpha's wireless semiconductor sector had sales of $28.4 million for the six months ending September 1998 and $14.3 million for the September quarter.
- Gross margins for the Wireless Semiconductor Sector were 41 percent.
- Increased research and development dollars were invested in the wireless semiconductor sector. The company invests more than 75 percent of its R&D dollars in the wireless semiconductor sector.

Anadigics

Anadigics announced revenue of $22 million, down 11.9 percent from the prior quarter and 25.1 percent from the year-earlier quarter. The company reported break-even profits prior to accounting for special charges, which resulted in a $5.0 million loss for the period compared to a $3.9 million profit the year-earlier quarter.

- Wireless sales increased 12 percent over the prior quarter.
- Anadigics wrote down $3.5 million of wireless inventory semiconductor inventory consisting primarily of single-band power amplifiers for wireless handsets.
- Sales of semiconductors for cellular and PCS applications decreased to $8.3 million in the third quarter of 1998 from $17.1 million for the same quarter of 1997, a decrease of 51 percent.

Celeritek

Celeritek's revenue declined 20 percent to $10.83 million in the third quarter with a loss of $486,000. Semiconductor revenue increased 5 percent. The company had projected that semiconductor revenue would decline in the quarter in its last quarterly report. The company made the following announcements in its quarterly report:

- A $5.9 million purchase agreement for 4.8-volt power amplifiers was announced with a major Japanese handset manufacturer for delivery over the next 18 months.
- Celeritek received a purchase agreement valued at $1.2 million for gallium arsenide (GaAs) power amplifier ICs for satellite handsets for delivery over the next 18 months.

- The company opened a new design center in Ireland that will focus on designs of GaAs radio frequency (RF) ICs and assemblies.

RF Micro Devices

Revenue for the third quarter increased 243 percent to $31.4 million over the year earlier and 34 percent over the prior quarter. Profits increased 188.6 percent to $2.36 million over the year-earlier quarter.

- Products based on GaAs heterojunction bipolar technology (HBT) technology represented 89.2 percent of the company's revenue for the third quarter of 1998.
- Revenue for HBT products increased 312 percent over the third quarter of 1997, while silicon revenue increased 207 percent for the same periods.
- Shipments to customers outside the United States represented 60 percent of revenue for the third quarter, a decline from 69 percent for the year earlier quarter.
- Sales to South Korean customers were $3.8 million or 12.1 percent of revenue for the third quarter.
- The company lists its major handset customers as Nokia, Hyundai, Philips Consumer Communications, Maxon, Pantech, Samsung, and LG Information and Communications. Its major infrastructure customers include Motorola, Powerwave, SCI systems, and Spectrian.
- Nokia represented about 42 percent of the company's revenue, or $19 million, during fiscal 1998, which ended in March 1998.

Rockwell Semiconductor Systems (Now Known as Conexant Systems)

Conexant Systems, the new name for Rockwell Semiconductor Systems, released its prospectus for its initial public offering for the year ending September 1998. This is the first public release of the semiconductor company's financial performance. Conexant's wireless communications semiconductor business reached $170 million for the fiscal year 1998, which ended in the third quarter 1998, an increase of 47.9 percent from fiscal 1997. This is an increase of 32.4 percent over fiscal 1997.

- Rockwell's customers include Casio Phonemate, Ericsson, Nokia, Samsung, Nortel, QUALCOMM, NEC, SANYO, Sharp, Sony, and Uniden.
- Dataquest estimates that Rockwell's revenue for power amplifier products was $56 million in calendar year 1997. Its revenue for cordless phone chipsets is estimated to be $30 million for the same period, mostly from 900-MHz spread spectrum phones.
- Rockwell claims to be the largest supplier of GaAs power amplifier products for digital cellular handsets. Conexant is also the largest supplier of 900-MHz digital spread spectrum cordless chipsets.

Texas Instruments

TI's overall business declined 8 percent to $1.9 billion for the third quarter. Orders, excluding the memory business, which was sold to Micron Technology, were up 8 percent from the prior quarter. The company reported the following results in its report:

- TI's semiconductor operations had revenue of $1.53 billion in the third quarter of 1998, a decrease of 8.47 percent from the same quarter of 1997. The operation produced a profit of $363 million, down 8.33 percent from the same quarter of 1997.
- TI revised its estimate of the 1998 digital cellular handset market to $140 million handsets from its previous estimates of $125 million.
- Digital signal processor (DSP) revenue increased 17 percent from the third quarter of 1997, primarily because of strength in the wireless communications market.
- Wireless chipset demand drove orders for the quarter up by 8 percent over the prior quarter.

TriQuint Semiconductor

TriQuint reported revenue of $29.1 million up 66 percent over the same quarter of 1997. Net income grew 118 percent to $2.9 million.

- In 1997, Nortel accounted for about 10 percent of TriQuint's revenue. Raytheon TI Systems accounted for about 10 percent of TriQuint's business for the nine months ending in September 1998.
- The company reported 64 new "major" design wins, each representing potentially $100,000 of new business for the company. If these design wins achieve their objectives, Triquint will achieve annualized revenue growth of $25.6 million. Eighteen of these design wins were in the wireless business.

VLSI Technology

VLSI Technologies reported revenue of $130 million in the third quarter of 1998, a decrease of 27.8 percent from the same quarter one year earlier. The company reported losses for the quarter of $3.6 million. The company reported the following for the quarter:

- Revenue from VLSI's top 20 customers represented 75 percent of its total revenue for the first nine months of 1998, an increase from 67 percent of its business for the first nine months of 1997.
- Ericsson, VLSI's largest customer, accounted for 28 percent of its business for the first nine months of 1998, about the same as its 29 percent share for the year 1997.
- The company's two major markets are the communications and the digital consumer entertainment markets.
- International revenue declined to 47.8 percent of revenue for the first nine months of 1998 from 49.5 percent for the same period of 1997. This drop

was attributed to declines in orders and average selling prices in its communications and digital consumer customers.

Dataquest Perspective

Overall industry performance during the quarter continued strong, although not strong enough to support growth for all players in the industry. Dataquest's forecast for digital handsets for 1998 is 135 million handsets, a growth rate of 37.3 percent. Companies' reports indicate that they are on target to reach this target or possibly exceed it. Wireless infrastructure revenue is expected to grow 11.8 percent from 1997 to 1998. Companies' reports indicate that they are on target to achieve this target as well. The challenges that companies are facing can be attributed to the following factors:

- The Asia/Pacific financial crisis is affecting companies that are closely tied to Korea's wireless rollout. Companies particularly affected include independent power amplifier manufacturers such as Spectrian, Powerwave, and producers of microwave transmission equipment. Companies with strong positions on China such as Ericsson, Nokia, and Motorola were not as seriously affected by the crisis. Companies also reported that they are receiving somewhat increased activity from Korean companies (LGIC re-emerged as a major customer in Spectrian's quarterly report).
- Weak product positioning has affected companies such as Ericsson and Motorola. Ericsson fell behind in announcing digital phones and has to accept lower prices for its phones and therefore lower revenue growth. Motorola has been affected significantly by the strong decrease in analog phone revenue, which has offset the company's growth in digital phones. Dataquest estimates that analog phone revenue will decrease by 27 percent from 1997 to 1998. Motorola's reports indicate that the decline could be worse than expected. As both companies introduce new products, revenue is expected to increase, pulling suppliers' revenue up as well. The challenge for Motorola and Ericsson will be to regain momentum lost to Nokia.

- Standards positioning was the third important factor. CDMA and Global System for Mobile Communications (GSM) are the current growth leaders in the cellular/PCS business. Ericsson's strong position in GSM infrastructure has supported continued growth in its infrastructure business. Its leadership position in all markets moderated its growth somewhat because of regional factors. QUALCOMM continued to do well as CDMA continues to grow faster than the industry overall. Dataquest's forecast shows CDMA becoming the second-highest standard in 1999 in terms of handset unit volume. CDMA is expected to grow at nearly twice the rate as GSM for the 1997-through-2002 period. The continued growth of CDMA should also support growth in the infrastructure businesses of Lucent and Motorola. Nokia has positioned itself as a key supplier in the GSM 1900 segment and as a result has experienced high growth as operators continue to install and upgrade their GSM 1900 cell sites to provide greater capacity for supporting the rapid subscriber growth in the GSM market.

Other points worth noting are itemized as follows. The dynamics of this fast-changing industry continue to provide opportunities for semiconductor companies to achieve high growth and profitability, sometimes at the expense of their competitors.

- RF Micro Devices established itself as a major player in the cellular/PCS power amplifier business. An estimated 89 percent of the company's quarterly revenue, or $28 million, was for HBT power amplifier products in the quarter, putting the company in a position to challenge Conexant as the leading supplier of GaAs power amplifier products for digital cellular subscriber devices.
- The growth of GaAs revenue from Conexant and RF Micro Devices and their presence in GSM applications indicates that GaAs is beginning to establish itself as the technology of preference for power amplifier applications. Dataquest expects that this development will result in decreased demand for power amplifier modules in digital cellular applications.
- Another catalyst for changing positions in the industry will come from the emergence of mobile wireless data. As wireless operators upgrade their networks to be able to handle higher data rates, companies providing data-centric terminals that provide access to the sources of data content subscribers need will profit from the growth in demand for these products and services.

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Perspective

Wireless Semiconductors and Applications - Worldwide

Technology Analysis

Radio Frequency Semiconductor Technology in Wireless Handsets

Abstract: *With more than 500 million cellular/PCS subscribers expected by 2002, the demand for handsets continues to grow at a high rate. At the same time, customers demand lower prices and better service from their cellular phones. These improvements will happen only with the continued integration of the handset ICs, which represent nearly 50 percent of the cost of a wireless handset. Three technologies important to this integration process are gallium arsenide, silicon-germanium BiCMOS, and silicon-on-insulator. This Perspective explores the trends in wireless handset semiconductor technology and the impact on handset design.*

By Stan Bruederle and Dale Ford

The Exploding Cellular/PCS Subscriber Market

Dataquest estimates that there will be more than 500 million cellular/personal communications services (PCS) subscribers by 2002, using phones designed for the three popular standards: Global System for Mobile Communications (GSM), code-division multiple access (CDMA), and Digital Advanced Mobile Phone Service (D-AMPS) and its Japanese derivative, Personal Digital Cellular (PDC). Annual digital cellular/PCS phone production will grow from 98.6 million units in 1997 to 312 million units by 2002. In addition, Dataquest estimates that by 2002, 90 million cordless phones and 57 million pagers will be produced annually, for a total of more than 450 million wireless devices produced per year. Table 1 shows annual worldwide production of analog and digital cellular/PCS and other wireless subscriber devices per year from 1997 to 2002.

Dataquest

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(For Cross-Technology, file in the Semiconductor Application Markets binder)

Table 1
Worldwide Production of Wireless Subscriber Devices, 1997 to 2002 (Millions of Units)

	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Cellular/PCS	123.8	153.7	185.7	229.6	272.4	317.5	20.7
Other Wireless	101.2	110.1	120.8	130.8	138.2	148.3	7.9
Total	**225.0**	**263.8**	**306.5**	**360.4**	**410.6**	**465.8**	**15.7**

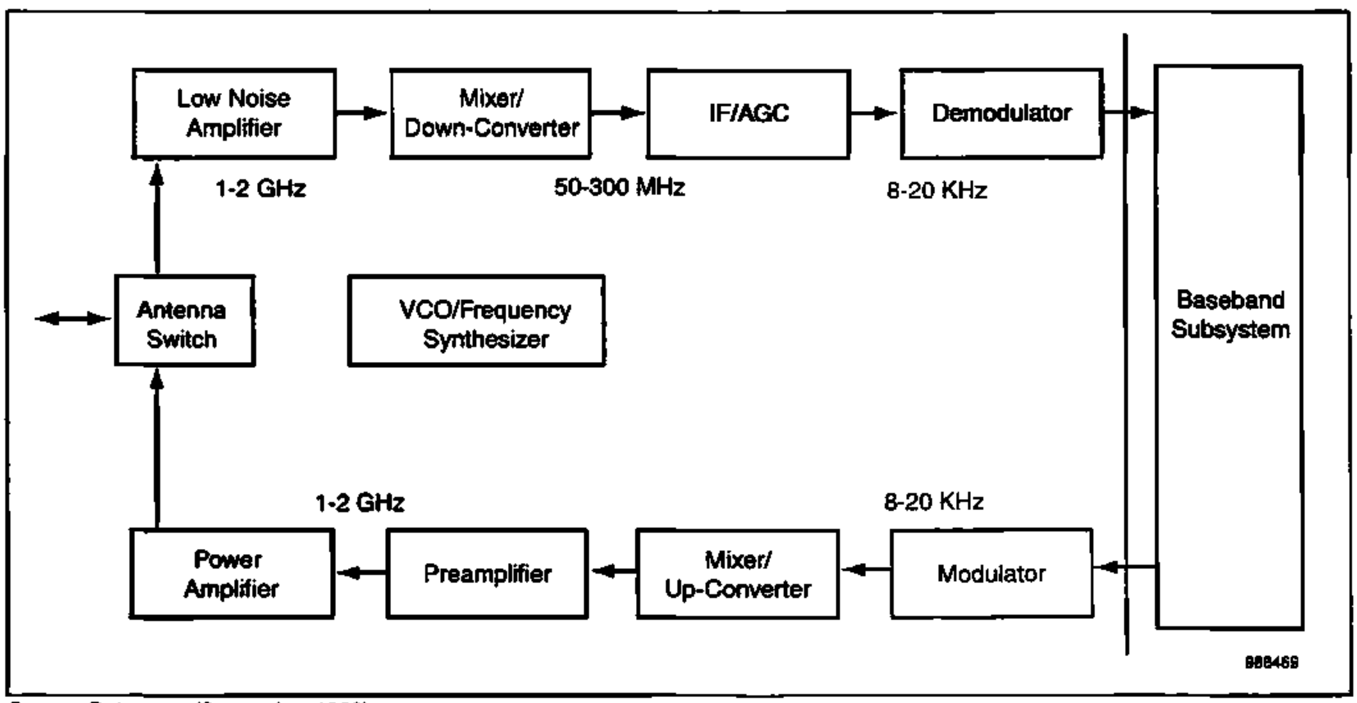
Source: Dataquest (September 1998)

Each of these devices has a radio frequency (RF) transmitter/receiver or a receiver in it. Each of these contain $5 to $30 worth of RF semiconductor devices, representing a worldwide market of $7 billion by 2002. This represents an extremely important growth opportunity for a select group of semiconductor manufacturers that design and market (and maybe produce) semiconductor devices for RF applications. This Perspective will focus on the largest and fastest-growing market for RF semiconductor devices, the digital cellular/PCS handset application market.

Inside a Cellular/PCS Handset

A cellular/PCS handset includes two major subsystems, the RF/intermediate frequency (IF)/power amplifier subsystem and the baseband subsystem. Figure 1 shows a generalized diagram of a handset featuring the RF/IF/power amplifier subsystem.

Figure 1
RF/IF/Power Amplifier Subsystem



Source: Dataquest (September 1998)

The technology requirements for the handset are determined by two considerations, the frequency of operation of the functional blocks at the lowest possible power and the performance requirements of the system. On examining these requirements, we see that a cellular phone can be produced mostly with silicon technology. There are two requirements that determine the technology required, frequency and performance characteristics. The front end of a handset must operate at frequencies of 1 to 2 GHz, the IF section at 50 to 300 MHz, and the modulator/demodulator and baseband sections at tens of kHz to a few MHz. As a general rule, the front end of the receiver can be designed with either gallium arsenide (GaAs) or BiCMOS technology. Power amplifiers are currently made with silicon discrete or GaAs technology; the frequency synthesizer is made with BiCMOS technology; and the IF strip and the modulators/demodulators are generally made with linear silicon technology. Table 2 shows the key characteristics and the technologies used for each functional block in a typical cellular/PCS handset.

Table 2
Technology Selection in Cellular/PCS Phones

RF/IF Section	Key Characteristics	Technology
Transmit/Receive Switch	Low insertion loss Adequate power throughput	PIN diodes usually supplied as part of a module with filter
Low Noise Amplifier and Mixer (Down-Converter)	1-2 GHz frequency Low noise figure High linearity Adequate gain	GaAs or BiCMOS
Frequency Synthesizer and Voltage-Controlled Oscillator (VCO)	Low phase noise High stability 1-2 GHz input frequency	BiCMOS for frequency synthesizer linear or discrete for VCO
IF Amplifiers and Automatic Gain Control	50-300 MHz frequency Adequate gain and gain control	Bipolar or CMOS linear
Demodulator/Modulator	Voice frequency High accuracy	Bipolar or CMOS linear
Transmit Amplifiers	1-2 GHz frequency High power output (30-36 dBm) High linearity High power-added efficiency (low power)	GaAs IC or discrete MOS in a module

Source: Dataquest (September 1998)

Market Trends

The most significant forces driving the cellular/PCS handset market are pricing and the move to dual-band handsets, two conflicting forces that can be mitigated only by continued advances in IC technology.

Handset manufacturers have announced price declines in cellular/PCS handsets of 25 to 35 percent per year. We foresee this trend continuing for some time as more companies in the Asia/Pacific region enter the market supported by weak currencies and suppliers that provide them with turnkey high-integration design solutions, such as CommQuest's chipsets, that can be quickly launched into volume production. These events place pressure on the leaders (Nokia, Ericsson, Motorola, and QUALCOMM) to provide next-generation dual-band phones at attractive prices.

It is worthwhile to examine the economics of a cellular/PCS handset product before we consider the next steps for the industry. Dataquest has analyzed the semiconductor content of a variety of mainstream wireless handsets. Using as an example the Ericsson CF388 PCS 1900 phone, which we analyzed in the fourth quarter of 1997, we have identified a total of 380 electronic components in the handset. Of these, 46 are semiconductors, 322 are passive components, and 12 are other components. Of the semiconductor components, 21 are discrete devices, 15 are integrated circuits, and 10 are optoelectronic devices. A high-integration solution for the handset could reduce the IC count to five devices: a transmit power amplifier made from GaAs, a receiver front end made from GaAs or BiCMOS, an IF frequency synthesizer section made from BICMOS, a data conversion section made from mixed-signal BiCMOS, and a baseband section made from high-integration BiCMOS. After all of this effort, we have reduced the total component count from 380 to 370. Is this reduction worth the effort? Yes. The ICs represent almost half of the total cost of the handset and the greatest opportunity for cost reduction. Table 3 provides a cost analysis of the cellular/PCS handset.

Table 3
Cellular/PCS Handset Cost Analysis

Category	Value ($)	Percentage of Cost
IC	65.88	47.8
Manufacturing Value Added (MVA)	22.30	16.2
Disc/Passive/Other	16.95	12.3
PC Card	16.24	11.7
Filters/Crystals/VCOs	11.17	8.1
Display	5.35	3.9
Total	**137.89**	**100.0**

Source: Dataquest (September 1998)

These components also leverage the other costs, so that increased integration leads to reductions in the costs of the MVA, other components, and PC card.

Technology Analysis

Implementing an integration plan for a wireless handset is more complicated than for an all-digital system. As long as the design solution is based on a superhetrodyne receiver, the RF/IF section will remain essentially the same. An integrated solution will require a high-frequency mixed-signal technology. There are several candidates for this technology. These include BiCMOS, silicon-germanium enhanced BiCMOS, and silicon-on-insulator (SOI) technologies. Each of these offers important characteristics for the integration of wireless handsets. The following challenges have to be met to accomplish true system-level integration of a wireless handset:

- Meet the technical characteristics listed in Table 2:
  - High linearity
  - High efficiency
  - Low noise figure
  - Adequate gain
  - Low phase noise
  - High stability
- Integrate linear and digital functions
- Achieve high-frequency (2-GHz) and low-power functions on the same chip
- Achieve very high complexity (1 million gates) at low cost

The technology alternatives that are available for system-level integration of wireless handsets include GaAs for high-linearity power amplifiers, BiCMOS, silicon-germanium-enhanced BiCMOS and/or SOI for the rest of the receiver, and CMOS for the baseband processing. In the long term, silicon-germanium-enhanced BiCMOS with high-functionality CMOS digital capability could offer the possibility of integrating the RF/IF and baseband sections of the receiver onto a single chip. This could be further enhanced by SOI technology. Dataquest believes that the power amplifier will remain a separate building block and will most likely be manufactured from GaAs technology as handset designers continue to demand higher linearity and better efficiencies from their power amplifier suppliers.

In the following sections, Dataquest examines each of the technologies, then looks at possible technology road maps for semiconductors in handsets in more detail.

GaAs

GaAs has become a technology of choice for microwave monolithic IC (MMIC) power amplifiers (particularly in D-AMPS and CDMA handsets) and receiver front ends. The power amplifier is probably the most important function in the handset because it determines talk time and the battery life of the handset. Silicon laterally diffused MOS (LDMOS) discrete modules are used for power amplifiers in most GSM handsets, and BiCMOS is used in some handsets for the receiver low noise amplifier and mixer. Dataquest expects that designers are increasingly using GaAs MMICs for power amplifier designs, although the trend toward dual-band handsets will most likely extend the usage of modules for dual-chip configurations and for providing 50-ohm inputs and outputs.

Three alternative GaAs technologies have emerged as contenders for the power amplifier socket. All have demonstrated the ability to operate at 3V battery voltage.

The most widely used and lowest-cost technology is the metal semiconductor field-effect transistor (MESFET) technology, a relatively straightforward GaAs technology to manufacture that requires about 12 mask steps. MESFET technology can be processed with standard process technologies used for silicon devices.

Another alternative technology is pseudomorphic high electron mobility transistor (PHEMT) technology. PHEMT devices use heterojunction processes that use a different material such as gallium aluminum arsenide (GaAlAs) to produce a GaAs/GaAlAs junction to enhance performance and frequency of operation. Theoretically, this difference produces a device that will operate at higher efficiencies and therefore lower power. Producers of PHEMTs claim higher linearity as well. Molecular beam epitaxy is generally used to deposit the heterostructure layer on the GaAs substrate for PHEMTs and heterojunction bipolar transistors (HBTs), which will be discussed next. Both MESFETs and PHEMTs require negative power supply voltages. This requires additional circuitry that can be created on chip or externally (GaAs devices make good DC-to-DC converters).

The third GaAs alternative technology is HBT technology. This technology uses heterostructures similar to those used in PHEMT technology. However, HBTs are bipolar devices rather than MOS-type devices. As a result, HBTs operate from a single positive power supply. HBTs require two more mask steps, making the processing cost a little higher.

Both PHEMTs and HBTs have a higher cutoff frequency and maximum oscillation frequency than MESFET devices. The higher performance of these technologies comes at a higher wafer manufacturing cost. This higher cost is based primarily on the cost of the epitaxial wafer required for heterostructure devices, which is several times the cost of a wafer for producing MESFET technology. Manufacturers of PHEMT and HBT technologies are able to offset this higher cost by designing smaller chips, resulting in more die per wafer and thus a lower cost per chip. The die size reduction for HBT devices is actually sufficient to make the cost of the two equivalent die essentially equal.

Given these trade-offs, it is not clear that designers have declared any technology the winner. New designs include MESFET, PHEMT, and HBT power amplifier designs. At least for the short term, the jury is still out. It does seem clear that GaAs technology will be a key technology for power amplifiers for the foreseeable future.

Integration Technologies

Two new technologies offer significant opportunities for providing system-level integration solutions for wireless handsets: silicon-germanium-enhanced BiCMOS and SOI. These technologies offer the higher performance and lower power required for wireless handsets. Each is capable of system-level integration of the linear and digital functions required to create lower costs and higher levels of functionality for the multimode multiband wireless handsets being introduced by major handset suppliers.

Silicon-Germanium-Enhanced BiCMOS

About 10 years ago, IBM launched an R&D project to develop a higher-performance bipolar technology using silicon-germanium heterostructures for use in the company's next generation of mainframe computers. This technology was not chosen for that application; a different architecture was selected that used CMOS very large scale integration technology for those applications. As communications emerged as a high-growth market for the next decade, IBM identified this technology for creating design solutions for wireless communications applications.

As an enhanced form of BiCMOS, which is already an important technology used in wireless handsets, silicon-germanium-enhanced BiCMOS offers higher-frequency response than standard CMOS, making it possible to create lower-power solutions to handset RF/IF and high-frequency data conversion designs. Several other manufacturers have recognized the potential of silicon-germanium-enhanced BiCMOS for wireless applications. Silicon-germanium-enhanced BiCMOS currently represents an excellent technology for integrating the RF/IF section of the wireless handset. It is also capable of producing excellent high-speed analog-to-digital and digital-to-analog converters. Figure 2 shows a process diagram of a silicon-germanium-enhanced BiCMOS device.

The germanium is deposited as a thin-film base structure. This structure increases the mobility of the mobility electrons in the base, thereby increasing the frequency response of the bipolar transistor. Only the base area of the bipolar transistor is enhanced. As a result, the area of the device in which silicon-germanium is used is very small. This fact is important because the crystal structures of silicon and germanium are not entirely compatible. The lattice spacing of germanium is slightly larger (by 4 percent) than that of silicon. This difference can cause defects in the silicon at the heterostructure interface. Figure 3 shows what causes this phenomenon.

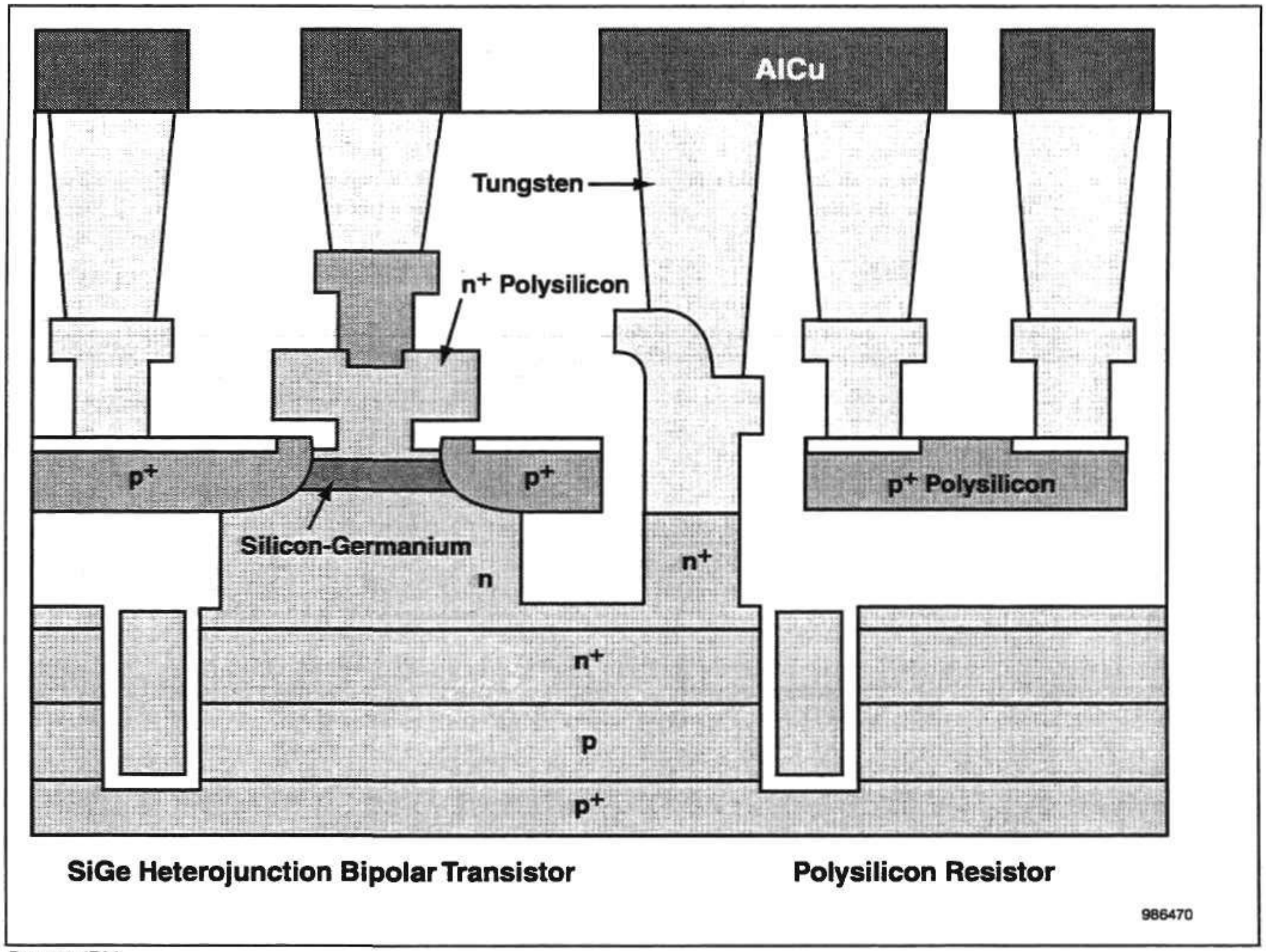
By controlling the deposition of the germanium material very carefully, this heterojunction can be created free of defects, making a very high-performance bipolar device.

Applying this technique to BiCMOS technology creates high-speed, low-power bipolar devices and low-power, high-density logic devices for implementing the digital control functions. In the longer term, it will be possible to integrate the data conversion with this technology as well. All of the pieces have been built individually. Over time they will be integrated in fewer silicon chips with silicon-germanium technology.

Silicon-on-Insulator

SOI technology was developed in the late 1960s as a technique for creating radiation-hardened ICs. Silicon-on-sapphire was originally used as the material. Other materials have been developed during the past 30 years, the most common creating a layer of silicon dioxide on a silicon substrate. SOI technologies have been found to offer a variety of benefits because of the reduction of silicon junction isolation and the resulting reduction in charge storage in semiconductor devices. SOI devices exhibit higher operating frequency, lower power, the ability to operate at high temperatures, and the earlier-mentioned radiation hardness now important for applications on satellites operating in the high-radiation environment of space.

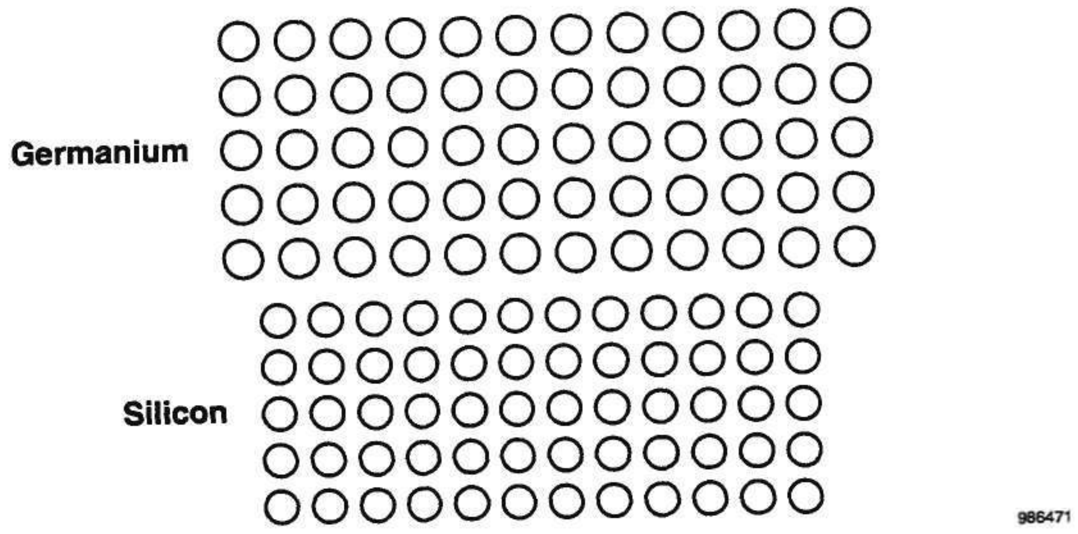
Figure 2
Silicon-Germanium-Enhanced BiCMOS Structure



Source: IBM

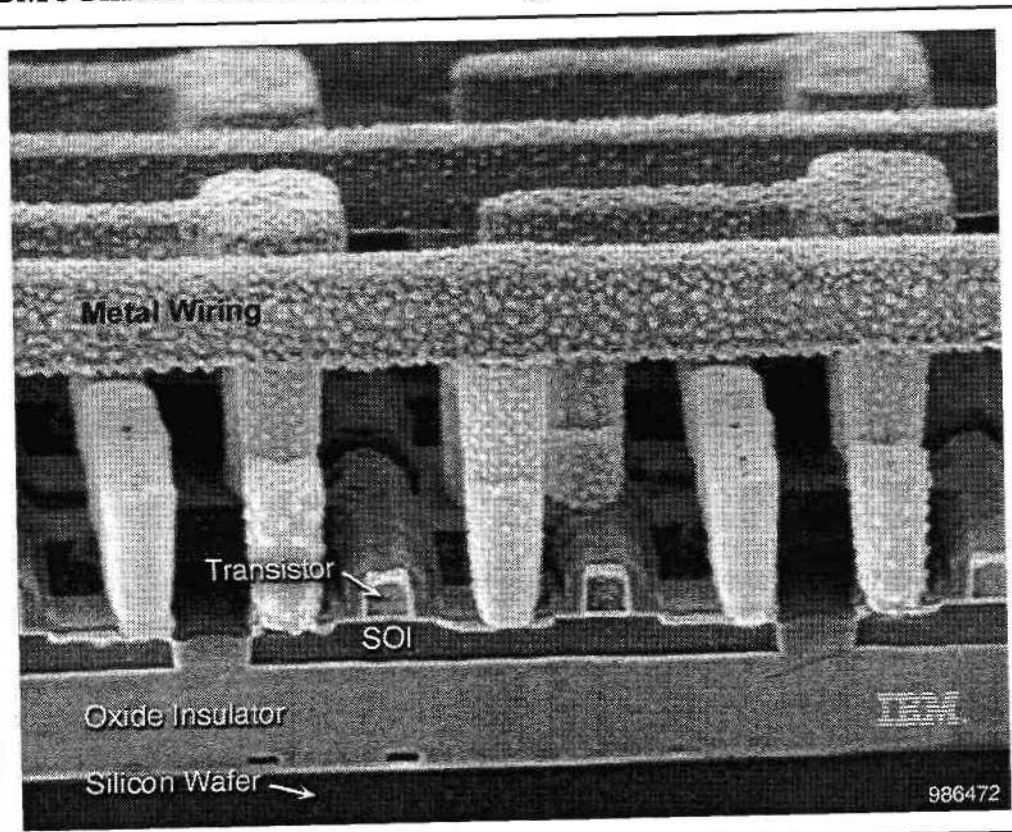
Two recent announcements by IBM and Peregrine Semiconductor heralded the mass commercialization of SOI technology. Figures 4 and 5 provide a picture of each of the technologies.

Figure 3
Different Lattice Structures of Silicon and Germanium



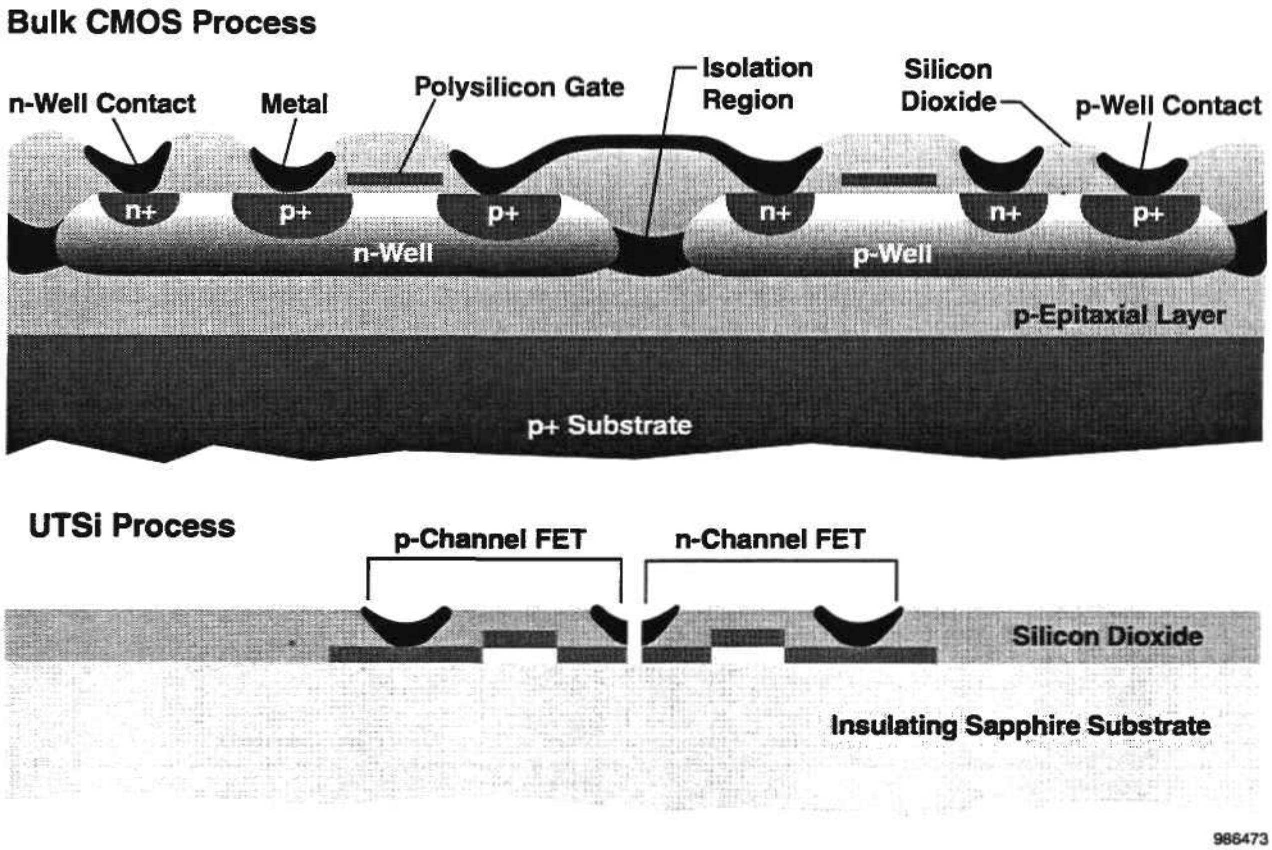
Source: Dataquest (September 1998)

Figure 4
IBM's Silicon-on-Insulator Technology



Source: IBM

Figure 5
Peregrine's Silicon-on-Sapphire Technology



Source: Peregrine Semiconductor

Both technologies essentially encapsulate each transistor in an insulating compartment. IBM uses a silicon substrate with a thin layer of silicon dioxide grown on top of it. Peregrine uses a sapphire substrate with a thin layer of silicon grown or deposited on top of it. In both cases, the p and n wells are eliminated. Devices are now electronically isolated from one another, reducing the interactions that can occur with junction-isolated devices.

IBM has portrayed SOI technology as a necessary step in the continuing progression of semiconductor technology according to Moore's Law, and the company is focusing its initial use of the technology on digital microprocessor applications. Peregrine has focused its use of the technology on communications applications with its initial offering of frequency synthesizer products.

Dataquest Perspective

So how will the future look, given these developments? Dataquest thinks that handsets will progress in the following manner:

- Power amplifiers will continue to migrate toward GaAs technology, with MESFETs, PHEMTs, and HBTs competing for the socket share in new designs. As handsets become more complex, we expect to see modules merge with integrated power amplifier solutions to offer single 3V or lower power supply multiband multimode devices with 50 ohms input and output in a single package.
- The rest of the RF/IF section can be integrated with BiCMOS or silicon-germanium-enhanced BiCMOS. Dataquest believes that the superior frequency response of silicon-germanium-enhanced BiCMOS will result in lower-power RF solutions, giving the technology the edge for PCS applications. An alternative solution for this application is SOI technology. SOI produces high-linearity, low-noise transistors with a frequency response of 50 GHz, comparable to GaAs or silicon-germanium-enhanced BiCMOS. In the longer term, this section of the receiver will include the data conversion devices that interface between the mixed-signal RF/IF section and the digital baseband section of the handset. For the next five years, there will continue to be a variety of solutions for the RF/IF section and the data conversion sections, including integrated solutions. These solutions will require two to three packages to implement.
- The baseband will continue to be integrated using mixed-signal CMOS technology. Solutions will be offered that reduce power using SOI technology. Dataquest believes that the memory will be integrated onto the baseband subsystem, resulting in a true single-chip baseband solution within five years.

It is important to recognize the role that SOI can play in this market. If SOI is successful in establishing a broad base of acceptance in both the radio and baseband sections of wireless handsets, it will eventually become possible to integrate the entire handset, except the power amplifier, onto a single high-performance, low-power chip. For this possibility to be realized, it will be necessary for SOI technology to become accepted by a broad base of semiconductor companies that supply baseband and radio solutions to the wireless communications applications market.

Either way, this progression will produce a five- to six-chip multiband multimode handset solution (including memory) within the next five years. In this time frame, the handset as we know it today will become a commodity, and the top-tier handset manufacturers will be developing broadband, multiband, multimode, multimedia handsets for third-generation applications.

Perspective

Wireless Semiconductors and Applications - Worldwide

Market Analysis

Second Quarter Wireless Update: It's A Mixed Bag

Abstract: *A review of second quarter performance of selected suppliers of wireless infrastructure, subscriber equipment, and semiconductors reveals a turbulent market where suppliers are experiencing mixed results depending on which markets and customers they are supplying with products. Semiconductor companies' performance is tightly coupled with the fates of the markets to which they are supplying their products.*
By Stan Bruederle

Wireless Equipment Manufacturers Report Strong Second Quarter (Mostly)

In the second quarter, major wireless equipment manufacturers reported strong revenue and earnings growth. The exception was Motorola. Strong undercurrents created varying results for companies depending on how they positioned themselves in the world markets. This Perspective will focus on cellular/personal communications services (PCS) companies, events, and trends.

Ericsson

Ericsson reported strong growth in all regions except North America. Continuing price pressure on the company's products was reflected in its report that contracts have changed from long-term agreements to frame agreements. These are more general agreements that enable customers to book orders close to delivery time. Some frame agreements are also structured to enable customers to take advantage of price changes in a market where prices are declining. Ericsson's management stated in a related announcement that cellular handset prices have been declining roughly 25 percent per year and are likely to continue to do so for the next few years, making it possible for operators to reduce phone subsidies.

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The company reported delivery problems in its new generation of switching systems, which affected its Mobile Systems (wireless infrastructure) group. Nevertheless, revenue for Mobile Systems grew 20 percent in the first six months of the year compared with the same period in 1997.

Ericsson reported that handset revenue grew 19 percent for the first six months of 1998 versus the same period of 1997. However, revenue for the second quarter of 1998 was flat as compared with the same period in 1997, reflecting the effects of the company's having missed a market window with its next generation of phones, Nokia's success in the handset market in Europe and North America, and price reductions.

Significant announcements by Ericsson during the period were that its World Phone would begin shipping in 1999. This phone is designed to take advantage of Ericsson's strong presence in the Americas with Digital Advanced Mobile Phone Service (D-AMPS) and the rest of the world with Global System for Mobile Communications (GSM). The company offers this phone as providing true world coverage while at the same time continuing its agenda of snubbing cdmaOne as a legitimate world standard.

Last quarter Ericsson introduced the proposed Bluetooth short-range wireless network standard along with Intel, Nokia, IBM, and Toshiba. According to Ericsson, more than 100 companies have committed to use Bluetooth.

Motorola

Motorola was significantly affected by the Asian economic situation and its still emerging position in digital phones. As a result revenue from its cellular business declined by 1 percent from the same period last year, while orders were down 11 percent.

The following excerpt from Motorola's second quarter press release provides an indication of current business conditions:

"Cellular Subscriber Sector (CSS) sales and orders declined. Sales and orders were higher in Europe, lower in Pan America and significantly lower in Asia. Sales of digital products continued to increase versus last year. This increase was entirely offset by a decline in sales of analog products, caused by a continuing trend of demand shift to digital products.

"Cellular Infrastructure Group (CIG) sales increased while orders were significantly lower. Sales were up significantly in Japan and Pan America, lower in Europe and significantly lower in Asia. Orders were higher in Europe, lower in Asia and Pan America, and significantly lower in Japan than a year ago when an unusually high level of orders was recorded on a contract to build a nationwide Code Division Multiple Access (CDMA) system. The cellular infrastructure business has been historically characterized by large orders and irregular purchasing patterns, which can cause volatility in quarterly growth rates."

Motorola announced the reorganization of several of its communications businesses representing roughly 57 percent of its 1997 revenue into one operation, which it calls the Motorola Communications Enterprise (MCE). The only large business unit not part of MCE is the Semiconductor Products Sector, which had revenue equal to the roughly $8 billion difference between MCE and the company's total revenue.

Nokia

Nokia has been the star this year, gaining share in phones worldwide against all competitors and experiencing rapid growth in its infrastructure business unit. Nokia's phone business grew 50 percent in the second quarter after achieving 29 percent growth in the first quarter for a total growth of 40 percent in the half. This performance compares to declining sales for Motorola handsets and 19 percent growth for Ericsson in the same period. Dataquest's forecast for 1997-to-1998 handset factory revenue growth is 9 percent. Nokia is clearly a star. Nokia began shipping dual-band phones for the North American market with its 6160 model in the first quarter of 1998. The 6150 dual-band GSM phone was introduced in June and is expected to be in volume production in the third quarter.

QUALCOMM

QUALCOMM reported revenue for the quarter ending June 28 to be $875 million, up from $520 million in the year earlier quarter. The company shipped more than 1.3 million phones and 4 million chipsets. The number of phones shipped represents almost one-fourth of the total shipped since QUALCOMM began shipping CDMA phones. The total number of chipsets shipped reached more than 20 million in the quarter.

Nortel

Nortel revenue for wireless networks increased 11 percent for the second quarter and 15 percent for the first half of 1998 compared with the same periods one year ago. Revenue was $937 million for the quarter and $1,850 million for the half. Revenue for the similar periods in 1997 was $920 million and $1,606 million, respectively.

Independent Hardware Suppliers Experience Tough Quarter

Suppliers of infrastructure-related hardware experienced another tough quarter as demand from customers in Asia dried up, forcing suppliers to scramble to find replacement business elsewhere. Suppliers of power amplifiers, repeaters, microwave radios, and related equipment reported slow growth for the second quarter.

Spectrian

Spectrian manufactures power amplifiers for wireless base station equipment. The company sells its products to companies that manufacture infrastructure equipment and to wireless network operators.

Spectrian's second quarter revenue dropped to $30.8 million in 1998 from $45.8 million for the same quarter in 1997. During the quarter, 92 percent of the company's business came from three customers, Nortel (66 percent), QUALCOMM (14 percent), and Nortel Matra Communications (12 percent). The company's top five customers represent 98 percent of its business. Competition with Powerwave and some resulting loss of business, coupled with the impact of the Korean economic crisis, which resulted in declining business from LG Information & Communications, were the major causes of the revenue decline. Spectrian announced that it expects this situation to continue for several more quarters, because the Asian crisis has created a much more competitive power amplifier market as suppliers scramble to find customers to replace the lost Korean business.

Powerwave

Powerwave revenue declined to $21.1 million in the second quarter 1998 from $27.4 million, a decline of 22.7 percent. The company attributed this decline to reduced sales of power amplifiers for PCS services particularly in Korea. This was partly offset by an increase in revenue for cellular multicarrier linear amplifiers (MCLAs) to customers in North America and other countries outside of Asia. MCLAs accounted for roughly 90 percent of sales in the second quarter of 1998 compared with the same quarter of 1997. PCS products decreased from 48 percent of sales in 1997 to 8.3 percent of sales in the second quarter of 1998. International sales declined from 89 percent of sales in second quarter 1997 to 34 percent in the same period of 1998. The company's gross profits increased to 40.4 percent of revenue in second quarter 1998 from 38.4 percent of revenue for the same period of 1997. This improvement was primarily because of a shift in product mix from single-carrier amplifiers to MCLAs.

Powerwave derived 55.2 percent of its business ($11.6 million) from BellSouth Cellular Corporation, Metawave Communications Corporation, and Nortel, up from 3.2 percent of the company's revenue in the 1997 period. For the first six months of 1998, 86 percent of Powerwave's revenue came from seven customers: BellSouth, Metawave, and Nortel, in North America, and Hyundai, LGIC, Samsung, and SK Global, in South Korea. In the same period of 1997, three South Korean customers (Hyundai, LGIC, and Samsung) accounted for 86 percent of the company's business.

Powerwave has done a masterful job of dealing with the dynamic conditions faced by the wireless communications industry in 1998. The company repositioned itself geographically, established a new customer base, and shifted its product mix within a 12-month period of intense competition created by the Asian financial crisis.

Semiconductor Suppliers Have Mixed Results

Alpha Industries

Alpha Industries reported sales of $30 million for the June 1998 quarter, an increase of 16 percent over $25.7 million for the same quarter of 1997. The company's wireless revenue was $14.1 million, or 47 percent of total revenue. One customer, which we believe to be Motorola, represents 25 percent of Alpha's business. Alpha indicated that it expected to gain market share in the handset radio frequency/intermediate frequency (RF/IF) market starting in late summer. The company's book-to-bill ratio for the June quarter was 1.0, indicating that revenue for the next quarter will be flat. This situation is attributed to the transition to dual-band phones at major OEMs. The company has dual-band products in qualification at each major OEM.

Alpha has made a major commitment to the wireless market. It is investing 75 percent of R&D and 85 percent of capital spending in wireless communications semiconductor products. The company is moving to pseudomorphic high electron mobility transistor (PHEMT) technology for its next-generation wireless products.

Anadigics

Anadigics reported revenue for second quarter 1998 of $22.7 million, an increase of $4 million or 21 percent over the same period of the prior year. Wireless revenue was $7.5 million, $1.5 million or 17 percent less than its $9 million revenue for the same period a year earlier. Anadigics' wireless book-to-bill ratio was positive in the period, indicating that revenue will grow in the next quarter. Wireless devices were the strongest booking area for the period. Wireless revenue for 1997 was $60 million, mostly from power amplifier products. Power amplifiers accounted for 33 percent of the company's revenue in the second quarter, down from 48 percent for the prior quarter. The company commented that its business has been affected adversely by its heavy dependence on QUALCOMM and the Asian market. Anadigics lost CDMA customers in 1997.

Sales of 3V power amplifiers are expected to begin in 1999. Current bookings are for 4.8V dual-band products. Prices are dropping 10 to 15 percent per year. Competition is very strong in power amplifiers from other GaAs suppliers and from some silicon suppliers. Ericsson is a major wireless customer, accounting for nearly 10 percent of Anadigics' total revenue.

Anadigics has evaluated several technology alternatives, including PHEMT, heterojunction bipolar transistor (HBT), and silicon-germanium. The company is planning to stay with metal semiconductor field-effect transistor (MESFET) technology for its power amplifiers and the lowest-cost solution. The company views silicon as a competitive technology for GSM because of its lower duty cycle and lower linearity requirements.

Wafer starts are currently running at 50 percent of capacity. The company expects to be operating at full capacity in three to four quarters and will be starting a new fab by mid-1999. Gross margins are not expected to increase in the short term because of lower-than-expected yields on new products (fiber-optic drivers and dual-band power amplifiers).

Celeritek

Celeritek's revenue for the second quarter was $10.2 million, down from $12.6 million in the second quarter of 1997. Semiconductor revenue was $3.7 million or 36 percent of total revenue, achieving solid growth over the same period in 1997. The company reported that semiconductor revenue would decline in the next quarter. In early June, Celeritek announced that it had received order delays and cancellations from several customers including some in the wireless handset markets, resulting in projected losses for the next two quarters.

RF Micro Devices

RF Micro Devices has been a star among the RF semiconductor companies. The company reported revenue of $23.2 million for the second quarter, compared with $10.2 million for the same period in 1997, an increase of 127 percent. The company has stated that 42 percent of its business in 1998 came from Nokia, where it has significant designs in Nokia's industry-leading 6100 family of handsets. Other important handset customers include Philips and Samsung. Declining revenue in Asia (South Korea) was more than offset by increased revenue elsewhere. It appears that the company has been constrained in its growth opportunities by its commitments to Nokia. However, with its new fab in production, RF Micro Devices may be expected to begin its efforts to expand its position in the market to achieve its projected 40 percent per-year five-year growth estimates.

RF Micro Devices reported declining gross margins in the second quarter because of ramping volume of wireless handset production and the relatively high manufacturing costs associated with production on three-inch GaAs wafers (supplied by TRW). The company's new four-inch wafer fab, which began production in the second quarter, is expected to alleviate this situation somewhat. However, competition in the wireless power amplifier market is fierce, and price pressure will keep margins under pressure. During the quarter, 87 percent of the company's revenue came from GaAs HBT products.

While RF Micro Device's revenue is currently heavily based on its GaAs HBT technology, the company is also gaining wireless handset designs with its silicon-based products. The company announced design wins at Philips Consumer Communications in high-integration CDMA transmit-and-receive components in two new handsets, the PCC 6820 digital PCS handset and the PCC 6830 digital/analog dual-band handset.

TriQuint Semiconductor

TriQuint reported second quarter revenue of $27.9 million, compared with $18.5 million a year earlier. Revenue growth was primarily because of the acquisition of Raytheon TI Systems' (RTIS') monolithic microwave integrated circuit (MMIC) operations. The company also reported revenue increases in its wireless and foundry businesses, while revenue from its telecom and data communications businesses declined. TriQuint has foundry agreements with Ericsson and QUALCOMM whereby the company manufactures custom products designed by these customers. Of the company's new designs, 60 percent are in the wireless segment, which accounts for about 44 percent of TriQuint's revenue.

The company states that no customer consumes more than 10 percent of its production. Key wireless customers include Ericsson, Philips, Lucent, QUALCOMM, Nokia, and Panasonic.

With its acquisition of RTIS' MMIC operations, TriQuint has the capability to produce GaAs PHEMT and HBT technology. At present, the company appears to be committed to its MESFET technology for cellular/PCS wireless applications. TriQuint has recently introduced new power amplifier products for handset applications. This is an increased emphasis for the company. Up to this point TriQuint's presence in wireless handsets has been primarily in the receive circuits.

Dataquest Perspective

The wireless communications market has shifted from high growth to mixed growth. The industry still has a positive long-term outlook. Dataquest forecasts that the subscriber base will grow to more than 500 million by 2002. Major cellular equipment providers forecast 600 to 800 million subscribers in that time frame. But in the short term, the market is in transition, and company performance is mixed. For example, the independent power amplifier manufacturers have been highly dependent on the growing South Korean digital cellular/PCS market for their revenue. They have suffered from the pullback on contracts from Korean companies for infrastructure equipment, and have had to quickly reposition themselves in the North American market. In spite of their efforts, they have experienced declining sales and have had to reschedule orders for semiconductors, affecting suppliers of RF power devices and other products used in these systems. Companies that have positioned themselves to supply infrastructure products to China, such as Ericsson and Nokia, have been able to avoid the effects of the Asian financial crisis so far. Motorola did not experience the same level of offsetting orders in Asia and saw a significant decline in orders in Japan as a result of having finished installing the DDI and IDO CDMA infrastructure projects.

In the handset business, RF Micro Devices had a stellar quarter as a result of its presence in Nokia's industry-leading 6100 family. Anadigics' performance in wireless was affected by slower demand at Ericsson, as that company was late in getting its new products to market and lost share to Nokia in important markets. Alpha Industries has done well and is expected to benefit from its designs in Motorola's new digital handsets as they ramp into production. Companies supplying products to Motorola's analog handsets (mostly Motorola itself) are suffering from the steep decline in analog handset sales, as reported in Motorola's quarterly report. This decline had already become apparent from Dataquest's market share analysis indicating that Motorola lost significant share of the RF/IF/power amplifier semiconductor market in 1997. Like Alpha, TriQuint appears to be positioning itself to benefit from Ericsson's expected introduction of its new digital handsets, which should rejuvenate Ericsson's handset business and provide TriQuint and Anadigics with revenue growth.

We can expect to see more of the same for the rest of 1998. The next major driver in the infrastructure market will be demand for systems to enhance network performance in the major markets and continued expansion of cellular infrastructure in emerging markets. Network performance may be the initial driver of demand for third-generation technology over the next few years. Some infrastructure suppliers expect network performance to be a more important demand driver than microcells.

Perspective

Wireless Semiconductors and Applications

Technology Analysis

Analog and Mixed-Signal IC Applications in Digital Cellular Phones

Abstract: *Digital cellular telephones represent one of the most important application markets for analog and mixed-signal ICs. Total consumption of analog and mixed-signal ICs in digital cellular phones, excluding RF ICs, is projected to exceed $1.9 billion by 2002. This Perspective examines the forces driving the success of the wireless market and the use of analog and mixed-signal IC in digital cellular phones.*
By Jim Liang and Dale Ford

Cellular Telephone Market Overview

The number of worldwide cellular/PCS subscribers has grown tremendously in the last few years. As this growth continues, the wireless handset market will expand from 124 million units in 1997 to 293 million units in 2002. Worldwide production of cellular telephone handsets is projected to grow at a solid 19 percent compound annual growth rate (CAGR) during the next five years, as shown in Table 1. Although analog handsets represented 38 percent of total production in 1996, digital handsets, growing at a CAGR of 24 percent, will account for 98 percent of worldwide production by 2002.

The digital handset market exploded in Europe during the 1990s as the European countries agreed on the unified standard, called the Global Standard for Mobile Communications (GSM). The European market had experienced very low cellular penetration rates before then. With the introduction of the GSM standard, which allowed easier roaming among countries, the market took off and quickly became the largest digital cellular market in the world. Many countries in other regions have adopted the GSM standard. The Americas market has been slower than expected to adopt

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digital technology; as a result, digital handset shipments accounted for less than 10 percent of the total Americas handset shipments in 1996. However, the digital handset market in the Americas region has grown rapidly in the last few years and should continue to experience strong growth.

Table 1
Worldwide Cellular and Broadband PCS Telephone Handset Production by Type (Thousands of Units)

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Cellular/PCS	78,624	123,841	149,562	179,333	217,102	256,097	293,445	19
Total Analog	29,835	25,241	18,362	14,148	11,397	8,547	4,520	-29
Total Digital	48,789	98,600	131,200	165,185	205,705	247,550	288,925	24

Source: Dataquest (June 1998)

Further insight into the wireless market is available in Dataquest's Market Trends Report *Communications Application Markets—Cellular/Broadband PCS and Cordless Telephones* (CSAM-WW-MT-9707, December 1997).

How Cellular Phones Work

Cellular telephones involve a relatively low-power handset corresponding with a local base station, of which there are many. The area surrounding the base station is called a "cell," and this can be visualized as a honeycomb. This simple concept yields powerful benefits. The handset can be small and light because it does not need to transmit over long distances. A large number of subscribers can be connected simultaneously because their signals travel only short distances and do not overlap with those in other cells. Traveling phones moving from one cell to another during a conversation can be accommodated by a central control's handing over responsibility for the handset from one base station to another.

Analog Cellular Phones

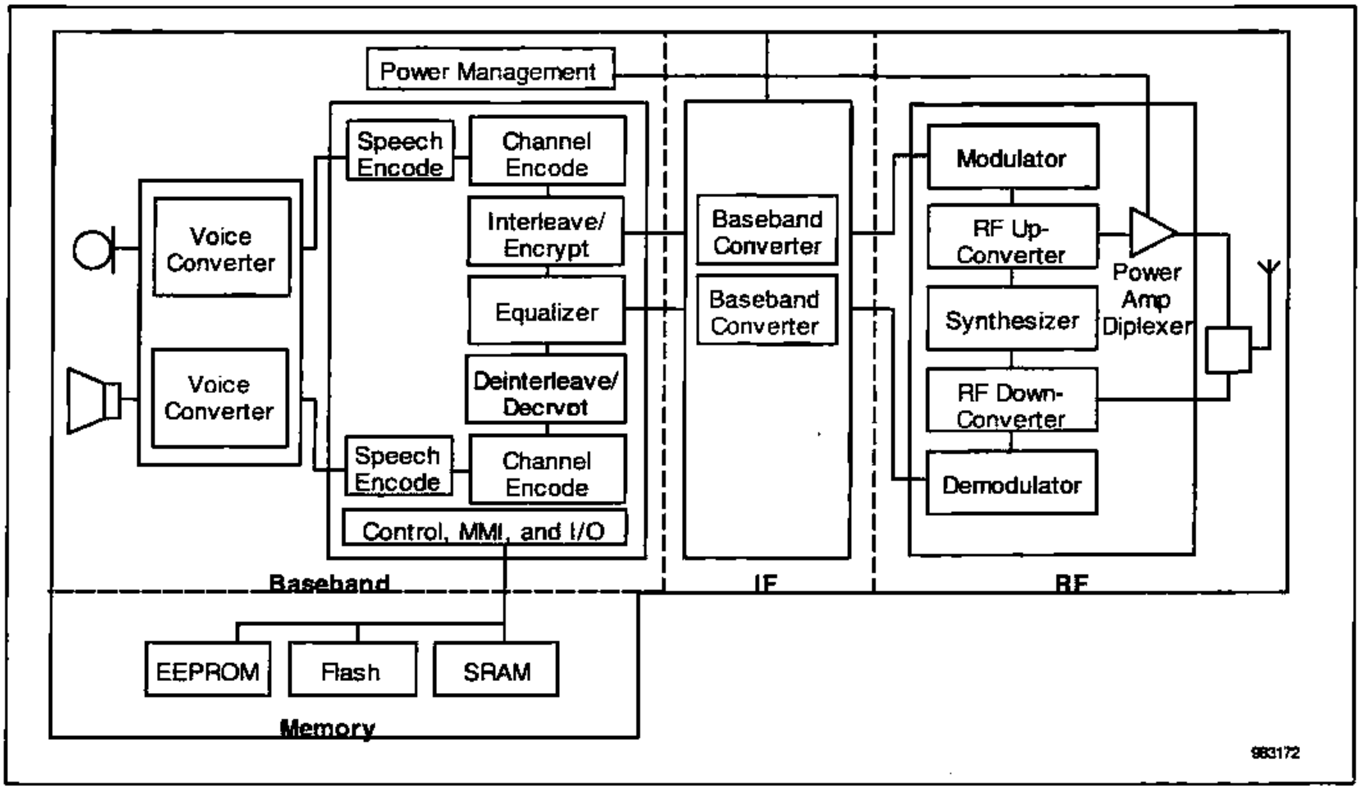
Analog cellular telephones were the initial standard deployed in the early days of cellular telephony. Voices are transmitted and received using a time-division multiplexing scheme, in which periodic samples of the voice are frequency modulated (FM) on a carrier frequency. The advantage of an analog approach is a straightforward, minimal design for both handsets and base stations. A disadvantage, it turns out, is a lack of security for both the information (the voice) and the control signals the phone uses to stay synchronized with the cellular network. This minor technical issue became a major financial opportunity for some ethically challenged members of society, who "clone" telephone serial numbers to circumvent usage fees. Another segment of society was able to listen in on, and record, phone calls with simple scanning receivers. A better solution was needed.

Digital Cellular Phones

Digital cellular telephones were the answer to these issues. Instead of transmitting the voice as an FM signal, the signal was digitized and sent as ones and zeros over a network optimized for digital traffic. A major benefit of this change is the ability to service multiple handsets with a single operation frequency instead of tying up a frequency slot per handset, yielding a dramatic increase in network call capacity. Digital handsets also have better energy efficiency, yielding longer battery lives. Furthermore, encryption was added for both serial number and voice data, making cloning extremely difficult. The initial digital standard was a European product using the GSM standard; since then, other digital standards—code-division multiple access (CDMA, or IS-95) and time-division multiple access (TDMA, or IS-54 and IS-136)—have emerged.

Figure 1 shows a block diagram of a typical digital cellular telephone, which comprises a radio frequency (RF)/intermediate frequency (IF) section, and a baseband section. The RF/IF section handles transmission and reception of RF signals. The baseband section processes communication signals at baseband frequencies.

Figure 1
Digital Cellular Telephone Block Diagram

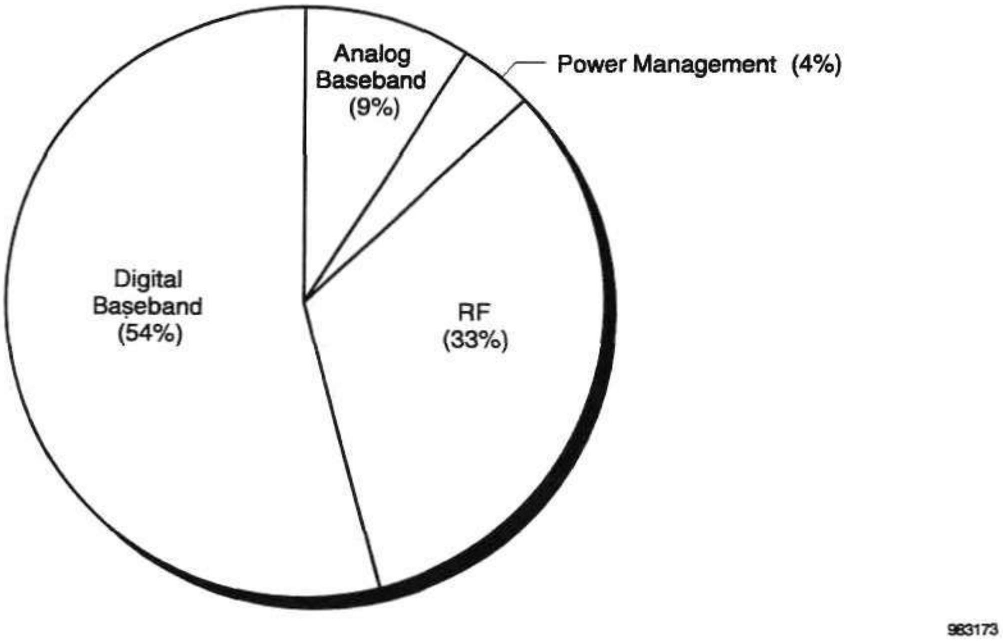


Source: Dataquest (June 1998)

Analog and Mixed-Signal ICs in Digital Cellular Phones

The semiconductors used in digital cellular phones can be categorized into three major types: power management semiconductors, baseband semiconductors, and RF semiconductors. Power management semiconductors are involved in supplying power to the phone. Baseband semiconductors include digital baseband ICs and analog baseband ICs. RF semiconductors include RF ICs and discrete transistors and diodes. Figure 2 shows an estimated breakout of semiconductor content in today's typical digital cellular handsets.

Figure 2
Estimated Semiconductor Content in Digital Cellular Handset



Source: Dataquest (June 1998)

The digital baseband semiconductors include digital signal processors (DSPs), microcontrollers (MCUs), and memory. Power management ICs, analog baseband ICs, and RF ICs are the analog and mixed-signal ICs used in digital cellular phones, and these are discussed further in the following sections.

Power Management ICs

Power management in cellular phones represents one of the hottest applications for analog ICs, not only because of the growth of the cellular phone market itself, but also because of the increasing need for longer battery life (which translates into longer talk time) and higher performance.

Power management ICs in cellular phones, also called voltage regulators, provide regulated voltage supply to various sections of the phone. Voltage regulators convert one DC voltage to another DC voltage. In the broad category of voltage regulators, there are two subcategories: linear regulators and switching regulators.

Linear regulators can only step down, providing output voltage that is smaller than input voltage. Switching regulators, which consist of switch, inductor, rectifier, and capacitor, can either step up (or "boost") voltage or step down (or "buck") voltage. Linear regulators have the advantages of low noise and good transient response but the disadvantage of poor power dissipation on the pass element. Switching regulators, on the other hand, can provide higher levels of power with greatly reduced thermal problems, because the power transistor is on for only a small fraction of the total time.

As a result, switching regulators are favored today for use with Pentium II-based microprocessors because of the high power involved. In digital cellular phones, a special type of linear regulators called low dropout (LDO) regulators are used. This is because they not only have lower noise, which contributes to good RF performance, but they also provide very low dropout voltage, resulting in higher conversion efficiency. Typically, multiple LDO regulators are used in a cellular phone to supply voltages to different sections of the phone.

The drive toward longer battery life and higher performance has challenged LDO regulator suppliers. Longer battery life means high conversion efficiency from the LDO regulator, which requires low dropout voltage and low quiescent current; higher performance means good RF characteristics from the LDO regulator, such as high ripple rejection and low noise. LDO regulators have been available in three different process technologies: bipolar, CMOS, and BiCMOS. Bipolar LDO regulators provide low noise but have the disadvantage of high dropout voltage and high quiescent current, which contribute to shortened battery life. CMOS LDOs offer very low dropout voltage and quiescent current orders of magnitude lower than bipolar LDOs, but they have higher noise. BiCMOS LDOs employ a bipolar pass transistor for high ripple rejection and hence low noise and CMOS circuitry for reduced quiescent current, but they still fall short in the area of low dropout voltage, compared to CMOS LDOs. The BiCMOS solution probably offers the best performance of the three options, but the cost of using a BiCMOS process is higher than that of straight CMOS. There certainly exist ample opportunities for more innovative solutions that provide "ideal" LDO regulators for cellular phones at the lowest cost.

The major players participating in the power management arena for digital cellular phones include National Semiconductor Corporation, Micrel Semiconductor Inc., Linear Technology Corporation, Maxim Integrated Products Inc., Texas Instruments Inc., SGS-Thomson Microelectronics B.V., Toko Inc., and Impala Linear Corporation. Table 2 lists all the major players, with comments on their competitive positions. Dataquest does not provide power management IC revenue estimates for individual suppliers of ICs for digital cellular because they have not been surveyed at this detailed level.

The total power management IC market in 1997 is estimated to be about $2.5 billion, and the total value of power management ICs used in digital cellular phones in 1997 is estimated to be about $291 million.

Table 2
Major Players in Power Management ICs for Digital Cellular Phones

Companies	Comments
National Semiconductor	First to market with LDO regulator solution for wireless market; the current market leader
Micrel	Fast-growing new entrant; gaining market share
Linear Technology	Specializes in high-performance LDOs
Maxim	Specializes in high-performance LDOs
Texas Instruments	Made significant inroads in 1997 in power management to complement its DSP and mixed-signal leadership in cellular phone market
SGS-Thomson	Expertise in power processes; close relationship with Nokia and Ericsson
Toko	Specializes in low-cost LDOs
Impala Linear	Start-up company specializing in high-performance CMOS LDOs

Source: Dataquest (June 1998)

Although there is increasing trend to integrate separate functions of the cellular phone into a single chip, power management will likely remain independent because of the complexity of the analog processes involved in making power management ICs. Furthermore, the increasing need for longer battery life and higher performance will continue to stimulate the growth of power management solutions. As a result, power management ICs in digital cellular phones are projected to grow at a strong CAGR of 18 percent for the next five years, from $291 million in 1997 to $665 million by 2002.

Analog Baseband ICs

The analog baseband functions include voice coder/decoder (CODEC), and RF CODEC. The voice CODEC, linking the digital baseband to the microphone and speaker, sends a user's voice to the digital baseband and allows the received signal to be heard through the earphone speaker. The RF CODEC, linking the digital baseband to the RF subsystem, converts an outgoing digital data stream from the digital baseband into a modulation format appropriate to the transmission standard and converts an incoming signal received by the RF subsystem for further processing by the digital baseband. These two analog baseband functions, often referred to as baseband interface functions, provide an analog front end to digital communication systems and not only link digital baseband with users' voices and RF signals but also carry a great deal of the processing workload, such as maintaining signal quality, extending talk time, and improving overall system performance.

Unlike power management, where analog technology is key, the name of the game in supplying analog baseband CODECs is mixed-signal technology. Only companies with both analog and digital design and process expertise can compete well in this market. The major players that supply analog baseband CODECs include Texas Instruments, Motorola Incorporated, Lucent Technologies Microelectronics Group, NEC Corporation, Philips Semiconductors Inc., Siemens AG, VLSI Technology Inc., QUALCOMM Incorporated, DSP Communications Inc., and Analog Devices Inc. Table 3 lists the major players, with comments on their competitive positions.

Dataquest does not provide analog baseband revenue estimates for individual vendors because they have not been surveyed at this detailed level.

It is evident that all these suppliers have very significant mixed-signal expertise. And not surprisingly, the four leading DSP suppliers—Texas Instruments, Lucent Microelectronics, Analog Devices, and Motorola—are all active players, aiming to offer complementary mixed-signal DSP solutions for the wireless market. Furthermore, some of the players are vertically integrated wireless OEMs themselves, with in-house semiconductor business units that supply both internal and external customers.

The total analog baseband IC market for digital cellular phones in 1997 is estimated to be around $641 million. Since there is an increasing trend toward integrating the analog baseband CODECs and the digital baseband functions onto a single chip, the analog baseband ICs are projected to grow at a moderate CAGR of 14 percent for the next five years, from $641 million in 1997 to more than $1.2 billion by 2002.

Table 3
Major Players in Analog Baseband ICs for Digital Cellular Phones

Companies	Comments
Texas Instruments	Major supplier to first-tier OEMs Ericsson and Nokia; in-house DSPs
Motorola	Wireless OEM itself; in-house DSPs; trying to shift away from analog cellular and ramp up digital cellular
Lucent Microelectronics	In-house DSPs; announced an integrated DSP and voice CODEC chip for CDMA
NEC	Strong system-level ASIC technology
Philips	Wireless OEM itself with in-house semiconductor unit
Siemens	Wireless OEM itself with in-house semiconductor unit
VLSI Technology	Supplier of baseband ASICs for GSM
QUALCOMM	Wireless OEM itself; strong player in supplying baseband chipsets for CDMA
DSP Communications	Supplier of baseband ASICs for TDMA and CDMA; licensed CDMA technology from QUALCOMM
Analog Devices	Supplier of GSM chipsets to wireless OEMs such as Philips and Siemens

Source: Dataquest (June 1998)

RF ICs

RF ICs are mainly amplifiers, transmitters/receivers, and synthesizers. Amplifiers include power amplifiers for transmission of the radio signal and low-noise amplifiers (LNAs) for reception of a radio signal. Transmitters/receivers, along with synthesizers, handle many of the transceiver modulation/demodulation functions.

RF amplifiers represent the largest segment within RF ICs. A large portion of amplifiers, especially the power amplifiers supplied for cellular phones today, are based on gallium arsenide (GaAs), with the major players being Anadigics Inc., TriQuint Semiconductor Inc., and RF Micro Devices Inc. The other RF ICs, such as transmitters/receivers and synthesizers, are mostly silicon-based and made with a bipolar process. The major suppliers of transmitters/receivers include Hewlett-Packard Company, Motorola, Philips, Siemens, and NEC; the major suppliers of synthesizers include National Semiconductor, Motorola, Philips, and Fujitsu Ltd.

Texas Instruments has thrived on supplying baseband semiconductors for the digital cellular market. In a move to provide full solutions for the digital cellular market and lay the groundwork for the single-chip cellular phone, TI has announced its own RF products such as LNAs, receivers, and synthesizers, and is expected to announce power amplifier products in the near future. More detailed analysis of TI's wireless move is available in the Dataquest Perspective "Texas Instruments and its New Analog Thrust" (SEMI-WW-DP-9804, May 1998).

Silicon germanium (SiGe) technology has emerged as a potential alternative to GaAs and silicon technologies. The primary advantage of SiGe technology is that it leverages traditional silicon CMOS and bipolar processing to achieve higher-frequency performance and reduced power consumption. IBM has been the leading proponent of SiGe technology for the wireless market and has developed extensive SiGe technology in-house over the past few years. In a move to remedy its lack of wireless design expertise, IBM acquired CommQuest Technologies Inc., a chip design house known for its wireless communications design skills. With CommQuest's wireless know-how and its own pioneering SiGe effort, IBM has laid plans to provide single-chip cellular solutions, including RF and baseband parts, using its SiGe technology.

A more detailed analysis of RF semiconductors for wireless applications, including an RF IC market size forecast, will be available from Dataquest's Wireless Semiconductor Application Markets Worldwide (WSAM-WW) program, to be launched in July.

Analog and Mixed-Signal IC Market Size Estimate

Table 4 shows current market size estimates and growth projections for power management ICs and analog baseband ICs in digital cellular phones. Total consumption of analog and mixed-signal ICs in digital cellular phones, excluding RF ICs, is projected to exceed $1.9 billion by 2002. The RF IC market size and projections will be published by Dataquest's Wireless Semiconductor Application Markets Worldwide program.

Table 4
Digital Cellular Handset Consumption of Power Management and Analog Baseband ICs

	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Units (K)	48,789	98,600	131,200	165,185	205,705	247,550	288,925	24
Power Management ($M)	178	291	365	443	518	592	665	18
Analog Baseband ($M)	398	641	771	894	1,018	1,136	1,245	14
Total ($M)	575	932	1,136	1,336	1,537	1,728	1,910	15

Source: Dataquest (June 1998)

Dataquest Perspective

Although the remarkable growth of the PC market in the last decade has been the driving force behind the growth of semiconductors, Dataquest believes the communications market, including wireless communications and wired communications, will join the PC market as driving forces behind semiconductor growth for the next decade.

The surge in sales of digital cellular telephones has provided tremendous profit opportunities for companies supplying this market. With further penetration of digital cellular in underdeveloped regions of the world, the digital cellular market will continue to expand. Dataquest believes that analog/mixed-signal and RF technologies will be among the key weapons that allow semiconductor vendors to win in this expanding wireless market.

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Perspective

Wireless Semiconductors and Applications

Product Analysis

Wireless Semiconductor Industry Activity Heats Up in February

Abstract: *This Perspective provides a summary review and analysis of important semiconductor announcements in the wireless industry during February 1998. A significant number of important product announcements, ranging from basic process technologies to new baseband and RF chipsets, were made.*
By Dale Ford

A Flurry of Product Announcements

February saw a significant number of important product announcements, ranging from basic process technologies to new baseband and radio frequency (RF) chipsets. The products unveiled during this month provide a valuable insight into progress and developing competition in the wireless semiconductor industry. This Perspective will provide a brief summary and analysis of important product announcements in:

- Silicon-germanium (SiGe) technology
- Lower-power and dual-band gallium-arsenide (GaAs)ICs
- New chipsets for code-division multiple access (CDMA) in both baseband and intermediate frequency/radio frequency (IF/RF) solutions
- Wireless LAN chipsets based on the IEEE 802.11 standard
- Silicon-on-insulator (SOI) technology
- Other developments

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IBM Microelectronics Acquires CommQuest and Promotes SiGe

IBM and CommQuest Technologies Inc. announced on February 11 that they have entered into a merger agreement. The companies believe the merger will speed industry development of a new generation of multifunction, low-cost, mobile "information appliances," capable of communicating over voice and data networks. Such devices are a key element in IBM's vision of the future of computing and include products such as single-chip, watch-size cellular phones, and a handheld device that will provide cellular phone, e-mail, global positioning, and Internet access.

CommQuest, a privately held company based in Encinitas, California, designs and markets advanced semiconductors for wireless communications applications such as cellular phones and satellite communications. The merger will combine IBM's leadership in semiconductor technology and manufacturing with CommQuest's recognized chip design and systems skills for wireless communications products. The companies will immediately broaden efforts to sell CommQuest communications chip products through IBM's extensive sales network.

IBM expects the merger will accelerate the use of its unique (SiGe) semiconductor technology. IBM believes silicon germanium is an ideal technology for wireless communications applications because it can operate at extremely high speeds with low power requirements. Joint product development will also include the use of IBM's copper chip technology, which could allow further reductions in communications system power requirements.

The new organization will become a unit of IBM's Microelectronics Division. The merger transaction will be financed from IBM's cash on hand. IBM confirmed reports that it will pay $180 million for CommQuest. However, it is understood that the total acquisition costs will actually approach $200 million.

CommQuest has built its products and business around its innovative and proprietary Communications Applications Specific Processor (CASP) architecture. At the heart of this architecture is a library of functional blocks that perform specific communication functions. CommQuest believes this system will permit the development of flexible and highly efficient communications solutions that are superior to traditional digital signal processing-based (DSP) products. CommQuest's current product line includes: a highly integrated, multiband global system for mobile communications (GSM) and advanced mobile phone service (AMPS) cellular chipset for handsets; a single-chip demodulator/decoder for direct broadcast satellite (DBS) set-top boxes; a frequency-division multiple access (FDMA)/CDMA/time-division multiple access (TDMA) satellite communications modem; and a single-chip, multinetwork modem. CommQuest earned a design-win in 1977 for its three-chip GSM baseband/IF solution with selected third-tier cellular handset OEMs. CommQuest had strong expectations for its two-chip GSM solution, announced in January. Last December, CommQuest announced a $19 million contract for the design of a single-chip modem for Rockwell's Universal Modem System (UMS) under development for the U.S. Army.

Last year, IBM began a high-profile campaign to promote its SiGe process, which it had been refining for many years. IBM believes it can produce highly efficient, integrated, cost-effective products using this technology, which is superior to wireless semiconductor solutions based on GaAs and traditional silicon technologies. IBM initially screened more than 60 companies as potential partners for its SiGe products. IBM representatives visited 20 companies from last June through August.

The results of those meetings are a matter of disagreement between IBM and some of the companies it visited. IBM claims that it decided there were too many potential conflicts in working with companies developing GaAs-based products. As a result, IBM never offered its SiGe technology to these companies. Various GaAs semiconductor companies indicated to Dataquest that they were not convinced that SiGe could meet their requirements, and passed on the opportunity to partner with IBM. In a related effort, IBM has developed a strategic foundry partnership model for SiGe. It has entered into working agreements with Northern Telecom Inc., Hughes Electronics, Tektronix Incorporated, Harris Semiconductor Inc., and National Semiconductor Corporation for supplies of chips and packaging devices. Convinced of the potential of its SiGe process, IBM invested in CommQuest as another vehicle to enter the market directly.

IBM claims that its SiGe products will offer twice the power efficiency of GaAs at two or three times less cost. IBM says it can achieve this cost advantage through process improvements that enable higher yields in a 0.25-micron process on eight-inch wafers. However, IBM notes that there are 34 mask steps in producing SiGe ICs. The company says that its flip-chip packaging technology works very well with SiGe. IBM anticipates that two-thirds of its SiGe business will come from customer-specific products and that it will introduce standard products later this year.

Red Herring, the technology monthly magazine, named CommQuest as one of its "Top 100 Technology Companies for 1997" and estimated the company's revenue at $24 million in 1997, up from $9 million in 1996. A purchase price of $180 million to $200 million would indicate that IBM is basing its valuation heavily on the combined potential offered by CommQuest and SiGe. IBM is hoping to reap early benefits on its investment. In IBM's conference call the company indicated that it is in the process of qualifying its SiGe technology for bipolar and BiCMOS and plans to introduce a true single-chip cellular solution including baseband and RF systems in early 1999. IBM stated that it would start with a multichip module and eventually move to a single-die product.

Deals such as the IBM and CommQuest merger are occurring more frequently in the semiconductor industry and would seem to parallel a trend in professional sports organizations such the National Football League and the National Basketball Association. As the sports pages announce multimillion dollar contracts for rookies fresh out of college or high school, commentators wonder about the wisdom of investing such large sums in these young athletes. Even though they may possess great talent and promise, they still have not proven themselves on the field of top-level competition. However, in an effort to win championships or lucrative television deals, the value of these contracts with young athletes reaches new, unimaginable heights each year. IBM has now invested a major sum in its "highly talented athlete" as it enters the highly competitive arena of wireless communications and "information appliances." It should expect a bruising battle as it fights seasoned veterans to reach the playoffs and contend for the top prize: a contract with tier-one and tier-two OEMs.

QUALCOMM Unveils New CDMA Chips for IS-95B along with Vision for Future

At the end of February, QUALCOMM Incorporated announced its plans to support the IS-95B CDMA system and unveiled its next-generation baseband and RF/IF chips for handsets and infrastructure that will support this standard. The key benefit if the IS-95B standard is its support for higher data-rate communications. It also provides improvements in soft handoffs and interfrequency hard handoffs. QUALCOMM expects service providers to benefit from support of Medium Data Rates (MDR) of 57.6 Kbps with initial requirements of 28.8 Kbps and 57.6 Kbps on the forward link and 14.4 Kbps on the reverse link. Eventually, data rates of 115 Kbps will be supported in the standard. This improvement in performance is achieved by aggregating up to eight CDMA traffic channels for data transmission. A new lineup of advanced chips was announced that will provide the platform for developing new systems and handsets based on the IS-95B standard.

MSM3000 CDMA Handset Baseband Modem

The MSM3000 is a next-generation mobile station modem baseband solution that features data rates greater than 64 Kbps along with a new microprocessor architecture and advanced power control features. In addition to proprietary CDMA building blocks, an ARM7 TDMI microcontroller has been incorporated into this design, replacing the x86 cores used in previous CDMA baseband chips from QUALCOMM. This is yet another win for the highly popular ARM architecture in the wireless world. The existing MSM code base and the real time operating system (RTOS) are being ported to the ARM and relayered to smooth migration to the new architecture.

The new SuperFinger demodulator architecture in this chip supports simultaneous demodulation of up to six or eight channels. A new sleep controller is expected to enable 200 hours of standby time using an 800 mAh battery in CDMA mode and double standby time for AMPS mode operation. The chip supports 8K and 13K QUALCOMM Code Excited Linear Prediction (QCELP) and Enhanced Variable Rate Coder (EVRC) vocoders as well as new voice recognition functions.

The chip will be fabricated in a 0.35-micron process at 2.7V minimum and later moved to a 0.25-micron process at 2.3V minimum. The MSM3000 can be combined with the new IF and RF integrated solutions described below to make up all the system hardware necessary for an entire IS-95A or IS-95B

CDMA-compliant subscriber unit. The first engineering samples are expected to be available this summer, with production quantities planned for later in 1998.

CSM2000 CDMA Infrastructure Baseband Modem

The CSM2000 is a multiple-channel CDMA digital baseband modem capable of supporting up to eight forward link channels and eight reverse link channels. This will allow it to support IS-95B data rate services. This chip promises to provide more than 75 percent power savings when replacing eight CSM1.0 devices and 25 percent when replacing eight CSM1.5 devices. It requires a power supply operating between 21.7V and 3.6V. The footprint of the CSM2000 is only 18 percent of the area occupied by eight CSM1.5 devices. Engineering samples are expected in the third quarter of 1998, with volume production starting in the fourth quarter of 1998.

IFR3000 and IFT3000 Intermediate Frequency Chipset

The IFR3000 and IFT3000 chipset performs all of the signal processing functions required between the digital baseband and the RF front end for IS-95 CDMA applications. This new IF chipset should enable an area reduction of at least 45 percent over previous chipsets and will operate at a supply voltage down to 2.7V. The chipset will interface directly with MSM2300 and MSM3000 baseband chips. The IFR3000 includes receive power control through a 90dB dynamic range automatic gain control (AGC) amplifier, IF mixer for downconverting, and analog-to-digital (A/D) converters for interfacing with the baseband. The IFT3000 includes a D/A converter for interfacing with the baseband, an IF mixer for upconverting, transmit power control through 85dB dynamic range AGC amplifier, and a programmable phase lock loop (PLL). Engineering samples are expected in the third quarter of 1998 with volume production starting in the fourth quarter of 1998.

U1000 and U1100 RF Upconverters

The U1000 wideband upconverter and U1100 dual-band upconverter are designed to work with the QUALCOMM family of IF chipset solutions. Their RF output performance has been specifically characterized over the cellular frequency band, U.S. personal communications services (PCS) frequency band (1900 MHz), and Korean PCS frequency band (1800 MHz). The U1100 dual-band upconverter includes two selectable RF outputs to accommodate the dual-band/dual-mode CDMA phone applications. The chips will operate over a supply voltage of 2.7V to 3.78V. Device samples are planned for March 1998 with production volumes expected in May 1998.

A Vision of the Path to "Third Generation" Systems

In comments that he delivered at the 1998 Robertson Stephens technology conference, Harvey White, president of QUALCOMM, provided a brief outline of how his company sees the evolution of wireless communications developing and expressed concerns about the International Telecommunications Union's (ITU) Third-Generation (3G) standard that was recently approved. QUALCOMM's road map moving beyond IS-95B is evolutionary in nature with the following future standards:

- IS-95C standard—64- to 100-Kbps data rate; doubles CDMA capacity; compatible with A&B standards; plan to deploy in 1999
- IS-95HDR standard—1+ Mbps in 1.25-MHz channel and up to 2.5 Mbps in 2.5-MHz channel
- Integrated wireless data solutions

A brief summary of comments and concerns regarding the ITU 3G standard and European/Japanese alliance made by Mr. White:

- This system envisions 5 MHz of bandwidth availability, which will exclude the participation of as many as two-thirds of service providers worldwide.
- This is not an efficient system for voice, and it is still voice that pays the bills.
- Availability and timing of service turn-on is highly uncertain because of development by committee process and creation of a separate system.
- QUALCOMM believes in an evolutionary process of higher data-rate provisioning as described above instead of trying a sudden jump to a 5-MHz system.
- In any event, QUALCOMM insists that those who claim the ITU 3G standard excludes its patents are incorrect. QUALCOMM has strong patent positions, with 127 patents issued and 361 patents pending. In support of its stance, QUALCOMM quotes Peter Hildebrand, chair of the mobile subcommittee of the European Telecommunications Standards Institute (ETSI), who said, "The intellectual property rights held by QUALCOMM lie at the heart of the UMTS 2000 standard."

Shortly after this conference, the CDMA Development Group (CDG) passed a resolution on 3G standards calling for worldwide efforts toward convergence and efforts to develop a common CDMA technology standard. Specific discussion of GSM, the IMT-2000 standard, and various regional efforts was directed toward the benefits of a unified standard. Although the CDG is correct in noting the benefits of a unified standard, it will not be a simple matter of achieving this nirvana. Just as QUALCOMM points to its patent portfolio with pride as a source of value, other companies will also be seeking to leverage similar technology claims to position themselves for benefit in this future system. As other global standards efforts such as DVD and digital TV (DTV) can attest, there are great hurdles to leap before realizing a common global standard. However, the CDG's statement still holds out hope that efforts will be made in the direction of avoiding another standards battle in third-generation systems.

DSP Communications Begins Volume Production of CDMA Chipset

On February 23, DSP Communications Inc. announced commencement of volume production of CDMA baseband processor chipsets. First volume production deliveries were expected during the first quarter of 1998 and further quantities are scheduled for delivery to OEM handset manufacturers beginning in the second quarter. DSPC's D5411 CDMA chipset, consisting of a CDMA digital ASIC and an analog interface ASIC, will be used in dual-mode and dual-band handsets based on the IS-95A standard. The chipset offers any one of several analog modes, including AMPS, Japan Total Access Communications System (JTACS), or Nordic Total Access Communications System (NTACS). DSPC is also promising to offer more highly integrated solutions that will enable smaller size, lower price, and better power efficiency in the coming months.

DSPC anticipates handsets based on its chipset will be available in the market by mid-1998. It announced earlier that it had captured design-wins for its CDMA chipset with Kyocera Electronics Inc., Siemens AG, Fujitsu Ltd., and Kenwood Corporation. However, shortly after the DSPC announcement, Siemens announced it is pulling back from producing CDMA handsets while it re-evaluates its third-generation CDMA-product strategy. Also, it appears that DSPC may have lost one of its Japanese clients.

However, this is still an important milestone for DSP Communications. It first announced its CDMA license agreement with QUALCOMM in November 1995. By summer 1996 DSPC was publishing product overviews of its first announced CDMA chipset product, the D5401, and exploring preliminary plans to begin delivering samples of its chipset in the second quarter of 1997 followed by volume production in the third quarter of 1997. The intervening period between mid-1996 and now has been turbulent for DSPC with both significant highs and lows. During 1996 and most of 1997, almost all of DSPC's revenue have come from its personal digital cellular (PDC) chipset products shipped into the Japanese market. During 1997, DSPC had to manage a difficult product transition as it migrated to a new PDC chipset product generation. Given the importance of the PDC market to its revenue base, this transition consumed significant resources. The good news for DSPC is that it appears to have weathered the storm and emerged with a continuing solid presence in the PDC market.

In order to stay on a growth path for the long term and reduce the risk of being highly dependent on a single market, DSPC has been developing products targeted at the TDMA (IS-136) and CDMA markets. One of the high points of 1997 came with the first shipments of its IS-136 products to key customers including NEC Corporation. However, planned shipments of CDMA products continued to slip through the year. By the time DSPC announced the first sample shipments of its CDMA chipset to OEMs, the company had moved to its next-generation product, the D5411. A top-line comparison of the data sheets for the D5401 and D5411 reveals that the latest-generation product delivers significant improvements in package size and pin count, but a mixed bag in power consumption. The digital ASIC has been reduced from a 144-pin TQFP with 0.5mm pitch to a 120-pin TQFP with 0.4mm pitch. The analog interface ASIC has been reduced from 100 pins to 80 pins. However, while the specification for power consumption in CDMA idle mode (for continuous receive) has been reduced from 35mA to 26mA, the figure for CDMA traffic mode has increased from 50mA to 58mA and analog standby mode has increased from 2mA to 5.3mA. Almost all other specifications for the chipset appear to remain the same.

The CDMA baseband chipset competition is expanding dramatically in 1998. During the initial phase of the CDMA market, QUALCOMM had been the sole supplier of baseband chipsets. Nokia was the first to deliver a CDMA handset that did not use a QUALCOMM chipset at the end of 1997. Its handset was based on an internal design. Motorola Incorporated just announced plans to deliver a handset using an internally developed chipset after experiencing repeated delays in reaching the market. DSP Communications and VLSI Technology Inc. will start delivering chips into the merchant market this year. LSI Logic Corporation, the other CDMA chipset licensee, has not announced any specific market or product plans for CDMA. The continual question being addressed in the semiconductor and wireless industry is what impact the Asian financial crisis will have on industry and business fortunes. This issue was highlighted when QUALCOMM recently announced order cancellations and delays for its CDMA chipset from major Korean manufacturers. DSPC's lineup of customers for its CDMA chipset would seem to indicate that this will not be a major issue for it. The Japanese OEMs will likely be targeting the new CDMA market in Japan.

With the experience already gained in competing in the PDC and TDMA (IS-136) markets, DSP Communications should be a solid competitor in the CDMA chipset market and benefit significantly from the strong growth forecast for this segment. However, another major distraction that could hinder DSPC in its market efforts is a class-action lawsuit filed against the company in February by stockholders, charging company officers and directors with securities violations. Juggling the demands of lawyers and courts while staying focused on pursuing multiple markets will add a significant element of risk for DSPC.

Lucent Technologies Introduces New Integrated EVRC Chip

At the Wireless '98 show, Lucent Technologies Microelectronics Group introduced an integrated chip for cellular phones that doubles the memory of its previous-generation device and makes possible smaller phones with more advanced features. The chip, called EVRC PRO is Lucent's second-generation EVRC speech coding device for the CDMA market. The new chip integrates a DSP and voice codec on the same chip. In Lucent's earlier EVRC offering, the voice codec function is on a separate chip. In addition, the 72 kilowords of ROM is twice the amount of the earlier product. This additional memory will allow handset manufacturers greater flexibility in offering enhanced features such as voice recognition, noise reduction, and acoustic echo cancellation. The DSP in the chip can deliver 100 MIPS at 3V. Lucent announced its first EVRC chipset for CDMA handsets in November 1997 and noted that it had orders from Samsung Electronics Company Ltd., Hyundai Electronics Co. Ltd., and LG Information and Communications. Pricing for the chip will be $10 to $12 in 100,000 unit quantities.

The EVRC PRO works as a companion chip to the MSM2.2 and MSM2300 CDMA baseband chipset from QUALCOMM. Lucent Technologies, currently the only company shipping EVRC chips for the CDMA market, claims to have shipped 1.5 million units of its first product since its November announcement. When asked about the impact of the financial crisis in South Korea and QUALCOMM's announcement of order cancellations, Lucent officials indicated that they had seen no delays or cancellations from their Korean customers for their EVRC product. Because the Korean market is the dominant driver of demand for EVRC-capable handsets, this will be a critical market to watch. Based on Lucent's comments, it would appear that manufacturers are proceeding with their production plans for high-end handsets and the market demand is slowing for basic models. The development or timing of implementation in other markets such as the United States remains uncertain. Most service providers are remaining silent about their plans for deploying EVRC capability in their systems. While South Korea has proven to be a lucrative market opportunity, adoption of the EVRC capability by service providers in other regions would be valuable to Lucent not only in expanding its market opportunity but also by reducing the market risk.

Although this was not highlighted in its announcement, the EVRC PRO is another product from Lucent that incorporates its FlashDSP technology. This technology provides a major advantage to system designers by reducing the time required to develop and bring a product to market by as much as six months. It appears that Lucent is now incorporating this capability in all of its products.

The GEC Plessey (Mitel) Dual-Band CDMA RF/IF Chipset Solution

Although GEC Plessey Semiconductors did announce details of its dual-band CDMA chipset solution, the Planets chipset, in the last half of 1997, it was expecting to move to production volumes in the first quarter of 1998 when GEC Plessey was acquired by Mitel Corporation. Samples of its solution were available in 1997. There are five components in the GEC Plessey chipset, which operates at 2.7V:

- Venus: An integrated RF receiver and downconverter operating in the 900-MHz and 1900-MHz bands. It is produced in a BiCMOS process.
- Saturn: A dual-band IF receiver with automatic gain control. It is produced in a BiCMOS process.
- Jupiter: An I/Q CDMA and FM filter. It is produced in a BiCMOS process.
- Pluto: A baseband interface chip that integrates A/D and D/A converters, frequency synthesis for two VHF VCOs, and a set of general-purpose A/D converters. This chip is built on a mixed-signal CMOS.
- Moon: A dual-band transmitter including a quadrature modulator, a low-pass filter, and a two-stage AGC amplifier. This chip is built on an advanced bipolar process.

The product road map for the Planets chipset calls for migration to a four-chip solution through the integration of the Venus and Saturn chips, creation of a tri-mode chipset, and eventually reduction to a three-chip solution.

Harris Semiconductor Enters the CDMA RF/IF Chipset Market

The most recent entrant to the CDMA chipset market is Harris Semiconductor Inc. with its 800-MHz dual-mode CDMA chipset. This chipset, which conforms to the IS-95A standard, represents Harris Semiconductor's first cellular product. Harris claims that its solution will operate down to 2.7V and will support both QUALCOMM- and DSP Communications-based designs. The components include:

- HFA3665: A downconverter with AGC
- HFA3667: An upconverter with gain control
- HFA3765: A quadrature IF demodulator with AGC
- HFA3767: A quadrature modulator with AGC

Plans call for the chipset to be available in production quantities in spring 1998 at a price of $14.

TriQuint Semiconductor Unveils 3V GaAs Power Amplifiers

The continuing drive to increase talk and standby time and to reduce handset size and weight is pushing handset manufacturers to migrate to single-cell lithium ion (LiIon) and three-cell nickel metal hydride (NiMH) with their higher energy density cells. This means that the majority of new handset designs are using 3.6V cells. Handset designs using 5V power amplifier (PA) components together with lower-voltage battery cells have had to use bulky voltage-doubling circuitry to provide the necessary voltage supply. TriQuint Semiconductor Inc. has timed the launch of its new family of 3V power amplifiers to meet the needs of the latest generation of cellular/PCS handsets.

In launching its latest PA products, TriQuint described its development effort, which includes a low-voltage, low-cost MESFET process technology; low-thermal impedance, low-source inductance, and low-cost packaging; an automated, high-speed test suite; and volume manufacturing capability. TriQuint says that its MESFET process development efforts have resulted in products with a reduced knee voltage, permitting more signal swing and higher current densities, low parasitic passives and high Q interconnects, a planarized encapsulated structure that enables silicon packaging techniques, and lower overall cost.

At the Wireless Symposium on February 10, TriQuint announced the first products in its new PA family:

- TQ7541 (European DCS1800) and TQ7641 (US PCS 1900): 40dB power control via simple drain control circuit, extremely small applications board; baseband interface circuitry; and fail-safe operation (supply sequence applied internally). Pricing is $5.59 in 10,000-unit quantities.
- TQ7121 (TDMA IS-136 dual-mode cellular) and TQ7621 (TDMA IS-136 PCS band): 42 percent cellular-band efficiency and 30 percent PCS-band efficiency; single 3.4V operation; PA shutdown between time slots

possible which further improves efficiency; baseband CMOS interface circuitry, included. Pricing for the TQ7121 is $5.32 in 10,000-unit quantities and for the TQ7621 is $5.86 in 10,000-unit quantities.

- TQ7111 (IS-19 AMPS): Guaranteed efficiency greater than 55 percent and typically more than 60 percent; extremely small applications board; lower cost than module and doubler; also usable in ISM band with minor circuit modifications. Pricing is $4.79 in 10,000-unit quantities.

Anadigics Announces Dual-Band and 3V Power Amplifier Families

In 1997 Anadigics Inc. shipped 37 million GaAs ICs to reach a cumulative total of 100 million GaAs ICs since 1990. The cellular and PCS markets were responsible for all of Anadigics' revenue growth in 1997. Anadigics' total 1996 revenue of $69 million was divided among the following sources: 35 percent from cellular and PCS ($24 million), 43 percent from cable and broadcast ($30 million), 17 percent from fiber optic ($12 million), and four percent from other sources (because of rounding, the percentages do not add up to 100). In 1997 Anadigics' revenue increased by $34 million to $103 million. Revenue from cellular and PCS grew by over $35 million to $59 million or 58 percent of Anadigics' total 1997 revenue. Cable and broadcast accounted for 29 percent and fiber and optic 11 percent of its revenue. During the fourth quarter of 1997 Anadigics' gross margins slipped because of problems with packaging and assembly. The company says it has resolved these problems and expects to move forward with strong 1998 results. With the completion of its new fab facility, the company expects its two fabs to support $500 million in sales.

The announcement of four new 3V power amplifiers and two new dual-band, dual-mode power amplifiers will help provide Anadigics with renewed momentum in the early part of 1998. These new products should find strong demand from the three major forces driving the cellular/PCS handset market: lower power, smaller size, and improved service coverage through dual-mode and dual-band access. While nominal performance for its new power amplifiers is at 3.6V, Anadigics states that the amplifiers are designed to meet common cellular specifications at as little as 2.7V. Anadigics also plans to introduce additional 3V products throughout the year. All of these products are produced using high-volume, cost-reduced GaAs MESFET technology. Anadigics also employs what it calls "Intelligent Power" technology. This adjusts the power consumption of the IC based on needed output power and also enables temperature compensation for optimal performance. The four products introduced in February are:

- AWT936: A 3.6V single-mode power amplifier for GSM applications in the 900-MHz band. Pricing is $4 in 100,000-unit quantities.
- AWT937: A 3.6V power amplifier for AMPS applications. Pricing is $4 in 100,000-unit quantities.
- AWT938: An integrated power amplifier for 800-MHz AMPS/CDMA applications. Pricing is $4.50 in 100,000-unit quantities.

- AWT939: A dual-mode power amplifier for AMPS/DAMPS(IS-136). Pricing is $4.50 in 100,000-unit quantities.

Anadigic's new dual-band, dual-mode GaAs power amplifiers will allow designers to reduce cost and size from designs that currently use two separate amplifier designs. Both of these amplifiers are manufactured using GaAs MESFET technology and are packaged in 28-pin thermally enhanced SSOP plastic packages. Brief specifications for these parts are:

- AWT918: A 4.8V single-supply dual-band amplifier for GSM900/DCS1800, AMPS/GSM1900, and GSM900/GSM1900 applications. It is composed of a single three-stage amplifier chain with two inputs and one output. Pricing is $7 in 100,000-unit quantities.
- AWT920: A dual-band amplifier for CDMA/AMPS. One chain is a two-stage amplifier and operates in the 824-to-849-MHz band and the other chain is a three-stage amplifier operating in the 1850-to-1910-MHz band. Pricing is $7 in 100,000-unit quantities.

Anadigics' $59 million in PCS and cellular revenue in 1997 were spread across multiple standards and handset types. Split by standard, its revenue were: 39 percent GSM, 28 percent CDMA, 24 percent TDMA, and 9 percent analog. Broken down by handset type, the revenue were: 60 percent single-band cellular; 30 percent single-band PCS, and 6 percent dual-band handsets. Anadigics believes that in 1997 50 to 60 percent of all handsets still used power amplifier solutions based on silicon technology. Given the performance of GaAs power amplifiers at low voltage and high frequency and a preference for ICs over hybrid and discrete solutions, the company believes that 1998 will mark a major shift to GaAs power amplifiers in the cellular and PCS markets.

Philips Semiconductors Delivers WLAN and FracN Synthesizer Products

At the Wireless Symposium held in Santa Clara in February, Philips Semiconductors Inc. emphasized two new products: an IEEE 802.11-compliant wireless LAN (WLAN) chipset that supports both direct sequence spread spectrum (DSSS) and frequency hopping (FH) solutions and a new fractional-N (FracN) synthesizer.

Wireless LAN Chipset

Philips said that its 802.11-compliant WLAN chipset is the first to merge antenna, radio, and baseband capabilities into an integrated solution suitable for PC Memory Card Internal Association (PCMCIA) applications. It was developed in partnership with Lucent Microelectronics, which supplies the WaveLAN baseband chipset. There are three new chips in the Philips solution in addition to a synthesizer that was released in 1997.

- SA1630 quadrature IF transceiver: A 70-400-MHz I/Q transceiver that contains both an up and down mixer driven by a common local oscillator (LO).

- SA2410 2.45-GHz RF power amplifier and transmitter/receiver switch: A GaAs monolithic amplifier that operates from 3V to 5.5V and consumes 125mA with an output of 18.5dB.
- SA2420 low voltage RF transceiver: A combined low-noise amplifier, receive mixer, transmit mixer, and LO buffer BiCMOS IC.

Peregrine Semiconductor Announces SOI Technology Deal with Motorola

Peregrine Semiconductor Corporation announced that it will join Motorola in a collaborative relationship to explore the applications for Peregrine's advanced process technology for wireless semiconductors. Peregrine will provide technical details of its Ultra-Thin Silicon (UTSi) CMOS process capabilities for use by Motorola's Wireless Subscriber RF/IF Division. The companies believe that Peregrine's SOI process will be useful in making high-frequency wireless devices with lower power consumption. They are also pointing toward its potential to deliver single-chip baseband/RF devices for wireless applications. Peregrine's UTSi process involves fabricating a thin layer of silicon on sapphire, which acts as an insulating substrate. Peregrine's current product offerings have focused on two main market segments: 1-2.5-GHz RF devices and low-voltage radiation-tolerant digital ASICs. Applications of these products are found in satellites. Peregrine believes it has unlocked the secret of manufacturing SOI devices in commercial quantities at competitive costs. In the initial phase of the partnership, the companies will market a PLL using Peregrine's technology. The companies are evaluating the expansion of their efforts to mixer/low-noise amplifier (LNA) combinations, and single-chip baseband/RF devices.

Hewlett-Packard Targets Multiple Markets

RF and power amplifier products targeting multiple wireless markets were introduced by Hewlett-Packard Company at February's Wireless Symposium. The highlights of its product introductions are:

- AT-38043: A driver amplifier with applications in GSM, AMPS, ISM, SMR, and CATV products
- A family of SC-70-lead diodes with unique configurations: These Schottky and PIN diode configurations offer optimized solutions for cellular handset, base station, WLAN, and DBS systems. They are 40 percent smaller than industry standard SOT-23/143 packages and will be priced similarly to larger packaged diodes.
- GaAs monolithic microwave ICs (MMICs) for digital radio and local multipoint distribution service (LMDS) applications: The three products in this category are a 20-to-43-GHz up/down converter, a 17.7-32-GHz amplifier, and a 17.7-to-32-GHz amplifier with integrated output power detector.
- Ultraminiature 3V GaAs amplifiers: The MGA-83563 power amplifier is targeted at wireless data devices and the MGA-85563 low-noise amplifier is optimized for use in cellular/PCS handsets and wireless data.

- A complete RF 1.5-2.5-GHz chipset: This four-chip solution contains nearly all the active RF functionality required for Digital European Cordless Telecommunications (DECT) and IEEE 802.11 applications. The package sizes enable products in the PCMCIA form factor.

Impala Linear Corporation Gains Visibility with LDO Linear Regulator

A start-up company based in Sunnyvale, California, with fewer than 50 employees, Impala Linear Corporation began discussing its new low dropout (LDO) linear regulator in closed-door meetings in February. Announced on March 16, the ILC7081 offers an extremely compelling solution to a performance problem in wireless and portable applications. Traditionally, systems designers have had to make trade-offs in their design decisions for linear regulators. LDOs based on CMOS technology have offered longer battery life by providing low dropout voltages, low ground current, and high output voltage accuracy. On the other hand, bipolar LDOs have offered superior RF performance with higher ripple rejection, tight dynamic line regulation and load regulation, low noise, and high peak output current. By developing a process innovation on standard CMOS, Impala Linear Corporation has developed an LDO that offers both longer battery life and superior RF performance. Competitive benchmark numbers shown by Impala Linear promise very impressive performance gains with the new LDO technology. In a typical cellular/PCS handset, Impala Linear says that its product can increase talk time by 20 percent, reduce bill-of-materials cost in the power supply by 20 percent, and enable a 20 percent smaller power supply footprint. Impala Linear also boasts an impressive customer list including Motorola, QUALCOMM, Nokia, Ericsson, Samsung, Panasonic Communications, and Systems Co., NEC, Sony Corporation, and Trimble Navigation Inc. for wireless communications; Psion plc, Philips, Casio Computer Company Ltd., Sharp Electronics Corporation, Telxon Corporation, Sony, Hewlett-Packard, and Tektronix Incorporated for portable electronics; and Compaq Computer Corporation, IBM, Apple Computer Inc., Toshiba Corporation, and Acer Computer International Ltd. for personal computers.

As a fabless, analog, and mixed-signal company, Impala Linear's business model calls for it to leverage core technology in process, device structures and analog/mixed-signal design to offer synergistic RF and power management IC solutions. The success that Impala Linear has achieved with this product bodes well for its continuing role as a valuable contributor to the wireless industry.

Dataquest Perspective

The pace of innovation and competition appears to have moved up a step with the burst of energy exhibited by a flurry of product announcements in early 1998. The high growth rates that wireless markets have achieved has attracted an ever-expanding array of semiconductor companies to the industry. However, the performance bar was moved up more than a few notches with the promised performance of these products. The environment of stiff cost competition, expanding performance demands, and fast time to market that has been created in this industry leaves very little margin for error or delay. Companies must execute with a high degree of precision in delivering products today while developing the technologies and processes that will allow them to play again tomorrow. In the past, the wireless industry has created a semiconductor market that caused Dataquest to describe it with the phrase, "A rising tide lifts all chips." This environment is changing, and over the coming two to three years the increasing level of competition will lead to some companies emerging as clear leaders, while others will struggle to stay in the game.

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Perspective

Wireless Semiconductors and Applications

Technology Analysis

Flash Talks in Digital Cellular Phones

Abstract: *Digital cellular telephones represent the single largest market for flash memory, forecast to be near $1.4 billion in 2001. This Perspective details flash memory use in digital cellular telephone handsets and the wireless market forces driving the success of the segment. Cellular telephone market statistics, including market share leaders, are summarized, and the market for flash memory market size in digital cellular phones is detailed.*

By Bruce Bonner and Dale Ford

Cellular Telephone Market Overview

As the number of worldwide cellular/PCS subscribers increases from 133.8 million in 1996 to 550 million in 2001, the handset market will be driven from 66.5 million units to 233.0 million units. Worldwide production of cellular telephone handsets is forecast to grow at a strong 25 percent compound annual growth rate (CAGR) during the next five years, as shown in Table 1 and Figure 1. Although analog handsets represented more than 85 percent of production in 1993, digital handset shipments surpassed analog handsets in 1996 with 62 percent of total production. By 2001, digital cellular handsets will account for 96 percent of worldwide production.

Cellular telephones based on Global Standard for Mobile Communications (GSM) technology represent the large majority of digital cellular phones, following the adoption of a common standard in Europe. However, multiple digital standards are competing for market acceptance in the United States and around the world. Digital telephones are expected to experience rapid growth, with dual-mode analog/digital cellular/PCS telephones representing the majority of the Americas cellular/PCS handset market by 1998, expected to exceed 167 million subscribers by 2001. Increasingly, these subscribers are using their cellular/PCS telephones for personal calls and

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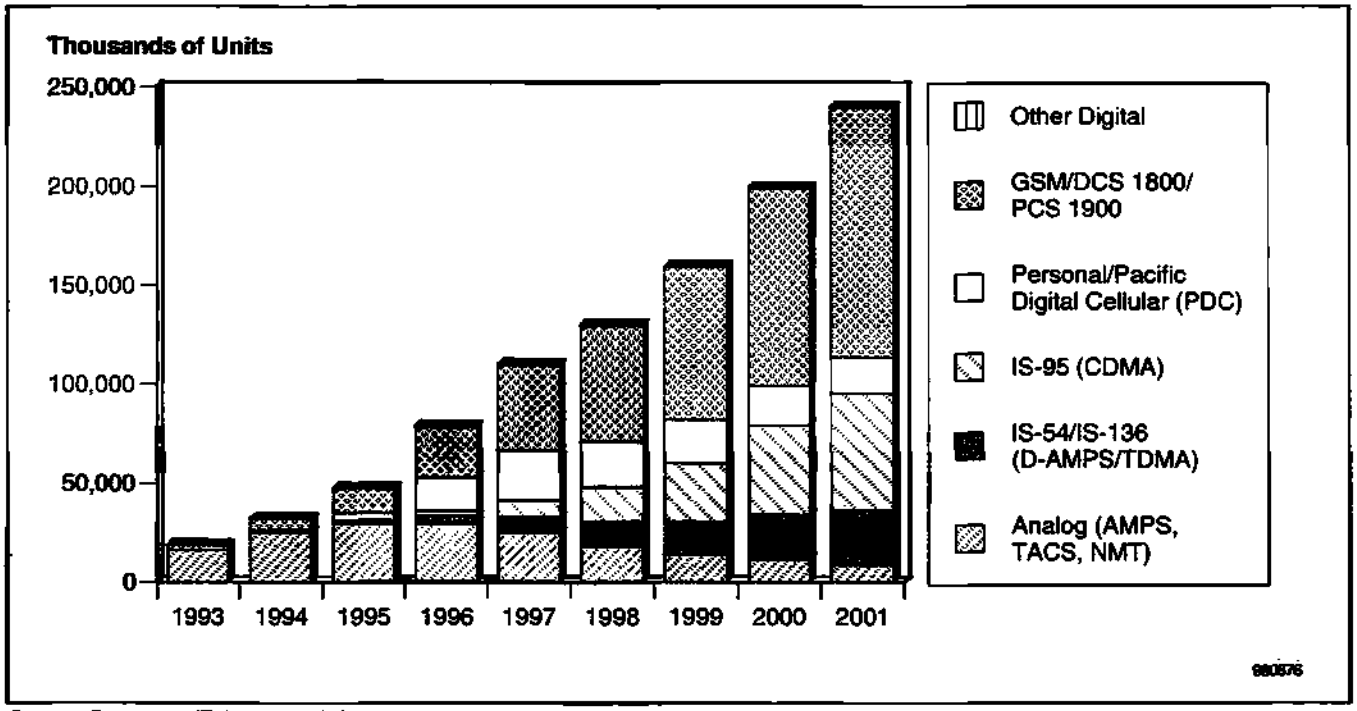
safety. Surveys have found that almost 60 percent of all cellular use in the United States is for personal calls.

Table 1
Worldwide Cellular and Broadband PCS Telephone Handset Production by Type (Thousands of Units)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Total Cellular/PCS	18,741	32,008	47,404	78,592	109,863	129,856	159,453	199,418	240,121	25.0
Total Analog	16,275	25,058	29,613	29,835	25,241	18,362	14,148	11,397	8,547	-22.1
Total Digital	2,466	6,950	17,791	48,757	84,622	111,494	145,305	188,021	231,574	36.6
NA-TDMA	156	577	1,613	3,764	7,614	12,342	16,547	22,806	27,973	49.4
CDMA	0	0	20	2,500	8,650	17,450	29,530	45,115	59,017	88.2
PDC	0	961	3,958	16,993	25,020	22,920	21,915	20,140	18,342	1.5
GSM/DCS1800/PCS-1900	2,310	5,412	12,200	25,500	43,333	58,732	77,181	99,728	125,965	37.6
Others	-	-	-	-	5	50	132	232	277	-

Source: Dataquest (February 1998)

Figure 1
Worldwide Cellular and Broadband PCS Telephone Handset Production by Type



Source: Dataquest (February 1998)

The digital GSM handset market exploded in Europe during the 1990s as the European countries agreed on the unified GSM standard. This market had experienced very low cellular penetration rates before then. With the introduction of the GSM standard, which allowed easier roaming between countries, the market took off and quickly grew to become the largest digital cellular market in the world. Many countries in other regions have also adopted the GSM standard. However, the U.S. and Americas market has been much slower than expected to adopt the digital technology.

Further insight of the handheld wireless market is available in Dataquest's Market Trends Report *Communications Application Markets—Cellular/Broadband PCS and Cordless Telephones* (CSAM-WW-MT-9707, December 1997).

Market and Brand Leaders

The cellular telephone handset market is dominated by a small number of manufacturers, as shown in Table 2. The vast majority of flash for cellular phones is used in digital cellular phones, the leaders which are detailed in Table 3.

How Cellular Phones Work

Cellular telephones involve a relatively low-power handset corresponding with a local base station, of which there are many. The area surrounding the base station is called a "cell," and this can be visualized as a honeycomb. This simple concept yields powerful benefits. The handset can be small and light because it does not need to transmit long distances. A large number of subscribers can be connected simultaneously because their signals travel only a short distance and do not overlap with those in other cells. Traveling phones that move from one cell to another during a conversation can be accommodated by a central control's handing over responsibility for the handset from one base station to another. Multiple phones in the same area can be used at the same time by using multiple frequencies.

Table 2
Worldwide Total Cellular/PCS Telephone Market Share in 1996

Manufacturer	Shipments (K)	Unit Market Share (%)
Motorola	17,874	26.9
Nokia	13,414	20.2
Ericsson	8,035	12.1
Panasonic	5,307	8.0
NEC	4,518	6.8
Mitsubishi	1,990	3.0
Kyocera	1,967	3.0
Siemens	1,860	2.8
Toshiba	1,842	2.8
Others	9,732	14.6
Total	**66,539**	**100.0**

Source: Dataquest (February 1998)

Table 3
Worldwide Digital Cellular Telephone Market Share in 1996

Manufacturer	Shipments (K)	Unit Market Share (%)
Nokia	7,032	18.8
Ericsson	6,666	17.8
Motorola	6,183	16.5
Panasonic	3,816	10.2
Siemens	1,837	4.9
NEC	1,786	4.8
Mitsubishi	1,488	4.0
Kyocera	1,197	3.2
Sony/QUALCOMM	1,099	2.9
Alcatel	948	2.5
Fujitsu	842	2.3
Toshiba	752	2.0
Philips	749	2.0
Denso	730	2.0
Others	2,285	6.1
Total	37,410	100.0

Source: Dataquest (February 1998)

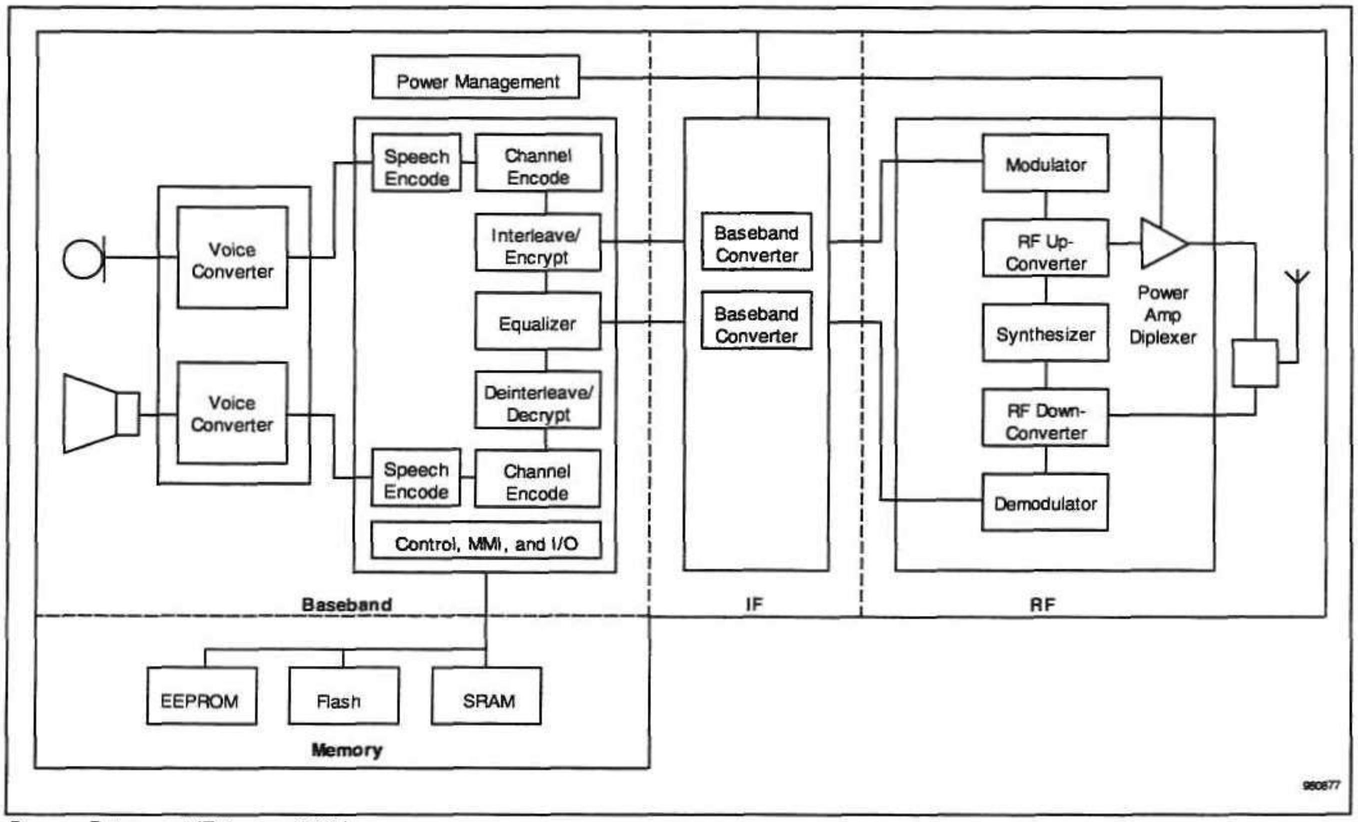
Analog Cellular Phones

Analog cellular telephones were the initial standard deployed in the early days of cellular telephony. Voices are transmitted and received using a time-division multiplexing scheme, where periodic samples of the voice are frequency modulated (FM) on a carrier frequency. The advantages of an analog approach are a straightforward, minimal design for both handsets and base stations. A disadvantage, it turns out, is a lack of security for both the information (the voice) and the control signals the phone uses to stay synchronized with the cellular network. This minor technical issue became a major financial opportunity for some ethically challenged members of society, who would "clone" telephone serial numbers to circumvent usage fees and having an identifying number associated with calls. Another segment of society was able to listen in on, and record, phone calls with simple scanning receivers. A better solution was needed.

Digital Cellular Phones

Digital cellular telephones were the answer to these issues. Instead of transmitting the voice as an FM signal, it was digitized and sent as ones and zeros over a network optimized for digital traffic. A major benefit of this change is the ability to service multiple handsets with a single operation frequency instead of tying up a frequency slot per handset, yielding a dramatic increase in network call capacity. Digital handsets also have better energy efficiency, yielding longer battery lives. But at the same time a digital standard was being created, encryption was added for both serial number and voice data, making cloning extremely difficult. The initial digital standard was a European product using the GSM standard; since then, Code-Division Multiple Access (CDMA, or IS-95) and Time-Division Multiple Access (TDMA, or IS-54 and IS-136) are the other digital standards that have been propagated. A block diagram of a typical digital cellular telephone is shown in Figure 2, which shows a clear separation between the radio frequency (RF) and intermediate frequency (IF) sections and the baseband section. The baseband circuitry controls both the function of the phone and its connection with the telephone network, using specific protocols for the system in which it is being used. But digital cellular phones are much more complex than analog models, which gave rise to the use of flash memory in them.

Figure 2
Digital Cellular Telephone Block Diagram



Source: Dataquest (February 1998)

Memory Use in Cellular Phones

As shown in the figure, three types of discrete memory are typically used in cellular phones: SRAM, flash memory, and EEPROM. SRAM is used to store information temporarily in conjunction with the baseband microcontroller. This is for interaction with both base stations and the cellular network and for remembering the status of functions used by the user. EEPROM is employed like SRAM, but as a nonvolatile memory for small amounts of operating data. Flash memory stores the firmware, the operation software, of the microcontroller. Flash memory was originally pressed into service by

European cellular phone manufacturers for the rollout of GSM, when they needed regulatory approval of models they wanted to sell but for which the firmware was likely to change. The signaling protocols were complex, and they did not want delays in getting to market because a phone had to be resubmitted for approval with hardware changes. Flash memory came to the rescue by allowing the changes to be implemented in software and to be updated as necessary, mainly in production lines, but also for field units if they were returned to a service center. Analog phones normally do not use flash because the code size is small and simple, allowing a nonupdatable memory such as mask ROM or one-time-programmable EPROM to be used.

Flash Memory Use in Digital Cellular Phones

Flash memory is used as a reprogrammable storage medium for operating software in the cellular phone. It is normally written just once, when the phone is originally assembled. After that, the ability to update the code is an "insurance policy" for either a protocol function or a feature visible to the user. One idea floating in the cellular industry is for "over the air" updates to a phone—the flash memory could have a new program written to it from information moved to it over the cellular network itself. Although this *could* be used to fix bugs, the concept is more attractive to service providers because they could use it to sell new features, such as voice mail, to subscribers for additional monthly fees. This would be a win-win situation: the flash makers would sell more expensive and larger chips to the market, and more revenue would come to the providers. Alas, it is not to be for some time, because it requires extensive changes in a cellular network infrastructure focused on delivering real-time voice, not operating code.

A recent departure from this paradigm is the consolidation of the EEPROM function into the flash chip, which is discussed in more depth later.

Key Flash Device Issues

Key areas of interest for cellular phone design engineers using flash memory are operating voltage, architecture, packaging, density, speed, and standardization.

Voltage

The coin of the realm for cellular flash is low operating voltage. This is a compatibility issue, because the rest of the logic in the phone reduces power dissipation as voltage is reduced. The power consumption of the flash device is not reduced as a direct result of this—in fact, it could go up if other steps were not taken, because the flash cell uses high voltages for programming and erase. The benefit of lower voltage is longer battery life, both for standby and talk time, and lighter, smaller telephones from the reduced battery size.

Because cellular phones are the largest market for flash memory, many innovative products have been developed for the application. Advanced Micro Devices Inc. introduced a 1.8V 8Mb device, the Am29SL800, and Intel Corporation has 2.7V chips compatible with 1.8V logic levels in its Smart 3 product family. The Intel smart voltage concept allows both single- and dual-voltage supply operation. The dual supply usage, when an optional V_{pp} voltage is connected, speeds up programming considerably, an issue for production line loading of the contents of an entire memory. Companies are now starting work on 0.9V devices! Although these are probably at least two years away, flash companies are being driven very hard by cellular phone manufacturers, which are themselves in a fiercely competitive environment, and there is no doubt that voltage and energy will continue to drop as a result.

An interesting aspect of the AMD 1.8V product is what the company calls "zero power." This is an automatic power down to the "sleep" mode, which takes only nanoamperes of supply current, when the device is not being accessed. This addressed another concern of digital cellular phone designers: low energy usage. Instantaneous power consumption does not matter, per se. What is important is *energy*, and energy equals power times time. To say it another way, the key is the "area under the curve." This is an issue for flash because the physics of operating a flash chip do not change just because the operating voltage goes down. It still takes so many electrons on the floating gate to program a cell, and the energy required to do that stays constant no matter what the supply voltage is. This is a prime area for innovation in different technology approaches, such as DiNOR from Mitsubishi Corporation. New thinking is probably required for substantial energy usage reductions.

Architecture

Architectural issues for this application are more complex than for many other uses. The starting point is the assumption of an x16 data path, because the flash is connected to a high-performance microcontroller, often RISC-based, in a direct execute manner. A second issue is the need for asymmetrical "boot block" organizations to allow both code and control information to be stored and used efficiently. The third challenge for flash is consolidation of the EEPROM and flash memory into a single chip for space and cost savings.

As discussed previously, cellular phones use flash for "code storage," but the handsets also need to store small amounts of data during operation. Currently, this need is being filled by EEPROMs, sometimes with multiple EEPROMs in a single unit. The obstacle to moving this auxiliary storage to the flash chip is that flash is not a direct-overwrite implementation as EEPROM is, and the erase block where the data is located must sometimes be used to reset the information. Currently, an erase function in a flash chip puts it off line, not allowing it to continue executing code in parallel, which is a need for real-time operation. Writing data has the same issue. This is a problem.

One solution to this problem is called "read while write" (RWW). The flash device can be designed with duplicate peripheral circuitry for separate sections of the flash memory array. This allows concurrent reading of program information while a write or erase operation is occurring in a different part of the chip. AMD has introduced "simultaneous read/write" flash, the Am29DL800, that allows this. This 8Mb part has the flash divided into two banks, one having large "code" blocks of 64KB and the other having two 32KB, two 16KB, and four 8KB "data" sectors.

Another approach is "software read while write," where a mini-OS in the phone manages the read/write transactions to the flash chip. Intel's Smart 3 Advanced Boot Block family, with 4Mb, 8Mb, and 16Mb memories, does this with Intel's Flash Data Integrator (FDI) software, which is supplied free of charge to designers. This device has eight 8KB data blocks and up to 31 64KB main blocks for code or data. Phone design engineers to date have preferred the straightforward hardware RWW approach, but Intel has gained early acceptance from some key cellular phone manufacturers with the software technique.

Another solution is putting a small EEPROM section on a larger flash chip, giving an integrated solution to the same problem. This is the ultimate RWW chip, but it is not very flexible as the size of the read-write memory is fixed.

Packaging

A final trend in the wireless phone industry is the constant push to make the electronics as physically small as possible. For flash, this will take two directions: either including flash in another system chip, such as the digital signal processor (DSP), or using advanced packaging techniques to shrink the footprint of the chip on the printed circuit board (PCB).

Embedding flash (or any memory type, for that matter) is an important trend in the consumer electronics industry, and it will be used when the amount of memory is small enough not to raise the cost of the one-chip solution significantly over the cost of a two-chip solution. Because the code size in these products is currently 8Mb to 16Mb, this merging of functions is not yet economical, so a physical approach is more appealing.

Most flash chips used in cellular handsets have a TSOP plastic package, which is thin and small. But an increasingly popular way to shrink the flash package is to use chip scale packaging (CSP) technology. Most of these packages are variations of a ball grid array (BGA) method of electrically and mechanically attaching the device to the PCB. Another method is to place a memory die directly on the PCB and attach by the chip-on-board (COB) or flip-chip methods. Although this is theoretically possible now, there are many hurdles to high-volume supply and use of these, most of which are fixed by CSP. Dataquest expects CSP to win in the digital wireless flash market soon, and flip chip to become the method of choice eventually.

Density

The density sweet spot for digital cellular phones shipping now is 8Mb, but that is for the character sets of Europe and the Americas. As sales increase in Asia/Pacific and Japan, density increases to 16Mb for the more pictorial characters used there. Dataquest expects density also to increase as processor performance increases, with more code able to be executed in real time by a faster clock rate. Multifunctional units that may operate as either analog or digital phones increase the complexity of the code, and therefore its size, which is now 16Mb. Japanese Personal Digital Cellular (PDC) phones are expected to begin a transition to 32Mb later this year.

Density may also increase if new features, such as downloaded voice mail, are deployed by service providers. This would allow a user to listen to messages while not on the air (with charges) and perhaps respond to them off line for transmission later. Smart phones, which include the functionality of a handheld PC or organizer, would also need some form of mass storage-optimized flash. A possible new standard for this application is the Multimedia Card form factor proposed by SanDisk Corporation and endorsed by Siemens, Nokia, Ericsson, and Motorola Incorporated.

Speed

Read access time shows the most direct adverse effects of lowering the operating voltage of a flash memory. For instance, a 5V 70ns device may slow to 120ns at 3V. In some cases, where an older, slower microcontroller is used, this is not an issue. But many new chipsets have RISC processors and a "need for speed." To make matters worse, cellular phone integrated circuits must operate over a negative 40° to positive 85°C temperature range. Currently, 120ns is sufficient, but speed varies greatly, from products under 100ns to those with latencies of 200ns.

Dataquest foresees the use of architecture techniques, such as "page mode" designs, to give increased performance at lower voltages.

Standardization

An issue that continues to dog cellular phone design engineers is a lack of standardization for flash memory in general, especially for the devices used in advanced cellular handsets. Some of the blame for this must go to Intel and AMD, which continue to have different strategies for implementing cutting-edge designs. Pinouts and protocols continue to be different between them, not to mention erase block architectures. But the largest handset providers are pushing the flash vendors for innovative products that solve their problems, and the suppliers are responding as well as they can and as quickly as they can, which leaves standardization in the dust. Designers are advised to allow for multiple sourcing of flash chips at the earliest possible times in their design cycles to maximize purchasing flexibility, because drop-in substitutes do not exist in many cases.

Flash Market Size Estimates for Application

Table 4 shows digital cellular telephone flash consumption.

Dataquest Perspective

The tremendous surge in sales of digital cellular telephones makes this the largest opportunity by far for flash vendors. As these units ramp up in underdeveloped areas, worldwide sales will continue to expand. Because the cost of a wireless phone is typically subsidized by a service provider, normal consumer demand elasticity is not an issue; the true cost of the handset is hidden from consumers and amortized into monthly charges.

Table 4
Digital Cellular Telephone Flash Consumption

	1993	1994	1995	1996	1997	1998	1999	2000	2001	CAGR (%) 1996-2001
Units (K)	2,466	6,950	17,791	48,757	84,622	111,494	145,305	188,021	231,574	37
Megabits (K)	9,864	34,750	106,746	341,299	676,976	1,114,940	1,743,660	2,632,294	3,705,184	61
Dollars (K)	66,311	126,004	223,250	589,712	590,858	727,080	898,078	1,139,325	1,376,226	18

Source: Dataquest (February 1998)

The flash market recently has been very trying for the participants. They are shipping more and more product and bits but are collecting less money. Part of this has to do with a larger supplier base, but it also is because the largest cellular phone manufacturers, Motorola, Ericsson, and Nokia, wield tremendous power with flash suppliers and are able to procure at commodity prices advanced products that should have hefty premiums instead.

Finally, Dataquest sees this market continuing to be key for the flash memory industry. The application values flash functionality and has the budget to pay for it. The level of innovation will prevent a true supply/demand free for all—but, as with most semiconductor sectors, this market is not for the faint of heart.

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Perspective

Wireless Semiconductors and Applications

Market Analysis

Semiconductors in Digital Cellular Infrastructure Equipment

Abstract: *Dataquest estimates that the worldwide market for semiconductors used in digital cellular/PCS base transceiver subsystems was $1.6 billion in 1997, to grow to $2.5 billion by 2002. The most important semiconductor products used in cellular base station applications are RF power discrete devices and DSP products, both of which command high prices and are used multiple times in each system. The greatest usage is in the base transceiver subsystem segment, which represents more than 75 percent of the total. System trends will affect demand for semiconductors, including moving from single-channel to multichannel power amplifiers, more robust algorithms for processing baseband signals, techniques for processing more baseband channels with fewer DSPs, moving digital processing of RF/IF signals closer to the antenna, and increasing demand for microcells, picocells, and repeaters to improve network performance and extend coverage.*

By Stan Bruederle

Worldwide Market Size and Forecast

Worldwide digital cellular infrastructure production is estimated to total $28.8 billion in 1997 and is projected to grow to $41.0 billion by 2002. GSM, digital AMPS, PCS, and CDMA are expected to be the primary growth drivers for the five-year period, with GSM taking the dominant position in global installations and digital AMPS being primarily a U.S. market. Dataquest's forecast of worldwide base transceiver subsystem (BTS) equipment revenue and semiconductor content is shown in Table 1.

Dataquest

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Table 1
Digital Cellular/PCS Equipment Revenue and Semiconductor Content (Millions of Dollars)

	1996	1997	1998	1999	2000	2001	2002
Cell Site Revenue	20,456	28,485	30,803	32,845	35,647	38,500	41,000
BTS Semiconductor Content	1,125	1,595	1,756	1,905	2,103	2,310	2,501
Semiconductor Content Ratio (%)	5.5	5.6	5.7	5.8	5.9	6.0	6.1

Source: Dataquest (June 1998)

Equipment Analysis

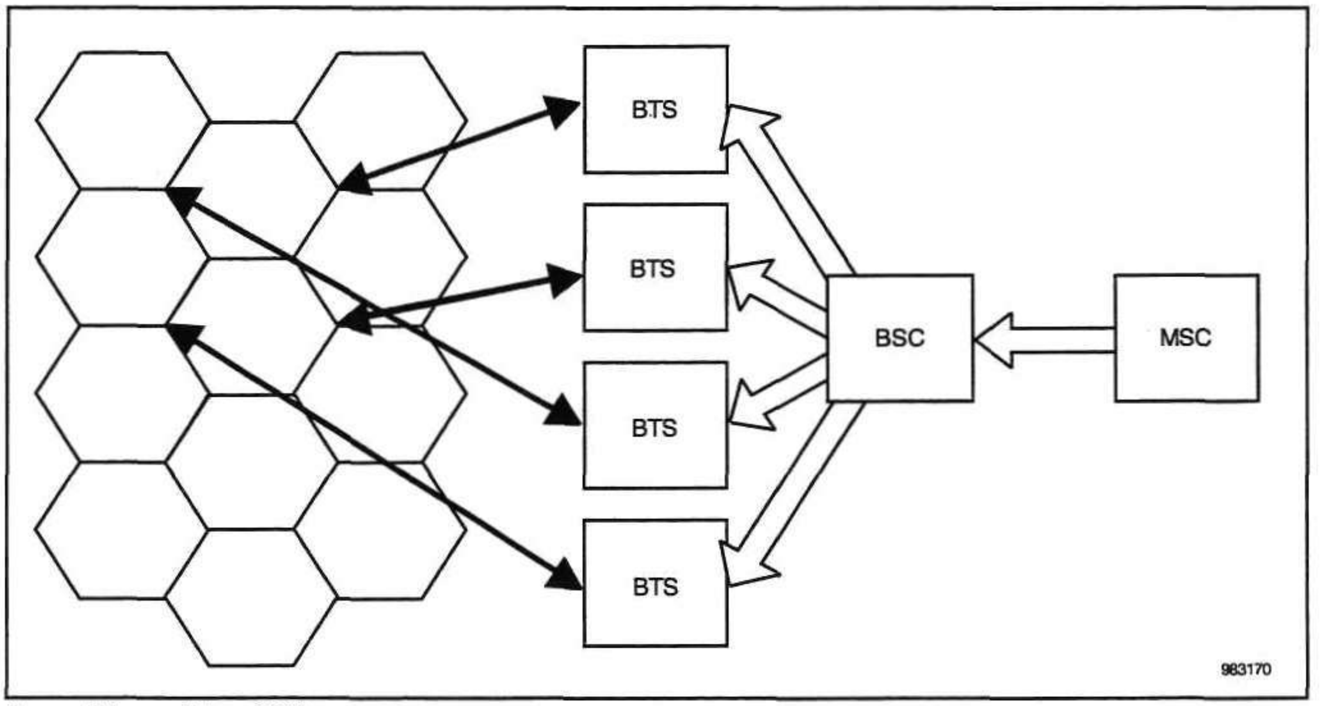
Definitions

Cellular infrastructure equipment is made up of three subsystems, the base transceiver subsystem, the base station controller (BSC) and the mobile switching center (MSC). This Perspective will discuss all three subsystems but will focus on the first, because the BTS contains more than 75 percent of the semiconductor content in the cellular/PCS infrastructure.

Cellular networks must operate in a variety of environments—low-density areas, where few structures interfere with signals, high-density areas, where many structures interfere with signals, and indoors. Equipment suppliers provide a variety of systems to operate effectively in these environments. Macrocells are designed for wide area coverage where mobile phones are moving rapidly. A common example is an open city area. Microcells are designed to operate in cities among tall buildings, where a cell might cover a city block and be placed below building level. Microcells are also placed along freeways, where off-road coverage is not important. Picocells are designed for operation within buildings. A fourth concept has been proposed called a "personal cell," which would replace the cordless base unit in the home. This futuristic idea would mean substantially lower costs than are possible with current semiconductor technology.

Figure 1 shows a network structure made up macrocell installations. Cell designs vary, depending on conditions. One BSC controls several macrocells (10 to 50), while several MSCs control a local service area in a high-density region. The BSC can be within the same box as a BTS or can be separate. A microcell can have the BTS and the BSC together or can have a BSC controlling several BTSs; a picocell is only the BTS. A separate BSC controls several BTSs. Some base station designs do not use a special mobile switching office but use the telephone network switching office for mobile call switching. QUALCOMM Incorporated's base station equipment is designed around this architecture. Each of these subsystems, regardless of how organized, essentially contains the functions described in the next sections.

Figure 1
Cellular Infrastructure Architecture



Source: Dataquest (June 1998)

Base Transceiver Subsystem

Subsystem Architectures

The BTS receives and transmits the communications signal and performs the signal processing that provides compressed digital baseband and control signals to the base station controller or the mobile switching center. It passes a compressed digital baseband signal on to the base station controller for speech processing and forwarding to the telephone network through the MSC. The BTS can be integrated with the BSC or be separate from it. An integrated BTS/BSC is called a base station subsystem (BSS). Dataquest uses an average price of $300,000 for cellular cell sites and about $180,000 for PCS cell sites.

System Trends

Macrocell. Macrocell BTSs feature increasingly flexible designs, offering operators the opportunities to service multiple access modes from one base station. In North America, AMPS, D-AMPS, CDMA, and possibly PCS 1900 could be offered, whereas in Europe, operators offer 900-MHz and 1.8-GHz GSM services. An important difference between the United States and Europe is the large analog cellular system that is in place in the United States. As a result, the U.S. digital system is being installed as an addition to the analog system.

A BTS consists of a number of transceivers, one or more linear amplifiers, and an antenna assembly. A BTS can contain as many as several hundred transmit/receive channels. Examples described in company literature describe a basic system with as many as 200 analog channels or 300 digital channels. Newer systems are designed for installation of analog and digital transceivers in the same base station. Each transceiver is made up of a transmitter and receiver for each carrier frequency which is split into three channels for D-AMPS and 10 channels for GSM, eight of which are voice channels.

Receiver. Each receiver has a low-noise amplifier front end. To improve performance, low-noise amplifiers are being designed to be placed on each receiving antenna where the received signal is strongest. The output is combined and mixed down to the intermediate frequency and then demodulated. The demodulated analog signal is converted to digital format, equalized, channel decoded, and decrypted. The resulting compressed digital speech signal is sent to the base station controller, where voice decoding is done and the signal handled according to the control information that accompanies the voice signal.

Several companies offer products that can enhance the performance of the receiver. One that appears interesting is low-noise amplifiers and very sharp filters designed using superconducting device technology. These products provide extremely low-noise front end amplifiers and extremely sharp filters with very low insertion loss.

Transmitter. The transmitter side of a transceiver receives the compressed digital voice signal from the BSC or MSC, encrypts and channel codes it, and converts it to analog format. The analog voice signal modulates the RF carrier and is upconverted to the carrier frequency. The modulated RF signal is preamplified and sent to the power amplifier for transmission to the wireless network.

Power Amplifier. The power amplifier in the transmitter section of a macrocell will be about 35W to 45W per carrier. System designers are designing broadband amplifiers that can amplify multiple carriers simultaneously and eliminate the need for tuned cavity combiners. These power amplifiers operate up to several hundred watts and must have extremely linear characteristics. The power per carrier is determined by the requirements for achieving a reliable communications link with each mobile phone in the coverage area. The industry is shifting from single-carrier power amplifiers to multiple-carrier power amplifiers. Multiple-carrier amplifiers are more expensive than single-carrier devices, but the replacement of several single-channel amplifiers by one multichannel amplifier and the savings in other subsystems more than make up for the difference in installation, operating, and maintenance costs. In addition to offering cost savings, multicarrier amplifiers make it possible to improve network performance through dynamic channel allocation between adjacent cells or sectors. Most of the power amplifiers being shipped today are still single-carrier models.

Other Cell Subsystems

Microcell. A microcell power amplifier will produce up to 5W of power per carrier and process only a few channels. A microcell serves a small area between buildings in a city. Microcells can also be used in a second layer within a cell to increase capacity in a high-density area. Companies are now designing microcells to support multiple access modes.

Picocell. A picocell power amplifier will produce less that 1W of power for use on one floor of a building. A picocell could easily use the same technology as a handset, supplemented with the call control functions required in a base station.

Repeater. A repeater is an amplifier that is used to pick up signals in areas where coverage is relatively weak and traffic is relatively light and forward them to the base station. Repeaters have not been widely used, in spite of their lower cost of operation. One estimate indicates that up to 40 percent of cell sites could be replaced by repeaters.

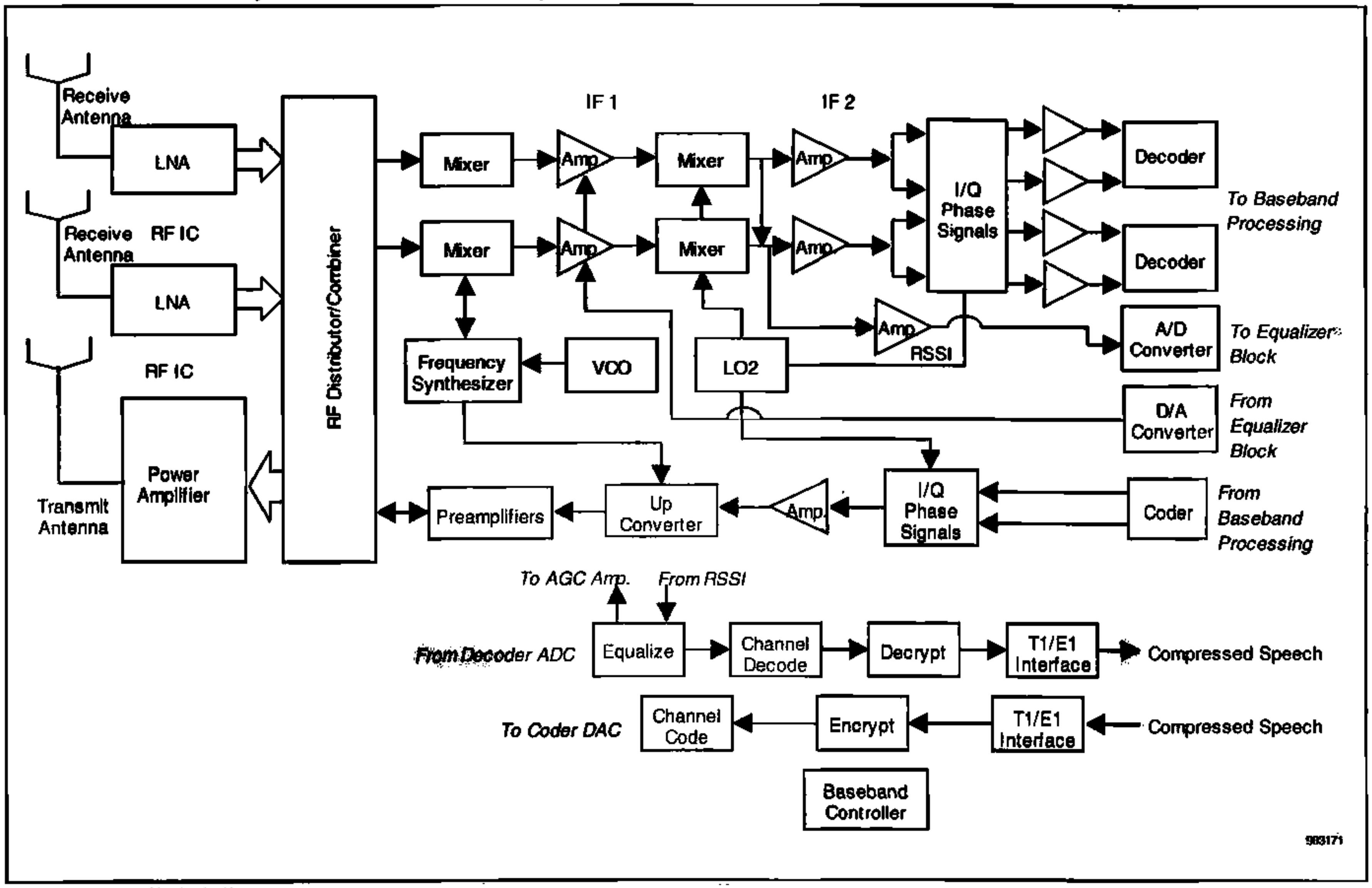
Design Objectives. The base station design determines the quality of the cellular communications system. Although power, size, and cost limit the performance possible with a wireless handset, the base station can be designed to provide the highest possible transmission and receiving quality. Receivers can therefore be designed with very sensitive and low-noise front ends, which results in high receiver performance. The superconducting receiver front ends mentioned earlier can significantly improve the backward channel performance.

Semiconductor Content. A BTS contains one transceiver for each carrier. In TDMA, a carrier is one operating frequency. Each carrier will have three channels for digital AMPS or eight channels for GSM. A BTS macrocell frame will have up to 24 transceivers for TDMA or 12 transceivers for GSM. Each transceiver will contain a low-noise amplifier, a mixer, intermediate frequency (IF) amplifiers, a phase-locked loop local oscillator, and modulator/demodulator circuits, which are often digital signal processor (DSP) blocks. Some systems are being designed with the low-noise amplifier located near the antenna to improve the sensitivity of the receiver. In this case, a single front-end amplifier amplifies all the incoming signals and distributes them to individual transceivers as required.

Because size and power are not limiting factors in base station design, designers choose between discrete, module, and integrated implementations. Common transceiver sections between product families can be used to maximize the volume of the devices used to implement the BTS functions. Figure 2 shows one example of the subsystem blocks of a TDMA base transceiver system. This diagram shows one transceiver, one baseband signal processing block, and one power amplifier.

Base station designs last substantially longer than handset designs, with new designs being released every two to three years. Base stations are modular, and subsystems can be upgraded to improve performance and lower cost without having to upgrade an entire installation. Thus, although an installation may not be replaced for 10 years, the technology within it may change significantly over that period as network services and requirements evolve.

Figure 2
Base Transceiver Subsystem Generic Block Diagram



Source: Dataquest (June 1998)

Dataquest estimates that the value of the semiconductor content in a base transceiver subsystem is about $11,500. The radio frequency/intermediate frequency (RF/IF) section contains about 21 percent, the baseband section about 38 percent, and the power amplifier about 41 percent of the value of the semiconductors used in the BTS.

Base Station Controller (BSC)

Subsystem Architectures. The BSC processes the baseband signal produced by the BTS and monitors the cells and directs the traffic within the cell group that it controls. It deals with handoffs and provides data paths for information being sent between the BTS and the MSC. The resulting signals are sent to the MSC through a T1/E1 interface. The BSC can also be integrated with the BTS or with the MSC, or it can stand alone, controlling several BTSs. How this is done affects the level of integration possible in a base station system. It is common to have a BSC control from 10 to 50 BTSs. A base station controller performs functions similar to those performed by a small switch or PBX. Dataquest has not completed analysis of the content of a base station controller. However, as a rough assessment, given that one BSC controls a relatively large number of BTSs, the revenue contribution of a BSC to the semiconductor usage in a cellular network should be less than 10 percent of the total semiconductor content of the wireless network infrastructure. This would result in an increase of about 0.5 percent in the semiconductor content of a cellular installation.

Design Objectives. A BSC contains a signal-processing section that performs voice coding and decoding and echo canceling and an embedded computer that controls the DSP section and provides traffic and cell management activities. It is designed to provide high speech quality and to reliably manage the traffic within its control space and to the telephone network. Increasingly sophisticated voice coding schemes demand increasing processing power from the DSP devices that perform this function.

Semiconductor Content. The BSC contains several DSP devices, 32-bit embedded microprocessors, flash memory for program storage, SRAM and DRAM for working storage, application-specific ICs (ASICs), real-time clock devices, and T1/E1 interface blocks. DSP devices handle the highest-volume and most important functions in the BSC. Each channel requires speech processing. As higher-performance DSP products are brought to market, it becomes increasingly possible to process baseband signals from multiple channels on one DSP chip.

Mobile Switching Center

The switching center is a telecommunications switch that routes mobile calls between the cellular and fixed telephone networks. It operates as a central office switch for the cellular network. Thus, primary suppliers of MSCs are the same companies that supply central office switches to the fixed telephone network. MSCs are relatively complex systems, but there are only a few in any given cellular installation. For example, a network supporting more than 1 million subscribers might have four MSCs.

Supplier Analysis

Major Equipment Players and Estimated 1997 Infrastructure Equipment Revenue

The major suppliers of wireless infrastructure equipment are shown in Table 2, with their estimated equipment and related semiconductor purchases for 1997.

Table 2
Cellular Infrastructure Manufacturers' Estimated Equipment Revenue and Estimated Semiconductor Content, 1997 (Millions of Dollars)

Company	Infrastructure Revenue	BTS Semiconductor Content
Ericsson	7,500	420
Lucent	3,900	218
Motorola	3,500	196
Nortel	3,400	130
Nokia	3,140	151
Alcatel	2,000	112
QUALCOMM	420	24
Others	4,625	344
Total	**28,485**	**1,595**

Source: Dataquest (June 1998)

Major Semiconductor Manufacturers

Table 3 shows suppliers of products to wireless base stations.

The key product areas in base stations are the transceiver section, which produces the signal that goes into the baseband processing subsystem, and the signal-processing section, which produces the compressed digital speech signal that is processed by the BSC and forwarded through the telephone network to its final destination.

Estimated Revenue

Dataquest has developed a first-level estimate of BTS revenue by creating a rough estimate of semiconductor content for the key BTS components, the RF/IF section, the baseband section, and the power amplifier section. Dataquest's first estimates for the distribution of semiconductor costs between the RF/IF section, the baseband, and power amplifier sections are 21 percent, 38 percent and 41 percent, respectively, indicating that the greatest opportunities for semiconductors are the baseband and power amplifier sections. Dataquest estimates that the value of the total semiconductor content of a BTS is about $11,500 for a macrocell BTS. The main products used in these sections are DSP processors in the baseband section and RF power transistors in the power amplifier section. Custom IC solutions are developed for the transceiver RF/IF modules, based on the designs of handset devices adapted to the base station environment. Other standard products that are offered for the RF/IF section frequency are synthesizers, mixers/downconverters, modulator/upconverter combinations, and general-purpose amplifier stages.

Table 3
Base Station Semiconductor Suppliers and Product Offerings

Company	DSP	MPU	RF/IF IC	Memory	RF Power Discrete	Data Conversion
AMD		x		x		
Texas Instruments	x		x			
Motorola	x	x	x	x	x	x
Lucent	x		x			x
Intel		x		x		
National		x	x			x
Ericsson			x		x	
TriQuint			x			
RF Micro Devices			x			
Anadigics			x			
Alpha Industries			x			
NEC	x		x	x	x	
Hewlett-Packard			x			
Maxim Integrated Products						x
Philips			x		x	x
Analog Devices	x				x	
Fujitsu			x	x	x	

Source: Dataquest (June 1998)

Competitive Analysis

A few companies are well positioned to profit from the market for semiconductor products in base station applications, particularly, in the longer term, those with high-performance DSP products, high-power RF power discrete products, and GaAs RF/IF ICs. The companies best positioned in these applications are Texas Instruments Inc., Lucent Technologies, and Motorola Incorporated for high-performance DSPs and Motorola for RF power discrete transistors and modules and RISC embedded microprocessors (MPUs). Motorola has a dominant position in the RF power discrete semiconductor product segment, while Texas Instruments and Lucent are strong in DSPs. Many companies are able to supply RF/IF ICs for the transceiver modules in base stations, including Anadigics Inc., TriQuint Semiconductor Inc., Alpha Industries Inc., RF Micro Devices Inc., Motorola, Philips Semiconductors Inc., and National Semiconductor Corporation.

The key to gaining and maintaining a strong position in the base station market is to provide designers with the means to achieve better network performance at lower cost. For DSP suppliers, that means higher-performance DSP products that can perform increasingly sophisticated algorithms on more channels, thus reducing the cost of the baseband functions in the BTS system. For suppliers of RF power devices, it means devices that can provide high- power, highly linear broadband amplification of multiple carriers in macrocells and microcells, ultimately making it possible for a BTS to have one power amplifier per cell covered.

Dataquest Perspective

Although the market for semiconductors in wireless infrastructure equipment is smaller than the handset market, it is still a large market with several large and profitable segments. In particular, RF power products and DSP products, which are relatively high-priced devices, are used multiple times in a base station system. Motorola's Semiconductor Products Sector is well-positioned in RF power devices and embedded microprocessors and Texas Instruments and Lucent Technologies are well-positioned in DSPs for this market. The RF/IF segment of the market is much more competitive, with many companies offering technologies that fit these applications. As a result, this market segment is much less concentrated than the others.

The key forces driving the market for the next five years are the following:

- Replacement of single-channel power amplifiers with multichannel power amplifiers
- Development of more robust algorithms for processing baseband signals
- Development of techniques for processing more baseband channels in fewer DSP devices, a trade-off against the trend toward more robust baseband signal-processing algorithms
- Moving the digital processing of RF/IF signals closer to the antenna. This step is necessary for the introduction of software-defined radios in the BTS.
- Increasing demand for microcells, picocells, and repeaters that fill in "dead spots" and extend the network into buildings locations now served by the wired network

Those trends are driving the need for the following:

- Higher-power, more linear RF power devices
- Higher-performance DSPs
- High-performance data converter products and digital filters for down conversion to baseband signals
- Highly integrated system-level solutions that reduce cost and improve quality of the wireless telephone network

As these trends evolve, Dataquest expects that the current competitors will develop or acquire the technologies that they need to protect their market positions. This will be particularly important in applications related to software-defined radio techniques, an important area for companies supplying devices for the RF/IF section of the BTS to watch during the next five years.

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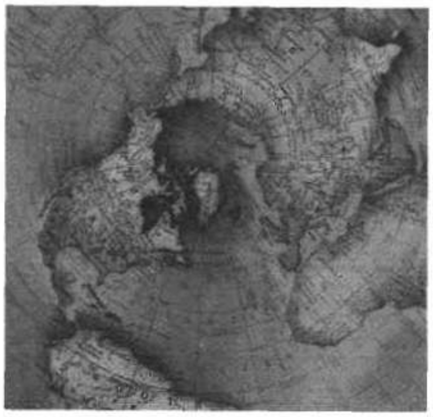

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Chapter 1
Market Statistics Overview and Methodology

Each year, Dataquest surveys leading systems vendors to estimate annual sales and to develop industry market size estimates. In semiconductors, the surveys currently cover the activity of more than 150 vendors worldwide (this varies annually according to mergers, acquisitions, liquidations, start-ups, and other factors) in four world regions.

This primary research is supplemented with additional research to verify market size, shipment totals, and pricing information. Sources of data used by Dataquest include, but are not limited to, the following:

- Interviews with manufacturers, distributors, and resellers
- Information published by major industry participants
- Estimates made by reliable industry spokespersons
- Government data or trade association data
- Published product literature and price lists
- Relevant economic data
- Articles in both the general and the trade press
- Published company financial reports
- Reports from financial analysts
- Information and data from online and CD-ROM data banks
- End-user surveys

Dataquest believes the data presented in the Market Statistics documents is the most accurate and meaningful available. Despite the care taken in gathering, analyzing, and categorizing the data, careful attention must be paid to the definitions used and assumptions made. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groupings, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between data provided by Dataquest and that provided by other research organizations.

Chapter 2
Semiconductor Application Market Segmentation

Semiconductor application markets, as analyzed by Dataquest, are based on six application segments. This section describes these six segments to guide both survey participants and clients. These definitions may occasionally be revised, altered, or expanded to reflect changes in electronic technology.

The six electronic equipment segments that Dataquest has defined are data processing, communications, industrial, consumer, military/civil aerospace, and transportation. Each segment is broken into smaller systems group categories. Most categories are groups of products; some categories are simply one-product categories. The breakdown of electronic equipment segments provides information on which electronic products are included within the segments; it does not indicate what data is available.

The following list gives Dataquest's semiconductor application markets hierarchy:

Data processing

- Computer
  - Supercomputer
  - Mainframe computer
  - Midrange computer
  - Entry-level server
  - Workstation
  - PC
  - Motherboard
  - Handheld computer
- Data storage device
  - Rigid disk drive
  - Removable disk drive
    - Flexible disk drive
    - Rigid disk cartridge drive
  - Optical disk drive
    - Magneto-optical and phase-change disks
    - WORM optical disk drive

- DVD
  - DVD-ROM
  - DVD-Recordable drive
  - DVD-ReWritable drive
- CD drive
  - CD-Recordable drive
  - CD-ReWritable drive
- PD drive

- Tape drive
- Other data storage
  - RAID subsystem

- Input/output device
  - Printer
    - Serial printer
    - Line and specialty printer
    - Page printer
  - Monitor
  - Other input/output device
- Dedicated system
  - Copier
    - Analog copier
    - Digital copier
  - Expandable organizer (personal organizer)
  - Chip card
    - Memory card
    - Smart card (IC card)
  - Other dedicated system
- Other data processing
  - Sound/audio board
  - Digital video board
  - Graphics accelerator board

Communications

- Premise telecom
  - Image and text communications
    - Facsimile machine (for facsimile card, see modem)
    - Video teleconferencing
    - Telex/teleprinter
    - Videotex
  - Data communications equipment
    - Modem (modem card and fax card)
    - Digital WAN system
    - Front-end processor
    - LAN card
    - LAN/internetworking
      - Hub
      - Switch
      - Router
    - Remote access system
    - VSAT
  - Premise voice system
    - Premise switching
    - Voice messaging
    - Interactive voice response
    - Automatic call distributor
  - Telephone terminal
    - Answering machine
    - Telephone
      - Corded telephone
      - Standard telephone
      - Multifunction corded telephone
      - Cordless telephone (analog and digital)
      - Internet/screen phones
      - Other telephone terminal
- Public telecom
  - Transmission
  - Central office switch

- Mobile communications
  - Cellular/broadband PCS/ESMR handset
    - Analog cellular
    - Digital cellular/broadband PCS/ESMR
  - Pager (one- and two-way)
  - Mobile communications infrastructure
  - Other mobile communications
- Broadcast and studio
  - Audio
  - Video
  - Other broadcast and studio
- Other telecom

Industrial

- Security/energy management
  - Alarm system
    - Intrusion detection
    - Fire detection
  - Energy management
- Manufacturing system
  - Semiconductor production
  - Control
  - Process control
  - Control and processing display
  - Robot
- Test and measuring equipment
  - ATE-semiconductor equipment
  - Nuclear electronics
  - Other test and measurement
- Medical equipment
  - Diagnostic
  - Therapeutic
  - Patient monitoring/measuring system
  - Surgical support
  - Irradiation equipment
- Other industrial system

Consumer

- Audio
  - Personal/portable stereo
  - Stereo component
  - Musical instrument
- Video
  - VCR, VTR
  - Camcorder
    - Analog camcorder
    - Digital camcorder
  - Videodisc player
  - Television
    - Color television/HDTV
    - DTV
    - Black-and-white television
  - Cable/satellite set-top receiver
  - Set-top box
    - Analog
    - Digital
      - Direct broadcast satellite
      - Cable TV
      - Terrestrial
      - Others
    - Internet
- Personal electronics
  - Video game (system and cartridge)
    - Video game controller
    - Video game cartridge
  - Camera
    - Digital still camera
    - Other camera
  - Watch
  - Clock
  - Electronic toy

- Appliance
  - Heating, ventilation, and air conditioning
  - Microwave oven
  - Washer and dryer
  - Refrigerator
  - Dishwasher
  - Range and oven
- Other consumer

Military/civil aerospace

- Radar/sonar/reconnaissance
- Missile/space
- Navigation
- Electronic warfare
- Aircraft flight system
- Command, control

Transportation

- Entertainment
  - Auto stereo
- Vehicle/body control
  - Antilock braking system (ABS)
  - Other vehicle/body control
- Driver information
  - Automotive navigation system
  - Other driver information
- Power train
  - Auto engine control unit (ECU)
  - Other power train
- Safety and convenience
  - Air-bag control unit
  - Other safety and convenience

Chapter 3
Semiconductor Application Market Definitions

The semiconductor application market definitions in Tables 3-1 through 3-6 are presented in the same order as the market segmentation in the previous chapter.

Table 3-1
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Data Processing	**Includes computers, data storage, input/output device, dedicated systems, and other data processing.**
Computer	Includes supercomputers, mainframe computers, midrange computers, entry-level servers, workstations, PCs, motherboards, and handheld computers. Includes the value of aftermarket sales of single in-line memory modules (SIMMs) and dual in-line memory modules (DIMMs). Does not include storage, keyboards, add-in cards for graphics, video, audio, LAN, and modems and displays except for built-in displays.
Supercomputer	A high-performance computer designed for either numerically intensive applications or commercial functions that require extensive and rapid computational capabilities. These systems include computing technologies such as vector, superscalar symmetric multiprocessing (SMP), and massively parallel processing. Massively parallel processing systems are defined as systems configured with 32 or more processors. Typically, these systems run in cool rooms, with or without raised floors, or environmentally controlled office habitats and require a dedicated support organization. Applications that lend themselves to the supercomputer platform include atmospheric simulation, pharmacological testing, and nuclear development, as well as very high-level decision support and online analysis.
Mainframe Computer	A general-purpose information system with a starting price of more than $100,000. CPU bit width ranges are typically 64 bits. The physical environment may or may not have special environmental controls and requires full-time support by professional computer systems support staff. The number of concurrent users exceeds 100. Dataquest views a mainframe system shipment as the CPU, the basic storage configuration (not including direct-access storage devices); the operating system (the system must be "bootable"); and the operator's console. Dataquest does not routinely count upgrades unless the system footprint changes.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Midrange Computer	This category includes all multiuser systems that fall between workstations and mainframes. These are multiuser systems that may or may not run proprietary operating systems. With the evolution of client/server computing and the systems that define this market, traditional midrange product categories are becoming obsolete. The HP 9000 and the HP 3000, Digital Equipment Corporation's VAX systems, and the IBM AS/400 line are joined by the dedicated server products from vendors such as Auspex, NetFRAME, and Compaq to form the midrange product category. Office systems, proprietary turnkey computing solutions common in Japan, are also included in the midrange category. Systems designed as servers from workstation vendors are also included here. The category includes midrange-class servers. The key distinctions between the midrange-class server and the server-marketed PC (included under PCs) are price and the average number of CPUs included in the base system. Midrange-class servers ship with more than one CPU and generally cost more than $15,000.
Entry-Level Server	Typically, a server with roots in the PC/Intel architecture (IA). An entry-level server is a shared computer on a network that can be used for simple tasks such as handling print requests and for more complex tasks such as acting as a repository and distributor of data. Systems that were formerly labeled "Server-marketed PCs" by Dataquest are included in this category.
Workstation	Dataquest classifies workstations by a composite of attributes, including their hardware and software features and, more significantly, the manner in which they are brought to market; PCs marketed as workstations are included. These systems must meet a minimum technical specification and be sold and marketed as workstations. Workstations are typically based on 180-MHz or better Pentium II-class or RISC CPU architectures with high-performance graphics, operating system, and system architecture. In general, a workstation must include integrated floating-point processing, integrated networking, and a 32-bit or 64-bit multitasking operating system, as well as configurations that support high-resolution graphics capabilities (typically 1-megapixel display) and 3-D graphics functionality. The category includes traditional UNIX workstations, workstations running Windows NT or proprietary operating systems, and Pentium II-class (or compatible) systems running Windows NT or other advanced operating systems, such as NeXTSTEP and Solaris. Systems shipped with Windows 95 are not included; they are included in PCs. There are three segments of workstations: entry level, midrange, and superworkstation.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
	An entry-level workstation is typically priced between $2,000 and $7,500, usually less than $10,000 for a fully configured system. These systems are typically cost-reduced models targeted at price-sensitive end users. They may support only uniprocessor configurations and mainly run 2-D graphics with some limited 3-D graphics capabilities that may be integrated on the system motherboard. Typically, entry-level workstations do not have the expandability of a midrange workstation and cannot achieve the same levels of application performance or other capabilities available in more expensive models. Examples are the HP 9000 Model 712, IBM RS/6000 43P/140, Digital AlphaStation 255, and Sun SPARCstation 5. Also included are most of the Windows NT/Intel Pentium Pro-based PC workstations, such as the Intergraph TDZ 310, HP Vectra XW, Digital Personal Workstation 200I, Compaq Professional Workstation, and IBM IntelliStation.
	Midrange workstations are the traditional workstation configuration designed for the technical user who requires more power, better graphics, and more memory and storage. They have higher performance, may support two or more processors, and cost between $7,500 and $20,000. The list price of a fully configured model with the fastest processor options and top-of-the-line graphics subsystems can be as much as four times the price of a minimally configured system and considerably higher than the entry point for a superworkstation.
	Superworkstations have the highest combination of CPU and graphics performance and usually address scientific, engineering, and other computationally oriented problems. Base prices can be as low as $20,000 for a minimally configured system and can go up to more than $200,000 for multi-CPU systems that are essentially graphics supercomputers with the capability to handle very large and complex data models.
PC	A general-purpose computer that is distinguished from other computers by its adherence to hardware and software compatibility. This compatibility drives high unit volumes of commoditylike products that do not require on-site technical support. High-performance features (such as networking, graphics, and a virtual multiuser/multitasking operating system) are normally optional and not integral system features. Intel x86-compatible and Macintosh personal computers are two platforms in this product segment. A single-user PC's resident operating system is typically DOS, OS/2, Windows, or Mac OS. PCs have a performance ceiling that is lower in system compute performance, I/O channel speed, and disk speed than that of advanced workstations; normally, standard graphics are about 760 x 1280 pixels and optional high-end graphics are limited, compared to workstations. Although Dataquest's Computer Systems and Peripherals group views PCs as a unit comprising a CPU, a monitor, and a keyboard, the semiconductor applications programs, for the purposes of counting semiconductors, excludes motherboards, monitors, keyboards, storage, and other peripherals because they are covered elsewhere. Dataquest's PC shipment data also excludes systems assembled from component parts purchased in electronic stores or other outlets. This PC category does not include handheld computers or personal organizers. PCs can be subdivided into deskbound and transportable PCs.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
	Deskbound PCs are PCs with either a deskside or desktop configuration. Deskside PCs are designed to stand vertically beside or underneath a user's desk. The primary design distinguishes a deskside from a desktop unit in that it keeps a sideways orientation and in that drive bays usually remain horizontal when the CPU is placed on the floor. Desktop PCs are all PCs intended for use on a user's desktop or work surface and not designed to be readily moved from place to place. Switchable models, either desktop or deskside, fit into this category.
	A transportable PC is a system that meets all other personal computer criteria but is designed to be easily moved from place to place. The case style may be identified as a lunch box, and the system is completely self-contained and can be carried as a single unit, which includes a keyboard, a display, mass storage, and the main system unit. Its primary source of power is AC power. Its typical weight is 18 to 20 pounds. Included in this category are laptop PCs, which meet all criteria for a transportable personal computer but are smaller and lighter. In addition to the difference in size and weight, they are distinguished from transportables by case design, which is typically a clamshell. System weight is usually less than 15 pounds. A laptop's power source is either AC or DC. Included in this category are notebook PCs, which meet all criteria for laptop DC personal computers but are smaller and lighter. The case style typically measures 8.5 x 11 inches or A4 size. Weight typically is less than 8 pounds with the battery. Included as notebook PCs are tablet devices (which are distinguished by a pen-based operating system using a pen as a primary input device rather than a keyboard) and ultraportable PCs (a notebook PC without an internal floppy disk drive, typically weighing 4 pounds or less).
Motherboard	A PC system board consisting of a printed circuit board with semiconductor and nonsemiconductor components that are all soldered down; the value of the CPU and memory are excluded. The list of semiconductor components includes a minimum of a core logic chipset, clock controller, real-time clock, keyboard controller, any additional glue logic required to interface between the core logic chipset and CPU, cache memory, main memory, and expansion bus (such as PCI). The list of semiconductor components may include a graphics controller, mass storage interface, serial and parallel I/O, voltage converter, or audio controller, as long as they are soldered down.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Handheld Computer	A general-purpose computer that is designed to be held comfortably in a user's hand. It is based on an operating system, microprocessor, and reference platform, like a personal computer, but is distinguished by its size, weight, and physical usage. It is typically designed to be carried in a pocket, briefcase, or purse; weighs two pounds or less; and does not require a flat surface for use. It is also designed to be used with batteries as its primary power source. As with other portable computers, input can be keyboard-based, pen-based, or both, with a potential for voice-based input. This category excludes expandable organizers, which are included in dedicated systems. This category also includes standard handhelds—general-purpose computers that are distinguished from organizers by their adherence to hardware and software compatibility standards. The standard handheld operating systems are licensed and available to multiple manufacturers, and application development and memory expansion are open to third-party developers and may be distributed in a standard format (such as PCMCIA). Standard handhelds typically measure 4 x 7 x 1 inches (this varies) and weigh about one pound (this is also likely to vary). The primary applications are personal information management (PIM) and communications. A subcategory of the standard handheld market is industrial handhelds, which are developed for field operations use and are "ruggedized" for other specialized use. These systems are not marketed to consumers. Inventory control devices are not included. Examples are the 3Com Pilot, the Casio Cassiopeia, the Hewlett-Packard OmniGo, and Windows CE systems.
Data Storage Device	Includes rigid disk drives, removable disk drives, optical disk drives, tape drives, and other data storage.
Rigid Disk Drive	A rigid disk drive (RDD) stores digital information on a round platter made of polished aluminum or a ceramic material. The information is written and read from the platters by recording heads mounted on the end of an arm. The arm is positioned over the desired area of the disk by a sophisticated control circuit that guides an actuator motor's movement. The data is amplified, decoded, and transmitted to the computer by the disk drive electronic circuits. The manner in which the information is presented to the computer is determined by the interface characteristics of the disk drive. Examples of interfaces include SCSI and the PC-AT bus, sometimes called IDE, EIDE, ATA, or UDMA.
Removable Disk Drive	A drive that houses a removable disk protected by a jacket. Dataquest defines two types of removable disk drives: flexible disk drives, and rigid disk cartridge drives.
Flexible Disk Drive	A drive that reads and writes data to removable flexible media made of a polyester substrate, which is coated with a magnetic material and housed in a protective jacket. Dataquest segments flexible disk drives into two main categories based on drive capacity. Low-capacity flexible drives are defined as drives with a capacity of less than 20MB, and high-capacity flexible drives are drives with a capacity of 20 MB or greater.
Rigid Disk Cartridge Drive	A disk drive that reads and writes data to magnetic rigid media that is housed in a protective jacket. The removable disk cartridge, which contains the media, is inserted into the drive for a read or write operation.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Optical Disk Drive	An optical disk drive (ODD) is a data storage device that records and stores computer data on removable media using laser technology. Its categories are CD ROM; CD-Recordable-Recordable (CD-R); CD-ReWritable (CD-RW), phase-change disk (PD), DVD-ROM, DVD-Recordable, DVD-ReWritable, write-once read-many (WORM) optical drive; and rewritable ODD.
Magneto-Optical and Phase-Change Disks	Magneto-optical (MO) and phase-change disks are ODDs that use removable media that can be erased and reused many times (also called erasable optical disk drives). Many of these drives include multifunction capability. This category includes multifunction drives that are capable of reading from and writing to both rewritable and WORM media.
WORM Optical Disk Drive	A WORM drive can read and write data using various types of removable optical disk media.
DVD	Digital versatile disc (DVD) is essentially a high-density CD. DVD drives use discs that are the same size as CDs but have a much higher storage capacity. The category includes all versions: DVD-ROM, DVD-R, and DVD-ReWritable drives This category also includes rewritable optical drives that are compatible with DVD-ROM but depart from the DVD-RAM specification. An example of this is DVD+RW.
DVD-ROM	A drive that reads high-capacity CD-ROM discs with capacities ranging from 4.7GB to 17GB, depending on the number of surface and active layers, as well as current-capacity CD-ROM discs.
DVD-Recordable Drive	A drive that reads or records the DVD-ROM version of WORM technology.
DVD-ReWritable Drive	A drive that reads, writes, and rewrites media based on phase-change technology. The drive also reads DVD-ROM and DVD-R media.
CD Drive	CD-ROM discs are 4.7 inches (12cm) in diameter, have a 1.6-microinch-pitch single-spiral track, and have 2,048 data bytes per sector. This category includes CD-ROM, CD-R, and CD-RW drives.
CD-Recordable Drive	A drive that reads or records the DC-ROM version of the WORM technology. These discs conform to ISO 9660 standards and can be read in CD-ROM drives.
CD-ReWritable Drive	A drive that reads, writes, and rewrites CD-ROM standard media based on phase-change technology. The drive also records CD-R media and reads CD-ROM discs, as well as disks recorded on a CD-R drive.
PD Drive	A PD drive reads, writes, and rewrites non-CD-ROM standard media based on phase-change technology. The drive also reads CD-ROM discs, as well as discs recorded on a CD-R drive.
Tape Drive	Records and stores computer data on removable magnetic media. A tape drive is synonymous with a tape transport. It consists of the mechanism that controls the movement of the media past the read/write head or heads, the electronics that control the movement of the tape, and the processes required for recording or reading data. In products in which the drive level interface is embedded or integrated with the drive, the definition of a tape drive also includes this interface.
Other Data Storage	Consists of redundant arrays of independent/inexpensive disks (RAID) subsystems and in the future may include technologies such as holographic storage and solid-state drives.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
RAID Subsystem	A RAID subsystem is a set of disk drives (at least three) for which I/O is managed from either host-based software or a controller. All forms of RAID are in this category, including mirroring or striping. RAID configurations be embedded internally or externally to the server, as in a typical disk subsystem. Some examples of RAID systems include: IBM's RAMAC and 7133, EMC's Symmetrix 3000 and 5500, HDS 7700, Sun SPARCarray 3000 and 5000, and Digital Equipment's 410. For the purposes of the Semiconductor Applications programs database (and to avoid double-counting), this category includes the value of the RAID controller board, adapter cards, power, and packaging but does not include the value of storage drives, which are accounted for in other storage categories.
Input/Output Device	Includes all equipment that transfers data between the CPU and a peripheral device.
Printer	An output device that uses computer-originated, digital electronic signals to create alphabetic, numeric, or graphic symbols, that will print onto various types of media, and that has a print width of 80 columns of output at a pitch of 10 or greater.
Serial Printer	A serial printer produces images using a print head that travels across the width of the paper on a carriage mechanism. This category includes serial impact dot matrix printers (a printer that creates a character image by selectively placing individual dots on the substrate using mechanical force), serial nonimpact ink jet printers (a printer that creates the desired image one character at a time by emitting ink from an array of orifices or nozzles), and serial nonimpact thermal transfer printers (a printer that creates the desired image one dot at a time using point-specific heat to transfer ink from a ribbon to a receiving substrate).
Line and Specialty Printer	Includes printers that print one line at a time and specialty printers such as thermal printers and ticket printers, among others.
Page Printer (Laser)	A printer that prints one page at a time. These are electrophotographic printers in which laser beams are used to transfer images to a photoreceptor (drum). They have the ability to buffer, in part or in whole, a page of images received from an electronic source and then to transfer these images to a receiving substrate.
Monitor	A self-contained video display device that attaches directly to a computer and displays the contents of the computer's video memory. A monitor contains no data formatting or editing capability, nor does it contain any type of networking capability. Included are color monitors with interfaces capable of interpreting signals containing separate color components (normally the three primary colors, red, green, and blue) and monochrome monitors based on a single-color CRT. These monitors normally display in shades of white, green, or amber. They may or may not have the ability to display multiple shades of a monochromatic color. Also included are standalone flat panel displays (FPDs) and LCD monitors.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Other Input/Output Device	Includes network computers (NCs), terminals, scanners, multifunction devices (which will include two of the following capabilities: fax, copier, scanner, or printer), monitor speakers, mice, joysticks, keyboards, headsets, card readers, and data converters, among others. Videoconferencing and PC telephony equipment are not included in this category but in the communications segment.
Dedicated System	Dedicated data processing systems such as copiers, personal organizers, chip cards, and other systems.
Copier	Both analog (optical technology) and digital (digital scanning technology) copiers.
Analog Copier	An analog copier captures and transfers images using optical or "light lens" technology in which the image is flash illuminated on the platen, then transferred to the photoconductor through a series of lenses and mirrors. The latent image is then transferred from the photoconductor to paper through the electrophotographic process.
Digital Copier	A digital copier captures images using digital scanning and transfers images using electronic impulses in which the image is scanned from the platen and digitized into electronic data. The electronic data is processed to enable the image to be transferred to the photoconductor. The electronic image data is transferred to the photoconductor through the light impulses of a laser or LED to "write" the image to the photoconductor material. The latent image is then transferred from the photoconductor to paper through the electrophotographic process, as with an analog copier.
Expandable Organizer (Personal Organizer)	A general-purpose computer that is distinguished by its size, in addition to its functionality. Organizers measure about 3 x 6 x 0.75 inches, weigh less than one pound, have a keyboard, and operate on batteries. Expandable organizers are distinguishable by the ability to allow the user to add applications and memory and by expansion that is typically proprietary to a particular device or device family. The primary application is personal information management. Organizers typically have proprietary operating systems. Personal organizers may eventually include some wireless communications capability. Examples are the Psion Siena and Sharp Zaurus.
Chip Card	A flat, plastic card, the size of a credit card, that has one or more integrated circuits on board. A chip card can exchange data with a chip card reader that physically interfaces with the card or uses radio frequency (RF) signals to add or extract data (contact or contactless).
Memory Card	A chip card that has a memory IC on board, most commonly EEPROM. Memory cards do not have a microprocessor or microcontroller but may include other types of logic on board, such as security or cryptography functions.
Smart Card (IC Card)	A chip card that has a microprocessor or microcontroller on board.
Other Dedicated System	Includes calculators, typewriters, word processors, point-of-sale systems (cash registers, bar code readers, and credit card checkers), dictating/transcribing equipment, and funds-transfer machines (ATMs/cash dispensers), among others.

Table 3-1 (Continued)
Semiconductor Application Market Definitions: Data Processing

Product	Definition
Other Data Processing	Includes sound/audio, digital, and graphics accelerator boards. This includes all boards, whether shipped to computer OEMs or to a channel.
Sound/Audio Board	PC add-in cards that are audio-centric and are compatible with industry-standard sockets.
Digital Video Board	PC add-in cards that are digital video-centric and are compatible with industry-standard sockets. This category includes DVD-video decode and encode boards.
Graphics Accelerator Board	PC add-in cards that are graphics-centric and are compatible with industry-standard sockets.

Source: Dataquest (September 1998)

Table 3-2
Semiconductor Application Market Definitions: Communications

Product	Definition
Communications	**Includes premise telecom equipment, public telecom equipment, mobile communications equipment, broadcast and studio equipment, and other telecom equipment.**
Premise Telecom	Includes telecommunications equipment on private premises such as image and test communication equipment, data communication equipment (WAN/LAN and remote access), premise voice systems, and desktop terminals (telephones excluding mobile handsets).
Image and Text Communications	Includes fax machines, video teleconferencing, telex/teleprinters, and videotex.
Facsimile Machine (For Facsimile Card, See Modem)	An electronic device that transmits printed matter or pictures and reproduces them. Includes those with answering machines and cordless handsets.
Video Teleconferencing	Equipment used to compress and play real-time video of meetings between groups or individuals. The category includes equipment that is permanently installed and configured in a room, equipment that can be moved from room to room on a rolling cart and that uses dedicated communications equipment apart from the computer (which in most cases is a workstation but could be a PC), equipment integrated into a PC or workstation (generally on one board that sits in a bus slot), and voice recognition boards that recognize human speech and translate it to computer text; it includes video telephones.
Telex/Teleprinter	A typewriterlike terminal with a keyboard and built-in printer, often a portable unit.
Videotex	An electronic service that provides access to remote computer databases using a computer, a terminal, or a modified television. Includes both "broadcast" videotex (one-way digital data transmissions) and "interactive" videotex (two-way, interactive communication). Broadcast videotex includes Oracle and Ceefax (British). Interactive videotex includes the Prestel (British) and Teletel (French) systems.
Data Communications Equipment	Includes modems, digital WANs, front-end processors, LANs, remote access equipment, and very small-aperture terminals (VSATs).
Modem (Modem Card and Fax Card)	An electronic device that provides modulation and demodulation functions for data signals transmitted over telephone lines. It converts digital data to analog data for transmission over leased lines or the analog public switched telephone network (PSTN). The category includes internal card modems, external modems, PC card modems, and fax cards.
Digital WAN System	The hardware and peripheral equipment that enable connections of multiple local area networks. Connections are made with a high-speed digital line called a backbone. Equipment includes T/E1 and T/E3 carrier multiplexers, fractional and sub-T1 multiplexers, inverse multiplexers, asynchronous transfer mode (ATM) concentrators, integrated access devices (IADs), cell switches (ATM switches), frame relay switches and access devices, and X.25 packet assembler/disassemblers and switches. Includes data service units (DSUs) and channel service unit (CSUs).

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Front-End Processor	Input/output system that interfaces with telecommunications lines for large server systems.
LAN Card	Local area network cards, or network interface cards (NICs), are the printed circuit boards that plug into the expansion slot or slots of a PC, workstation, server, or host terminal to allow connection to a LAN. NICs are designed in accordance with either IEEE or ANSI protocol standards; the most common are Ethernet, token ring, fiber-distributed data interface (FDDI), and ATM. (Workstation and host NICs are segmented into only FDDI, ATM, and Others categories.)
LAN/Internetworking	Includes hubs, switches, and routers.
Hub	A shared-media hub is a LAN device that connects multiple PCs through one segment on the network. For example, on a 12-port Ethernet hub, all ports share the 10-Mbps bandwidth available. A hub typically supports centralized control of optional functionality such as port monitoring and connectivity status.
Switch	A LAN device that provides a discrete LAN segment to one or more users on each switched port. For example, on a 12-port Ethernet switch, each port has its own dedicated 10-Mbps bandwidth. Switches are managed in a fashion similar to hubs. Switches that include layer-3 capability can also support routing functionality (see routers).
Router	A network control device used to determine the path for data transmission between devices within a network and between devices in different networks. Routers are typically software controlled and can be programmed, for example, to provide the least expensive, fastest, or least congested of the available data paths, depending on the network configuration and administrative preferences. Routers can also be deployed as filtering agents to provide discriminatory access to certain network segments and resources.
Remote Access System	Includes remote access concentrators and remote access servers. Remote access concentrators are very high-density systems with channelized T1/E1 or T3/E3 interfaces that combine modem pools, routing, and remote access server functionality into a single platform. Remote access servers are low density, with the largest having more than eight ports.
VSAT	A very small-aperture terminal (VSAT) is a satellite data communications terminal.

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Premise Voice System	Includes premise telecommunications functions as detailed below
Premise Switching	Voice equipment that provides switching or call-routing functions. Includes such equipment as PBX telephone systems (a telephone switching system on customer premises that allows telephones to interface to the public telephone central exchange or office when the user dials an access code) and key telephone systems (a customer-premises telephone-switching system that allows telephones to interface to the public telephone central exchange office only via key access, without using an access code). This category includes the electromechanical 1A2 and electronic segments. Requires the use of station equipment designed for the systems and key hybrid systems. Premise line cards are included within the equipment.
Voice Messaging	A computer-based system that enables flexible, nonsimultaneous voice communications.
Interactive Voice Response	A system that allows a user to access a host computer or resident database through the use of a keypad of a touch-tone telephone or through voice-recognition technology. Once the database is accessed, the user can input data, extract data, or manipulate data found in the computer database.
Automatic Call Distributor	A specialized phone system used for handling and routing many incoming calls.
Telephone Terminal	A multiplexer where all tributaries are terminated from the high-speed signal. The category includes answering machines and corded and cordless telephones; does not include cellular/broadband PCS/ESMR phones.
Answering Machine	Both standalone and integrated answering machines, including any telephone terminal that includes an answering machine. Integrated telephone answering machines include devices that can play an outgoing message and record an incoming message and that include a telephone; they may be solid state (digital) or tape-based. Standalone answering machines include devices that can play an outgoing message and record an incoming message but that exclude a telephone; they may be solid state (digital) or tape based. To avoid double-counting, any corded or home cordless telephone that has an integrated answering machine is included in the answering machine category. Excluded are fax machine/answering machine products, which are categorized under Facsimile.
Telephone	Customer premise equipment (CPE) capable of transmitting voice communications via either wireless or wireline access. Includes corded telephones and cordless telephones and others; excludes mobile handsets.
Corded Telephone	Includes standard corded telephones and multifunction corded telephones.
Standard Telephone	Includes all one- and two-piece telephones that connect by a cord directly to the PSTN or a PBX. These have a limited range of additional capabilities; as a maximum, these would include a "last-number redial" facility and limited telephone number memory (a maximum of 10 numbers).

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Multifunction Corded Telephone	Includes feature, multiline, smart telephones, and standalone caller ID boxes. Feature telephones include, as a minimum, a liquid crystal display, last-number redial, and memory for 10 or more telephone numbers. They usually also include on-hook dialing or speakerphone capability. Multiline telephones have more than one phone line attached. Smart telephones are highly featured and may have VGA display, caller ID, an answering machine, and a modem, among other features.
Cordless Telephone	A telephone for use with the PSTN comprising two separate components: a portable handset containing microphone, loudspeaker, and dial keypad and a fixed base PSTN access unit, which are interconnected by a radio link rather than a wire. This category includes all telephones with a handset that has no wired connection to the PSTN or PBX. The major difference between cordless telephones and cellular phones is the lack of ability to roam from one base station to another or the ability to roam only at pedestrian speeds; these are categorized as home based and low mobility. Home-based cordless handsets are distinguished by the ability to communicate only with one base station in the home or small business. Low-mobility cordless handsets are cordless handsets that can be used to roam outside the home and can communicate with a service provider's infrastructure or multiple base stations in an office. They are usually distinguished from cellular by being able to communicate only at pedestrian speeds. Includes analog cordless telephones and digital cordless telephones.
Analog Cordless	Current examples of analog cordless are single-channel, 10-channel, 24-channel, CT-0, CT-1, and 900-MHz analog.
Digital Cordless	Current examples of digital cordless are PHS, DECT and CT-2, 900-MHz digital, and 900-MHz spread spectrum, among others.
Internet/Screen Phones	Telephone-based Internet appliances that typically incorporate touch screens or small keyboards. These devices often support both Internet browsing and e-mail functions. Likewise, they generally feature caller ID and personal information management functions. This category also includes standalone Internet telephony devices that transmit packetized voice over data networks.
Other Telephone Terminal	Includes standalone caller ID boxes, audioconferencing systems, and telephone headsets, among others.
Public Telecom	Key equipment involved in the public switching and transmission markets.
Transmission	Includes fiber-optic (SONET/SDH) and nonfiber-optic transmission systems consisting of primarily digital cross-connects, digital access transceivers, multiplexers, repeaters, optical fibers, wireless transceivers, power systems, and optical network units. Transmission systems comprise the local telephone line (local loop), the trunk lines (conduits between switches), and the long distance lines.
Central Office Switch	A telecommunications switch used by public carriers and competitors; includes subscriber line cards.

Table 3-2 (Continued)
Semiconductor Application Market Definitions: Communications

Product	Definition
Mobile Communications	Includes cellular/broadband PCS/ESMR handsets, pagers, and mobile communications infrastructure, among others.
Cellular/Broadband PCS/ ESMR Handset	Includes analog cellular and digital cellular/broadband PCS/ESMR handsets.
Analog Cellular	Includes all AMPS, TACS, NMT, and other cellular handsets.
Digital Cellular/Broadband PCS/ESMR	Includes all handsets (hand portable, transportable, and mobile) that have a radio link to a cellular or microcellular base station. The cellular system maintains a control link with each handset, whether stationary or moving at speed, and controls an automatic seamless handover from one cell base station to the adjacent cell as the handset user moves. Includes handsets that conform to the following standards: GSM, DCS 1800, PCS 1900, NA-TDMA (IS-54/ 136), CDMA (IS-95), PDC, and Omnipoint. Also includes any hybrids of the above, including cellular cordless handsets, ESMR handsets, and next-generation products such as Universal Mobile Telephone System (UMTS) and Future Public Land Mobile Telephone System (FPLMTS). Also includes smart phones, a category of wireless offering advanced voice and data capabilities such as fax and e-mail, Internet access, data access, and a schedule manager.
Pager (One- and Two-Way)	Includes all tone-only, tone-and-voice, digital (numeric), and alphanumeric paging devices; also includes paging devices developed for use in narrowband PCS service. These pagers have limited two-way messaging capability and can also serve as "mobile answering machines." Also includes pagers that have acknowledgment capability.
Mobile Communications Infrastructure	A system that includes base station and microcell equipment for PCS, cellular, paging, and other wireless radio communications. Interconnection between cell sites and mobile telephone switching offices (MTSOs) is typically done via microwave links, fiber optics, or high-capacity landlines. Two components are the base station controller (BSC) and the switch. The BSC controls the voice channels and power controls.
Other Mobile Communications	Includes two-way land mobile radio (walkie-talkies), emergency equipment for police and fire departments and the U.S. Secret Service, taxi communications, and radio checkout, among others.
Broadcast and Studio	Includes audio, video, and other broadcast and studio equipment.
Audio	Broadcast and studio audio equipment.
Video	Broadcast and studio video equipment.
Other Broadcast and Studio	Includes transmitters and RF power amplifiers, studio transmitter links, cable TV equipment (head end and transmission), closed circuit TV equipment, and other studio/theater and broadcast and sound equipment; also includes all equipment related to these items.
Other Telecom	Other telecom equipment not elsewhere counted, such as intercommunications systems.

Source: Dataquest (September 1998)

Table 3-3
Semiconductor Application Market Definitions: Industrial

Product	Definition
Industrial	**Includes security/energy management, manufacturing systems, test and measuring equipment, medical equipment, and other industrial systems.**
Security/Energy Management	Includes alarm systems and energy management.
Alarm System	Includes intrusion detection and fire detection systems.
Intrusion Detection	Includes all equipment for intrusion detection, such as control panels, touch pads, motion detectors, and alarms; excludes closed circuit TV, which is in the communications segment under Broadcast and Studio.
Fire Detection	Includes all equipment for fire detection, such as smoke alarms, phone interconnects, touch pads, and control panels.
Energy Management	Includes heating, ventilation, and air conditioning systems; excludes residential systems, which are included in Consumer Appliances.
Manufacturing System	Includes semiconductor production equipment, control and process control equipment, control and processing display equipment, and robots.
Semiconductor Production	Semiconductor manufacturing equipment for fabrication, such as steppers, spray processors, and scrubbers.
Control	Includes motor controls, starters, contactors, pilot circuit devices, crane controls, and other controls and parts.
Process Control	Controls for temperature, liquids, gas, and other variables, such as thermostats.
Control and Processing Display	Includes electronic systems (unified and nonunified architecture type), multifunction process computers, pneumatic systems, annunciators, physical property and kinematic test and measuring equipment, and other process instruments and parts.
Robot	Includes both servo-controlled and nonservo-controlled robots, hobby and experimental robots, and all accessories and parts.
Test and Measuring Equipment	Includes automatic test equipment (ATE)-semiconductor equipment, nuclear electronics, and other test and measurement equipment.
ATE-Semiconductor Equipment	Includes semiconductor dedicated and board automatic test equipment.
Nuclear Electronics	Includes all equipment using nuclear technology except diagnostic medical equipment and all specialized equipment for nuclear applications.
Other Test and Measurement	Includes equipment for testing, measuring, and analyzing, such as microwave testers, time measuring and counting equipment, multimeters, signal-generating equipment, and standards and calibration equipment, oscilloscopes, and test and measurement equipment.

Table 3-3 (Continued)
Semiconductor Application Market Definitions: Industrial

Product	Definition
Medical Equipment	Includes diagnostic, therapeutic, patient monitoring and measuring systems, surgical support equipment, and irradiation equipment.
Diagnostic	Includes electrocardiography, electromyography, endoscopic, respiratory, and audiological equipment; scanning devices and nuclear magnetic resonance imaging devices; and other diagnostic equipment.
Therapeutic	Includes pacemakers, defibrillators, electrosurgical and diathermy equipment, and other therapeutic equipment.
Patient Monitoring/Measuring System	Includes equipment for intensive care, perinatal care, respiratory care, and other patient monitoring equipment.
Surgical Support	Includes equipment for surgical support systems.
Irradiation Equipment	Includes medical X-ray equipment of all types such as diagnostic, dental, and therapeutic, as well as parts and accessories.
Other Industrial System	Includes vending machines, automatic service equipment, commercial clothes-washing equipment, teaching machines and aids, particle accelerator electronic equipment, electron microscope, and scientific equipment not elsewhere counted.

Source: Dataquest (September 1998)

Table 3-4
Semiconductor Application Market Definitions: Consumer

Product	Definition
Consumer	**Includes audio, video, personal electronics, appliances, and other consumer electronics.**
Audio	Includes consumer audio equipment.
Personal/Portable Stereo	A personal/portable stereo with any combination of compact disc player, MiniDisc player, DVD audio player, cassette player/recorder, or headphones; also includes boom boxes and clock radios.
Stereo Component	Includes radio receivers, cassette players/recorders, CD/MD/DVD audio players, amplifiers, equalizers, mixers, and speakers that can be individually purchased for the home. Includes rack audio systems (which have rack-mounted components usually sold as a set) and minishelf systems that typically do not have a handle (as boom boxes do) and are not built for portability; excludes personal/portable stereos.
Musical Instrument	Electronic musical instruments such as keyboards.
Video	Includes consumer video equipment.
VCR, VTR	Includes videocassette recorder (VCR) and videotape recorder (VTR); does not include TV-VCR combinations.
Camcorder	Includes analog and digital camcorders.
Analog Camcorder	Traditional analog camcorders, which may include vibration or shake compensation and digital zoom.
Digital Camcorder	Camcorders based on the Digital Video (DV) format specification for home-use digital camcorders.
Videodisc Player	Includes DVD players, laser disc players, and Video CD players. Does not include DVD products targeted at the PC market; those are a subcategory of Optical Disk Drives. Does not include the DVD encode/decode board, which is in Other Data Processing. Video CD players use MPEG-1 technology for storage of full-motion video and are also used in karaoke applications. DVD players use MPEG-2 technology and Dolby digital technology for storage of full-motion video and audio, currently for playback only but eventually for recording and rewriting also. Laser disc players play back video stored in an analog format on an optical disk.
Television	Includes televisions.
Color Television/HDTV	Includes LCD-based and TV-VCR combinations and analog high-definition TV (HDTV) receivers.
Digital Television/DTV	Digital TV (DTV) includes SDTV (standard-definition TV) and digital HDTV.
Black-and-White Television	Monochrome televisions.
Cable/Satellite Set-Top Receiver	TV converter boxes that allow viewers to view programs from cable TV, telephone, or wireless network sources.
Set-Top Box	Converter boxes that sit on top of TVs and allow viewers to view programs from cable TV, telephone, wireless networks, or broadcast satellite sources; includes pay-TV receivers.
Analog Set-Top Box	A set-top box that decodes and enables access to analog-based TV services; includes analog cable, analog satellite, and analog wireless cable.

Table 3-4 (Continued)
Semiconductor Application Market Definitions: Consumer

Product	Definition
Digital Set-Top Box	Digital converter boxes sit on top of a TV and act as converter devices for digital information over cable TV, satellite, terrestrial, telephone, or wireless networks to television sets. These boxes are capable of digital reception and decompression.
Direct Broadcast Satellite	Direct broadcast satellite (DBS) devices have a set-top box element plus a receiving satellite dish to receive signals from a satellite.
Cable TV	TV converter boxes that allow viewers to view digitally compressed programs from cable TV.
Terrestrial	Set-top box receiver/decoder that allows the viewing of digitally compressed TV signals transmitted from land-based TV transmitter masts.
Others	Includes DTV set-top boxes, multipoint multichannel distribution system (MMDS), advanced digital subscriber line (ADSL), and local multichannel distribution system (LMDS) pay-TV receivers.
Internet	Internet television set-top boxes use the television as the primary user interface. These devices are connected to the Internet via the phone line or cable TV line and employ a variety of analog or digital modem technologies. These appliances generally have few or no voice telephone capabilities. This product is exemplified by the WebTV.
Personal Electronics	Includes video games, cameras, electronic watches, clocks, and toys.
Video Game (System and Cartridge)	Microprocessor-based devices that are handheld or console based and play video games housed on cartridges or CD-ROMs; includes CD-ROM peripherals.
Video Game Controller	Controller hardware for both handheld and console video games.
Video Game Cartridge	Video games delivered by semiconductor ROM.
Camera	Includes traditional and digital still cameras.
Digital Still Camera	Still camera that records images on memory chips or a disk instead of film.
Other Camera	Camera that records images on film.
Watch	Electronic watches.
Clock	Electronic clocks.
Electronic Toy	Electronic toys such as remote-control toy vehicles and "talking" toys, among others.
Appliance	Consumer appliances.
Heating, Ventilation, and Air Conditioning	Heating, ventilation, and air conditioning systems for residences.
Microwave Oven	Microwave ovens for residences.
Washer and Dryer	Washers and dryers for residences.
Refrigerator	Refrigerators for residences.
Dishwasher	Dishwashers for residences.
Range and Oven	Includes microwave/range/oven combinations.
Other Consumer	Includes automatic garage door openers, electronic tape measures, electronic tire gauges, and other consumer equipment not counted elsewhere.

Source: Dataquest (September 1998)

Table 3-5
Semiconductor Application Market Definitions: Military/Civil Aerospace

Product	Definition
Military/Civil Aerospace	**Includes radar/sonar/reconnaissance, missile/space, navigation, electronic warfare, aircraft flight systems, and command/control systems.**
Radar/Sonar/Reconnaissance	All forms of radar system (ground, ship, airborne, and space), sonar systems, electro-optic sensors, identify-friend-or-foe (IFF) systems, proximity fuses, passive sensors, and dedicated support equipment; includes both civilian and military use.
Missile/Space	Guidance, control, and electronics payload for spacecraft and their launch systems and dedicated ground support equipment; includes both civilian and military use. Also includes missile guidance and control and dedicated support equipment.
Navigation	Navigation equipment used by aircraft, ships, and ground vehicles, including autopilots, beacons, collision-warning devices, and direction finders; includes both civilian and military use.
Electronic Warfare	Includes countermeasures (for example, jamming), counter-countermeasures, and various specialized electronics and communications intelligence systems.
Aircraft Flight System	Onboard avionics systems (cockpit instruments and distributed controls) not counted elsewhere; includes both military and civilian use.
Command and Control	Specialized computer and networking systems not covered in the data processing and communications categories.

Source: Dataquest (September 1998)

Table 3-6
Semiconductor Application Market Definitions: Transportation

Product	Definition
Transportation	**Includes entertainment, vehicle/body control, driver information, power train, and safety and convenience.**
Entertainment	Currently, this category includes only auto stereo.
Auto Stereo	Includes integrated AM/FM stereo radio receivers, AM/FM radio/cassette combinations, AM/FM radio/cassette/CD combinations, all in-car audio stereo AM/FM radio-based systems, amplifiers, terrestrial digital audio broadcast (DAB) receivers, and DSP surround-sound Pro Logic.
Vehicle/Body Control	Includes antilock braking systems (ABS) and other vehicle/body control.
Antilock Braking System	Includes electronic ABS control units for two-wheel ABS systems, and four-wheel ABS systems for passenger cars, electronic ABS control units for two-wheel and four-wheel ABS systems for light trucks, electronic ABS control units for commercial vehicles, ABS systems for trailers and heavy trucks, and electronic ABS control units for motorcycles; also includes ABS with integrated traction control systems.
Other Vehicle/Body Control	Includes active suspension, central door locking, integrated body computer with security/advanced on-board diagnostics, keyless entry, lighting control, multiplex node control (diagnostic), multiplexed door operations, power window/mirror/seat/sunroof, and tire pressure monitor; also includes dynamic vehicle control systems—semiactive suspension/active suspension, driving stability/chassis control, collision avoidance, and electronic/electrical power steering.
Driver Information	Includes automotive navigation systems and other driver information.
Automotive Navigation System	Includes only navigation systems with CD-ROM digital map system, global positioning system (GPS) positioning, LCD monitor and gyroscope for dynamic vehicle navigation, and visual and audio interaction navigation systems.
Other Driver Information	Includes traffic information systems/traffic guidance systems, route guidance systems, electronically controlled dashboard instrumentation, trip computers, diagnostic displays, digital clocks, digital compasses (electronic), and speech recognition/synthesis.

Table 3-6 (Continued)
Semiconductor Application Market Definitions: Transportation

Product	Definition
Power Train	Includes auto engine control unit (ECU) and other power train.
Auto Engine Control Unit	Includes electronic engine control units for gasoline and diesel fuel carburetor/injection engines for cars and trucks. Electronic engine control units for gasoline-powered cars include electronically controlled carburetor systems, single-point injection systems, and multipoint injection systems; also includes electronic control units where ignition control (breakerless/distributorless or adaptive/digitally programmed) is integrated with carburetor or injection control unit. Electronic engine control units for diesel-powered cars include electronically controlled direct injection systems and indirect injection (distributor) systems; manages spark or fuel injection or both.
Other Power Train	Includes engine immobilizers, cruise control, intelligent cruise control, automatic transmission electronic control units, semiautomatic transmission control, adaptive transmission control, and standalone ignition control systems.
Safety and Convenience	Includes air-bag control units and other safety and convenience systems.
Air-Bag Control Unit	Includes electronic control units for single or dual air-bag systems for driver and front passenger, electronic control units for rear-seat air-bag systems for rear passengers, and electronic control units for side-impact air-bag systems for front and rear-seat passengers.
Other Safety and Convenience	Includes side-impact air-bag crash sensors (front or rear seats), standalone car alarm systems, noise-cancellation systems/electronic mufflers, and heating, ventilation, and air conditioning (HVAC) and climate control systems (electronically adjusted temperature control).

Source: Dataquest (September 1998)

Chapter 4
Worldwide Geographic Region Definitions

Definitions

The following section provides Dataquest's regional geographic definitions. The regional country definitions used for Dataquest's semiconductor application markets research differ somewhat from the official definitions but match at the regional level.

Asia/Pacific Region

Countries being covered are Australia, China, Hong Kong, India, Indonesia, South Korea, Malaysia, Singapore, Taiwan, and Thailand.

Rest of Asia/Pacific

The rest of Asia/Pacific includes American Samoa, Ashmore and Cartier Islands, Baker Island, Bangladesh, Bhutan, Bouvet Island, Brunei, Cambodia, Christmas Island, Cocos (Keeling) Islands, Cook Islands, Coral Sea Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Kiribati, Laos, Macau, Maldives, Marshall Islands, Midway Islands, Mongolia, Myanmar (Burma), Nauru, Nepal, New Caledonia, New Zealand, Niue, Norfolk Island, Northern Mariana Islands, North Korea, Pakistan, Palau, Palmyra Atoll, Papua New Guinea, Paracel Islands, Philippines, Pitcairn Islands, Solomon Islands, Spratly Islands, Sri Lanka, Tokelau, Tonga, Tuvalu, Vanuatu, Vietnam, Wake Island, Wallis and Futuna, and Western Samoa.

Western Europe Region

Countries being covered are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom.

Rest of Western Europe

The rest of Western Europe includes Andorra, Cyprus, Faroe Islands, Gibraltar, Greenland, Guernsey, Iceland, Isle of Man, Jersey, Liechtenstein, Luxembourg, Malta, Monaco, San Marino, and Svalbard.

Central/Eastern Europe Region

Countries being covered are Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russia, Slovakia, and Ukraine.

Rest of Eastern Europe

The rest of Eastern Europe includes Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Croatia, Georgia, Kazakhstan, Kyrgyzstan, Macedonia, Moldova, Romania, Slovenia, Tajikistan, Turkmenistan, Uzbekistan, and Yugoslavia (Serbia and Montenegro).

Japan Region

Japan

Latin America Region

Countries being covered are Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela.

Rest of Latin America

The rest of Latin America includes Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, Cayman Islands, Clipperton Island, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Islas Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Navassa Island, Netherlands Antilles, Nicaragua, Panama, Paraguay, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Tortola (British Virgin Islands), Trinidad and Tobago, Turks and Caicos Islands, Uruguay, and Virgin Islands (St. John, St. Croix and St. Thomas).

Middle East/Africa Region

No countries are being covered in this region.

Rest of Middle East/Africa

The rest of the Middle East/Africa region includes Afghanistan, Algeria, Angola, Bahrain, Bassas da India, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Europa Island, Gabon, Gambia, Ghana, Glorioso Islands, Guinea, Guinea-Bissau, Iran, Iraq, Israel, Jordan, Juan de Nova Island, Kenya, Kuwait, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Morocco, Mozambique, Namibia, Niger, Nigeria, Oman, Qatar, Reunion, Rwanda, Saint Helena, Sao Tome and Principe, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Syria, Tanzania, Togo, Tromelin Island, Tunisia, Turkey, Uganda, United Arab Emirates, Western Sahara, Yemen, Zaire, Zambia, and Zimbabwe.

North America Region

Countries being covered are Canada and the United States.

Semiconductor Applications Regional Definitions

As noted previously, the semiconductor regional definitions differ somewhat from Dataquest standard regional definitions because of semiconductor industry reporting standards. The following shows the regional definitions (for specific country detail in each region, see the prior section):

- Americas
  - North America
  - Latin America

- Japan
- Europe, Middle East, and Africa
    - Western Europe
    - Central and Eastern Europe
    - Middle East/Africa
- Asia/Pacific

Chapter 5
Research Metrics

Overall general research metric definitions are as follows:

- Manufacturer: A producer of branded or unbranded finished products. A manufacturer could be a contract manufacturer, an original manufacturer, or both.
- Original component manufacturer: A manufacturer that designs and produces components such as semiconductors and design tools either for sale under its brand name or for use internally.
- Original equipment manufacturer (OEM): A manufacturer that produces and sells goods from components usually bought from other manufacturers. An OEM makes, designs, or builds complete products for sale.
- Contract equipment manufacturer: A manufacturer that produces equipment for sale under another company's brand to the specifications of the other company's design.
- Contract component manufacturer: A manufacturer that produces components under an original manufacturer's brand name or that produces components for a vendor that brands them.
- Vendor: A vendor is the last entity in the chain that brands a product and sells it either directly to end users or through a channel. A vendor may design and manufacture its own products, assemble complete systems from components produced by others, or procure products from an OEM or contract manufacturer. A vendor may also provide services, maintenance or nonmaintenance, for its own products or for other vendors' products and may also provide services for information technologies.
- End user: The final user of a product or the final purchaser of maintenance or nonmaintenance service for the information technology products. The final purchaser may or may not be the actual end user, but the product stops at the end user.
- Brand: The name put on a product marked by an original manufacturer's or vendor's name.
- Production location: The location where the bulk of the semiconductor content is added to the electronic equipment.
- Equipment factory revenue: The value of production. It is the money value of the commodity transaction between the manufacturer and the point of entry into distribution.
- Equipment factory units: The sum of finished products from a factory.
- Equipment unit shipments: The sum of finished products delivered from the factory to the end user, another vendor, or a distribution channel.
- Factory average selling price (ASP): The average price received by a manufacturer for a finished product delivered to the end user, another vendor, or a distribution channel.

- Compound annual growth rate (CAGR): The annualized rate of revenue or unit shipment growth over a given time period, assuming growth takes place at an annually compounded rate.
- Semiconductor content: That portion of equipment value attributable to semiconductors.
- Semiconductor total available market (TAM): Estimated total semiconductor consumption by the producers of a particular type of electronic equipment.

Chapter 6
Exchange Rate Definitions

Exchange rates are the market-determined rates at which foreign currencies may be converted into a specified currency (for example, U.S. dollars) expressed as foreign currency units per one unit of the specified currency (for example, yen per dollar). The process for determining the exchange rates is outlined in the Dataquest Research Methodology Guide (RSOP-NA-GU-9703).

Dataquest's research of electronic equipment markets and semiconductor consumption within those markets combines data from many countries. Most countries use currencies other than the U.S. dollar, and these have fluctuating exchange rates relative to the dollar. Because we research electronic equipment production and semiconductor consumption in several regions of the world with the goal of reporting comparable regional values and worldwide market trends, Dataquest uses the U.S. dollar as a common currency for comparisons and aggregation. As a general rule, we collect data and formulate forecasts in local currencies and then convert them to U.S. dollars using applicable exchange rates. Dataquest maintains a database of historical exchange rates that is updated monthly. Dataquest does not forecast exchange rates. Instead, we assume future exchange rates will reflect current exchange rates. Dataquest always reports the exchange rates incorporated in our research.

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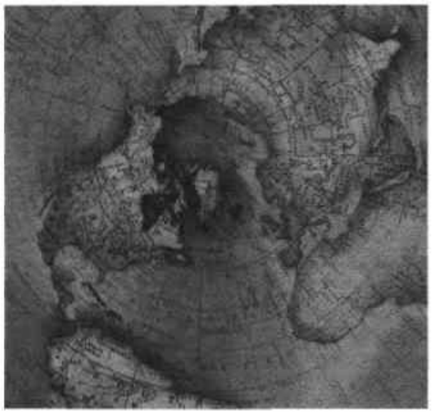
Market Statistics



Dataquest

Cellular/Broadband PCS and Cordless Telephone Application Markets

Industry Trends

Program: Wireless Semiconductors and Applications - Worldwide
Product Code: WSAM-WW-IT-9802
Publication Date: December 14, 1998
Filing: Reports

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Chapter 1
Executive Summary

Worldwide production of cordless telephone handsets and base stations is forecast to grow at a strong 9.7 percent compound annual growth rate (CAGR) during the next five years, expanding from 57.5 million units in 1997 to 91.5 million in 2002. Digital handset production will grow at a 36.5 percent CAGR during this period and account for nearly 73 percent of all shipments by 2002. Production of analog cordless telephones will decline over the next five years, while handsets based on 900-MHz digital, 900-MHz spread spectrum, Personal HandyPhone System (PHS), Digital Enhanced Cordless Telecommunications (DECT), and second-generation cordless telephone (CT-2) will drive overall market growth. A major surge in the U.S. cordless handset market since 1997 has been driven by 900-MHz handsets of all varieties as they have come down the price curve. It is expected that the 900-MHz category will continue to significantly expand its percentage of the U.S. market over the forecast period. The worldwide semiconductor market for cordless telephones and base stations was $2.02 billion in 1997. The majority of this market was for analog handsets. However, the semiconductor market for digital handsets will overtake the analog handset market in 1998 on a revenue basis. By 2002, the semiconductor market for cordless handsets is forecast to reach $2.78 billion.

More than 203 million people subscribed to cellular services worldwide by the end of 1997, with 35 percent in the Americas, 32 percent in Europe, 33 percent in the Asia/Pacific and Japan regions, and 3 percent in Africa and the Middle East. The number of subscribers using analog handsets dropped from 61 percent worldwide in 1996 to less than 45 percent in 1997. The percentage of total subscribers using digital handsets will jump to more than 91 percent in 2002, and analog subscribers will drop to less than 9 percent of the total by 2001. Europe and Japan represented more than 65 percent of the world market for digital handsets in 1997. The strong growth of digital markets in Asia/Pacific and the Americas will result in these regions' driving almost 57 percent of the digital handset market by 2002. By 2002, the market for digital cellular handsets will top 301 million units.

An increase in worldwide cellular/personal communications services (PCS) subscribers, from 203.8 million in 1997 to 647 million in 2002, will drive the handset market from 107.8 million units to 308.0 million units in the same period. Worldwide production of cellular telephone handsets is forecast to grow at a strong 20.7 percent CAGR during the next five years. Although analog handsets represented more than 85 percent of the production in 1993, digital handset shipments surpassed analog handsets in 1996 with 62 percent of total production. By 2002, digital cellular handsets will account for nearly 99 percent of worldwide production. Cellular telephones based on Global System for Mobile Communications (GSM) technology represent the large majority of digital cellular phones with the adoption of a common standard in Europe. However, multiple digital standards are competing for market acceptance in the United States and around the world. The semiconductor market for cellular handsets is forecast to grow from $8.03 billion in 1997 to $11.76 billion in 2002.

Project Analyst: Dale Ford

Chapter 2
Introduction and Methodology

This document is the fourth in a series of six that provide reference information and analysis about the principal system application markets for semiconductors. The six areas are data processing, wireline communications, wireless communications and fixed terminals, consumer electronics, automotive electronics, and a combined document on industrial, military, and civil aerospace electronics. Each document brings forth basic information about the opportunity offered by system market size (in production terms) in revenue, units, and average selling price (ASP); system market and product feature trends; hardware architecture trends and semiconductor device opportunities; semiconductor content and market forecast; and a listing of key OEMs.

The communications electronics semiconductor application market is examined through the publication of five separate documents, as follows:

- Modem and Remote Access System Semiconductors and Application Markets
- Pager and Satellite Communications Application Markets
- LAN and WAN Semiconductors and Application Markets
- Public, Premise, and Telephone System Semiconductors and Application Markets
- Cellular/Broadband PCS and Cordless Telephone Application Markets

This document provides reference information and analysis about cellular/broadband PCS and cordless telephone application markets for semiconductors. It brings forth basic information about the opportunity offered by particular systems, as follows:

- System market size (in production terms) in revenue, units, and ASP
- System market and product feature trends
- Hardware architecture trends and semiconductor device opportunities
- Semiconductor content and market forecast
- A listing of key OEMs

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers as well as analyst knowledge and opinion. Some of the primary sources include Dataquest's own services. Secondary sources include various governmental and trade sources on sales, production, trade, and public spending. Semiconductor content assumptions are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative systems.

The brand share information presented in this book comes from The Scout Report® of The Polk Company. The Scout Report® has been designed to accurately measure the retail purchase activity of U.S. households. Based on a widely accepted survey methodology, the sample is drawn quarterly from a nationally representative group of 50,000 respondents, and response rates average 70 percent. Brand shares reported in The Scout Report® are point estimates of the actual brand shares and have a small margin of error. Brand shares are based on a representation of retail sales to end-user consumers in the United States and may not correspond directly to other commonly reported measures of product movement such as production or wholesale shipments.

The forecast methodology is based on various methods and assumptions, depending on the area. To form a solid basis for projecting system demand, capital, government, and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes, and government policies are also considered. Semiconductor content forecasts are based on interviews of system marketers and designers (including makers of enabling semiconductor technology) along with an analysis of historical trends.

Chapter 3
Cordless Telephones

Market and Production Trends

Worldwide production of cordless telephone handsets and base stations is forecast to grow at a strong 9.7 percent CAGR during the next five years (see Table 3-1). Digital handset production will grow at a 36.5 percent CAGR during this period and account for nearly 73 percent of all shipments by 2002. Production of analog cordless telephones will decline over the next five years, while handsets based on 900-MHz digital, 900-MHz spread spectrum, PHS, DECT, and CT-2 will drive overall market growth (see Table 3-2 and Figure 3-1). Table 3-3 and Figure 3-2 show that production in the Americas will remain relatively minor. Compared to worldwide production, it represents less than 3 percent of worldwide production. Production in the Americas of digital cordless telephones will be driven by demand for 900-MHz products.

Table 3-1
Worldwide Cordless Telephone Handset and Base Station Production

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Analog (1/10/25 Channel, 900-MHz Analog)											
Units (K)	35,234	37,473	42,407	42,699	43,446	41,553	38,474	34,374	28,428	24,986	-10.5
Factory ASP ($)	65	64	58	54	53	50	48	47	46	43	-4.3
Factory Revenue ($M)	2,285	2,390	2,472	2,312	2,302	2,093	1,857	1,609	1,295	1,065	-14.3
Semiconductor Content ($)	29	29	29	27	27	27	28	28	29	29	1
Semiconductor Market ($M)	1,037	1,098	1,238	1,150	1,182	1,132	1,086	970	815	715	-9.6
Digital (CT-2, DECT, PHS, 900-MHz Digital/Spread Spectrum)											
Units (K)	155	550	4,219	10,016	14,057	23,504	34,257	45,633	56,852	66,563	36.5
Factory ASP ($)	239	199	182	140	124	101	84	72	63	56	-14.7
Factory Revenue ($M)	37	110	767	1,399	1,736	2,367	2,868	3,290	3,580	3,717	16.4
Semiconductor Content ($)	109	100	85	68	60	50	43	38	34	31	-12.3
Semiconductor Market ($M)	17	55	360	678	840	1,166	1,459	1,725	1,949	2,068	19.7
Total Production											
Units (K)	35,389	38,023	46,626	52,715	57,503	65,057	72,730	80,007	85,280	91,549	9.7
Factory ASP ($)	66	66	69	70	70	69	65	61	57	52	-5.8
Factory Revenue ($M)	2,322	2,499	3,239	3,711	4,038	4,460	4,725	4,899	4,876	4,781	3.4
Semiconductor Content ($)	30	30	34	35	35	35	35	34	32	30	-2.9
Semiconductor Market ($M)	1,054	1,153	1,598	1,829	2,022	2,298	2,545	2,695	2,764	2,783	6.6
Regional Unit Production Trends (Percentage of World Unit Production)											
Analog Handsets											
Americas	3	3	3	3	3	3	3	3	2	0	-
Europe	8	10	10	11	9	8	8	8	8	8	-
Japan	34	28	19	15	16	17	17	18	21	22	-
Asia/Pacific	55	58	68	71	72	72	72	71	69	70	-
Digital Handsets											
Americas	23	11	4	3	3	2	2	1	1	1	-
Europe	46	34	39	34	43	44	40	36	34	33	-
Japan	16	44	52	53	26	13	10	8	7	7	-
Asia/Pacific	15	11	5	10	28	41	48	54	58	59	-

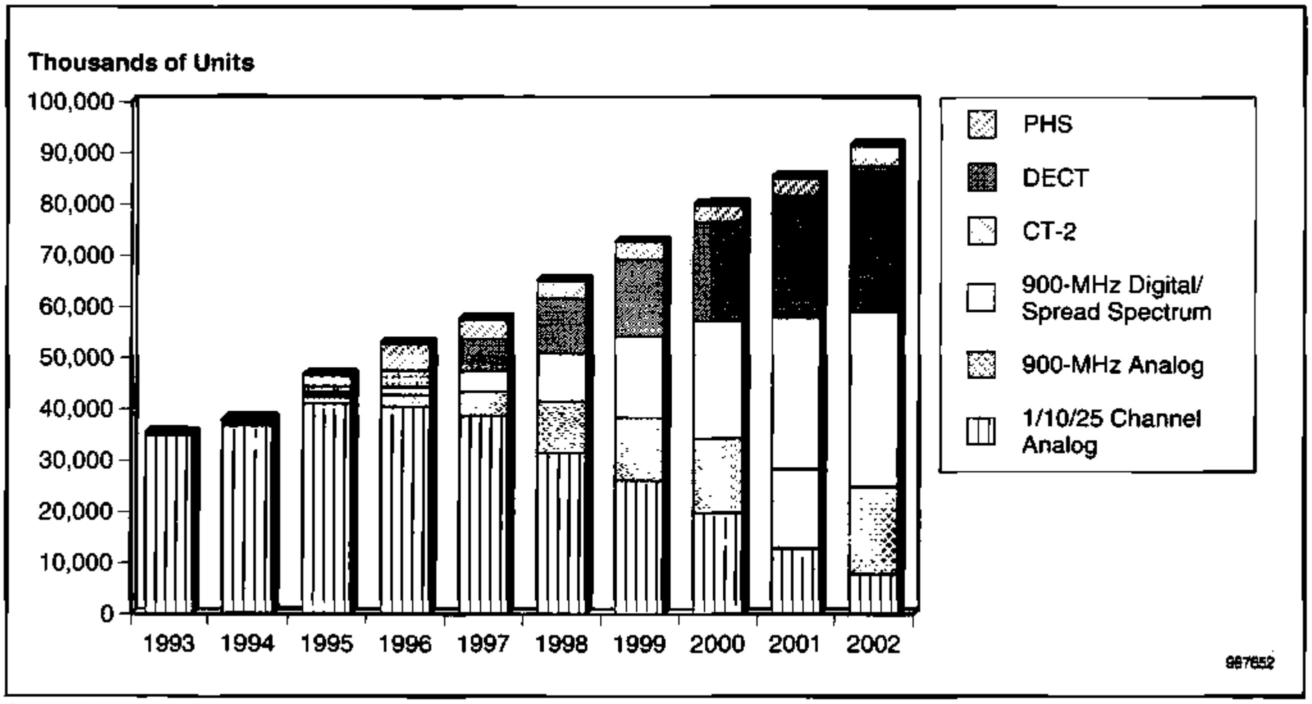
Note: One handset with or without a base station equals one unit. In some cases, multiple handsets are sold with one base station; in the case of CT-2, a base station is not included.
Source: Dataquest (November 1998)

Table 3-2
Worldwide Cordless Telephone Handset Production by Type (Thousands of Units)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Cordless	**35,389**	**38,023**	**46,626**	**52,819**	**57,502**	**65,056**	**72,729**	**80,006**	**85,279**	**91,548**	**9.7**
Total Analog	35,234	37,473	42,407	42,803	43,446	41,553	38,473	34,373	28,428	24,985	-10.5
1/10/25 Channel Analog	34,934	36,810	41,131	40,506	38,718	31,523	26,150	19,877	12,880	7,823	-27.4
900-MHz Analog	300	663	1,276	2,297	4,728	10,030	12,323	14,496	15,548	17,162	29.4
Total Digital	155	550	4,219	10,016	14,056	23,503	34,256	45,633	56,851	66,563	36.5
900-MHz Digital/Spread Spectrum	84	143	406	1,414	3,986	9,323	15,806	23,013	29,641	34,213	53.7
CT-2	50	126	441	250	100	80	50	20	10	-	-100.0
DECT	21	62	1,190	3,130	6,120	10,700	15,000	19,100	23,500	28,300	35.8
PHS	-	218	2,182	5,222	3,850	3,400	3,400	3,500	3,700	4,050	1.0

Source: Dataquest (November 1998)

Figure 3-1
Worldwide Cordless Telephone Handset and Base Station Production



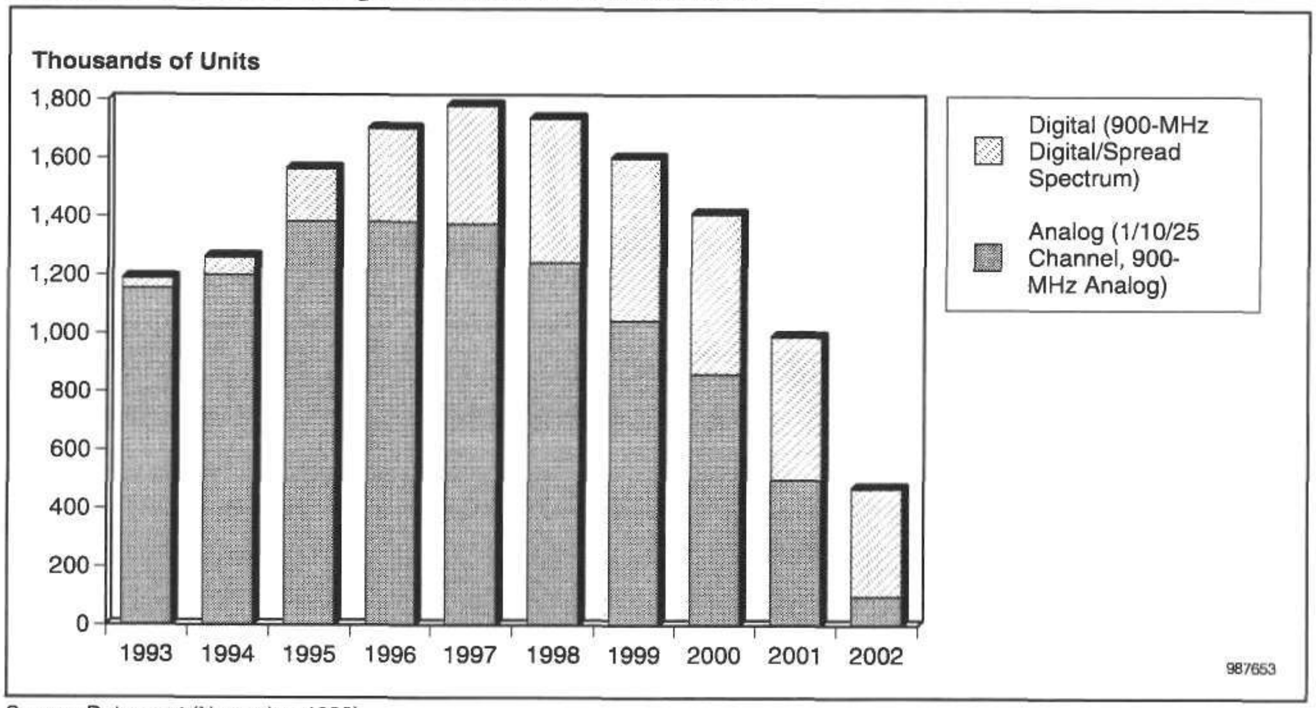
Source: Dataquest (November 1998)

Table 3-3
Americas Cordless Telephone Handset and Base Station Production

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Analog (1/10/25 Channel, 900-MHz Analog)											
Units (K)	1,154	1,201	1,384	1,383	1,375	1,243	1,046	861	500	100	-40.8
Factory ASP ($)	73	71	68	66	64	61	58	55	52	48	-5.5
Factory Revenue ($M)	84	85	94	91	88	76	61	47	26	5	-44.1
Semiconductor Content ($)	29	30	31	32	32	31	30	30	29	28	-2.6
Semiconductor Market ($M)	34	36	43	44	44	39	31	25	15	3	-42.4
Digital (900-MHz Digital/Spread Spectrum)											
Units (K)	35	60	180	319	406	494	555	548	490	370	-1.8
Factory ASP ($)	230	213	175	140	116	95	80	71	64	56	-13.6
Factory Revenue ($M)	8	13	31	45	47	47	45	39	31	21	-15.2
Semiconductor Content ($)	119	118	103	83	69	58	49	44	40	35	-12.8
Semiconductor Market ($M)	4	7	19	27	28	28	27	24	19	13	-14.4
Total Production											
Units (K)	1,189	1,261	1,564	1,702	1,781	1,737	1,601	1,409	990	470	-23.4
Factory ASP ($)	77	78	80	80	76	71	66	61	58	54	-6.5
Factory Revenue ($M)	92	98	125	136	135	123	105	86	57	25	-28.4
Semiconductor Content ($)	32	34	39	41	41	39	37	35	34	34	-3.7
Semiconductor Market ($M)	38	43	61	70	72	67	59	49	34	16	-26.2

Source: Dataquest (November 1998)

Figure 3-2
Americas Cordless Telephone Handset Production



Source: Dataquest (November 1998)

The primary market driver of cordless telephones in the Americas has been the residential market. The residential cordless phone market continues to advance as the convenience and continuing price/performance improvements of cordless telephones keep attracting new users. With a 70 percent household penetration rate in the United States, there is nothing to prevent cordless phones from being in every home. The Americas cordless telephone and base station market forecast is shown in Table 3-4.

Table 3-4
Americas Cordless Telephone Handset and Base Station Market

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Analog (1/10/25 Channel, 900-MHz Analog)											
Units (K)	18,733	19,509	22,723	23,344	26,001	23,822	21,924	20,668	20,609	20,870	-4.3
Factory ASP ($)	65	66	56	53	52	51	48	46	44	41	-4.9
Factory Revenue ($M)	1,211	1,280	1,283	1,232	1,355	1,223	1,050	954	907	848	-9.0
Digital (900-MHz Digital/Spread Spectrum)											
Units (K)	39	114	299	1,116	3,263	7,983	12,602	17,748	20,609	23,346	48.2
Factory ASP ($)	230	213	175	140	116	95	80	71	64	56	-13.6
Factory Revenue ($M)	9	24	52	156	378	755	1,012	1,264	1,319	1,300	28.0
Total Market											
Units (K)	18,772	19,623	23,022	24,460	29,264	31,805	34,526	38,416	41,217	44,217	8.6
Factory ASP ($)	65	66	58	57	59	62	60	58	54	49	-3.9
Factory Revenue ($M)	1,220	1,304	1,335	1,388	1,733	1,977	2,062	2,219	2,226	2,147	4.4

Source: Dataquest (November 1998)

Brand Share Leaders

Table 3-5 lists the leading vendors of digital cordless handsets based on the different digital standards. Tables 3-6 and 3-7 list the unit and revenue brand share leaders in cordless telephones in the U.S. market for 1996 and 1997, respectively. Table 3-8 presents a list of cordless telephone suppliers and manufacturers in the Asia/Pacific region, where most production takes place.

Table 3-5
Leading Vendors of Digital Cordless Handsets

DECT	CT-2	PHS	900-MHz
Siemens	Sony	Kyocera	Uniden
Hagenuk	Motorola	Sharp	Toshiba
Ericsson	Philips/Lucent	Matsushita	Sony
Grundig	Dassault	SANYO	VTech
Philips	Sagem	Toshiba	SANYO
Alcatel	Kenwood	Casio	Philips/Lucent
Dancall	Nortel	Kenwood	Matsushita
Matsushita	Ericsson	Mitsubishi	Xsys New Media Technologies (Cincinnati Microwave)
Ascom	GPT	NEC	Thomson Consumer Electronics
Basari	Matra	JVC	Hyundai
Bosch	Multitone	Pioneer	LG Electronics
DeTeWe		Uniden	
Kirk Telecom			
Matra			

Source: Dataquest (November 1998)

Table 3-6
U.S. Cordless Telephone Brand Share Leaders, First Quarter 1996 through Fourth Quarter 1996

Brand	Unit Market Share (%)	Revenue Market Share (%)
AT&T (Lucent)	22.4	22.1
General Electric (GE)	17.0	12.5
BellSouth	11.9	8.6
Uniden	11.5	11.5
Sony	9.0	10.7
Panasonic	6.0	8.4
Southwestern Bell	3.7	2.6
Radio Shack	2.9	3.1
Cobra	2.5	2.8
Toshiba	1.7	2.3
Others	11.4	15.4
Total	**100.0**	**100.0**

Source: The Scout Report® / The Polk Company

Table 3-7
U.S. Cordless Telephone Brand Share Leaders, First Quarter 1997 through Fourth Quarter 1997

Brand	Unit Market Share (%)	Revenue Market Share (%)
AT&T (Lucent)	17.3	14.9
General Electric (GE)	14.6	10.8
BellSouth	12.0	8.3
Uniden	10.6	11.4
Sony	9.7	11.9
Panasonic	6.0	8.8
Southwestern Bell	3.8	2.4
Radio Shack	3.5	3.6
Toshiba	2.2	3.0
Cobra	1.7	2.1
Other	18.6	22.8
Total	**100.0**	**100.0**

Source: The Scout Report® / The Polk Company

Table 3-8
Cordless Telephone Suppliers and Manufacturers in Asia/Pacific

Company	46/49 MHz	900 MHz	CT-1/CT-2	DECT	Location
Advanced Communications Tech		X			Taiwan
Alco Communications	X				Hong Kong
Allitex Electronics	X				Hong Kong
Alpha Telecom		X			Taiwan
Ascoba Company	X				Hong Kong
Astalic Technologies	X				Singapore
Avantec Manufacturing	X				Hong Kong
Bitronic Telecommunications	X	X			Taiwan
Cad Cam Industries		X			Hong Kong
Cantel Electronics	X				Hong Kong
CCT Telecom	X	X			Hong Kong
Chateau Technical		X			Taiwan
Citi Sound Electronic	X				Hong Kong
Comedge Communications		X			Singapore
Como International Corp.	X				Singapore
Compu-Technic Electronics & Telecom	X				Hong Kong
Dae Ryung		X			South Korea
Dialer and Business Electronics		X			Taiwan
Diocean International	X				Taiwan

Table 3-8 (Continued)
Cordless Telephone Suppliers and Manufacturers in Asia/Pacific

Company	46/49 MHz	900 MHz	CT-1/CT-2	DECT	Location
Elly Electronics	X				Hong Kong
Farbell Electronics				X	Hong Kong
Fortune Electronics	X				Hong Kong
G&B Company	X				Hong Kong
George Tang Industrial		X			Taiwan
Getek Telecom	X				Hong Kong
Gimajasa	X				Hong Kong
Good Youth	X				Hong Kong
Grandetel Technologies	X				Hong Kong
Great Electronics Corp.	X				Taiwan
Guangdong Xinhui Communication	X				China
Haitai Electronics	X				South Korea
Hangchang Corp.	X				South Korea
Hanson Telecom	X				South Korea
Health Genius International	X				Hong Kong
Hermes Electronics	X				Hong Kong
High Mart International	X				Taiwan
Hitron Technology				X	Taiwan
Hung Tat Electonic	X				Hong Kong
Hyundai Electronics		X			South Korea
Infosonics Industrial	X				Hong Kong
JSW Pacific Corp.	X				Taiwan
Kaigin	X				Taiwan
Kingtel Telecommunication	X				Taiwan
Kinpo Electronics	X				Taiwan
Kuo Feng Corp.		X			Taiwan
Lancon Communications	X				Taiwan
LC Development	X				Hong Kong
Leson Electronics	X				Hong Kong
LG Electronics		X			South Korea
Maratz		X			Japan
Maxfaith Electronics	X				Hong Kong
Maxtone Electronics	X				Hong Kong
May International		X			Hong Kong
Ming Hing Electronic Industrial	X				Hong Kong

Table 3-8 (Continued)
Cordless Telephone Suppliers and Manufacturers in Asia/Pacific

Company	46/49 MHz	900 MHz	CT-1/CT-2	DECT	Location
Mirae Communication		X			South Korea
Nixxo Telecom			X		South Korea
Northridge Pacific International	X				Taiwan
Northwestern Bellphones International	X				Taiwan
Otron Chanhwa Telecommunication		X			South Korea
Pacific Technology			X		Taiwan
Panasonic Singapore	X				Singapore
Panyu Tendy Electronics	X				China
Polyfund Corp.	X				Taiwan
Quanzhou Baotong Electronics	X				China
Racer Electronic	X				Taiwan
RCR Electronics Manufacturing	X				Hong Kong
Royal Bright International	X				Taiwan
Sankei	X				Singapore
SANYO Electric	X				Japan
Scientech Electronics		X			Taiwan
Senao Communication Singapore	X				Singapore
Senao International	X	X			Taiwan
Shanghai Dbel Electronics		X			China
Shenzhen Baoan Meiyi Electronic	X				China
Shenzhen Phonestar Communication	X				China
Shenzhen Rainbow Electronics		X			China
Shenzhen Shekou Jin Juo Science & Tech	X				China
Shenzhen Shenda TCL Communication	X				China
Shinwoo Telecom		X			South Korea
Solomon Technology Corp.	X				Taiwan
Sony		X			Japan
Star Fair Electronics	X				Hong Kong
Sunny Telecoms	X				Hong Kong
Surestar Electronics	X				Hong Kong
System Telecommunication & Computer		X			Taiwan
Tae Kwang		X			South Korea
Tailyn Communication	X				Taiwan
Tamagawa Electric	X				Japan
TCL Communication	X				Hong Kong
TEC Telecommunications	X				Hong Kong
Telefield	X				Hong Kong
Teletrade	X				Taiwan

Table 3-8 (Continued)
Cordless Telephone Suppliers and Manufacturers in Asia/Pacific

Company	46/49 MHz	900 MHz	CT-1/CT-2	DECT	Location
Telik Industrial	X				Hong Kong
Telital Hong Kong		X			Hong Kong
Telson Electronics		X		X	South Korea
Thomson Consumer Electronics	X				Singapore
Tranbon Electronic Industrial	X				Taiwan
U-Tech Enterprise	X				Taiwan
VTech Communications	X	X		X	Hong Kong
Wanon Industries	X				Hong Kong
Wavetek Technology	X				Taiwan
Wellsing Corporation	X				Taiwan
Wing Cheong International Electrical	X				Hong Kong
Wonderland Telecommunication Industrial	X				Hong Kong
Yuyang Information & Communications			X		South Korea
Zhangnan Radio Factory		X			China

Source: Dataquest (November 1998)

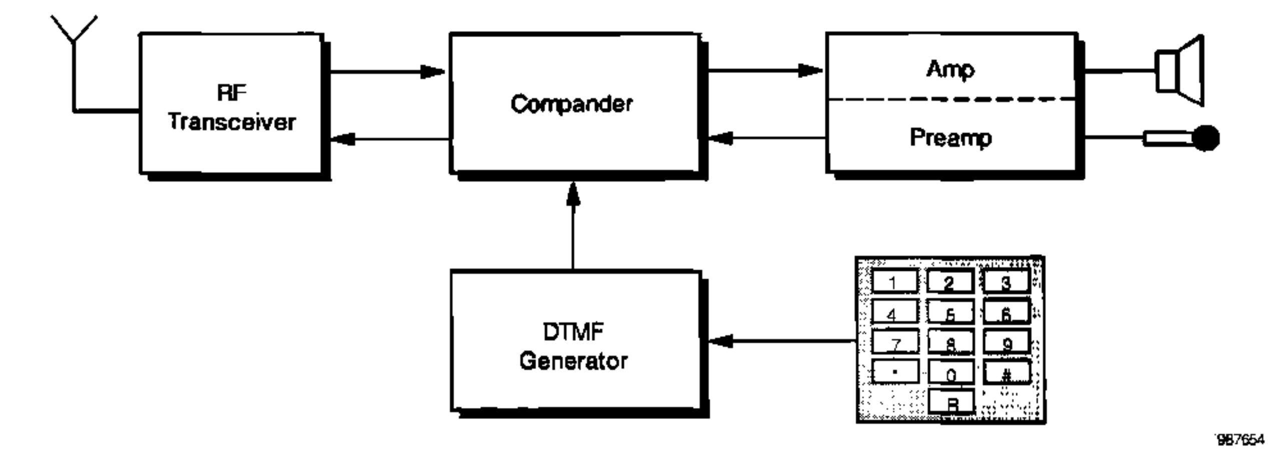
Feature and Technology Trends

There is a great deal of overlap in technologies and markets among cellular, cordless, and PCS. The 900-MHz digital cordless technology (DCT) is meant to be used within 100 meters of a base station. However, the 900-MHz spread spectrum telephones have the potential to increase that range by five to six times. The PHS, CT-2, CT-2+, and DECT handsets can be used as basic cordless phones in the home/office or as a low-mobility PCS system outside the home.

Despite the problems of analog cordless telephones, such as poor speech quality, channel interference, and lack of privacy, there are some new technical and device performance improvements that have prolonged the analog cordless life cycle. New 25-channel cordless phones have found strong market acceptance in the United States and have established a lower price-point segment that has extended the analog near-term growth rate in the United States. However, 900-MHz handsets of all varieties have driven a major surge in the U.S. cordless handset market in 1997 and 1998 as they have come down the price curve. It is expected that the 900-MHz category will continue to significantly expand its percentage of the U.S. market over the forecast period.

Figure 3-3 is a simplified diagram of a typical analog cordless telephone; a significant portion of the semiconductor cost is in the radio section. Opportunities still exist for greater levels of integration, improved performance, and noise reduction. One advantage that digital cordless telephones will have over analog cordless telephones is that they will be smaller in size. To help sustain the market for analog cordless, many OEMs are demanding that semiconductor vendors supply 3V operation devices. This reduces battery requirements, which are the most significant contributors to the weight and volume of bulky analog cordless telephones.

Figure 3-3
Simplified Analog Cordless Telephone



Source: Dataquest (November 1998)

Digital Cordless

DCTs will supersede analog cordless by the year 2000. (Digital cordless has a number of regional and proprietary supporting standards.) The essential objectives in the development of digital telephones is to improve the following areas of performance over analog cordless:

- Superior speech quality
- Better range and propagation capabilities
- Secure speech/secure base station access
- Much greater user densities

To achieve these objectives, digital standards employ some of the following techniques:

- Speech compression: All current DCTs use 32-Kbps, adaptive differential pulse-code modulation (ADPCM).
- Access methods such as time-division multiple access (TDMA) and time-division duplex (TDD)
- Higher frequencies (ranging from 900 MHz to higher frequencies in the ISM band) for better propagation
- New frequency allocation, with more bandwidth

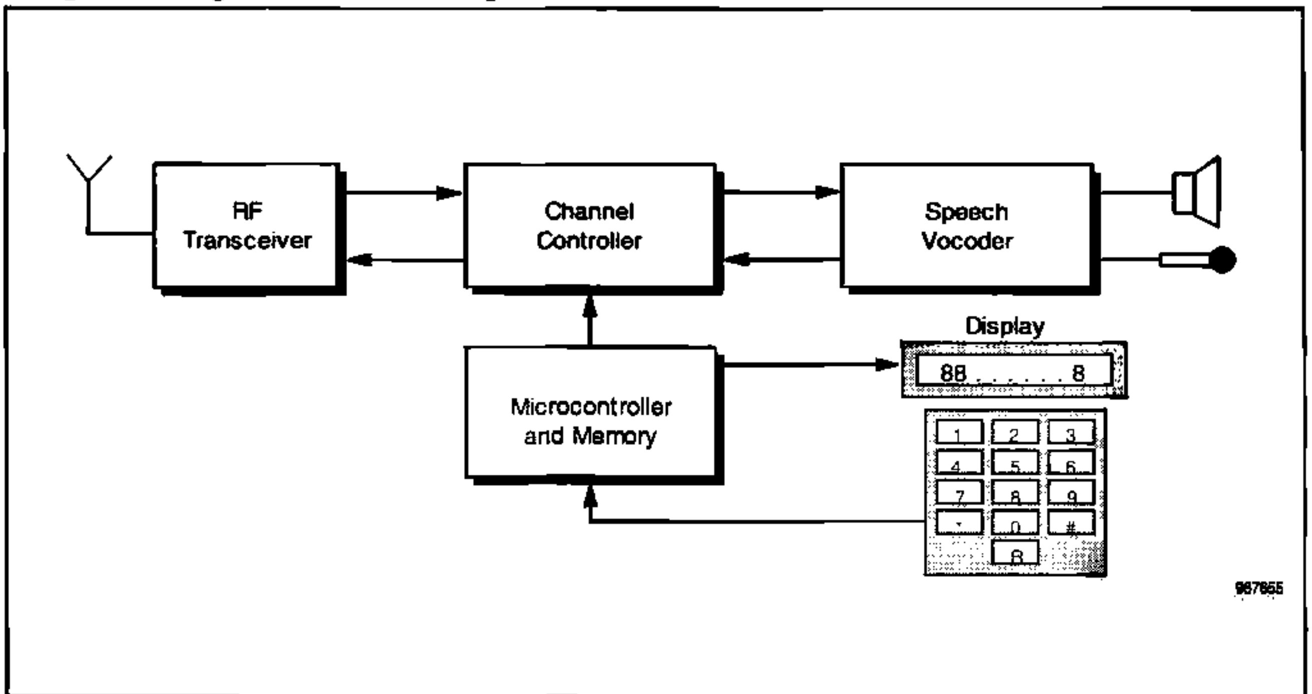
These capabilities have opened up additional opportunities for cordless from the present domination by residential users to business users (wireless PBX/key systems) and telepoint.

The current lineup of digital cordless systems/standards includes 900-MHz digital, 900-MHz spread spectrum, CT-2 (and variants), DECT, and PHS for Japan. The last two have been designed from scratch to support very high user densities. The standards have also addressed the additional opportunities of public access (telepoint) and business users where this will be a major advantage. These standards also support roaming (at pedestrian speeds), which of course is mandatory in an office environment, as users move throughout a building from one base station area to another. This roaming capability has driven a strong market for PHS as a low-mobility system in Japan. However, with the lower price of digital cellular handsets in Japan, the PHS market there suffered a severe downturn during the past two years. Service providers in Japan have been working to reposition and recapture momentum for the PHS market. The PHS system provides the foundation for the low-mobility Personal Access Communications Service (PACS) standard in the United States. DECT technology drives the proposed wireless communications premise equipment (WCPE) standard.

Figure 3-4 is a simplified diagram of a digital cordless telephone, showing the key elements:

- Speech vocoder
- Channel controller
- Microcontroller/memory
- Radio frequency (RF) transceiver

Figure 3-4
Simplified Digital Cordless Telephone



Source: Dataquest (November 1998)

State-of-the-art semiconductor solutions have now integrated all baseband (non-RF) functions into a single chip with the exception of memory. These single-chip DCT devices include the following:

- Voice pulse-code modulation (PCM) coder/decoder (CODEC)
- Channel processor: TDMA controller and signaling protocol processor
- 8-bit microcontroller with keyboard, display interface, and dual-tone multifrequency (DTMF) dialer

Some of these highly integrated devices are already available with 3V operation, with volume prices in the range of $8 to $12. The RF section represents the most significant opportunity for integration and cost reduction.

Digital cordless and digital cellular exhibit certain similarities. Table 3-9 shows that there are some key differences that will always keep a significant price differential between the opposing types of telephone.

The European digital cordless market has two competing solutions: CT-2 and DECT standards. Table 3-10 outlines the comparisons between these two systems. The lower-cost RF solutions and the high level of support from semiconductor vendors have made DECT the winner in the DCT battle. The overall component costs (including costs for all semiconductors and other components such as filters) for DECT were lower than CT-2 in 1995. Siemens AG delivered a low-cost chipset solution that has driven the large majority of DECT handset production since 1996. Figure 3-5 shows a second-generation DECT product from VLSI Technology Inc. that incorporates highly integrated solutions for both the RF and voice/channel CODEC/controller. The latest semiconductor solutions suggest that second- and third-generation telephones will have about seven devices for a complete solution (see Table 3-11). CT-2 handsets will continue to drive a niche market, being used in specific markets and more limited in size, whereas DECT handsets will become a much larger, broad-based market in Europe and other regions.

Table 3-9
Differences between Digital Cordless and Digital Cellular Telephones

Feature	Cordless	Cellular
Speech Compression	ADPCM	VSELP/RPE-LTP/QCELP
	32 Kbps	7.25/13 Kbps
	G.722 CODEC	DSP
Equalizer	No	Yes
Encryption	In some models	Usual
Power Output	Usually fixed at <250mW (900-MHz spread spectrum is variable between 1mW to 1W)	Usually variable at >250mW
Cell/Base Station Handover	Not usual (where possible under handset control)	Mandatory (under base station control)

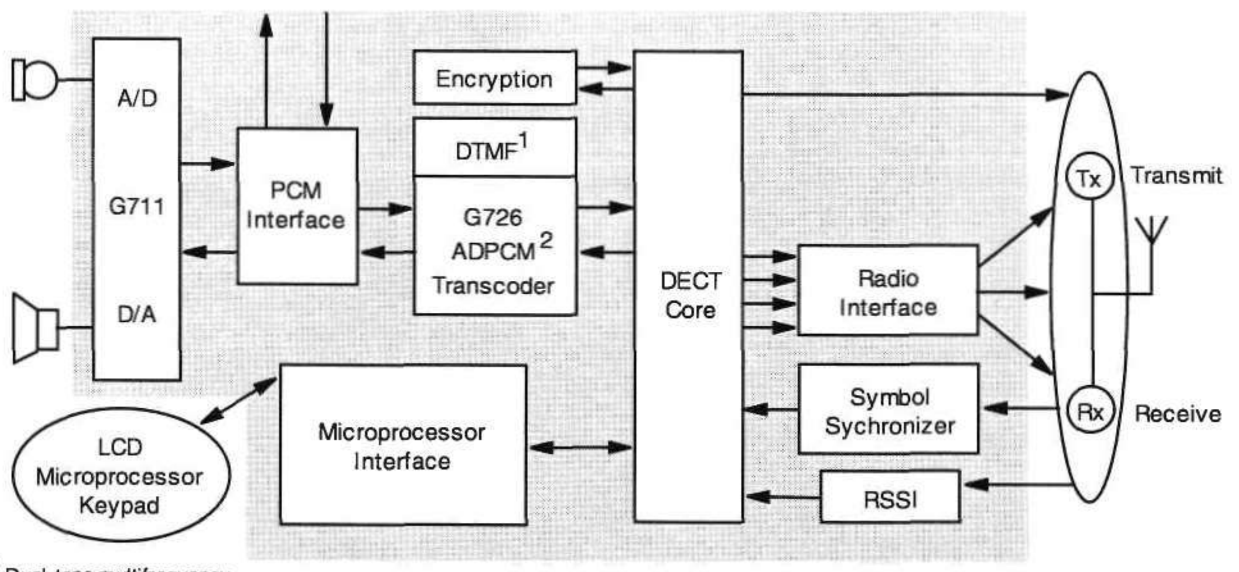
ADPCM = Adaptive differential pulse-code modulation
VSELP = Vector sum excited linear predictive coding
RPE-LTP = Regular pulse excitation, long-term prediction
Source: Dataquest (November 1998)

Table 3-10
DECT and CT-2 Specification Comparison

Specification	CT-2	DECT
Radio Frequency Band (MHz)	864-868	1880-1900
Bandwidth (MHz)	4	20
Channelization	FDMA	TDMA/FDMA
Channel Spacing	100 KHz	1.728 MHz
Number of Frequency Channels	40	10
Voice Channels per Frequency Channel	1	12
Duplex Method	TDD	TDD
Total Duplex Channels	10	120
Speech Coder	ADPCM	ADPCM
Bit Rate (Kbps)	32	32
Channel Bit Rate (Kbps)	72	1,152
Modulation Technique	GFSK	GMSK
Voice and Data	No	Yes
Frame Time (ms)	2	10
Peak Transmit Power (mW)	10	250
Average Transmit Power (mW)	5	10

FDMA = Frequency division multiple access
GFSK = Gaussian frequency shift keying
GMSK = Gaussian mean shift keying
Source: Dataquest (November 1998)

Figure 3-5
DECT Handset Block Diagram



[1] Dual-tone multifrequency
[2] Adaptive differential pulse-code modulation

Source: VLSI Technology

Table 3-11
DECT Semiconductor Solution—Third Generation

Function of Devices	Number	Semiconductor
Integrated Power Amplifier	1	GaAs linear*
RF Front End	3	RF linear
Voice CODEC/Channel Controller/Microcontroller	1	MOS logic (ASIC)
Baseband Analog Circuit (ROM/RAM/EEPROM)	1	MOS micro
Memory (EEPROM)	1	MOS micro

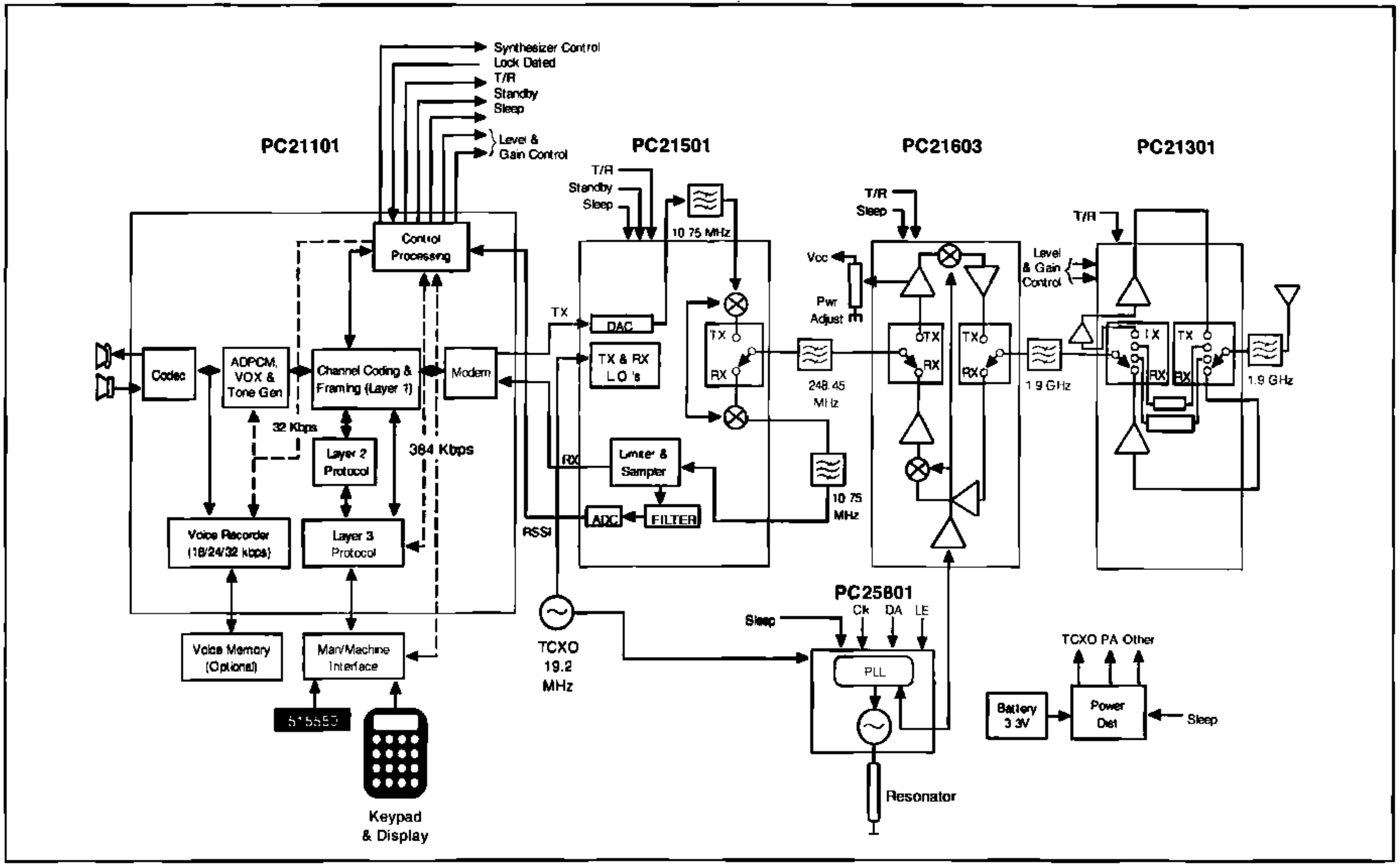
*GaAs = Gallium arsenide
Source: Dataquest (November 1998)

The PHS and 900-MHz spread spectrum handsets are already benefiting from highly integrated chipset solutions. Figure 3-6 shows a PHS handset design using a Rockwell chipset, which is used in a number of PHS handsets. Figure 3-7 shows Rockwell's chipset for a 900-MHz spread spectrum handset, which had its first design win in the SANYO Fischer handset.

Semiconductor Opportunities

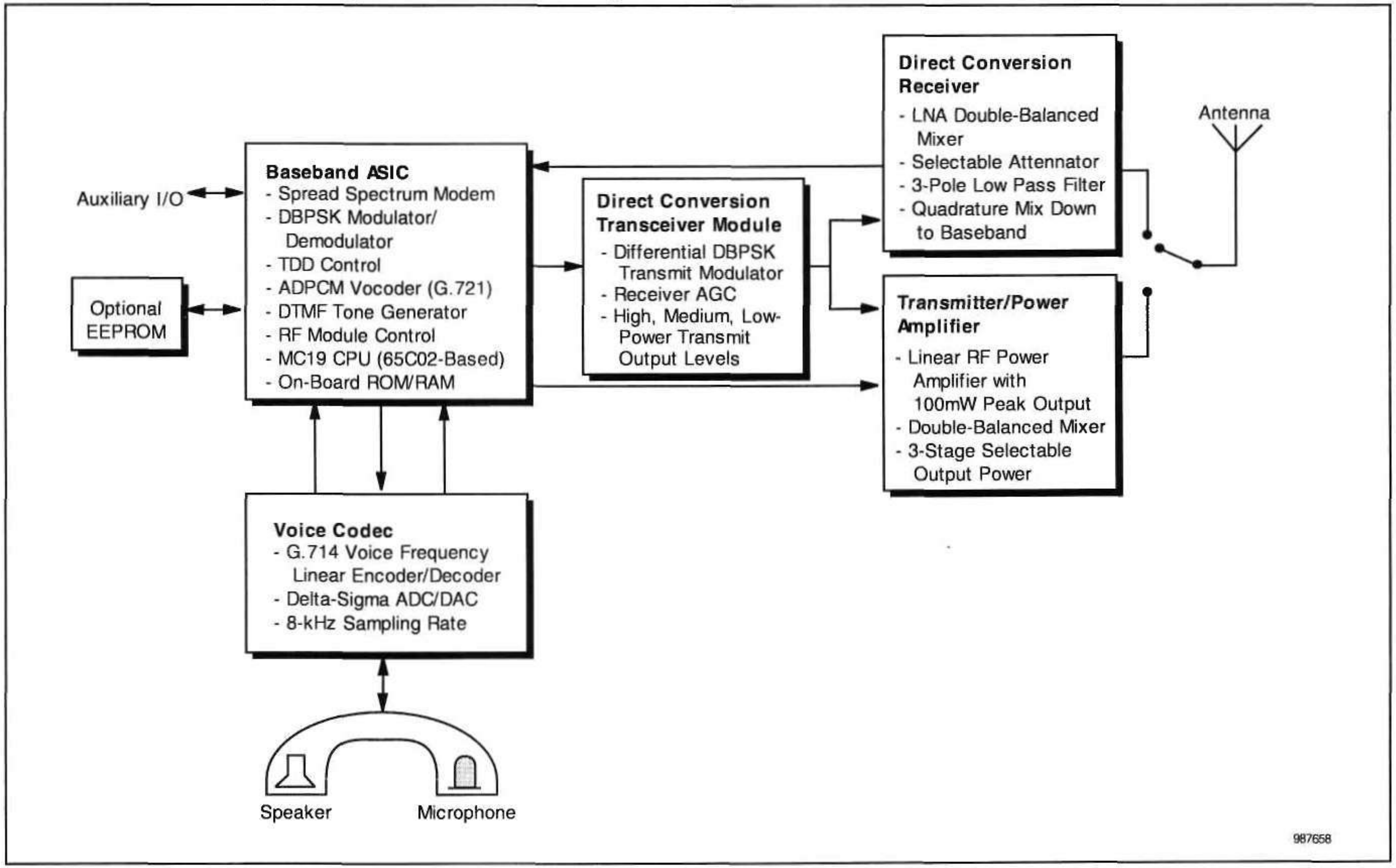
The worldwide semiconductor market for cordless telephones and base stations was $2.02 billion in 1997. The majority of this market was for analog handsets. However, the semiconductor market for digital handsets will overtake the analog handset market in 1998 on a revenue basis. With the overlap between cellular and cordless telephone technologies, many of the semiconductor market opportunities are the same for both products. Chapter 4 provides a detailed listing of these opportunities.

Figure 3-6
PHS Handset Design Using Rockwell Chipset



Source: Rockwell

Figure 3-7
Rockwell's 900-MHz Spread Spectrum Cordless Telephone Chipset



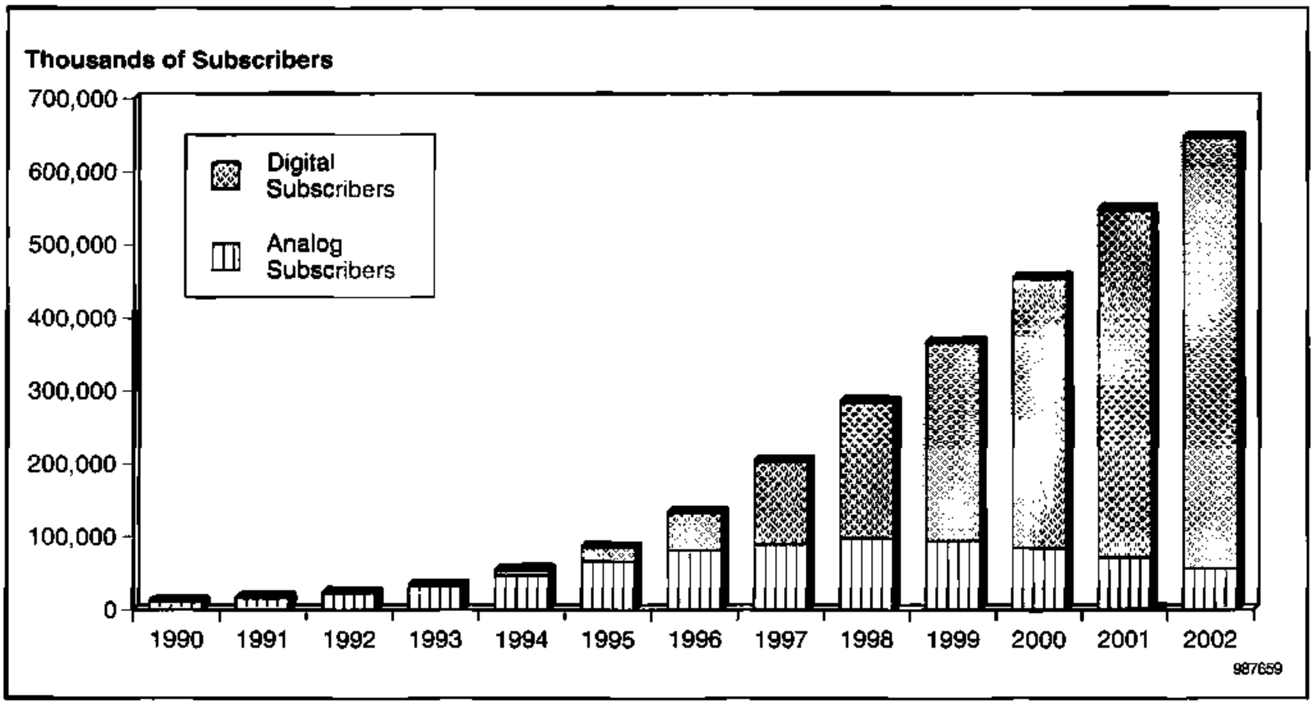
Source: Rockwell

Chapter 4
Cellular and Broadband PCS Telephones

Market and Production Trends

More than 203 million people were subscribing to cellular services worldwide by the end of 1997, with nearly 35 percent in the Americas, 32 percent in Europe, 33 percent in the Asia/Pacific and Japan region, and 3 percent in Africa and the Middle East. The Americas share of subscribers will decrease to 32 percent by 2002, while the Asia/Pacific and Japan subscribers will grow to over 35 percent of the worldwide cellular population. The number of subscribers using analog handsets dropped from 61 percent worldwide in 1996 to less than 45 percent in 1997. The percentage of total subscribers using digital handsets will jump to more than 91 percent in 2002, and analog subscribers will drop to less than 9 percent of the total by 2001 (see Figure 4-1). Table 4-1 provides a brief description of the cellular services in countries with the largest cellular subscriber populations. The highest levels of cellular telephone population penetration are found in the Scandinavian countries. The penetration of cellular telephones in the United States reached 20 percent of the population by the end of 1997.

Figure 4-1
Worldwide Cellular and Broadband PCS Subscribers



Source: Dataquest (November 1998)

Table 4-1
Major International Cellular/PCS Markets

Country	Number of Subscribers* (Thousands)	Type of System	Cellular Carriers
United States	53,503	AMPS/CDMA/D-AMPS/PCS-1900/Omnipoint/(Multiple PCS)	Two cellular operators per market in 306 metropolitan statistical areas and 428 rural service areas. Two PCS operators in 99 MTAs and four operators in 986 BTAs
Japan	28,745	NTT/JTACS/PDC-800/PDC-1500/CDMA	NTT DoCoMo, DDI, IDO, Tu-Ka, Kansai Digital Phone, Tokyo Digital, and Tokai Digital
China	13,740	AMPS/TACS/GSM/DCS-1800/ETDMA/CDMA	MPT, various regional operators (PTAs), CESEC, Unicom, and Great Wall Mobile
Italy	11,760	ETACS/GSM	Telecom Italia and Omnitel Pronto Italia
United Kingdom	8,463	TACS/GSM/DCS-1800	Cellnet, Vodafone Group, Mercury One-2-One, and Hutchinson Orange
Germany	8,322	C-Netz/GSM/DCS-1800	De Te Mobile, Mannesmann Mobilfunk, and E-Plus Mobilfunk
South Korea	6,896	AMPS/CDMA	Korea Mobile Telecom, Shinsegi, Habsol, and LG Telecom
France	5,780	NMT/GSM/DCS-1800	France Telecom, Ligne SFR, and Bouygues
Brazil	5,462	AMPS/D-AMPS	Telebrasilia, Teleri, Regional
Spain	4,337	NMT/TACS/GSM	Telefonica and Airtel
Canada	4,117	AMPS/D-AMPS/PCS-1900/CDMA	-
Sweden	3,188	NMT/GSM/DCS-1800	Comvik, Swedish Nordic Tel, and Telia Mobitel
Australia	2,865	AMPS/GSM	Australia Telecom, Vodafone PTY, and Optus Communications
Finland	2,147	NMT/GSM	Oy Radiolinja and Telecom Finland
Malaysia	2,125	NMT/TACS/AMPS/DAMPS/GSM/DCS-1800	-
Hong Kong	2,086	AMPS/TACS/ETACS/GSM/D-AMPS/CDMA/DCS-1800	-

Table 4-1 (Continued)
Major International Cellular/PCS Markets

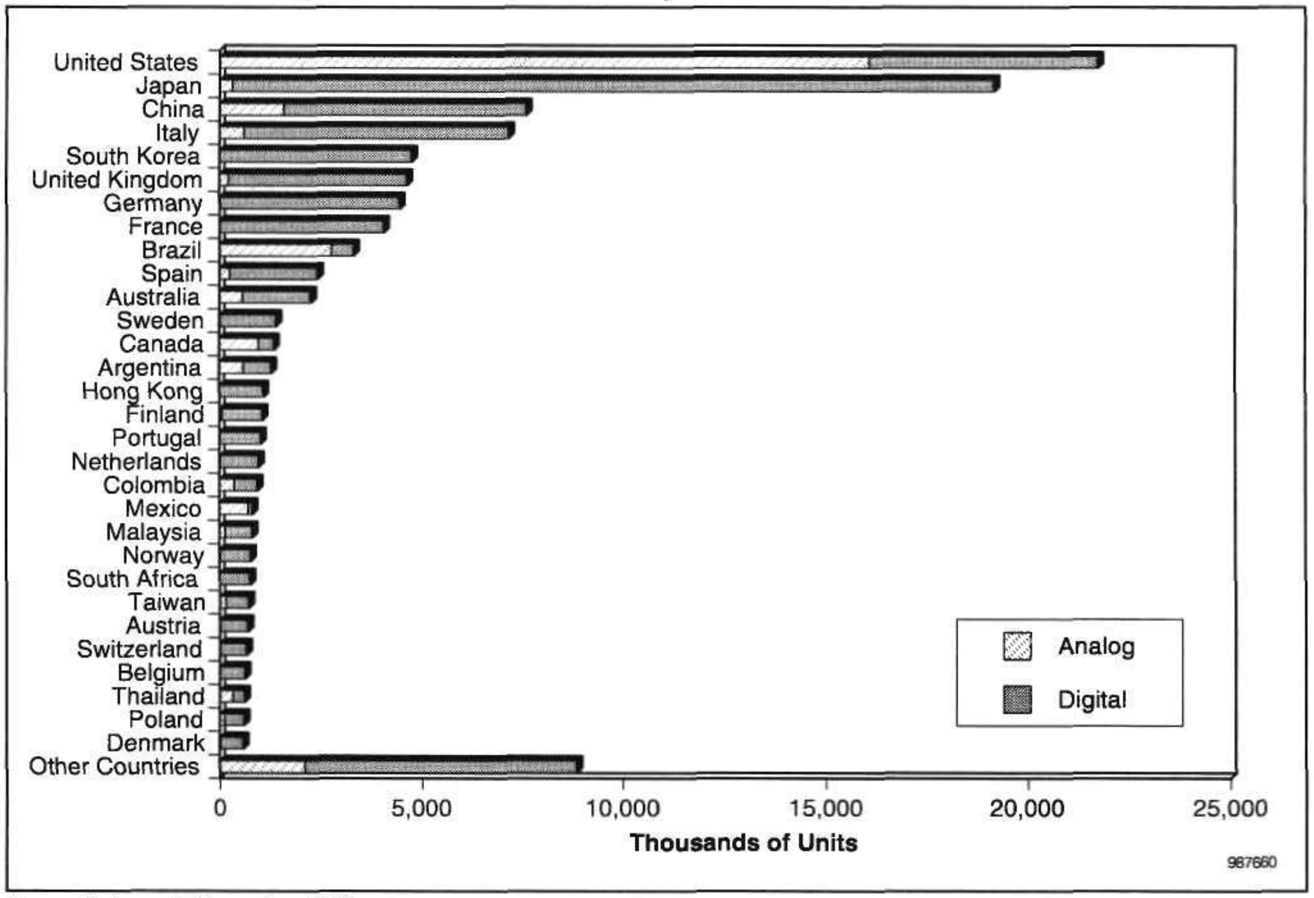
Country	Number of Subscribers* (Thousands)	Type of System	Cellular Carriers
Thailand	1,957	AMPS/NMT/GSM/ DCS-1800/PDC	Communications Authority of Thailand, Advanced Information Services, and Total Access Communications
Argentina	1,925	AMPS/N-AMPS/D-AMPS	CRM-Movicom, Cia de Telefonos del Interior, Telefonica de Argentina, and Telecom Argentina
Mexico	1,736	AMPS	Nine nonwireline companies and one wireline company
Netherlands	1,717	NMT/GSM	PTT and Libertel
Norway	1,674	NMT/GSM	Telemobil and Netcom
Taiwan	1,573	AMPS/GSM	Directorate General of Telecommunications
Portugal	1,507	C-450/GSM	CTT, Telecel, and TMN
South Africa	1,476	C-450/GSM	PTT, MTN, and Vodacom
Denmark	1,475	NMT/GSM	TeleDanmark Mobil and Sonofon
Israel	1,400	AMPS/N-AMPS/D-AMPS/GSM/CDMA	-
Colombia	1,367	AMPS/D-AMPS	Celcarive, Celumovil, Comcel, Occel, Cocelco
Philippines	1,226	AMPS/NAMPS/TACS/ GSM/D-AMPS/CDMA	-

AMPS = Advanced Mobile Phone Service
DAMPS = Digital AMPS
N-AMPS = Narrowband AMPS
DCS = Digital Cellular System
ETDMA = Enhanced time-division multiple accessNMT = Nordic Mobile Telephone
NTT = Nippon Telephone and Telegraph
PDC = Personal digital cellular
TACS = Total Access Communications System
ETACS = Enhanced TACS
JTACS = Japan TACS
*Number of subscribers as of end of 1996
Source: Dataquest (November 1998)

In 1997, the United States continued to lead all other markets in total shipments of cellular handsets, followed by Japan (see Figure 4-2). However, shipments in the United States continued to be dominated by analog handsets, while Japan's market was driven by digital services. Japan ended the sale of analog services in 1997. The Americas market will continue to be the principal driver of a dwindling analog handset market (see Figure 4-3). Europe and Japan represented more than 65 percent of the world market for digital handsets in 1997. The strong growth of digital markets in Asia/Pacific and the Americas will result in these regions' driving almost 57 percent of the digital handset market by 2002 (see Figure 4-4). By 2002, the market for digital cellular handsets will top 301 million units.

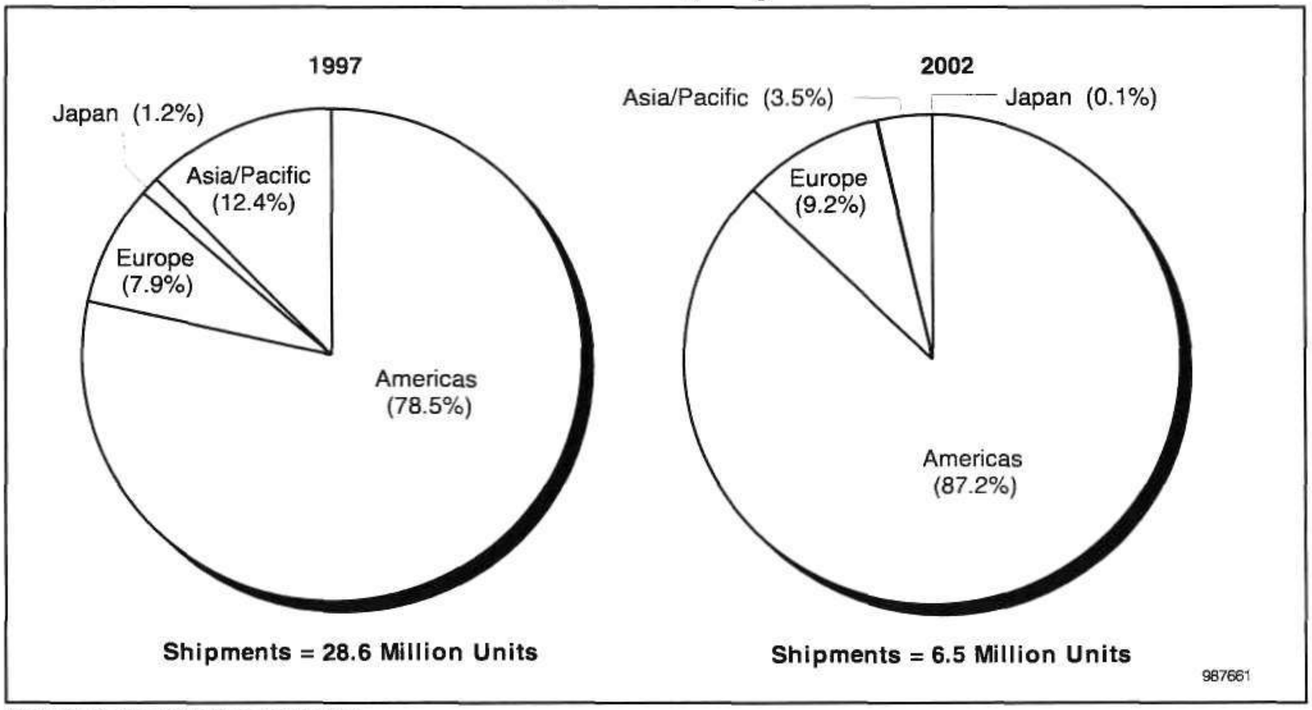
An increase in worldwide cellular/PCS subscribers, from 203.8 million in 1997 to 647 million in 2002, will drive the handset market from 107.8 million units to 308.0 million units in the same period (see Table 4-2). Worldwide production of cellular telephone handsets is forecast to grow at a strong 20.7 percent CAGR during the next five years. Figure 4-5 and Tables 4-3 and 4-4 show the worldwide forecast for cellular telephone handset production. Although analog handsets represented more than 85 percent of the production in 1993, digital handset shipments surpassed analog handsets in 1996 with 62 percent of total production. By 2002, digital cellular handsets will account for nearly 99 percent of worldwide production.

Figure 4-2
Handset Market Shipments in Major Country Markets in 1996



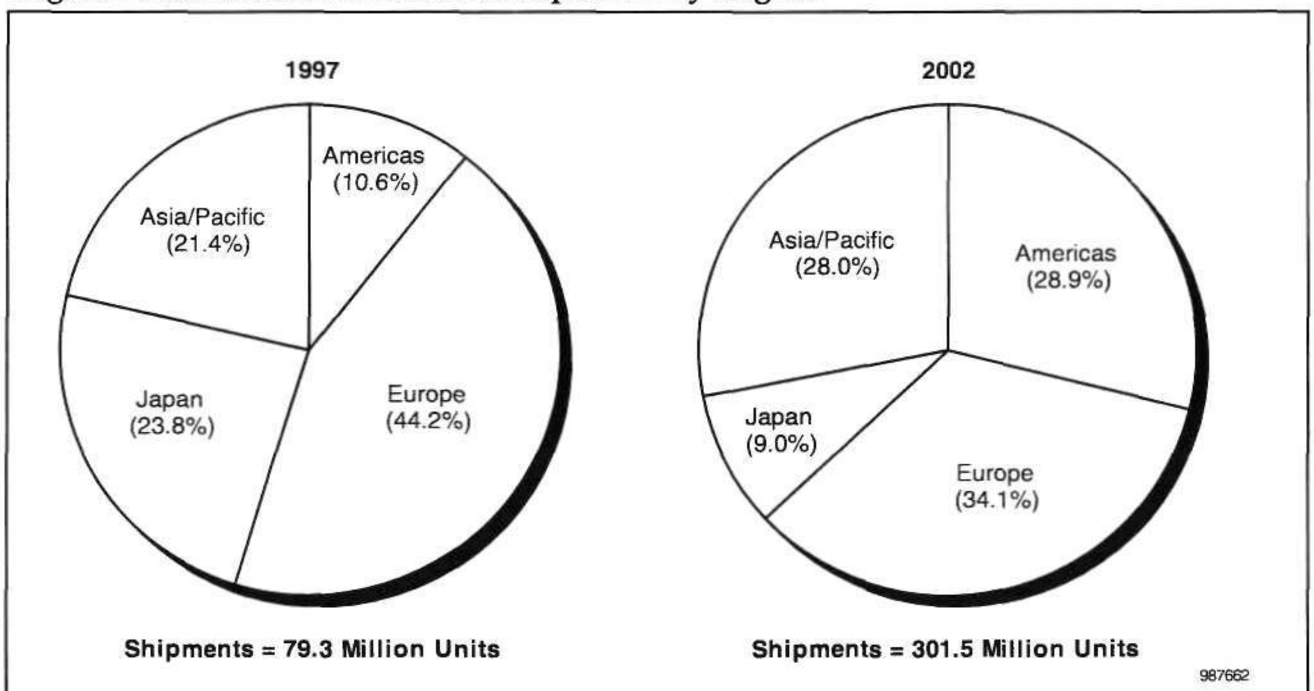
Source: Dataquest (November 1998)

Figure 4-3
Analog Cellular Handset Market Shipments by Region



Source: Dataquest (November 1998)

Figure 4-4
Digital Cellular Handset Market Shipments by Region



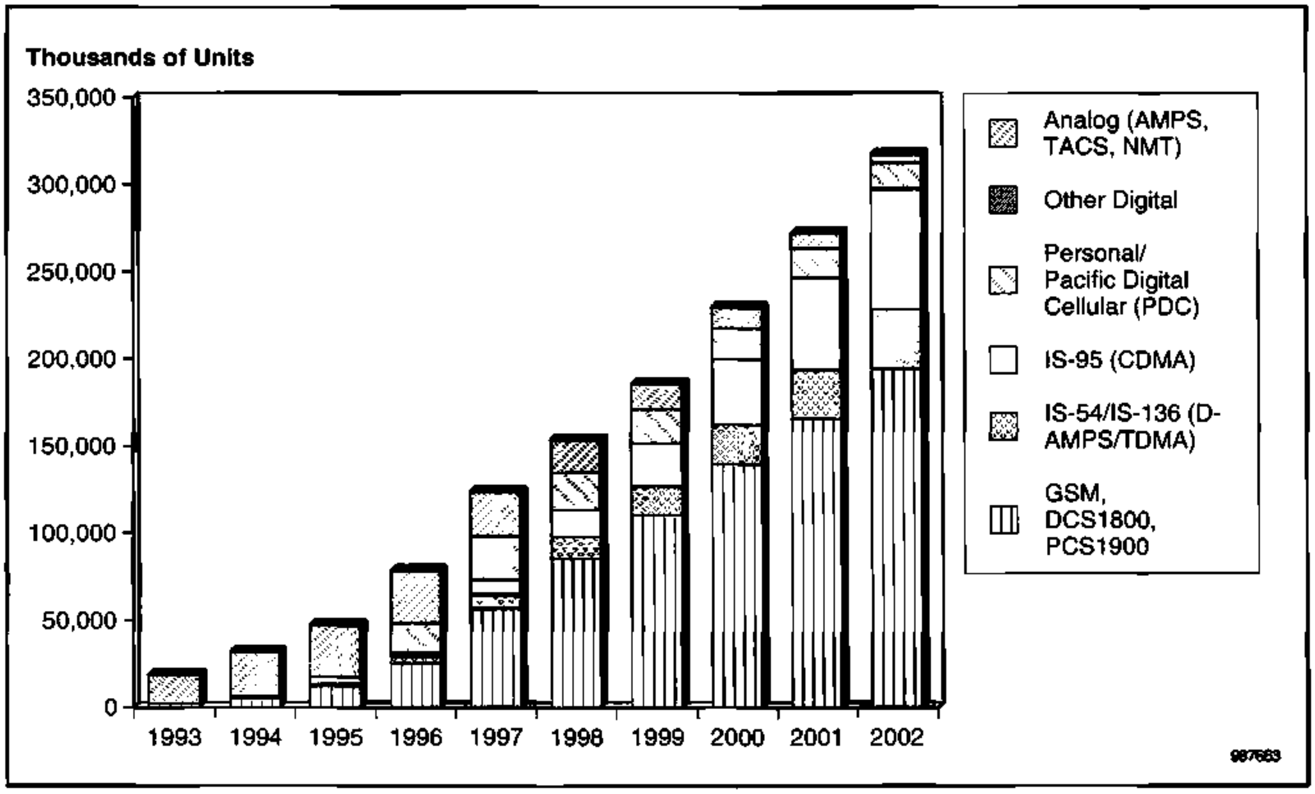
Source: Dataquest (November 1998)

Table 4-2
Worldwide Cellular and Broadband PCS Telephone Market

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Subscribers (K)	**34,239**	**54,854**	**85,448**	**133,489**	**203,767**	**285,085**	**366,266**	**454,517**	**547,900**	**647,061**	**26.0**
Total Units (K)	**16,411**	**29,075**	**41,964**	**66,219**	**107,853**	**142,228**	**177,831**	**219,820**	**259,936**	**307,949**	**23.3**
Analog Units (K)	14,836	23,604	28,591	29,639	28,558	26,862	19,877	13,277	9,129	6,479	-25.7
Digital Units (K)	1,575	5,471	13,373	36,580	79,295	115,366	157,953	206,543	250,808	301,470	30.6
Overall Factory ASP ($)	486	453	407	349	294	242	202	174	152	140	-13.8
Analog Factory ASP ($)	473	435	387	323	251	207	173	145	128	115	-14.5
Digital Factory ASP ($)	609	532	451	370	309	250	205	175	153	141	-14.6
Total Factory Revenue ($M)	**7,973**	**13,166**	**17,100**	**23,101**	**31,685**	**34,413**	**35,862**	**38,145**	**39,525**	**43,114**	**6.4**
Analog Factory Revenue ($M)	7,014	10,256	11,072	9,580	7,178	5,567	3,447	1,929	1,168	742	-36.5
Digital Factory Revenue ($M)	959	2,910	6,028	13,521	24,507	28,846	32,415	36,216	38,357	42,371	11.6

Source: Dataquest (November 1998)

Figure 4-5
Worldwide Cellular and Broadband PCS Telephone Handset Production by Type



Source: Dataquest (November 1998)

Table 4-3
Worldwide Cellular and Broadband PCS Telephone Handset Production

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Analog Production											
Units (K)	16,275	25,058	29,613	29,835	25,241	18,362	14,148	11,395	8,550	4,520	-29.1
Factory ASP ($)	466	428	378	309	230	195	165	141	125	112	-13.4
Factory Revenue ($M)	7,587	10,721	11,203	9,232	5,803	3,587	2,336	1,602	1,067	507	-38.6
Semiconductor Content ($)	44	43	43	39	32	28	24	21	19	18	-10.5
Semiconductor Market ($M)	717	1,072	1,268	1,170	797	506	342	242	162	82	-36.5
Digital Production											
Units (K)	2,467	6,951	17,791	48,789	98,600	135,350	171,510	218,205	263,875	312,950	26.0
Factory ASP ($)	601	504	440	355	294	233	196	170	149	138	-14.0
Factory Revenue ($M)	1,483	3,506	7,826	17,330	29,005	31,551	33,638	37,002	39,293	43,309	8.3
Semiconductor Content ($)	151	125	109	92	73	58	49	44	39	37	-12.6
Semiconductor Market ($M)	372	872	1,943	4,480	7,235	7,877	8,444	9,541	10,378	11,679	10.1
Total Production											
Units (K)	18,742	32,009	47,404	78,624	123,841	153,712	185,658	229,600	272,425	317,470	20.7
Factory ASP ($)	484	444	401	338	281	229	194	168	148	138	-13.3
Factory Revenue ($M)	9,071	14,227	19,029	26,562	34,808	35,138	35,974	38,603	40,360	43,815	4.7
Semiconductor Content ($)	58	61	68	72	65	55	47	43	39	37	-10.6
Semiconductor Market ($M)	1,090	1,943	3,211	5,650	8,032	8,383	8,786	9,784	10,540	11,761	7.9
Regional Unit Production Trends (Percentage of World Production)											
Analog Handsets											
Americas	52	48	46	51	56	45	38	33	23	20	-
Europe	18	22	21	17	10	11	11	9	9	11	-
Japan	15	13	14	10	2	0	0	0	0	0	-
Asia/Pacific	14	17	19	22	32	44	51	58	68	69	-
Digital Handsets											
Americas	6	8	9	9	10	15	17	19	19	19	-
Europe	94	78	69	51	55	59	58	56	52	47	-
Japan	0	14	22	32	23	14	10	8	6	6	-
Asia/Pacific	0	0	0	7	12	12	15	17	23	29	-

Source: Dataquest (November 1998)

Table 4-4
Worldwide Cellular and Broadband PCS Telephone Handset Production by Type (Thousands of Units)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Total Cellular/PCS	**18,742**	**32,009**	**47,404**	**78,624**	**123,841**	**153,712**	**185,658**	**229,600**	**272,425**	**317,470**	**20.7**
Total Analog	16,275	25,058	29,613	29,835	25,241	18,362	14,148	11,395	8,550	4,520	-29.1
Total Digital	2,467	6,951	17,791	48,789	98,600	135,350	171,510	218,205	263,875	312,950	26.0
NA-TDMA	157	577	1,620	3,796	8,025	12,650	16,675	22,800	27,975	34,050	33.5
CDMA	0	0	20	2,500	8,650	15,450	24,800	37,500	53,000	69,000	51.5
PDC	0	962	3,951	16,993	25,020	21,500	19,400	18,000	16,575	14,825	-9.9
GSM/DCS-1800/PCS-1900	2,310	5,412	12,200	25,500	56,900	85,700	110,500	139,675	166,050	194,750	27.9
Others	-	-	-	-	5	50	135	230	275	325	130.5

Source: Dataquest (November 1998)

Cellular telephones based on GSM technology represent the large majority of digital cellular phones with the adoption of a common standard in Europe providing a platform for acceptance of the standard around the world. However, multiple digital standards are competing for market acceptance in the United States and around the world. Digital telephones are expected to experience rapid growth, with dual-mode analog/digital cellular/PCS telephones representing the majority of the Americas cellular/PCS handset market by 1998. Table 4-5 and Figure 4-6 show the forecast for the Americas cellular/PCS telephone market. Figure 4-7 shows the growing number of Americas cellular/PCS telephone subscribers, expected to exceed 206 million people by 2002, that are driving the handset market forecast. An increasing number of these subscribers are using their cellular/PCS telephones for personal calls and safety. Surveys have found that almost 60 percent of all cellular use in the United States is for personal calls.

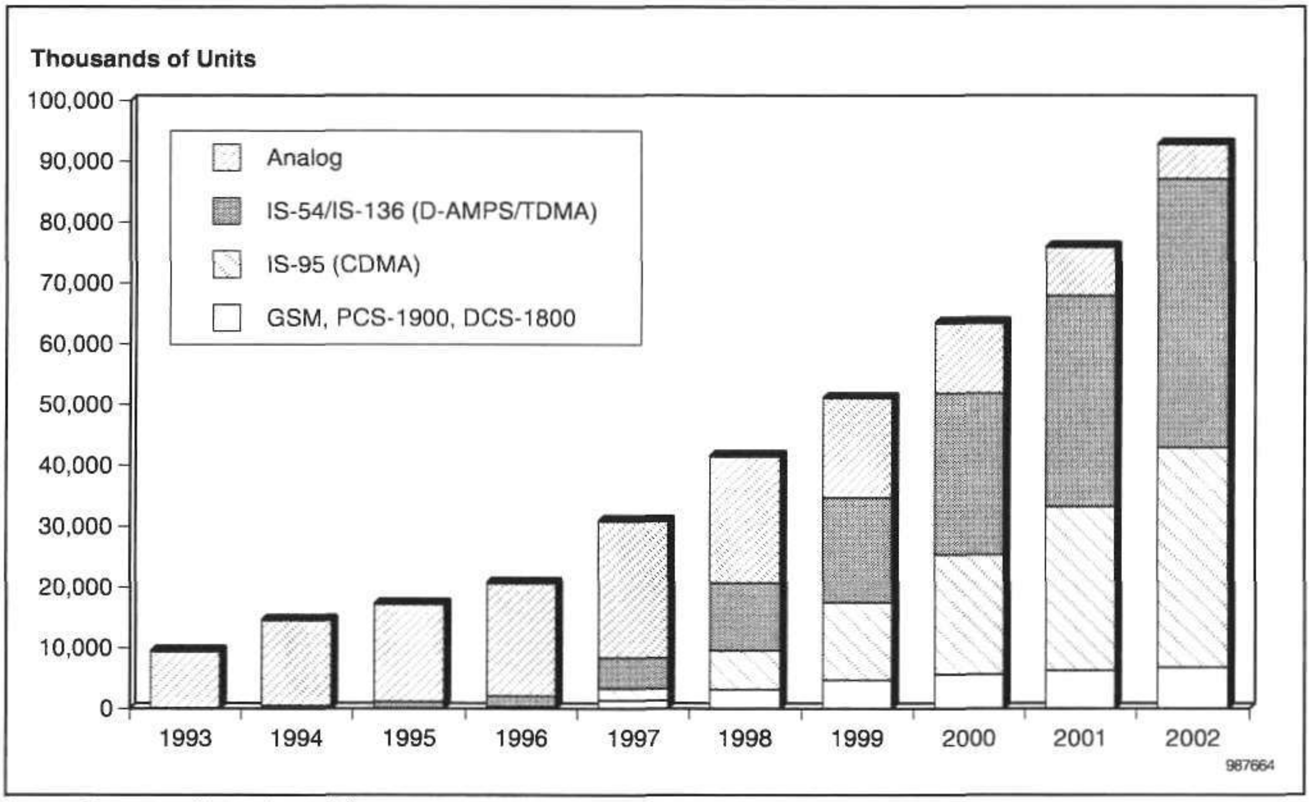
The digital GSM handset market exploded in Europe during the 1990s as the European countries agreed on the unified GSM standard. This market had experienced very low cellular penetration rates before then. With the introduction of the GSM standard, which allowed easier roaming between countries, the market took off and quickly grew to become the largest digital cellular market in the world. Many countries in other regions have also adopted the GSM standard. However, the Americas market has been much slower comparatively in accepting the digital technology.

Table 4-5
Americas Cellular and Broadband PCS Telephone Market Forecast

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Analog Cellular											
Units (K)	9,318	14,005	16,047	18,525	22,432	20,749	16,331	11,502	7,973	5,643	-24.1
Factory ASP ($)	456	426	378	318	275	222	178	147	130	116	-15.9
Factory Revenue ($M)	4,249	5,966	6,066	5,891	6,169	4,606	2,907	1,691	1,037	655	-36.2
Digital Cellular / Broadband PCS											
Units (K)	139	529	1,142	2,093	8,424	20,738	34,727	51,918	67,933	87,184	59.6
NA-TDMA	139	529	1,092	1,706	5,065	11,131	17,235	26,550	34,659	44,225	54.2
CDMA	0	0	0	42	1,964	6,372	12,725	19,678	26,958	36,098	79.0
GSM/PCS-1900/DCS-1800	0	0	50	346	1,395	3,235	4,767	5,689	6,316	6,861	37.5
Others	0	0	0	0	0	0	0	0	0	0	NM
Factory ASP ($)	850	575	424	353	321	259	214	181	160	147	-14.5
Factory Revenue ($M)	118	304	484	739	2,706	5,364	7,429	9,411	10,842	12,794	36.4
Total Market											
Units (K)	9,457	14,534	17,189	20,619	30,856	41,487	51,057	63,419	75,906	92,827	24.6
Factory ASP ($)	462	431	381	322	288	240	202	175	156	145	-12.8
Factory Revenue ($M)	4,367	6,270	6,550	6,630	8,875	9,970	10,336	11,102	11,878	13,449	8.7

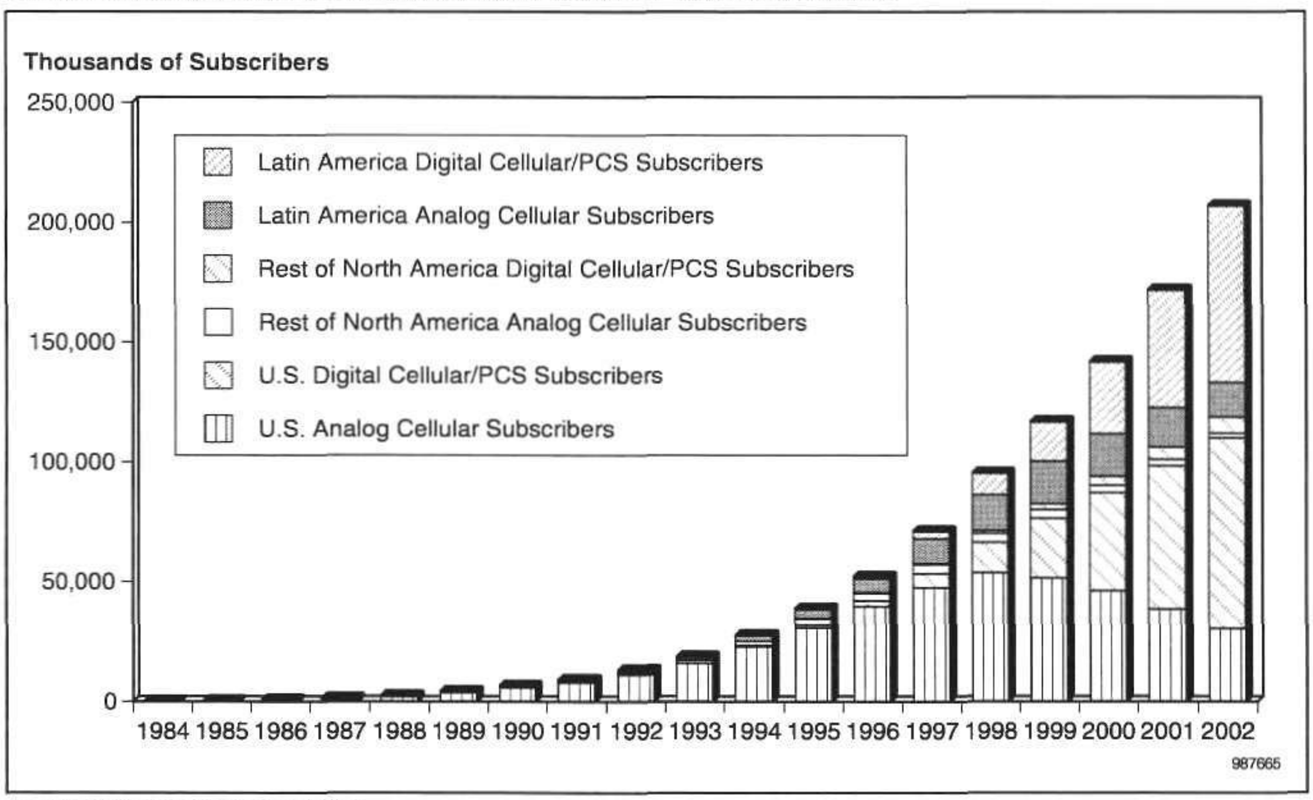
NM = Not meaningful
Source: Dataquest (November 1998)

Figure 4-6
Americas Cellular and Broadband PCS Handset Market



Source: Dataquest (November 1998)

Figure 4-7
Americas and U.S. Cellular and Broadband PCS Subscribers



Source: Dataquest (November 1998)

Digital (dual-mode) handset shipments accounted for less than 10 percent of the total Americas handset shipments in 1996. However, this number is expected to account for half of the market in 1998. The slower, early acceptance of digital handsets in the U.S. market in particular has been because of the following factors:

- The higher price of digital phones compared with analog. Low-priced analog handsets have been very popular items as many consumers seek an economical entry into the market. Cellular service providers had to push handset manufacturers for increased shipments of analog Advanced Mobile Phone Service (AMPS) handsets in 1996 as this part of the consumer market continued to expand. Through 1996, the promotion of digital services and handsets by the service providers was not very aggressive. This trend started to shift dramatically in 1997 with strong digital service promotions targeting both business and consumers.
- The voice quality of early digital handsets was widely criticized by experienced cellular subscribers, who found it inferior to the voice quality offered by analog handsets. It is expected that newer speech technologies will improve voice quality in the digital handsets.
- Limited consumer awareness of meaningful digital benefits, including increased talk time and privacy enabled by encryption. Again, service providers are now demonstrating more attractive digital benefits to consumers, including more favorable pricing for their services.
- The availability of digital service in relatively few markets. This is becoming less of a problem as new digital systems are coming online with significantly expanded coverage areas.

The Americas production of cellular/PCS handsets shown in Table 4-6 reflects the beginning of improved digital handsets in the Americas markets beginning in 1996.

The rollout of digital cellular and PCS services will require additional investment in infrastructure equipment. Table 4-7 shows an estimate of the worldwide cellular infrastructure market for the GSM standard and the semiconductor opportunity it drives.

Table 4-6
Americas Cellular and Broadband PCS Telephone Production

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Analog Production											
Shipments (K)	8,474	12,123	13,702	15,079	14,121	8,312	5,398	3,775	2,000	900	-42.3
Factory ASP ($)	448	420	370	310	246	220	184	160	135	121	-13.2
Handset Factory Revenue ($M)	3,796	5,092	5,070	4,674	3,474	1,829	993	604	270	109	-50.0
Semiconductor Content ($)	43	42	42	39	32	29	25	23	21	20	-9.0
Semiconductor Market ($M)	364	509	575	588	452	237	135	85	41	18	-47.5
Digital Production											
Shipments (k)	157	577	1,640	4,621	9,985	20,000	29,110	40,680	49,625	57,925	42.1
Factory ASP ($)	620	500	404	355	300	247	206	176	154	143	-13.8
Handset Factory Revenue ($M)	97	289	663	1,641	2,996	4,939	6,003	7,171	7,654	8,266	22.5
Total Semiconductor Content ($)	165	135	115	97	80	64	53	46	41	39	-13.4
Semiconductor Market($M)	26	78	188	450	798	1,288	1,536	1,880	2,039	2,250	23.1
Total Production											
Shipments (K)	8,631	12,700	15,342	19,700	24,106	28,312	34,508	44,455	51,625	58,825	19.5
Factory ASP ($)	451	424	374	321	268	239	203	175	153	142	-11.9
Handset Factory Revenue ($M)	3,894	5,380	5,733	6,315	6,469	6,768	6,996	7,775	7,924	8,375	5.3
Semiconductor Content ($)	45	46	50	53	52	54	48	44	40	39	-5.7
Semiconductor Market ($M)	390	587	764	1,038	1,249	1,525	1,671	1,965	2,080	2,268	12.7

Source: Dataquest (November 1998)

Table 4-7
Worldwide Mobile Infrastructure Equipment Production Forecast

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Revenue ($M)	9,730	11,083	14,071	20,456	26,746	29,888	31,801	34,966	37,569	40,455	8.6
Semiconductor Market ($M)	632	743	943	1,452	1,952	2,212	2,385	2,692	2,930	3,196	10.4
Percentage of Production Revenue by Region											
Americas	40	39	39	39	36	33	31	30	28	26	-
Europe	38	38	37	35	36	40	41	41	41	42	-
Japan	23	23	24	26	26	24	25	26	27	29	-
Asia/Pacific	-	-	0	1	2	3	3	3	3	3	-

Note: Percentages may not add up to 100 percent because of rounding.
Source: Dataquest (November 1998)

Market and Brand Share Leaders

The leading GSM handset vendors during 1997 are as follows:

- AEG Corporation/Matra Communications S.A.
- Alcatel Telecom
- Bosch
- Dancall
- Ericsson
- Hagenuk Telecom GmbH
- Matsushita Electric Industrial Company Ltd.
- Maxon
- Mitsubishi Electronics America Inc.
- Motorola Incorporated
- NEC
- Nokia Corporation
- Orbitel Mobile Communications Ltd.
- Philips Electronics NV
- Siemens
- Sony

Table 4-8 presents the worldwide market share for cellular/PCS handsets. Tables 4-9 and 4-10 provide a breakdown of market shares for analog and digital handsets, respectively. Tables 4-11 and 4-12 give the market shares for cellular handset manufacturers in North America and Latin America. Table 4-13 lists the principal TDMA (IS-54/IS-136) equipment suppliers. The members of the CDMA Development Group (CDG) are listed in Table 4-14.

Table 4-8
Worldwide Total Cellular Telephone Market Share, 1997

Manufacturer	Shipments (K)	Unit Market Share (%)
Motorola	25,327	23.5
Nokia	20,593	19.1
Ericsson	15,914	14.8
Panasonic	8,627	8.0
NEC	5,908	5.5
Samsung	3,974	3.7
Siemens	3,697	3.4
Mitsubishi	3,564	3.3
Sony	2,776	2.6
Alcatel	2,631	2.4
Others	14,806	13.7
Total	**107,818**	**100.0**

Source: Dataquest (November 1998)

Table 4-9
Worldwide Analog Cellular Telephone Market Share, 1997

Manufacturer	Shipments (K)	Unit Market Share
Motorola	14,547	51.0
Nokia	6,994	24.5
NEC	1,773	6.2
Ericsson	1,601	5.6
Audiovox	1,256	4.4
Others	2,352	8.2
Total	**28,523**	**100.0**

Source: Dataquest (November 1998)

Table 4-10
Worldwide Digital Cellular Telephone Market Share, 1997

Manufacturer	Shipments (K)	Unit Market Share
Ericsson	14,312	18.0
Nokia	13,600	17.2
Motorola	10,781	13.6
Panasonic	8,082	10.2
NEC	4,135	5.2
Samsung	3,779	4.8
Siemens	3,684	4.6
Mitsubishi	3,302	4.2
Alcatel	2,630	3.3
Sony	2,379	3.0
Philips	1,952	2.5
Fujitsu	1,563	2.0
LG	1,541	1.9
Toshiba	1,318	1.7
Qualcomm	1,207	1.5
Kyocera	1,111	1.4
Others	3,918	4.9
Total	**79,295**	**100.0**

Source: Dataquest (November 1998)

Table 4-11
North America Total Cellular Telephone Market Share, 1997

Manufacturer	Shipments (K)	Unit Market Share
Motorola	9,428	40.8
Nokia	4,812	20.8
Ericsson	3,335	14.4
NEC	1,366	5.9
Audiovox	1,256	5.4
Qualcomm	1,043	4.5
Sony	654	2.8
Samsung	432	1.9
Others*	797	3.4
Total	**23,124**	**100.0**

*Others include Panasonic, Mitsubishi, AEG/Matra, Siemens, Toshiba, and AT&T/Lucent/Philips.
Source: Dataquest (November 1998)

Table 4-12
Latin America Total Cellular Telephone Market Share, 1997

Manufacturer	Shipments (K)	Unit Market Share
Motorola	3,187	41.2
Nokia	2,840	36.7
Ericsson	1,296	16.8
Panasonic	155	2.0
Sony	108	1.4
NEC	80	1.0
Qualcomm	39	0.5
Others	28	0.4
Total	**7,732**	**100.0**

Source: Dataquest (November 1998)

Table 4-13
Leading TDMA (IS-54/IS-136) Equipment Suppliers

Handset Suppliers	Infrastructure Manufacturers
Audiovox	Astronet
Blaupunkt	Lucent
Ericsson/GE	Celcord
Hughes	Ericsson
Motorola	Hughes
NEC	Northern Telecom
Nokia	
Philips	
Uniden	
Sony	
Technophone	
Mitsubishi	
Novatel	

Source: Dataquest (November 1998)

Table 4-14
CDMA Development Group (CDG) Members

Cellular and PCS Operators	Subscriber Unit Manufacturers	Network Equipment Manufacturers	Test Equipment Manufacturers	Other Companies
360 Communications	Acer Peripherals	Hitachi Telecom	Anritsu Wiltron	3Com
AirTouch Communications	ALPS Electric (USA)	Hughes Network Systems	Comarco Wireless Technologies	Acer Peripherals
ALLTEL	Audiovox Cellular	Hyundai Electronics	Grayson Wireless	ADC NewNet
Ameritech	Denso International America	LG Information and Communications	Hewlett-Packard	Alcatel
BCTEL Mobility	Fujitsu	Lucent	IFR Systems	Aldiscon
Bell Atlantic Mobile	Hyundai	Motorola	LCC	Allgon
Bell Mobility	Kyocera	NEC	Noise Com	Certicom
Clearnet	LG Information and Communications	Northern Telecom	SAFCO	Compaq Computers
DDI Corp.	Lucent	QUALCOMM	Tektronix	DSP Communications
Enterprise Communications	Maxon	Samsung	Telecom Analysis Systems	ETRI
Globalstar	Motorola		Wavetek	Fujant
GTE Wireless	NEC America			LSI Logic
Hansol PCS	Nokia			Metawave
Hutchinson Telecom	Oki Telecom			Mobile Systems International
IDO Corporation	Philips			MTCC Panasonic
Iridium	QUALCOMM			NEC Electronics
IUSACELL	Samsung			RADWIN
Korea Telecom	SANYO			Repeater Technologies
Korea Telecom Freetel	Sharp			Sema Group
LG Telecom	Siemens			SnapTrack
MCI	Sony			Sun Microsystems
Metrosel	Telson			Technology Partnership
MobileOne				Telogy Networks
NextWave				Telular Corp.

Table 4-14 (Continued)
CDMA Development Group (CDG) Members

Cellular and PCS Operators	Subscriber Unit Manufacturers	Network Equipment Manufacturers	Test Equipment Manufacturers	Other Companies
PelePhone Communications				Texas Instruments
PrimeCo Personal Communications				TruePosition
Komselindo				Unwired Planet
Shinsegi				VLSI Technology
SK Telecom				Wireless Facilities
Sprint PCS				
Tata Teleservices				
U S WEST				

Source: CDG Development Group

Feature and Technology Trends

Since the commercial launch of cellular systems in the early 1980s, there have been a number of different regional analog cellular systems, which are reviewed in Table 4-15. Some of the technical differences between the digital cellular and cordless standards are highlighted in Table 4-16.

Countries that use AMPS cellular systems are as follows: Angola, Anguilla, Antigua, Argentina, Aruba, Australia, Bahamas, Bangladesh, Barbados, Barbuda, Belize, Bermuda, Bolivia, Brazil, Brunei, Burma, Burundi, Cambodia, Canada, Cayman Islands, Chile, China, Colombia, Costa Rica, Côte d'Ivoire, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Fiji, Gabon, Georgia, Ghana, Grenada, Guadeloupe, Guam, Guatemala, Guyana, Hong Kong, Indonesia, Israel, Jamaica, Kazakhstan, Korea, Laos, Lebanon, Madagascar, Malaysia, Martinique, Mexico, Montserrat, Myanmar, Nauru, Netherlands Antilles, New Zealand, Nicaragua, Pakistan, Papua New Guinea, Paraguay, Peru, Philippines, Russia, Samoa (American), Singapore, Sri Lanka, St. Kitts/Nevis, St. Lucia/St. Vincent/Grenadines, St. Martin/Bartholemy, Suriname, Taiwan, Thailand, Trinidad and Tobago, Turkmenistan, United States, Uruguay, Venezuela, Vietnam, Virgin Islands, Zaire, and Zambia.

Table 4-15
Analog Cellular Network Standards

	AMPS	TACS	NMT-450	NMT-900
Frequency Band (MHz)				
Tx	824-849	871-904	453-456	890-915
Rx	869-894	916-949	463-468	935-960
Carrier Spacing (kHz)	30	25	25	12.5
Access Method	FDMA	FDMA	FDMA	FDMA
Modulation Scheme	PSK	PSK	FFSK	FFSK
Implementation	Australia, Canada, Hong Kong, Japan, and the United States	Greece, Italy, Spain, and the United Kingdom	Austria, Belgium, Scandinavia	Netherlands, Scandinavia, Switzerland

AMPS = Advanced Mobile Phone System
FDMA = Frequency division multiple access
FFSK = Fast frequency shift keying
PSK = Phase shift keying
TACS = Total Access Communications System
Source: Dataquest (November 1998)

Table 4-16
Digital Cellular and Digital Cordless Standards, Technical Differences

	GSM[1]	DCS-1800[2]/ PCS-1900	IS-54/IS-136	PDC[3]	IS-95	CT2[4]	DECT[5]	PHS[6]
Frequency	935-960 MHz 890-915 MHz	1.7-1.9 GHz 1.8-2.0 GHz	824-849 MHz 869-894 MHz 1.8-2.0 GHz	810-826 MHz 940-956 MHz 1429-1441 MHz 1447-1489 MHz 1501-1513 MHz	824-849 MHz 869-894 MHz 1.8-2.0 GHz	864-868 MHz	1.88-1.9 GHz	1.9 GHz
Access Method	TDMA[7]	TDMA	TDMA	TDMA	CDMA	TDMA	TDD/ TDMA	TDD/TDMA
Modulation	GMSK[8]	GMSK	π/4 DQPSK[9]	π/4 DQPSK	QPSK[10] DQPSK	Two-level GFSK	GMSK	π/4 DQPSK
Speech CODEC	RPE-LTP[11] 8/13 Kbps	RPE-LTP 8/13 Kbps	VSELP[12] 7.25/13 Kbps	VSELP/PSI-CELP 11.2/5.6 Kbps	ADPCM[13] 8.55/13 Kbps	ADPCM 32 Kbps	ADPCM 32 Kbps	ADPCM 32 Kbps
Output Power	20mW to 20W	2.5mW to 1W	2.2mW to 6W	Up to 2W	0.2W to 6.3W	1mW to 10mW	250mW	10mW (Indoor) 500mW (Outdoor)
Channel Spacing	200 kHz	200 kHz	30 kHz	25 kHz	1.23 MHz	100 kHz	1.728 MHz	300 kHz
Number of Frequencies	124	374	832	1,600	10	40	10	40
Time Slots	8	8	3	3	NA	2 (TDMA) 40 (FDMA)[14]	24 (2 x12)	8 (2 x4)

[1]Global system mobile
[2](PCN) digital cellular
[3]Personal/Pacific digital cellular
[4]Digital cordless telephone
[5]Digital enhanced cordless
[6]Japanese digital cordless Personal Handyphone System
[7]Time-division multiple access
[8]Gaussian mean shift keying
[9]Differential quadrature phase shift keying
[10]Quadrature phase shift keying
[11]Regular pulse excitation, long-term prediction
[12]Vector sum excited linear predictive coding
[13]Adaptive differential pulse-code modulation
[14]Frequency-division multiple access
Source: Dataquest (November 1997)

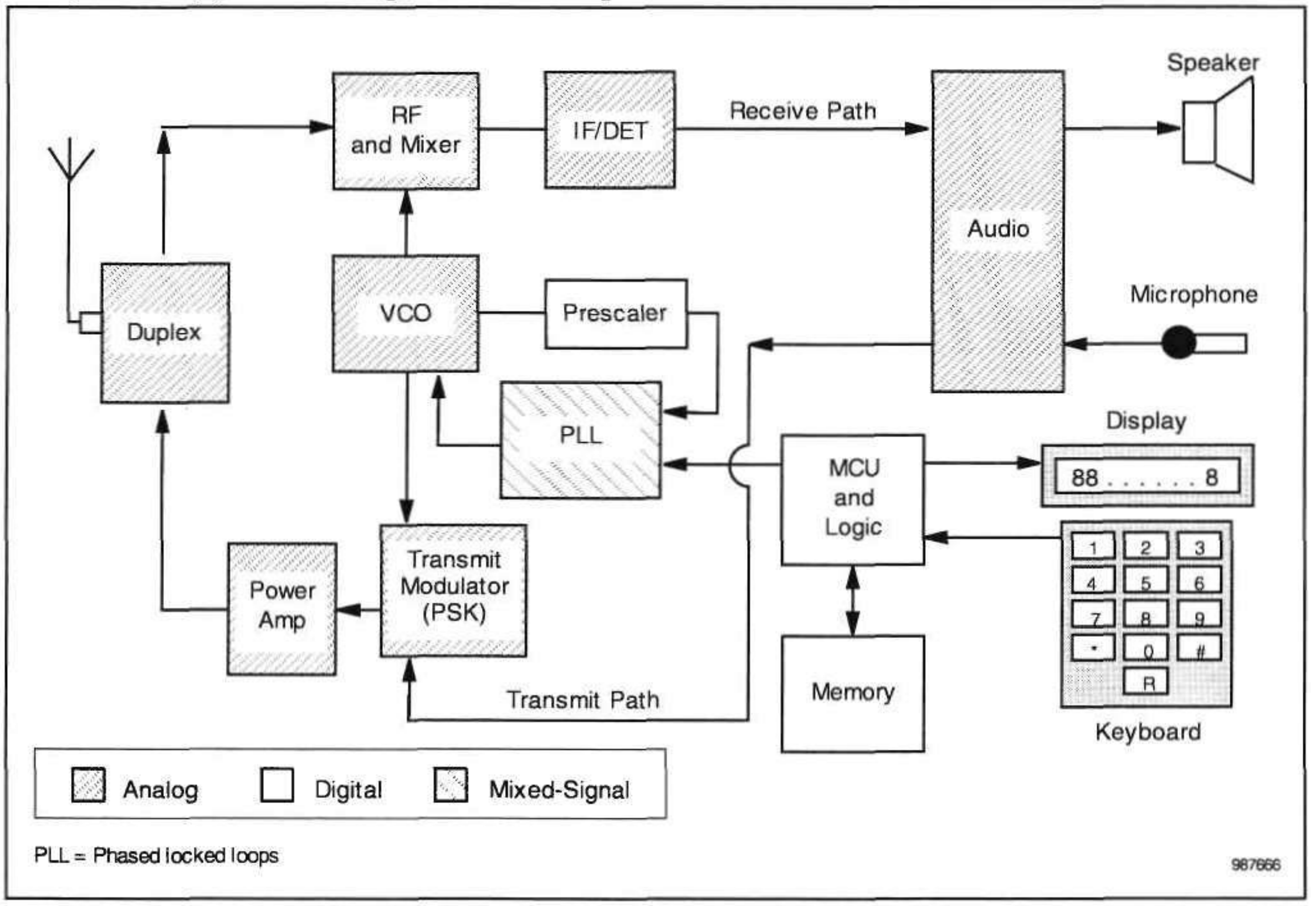
Figures 4-8 and 4-9 show an AMPS (analog) cellular and a dual-mode (digital) phone (based on TDMA or CDMA access). A digital or dual-mode phone can be separated into two major sections, the baseband and the RF or access arrangement. New designs of these phones have reduced the chip count to four or five chips, from earlier designs that use eight to 12 ICs and dozens of discrete components and passive filters. In digital cellular and PCS, the baseband and transmission/reception sections of the phone deal primarily with digitized bit streams. There are six major functions in the baseband section, as follows:

- Audio interface/CODEC: Manages amplification, signal conditioning, analog-to-digital and digital-to-analog to the handset speaker and microphone. This functionality can also include the full duplex speakerphone circuit and voice recognition circuits.
- Vocoder: Encodes and compresses the digitized voice according to specification, such as vector sum excited linear predictive coding (VSELP) for the IS-54.
- Baseband CODEC: Takes the compressed voice bit stream (or data stream) and prepares it for the transmission by putting it into the right time slot for TDMA or several channels according to CDMA. Dual-mode and AMPS phones also use frequency-division multiple access (FDMA) "channelization."
- Modem: Optional for accepting computer bit streams and converting them for transmission over voice channel. It can include "packetizing" for the new data standards, such as cellular digital packet data (CDPD) at 108 bytes per packet or Mobitex.
- Microcontroller: 8-bit or 16-bit for handling dialer, ringer, and LCD control and interface
- Memory: A 64Kb EEPROM/flash for user presets and SRAM (32Kb x 8) for the same purpose or for a scratch pad

The RF or access arrangement section has two major functions, transmission and reception, and involves at least six ICs and numerous discrete transistors and diodes (including gallium arsenide [GaAs] versions), passive filters, and oscillators. There are three major functions in the RF section:

- Differential quadrature phase shift keying (DQPSK) transmitter and receiver, which handle many of the transceiver modulation functions. Dual-mode and AMPS phones use phase shift keying for modulation as well.
- Phase locked loops (at least two), prescalers, and a voltage-controlled oscillator (VCO) for generating necessary frequency signals
- Power amplifier for transmission and a low-noise amplifier for reception

Figure 4-8
Simplified Typical Analog Cellular Telephone

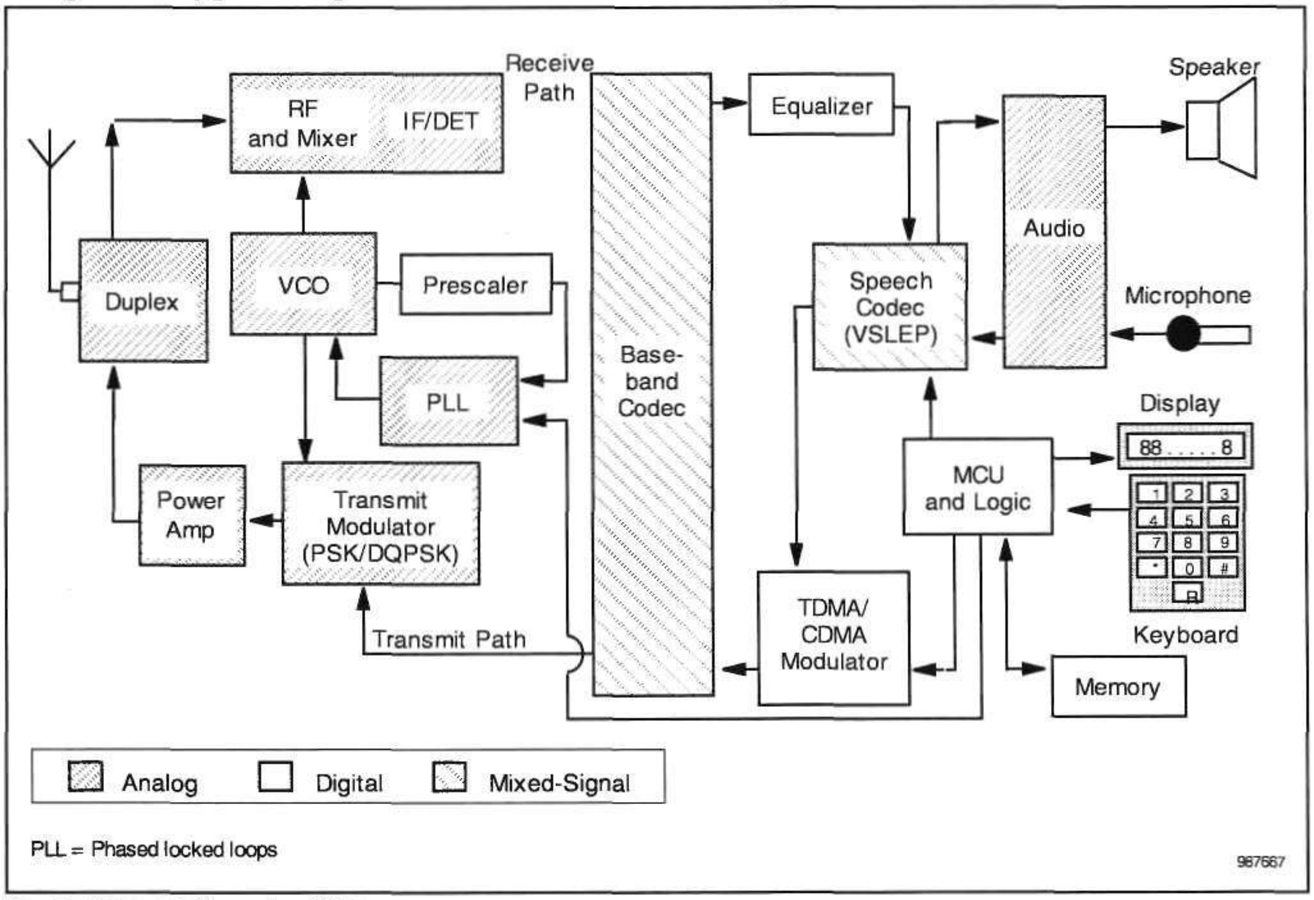


Source: Dataquest (November 1998)

The principal contenders for digital encoding are TDMA, extended-TDMA (E-TDMA), and CDMA. Figure 4-10 provides an illustration of how these technologies work. In converting to digital encoding, it is necessary that both the base station equipment at the service provider and the subscriber handsets have the same standard. It has been decided that a new digital system will be backward-compatible with AMPS. This decision is forcing the carriers to use dual-mode technology capable of AMPS and either TDMA or CDMA, the leading digital contenders. Figure 4-11 shows an example of a PCS network topology.

The Cellular Telecommunications Industry Association (CTIA) has endorsed the use of dual-mode technology based on TDMA. This combination is also known as standard IS-54. A new enhanced standard based on IS-54 was introduced in 1995. This standard, called IS-136, provides improved voice quality and power savings. Shipments of IS-136 handsets started in 1996. TDMA, as the name implies, provides time slots for various users and can achieve a threefold improvement in time capacity over AMPS. The major equipment backers of TDMA include AT&T Corporation, Ericsson-General Electric Company (joint venture), and Motorola-Northern Telecom Inc. (joint venture for base stations).

Figure 4-9
Simplified Typical Digital/Dual-Mode Cellular Telephone



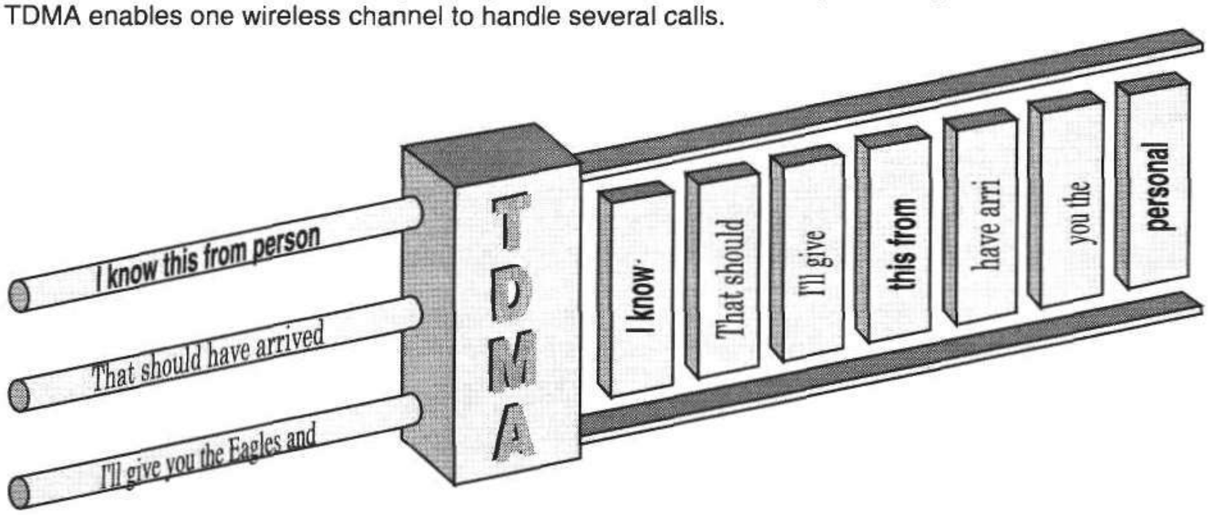
Source: Dataquest (November 1998)

CDMA technology has also been endorsed as a standard and has been labeled IS-95. CDMA employs spread-spectrum techniques. According to a key patent holder and licenser, QUALCOMM Incorporated of San Diego, California, CDMA has the capability of improving channel capacity 10 or 20 times over AMPS. In actual implementations, the capacity gains are about eight times more than AMPS. CDMA backers include AT&T, Nokia, Motorola, Sony Corporation of America, and QUALCOMM.

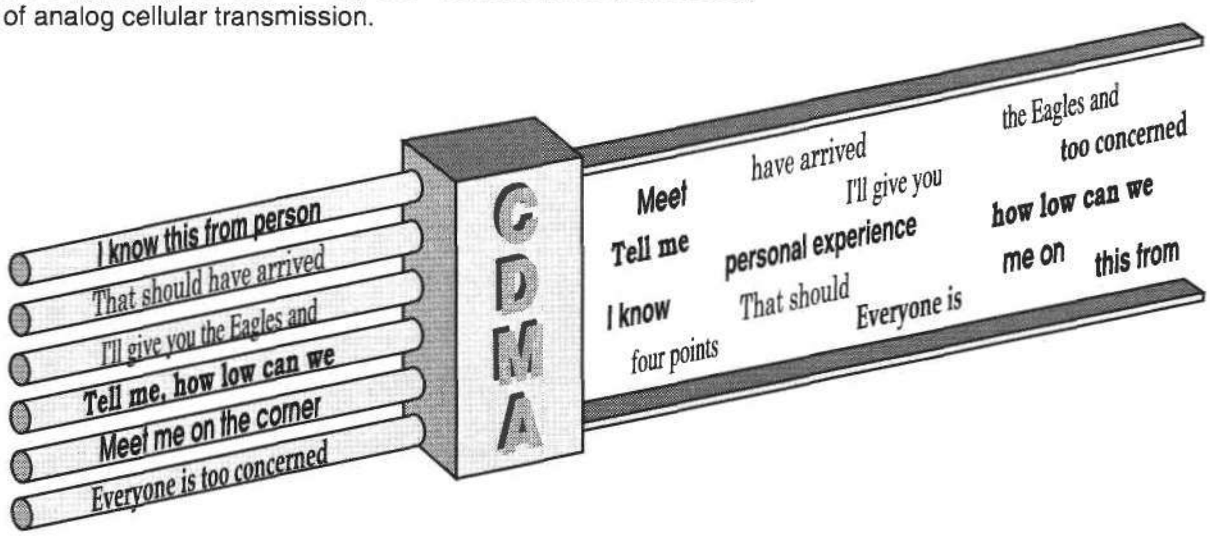
In addition to the IS-54/IS-136 and IS-95 standards, a number of other standards are competing for the PCS market in the United States. The most recent standard to receive interim status approval is the Omnipoint standard, which employs a combination of TDMA, CDMA, and FDMA technologies. This standard has been labeled IS-661 and has the support of Nortel, Ericsson, JRC International, and Texas Instruments Inc. These companies will supply various components from the infrastructure to the handsets that are needed in this system. The PCS-1900 technology is based on the GSM standard and uses TDMA technology. The first PCS systems to come to the market in the United States are based on the PCS-1900 technology. The PACS and WCPE standards will be limited to niche-market implementations. Table 4-17 lists the digital technology endorsements by major U.S. mobile carriers and winners of the first broadband PCS auction.

Figure 4-10
TDMA and CDMA Digital Transmission Technologies

Two emerging forms of digital transmission can save spectrum space in both cellular phones and the PCS of the future. Time-division multiple access (TDMA) chops calls into pieces of data that are identified on the receiving end by the time slots to which they are assigned. TDMA enables one wireless channel to handle several calls.



The second technology, code-division multiple access (CDMA), spreads its pieces of calls across a wide swath of communications frequencies. The fragments carry a code identifying their phone of origin, and the receiving station uses the code to identify and reconstitute the original signal. CDMA may offer 10 to 20 times the capacity of analog cellular transmission.



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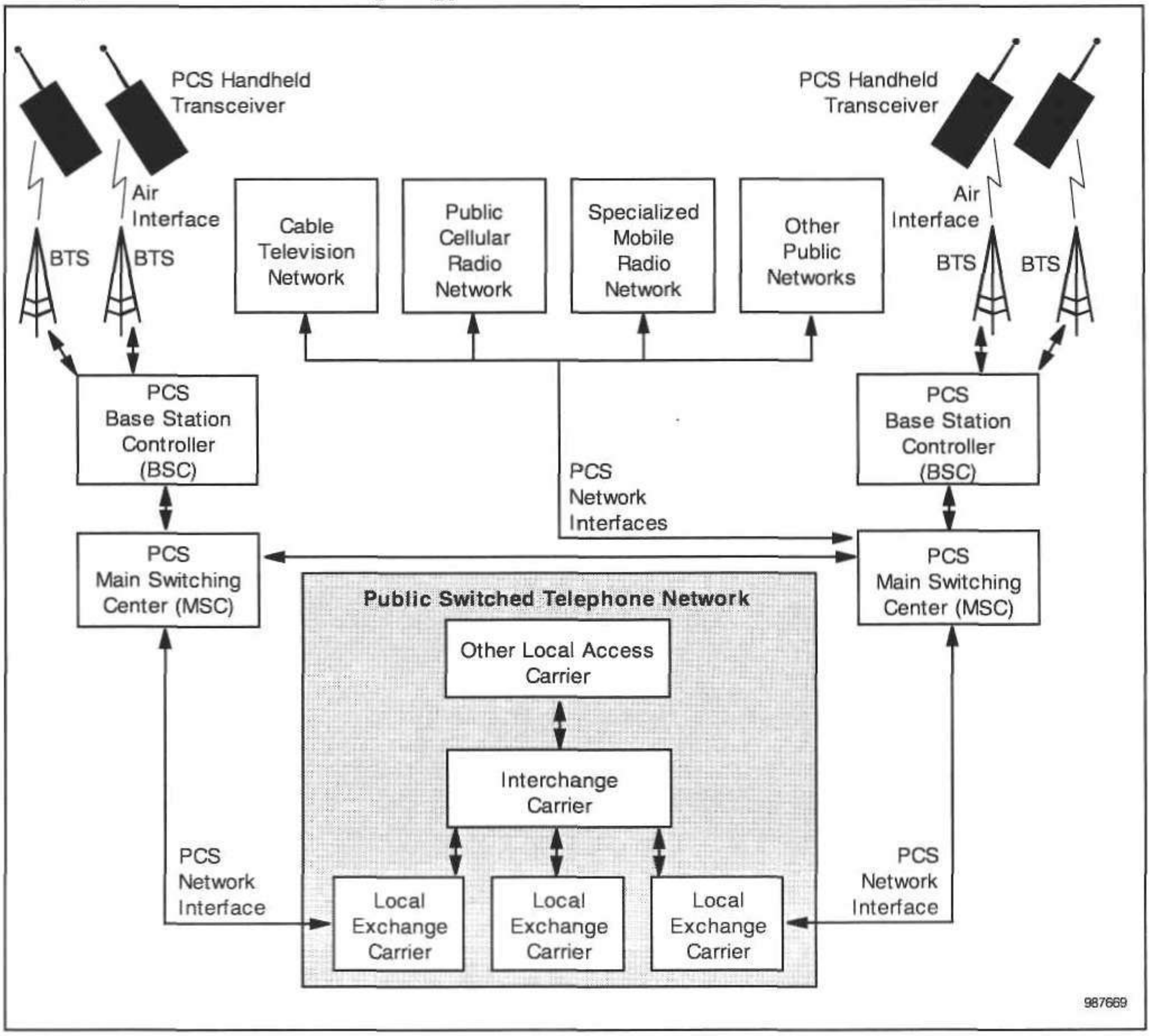
Source: Eric Zimits, Volpe, Welty & Co.

Figure 4-11
Example of PCS Network Topology



Source: Dataquest (November 1998)

Table 4-17
Major U.S. Cellular/PCS Players: Their Technology Selections and Digital Launches

Service Provider	NA-TDMA	CDMA	PCS-1900 (GSM)
Cellular			
360 Communications (Sprint)		X	
AirTouch Cellular		X	
ALLTEL		X	
AT&T Wireless Services	X		
Ameritech Cellular		X	
Bell Atlantic Mobile		X	
BellSouth Cellular	X		
Cellular Communications	X	X	
Comcast		X	
GTE Mobilnet		X	
NYNEX Mobile		X	
Southwestern Bell Mobile	X		
United States Cellular	X	X	
U S WEST		X	
PCS			
American Personal Communications			X
American Portable Communications			X
Ameritech		X	
AT&T Wireless Services	X		
BellSouth			X
Centenial Cellular		X	
GTE Mobilenet		X	
Omnipoint			X*
PCS PrimeCo		X	
Pacific Bell Mobile			X
Powertel PCS Partners			X
Southwestern Bell Mobile	X		
Sprint Telecommunications Venture (STV)		X*	
Western Wireless			X

*Combination of PCS-1900 and Omnipoint standards
Source: Dataquest (November 1998)

A new category of wireless products called "smart phones" reached the market in 1996. This is a loosely defined category, but the devices typically offer advanced voice and data capabilities for the high-end consumer or mobile professional. The first company to market with a product was Nokia. It introduced its Nokia 9000 Communicator at the March 1996 CeBIT trade show. In addition to wireless voice communications, this product offers two-way facsimile and e-mail capabilities, Internet access, corporate and personal computer data access, and a schedule manager. The Nokia 9000 was rolled out in the European and Asian markets in 1996. Intel Corporation supplied the microprocessor and flash memory components for the system, and Geoworks Corp. supplied the operating system, Geos 3.0. Mitsubishi also announced a smart phone at the CTIA trade show in Dallas in 1996. This handset uses CDPD to provide advanced data communications over the analog cellular network. Alcatel is working with Sharp Electronics Corporation to develop a smart phone based on GSM technology, and Ericsson is also developing a smart phone.

As stated previously, digital cellular handsets based on GSM technology represent the large majority of digital cellular telephones. The unified European standard has enabled strong growth in this market. More than 100 countries have adopted the GSM standard. Some of the countries that operate or plan to operate GSM systems are as follows: Albania, Andorra, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belgium, Bosnia Herzegovina, Brunei, Bulgaria, Burkina Faso, Cambodia, Cameroon, Canada, Chile, China, Congo, Côte d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Ethiopia, Fiji, Finland, France, French Polynesia, French West Indies, Georgia, Germany, Ghana, Gibraltar, Greece, Guinea, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Ireland, Jordan, Kenya, Italy, Kuwait, Laos, Latvia, Lebanon, Lesotho, Libya, Lithuania, Luxembourg, Macau, Macedonia, Madagascar, Malawi, Malaysia, Malta, Mauritius, Monaco, Mongolia, Morocco, Mozambique, Namibia, Netherlands, New Caledonia, New Zealand, Norway, Oman, Pakistan, Papua New Guinea, Philippines, Poland, Portugal, Qatar, Romania, Russia, Saudi Arabia, Senegal, Seychelles, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syria, Taiwan, Tanzania, Thailand, Turkey, United States, Uganda, Ukraine, United Arab Emirates, United Kingdom, Uzbekistan, Vietnam, Yugoslavia, and Zimbabwe.

There is much activity to reduce component count in these systems. Table 4-18 shows the semiconductor technology solutions for second- and third-generation handsets. Figure 4-12 is a block diagram of a second-generation GSM telephone that supports voice and data services. Figure 4-13 shows a block diagram of a CDMA handset. Although base stations do not ship in the same quantities as handsets, they are semiconductor rich and represent a significant opportunity for semiconductor manufacturers. Figure 4-14 presents a simple block diagram of a wireless base station.

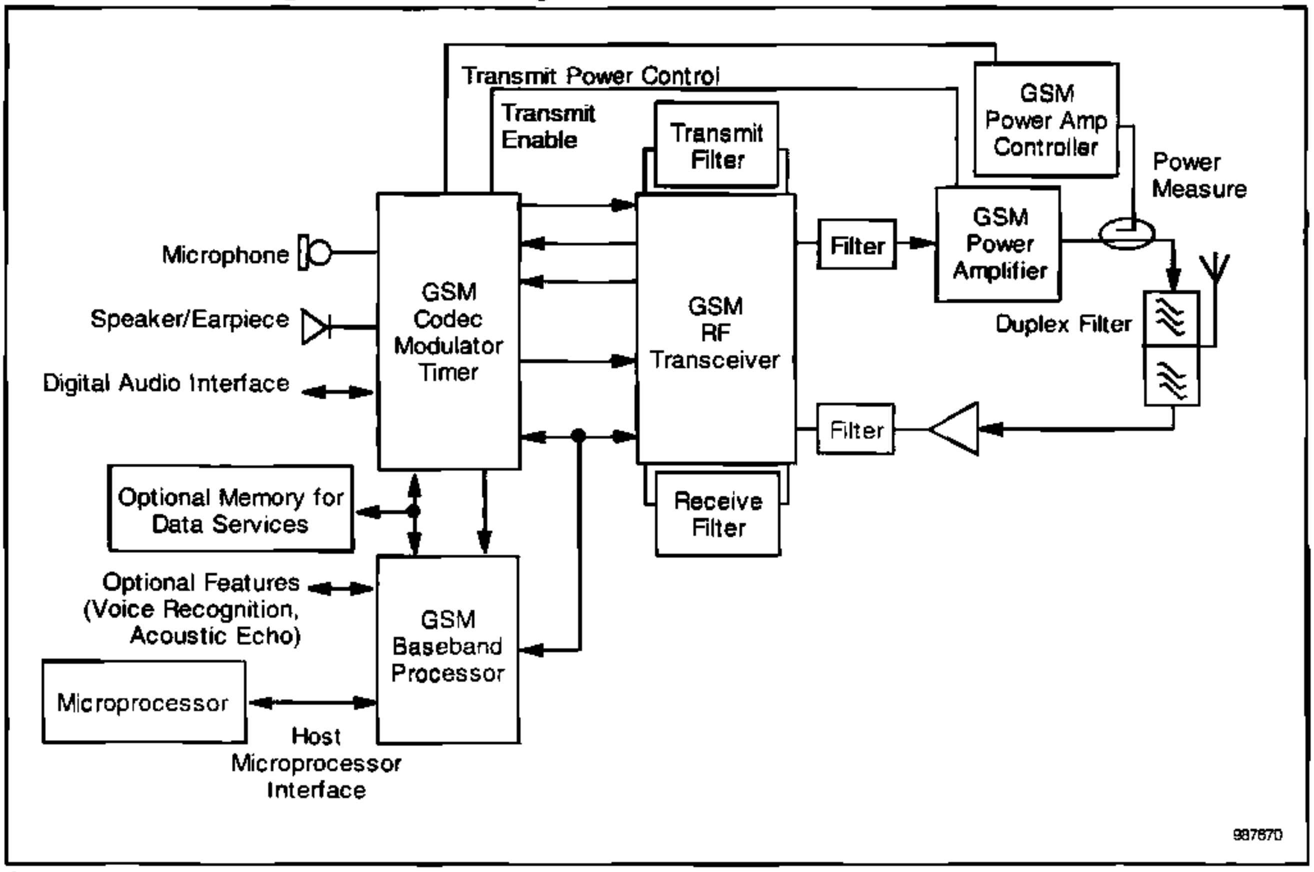
Figures 4-15 and 4-16 present the RF allocation for the new broadband PCS services and the overall wireless spectrum allocation for various wireless applications in the United States.

Table 4-18
GSM Telephone Handset Semiconductor Devices

Function	Number of Devices	Semiconductor
Integrated Power Amplifier	1	Analog (GaAs)
RF Front End	1 to 4 (or discretes)	RF linear
Baseband Processor, Channel Controller, Voice Processor, Microcontroller/Microprocessor, Audio I/O	1 to 4	Mixed-signal (ASIC), DSP, Microcomponent
Flash, EPROM, SRAM	3	MOS memory

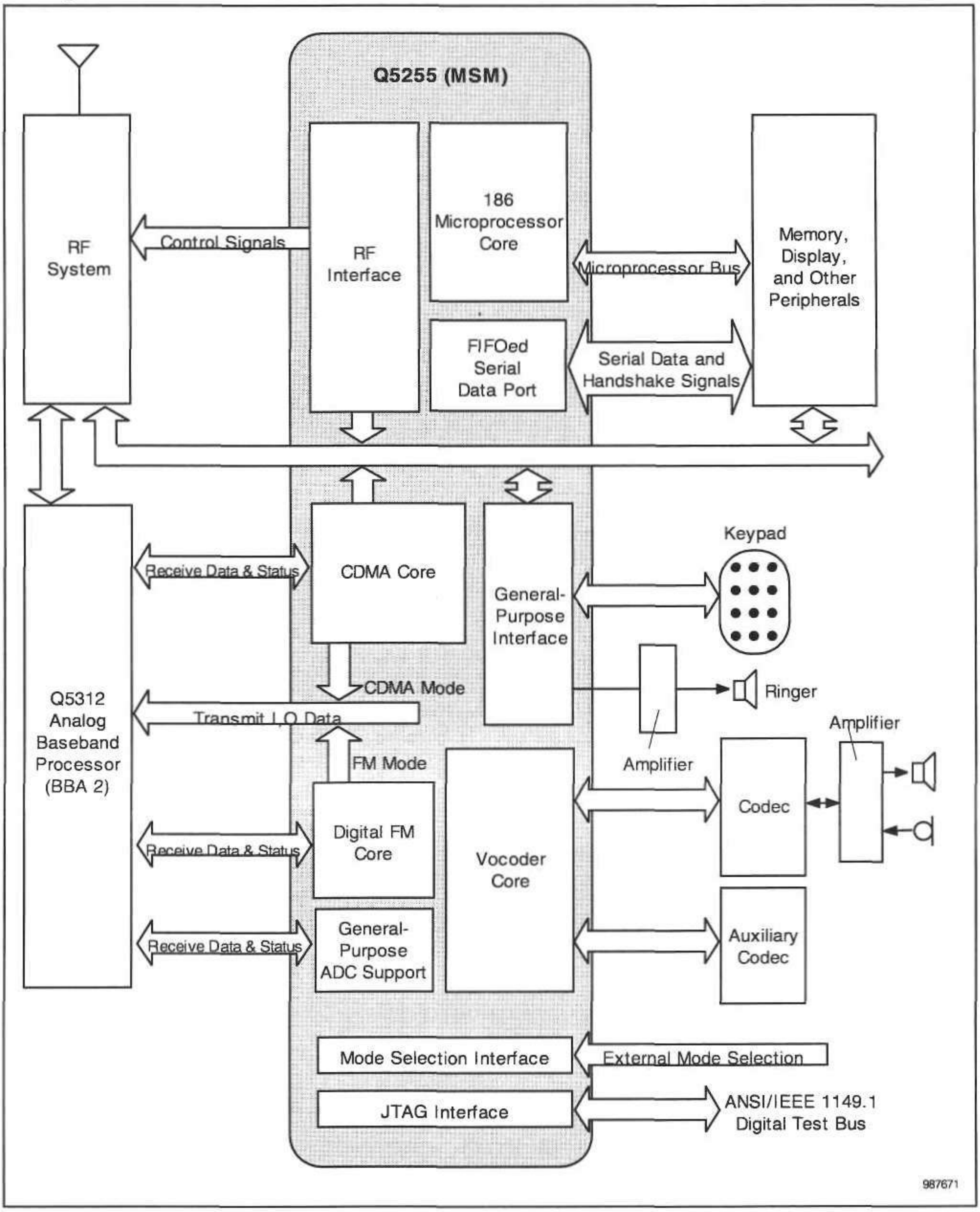
Source: Dataquest (November 1998)

Figure 4-12
GSM Cellular Telephone Block Diagram



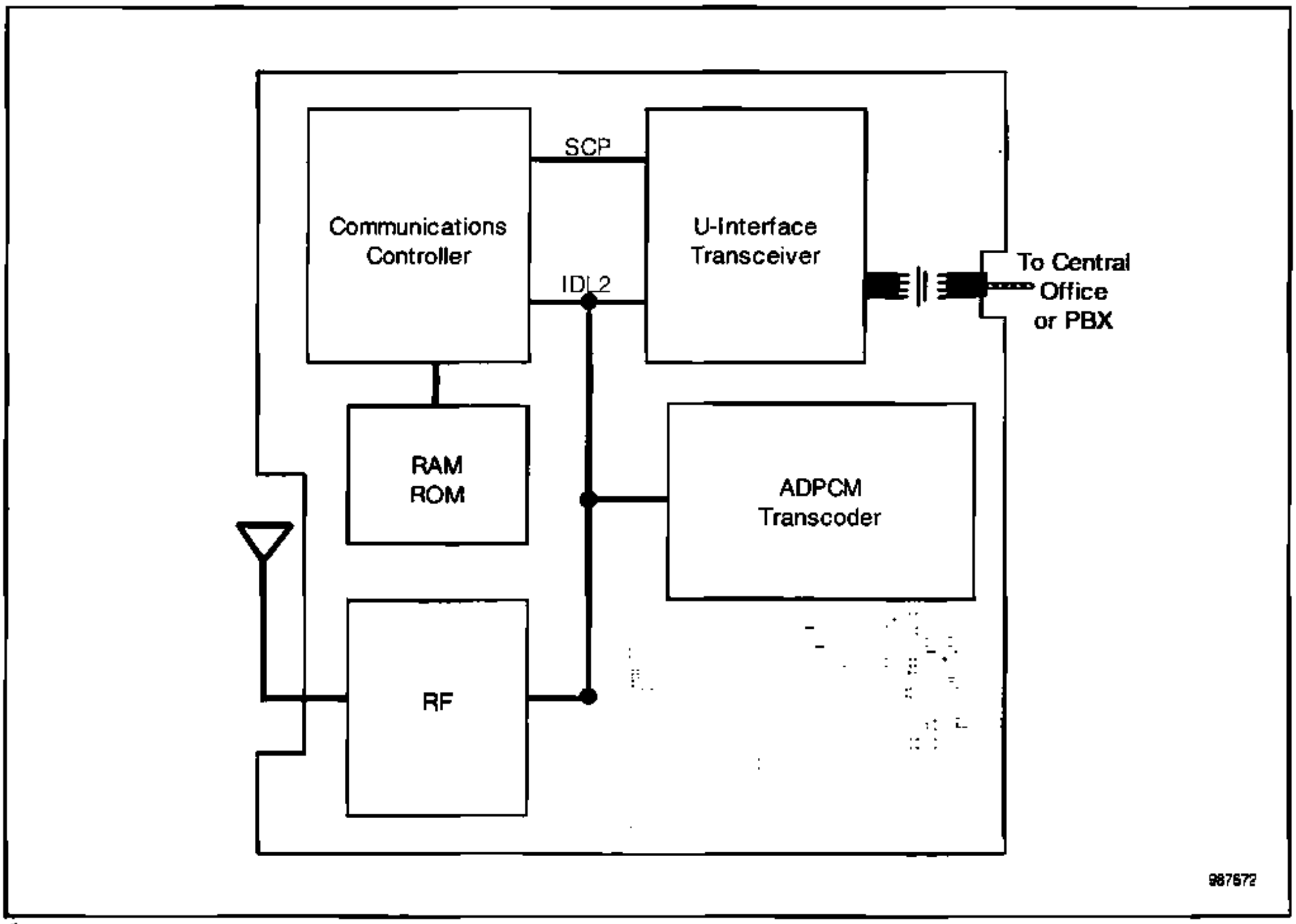
Source: AT&T Microelectronics

Figure 4-13
Example of a CDMA Handset



Source: QUALCOMM

Figure 4-14
Simple Block Diagram of a Wireless Base Station



Source: Motorola

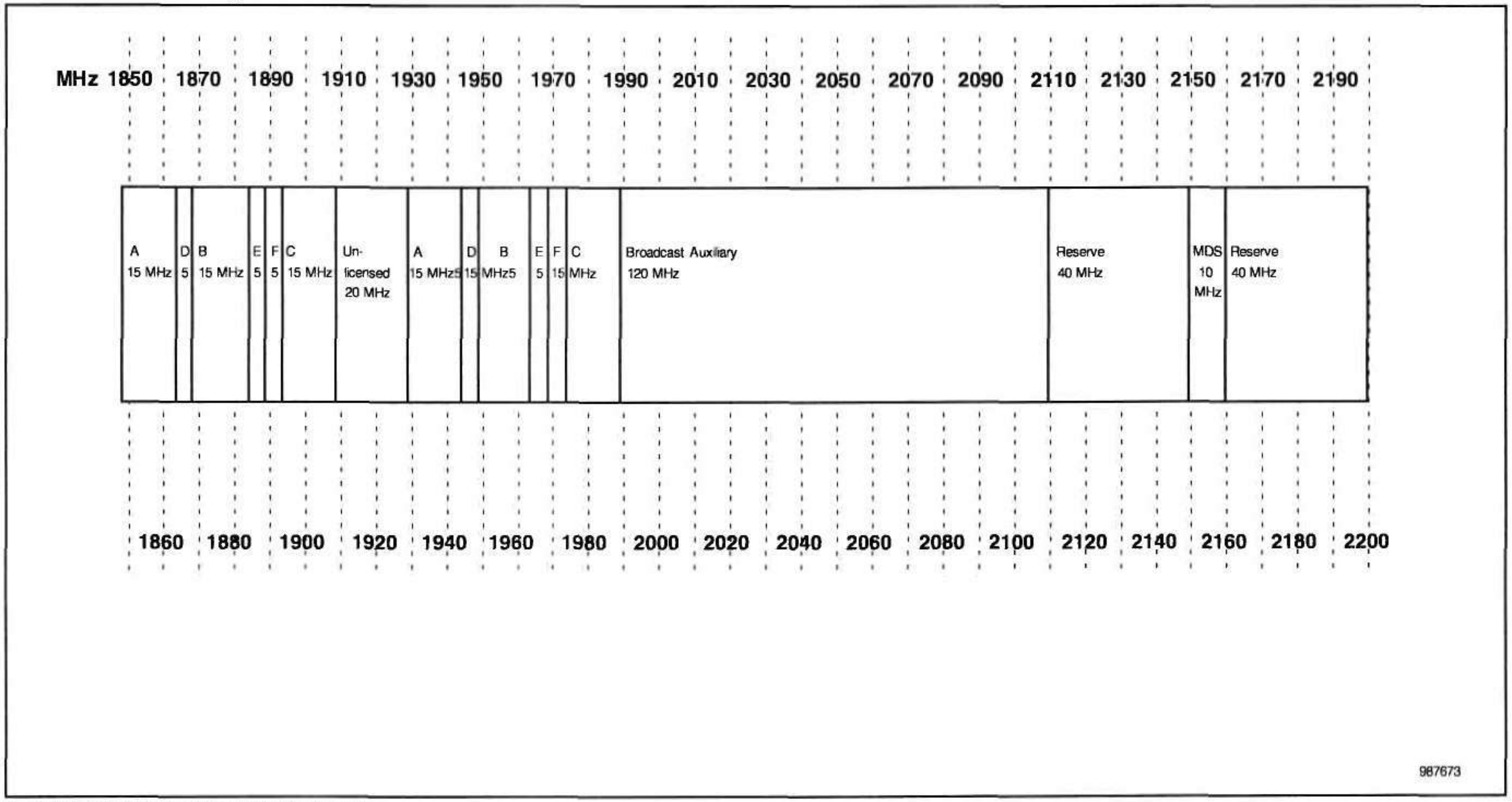
Third-Generation Cellular

As many as 10 organizations have submitted proposals for consideration as part of the International Mobile Telecommunications (IMT)-2000 initiative launched by the International Telecommunications Union (ITU) to develop third-generation wireless standards. Soon after the June 30 deadline for submission of proposals, the ITU announced it will move ahead quickly with the standardization process.

Three proposals are based on wideband code-division multiple access (W-CDMA), one from the European Telecommunications Standards Institute (ETSI), one from the United States' T1P1 (a subcommittee of Committee T1 sponsored by the Alliance for Telecommunications Industry Solutions and accredited by the American National Standards Institute), and one from Japan's Association of Radio Industries and Businesses.

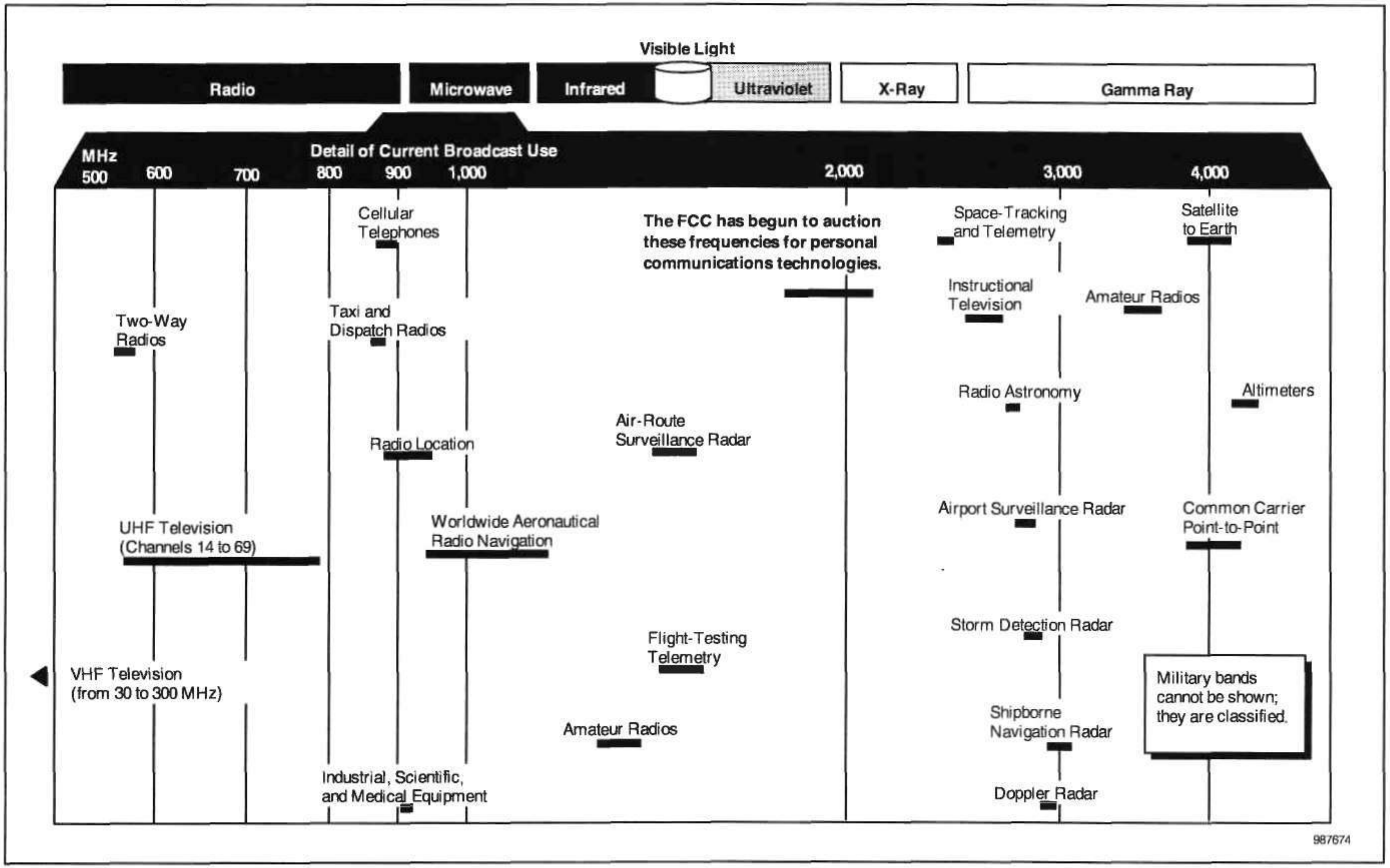
The ETSI proposal also includes the time-division multiple access (TDMA)/CDMA component for low mobility applications. Also, a low-mobility proposal based on DECT was submitted.

Figure 4-15
Broadband PCS Spectrum Plan



Source: Federal Communications Commission

Figure 4-16
The Wireless Spectrum



Source: New York Times, Dataquest (November 1998)

The Telecommunications Industry Association (TIA) submitted cdma2000, a proposal based on cdmaOne technology, and UWC-136, based on the IS-136 TDMA standard. Both cdmaOne and IS-136 originally were developed as U.S. cellular standards and have been widely implemented internationally.

The TIA also submitted a proposal for wideband integrated services digital network multimedia services (WIMS). The proposal, similar in several respects to W-CDMA, has been proposed by New Jersey-based Golden Bridge Technologies, with input from AT&T Laboratories, Hughes Network Systems, InterDigital Communications Corporation, and Oki Telecom Inc.

Korea's Telecommunications Technology Association submitted two CDMA-based proposals along with a satellite component, and China's telecommunications administration proposed a hybrid system for low mobility applications.

Three organizations submitted satellite-based proposals. European Space Agency proposed two systems: One is based on W-CDMA, and the other is a hybrid TDMA/CDMA option. ICO Global Communications, the London-based spin-off of Inmarsat, submitted its proposed low-earth orbit satellite system, and Inmarsat, itself in the process of making a transition from an intergovernmental organization to a corporate entity, proposed a system to provide mobile and fixed services to the rural and remote areas.

Semiconductor Opportunities

The worldwide cellular/PCS telephone handset semiconductor market reached $8.03 billion in 1997 and is forecast to grow to $11.76 billion in 2002. Specific IC opportunities for digital cordless, cellular, and PCS telephones include the following:

- 3V versions of all activities
- Thin quad flat packages (QFPs) for PCMCIAs (PC Cards) for personal digital assistants (PDAs)
- Speech and baseband CODECs
- Speakerphone and voice recognition circuits
- TDMA/CDMA modulators
- CDPD/Mobitex modem/packetizer (for data communications)
- Phase locked loops/prescalers
- RF power/low-noise amps (902 to 928 MHz, 1.8 to 1.9 GHz)
- IF IC and discretes (oscillators, amps, frequency detection, and filters)
- 12-/24-bit MCU (with LCD driver)
- Voice recognition (DSP-based)
- Memory (EEPROM-serial, SRAM-optional, and flash)
- Various integrations of these

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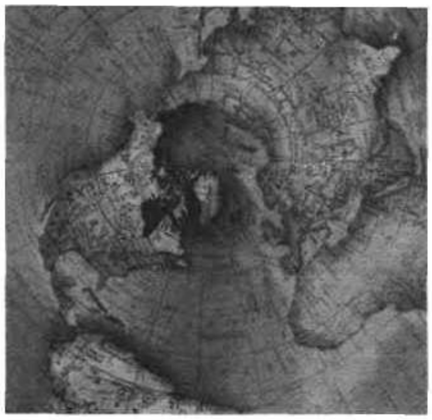

Dataquest

Europe, Middle East, and Africa: GSM Handset Production and Semiconductor Market, 1997-2002

Focus Report

Program: Wireless Semiconductors and Applications - Worldwide
Product Code: WSAM-WW-FR-9802
Publication Date: December 21, 1998
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Chapter 1
Executive Summary

Europe, Middle East, and Africa (EMEA) production of global system for mobile communications (GSM) handsets totaled 54 million units in 1997. This was another year of tremendous growth—more than 100 percent compared with 1996 production of 25 million. This makes digital cellular handsets the most prolifically produced of the major electronic equipment systems in the EMEA region, far exceeding PCs or TVs. This year of exceptional growth has established digital cellular handsets as the second-largest EMEA electronics market for semiconductors at $3.7 billion, accounting for 12.4 percent of the total market.

Dataquest expects production growth to slow in the coming years, but still to achieve an average 22 percent annual growth rate over the forecast period from 1997 to 2002. EMEA production will be mainly to supply the EMEA market, but will continue to produce for export markets, especially Asia/Pacific.

In Dataquest's expectations for future growth, we have considered the impact of the Asian financial crisis on this market and the likely impact on EMEA production. An issue of continued concern is the viability of OEMs currently producing GSM handsets, as there are so many.

Recent events have shown that no company's future is assured in the GSM market, with the acquisition of Dancall by Bosch, and Nortel recently ceasing production at its AEG/Matra operation. Second- and third-tier players will continue to grow faster than the average GSM OEM, although some will face increasing competition from the three major players, which have an awesome volume advantage. This cost and volume advantage is addressed by chipset vendors selling to the lower-tier players; these vendors can offer leading-edge semiconductor solutions, thus minimizing the massive ASIC development costs that the top OEMs would otherwise face.

This Focus Report forecasts the trends in the devices used in GSM handsets. It also identifies which OEMs have the greatest semiconductor purchasing power, and how they use this against semiconductor vendors.

Note on Data

Data is based on September 1998 estimates. Totals in this Focus Report may not add up because of rounding.

Chapter 2
EMEA GSM Market Drivers

Worldwide digital cellular handset production is dominated by Europe. European production account for 55 percent, remaining the primary production region for GSM handsets. Production is driven by market growth in the EMEA region and Asia/Pacific and the GSM1900 market in the United States. Dataquest expects Asia/Pacific, including Japan, to become the world's largest regional market for digital cellular, predominantly GSM, by 1999. As the market in each of these regions grows, Dataquest anticipates that production will move from Europe to local production facilities, especially in Asia. We expect the major players to have begun moving production to Asia in 1997, in particular to China.

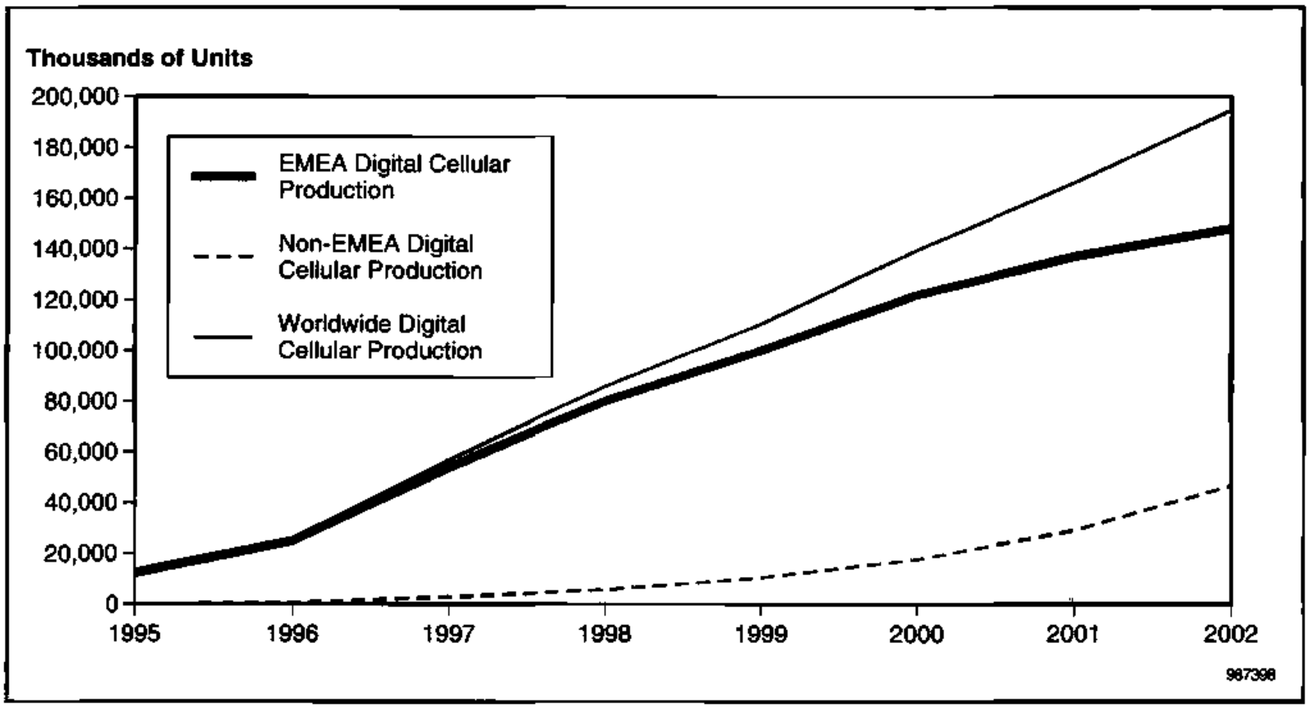
Local production in Asia will grow strongly, but Europe will still be a major supplier to this region throughout the forecast period. However, the trend toward local production is balanced by the difficulty of producing highly sophisticated electronic products at a distance from the R&D and engineering centers based in Europe. This problem of transferring production to local markets is complicated further by the continued shortening of product life cycles; it gives little time for long production runs and yield improvements before a product design is superseded. Currently, product life cycles are about nine to 18 months, as models are continuously replaced or enhanced with additional features and functions.

Figure 2-1 shows Dataquest's forecast for GSM cellular handset production. The EMEA region dominates the forecast period, accounting for three-fourths of all GSM production by 2002. Nonetheless, non-EMEA production is expected to grow rapidly.

Table 2-1 shows GSM handset production in the EMEA and non-EMEA regions. The growth rate over the forecast period in non-EMEA regions exceeds 74 percent, accounting for approximately one-fourth of the worldwide production of GSM in 2002.

Table 2-2 shows Dataquest's forecast of factory average selling prices (ASPs) for digital cellular handset production in the EMEA region. There has been rapid price erosion to fuel the growth in market demand. This price erosion has been driven by competitive pressure between OEMs, and the pressure has been passed down to semiconductor vendors to provide the major contributor to cost reduction. As unit production has increased, this has helped to drive down costs owing to economies of scale.

Figure 2-1
Worldwide and EMEA GSM Cellular Handset Production Forecast, 1995 to 2002



Source: Dataquest (September 1998)

Table 2-1
Worldwide and EMEA GSM Cellular Handset Production Forecast, 1995 to 2002 (Thousands of Units)

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
EMEA Production	12,200	25,000	54,000	80,000	100,000	122,000	137,000	148,000	22.3
Non-EMEA Production	0	500	2,900	5,700	10,500	17,675	29,050	46,750	74.4
Worldwide Production	12,200	25,500	56,900	85,700	110,500	139,675	166,050	194,750	27.9

Source: Dataquest (November 1998)

Table 2-2
EMEA Digital Cellular Handset Factory ASP and Revenue Forecast, 1995 to 2002

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
GSM Handset Production (Units K)	12,200	25,000	54,000	80,000	100,000	122,000	137,000	148,000	22.3
Factory ASP ($)	420	350	280	232	193	170	150	140	-12.9
Factory Revenue ($M)	1,281	8,750	15,120	18,560	19,300	20,740	20,550	20,720	6.5

Source: Dataquest (September 1998)

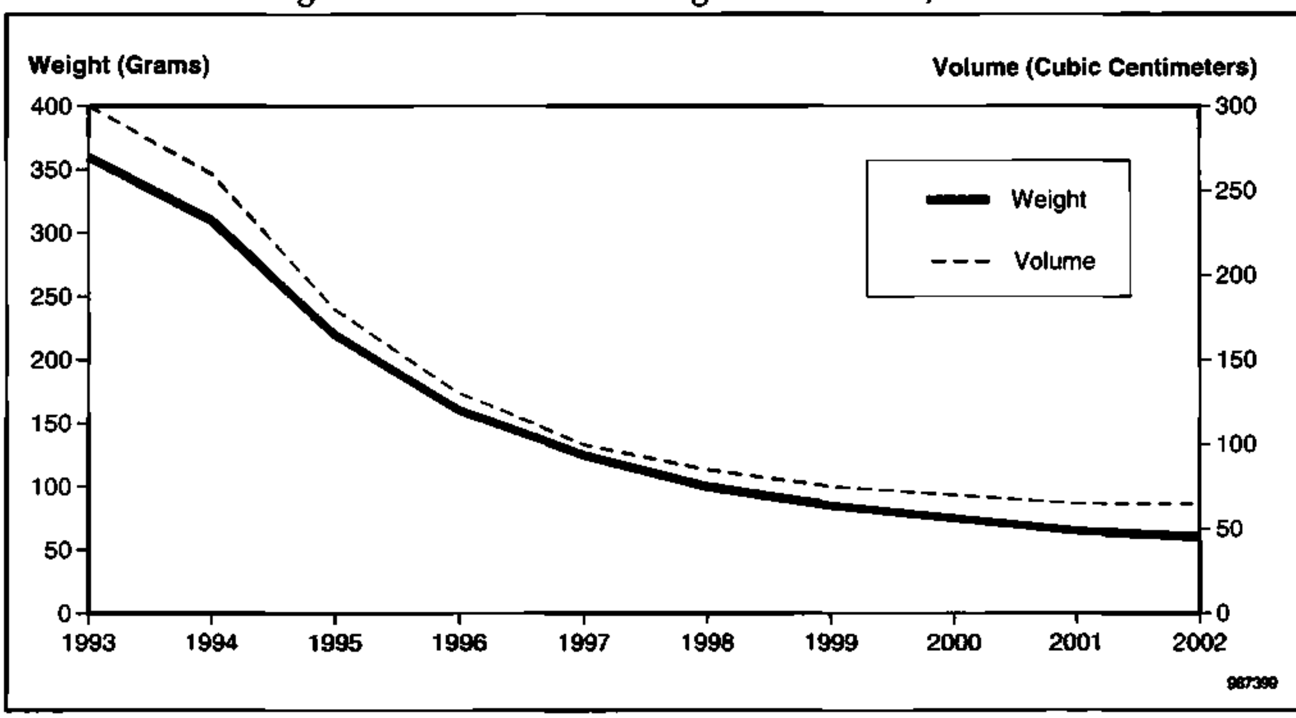
Chapter 3
Product Developments and Trends

Component integration continues in both active and passive components. The weight and volume savings that it generates can be used as follows:

- To manufacture smaller telephones
- To add bulky or heavy components that provide unique capabilities

The main driver for handset OEMs has been to reduce weight and volume, as shown in Figure 3-1; now that these parameters are reaching an ideal, attention is being turned to other areas. The main contributor to weight and volume reduction has been semiconductor component integration. This semiconductor component integration usually has an associated reduced operating voltage, which helps to reduce the overall power consumption and, in turn, the number of battery cells and cell size (capacity).

Figure 3-1
EMEA Trends in Digital Cellular Handset Weight and Volume, 1993 to 2002



Source: Dataquest (September 1998)

It is the reduction in power consumption and hence the reduced battery requirement that have provided the biggest reduction in weight. During the 1993 to 2002 period, battery technology has been improving, giving better gravimetric and volumetric efficiencies as handsets have moved from nickel cadmium (NiCad), to nickel metal hydride (NiMH) to lithium-ion batteries. This improvement in semiconductor technology and battery technology has driven down the operating voltage in mobile phones over the past few years and is expected to continue doing so, as follows:

- 1995: 5.0V
- 1997: 3.0V
- 1999: 1.8V

Product Segmentation Trends

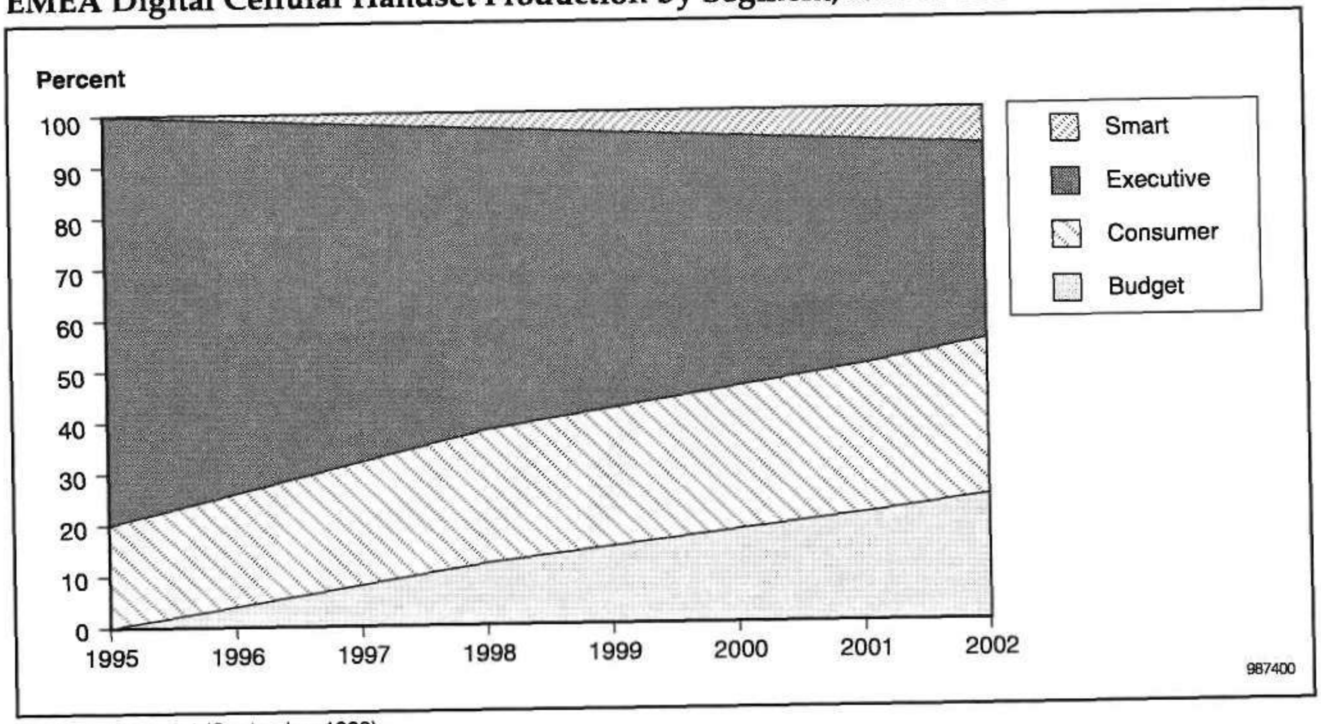
New GSM products are now driven by end-market segments, as vendors offer differentiated products to meet market demand. The following are the four key segments:

- Budget
- Consumer
- Executive
- Smart

OEMs are no longer expected to have just a GSM phone; it will be a phone designed to a meet a specific market segment. The phone will have the style, features, functions and price to appeal to a specific user group. Figure 3-2 shows the percentage of digital cellular handset production in the EMEA region by market segment. Although in the main, OEMs design handsets specifically for each of these four segments, often in this fast-moving market, phones designed for the higher-end segments—executive and smart—migrate down to the budget segment as they come to the end of their life cycle.

The development time, cost, and resources required to develop the technology for each successive handset model means that, in practice, OEMs develop a single technology platform, which they package and market for each market segment. This has implications for semiconductor vendors as there is little cost difference between using a common technology platform for a high-end executive handset and a low-end budget phone. Therefore, OEMs will be making a return on their investment across a range of products—some with very low margins but high volume shipments, others with very high margins but low volume shipments, but all with the same core semiconductor content.

Figure 3-2
EMEA Digital Cellular Handset Production by Segment, 1995 to 2002



Source: Dataquest (September 1998)

Multimode and Multiband Technology

The following three new notable aspects to digital cellular phones will emerge in the next few years:

- Internet access
- Smart phones
- Multimode and multiband handsets

Since the early 1990s, when GSM was introduced, many skeptical industry experts have been surprised by its seemingly astronomic growth rate and its dominance as a standard worldwide.

One of the first derivatives of the 900-MHz GSM (GSM900) standard was GSM1800, which built on the protocol, air interface, and network architecture of GSM but increased the frequency band used to 1800 MHz. This microcellular approach provides for much higher levels of subscribers or user density per cell, but requires smaller cells. These small cells are needed because of the poorer propagation characteristics of higher-frequency transmissions. So, for a given area of coverage, more base stations are required, but they can support a significantly increased subscriber density.

GSM1800 networks are used by many personal communications network operators, usually in urban areas with high population densities. It has been acknowledged that both systems—GSM900 and GSM1800—have their merits, and the opportunity has now been created for handsets that can operate on both systems. Handsets that can work in both of these bands have been labeled "dual band." Handsets that can also operate in other bands, such as the GSM derivative GSM1900 in the United States, we have defined as "multiband." This report will use the term multiband to refer to all digital cellular handsets that operate in more than one band.

The alternative to multiband operation that is also receiving much attention is "multimode" operation. Unlike multiband handsets that have a common protocol, air interface, and network architecture, multimode handsets support more than one type of protocol and air interface. The two modes under consideration in EMEA are digital cellular and digital cordless, specifically GSM900/DECT or GSM1800/DECT, where DECT is the Digital Enhanced Cordless Telephony standard.

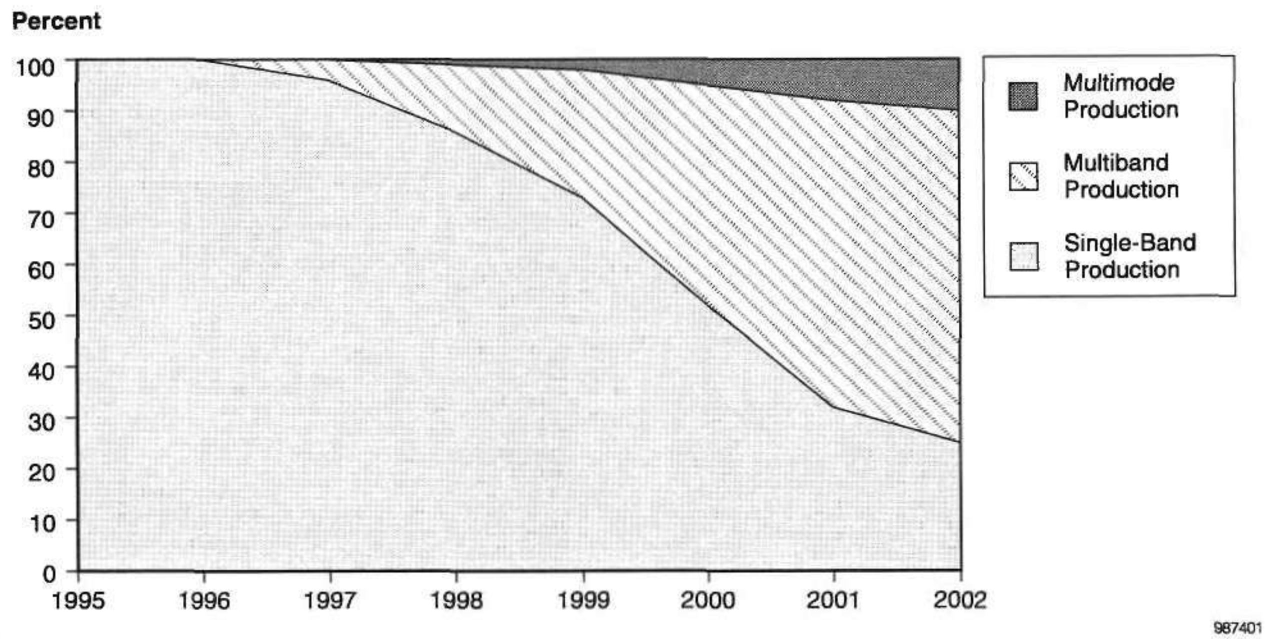
There is a strong bias at present toward multiband handsets, driven by the differing requirements of the two types of operator, GSM900 and GSM1800. GSM1800 operators want to offer international roaming onto GSM900 networks, so they need a multiband handset that can "band switch" from GSM1800 to GSM900 and vice versa when the handset is switched on in a country outside the home network. Alternatively, GSM900 operators in some countries are being offered additional spectrum in the 1800-MHz band, which will be utilized to offer cost-effective additional coverage in urban areas. This type of multiband operation is subtly different; the ideal is to have "band-aware" handsets that can switch midcall from GSM900 to GSM1800 infrastructure. Band-aware handsets are more difficult to implement, but are mainly a software issue rather than a hardware one.

Multimode phones are at the early stages of market introduction. In 1998, British Telecommunications (BT) will launch a service called BT One-phone, a combined GSM900 and DECT handset supplied by Ericsson. The multimode system is also expected to be introduced in Sweden in 1999. The business model for single-business cellular operators is not clear with this technology, but for fixed telecommunications operators that can form alliances with cellular operators, it provides a compelling solution for consumer and business users alike: one phone and one number, whatever the location—home, office, or mobile.

Dataquest is less optimistic about the prospects for multimode handsets, as we expect cellular operators to compete aggressively against DECT in its standalone form, especially in the wireless PBX and Telepoint applications. Operators are unwilling to specify to OEMs that they require multimode handsets, as there is no obvious mechanism to recover any subsidy from DECT-based calls, which are usually made via the Public Switched Telephone Network (PSTN).

Figure 3-3 shows that multimode handsets are expected to account for nearly 10 percent of digital cellular handset production by 2002, or nearly 15 million units. By 2002, more than 50 percent of handsets produced in the EMEA region will be multiband. Over the same period, we expect a more rapid change to multiband handsets for the European market. This is masked because Europe is a production center for other regions where we do not expect to see multiband adopted so quickly.

Figure 3-3
EMEA Digital Cellular Handset Production by Technology, 1995 to 2002



Source: Dataquest (September 1998)

A new trend in the market is prepaid subscriber identification module (SIM) cards that could tip the scale in favor of multimode handsets. This relatively new direction for the cellular operator benefits both operator and subscriber. A new subscriber to a network buys just a SIM card usually for a 12-month period, sometimes paying up front, for line rental and a certain value of calls per month. Therefore, the operator does not have to subsidize a handset, and the subscriber is free to choose any handset they wish or to use a previously owned handset. In this type of market, informed users may want to combine the benefits of a cellular handset with those of a digital cordless phone at home or in the office.

Smart Phones

Since the landmark introduction of the Nokia 9000 smart phone at CeBIT 96, there has been a resounding silence from other OEMs in this segment at the highest end of the market. Recent announcements by Motorola and Alcatel suggest that it is about to grow, although it is expected to remain a minor segment.

Nokia recently launched an upgraded version of the 9000: the 9110. It is mainly a repackaging exercise, but one that uses the latest GSM technology platform in the communications part of the communicator.

Motorola's development is based on in-house expertise in cellular and product developments in communications-centric organizers, where it has acquired handwriting-recognition capability. However, the product seems to be a phone first and foremost, with organizing and messaging capabilities added. Its format is certainly more appealing than the Nokia 9000, although it does not have the drawback of being a phone and a computer at the same time.

In the fall of 1997, Alcatel announced the availability of the One Touch Com, its joint development with Sharp. The product's design heritage accounts for its elegance. It is a GSM phone with an integrated organizer—and an organizer with an integrated GSM phone, such is the close integration of the two capabilities. Care has been taken to ensure that the capabilities of each are maximized, and Sharp's influence is clear in avoiding making this a GSM phone with added organizer. The One Touch Com is intended as a PC companion, allowing the phone to be "docked" with the office PC wirelessly, via an integrated infrared port (compliant with IrDA) or desktop docking station. This allows the user to use the One Touch Com as an extension of the office computer and software applications and to synchronize data on two systems. It also offers notification and access to Internet and corporate e-mail services and, at the touch of an icon, switches from portrait to landscape for easy viewing of text messages.

The One Touch Com is comparable in size and weight with phones of 1996 in the 200 g class, but that is where the similarity ends. It has no keyboard—just two buttons, to start a call and to end a call. Other functions are on a touch- and context-sensitive virtual LCD keyboard, where fingers can be used just like on a real keyboard.

Other handset OEMs are conspicuous by their absence from this segment. Ericsson has taken an alternative approach by launching an Ericsson-branded handheld PC with easy connection to a range of Ericsson digital cellular handsets. Ericsson has also been a key player in pushing the idea of IrDA connectivity from phone to phone and phone to PC/PDA. It seems clear from this trend that, in the short term, handsets will offer limited wireless connectivity using infrared links.

A new technology—Bluetooth—has recently been announced that could turn this debate between integrated or separate phones/PDAs on its head. Bluetooth uses a short-range radio link. The protocol enables the exchange of information between many devices including mobile phones, notebook PCs, handheld PCs, and associated peripherals. The radio will operate on the globally available 2.45-GHz ISM "free band." This means that there will be no hindrance to international travelers using Bluetooth-enabled equipment anywhere in the world. Unlike infrared, which has been introduced on many PCs and some mobile phones, Bluetooth does not require line of sight for connection and can therefore operate when devices are in pockets, briefcases, and so on.

The baseband protocol is a combination of circuit and packet switching, making it suitable for both voice and data. Each voice channel supports a 64-Kbps synchronous (voice) link. The asynchronous channel can support an asymmetric link of up to 721 Kbps in either direction, while permitting 57.6 Kbps in the return direction—all in all, fast enough to cope with the vast majority of proposed data rates over cellular. The nominal link range is 10cm to 10m, but can be extended to more than 100m by increasing the transmit power.

Users of mobile communications have been crying out for industry-standard connectors for years. The industry, though, steadfastly refused to heed these cries, and often for good reasons. It claimed that enforced use of one particular type of connector would variously inhibit design freedom, limit benefits of miniaturization, reduce possible competitive advantages, and so on. However, Bluetooth goes beyond simply providing a universal connector for mobile communications to opening up an environment in which all devices can be connected effortlessly, even unconsciously.

There has been much debate as to the relative benefits of communicator devices, such as the Nokia 9000, that combine many functions in a single product, versus distributed devices where the mobile phone is one component along with a separate handheld PDA. Bluetooth substantially strengthens the argument for the distributed devices concept—all wirelessly connected in a so-called personal area network. Indeed, the fact that Ericsson has not launched a communicator product suggests that it may already have determined a product strategy based on this concept.

Internet Access

GSM handsets already include as standard a simple messaging protocol called short messaging service (SMS). This allows for 160-character messages to be sent or received by a handset. Messages can be joined together up to four at a time to create larger messages. Specialist service providers can deliver e-mail via the SMS system.

In 1997, a number of handset manufacturers announced handsets with Internet access, using the data capabilities (usually 9.6 Kbps) of GSM. This Internet access is to the handset rather than to a connected notebook computer. The main challenge is to prepare information so that it can be used easily on a mobile phone display, which is rarely more than three lines of 12 characters. Internet access is being implemented in one of two methods, which are as follows:

- Nokia has developed a specialist Web server called Nokia Netgate that allows access to the World Wide Web and adapts the information for presentation on the handset using dedicated software called Web Viewer. This requires each cellular operator to have a Nokia Netgate as part of the infrastructure.
- U.S. start-up company Unwired Planet's solution is to push responsibility for making Internet messages suitable for a mobile phone back to the original Web site. Web sites will convert or prepare information from the normal HTML format to handheld device markup language (HDML). These HDML pages are requested and received using the normal SMS service of an operator. The information is then decoded and presented on the handset display, using software in each handset.

Chapter 4
OEM Competitive Analysis and Semiconductor Spending

Dataquest's EMEA digital cellular handset production estimates for 1997, shown in Table 4-1, show that the top 10 manufacturers grew their output by 115 percent over 1996. The average growth for all manufacturers is estimated to have been 116 percent. In 1997, the top 10 manufacturers lost market share to the smaller players, whose growth rates typically exceeded the market average.

The top 10 OEMs can be broken down into three distinct groups: four companies that grew at nearly the industry average growth rate; two companies that grew well below the industry growth rate; and four companies that far exceeded the industry growth rate. In 1997, one company was affected by acquisition, when Bosch bought Dancall.

The four companies that achieved impressive growth in 1997 over 1996 were Philips (214 percent), Alcatel (155 percent), NEC (300 percent), and Dancall (180 percent). Four companies grew at about the industry growth rate: Nokia (108 percent), Ericsson (108 percent), Motorola (115 percent), and Panasonic (100 percent). Two companies grew below the industry growth rate: Siemens (83 percent) and AEG/Matra (86 percent). The companies listed under "others" include Mitsubishi, Sagem, Hagenuk, Ascom, Sony, Benefon, Telital, and Aselsan; together these also showed impressive growth rates averaging 133 percent.

Table 4-1
EMEA Digital Cellular Handset Production Share Rankings by OEM, 1996 and 1997 (Thousands of Units)

Final 1996 Rank	Final 1997 Rank	OEM	Final 1996 Production	Final 1997 Production	Growth: 1997 over 1996 (%)
1	1	Nokia	6,500	13,500	108
2	2	Ericsson	6,000	12,500	108
3	3	Motorola	4,800	10,300	115
4	4	Siemens	2,350	4,300	83
7	5	Philips	1,050	3,300	214
5	6	Alcatel	1,100	2,800	155
6	7	Panasonic	1,100	2,200	100
8	8	AEG/Matra	700	1,300	86
9	9	NEC	250	1,000	300
11	10	Dancall (Bosch)	250	700	180
		Top 10 Manufacturers	24,100	51,900	115
		Others	900	2,100	133
		Total	**25,000**	**54,000**	**116**

Source: Dataquest (September 1998)

The top four companies—Nokia, Ericsson, Motorola, and Siemens—hold 75 percent of production, and the top 10 companies control 96 percent of production. This market dominance by such a small number of players makes it unlikely that any of the existing smaller or new players will be in a position to threaten their domination within the forecast period.

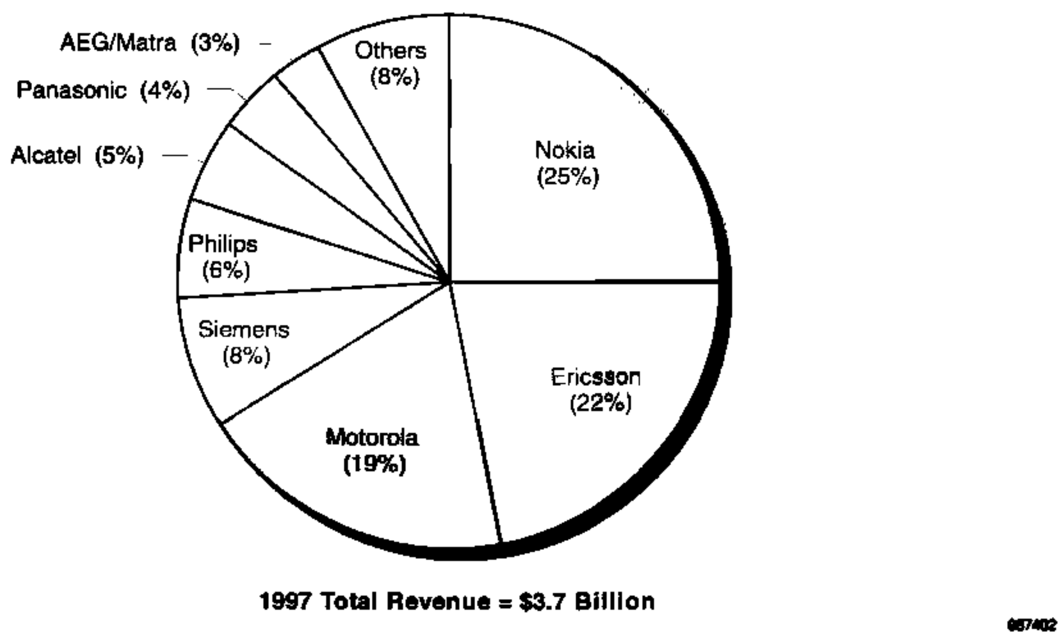
So far, all OEMs have experienced increased production year on year. In 1998, the effects of the Asian financial crisis are expected to impact the fast-growing market there—a major export region for EMEA production. This situation will be eased slightly by the fact that China, the single largest country in the world for GSM, has been little affected by the Asian financial crisis. Some OEMs in 1998 will experience new challenges and low production growth, as they compete to utilize production capacity that has ramped up over the past few years.

Not all the players are expected to survive. The difference in competitive advantage driven by volume is so great between the leaders and the third-tier players that some companies may need to exit the market. Some are probably staying only to maintain a presence in anticipation of the next generation of cellular technology, where they may be able to start on a more equal basis.

OEM Semiconductor Opportunity

Figure 4-1 shows the estimated 1997 semiconductor spending of each of the major players in the EMEA region in percentage terms.

Figure 4-1
EMEA Digital Cellular Semiconductor Market Revenue by OEM, 1997



Source: Dataquest (September 1998)

Dataquest estimates that Nokia was the biggest consumer of semiconductors in 1997, with 25 percent of the estimated market of $3.7 billion. Nokia's semiconductor spending for digital cellular handsets last year represented almost 3 percent of the total EMEA semiconductor market of $30.05 billion.

Table 4-2 shows Dataquest's estimates for average semiconductor content in digital cellular handsets by OEM. The major players have a cost benefit that is mainly driven by volume. They are also key users of ASIC technology, which, although it has high development costs, gives a time-to-market advantage and lower pricing of semiconductor components.

Increasingly, the smaller players are turning to chipset vendors. The semiconductor cost differential between the larger players and the third-tier players will place chipset vendors under increasing pressure to reduce prices to the third-tier players—otherwise their customers will be unable to compete.

Table 4-2
EMEA Digital Cellular Semiconductor Spending by OEM, 1997

OEM	Production Units (K)	Semiconductor Content ($)	1997 Semiconductor Spending ($M)
Nokia	13,500	66	891
Ericsson	12,500	67	838
Motorola	10,300	69	711
Siemens	4,300	73	314
Philips	3,300	64	211
Alcatel	2,800	72	202
Panasonic	2,200	74	163
AEG/Matra	1,300	75	98
Others	3,800	79	300
Total	**54,000**	**69**	**3,726**

Source: Dataquest (September 1998)

Chapter 5
European GSM Cellular Semiconductor Market

Semiconductor Opportunity

The EMEA semiconductor market for digital cellular handsets (shown in Table 5-1) was more than $3.7 billion in 1997 and is expected to grow to more than $5.3 billion by 2002, with a compound annual growth rate (CAGR) of 7.4 percent over the period. The market was driven by substantial growth in unit production up to 1997, but now growth is expected to slow. The value of semiconductor content will continue its decline with a negative CAGR of 12.2 percent over the forecast period. The effect of this erosion is to slow the growth rate in the overall value of the market; it is driven by the OEMs' requirement for lower and lower factory selling prices to sustain market growth.

The average semiconductor content shown in Table 5-2 does not meet the aggressive targets set by some OEMs, which have been suggesting a $40 semiconductor target by 2000. However, the average semiconductor content does not show the effect of the increasingly segmented market discussed earlier. Table 5-2 shows the semiconductor content associated with each of the handset market segments. We expect the content of a simple voice-only GSM handset to fall to $36 by 2002. The bulk of the digital cellular market will be in the consumer and executive segments.

Table 5-1
EMEA GSM Cellular Handset Production and Average Semiconductor Market Forecast, 1995 to 2002

	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
GSM Cellular Handset Production (Units (K)	12,200	25,000	54,000	80,000	100,000	122,000	137,000	148,000	22.3
Semiconductor Content ($)	105	87	69	55	47	42	38	36	-12.2
Semiconductor Market ($M)	1,281	2,175	3,726	4,400	4,700	5,124	5,206	5,328	7.4

Source: Dataquest (September 1998)

Table 5-2
EMEA GSM Cellular Semiconductor Content Forecast by Handset Segment, 1995 to 2002 (Dollars)

Segment	1995	1996	1997	1998	1999	2000	2001	2002
Budget	85	75	59	47	40	36	33	31
Consumer	93	80	64	50	43	39	35	33
Executive	108	88	69	55	47	42	38	37
Smart	240	210	170	130	100	80	70	61
Average	105	87	69	55	47	42	38	36

Source: Dataquest (September 1998)

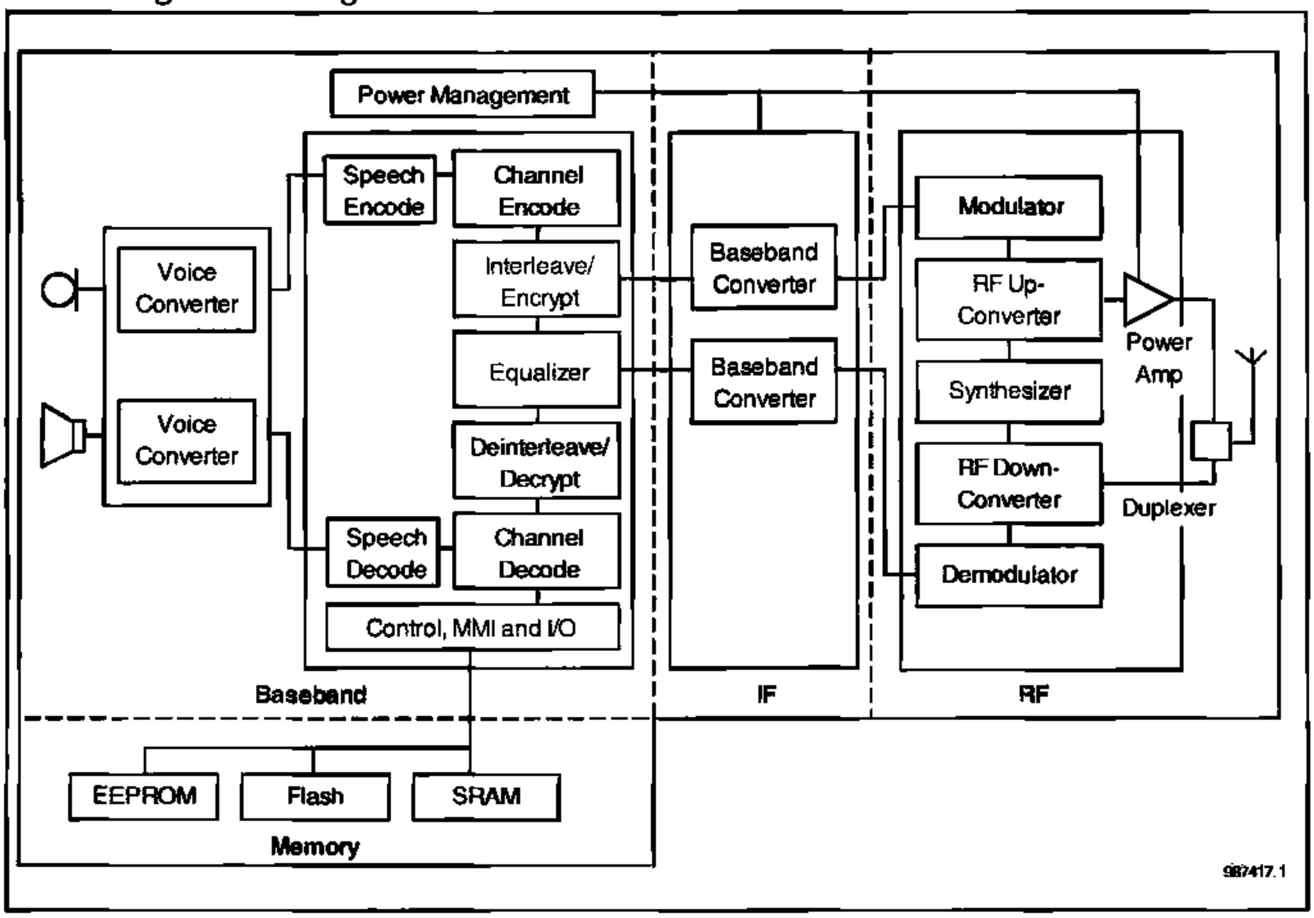
By 2002, digital cellular handsets will be very different from those of today. Simple GSM, voice-only handsets with a semiconductor content approaching $31 will be at the budget end of the market, but fortunately will not form the major part of the overall market. By then, handsets are likely to be much more data intensive; they will have Internet access and voice recognition and support ISDN data rates. Most will probably be multiband, supporting both GSM900 and GSM1800, and some may include GSM1900 to allow roaming in the United States. Some will be multimode, supporting both GSM and DECT.

Chapter 6
GSM Device and Technology Trends

Figure 6-1 shows a block diagram of a typical digital cellular phone, which comprises an RF/IF section and a baseband section. The RF/IF section handles the transmission and reception of RF signals. The baseband section processes communications signals at baseband frequencies.

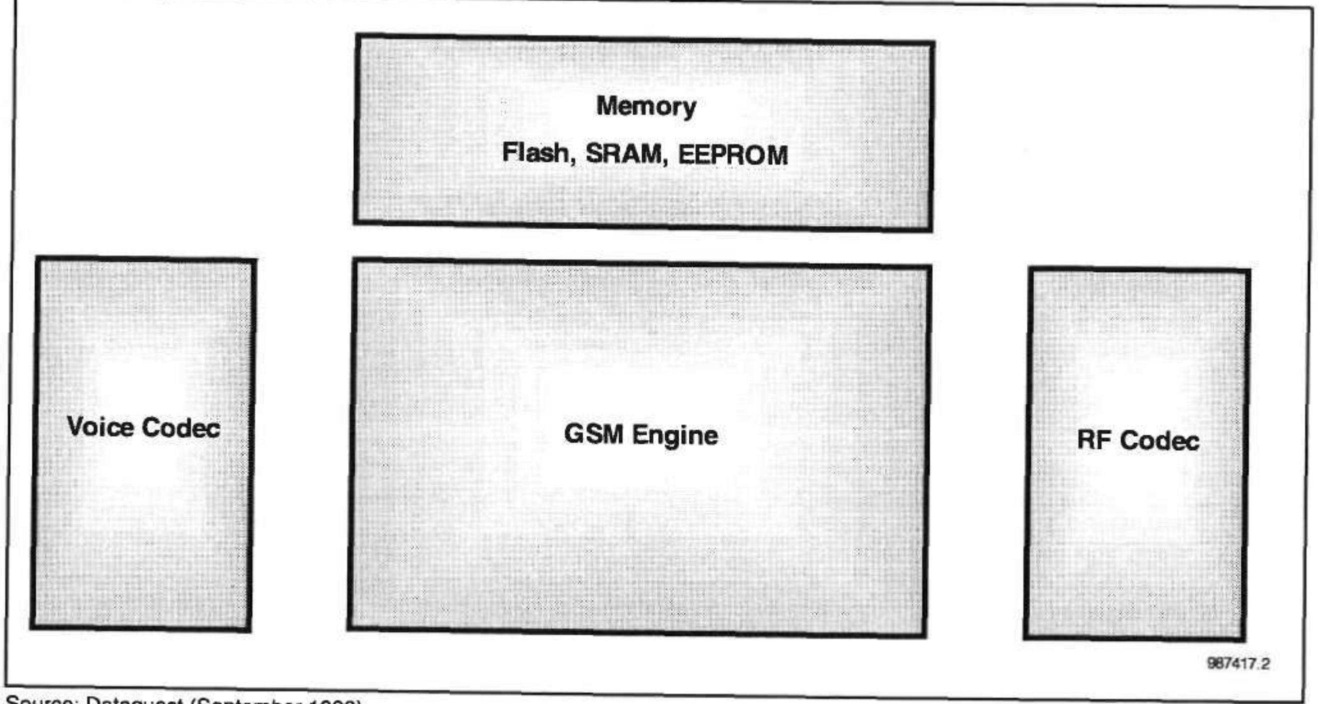
The greatest level of integration will occur in the baseband function; Figures 6-2 to 6-4 show how Dataquest expects this function to evolve up to 2002. Figure 6-3 shows that we expect to see the SRAM of a handset integrated by 2000 and the baseband to be a maximum of two devices. Figure 6-4 shows that, by 2002, we expect to see all memory technologies included on a single-chip baseband device.

Figure 6-1
Block Diagram of a Digital Cellular Handset



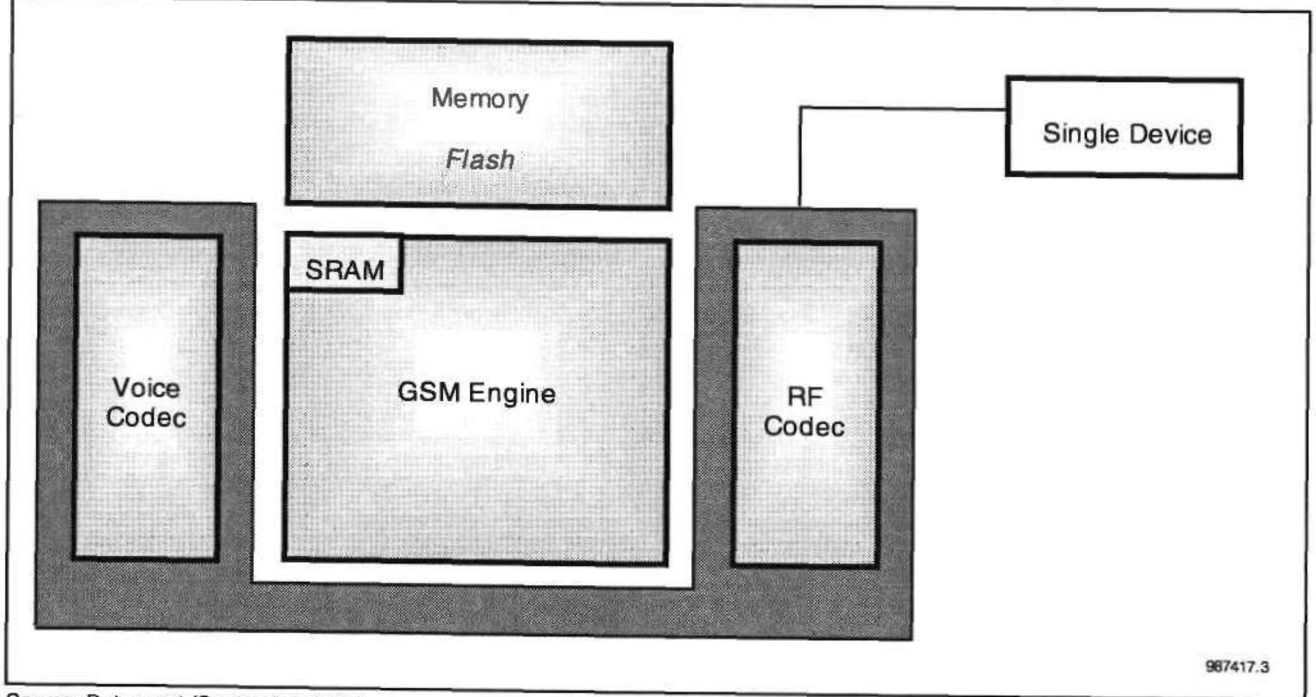
Source: Dataquest (September 1998)

Figure 6-2
EMEA Digital Cellular Handset Semiconductor Baseband Architecture, 1998



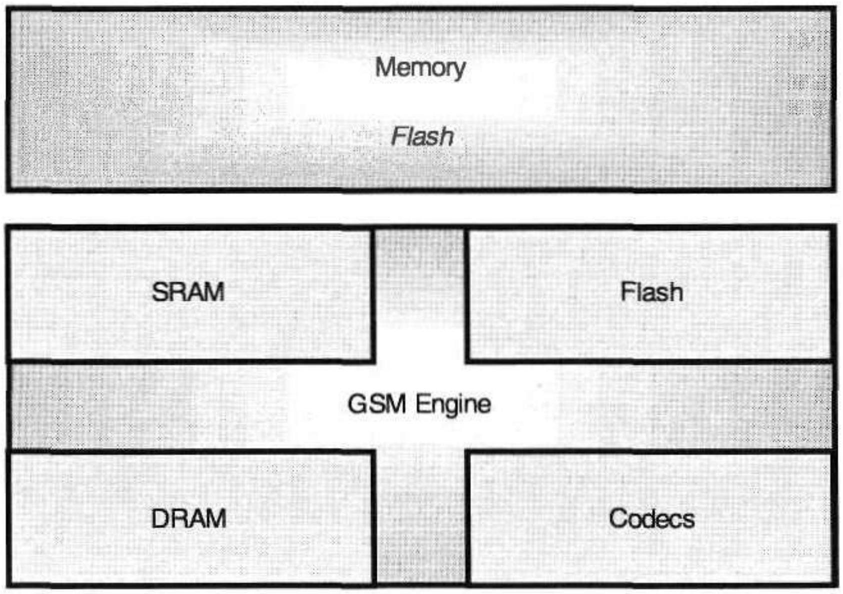
Source: Dataquest (September 1998)

Figure 6-3
EMEA Digital Cellular Handset Semiconductor Baseband Architecture, 2000



Source: Dataquest (September 1998)

Figure 6-4
EMEA Digital Cellular Handset Semiconductor Baseband Architecture, 2002



Source: Dataquest (September 1998)

System Implementation

Although the fundamental architecture of GSM terminals will remain more or less unchanged, the physical implementation of functions will change considerably. This will be seen mainly in terms of increased integration of (currently separate) system functions. GSM terminal manufacturers have been at the forefront of system-level integration (SLI) developments because of the benefits of SLI technology for this type of high-volume application.

Dataquest research among OEMs that have adopted SLI solutions shows a range of reasons for adopting the technology. The top three factors (listed in order of importance to the OEM) are as follows:

- More cost-effective system manufacturing—This factor was listed as the most important reason for adopting SLI technology. Having fewer devices in the final system means that component assembly and testing at the PCB level is considerably simplified; this assumes that appropriate design-for-test methodologies have been used in the design of the SLI devices. OEMs were able to manufacture significantly more systems with a given manufacturing plant and, in some cases, were able to delay or cancel plans to construct a new assembly operation. The cost savings to OEMs are enormous.

- Lower product cost—Systems manufacturers are able to reduce the per-unit cost of equipment that uses SLI devices; this is related to the previous point. Costing issues are difficult to assess between companies because different companies take account of different factors in their costing calculations. For example, some companies disregard product development costs and consider only component and manufacturing costs in the per-unit costs of the product. However, cost was mentioned sufficiently frequently to place it second in the overall SLI advantages.
- Lower power dissipation—Traditional system architecture involves a number of separate devices communicating via an onboard bus. The track length and associated capacitance is relatively high in such a system. When these tracks are driven at frequencies of several tens of megahertz (typical in a GSM terminal), significant power is dissipated. Where several devices are reduced onto a single chip, the resulting power reduction can be considerable.

During the 1996 to 1997 period, GSM terminals were implemented with approximately one-third of the semiconductor value in each of the ASIC, ASSP, and general-purpose standard product categories. Over the forecast period, Dataquest expects usage of general-purpose devices (mainly in the form of memory, MCUs, and PLLs) to decrease. They will be replaced by ASICs initially and by cores later on. ASSPs are likely to retain their approximate share, largely in the form of RF functions, audio CODECs, and GSM engines. GSM engine ASSPs are most likely to appeal to second-tier OEMs and new market entrants; these companies need a solution that offers fast time to market without requiring detailed system knowledge. ASSPs are also an attractive product for semiconductor vendors, as they are premium priced and can have a relatively short revenue ramp-up from the point of design-in. Market-leading OEMs are likely to continue implementing GSM engines as ASICs in which they can embed their proprietary intellectual property.

Implementation of System Functions

RF/IF Functions

RF/IF functions are implemented predominantly as ASSP devices in GSM terminals and are likely to continue as such throughout the forecast period. However, Dataquest believes that both ASSP and general-purpose standard products, such as PLLs and high-frequency transistors, will lose share to ASIC implementations. Increasingly, PLLs and VCOs will be seen as cores for use in ASIC implementations. At the same time, CMOS gradually will displace some of the BiCMOS, bipolar, and GaAs typically found in this part of the system.

Baseband Functions

Approximately 30 percent of baseband functions are implemented as general-purpose standard products—mostly in the form of MCUs and memory. However, standalone MCUs are disappearing rapidly, becoming cores in GSM engine devices. Memory devices will also migrate gradually into the engine to a point where, by 2002, 30 percent of SRAM and 20 percent of flash memory will be cores.

Most GSM engines will remain as ASIC devices (including both ASIC and core revenue), while an increasing share will be taken by ASSPs—growing from 20 percent to 25 percent of the total over the forecast period. At the end of the forecast period, the GSM engine will be a highly complex device incorporating not only MCU and memory, but also the audio CODEC. This will probably contain a DSP core, adding to the complexity and size of this subsystem.

Power Management

Power management is becoming an increasingly critical system element in GSM terminals. Driven by the need to maximize battery life, this subsystem provides power to each system function and controls battery charging. Its value will grow from 2.2 percent to 4.2 percent of semiconductor content over the forecast period. Most power management functions are implemented as ASSP devices, but this will change as ASIC cores become the dominant form of implementation. By 2002, the dedicated power management ASIC will cease to exist as the function merges with other devices, notably audio CODECs and GSM engines. Over this period, BiCMOS—the dominant technology for power management—will be challenged hard by CMOS, facilitating higher levels of integration.

Chapter 7
Dataquest Perspective

Until now, the GSM handset market has been dominated by three major players: Nokia, Ericsson, and Motorola. These companies have significant capabilities in cellular handset design and were fundamental in the development of the GSM standard within the standards body, ETSI. They have utilized this intellectual property to help them gain market share and to implement their know-how in silicon using ASICs. For some second- and third-tier players, the difficulty in gaining this wealth of intellectual property has been solved by using chipsets and software (protocol stacks) from merchant suppliers. A number of chipset vendors can now offer a complete solution: chipset, reference design, and tested and approved software.

The EMEA semiconductor market for digital cellular continues to thrive and is expected to grow to more than $5.3 billion by 2002. The market is showing the first signs of maturity as it segments to serve different user needs: budget, consumer, executive, and smart phones.

Over the next few years, semiconductor vendors will have a great opportunity to provide products and support to OEMs in the move to multiband and multimode terminals. Custom suppliers to the major handset vendors will be successful if they can continue to supply low-cost solutions with increased gate count and lower power consumption year on year. Dataquest estimates that in 1998 the semiconductor spending for a single OEM could be as much as $1 billion, which will attract some of the major market players. As no semiconductor vendor can be assured of future business based on past performance alone, the rewards are too much to resist.

The features and functions expected to be incorporated in digital cellular handsets for the EMEA market during the forecast period are expected not only to continue to provide challenges, but also to enable solutions that can be taken to other cellular markets around the world.

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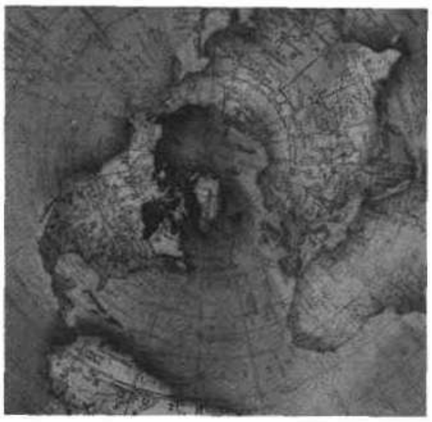

Dataquest

Semiconductors in Cellular/PCS Infrastructure

Focus Report

Program: Wireless Semiconductors and Applications - Worldwide
Product Code: WSAM-WW-FR-9801
Publication Date: October 19, 1998
Filing: Reports

Semiconductors in Cellular/PCS Infrastructure

Focus Report

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Chapter 1
Executive Summary

The cellular/PCS infrastructure industry represents a $2 billion semiconductor opportunity, increasing to more than $3 billion by 2002. The industry supports 125 million subscribers in 1997, growing to more than 500 million by 2002.

Key trends that are changing the industry include the following:

- Continuous cost improvements to existing networks that make it possible to reduce service charges and increase coverage by adding new equipment
- Provision of more complete coverage by filling in dead spots in the service areas
- Improved quality of service in terms of speech quality and access to the network
- Enhanced system abilities to adapt to traffic conditions to provide quality service at prices competitive with wireline telephone service
- Over the long term, development of a global network that can be accessed by anyone at any time and that can provide multimedia-services to customers of wireless communications services

The industry is moving toward standardization; however, the transition is not a smooth one. Most regions are using several standards, with the Americas, especially North America, being the most open in terms of the choices of standards available to operators. As a result, while Global System for Mobile Communications (GSM) is becoming the recognized worldwide standard, a number of standards will be available for the foreseeable future. Semiconductor suppliers can look forward to growing demand for their products in a variety of standards during the next five years.

The use of microcells or picocells for increasing capacity and building applications is proceeding at a slower pace than many have expected. Because of the relatively high cost of adding micro- or picocells, they are being used only in areas where the need for added capacity is significant and critical. Dataquest estimates that less than 5 percent of base stations shipped in 1997 were micro- or picocells. This number is expected to increase to 10 to 15 percent of base station shipments by 2000.

Wireless systems use the widest spectrum of semiconductor devices of any application, from highly specialized radio frequency (RF) and digital signal processing (DSP) devices to general-purpose discrete and linear devices. No one company supplies the entire range of products required for wireless infrastructure equipment. As a result, most semiconductor companies that actively support the wireless infrastructure market focus on products for a few subsystems within the base station equipment. Only a few semiconductor companies with products that generally fit wireless infrastructure applications make an effort to develop this market.

New technologies that are becoming important in wireless infrastructure include the following:

- High-performance DSP products that reduce cost and ultimately become critical for software-defined radios, expected to emerge after 2000
- High-performance data conversion products capable of sampling intermediate frequency (IF) and, ultimately, RF signals for creating multicarrier transceivers and digital radios
- High-speed digital up- and down-converters for the same applications
- Smart antennas that make it possible to adapt the base station to traffic patterns, providing increased capacity through digital signal processing

Third-generation (3G) wireless promises someday to provide enhanced system performance and universal coverage. While the governing agencies and the major players are determining the standards for 3G, the technology will be applied to the existing infrastructure to increase capacity and improve service. As the rollout progresses, companies will begin offering products and services that will identify the applications that will drive 3G services and, ultimately, the final rollout of 3G networks and services.

Chapter 2
Introduction

Dataquest estimates that 125 million people used cellular/PCS services in 1997. This number is projected to increase to more than 500 million by 2002.

This report analyzes trends in semiconductor consumption in cellular and PCS base station equipment. This market is forecast to grow at a compound rate of 8.7 percent per year between 1997 and 2002, supporting a semiconductor growth rate of 10.4 percent per year. Table 1-1 shows Dataquest's forecast for cellular/PCS infrastructure equipment revenue and related infrastructure revenue.

Table 1-1
Cellular/PCS Infrastructure Equipment and Semiconductor Revenue

	1997	1998	1999	2000	2001	2002
Equipment Revenue ($B)	26.7	28.9	31.8	35.0	37.6	40.5
Annual Growth (%)	-	4.7	10	10	7.4	7.7
Semiconductor Revenue ($M)	1,952	2,212	2,385	2,692	2,930	3,196
Annual Growth (%)	-	13.3	7.8	12.8	8.8	9.1

Source: Dataquest (August 1998)

Technology and market shifts will challenge current leaders and provide opportunities for new players to improve their competitive positions in this dynamic market. Key trends that are changing the industry include the following:

- Continuous cost improvements to existing networks that make it possible to reduce service charges and increase coverage by adding new equipment
- Provision of more complete coverage by filling in dead spots in the service areas
- Improved quality of service in terms of speech quality and access to the network
- Enhanced system capabilities to adapt to traffic conditions to provide quality service at prices competitive with wireline telephone service
- Over the long term, development of a global network that can be accessed by anyone at any time and that can provide multimedia-services to customers of wireless communications services

These objectives will be met by continued improvements in semiconductor technology used in the design of base transceiver systems (BTS) and base station controllers (BSC). Dataquest believes that the order of priority for upgrading the wireless network will be as follows:

- There will be extensive investment in increasing the quality of the current network to achieve improved coverage and voice quality.
- There will be extensive investment to lower service costs to make wireless service competitive with wireline service.

- In the medium term, operators will supply phones that provide global coverage.
- In the long term, operators will provide 3G network technology that will provide worldwide access to broadband multimedia services.

Based on these priorities, Dataquest has devised the following system trend analysis for the evolution of wireless infrastructure for the next five years and beyond. These trends provide a view into future requirements for semiconductor products and technologies in wireless infrastructure systems.

Chapter 3
Current Wireless Infrastructure Trends

The current wireless infrastructure varies for each region of the world based on the timing and objectives of the governing agencies in each region. The following discussion provides a top-level summary of regional network standards and future directions.

Regional Trends

North America

North America has had the mixed benefit of building a successful analog network that provided wide area coverage of the United States and Canada in the 1980s. This network was significantly superior to the multi-standard European structure with different standards (NMT and TACS) serving different countries, making the use of the same phone by cross-European travelers impossible. The Federal Communications Commission (FCC) adopted a competitive model for the rollout of digital technology with the intent of creating a more competitive environment that would force prices down and increase usage of wireless communications services. In its Third Annual Commercial Mobile Radio Services (CMRS) Report, released in June 1998, the FCC concluded that its strategy has resulted in an increase in the number of service providers to three or more in basic trading areas covering nearly 220 million people in an essentially unregulated environment. The report indicates that this competition has resulted in a wide variety of services being offered to consumers at increasingly lower price points. These services include voice mail, paging, messaging, and data communications. The report also points out that the competition is concentrated around major population areas where more licenses have been purchased. This outcome should not be too surprising, as service providers have focused on the markets with the greatest revenue potential (highest populations) first.

The result of this strategy has been that wireless services in North America currently consist of digital services in more populated areas backed up by analog service to provide nationwide coverage (or at least the perception of nationwide coverage). Customers have the option of selecting D-AMPS, CDMA 1900 PCS, or GSM 1900 PCS, backed up by the analog network where digital service is not available. The slower-than-expected rollout of personal communications services (PCS) has left many PCS licensees with insufficient resources to build out their networks. The larger PCS service providers, such as Sprint and AT&T, are forming alliances with selected smaller providers that allow the partners to market their services under the AT&T or Sprint PCS brands and receive financial help in installing the infrastructure from their wealthier partners. As a result, the majors are able to provide coverage in attractive areas without having to buy the licenses. In return, the smaller partners are able to provide services and begin generating revenue. The selection of services offered is up to the service providers, with very little regulation by the FCC.

Europe, Africa, and the Middle East

The European, African, and Middle Eastern markets are quickly adopting the GSM standards for wireless communications services. For this reason, the rollout is much more orderly than the free-market chaos of North America. One result is that GSM is rapidly becoming the world standard outside of the Americas, serving the largest number of subscribers and growing. In contrast to the situation in the Americas, where addition of new frequencies has been treated in a manner tending to expand competition, the introduction of GSM 1800 PCS services has been structured to extend the capacity of the GSM network. Dual-band GSM phones are able to hand off calls between the bands seamlessly, enabling service providers to expand capacity available to their customers. Outside of Western Europe, code division multiple access (CDMA) is being considered as an alternative to GSM-based systems.

The significant challenge to GSM is CDMA, championed by QUALCOMM and the other major U.S. infrastructure suppliers (Motorola, Lucent, and Nortel) and being adopted by European infrastructure suppliers, except for Ericsson and Nokia. The extent to which CDMA will penetrate these markets is yet to be determined. Wide-band CDMA is being considered for the 3G network, which is intended to provide broadband services capable of handling multimedia, Internet, and video-conferencing services.

Asia/Pacific

GSM has established itself in Asia. However, each country in Asia has selected a different set of standards for its services; for example:

- Korea has selected CDMA technology for its digital cellular service.
- Hong Kong has almost as great a variety of standards in place as the Americas.
- Malaysia has selected GSM for the most part.
- The Philippines has standardized on CDMA, but continues to use the existing analog network.
- Thailand has settled on GSM and CDMA.
- The most important country in Asia, China, has GSM and CDMA networks, although GSM appears to be emerging as its digital standard. China also will continue to make widespread use of its analog network.

Japan

Japan's PDC network has grown faster than any other cellular network. As a result, its network is rapidly approaching its capacity limitations, and the country is rapidly undertaking its 3G infrastructure rollout and pushing the European universal mobile telecommunications (UMTS) standard, and apparently will be the first to adopt the UMTS standard. Although Japan has been behind in its wireless programs, its 3G rollout could place it at the leading edge of wireless technology as technology-hungry Japanese users will have the opportunity to quickly adopt 3G multimedia service offerings made possible by the broadband capabilities of the 3G technology. Because of this push, Japan plans to be investing in new infrastructure starting in 2000 and beyond. The important question for Japan is whether it will have the financial wherewithal to make the investments required to install the 3G infrastructure in the target time frame, given the current state of its economy.

Meanwhile two CDMA networks have been deployed in Japan. These networks will provide additional capacity that is needed to supply the growing Japanese subscriber base. The presence of these new networks raises the question of the need for a major investment in new technology at this time.

Equipment Trends

The network development path for wireless infrastructure is driven by the following priorities:

- Provide coverage in the areas where service is to be offered
- Provide quality connections for subscribers throughout the network
- Add capacity to handle the traffic loads in high-usage areas
- Provide services that result in expanded usage of the network

During the first phase of the rollout of a network, large macrocells are installed to provide maximum coverage in the shortest possible time. When this installation is completed, there are still areas where coverage is not adequate and quality is poor. At this stage, network providers take steps to improve the quality of coverage. A number of techniques are used to accomplish this objective, including the following:

- Adding macrocells to enhance coverage
  - First by sectorization of existing cells
  - Then by cell-splitting or replacing one macrocell by several smaller macrocells
- Upgrading cell sites to improve performance
  - By adding new equipment often supplied by a third party, such as repeaters or high-performance front-end systems
  - By upgrading base station antennas
  - By adding software enhancements
- Adding microcells to provide additional coverage in low-performance areas

Once adequate quality of service has been achieved, operators will address the need to provide additional capacity in high-traffic areas, usually in cities around freeways heavily traveled by mobile users during high-traffic periods. Operators accomplish this end in several ways. The first is to add transceivers to existing macrocells. This is the least expensive way to increase capacity, as it requires no additional spending on new cell sites and avoids the challenges that accompany finding and gaining approval for new sites. This is the common practice in CDMA installations, where adding one transceiver adds substantial capacity to the base station capacity. Once the capacity of macrocells is reached or the macrocells no longer accomplish the operator's objectives, two options are available. One option is to provide new frequency bands for additional services, as has been done with GSM1800 in those parts of the world where GSM has become the established standard. The other option is to create layered implementations of microcells that reuse the existing frequencies within macrocells to provide additional capacity. Setting up new frequencies requires auctioning of new licenses and creating a complete new infrastructure, including macrocell sites, whereas microcells can be installed within existing licenses. The approval process is generally easier with microcells as they are less invasive than macrocells. Regulating bodies and operators in the United States and Europe seem to prefer creating new frequency allocations to installing microcells, as Dataquest estimates that less than 5 percent of cell sites worldwide are microcells. This number is expected to expand to 10 to 15 percent by the year 2000. This expansion would equate to about 7,500 microcells being shipped in 1997 and 20,000 to 30,000 being shipped yearly by 2000. Motorola claims to have shipped 2,500 microcells as of the end of 1997. Two of Motorola's significant installations are in Paris, where the company has installed 600 microcells, with the intention to have 1,000 installed by the end of 1998, and the Belgacom Towers in Belgium. The Belgacom Towers project involved equipping two 30-story towers, an eight-story pavilion, and a three-story parking lot with wireless infrastructure that provides essentially complete coverage. The installation required eight two-transceiver picocells connected by fiber-optic cables with antennas on each floor of the building. The system designers had to deal with widely varying signal power as a function of whether people had their office doors open or closed and other variables. The completed system provides greater than 95 percent coverage with effective handoff to the cellular network that provides service outside of the building.

Infrastructure equipment providers have had microcells and picocells in their product portfolios for several years. The usage of microcells and picocells is rolling out more slowly than might have originally been expected. With the initiation of wireless PCS licenses in the 1,800- and 1,900-MHz bands, the use of these licenses seems to be the near-term solution to the requirement for additional capacity in the network. Operators are in the process of offering dual-band phones that can seamlessly hand off from one band to the other, depending on the capacity requirements in the area.

As a means of improving coverage in their areas, operators are adopting a number of techniques that require new or different base station equipment. Examples include the following:

- Multisector base station strategies that subdivide macrocells into smaller coverage areas to permit handling of heavier traffic loads
- Cell-splitting strategies where one macrocell is divided into several smaller cells, requiring the establishment of several new cell sites to replace the original site
- Adaptive spectrum allocation by allocating channels between adjacent sectors based on traffic loads
- Addition of microcells in multitiered configurations that permit frequency reuse within cells
- Installation of repeaters, which enable operators to in effect bring the base station to the customers in dead spots
- Installation of high-performance receiver filters and low noiseamplifiers based on high-temperature superconductor technology

A brief discussion of the advantages and disadvantages of each of these options follows.

A repeater performs the same function as a microcell in a much simpler fashion by using one or two channels of a nearby base station and passing local subscribers to the base station, in effect acting as a base station extender. The base station radio still processes calls, but the base station can now provide better coverage. The disadvantage of this approach is that operators may choose to forgo this option and install microcells that provide the added coverage without being penalized by the base station capacity that is used by the repeater. This becomes a situation-dependent choice for the operator: If the operator has some available capacity, a repeater will be used; if not, a microcell will be set up. An operator could choose to use a repeater for a period of time, then install a microcell when circumstances dictate.

Receiver RF filters and low noise amplifiers based on high-temperature superconductor and cryogenic technology can enhance the performance of a macrocell substantially. This is a relatively new technique that is being qualified by a number of operators in areas requiring large-area coverage with relatively low population densities. Operators have reported that they have experienced 20 percent lower call drop rates and other improvements at a cost of about 15 percent of the base station cost. This appears to be the only hardware technology that, when added to a base station, improves the performance of the reverse channel. Companies making these products include Conductus in Sunnyvale, California; Illinois Superconductor in Chicago, Illinois; and Superconductor Technologies in Santa Barbara, California. These companies are beginning to see multiple system orders from system operators. Initial interest is in the United States; however, international interest has been growing as operators in Japan and the Asia/Pacific region have started testing systems in their networks.

Most base stations are now designed to provide three or six sector configurations. Three sector configurations are most common. Wireless operators have apparently used this strategy as the means of increasing coverage for a reasonable cost. The next step for an operator is to use adaptive spectrum allocation, which allows the base station to allocate frequencies from one cell to another when traffic demands require. This strategy requires that operators switch from single-carrier power amplifiers to multicarrier linear power amplifiers (MCLAs). An MCLA replaces several single carrier amplifiers. As a result an MCLA must operate at substantially higher power in order to amplify several carriers at one time. Doing so makes it possible for the base station to redirect a carrier from a cell that has lower traffic levels to one that has higher traffic levels. MCLAs are currently used most widely in CDMA base stations because of their inherent broadband characteristics. A broadband amplifier is required for the 1.25-MHz bandwidth of CDMA systems. MCLAs are used in Digital Advanced Mobile Phone Service (D-AMPs) applications as well, as they provide flexibility to the operators who provide dual-mode analog and digital cellular services to their subscribers as they roll out their new digital networks and support the continuing demand for analog services by limited usage subscribers. Dual-mode service has occurred primarily in North America. We expect to see increased usage of MCLA power amplifier subsystems worldwide as operators begin to implement enhanced features in their base station equipment.

We are just beginning to see the installation of microcells to fill out networks in selected areas. Dataquest estimates that as of the end of 1997, about 10,000 microcells have been installed worldwide, with 7,500 of them installed in 1997. This number represents about 5 percent of the approximately 150,000 BTS installations worldwide in 1997. Dataquest estimates that microcells will represent as many as 10 to 15 percent of BTS shipments by 2000, or about 26,000 to 39,000 BTS microcell shipments. This number will represent 60,000 to 70,000 transceivers out of a total of more than 800,000 that are expected to be shipped in 2000. This represents a relatively modest usage of microcells over this period, indicating that the bulk of new installations are in emerging markets that are adopting wireless phone service, in Latin America, Africa, the Middle East, and Asia, particularly China. The installation of microcells is occurring in more mature markets like Europe, North America, and selected Asian countries. As the emerging markets mature, there will be a wave of installations of microcell sites to improve quality of service and add capacity to networks.

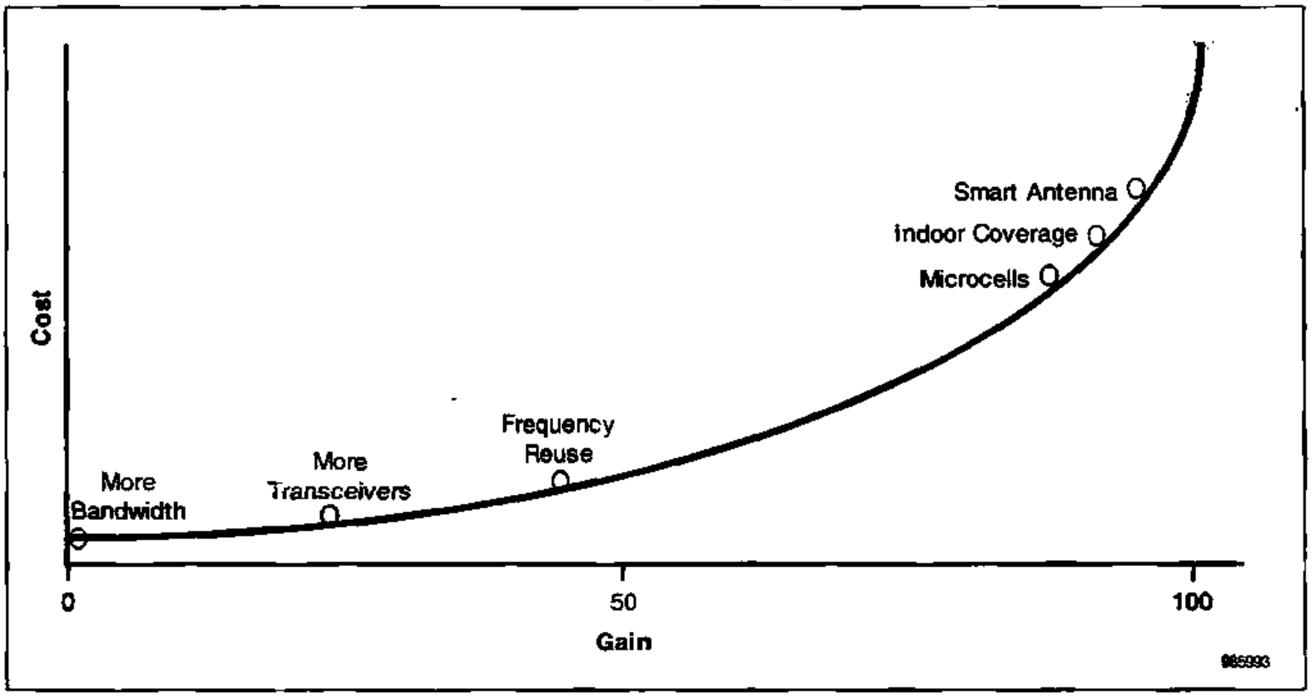
It is worthwhile to understand the progression to the usage of microcells in cellular/PCS networks. Microcells are one of several tools that operators have for increasing the quality and capacity of their networks. Studies published by network operators identify six classes of solutions for improving the quality or capacity of the network, listed in order of cost from lower to higher cost (these are discussed relative to GSM systems):

- Increased available bandwidth
- Added transceivers
- Frequency reuse (cell-splitting)
- Microcells
- Indoor coverage
- Smart antennas

Figure 3-1 shows the relative cost and performance gain for the different approaches.

These approaches are applied based on the traffic density in the coverage area. Because the approaches that provide the greatest gain also incur the greatest cost, they are used only where large gains in capacity are required. Capacity demands for a network evolve over several years. Operators must decide how to increase their capacity as demands on the network evolve. Continued demand for macrocells indicates that the need for high-capacity solutions is still limited.

Figure 3-1
Cost versus Gain for Different Network Capacity Improvement Approaches



Source: Telecom Italia Mobile

Spectrum Solutions

If the available bandwidth in the cell has not been used, the operator has a variety of solutions available. The general progression has been to turn first to sectorization, by creating a three-sector cell where one omnidirectional cell previously existed. This is a straightforward solution that simply requires redesigning the base station architecture in an existing macrocell. The next alternative is cell-splitting, in which a macrocell is replaced by several smaller macrocells. This alternative requires finding new cell sites, which can be a long involved process of finding and receiving approval for a new site. As cell-splitting continues to reduce the size of cells, the operators reach the point in highest traffic areas where they are using microcells that are overlaid on the macrocells. The movement to microcells has just begun in the last two to three years, as is demonstrated by the relatively small percentage of microcells installed to date.

The next step that is expected to begin rolling out over the next three years is the use of the PCS 1800 networks and dual-band phones that can seamlessly hand off between the two bands. Cellular operators in Europe have bought licenses to the PCS band allocations enabling them to use this spectrum for capacity expansion. With the network in place, the operators will now be selling dual-band phones to new subscribers, enabling the PCS network to be used for further capacity expansion.

Semiconductor Content Analysis

It is necessary to consider each of the three system architectures separately when analyzing semiconductor content in cellular/PCS base station equipment. While the system structures are similar, the architectures for GSM, D-AMPS, and CDMA are sufficiently different to require them to be analyzed separately.

All cellular base station equipment can be grouped into three subsystems: the BTS, the BSC, and the mobile switching center (MSC). While the base station controllers and mobile switching centers are generally of the same architecture, the BTS is different for each system. The following discussion will focus on the BTS architecture for each of the three system radio architectures. It is important to understand each of the cellular/PCS radio architectures when analyzing semiconductor opportunities. Each transceiver is very different. Although GSM and D-AMPS are both time-division multiple access (TDMA)/frequency-division multiple access (FDMA) architectures, each was designed with different objectives. The objective of D-AMPS was to be upwardly compatible with the existing and very successful analog AMPS system in the United States. This digital system was developed by Ericsson to compete with Motorola's narrowband AMPS system, which offered the same increase in capacity using analog technology. As a result, the D-AMPS architecture consists of three 8-Kbps voice channels within the same 30-KHz carrier channel as AMPS. Each transceiver card processes one carrier channel and three voice or traffic channels. Because GSM did not have to be overlaid in the existing variety of incompatible analog systems in Europe, it was designed from the ground up and optimized for digital communications. A GSM carrier is 200 KHz with eight 22.8-kbps traffic channels, of which seven are used for voice traffic and one for control signaling. The standard allows for two 11.4-kbps half-rate traffic channels, which would make it possible to double the system capacity with some decrease in call quality. Current systems do not currently use half-rate traffic channel schemes, although current base station equipment is capable of processing both half- and full-rate channels.

GSM and D-AMPS. Dataquest estimates that by 2002, GSM subscribers will represent about 60 percent of all cellular/PCS subscribers and 46 percent of the transceivers shipped. It must be kept in mind that one GSM transceiver can process more than twice as many traffic channels as a D-AMPS transceiver (133 percent more to be exact). Each transceiver in a GSM system can process as many channels as 2-1/3 transceivers in a D-AMPS system. A 42-traffic-channel GSM BTS will have six transceiver cards, while a D-AMPS BTS will have 14 transceiver cards.

Dataquest estimates that there will be 370,000 GSM transceivers and 406,000 D-AMPS transceivers shipped in 2001 (see Table 3-1). This estimate equates to 2.6 million traffic channels. Table 3-2 provides Dataquest's estimates of traffic channels shipped for 1997 through 2001 for each standard. Note that the number of CDMA traffic channels can be only roughly estimated based on subscriber growth for the CDMA standard.

Table 3-3 provides a description of the products required for the BTS of a TDMA system. The RF/IF sections of a GSM and a D-AMPS transceiver are essentially the same. Although the modulation schemes are somewhat different, with GSM being more sophisticated, the required functions, such as slow frequency hopping, can be performed by very large scale integration (VLSI) devices. Dataquest believes that the additional complexity of the GSM transceiver is more than offset by the reduction in transceiver cards required to process the same number of traffic channels in a GSM BTS, compared with a D-AMPS BTS. The following paragraphs discuss semiconductor usage in the major functional blocks for both GSM and D-AMPS transceivers, identifying the differences in the process. We will discuss the receiver first.

Figure 3-2
Base Station Transceiver System Semiconductor Usage

Front-End Processing
- Low Noise Amplifier
- RF Filter
- Down-Converter
- Local Oscillator

Semiconductors Used:
- Microwave Transistors
- GaAs/Silicon
- Schottky Diodes
- Pin Diodes
- Varactor Diodes
- Modules

IF Processing
- Variable Gain Amplifier
- Gain Control
- Second IF Mixer
- Local Oscillator
- Demodulator
- I-Q Generation

Semiconductors Used:
- RF Amplifiers (Silicon)
- Schottky Diodes
- RF Modem Chips
- Operational Amplifiers

Loop Filter
- Frequency Synthesizer
- Reference Clock
- Control Functions

Semiconductors Used:
- PLL ICs (BiCMOS)
- RF Amplifiers
- Modules

Baseband Processing
- Data Conversion
- Equalization
- Channel Coding/Decoding
- Encryption/Decryption
- T1/E1 Interface
- Embedded Control
- Frequency Synthesizer Control Functions

Semiconductors Used:
- A/D Converters
- D/A Converters
- DSP Blocks
- Analog Interface ICs
- Embedded Microprocessors
- SRAM
- Flash Memory
- CMOS ASICs

Power Amplifier

Semiconductors Used:
- Microwave Power Transistors
  - Silicon LDMOS
  - GaAs
  - Silicon Bipolar
- Operational Amplifiers
- Microwave Power Amplifier ICs
- Analog ASICs

Modulator
- Modulator
- Variable Gain Amplifier
- Up-Converter
- Preamplifier

Semiconductors Used:
- Schottky Diodes
- RF Amplifiers
- Microwave Power Amplifiers
- Microwave Power Transistors
  - Silicon LDMOS
  - GaAs
  - Silicon Bipolar
- Modules

Source: Dataquest (August 1998)

Table 3-1
Number of GSM, D-AMPS, and CDMA Transceiver Units Shipped, 1997 to 2001

	1997	1998	1999	2000	2001
GSM	235,100	295,600	332,000	351,800	370,900
D-AMPS	162,500	261,000	391,700	431,400	405,700
CDMA	9,800	20,000	40,000	65,000	100,000

Source: Dataquest (August 1998)

Table 3-2
Number of GSM, D-AMPS, and CDMA Traffic Channels Shipped, 1997 to 2001

	1997	1998	1999	2000	2001
GSM	1,645,700	2,069,000	2,324,000	2,462,600	2,596,300
D-AMPS	487,500	783,000	1,175,000	1,294,200	1,217,100
CDMA	147,000	300,000	600,000	975,000	1,500,000

Source: Dataquest (August 1998)

The technologies used in cellular transceivers are selected based on the performance requirements of the system. Ultra-high-frequency performance is required only in the front end of the receiver and the final amplifier stage of the transmitter. The rest of the system can be designed with silicon technology. The number of products that are specially designed for base station equipment is relatively small. Semiconductor companies that focus on the base station applications generally target the power amplifier and baseband sections of the base station system. These sections represent the greatest content value in the system. Dataquest estimates that the power amplifier and the baseband sections of the BTS represent nearly 80 percent of the semiconductor value in the BTS. This fact, coupled with somewhat reduced levels of competition in this area, makes these applications attractive to dominant companies like Motorola (power discrete transistors), Texas Instruments (DSP), and Lucent Technologies (DSP). The RF/IF section of the BTS represents about 20 percent of the semiconductor content and is serviced by a larger number of companies, including Anadigics, Celeritek, Fujitsu, Hewlett-Packard, Hitachi, Hittite Microwave, M/A-COM, Motorola, Philips, RF Micro Devices, Rockwell, Siemens, Stanford Microdevices, Toshiba, and TriQuint. Of these, HP, M/A-COM, and Stanford Microdevices appear to be targeting the BTS market as an opportunity. Although this market is relatively small ($378 million in 1998), it appears to be a good $100 million opportunity for a company that chooses to focus on it and become a dominant player.

CDMA. The transceiver subsystem in a CDMA base station is very different from a TDMA system. CDMA base stations currently include, depending on capacity demands, from one to as many as five broadband transceiver cards that receive and transmit a 1.25-MHz carrier. The transceiver functional blocks are similar but operate differently. Table 3-4 provides an overview of CDMA transceiver functions.

Table 3-3
Semiconductor Usage in the Key Functions of a TDMA Base Station Transceiver

Low Noise Amplifier (LNA)	The first stage of the TDMA transceiver is the low noise amplifier or LNA. This function is generally performed using low noise discrete gallium arsenide (GaAs) or silicon transistors. The LNA usually a three-stage design. The first stage is selected to provide a very low noise figure, which sets the sensitivity of the receiver. The two following stages are selected to meet the gain requirements for the LNA stage of the system.
Down-Converter	The first down-converter is generally designed as a double-balanced mixer using Schottky diodes with very fast switching times and low forward voltages. This stage down-converts the 800/900- to 1,800/1,900-MHz RF signal to a 200- to 300-MHz first IF signal.
Local Oscillator (LO)	The local oscillator is either a discrete semiconductor design or a module specifically designed for this purpose. Local oscillators are optimized for low phase noise. This is a voltage-controlled oscillator that produces an output equal to the difference between the RF frequency and the IF frequency. These modules are generally designed with discrete transistors and voltage-variable varactor diodes.
Frequency Synthesizer	The frequency synthesizer is usually designed with standard VLSI phase-locked loop (PLL) devices designed for cellular/PCS systems. The same products are generally used for both handsets and BTS transceivers. BiCMOS technology has become the technology of choice for this application. Bipolar technology is the best choice for the high-frequency prescaler function, while the rest of the device can be designed with CMOS technology. This function along with the local oscillator can be supplied as a module.
Frequency Synthesizer Controller Block	The frequency synthesizer is programmed by a control block. This block selects the frequency channel and provides other frequency control functions required by the cellular/PCS network, such as frequency hopping and channel selection. This block is designed with one or more custom ASIC devices to the system manufacturer's specification.
First IF Amplifier	The first IF stage is designed with standard general purpose analog IC amplifiers. This stage generally has a variable gain stage for implementing automatic gain control. For cellular and PCS systems this stage is used for adjusting the output power of the BTS and the handset to optimize network performance and extend the life of the handset battery. General purpose operational amplifiers are used to provide received signal strength indicator (RSSI) feedback to the variable gain stage.
Second Down-Converter and IF Amplifier	Most base station transceivers are designed with dual conversion IF sections. The second IF stage down-converts the signal to some 10s of MHz and further filters the signal for the following demodulation stage. This fixed gain stage uses standard silicon amplifier and mixer ICs.
Demodulator and Analog-to-Digital (A/D) Converter	The demodulator in a base station transceiver is usually a silicon mixed-signal BiCMOS IC similar to the ones used in handsets. This device produces the I and Q baseband outputs that are digitized and passed on to the baseband section of the transceiver.

Table 3-3 (Continued)
Semiconductor Usage in the Key Functions of a TDMA Base Station Transceiver

Digital-to-Analog (D/A) Converter and Modulator	This function provides the first step in the transmit chain and uses the same BiCMOS technology as the receive demodulator and A/D converter function. It combines the I and Q phase baseband signals and creates the modulated baseband signal to be transmitted to the mobile handset.
Up-Converter	This is a CMOS mixer circuit that raises the modulated baseband signal back to the frequency of the RF signal.
Preamplifier	The preamplifier is usually a variable-gain amplifier that can be made with GaAs or silicon technology. The gain is determined based on the strength of the received signal at the base station.
Power Amplifier	The power amplifier is designed using power discrete GaAs, bipolar, or laterally diffused MOS (LDMOS) transistors. Some D-AMPS systems are using linear amplifiers that are capable of amplifying multiple carriers called MCLAs. These have higher output power than single carrier amplifiers and are much more sophisticated in their design. A typical MCLA is designed with a number of power transistors in two or three stages along with a feedback loop that consists of two stages of amplifiers and an analog ASIC controller. This section of the transceiver can represent a significant part of the transceiver cost. Dataquest estimates that the cost for this section is in the range of 40 percent of the cost of the semiconductors in the BTS.

Source: Dataquest (August 1998)

Table 3-4
Semiconductor Usage in the Key Functions of a CDMA Base Station Transceiver

Low Noise Amplifier	The LNA of the CDMA transceiver must amplify the 1.25-MHz carrier for the system. This device must be able to accurately amplify a broadband signal as compared with the 30-KHz to 200-KHz carriers of D-AMPS and GSM systems. As with TDMA systems, this function is generally performed using low noise discrete GaAs or silicon transistors to meet the same noise and sensitivity characteristics as the TDMA systems. The LNA is usually a three-stage design similar to TDMA LNAs.
Down-Converter	The first down-converter is generally designed as a double-balanced mixer using Schottky diodes with very fast switching times and low forward voltages. This stage down-converts the 800/900- to 1,800/1,900-MHz RF signal to a 200- to 300-MHz first IF signal.
Local Oscillator	There is one LO in a CDMA system, whereas a TDMA system generally has two, one for the receive side and one for the transmit side. These modules are generally designed with discrete transistors and voltage-variable varactor diodes.
Frequency Synthesizer	The frequency synthesizer in a CDMA system is designed to implement the spreading sequence for decoding the receive signal and coding the transmit signal. The output of the frequency synthesizer is synchronized with the base station. CDMA frequency synthesizers are usually designed with standard VLSI PLL devices designed for cellular/PCS systems, although QUALCOMM offers hybrid-frequency synthesizers that combine direct digital synthesis and PLL techniques. Like TDMA, BiCMOS technology has become the technology of choice for this application. Bipolar technology is the best choice for the high-frequency prescaler function, while the rest of the device can be designed with CMOS technology.
Frequency Synthesizer Controller Block	The frequency synthesizer is programmed by a control block, which, for CDMA, produces the spreading sequence. This block is designed with one or more custom ASIC devices to the system manufacturer's specification.
First IF Amplifier	The first IF stage is designed with standard general-purpose IC amplifiers. This stage generally has a variable gain stage for implementing automatic gain control for adjusting the output power of the BTS and the handset to optimize network performance and extend the life of the handset battery.
Second Down-Converter and IF Amplifier	Most base station transceivers are designed with dual conversion I.F. sections. The second IF stage down-converts the signal to some 10s of MHz and further filters the signal for the following demodulation stage. This fixed gain stage uses standard silicon amplifier and mixer ICs.
Demodulator and A/D Converter	The demodulator in a base station transceiver is usually a silicon mixed signal BiCMOS IC similar to the ones used in handsets. This device produces the I and Q baseband outputs that are digitized and passed on to the baseband section of the transceiver.
D/A Converter and Modulator	This function provides the first step in the transmit chain and uses the same BiCMOS technology as the receive demodulator and A/D converter function.
Up-Converter	This is usually a diode mixer circuit that up-converts the baseband signal to the RF frequency.

Table 3-4 (Continued)
Semiconductor Usage in the Key Functions of a CDMA Base Station Transceiver

Preamplifier	The preamplifier is usually a broadband variable gain amplifier that can be made with GaAs or silicon technology. The gain is determined based on the strength of the received signal at the base station.
Power Amplifier	The power amplifier is designed using power GaAs, bipolar, or LDMOS transistors. CDMA systems require the use of linear amplifiers that are capable of amplifying broadband carriers. A typical MCLA is designed with a number of power transistors in two or three stages along with a feedback loop that consists of two stages of amplifiers and an linear controller block. The control block can be designed as an ASIC as has been done by Spectrian. CDMA power amplifiers are significantly overdesigned to achieve the high linearity required for CDMA systems. This section of the transceiver can represent a significant part of the transceiver cost. Dataquest estimates that the cost of this section is in the range of 40 percent of the cost of the semiconductors in the BTS.

Source: Dataquest (August 1998)

Base Station Controller

The BSC system performs three functions for the network.

- It manages the calls originating within its coverage area (one BSC controls 10 to 40 or 50 cell sites).
- It monitors the performance of the system within its coverage area.
- It connects the cell sites with the MSC.
- It converts (transcodes) the voice-coded voice channels to PCM channels that are sent between the BSC and other BSCs and the MSC to be forwarded to and received from the fixed telephone network when required.

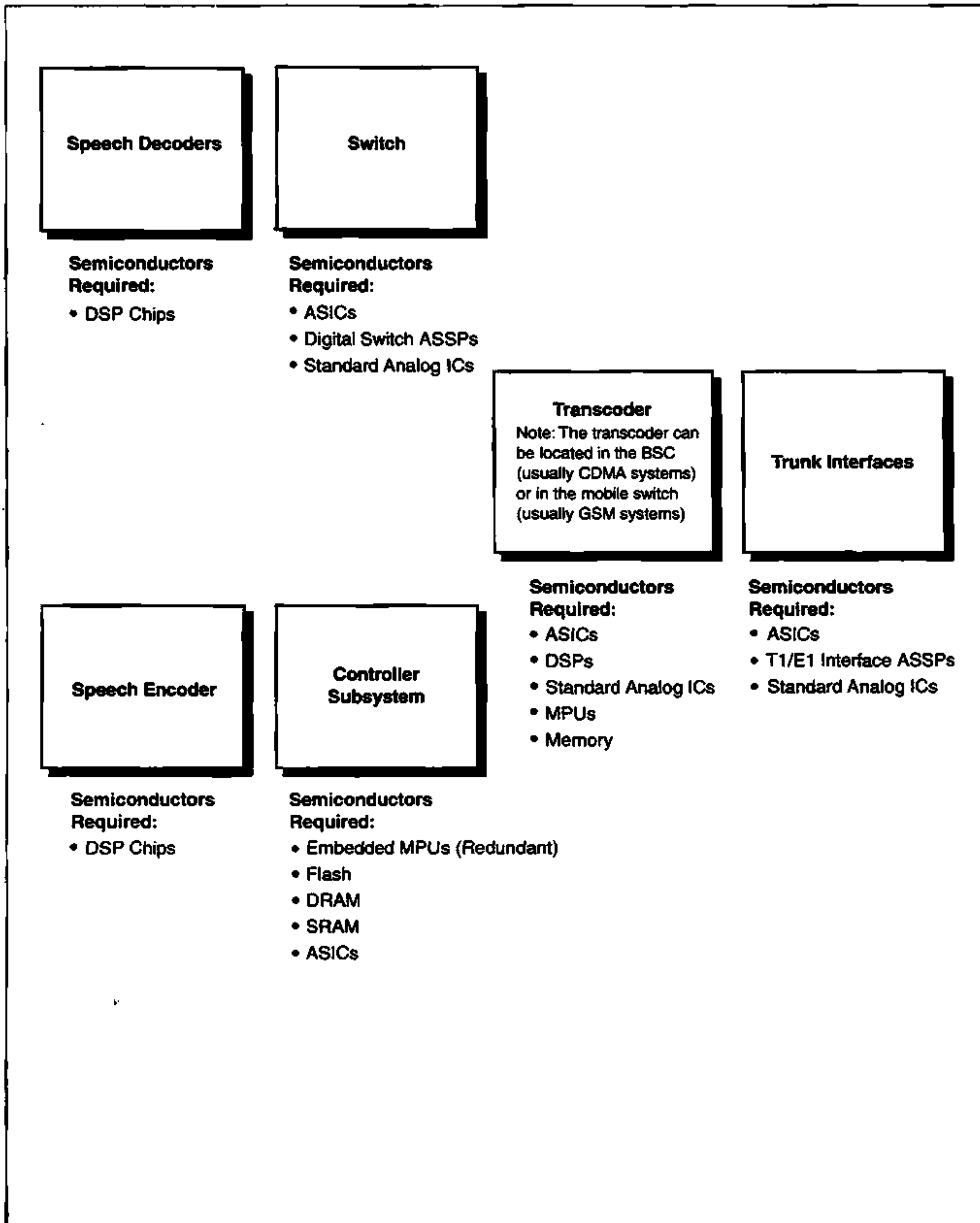
The major functions within the BSC are the speech encoders, the speech decoders, a telephone switch, and a computer control system. Figure 3-3 shows the key blocks and the important semiconductor products used in each of them. Some of the key suppliers of these products include TI and Lucent for DSP products, Analog Devices and National Semiconductor for data conversion blocks, Motorola and other suppliers of embedded MPUs for embedded processors, and Mitel and Lucent for switch products.

Some system architectures distribute the BSC functions between the BTS and the MSC. This distribution is particularly likely in CDMA systems. Both Lucent and QUALCOMM state that their systems operate with the BSC functions distributed. Motorola's literature shows a BSC subsystem.

Supplier Analysis

The range of semiconductors used in base station equipment is very diverse, especially considering the range of all components used in this equipment. This report will focus on the semiconductor supply base.

Figure 3-3
Base Station Controller Semiconductor Usage



Source: Dataquest (August 1998)

No one company supplies the entire range of products for cellular/PCS base station equipment. The competitive environment varies from subsystem to subsystem. For example, Motorola, TI, and Lucent are major players in the baseband BTS and transcoder sections of the system. Motorola has a major share of the revenue that come from the power amplifier and seems to be strengthening that position by establishing lateral DMOS as the technology of choice for power amplifier designs. Motorola also has a strong position in the embedded processor section of the base station controller. The RF/IF section of the BTS is not dominated by any one supplier. A few companies supply a wide array of products into this part of the system. These include HP, M/A-COM, Motorola, Alpha Industries, QUALCOMM, and RF Micro Devices. No single company dominates this segment of the market at this time.

Other suppliers of products to the BTS and BSC systems provide DRAM, SRAM, EEPROM, flash memory, ASICs, and standard linear and digital functional building blocks. Table 3-5 lists suppliers of the key components of the base transceiver subsystem.

Table 3-5
Semiconductor Suppliers for Base Station Transceiver Equipment

Company	Transmit-Receive Switch	LNA	Mixer	Frequency Synthesizer	VCO	FS Control	IF Section	A/D Converter	Power Amplifier
Alpha Industries	X	X	X		X				
Anadigics	X	X	X						
Analog Devices								X	
Celeritek		X	X						
Ericsson		X	X						
Exar								X	
Fujitsu	X		X	X					
GHz Technology									X
Hewlett-Packard	X	X	X						
Hitachi				X					X
Hittite Semiconductor		X							
IBM									
IDT									
LSI Logic						X			
Lucent						X		X	
M/A-COM	X	X	X		X				
Maxim								X	
Mitsubishi		X							X
Motorola	X	X	X	X	X	X	X		X
National Semiconductor				X		X	X	X	
Pacific Monolithics									X
PeregrineSemiconductor				X					
Philips	X	X					X		X
QUALCOMM			X	X	X	X			
RF Microdevices	X	X	X				X		
Rockwell									
Siemens						X	X		
STMicroelectronics						X	X	X	X
Stanford Microdevices	X	X							
Texas Intruments				X		X	X		
Toshiba									X
TriQuint	X	X	X						

Table 3-5 (Continued)
Semiconductor Suppliers for Base Station Transceiver Equipment

Company	Demodulator	Baseband	Baseband Control	D/A Converter	Modular	Preamplifier	Power Amplifier
Alpha Industries						X	
Anadigics						X	
Analog Devices		X		X			
Celeritek							
Ericsson							
Exar				X			
Fujitsu							
GHz Technology							X
Hewlett-Packard						X	
Hitachi						X	X
Hittite Semiconductor							
IBM		X	X				
IDT			X				
LSI Logic			X				
Lucent		X		X			
M/A-COM							
Maxim				X			
Mitsubishi						X	X
Motorola	X					X	X
National Semiconductor		X		X			
Pacific Monolithics							X
PeregrineSemiconductor							
Philips					X	X	X
QUALCOMM		X					
RF Microdevices							
Rockwell							
Siemens							
STMicroelectronics							X
Stanford Microdevices						X	
Texas Intruments		X	X				
Toshiba						X	X
TriQuint						X	
VLSI Technology			X				

Technology Trends

The most important trends in base station equipment design are driven by the customer's need to provide quality wireless phone service at a competitive cost. Semiconductor technology is assisting this effort as follows:

- Higher-performance DSP devices are making it possible to process more complex algorithms at lower cost or to reduce package count and therefore the cost of base station hardware. TI, Lucent, and Analog Devices have all made recent announcements in this area.
- The trend toward digital radio technology is providing opportunity for new companies to enter this market. Harris Semiconductor is a leading supplier of digital down-converters and up-converters. These products, when coupled with high speed A/D converters, make it possible to eliminate part of the IF section of the transceiver and the expensive passive components required in that section of the system. Other companies entering into this emerging area include Gray Chip (digital up- and down-converters), National Semiconductor (A/D converters), Analog Devices (A/D converters and digital up- and down-converters), and Lucent (A/D converters). Dataquest believes that it will be important for suppliers to provide both of these products to be successful in this next wave of new technology. Current products are capable of sampling and converting the first IF frequency of the receive channel and digitally down-converting that to baseband. Ultimately it will become necessary to sample the RF signal directly. The first benefit of digital IF processing is the ability to sample multiple carriers at a time. This capability results in a cost reduction because one digital receive circuit can do the job of several analog receive circuits. The long-term benefit of digital radios will be the emergence of software-defined radios, which will be programmed to meet different standards rather than unique hardware being required for each standard. This development will be particularly beneficial for base station equipment, which will become standardized and programmed at installation for the standards and network architecture requirements. Software-defined radios are expected to be used in 3G wireless infrastructure equipment, which is expected to become more widely used in equipment delivered after 2000.
- Smart antenna technology will become more widely used over the next five years. This use will drive demand for more DSP products for signal processing and selecting the appropriate received signal. Smart antennas are being used to reduce cochannel interference, to reduce the effects of multipath delays, and to increase the range of base stations. Trials are currently being undertaken. The technology is expected to become widely used within the next five years and will most likely be generally used in 3G infrastructure installations. Ericsson has recently announced a trial of its adaptive antenna technology with Mannesman in Germany. This technology operates in both the uplink and downlink network connections.

Third-Generation Wireless Infrastructure

Dataquest's current forecast assumes that significant shipments of 3G infrastructure equipment will occur beyond the forecast period. Third-generation cellular/PCS technology is a controversial issue, with European and U.S. forces vying to influence the decision of the International Telecommunications Union (ITU) in determining the standards for 3G wireless technology.

A 3G wireless access system called IMT-2000 has been conceived to provide a ubiquitous, global wireless communications network that can provide subscribers with the following:

- Anywhere, anytime communications
- A range of services from current voice and simple data services to access to broadband multimedia services like video conferencing or communications
- Software-updatable terminals
- The same service anywhere

There has also been some discussion about operators using the 3G frequency allocations to expand network capacity in high-density areas of the world in order to provide wireless service to the expanding subscriber base and to offer broadband wireless access as an alternative to wired communications.

Europe, with its successful GSM worldwide standard, has taken the lead in proposing a single standard solution to the ITU through the European Telecommunications Standards Institute (ETSI). The United States has submitted several alternative recommendations to the ITU based on IS-136, CDMAOne, and W-CDMA. The results of the ITU's decision process will impact the industry and place some companies in advantageous positions for benefiting from the emergence of 3G wireless networks. Although this change ultimately will affect the fortunes of semiconductor companies based on the alignments they have made, the key issues now revolve around the timing of the market and the general impact that 3G wireless communications will have on the semiconductor industry. In the meantime, a migration toward the third generation is proceeding on its own. For example, CDMA 1900 PCS operators are demanding additional capacity for their systems. Starting in 1999 or early 2000, this demand will be addressed by a technology called 3G Phase 1, which implements W-CDMA on IS-95. This technology doubles the capacity of the IS-95 carrier. Also, the technology provides increased bandwidth. While the maximum stated bandwidth is 144 Kbps, the practical data rate is around 64 Kbps. This enhanced standard requires a phone that will operate in the 3G Phase 1 mode to gain the added bandwidth available. This technology, if it becomes widely used, could represent the next wave of demand in the infrastructure market.

The Impact on the Semiconductor Industry

Two factors will impact the semiconductor requirements of 3G wireless equipment. First, the wideband multimedia service capabilities will demand significantly more DSP MIPS, requiring more powerful and more expensive DSP devices. Also, broadband communications will require techniques that provide stable, low-variation signals that can be decoded with very low bit-error rates to assure high-quality content. This change will require more sophisticated transmitters and receivers that employ microdiversity techniques to assure high-quality performance. Second, software-configurable radios will require digital transceiver technology that is still expensive compared with existing analog radio technology. The good news is that the semiconductor industry is developing technology that will be able to handle the demands of 3G wireless infrastructure. The bad news is that the cost is still relatively high compared to existing infrastructure. Therefore, wireless operators will have to find ways to generate higher-value services to pay for the new infrastructure.

This need leads to another consideration that will impact the semiconductor industry: content. The primary source for broadband content is the Internet. Actual use of the Internet in the mobile environment does not currently exist in any significant way. It will be necessary for high-value mobile Internet applications to evolve over time before the operators will be able to begin recovering their investments. As a result, services valued by mobile subscribers may not be in widespread use until 2003 to 2005. This picture suggests a slow ramp-up of 3G wireless infrastructure. A reasonable scenario being proposed by the leading system companies includes an interim generation of moderate bandwidth in the range of 200 Kbps to 300 Kbps, better than the 56-kbps rates currently available in homes or in hotels for mobile people. The rollout of these technologies will happen over a period of time, depending on the emergence of applications that create demand for the technology. A reasonable time frame might look as follows:

- Network trials of GPRS and related services—1999 to 2000
- Development and acceptance of applications requiring broadband wireless services—1999 to 2001
- Expansion of the existing network for enhanced bandwidth GSM/CDMA services—2000 to 2003
- Investment in 3G infrastructure for providing broadband services identified using 2.5G technology—2002 to 2004
- Introduction of 3G services based on the experience gained though the trials and experience gained during trial periods—2004 and beyond

Third-generation wireless technology will require different semiconductor technology from what is currently being used in current generation base stations. Changes will occur in three areas:

- Digital radios will appear first to reduce cost by decreasing the number of transceiver cards required per carrier in TDMA systems
- Broadband power amplifiers will be come a necessity in TDMA systems
- Extremely high-performance baseband processing will be required to process the additional information content of broadband services that will require thousands of DSP MIPS

The semiconductor industry is ahead of equipment industry needs in providing the products and technologies that meet these requirements. Standard products that fit these applications are available from a variety of suppliers.

Digital Radios

Digital radios require two new types of functions: high sample rate A/D converters to sample and digitize the RF signal directly and digital downconverters to reduce the digital signal to baseband. Initially, digital radios will be implemented to reduce cost, then to implement software-defined functions that will enable 3G systems to operate effectively in the multistandard 3G environment. Several semiconductor companies are currently developing or offering products that fit into digital radio applications.

High Rate-Sampling A/D Converters. National Semiconductor, Lucent, Philsar, and Analog Devices all offer 65 megasamples per second (MSPS) A/D converters that are capable of sampling IF signals of up to 300 MHz. In a receiver designed for broadband reception, one of these devices can sample a broadband IF signal containing several down-converted carriers. Using this process, several receivers can be combined on one card, reducing the number of cards required per carrier. System manufacturers are in the design phase with this technology.

Digital Down-Converters. The output of a sampled IF signal must be down-converted to baseband digitally. The digital down-converter must operate at the same sample rate as the A/D converter. Harris Semiconductor, Analog Devices, Philsar, and Graychip produce digital down-converters that operate at 65 MSPS.

New technologies such as silicon-germanium BiCMOS and silicon-on-insulator technologies promise to raise the performance of these devices to higher levels, enabling further cost reductions and performance improvements in base station equipment.

Broadband Power Amplifiers

Broadband multicarrier linear power amplifiers are widely used in CDMA and D-AMPS systems and are being introduced for GSM systems. This existing technology will be adapted to 3G systems when required. Independent power amplifier companies are already positioning themselves as suppliers of this technology. The demand for these systems will significantly increase demand for higher-power discrete RF power transistors to capabilities of several hundred watts.

High-Performance Baseband Processing

The leading DSP suppliers for wireless infrastructure equipment are already positioning themselves for 3G baseband requirements. TI has introduced the 2,000-MIPS 320C6x DSP processor as a solution for 3G infrastructure applications. This chip has raw processing power several times that of other companies' comparable offerings. Motorola has addressed this need by off-loading its 56300 DSP core with coprocessors, creating specialized solutions for transceiver baseband and transcoder applications. Lucent is tailoring products in its 16000 DSP family to wireless infrastructure applications as well. Lucent's approach is to craft the DSP architecture to the applications. It offers the "application cube" as a means of comparing its products with others. The application cube measures a DSP's performance efficiency in terms of code size, power, and MIPS/function for a particular solution. Analog Devices offers its 21000 SHARC architecture for these applications. Engineers designing 3G baseband systems will have many choices that will have to be evaluated carefully to determine the best solution for the application. Dataquest expects that suppliers will offer reference designs that will show their solution at its best to win designs.

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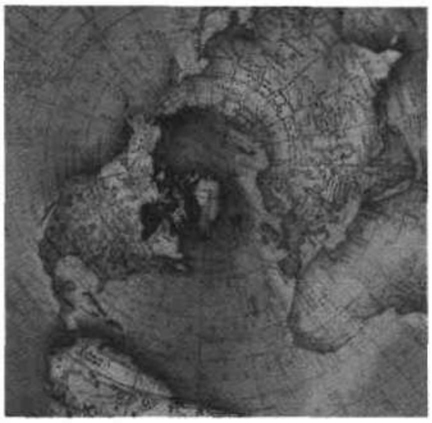

Dataquest

Pager and Satellite Communications Application Markets

Industry Trends

Program: Wireless Semiconductors and Applications - Worldwide
Product Code: WSAM-WW-IT-9801
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Chapter 1
Executive Summary

In the midst of the introduction of new, advanced products and services at lower prices, the paging industry entered a difficult period during 1997 and the first half of 1998. While subscribers continued to grow at a reasonably strong rate, paging service providers struggled with key issues related to their profitability. In addition to reducing inventories and delaying orders for pagers, service providers have struggled with the introduction of new services based on two-way paging and voice technologies. These delays and setbacks have resulted in a contraction in shipments of pagers and demand for related semiconductors during the past 18 months. There were almost 145 million pager users worldwide by the end of 1997. The number of pager subscribers worldwide continues to grow at a solid pace in spite of subscriber decreases in some countries such as Japan. On the positive side, the paging market in Europe has found new life. The strongest markets continue to be found in the United States and Asia/Pacific, especially China.

Worldwide pager production is forecast to rebound in 1998, following a dip in production in 1997. The Dataquest forecast calls for continued growth through 2002 with unit shipments approaching 56 million in 2002. Development of the two-way paging market has been delayed by various technical problems and constraints on supplies of hardware. Dataquest remains optimistic about the development of this market and, in spite of some highly visible setbacks, expects new services and relaunched services to find success in 1998. Paging hardware for new applications such as meter reading began shipping in 1997 and is expected to provide a significant boost to the pager market. New applications such as meter reading are grouped under the category of "fixed-unit" pagers. Motorola Incorporated is the world's leading supplier of pagers and paging technology. However, the number of pager manufacturers and suppliers is large—most of them having operations in the Asia/Pacific region.

Subscriptions to one-way pager services in the Americas grew by 6.9 million in 1997 and are expected to grow by 4.6 million in 1998 (see Figure 3-4). Shipments of alphanumeric pagers in the Americas are forecast to grow by more than a 12 percent compound annual growth rate (CAGR) through 2002, and shipments of narrowband Personal Communication Services (PCS) pagers are forecast to grow by a 119 percent CAGR during the same time period as pager subscribers take advantage of new services. While traditional paging services in the Americas are predicted to reach 67.3 million subscribers by 2002, demand for narrowband PCS services will add another 15.4 million subscribers and an installed base of 1 million fixed-unit pagers to the overall Americas pager market during the same time period.

Motorola is promoting the new FLEX family of paging protocols as the platform that will move the paging industry into the 21st century. It has moved aggressively to establish FLEX as a worldwide de facto standard for pagers. The term FLEX has become synonymous with next-generation paging technology. As of March 1998, the FLEX protocol had been adopted by 229 carriers in 48 countries that represent 92 percent of the worldwide pager subscriber base. FLEX chipsets bring down a major technological barrier to the development of next-generation products and will enable new products, ranging from pagers to personal digital assistants (PDAs) to TVs, that incorporate FLEX technology.

Motorola developed the first two-way paging device, the Tango. The Tango, which was based on ReFLEX technology, was phased out and replaced by a new portfolio of devices. The next messaging device introduced by Motorola was the PageWriter 2000. Motorola also introduced a scaled-back PageWriter, the PageWriter 250. A fourth messaging device, the PageFinder, is basically a low-end pager with acknowledgment capability. Motorola's Tenor voice pager is positioned as a mobile answering machine. Wireless Access Inc. is currently the only other supplier of two-way messaging devices based on ReFLEX technology. The AccessLink II is the most recent product announced by Wireless Access, and it is based on the ReFLEX50 protocol.

The European Radio Message System (ERMES) is a second-generation paging standard that has been backed by European Union (EU) members. With various delays creating problems for ERMES implementation, proponents of the FLEX protocol have been attempting to promote FLEX as a standard in Europe. By December 1997, the number of signatories to the ERMES Memorandum of Understanding (MoU) had grown to 50, but there were only 16 operators in 12 countries offering services. So far, ERMES has not had a dramatic impact on the market. Only in France, where it has been marketed aggressively by paging operators, has it really taken off. In 1998, the European Commission (EC) indicated that as long as a common digital standard is implemented across the region, it does not matter which one it is—a considerable retreat. This opened the way for the Motorola FLEX technology and associated systems such as ReFLEX.

According to a recent count, 1,335 communications satellites were scheduled for launch between the middle of 1997 and 2006. According to an International Telecommunications Union (ITU) spokesperson, more satellites are expected to be launched in the next 10 years than all of those put in orbit over the past 30 years. Satellites planned for use in the delivery of global mobile communications commercial services accounted for 627 satellites, nearly one-half of the satellites scheduled to be put into service over the next 10 years.

Chapter 2
Introduction and Methodology

The communications electronics semiconductor application market is examined through the publication of six separate documents as follows:

- Modem (analog and digital) and other remote access application markets
- Corded telephone and answering machine application markets
- Paging/narrowband PCS and emerging application markets
- LAN and wide area network (WAN) application markets
- Public network application markets
- Cellular/broadband PCS and cordless telephone application markets

This document provides reference information and analysis about paging and satellite communications application markets for semiconductors. It offers basic information about the opportunities presented by particular systems:

- System market size (in terms of production) in revenue, units, and average selling prices (ASPs)
- System market and product feature trends
- Hardware architecture trends and semiconductor device opportunities
- Semiconductor content and market forecast
- A listing of key OEMs

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinion. Some of the primary sources include Dataquest's own services. Secondary sources include various governmental and trade sources on sales, production, trade, and public spending. Assumptions about semiconductor content are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative systems.

The forecast methodology is based on various methods and assumptions, depending on the area. To form a solid basis for projecting system demand and capital, government, and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes, and government policies are also considered. Semiconductor content forecasts are based on interviews with system marketers and designers (including makers of enabling semiconductor technology), along with an analysis of historical trends.

Chapter 3

Pagers (One-Way, Acknowledgment, Two-Way, and Digital Voice)

Market and Production Trends

Worldwide Trends

In the midst of the introduction of new, advanced products and services at lower prices, the paging industry entered a difficult period during 1997 and the first half of 1998. While subscribers continued to grow at a reasonably strong rate (see Table 3-1 and Figure 3-1), paging service providers struggled with key issues related to their profitability. In addition to reducing inventories and delaying orders for pagers, service providers have struggled with the introduction of new services based on two-way paging and voice technologies. These delays and setbacks have resulted in a contraction in shipments of pagers and demand for related semiconductors during the past 18 months.

The pager has moved from being simply a "beeper" to playing a role in new PCS markets, delivering text messages, providing limited two-way messaging, serving as a mobile answering machine, and offering nationwide and multicountry coverage. It is also finding new applications in industries, such as vending machines and utilities, where it can monitor inventory levels and power consumption. The continued development of new services and products for the paging market is essential to its long-term health. Many concerns are being raised about the viability of the paging industry in light of new capabilities offered by digital cellular and broadband PCS such as text messaging. However, Dataquest maintains a positive outlook for the overall paging industry and believes that it will emerge from its current difficulties better-positioned for profitable growth.

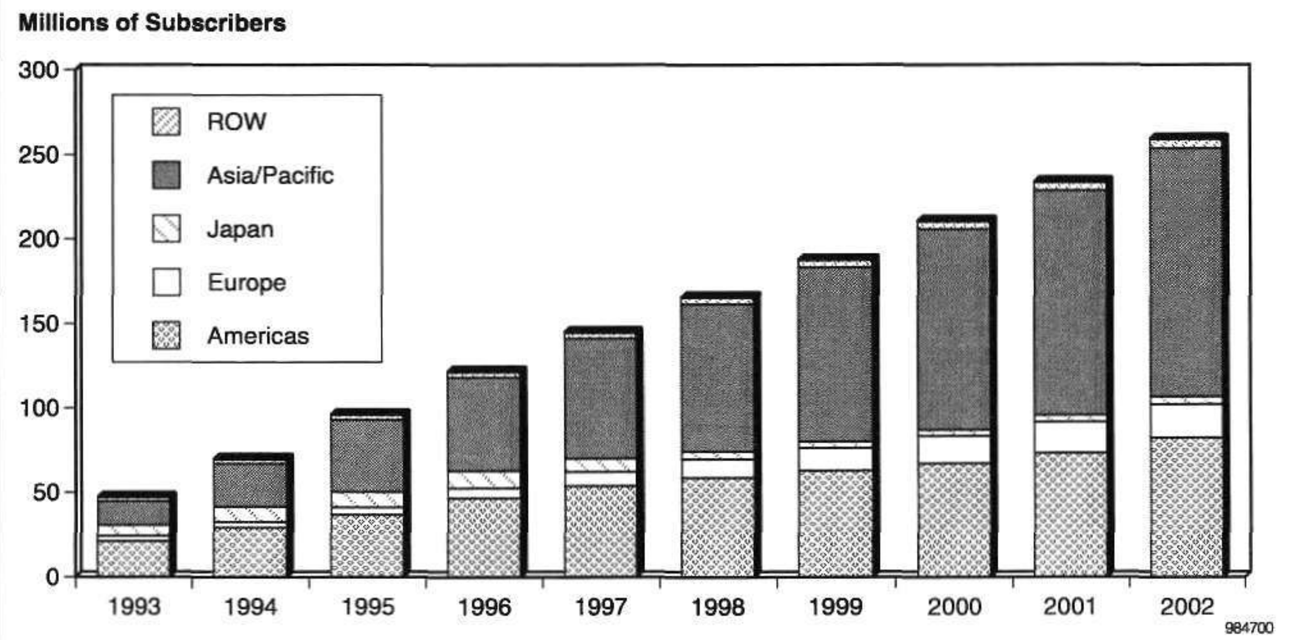
There were almost 145 million pager users worldwide by the end of 1997. The number of pager subscribers worldwide continues to grow at a solid pace in spite of subscriber decreases in some countries such as Japan. On the positive side, the paging market in Europe has found new life. The strongest markets continue to be found in the United States and Asia/Pacific, especially China. At the beginning of 1998, the United States, China, Japan, and South Korea still accounted for more than 80 percent of the world's pager subscribers, as shown in Figure 3-2. While Japan is experiencing various difficulties in its paging markets, other countries are expected to add to the overall worldwide pager market growth. Singapore has the highest pager penetration rate in the world, followed by South Korea, the United States, Hong Kong, Taiwan, the Netherlands, Japan, the United Arab Emirates, Kuwait, Puerto Rico, Canada, and Malaysia. China has a penetration rate approaching 5 percent; India, Latin America, Indonesia, and Eastern Europe have penetration rates below 1 percent. These regions account for 60 percent of the world's population and are experiencing strong growth in pager subscribers. The Asia/Pacific region accounted for nearly one-half of the worldwide paging subscriber population at the end of 1997 and is forecast to pass 56 percent of the worldwide market by 2002. Even Europe has experienced new vitality in its pager markets and is forecast to expand its subscriber population by an 18.7 percent CAGR over the next five years.

Table 3-1
Worldwide Pager Market (One-Way and Two-Way)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Subscribers Worldwide (M)	**47.2**	**70.0**	**96.0**	**121.5**	**144.6**	**165.6**	**187.5**	**210.5**	**233.6**	**259.2**	**12.4**
Americas	21.5	29.4	37.0	46.9	54.0	59.0	63.1	67.6	73.7	82.7	8.9
Europe	3.2	3.5	4.4	5.8	8.4	11.0	13.6	16.1	18.4	19.8	18.7
Japan	6.3	8.8	9.0	10.3	8.0	4.5	3.8	3.5	4.0	4.5	-10.9
Asia/Pacific	13.9	25.6	42.8	55.5	70.9	87.4	103.1	118.9	132.8	147.0	15.7
ROW	2.3	2.6	2.8	3.0	3.3	3.7	4.0	4.4	4.8	5.2	9.5
Unit Shipments (K)	**19,653**	**30,030**	**38,695**	**43,351**	**44,620**	**45,059**	**47,548**	**50,446**	**52,033**	**55,944**	**4.6**
One-Way Subscriber	19,653	30,030	38,679	43,336	44,461	44,622	46,413	47,755	47,276	47,158	1.2
Two-Way Subscriber	-	-	15	14	159	412	1,080	2,571	4,455	8,282	120.6
Two-Way Fixed-Unit	-	-	-	-	0.6	24.4	55.3	120.8	302.0	505.0	284.6
Factory ASP ($)	**85**	**81**	**76**	**75**	**76**	**79**	**82**	**84**	**85**	**85**	**2.1**
One-Way	85	81	76	75	72	71	68	62	56	51	-6.7
Two-Way	-	-	245	210	171	139	119	109	98	89	-12.2
Two-Way Fixed-Unit	-	-	-	-	160	129	110	101	91	82	-12.6
Factory Revenue ($M)	**1,662**	**2,417**	**2,937**	**3,253**	**3,228**	**3,229**	**3,291**	**3,253**	**3,111**	**3,183**	**-0.3**
One-Way	1,662	2,417	2,933	3,250	3,201	3,168	3,156	2,961	2,647	2,405	-5.6
Two-Way	-	-	4	3	27	57	129	280	437	737	93.6
Two-Way Fixed-Unit	-	-	-	-	0.1	3.1	6.1	12.2	27.4	41.2	236.0

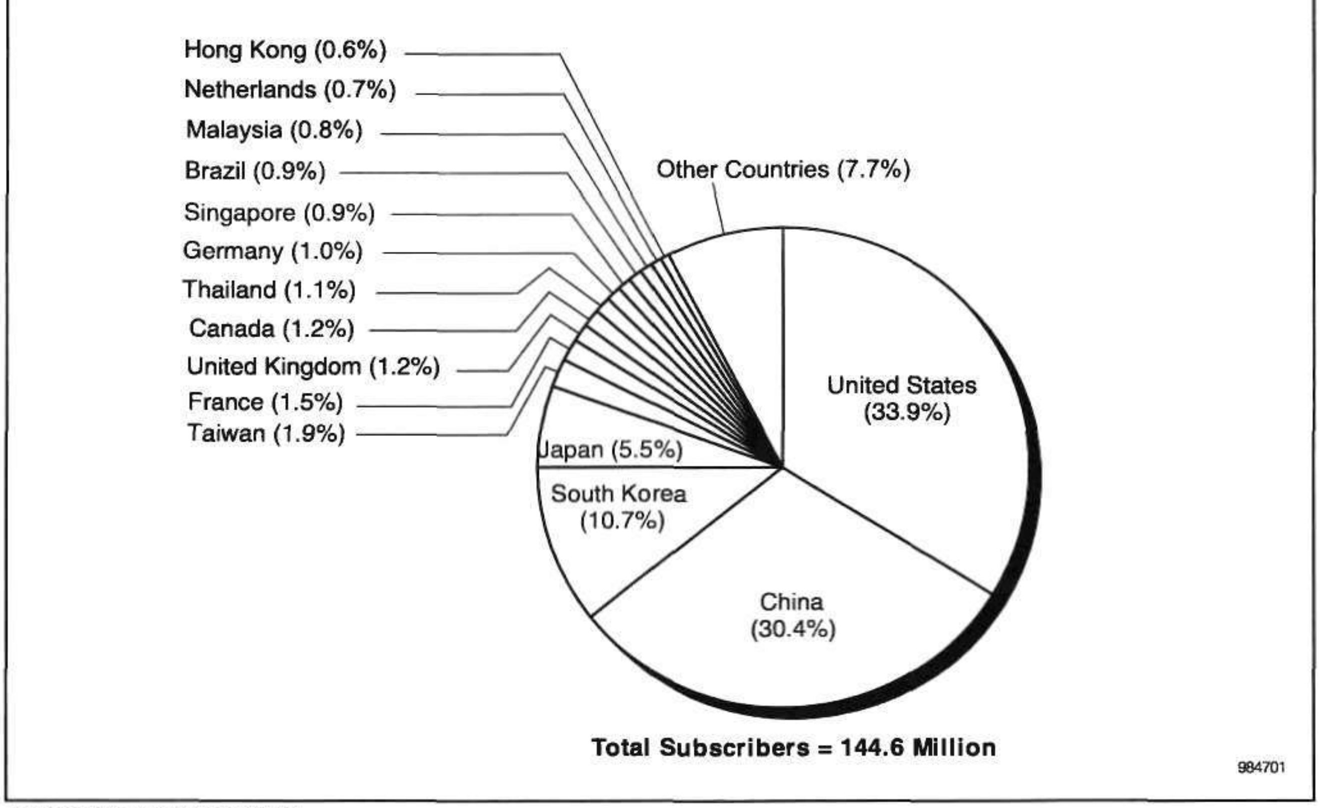
Source: Dataquest (July 1998)

Figure 3-1
Worldwide Pager Subscribers (One-Way and Two-Way)



Source: Dataquest (July 1998)

Figure 3-2
Pager Subscribers by Major Country Markets (January 1998)



Source: Dataquest (July 1998)

Worldwide pager production is forecast to rebound in 1998, following a dip in production in 1997. The Dataquest forecast calls for continued growth through 2002 with unit shipments approaching 56 million in 2002 (see Table 3-2 and Figure 3-3). Although numeric pagers have accounted for the largest share of production, new unit growth is being driven by products such as alphanumeric and acknowledgement pagers. In 1997, alphanumeric pagers represented over one-fourth of worldwide production. By 2001, they will account for almost two-thirds of total pager production. Development of the two-way paging market has been delayed by various technical problems and constraints on supplies of hardware. Dataquest remains optimistic about the development of this market and, in spite of some highly visible setbacks, expects new services and relaunched services to find success in 1998. Unless otherwise noted, the term "two-way pager" in this report refers to the entire class of paging devices providing narrowband PCS, ranging from simple acknowledgment paging to interactive two-way messaging and digital voice pagers that serve as mobile answering machines.

Motorola is the world's leading supplier of pagers and paging technology. However, the number of pager manufacturers and suppliers is large—most of them having operations in the Asia/Pacific region. A list of pager manufacturers and suppliers is presented in Table 3-3.

Americas Trends

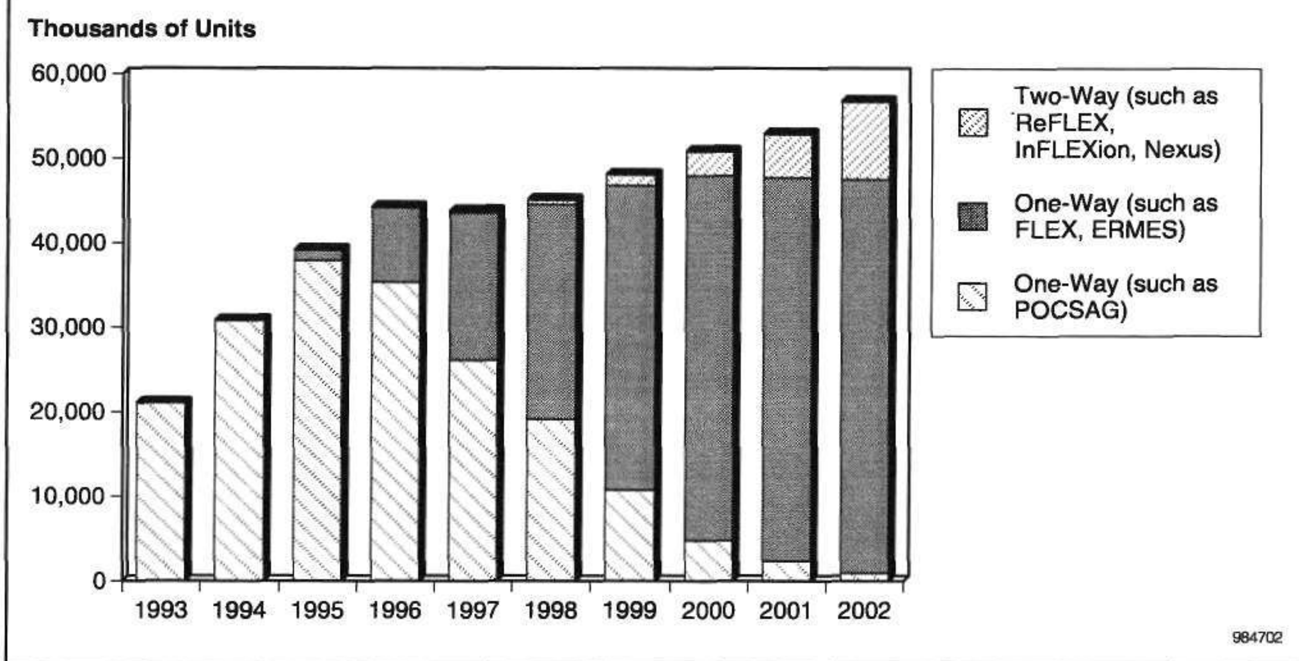
Subscriptions to one-way pager services in the Americas grew by 6.9 million in 1997 and are expected to grow by 4.6 million in 1998 (see Figure 3-4). Shipments of alphanumeric pagers in the Americas are forecast to grow by more than a 12 percent CAGR through 2002, and shipments of narrowband PCS pagers are forecast to grow by a 119 percent CAGR during the same time period as pager subscribers take advantage of new services. Additionally, paging hardware for new applications such as meter reading began shipping in 1997 and is forecast to provide a significant boost to the pager market. New applications such as meter reading are grouped under the category of "fixed-unit" pagers in this report. Also, because these pagers require two-way paging technology, their worldwide shipments are included in the two-way pager category in the worldwide production forecast. Table 3-4 and Figure 3-5 show the forecast for the Americas paging market.

Table 3-2
Worldwide Pager Production

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Units (K)	**21,064**	**30,840**	**39,163**	**44,201**	**43,748**	**45,084**	**48,057**	**50,825**	**52,875**	**56,705**	**5.3**
Numeric	18,852	27,262	33,171	35,427	31,936	28,388	23,041	21,803	19,978	18,546	-10.3
Alphanumeric, Digital Voice, Industrial	1,896	3,392	5,875	8,752	11,812	16,696	25,016	29,022	32,898	38,159	26.4
Other (Tone, Tone and Voice)	316	185	117	22	-	-	-	-	-	-	-
Units (K)	21,064	30,840	39,163	44,201	43,748	45,084	48,057	50,825	52,875	56,705	5.3
One-Way (such as POCSAG)	21,064	30,838	37,948	35,356	26,143	19,161	10,758	4,795	2,388	955	-48.4
One-Way (such as FLEX, ERMES)	-	1	1,200	8,829	17,429	25,399	36,015	43,151	45,350	46,550	21.7
Two-Way (such as ReFLEX, InFLEXion, Nexus)*	-	2	15	16	177	524	1,284	2,879	5,137	9,200	120.5
Factory ASP ($)	**84**	**80**	**76**	**75**	**72**	**71**	**69**	**64**	**59**	**56**	**-5.0**
One-Way	84	80	76	75	72	71	67	61	55	50	-7.0
Two-Way*	-	245	242	202	167	134	117	107	96	87	-12.3
Factory Revenue ($M)	1,769	2,465	2,969	3,302	3,162	3,222	3,303	3,252	3,141	3,173	0.1
One-Way	1,769	2,465	2,965	3,299	3,133	3,151	3,153	2,944	2,647	2,375	-5.4
Two-Way*	-	0.4	3.7	3.3	29.5	70.4	149.8	308.0	494.0	798.1	93.4
Semiconductor Content ($)	14	**13**	**13**	13	**13**	**13**	**13**	**14**	**14**	**15**	**3.3**
One-Way	14	13	13	13	13	12	12	12	12	12	-0.6
Two-Way*	-	47	47	44	43	40	38	35	32	29	-7.6
Semiconductor Market ($M)	289	403	497	575	552	569	619	689	745	842	8.8
One-Way	289	403	496	574	545	548	571	590	582	575	1.1
Two-Way*	-	0.1	0.7	0.7	7.6	20.7	48.3	99.5	162.4	267.2	103.7
Regional Unit Production Trends (Percentage of World)											
Americas	37	39	34	37	33	29	27	28	29	30	-
Europe	3	2	2	2	3	3	3	4	4	4	-
Japan	39	29	27	16	13	10	8	7	6	5	-
Asia/Pacific	21	29	36	45	51	58	61	62	61	61	-

*Includes both mobile and fixed-unit paging systems
Source: Dataquest (July 1998)

Figure 3-3
Worldwide Pager Production



Note: Two-way includes both mobile and fixed-unit paging systems.
Source: Dataquest (July 1998)

Table 3-3
Pager Manufacturers and Suppliers

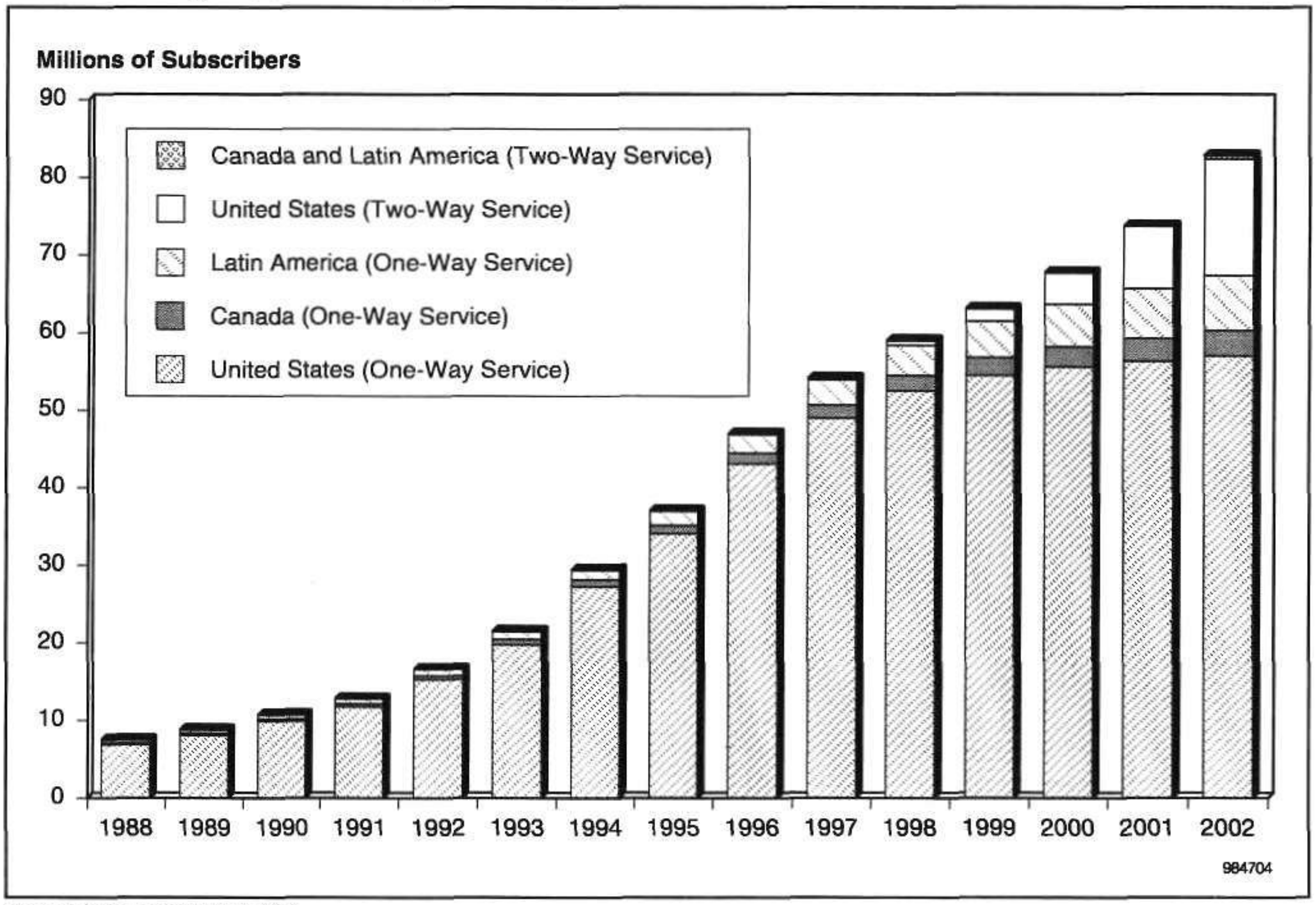
Company	Location
Acyclon Electronics	Belgium
Birdy Electronics	Hong Kong
BW Trading Company	Hong Kong
Casio	Japan
Ericsson Radio Messaging	Sweden
Everong Mobilcom (Samsung)	South Korea
Glenayre (Wireless Access)	United States
Globule Telecom	South Korea
Gold Apollo	Taiwan
Goldtron Telecom	Singapore
Group Sense	Hong Kong
Hantel	South Korea
Hephzibah	South Korea
HFCL Kongsun	South Korea/India
Houly Company	Taiwan
HEC	South Korea
IBM/Swissphone	Italy/Switzerland
Infomobile	France
Inventel	France
Kongsung Communication & Elec.	South Korea

Table 3-3 (Continued)
Pager Manufacturers and Suppliers

Company	Location
Kokusai	Japan
LG Electronics	South Korea
Matsushita Electric	Japan
Maxon	Multiple locations
Mini Micro Methods	Hong Kong
Mirae Communications	South Korea
Motorola	Multiple locations
Nerval	Hong Kong
NEC	Japan/United Kingdom
Nippon Telephony	Taiwan
Nixxo Telecom	South Korea
Oi Electric Company	Japan
Option International	Belgium
Pagerola	Taiwan
Pantech	South Korea
PCSI	United States
Philips	Multiple locations
Plantronics	Hong Kong
Prod-Art Technology Group	Hong Kong
Pro-Teck Electronics	Taiwan
Rexon Technology	Taiwan
RF Tech	South Korea
RJP International	Hong Kong
Samsung	South Korea
Seacorp Communications Systems	Hong Kong
Signal Technology	Taiwan
Smartek Technology	Taiwan
Sony	Multiple locations
Star-Fact International	Taiwan
Standard Telecom	South Korea/United States
Swatch	Switzerland
Swissphone	Switzerland
Truly Electronics Manufacturing	Hong Kong
Uniden	Multiple locations
Vis'tel Communications	United States
Wan Pen Company	Taiwan
Wavecom	France
Wide-Hertz Technology	Taiwan

Source: Dataquest (July 1998)

Figure 3-4
Americas Pager Subscribers (Millions)



Source: Dataquest (July 1998)

In the United States, financial difficulties and bankruptcies are driving continued consolidation in the paging industry. Although service providers have been adding large numbers of new subscribers, price competition has limited or prevented them from achieving profitable revenue streams. As a result, consolidation reached even the larger national providers in 1997 and 1998. Even major players such as AT&T Wireless Services Inc. have sold their paging services to other service providers. The leading nationwide paging service providers are SkyTel Communications Inc. (formerly Mtel), Arch Communications Group Inc., MobileMedia Corporation, Metrocall Inc., Paging Network Inc. (PageNet), AirTouch Communications Inc., TSR Wireless LLC, and PageMart Wireless Inc. PageMart is a good example of one of the faster-growing providers of paging services in the United States. In the first quarter of 1997, the company announced plans to move beyond offering nationwide coverage to create a footprint covering the North American Free Trade Agreement (NAFTA) trading bloc countries and most of Central America. Through agreements with pager service providers in other countries, it will operate at the same 900-MHz frequency throughout its coverage area and offer subscribers coverage ranging from Canada to the Panama Canal.

Table 3-4
Americas Pager and Narrowband PCS Market

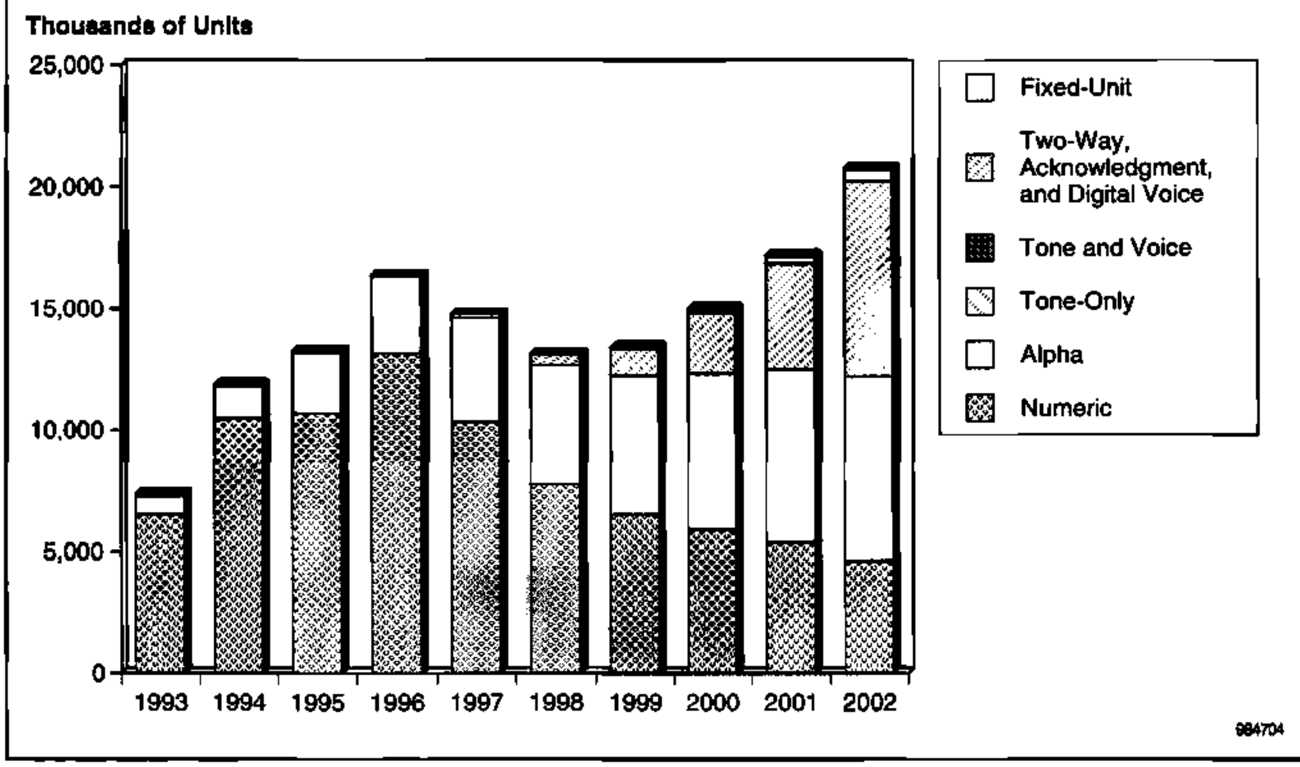
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Americas Subscribers (M)	**21.5**	**29.4**	**37.0**	**46.9**	**54.0**	**59.0**	**63.1**	**67.6**	**73.7**	**82.7**	**8.9**
United States (Two-Way Service)	-	-	0.02	0.03	0.2	0.6	1.6	4.0	8.0	15.0	146.1
Canada and Latin America (Two-Way Service)	-	-	-	-	-	-	-	0.01	0.04	0.40	NM
United States (One-Way Service)	19.8	27.3	34.1	43.1	49.0	52.5	54.5	55.6	56.3	57.0	3.1
Canada (One-Way Service)	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.0	3.3	14.3
Latin America (One-Way Service)	1.0	1.2	1.8	2.4	3.2	3.9	4.7	5.5	6.4	7.1	17.3
One-Way Pagers											
Subscribers (M)	21.5	29.4	37.0	46.9	53.8	58.4	61.5	63.6	65.7	67.3	4.6
Total Shipments (K)	7,349	11,858	13,221	16,342	14,624	12,677	12,269	12,334	12,515	12,212	-3.5
Numeric	6,551	10,489	10,712	13,159	10,355	7,775	6,537	5,925	5,409	4,622	-14.9
Alpha	751	1,341	2,488	3,179	4,267	4,901	5,731	6,408	7,106	7,590	12.2
Tone-Only	27	16	8	2	1	1	-	-	-	-	-100.0
Tone and Voice	20	12	12	1	-	-	-	-	-	-	NM
Factory ASP ($)	81	77	79	73	71	70	68	64	59	55	-5.0
Factory Revenue ($M)	595	918	1,050	1,187	1,042	887	834	789	743	674	-8.3
Two-Way Pagers (Narrowband PCS)											
Subscribers (M)	-	-	-	-	0.2	0.6	1.6	4.0	8.0	15.4	147.4
Total Shipments (K)	-	-	15	14	159	412	1,070	2,530	4,350	8,002	119.1
Factory ASP ($)	-	-	245	210	171	139	119	109	98	88	-12.4
Factory Revenue ($M)	-	-	4	3	27	57	128	275	424	675	90.2

Table 3-4 (Continued)
Americas Pager and Narrowband PCS Market

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
Fixed-Unit Pagers											
Installed Base (K)	-	-	-	-	0.6	25.0	80.0	200.5	501.5	1,004.0	341.3
Total Shipments (K)	-	-	-	-	1	24	55	121	302	505	284.6
Factory ASP ($)	-	-	-	-	160	129	110	101	91	82	-12.6
Factory Revenue ($M)	-	-	-	-	0.1	3.1	6.1	12.2	27.4	41.2	236.0
Total Pagers											
Subscribers and Installed Base (M)	21.5	29.4	37.0	46.9	54.0	59.0	63.1	67.8	74.2	83.7	9.2
Total Shipments (K)	7,349	11,858	13,236	16,356	14,783	13,114	13,394	14,984	17,167	20,719	7.0
Factory ASP ($)	81	77	80	73	72	72	72	72	70	67	-1.5
Factory Revenue ($M)	595	918	1,054	1,190	1,069	947	968	1,076	1,194	1,390	5.4

NM = Not meaningful
Source: Dataquest (July 1998)

Figure 3-5
Americas Pager and Narrowband PCS Market



Source: Dataquest (July 1998)

While traditional paging services in the Americas are predicted to reach 67.3 million subscribers by 2002, demand for narrowband PCS services will add another 15.4 million subscribers and an installed base of 1 million fixed-unit pagers to the overall Americas pager market during the same time period. In addition to the United States, Canada, Mexico, Chile, Brazil, and Argentina are proceeding with plans for narrowband PCS services. (Two-way data and voice paging products have also been demonstrated by Motorola in China, India, the Netherlands, France, and Singapore.) American Paging Incorporated and Upper Canada Communications Group Inc. (UCCG) have entered into an agreement to coordinate development of narrowband PCS services. This alliance has gained approval from the U.S. Federal Communications Commission (FCC) and Industry Canada to construct and operate transmitters that will allow it to develop a North American network using matching frequencies.

The auctions for narrowband PCS licenses in the United States were completed in 1996. The winners of the first two auctions for national and five regional licenses are shown in Table 3-5. Unfortunately, while service providers were anxious to roll out services as soon as possible, additional system and technology development issues had to be addressed. This has resulted in delayed introductions of new narrowband PCS services, while key equipment suppliers such as Motorola, Wireless Access, and Glenayre Technologies Inc. worked to produce infrastructure equipment and subscriber units. (Wireless Access was acquired by Glenayre in November 1997.) On September 18, 1995, SkyTel announced the availability of the first nationwide two-way paging service. Although SkyTel had reached 24,100 subscribers by the second quarter of 1996, its rollout was hindered by various systems problems that limited total subscribers to fewer than 30,000 by the end of 1996.

SkyTel embarked on a relaunch of its two-way services beginning in April 1997, expecting that, by then, the top 30 U.S. cities would have adequate return-path coverage. The company has increased the number of both transmitters and receivers in its system and the ratio of receivers to transmitters from 3:1 to 5:1. SkyTel set a target of 200,000 net subscriber additions for 1997 and finally reached 158,600 total subscribers by the end of 1997. By the end of the first quarter of 1998, it had nearly 225,000 total subscribers to its advanced messaging services.

Table 3-5
U.S. Narrowband PCS Auction Winners

National Licenses	Regional Licenses
PageNet	PageMart (all five regions)
AT&T Wireless Services[1]	CONXUS (all five regions)
SkyTel	MobileMedia PCS[2] (all five regions)
AirTouch Paging	American Paging[3] (all five regions)
MobileComm/MobileMedia[2]	AirTouch Paging (three regions)
PageMart	Adelphia Communications[4] (Lisa-Gaye Shearing) (three regions)
	Benbow PCS Ventures (two regions)
	Ameritech Mobile Services (one region)
	Insta-Check Systems (one region)

[1]Sold by AT&T to Metrocall, including one of two nationwide narrowband PCS licenses. The disposition of the second license is still undetermined.
[2]Entered bankruptcy. Sold to Arch Communications.
[3]Merged with TSR Paging to form TSR Wireless.
[4]Renamed PageCall. Sold all three licenses to Benbow PCS Ventures.
Source: Dataquest (July 1998)

PageNet was the second company to deliver narrowband PCS services in the U.S. market and the first to introduce a voice paging service using Motorola's InFLEXion technology. It began with a "soft" launch of its VoiceNow service on February 24, 1997, in Dallas and planned to move to a full marketing campaign and introduction of services in San Francisco in mid-March. PageNet planned to complete a nationwide rollout over the following 12 months. It promoted the VoiceNow service as a mobile answering machine using the InFLEXion-based paging unit to receive and store digital voice messages sent to a subscriber. In the fully implemented system, PageNet planned to deploy 1,700 transmitter/receiver stations. However, after experiencing disappointing sales and critical technical problems in the Dallas market, PageNet canceled its introduction of VoiceNow service in any additional markets. Total subscribers to the VoiceNow service peaked at just over 3,000 at the end of the third quarter of 1997. PageNet plans to relaunch a narrowband PCS service in the Chicago market in 1998. If it is successful with its new marketing approach in Chicago, PageNet plans to introduce services in additional cities.

Other service providers are at various stages of delivering, launching, or planning services based on narrowband PCS technologies. They are as follows:

- CONXUS Communications Inc.—The Pocketalk service, which was launched in the Washington, D.C./Baltimore and South Florida areas in November 1997, was the second major voice paging introduction. In the first 90 days of service, more than 6,000 subscribers signed up for the service, and by March 1998, services were expanded to Dallas/Ft. Worth, Houston, Orlando, Tampa/St. Petersburg, Los Angeles, and Chicago. By the end of the third quarter of 1998, CONXUS plans to have covered about 90 million people in major cities with various systems. CONXUS has deployed a paging network using equipment from Glenayre that is capable of supporting ReFLEX25 data services and InFLEXion voice services. Major investors in CONXUS include Metrocall and Arch Communications.
- PageMart—Construction of a narrowband PCS ReFLEX25 network is under way in 16 markets. Plans call for the initial launch of 1.5-way paging services to move to full two-way interactive services by the end of 1998. A limited supply of subscriber devices is listed as one of the factors impeding a launch of two-way services.
- Metrocall—AT&T Wireless Services announced in March 1997 that it would not deploy the Personal Air Communications Technology (pACT) two-way paging network it had been developing. By 1998, the company had decided that its messaging division was not a core business and began seeking buyers. In July 1998, Metrocall bought AT&T Wireless Services, and, as part of the deal, it received one of AT&T's nationwide narrowband PCS licenses. Metrocall plans to meet the FCC's minimum build-out requirements by September 1999, and it will look to telemetry and two-way services as possible applications. AT&T Wireless Services retains its second nationwide license and has not announced its plans for this license.
- Arch Communications—Implementation of its network is scheduled to begin in 1998. The company currently holds equity positions in both CONXUS and Benbow PCS Ventures Inc. and is reselling advanced paging services from both of these companies.

- MobileComm Inc.—MobileMedia was acquired by Arch Communications in September 1998. Previously in a state of bankruptcy, MobileMedia/MobileComm has been beta testing narrowband PCS services in Dallas and San Francisco; it had plans to complete a nationwide buildout by early 1999.
- Benbow PCS Ventures—In addition to the two regional narrowband PCS licenses it acquired at the auction, Benbow PCS Ventures acquired PageCall with its three regional licenses, to complete a nationwide footprint. Benbow PCS Ventures expects to begin offering advanced paging or messaging services sometime late in 1998 or early 1999. It is currently testing InFLEXion services in San Diego using Glenayre network equipment and subscriber units from Motorola. It also expects to begin ReFLEX25 testing soon.
- TSR Wireless—American Paging merged with TSR Paging to form TSR Wireless. At one time, it had been working with Nexus Telocation Systems Ltd. to develop a paging competitor to the FLEX technologies. However, this relationship has taken a bad turn, and the companies are currently battling in court. TSR Wireless has been testing a ReFLEX25 paging system in Pittsburgh since August 1997. It has been reported that TSR Wireless plans to introduce narrowband PCS services in 1998.
- AirTouch Paging—Little information has been released on the development of its system. Some reports indicate that it has plans to introduce narrowband PCS services in 1998.
- Ameritech Mobile Services—It is not actively developing narrowband PCS services currently.
- Insta-Check Systems Inc.—There is no recent information on its plans.
- Bell Mobility—It began testing advanced voice messaging services in Canada in early 1997.

A number of financial analysts and industry watchers have begun to question the viability of the narrowband PCS business in light of the recent financial difficulties in the paging industry and the introduction of cost-effective messaging capabilities through broadband PCS services. Dataquest remains optimistic about the prospects for the narrowband PCS market, based on its belief that it presents the most efficient and cost-effective solution for the mobile messaging and data communications needs of mobile professionals. While a number of consumer surveys have touted the preference of consumers for the types of services afforded by narrowband PCS, current pricing of systems and hardware will limit this market to the high end of the market in the near term.

Motorola is the dominant supplier of pagers to the Americas market, with more than a 75 percent market share. Most pagers sold in the Americas are produced in the Americas region. In addition to Motorola, other major OEMs in the market include NEC Corporation, Uniden America Corporation, Panasonic Communications & Systems Company/Matsushita Electric Industrial Company Ltd., Samsung Telecommunications America Inc., Hyundai Electronics Company Ltd. (HEC), Goldstar Technology Inc., and Philips Consumer Communications LP. A number of relatively new market entrants have set aggressive goals for the paging market. These companies are Wireless Access (Glenayre), Sony Corporation, Casio Computer Company Ltd., Standard Telecom America Inc., and Philips. Table 3-6 shows the Americas pager production forecast.

Table 3-6
Americas Production of One-Way and Two-Way Pagers

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	CAGR (%) 1997-2002
One-Way Pagers											
Units (K)	7,800	11,994	13,533	16,170	14,429	12,636	12,275	12,352	12,485	12,183	-3.3
Factory ASP ($)	80	78	79	73	71	70	68	63	59	55	-5.1
Factory Revenue ($M)	627	931	1,064	1,173	1,026	882	830	784	736	668	-8.2
Semiconductor Content ($)	12	12	12	12	12	12	12	12	12	12	0.3
Semiconductor Market ($M)	94	144	164	196	176	156	152	154	155	151	-3.0
Two-Way Pagers/Narrowband PCS											
Units (K)	-	2	15	16	106	324	827	1,627	2,641	4,337	110.2
Factory ASP ($)	-	245	241	337	171	129	117	107	95	82	-13.6
Factory Revenue ($M)	-	-	4	5	18	42	97	174	252	357	81.7
Semiconductor Content ($)	-	47	47	80	45	38	37	35	31	28	-9.1
Semiconductor Market ($M)	-	-	1	1	5	12	31	56	83	121	91.1
Two-Way Fixed-Unit Pagers											
Units (K)	-	-	-	-	0.6	24.4	54.1	114.8	241.6	353.5	258.1
Factory ASP ($)	-	-	-	-	160	129	110	101	91	82	-12.6
Factory Revenue ($M)	-	-	-	-	0.1	3.1	6.0	11.6	21.9	28.8	212.9
Semiconductor Content ($)	-	-	-	-	44	40	38	35	32	30	-7.7
Semiconductor Market ($M)	-	-	-	-	0.03	0.98	2.06	4.02	7.73	10.43	230.6
Total Pagers											
Units (K)	7,800	11,996	13,548	16,186	14,536	12,985	13,156	14,094	15,367	16,873	3.0
Factory ASP ($)	80	78	79	73	72	71	71	69	66	62	-2.8
Factory Revenue ($M)	627	931	1,067	1,178	1,044	927	933	969	1,009	1,054	0.2
Semiconductor Content ($)	12	12	12	12	12	13	14	15	16	17	6.1
Semiconductor Market ($M)	94	144	164	197	181	169	185	215	246	283	9.3

Source: Dataquest (July 1998)

Feature and Technology Trends

Systems and Standards

The pager has begun a metamorphosis into a true personal communications device. The evolution of paging devices from simple beepers or vibrators into robust devices that will provide services from wireless e-mail to mobile answering machines is shown in Figure 3-6. The new services that will be enabled by narrowband PCS technology include two-way messaging, acknowledgment paging, enhanced voice messaging (mobile answering machine), facsimile transmission, Internet access, and e-mail communications. New paths of communication have been opened that will make the pager a valuable access point to a network that includes portable and desktop computers, fax machines, telephones, corporate LANs, the Internet, and other pagers and cellular phones. Figure 3-7 provides an illustration of how new advanced messaging networks will operate.

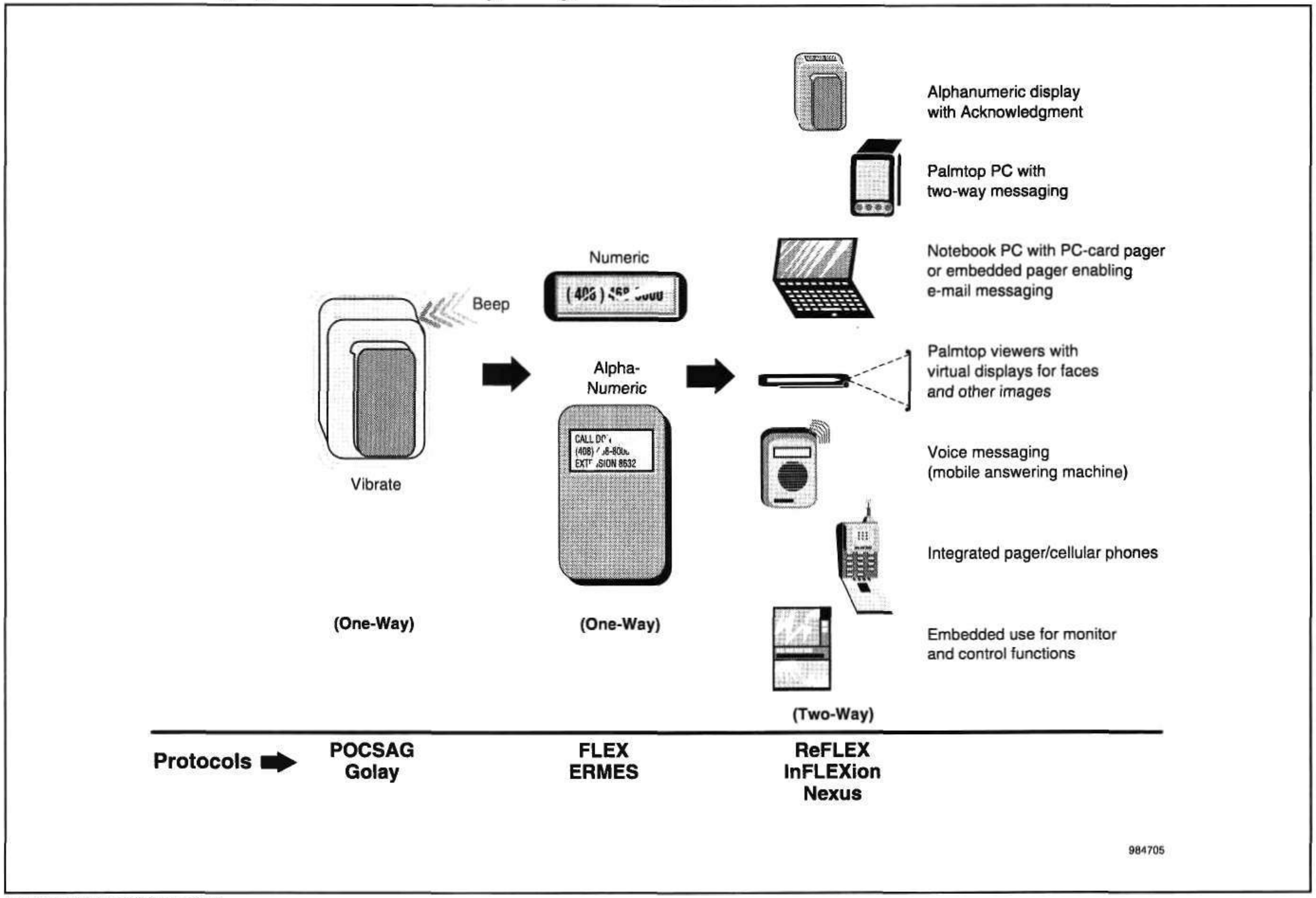
The FLEX Protocol Family

Motorola is promoting the new FLEX family of paging protocols as the platform that will move the paging industry into the 21st century. It has moved aggressively, investing over $100 million to accomplish its desire to establish FLEX as a worldwide de facto standard for pagers. The establishment of FLEX as a high-tech brand name in 1995 was very successful as the term FLEX became almost synonymous with next-generation paging technology. The FLEX brand is becoming to pagers what "Pentium" is to the PC industry.

High-Speed One-Way Paging. The FLEX one-way messaging protocol was introduced by Motorola in June 1993. Motorola describes the major benefits of this protocol as the following:

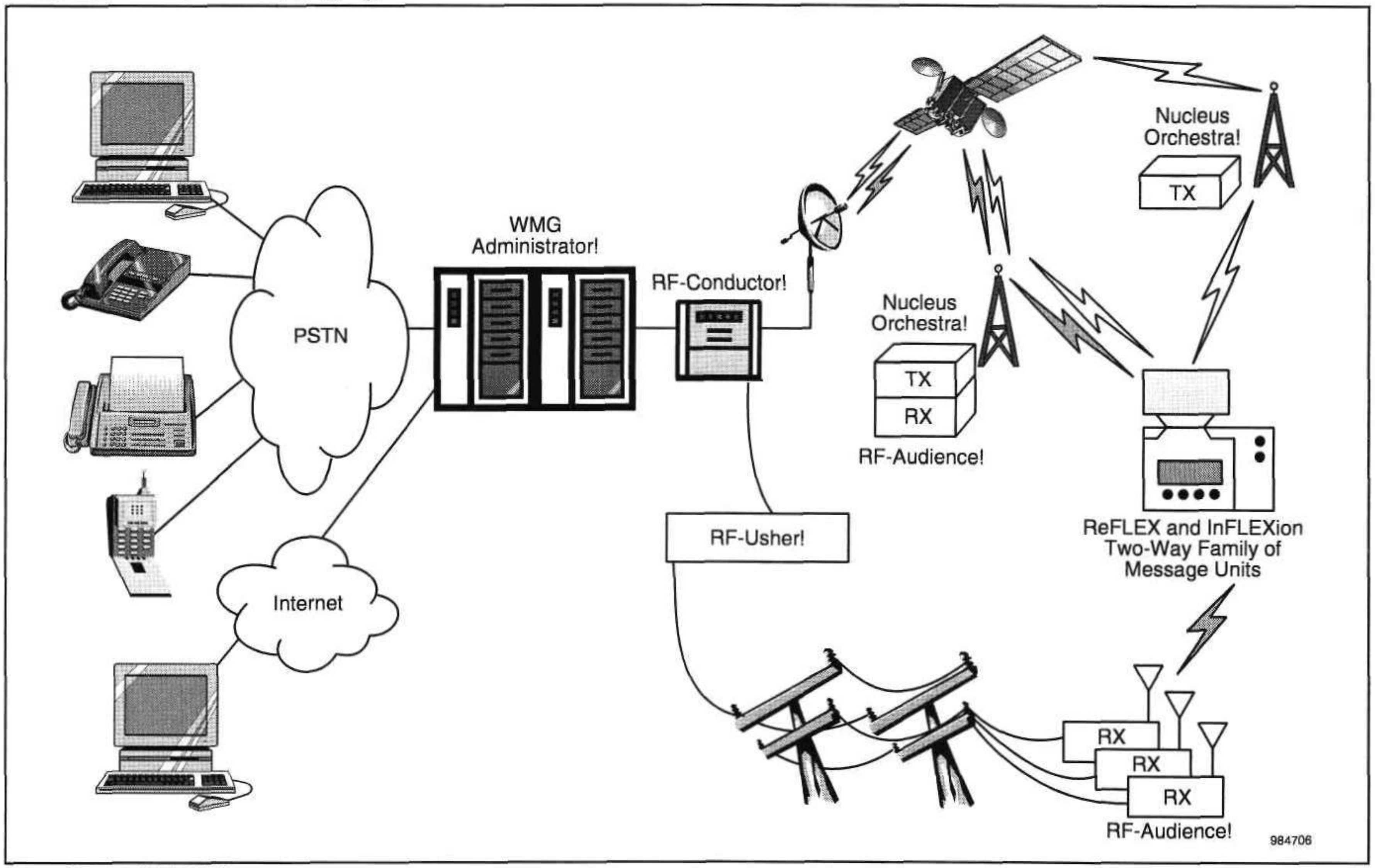
- Capacity and speed—FLEX operates at speeds of 1,600 bps, 3,200 bps, and 6,400 bps, compared to the Post Office Code Standardization Advisory Group (POCSAG) protocol with 2,400 bps. The original FLEX system could support up to 1 billion individual addresses and up to 600,000 pagers per channel.
- Battery life—The use of a "synchronous" time slot protocol allows the pager to search for messages at specific times and conserve battery power.
- Flexibility—The FLEX system is designed to coexist with a POCSAG or Golay system so that an operator can operate a channel with two protocols prior to dedicating an entire channel to FLEX.
- Data integrity—Accurate message delivery is enabled by improving protection from signal fading and implementing checksum validations, message numbering, and positive end-of-message control.

Figure 3-6
The Evolution of Paging Terminals: Yesterday, Today, and Tomorrow



Source: Dataquest (July 1998)

Figure 3-7
Motorola's Advanced Messaging Solution



Source: Dataquest (July 1998)

Since the release of the original FLEX protocol, Motorola has announced additional enhanced versions of the protocol. Version 1.8 enabled backward compatibility with earlier versions of FLEX and allowed greater flexibility in the use of frequencies so that networks can be assembled and managed more easily and the number of unique addresses can be increased fivefold. The FLEX-TD protocol was developed to meet the needs of the Japanese market. This protocol is based on a combination of FLEX technology and elemental technology from NTT DoCoMo. Version 1.9 of the FLEX protocol was announced in March 1998, and enabled the following enhancements:

- Unique simulcast system identifier (SSID) for determining geographic location
- Dynamic group messaging and message sequence numbering for efficient and reliable delivery of broadcast information
- Consistent FLEX time updates accurate to within 1/100th of a second
- New and enhanced decoding operations and defined character sets for over 30 languages
- An added status information field that enables the "FLEX Suite" of application-enabling protocols
- Enabled compatibility for advanced features such as compression, encryption, and over-the-air programming
- New addressing methods that increase potential capacity by four times
- Increased minimum FLEX transmission that can enable battery-life increases up to 50 percent

As of March 1998, the FLEX protocol had been adopted by 229 carriers in 48 countries that represent 92 percent of the worldwide pager subscriber base. FLEX technology adopters include 18 of the top 20 U.S. service providers, over 21 major carriers in China, and top operators in South Korea, Indonesia, Singapore, Malaysia, Thailand, Latin America, Canada, and Japan. It is a national standard for high-speed paging in Japan, Korea, India, Russia, and China. There are over 80 licensees of the FLEX technology. Between December 1994 and March 1998, more than 30 million FLEX technology-enabled devices were shipped. The following are key developments related to the FLEX protocol during 1997 and the first half of 1998:

- It was announced in May 1998 that the Wireless Application Protocol (WAP) specifications will support the FLEX and ReFLEX paging protocols.
- A strategic agreement took place between Microsoft Corporation and Motorola in January 1998 to develop products and technology enabling wireless communications on mobile devices based on the Windows CE operating system. Under the agreement, Motorola will design, manufacture, and sell a set of wireless modules for Windows CE-based devices that provide paging capabilities through FLEX technology.

- In December 1997, the ITU approved the inclusion of FLEX technology in the recommendations on codes and formats for radio paging.
- The Synapse pager card for enabling FLEX-based paging on 3Com Corporation's PalmPilot platform was developed. Beta testing of the new card developed by Motorola and the service offered by PageMart was completed by the summer of 1998.
- Paging networks based on the FLEX protocol were implemented in Western and Eastern European countries (the United Kingdom, Germany, Russia, Poland, the Ukraine, Hungary, and Lithuania).

In its efforts to expand the FLEX pager market, Motorola has worked to enable the development of various products based on the FLEX protocol. In a continuation of earlier licensing approaches, Motorola began by selling FLEX licenses to different systems manufacturers. However, without significant applications and technology support, systems manufacturers were finding it difficult to develop FLEX products. Under this licensing arrangement, NEC was the only company other than Motorola that was able to bring a FLEX pager to the market.

Beginning in 1995, Motorola began pursuing a new strategy for promoting the development of FLEX-based products. It announced that it had licensed Texas Instruments Inc. to produce a FLEX chipset that vendors could use to create FLEX-based products. This announcement has been followed by major announcements with other key semiconductor vendors, such as Philips, Wireless Access, and Taiwanese companies under the administration of the Industrial Technology Research Institute (ITRI). Wireless Access, now a part of Glenayre, is licensed as a supplier of both ReFLEX-based pagers and chipsets. Philips is licensed for the entire FLEX family, including FLEX, ReFLEX, and InFLEXion. ITRI can administer licenses for the FLEX technology with Taiwanese chip suppliers. With this new arrangement, manufacturers can purchase a FLEX chipset from Motorola or one of the licensed semiconductor suppliers and develop a FLEX-based product without obtaining a license directly from Motorola.

The FLEX chipsets bring down a major technological barrier to the development of next-generation products and will enable new products, ranging from pagers to PDAs to TVs, that incorporate FLEX technology. By early 1997, there were over 42 different product designs around the world at different stages that incorporated the FLEX chip. Innovative products such as the MessageMan Chinese-language pager from Eten Information Systems Co. and the receiver for the AirMedia Live Internet service are based on the FLEX chip product. Products from Casio, Sony, and Standard Telecom also incorporate the FLEX chip. A list of the FLEX family licensees is given in Table 3-7.

Table 3-7
FLEX Family Licensees

Pagers	Infrastructure	Test Equipment	Chipsets
Casio (F, FT)	Complex Communication Systems (F)	Advanced Signal (F, FT, R, I)	ITRI (F)
Ericsson (F)	Eagle Wireless International (F)	Cat Data (F)	Motorola (F)
Everon Mobilcom (F)	EcoSoft GTCO (F)	Complex Communication Systems (F)	Philips Semiconductor (F, R, I)
Hantel (F)	Elsyton (F)	Cromack Industries (F, FT, R, I)	TI (F)
Kokusai (F, FT)	Enhanced Messaging Systems (F)	Focus Infocom (F)	Wireless Access (R, I)
Matsushita Electric (F, FT)	ERG Telecommunications (F)	Grayson Wireless (F, R, I)	
Maxon America (F)	Ericsson Radio Messaging (F)	Hark Systems (F)	
Mirae Communications (F)	Genie Telecommunications (F)	HP (F, R, I)	
Motorola (F, R, I)	Glenayre (F, R, I)	IFR Systems (F, R, I)	
NEC (F, FT)	Hark Systems (F)	Jung Jin Electronics (F)	
Pantech (F)	Industrial Software Partners (F)	Linktronic Systems (F, FT)	
Philips Consumer Communications (F, R, I)	JP Systems (F, R)	Mobile Systems (F)	
Samsung Telecom (F)	LSE (F)	Motorola (F, R, I)	
Standard Telecom (F)	Mini Micro Methods (F)	Philips Consumer Communications (F, R, I)	
Uniden (F, R, I)	Motorola (F, R, I)	R&D Technology (F)	
Video Guide (F)	Operator Hungaria (F)	Ramsey Electronics (F)	
Wireless Access (R, I)	Page-Link Technology (F)	Rohde & Schwartz (F, FT, R, I)	
	Philips Consumer Communications (F, R, I)	Sandstone Research Sciences (F)	
	Rohde & Schwarz (F, R, I)	Statistical Control Systems (F)	
	Samsung Telecom (F)	Tescom (F)	
	Statistical Control Systems (F)	TGA Systems (F)	
	Tecnomen Oy (F)	Wavetek (F, R, I)	
	TeleLink Communications (F)	Zetron (F)	
	TGA Systems (F)		
	Triple P Telematics (F)		
	Zetron (F)		

F = FLEX
FT = FLEX-TD
R = ReFLEX
I = InFLEXion
Source: Motorola Incorporated

Two-Way Messaging, Acknowledgment Paging, and Enhanced Voice Messaging. Motorola developed the first two-way paging device, the Tango pager. This unit was used by SkyTel in its initial launch of its narrowband PCS service. The Tango, which was based on ReFLEX technology, was phased out in April 1997, and replaced by a new portfolio of devices. The next messaging device to be introduced by Motorola was the PageWriter 2000, in September 1996. Described as a pocket messaging center, the PageWriter 2000 incorporates a QWERTY keyboard and a backlit screen with 240x160-dpi resolution in a 1.1x 3.7x 2.8-inch package weighing 6.3 ounces. The pager is based on Memos, Motorola's new open operating environment for messaging products, and operates on the ReFLEX two-way paging protocol networks. This unit went through extensive beta testing throughout the remainder of 1996 and became commercially available in 1997. SkyTel offers the PageWriter in its narrowband PCS offerings. The PageWriter is also available directly from Motorola for purchase by users for $399. In addition to the chipsets for implementing the ReFLEX protocol, other key chips in this product are the 68000 DragonBall processor, 1MB of flash memory, and 256KB of RAM. Motorola also introduced a scaled-back PageWriter in 1997, the PageWriter 250, which is priced under $300. A fourth messaging device from Motorola, the PageFinder, is basically a low-end pager with acknowledgment capability.

The Memos operating environment is a key element in Motorola's effort to carefully architect a complete wireless system that will provide a platform for many different types of "messaging-centric" devices. The company hopes that this new orientation will prove to be successful in the market, as opposed to the "computing-centric" handheld products that have struggled over recent years. It is Motorola's desire to support the development of a wide range of devices and applications that are based on the Memos operating system and the FLEX family of two-way paging protocols. In addition to the DragonBall, Motorola has ported the Memos operating system to the Cirrus Logic ARM710-based CL-PS7110 family.

Motorola's Tenor voice pager was initially deployed in the PageNet VoiceNow service and positioned as a mobile answering machine. Initial pricing for the device was $230, or it could be leased for $10 per month. Tenor is based on InFLEXion technology and receives and stores up to three minutes of messages. It also acknowledges receipt of a message back to the network. The size of a deck of cards and weighing about 5.5 ounces, it can operate up to six weeks on a 9V battery. Messages can be played back at 10 different volume settings.

Wireless Access, a subsidiary of Glenayre, is currently the only other supplier of two-way messaging devices based on ReFLEX technology. The first product introduced by Wireless Access was the AccessLink, which was based on the ReFLEX50 protocol; incorporated a four-line, 20-character backlit alphanumeric display; and had an onscreen virtual keyboard. It could be used to reply to messages with custom text or preset responses stored in the pager. It could also originate messages. It used 128K RAM for storage of up to 450 messages and 128K flash memory for program storage. SkyTel supported the AccessLink in its two-way messaging service. The initial retail price for the device was $350. Wireless Access shipped about 80,000 units of the first AccessLink devices but stopped manufacturing this model around January 1998. In July 1998, Wireless Access announced the AccessLink II, a smaller two-way device with more features than the first model. This pager is based on the ReFLEX50 protocol. It has been undergoing beta tests prior to its planned availability from SkyTel in August 1998. Pricing for this new model is expected to be below the $350 cost of the first model. Wireless Access is also supplying the AccessMate, which supports 1.5-way paging to PageMart, PageNet, and other carriers.

Entering 1997, Motorola had developed the FLEX family of paging technologies into the dominant platform for the next generation of paging services and products. While other two-way protocols and standards experience major difficulties, it is expected that narrowband PCS products and services employing FLEX technologies will begin to generate additional momentum in the marketplace in 1998. Table 3-8 presents a comparison of the ReFLEX and InFLEXion technologies.

Table 3-8
The ReFLEX and InFLEXion Technologies

	ReFLEX	InFLEXion
Standard Interface Support	IP, OSI, PCIA (TME), phone	IP, OSI, PCIA (TME), phone
FLEX-Compatible	Yes	Yes
Modulation	Four-level FSK	Four-level FSK; others
Simulcast	Yes	Yes
Capacity		
Outbound (Forward Channel)	Up to 19.2 Kbps (ReFLEX25) [1] Up to 25.6 Kbps (ReFLEX50)	Up to 112 Kbps[1]
Inbound (Return Channel)	800 bps, 1.6 Kbps, 6.4 Kbps[2] 9.6 Kbps over 12.5 kHz	800 bps, 1.6 Kbps, 6.4 Kbps[2] 9.6 Kbps over 12.5 kHz
Capacity Upgradable	Yes	Yes
Services/Applications		
Voice	No	Yes
Simple Acknowledgment	Device, user	Device, user
Multiple Response/ Preprogrammed	Yes	Yes
Two-Way Data Messaging	Yes	One-way voice, two-way data
Functionality		
Roaming	Yes	-
In-Building Penetration	Excellent	Excellent
Response Time/Message Delay	Depends on system design	Depends on system design
Location Technology	To a single transmitter	To a single transmitter
Encryption	Yes (option)	Yes (option)
Authentication	Yes (option)	Yes (option)

[1]Over 50 kHz
[2]Over a specified bandwidth, four times as much in 50 kHz
Source: Motorola Incorporated

The ERMES, Nexus, and pACT Protocols

ERMES. ERMES is a second-generation paging standard that has been backed by EU members hoping to generate a success similar to that of the Global System for Mobile Communications (GSM) in the digital cellular world. In developing a standard that allowed roaming across Europe, it was hoped that enough momentum would be created for ERMES to establish itself as a global standard. ERMES was scheduled for introduction in 1992, but the first services did not begin until late 1995. By the end of 1996, it had captured between 1 and 2 percent of the European paging market. There were 26 signatories to the ERMES MoU by the end of 1996. By January 1997, ERMES service was available in six countries: France, Finland, Switzerland, the Netherlands, Hungary, and Saudi Arabia. By December 1997, the number of signatories to the ERMES MoU had grown to 50, but there were only 16 operators in 12 countries offering services. Denmark, Sweden, the Ukraine, the Czech Republic, Kuwait, and the United Arab Emirates had been added to the list of countries with ERMES-based paging services. Operators in the United Kingdom and Germany have licensed ERMES, but various technical problems in these countries have prevented the rollout of services. So far, ERMES has not had a dramatic impact on the market. Only in France, where it has been marketed aggressively by paging operators, has it really taken off. Table 3-9 lists the licensees for ERMES equipment.

Problems with interference have plagued the introduction of ERMES. First, commercial deployment in Germany was delayed in 1993 when it was discovered that the 164-MHz-to-165-MHz radio band used by ERMES interfered with some television station broadcasts. In 1996, new problems were discovered during attempts to develop the two-way messaging capability. It appears that the return channel operates too close to a transmit channel carrier frequency. These types of problems may limit the use of ERMES to providing enhanced one-way messaging services instead of full two-way communications. With various delays creating problems for ERMES implementation, proponents of the FLEX protocol have been attempting to promote FLEX as a standard in Europe.

Because of strong political feelings behind the ERMES standard, a battle between ERMES and FLEX started to take shape in Europe toward the end of 1996. Operators, through the European Public Paging Association (EPPA), have argued that they should be allowed to choose their own technology, meaning that they wanted the option of implementing non-ERMES protocol networks such as FLEX. In 1998, the EC indicated that as long as a common digital standard is implemented across the region, it does not matter which one it is—a considerable retreat. This opened the way for the Motorola FLEX technology and associated systems such as ReFLEX, which includes two-way paging. One operator in Germany, Deutsche Funkruf GmbH (DFR), launched a commercial FLEX protocol-based network in August 1997. Additional FLEX networks were also introduced in France (France Telecom Mobiles Radiomessagerie) and the United Kingdom (PageOne Communications and BT Mobile) in early 1998.

Table 3-9
ERMES Pager and Infrastructure Equipment Manufacturers

Pagers	Infrastructure	Test Equipment	Chipsets	PCMCIA Cards
Acyclon Electronics	ATM Computer	Complex Communication Systems	Advanced Reality Technology	IBM-Swissphone
Ericsson	Comlab	RC Engineering	Ericsson	Infomobile
Goldtron Telecom	ERG		Ginjet Technology	Option International
HFCL Kongsun	Ericsson		Swissphone	
Inventel	Glenayre Electronics		Winbond Electronics	
Maxon	KCC Russia			
Motorola	Nuova Elit			
NEC	Rohde & Schwarz			
Oi Electric	Tecnomen			
Philips	Triple P			
Smartek				
Swatch				
Swissphone				
Wavecom				
Wide-Hertz Technology				

Source: ERMES MoU Organization

Nexus. Another alternative technology comes from Nexus Telecommunications Systems Ltd. of Israel. Based on Israeli military technology, the Nexus pagers would operate on a frequency-hopping spread spectrum network called NexNet and offer a lower-cost, lower-performance solution. One of the principal ways that this standard saves costs is in the infrastructure architecture. Carriers need to add only a return network to their existing outbound paging network. The first commercial two-way paging services based on Nexus technology were scheduled to be offered in Australia. Plans called for infrastructure to be in place and subscriber units available for an April 1997 introduction. The first order for the Nexus system was placed by a Russian service provider, with plans to eventually offer an automatic vehicle location service in addition to two-way paging. Samsung has signed a nonexclusive licensing agreement to manufacture the two-way TAG pager for Nexus. The anticipated retail price of the pager was $200.

Nexus is also promoting its system to U.S. service providers. The technology has been adapted for use in the unlicensed 902-MHz-to-928-MHz industrial, scientific, and medical band. Nexus had already entered into a joint venture with American Paging to form American Messaging Services. The new company was established to offer two-way messaging and was conducting trials in Chicago. However, the joint venture between Nexus and American Paging, now TSR Wireless, has dissolved into a lawsuit and counter-lawsuit, with each party claiming that the other did not meet the terms of their agreement.

pACT. AT&T Wireless Services, Pacific Communication Sciences Inc. (PCSI), and Ericsson had announced their decision to develop a competing two-way paging technology called pACT. AT&T Wireless Services and LanSer Telecom Inc. of Canada planned to use this technology in the narrowband PCS services they would provide. The pACT protocol is rooted in cellular digital packet data (CDPD) technology and, because of its extensive use of Internet Protocol (IP), it was touted as being easy to integrate with other networks. The formation of a new industry organization, the pACT Vendor Forum, with 24 founding companies, was announced in July 1996. pACT networks were being tested in San Diego and Seattle, with commercial deployment planned for the first quarter of 1997.

In March 1997, AT&T Wireless Services terminated the development of its two-way paging network based on the pACT paging technology. After spending $160 million in licensing fees in the U.S. narrowband PCS auctions and after almost three years of development, AT&T Wireless Services decided that its paging business was a low priority and determined to refocus its investments to expand into the local telephone business and to build up its broadband PCS infrastructure. The status of AT&T Wireless Services' paging project had been uncertain since December 1996, when the company placed it on hold. AT&T took on the paging business as part of its acquisition of McCaw Cellular Inc. in 1994. With the termination of the pACT-based paging business, more than 100 employees were laid off, and the long-term business strategy for the messaging group, which employs 2,000 people at AT&T Wireless Services, was reassessed. The breakup of PCSI and the sale of its semiconductor and infrastructure groups had created earlier questions about possible impacts on the pACT technology development. Although there were efforts to promote the pACT technology to other countries and service providers, the loss of AT&T as the primary supporter of the technology proved to be the knock-out punch for pACT-based paging technology.

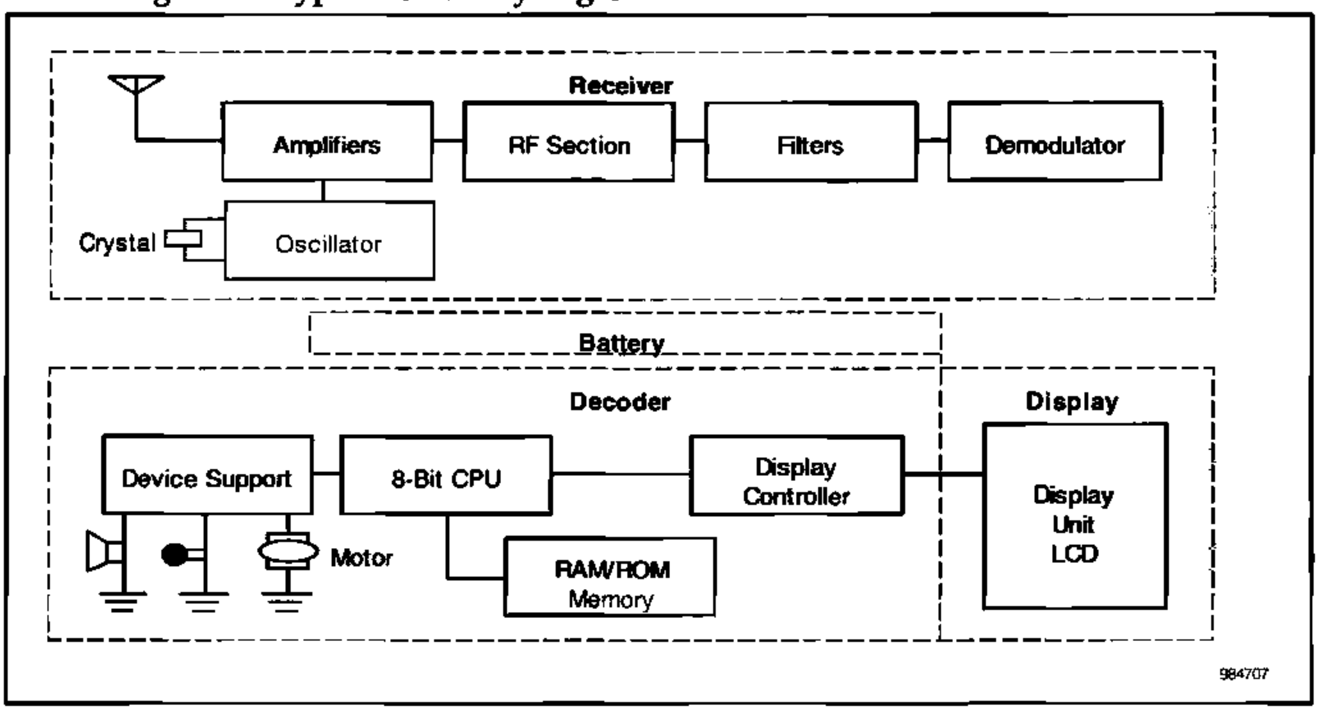
Semiconductor Trends

Traditional POCSAG Pagers

Pagers have changed dramatically in the past decade, taking advantage of microminiaturization, microprocessor advances, and extended battery life. Perhaps the most important feature of the traditional one-way pagers is their small size. Credit card-size pagers are now available, and wristwatch pagers manufactured by Motorola and others have also debuted.
Figure 3-8 shows a block diagram of a one-way pager, which consists of the following modules:

- Receiver—Includes the antenna, amplifier, and filter sections for amplifying and filtering the incoming radio frequency (RF) paging signal
- Decoder—Includes microprocessor and memory to decode, manage, and store messages
- Display—Displays messages and other information
- Battery—Provides power

Figure 3-8
Block Diagram of Typical One-Way Pager



Source: SkyTel Technologies

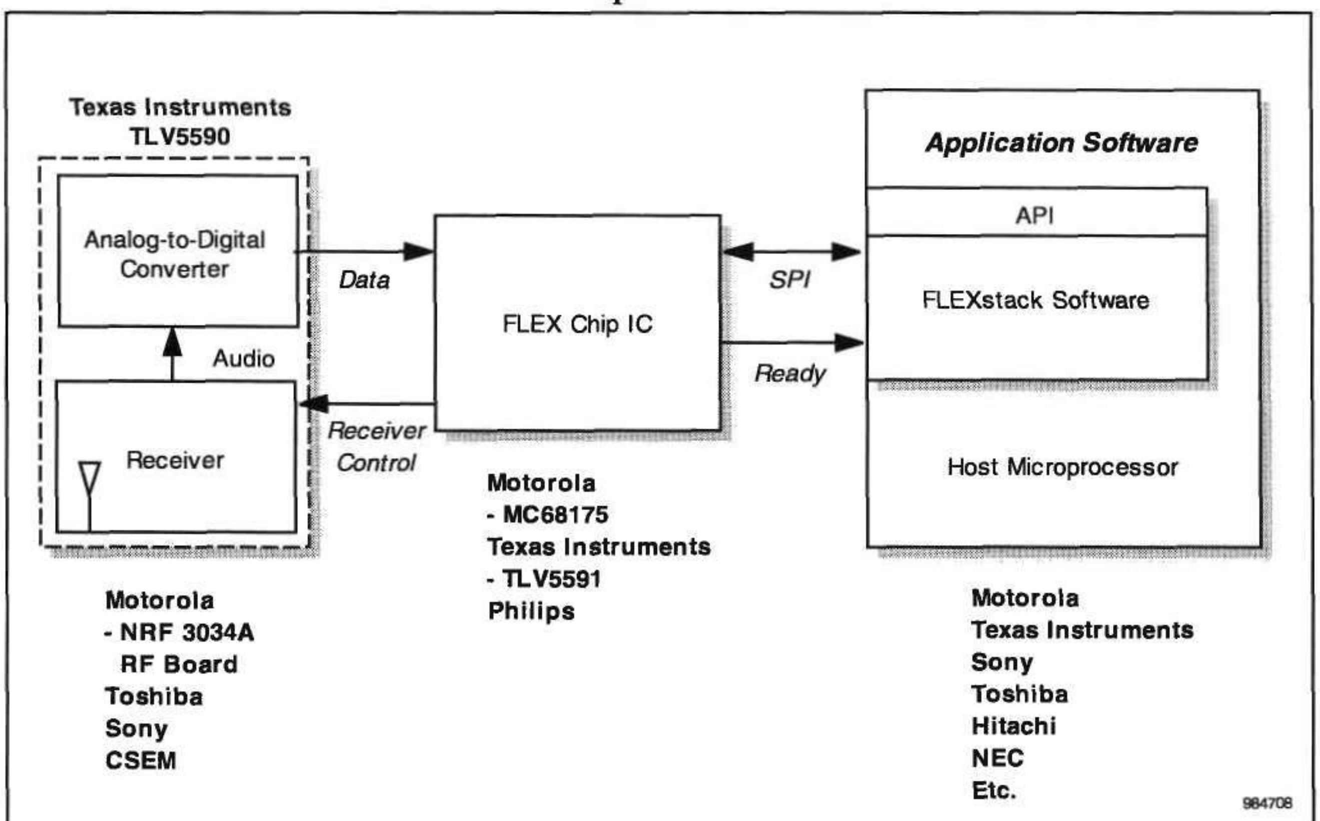
Some of the features offered by one-way pagers are the following:

- Numeric and alphanumeric paging
- Retaining and playing back received messages
- Vibration alert or buzzer alert
- Scrolling LCD display
- 24-hour built-in clock
- Time stamp
- Low-voltage alarm
- Canned messages

FLEX Pagers

As shown in Figure 3-9, a manufacturer can purchase a FLEX chip and also obtain, royalty-free, the FLEXstack Software and application program interface (API). The manufacturer can then invest its efforts in designing the receiver and user interface. The manufacturer is also free to select the microprocessor that best serves a particular application. Figure 3-9 provides a partial list of semiconductor manufacturers with microcontrollers (MCUs) that could be used in low-power wireless applications.

Figure 3-9
The FLEX Wireless Communications Chipset



Source: Motorola Incorporated

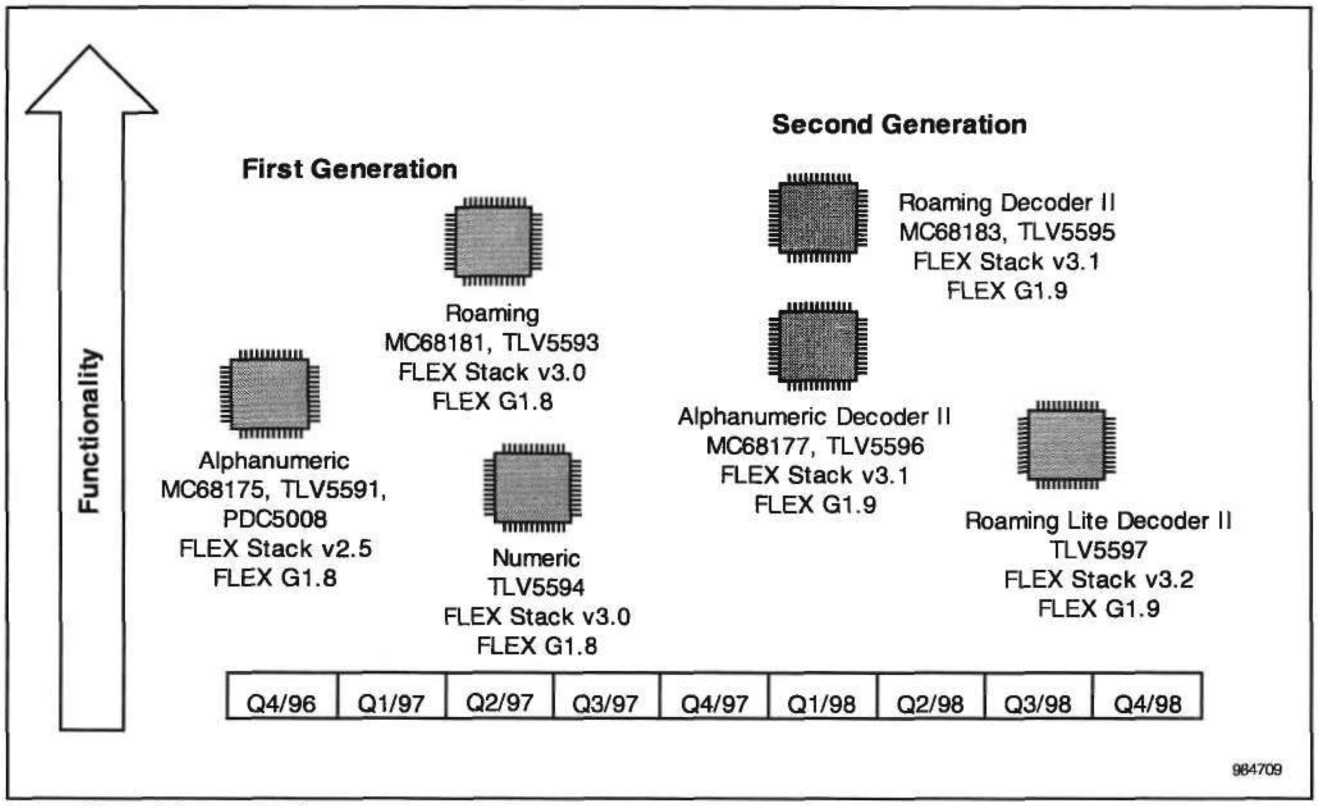
The semiconductor companies holding licenses to supply FLEX chips are Motorola, TI, Taiwan's ITRI, and Philips Semiconductors. The first products built around the FLEX chip started to come to market in early 1997. TI announced the availability of its two-chip FLEX chipset, the TLV5590 and TLV5591, targeted at alphanumeric devices, in November 1996. Its chipset began shipping in production quantities in January 1997, and early design-wins were in a Motorola pager and the Ex Machina receiver used for the AirMedia Live! service. Motorola began sample shipments of its 68175 FLEX chip in November 1996 and moved to full production in February 1997. Its early design-win came in the Casio 68175 pager. Motorola also introduced a new member of the HC11 family, optimized for paging applications. The 68HC11PH8 MCU has been optimized for use in FLEX pagers and is designed for low noise and low power. In addition to the MCU core, this device also contains 48Kb of ROM, 2Kb of RAM, and 768 bytes of EEPROM.

Important enhancements to the FLEX chip product that were implemented in 1997 and 1998 are the following:

- The first generation of FLEX chips were optimized for use in alphanumeric pagers. In April, Motorola announced a new FLEX chip optimized for use in numeric pagers. This chip will have the same basic architecture as the earlier version except that it will have only four addresses and single-phase transmission. Most importantly, this chip is priced so that the complete semiconductor solution for a FLEX numeric pager will be equivalent to the semiconductor cost for a POCSAG numeric pager. In addition to strategic pricing on the FLEX chip itself, the new chip for numeric pagers enables cost reductions for the MCU and memory as well. Confident about the demand for this product, the company processed risk wafers so that chips were available at the time of the announcement. This announcement will accelerate the displacement of POCSAG pagers by FLEX pagers. Dataquest expects production of one-way pagers to shift almost completely to the FLEX protocol by 2002.
- In many countries, such as China and South Korea, local paging service providers dominate the market and operate over slightly different frequency bands. This creates obstacles to roaming among regions with paging services at different frequencies. The FLEX 1.8 specification incorporates roaming as one of its important features. In June 1997, Motorola introduced a new roaming FLEX chip solution that solves the problem of roaming across different frequencies. Basically, if the roaming FLEX chip does not find a paging signal at the current frequency, it will go into a seek mode until it finds a frequency with a paging signal. This chip is pin-compatible with the current generation of FLEX chips. New FLEXstack Software should also be made available in June 1997.

- Three new chips to support FLEX version 1.9 in various applications will be shipped to the market in 1998. The FLEX Roaming Decoder II was introduced in April 1998 and will have applications in high-end pagers targeted at the Asia/Pacific market. The FLEX Alphanumeric Decoder II was also introduced in April 1998 and is targeted at applications such as PalmPilot products. Both of these chips are available from Motorola and TI. The Roaming Lite Decoder II is planned for introduction in September 1998 and will find its most likely applications in numeric pagers targeted at the Asia/Pacific market. All of these chips will enable an additional level of integration because they will incorporate an internal FM demodulator. Cost reductions will be achieved for this generation of chips by moving to 0.35-micron technology. Finally, an increase of up to 25 percent in battery life will be possible through managing sleep modes more efficiently. The product road map for the various FLEX chipsets is shown in Figure 3-10.

Figure 3-10
FLEX Decoder Solutions Road Map

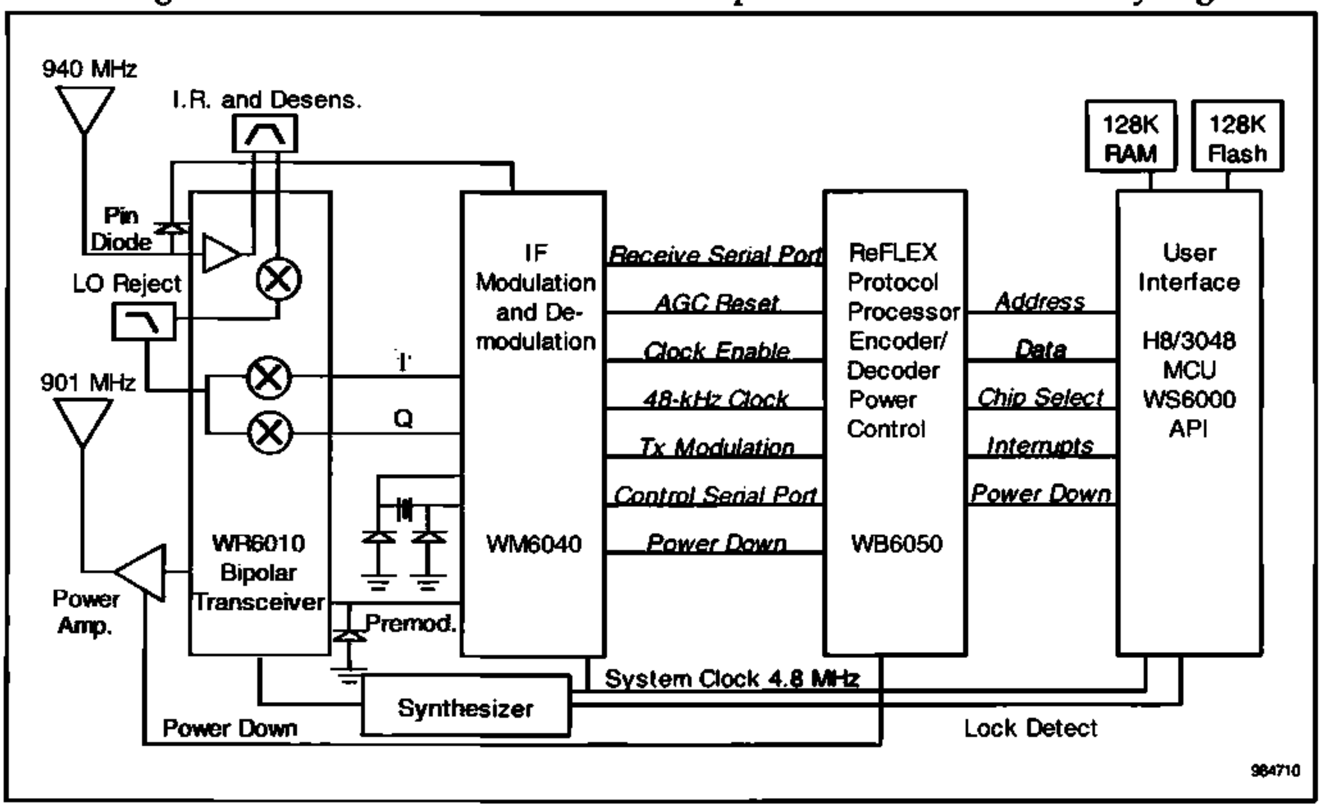


Source: Motorola Incorporated

ReFLEX and InFLEXion Pagers

The new generation of narrowband PCS pagers used for enhanced messaging presents new semiconductor opportunities for chipset and digital signal processing (DSP) products in the high-end devices and will expand the consumption of memory and RF devices in this segment. Wireless Access and Philips Semiconductors have been licensed to sell ReFLEX and InFLEXion chipsets in the merchant market. Figure 3-11 presents a block diagram of the Wireless Access ReFLEX chipset solution for a two-way pager. The series 6000 chipset can be electrically switched between ReFLEX25 and ReFLEX50. Wireless Access provides a complete antenna-to-user interface solution that includes the Hitachi H8/3048 embedded controller. The company has already charted a 50 percent reduction in die size and cost for future generations of the chipset. The chips for the complete ReFLEX paging solution are fabricated by Maxim Integrated Products Inc., IMP Inc., and Toshiba Corporation. Wireless Access also ships paging devices and is currently shipping AccessLink pagers based on the ReFLEX50 protocol to SkyTel.

Figure 3-11
Block Diagram of a Wireless Access ReFLEX Chipset Solution for a Two-Way Pager



Source: Glenayre Technologies Inc. (Wireless Access Inc.)

The POMP-15 processor from Lucent Technologies has been designed into all of Motorola's current two-way data and voice messaging products, Tenor, PageFinder, and PageWriter 2000 and 250. Lucent and Motorola have also announced that Lucent has been chosen to provide semiconductor chips for several Motorola two-way messaging units now under development. The POMP-15 chip incorporates a DSP 1600 core, 48KB of on-chip programmable ROM or flash, 4KB of SRAM, a 10-bit successive approximation analog-to-digital converter (ADC), a 12-bit sigma-delta digital-to-analog converter (DAC), and application clock generation. It features 0.7-mA/MIPS (million instructions per second) operation, 0.55-micron geometries, and a minimum operating voltage of 2.4V. The Motorola narrowband PCS pagers are the first major design-win for the POMP processor.

Chapter 4

Satellite-Based Mobile Communications Commercial Services

Satellite-Based Services

Satellite-based mobile communications commercial services are typically classified into the following categories:

- Geostationary—These satellites occupy an orbital position 36,000km above the earth and remain in a stationary position relative to the earth itself. The world's major existing telecommunications and broadcasting satellites fall into this category.
- Nongeostationary—These satellites occupy a range of orbital positions and do not maintain a stationary position but instead move in relation to the earth's surface.
  - Little LEO (low earth orbit)—Positioned between 700km and 1,500km above the earth and measuring about 1 meter cubed, these satellites provide mobile data and messaging services such as two-way paging, electronic mail, and electronic fax.
  - Big LEO—Positioned between 700km and 1,500km above the earth and larger than Little LEO satellites, these systems will provide real-time voice services in addition to data services. They will be used to provide global mobile phone services via personal handsets.
  - MEO (medium earth orbit)—Positioned 10,000km above the earth, these systems provide mobile telephony services.

To achieve global coverage, the new LEO systems will comprise several satellites orbiting in a constellation around the earth. These satellites will pick up signals and transfer them to their destination site via interconnection with other satellites in the constellation, or by interconnection to a series of earth stations on the ground and then to the terrestrial network.

According to a recent count, 1,335 communications satellites were scheduled for launch between the middle of 1997 and 2006. According to an ITU spokesperson, more satellites are expected to be launched in the next 10 years than all of those put in orbit over the past 30 years. Satellites planned for use in the delivery of global mobile communications commercial services accounted for 627 satellites, nearly half of the satellites scheduled to be put into service over the next 10 years. U.S. and European companies combined have announced plans to place nearly 250 satellites in orbit to support narrowband voice and data services. Also, about a dozen companies have announced projects totaling more than 300 satellites that would provide high-bandwidth Internet and video services beginning in 2000.

In their projections for the potential market, satellite service providers are setting ambitious targets. Iridium LLC anticipates servicing 650,000 voice subscribers and 350,000 paging subscribers worldwide by the end of 2000. Globalstar has estimated the total worldwide market for mobile and fixed voice services delivered via satellite to be 30 million potential subscribers. Odyssey put the number at 40 million, and ICO Global Communications, which absorbed Odyssey, sets the number at 50 million potential subscribers. Obviously, these projections represent the high end of the expected market.

Beginning in 1995, the commercial satellite industry began to move toward reality with the deployment of the first satellites and the granting of major licenses from the FCC in the United States. During 1995, two systems launched their first satellites into orbit, and three other systems received FCC licenses. American Mobile Satellite Corporation (AMSC) launched its first geostationary satellite above North America, and Orbital Communications Corp. (Orbcomm) launched the first two satellites of its planned system of 36 satellites. AMSC brought its Skycell service to the market in December 1995, and by the end of the second quarter of 1996, it had 9,200 subscribers. By the end of 1997, it had expanded its base to 32,400 subscribers. In December 1997, Orbital Communications launched eight more satellites, and by July 1998, the Orbcomm system had 12 operating satellites. Plans call for a basic constellation of 28 Orbcomm satellites to be in place by late summer 1998 so that services can be launched in 1999 while the remaining eight satellites are placed into orbit. Orbcomm has also received authorization to operate in Japan, Malaysia, and Canada. Gaining approval from various countries for their operations is a critical issue for satellite service providers. To accomplish this, they must show that they are not a threat to the local service providers and that they will not interfere with local spectrum usage. To encourage competition in domestic and international markets, the FCC adopted policies in November 1997 that will permit non-U.S.-licensed satellites to provide services in the United States.

Motorola's Iridium, Loral Space & Communications Ltd.'s and QUALCOMM Incorporated's Globalstar, and TRW Inc.'s Odyssey all received FCC licenses for their systems in 1995. Constellation Communication Incorporated, with its ECCO system, and Mobile Communications Holdings Inc., with its Ellipso system, both received licenses from the FCC for their systems in July 1997. By the end of May 1998, Iridium had launched and deployed its complete constellation of 66 satellites. It had also installed the necessary equipment in 11 of its 12 gateway terminals. By May 1998, Iridium had secured 190 service provider and roaming agreements, giving Iridium 80 countries in which it has at least 75 percent market access. Iridium has signed license agreements to operate in 50 markets and plans to be licensed in 100 markets by its service launch date in September 1998. The U.S. Department of Defense became the first Iridium customer, entering into an agreement in February 1998. The U.S. military is also exploring a potential contract with Globalstar. The phones for the Iridium system will be supplied by Motorola and Kyocera Electronics Inc. Handset pricing is projected to start at about $3,000, with cellular cartridges accommodating different standards priced at about $500.

Globalstar had eight satellites in orbit after a successful launch of four new satellites in April 1998. It is was originally anticipated that Globalstar would have 16 gateways in operation when it began delivering services in 1999. However, the loss of 12 satellites in a September 1998 rocket launch crash has now delayed the system deployment. In the first major industry consolidation, TRW integrated its interests in Odyssey with ICO Global Communications. This move means the demise of the planned 12-satellite Odyssey MEO system. TRW will give its license back to the FCC and take an equity position in ICO Global Communications. TRW will now focus its efforts on helping ICO Global Communications obtain authority for a 10-satellite MEO system to operate in the United States and other countries.

Perhaps the most ambitious project that has been announced is the Teledesic system, which is backed by AT&T (24 percent original ownership), Bill Gates (30 percent original ownership), and Craig McCaw (30 percent original ownership). Because of cost considerations, the scale of the system was reduced from 840 satellites to 288 satellites. The original cost of the system was projected to be $9 billion. This system is designed to deliver broadband data services. Teledesic received significant financial backing from two major sources in early 1998. First, Prince Alwaleed, a billionaire nephew of Saudi Arabia's King Fahad, invested $200 million in Teledesic. Second, Motorola abandoned its competitive efforts in its Celestri and M-Star system to join forces with Teledesic. Motorola will become the new prime contractor on the Teledesic team and receive a 26 percent stake in Teledesic in return for a combination of cash and development work that will be redirected from Celestri. The remaining potential competitors to Teledesic are Cyberstar, a geostationary system backed by Loral; SkyBridge, a LEO system backed by Loral and Alcatel Alsthom; and Spaceway, a geostationary system being developed by Hughes Communications Inc.

Table 4-1 presents a summary of the major operating and proposed mobile commercial communications satellite systems. A U.S. government report issued in 1997 predicted that as many as four Big LEO and three Little LEO constellations will be deployed and able to sustain operations between 1996 and 2005.

Table 4-1
Satellite-Based Service Systems and Proposals

Company	System Name	Number of Satellites	Target Service[1]	Satellite/ System Type	System Deployment Cost ($B)	Potential Services	Comments
AMSC (Hughes, AT&T Wireless, Motorola, SingTel)	Skycell	1	1995	Geostationary	0.6	Voice, data	Holds FCC license; one satellite, AMSC-1, in place and functioning; offers coverage throughout U.S., including Alaska and Hawaii; Skycell system operational in December 1995; 9,200 subscribers by June 30, 1996; 20,300 subscribers by February 28, 1997; 32,400 subscribers by the end of 1997; acquired ARDIS, a two-way wireless data service provider based on a terrestrial network, in March 1998
Celsat America (Hughes, Nortel)	Celstar	3	2000	Geostationary	1.4	Voice, data, fax, paging	-
Constellation Communication	ECCO	54	2001	Big LEO	2.8	Voice, data, fax, position location	Received FCC license in July 1997 after initially being denied approval due to financing; Orbital Sciences will manufacture and launch the first 12 of Constellation Communication's satellites
E-SAT	-	6	-	Little LEO	-	Data messaging services for gas and electric utilities, data support of DBS satellite, environmental monitoring	Received Little LEO license from FCC in 1998
Final Analysis Communication Services	Faisat	38 (Plus 6 spares)	2000	Little LEO	-	Data messaging, vehicle tracking, remote meter reading	Received Little LEO license from FCC in 1998

Table 4-1 (Continued)
Satellite-Based Service Systems and Proposals

Company	System Name	Number of Satellites	Target Service[1]	Satellite/ System Type	System Deployment Cost ($B)	Potential Services	Comments
Globalstar (Loral, QUALCOMM)	Globalstar	48	Mid-1999	Big LEO	2.5	Voice, data, fax, paging, short message service, position location	Received FCC approval in 1995; first satellite launch in December 1997; eight satellites launched by May 1998; has agreement to provide service in China; current plans for coverage in 100 countries; network deployment delayed by rocket launch crash in September 1998 that destroyed 12 satellites; CDMA air interface
Hughes	Spaceway (Galaxy)	12	2000	Geostationary	-	Voice, data, video, broadband services	-
ICO Global Communications (Inmarsat-P, TRW)		20	2000	MEO (Big LEO)	4.6	Voice, data, fax, paging	Offshoot of Inmarsat; satellite launches planned to begin in 1998; major consolidation when TRW integrated its Odyssey system with ICO; took an equity position in ICO; TDMA air interface
Iridium (Motorola, Lockheed Martin, Raytheon, multiple international backers)	Iridium	66 (Plus 6 spares)	Nov. 1998	Big LEO	3.4	Voice, data, fax, paging, messaging, position location	Received FCC approval in 1995; announced GSM memorandum of understanding membership; first satellite launch in January 1997, delayed by Delta II rocket explosion; entire constellation deployed by May 1998 with 11 gateways equipped; licenses signed for 50 markets with 100 markets planned for launch of services; handset pricing starting around $3,000; TDMA air interface
LEO One USA	LEO One	48	2001	Little LEO	0.3	Vehicle tracking, status monitoring, data acquisition, e-mail, security monitoring	Received Little LEO license from FCC in 1998
Loral	Cyberstar		1999	Geostationary		Broadband services	-

Table 4-1 (Continued)
Satellite-Based Service Systems and Proposals

Company	System Name	Number of Satellites	Target Service[1]	Satellite/ System Type	System Deployment Cost ($B)	Potential Services	Comments
Mobile Communications Holdings	Ellipso	17	2000	MEO and Little LEO	0.9	Voice, data, paging, e-mail	Received FCC license in July 1997 after initially being denied approval due to financing
Orbital Sciences	Orblink	7		MEO		High-speed data transmission	-
Orbital Communications (A unit of Orbital Sciences)	Orbcomm	48	1999	Little LEO	0.3	Data	Holds FCC license; 28 satellites planned to be in place and functioning by late summer 1998; expanded its total constellation size from 36 to 48 after receiving second Little LEO license allocation; has authorization for operation in U.S., Canada, Japan, and Malaysia
SkyBridge (Alcatel Alsthom, Toshiba, Loral)	SkyBridge	80	2001	Big LEO	4.2	Broadband services	Applied for FCC approval
Teledesic	Teledesic	288	2003	LEO	9.0[2]	Broadband services	Received FCC approval; backed by AT&T, McCaw, Gates, Motorola, and Boeing; plans to begin launches in 2000 and complete system in 18 months; scaled number of satellites back from 840 to 288 due to cost considerations originally projected at $9 billion; TDMA air interface
TMI Communication	MSAT	2	1996	Geostationary	0.5	Voice, data	Sold a half-interest in its MSAT-1 satellite to AMSC and leased its MSAT-2
VITA	VITASat	40	Q4/98	Little LEO	0.01	Data for educational, humanitarian, and development purposes	Holds two satellite licenses under Pioneer's Preference; received additional licenses in second round; lost first satellite during failed launch attempt; in arrangement with Final Analysis, was able to launch replacement satellite

[1]Indicates start of initial service. Full-constellation deployment and full service would follow over four to five years, typically.
[2]This number was quoted as the cost when Teledesic planned to launch 840 satellites. Now that it has scaled back to 288 satellites, a revised cost figure has not been published.
Source: Dataquest (July 1998)

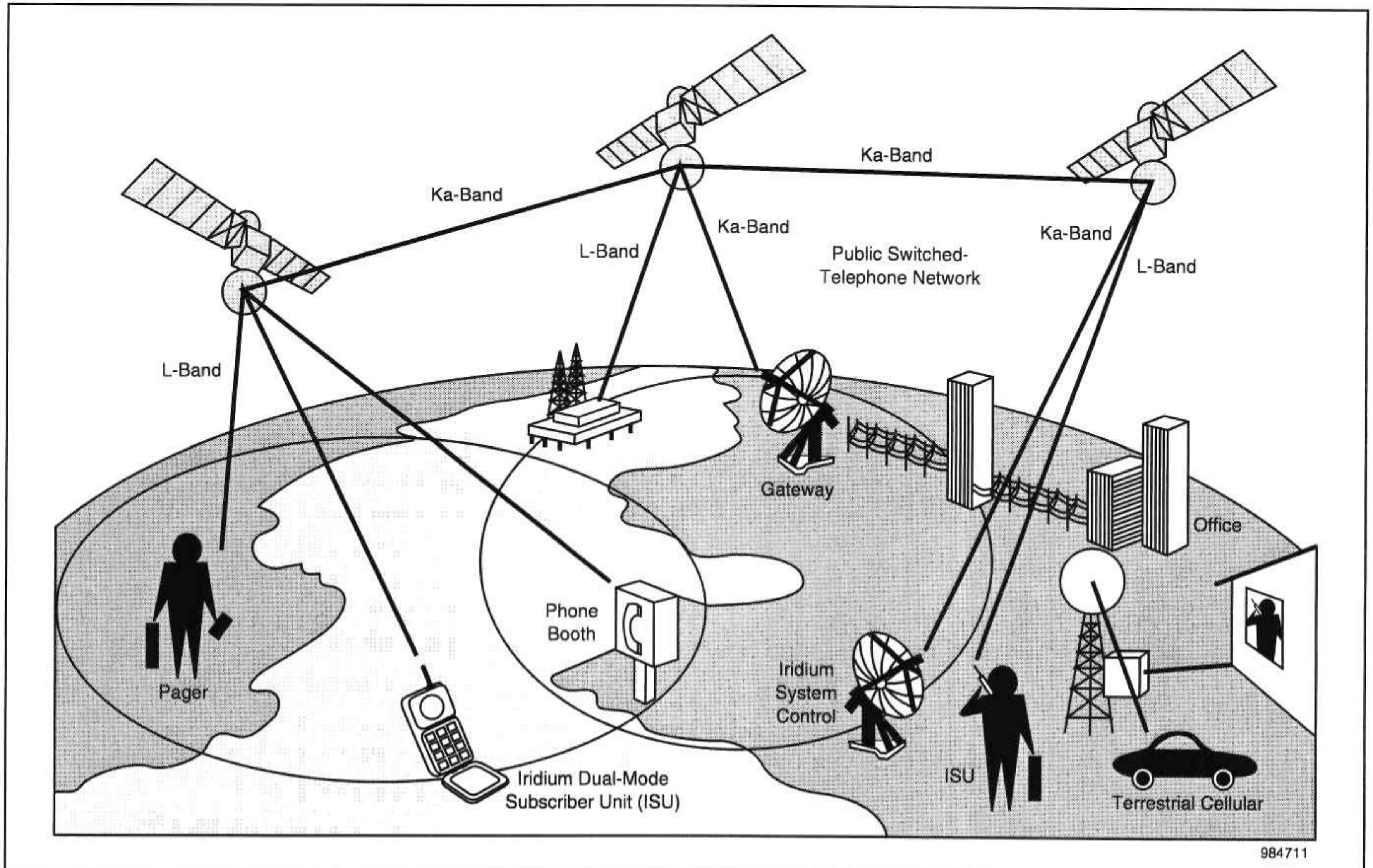
In addition to the systems described in Table 4-1, a new round of proposals is already being made for higher-performance systems. Some of the most prominent proposals are as follows:

- Iridium is developing plans for a new 96-satellite system called Macrocell MSS that would be able to send voice and data up to 80 times as fast as the current 66-satellite Iridium system. Operation of this system is proposed for 2002.
- Globalstar and 10 other companies have proposed a second 64-satellite network that would supplement its currently planned network in high-traffic regions.
- Mobile Communications Holdings has proposed a 26-satellite system capable of handling up to three times the voice and data traffic of its first system.

While all of these systems have the use of satellites as a switching and transmission system in common, they can vary significantly in the types of service they will offer. For example, the Teledesic system would provide communications for videoconferencing, computer networking, and other services as part of the spectrum called the Ka-band. The system would not compete with the global pocket telephone satellite systems being built by Motorola, TRW, and Loral. Figure 4-1 presents a depiction of Motorola's proposed Iridium system. Motorola's Iridium and Loral's Globalstar would also target slightly different markets. The Iridium would seek deep-pocketed business travelers, while the Globalstar system is targeting a general worldwide market. They also differ significantly in the architecture of their systems. The Iridium system would pass signals between its more complicated satellites, while the Globalstar system would relay communications using ground stations, which are easier to maintain and modify. The time-division multiple access (TDMA) and code-division multiple access (CDMA) technologies are also competing in the satellite communications arena. The Globalstar system uses CDMA as the air interface, and the Iridium system will use TDMA technology.

AMSC, which is co-owned by Hughes Communications, AT&T Wireless Services, Motorola, and Singapore Telecommunications Ltd. (SingTel), launched its first satellite in the spring of 1995 to a geostationary orbit 23,000 miles above Lubbock, Texas. This system presents a good example of the type of service and hardware offered in a satellite-based system. AMSC began offering mobile voice and data application services in December 1995 to a variety of users, including the land mobile, maritime, aeronautical, and fixed-site markets. The satellite can support hundreds of thousands of subscribers and provides dual-band satellite/cellular service for seamless coverage. AMSC's Skycell Satellite Roaming Service has agreements with 156 cellular carriers across the United States to be authorized service providers. Westinghouse Electronic Corporation's Series 1000 dual-band phones, which cost about $2,000, are available as units to be mounted in vehicles or in briefcases equipped with satellite dishes. Talk time averages $1.50 per minute, and customers pay a $25-per-month access fee. Its primary customers are in the transportation and field service markets. End-user terminals for the AMSC system are manufactured by Mitsubishi Electronics America Inc. The Mitsubishi ST151 Transportable Satellite Telephone measures 14 inches square and 4-3/4 inches deep and weighs less than 28 pounds. The phone allows a user anywhere within AMSC's service area—North America and 200 miles of coastal waters—to place and receive calls.

Figure 4-1
Motorola's Iridium: A LEO Satellite Network



Source: Motorola Incorporated

Many of the mobile satellite system (MSS) telephones that are being designed will operate on both cellular and satellite systems and are expected to cost between $600 and $750 at introduction. However, some phones will range even higher. The Iridium handset will cost $3,000 at introduction, and services were originally projected to be sold for $3.00 per minute. However, competitive pressures are already pushing pricing toward $1.50 per minute, and they could decline even more as the market begins to support volume shipments. None of the business plans envision volumes that approach the current cellular handset market. Other planned MSS phones will weigh as little as 6 pounds. QUALCOMM will manufacture the handset for the Globalstar system. This dual-mode phone will use CDMA technology and weigh about 12 ounces, at a cost of $750.

Some projections have placed the market for satellite-based services at $160 billion over the next decade, and this has lured more than $54 billion in combined proposals for satellite networks that would require the launch of hundreds of satellites. The proposed systems include the following:

- $28 billion for 155 geostationary satellites and their launchers
- $10 billion for Big LEO global telephone satellites and $350 million for Little LEO mobile messaging satellites
- $16 billion for Ka-band broadband fixed satellites

In addition to technological hurdles, significant financial hurdles still stand in the way of the development of satellite communications. There has been a race for financial backing. However, these systems are viewed as high-risk investments by the financial community because of fears that not all of the systems can be successful. Constellation Communication and Mobile Communications Holdings were initially denied licenses by the FCC because of concerns over financing. A bond offering from Iridium was pulled from the market in 1995 when investors demanded a return that Iridium considered too high. The most recent financial impact was felt when Orbcomm withdrew its initial public offering (IPO). Orbcomm found weak investor response to its offering and decided it was not comfortable with the valuation it would receive in the financial markets. The basic message to companies seeking to compete in the satellite services sector is that they must make investors reasonably comfortable with the technology risks, distribution risks, and market risks. Achieving this is not a simple task.

An added risk that jumped into the headlines in January 1997 is the possibility of a rocket explosion. The explosion of a Delta II rocket delayed the launch of the first three Iridium satellites that were to be launched by the end of January. The loss of 12 Globalstar satellites in September 1998 brought a painful reminder to the industry of this risk. System failures of all types create an added component of risk and cost to the systems. This has shaped the architecture of various systems as system developers seek to reduce costs from system failure. At a minimum, most systems include back-up satellites in orbit to use as spares in case a primary satellite fails.

A hurdle that was cleared in 1997 was a four-year dispute over spectrum allocation between mobile satellite companies such as Teledesic, Odyssey (TRW), and Hughes, and local multipoint distribution service (LMDS), or "wireless cable," providers such as CellularVision USA Inc. The dispute revolved around allocation of the 28-GHz band, or Ka-band, among different systems. Under an FCC ruling, systems such as Teledesic will be allocated 500 MHz in the 28-GHz band for primary use. This agreement helped to remove one of the last hurdles for FCC licensing of the Teledesic system. Spectrum allocation issues have to be coordinated on a worldwide level for systems such as Satellite Communications. The ITU, a United Nations organization, has the responsibility of dealing with worldwide spectrum allocation coordination. The World Radio Conference (WRC) is the forum where proposals are made and issues are deliberated and decided by the organization.

In April 1998, a critical spectrum allocation issue was finally resolved that allowed additional licenses to be granted for Little LEO services. Originally, the FCC had planned to auction the spectrum for the second round of Little LEO licenses. The first round of licenses was awarded in 1992 to Orbcomm, Volunteers in Technical Assistance (VITA), and a third company that was eventually forced to withdraw. These initial licenses were not auctioned because the various competitors were able to reach a bandwidth-sharing agreement. It was the desire of most industry players to avoid an auction in the second round because of the added financial burden it creates. In the second round of license allocation for Little LEO systems, seven companies were competing for five available licenses. The situation was finally solved when Orbcomm, a unit of Orbital Sciences, purchased CTA Commercial Systems, and Starsys Global Positioning Inc., backed by General Electric Company, withdrew from the competition. The remaining five applicants were able to reach an agreement on a spectrum-sharing plan. Little LEO licenses were awarded by the FCC to E-SAT Inc., Final Analysis Communications Services, Orbcomm, LEO One USA Corporation, and VITA.

There still remains a significant spectrum allocation hurdle for Little LEO companies from the global perspective. At the WRC held in Geneva, Switzerland, in December 1997 (WRC-97), the allocation of spectrum below 1 GHz for Little LEO systems was denied for the second time. This request was also denied in 1995 at WRC-95. The only positive outcome was a resolution to study the potential for global data satellite systems causing interference to terrestrial fixed and mobile wireless licensees. The results of this study will be presented at the next WRC in 1999.

Stratospheric Solutions

While not classified as satellites, a new category of high-altitude mobile communications systems is under active development. These systems would be positioned in the stratosphere, 50,000 to 70,000 feet (10 to 13 miles) above the earth's surface. At least four companies in the United States are developing stratospheric telecommunications networks using high-altitude planes or balloons. They are as follows:

- Sky Station International Inc. is a Washington, D.C.-based company hoping to launch its first balloon in 2000. Its ultimate goal is to place at least 250 balloons over every major urban area in the world.
- Angel Technologies Corporation is based in St. Louis and is set to begin flight tests on its high-altitude long-operation (HALO) aircraft. The company hopes to start offering high-speed Internet access to consumers and businesses starting in 2000. It estimates that a 1.5-Mbps connection would cost about $40 per month.
- Skysat Communications Network Corp. is based in New York.
- Platforms International Corp. is based in Redlands, California.

These systems face many challenges, including potential financing hurdles, as they attempt to find investors willing to support these untested ideas.

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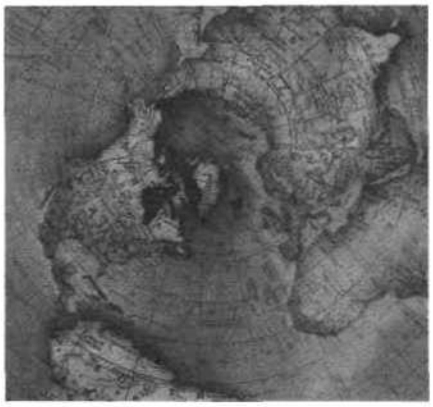

Dataquest

Wireless Communications Semiconductors in 1998

Competitive Trends

Program: Wireless Semiconductors and Applications
Product Code: WSAM-WW-CT-9801
Publication Date: June 29, 1998
Filing: Reports

Wireless Communications Semiconductors in 1998

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Chapter 1

Executive Summary

The total wireless semiconductor market for analog and digital cellular handsets, analog and digital cordless handsets, pagers, wireless LAN products, and wireless modems grew by $2 billion to $8.9 billion in 1997, a growth of nearly 30 percent. The battle for the top overall position in the wireless semiconductor market ended in a virtual three-way tie in 1997, with Motorola Incorporated continuing its slide and Philips Electronics NV and Siemens AG moving up to challenge for the No. 1 ranking. Less than $10 million separated the three companies, with Motorola barely coming out on top with $790 million followed by Philips at $789 million. However, Motorola is still traveling in the wrong direction, and the race for the No. 1 position in 1998 appears to be between Philips and Siemens. Texas Instruments Inc.'s No. 5 ranking, with $669 million, is a significant achievement in light of the fact that it is based completely on its commanding lead in the baseband market. The other top 10 companies benefit from product offerings in both the baseband and radio frequency (RF)/intermediate frequency (IF)/power amplifier markets. With the exception of Motorola, the growth experienced by the top 10 companies is remarkable, with annual growth rates typically from 25 to 55 percent. Lucent Technologies staged a major comeback in 1997 with a growth of 62.6 percent, climbing back up the rankings to No. 8. Also, strong growth propelled three companies into the top 20 for the first time—Analog Devices Inc., Sony Corporation, and Rockwell International Corporation.

Digital technologies have reshaped the competitive landscape for semiconductor suppliers in the wireless markets and opened the door for relatively new companies in this market to capture sizable revenue in the digital cordless and cellular semiconductor markets. Vendors such as TI and Lucent, which possess strong digital signal processing (DSP) and ASIC/ASSP products, have been very aggressive in capturing significant business opportunities in the baseband markets. Companies such as ALPHA Industries Inc., Anadigics Inc., RF Micro Devices Inc., and TriQuint Semiconductor Inc. have leveraged their gallium arsenide products to drive major revenue growth in the wireless markets. Dataquest expects continued strong growth in the wireless segment, accompanied by ongoing relentless competition among chip suppliers.

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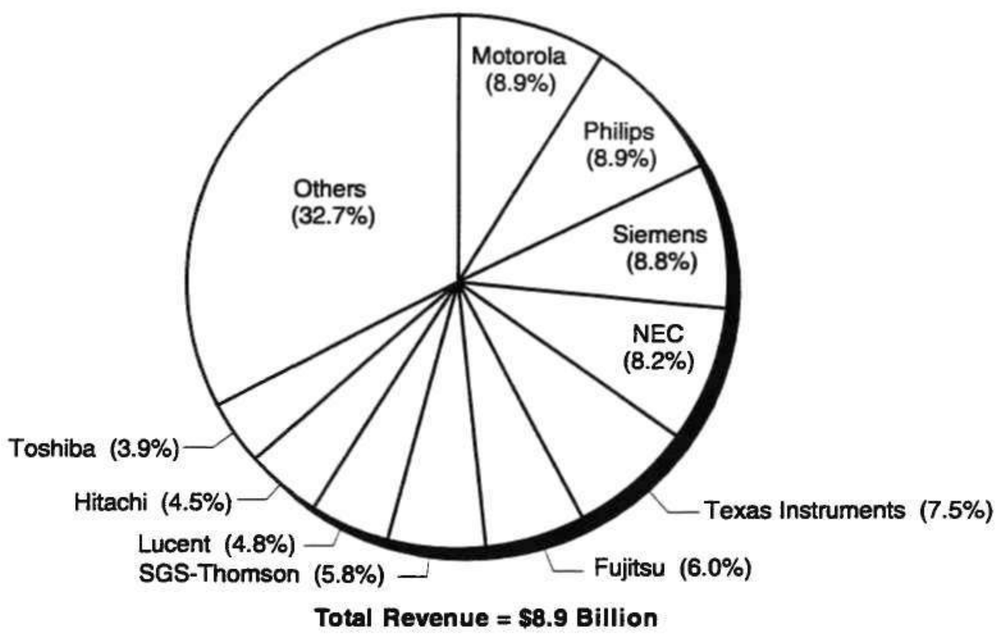
Chapter 2

Wireless Communications Semiconductor Competitive Trends

The battle for the top overall position in the wireless semiconductor market ended in a virtual three-way tie in 1997 with Motorola continuing its slide and Philips and Siemens moving up to challenge for the No. 1 ranking. TI's No. 5 ranking is a significant achievement in light of the fact that it is based completely on its commanding lead in the baseband market. The other top 10 companies benefit from product offerings in both the baseband and RF/IF/power amplifier markets (see Figure 2-1 and Tables 2-1 and 2-2). With the exception of Motorola, the growth experienced by the top 10 companies is remarkable, with annual growth rates typically from 25 to 55 percent. Lucent staged a major comeback in 1997 with a growth of 62.6 percent, climbing back up the rankings to No. 8. Also, strong growth propelled three companies into the top 20 for the first time—Analog Devices, Sony, and Rockwell. Table 2-3 presents the rankings for combined shipments of ASIC and ASSP products into the wireless markets. Siemens' industry-leading shipments of wireless ASSP solutions have pushed it into the top position. TI is the leading supplier of ASIC products for wireless communications and ranks No. 3 among suppliers of dedicated wireless communications-specific semiconductors (combined ASSP and ASIC revenue).

Figure 2-1
1997 Worldwide Revenue Market Share of the Top 10 Vendors of Wireless Communications Semiconductors*



*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-1
Worldwide Revenue of the Top 20 Vendors of Wireless Communications Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Motorola	987	899	790	-12.1	13.1	8.9
2	2	2	Philips	457	597	789	32.2	8.7	8.9
5	4	3	Siemens	282	533	780	46.3	7.8	8.8
3	3	4	NEC	402	570	732	28.4	8.3	8.2
11	5	5	Texas Instruments	182	458	669	46.0	6.7	7.5
4	6	6	Fujitsu	331	424	536	26.3	6.2	6.0
8	8	7	SGS-Thomson	204	328	515	56.9	4.8	5.8
6	10	8	Lucent	251	265	431	62.6	3.9	4.8
7	7	9	Hitachi	217	355	405	14.1	5.2	4.5
10	9	10	Toshiba	183	295	350	18.9	4.3	3.9
9	11	11	Matsushita	202	261	336	29.0	3.8	3.8
49	15	12	QUALCOMM	3	150	305	103.3	2.2	3.4
12	12	13	SANYO	171	227	303	33.2	3.3	3.4
15	14	14	VLSI Technology	83	165	256	55.3	2.4	2.9
13	13	15	Oki	120	189	220	16.1	2.8	2.5
14	16	16	Mitsubishi	87	95	121	27.0	1.4	1.4
17	17	17	National Semiconductor	65	90	100	11.1	1.3	1.1
27	23	18	Analog Devices	27	56	98	74.5	0.8	1.1
24	26	19	Sony	36	43	94	118.8	0.6	1.1
25	28	20	Rockwell	32	36	88	144.4	0.5	1.0
			Others	611	824	996	20.9	12.0	11.2
			Total	**4,930**	**6,861**	**8,913**	**29.9**	**100.0**	**100.0**

*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Note: Columns may not add to the totals shown because of rounding.
Source: Dataquest (June 1998)

Table 2-2
1997 Worldwide Revenue of the Top 10 Vendors of Wireless Communications Semiconductors by Segment*
(Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	Total Wireless Revenue	RF/IF/ Power Amp	Analog Cordless Baseband	Digital Cordless Baseband	Analog Cellular Baseband	Digital Cellular Baseband	Pager Baseband	Other Baseband
1	1	1	Motorola	790	343	8	0	184	175	80	1
2	2	2	Philips	789	463	26	8	67	179	46	0
5	4	3	Siemens	780	440	5	152	0	183	0	0
3	3	4	NEC	732	425	36	11	20	214	26	0
11	5	5	Texas Instruments	669	0	2	7	6	630	22	2
4	6	6	Fujitsu	536	420	17	11	29	59	0	0
8	8	7	SGS-Thomson	515	383	0	5	12	115	0	0
6	10	8	Lucent	431	50	0	8	0	366	7	0
7	7	9	Hitachi	405	253	8	6	11	121	6	0
10	9	10	Toshiba	350	220	18	12	5	89	6	0
			Others	2,917	1,451	69	158	138	1,022	47	33
			Total	**8,913**	**4,448**	**189**	**378**	**471**	**3,152**	**240**	**35**

*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-3
1997 Worldwide Revenue of the Top 15 Vendors of Dedicated Wireless Communications-Specific Semiconductors (Millions of U.S. Dollars)

Rank 1997	Company	ASIC	ASSP	Total Wireless Comm-Specific	Total Wireless Comm-Specific Market Share (%)
1	Siemens	0	767	767	9.5
2	Motorola	408	307	715	8.9
3	Texas Instruments	598	70	669	8.3
4	NEC	376	280	656	8.2
5	Philips	254	320	574	7.1
6	SGS-Thomson	374	121	496	6.2
7	Lucent	381	50	431	5.4
8	Fujitsu	198	227	425	5.3
9	Hitachi	233	111	344	4.3
10	Matsushita	235	91	327	4.1
11	Toshiba	188	134	322	4.0
12	QUALCOMM	0	305	305	3.8
13	VLSI Technology	256	0	256	3.2
14	Oki	55	158	213	2.6
15	SANYO	59	135	193	2.4
	Others	276	1,072	1,348	16.8
	Total	3,892	4,149	8,041	100.0

*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Note: Columns may not add to the totals shown because of rounding.
Source: Dataquest (June 1998)

It is important to note that these market shares are based on semiconductor shipments into analog and digital cellular and cordless handsets, pagers, wireless LAN products, and wireless modems. The revenue from semiconductors sold into the wireless infrastructure market is not represented in these rankings. If the revenue for wireless infrastructure were included in these tables, the total revenue for some of the top players, such as TI and Lucent, would be boosted by about $100 million. As part of the launch of the new Wireless Semiconductor Applications Worldwide service, Dataquest is devoting additional resources to research the wireless infrastructure market and plans to publish wireless rankings for 1998 that will include revenue from wireless infrastructure.

Digital technologies have reshaped the competitive landscape for semiconductor suppliers in the wireless markets and opened the door for relatively new companies in this market to capture sizable revenue in the digital cordless and cellular semiconductor markets. Vendors such as TI and Lucent, which possess strong DSP and ASIC/ASSP products, have been very aggressive in capturing significant business opportunities in the baseband markets. Companies such as ALPHA Industries, Anadigics, RF Micro Devices, and TriQuint have leveraged their gallium arsenide products to drive major revenue growth in the wireless markets.

Dataquest expects continued strong growth in the wireless segment, accompanied by ongoing relentless competition among chip suppliers. Varying semiconductor solutions are being delivered to the market, ranging from highly customized solutions tailored for "tier-one" handset manufacturers to complete chipset solutions for "tier-two" and "tier-three" players that will seek effective, low-cost solutions in this high-growth market.

Suppliers of RF/IF products are being challenged to hold their market share as new wireless products are developed for higher ranges in the frequency spectrum, such as the 2-GHz "personal communications" markets. As part of the competition, the debate over the relative merits of traditional silicon versus gallium arsenide and silicon germanium solutions will be advanced by companies with technology strengths in each area.

The Players

Some of the leading and notable competitors in this market are as follows:

Motorola

For the second year in a row, Motorola saw a major decline in its wireless semiconductor revenue. While Motorola continues to command a strong presence in the declining analog cellular market, it has failed to compete effectively in the second-generation digital handset markets that are driving the overall industry growth. Between 1994 and 1997, Motorola's overall market share slumped from 23.8 percent to 8.9 percent, and its total 1997 revenue of $790 million dropped below its 1994 revenue of $799 million. Motorola has suffered double setbacks in the incredibly hot digital handset market. With its heavy reliance on internal sales, the Motorola semiconductor business was heavily impacted by the loss of market share suffered by its subscriber products group.

Compounding its troubles, the Motorola semiconductor group has also lost significant internal design-wins to outside competition. In the key emerging segment of digital cellular and digital cordless baseband semiconductors, Motorola has now slipped to No. 8 with less than a 5 percent market share. The semiconductor group was shaken up during the last half of 1997 by a major reorganization driven by its new leader, Hector Ruiz. With a new business unit focused on the wireless communications application market, Motorola will work to recapture some momentum as it moves into 1998. To turn its business around, Motorola will have to establish a presence in the merchant market. Its strongest offering yet in this market came with the recent introduction of its new dual-core, 1.8V products targeted at the IS-136 baseband market. Based on the M-Core microcontroller unit (MCU) and the DSP56600 DSP, these products are leveraged from an ASIC that Motorola developed for Nextel Communications' successful iDEN handset. This new offering is a positive step in turning around Motorola's fortunes in this critical market.

Philips

The combination of strong products in both the baseband and RF/IF/power amplifier markets has propelled Philips into a virtual tie for the top position in the wireless communications markets. Philips offers a broad array of wireless semiconductor solutions for a variety of market segments. It has boosted its revenue with the success of its Global System for Mobile Communications (GSM) handset business, where the semiconductor division has key design-wins. Philips moved past Motorola as the leading supplier of RF/IF/power amplifier semiconductors and maintained its 7.3 percent market share in the baseband segment, although it slipped behind Lucent and Siemens to No. 5 in this segment.

The aggressive growth plans of the new Philips Consumer Communications company should provide a continuing boost to Philips Semiconductors Inc.'s presence in the digital handset segment. However, it will have to compete to maintain its design-wins in this new company against Lucent's semiconductor group, which also has strong contacts in this merger formed by Philips and Lucent. Also, as a licensee of the FLEX paging technology, Philips has positioned itself to continue its strong participation in the future of the paging market. Unfortunately, the paging markets have experienced some difficulties recently. However, Dataquest expects the paging market to offer solid growth opportunities over the five-year forecast period.

Siemens

Riding high on its successes in the GSM and Digital European Cordless Telecommunications (DECT) markets, Siemens boasted a 46 percent growth rate in its 1997 revenue, the highest among the top five, as it moved up from No. 4 to No. 3 in the overall rankings. It only trails Motorola by $10 million and appears to have the momentum to compete with Philips for the No. 1 position in 1998. In addition to its strong performance as a supplier of RF/IF chips for digital products, it also continues to experience high growth in DECT and GSM baseband chipsets. Siemens has dominated the DECT market as a supplier of chips for its own leading internal client as well as other leading DECT handset suppliers.

A key challenge for Siemens will be to expand its digital cellular baseband semiconductor business in the merchant market. Central to Siemens' efforts in the merchant market is its GOLD chipset family, which it is marketing to tier-two and tier-three handset manufacturers. Also, Siemens unveiled a second major component to its merchant market strategy with the recent introduction of the Carmel DSP architecture. It is working to establish this new DSP architecture as the leading, open-standard DSP for wireless communications and has already announced a licensing agreement with LSI Logic Corporation. If successful, this new DSP architecture could boost Siemens into a highly competitive position in the merchant digital cellular baseband market.

NEC

Dropping back to No. 4 in the overall market, NEC Electronics Inc. has benefited by its strong presence in the Japanese personal digital cellular (PDC) market, which grew to 25 million units of production in 1997, rivaling the GSM market. Also, NEC benefited from its internal design-win in the NEC GSM handset, which quadrupled its shipments in 1997 to 1 million units.

Among Japanese companies competing in the wireless communications market, NEC has emerged as one of the key companies offering semiconductor solutions for both domestic manufacturers and key equipment manufacturers in other geographic regions. It possesses solid product offerings in both the RF/IF and baseband segments. However, NEC will be challenged to keep pace with other global competitors, as the PDC market is expected to level out as code-division multiple access (CDMA) handsets are introduced into the Japanese market in 1998. It will have to make stronger inroads in the GSM and North American time-division multiple access (NA-TDMA) segments if it hopes to maintain its 1997 ranking. In the long run, it will also need to work to establish a stronger position for the third-generation markets. It does not appear likely that NEC will be able to hold its overall market position in 1998.

Texas Instruments

In the face of renewed, vigorous competition in the important digital cellular/cordless baseband segment, TI was able to successfully defend its leading market share of 18 percent as it grew its revenue by almost 49 percent. It continues to leverage its key design-wins in leading companies such as Nokia and Ericsson in the GSM market and many of the major PDC handset manufacturers. Although TI lost ground to NEC in the PDC market, it gained new design-wins with QUALCOMM Incorporated and Samsung Electronics Company Ltd., leading CDMA handset manufacturers. TI's $669 million in baseband revenue allowed it to maintain its No. 5 overall wireless semiconductor ranking in 1997.

TI also expanded its business significantly in the pager baseband markets. However, TI has recognized that its nonparticipation in the RF/IF/power amplifier markets is a critical competitive weakness. During 1997, TI moved to enter the RF/IF side of the wireless communications business and announced its first competitive products in the merchant market in early 1998. Success in this endeavor will be necessary for TI to compete for the top overall position in the wireless communications market.

Lucent

The award goes to Lucent as the most improved competitor for 1997 as it successfully re-energized its business in the wireless markets and fought aggressively to drive its revenue up by more than 62 percent. Lucent gained a boost from Motorola's improved performance in the GSM markets and also regained ground with Nokia. Also, Lucent cracked the CDMA market with shipments of its enhanced variable rate coder/decoder (CODEC) to Korean manufacturers.

A number of its successes and announcements in 1997 provide evidence that it has truly rebounded from its 1996 woes. Lucent's new DSP 16000 architecture, which it announced in 1997, demonstrates that it is continuing to deliver highly competitive products to the market. Its Flash-DSP products are also providing competitive advantages and have allowed it to capture major design-wins in Motorola's next-generation, two-way paging products. Ultimately, Lucent deserves credit for deliberately selecting key markets to focus on and successfully executing a solid business plan to reposition itself as a strong competitor in the wireless markets.

QUALCOMM

Once again, as the only supplier of CDMA baseband products for most of 1997, not including the baseband analog processor, QUALCOMM more than doubled its wireless semiconductor revenue to move up to No. 12 in the overall rankings and No. 4 as a supplier of digital cellular/cordless baseband chips. The company supplied all of the CDMA baseband solutions both to its internal customers and to the major Korean manufacturers such as Samsung and LG Electronics Inc. Nokia was the first company to introduce a CDMA handset that did not use a QUALCOMM baseband solution. Motorola continued to struggle to bring a CDMA handset to market through early 1998. However, QUALCOMM's strongest competition will come from CDMA licensees VLSI Technology Inc., LSI Logic, and DSP Communications Inc. All three companies have announced plans to start shipping products in 1998.

The other significant threat to QUALCOMM's growth is the troubled South Korean economy. QUALCOMM announced in early 1998 that key Korean customers had pushed out orders for CDMA baseband products because of slowing business. Unless other markets are able to drive solid overall growth in 1998, it could be a difficult year for QUALCOMM. However, with its strong intellectual property and central market position in CDMA-based systems, QUALCOMM's semiconductor group will continue to be one of the prime beneficiaries of the growth in CDMA markets in the long term. In early 1997, QUALCOMM announced a complete lineup of highly integrated baseband, IF, and RF semiconductor solutions for both handsets and infrastructure based on the IS-95B standard. This strong product offering will be a critical component to QUALCOMM's efforts to maintain a strong presence in the development of third-generation cellular markets.

VLSI Technology

Continuing to nurture its strong partnership with Ericsson, VLSI achieved another year of strong revenue growth with an increase of more than 55 percent in the wireless communications market. In fact, Ericsson has become such a significant customer that VLSI disclosed its 1996 revenue from Ericsson in its filings with the U.S. Securities and Exchange Commission (SEC). VLSI is also working to develop business with tier-two and tier-three companies with its GSM chipset solution and announced a single-chip, 3.6V GSM baseband product, the OneC.

This dual-core baseband product is scheduled for volume production in the first half of 1998. VLSI has also announced plans to begin shipments for the CDMA (IS-95) standard during 1998. Further, VLSI has established a development platform called the "Standard Communication Platform," which will provide the basis for developing baseband solutions for multiple standards.

If VLSI continues to maintain its strong partnership with Ericsson and is able to deliver a competitive solution for second- and third-tier vendors and the CDMA markets, it will be in a strong position to defend its top five ranking in the digital baseband markets in 1998.

Rockwell

Rockwell International Corporation's success in breaking into the top 20 rankings was driven principally by its success in the chipset market for 900-MHz digital spread spectrum (DSS) cordless telephones and from its shipments of power amplifiers in the cellular and personal communications services (PCS) markets. Rockwell was the clear No. 1 supplier of chipset solutions for the 900-MHz DSS cordless market, with products such as the Nightingale that realized a number of strong design-wins. Entering 1998, Rockwell announced a new, highly integrated, complete antenna-to-microphone chipset solution for 900-MHz DSS cordless phones called the Hummingbird. At the same time, Rockwell priced the chip very aggressively. There are two possible motivations behind the aggressive pricing. First, Rockwell is attempting to enable lower-cost products that will stimulate even stronger growth in the market; and second, it is probably anticipating new competition and seeking to establish a defensible leadership position in this market. A significant increase in the growth of the 900-MHz DSS market will be necessary for Rockwell to build on its revenue in this segment in 1998.

The second major announcement in early 1998 from Rockwell was its complete chipset solution for GSM cellular handsets. Rockwell should be another strong competitor in what has become a very crowded GSM chipset market.

Anadigics

Emerging as one of the leaders in the GaAs market for digital cellular handsets, Anadigics shipped 37 million GaAs ICs in 1997 to reach a cumulative total of 100 million GaAs ICs since 1990. The cellular and PCS markets were responsible for all of Anadigics' revenue growth in 1997. During the fourth quarter of 1997, the company encountered difficulties because of problems with packaging and assembly. Entering 1998, Anadigics announced that it had solved its problems, and with the announcement of four new 3V power amplifiers and the new fab facility, it expects to have another successful year in 1998.

RF Micro Devices

Growing its business in the digital cellular handset markets by nearly 139 percent to $43 million, RF Micro Devices has invested in a new foundry to provide a platform for continued strong growth. In the past, RF Micro Devices has built its business in the GaAs markets in partnership with TRW Incorporated, which provided a GaAs foundry service. With the opening of its new four-inch GaAs wafer fab, RF Micro Devices will be able to offer its customers two independent supply sources for its products and meet the burgeoning demand for its products. By early 1998, RF Micro Devices was running at 1,200 to 1,500 wafers per month and producing 1 million chips per week. Digital cellular handsets drove 60 percent of the company's total business, followed by infrastructure sales, which accounted for 10 to 12 percent of its revenue. RF Micro Devices has design-wins with tier-one GSM vendors such as Nokia and a relationship with almost every CDMA handset manufacturer. In early 1998, the company appeared to be in position for another strong year of growth as an important supplier of GaAs products to the digital cellular markets.

Sony

Sony has been strengthening its semiconductor business in a number of markets, including the wireless arena. Sony has built on its CDMA manufacturing relationship with QUALCOMM to establish a design center for digital cellular semiconductor products in Southern California and has derived new revenue from shipments of products such as its baseband analog processor for CDMA handsets.

DSP Communications

After emerging as one of the shooting stars of 1996 and establishing a position in the top 10 of the digital cellular/cordless baseband market, DSP Communications stumbled in 1997. A difficult product transition in its central PDC baseband chipset market resulted in overall revenue dropping to $80 million and slipping to No. 14 in the digital cordless/cellular baseband market. By the end of 1997, the company had worked through its difficulties and was gaining momentum with shipments of IS-136 baseband products. It continued to build on this momentum with the announcement of production of its CDMA chipset in early 1998. However, new setbacks hit DSP Communications with the announcement that Siemens, a major design-win for the CDMA market, was pulling back from the CDMA markets, followed closely by a class-action lawsuit filed against company officers. If DSP Communications is able to weather some of its new adversities and keep focused on the new market opportunities in IS-136 and CDMA, it should be able to return to a solid growth pattern in 1998.

Market Shares by Major Segment

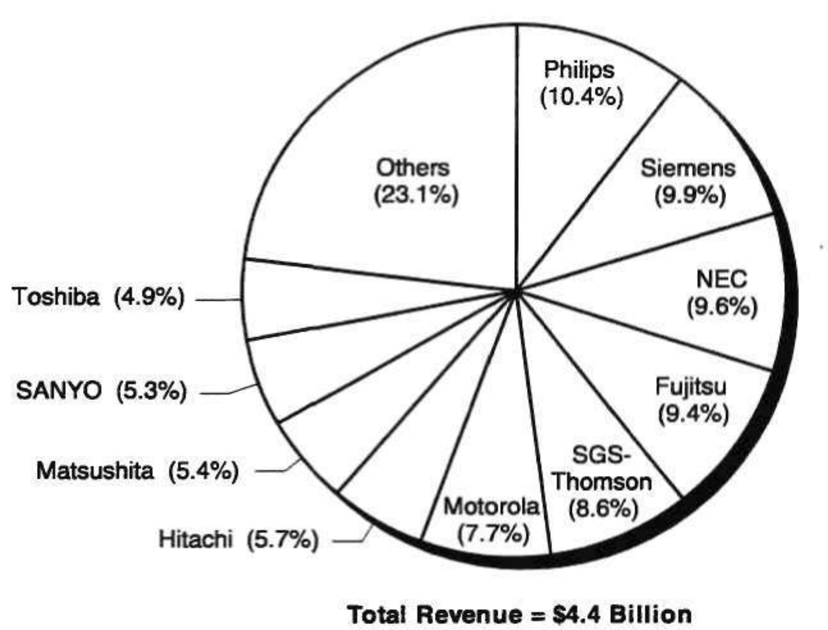
Figure 2-2 and Table 2-4 show the market shares for suppliers of RF/IF chips in the analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager markets. The competition for the No. 1 position in the wireless communications semiconductor market has become a virtual three-way tie between Motorola, Philips, and Siemens, with Motorola holding a razor-thin lead of $790 million to Philips' $789 million. However, Motorola is still traveling in the wrong direction, and the race for No. 1 in 1998 appears to be between Philips and Siemens.

TI successfully defended its position in the digital cellular/cordless baseband semiconductor market in 1997 and, combined with Motorola's decline, captured the top position in the overall wireless baseband semiconductor segment. TI continues to be the clear leader in the important digital baseband semiconductor segment. These results are shown in Figures 2-3 and 2-4 and Tables 2-5 and 2-6. Table 2-7 presents the market shares for baseband semiconductors in analog cordless and cellular products.

Looking at the market from a slightly different perspective, Table 2-8 presents the market shares for all cellular baseband semiconductors, analog and digital. Based on its strong performance in digital cellular markets, TI maintained its top position. Tables 2-9 and 2-10 show the market shares for the analog cellular and digital cellular baseband markets, respectively. More detailed market shares for the digital cellular baseband markets are shown in Tables 2-11 through 2-13.

Table 2-14 shows the market shares for baseband chips in the combined analog and digital cellular markets. The continuing major role of Japanese companies in the analog cordless telephone market is seen in Table 2-15, while a new group of major chips suppliers is shown in Table 2-16, led by Siemens and its dominance of the DECT market and followed by Rockwell with its dominance in the 900-MHz spread spectrum market. Finally, the top 10 suppliers of baseband chips for pager products are presented in Table 2-17. Motorola, Philips, and NEC continue with their strong presence in this market segment. New entrants such as TI and Lucent are already showing the benefits of licensing the new FLEX technologies from Motorola.

Figure 2-2
1997 Worldwide Revenue Market Share of the Top 10 Vendors of RF/IF/Power Amp Semiconductors for Wireless Communications*



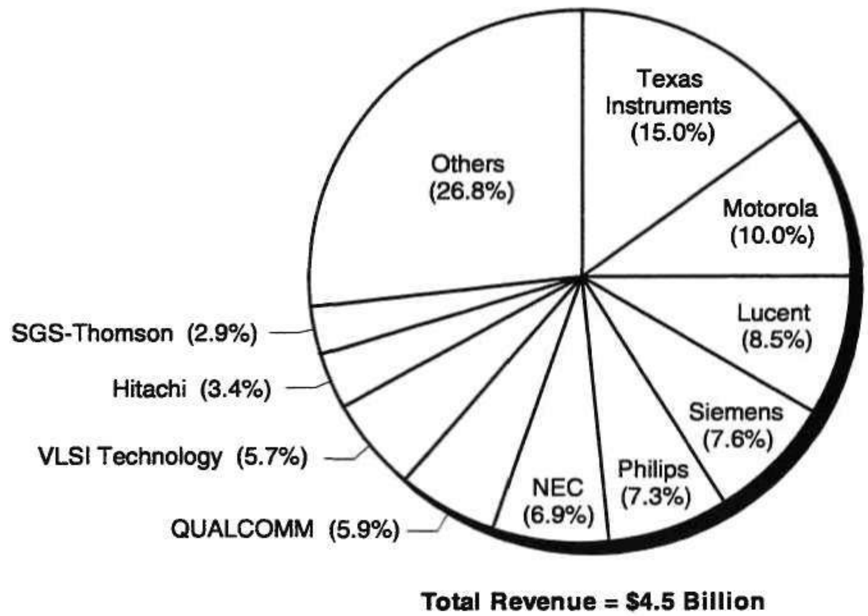
*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-4
Worldwide Revenue of the Top 25 Vendors of RF/IF/Power Amp Semiconductors for Wireless Communications* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
2	2	1	Philips	263	345	463	34.2	10.1	10.4
5	3	2	Siemens	189	324	440	35.8	9.5	9.9
4	4	3	NEC	231	312	425	36.2	9.1	9.6
3	5	4	Fujitsu	253	300	420	40.0	8.8	9.4
8	6	5	SGS-Thomson	136	235	383	63.0	6.9	8.6
1	1	6	Motorola	485	415	343	-17.3	12.1	7.7
9	7	7	Hitachi	125	218	253	16.1	6.4	5.7
6	9	8	Matsushita	156	185	240	29.7	5.4	5.4
7	10	9	SANYO	137	182	235	29.1	5.3	5.3
10	8	10	Toshiba	114	187	220	17.6	5.5	4.9
11	12	11	Mitsubishi	78	86	109	26.7	2.5	2.5
12	11	12	National Semiconductor	65	88	100	13.6	2.6	2.2
13	13	13	Oki	43	70	90	28.6	2.0	2.0
17	17	14	Sony	24	30	75	150.0	0.9	1.7
14	14	15	Hewlett-Packard	38	62	70	12.9	1.8	1.6
20	21	16	Anadigics	19	25	59	140.8	0.7	1.3
24	24	17	Rockwell	10	14	56	300.0	0.4	1.3
15	16	18	Lucent	36	40	50	25.0	1.2	1.1
15	15	19	Mitel (GEC Plessey)	36	40	43	6.4	1.2	1.0
31	22	19	RF Micro Devices/TRW	4	18	43	138.9	0.5	1.0
38	17	21	QUALCOMM	1	30	40	33.3	0.9	0.9
19	17	22	TriQuint Semiconductor	20	30	37	23.3	0.9	0.8
17	20	23	TEMIC	24	28	29	3.6	0.8	0.7
27	27	24	ALPHA	7	9	27	200.0	0.3	0.6
21	26	25	NJRC	14	12	25	101.6	0.4	0.6
			Others	100	134	173	29.4	3.9	3.9
			Total	**2,607**	**3,419**	**4,448**	**30.1**	**100.0**	**100.0**

*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment.
Note: Columns may not add to the totals shown because of rounding.
Source: Dataquest (June 1998)

Figure 2-3
1997 Worldwide Revenue Market Share of the Top 10 Vendors of Baseband Semiconductors for Wireless Communications*



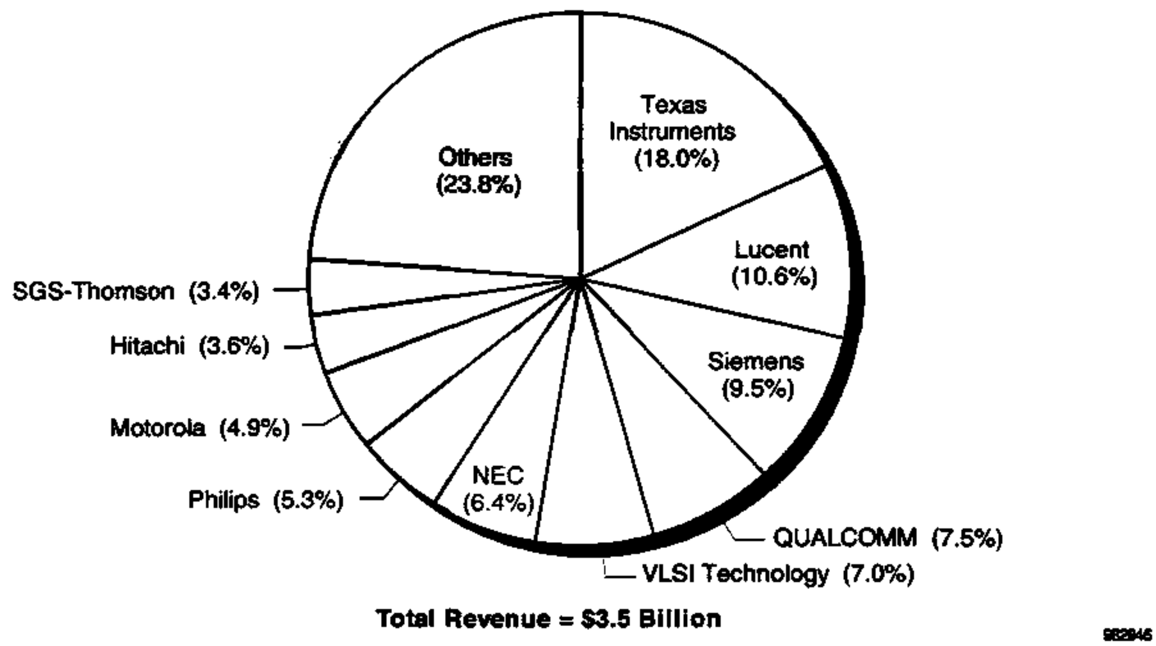
*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-5
Worldwide Revenue of the Top 20 Vendors of Baseband Semiconductors for Wireless Communications* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
4	2	1	Texas Instruments	182	458	669	46.0	13.3	15.0
1	1	2	Motorola	502	484	447	-7.7	14.1	10.0
2	5	3	Lucent	215	225	381	69.3	6.5	8.5
6	6	4	Siemens	93	209	340	62.7	6.1	7.6
3	4	5	Philips	194	252	326	29.4	7.3	7.3
5	3	6	NEC	171	258	307	18.9	7.5	6.9
35	10	7	QUALCOMM	2	120	265	120.8	3.5	5.9
8	7	8	VLSI Technology	83	165	256	55.3	4.8	5.7
7	8	9	Hitachi	92	137	152	10.9	4.0	3.4
12	13	10	SGS-Thomson	68	93	132	41.6	2.7	2.9
11	12	11	Toshiba	69	108	130	21.0	3.1	2.9
10	11	12	Oki	77	119	130	8.8	3.5	2.9
9	9	13	Fujitsu	78	124	116	-6.8	3.6	2.6
14	15	14	Matsushita	46	76	96	27.4	2.2	2.2
20	17	15	Analog Devices	24	51	92	79.8	1.5	2.1
18	14	16	DSP Communications	37	87	80	-7.5	2.5	1.8
14	16	17	AKM Semiconductor	46	69	79	14.5	2.0	1.8
19	21	18	SANYO	34	45	68	49.7	1.3	1.5
14	20	19	Samsung	46	47	51	8.5	1.4	1.1
14	18	20	TEMIC	46	50	50	0	1.5	1.1
24	22	20	Alcatel Mietec	19	31	50	61.3	0.9	1.1
			Others	201	234	250	6.5	6.8	5.6
			Total	**2,323**	**3,442**	**4,465**	**29.7**	**100.0**	**100.0**

*Analog cordless, digital cordless, analog cellular, digital cellular/PCS, wireless LAN, wireless modem, and pager. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Note: Columns may not add to the totals shown because of rounding.
Source: Dataquest (June 1998)

Figure 2-4
1997 Worldwide Revenue Market Share of the Top 10 Vendors of Digital Cellular/ Broadband PCS and Digital Cordless/Low-Mobility PCS Baseband Semiconductors*



*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-6
Worldwide Revenue of the Top 20 Vendors of Digital Cellular/Broadband PCS and Digital Cordless/Low-Mobility PCS Baseband Semiconductors*
(Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
2	1	1	Texas Instruments	168	428	637	48.8	18.6	18.0
1	2	2	Lucent	215	225	374	66.2	9.8	10.6
4	3	3	Siemens	84	202	335	65.8	8.8	9.5
27	7	4	QUALCOMM	2	120	265	120.8	5.2	7.5
5	5	5	VLSI Technology	68	149	245	64.7	6.5	7.0
6	4	6	NEC	67	163	225	37.7	7.1	6.4
12	9	7	Philips	31	89	187	110.1	3.9	5.3
3	6	8	Motorola	131	126	175	38.5	5.5	4.9
7	8	9	Hitachi	54	105	127	21.0	4.6	3.6
8	14	10	SGS-Thomson	44	75	120	60.0	3.3	3.4
10	12	11	Oki	36	80	107	33.1	3.5	3.0
12	13	12	Toshiba	31	78	101	30.3	3.4	2.9
14	15	13	Analog Devices	23	50	91	82.0	2.2	2.6
9	10	14	DSP Communications	37	87	75	-13.9	3.8	2.1
18	16	15	Matsushita	17	46	71	54.3	2.0	2.0
11	11	16	Fujitsu	35	84	70	-16.7	3.7	2.0
16	16	17	AKM Semiconductor	20	46	64	39.1	2.0	1.8
17	18	18	Alcatel Mietec	19	31	48	54.8	1.3	1.4
19	21	19	TEMIC	11	19	40	110.5	0.8	1.1
15	19	20	Rockwell	22	22	32	45.5	1.0	0.9
			Others	39	73	142	95.1	3.2	4.0
			Total	**1,152**	**2,297**	**3,530**	**53.7**	**100.0**	**100.0**

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-7
Worldwide Revenue of the Top 15 Vendors of Analog Cellular and Analog Cordless Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Motorola	269	264	192	-27.3	29.0	29.1
2	2	2	Philips	127	123	93	-24.4	13.5	14.1
3	3	3	NEC	81	72	56	-22.1	7.9	8.5
5	5	4	Fujitsu	43	40	46	13.9	4.4	7.0
4	4	5	Austria Mikro Systeme	49	43	30	-30.2	4.7	4.5
7	7	6	Samsung	38	37	29	-21.6	4.1	4.4
10	10	7	Toshiba	33	25	23	-7.5	2.8	3.5
6	6	8	Oki	41	39	23	-41.0	4.3	3.5
15	17	9	SANYO	15	16	20	29.0	1.7	3.0
9	9	10	Hitachi	34	28	19	-32.1	3.1	2.9
11	11	11	AKM Semiconductor	26	23	15	-34.8	2.5	2.3
17	13	12	Mitel (GEC Plessey)	13	20	13	-35.3	2.2	2.0
12	14	13	SGS-Thomson	24	18	12	-35.0	2.0	1.8
15	16	14	VLSI Technology	15	16	11	-31.9	1.8	1.7
14	15	15	Matsushita	18	17	10	-38.3	1.8	1.5
			Others	139	130	68	-47.9	14.3	10.3
			Total	**965**	**911**	**660**	**-27.5**	**100.0**	**100.0**

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-8
Worldwide Revenue of the Top 20 Vendors of Analog Cellular and Digital Cellular/ Broadband PCS Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
3	1	1	Texas Instruments	172	418	636	52.0	15.3	17.5
2	3	2	Lucent	204	210	366	74.3	7.7	10.1
1	2	3	Motorola	390	380	359	-5.7	13.9	9.9
32	8	4	QUALCOMM	2	120	265	120.8	4.4	7.3
4	5	5	Philips	131	183	246	34.4	6.7	6.8
6	6	6	VLSI Technology	80	158	243	54.1	5.8	6.7
5	4	7	NEC	105	191	234	22.3	7.0	6.4
15	10	8	Siemens	37	99	183	84.8	3.6	5.1
6	7	9	Hitachi	80	125	132	6.0	4.6	3.6
8	11	10	SGS-Thomson	65	90	127	40.8	3.3	3.5
10	12	11	Oki	52	87	95	9.2	3.2	2.6
14	14	12	Toshiba	41	75	94	26.3	2.7	2.6
18	16	13	Analog Devices	24	51	92	79.8	1.9	2.5
9	9	14	Fujitsu	59	103	88	-14.9	3.8	2.4
13	15	15	AKM Semiconductor	44	66	75	13.6	2.4	2.1
15	13	16	DSP Communications	37	86	69	-20.3	3.2	1.9
17	17	17	Matsushita	27	51	64	27.0	1.9	1.8
20	20	18	Alcatel Mietec	16	28	47	67.9	1.0	1.3
12	18	19	TEMIC	45	49	43	-12.2	1.8	1.2
11	19	20	Austria Mikro Systeme	50	46	40	-14.1	1.7	1.1
			Others	105	115	127	10.6	4.2	3.5
			Total	1,766	2,730	3,623	32.7	100.0	100.0

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-9
Worldwide Revenue of the Top 15 Vendors of Analog Cellular Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Motorola	260	255	184	-27.8	35.3	39.1
2	2	2	Philips	103	98	67	-31.6	13.6	14.2
8	7	3	Fujitsu	27	25	29	14.2	3.5	6.2
3	3	4	Austria Mikro Systeme	46	40	27	-32.5	5.5	5.7
4	4	5	NEC	44	37	20	-45.7	5.1	4.2
9	8	6	AKM Semiconductor	26	23	15	-34.8	3.2	3.2
16	10	7	Mitel (GEC Plessey)	12	19	13	-31.2	2.6	2.8
10	11	8	SGS-Thomson	24	18	12	-35.0	2.5	2.5
7	9	9	Hitachi	28	22	11	-50.0	3.0	2.3
12	13	10	VLSI Technology	15	16	11	-31.9	2.2	2.3
5	5	11	TEMIC	35	31	10	-67.7	4.3	2.1
6	6	11	Oki	29	28	10	-64.3	3.9	2.1
13	14	13	Matsushita	14	13	8	-34.6	1.7	1.7
15	15	13	Cherry Semiconductor	13	12	8	-31.7	1.7	1.7
11	12	15	Samsung	18	17	7	-58.8	2.4	1.5
			Others	80	69	39	-43.6	9.6	8.3
			Total	**774**	**723**	**471**	**-34.8**	**100.0**	**100.0**

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-10
Worldwide Revenue of the Top 20 Vendors of Digital Cellular/Broadband PCS Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
2	1	1	Texas Instruments	160	408	630	54.4	20.3	20.0
1	2	2	Lucent	204	210	366	74.3	10.5	11.6
24	6	3	QUALCOMM	2	120	265	120.8	6.0	8.4
4	4	4	VLSI Technology	65	142	233	63.7	7.1	7.4
5	3	5	NEC	61	154	214	38.6	7.7	6.8
9	8	6	Siemens	34	97	183	88.7	4.8	5.8
11	10	7	Philips	28	85	179	110.6	4.2	5.7
3	5	8	Motorola	130	125	175	39.6	6.2	5.5
6	7	9	Hitachi	52	103	121	18.0	5.1	3.8
7	12	10	SGS-Thomson	41	72	115	59.7	3.6	3.6
13	15	11	Analog Devices	23	50	91	82.0	2.5	2.9
12	13	12	Toshiba	27	67	89	33.8	3.3	2.8
13	14	13	Oki	23	59	85	44.1	2.9	2.7
8	9	14	DSP Communications	37	86	69	-20.3	4.3	2.2
15	16	15	AKM Semiconductor	18	43	60	39.5	2.1	1.9
10	11	16	Fujitsu	32	78	59	-24.4	3.9	1.9
17	17	17	Matsushita	13	38	56	47.4	1.9	1.8
16	18	18	Alcatel Mietec	16	28	47	67.9	1.4	1.5
18	19	19	TEMIC	10	18	33	83.3	0.9	1.0
19	20	20	Austria Mikro Systeme	4	6	13	108.3	0.3	0.4
			Others	12	19	72	276.3	0.9	2.3
			Total	**992**	**2,007**	**3,152**	**57.1**	**100.0**	**100.0**

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-11
Worldwide Revenue of the Top 15 Vendors of GSM, DCS-1800, and PCS-1900 Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
3	1	1	Texas Instruments	86	218	369	69.3	21.5	20.8
1	2	2	Lucent	164	170	315	85.3	16.8	17.8
4	3	3	VLSI Technology	62	126	205	62.7	12.4	11.6
6	5	4	Siemens	34	97	183	88.7	9.6	10.3
7	7	5	Philips	25	58	161	177.6	5.7	9.1
2	4	6	Motorola	104	107	145	35.5	10.6	8.2
5	6	7	SGS-Thomson	41	72	115	59.7	7.1	6.5
9	8	8	Analog Devices	20	43	85	97.7	4.2	4.8
7	9	9	Hitachi	25	40	48	20.0	3.9	2.7
10	10	10	Alcatel Mietec	16	28	47	67.9	2.8	2.7
12	11	11	TEMIC	10	18	33	83.3	1.8	1.9
11	12	12	NEC	12	16	26	62.5	1.6	1.5
13	13	13	Oki	4	10	18	80.0	1.0	1.0
13	14	14	Austria Mikro Systeme	4	6	13	108.3	0.6	0.7
-	15	15	IBM (CommQuest)	0	4	6	50.0	0.4	0.3
			Others	3	1	3	200.0	0.1	0.2
			Total	610	1,014	1,772	74.7	100.0	100.0

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-12
Worldwide Revenue of the Top 10 Vendors of PDC Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	2	1	NEC	46	126	167	32.5	18.1	21.3
2	1	2	Texas Instruments	45	131	127	-3.1	18.8	16.2
5	5	3	Toshiba	26	65	85	31.8	9.2	10.8
6	6	4	Hitachi	24	56	64	15.3	8.0	8.1
8	7	5	AKM Semiconductor	18	43	60	39.5	6.2	7.6
3	3	6	DSP Communications	37	85	59	-31.2	12.2	7.4
9	8	7	Oki	16	41	55	34.1	5.9	7.0
10	9	8	Matsushita	13	37	54	45.9	5.3	6.9
4	4	9	Fujitsu	32	76	53	-30.3	10.9	6.7
7	10	10	Lucent	20	23	18	-21.7	3.3	2.3
			Others	11	16	44	175.0	2.3	5.6
			Total	**288**	**698**	**786**	**12.5**	**100.0**	**100.0**

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-13
Worldwide Revenue of the Top 10 Vendors of NA-TDMA (IS-54/IS-136) Baseband Semiconductors* (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Texas Instruments	29	58	102	77.4	37.3	37.5
4	3	2	VLSI Technology	3	16	28	71.9	10.4	10.1
2	4	3	Motorola	24	15	27	80.0	9.7	9.9
3	2	4	Lucent	20	17	26	52.9	11.0	9.6
4	5	5	NEC	3	12	21	70.8	7.8	7.5
4	6	6	Philips	3	8	18	125.0	5.2	6.6
4	6	7	Oki	3	8	12	50.0	5.2	4.4
-	12	8	DSP Communications	0	1	10	900.0	0.6	3.7
4	8	9	Hitachi	3	7	9	28.6	4.5	3.3
-	10	10	Fujitsu	0	2	6	200.0	1.3	2.2
			Others	4	11	14	33.3	6.8	5.1
			Total	**92**	**154**	**272**	**76.6**	**100.0**	**100.0**

*Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-14
Worldwide Revenue of the Top 15 Vendors of Analog Cordless and Digital Cordless/ Low-Mobility PCS* Baseband Semiconductors (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Siemens	56	110	157	42.7	23.0	27.7
2	2	2	NEC	43	44	47	6.8	9.2	8.3
4	3	3	SANYO	25	35	35	1.4	7.2	6.2
4	4	4	Oki	25	32	35	7.8	6.7	6.1
3	5	5	Philips	27	29	34	17.2	6.1	6.0
7	7	6	Rockwell	22	22	32	45.5	4.6	5.6
6	6	7	Toshiba	23	28	30	7.1	5.9	5.3
9	9	8	Fujitsu	19	21	28	33.3	4.4	4.9
12	11	9	Sharp	10	19	23	21.1	4.0	4.1
8	10	10	Samsung	20	20	22	10.0	4.2	3.9
15	14	11	Matsushita	8	12	17	41.7	2.5	3.0
16	16	12	Hitachi	8	9	14	64.7	1.8	2.5
19	17	13	VLSI Technology	3	7	13	84.3	1.5	2.3
14	7	14	Texas Instruments	9	22	9	-59.1	4.6	1.6
17	18	14	Mitsubishi	4	6	9	50.0	1.3	1.6
			Others	51	63	62	-1.0	13.2	11.0
			Total	**351**	**478**	**567**	**18.6**	**100.0**	**100.0**

*Includes DECT, CT-2, PHS, 900-MHz digital, and 900-MHz DSS systems. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-15
Worldwide Revenue of the Top 10 Vendors of Analog Cordless Baseband Semiconductors (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	NEC	37	35	36	2.9	18.6	19.0
2	2	2	Philips	24	25	26	4.0	13.3	13.8
3	3	3	Samsung	20	20	22	10.0	10.6	11.6
6	5	4	SANYO	15	16	20	29.0	8.2	10.6
4	4	5	Toshiba	19	17	18	5.9	9.0	9.5
5	6	6	Fujitsu	16	15	17	13.3	8.0	9.0
7	8	7	Oki	12	11	13	18.2	5.9	6.9
9	9	8	Motorola	9	9	8	-11.1	4.8	4.2
10	10	8	Hitachi	6	6	8	33.3	3.2	4.2
10	11	10	Siemens	6	5	5	0	2.7	2.6
			Others	27	30	16	-45.8	15.7	8.5
			Total	**191**	**188**	**189**	**0.5**	**100.0**	**100.0**

Source: Dataquest (June 1998)

Table 2-16
Worldwide Revenue of the Top 10 Vendors of Digital Cordless/Low-Mobility PCS* Baseband Semiconductors (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Siemens	50	105	152	44.8	36.2	40.2
2	2	2	Rockwell	22	22	32	45.5	7.6	8.5
3	3	3	Oki	13	21	22	2.4	7.2	5.7
6	6	4	Sharp	8	17	20	17.6	5.9	5.3
5	5	5	SANYO	10	19	15	-21.1	6.6	4.0
9	10	5	Matsushita	4	8	15	87.5	2.8	4.0
11	11	7	VLSI Technology	3	7	13	84.3	2.4	3.4
9	8	8	Toshiba	4	11	12	9.1	3.8	3.2
8	9	9	NEC	6	9	11	22.2	3.1	2.9
11	12	9	Fujitsu	3	6	11	83.3	2.1	2.9
			Others	38	65	75	16.0	22.4	20.0
			Total	**160**	**290**	**378**	**30.3**	**100.0**	**100.0**

*Includes DECT, CT-2, PHS, 900-MHz Digital, and 900-MHz DSS Systems. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Table 2-17
Worldwide Revenue of the Top 10 Vendors of Pager Baseband Semiconductors (Millions of U.S. Dollars)

Rank 1995	Rank 1996	Rank 1997	Company	1995	1996	1997	1996-1997 Change (%)	1996 Market Share (%)	1997 Market Share (%)
1	1	1	Motorola	102	94	80	-14.9	41.1	33.3
2	2	2	Philips	36	40	46	15.0	17.5	19.2
3	3	3	NEC	23	23	26	13.0	10.0	10.8
10	4	4	Texas Instruments	1	18	22	22.2	7.9	9.2
4	5	5	Matsushita	11	13	15	15.4	5.7	6.3
5	6	6	Samsung	8	10	11	10.0	4.4	4.6
5	7	7	SANYO	8	9	8	-11.1	3.9	3.3
-	-	8	Lucent	0	0	7	NM	0	2.9
7	9	9	Toshiba	5	5	6	20.0	2.2	2.5
8	10	9	Hitachi	4	4	6	50.0	1.7	2.5
			Others	5	13	13	0.1	5.7	5.4
			Total	**203**	**229**	**240**	**4.8**	**100.0**	**100.0**

NM = Not meaningful
*Includes POCSAG, FLEX Family, ERMES, and Nexus Systems. Does not include semiconductors used in infrastructure equipment. Does not include memory or optoelectronics components.
Source: Dataquest (June 1998)

Supplier Matrix

A listing of suppliers in the different wireless communications market segments is provided in Table 2-18.

Table 2-18
Wireless Communications Semiconductor Supplier Matrix

Company	RF/IF	Analog Cordless Baseband	Analog Cellular Baseband	Digital Cordless Baseband	Digital Cellular Baseband	GSM Baseband	PDC Baseband	NA-TDMA Baseband	CDMA Baseband	Pager Baseband
Advanced Micro Devices	X	-	-	-	-	-	-	-	-	-
AKM Semiconductor	-	-	X	X	X	-	X	-	-	-
Alcatel Mietec	-	-	-	X	X	X	-	-	-	X
ALPHA	X	-	-	-	-	-	-	-	-	-
Anadigics	X	-	-	-	-	-	-	-	-	-
Analog Devices	X	-	X	-	X	X	X	X	-	-
Austria Mikro Systeme	-	X	X	X	X	X	-	-	-	-
Celeritek	X	-	-	-	-	-	-	-	-	-
Cherry Semiconductor	-	-	X	-	-	-	-	-	-	-
Daewoo	X	X	-	-	-	-	-	-	-	-
DSP Communications	-	-	-	X	X	-	X	X	X	-
Ericsson	X	-	-	-	-	-	-	-	-	-
Exar	X	-	-	-	-	-	-	-	-	-
Fujitsu	X	X	X	X	X	-	X	X	-	-
Harris	X	-	-	-	-	-	-	-	-	-
Hewlett-Packard	X	-	-	-	-	-	-	-	-	-
Hitachi	X	X	X	X	X	X	X	X	-	X
Holtek	-	X	-	X	-	-	-	-	-	-
Hughes	X	-	-	-	-	-	-	-	-	-
Hyundai	X	X	X	-	-	-	-	-	-	-
IBM (CommQuest)	X	-	X	-	X	X	-	-	-	-
IMI	X	-	-	-	X	-	-	X	-	-
LG Semicon	X	-	X	-	X	-	-	-	-	X
LSI Logic	-	-	-	-	X	X	-	-	X	-
Lucent	X	-	-	X	X	X	X	X	X	X

Table 2-18 (Continued)
Wireless Communications Semiconductor Supplier Matrix

Company	RF/IF	Analog Cordless Baseband	Analog Cellular Baseband	Digital Cordless Baseband	Digital Cellular Baseband	GSM Baseband	PDC Baseband	NA-TDMA Baseband	CDMA Baseband	Pager Baseband
M/A COM	X	-	-	-	-	-	-	-	-	-
Matsushita	X	X	X	X	X	-	X	X	-	X
Micronas Intermetall	X	-	-	-	-	-	-	-	-	-
Mitel (GEC Plessey)	X	-	X	X	X	X	X	X	-	X
Mitsubishi	X	X	X	X	-	-	-	-	-	-
Motorola	X	X	X	-	X	X	X	X	-	X
National Semiconductor	X	-	-	X	-	-	-	-	-	-
NEC	X	X	X	X	X	X	X	X	-	X
NJRC	X	-	-	-	X	-	X	-	-	-
Oki	X	X	X	X	X	X	X	X	-	-
Pacific Monolithics	X	-	-	-	-	-	-	-	-	-
Philips	X	X	X	X	X	X	-	X	-	X
QUALCOMM	X	-	-	-	X	-	-	-	X	-
Raytheon	X	-	-	-	X	-	-	-	-	-
RF Micro Devices/TRW	X	-	-	-	-	-	-	-	-	-
Ricoh	-	-	-	X	X	-	X	-	-	-
Rockwell	X	-	-	X	-	-	-	-	-	-
Samsung	X	X	X	-	X	-	-	-	X	X
SANYO	X	X	-	X	X	-	X	-	-	X
Seiko Epson	-	-	-	X	X	-	X	-	-	X
SGS-Thomson	X	-	X	X	X	X	-	-	-	-
Sharp	X	X	X	X	X	-	X	-	-	X
Siemens	X	X	-	X	X	X	-	-	-	-
Sony	X	-	X	X	X	-	X	-	-	X
TDK Semiconductor	X	-	X	-	X	-	-	-	-	-
TEMIC	X	-	X	X	X	X	-	-	-	-
Texas Instruments	X	X	X	X	X	X	X	X	X	X

Table 2-18 (Continued)
Wireless Communications Semiconductor Supplier Matrix

Company	RF/IF	Analog Cordless Baseband	Analog Cellular Baseband	Digital Cordless Baseband	Digital Cellular Baseband	GSM Baseband	PDC Baseband	NA-TDMA Baseband	CDMA Baseband	Pager Baseband
Thomson CSF	X	-	-	-	-	-	-	-	-	-
Toko	-	-	X	-	-	-	-	-	-	-
Toshiba	X	X	X	X	X	-	X	X	-	X
TriQuint Semiconductor	X	-	-	-	-	-	-	-	-	-
VLSI Technology	-	-	X	X	X	X	-	X	X	-
Winbond Electronics	-	X	-	X	-	-	-	-	-	-
Zilog	-	X	-	X	-	-	-	-	-	X

Source: Dataquest (June 1998)

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