Need for miniaturization and invention of the silicon integrated circuit.

Text of a talk given by Charles Phipps on September 11, 2008 at a TI seminar marking the 50th anniversary of Jack Kilby's contribution to the invention of the IC.

By the mid 1950's, the first generation of transistorized equipments had gained recognition for their dramatic reductions in size, weight, and power consumption. Opportunities were being explored for equipments of greatly increased complexity, requiring thousands of circuits. These densities posed major challenges for assembly costs as well as size and weight limits.

An insight into a more serious problem for future equipment generations, consisting of thousands of circuits, was given by Jack Morton of Bell Labs in a paper called the "tyranny of numbers". Citing the many interfaces of dissimilar materials and loosely controlled processes for components, their terminals and interconnections, which directly contribute to potential reliability problems, he projected that industry was at the threshold of more and more frequent equipment failures

Early developments programs were initiated by the military services to remove these barriers. For military applications, it was desirable that future equipments fit into the same space and weight allocations as current equipments. With the advent of space initiatives in late 1958, extreme miniaturization assumed more importance and captured the imagination of the popular press.

. Concurrently with these activities, Pat Haggerty suggested to Willis Adcock that semiconductor technology might provide a solution to simplifying circuit interconnections and assembly. After a search of several months for a person to explore this project, Willis selected Jack Kilby. Jack's experience at Centralab was unique for the task. He had developed silk screen circuits for miniature hearing aids, and after attending Western Electrics' seminar on Transistors in 1954, he successfully set up a germanium transistor line for hearing aids.

Within a remarkably short period after joining TI in May 1958, Jack had explored and set aside several approaches and by the end of July defined a silicon solution with all circuit elements formed in situ. A subtle, but important, aspect was that it identified paths for each circuit element and did not change the basic approach to circuit design, so that the large body of circuit knowledge residing in equipment houses could be readily be applied to the transition to integrated circuits. This was not the case for most of the other concepts. .

TI's actions

A short time after the demonstration of the integrated circuit, Haggerty held a seminar for senior managers and technology personnel at TI, to provide a forum for emphasizing the significance of this development and to seek a strategic direction that would allow TI to have a major position in this new industry. Questions were asked that had no immediate answers.

It was surmised that almost all circuitry being assembled were analog circuits, requiring tighter circuit element tolerances, or inductance, or linearity, all of which could not be accomplished by silicon integrated circuit. While future computer products would impact and increase the number of digital circuits used each year, it could only be speculated whether this might be 20 % or as high as 50 % of all circuits assembled in 10 years.* For this new market, would integrated circuits replace 30% or 70% of all circuitry being assembled ? What price leverage would be necessary to achieve these penetration levels? All we could answer was that it would be large and must be pursued. Over the next five years, Haggerty would meet with Kilby and myself to review new analyses seeking answers to these questions and adjusting the strategy for the integrated circuit business. We were a trial activity for the development of the OST system, and many of these sessions ended in frustrating lectures by him that we did not understand the difference between a tactic and a strategy.

During the fall of 1958, funding for a development program was discussed with the military services. The only positive response came from the Avionics Lab in Dayton, Ohio. A maverick department head, Dick Alberts, saw the significance of the silicon integrated circuit and was determined to fund the program, despite the opposition of the Air Force Command in Washington DC. An R&D program began in the spring of 1959 to explore silicon phenomena, such as field effect devices, thermal feedback, optical emissions etc. in order to perform analogue circuit element functions. Concurrently, custom engineering programs for individual logic circuits were funded by a handful of labs and military system houses over the next few years.

The public announcement of the integrated circuit's invention was made by Pat Haggerty at the New York Athletic Club by Pat Haggerty in March, 1959, concurrent with the IEEE show, which was the major trade show for the electronic industry. It aroused curiosity and interest, but the principal news story was Fairchild's announcement of the planar process applied to two silicon transistors that were immediately available.

The next few years were a period of frequent seminars highlighting presentations for each of approaches to circuit technology. The speakers could only talk of future benefits and offer little in the way of example applications or even specific data. The silicon integrated circuit, which we called Solid Circuit, came under regular attack for lack of information regarding yield, cost, and performance vs assembled logic circuits. Thermal barriers, handling and packaging limitations, and unknown reliability limitations were also cited. In March, 1960, an engineering evaluation unit, the 502, was announced (photo with Kilby and Lathrop), and 2-6 units per month were sold.

- Digital circuits did not become greater than 50% of all circuits used in the US until 1968.

Commercialization

Early in 1960, the Air Force provided Manufacturing Methods funding to build a pilot line for consistent processing. This became the first clean room at TI. Earlier, Jay Lathrop, who had pioneered photolithographic processes for fuse circuits at Diamond Labs had been hired by TI's Research and Engineering. Jay struggled to get Kodak's attention to make modifications to photo emulsions needed for integrated circuits and finally through the Air Force's intervention he did get some application work done. At that time photo emulsions were principally used for chemical milling of air frame spars and wing parts. The first question Kodak asked the Air Force, how many tank cars per year will this application use?

In 1960, Kilby developed a relationship with Autonetics' engineering management responsible for the development of the Minuteman II guidance system. They ordered some logic circuits for an evaluation study, identified as Monica. However, there was only slow movement towards acceptance of integrated circuits by the military systems houses, and we could not get any to make a commitment. In late 1960's, we persuaded Dick Alberts that a demonstration vehicle was needed that would answer initial critical issues: can an equipment of moderate complexity really function and meet predictable performance, and can IC's be handled and assembled in high density packaging, without thermal problems, ? A nine month program was defined by Harvey Cragon and the Manufacturing Method contract amended to provide funding.

As time drew near for the delivery of this demonstration equipment in September 1961, the Air Force requested that TI present a formal seminar for the management of major system houses at three locations, with Haggerty presenting the integrated circuit story. This was quickly organized and invitations sent out. To complete the impact of this demonstration equipment, a catalogue line of six circuits that had the same parameters and could work readily together was announced, and the Series 51 circuit set was made available for late 1961 delivery. This was the clinching event that launched TI's product program.

This first product line was RCTL logic featuring low power, moderate speed, 150 ns delays, and decent noise margins. It was packaged in 10 lead flat packs. Fine line dimension could probably be measured in mils, and it was fabricated on 7/8 inch wafers. About the same time Fairchild released a few RTL logic circuits, featuring 30-50 ns delay, but they had poor noise margins.

Throughout 1962, Series 51 was designed into a large number of military programs, but production orders were not realized. We were slow to understand that the time delay from when IC's were designed into equipments until production could be as long as several years, and that a number of designs never made it to production. Haggerty was skeptical of marketing and sales effectiveness in 1962, and in addition, we were continually measured against Fairchild's delay times by the computer people and rated as second best, much to Haggerty's chagrin.

TI’s product strategy was marked by the complexity of its products, often offering multiple logic circuits in one package, and taking advantage of the 10-14 leads in the flat pack configuration. These were hallmarks of Kilby’s leadership, insisting that integrated circuits be strongly differentiated from prior semiconductor products. Fairchild and other used the round T0 8 package similar to transistor packaging, and emphasized simple circuits and small die size. Market positioning also emphasized this difference with the creation of the Series nomenclature for each compatible product line. It was used for all subsequent bipolar logic catalogue lines, and became a strong identifier for TI products.

In April, 1962, Autonetics issued an RFP for 9 logic circuits and 4 analog/pulse circuits for the Minuteman II guidance platform. The spec required both engineering and production quotes over a five year period. Haggerty took over the strategy for TI’s response and over several weeks we spent late nights analyzing data and discussing TI’s response. Haggerty insisted that all 13 circuits be bundled as one package, winner take all. Learning curves estimates were applied for the production runs. In the fall, TI was announced as the winner and prime source. It was a significant win, but its execution damaged TI’s performance in the marketplace for several years.

If 1961 and 62 were could be characterized as exciting years with their expectations and successes, then 1963 and much of 1964 were a valley of disappointments and frustrations demanding full attention to operational details and disciplines. The Autonetics program consumed all of design engineering and multiple processes had to be introduced for these circuits. This was beyond the disciplines that existed for process and product engineering, and for much of 1963, the processing of all products became sporadic and undeterminable. The widespread extent of Series 51 design wins became apparent, as the product line was placed under DOD order board allocation for most of the year. Although a new catalog line, Series 53, was introduced, it was ineffective due to limited availability.

Major operational discontinuities between integrated circuit and transistor departments limited reaching out to others for assistance. IC manufacturing was front end centric with many layers of image transfers and more capital intensive, the flat package with its thin leads used special plastic carriers for handling and testing, and functional testing IC’s was more complex and there was no parametric sorting to improve yield. For many of these challenges, Jack contributed solutions, and his role was that of the entrepreneur long before the term became widely used.

Earlier I noted the long delay from a design win until volume orders, resulting in a much longer negative cash flow than that for new a transistor, which were usually inserted into production within 4-6 months. This expense was further impacted by much larger size of IC design teams, 3 to 5 times more engineers than the of 2-3 persons for a transistor design.

To the frustrations of the Semiconductor Group's Division management, the IC program with its long delays in gaining neutral cash flows, continuous reach for new process and packaging technologies and looser financial disciplines had major losses during these years, whereas transistor departments, particularly IBM transistor program, was generating good profits. Management's reaction was similar to that of venture capitalists, and in the first 5 years, there were five different department heads and a turnover of many of the managers reporting to them.

In the second half of 1964, Jerry Luecke's engineering team designed the initial TTL line, Series 54, was introduced late in the year. A product strategy was pursued for compatible lines for low power, and high speed, with same pinouts and functions were introduced in the following year, along with MSI functions. Production became more consistent, and with the introduction of dual inline plastic packaging in 1966, TI regained its leadership in the IC market place. TI's IC revenues in 1966 were about $30 million*, and within seven years, IC revenues increased nearly 10 times. Plastic dual in line packaging and TTL opened the minicomputer, computer peripherals and terminals, instrumentation and industrial control markets.

In retrospect, 1965-67 were a watershed period marking the end of developments for bipolar digital IC's and the early beginning of developments for the MOS LSI era. Kilby returned to the Development labs in 1964, and pursued new integrated circuit initiatives including wafer level integration, thermal printing, and memory array interconnections.

In the decade of the 1960's, Pat Haggerty drove the strategy and closely followed its execution. One of his many legacies was that TI was among the few semiconductor companies serving the open market that successfully managed the transition from transistors to bipolar IC's and to MOS IC's.

About 1968, Jack transferred to Marketing and interacted with customers for advanced programs serving emerging markets. Sitting on the side lines and seeing others implement his ideas was not satisfying to Jack, and in 1970, he left TI to begin a career as an independent consultant.

Among Jack's legacies were a patent portfolio with pioneering integrated circuit patents that were important to TI's overall patent position for much of the next 30 years.

Jack was an early entrepreneur, passionately pursuing success in the market place, and he felt at home at the bench or on the manufacturing floor and enjoyed working with young engineers, coaching and assisting them in their career development. His unique technical and creative leadership spanned 12 years at TI, and after leaving TI, he continued as a consultant for many years.

* WW IC market in 1966 was $158 million, and TI had 20% market share.