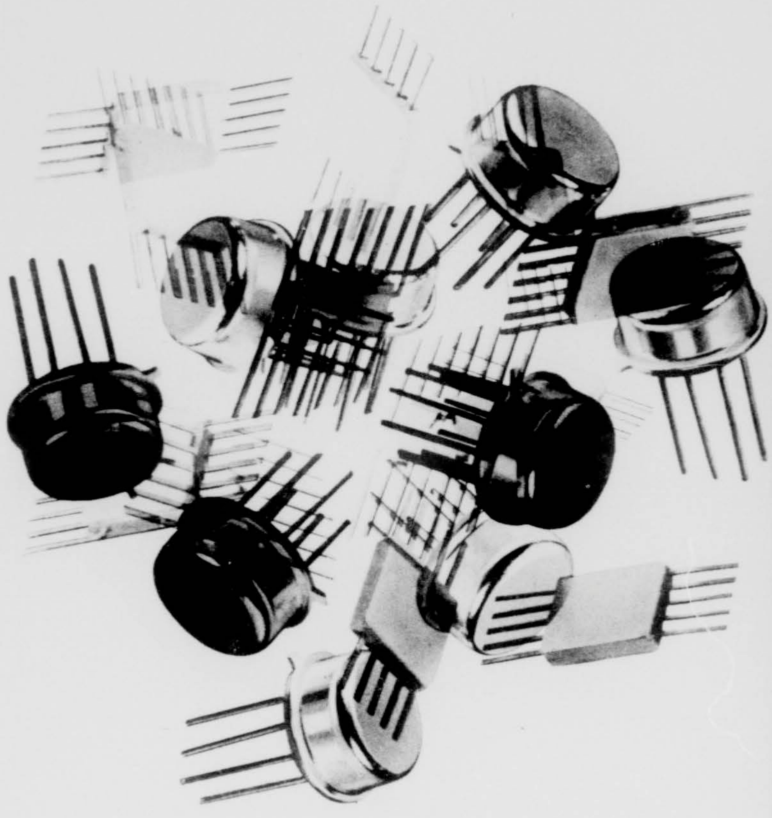
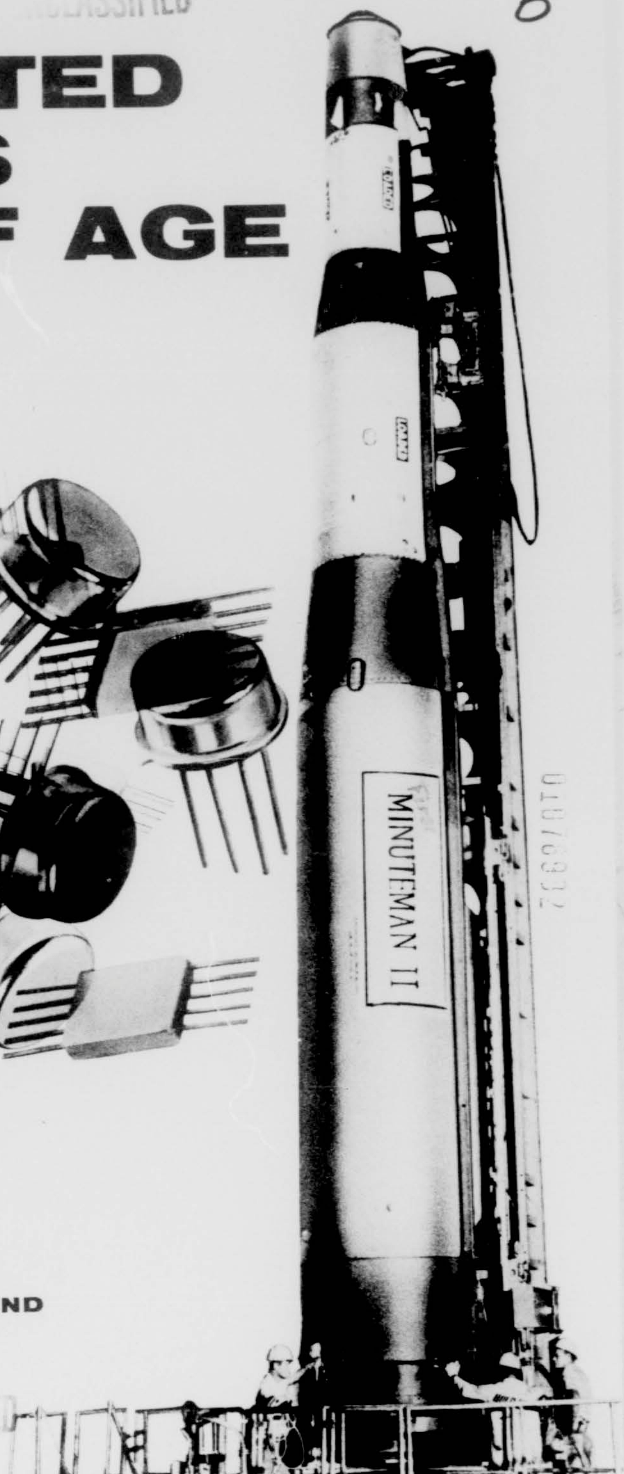
BLANK

UNCLASSIFIED

6

INTEGRATED CIRCUITS COME OF AGE





AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

WASHINGTON, D. C.

UNCLASSIFIED

IRIS WORKSHEET

006 OLD REEL NUMBER

016 CALL NUMBER (30AN)

005 IRIS NUMBER (10AN)

01078902

026 OLD ACCESSION NUMBER (12AN)

018 MICROFILM REEL/FRAME NUMBER

001843

SECURITY WARNING/ADMIN MARKINGS

RD FR CN SA WI NF PV FO FS

ORAL HISTORY CAVEAT
01 02 03 04

NO CONTRACT

PROPRIETARY INFO

THIS DOCUMENT CONTAINS NATO ________ INFO

501 DOCUMENT SECURITY

501

U

DOWNGRADING INSTRUCTIONS

DECLASSIFY ON

REVIEW ON

CLASSIFICATION AND DOWNGRADING INSTRUCTIONS FOR

502

____ / ____ / ____

TITLE ABSTRACT LISTINGS

028

REF ________ DEST DUP OF ________

INSERT TO ________ DUP OF ________

027 NUMBER IN AUDIO REEL SERIES

CATALOGING RECORD

MAIN ENTRY *(Use one)* (150AN)

100 - PERSONAL NAME

109 - ISSUING AGENCY

129 - TITLE AS MAIN ENTRY

TITLE *(Use one)* *(DO NOT USE IF TITLE IS MAIN ENTRY)* (150AN)

220 ________

OR CHECK:

☐ 2210 ORAL HISTORY

☐ 222E END OF TOUR REPORT

☐ 223H HISTORY (AND SUPPORTING DOCUMENTS)

☐ 224C CHECO MICROFILM

☐ 226Q CORRESPONDENCE

☐ 226Z PAPERS

☐ 227P CALENDAR

250 TITLE EXTENSION: ENTER VOLUME NUMBER, PARTS, ETC. (20AN)

DATES: ONLY 264 OR 265 MUST BE COMPLETED. SUPPLY BOTH IF KNOWN

264 INCLUSIVE DATE ____/____/____ TO ____/____/____
DD MM YY DD MM YY

IF DATE ESTIMATED, CHECK HERE ☐

265 DATE OF PUBLICATION ____/____/____
DD MM YY

300 TOTAL PAGES ________

AFSHRC FORM 7 MAY 82 PREVIOUS EDITIONS ARE OBSOLETE

UNCLASSIFIED

INTEGRATED CIRCUITS COME OF AGE

AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WASHINGTON, D. C.

UNCLASSIFIED

FOREWORD

Our successes with major systems often overshadow the importance of the basic supporting technology developments that make these successes possible. This report covers one of these technologies—the integrated circuit—its origin and development, its present status, and its future impact.

The birth and explosive growth of integrated circuits can be directly attributed to a combination of wise policy direction by the Department of Defense; initiative, stimulation and dynamic management by the Air Force Systems Command; and spirited response by industry. The story is dramatic proof that the frontiers of our technology can continue to be rolled back by intelligent and imaginative assumption of risk, proper allocation of resources, and reliance on scientific ingenuity.

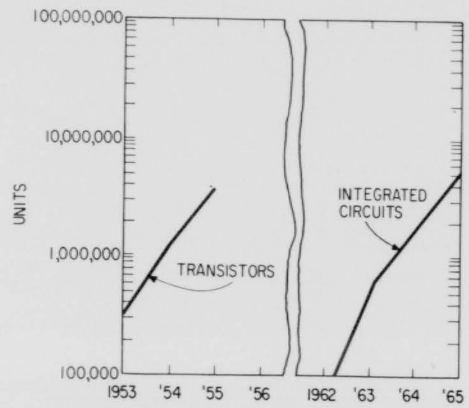
It is important to understand that this technology was based on a growing operational problem rather than the normal evolution of a new technical phenomenon. The problem demanded a major scientific advance involving considerable financial and technical risk. The solution proposed by the Air Force was criticized by some and questioned by others. The fact that the technology was successfully developed makes it important to review and comprehend the degree of participation of our government laboratories, so that existing and future programs may profit by the lessons learned.

B. A. Schriever

B. A. SCHRIEVER
General, USAF
Commander, Air Force
Systems Command

TABLE OF CO

TABLE OF CONTENTS



A comparison of the number of units shipped during the early growth period of the transistor, 1953 to 1956, and of the integrated circuit, 1962 onward, shows the rapid growth of the integrated circuit. The growth of integrated circuits is even more pronounced when it is realized that each integrated circuit can displace several transistors.

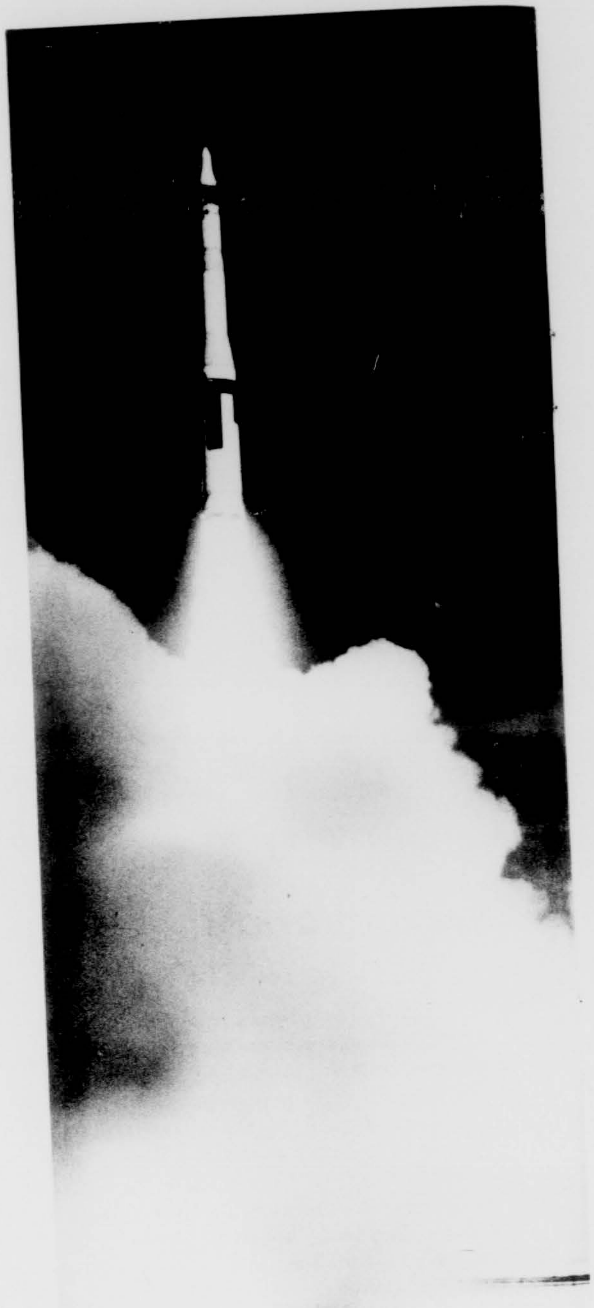
INTRODUCTION

In the short span of years from 1958 to 1964, a revolutionary technique for fabricating electronic circuits was introduced, demonstrated, and accepted. This new technique results in exceptionally small, highly reliable complete electronic circuits; commonly called *integrated circuits.* This report discusses the development of integrated circuits from their earliest beginning to their present widespread use in military and commercial electronic equipment.

The development of integrated circuits is, in large part, the story of imaginative planning and aggressive management by the U. S. Air Force in starting and supporting a bold, new research and development program. This support, combined with substantial industry participation, resulted in an accelerated breakthrough in the field of electronics. The rapid advance of integrated circuit technology is attributable in large part to the management decisions made by the Air Force and the Department of Defense . . . decisions such as to:

- institute a high-risk research program,
- initiate research and development with a minimum of time-consuming review of technical feasibility,
- utilize concentrated, massive funding to obtain rapid results,
- integrate government and industry efforts to ensure quick development of each research advance without detailed supervision by all echelons of government,
- incorporate the emerging technology into existing projects to take early advantage of the breakthroughs and demonstrate their technical value.

It is the purpose of this report to point up the significance of these decisions on the development of the integrated circuit, particularly in light of their profound effects on the military and industry.



The Minuteman II Intercontinental Ballistic Missile was the first major weapon system to make extensive use of integrated circuits.

ROOTS OF THE CONCEP

After World War II, the trend was tow
more complex military electronic equipm
to meet expanding mission requirements. T
few simple groups of individual compon
previously associated with electronic eq
ment, such as transmitters and receivers, w
rapidly being supplemented by additio
more complex circuits. The result was a
mendous increase in the number of indi
ual components and interconnections betw
them—each of which was a possible poi
failure. This, coupled with lack of highl
liable parts, compounded the failure rate p
lem. It was during this period that the
between failures of complex airborne
tronic equipment was occasionally meas
in minutes.

The invention of the more rugged and
able transistor in 1948 promised some r
from the reliability problem. But the imp
reliability of transistors was not enou
offset the rapid expansion in the numb
individual components necessary in the
complex equipment.

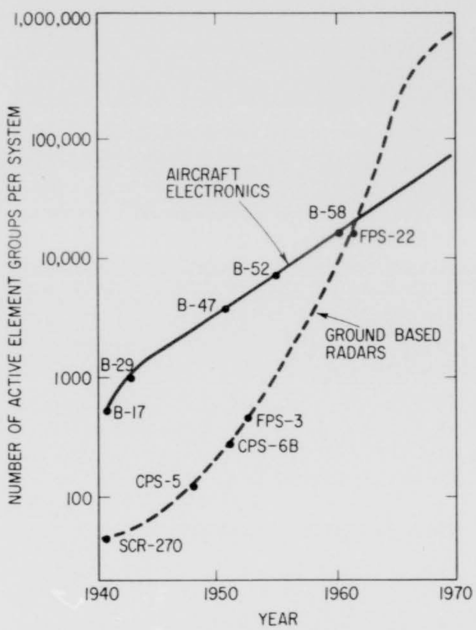
THE PROBLEM

Continuing this trend through the late
Air Force electronic equipment had b
so immensely complex that componen

ROOTS OF THE CONCEPT

After World War II, the trend was toward more complex military electronic equipment to meet expanding mission requirements. The few simple groups of individual components previously associated with electronic equipment, such as transmitters and receivers, were rapidly being supplemented by additional, more complex circuits. The result was a tremendous increase in the number of individual components and interconnections between them—each of which was a possible point of failure. This, coupled with lack of highly reliable parts, compounded the failure rate problem. It was during this period that the time between failures of complex airborne electronic equipment was occasionally measured in minutes.

The invention of the more rugged and reliable transistor in 1948 promised some respite from the reliability problem. But the improved reliability of transistors was not enough to offset the rapid expansion in the number of individual components necessary in the more complex equipment.



The increasing complexity of aircraft electronic equipment after World War II is demonstrated by the twelvefold increase in the number of active electronic components from the B-17 to the B-58 bomber. An even greater increase is depicted for ground based radars.

THE PROBLEM

Continuing this trend through the late 1950's, Air Force electronic equipment had become so immensely complex that component and

The Westinghouse integrated circuit held by the tweezers is equivalent to all the resistors, capacitors, diodes, and transistors shown in the foreground.

interconnection failures seriously threatened the accomplishment of even routine operational tasks. Of equally serious consequence, was the rapid snowballing of dollars, manpower, and time necessary for the support functions—such as supply, maintenance, and training. In short, the entire mission capability of the U. S. Air Force was threatened. A new approach to electronic technology was desperately needed.

THE NEW CONCEPT

The new concept, defined first by the Air Force in 1958, was for a long technical leap forward; not just a stop-gap improvement. The proposed new devices, however, required an awesome set of specifications. They had to be at least ten times more reliable than the existing individual components and had to feature an equally drastic reduction in size and weight. They had to cost less than the individual parts they replaced but had to provide at least the same performance levels.

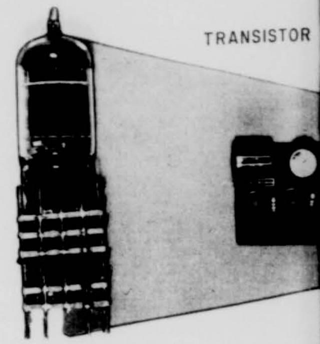
Stimulated by ideas emerging from industry and from the scientific community, the Air Force proposed to the Department of Defense a revolutionary solution. Earlier improvements in reliability had been brought about by the transistor. From this already highly developed technology, it was possible to extrapolate a concept of electronic design in which a single block of material could be made to perform the function of an entire circuit. This radical concept—*molecular electronics*—was the approach selected and pursued by the Air Force to solve the reliability problem. The integrated circuit is the first practical and useful output of this concept.

In deciding on the molecular electronics approach, the Air Force hoped to "leap frog" two other techniques, because they did not offer sufficient reliability improvement. These techniques, then under study, were the modular and thin-film approaches.

THE MODULAR APPROACH

In the late 40's and early 50's, the National Bureau of Standards, working under Navy sponsorship, developed *Tinkertoy*, a mechanized production line for electronic assemblies. The Tinkertoy consisted of a tiered assembly of individual parts, with riser wire interconnections and an electron tube mounted on the top of the module. This allowed the removal of heat and permitted tube replacement in case of failure. Size and cost reductions were Tinkertoy's main advantages.

The *Micro-module* concept, sponsored by the Army Signal Corps, was a direct descendant of the Tinkertoy program, with one major change: the transistor, with its longer life, could be made an integral part of the assembly. The Micro-Module showed a reliability improvement over other transistorized circuits —however, it still contained individual parts



Evolution of electronic circuits from the early

and interconnections, with their inher
liability problems. The justification
Micro-Module program was, again, siz
tion, plus automated assembly, with it
tial cost reduction.

THE THIN-FILM APPROAC

Another approach for reducing the s
increasing the reliability of electroni
ment was fostered by the Navy: *thin-*
cuit technology. These circuits were p
by depositing films on an inactive sub
form individual resistive and capaci
tronic parts and their interconnection
devices, such as transistors, were fabr
separate items and connected into the
Thin-film circuits are best character
potential for small size and automati

THE MOLECULAR ELECTRONICS APPROACH

To the Air Force, neither the Micro
nor the thin film represented an
solution to the most important prob
ability. A completely different app
needed; an approach in which the le
lem, miniaturization, was secondary

Air Force management, working toge
such organizations as Westinghouse

The Westinghouse integrated circuit held by the tweezers is equivalent to all the resistors, capacitors, diodes, and transistors shown in the foreground.

interconnection failures seriously threatened the accomplishment of even routine operational tasks. Of equally serious consequence, was the rapid snowballing of dollars, manpower, and time necessary for the support functions—such as supply, maintenance, and training. In short, the entire mission capability of the U. S. Air Force was threatened. A new approach to electronic technology was desperately needed.

THE NEW CONCEPT

The new concept, defined first by the Air Force in 1958, was for a long technical leap forward; not just a stop-gap improvement. The proposed new devices, however, required an awesome set of specifications. They had to be at least ten times more reliable than the existing individual components and had to feature an equally drastic reduction in size and weight. They had to cost less than the individual parts they replaced but had to provide at least the same performance levels.

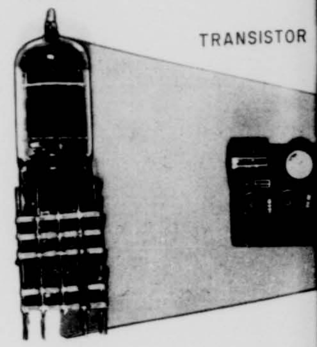
Stimulated by ideas emerging from industry and from the scientific community, the Air Force proposed to the Department of Defense a revolutionary solution. Earlier improvements in reliability had been brought about by the transistor. From this already highly developed technology, it was possible to extrapolate a concept of electronic design in which a single block of material could be made to perform the function of an entire circuit. This radical concept—*molecular electronics*—was the approach selected and pursued by the Air Force to solve the reliability problem. The integrated circuit is the first practical and useful output of this concept.

In deciding on the molecular electronics approach, the Air Force hoped to "leap frog" two other techniques, because they did not offer sufficient reliability improvement. These techniques, then under study, were the modular and thin-film approaches.

THE MODULAR APPROACH

In the late 40's and early 50's, the National Bureau of Standards, working under Navy sponsorship, developed *Tinkertoy*, a mechanized production line for electronic assemblies. The Tinkertoy consisted of a tiered assembly of individual parts, with riser wire interconnections and an electron tube mounted on the top of the module. This allowed the removal of heat and permitted tube replacement in case of failure. Size and cost reductions were Tinkertoy's main advantages.

The *Micro-module* concept, sponsored by the Army Signal Corps, was a direct descendant of the Tinkertoy program, with one major change: the transistor, with its longer life, could be made an integral part of the assembly. The Micro-Module showed a reliability improvement over other transistorized circuits —however, it still contained individual parts



Evolution of electronic circuits from the early

and interconnections, with their inhe
liability problems. The justification
Micro-Module program was, again, siz
tion, plus automated assembly, with it
tial cost reduction.

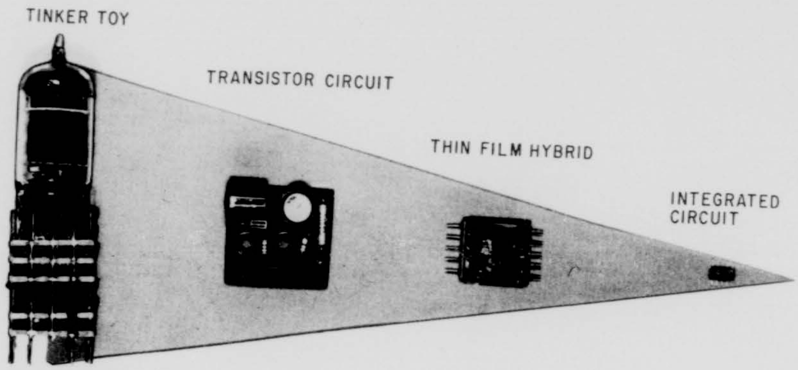
THE THIN-FILM APPROAC

Another approach for reducing the s
increasing the reliability of electroni
ment was fostered by the Navy: *thin-*
cuit technology. These circuits were p
by depositing films on an inactive sub
form individual resistive and capaci
tronic parts and their interconnection
devices, such as transistors, were fabr
separate items and connected into the
Thin-film circuits are best characteri
potential for small size and automati

THE MOLECULAR ELECTRONICS APPROACH

To the Air Force, neither the Micro
nor the thin film represented an
solution to the most important prob
ability. A completely different app
needed; an approach in which the le
lem, miniaturization, was secondary.

Air Force management, working toge
such organizations as Westinghouse



Evolution of electronic circuits from the early Tinkertoy to the modern integrated circuit.

and interconnections, with their inherent reliability problems. The justification for the Micro-Module program was, again, size reduction, plus automated assembly, with its potential cost reduction.

THE THIN-FILM APPROACH

Another approach for reducing the size and increasing the reliability of electronic equipment was fostered by the Navy: *thin-film circuit* technology. These circuits were produced by depositing films on an inactive substrate to form individual resistive and capacitive electronic parts and their interconnections. Active devices, such as transistors, were fabricated as separate items and connected into the circuits. Thin-film circuits are best characterized by a potential for small size and automation.

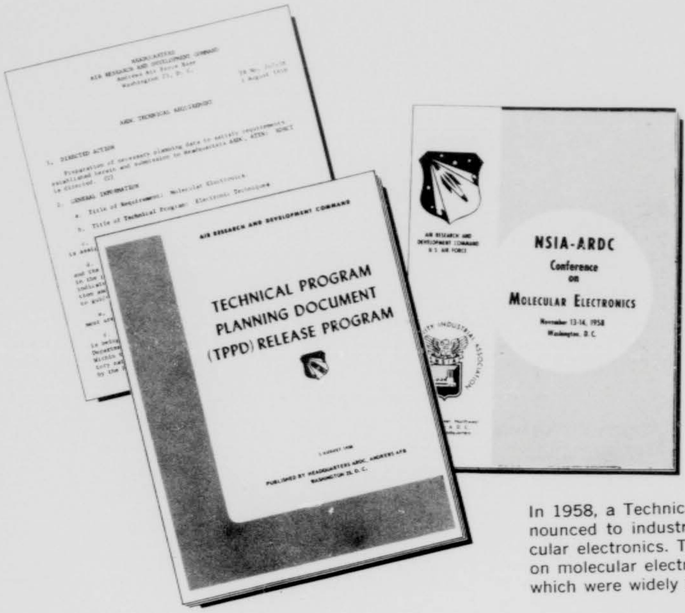
THE MOLECULAR ELECTRONICS APPROACH

To the Air Force, neither the Micro Module nor the thin film represented an adequate solution to the most important problem—reliability. A completely different approach was needed; an approach in which the lesser problem, miniaturization, was secondary.

Air Force management, working together with such organizations as Westinghouse, evolved the concept of *molecular electronics:* a single piece of solid material synthesized to achieve a complete circuit function. Dr. H. V. Noble and other research directors at the Wright Air Development Center (WADC) were the first to propose, in 1953, development of these functional electronic blocks for the Air Force. Nothing concrete resulted at this early date. But the direction in which the Air Force ultimately would move had been set. During the period 1956 to 1958, Air Force study groups established specifications for improved reliability in electronic equipment. Their studies confirmed that a drastic improvement was needed. Col. C. H. Lewis and Mr. F. E. Wenger of the Headquarters Air Research and Development Command (ARDC) supported by the group under Dr. J. E. Keto at WADC, documented in 1958 the need for solid blocks of material capable of performing a complete circuit function.

THE INTEGRATED CIRCUIT CONCEPT

Another approach to molecular electronics, called integrated circuits, was emerging. The integrated circuit concept involves a block of transistor-type solid material in which individual areas are also synthesized to obtain certain electrical properties such as resistance. These areas are interconnected within the



In 1958, a Technical Program Planning Document announced to industry the Air Force's interest in molecular electronics. This same year, the first conference on molecular electronics was held, the proceedings of which were widely circulated.

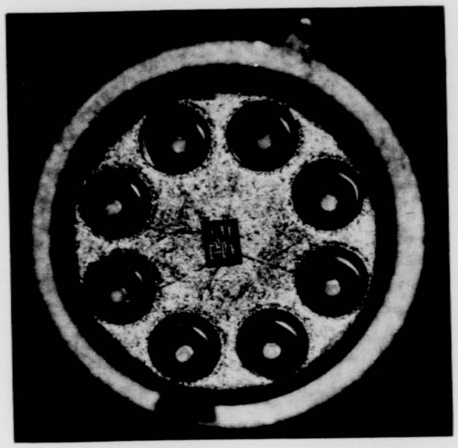
block to perform for the first time in a solid block a complete circuit function, similar to the way in which individual parts are used to make up a conventional circuit.

The origin of the integrated circuit concept is traced to G. W. A. Dummer of the British Royal Radar Establishment who, at the May 1952 Electronic Components Conference in Washington, D. C., stated:

> "With the advent of the transistor and the work in semiconductors generally, it seems now possible to envisage electronics equipment in a solid block with no connecting wires. The block may consist of layers of insulating, conducting, rectifying and amplifying materials, the electrical functions being connected directly by cutting out areas of the various layers."

This idea, and the inventions of such early innovators as J. S. Kilby and Dr. H. W. Henkels, are the roots of the integrated circuit as we know it today.

In summary, there existed a defined need, proposed to be satisfied by a vague research concept known as molecular electronics. There also existed a specific development, with no defined goal, evolving from the advancing semiconductor technology. It will now be shown how these were merged into one vital effort.



Magnified view of an integrated circuit showing the individual areas that represent separate electrical components, such as resistors, capacitors, and transistors.

DEVELOPMENT OF

In 1957, the over-all industry resp
Force interest in molecular electro
enthusiastic. Nevertheless, the Ai
in particular, the Aero-Electronics
of the Air Research and Develop
mand (ARDC) and the Electron
ogy Laboratory of Wright Air D
Center, actively supported imme
tion of a research and developme
in molecular electronics. Finally,
Colonel Lewis and other ARDC
bers after surveying industry rea
a responsive chord at Westing
ARDC staff prepared a compre
line of a program for the dev
materials and devices utilizing th
electronics concept. The progra
concentrated, massive funding to
results, along with close liaison
contractor and government lab
that prompt advantage could be t
advance. Coordination of the over
between the Air Force and ot
organizations was to be provided
ory Group on Electron Tubes (A
Department of Defense. To insu
sults, the Air Force proposed th
program be conducted by one co
the materials, components, equip
tems considerations were all in
the one concept. It was realized
up such a program would be hig
tal to its timely success. By bringi
proposal, the Air Force showed i
to take a high risk if the pote
were great enough.

DEVELOPMENT OF THE CONCEPT

In 1957, the over-all industry response to Air Force interest in molecular electronics was unenthusiastic. Nevertheless, the Air Force and, in particular, the Aero-Electronics Directorate of the Air Research and Development Command (ARDC) and the Electronic Technology Laboratory of Wright Air Development Center, actively supported immediate initiation of a research and development program in molecular electronics. Finally, in late 1957, Colonel Lewis and other ARDC staff members after surveying industry reaction struck a responsive chord at Westinghouse. The ARDC staff prepared a comprehensive outline of a program for the development of materials and devices utilizing the molecular electronics concept. The program called for concentrated, massive funding to assure rapid results, along with close liaison between the contractor and government laboratories so that prompt advantage could be taken of each advance. Coordination of the over-all program between the Air Force and other military organizations was to be provided by the Advisory Group on Electron Tubes (AGET) of the Department of Defense. To insure timely results, the Air Force proposed that the entire program be conducted by one company, since the materials, components, equipment and systems considerations were all interrelated in the one concept. It was realized that breaking up such a program would be highly detrimental to its timely success. By bringing forth this proposal, the Air Force showed its willingness to take a high risk if the potential rewards were great enough.

"In the light of the solid accomplishments of the past years, it is interesting and amusing to remember the intensity of the prophetic-visionary element in 1959-1960. A revolution of both impressive and disturbing dimensions was predicted. The rapid annihilation of the components industry (or, alternatively, of the equipment manufacturing industry) was postulated along with the doom of traditional technical disciplines (no more physicists, chemists, etc., and certainly no circuit designers, but just super-generalists with all-embracing knowledge who will conceive systems and build them using appropriate sets of molecules)."

"This mumbo-jumbo was somewhat irritating; prophets, by definition inspired dilettantes, always irritated the down-to-earth detail types. In reality, the prophets fulfilled an important function beyond that of the more sober analysts who favored integrated electronics merely on the bases of needs and technical feasibility. Their description of the future injected emotion and a degree of salubrious panic, shocking profession and industry into rapid activity, an activity which soon proved to be quite down-to-earth, scientific, and methodical. . . ."

". . . . The combination of identified needs-objectives, and available or semi-available technical base was aided materially by stimulation and sophisticated management on the part of the Department of Defense and by auspicious competitive factors in the electronics industry. DOD recognized very early the need for integrated electronics and its significance for defense systems. Not only were substantial sums made available to industry, but optimum use was made of these funds by concentrating them and not dispersing them in the form of many micro-contracts with micro-objectives. A few contracts with major objectives were placed with a few industrial organizations. The contracts soon produced results and stimulated activity in those less fortunate, companies who preferred entering integrated electronics at their own expense to being left behind. . . ."

"Incidentally, the successful history of integrated electronics, if viewed as primarily the result of clearly identified needs, efficient utilization of available technological base, and good management by the Department of Defense, is an interesting illustration of a contention of a well-known military figure that the solution of our principal problems in defense systems resides not in the area of technology, but in that of management."*

*From the preface by A. P. Stern to the Special Issue on Integrated Electronics, Proceedings of the IEEE, Vol 52, No. 12, December, 1964.

THE FIRST MOLECULAR ELECTRONIC CONTRACT

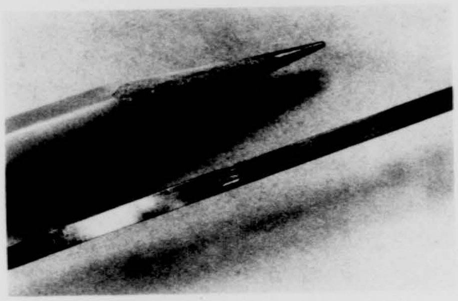
At the time in 1958 when the molecular electronics program was proposed, the Air Force already had apportioned all its research and development funds for fiscal year 1959. But with the very active support of James M. Bridges of the Office of Defense Research and Engineering of the Department of Defense, $2,000,000 in emergency funds were provided to start the program. The proposed plan called for spending that money in only ten months at Westinghouse—an approach severely criticized by both the scientific community and AGET, because it was based on "abstract" requirements and not scientific fact. Fortunately, however, this conservative attitude was overruled and the contract begun in April 1959.

Westinghouse and the Air Force spent a difficult year attempting to deliver solid evidence of accomplishment: namely, working circuit blocks. Also undertaken were system studies exploring the possibility of utilizing molecular electronics in specific pieces of electronic equipment then in use. The success of this initial contract led to a $2,600,000 extension in early 1960.

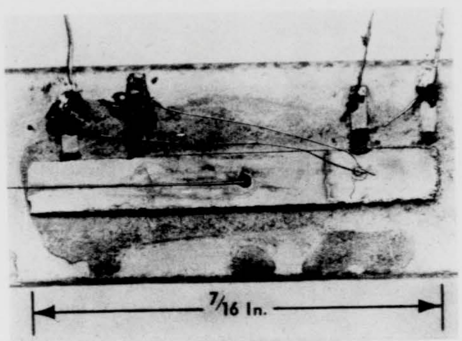
THE FIRST SILICON INTEGRATED CIRCUIT CONTRACT

As a logical outgrowth of the rapidly expanding transistor technology, the feasibility of building integrated circuits had been discussed as early as 1955 at Texas Instruments by P. J. Haggerty, President, and Dr. W. Adcock, Director of Research. In 1958, J. S. Kilby of Texas Instruments succeeded in fabricating the first complete circuit in a single piece of material. The single material block contained the equivalent elements for individual components, such as transistors, resistors, and capacitors, all interconnected in one circuit. Reliability was increased greatly since component interconnections were thereby eliminated.

By October 1958, working models of two types of circuits, oscillators and multivibrators, had been fabricated. These were shown to Captain E. B. Richter of the Air Force Electronic Technology Laboratory of WADC, who reported on their development. Demonstrations were arranged for Dr. H. V. Noble and Mr. R. Alberts of WADC. Based on these demonstrations, the Air Force proposed a development program to be conducted at Texas Instruments to exploit this promising breakthrough in circuit fabrication. Again, by imaginative planning and concentrated funding,



Early molecular circuit blocks on a dendritic strip developed under the first Air Force contract with Westinghouse.

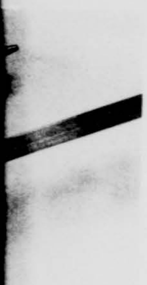


Magnified photo of an early integrated circuit developed at Texas Instruments.

LOS ANGELES, C
electrical engineering
house Electrical Corpor
which the complete ampl
A conventional amplifie
similar components, wou
connections as the mole
mean a far greater degr
stration was one of a v
which were shown here b

Westinghouse press release announcing su thereby elimi-

els of two types
tivibrators, had
own to Captain
rce Electronic
ADC, who re-
Demonstrations
Noble and Mr.
n these demon-
sed a develop-
cted at Texas
omising break-
Again, by imag-
rated funding,



n dendritic strip
e contract with

d circuit devel-

LOS ANGELES, Calif., Feb. 2, 1960 -- To demonstrate a new electrical engineering concept known as molecular electronics, Westinghouse Electrical Corporation scientists utilized a phonograph system in which the complete amplifier was replaced by the tiny units shown here. A conventional amplifier, with its tubes, capacitors, resistors and similar components, would have perhaps ten times as many soldered connections as the molecular electronic system. Fewer such connections mean a far greater degree of reliability. The phono-amplifier demonstration was one of a variety of working molecular electronic sub-systems which were shown here by Air Force and Westinghouse representatives.

Westinghouse press release announcing successful development of first working circuit blocks in 1960.

the Air Force proposed to bring a new development to practical fulfillment in a short time.

In June 1959, a $1,150,000 contract was awarded to Texas Instruments. The contract called for the development of integrated circuits capable of performing several specific circuit functions. Rapid progress using silicon as the basic material resulted in the development of practical models of various circuits.

In late 1960, research and development had progressed so rapidly that the integrated circuit was outgrowing its status as a laboratory curiosity. Air Force planners recognized that production facilities soon would be required if the laboratory advances being made daily were to be applied to new equipments then being designed. To keep pace with this growth, the Air Force awarded to Texas Instruments in December 1960 a $2,100,000 production refinement contract for the development of production processes and special equipment needed for the fabrication of integrated circuits in bulk quantities. The contract resulted in a pilot assembly line, capable of turning out 500 integrated circuits a day.

An exhibit booth at the 1961 Institute of Radio Engineers Convention in New York announcing the development of Fairchild's first integrated circuits.

THE FIRST INTEGRATED CIRCUIT EQUIPMENT

As late as 1961, the industrial and scientific communities still voiced doubts as to the worth of integrated circuits from an equipment and systems viewpoint. To alleviate these doubts, and to further exploit the experience obtained under the earlier equipment-oriented Westinghouse program, the Air Force proposed the building of a representative piece of electronic equipment using integrated circuits.

Under Air Force sponsorship, the building of a digital computer was introduced into the Texas Instruments production program. Two identical computers were built: one with 9000 individual components, and one containing only 587 integrated circuits. Demonstrations of these two equipments in October 1961 were made to packed technical audiences in Dayton, Washington, and Los Angeles. The joint Texas Instruments—Air Force demonstrations were given by P. J. Haggerty of Texas Instruments, and Col. A. Wallace, Mr. R. Feik, and Capt. L. Roesler of the Air Force.

The success of the demonstrations in obtaining acceptance of integrated circuits was revealed by renewed industry interest. Companies that had been watching from the sidelines the progress of the Air Force-supported programs at Westinghouse and Texas Instruments began company-funded research and development programs. Fairchild, without government support and spurred by the increasing tempo of government and industry efforts, developed its first circuits in 1961.

In summary, the years 1960 and 1961 were eventful ones. Early in 1960, both the Army and Navy expressed extreme interest in integrated circuit feasibility models. However,

Military and industrial personnel viewing the integrated circuit computer produced by Texas Instruments. The computer is entirely contained in the block (blue) mounted on the hexagonal display board. The unit at the left is the same computer constructed using individual components. A close-up of the integrated circuit computer is shown below.

e fabrication of in-
quantities. The con-
sembly line, capable
ated circuits a day.

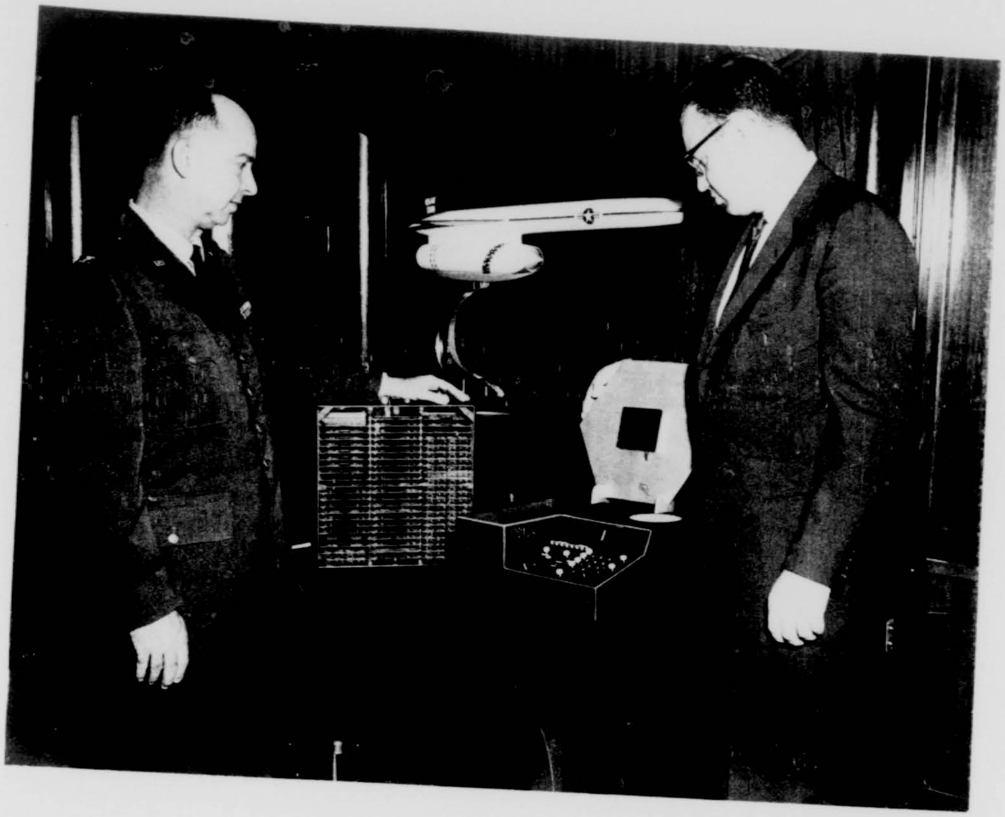
RATED
NT

trial and scientific
doubts as to the
ts from an equip-
oint. To alleviate
er exploit the ex-
he earlier equip-
e program, the Air
ng of a represen-
equipment using

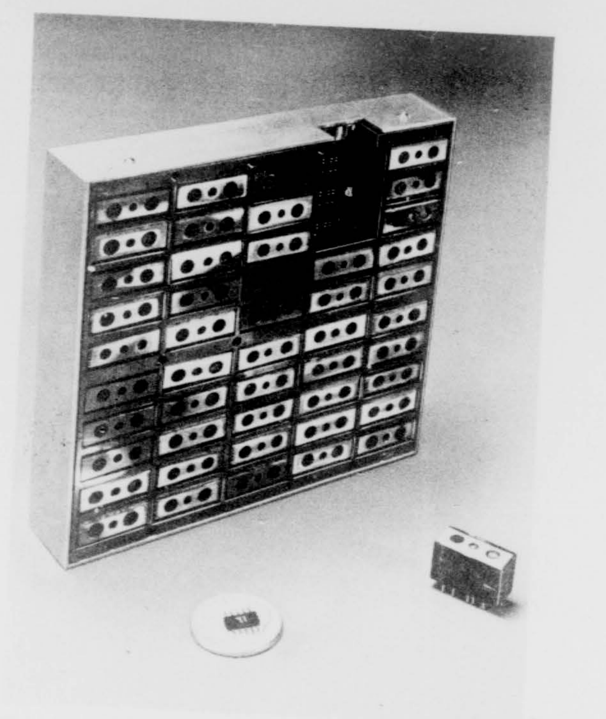
o, the building of
roduced into the
on program. Two
lt: one with 9000
one containing
Demonstrations
ctober 1961 were
udiences in Day-
geles. The joint
e demonstrations
of Texas Instru-
Mr. R. Feik, and
orce.

tions in obtain-
circuits was re-
terest. Compa-
m the sidelines
supported pro-
as Instruments
ch and devel-
ithout govern-
the increasing
stry efforts, de-

nd 1961 were
oth the Army
terest in inte-
els. However,



Military and industrial personnel viewing the integrated circuit computer produced by Texas Instruments. The computer is entirely contained in the block (blue) mounted on the hexagonal display board. The unit at the left is the same computer constructed using individual components. A close-up of the integrated circuit computer is shown below.



they elected to continue to emphasize previously selected approaches—leaving the exploitation of the integrated circuit concept to the Air Force. These two services and NASA, however, also conducted modest programs in integrated circuit development and application.

In 1961, a variety of functional electronic blocks were delivered by Westinghouse. Texas Instruments published specification sheets and announced commercial availability of a line of integrated circuits, such as the SN-51 digital circuits developed in part with NASA support. Fairchild and other companies entered the integrated circuit market. Articles on integrated circuits began to appear in journals, technical magazines, and newspapers. Mr. P. J. Klass in *Aviation Week and Space Technology* continuously reported the latest advances as did *Electronics News*, *Electronics*, and other trade publications.

By the end of 1961, Westinghouse had shifted its research from the broadest concept of molecular electronics to focus on its first practical outgrowth: integrated circuits. Westinghouse established a Molecular Electronics Division to produce silicon integrated circuits, while Texas Instruments formed a Molecular Electronics Branch for advanced research and exploitation of the silicon integrated circuit.

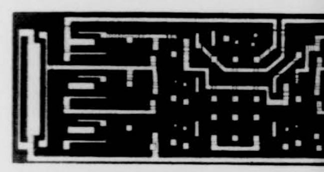
The rapid development of the integrated circuit concept during these early years was due in large part to effective management and unequivocal support by the Air Force. The overall achievement was the merging, with spectacular results, of two separate programs—one to satisfy a critical military need for reliability; the other to advance the state of transistor technology. Out of this came the first significant molecular electronic device: the silicon integrated circuit.

Non-technical articles on integrated circuits appeared in many newspapers and magazines such as the above.

A PERIOD OF GR

Momentous technological adva
sign and fabrication of integrate
made between 1961 and 1964.
sponsored a program at Motor
integrated circuits by combining
acteristics of thin-film technol
integrated circuit. Fairchild S
under a company-funded prog
fully adapated the planar te
used for fabricating transistor
grated circuit. With these tec
child produced a line of off-
grated logic circuits to add to
Texas Instruments off-the-shelf

The availability of off-the-shelf
cuits reduced drastically the tim
design of digital electronic equip
cifying an available integrated
equipment designer could sa
hours required for design of i
cuits. If necessary, the designe
nate his own integrated circuit.
development programs, it was
to set up the manufacturing p
special integrated circuit. To o
universal integrated circuits bloc
be used as the basis for a varie
were developed. These univers

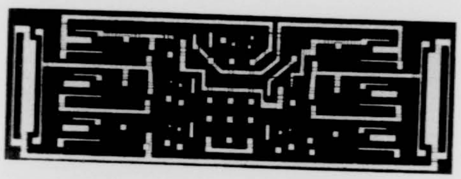


This Sprague universal integrated circ
0.070 inch by 0.200 inch, is equivalent
components: 7 transistors, 7 diodes, 9
capacitors. The small rectangular are
these components can be interconnecte
metallic conductors to form several ty
The interconnections shown are for a fli

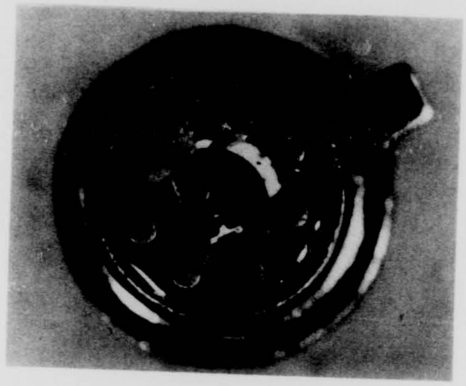
A PERIOD OF GROWTH

Momentous technological advances in the design and fabrication of integrated circuits were made between 1961 and 1964. The Air Force sponsored a program at Motorola to improve integrated circuits by combining the best characteristics of thin-film technology with the integrated circuit. Fairchild Semiconductor, under a company-funded program, successfully adapated the planar techniques then used for fabricating transistors to the integrated circuit. With these techniques, Fairchild produced a line of off-the-shelf integrated logic circuits to add to the existing Texas Instruments off-the-shelf line.

The availability of off-the-shelf integrated circuits reduced drastically the time required for design of digital electronic equipment. By specifying an available integrated circuit, the equipment designer could save the many hours required for design of individual circuits. If necessary, the designer could originate his own integrated circuit. But in most development programs, it was too expensive to set up the manufacturing processes for a special integrated circuit. To overcome this, *universal integrated circuits blocks* that could be used as the basis for a variety of circuits were developed. These universal integrated circuits consisted of many unconnected components on a single circuit block. The equipment designer who needed only a few integrated circuits of a certain type could arrange the specific interconnection pattern that would satisfy his particular requirements. In this way, useful integrated circuits could easily be developed for design purposes—at a cost well below that for custom production integrated circuits. The availability and reasonable cost of these universal circuits has done much to encourage the use of integrated circuits in all phases of new equipment research and development.



This Sprague universal integrated circuit block, only 0.070 inch by 0.200 inch, is equivalent to 31 individual components: 7 transistors, 7 diodes, 9 resistors and 8 capacitors. The small rectangular areas representing these components can be interconnected by depositing metallic conductors to form several types of circuits. The interconnections shown are for a flip-flop.

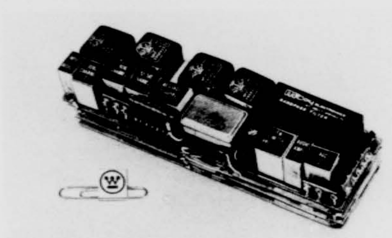


Magnified view of an early Fairchild planar integrated circuit.

THE SYSTEMS RESEARCH VEHICLE CONCEPT

Once the feasibility of integrated circuits was established, the next step was their application to electronic equipments. To demonstrate the feasibility of these applications, the Molecular Electronics Group at Wright-Patterson Air Force Base originated, and had included in the original Westinghouse contract, the

This 30-megacycle command control receiver, also built with integrated circuits, contains a high percentage of linear and digital circuit blocks. The interior of this tiny receiver is shown below.

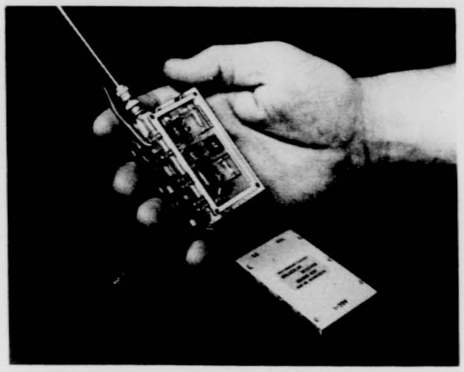


systems research vehicle concept. This concept involves the building of demonstration equipments to prove the validity of utilizing integrated circuits where transistors previously had been used.

The group, under R. D. Alberts, sponsored the development of three pieces of electronic equipment utilizing integrated circuits: a communications receiver, a telemetry encoder, and an infrared tracker. The construction of these equipments contributed a significant amount of new knowledge to the design of integrated circuit equipment—and the successful accomplishment of these projects resulted in a new approach to equipment design.

COMMUNICATIONS RECEIVER AN/ARC-63

The design and fabrication of the AN/ARC-63 communications receiver began at Westinghouse in 1960. The receiver was the first non-digital equipment to make extensive use of integrated circuits. The AN/ARC-63 represented a 35-to-1 reduction in size and weight and a 5-to-1 improvement in reliability over a comparable transistor version of the same receiver.



The AN/ARC-63 communications receiver was the first non-digital equipment to make extensive use of integrated circuits—with a resulting 35 to 1 reduction in size and weight over a comparable transistor version of the same receiver.

TELEMETRY ENCODER

The development of a telemetry encode
izing integrated circuits was started at
Instruments in 1961. This encoder was
the first integrated circuit version of an
ing transistorized equipment. Use of 28
grated circuits resulted in a much mor
able equipment and a 95% reduction
and weight over the equivalent transis
equipment. In addition, the required
ing power was only 10% of that requi
the transistorized version.

INFRARED TRACKER

Design and fabrication of an infrared
employing integrated circuits began at

The complete infrared search tracker made pr
this system is in the 18-inch collector optics mo

TELEMETRY ENCODER

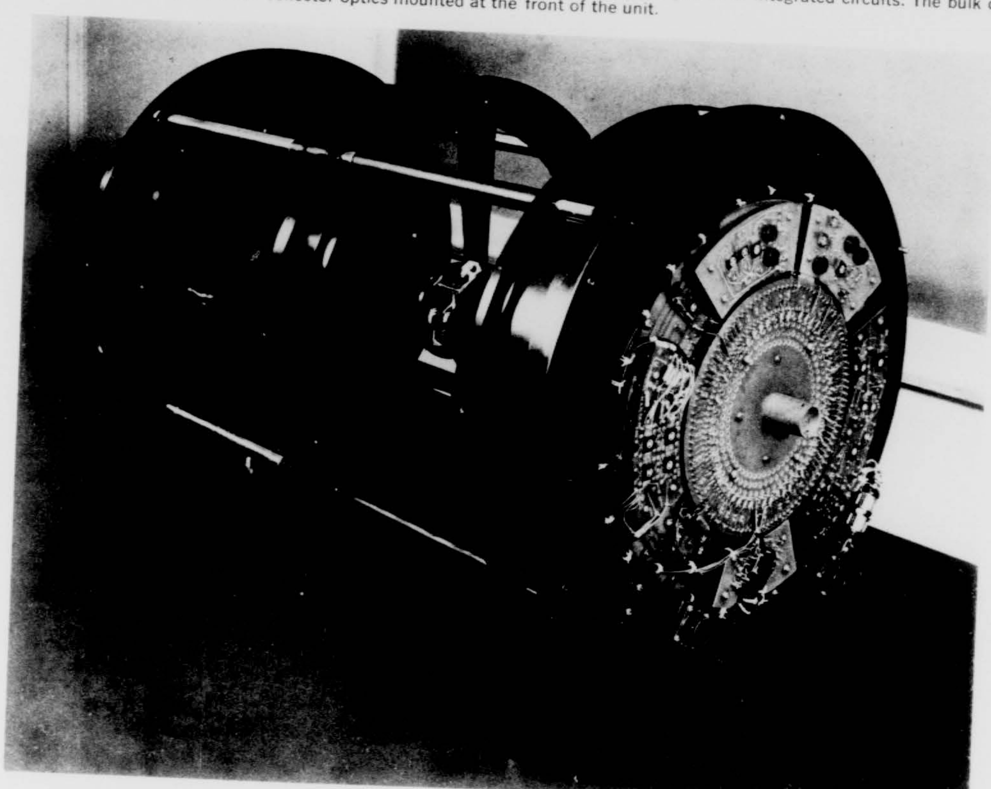
The development of a telemetry encoder utilizing integrated circuits was started at Texas Instruments in 1961. This encoder was to be the first integrated circuit version of an existing transistorized equipment. Use of 285 integrated circuits resulted in a much more reliable equipment and a 95% reduction in size and weight over the equivalent transistorized equipment. In addition, the required operating power was only 10% of that required by the transistorized version.

INFRARED TRACKER

Design and fabrication of an infrared tracker employing integrated circuits began at Westinghouse in June 1961. The tracker consisted of 100 individual infrared detector elements, each of which was followed by five separate amplifiers. Utilizing individual components for this system was a near impossibility since over 3600 parts would be required. Only by using integrated circuits was it practical to build the tracker within a reasonable size and weight limitation and with the required reliability.

The successful development of the AN/ARC-63, the telemetry encoder, and the infrared tracker established a new organizational concept of equipment design. This involved both the equipment designer and the integrated circuit designer. To achieve optimum results

The complete infrared search tracker made practical only through the development of integrated circuits. The bulk of this system is in the 18-inch collector optics mounted at the front of the unit.



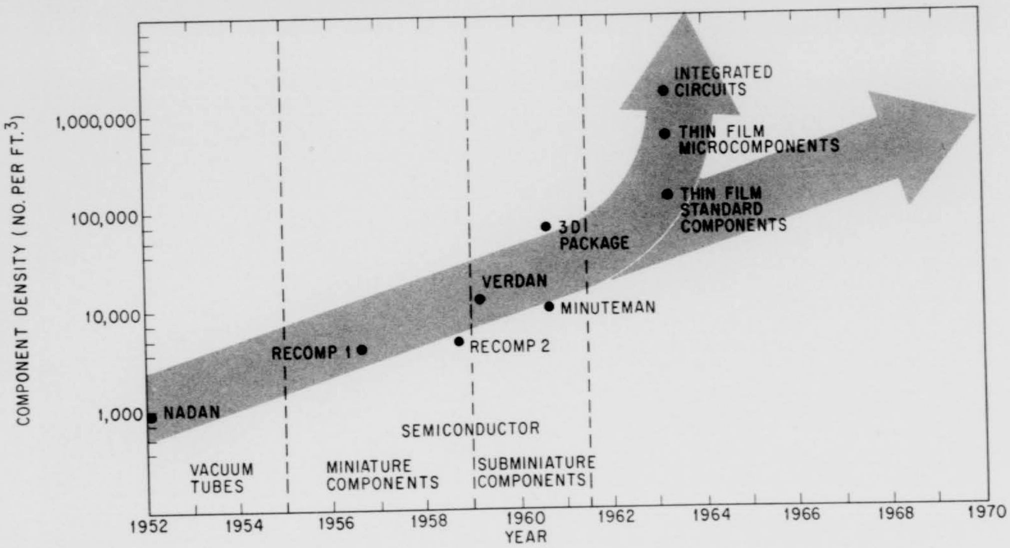
in these designs, close cooperation was required between the equipment group and the integrated circuit group. Equipment designers could not request integrated circuits which were beyond the current state of the art, and integrated circuit designers could not design their circuits independently of equipment design problems. From the working relationship a new industry design team emerged: an equipment designer assisted by an integrated circuit designer.

THE FIRST MAJOR SYSTEM—MINUTEMAN II

In 1962, the Autonetics Division of North American Aviation and the Air Force Ballistic Systems Division were in the midst of a design improvement program for one of the country's most important weapon systems: the Minuteman intercontinental ballistic missile. An improved Minuteman capable of longer range with no decrease in payload or reliability was needed. To design a new, higher performance propulsion system would involve a costly and lengthy program of propulsion system development and testing. The only other way to increase the missile's range was to reduce the size and weight of the existing electronic guidance package.

At this time, three possibilities for electronic miniaturization existed: thin films, Micro-Modules, and the integrated circuit. After exhaustive research, Autonetics proposed to the Air Force the use of the then emerging integrated circuit technology. In 1962, Minuteman II became the first major weapon system in development using integrated circuits.

Two years later, the first Minuteman II guidance computer using integrated circuits was successfully flight tested. A 50% reduction in weight with a resulting increase in range of many miles, and significant improvement in equipment reliability was achieved. Successful completion of this computer in such a short time served notice that integrated circuits must be accorded a competitive position in every future system design. The decision to use integrated circuits was of particular im-



Charting the component density possible with various miniaturization techniques showed that integrated circuits held the greatest promise for weight reduction in Minuteman II.

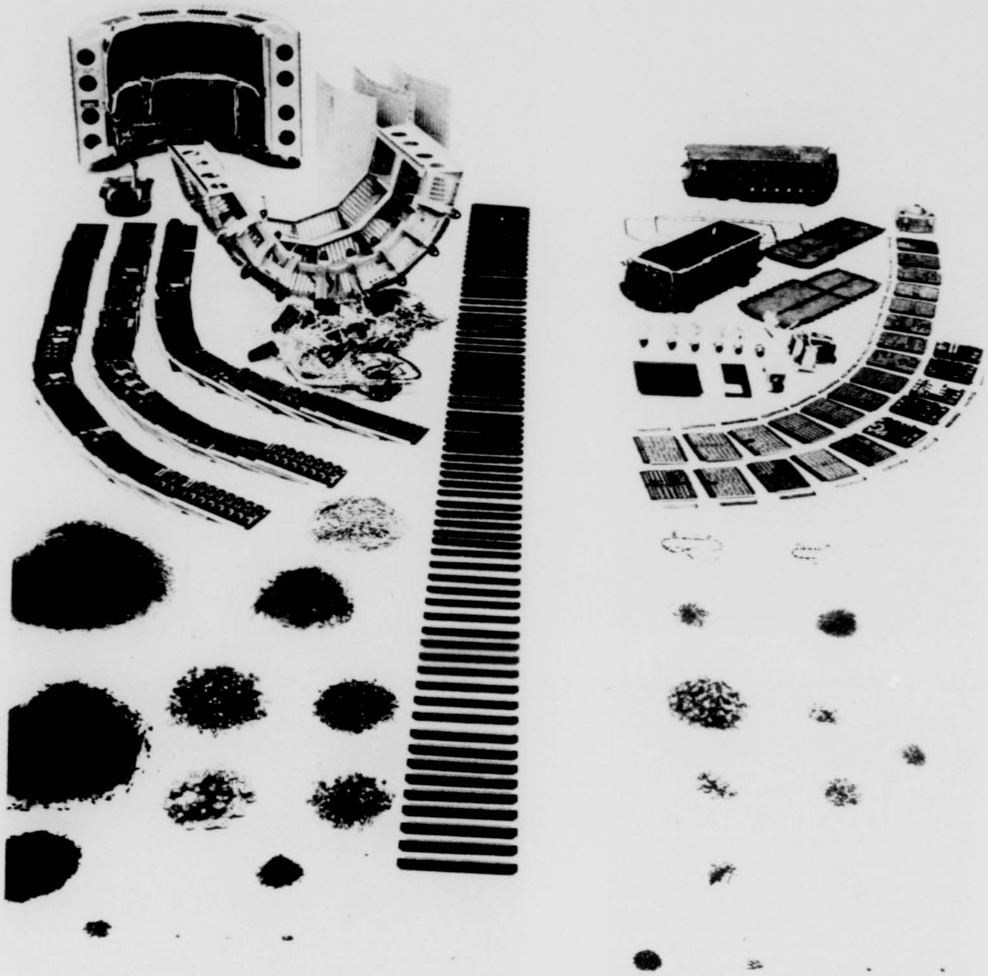
Comparison of the transistor version o
version used in Minuteman II (right)
weight that is attainable.

ropulsion sys-
he only other
ge was to re-
existing elec-

for electronic
films, Micro-
uit. After ex-
posed to the
nerging inte-
962, Minute-
apon system
circuits.

man II guid-
circuits was
reduction in
in range of
rovement in
d. Successful
uch a short
ted circuits
position in
decision to
rticular im-

circuits held



Comparison of the transistor version of the guidance computer used in Minuteman I (left) with the integrated circuit version used in Minuteman II (right) graphically illustrates the reduction in the number of components, size, and weight that is attainable.

portance to the semiconductor industry. The prospect of large production orders justified capital expenditures by industry for integrated circuit research and development.

OTHER SYSTEM PROGRAMS

Success of the systems research vehicle concept, and of the Minuteman II guidance computer, made obvious the inherent benefits of integrated circuits. The quickest way to take advantage of these benefits was to completely redesign existing equipment, using available integrated circuits. Marine Corps Col. A. Lowell of the Navy Bureau of Weapons, an ardent exponent of exactly this approach, started a broad program to place integrated circuits in Navy equipment in the shortest possible time. His first efforts involved direct replacement of printed circuit boards containing individual components by boards using integrated circuits. The production orders which resulted gave needed support to the emerging integrated circuit industry. Proposed integrated circuit development programs for a Loran C navigation receiver at Sperry, an integrated helicopter avionics system, and an integrated light attack avionics system also encouraged many companies to enter the field.

Colonel Lowell's continued advocacy of integrated circuits was an important factor in increasing industry's production
Large orders for integrated circui
units for the NASA Apollo guid
puter: the $9,000,000 Minuteman
—produced rapid expansions at Te
ments, Westinghouse, Motorola,
child. New companies, such as Sig
conix, General Micro-electronics, a
tro were founded primarily to m
integrated circuits. Interest was i
RCA, Sylvania, Raytheon, and TR
ment manufacturers, such as Radia
ported. Melpar, Collins Radio, a
started their own research and d
programs to keep up with the rap
in integrated circuit technology.

The integrated circuit Loran-C receiver on the right in comparison to the conventional Loran-C receiver on the left is three times more reliable, requires much less power, and is far simpler to use. The Air Force will use the improved receiver aboard the Apollo recovery aircraft, HC-130M.

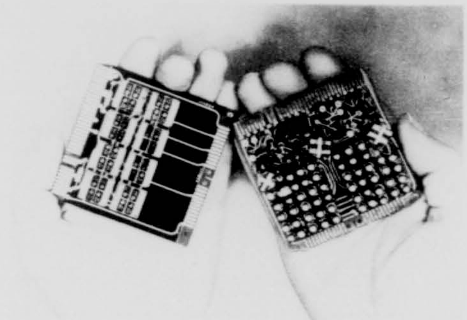
Ralph R. Ragan of Raytheon and Eldon
guidance computer of the NASA Apollo
is achieved by the use of integrated circ

grated circuits in
est possible time.
t replacement of
ining individual
g integrated cir-
s which resulted
emerging inte-
posed integrated
s for a Loran C
y, an integrated
nd an integrated
also encouraged
field.

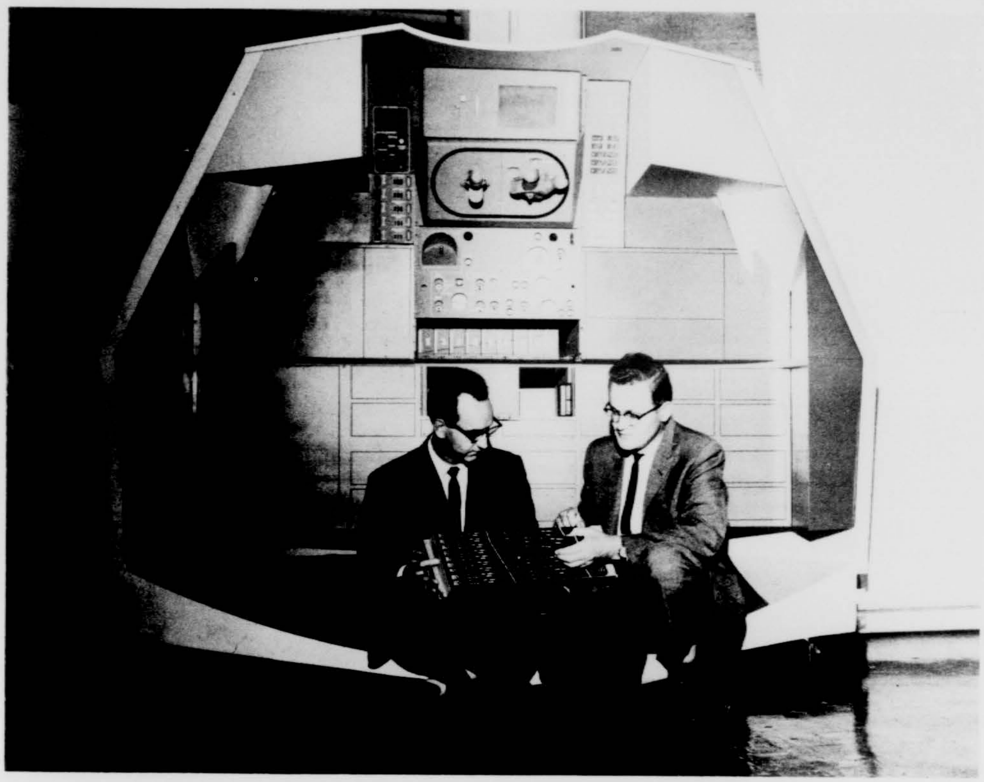
dvocacy of inte-
ortant factor in

ceiver on the left is
ll use the improved

increasing industry's production capability. Large orders for integrated circuits—200,000 units for the NASA Apollo guidance computer; the $9,000,000 Minuteman II contract—produced rapid expansions at Texas Instruments, Westinghouse, Motorola, and Fairchild. New companies, such as Signetics, Siliconix, General Micro-electronics, and Molectro were founded primarily to manufacture integrated circuits. Interest was increased at RCA, Sylvania, Raytheon, and TRW. Equipment manufacturers, such as Radiation Incorported, Melpar, Collins Radio, and Norden started their own research and development programs to keep up with the rapid advances in integrated circuit technology.



Printed circuit board on the left containing integrated circuits is a direct replacement for the board on the right containing individual components. The printed circuit boards are used in the Navy's W2F-1 early warning aircraft.



Ralph R. Ragan of Raytheon and Eldon Hall of M.I.T. check a tray of micrologic and "rope memory" modules for the guidance computer of the NASA Apollo spacecraft (shown mocked up at rear). The ultra-compactness of the computer is achieved by the use of integrated circuits.

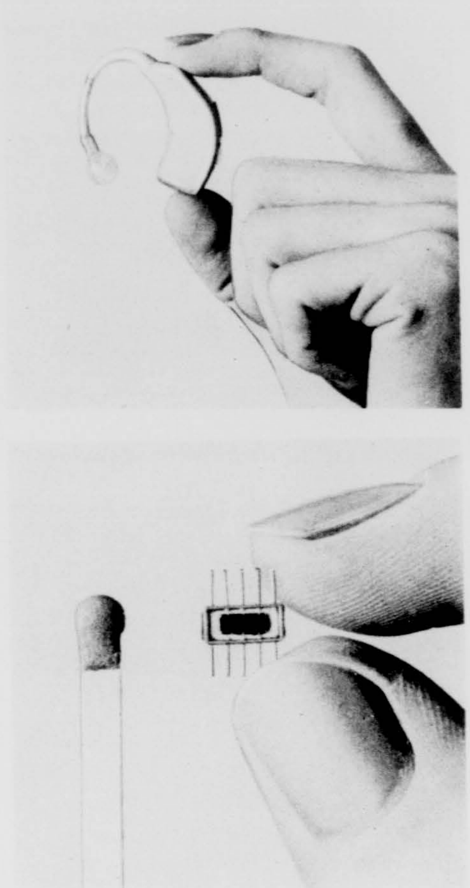
FIRST COMMERCIAL APPLICATION

The first commercial application of the integrated circuit appeared in a hearing aid developed by Zenith. The integrated circuit used was an adaptation of a highly reliable circuit developed for the Interplanetary Monitoring Platform (IMP) satellites of NASA. Zenith has reported that the integrated circuit hearing aid is 500% more reliable than their previous model.

THE WORD IS SPREAD

To keep abreast of advances in the integrated circuit field, the Air Force published word of new breakthroughs in technical reports. In 1962, it sponsored a program at ARINC Research Corporation to recommend means for the rapid changeover to integrated circuits in electronic equipment. Reports of this work were given wide distribution and helped to further focus industry's attention on the integrated circuit. In addition, articles on the new technology appeared in all technical journals and magazines. By 1964, interest was so widespread that the Institute of Electrical and Electronic Engineers (IEEE) published an issue of the "Proceedings of the IEEE" devoted exclusively to integrated circuits.

In summary, the period from 1961 to 1964 was one of extraordinary growth for the integrated circuit. Rapid advances were made at fabrication and production techniques. Emergence of the system research vehicle concept made it possible to prove the feasibility of utilizing integrated circuits in many equipments. Origination of the systems design concept resulted in new equipment designs that were previously impractical. Successful development of the first major system using integrated circuits encouraged their use in many other systems.



Upper photo is of Zenith's small behind-the-ear hearing aid, weighing 1/4 of an ounce with battery. Below is the integrated circuit for the unit.

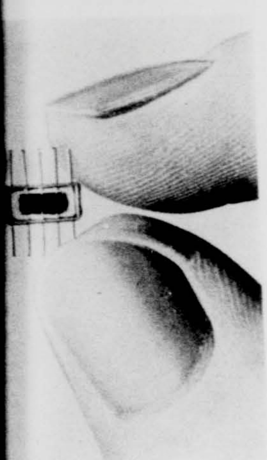
INTEGRATED CIRC IN 1965

In 1965, integrated circuits have
The predicted 10-to-1 improvem
bility has been achieved along w
size and weight reductions. Inc
bilities at higher frequencies and
ratings are being demonstrated
of integrated circuits has incre
dously, while prices have spirale
to below the cost of comparable
individual parts. Applications to
tronic equipment have reached a
integrated circuits are considere
almost all new equipment.

RELIABILITY

Today the reliability of the inte
is so high that it is difficult to o
operational failures to verify t
failure rates. The best reliability
has been collected by the M.I.T
tation Laboratory in designing
computer used in the manned s
Project Apollo. Exhaustive tests
the integrated circuits used in t
indicate an expected life of 20,0
or over *2000* years. The reliabili
tegrated circuit equipment pron
and even exceed that of this g
puter. However, these equipmen
this writing been in testing lo
provide definitive data.

The only requirement for dem
liability is that enough qualifie
enough patience be available



th's small behind-the-ear hearing
ounce with battery. Below is the
ne unit.

INTEGRATED CIRCUITS IN 1965

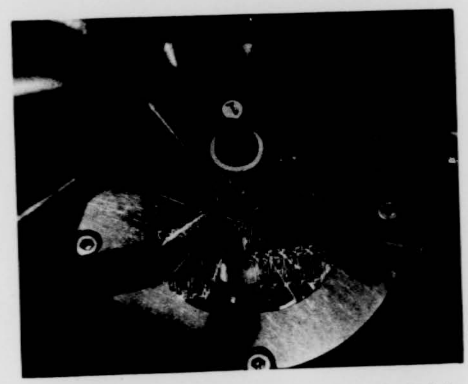
In 1965, integrated circuits have come of age. The predicted 10-to-1 improvement in reliability has been achieved along with dramatic size and weight reductions. Increasing capabilities at higher frequencies and higher power ratings are being demonstrated. Production of integrated circuits has increased tremendously, while prices have spiraled downward to below the cost of comparable circuits using individual parts. Applications to various electronic equipment have reached a point where integrated circuits are considered for use in almost all new equipment.

RELIABILITY

Today the reliability of the integrated circuit is so high that it is difficult to obtain enough operational failures to verify the forecasted failure rates. The best reliability data to date has been collected by the M.I.T. Instrumentation Laboratory in designing the guidance computer used in the manned space program, Project Apollo. Exhaustive tests since 1962 of the integrated circuits used in this computer indicate an expected life of 20,000,000 hours, or over *2000* years. The reliability of other integrated circuit equipment promises to equal and even exceed that of this guidance computer. However, these equipments have not at this writing been in testing long enough to provide definitive data.

The only requirement for demonstrating reliability is that enough qualified devices and enough patience be available to accumulate

The first use of integrated circuits in space was aboard the Interplanetary Monitoring Platform (IMP) satellite launched by NASA in November 1963.



An integrated circuit's performance is evaluated by functional testing on the wafer. This is done to avoid expensive single circuit handling and packaging of inoperative units.

the necessary test data. In some programs, it was feasible to assume that integrated circuits were reliable and to proceed without proving this by tests. When a production facility is mature and quality controls are such that foolish failures are minimized, this approach seems justified by experience. A good example is the integrated digital circuits used on the IMP satellite, which was launched in November 1963. These integrated circuits were the first put into space orbit and have performed satisfactorily since launch.

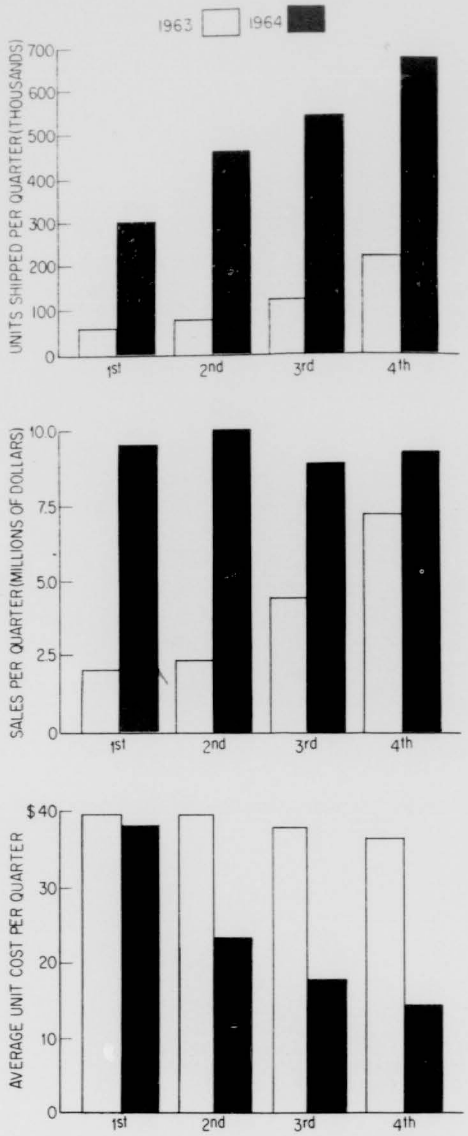
Improved reliability was the most important objective of the Air Force when it sponsored development of integrated circuits. Early expectations of a 10-to-1 improvement already have been achieved, and further improvements are anticipated. Implications of this improved reliability are just starting to become apparent: these include increased system effectiveness and operating time, reduced maintenance time, and lowered spare parts requirements. The real savings will come when more integrated circuit equipments are put into service.

PERFORMANCE

Technological advances in integrated circuits have been occurring so rapidly that performance characteristics of even the most recent types probably will become outmoded in the near future. At present, integrated circuits are capable of amplifying signals of 125 megacycles. For integrated circuit switches, such as those used in computers, the maximum switching speed is approximately 40 megacycles. For circuit applications where low power drain is required, integrated circuits which operate with total power dissipations of only 1 milliwatt are available, and for high power applications, circuits capable of 20-watt output have been developed.

PRODUCTION

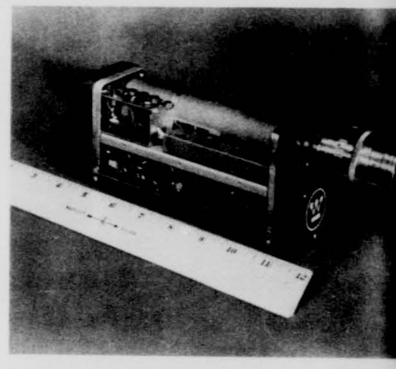
In the seven years since the first integrated circuit was fabricated, production has grown at a fantastic rate, while costs have dropped dramatically. During 1964, approximately two million integrated circuits were sold, at a total cost of $40,000,000. This number is expected to quadruple to eight million units in 1965. In 1966, it is estimated that 27 million integrated circuits will be produced. However, the number of circuits produced does not in itself give the actual growth picture since the cur-



Comparison of the integrated circuit market growth in 1963 vs. 1964. In 1963 the increase in units shipped was reflected in a rise in sales each quarter. In 1964, a major decrease in the average unit price resulted in fairly steady quarterly sales even though four times as many units were shipped.

rent trend is toward combining mor
more circuit functions in each integrat
cuit block. The integrated circuits desig
1963 were equivalent to 20 to 30 in
ual components; those designed in 1965
are equivalent to 80 or more indiv
components.

These increases in production rate and
ber of components replaced have result

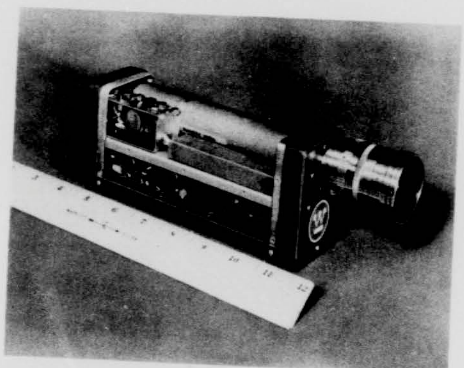


This miniature television camera incorporating
grated circuits is similar to the type included o
Apollo spacecraft.

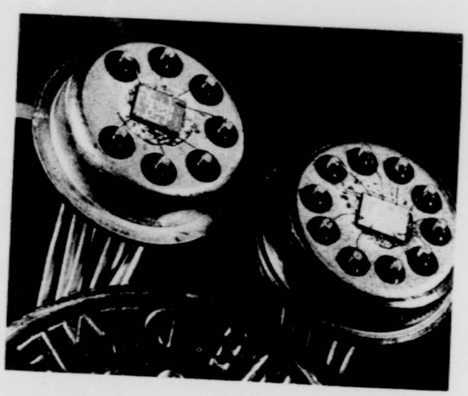
Norden integrated circuits in equipment for Polaris
marines are expected to be nine times more reli
than previous conventional components. Left is an
put buffer. Right is a low noise preamplifier. The
units were designed for the Ships' Inertial Naviga
System (SINS) equipment.

rent trend is toward combining more and more circuit functions in each integrated circuit block. The integrated circuits designed in 1963 were equivalent to 20 to 30 individual components; those designed in 1965 often are equivalent to 80 or more individual components.

These increases in production rate and number of components replaced have resulted in a drastic reduction in price. Today integrated circuits are competitive in cost with equivalent circuits consisting of individual components. In many cases, the integrated circuits are even cheaper. Four years ago, developmental samples of integrated circuits cost about $50 per circuit function; today, equivalent models cost only $1.50.



This miniature television camera incorporating integrated circuits is similar to the type included on the Apollo spacecraft.



Norden integrated circuits in equipment for Polaris submarines are expected to be nine times more reliable than previous conventional components. Left is an output buffer. Right is a low noise preamplifier. The two units were designed for the Ships' Inertial Navigation System (SINS) equipment.

APPLICATIONS

Promising applications are emerging in practically all types of electronic equipment. As of early 1965, the Army, Navy, and Air Force had active equipment contracts which call for the use of these devices.

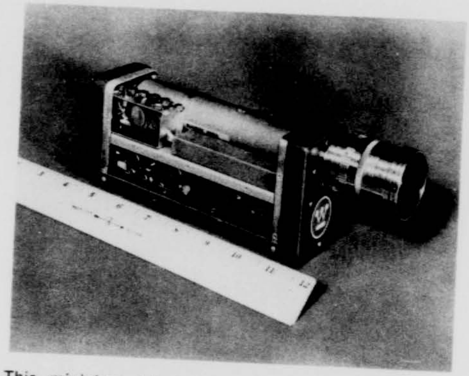
One of the largest users of integrated circuits at this time is the Apollo manned spacecraft program. Integrated circuits are being used in the guidance computer, the inertial navigation system, and the ground support systems. Two miniature television cameras incorporating integrated circuits are also included in the spacecraft. And, the digital control computer that monitors the fuel level in the attitude control engines will also employ integrated circuits. In fact, integrated circuits will be used in most significant pieces of electronic equipment on board the spacecraft.

The Air Force Minuteman II program is another large user of integrated circuits, with over 340,000 units produced for its guidance computer, flight control, and ground support equipments. Recently Autonetics ordered an additional $15,000,000 worth of integrated circuits for this program. Sylvania also is incorporating integrated circuits into the missile's silo command and communications systems.

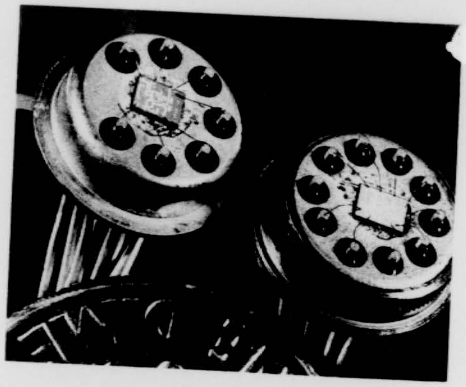
The Phoenix air-to-air missile system for the TFX F-111B aircraft will employ over 6000 integrated circuits, the majority of which will be used in the fire control computer. An integrated circuit logic multiplexer for the missile also has been developed by Westinghouse.

The Navy's new Mark 48 torpedo and the ground-based computer for the new cable rent trend is toward combining more and more circuit functions in each integrated circuit block. The integrated circuits designed in 1963 were equivalent to 20 to 30 individual components; those designed in 1965 often are equivalent to 80 or more individual components.

These increases in production rate and number of components replaced have resulted in a drastic reduction in price. Today integrated circuits are competitive in cost with equivalent circuits consisting of individual components. In many cases, the integrated circuits are even cheaper. Four years ago, developmental samples of integrated circuits cost about $50 per circuit function; today, equivalent models cost only $1.50.



This miniature television camera incorporating integrated circuits is similar to the type included on the Apollo spacecraft.



Norden integrated circuits in equipment for Polaris submarines are expected to be nine times more reliable than previous conventional components. Left is an output buffer. Right is a low noise preamplifier. The two units were designed for the Ships' Inertial Navigation System (SINS) equipment.

APPLICATIONS

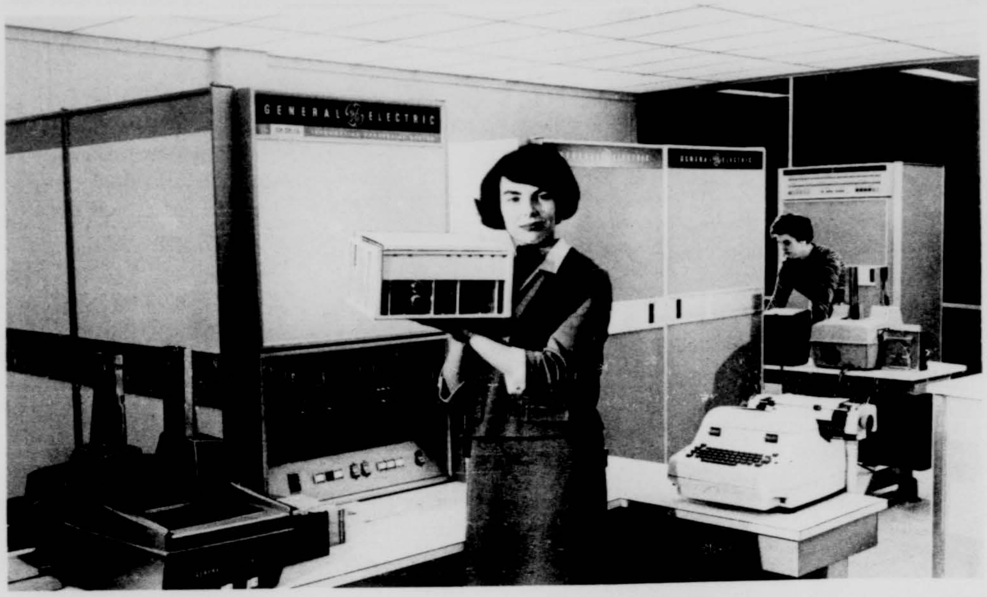
Promising applications are emerging in practically all types of electronic equipment. As of early 1965, the Army, Navy, and Air Force had active equipment contracts which call for the use of these devices.

One of the largest users of integrated circuits at this time is the Apollo manned spacecraft program. Integrated circuits are being used in the guidance computer, the inertial navigation system, and the ground support systems. Two miniature television cameras incorporating integrated circuits are also included in the spacecraft. And, the digital control computer that monitors the fuel level in the attitude control engines will also employ integrated circuits. In fact, integrated circuits will be used in most significant pieces of electronic equipment on board the spacecraft.

The Air Force Minuteman II program is another large user of integrated circuits, with over 340,000 units produced for its guidance computer, flight control, and ground support equipments. Recently Autonetics ordered an additional $15,000,000 worth of integrated circuits for this program. Sylvania also is incorporating integrated circuits into the missile's silo command and communications systems.

The Phoenix air-to-air missile system for the TFX F-111B aircraft will employ over 6000 integrated circuits, the majority of which will be used in the fire control computer. An integrated circuit logic multiplexer for the missile also has been developed by Westinghouse.

The Navy's new Mark 48 torpedo and the ground-based computer for the new cable



General Electric's 18 lb.. Model A-212 aerospace-oriented integrated circuit computer is shown here. In the cabinets in the background is a GE Model 225 general purpose computer using transistor circuits. The A-212 requires only 67 watts for operation.

sonar submarine-detection system both will use a multitude of integrated circuits. An integrated circuit version of the AN/UCC, a system that makes possible simultaneous transmission of multiple teletypewriter signals between ships or land stations over radio channels, is under construction at Honeywell. Fifty thousand integrated circuits will be supplied by Fairchild for use in this system. The Univac 1830 airborne computers, to be carried by the Navy E-2A aircraft as part of the Navy's "A-New" antisubmarine warfare program, each will use 3000 integrated circuits. Another 24,000 integrated circuits will be used in each airborne processor. Additional integrated circuits will be used in the E-2A radar computer indicator and automatic pilot systems.

Approximately 8000 integrated circuits will be employed in each of the seven Tactical Data Systems being built for the Marine Corps, as well as in the Army's AN/GXC facsimile equipment and TF-600 forward area secure communications system. Integrated circuits also are being used in a range-counter for a laser rangefinder, an FM/FM telemetry equipment for the Lance missile, a PCM data buffer subscriber set, and other Army equipments. In commercial equipment, particularly the data processing type, integrated circuits also hold promise of wide application. Integrated circuits will be used extensively in the *Spectra* line of computers recently announced by RCA. They are also being used by Univac, Control Data, and other data-processing equipment manufacturers.

In summary, 1965 was the year integrated circuits truly came of age. Improvements in reliability and performance have encouraged their widespread use in many new equipments. Increased production and the resultant drop in prices has made them economical for use in equipments ranging in size from small devices to complete systems. New applications for the integrated circuit are being discovered daily. A multitude of new equipment designs utilizing integrated circuits are now under development in both the military and industry.

THE FUTURE

The future of the integrated circu
related technology is expected to
pressive as its relatively short past.
diction of these future developme
ever, finds a much more receptive
among the scientific and technical
ties than did the initial predictions
integrated circuit. Achievements to
vide a large measure of assurance
present indications will be realized.

THESE EARLY PREDICTIO MET WITH WIDESPREAD SKEPTICIS

Early 1960 advertisement by Westinghouse to announce molecular electronics.

THE FUTURE

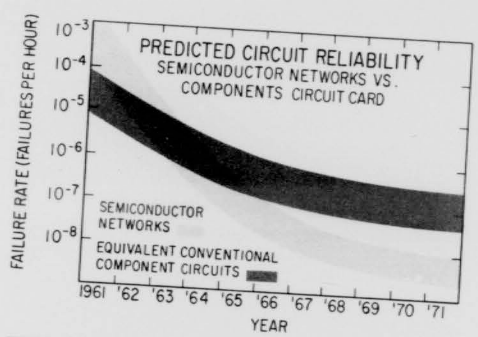
The future of the integrated circuit and its related technology is expected to be as impressive as its relatively short past. The prediction of these future developments, however, finds a much more receptive audience among the scientific and technical communities than did the initial predictions about the integrated circuit. Achievements to date provide a large measure of assurance that the present indications will be realized.

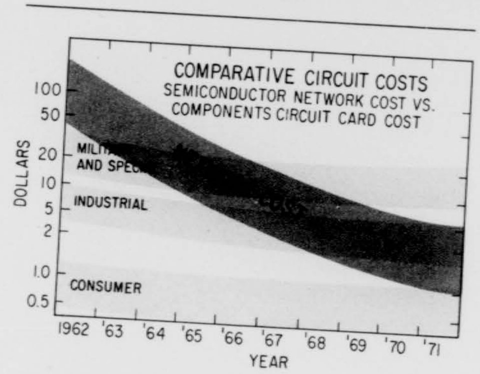
The most important single advance predicted is a further 10-to-1 increase in reliability. This increase is to be obtained by increasing the number of circuit functions that can be performed on a single block. The consequent decrease in number of interconnections will result in a higher over-all reliability. One proposed approach to reducing the number of interconnections is to eliminate the cutting of the silicon block into individual integrated

---

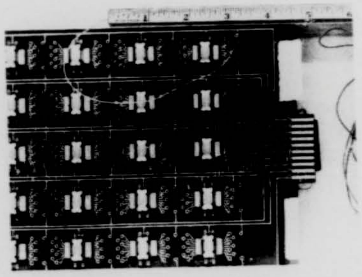
THESE EARLY PREDICTIONS MET WITH WIDESPREAD SKEPTICISM

Early 1960 advertisement by Westinghouse to announce molecular electronics.





These forecasted curves were used by P. E. Haggerty of Texas Instruments in his address of October 1961 introducing the first major molecular electronics equipment.



Breadboards such as these assist the engineer in designing integrated circuits into new equipment. These breadboards are for an FAA VOR receiver now under development.

"One of our Air Force contractors has recently submitted a proposal for work in molecular electronics which has all indications of being a true technical breakthrough. This proposal offers the last piece of the puzzle which allows us to move from basic to applied research in the area of molecular electronics. The technique to be investigated further by this project principally consists of reducing the number of component parts by designing and fabricating solid state materials into functional components rather than assembling a component from an assortment of parts."

Gen. Marvin C. Demler, USAF
speech given before NAECOM
May 4, 1959

These past Air Force expectations have already been fulfilled to a great extent. Future developments will further justify this early optimism.

circuits. Instead, metallic connecting wires would be deposited right on the block to link all the circuits together in the desired arrangement. In 1961, only about 50 circuits could be deposited on a standard 1-inch block. Today, over 150 circuits can be deposited on the same block, and it is anticipated that in the future the figure will be increased to as many as 1000 simple circuits. Two such blocks probably could provide the same performance as the 587 integrated circuits used in the first integrated circuit computer built in 1961.

Another important advance predicted is extended use of the systems research vehicle concept in designing new equipment not practical with conventional circuits. Some military electronic equipment must be capable of delivering large amounts of electrical power, far above the amounts possible with reliable solid-state devices, such as transistors and individual integrated circuit blocks. By using the systems research vehicle concept and by taking an over-all systems approach, the power of these individual devices effectively can be added together to obtain a higher power level. An example is the fully solid-state, phased-array terrain-avoidance radar being developed by the Air Force. The usual high-power transmitter tube and mechanical scanning antenna are being replaced by about 600 solid-state devices, each powering its own small antenna element. These antenna elements are electronically scanned and their outputs added together to provide a sufficient power level. In effect, the output tube and mechanical rotating antenna are being replaced by solid-state devices, with their increased reliability and lower power requirement, and with no weight penalty.

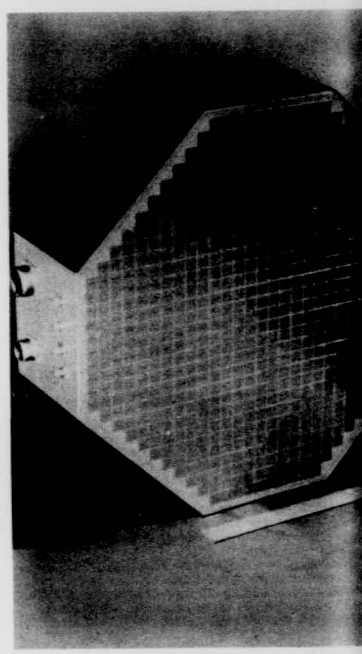
Perhaps the most important promise the future holds in electronics is further development of the molecular electronics concept. Continued advances in chemistry may result in electrical circuit functions accomplished close to the molecular level, with groups of chemical molecules actually performing the circuit functions. Such futuristic thinking is based, in fact, on research now being conducted on the light generated from semiconductor junctions. Investigation of such areas as phonon-phonon interactions, phonon-electron interactions, solid-state plasma, metal-based transistors, masers, and piezo-junction phenomena is providing insight into molecular processes. Organic chemists are close to possessing the tools and knowledge required to form complex materials with various desired properties. If these properties can be synthesized into major electronic functions, it may be possible to produce complete circuits in test tubes.

LESSONS FOR THE FUTU

Breakthroughs like the integrated ci
needed if the United States is to mai
lead in aerospace electronics. In the
integrated circuits, imaginative, bold
ment on the part of the Air Force res
a breakthrough many years earlier th
dustry had been left to develop this te
on its own. Technological gaps, like t
lighted by "Sputnik" in 1957 must be
if we are to remain ahead. Only by
taking high-risk/high-potential progr
Atlas intercontinental ballistic mis
Polaris nuclear submarine, the U-2 a
aircraft—can we achieve such si
advances.

It might be well to review again the k
agement factors responsible for the s
the integrated circuit program.

(1) Government personnel recogn



A mock up of a proposed radar designed usi
tional airborne radar, which it is designed

contractors has recently submitted
in molecular electronics which has
ing a true technical breakthrough.
the last piece of the puzzle which
om basic to applied research in the
ctronics. The technique to be inves-
this project principally consists of
r of component parts by designing
state materials into functional com-
assembling a component from an

arvin C. Demler, USAF
given before NAECOM
May 4, 1959

e expectations have already been
extent. Future developments will
arly optimism.

antenna elements are elec-
ed and their outputs added
vide a sufficient power level.
tput tube and mechanical ro-
are being replaced by solid-
ith their increased reliability
er requirement, and with no

ost important promise the fu-
lectronics is further develop-
nolecular electronics concept.
ances in chemistry may result
ircuit functions accomplished
olecular level, with groups of
cules actually performing the
ns. Such futuristic thinking is
on research now being con-
e light generated from semi-
nctions. Investigation of such
n-phonon interactions, phonon-
ctions, solid-state plasma, metal-
ors, masers, and piezo-junction
providing insight into molecu-
Organic chemists are close to
tools and knowledge required
plex materials with various de-
ies. If these properties can be
to major electronic functions, it
ble to produce complete circuits

LESSONS FOR THE FUTURE

Breakthroughs like the integrated circuit are needed if the United States is to maintain its lead in aerospace electronics. In the case of integrated circuits, imaginative, bold management on the part of the Air Force resulted in a breakthrough many years earlier than if industry had been left to develop this technology on its own. Technological gaps, like that highlighted by "Sputnik" in 1957 must be avoided if we are to remain ahead. Only by undertaking high-risk/high-potential programs—the Atlas intercontinental ballistic missile, the Polaris nuclear submarine, the U-2 and A-11 aircraft—can we achieve such significant advances.

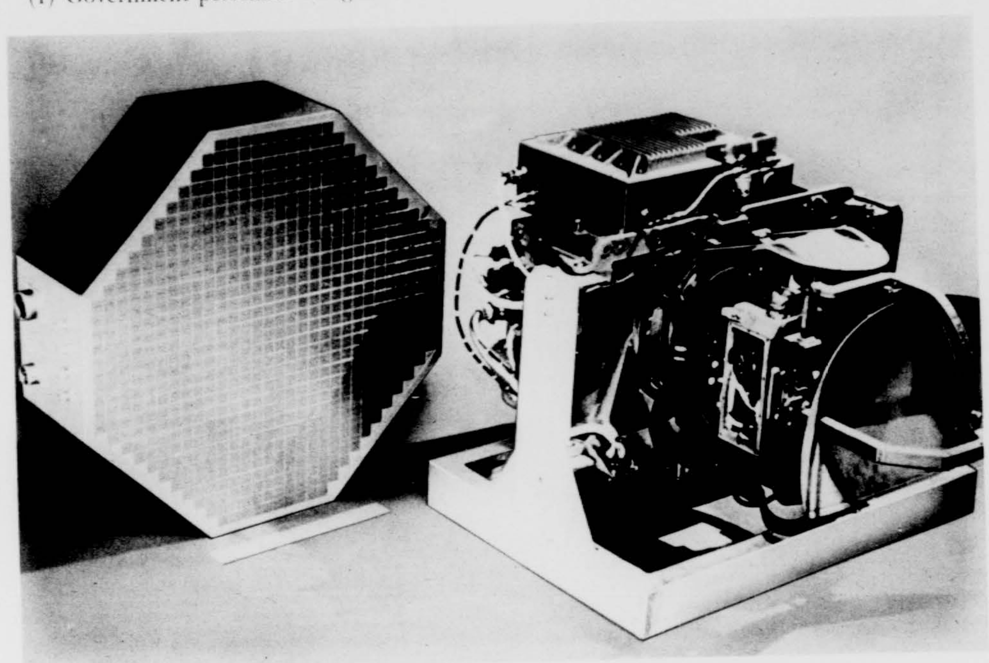
It might be well to review again the key management factors responsible for the success of the integrated circuit program.

(1) Government personnel recognized that there was a high risk involved. But more important, they realized the high payoff that could result. Consequently, they were bold enough to pursue their convictions with a program that was large enough to attract the attention of industry.

(2) The government upper management structure supported the program with funds, instead of conducting extensive, repeated reviews to determine whether the approach was technically feasible.

(3) It was recognized by government personnel that concentrated, massive funding was required if timely results were to be obtained. Such funding measures were therefore taken.

(4) As the program progressed and results were achieved, government research organizations saw to it that demonstration equipment was developed incorporat-

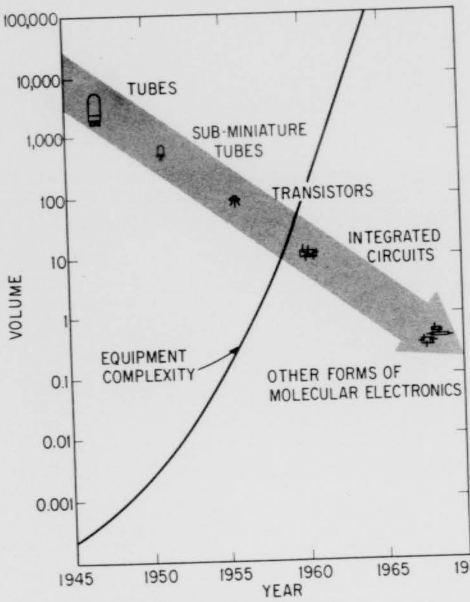


A mock up of a proposed radar designed using the systems research vehicle concept is shown on the left. A conventional airborne radar, which it is designed to replace, is shown at the right.

ing the new technology. In this way, military users and industry leaders were more easily convinced of the value of the advances being made.

In today's procurement climate, it is doubtful if any of the previously mentioned high-risk/high-potential programs could be approved in the expeditious fashion afforded the integrated circuit program in 1959. By act of Congress, approval by the Secretary of the Air Force is required for procurement of almost all research and development programs. In addition, the program must be reviewed to ensure that the approach selected is technically feasible. High-risk and costly programs are subjected to ever-increasing scrutiny. As a result, program objectives frequently are reduced so that they will not be subjected to continued, detailed reviews with their inherent loss of time. The few large programs finally approved then undergo another series of detailed reviews by the Department of Defense with additional delays.

In addition to the time delays, these reviews frequently voice criticisms to the effect that industry can accomplish this program without military support, and the approach is not adequately defined to ensure achievement. As a result, military research programs are becoming increasingly conservative in their goals. The high-risk approach is avoided—even though it may result in a significant breakthrough. The consequence of this policy may be felt in the future as a technological gap. It is hoped that the lessons learned in developing the integrated circuit may to some extent counteract this trend.



The relative decrease in the size of electronic equipment as a result of using smaller components is shown in this graph. Only through the development of more advanced molecular electronics can the size of the equipment be reduced further.

Cromley—

Planning Timidity Slowed Down Pace Of Space Program

By RAY CROMLEY

WASHINGTON (NEA) – The super-functioning of Gemini and Ranger shows the highly professional, steady progress the United States is making in space.

But it also illustrates (remember Gemini was 16 months behind schedule) that we are not taking full advantage of scientific breakthroughs.

The government sets up a technical plan for defense or space, then tends to stick to it, even though radical new discoveries made along the way may make that plan obsolete.

ONE OF the most sensational electronic advances in history is taking place right now in the development of molecular electronics in which tiny particles of certain materials can replace entire circuits. Research and development expected to take almost a decade were achieved in four years.

But the United States hasn't done the military-space planning necessary to make immediate full use of this extraordinary break-through. Some of the value of the speed of the research has thereby been lost.

Major leaps forward depend on standing back every so often and looking at the program with new glasses. As one top-flight military scientist puts it, "our planning has been a little too timid."

Another part of the space problem is that much government-financed research has become slow and plodding. Scientists are not allowed full freedom to exploit new ideas that aren't part of the program . . . .

A newspaper article from the Durham Sun on April 13, 1965.

APPENDIX

THE TECHNOLOGY

This report has been aimed at all
industry and government intereste
story of the integrated circuit. Tech
tails and descriptions have been avoid
interest of the nontechnical reader.
this appendix is included for those w
more information on the specific tech
advances that both accompanied a
possible the integrated circuit as w
today.

The rapid transition of the integrat
from a research idea to a producti
can be attributed largely to the
well-developed and well-understood
technology from which it grew.
nology was also the reason that the
electronics research program adopt
con integrated circuit as its first p
proach. The availability and advan
this technological base is an import
the integrated circuit story.

Before 1948, semiconductor researc
ported at the universities and in a
trial laboratories. The invention o
sistor by Bardeen, Brattain, and S
1948 (for which they received a N
was dependent on the availabili
single-crystal semiconductor mat
tremely pure material is a direct r
development of zone refining by P
Bell Telephone Laboratories. In
ing, a molten zone is established
one end of the ingot. The heat s
the resulting molten zone, is t
slowly to the other end. The im

APPENDIX

THE TECHNOLOGY BASE

This report has been aimed at all those in industry and government interested in the story of the integrated circuit. Technical details and descriptions have been avoided in the interest of the nontechnical reader. However, this appendix is included for those who desire more information on the specific technological advances that both accompanied and made possible the integrated circuit as we know it today.

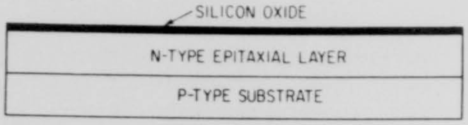
The rapid transition of the integrated circuit from a research idea to a production reality can be attributed largely to the previously well-developed and well-understood solid-state technology from which it grew. This technology was also the reason that the molecular electronics research program adopted the silicon integrated circuit as its first practical approach. The availability and advancement of this technological base is an important part of the integrated circuit story.

Before 1948, semiconductor research was supported at the universities and in a few industrial laboratories. The invention of the transistor by Bardeen, Brattain, and Shockley in 1948 (for which they received a Nobel prize) was dependent on the availability of pure single-crystal semiconductor materials. Extremely pure material is a direct result of the development of zone refining by Pfann of the Bell Telephone Laboratories. In zone refining, a molten zone is established by heating one end of the ingot. The heat source, with the resulting molten zone, is then moved slowly to the other end. The impurities are much more soluble in the liquid and thus stay in the molten zone. The low (a few parts per billion) impurity levels which are essential for transistor operation are obtained by repeated application of this refining method.

The specific technical improvements that made the silicon integrated circuit possible in 1958 are traceable to 1951-1952 when a major Air Force effort on silicon devices was initiated. This effort included the development of rectifiers and transistors, as well as crystal-growing and purification techniques. Over $5,000,000 in government funds and an even larger amount of corporate funding were required to bring the first silicon transistors to the market in 1953. The announcement by Texas Instruments of the successful operation of a company-developed silicon transistor further focused industry's attention on the importance of this material.

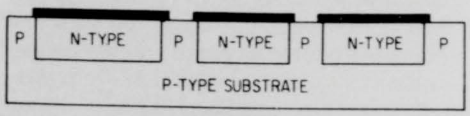
From 1958 to 1962, the Molecular Electronics Program at Westinghouse was based on processes which were used primarily for manufacturing high-power silicon devices. In the fabrication of integrated circuits, the ideal processes must be capable of introducing necessary impurities under conditions where the quality and dimensions are precisely controlled. It also is desirable that the processes can be used for manufacturing many circuits at the same time (called batch processing). The early processes used by Westinghouse did not maintain good dimensional tolerances and were not amenable to batch processing. Texas Instruments and Fairchild used diffusion tech-

The general process sequence for achieving a typical integrated circuit is shown in this illustration.



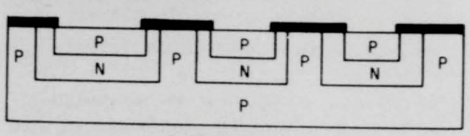
EPITAXIAL GROWTH

The total process sequence consists of a number of photoresist and diffusion steps that utilize the fundamental property of silicon oxide for prevention of impurity diffusion. Thus, the process starts with the deposition of an n-type epitaxial layer on a p-type substrate that has a resistivity of 10 ohm per cm. The n-type epitaxial region can be synthesized to have resistivities anywhere between 0.1 and 0.5 ohm per cm, as desired.



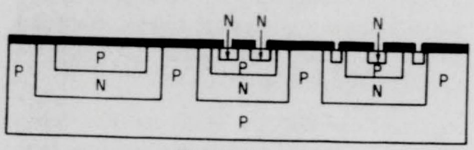
ISOLATION DIFFUSION

The n-type region is formed into individual islands by diffusing a heavy concentration of p-type impurity through the epitaxial layer until it connects with the p-type substrate.



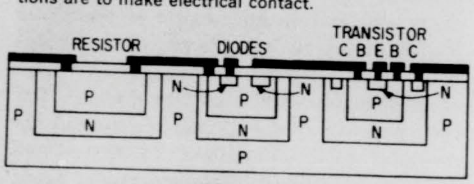
BASE DIFFUSION

Following reoxidation and photoresist, the base diffusion is achieved by diffusing a p-type impurity. Note that this region forms both the base of the transistor and the resistors.



EMITTER DIFFUSION

In this step, the oxide is shown removed to permit the shallower n-type emitter diffusion to occur. This step simultaneously forms the transistor emitter, the n-region of the diodes, and the ohmic contacts to the collector region of the transistor. After reoxidation, the oxide is removed at those points where the interconnections are to make electrical contact.

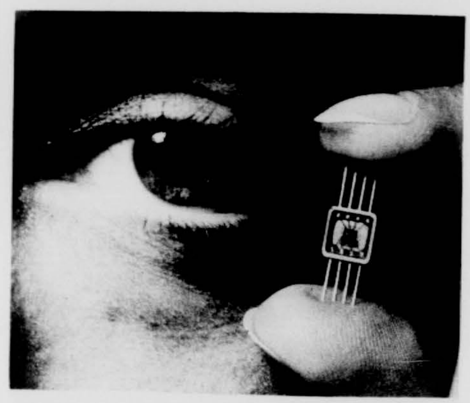


METALIZATION

In this last step, the aluminum metalization interconnections after evaporation and photoresistance are shown. This completes the process sequence in which resistors, diodes and transistors are formed simultaneously in a silicon wafer.

nology, which was invented by Bell Telephone Laboratories in 1955, and was better suited for making integrated circuits. Diffusion technology allowed them to make rapid strides. Westinghouse also attempted to apply dendritic crystal growth in germanium to integrated circuits. While scientifically the germanium-dendrite approach was correct, silicon turned out to be a much superior material for integrated circuits. Silicon dendrites did not exist with suitable properties. Westinghouse converted to wafer material, and developed a silicon diffusion technology. This transition was completed in 1963. At that time Westinghouse became a key producer in the integrated circuit industry.

The first Texas Instruments silicon integrated circuits used a diffusion process called the mesa process, which resulted in islands of the impurities above the surface of the silicon chip. This design had reliability problems, as

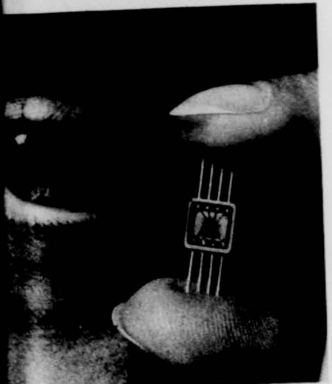


ELKRIDGE, Md., Sept. 11, 1963 -- Tiny electronic circuits, such as the one on the small black square replace as many as fifty separate components. This particular device was manufactured by Westinghouse, which today unveiled a new plant that is mass producing these tiny circuits.

Press release announcing opening of new Westinghouse plant at Elkridge, Maryland for production of silicon integrated circuits.

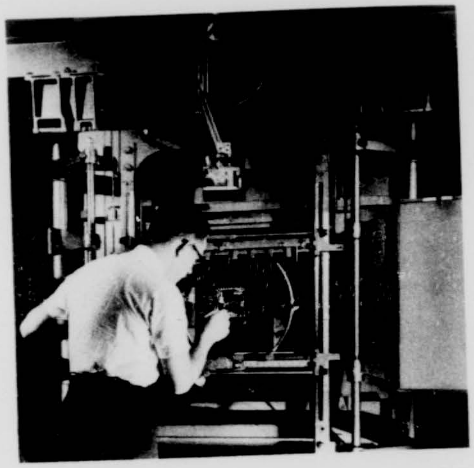
as invented by Bell Telephone
n 1955, and was better suited
egrated circuits. Diffusion tech-
d them to make rapid strides.
also attempted to apply den-
growth in germanium to
uits. While scientifically the
ndrite approach was correct,
out to be a much superior mate-
ated circuits. Silicon dendrites
with suitable properties. West-
verted to wafer material, and
licon diffusion technology. This
completed in 1963. At that time
became a key producer in the
uit industry.

s Instruments silicon integrated
a diffusion process called the
which resulted in islands of the
ove the surface of the silicon
sign had reliability problems, as



IDGE, Md., Sept. 11, 1963 -- Tiny
c circuits, such as the one on the
k square replace as many as fifty
components. This particular device
actured by Westinghouse, which
eiled a new plant that is mass
these tiny circuits.

announcing opening of new Westinghouse
dge, Maryland for production of silicon
cuits.



To make a monolithic integrated circuit, it is first necessary to make a series of masks that control the various diffusion, metallization, and oxidation steps in the manufacturing process. Shown here at Motorola is the inspection of one of these mask configurations drawn with an accuracy of 0.001 inch over its entire length. This massive camera, with a bellows that extends from 4 ft. to 14 ft., reproduces the configuration on a glass mask about the size of a dime on which there are 140 exact reproductions of the artwork shown.

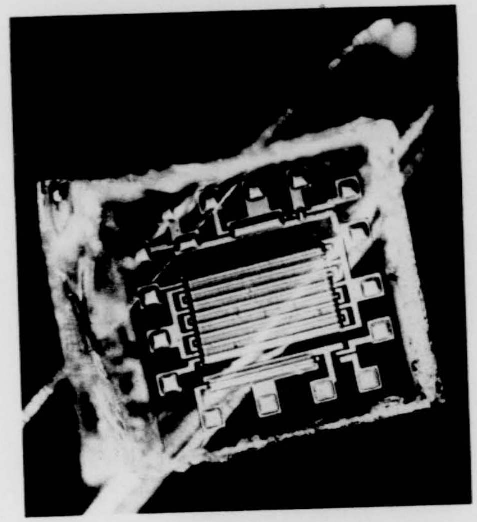
it required the use of bonded wires for interconnections.

A valuable property of silicon is the ease with which oxides are formed on its surface by exposure to high-temperature wet oxygen. This oxide layer is useful for masking during impurity diffusions and for protecting the surface against the environment after fabrication.

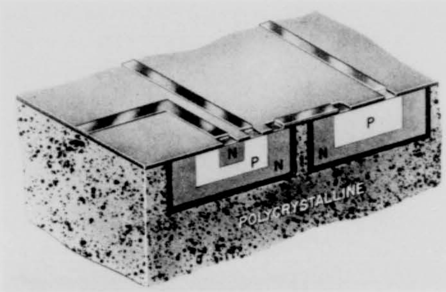
Photoprocessing techniques, adapted from the printing industry by J. Lathrop and J. Nall at the Diamond Ordnance Fuze Laboratory, were used to form patterns in the oxide layer. This allows selective diffusion of impurities into silicon with dimensional tolerances smaller than 0.0001 inch.

Photoprocessing, oxide masking, and impurity diffusion were combined to produce the planar process. This had been first exploited by Fairchild in 1960 to obtain high-reliability and high-performance silicon transistors. The adaption of planar processing by Fairchild and Texas Instruments to integrated circuits resulted in immediate improvements in their manufacturability and yield, a capability for more sophisticated circuits, and a relaxation of the surface protection requirements.

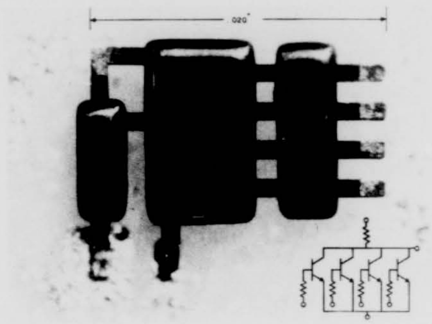
The early yields of silicon integrated circuits were low and the costs high because of inadequate process control and nonuniformity of starting materials. Dendritic materials had been proposed to alleviate these problems and could have helped had they been available. Epitaxy, a process for forming a single-crystal silicon layer on top of the single-crystal substrate, provided a more uniform surface for integrated circuit processing. This and other process improvements increased yields by a factor of 10, thereby reducing the cost of devices from about $50 to $5 each. Integrated circuits immediately became available for commercial applications, and the research and development activities were accelerated be-



The equivalent of a six-transistor radio is shown in the eye of an average sized sewing needle. This circuit was developed at North American Aviation's Autonetics Division, Anaheim, Calif. A new combination of materials—single crystal silicon on sapphire—is used to provide the required electrical isolation within the small area available.



The oxide layers (shown in color) isolate various sections of the integrated circuit and improve the frequency response.

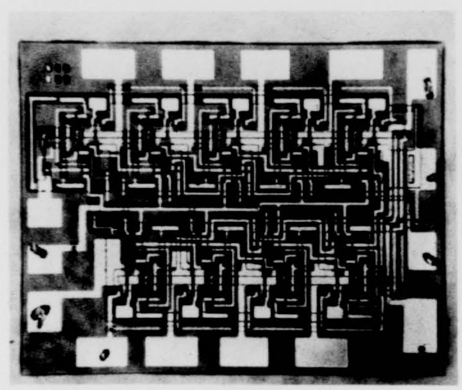


An ultra-high-speed logic circuit made by the new beam-lead structure devised at Bell Telephone Laboratories. Conventional planar techniques are used to form the transistor and resistor regions. Electrical isolation is accomplished by removing all unwanted material between components. The beam leads then remain to support and interconnect the isolated components.

cause of the increased size of the apparent market.

New technologies are currently being evaluated which should alleviate many of the performance limitations of integrated circuits. Because of the close proximity of the functional areas on the silicon chip, electrical isolation is extremely important. Several methods of isolation have been proposed; the most far-reaching requires the formation of single-crystal silicon films on a sapphire substrate. Another, and apparently more practical, approach involves the formation of oxide layers to isolate various sections of the integrated circuit substrate, thereby improving frequency response. A 4-to-1 improvement in the performance of some circuits has been predicted for circuits using these techniques.

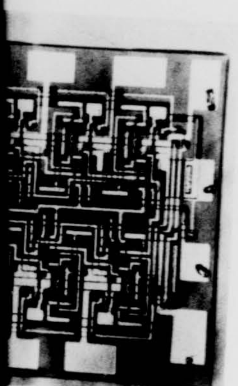
Most integrated circuits use the common transistor, which is bipolar (carriers of both polarities are important). An interesting development involves the field-effect, or unipolar, transistor. Field-effect action, or voltage-gated electron flow, has been predicted or shown in many materials, dating back to the 19th century. One of Shockley's early transistors involved this principle. Despite much work, field-effect devices were developed slowly because of fabrication difficulties and because experimental samples lacked the high-frequency capability of bipolar transistors. However, as the integrated circuit technology developed, it became obvious that high value capacitors were incompatible with the planar technology. This created a renewed need for devices with high input impedance, such as field-effect transistors. Because of the advanced technology, they now could be fabricated having more useful properties, both as individual elements and in integrated circuits. In the metal-oxide semiconductor (MOS) structure



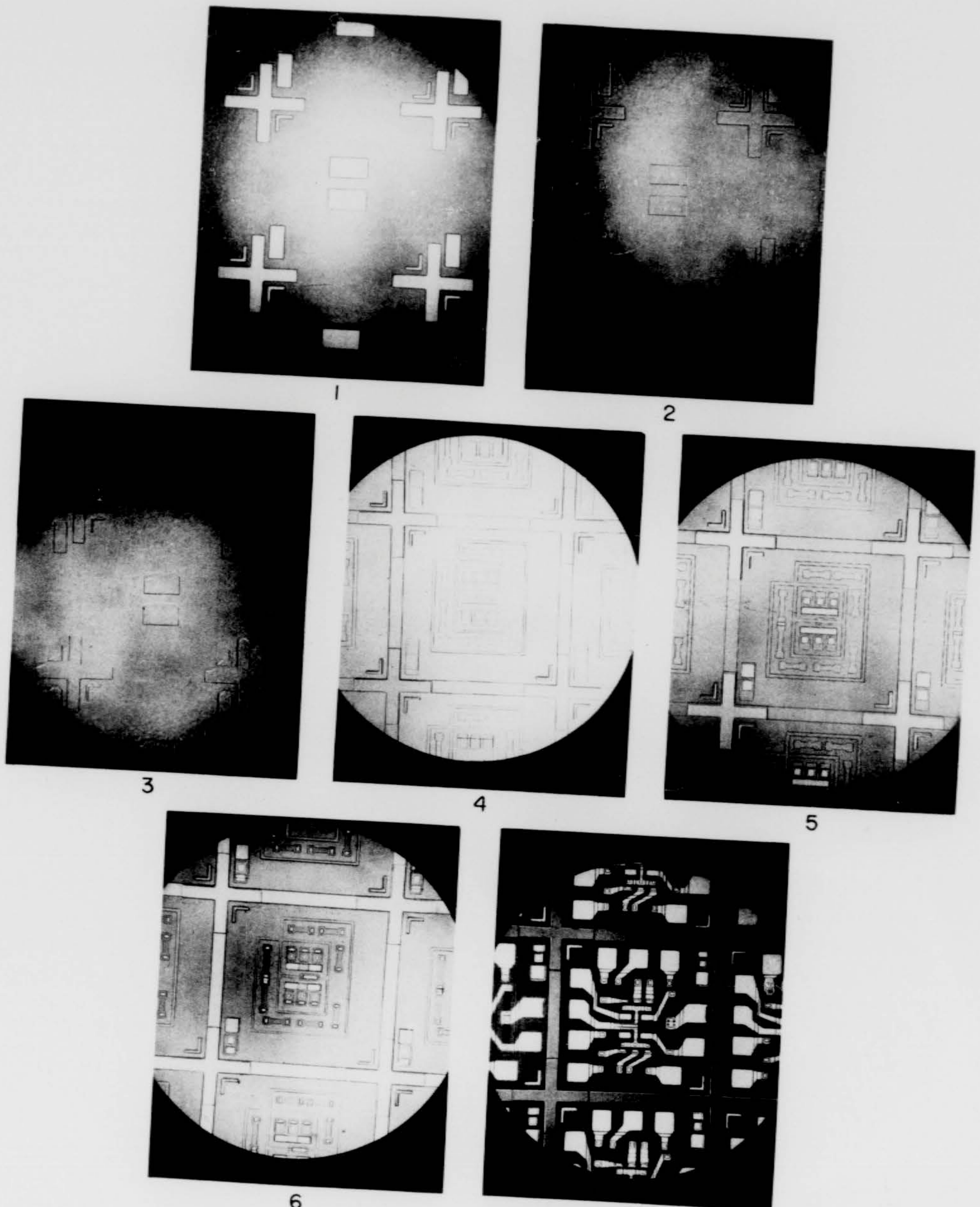
This duo-decade counter by General Micro-electronics is constructed on a single monolithic silicon chip. It is used for low power applications below a 100 kc counting rate. There are over 100 simple MOS field effect transistor circuits on this chip measuring only 0.068 inch by 0.084 inch.

ing frequency response. A
ent in the performance of
been predicted for circuits
iques.

ircuits use the common tran-
polar (carriers of both polar-
nt). An interesting develop-
e field-effect, or unipolar,
fect action, or voltage-gated
been predicted or shown in
ating back to the 19th cen-
ckley's early transistors in-
iple. Despite much work,
were developed slowly be-
n difficulties and because
ples lacked the high-fre-
f bipolar transistors. How-
grated circuit technology
e obvious that high value
ompatible with the planar
eated a renewed need for
nput impedance, such as
s. Because of the advanced
y could be fabricated hav-
perties, both as individual
tegrated circuits. In the
ductor (MOS) structure



General Micro-electronics is
nolithic silicon chip. It is
ons below a 100 kc count-
0 simple MOS field effect
hip measuring only 0.068



These seven photos illustrate the various masking sequences used in the manufacture of Fairchild's type 915 silicon monolithic integrated circuit.

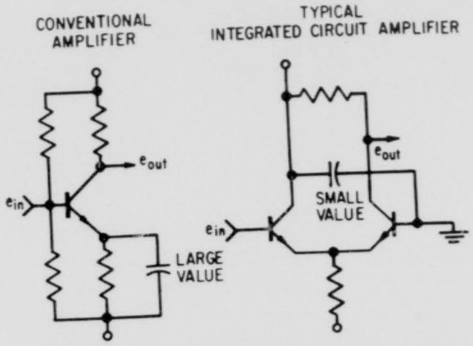
they have broad potential for future large arrays of integrated circuits.

Early equipment programs such as the telemetry encoder and the Minuteman II guidance system rapidly proved that in integrated circuit developments neither the equipment nor the component man could be dominant. Both are essential to obtain the full benefit of reliability as offered by monolithic structures in silicon. Circuit designers must understand the limitations of silicon technology so that the circuitry is adapted to the material rather than attempting to change the basic silicon technology.

This adaption to the unique properties of silicon technology can be illustrated by several examples. Close-tolerance resistors are difficult to obtain, but in many applications can be replaced by resistor ratios which can be accurately fabricated. Disadvantages due to the close proximity of the various regions on the integrated circuit were predicted. Close thermal coupling has sometimes proved to be an advantage, allowing better temperature stability than in discrete component circuits. Extreme shortness of conduction paths leads to higher frequency performance.

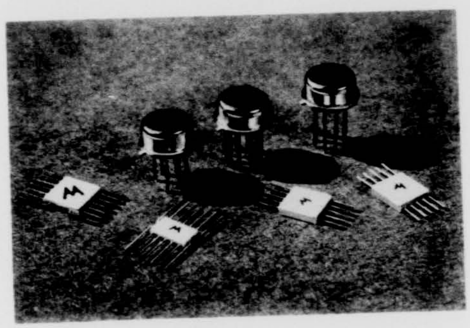
A more dramatic example of how the circuit designers' inherited ideas must change is illustrated by the inverted economics of active and passive components. For many years a major circuit-design objective was to minimize the number of expensive and unreliable active elements. With the transistor, passive components represented dimes and the transistors represented dollars, even though the reliabilities were similar. For silicon integrated circuits, however, the most expensive items are resistors and capacitors, because they consume a relatively large area on the silicon chip. A reorientation is necessary to maximize the active-device count and to minimize the number of passive components. New research directed toward functions using a multitude of active devices is necessary.

The packaging and interconnection problems



Differences in design approaches between conventional and integrated circuits are illustrated in these two amplifier stages. The integrated circuit design utilizes more transistors but reduces the number of resistors and eliminates the high value of capacitance.

with integrated circuits have been among the most difficult to solve. The Air Force, as early as 1959, encouraged Westinghouse and Texas Instruments to use the flat, rectangular hermetic package for integrated circuits. Others including Fairchild continued using transistor-type cans. The Minuteman II program and others have adopted the multi-layer printed circuit board for interconnections. New packaging techniques are being investigated. These include the hybrid technology of mounting integrated circuit dice on ceramic wafers, on which are also the film components and interconnections. Packaging and inter-

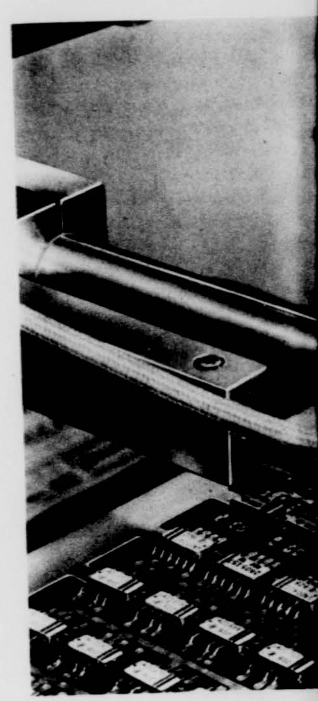


Integrated circuit packages, as typified by these from Motorola, include TO-5 cans and flat packages of varying dimensions and with a variety of pin numbers and lead configurations.

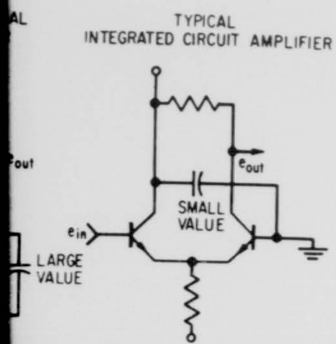
connection improvements must
advance in order to take full adv
integrated circuit.

Dramatic improvements in dis
have also come from advances
circuit technology. High-power
quency transistors, solid-state m
ments, and low cost, high perforn
such as transistors for UHF tune
cial TV, are some of the devic
benefited.

The examples which have been

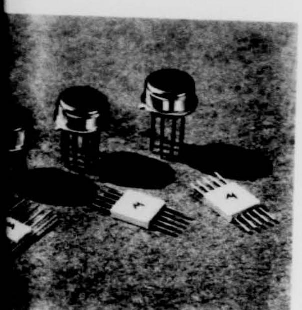


Pin-
to
the
net
der
a n
per
in



…sign approaches between conventional …rcuits are illustrated in these two am… …he integrated circuit design utilizes … but reduces the number of resistors …e high value of capacitance.

…d circuits have been among the …o solve. The Air Force, as early …raged Westinghouse and Texas … use the flat, rectangular her… for integrated circuits. Others …rchild continued using tran…. The Minuteman II program …ave adopted the multi-layer … board for interconnections. … techniques are being investi… …clude the hybrid technology of …grated circuit dice on ceramic …h are also the film components …ections. Packaging and inter-

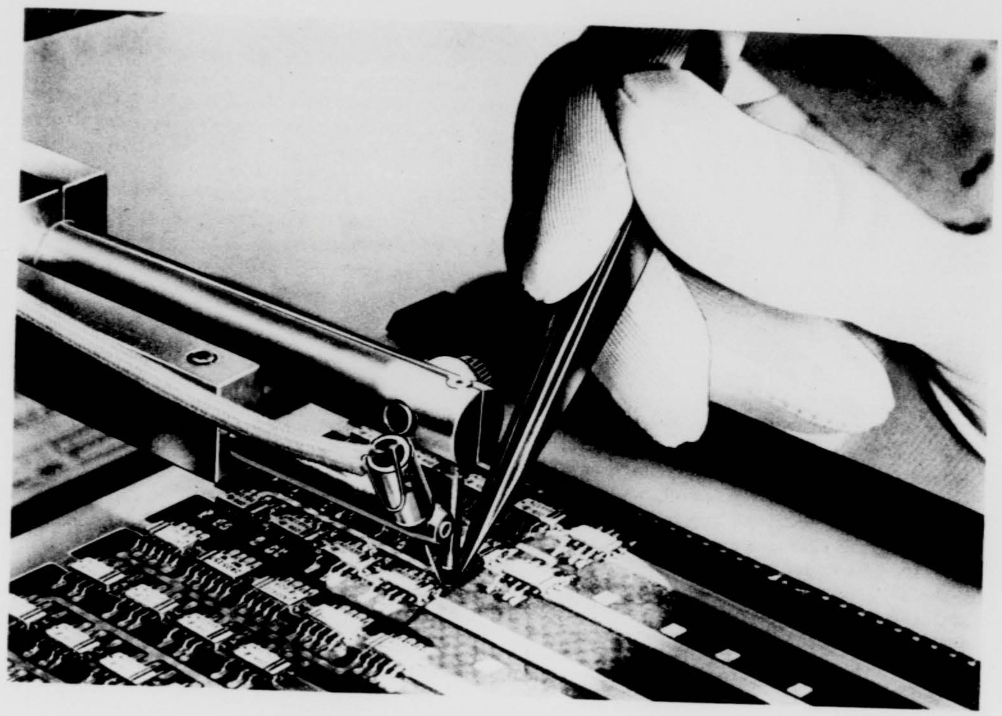


…ckages, as typified by these from …-5 cans and flat packages of vary… with a variety of pin numbers and

connection improvements must continue to advance in order to take full advantage of the integrated circuit.

Dramatic improvements in discrete devices have also come from advances in integrated circuit technology. High-power and high-frequency transistors, solid-state microwave elements, and low cost, high performance devices, such as transistors for UHF tuners in commercial TV, are some of the devices which have benefited.

The examples which have been cited demonstrate that ideas are only as good as the technologies available for their implementation. Continued government research support, through the Department of Defense's long-range supporting research program, produced the integrated circuit as a solution to the reliability and complexity problem which nearly stymied the advance of military systems. Continuing support of research in materials, phenomena, and techniques will allow further developments in molecular electronics for the next generation of application problems.



Pin-point controlled-temperature soldering is required to attach integrated circuits to multilayer boards for the Minuteman II at North American Aviation's Autonetics Division. Microminiaturized beryllium-oxide soldering tip (center) applies controlled heat to joint while a needle-nosed sensing device (left) monitors pad temperature. Operator's tweezers hold pre-formed solder in place.

"Those who are not designing equipment today using integrated circuits are already behind the main flow of American technology. None of us knows for certain where this new technology will lead us. It appears evident, however, that we are only at the beginning of a tremendous revolution in electronic system techniques, which has been made possible by mankind's increasing knowledge of the behavior of solid-state materials. We at Motorola think we are fortunate to be part of a profession that allows us to take part in this exciting progress."

Dr. C. Lester Hogan
Vice-President and General Manager
Motorola, Inc.
Semiconductor Products Division

"We feel that the most far-reaching effect of integrated circuits on electronic equipment will be realized through the use of circuits of ever-increasing complexity. This is presently being most successfully pursued through the use of the metal-oxide-silicon technology and is already resulting in circuitry one to two orders of magnitude more complex than the older types of integrated circuits. The resulting savings in development and manufacturing costs coupled with improved reliability should be of fundamental importance to the equipment manufacturer and user."

J. P. Ferguson
President,
General Micro-electronics, Inc.

"There is little question, I feel, but that integrated circuitry will be revolutionary both in its impact on electronics itself and in the expanded applications of electronics it will make possible. One clear illustration of the impact on electronics is the shift in design opportunity and responsibility it creates—a shift which becomes even more marked as the level of complexity of integrated circuits increases from what might be described as simple circuits to the electronic function level. As the volume requirements for integrated circuits increase, highly-automated, computer-controlled and relatively flexible production lines will supply circuits and electronic functions with the whole circuit or function attaining levels of reliability now achieved by high reliability individual devices. Costs will be appreciably less than for conventional circuitry, averaging perhaps one-half, but in some cases, such as for much digital circuitry, far below that. The electronics engineer will specify his integrated circuit or electronic function requirements in terms of input and output parameters expressed in a common computer language. The total production cycle time required from this specification of parameters to delivery of integrated circuits need be no more than two or three weeks. Further, the design engineer will have a much higher confidence level that his initial model will function as he intended than he can with conventional circuitry today. Moreover, the sharp improvement in reliability, accompanied by a marked decreased in cost, coupled with the ability to produce working models to specification rapidly, will allow the electronics engineer to devise equipment solutions which would be considered to be too complex to be practical today. In summary, the engineer will be able to apply electronics to solve not only more complex but a wider variety of problems. It is my strong conviction that integrated circuitry, because of these important gains in reliability, economy, and simplicity, is probably the key technical link which has long been needed for electronics to broaden its usefulness to all segments of our technologically-based society."

P. E. Haggerty
President,
Texas Instruments, Inc.

"Integrated circuits are of principal importance in the realization of the reliable and extremely complex electronics that will be required for the defense of our country and, in addition, allow this to be done at greatly decreased system costs."

Robert N. Noyce
Vice President and General Manager
Fairchild Semiconductor

"The use of devices such as flat-pack modules incorporating integrated circuits has an important potential in our military and space programs. Being ultra-microminiaturized and with whole function capability, their use makes possible the high-density packaging and ruggedness required for specialized applications. Continued development of integrated circuits with many more circuits on a single chip should further increase their value in the future."

D. Brainerd Holmes
Senior Vice President
Raytheon Company

ACKNOWLEDGEMENTS

Throughout this report mention has been made of some of the persons and organizations that participated in the development and growth of the integrated circuit. In addition to those specifically mentioned, there were many more which, unfortunately, had to be omitted because of space limitations.

The compilers of this report also gratefully acknowledge the many persons and companies who provided the material and information used in the preparation of this report.

AFSC (AAFB) 1966

BLANK