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THE INTEGRATED CIRCUIT

A CASE STUDY OF PRODUCT INNOVATION IN THE ELECTRONICS INDUSTRY

By

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A dissertation submitted to the Faculty of the School of Government and Business Administration of The George Washington University in partial satisfaction of the requirements for the degree of Doctor of Business Administration

June 5, 1966

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PREFACE

This dissertation is an in-depth study of a recent event currently having serious impact on the electronics industry. The event, broadly speaking, is the introduction and development of a new electronic component called the integrated circuit.

The principal task of the work is to reconstruct and to analyze the series of past events that led to the new product's initial development and the subsequent efforts that brought it to market. The transition of an idea from concept to product implementation can best be understood through an analysis sensitive to people, organizations, and external influences. The fundamental approach is to seek the fine detail which combined to delineate the broader movements rather than to depend upon generalizations relative to innovation in the business environment. The emphasis is neither to correlate the integrated circuit innovation to existing innovation theory, nor to construct a theoretical model that could pertain to technical innovation as a generic process. These subjects will be briefly discussed, but they do not represent the major thrust.

The study views innovation as a multi-dimensional occurrence. Since the Government had a major role in the birth and development of the integrated circuit, the innovation sequence that transpired must be examined relative to

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the special characteristics that typify Government agencies as sponsors of research and development projects and as ultimate customers for the finished product. The Government-industry relationship receives close scrutiny.

Extensive interviewing supported intensive research on the subject. Interviewees were drawn from industry, the military and space agencies, consulting firms, and academic and financial institutions. The business and technical press were the major sources of documentation for the chronologies of Chapters III and IV. For nearly three years, the author has participated in consulting efforts for various Government agencies relative to the optimum use of the new component. The final analysis and conclusions result from the combination of all three inputs--research, interviews, and author's professional background.

The dissertation is divided into six chapters. Chapter I describes the integrated circuit and briefly discusses some of its general background. The chapter also considers the academic and business relevance of the present study.

Chapter II reviews the innovation process as a factor in the functioning of the business enterprise. Innovation in the economic sense is only one particular specialized case of innovation in secular activities. It is a form of change and therefore has much in common with the change phenomenon as experienced in non-economic affairs.

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Chapters III and IV are basically chronological, not analytical. The influence of several contemporary trends, as viewed by the press media, is detailed. These trends and the attendant publicity are major contributors to the innovation process in question. Chapter IV recounts the introduction and initial development of the new component. In contrast to the latter innovation, a brief narrative of the invention of the vacuum tube and the transistor is offered.

Chapter V brings all the threads together in a critical analysis of the events leading up to the innovation. This chapter is evaluative; it seeks out motives and attempts to assess the events that transpired.

Chapter VI offers a set of conclusions. Some are very specific to the integrated circuit innovation, while others are broader in scope and ambition.

The study strives to highlight the detail indiscernible to macroscopic inspection.

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ACKNOWLEDGEMENTS

If the body of the dissertation is based upon traditional research techniques, its "blood" is derived from the many interviews which the author was privileged to conduct. Without these person-to-person contacts, the work would have been less incisive and considerably less interesting--both for myself and for the reader. My thanks to Dean Louis H. Mayo of The George Washington University and to Dr. Walter Radius of NASA's Office of Technology Utilization for their assistance in helping me obtain the travel grant that resulted in the numerous interviews.

To Dr. J. Hart Walters, Jr., I owe much of the neatness of thought and writing that may be attributed to this work. Throughout, he has allowed me the flexibility to seek new directions as I saw them. His suggestions and understanding are greatly appreciated.

To my wife, Berenice, I am grateful for the sustained support as encourager, critic-at-large, typist, and sympathetic listener.

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CHAPTER I

INTRODUCTION

The growth of the electronics industry to about 1960 was achieved through the introduction, development, and application of two major electronic components--first the vacuum tube, and then the transistor. Forty years spanned their respective births. The vacuum tube found the bulk of its applications in the consumer area. The transistor, created to fill an industrial need, has been used in a wide spectrum of fields both Government and non-Government.*

Less than twenty years since the transistor's oncoming, another electronic component has appeared which threatens to relegate the transistor to a limited area of applicability, just as the latter once did to the vacuum tube. As the transistor opened up new applications that were either impossible or impractical with its predecessor, so is the new entry achieving the same end.

This new component is called an integrated circuit (IC). Within the electronics industry there are several other terms which refer to exactly the same device. The term designated will be used in this paper for three reasons: (1) the author believes that it is more appropriate than the others, (2) it is

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*Throughout this paper, Government will refer to only the Army, Navy, Air Force, Department of Defense (DOD) and National Aeronautics and Space Administration (NASA).

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gaining the most acceptance, and (3) it is the shortest.

The integrated circuit is the only type of microelectronic component that has achieved any market significance. It offers extensive off-the-shelf product lines. Although the transistor market has grown considerably in the last two years--1965 sales of $405 million--the IC device has and will continue to displace the transistor and other semiconductor discrete components in many applications. In the fifties and even recently, the latter ousted the vacuum tube in a similar fashion. Although the two transitions--vacuum tube to transistor and transistor to integrated circuit--are not exactly comparable, the impact is very similar. Whereas the vacuum tube can be replaced by a single transistor, an integrated circuit always substitutes for several electronic devices, e.g., transistors, diodes, resistors, capacitors. The important fact is this: when an integrated circuit is used, a transistor is not. In the applications where both may be employed, the edge has shifted to the new entry.

Description of the Product

The product is small, very small. Although there are several variations, two configurations have gained the greatest acceptance. The first type, as might be expected, is a direct copy of the metallic package which housed transistors. It is a cylindrical shape, about 3/10 inch in diameter; its height is a bit less. Protruding out of the bottom may be as many as nine leads connecting the inside

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functions to the outside world; a transistor has only three such leads. Another shape that has gained in popularity, and one that has no antecedents with previous semiconductor products, is the rectangular-shaped "flat-pack." The most common one is 1/8 x 1/4 inch and less than 1/10 inch in height. Its connecting leads protrude out from the sides; the whole package is basically in one plane. The materials used for this type of package vary greatly; manufacturers prefer different combinations of glass, ceramic, and metal.

The product is always some variation of these configurations. The flat-pack is usually sold in a mechanical jig that protects the relatively fragile leads during shipment, testing, and assembly.

The small size, however, may be deceiving to the casual viewer. As with the transistor before it, the smaller volume is accompanied by a greater capability. The integrated circuit performs certain functions that were previously performed by combinations of resistors, transistors, diodes, and capacitors. It is by no means an across-the-board replacement; this likelihood does not seem remotely possible even if one looks into the far future. There is one area of application, however, in which its penetration has been great--digital computers. There are two major reasons why this has occurred. One is a function of the IC component itself, and the other is due to the nature of the digital computer design.

The integrated circuit works especially well in a switching "on-off" application, i.e., one in which there is no

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intermediate state, only "on" or "off" completely. A typical light switch is a good example. On the other hand, the type of application which requires a continuing degree of control and variation has, to date, not been significantly affected by this new technology. An example of this latter function is a radio volume control in which the electronic circuitry must be capable of high and low volumes and all the intermediate gradations.

The core of a digital computer consists of many circuits all in the "on" or "off" state. A few variations of basic digital circuits are used. Indeed, in the Apollo guidance computer only one type of logic circuit is employed to perform all the digital operations. Since, by parts count, there are many components and the variety is small, a splendid opportunity for integrated circuit application presents itself. The IC device can perform the needed function better than its substitutes and the high-volume potential, so important to a new product attempting to reduce its initial costs, is apparent. This combination is the reason for its success, and digital operations represent the bulk of its dollar volume and an even more disproportionate percentage of its unit sales. This situation should remain the same for at least another few years.

The product, then, is one that has found its greatest acceptance in digital applications, first with the military where reliability is critical and, when prices lowered sufficiently, with the makers of industrial computers who are

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much more cost-conscious.

Since the IC component is a semiconductor device, one would expect that the firms that had manufactured transistors would be the same as those that now sell integrated circuits. No such generalization holds. It is true for major IC firms, but there are participants in the IC field that were very strong in the transistor market and are now totally insignificant in the IC area. Other entities were created only to market the new devices; they never manufactured a transistor or diode. One firm relatively weak in the discrete semiconductor field is now relatively strong in the IC market.

The firms that market IC devices are, in the vast majority, corporations involved in activities having little or nothing in common with integrated circuits or even with the semiconductor technology. Without exception, this is true for the five major IC competitors accounting for about 80 to 90 per cent of the dollar volume and probably more of the units sold. There are a few weak IC participants only offering semiconductor products, and there is no corporate entity only making and marketing IC devices. Therefore, the manufacturers of IC product lines are a potpourri of interests; the vast majority of them are divisions of multi-divisional corporations. Their IC operation is only one part of the corporation's interest. This fact has presented some problems in the analysis for the dissertation.

It has been necessary to use the term "industry" in a manner somewhat apart from the more theoretical meaning, but

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closer to the practical usage. The broadest term, "electronics industry," which includes all aspects of microelectronics, refers to those companies or parts of companies that make and market electronic components, electronic equipments, and electronic systems used in the larger electronic units. The semiconductor components industry, or just the semiconductor industry, refers to those companies or divisions of companies that market a semiconductor line. For instance, Westinghouse offers many products, but only a small percentage of its income is derived from its semiconductor components' sales. Of interest here is the Westinghouse operation responsible for those sales. Similarly, the IC components industry, or just the IC industry, includes those operations that make and market IC devices. No other parts of the organization are relevant in this discussion except as they may affect the operations of concern.

Contemporary Relevance

Academic

First and foremost, the study is an investigation of an innovation in the literal sense of the word. The electronics industry offers a radically new product that has no obvious and direct predecessors. New markets are being developed, new firms have been created, and new applications for the product are being realized. Change with respect to all facets of the business is being examined.

As a corollary to the comment above, the study probes

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the broad factors which induce change relative to the opinions, actions, and thinking of the people and organizations concerned. It considers human motivations, how they were influenced by exogenous events and, in turn, how the persons affected reacted. These individuals are the ones involved in the basic decisions that put the innovation sequence on the path it took; some of them made the major critical decisions. By investigating the many details contributing to the major events, one can comment on their applicability to a broader, more macroscopic view of innovation in the business enterprise.

The IC technology, more so than any other innovation in the electronics industry, represents a new approach nurtured and supported by Government funds. It has since been utilized not only in military and space programs, but has "spun off" to many non-Government applications. To understand the IC innovation process one must comprehend the complex Government-industry relationship that existed. This has imposed a different set of conditions on the innovation process when contrasted to the circumstances that normally appertain when the Government is not involved as a research and development (R & D) sponsor.

Business

> Most of Wall Street could scarcely care less that Fairchild Camera & Instrument Corp. makes such diverse products as aerial reconnaissance systems, printing presses, and oscilloscopes.
>
> What catches Wall Street's fancy is Fairchild's prime position in integrated circuits--just about the hottest thing in electronics these days. Fairchild's

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> shares have stood out even in a market teeming with high fliers.[1]
>
> Microcircuits, in short, easily rate as the hottest thing in electronics these days. Already enjoying a sizzling growth, the remarkable little circuits seem destined to set an even more torrid pace in the years ahead, as technology advances and markets multiply.[2]

These are only two quotations from business periodicals indicating the interest generated in this new electronic component. The enthusiastic tone is typical. Business Week has reported the progress of the IC technology since 1959, the year from which its growth is dated.

Its penetration of commercial markets has been great enough that even non-technical, non-business publications have taken notice:

> One thing is certain: Miniaturization will unalterably change our lives and the lives of our children probably far beyond recognition. From tiny chips, and tiny chips of chips, the world of the future will grow.[3]

If the interest of the business world in the IC market has only been conspicuously evident in the last year or two, and the curiosity of the lay public has been aroused even more recently, major officials of the military and Department of Defense have been touting the technology over a more extended period:

---

[1]"What Made a High Flier Take Off at Top Speed," Business Week, October 30, 1965, p. 118.

[2]"Burning Up the Circuits," Barron's, August 9, 1965, p. 18.

[3]Charles Leedham, "The 'Chip' Revolutionizes Electronics," The New York Times Magazine, September 19, 1965, p. 68.

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> It is the opinion of many knowledgeable persons in the electronics industry that Microelectronics offers the brightest hope of attaining significant improvement in system reliability. And, in addition, Microelectronics offers the additional spin-offs of smaller size and weight, lower power consumption, ultimately, less cost too.[4]*

> It must be evident from what I have said this evening that I have considerable confidence in the great potential value of microelectronics in the future of military electronics. And I think these opinions are shared by most engineers who have been closely associated with military electronics for very long and have attentively followed the development and status of microelectronics.[5]*

In Chapter IV, a documentation is presented depicting the sustained interest exhibited by both military and industrial organizations since the inception of the IC development. In the early years of its growth, the new technology has had indispensable support from the military.

The electronics industry has been deeply concerned with the evolution of the IC component and has funded two major studies to predict the latter's growth and impact. In late 1962, Stanford Research Institute, under sponsorship from eight major industrial firms, forecast for microelectronic circuits a growing market dominated by the integrated circuit. By 1970,

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[4]Captain W.R. Boehm, USN, "Microelectronics--Its Impact on Naval Ships," Naval Engineers Journal, June, 1964, p. 367.

[5]James M. Bridges, Director, Office of Electronics, Office of the Director of Defense Research and Engineering, "An Assessment of Microelectronics." Paper read before the Fort Monmouth chapter of the Armed Forces Communications Electronics Association, February 21, 1963.

* In the two footnotes above, microelectronics is referred to, but perusal of the article itself indicates that the center of attention is the integrated circuit rather than some other microelectronic component.

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the sales for this component, it predicted, would reach $680 million.[6] One of the members of the SRI team commented:

> Impact of integrated components on the electronics industry will be felt more acutely in the second half of this decade than it will or is being in the first. . . .[7]

A similar study, also jointly backed by several private companies, was performed by Arthur D. Little, Inc. during 1962. In early 1963, the consulting firm predicted a 1972 market for integrated circuits of about $600 million.[8] It also stated that the greatest impact on industry will be in the latter half of the decade ending in 1972.

Both reports forecast considerable growth of microelectronic components with the greatest impact yet to come and the greatest share devoted to integrated circuits. There is disagreement, however, in the rate of growth. Stanford Research predicts 1970 IC sales of $680 million and Little's figure is less than half.

If the growth of the next five years even approximates the market expansion that has occurred over the last few years, the Little figures will turn out to be terribly conservative and SRI's estimates may even be low. The estimated IC revenue for the past four years is tabulated in Table 1.

In October, 1965, one trade journal listed seventeen

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[6]Barry Miller, "Report Sees Semiconductor Dominance," Aviation Week, December 10, 1962, p. 95.

[7]Ibid., p. 99.

[8]Barry Miller, "Study Forecasts Microcircuitry Growth," Aviation Week, February 25, 1963, p. 87.

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companies offering off-the-shelf IC components and another eighteen supplying them on a custom basis.[9]

TABLE 1

ESTIMATED INTEGRATED CIRCUIT SALES
1962 - 1965
(millions of dollars)

Year	IC Sales
1962	4 - 5
1963	16
1964	38
1965	77

Source: Electronic Industries Association

The importance of this new component far transcends its product growth. Its impact will be industry-wide thereby influencing the many other industries relying upon electronic equipments and systems. Computers are a prime example, but they do and will represent only one segment of the change patterns which the integrated circuit will induce.

---

[9]"Integrated Circuits Commercially Available," Electronic Industries, XXIV, No. 10 (October, 1965), p. 97.

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CHAPTER II

THE INNOVATION PROCESS

Innovation in the business enterprise is only one example of the application of change in social institutions. The economic environment places certain constraints on the change phenomenon, yet there are many characteristics in common with change as a generic process.

The Economic Environment for Innovation

To consider innovation in its proper perspective, one must delineate the innovating goals of the business. These are simple in concept. The innovation function is directed toward the introduction of and the purposeful realization of economically fruitful change into the business operations. It may take many forms, as has been recognized by Schumpeter:

> The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production and transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates.[1]

All these criteria may be valid subjects for innovation; this point will not be discussed here. Within this work, innovation will be considered in the context of that form of change that results in new products. Such an orientation is

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[1]Joseph A. Schumpeter, Capitalism, Socialism, and Democracy (3d edition; New York: Harper & Bros., 1950), p. 83.

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not intended to imply that new product introduction is necessarily topmost in the innovation hierarchy. It is readily admitted that a change in market areas of a given product, or a variation in the marketing technique, or a reduction in manufacturing costs can be just as salutary to the business enterprise as a new product commanding an "innovation profit" in the market place. Innovation, here, is directed to the intrinsic product itself and not to those factors determined by the outside world. Obviously, the nature of the new product is influenced by exogenous conditions in its entry to the market. For the purposes of this analysis, the innovation process is complete once a product has been created.

Innovation coupled with the marketing function may be considered to be the basic entrepreneurial tasks of any business.[2] Drucker concurs with Schumpeter; the innovation process may take on many forms beside the actual creation of a totally new product. Regardless of the nature of the change, Drucker's constant theme emphasizes that the need and search for innovation in its many forms must be an integral part of the business operation:

> Management must not forget that innovation is a slow process. Many companies owe their position of leadership today to the activity of a generation that went to its reward twenty-five or so years ago. Many companies that are unknown to the public [now] will be leaders in their industry tomorrow because of their

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[2]Peter F. Drucker, The Practice of Management (New York: Harper & Bros., 1954), p. 37.

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> innovations today. The successful company is always in danger of living off the accumulated innovating fat of an earlier generation.[3]

The idea of a time lag is introduced here. The act of innovation is carried out before the subsequent profits (if they do occur) are enjoyed. This requires discipline since the business must forego some of its preoccupation with the problems of today for the potential of tomorrow. By so doing, an "opportunity cost" is incurred. Resources that might otherwise be used for current problems are diverted to ventures that are future-oriented. A management should consider these costs and, theoretically, choose the alternative with the highest expected payout. If the investment in innovation efforts offers less overall return to the business firm than a similar investment for other activities, the innovation opportunities have been poorly chosen.

The business enterprise, through its people and its practices, is really a reflection of the past, less of the present, and practically nothing of the future. This is by no means an indictment; it could not happen otherwise. Herein lies the incipient danger: the needs of tomorrow will most certainly be different from those of today. The business firm must turn some of its resources, human and otherwise, to those areas of change in which relatively small innovations will turn operations that are "almost right" to those that are "completely right"; the latter transitions are generally low-

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[3] Ibid., p. 70.

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risk areas to which most of our R&D allocations are directed. The high risk area, however, is where the greatest profits--and the greatest losses--potentially lie, and from which the leadership position may be gained.

One eminently successful manager has commented upon this problem:

> I am coming to believe that all R&D in an industrial organization ought to be deliberately categorized as either (1) frankly exploratory or (2) tactics in fulfillment of a clearly expressed, or at least understood, company strategy.[4]

These categories would fall into low- and high-risk classifications. Haggerty believes that when the strategy is a breakthrough strategy, the success of which can radically change a company's growth and profits, then, sooner or later, a critical decision relative to expenditures for its product exploitation will have to be made. Such outlays will probably affect the operations of the firm in those particular periods in which the expense must be incurred. In such a situation, a tremendous responsibility rests on the shoulders of top management for such decisions may have lasting influences--for better or for worse.

Be it high- or low-risk, the innovation process must continue:

> This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists

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[4]Patrick Haggerty, President, Texas Instruments, "The Role of R&D in Future Profits," speech delivered before National Electronics Conference, Chicago, Illinois, October 9, 1962, and published in Electronic Industries, XXII, No. 1 (January, 1963), p. 227.

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in and what every capitalist concern has got to live in.[5]

Schumpeter suggests that the innovation process is achieved via three processes: new plant, new firms, new men.[6] The construction of new plant facilities, or perhaps the rebuilding of older plant, requires a non-negligible outlay of time and dollars. The appearance of new firms is also necessary although, in reality, the new firm may be part of an older corporate structure. Lastly, new men are associated with innovation. In essence, this is a recognition of the sociology of our industrial society. As will be noted later, one cannot speak of IC innovations without mentioning the people instrumental in bringing these changes to fruition. New faces may be seen in influential positions in completely new firms formed to capitalize on a particular innovation, or they may be part of the multi-divisional structure of a much larger firm. Whatever the means, the result is the same: the appearance of new men has created change in the previous economic structure of the industry. (This study only partly corroborates the latter point.)

The drive towards profitable innovation is motivated by many factors. The most often cited reason is that successful innovation creates future profits. Profit per se, however, is not a sufficient reason--necessary, but not total.

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[5]Schumpeter, p. 83.

[6]Joseph A. Schumpeter, Business Cycles (New York and London: McGraw-Hill Book Co., 1939), I, 93-94.

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Although it is a powerful stimulus, other factors must be included. Profit maximization by the firm as its only incentive must be seriously questioned: "The concept has become so general and hazy that it seems to encompass most of men's aims in life."[7]

Dean has suggested that other motives enter into the picture, e.g., more leisure time, easing of strained relations between corporate executives, restraining competition, maintaining management controls, fending off the demands of labor and/or the Government, and, generally, viewing non-pecuniary factors. There are undoubtedly other variables which are relevant--market share, long-term growth, antitrust actions--but certainly the maximization of long-run profit must be given consideration. Others have also placed certain limitations upon this principle.[8] Carter and Williams accept the theme of long-run profit maximization, but add that the nature of the innovating impulse is influenced by the particular environment of the firms concerned; one difference may relate to the size of the firms in question.

There are lasting assets gained by the entrepreneur who is first in his field:

> We would suggest that a major advantage in first arrival may be a marketing advantage: the prestige which attaches to the first creater of a product or process, the free

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[7]Joel Dean, Managerial Economics (Englewood Cliffs, N.J.: Prentice-Hall, 1951), p. 28.

[8]C. F. Carter and B. R. Williams, Investment in Innovation (London, New York, Toronto: Oxford University Press, 1958), p. 141.

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publicity which may accompany a discovery (for instance, in the pharmaceutical industry), and the advantage of time in building up contacts with customers.[9]

The factor of time is always critical, although there are some who would argue that it is better not to be the innovator but, if possible, to come into the field soon after the original introduction of a new product and copy from the originator. This has often been done but if market dominance has ultimately gravitated to the latercomer, it is most probably attributable not to his latecoming but to his excellence, comparative or absolute, in other facets of the business

Evidently some firms have been successful in their innovative ventures while others have been ineffective. It is useful to look at the firm as being influenced by both internal and external factors relative to the innovating process:

Internal

Although competition may be regarded as an essential spur to progress, its implementation as an operative method within the business organization may have definite limitations and perhaps deleterious effects.[10] It is based on the "economic man" concept that views the individual as being loathe to work, as constantly needing guidance and supervision,

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[9]C. F. Carter and B. R. Williams, Industry and Technical Progress (London, New York, Toronto: Oxford University Press, 1957), p. 160.

[10]Homer G. Barnett, Innovation--The Basis for Cultural Change (1st ed.; New York, Toronto, London: McGraw-Hill Book Co., 1953), p. 72.

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as desiring the most for the least input, and as viewing the job simply as the means by which he obtains his satisfactions elsewhere. As Dean has cited for managers, so too for workers. Many other factors besides the obvious tangible ones, e.g., salary, bonus, must be considered. Elton Mayo's Hawthorne experiments have revealed that the worker seeks rewards from his fellows, and the coincidence of the goals of the formal and informal organizations must be reviewed. In particular, the individual is impelled not only by the rewards and punishments of his formal employer but also by the needs and demands of his co-workers. One means of gaining recognition and acceptance may be through excellence and the resulting changes which may ensue. This concept was voiced by a Nobel prize-winning scientist relative to his chosen profession:

> We all like to excel in our chosen profession. My ego is satisfied when I see my name in The Physical Review (the leading American journal for reports on basic research in physics). A reasonable salary is important. I'm not interested in the rewards of Madison Avenue, but I want enough to support my family. These are reasons for going into any field. But basic research is a way of making nature talk. I get a great kick out of listening in, out of learning something which has not been known before. A society in which this can occur is a good one. Every morning I look out of my window at the George Washington Bridge, to see if it's still there. It warms me to think that I am a member of the civilization which produced this artistic monument--and I feel the same way about pure inquiry.[11]

The prestige-seeking innovator may view the innovation simply as a means to an end, but the resulting effect may be

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[11]Dr. Polykarp Kusch, as quoted in John Pfeiffer, "The Basic Need for Basic Research," The New York Times Magazine, November 24, 1957, p. 93.

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just as beneficial for the business. If these motivations and incentives are at work (and they always are to lesser or greater degrees), they may be superimposed upon the positive rewards the organization normally gives to those initiating useful change. As its corollary, indifference on the part of management to these factors may neutralize the influence of its own efforts to improve its operations through innovations introduced by the employees.

If the managers exert critical influence over their workers, both through direct and indirect means, then we must review the traits most desirable in them to accomplish the goal of raising the efficiency of the innovating effort. These men must, first of all, realize that change is a necessary ingredient in the life of the business firm:

> Investment in innovation is likely to be greater and more timely if firms are able to attract to their management and to their technical posts lively minds, keen to reach out and pull in new ideas, and not satisfied with the automatic repetition of past procedures.[12]

A lack of skilled manpower may lead to an indifferent attitude on the part of the firm to all forms of change. It may also introduce organizational and administrative impediments. Williams cites in his investigation that less than half of the companies reviewed in his 150-firm study had the proper liaison between the various departments that could facilitate the optimum allocation of the available R&D

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[12]Carter and Williams, Investment in Innovation, p. 141.

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funds.[13] Therefore, from his viewpoint, the appropriation of R&D expenditures relative to the needs and potential payoffs was faulty. He divided the firms doing this job poorly into two categories. The first treats scientists with indifference and deploys them in relatively menial jobs, while the second group treats them as individuals who, when properly cared for, will periodically come up with something new and usable.

The research operation, Williams claims, must be treated as an integrated entity along with the production and selling arms of the firm. It is the coordinated effort of the three which ultimately leads to a profitable result for the firm; a serious failing in any of these operations compromises the efforts of the other two. Williams' survey of the 300 innovations reviewed showed that the idea for the innovation originated outside the research department 70 per cent of the time, but it was the research group that made the idea practical.[14] The primacy of good communications is obvious. If the R&D group is isolated from the rest of the organization, it not only impedes the implementation of potentially fruitful ideas, but it also does not keep in touch with other parts of the organization closest to customers. The communication channel should be two-way, both for idea origination and for the actual creation of a want-satisfying product from idea to the customer.

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[13] B. R. Williams, "Science and Industrial Innovation," The Advancement of Science, XIII, 51 (December, 1956), 159.

[14] Ibid.

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The organization must look to its management structure and ascertain that "innovation in the blood" is always allowed to flow. Innovation may still occur in firms where the management is remiss in this capacity, but the probability of its occurrence with the desired salutary effects increases when the management hierarchy is so established that it accelerates and does not impede the innovation process. Williams also mentions that those firms keeping a sharp eye on their organizational structure tend to have a good record in innovations.

This same theme of emphasis on innovation urges an accompanying deemphasis on standard cost-price relationships, especially when the firm is operating in an industry noted for its rapid advances in technology and subsequent product line. Within this situation, the firm must concentrate its most creative talents on the innovation task. Timing is especially critical and, even if the firm is not the innovator, it must still make the choice to go in late, to go in at all, or perhaps to choose another direction for its efforts. In industries where fast technological change is the norm, economic theory must be based on the dynamics of technological advance.[15]

> The major problem . . . for any company which wishes to prosper where scientific progress dictates the pace

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[15]W. R. Maclaurin, "The Process of Technological Innovation: The Launching of a New Scientific Industry," The American Economic Review, XL, No. 1 (March, 1950), p. 91.

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of change is to be in on the new development or to get in at the proper time.[16] (Italics in original.)

External

The innovating firm is not only influenced by the variables within its own confines, but is also affected by the attitudes and institutions of the outside world. The quality of the educational system is critical. Mere inventiveness confines innovation to a very small range of possibilities. Invention refers to the creation of a new technique or means of performance; innovation is its application to a utilitarian, satisfying function. If the ground is fertile and if educational establishments have supplied a stream of persons knowledgeable in both the general and the particular, then we should expect the environment to have a positive effect upon the innovating process.[17]

If the business firm is affected by the secular institutions within the society, it is also dependent upon other business firms in its innovating efforts. Carter and Williams speak of the "gate effect" in which innovation by one firm sets off changes in others. Or, contrariwise, the successful implementation of an innovation by the originating enterprise requires subsequent innovations on the part of other firms. In industries such as aerospace and electronics, each is very dependent for successful innovations in its own

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[16] Ibid.

[17] Carter and Williams, Industry and Technical Progress, p. 163.

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areas upon firms specializing in the physical sciences. Without the latter--without a successful chain of innovations--the original innovation may not materialize. This mutuality is fostered by willingness to exchange information and a realistic business philosophy that no firm can profitably exist without the assistance of others.[18] The Carter and Williams study, performed in 1957, closed with these findings:

> We conclude this report by referring to two findings, one of which is encouraging, while the other shows the magnitude of the difficulties which remain. We find that technical progressiveness is to some extent related to financial success, and in particular that it may pay to be first in the field, rather than to allow the pioneering to be done by others. If these findings are correct, the forces of natural selection, stimulating the growth of profitable firms, are allied to those of technical progress. But, on the other hand, we suggest that backwardness is self-perpetuating, both in firms and in industries; the backward firm, even if it can be made to desire technical progress, is ill placed to command the resources (and in particular the human ability) necessary to begin that progress. It will take much ingenuity by industry and government to break up the crust of habit and to divert likely and able minds from the places where change is most likely to those where it is most needed.[19]

The Cultural Environment for Innovation

If the capitalistic system does embrace the innovation concept, one must look past the business domain to determine why this economic structure has been so typically American.

Why it has flourished in this country derives from a conglomerate of many reasons. One would have to examine

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[18] Ibid., pp. 175-176.

[19] Ibid., pp. 191-192.

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various socio-political-economic trends to arrive at an answer. It is necessary, as sociologist Homer G. Barnett has contended, to investigate the environment. He suggests that there is a positive correlation between individualism and innovative potential, that the individual must be allowed to follow his own whims and pursue his own world of experience. Given this form of backdrop, the promise of new ideas increases. An opposite climate, in turn, leads to a stultifying sameness that squelches personal curiosity and inquiry and channels all possible innovative expression down conventional and accepted paths.[20]

An offshoot of this is what Barnett calls "a tradition of expecting change."[21] Some cultures, or at least particular parts of specific cultures, are attuned to the oncoming of change. Admittedly, even in the most change-oriented cultures (and let us put our society into that category), change is generally restricted to only certain parts of the culture. If we expect new electronic products to spew out of our industrial complexes, or if we know that today's miracle drug will soon be replaced by an even greater miracle variation of the original, we do not expect--nor allow--similar volatility with respect to our family, our religion, or even our political structure. There are gradations, of course, but it is not an unreasonable assessment to allocate the anticipation and

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[20]Barnett, p. 65.

[21]Ibid., p. 56.

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desirability of change and innovation to particular cells of our society. Certainly, product change in segments of our industrial output, and especially in the electronics industry, is one of those cells; this is not only expected but necessary:

> For some industries, the incentives of competition are direct and immediately apparent. In such industries, if the market demands that firms innovate to stay alive, you can be sure those firms will innovate. For example, in the electronics industry, competition is so keen that those companies that fall even a little behind technologically are soon out of business.[22]

The cultural background not only places de facto constraints on those areas in which innovation is encouraged and expected but, even within these areas, it generally sets limits on the extent of the change that can occur. There is one school of thought that espouses the idea that every innovator is really only continuing a sequence of events originating before him. The innovator is more properly the continuer:

> (a) What is called an important invention is a perpetual accretion of little details, (b) probably having neither beginning nor definable limits, (c) tho [sic] it is hazily and somewhat arbitrarily defined by a word or phrase in the English language, and by our standardizing habits in thought and industry, as well as in language. (d) An invention is an evolution, rather than a series of creations, and much resembles a biologic process, because it has a basic kinship with this, thru innate human mentality.[23]

So the innovator is captive to his environment. Although destined to extend his cultural inventory, it places

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[22]Sumner Myers, "Attitude and Innovation," International Science and Technology, No. 46 (October, 1965), p. 92.

[23]S. C. Gilfillan, The Sociology of Invention (Chicago: Follett Publishing Co., 1935), p. 5.

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limitations on how far the excursion will go. The greater the number of ideas and the more varied they are, the greater the stockpile from which the potential innovator can draw. The available stockpile, it should be added, need not be constrained by national boundaries. The implications from this realization are many; the rewards accruing to an advanced society may be ever-increasing, while the lot of the more sterile and less advanced culture remains relatively bleak--if the two are in isolation and the latter does not borrow from the former.

This attitude of secular expectation of change is made much more specific through some of the thoughts of Carter and Williams.[24] They suggest that the creation of a public opinion proud of technical change is a vital ingredient in achieving that change. The reasoning almost becomes a bit circuitous, and an inbreeding situation may occur. Undoubtedly, one feeds upon the other. How the genesis comes about is not really very important. If the expectation for change does prevail (regardless of its origin, whether natural or contrived), it is enhanced by the realization of changes it has had some part in creating. This, in turn, nurtures the attitude and allows it to ramify into other areas.

In certain businesses (or any field of endeavor for that matter), a high premium is placed on tradition, and

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[24]Carter and Williams, Industry and Technical Progress, p. 176.

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change is looked upon with disdain. This is true in some trades in which the craft is transferred from father to son indefinitely. Even in today's culture, there are many professions in which "carrying on the tradition" is the cardinal rule. Where this attitude does prevail, change is not only discouraged but is not allowed. Some handicraft professions fall into this category. Before the advent of science as applied to industrial uses, it was necessary that this attitude hold sway since the transfer of knowledge was carried on in such a manner. As new scientific techniques began to appear, the need for personal communications became less, and industries grew more dependent upon large factories and the benefits of an industrial revolution. Attitudes necessary before now became impediments. If progress was to be made, if innovation was to occur, then the dominating ethic had to become one of encouraging new and novel techniques rather than the acceptance of tried and true methods. As stated before, the attitude toward change must be viewed as part of a macrocosm; the innovator is prone to his environment and, as a generalization, he is more in step with it than he is as an iconoclast.

Over the years, our institutions have become sensitive, to some degree, to their role in forming such opinions. They have become a positive part of the environment conducive to innovation and change. The graduate education system is often a strong force in this direction. If some of the secular institutions have a positive effect upon the innovating process

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there are persons who feel that the formal means by which inventions are brought forward are less than adequate: "It is a fair comment that industrial societies have shown little originality or ingenuity in creating institutions to ensure that all new ideas will be swept into the net and that nothing will be lost."[25]

It is sometimes contended that the patent system holds an august position, unchallenged and immune to criticism. Actually, however, the procedure is only one part of the many external institutions affecting the flow of useful innovations into the general community. It has sometimes been maintained that private enterprise itself might deliberately stoop to suppression of technological innovation if the change was to the firm's detriment. Although this idea does not carry much weight today, a "resistance to change" attitude may sometimes prevail which can have an equally frustrating influence. As far back as 1935 this was noted and commented upon:

> But still it is clear that invention is very valuable (especially the working up tho [sic] not the proposal of fundamental inventions), and that we should arrange our patent, bureaucratic, philanthropic, commercial and educational systems so as to obtain a much faster flood of it, especially in the most needed directions. And that the first best step toward this end would be a commission for a thoro and general inquiry, representing wider competencies and interests than just the patent industry. And we likewise need to do some social planning, not only to guide the inventions but also to meet their often hurt-bearing impact.[26]

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[25]John Jewkes, David Sawers, and Richard Stillerman The Sources of Invention (New York: St. Martin's Press, 1959), pp. 9-10.

[26]Gilfillan, pp. 157-158.

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Yet, criticism notwithstanding, the movement for more innovations affording beneficial results has gained momentum through the years, if not because of our formal institutions, then in spite of them.

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CHAPTER III

FACTORS ADVOCATING NEW ELECTRONIC PRODUCT

The transition of an idea from potential utility to salable product is influenced by many variables, both inside the firm and within the particular industry, as well as among industries. Considerations of the world totally outside the enterprise may have their impact. The firm does not operate in a vacuum; it is continually in a state of flux as people and ideas change. It is an antenna, willing or not, for the occurrences happening around it, both in the very particular and the general.

The integrated circuit resulted from a confluence of events that pressed for its creation by stressing certain trends and disallowing others. The five parts of this chapter describe the movements contributing to the product's emergence.

Research and development serves as the backdrop. This industry, more than any other, has generated an aggressive R&D-oriented image in which innovation is not only desirable but indispensable. It may be victim to its own Frankenstein.

Attempts to miniaturize electronic components and equipment have been carried on for two decades. To date, the integrated circuit is the acme of these efforts.

Reliability in all its ramifications has gained increasing importance since the Second World War. The IC

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component is, to a large degree, a response to that need.

The semiconductor industry itself, a burgeoning newcomer among its sister industries, saw the integrated circuit as a new product to be offered along with the rest of its semiconductor lines. The new device has created convulsions similar to those the transistor induced, yet different and more far-reaching in many respects.

Finally, the integrated circuit is a highly sophisticated technical product. The advance of the technology is the basic constraint, regardless of how urgent the other needs are.

Research and Development

There is no doubt that the ascendancy of Research and Development to its present status is a relatively recent phenomenon. "The fact appears to be that from and after World War I the entire world was in revolution, and the base of that revolution was technical far more than it was social."[1]

If change was "institutionalized" in the 20th century, its roots trace back to earlier years.

The original founding and settlement of America were predicated on change: the desire to do things differently or the need to find a new way of life. Our subsequent history

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[1]Adolf A. Berle, Jr., The 20th Century Capitalist Revolution (New York: Harcourt, Brace and Co., 1954), p. 23.

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has been a continuum of change. The reasons for this are manifold; suffice to say that the idea of newness and innovation became a part of our motleyed national character. Alexis de Tocqueville wrote more than a century ago:

> I accost an American sailor and inquire why the ships of his country are built so as to last for only a short time; he answers without hesitation that the art of navigation is every day making such rapid progress that the finest vessel would become almost useless if it lasted beyond a few years. In these words, which fell accidentally, and on a particular subject, from an uninstructed man, I recognize the general and systematic idea upon which a great people direct all their concerns.[2]

A theme, partly reminiscent of Frederick Turner's thesis, may apply:

> In the United States our prosperity has been largely based on cheap land and superabundant raw materials. Today our civilization has developed to such complexity that we cannot hope to maintain our position except through the assistance only science can afford. The research laboratory has become the prime mover for the machinery of civilization.[3]

The author of these words felt--in 1928--that a new era of science in industry was about to blossom forth, and the harbingers of its approach were the industrial research laboratories. A similar note of enthusiasm was struck by Vannevar Bush in 1945:

> Advances in science when put to practical use mean more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for

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[2]Leonard S. Silk, The Research Revolution (New York, Toronto, London: McGraw-Hill Book Co., 1960), pp. 204-205.

[3]Maurice Holland, "Research, Science and Invention," A Century of Industrial Progress, ed. F. W. Wile (Garden City, N.Y.: Doubleday, Doran & Co., 1928), p. 334.

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> learning how to live with the deadening drudgery which has been the burden of the common man for ages past. Advances in science will also bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression. But to achieve these objectives--to secure a high level of employment, to maintain a position of world leadership--the flow of new scientific knowledge must be both continuous and substantial.[4]

Has the attainment of new scientific knowledge, of the need for innovation and change, ever been brought to a more sanctimonious plane? And in 1947, the Scientific Research Board reported to President Truman that "the security of the United States . . . depends on the rapid extension of scientific knowledge."[5]

Business Week labeled that as one of the early gong warnings of a need for more basic research--presumably Government-sponsored.

The advantages of research and the resultant innovative changes that may accompany it have their antecedents in words and deeds that trace back to years before the past two decades. It is within this milieu that the American industrial complex, in part, has become the model of rapid industrial change and innovation, both in our own eyes as well as those of the rest of the world.

The value of R&D, although highly regarded today, has

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[4]Vannevar Bush, Endless Horizons (Washington, D. C.: Public Affairs Press, 1946), p. 41.

[5]"What Basic Research Means to Defense," Business Week, October 17, 1959, p. 136.

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yielded salutary results throughout a long span of years. One such study estimates that the United States spent about $39 billion on R&D efforts from its earliest days through to 1954.[6] Nearly half of that amount, about $17 billion, was spent in the 1950-1954 time span. From these inputs, Ewell suggests that "at least 0.5% and more likely 1.0% or more" of the long-term U. S. productivity increase results from R&D outlays. Also, the research conducted between 1928 and 1953 probably contributed $40 to $80 billion to the 1953 GNP of $365 billion. "It seems likely that basic research in which we put 5 to 6 percent of the total R. and D. investment, has the highest economic payoff in any area of research, although this is a very difficult proposition to prove."[7]

It was during the wartime period, however, that the R&D process was greatly concentrated and harnessed to a war machine effort in which time was the all-important variable. The planned application of scientific research with a fixed timetable was the radical departure. England's need to defend itself from a Nazi holocaust resulted in the invention of radar; the loss of previously-available accessibility to rubber markets forced the United States to come up with the synthetic rubber substitute; and, most famous of all, the Manhattan Project gave us the first atomic bomb. All these

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[6]Francis Bello, "Industrial Research: Geniuses Now Welcome," Fortune, LIII, No. 1 (January, 1956), p. 98.

[7]Ibid., p. 99.

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efforts required tremendous numbers of skilled personnel driving to a common goal. During war, naturally, the incentives for achievement are probably at a zenith. If the incentives were maximum, so too were some of the objectives being sought. And they were achieved! The postwar residual from these experiences was a growing awareness on industry's part of the applicability of these wartime efforts to peacetime industrial needs. Could the astounding achievements be duplicated by similar efforts by an organized business enterprise?

In reality, then, World War II did not generate the original idea of highly coordinated industrial research, but gave to it a tremendous accelerating momentum. It was the high concentration of effort that was the innovation, not the concept of the need or desirability for change.

Before World War II, spending on all forms of research was less than $1 billion per year. After the war, the postwar sellers' markets did not require or need much R&D support for business to thrive. It was not until the Korean War that R&D funding spurted again, and the Government let contracts in aviation, electronics, and other fields. This ultimately led to an increased military capability when the B-58 bomber, supersonic fighters, guided missiles, and more versatile atomic weapons came into the arsenal. The commercial jet age, inaugurated in 1958, reaped the harvest from military research in this era.

When the Korean War was over, the excess profits tax was dropped in 1953, other wartime restrictions were dissolved,

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and the industrial research boom had its genesis. The 1954 tax revision allowed research expenditures to be expensed, rather than capitalized as they had been previously. Up until 1953, the makers of industrial machinery were spending only 1¢ of each sales dollar for research, steel companies only 0.2¢ as compared to 3¢ for the electrical and chemical industries.[8] This was soon to change: ". . . The newest major force in the United States' economy--and one that may basically change it--is research."[9]

Some proponents state that this is not only desirable but indispensable to our nation's growth rate. In 1960, Leonard Silk wrote that at that time the U. S. population was increasing at the rate of 1.7 per cent, compounded.[10] This rapid increase implied there would be difficulty in maintaining the standard of living. In terms of per capita income: "We are going to have to run pretty fast just to stay in the same place. . . ."[11] The answer, according to Mr. Silk, would derive from the growth of scientific and technological knowledge. He was not alone:

> The fact is that research spending has been the nation's most fertile activity of the last two decades. From the labs has come a stream of new products, new

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[8]"Research Pay-off Looms Big," Business Week, September 21, 1957, pp. 129-130.

[9]Ibid., p. 129.

[10]Silk, p. 9.

[11]Ibid., p. 10.

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processes, and new materials that have helped keep the U. S. strong.[12]

This growth is the spur to investment which, in turn, is the sine qua non for our industrial system. Silk summed up his feelings accordingly:

> This research revolution seems to me to be a qualitative change in the economy--one of the same importance to future growth as the development of the concept of capital investment itself was during the past two centuries.[13]

That such a "revolution" was taking place is at least implied from the data of Figure 1. The graph shows that the industry's contributing share of the R&D dollar source continually decreased at a fairly uniform rate (for the years 1945-1959). For that time period, the total amount of R&D dollars increased by a factor of about 6.7, while the industry segment rose by five times. Obviously, the lion's share of this rising appropriation was forthcoming from the Government. Its contribution in toto rose ninefold, while its R&D funding to industry multiplied by over fifteen times. Using any yardstick that one chooses, the increase is tremendous in a relatively short span of time.

It is appropriate here to enter some dissenting opinions.

Although one may accept the direction as fact, it does not necessarily mean that one agrees with the trend. Jewkes

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[12]"A Chance to Tot up R&D's Score," Business Week, September 21, 1963, p. 152.

[13]Silk, p. 205.

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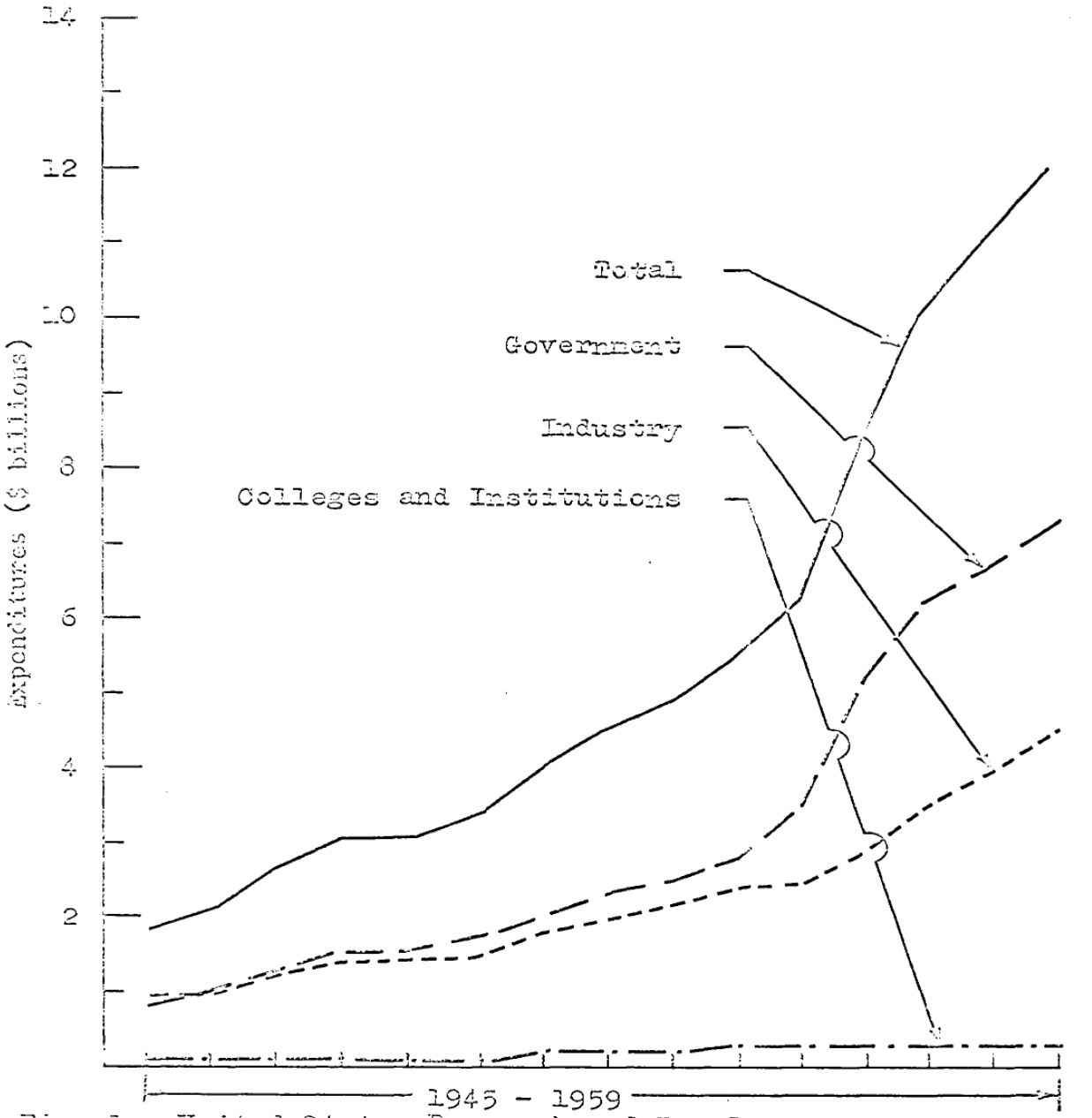


Fig. 1.--United States Research and Development Expenditures

Source: Silk, The Research Revolution

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suggests our preoccupation with R&D activities is attributable to the world situation in which offensive power continually outstrips the capability of defense.[14] There is no doubt that the current impetus for R&D is basically not propelled by inherent economic factors, but is a result of a pseudo-wartime state of affairs.

Even within the narrower economic point of view, Jewkes feels (as does Novick in the succeeding paragraphs) that at least part of the R&D euphoria is based upon the mistaken hypothesis that we believe we have come upon the techniques for ever-accelerating increases in innovations. There is a duality of beliefs: one half feels that the new devices and practices will lead to a cornucopia of plenty if accepted, while the opposite contention maintains that their rejection will lead to possible stagnation. The choice is between extremes with no stationary position allowed.

Some feel that our enthusiasm for R&D has led us down the path of self-delusion. One commentator of the scene feels that the swelling of the R&D stockpile is not quite legitimate: there are inflationary increases and nomenclature problems that make comparisons difficult, to cite just some of the examples.[15] For instance, Mr. Novick accepts the R&D expenditure for 1959 as $10 billion (which we note is different

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[14]Jewkes et al., pp. 235-236.

[15]David Novick, "What Do We Mean by Research and Development," California Management Review, II, No. 3 (Spring, 1960), 9-24.

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from Figure 1), and he allocates that amount accordingly:

TABLE 2

ESTIMATED BREAKDOWN OF R&D EXPENDITURES: 1959
(billions of dollars)

Step	Promise	$ Distribution
I	Brave New World	0.1
II	Possible use of new discovery	0.3
III	Application of new knowledge	2.6
IV	Improved application of existing knowledge	7.0*

*In Mr. Novick's original article, this figure was 6.0; from the gist of his comments, it was evident that the original deficiency of $1 billion was to be allocated to Step IV.

Source: David Novick, "What Do We Mean by Research and Development," California Management Review, II, No. 3 (Spring, 1960), p. 21.

Much of the rising expenditures in R&D funding, Novick suggests, is derived from our wanting them to go up. He maintains that the R&D portion attributable to the really new areas of knowledge--his Brave New World category--is clouded by unsatisfactory identification and accounting techniques.

(The contention of the author is that whether the reality of R&D expenditures is half myth, half truth, the awareness and enthusiasm is not subject to a similar criticism. This was the environment of the late fifties and early sixties, the particular time period which will preoccupy our attention in this paper. To appreciate fully the genesis of any innovation in the electronics (or any) industry at that time, one

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must realize that the prevailing mood was one in which R&D efforts were held in high esteem in many quarters. Whether this high opinion was based on sound reasoning, or whether we be a victim of self-delusion, is of secondary importance for our purposes.)

Even if we accept the R&D trend as only a partial reality, including all industries in one broad sweep as aggressive practitioners of the art may be erroneous. Some findings cited in 1960 imply that the R&D group is quite selective.[16] For example:

1. Practically all of the R&D activity performed by U. S. industry is confined to manufacturing companies. Generally, such industries as construction, utilities, banking, transportation, service fields, and retail and wholesale trade do not do a great deal of technical research.

2. Only four out of twenty-four industries in manufacturing account for more than two-thirds of the industrial R&D performed. They are listed below for 1959:

Industry	R&D Expense
Aircraft	$3.3 billion
Electrical	1.6 "
Machinery	0.7 "
Chemical	0.6 "

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[16]Dexter M. Keezer, "Research and Technology: A New Era Begins," The Management Review, XLIX, No. 2 (February, 1960), 23-27.

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Within these four manufacturing industries, the nature of the R&D work varies, with gradations as to how "basic" the research is.

3. Most of the research spending is done by large firms. This can be reasoned out partially on an intuitive level. Since R&D activity may require large outlays in dollars and manpower, the profitable breakeven point is obtainable only within large firms. In 1953, the National Science Foundation found that 73 per cent of the total expenditure for R&D in manufacturing was done by 2 per cent of the manufacturing companies, all of them with 5,000 or more employees. Mr. Keezer surmises that the 500 largest research spenders account for over 90 per cent of all the research spending done in this country:

> Moreover, a benign Providence who, so far, has loved us for our worries, has made the modern industry for a few large firms an almost perfect instrument for inducing technical change. It is admirably equipped for financial technical development. Its organization provides strong incentives for undertaking development and for putting it into use. The competition of the competitive model, by contrast, almost completely precludes technical development.[17]

If Galbraith is correct (and his opinion is by no means the consensus), then our capitalistic economic system, composed of oligopolistic groups within its major parts, is the modus vivendi for innovation. The closer the approximation to a pure competition, the less the inclination for

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[17]John K. Galbraith, American Capitalism, The Concept of Countervailing Power (Boston: Houghton Mifflin Co., 1952), p. 91.

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change; he cites the farmers as a particular example.

4. Industrial research is heavily dependent upon defense contracts. Government support is high in the primary defense industries (aircraft and electronics) and less so in the supporting industries (oil, rubber, chemicals).[18]

In some measure, Galbraith's contention that big business and not the highly competitive business is the spawning ground for innovation through its preponderance of R&D spending is confirmed. What Keezer's figures do not say, however, is where the innovations actually do occur. It does not necessarily follow that the greatest expenditures lead to the most fruitful returns. There has been, however, some evidence that R&D investment does offer a good return. One such advocate cited that companies plowing back 3 to 4 per cent of their sales into R&D ventures tend to have a yearly growth rate of 10 per cent, while the national average is about 3 per cent.[19] In his work, Edie has noted a fairly constant ratio between research and capital expenditures for manufacturing industries. It is in exactly this area, i.e., the relationship between R&D expenditures and subsequent outlays for capital spending, that we find what one commentator calls the "mighty multiplier" effect.[20] It is suggested that

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[18]Keezer, pp. 63-64.

[19]"A Company's Research Outlay May Reveal a Lot About It," Business Week, January 28, 1956, p. 126.

[20]Gilbert Burck and Sanford S. Parker, "The Mighty Multiplier," Fortune, L, No. 4 (October, 1954), p. 108.

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new technology forces the replacement of capital goods before they are physically rendered obsolete and, therefore, it is a constant stimulant for that market.

By the late fifties, this country was already involved in a wave of R&D ferment generally attributed in its origin to the relatively unprecedented technical deeds performed during the Second World War.

Perhaps it is reasonable to infer that President Kennedy was alluding to the outputs of this research revolution when, in his inaugural address in January, 1961, he said:

> Let both sides seek to invoke the wonders of science instead of its terrors.[21]

Miniaturization

Probably the first impression any observer has when he sees a microelectronic component for the first time--regardless of which type it is--is its remarkably small size. The functional utility forthcoming from these devices is contained in a volume considerably smaller than the package in which it is housed.

In today's military and space applications, the premium on small size is high in many areas. One might automatically think of some of the NASA projects, e.g., Gemini, Mariner, Surveyor, Apollo. The military, to a lesser degree, look to miniaturization in applications in which man and/or

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[21] Public Papers of the President, John F. Kennedy, 1961 (Washington: U. S. Government Printing Office, 1962), p. 2.

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equipment are airborne, or in situations where portability is important, as for equipment carried by the soldier. The Navy has to cope always with the problem of limited space on its ships. Therefore, with varying degrees of emphasis, both the Department of Defense and NASA look favorably upon equipments with reduced dimensions.

The consumer market, on the other hand, has generally been relatively indifferent to size in its product lines. It is only recently that some areas of consumer markets for electronic equipments have become more sensitive to the rather specialized functions in which size may be important to the buyer. The most obvious and spectacular example of this feature was the tremendous acceptance of transistorized radios in the late fifties. Here, performance was certainly compromised but the extremely small size offered more than compensating returns. There are many types of electronic system which have been made smaller through the use of transistors but, primarily, this was not the only or even the major motivation for switching from tubes to transistors. Improved reliability and reduced power consumption were important advantages.

The industrial market probably lies between the military-aerospace and consumer demands in its affinity for small size. For certain applications, it is willing to pay some premium for smaller size--but usually not a great amount, e.g., desk-top equipment.

The major efforts to miniaturize electronic components

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and ultimately electronic equipment stem from the military agencies. They not only advocated and needed space savings, but they funded the initial programs aimed at accomplishing the same. Sometimes, small size was not the only objective of a program that might lead to miniaturized components; often, it was not even a primary goal. Still, it was through these efforts that the initial interest in miniaturization was generated.

One of the earlier attempts to miniaturize electronic equipment, although this was not a major objective of the program, was the Army's auto-sembly technique. This work, which took place about 1949, was mainly a manufacturing method to alleviate some of the problems encountered in the fabrication of highly compact subminiature equipment designs. It employed conventional components connected to a copper conductor pattern on an insulating plastic base. After the components were mounted, a "one-shot" solder dip completed the sequence. Its adherents suggested that it would result in equipments smaller in size, more reliable, and less costly.

Tinkertoy

Project Tinkertoy was a major effort sponsored by the Navy's Bureau of Aeronautics to miniaturize and completely automate the manufacture of certain electronic components. The work was actually performed by the National Bureau of Standards (NBS).

Although this was probably the first major effort with

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this particular objective, NBS had worked on proximity fuses during World War II and had then faced similar problems. Proximity fuses were not very reliable; one source mentioned about 50 per cent. NBS was faced with the problem of speeding up their production; this required a new approach to their manufacture. The work done by NBS at the time, published in a report in 1947, served as the basis, in concept and manpower, for the Tinkertoy effort.

The Tinkertoy project was completed about November, 1953, after three years work and an expenditure by the Navy of over $4.7 million.[22] A pilot automatic factory was in operation by about November, 1953, in Arlington, Virginia.

The Navy itself was not anxious to enter the manufacturing business, but it wanted to encourage private industry to move in this direction. It was also interested in establishing a production facility that could be called on in emergencies. It could accomplish these objectives via two possible paths. First, if manufacturers felt the Navy would favor the given approach, a ready market for equipment using such components would be available. Navy interest and funding could in turn trigger a response from other agencies. Second, if manufacturers of industrial or consumer electronic equipments believed that such a technique would be advantageous in their own applications, then the market for Tinkertoy-like devices would increase; this circumstance would be favorable

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[22]"Microelectronics Today," Electronic Industries, XXI, No. 12 (December, 1962), p. 92.

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for the Navy in the long run, since they would not now be the only customers for these devices.

For whatever the particular motive, ACF Industries attempted to develop a commercial version of the Tinkertoy. The company put in over $1 million of its own into this project.[23] The program, called Compac for component package, was headed by former NBS personnel who had previously worked on Tinkertoy.

The Tinkertoy concept was based on a packaging technique centered about the vacuum tube. This emphasis--it began in the very early fifties before the transistor was a major factor in the industry--was to prove a major factor in the lack of acceptance which ultimately was its downfall. The vacuum tube, the active component in all electronic equipments through the late forties and early fifties, was the major obstacle to miniaturization efforts at that time. Because of its size, heat, and fragility, the tube set the limits to the extent of compactness (and reliability) inherent in electronic circuitry. The Tinkertoy consisted of a series of wafers connected by riser wires; typically, four to six wafers were stacked together. The ceramic wafers, or slices, housed the non-tube components, such as resistors and capacitors, with the topmost layer reserved for the vacuum tube. Each wafer was about 7/8 inch square and 1/16 inch thick, with some small

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[23]Edmund L. Van Deusen, "Electronics Goes Modern," Fortune, LI, No. 5 (June, 1955), p. 146.

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spacing between the layers.

The Tinkertoy program, begun before the ascendancy of the transistor, was fated to obsolescence since its completion occurred at about the same time the transistor began to have wide acceptance in military circles. It was obvious by 1955 that the direction of electronics was toward solid-state components. Production volumes for the latter were increasing, germanium transistors were gaining in favor, and the silicon transistor--particularly appropriate for military applications--was to be announced shortly thereafter in the spring of 1954.

Diamond Ordnance Fuze Laboratories 2-D Program

The Tinkertoy approach used a three-dimensional construction, i.e., tiers of wafers. Diamond Ordnance Fuze Laboratories (DOFL) was focusing on new ways of fabricating smaller-volume electronic assemblies. The program was geared to the needs of highly specialized applications where one-shot, high reliability ammunition concepts were of major concern. The method was a two-dimensional approach in which the electronic components were to be placed on a thin wafer substrate. By eliminating component packages where possible--mainly for the transistor--and using printed circuit techniques, it hoped to reduce the volume of its electronic circuits.

This type of approach, with variations, had been used previously for different applications. Methods had been

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developed to silk-screen resistors and capacitors on a ceramic substrate using silk-screen techniques, but their main emphasis was directed to only the passive components. The DOFL project strove to also include both transistors and diodes.

DOFL began its program in mid-1957, a year before the Micromodule program began and two years before the first molecular electronics contract was awarded to Westinghouse. Although some important progress was made, its work was ultimately eclipsed by the interest generated in the IC technology. In an article appearing in a May, 1959, journal, probably written at least six months previously, the workers on the DOFL program said:

> Under consideration at DOFL and elsewhere is the idea of starting with a block or slab of semiconductor such as silicon and converting various portions of the block to proper resistivity and type so as to achieve circuit function without resorting to separate resistors and capacitors.[24]

Micromodule

The Micromodule, simply stated, is basically a transistorized version of the Tinkertoy. The project was originally considered in 1957 and backed by the Army Signal Corps for about five years, from April, 1958, through fiscal 1963, at a reported cost to the Army of $26 million.

The Micromodule program was not an R&D effort. It was

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[24]T. A. Prugh, F. R. Nall, and N. J. Doctor, "The DOFL Microelectronics Program," Proceedings of the IRE, XLVII, No. 5, Part I (May, 1959), 893.

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sponsored with production funds, since the major objective was to devise a new electronic technique using available capabilities. Within four years, it was hoped, the Micromodule would be ready for equipments in mass-production.

In June, 1958, a major Army official said in reference to the Micromodule program:

> We [the Army] are embarked on a definitive microminiaturization program to provide the Army with a ten times reduction in size of its electronics with full military capabilities.[25]

This statement was made at the briefing session for representatives of various electronic firms. It was backed up by a two-year contract to RCA for $5 million. By mid-1959, the program had sixty participating companies working on the effort. The Army, at about that time, made its intent quite clear:

> Through the Micromodule concept, we [the Army] plan to provide as soon as possible a new potential for economical, automatic production of rugged, reliable military communications for a growing number of applications.[26]

The Micromodule, with miniaturization as its main objective, took full advantage of transistors. It would incorporate these devices, with other electronic components, on ceramic wafers about 0.31 inch square and about 0.01 inch thick. As with the Tinkertoy, riser wires would join the

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[25]"Army May Issue Modular Rules," Electronic News, June 9, 1958, p. 1.

[26]"R&D Lab Gets Major Role in Micromodule Pact," Electronic News, August 17, 1959, p. 50.

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spaced layers resulting in a much higher degree of volumetric efficiency. By their very nature, the circuits would be most appropriate initially for low-power applications.

The Army hoped that the other services--Air Force and Navy--would join in the program, and the implications from the literature were that it felt confident in ultimately obtaining tri-service approval for its project.

The Army expected that RCA, the prime contractor, would be prepared to deliver complete prototype equipments constructed almost entirely from the new components by 1962. (It should be noted here that the Micromodule program began about one year before the Air Force initiated its molecular electronics program with Westinghouse.)

By mid-1959, progress had been sufficient to warrant the Army to award RCA another $2.4 million for the production phase of the program. The work continued on and in September, 1961, a trade periodical article noted that:

> Micromodules are moving closer to commercial application as the result of exhaustive tests being conducted by the Army R&D Laboratory and RCA, N. Y.[27]

During this time period, RCA and some of its contractors were heavily advertising their participation in the program. Their ads usually carried the aura of state-of-the-art work in a technology which was (hopefully) to dominate electronics (in certain applications) in the future.

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[27]"Commercial Modules Due in Army, RCA Testing," Electronic News, September 18, 1961, p. 30.

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Again, in September, 1962, the Army announced increased funding for the project. An outlay of $8 million was to be appropriated in fiscal 1963; this was about twice that of the previous year, and brought the total allocation through fiscal 1963 to $26 million.[28] By March, 1963, the Army hoped to have a production output of 250,000 modules per year.

By the spring of 1963, the feasibility of integrated circuits had been proven, and the Army was on the defensive relative to its continuing support of the Micromodule concept. The Army maintained that the program would be continued:

> Despite some general feeling in the industry that the Army Micromodule program is already obsolete, the head of the Army Electronics Command said the program had not been passed by the state-of-the-art and was an active, going program.[29]

The Micromodule, it was maintained, was a structure and, as such, could be adapted to any technical improvement.

The Army and RCA in the summer of 1962, probably to counterbalance a growing interest in thin-film and integrated circuitry techniques, had decided to attempt to win over industry converts to the Micromodule concept. Findings on extensive reliability tests (presumably good) were to be released. Under Army sponsorship, P. R. Mallory & Co. was

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[28]Although the $8 million figure was reported in the press literature, Army officials claim that this amount was never spent. The final summary report for the program lists a total expenditure of only about $18 million.

[29]"Micromodule Program of Army Still Alive," Electronic News, April 1, 1963, p. 28.

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building an automated assembly line capable of turning out more than 200 Micromodules a day with the capacity to expand to 1,000 a day:

> However, companies building avionics for BuWeps [Bureau of Naval Weapons] and Air Force find these services generally prefer thin-film and semiconductor micro-circuitry.[30]

Fiscal 1963 proved to be the final funding for the five-year program. The program's conception in 1957 was a valid technological frontier then, but by 1963, and perhaps considerably earlier, other techniques were shown to be more valuable for military-aerospace applications. In effect, NASA and the other two services, by their backing of these other techniques, had left the Army alone in its support of the Micromodule concept. Also, the industry's general enthusiasm for the integrated circuit concept combined with its lack of interest in the Micromodule approach ultimately left the Army in an untenable position.

The Miniaturization Movement

Although the three programs just described were major attempts to reduce the size of electronic components and subsequent equipments, they represent only part of the "miniaturization movement." The efforts in thin films and integrated circuits were not primarily aimed at small size for its own sake, but they did accomplish this end when they satisfied their primary objectives, e.g., reliability, lower costs.

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[30]"Army to Push Micromodules," Aviation Week, August 27, 1962, p. 70.

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In April of 1957, the Institute of Radio Engineers held its first session devoted exclusively to microminiaturization. It was noted that the avionic demands of guided missiles, space vehicles, and high-speed aircraft were making new and revolutionary demands upon the electronic art. The changes needed would bring about radical departures in the traditional lines of demarcation between the component makers and users, it was said. Solid-state circuitry was foreseen as the modus operandi in which whole circuits could be placed in packages currently housing only single transistors. (At the time this was written--1957--these words were remarkably accurate in their foresight and prescience.)

Even before NASA had been formed and the country engrossed in a space effort, miniaturization efforts were to play a major role:

> With micro-miniaturization, the basic techniques and equipment are in hand to permit the first look at the moon's other side through scientific instruments mounted in a space ship far smaller, simpler, and cheaper than required to accommodate a human crew. . . .[31]

Moore believed that for missile applications, micro-miniaturization:

> . . . can have dramatic effects upon the missile's size, weight, hence its combat range, accuracy, and vulnerability and warhead effectiveness. . . .[32]

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[31]John R. Moore, General Manager of North American Autonetics, during conference of Institute of Radio Engineers in New York, N. Y. and cited by Philip Klass, "Solid-State Research Brews Upheaval," Aviation Week, April 8, 1957, p. 86.

[32]Ibid.

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In conclusion, the following was said:

> It would be a mistake to look upon microminiaturization only as size reduction. . . . The new components for future systems must meet new requirements on performance and environment. Foremost among these is the requirement for fantastic orders of reliability.[33]

Some of the trade periodicals were already commenting upon this new approach to electronics:

> Key words in electronic equipment design are miniaturization and ruggedness. Impetus for miniaturization comes, of course, from the military especially in design of aircraft and missile guidance equipment. But it means good business throughout our industry.[34]

By the spring of 1959, Business Week reported that virtually every company with a stake in electronics was doing some work in the subminiature field.[35] The prime emphasis was devoted to military electronics, but some of the more advanced computer machines were progressing in that direction. In several consumer applications, it added, electronic component miniaturization was not called for, since there were other elements making up the bulk of the size and weight. Texas Instruments was already predicting reduction in size through use of its new integrated circuit components on a scale similar to that experienced when the transistor replaced the tube in many applications.

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[33]Henry A. Stone, Jr., Bell Telephone Laboratories, as quoted in Philip Klass, "Solid-State Research Brews Upheaval," Aviation Week, April 8, 1957, p. 93.

[34]"Industry Outlook," Electronics, April 10, 1957, p. 93.

[35]"New Products," Business Week, April 4, 1959, p. 130.

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At this early stage, there was still a void between the theoretical and the obtainable. Some scientists and engineers working on advanced NASA work concurred in the belief that miniaturization techniques were desirable, but it was still difficult to obtain really reliable components also having the requisite small size.[36] (Needless to say, NASA requirements for small size represent the extreme.) There was still a good deal of knowledge, such as in materials research, that had yet to be learned.

In August of 1962, Fortune published an article entitled "Electronics Goes Microminiature."[37] In it, a report by P. R. Mallory & Co., was cited in which the firm had polled 250 individual scientists, engineers, and market specialists as well as ninety-eight potential users. The results of this survey indicated a potential market by 1980 of about $20 billion per year for thin-film and other microminiaturized components.

The expected benefits from microminiaturization were to be more than just those occurring in military equipments. Participants generally felt that increased industry emphasis on microminiaturization and higher reliability would result in economic advantages that would make American electronic products more competitive in export markets.

The major contributions of the various efforts to

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[36]"Miniaturization Brings Headaches and Benefits," Electronic News, October 19, 1959, p. 14.

[37]George A. W. Boehm, "Electronics Goes Microminiature," Fortune, LXVI, No. 2 (August, 1962), pp. 99-102, 176-182.

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achieve miniaturized electronic components lie in their placing a certain constraint on any attempts by the electronics industry to improve its components. Regardless of what other attributes a new development might have, if it resulted in no size reduction, it might be tolerated; if it required increased size, it would most probably not be acceptable. All the microelectronic techniques in vogue today and in the past decade have had smaller size as a secondary objective. Therefore, reduced size placed a constraint on the scientific thinking devoted to the development of new electronic components.

Reliability

Reliability, to the lay public, is usually a qualitative term. Especially for military operations, it is given very specific numerical values when electronic equipment is purchased. If an equipment is 100 per cent reliable, it will theoretically never fail when operated under given conditions. Equipment that is 75 per cent reliable, for instance, implies that of an infinite number of "identical" equipments operating under similar, allowable conditions, 75 per cent will operate satisfactorily for a specified number of hours, and 25 per cent will not. Similar to this latter concept is the idea of mean-time-between-failure (MTBF). An equipment with an MTBF of 1,000 hours will fail, on average, every 1,000 hours. (MTBF also incorporates the idea of an infinite number of similar items, all operated under identical conditions.) Both percentage and MTBF reliabilities are referred to in this chapter.

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Improved reliability can always be interpreted to mean longer, trouble-free lifetime for the equipment in question.

The reliability of their equipment, electronic and otherwise, has always been a prime concern for the military. In a war effort, the implications are obvious and will not be pursued at great length here. In critical applications where the reliability of the electronic equipment was not commensurate with the need, the best alternative was simply to double- and triple-up, e.g., if a particular target must be completely demolished, or if a given number of missiles had to land in a particular target area, the chances of success were raised by increasing the number of attacking planes or missiles launched, respectively. In wartime, the mission often justified such inefficiency; during peacetime, when other projects are competing for limited resources, the strain of such a strategy was obvious. On both counts, it was advisable to raise the reliability of the electronic equipment to be used.

Besides the more obvious problem of diminished striking power due to poor reliability, there is a second important corollary. Equipment, such as that in planes, has to be ready when called upon, but it will also, generally, be used many times over. As differentiated from a missile, which must be ready when called upon and then is not used again, the equipment serves many basically repetitive missions requiring continued maintenance. Such care entails time, equipment,

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and manpower--all translateable into costs.

Therefore, the outcome of poor reliability may be viewed on two fronts: the first in terms of the immediate mission, and the second with respect to the implications of sustained use. Both are of concern. The former consideration will be called Primary reliability factors and the latter Secondary reliability factors (Maintainability).

Primary reliability factors

In the late forties, all electronic equipment was designed about the vacuum tube. This component was not to experience the encroachment of the transistor until the mid-fifties. The tube was probably the least reliable element in electronic equipment, and it is logical that the initial efforts to improve the reliability of electronic systems centered its main attention upon this culprit.

In 1951, the Panel on Electron Tubes (PET), which later became part of the Advisory Group on Electron Devices (AGED), contracted with ARINC Research Corporation to investigate the tube reliability problem. This panel was a tri-service group, and the funding for the work came from the three services. The effort was actually administered through the Bureau of Ships (BuShips). This work, initiated during a period when the B-36 was having reliability problems in this area, lasted for about six years and was funded at about an average of $300,000 per year. ARINC Research had already been working on a similar problem for the private airlines relative

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to the latter's own electronic equipment. At about the same time, the Army funded Cornell University for a similar objective. Ultimately, the ARINC Research and Cornell efforts were brought together in a coordinated program.

The results of this work led to basically two conclusions: tubes can be made and tested better, and circuit design can be upgraded by teaching engineers how to use the good tubes properly to make them last longer. Special tests were recommended to guarantee minimum performance. Even before this program began, the Air Force, about 1948, had introduced a special line of vacuum tubes called the 6000 series; these tubes were subjected to a more severe test schedule.

The ARINC Research work, as mentioned earlier, extended over several years. This period through the mid-fifties marked the era when the transistor began to be produced in mass quantities and incorporated into the more advanced military electronic designs. Its attributes of smaller size and weight were readily obvious as was its lower power consumption. It was not nearly as apparent that its reliability was far superior. Theoretically, there was no inherent wear-out mechanism similar to that prevailing in all vacuum tubes. The latter would burn out--sometime. Since the basis of the vacuum tube is the control of the electron flow emanating from a heated filament, that filament must have a finite lifetime even if the manufacturing processes were "perfect." A group of tubes, supposedly identical when coming off the same

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production line, would follow a Gaussian (normal bell-shaped) failure distribution if subjected to the same life test conditions.

Even with the advent of transistors into military equipment, the vacuum tube was still to play a major role in the inventory problems associated with equipment already in the field. In 1958, the Air Force told electron tube manufacturers it was willing to pay up to twice the price for certain kinds of tubes in order to improve the reliability.[38]

In 1960, this policy was apparently bearing fruit. It was reported that certain tubes, previously costing the Air Force $2, were being bought for $4 under tighter procurement specifications. The lifetime of one particular tube improved sixteen times although five to ten times was more typical.[39]

The great reliability promise of the transistor lay in the absence of any known failure mechanism within a reasonably practical amount of time. If the theory augured such relative perfection, the manufacturing technology, at the beginning, did not permit the realization of this limit (which is true at the outset in the production of probably any technical component). It would take considerable funds even to prove what the failure rates were, if they really were far superior to their tube counterparts. Under any circumstances, it was

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[38]James O'Connor, "AF Ready to Pay More to Spur Tube Quality," Electronic News, September 15, 1958, p. 1.

[39]James O'Connor, "Navy, AF Requirements for Reliability Pay Off," Electronic News, November 7, 1960, p. 1.

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still to be many years before equipments and systems using the new transistor components would enter the military inventory.

Regardless of which electronic component was at fault, the subject of reliability, and electronic reliability in particular, gained increasing attention through the late fifties and early sixties.

Aircraft

As early as 1955, avionic manufacturers--those who design, produce, and sell the electronic equipment used in the plane--were warned by the military that the reliability of electronic equipment must be improved:

> The equipment manufacturer must take the lead in this effort [developing an advanced technology of reliability], not the Air Force. The equipment manufacturer must prepare the specifications, advise, and offer constructive criticism based on past experience.[40]

General Gerrity chided the industry that it was time to "get away from the radio and TV type of component" since the associated criteria for design and manufacture in those areas simply could not apply for modern weapon systems. He noted that studies of reliability of aircraft missions indicate that the latter are dependent upon the reliability and number of individual components.

The urgency for equipment that was reliable, simple, relatively maintenance-free, with adequate performance

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[40]Major Gen. Thomas P. Gerrity, as quoted in "USAF Warns Industry to Improve Avionics," Aviation Week, August 29, 1955, p. 13.

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characteristics was highlighted:

> We need to recognize that (a company's) reputation for good design is an important characteristic for a contract award, and proof that the design is good is a necessary condition for large scale production.[41]

The Air Force had perhaps been the military agency that had most greatly accentuated the need for higher reliability in its electronic equipments:

> We are pinning our hopes on military supremacy to a large extent on electronic equipment.[42]

Action was soon to be taken in this area. The Department of Defense issued a directive ordering that systems be tested before being put into mass production. This move can be attributed directly to the military's concern relative to the poor reliability in the electronic equipment being received from industry.

Years later, when the F-111 (TFX) contracts were negotiated, stringent reliability and maintainability clauses were inserted.

Missiles

If the reliability argument held for aircraft, then it was even more appropriate for missiles:

> I would like to emphasize . . . that the requirements for electrical power supplies and electrical equipment are more stringent for missiles than for inhabited aircraft. They are more stringent in terms of overall

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[41] Dudley C. Sharp, as quoted in "Avionics Unreliability Security Hazard," Aviation Week, March 26, 1956, p. 32.

[42] Ibid.

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> reliability and quality control and more severe in terms of the environment.[43]

It was emphasized that the loss of a million dollar missile might be due to the failure of the named--and relatively inexpensive--components.

This concern, early in 1957, was put into sharp focus by a high Air Force official:

> When the American people invest many millions of dollars in a single vehicle or missile, we must be absolutely certain that it will perform, without fail, the mission for which it has been designed.
>
> We cannot afford to have a multi-million dollar missile fail because of a faulty 50¢ part obtained on a low-bid contract. . . . Aside from costs, these things must not fail or go astray if they are carrying atomic warheads. They must go to the target and only to the target. Failures cannot be tolerated at the prices these vehicles and missiles cost and the havoc they can cause.[44]

Exactly this same theme--small, relatively inexpensive parts causing very costly failures--was reiterated some five years later when General Bernard Schriever, head of Air Force Systems Command (AFSC), traced a number of American missile failures to small, faulty "nickel and dime" components. He urged a heavy emphasis on reliability, coupled with a willingness to strike out in new directions and incur the risks involved.[45]

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[43]Brig. Gen. Leighton I. Davis, as quoted in "Holloman Commander Cites Need for Better Missile Components," Aviation Week, November 7, 1955, p. 55.

[44]Brig. Gen. Joseph D. Caldara, as quoted in "USAF Reliability Emphasis Grows," Aviation Week, April 1, 1957, p. 28.

[45]Walter Johnson, "Schriever Hits 'Nickel & Dime' Parts Failures," Electronic News, February 26, 1962, p. 18.

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This general concern was succinctly stated:

> Reliability is the key to successful missilery. . . . Without it we have nothing.[46]

By 1959, an intensive reliability improvement program for avionics equipment was launched by North American's Autonetics division for the Minuteman ballistic missile, WS-133A. The objective was to increase the then available reliability levels by a factor of 100. This missile, that has such an overriding need for super-reliability, remains in underground silos for long periods of time and, if and when called upon to strike, has to be immediately available.

In 1961, an Air Force official stated that the military would like to see an increase of ten or more in the reliability of the electronic equipment used in its space work.[47]

The feasibility of a DOD-sponsored electronic reliability improvement program for space needs was suggested in 1962. The objective of this project would be the development of electronic components, design techniques, and test methods optimized for the particular needs of space applications. The most serious problem to be faced, it was added, was the achievement of adequate operating lifetime of spaceborne electronic devices as well as obtaining the required electronic, scientific, and engineering resources needed to carry out these

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[46] W. H. Holaday, Director of Guided Missiles, as quoted in "Reliability Seen Key to Space," Electronics, July 4, 1958, p. 8.

[47] "Air Force Urges More Space Reliability," Electronics, February 3, 1961, p. 34.

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programs.[48]

Even by 1964, the need was still in evidence:

> With the advent of space systems, we have established a need for a new order of ingenuity in our thinking about reliability and a vast improvement in our practice of it. . . . The fact is that the progress we have made to date in system reliability, though notable in many instances, has simply not been adequate in an overall sense. To cite some examples--a failure of a $2 item in the launch of a space system caused the loss of a $2.2 million vehicle. In another space program, the failure of a $5 thermal shield that was poorly designed and inadequately tested resulted in a $23 million disaster. A failure of a $25 fuel valve in a ballistic missile brought about both loss of the bird and major damage to the launch site for a total bill of $22 million. This sort of experience is not solely related to unmanned systems. The approximately $50 million loss I have mentioned in these few examples would have bought a lot of additional reliability measures in each of these programs. . . . We are placing an increasing emphasis on parts. Since over 90% of our present systems unreliability is due to component parts failure, we have established an AFSC parts management program to assure the growth and use of a family of known reliable parts. . . .[49]

Shipborne equipment

The Navy, though not to the degree of the Air Force and NASA, has also advocated improved reliability for its shipborne electronic equipment.

If the importance of increased reliability in electronic components was sometimes elevated to lofty planes, it also had an impact in more mundane outlets. Some junior grade

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[48]Walter Johnson, "DD Considers Space Reliability Program," Electronic News, May 28, 1962, p. 1.

[49]Lt. Gen. H. M. Estes, Deputy Commander, Air Force Systems Command, as quoted in editorial "New Reliability Goals," Aviation Week, January 13, 1964, p. 21.

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Naval officers responsible for the operation of certain electronic equipments commented on the reliability and quality of components in these equipments accordingly:

Boy, if I could only talk. . . .[50]

The Navy asked industry to reduce complexity and cost of electronic equipment while increasing reliability. A major effort to improve reliability and maintenance was called for. One aggravating problem from the Navy's viewpoint--but this seems to be a common dilemma for all the services--was the loss of experienced personnel to maintain the electronic equipment.[51]

Space

The needs of space travel put a high premium on reliability. Coupled with the requirement for microminiaturization, electronic equipment would have to satisfy these two needs and simultaneously utilize a minimum amount of power. The reliability of the computer was especially critical and unless "giant strides" were accomplished many spares would have to be carried, and the computer would have to be accessible to the crew in flight to permit repair and servicing; both these occurrences would be unattractive.

For unmanned deep space probes, the problems are even

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[50]"NATO Tests Gear on Sea Maneuver," Electronic News, September 23, 1957, p. 1.

[51]Joe Radoff, "Reduce Complexity, Cost; Raise Reliability: Navy," Electronic News, September 17, 1962, p. 19.

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more demanding, since there is no chance for repair by humans. In 1960, the efforts to get better reliability, reduce payload component weights, and learn about space environment had not been adequate.[52]

> The industry talks about random failure rates of components. But in deep space probes of a year or more, there can be no random failures. We must not be content until we know why any component failed at all--and correct the fault.[53]

This same theme relating to the nation's space effort was later echoed by a high NASA official, when he said that the electronics industry must cope with systems reliability for deep space flights; more compact and flexible systems with less complexity and more reliable components are called for.[54]

Following the example set by the Air Force for its Minuteman program, NASA began to consider a component high-reliability program for its own purposes. The manned space program, in particular, would need strict reliability specifications for components destined for the Gemini and Apollo space vehicles.

The following excerpts abstracted from the editorial of a major trade journal of considerable influence pinpoint the concern:

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[52]Jack Robertson, "Parts Reliability Held Block to Solar Probe," Electronic News, April 18, 1960, p. 15.

[53]J. R. Burnett, as quoted in Jack Robertson, "Parts Reliability Held Block to Solar Probe," Electronic News, April 18, 1960, p. 15.

[54]D. H. Marion-Davis, "Swireco Puts Stress on Space Reliability," Electronic News, April 16, 1962, p. 1.

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> The problem of achieving 100% reliability in space exploration vehicles is tough enough, but the problem becomes even more acute when the space age moves--as it will shortly--into operational satellite systems for weather reporting, navigation, reconnaissance and communications. For in these systems a single minor component failure in a single satellite could disrupt the functioning of the entire system for the interval it would take to fire a replacement vehicle into the proper orbit. This would prove to be an extremely expensive process if the failure rate reached as high as the statistical rate now generally acceptable in high quality control industries. Because of the stringent weight limitations that space vehicles will have to live with in the foreseeable future, it will be impossible to add sufficient duplication of systems to achieve the standard of perfection required for long periods in the cruel environment of space. . . .
>
> When manned space systems are considered, the 100% reliability requirement becomes even more stringent. NASA and its individual contractors on the Mercury, Gemini, and Apollo programs face reliability requirements far greater than anything yet achieved in earth-bound engineering systems, and they must be achieved in this bitterly hostile environment of space. Not only will new concepts be required, but so will new equipment and operating techniques in developing these incredibly high standards of quality control and reliability. Such a philosophy will also play an important role in basic design of space hardware. Inevitably it will produce a fallout into the entire industrial cost.
>
> These new requirements of quality assurance and reliability are a hurdle that must be cleared if NASA's ambitious national space program is to reach its immediate goals. They also present a tremendous challenge to the management and technical direction of every firm in the aerospace business, and will be a major measure of their future success.[55]

In an interview in late 1963, the executive secretary of the National Aeronautics and Space Council stressed the needs and the lackings:

> Q: I understand you said recently that this country does not have an electronic capability to meet our space

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[55]Robert Hotz, editorial, "Reliability in Space," Aviation Week, June 11, 1962, p. 21.

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effort. Is this true?

A: (Welsh): I would probably not state it as strongly as that, but it is a fact that technological needs brought about so rapidly by our space program have resulted in an inadequacy in what was at one time an adequate electronic capability. Before our space program the industry may have been quite adequate but rapid developments have placed such strain and so many requirements on people and facilities that there is a great lag in electronics in our space effort.

Q. Are you speaking for the space program in general, or is there specific electronic equipment or a system where we have this lack of capability?

A: The whole program. Every phase has electronic equipment which must be reliable and function perfectly. The space program is far ahead of industry in its demand for sophisticated electronics.

Q: Would you say that reliability is the problem?

A: Reliability is definitely a key problem; we can't allow for breakdowns. Yet, reliability is a field in itself. High volume and low cost production in our country have been based on a certain margin for error--something less than perfection--an allowance for repair and maintenance. We just aren't geared for the demands of the space program which requires an entirely different attitude--that only the best is acceptable. Approximate measurements and approximate tolerances will not do in the space age. Selections of firms for space work, based on reputation for quality of output and manpower rather than on sales record and size of facilities will increase.[56]

If these liabilities were qualitative in nature, NASA suggested figures which showed that electronic failures were indeed very costly to the space program. NASA estimated that 40 per cent of its booster costs, 70 per cent of its major spacecraft dollars, and 90 per cent of its tracking data and acquisition funds go into electronics:

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[56]Interview with Dr. Edward C. Welsh, Executive Secretary of National Aeronautics and Space Council, as reported by Elmer T. Ebersol, "U.S. Needs Electronic Capability forSpace," Electronic Industries, XXII, No. 9 (September, 1963), pp. 28, 162.

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> A vast majority of our flight failures, not to mention flight delays, arise from electronic failures. . . .
>
> In the rapidly evolving technology of solid-state physics and electronics, we must take care that we are not hindered by self-imposed limitations of old circuit theory and wiring diagrams. . . .[57]

Secondary reliability factors

If reliability affects mission success in the short run, it also influences the cost of maintaining and operating a system over a sustained period of time.

It was cited that approximately 17 per cent of the Air Force budget, or roughly $3 billion (in 1956) went for avionic equipment, its maintenance, and the salaries of military and civilian personnel involved in its procurement, use, and maintenance. In earlier years, the figure had been 10 per cent:[58]

> Electronic products have to be more efficient, more reliable and far simpler from the maintenance point of view than anything yet offered. And they have to come faster than in the past.[59]

General Irvine later suggested that firms which can produce reliable, reasonably-priced components should get a fair share of the $7 billion annual Air Force outlay for hardware.[60]

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[57]James E. Webb, NASA Director, as quoted in C. Wendel, "Blame Electronics for Space Failures," Electronic News, May 25, 1964, p. 1.

[58]Dudley C. Sharp, as quoted in "Avionics Unreliability Security Hazard," Aviation Week, March 26, 1956, p. 32.

[59]Lt. Gen. C. S. Irvine, as quoted in "Better Equipment Wanted," Electronics, July 20, 1957, p. 27.

[60]"Electronics Newsletter," Electronics, May 9, 1958, p. 7.

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It was estimated that the cost to the military for work performed by civilian firms in fiscal 1957 for electronic maintenance was more than $300 million, and expected to increase.[61]

If the importance of improved reliability was an accepted fact, it was also obvious that its attainment would be costly. Industry was rightfully concerned in its concurrence of the prime need:

> Many voices have been raised about the cost of unreliability in terms of maintenance dollars and manpower. There is no question but that greater reliability in equipment will save considerable money in the long run. The question now before many of us is how to finance the present higher costs of obtaining greater reliability in the face of the ever-present problem of economic austerity. We must find better and cheaper ways to do the better job.[62]

This concern would be especially critical if the industry were to face a shrinking military and civilian market for its products.

A high DOD official addressed himself to this problem in mid-1958, stating that the Defense agency must be specific in its demands and willing to pay for the maintainability that "genuinely enhances readiness of our weapons and reduces our recurring cost."[63] The greater one-time initial cost is worth

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[61]"Military Repair Bills Double," Electronics, February 10, 1957, p. 5.

[62]F. L. Ankenbrandt, Manager, defense projects, RCA, as quoted by Walter Johnson, "Improved Reliability in Face of Cost Hikes Keys Parley," Electronic News, January 13, 1958, p. 1.

[63]E. J. Engoron, Director of Maintenance, Department of Defense, as quoted in Stuart Gellman, "Maintainability Gains Held Vital to Defense," Electronic News, June 2, 1958, p. 1.

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paying to incur the lower upkeep cost. Enhanced maintainability is an asset when achieved and a liability when lacking, it was noted.

Such an awareness was questioned even within the military establishment. Although the need for increased reliability and maintainability were patent--"otherwise we'll end up with a number of electronic 'white elephants' that cannot be kept on the air"[64]--some questioned whether the military were willing to pay the cost in terms of time and money for reliable equipment.

If the higher initial costs for better electronic equipment could be more than defrayed by reduced maintenance costs then, presumably, there should be a willingness to pay for this quality. The Air Force, one of its officials asserted, paid about $2 a year in maintenance costs for every $1 worth of airborne electronic equipment.[65] Therefore, the maintenance costs of electronic equipment and its associated unreliability costs were two of the most challenging management problems confronting both the military and industrial establishments.

This amount seemed small compared to the yearly $2 billion estimated cost of maintenance for Air Force electronic equipment that another official reckoned the cost to

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[64]Oliver G. Tallman, as quoted in "Payment for Reliability Held Vital for Services," Electronic News, November 17, 1958, p. 14.

[65]George M. Frake, "Cost of Maintenance, Unreliability Cited," Electronic News, June 13, 1960, p. 4.

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be.[66] By increasing first costs by some small percentage, it was argued, greater reliability and ultimate lower maintenance costs would be forthcoming.

The Semiconductor Industry

> Until 1948, electronics was synonymous with the vacuum tube, which in the course of a generation had shrunk from an object as large as (and sometimes as luminous as) an electric light bulb to a cylinder not much bigger than a man's thumb. Then three scientists at the Bell Telephone Laboratories invented the transistor and we moved from the Paleoelectronic into the Neoelectronic age.[67]

The transistor came into being in 1948. With it came the beginnings of the new electronic age. The industry spawned from the creation of the vacuum tube had remained an infant relative to other U. S. industries. This was to change, and the transistor was the means of its metamorphosis.

In a somewhat less sensational manner, the semiconductor diode and rectifier market grew apace. It is the combination of these semiconductor components--transistors, diodes, and rectifiers--that will be generally referred to as the semiconductor industry, although there are some other types of components, relatively small in consequence, which must also be included.

The graphs of Figure 2 indicate the industry's growth

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[66] Tom Slattery, "Equipment Unreliability Seen Boosting AF Costs," Electronic News, January 23, 1961, p. 45.

[67] Arthur C. Clarke, scientist, "Spark of the Second Industrial Revolution," The New York Times Magazine, December 9, 1962, p. 32.

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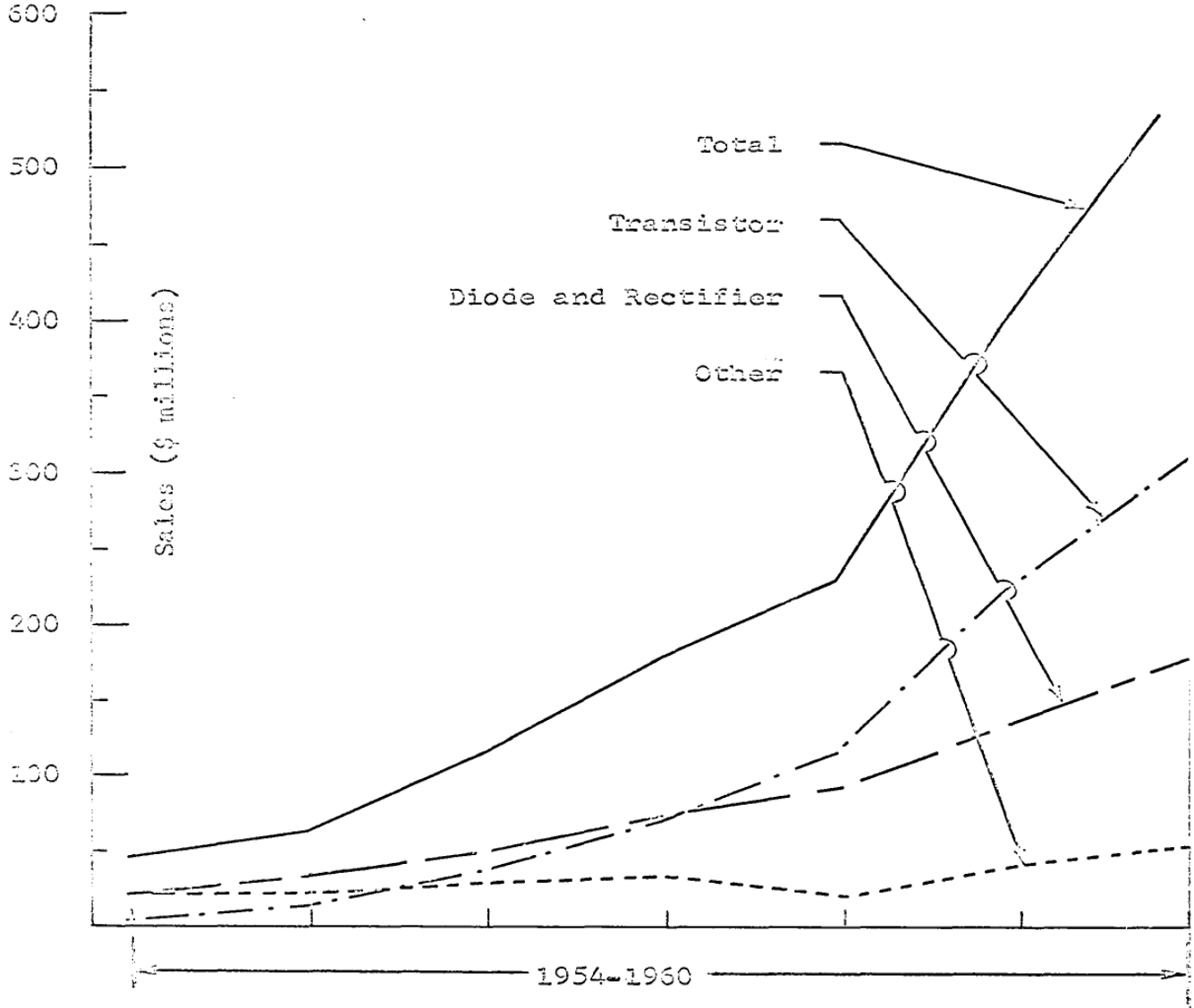


Fig. 2.--Semiconductor Industry Growth

Source: Electronic Industries Association

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rate since 1954, the earliest date from which figures have been compiled by Electronic Industries Association (EIA). In the seven-year period from 1954 to 1960 inclusive, the interval of greatest interest in this paper, the compounded yearly growth rate of the transistor business was nearly 100 per cent, i.e., each year, on average, the total revenue from transistor sales nearly doubled. For the industry in toto, the rate was nearly 50 per cent. In 1954, transistors brought in 1/8 the amount derived from the diode and rectifier sales; in 1960, that ratio changed in favor of the transistor by about 1.3:1. It is obvious that the climb of the industry was made on the back of the transistor.

In mid-1952, a transistor sellers' market prevailed:

> Transistors can be obtained in small numbers from several companies without too much delay. It is suggested that orders be placed for only those transistors which can actually be placed to good use.[68]

By 1954, transistors were making inroads. In late 1953, the best transistor cost about $8 each, considerably higher than most of its vacuum tube counterparts. In February, 1955, Business Week noted there were already nineteen manufacturers fabricating the new product.[69] Applications had greatly increased and the hearing-aid market--the first one for transistors--was only one of many areas where the component

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[68]Lt. Col. W. F. Starr, "Availability of Transistors," Proceedings of Symposium--Progress in Quality Electronic Components (Washington, D.C., May 5-7, 1952), p. 150.

[69]"Transistors: Growing Up Fast," Business Week, February 5, 1955, p. 86.

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was being contemplated for use. The mass consumer and industrial customers were being approached by transistor salesmen who could talk orders and delivery dates. Improved assembly techniques helped to cut the initially high prices, and the transistor's advantages relative to the vacuum tube--smaller, more reliable, less power-consuming--were aggressively touted by its proponents. Component manufacturers, ebullient with the rosy outlook, planned expansions.

The new markets began to grow. Besides the aforementioned hearing aid, the military planned to incorporate the transistor into some of the more obvious initial applications. The Army rushed it into production models of walkie-talkies. Manufacturers of avionic equipment were replacing 22 per cent of the vacuum tubes in equipment under development; the expectation was that within a year the penetration would jump to 38 per cent, and by 1957 it would be 50 per cent.[70]

In early 1956, Philco was already making plans for building the largest plant in the world for the manufacture of transistors; floor space was to be 100,000 square feet. The first electronic computer utilizing transistors--the IBM 608--was scheduled for 1956 delivery. The unit would use 3,000 transistors with an estimated volume reduction of 50 per cent and a 90 per cent decrease in power consumption.

By 1957, the press literature painted a dichotomous

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[70]"They Save Space, Weight, Heat," Business Week, September 17, 1955, p. 108.

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picture. The markets continued to multiply, but competitive strains were already being noted. Manufacturers planned conservative production increases of three times and, if each was very optimistic, it might go as high as a fivefold increase. The same men were more cautious relative to the industry in the aggregate. The total industry output of nearly thirteen million units in 1956 was expected to double, on the average, in 1957. Production would increase, but competition would be keen:

> It's a case of really fast industry expansion, and every one of the 35 or 40 companies in it is looking for a bigger slice of the market.[71]

Price attrition began to take effect. Figure 3 shows the average transistor prices for 1955-1959 in which the shipments are divided into two markets, military and non-military (there was no space market at that time). The average prices, however, may hide important salient features. Some mass-produced units used in portable radios fell in price by as much as 50 per cent during 1956. Although vacuum tubes were still cheaper, the transistor manufacturers looked to the huge home and car radio markets that beckoned if prices could be lowered. Two major firms had even predicted a 1965 market of 500 million units at an average price of less than 50¢.[72]

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[71]Alan M. Glover, General Manager, RCA semiconductor division, as quoted in "Grooming Transistors to Crack the Big Volume Markets," Business Week, February 2, 1957, p. 66.

[72]"Transistors Grow More Competitive as Prices Keep on Shrinking," Business Week, January 19, 1957, p. 38.

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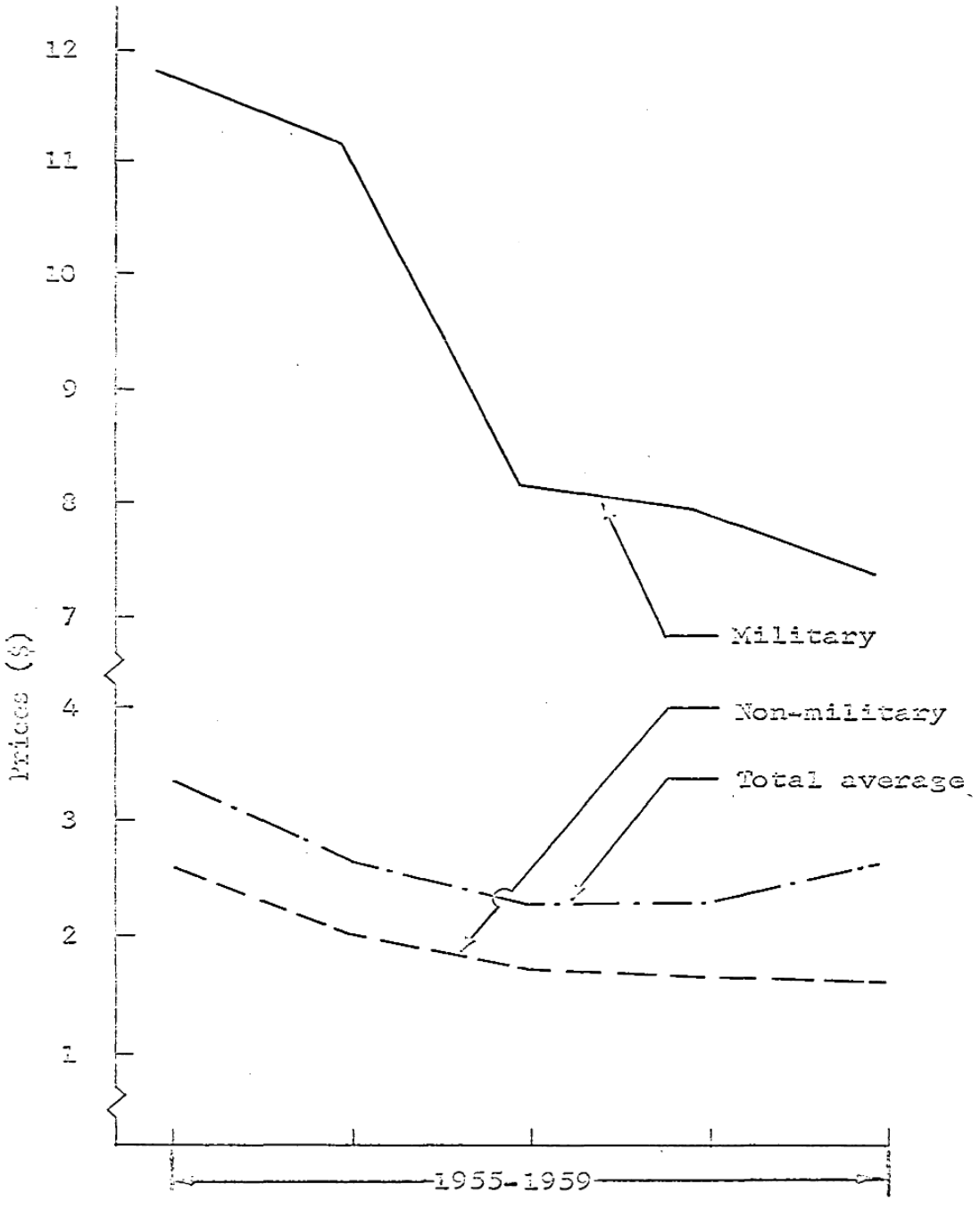


Fig. 3.--Average Transistor Prices

Source: Department of Commerce, Semiconductors

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There were questions even at this early stage whether the industry was profitable. One trade magazine doubted whether anyone was making a really high rate of return on its transistor manufacture (there was no criterion in this comment as to what "really high" was). It cited the cost breakdown of one producer as 35 per cent - labor, 25 per cent - materials, 20 per cent - engineering, and 20 per cent - overhead and profit. Another manufacturer had a breakdown as follows: direct labor - 17 per cent, materials - 26 per cent, factory burden - 6 per cent, administration and sales - 17 per cent, interest and amortization - 10 per cent, and profit - 24 per cent.[73]

Fortune magazine, reviewing the scene in mid-1957, made the following comments:

> A competitive shakeout is already underway in the semiconductor business. Such a shakeout is inevitable because semiconductor products are becoming standardized. Unlike the early days, when 70 to 80% of the semiconductors produced were rejects that couldn't be sold, most units today are as alike as peas in pods. . . . Ingenious machines are now being designed to mass produce transistors too.[74]

In late 1957, drastic price reductions were announced by some firms. Texas Instruments lowered prices on its silicon transistors up to 22 per cent and up to 35 per cent on silicon glass diodes; this was the second significant price

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[73]"Transistor Sales Potentials," Electronics, January 10, 1957, p. 16B.

[74]William B. Harris, "The Battle of the Components," Fortune, LV, No. 5 (May, 1957), p. 290.

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break on silicon transistors that the firm had made during 1957. Texas Instruments had a particularly strong hold in this market. Philco, with the aid of automatic production facilities for its transistor line, reduced prices up to 60 per cent on its silicon transistors.

The spectre of growing competition and new entrants gained substance:

> Copiers become marginal producers. They cause the degrading, and they typically lack the ability to shift from defensive to offensive.[75]

The euphoria, accompanied by lingering shadows of price slashing, was still very much in evidence in early 1959. West coast firms were busy "beefing up" their facilities in expectation of a larger share of the market. Mechanization was introduced and marketing staffs were expanded. There was an expectation that price declines would continue, and the transistor might become cost competitive with the vacuum tube.[76]

Even if the industry began to encounter pricing problems, the market was still very ripe for expansion:

> Electronics in general has seen a tenfold increase since WW II and another tenfold increase can be expected by 1970. This is the fantastic area of development where even the familiar vacuum tube circuits are being microminiaturized to 1/10, 1/100, and even 1/1000 of the original size and volume. This will mean a

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[75]Warren B. Hayes, operations manager, Pacific Semiconductor, Inc., "R&D Held Key to Life in Semiconduct Field," Electronic News, June 9, 1958, p. 13.

[76]"West Coast Makers Set Transistor Push," Electronic News, February 2, 1959, p. 12.

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> tremendous savings in bulk, weight, and power requirements for across-the-board application to all types of Army equipment.[77]

Towards late 1959, a new problem received increasing attention. Concern with foreign competitors, mainly Japan, began to chafe an industry that had domestic problems of its own.

The potential competition from foreign vendors for sales of an American-conceived product was noted as early as 1957. At that time, Fairchild News Service made a survey of European transistor manufacturers, present and potential; its results probably brought mixed reaction to the American producers.[78] The excellence of the transistor product and the capability to produce them in large quantities lagged far behind the U. S. In England, this lag was expected to lessen, and the British transistor industry saw 1957 as its most profitable year. Italy had two manufacturers of the product, and they expected that market to become bigger. Both countries and France invested in R&D programs. As late as 1961, one major French firm was reported to have invested $40 million for research in this area.[79]

It was Japan, however, that really caused the

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[77]Lt. Gen. A. G. Trudeau, Army Chief of R&D, as quoted by A. D. Cook, "Letter from the Editor," Electronic News, December 28, 1959, p. 2.

[78]"Big Transistor Strides in Europe," Electronic News, October 9, 1957, p. 12.

[79]A. D. Galloway, "Transistor Firms in France Invest Heavily in Research," Electronic News, March 22, 1961, p. 49.

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consternation (see Figure 4). In September, 1959, EIA requested the Office of Civil and Defense Mobilization to investigate the growing penetration of Japanese semiconductor products--transistors included--into U. S. markets on the grounds that our national security was imperiled. The relatively low production costs, due mainly to lower wage costs, coupled with extremely low marketing and transportation costs allowed the Japanese to sell in this country at prices with which the domestic producers could not compete. The 15 per cent import duty imposed upon these imports did little to ameliorate the problem.[80]

The Japanese transistor imports, up until that time, had been mainly of a low-quality variety, such as might be used in radios. There was a fear that these components could begin to penetrate the high-quality applications, which presumably were the areas in which profit margins were greater. One hedge used by American firms to minimize the deleterious effects of such an occurrence was investment into Japanese-based firms or the establishment of their own plants there. Both moves would allow them to capitalize on the lower Japanese labor rates. The Japanese firms, in turn, attempted to upgrade their semiconductor products and increase the manufacturing capability of their own plants.

At home, the domestic transistor producers urged the

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[80]Walter Johnson, "Japanese Transistor Import Probe Sought," Electronic News, September 21, 1959, p. 10.

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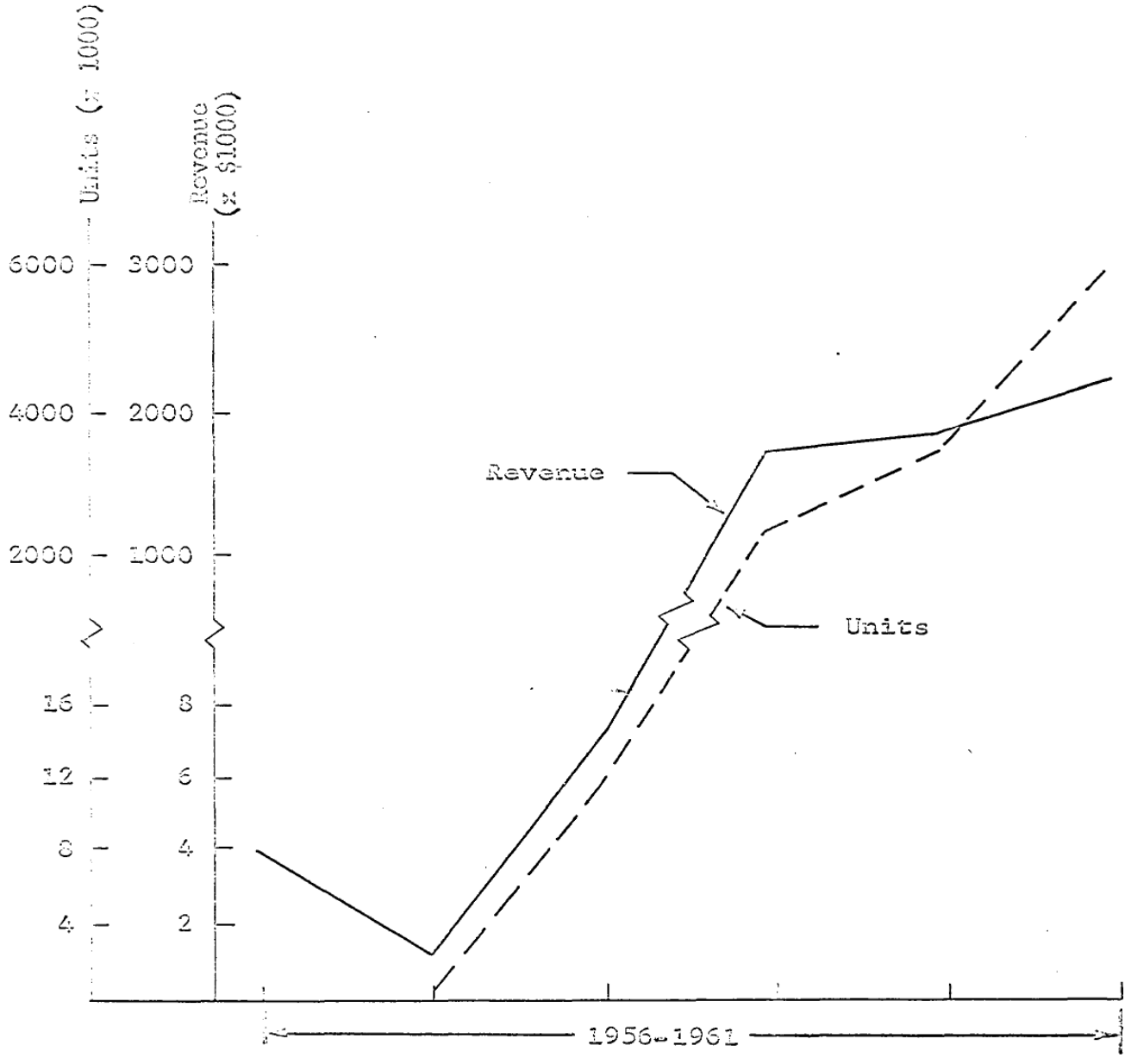


Fig. 4.--Japanese Transistor Imports

Source: Department of Commerce, Patterns and Problems of Technical Innovation in American Industry

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radio manufacturers "not to panic."[81] The transistor industry felt it would soon be able to compete with the Japanese even on a cost basis; this would occur when the console radio and television market materialized, and the high volume would drive down the unit costs (presumably resulting in lower prices).

The consumer electronic equipment makers were probably more sensitive to costs in hand. A limited survey showed that these manufacturers would use any component, regardless of its origin, if it would help to cut down on production costs.[82]

In the summer of 1962, the Office of Emergency Planning ruled that the semiconductor industry, though:

> . . . essential to the national security . . . is not threatened at the present time, or in the immediate future, by imports from Japanese sources.[83]

Continuing reports through 1963 indicated a rising production capability for the Japanese semiconductor industry.

In early 1960, Business Week ran an in-depth article on the semiconductor industry summarizing the merits of the transistor, some of its past history, the status of the industry, and some indications of the future:[84]

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[81]"U.S. Radio Firms Warned Don't Panic into Buying Japanese Transistors," Electronic News, May 11, 1959, p. 14.

[82]Jack Gorman, "Chicago Radio, TV Manufacturers Seeking Low-Cost Japanese Parts, Subassemblies," Electronic News, August 22, 1960, p. 90.

[83]Lloyd Schwartz, "Government Decides SCs from Japan No Threat to U.S. Firms," Electronic News, June 4, 1962, p. 1.

[84]"Special Report on: Semiconductors," Business Week, March 26, 1960, pp. 74-121.

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> In only 12 years, the semiconductor industry has accomplished enough to rank it, probably, as the world's fastest growing business. Not only that--it is an almost classic example of the particular kind of growth that technological innovation can fire up throughout the U. S. economy.[85]

The article placed heavy emphasis on the potential of a new semiconductor technology beginning to gain more attention. The advent of this innovation occurred at a time when the number of companies in the industry was levelling off; when one superior production technique had been made available that would increase yields, cut costs, and improve quality; and when vertical integration was being attempted by various firms--component firms upwards and systems companies downward.

In an accompanying editorial entitled "$500-Million on a Pinhead," it raised the industry to Olympian heights:

> For a case study of what organized research can mean to industrial growth there is nothing more startling than the semiconductor industry.
>
> From a glimmer in the minds of a small group of physicists 12 years ago, semiconductors have grown to a $500-million business. Few people outside the industry would recognize a transistor if they saw one. But, these tiny products--built to the scale of a pinhead--promise changes in the world comparable to those wrought by the steam engine.[86]

A Fairchild News Service survey in late 1960 confirmed some of the hard realities.[87] A broad range of technical

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[85] Ibid., p. 74.

[86] "$500-Million on a Pinhead," Business Week, March 26, p. 178.

[87] "Across-Board Competency New Transistor Field Need," Electronic News, July 25, 1960, p. 1, and "Transistor Entry Tightens," Electronic News, August 1, 1960, p. 1.

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competence was needed for transistor manufacturers to satisfactorily compete. Those firms that had established their growth via technical or marketing innovations could no longer depend upon these processes for sustained profitable operations; a broader range of competence was needed. Also, the ease of entry for newcomers was considerably more difficult since venture capital would be harder to come by and, due to the present industry status, more cash would be needed initially. The industry, one spokesman suggested, would have to turn to some of the newer technical fields.

By early 1961, the signs were obvious:

> We're reaching bottom pretty fast in the semiconductor business.[88]

Although new semiconductor products could still demand prices returning a high profit margin, they would have to compensate for the little or no profits being earned on the high-volume, standard production units. The possibility of "standard" profit margins similar to those achieved by the other component industries, such as capacitor and resistor, was becoming a reality for the semiconductor producers.

One trade magazine noted:

> The race will go to the lean, the hungry, the tough, the flexible. . . .
>
> Semiconductor business is increasing at a rate of 40% a year. Today there is twice as much production capacity as needed. Something has to give. . . .[89]

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[88]Angus Scott, Sales Manager, International Rectifier corp., as quoted in Robert Henkel, "Semicon Field is Optimistic," Electronic News, March 22, 1961, p. 11.

[89]"Electronics Newsletter," Electronics, July 7, 1961, p. 9.

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Many of the firms reacted in characteristic fashion. The discontinuance of unprofitable product lines, revamped inventory control systems, and organizational shakeups were various solutions tried by some major firms. Others resorted to offering new, miniature, reliable, high-density packages utilizing semiconductor components that would hopefully compete with the newer technologies then in vogue.

The shakeout in the industry would have been much more severe, one spokesman stated, were it not for the continued insertion of capital funds both to finance new product development and absorb losses brought about by price-cutting.[90] The industry problem, it was contended, was caused by very basic, fundamental factors not likely to disappear even when price stabilization did occur:

> These basic factors include a significantly lower rate of market growth, a decreasing tendency for the nature of the market to be changed as a result of changing technology, and an overpopulation of qualified producers--too many companies fighting to improve their position in a maturing market.[91]

A survey by Electronic News painted an equally gloomy picture.[92] No manufacturers questioned felt that prices had reached their lowest levels. Greater unit sales still were

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[90]Robert Henkel, "Outside Capital Seen Postponing Shakeout," Electronic News, September 4, 1961, p. 1.

[91]W. B. Hayes, Vice-President, Thompson Ramo Wooldridge, as quoted in Robert Henkel, "Outside Capital Seen Postponing Shakeout," Electronic News, September 4, 1961, p. 1.

[92]"Price Downtrend Seen Continuing for Transistors," Electronic News, September 18, 1961, p. 5.

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expected--due to a greater penetration of the foreign market, more forceful marketing efforts, and increased Government outlays--but profits, it was felt would not keep pace with sales. Greater diversification was also required, but, as Business Week noted, the customers would not tolerate prices based on the old "all-the-traffic-will-bear" philosophy.[93]

In late 1961, Business Week summed up the conditions with an article entitled "Glamor Industry Takes Its Lumps."[94] It recapitulated the problems already cited, but placed a considerable amount of the blame upon the financial community that had tolerated a sloppy accounting technique and had provided a ready cash market for unworthy enterprises. Mergers were urged; investment houses, although still underwriting new issues, were not able to obtain the high price-earnings multiples that had prevailed earlier. The dangers of too rapid growth were also pointed out wherein a small, one-man-managed firm experiences sharp sales increases, and the good small company becomes a poorly-run medium-sized firm with the attendant problems.

By 1962, the interest in the microelectronics technologies was at a crescendo pitch; firms were still striving to exist in the semiconductor market. Some manufacturers offered "universal" lines--one type of unit that can be used

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[93]"Wall Street Talks . . . ," Business Week, September 9, 1961, p. 166.

[94]"Glamor Industry Takes Its Lumps," Business Week, November 11, 1961, pp. 109-113.

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where many had been needed before. This, in reality, was an attempt to limit the product line by offering components with vastly expanded parameters. The price declines still were expected to continue--but in an orderly manner without "chaotic price slashing."[95]

Late in 1963, Philco Corporation, once very profitable as a transistor producer, dropped its entire transistor operation opting to put its resources into the microelectronics technology.

The semiconductor industry has had a beacon light shining upon it since its basic technical problems were solved in the early fifties. It was given a great deal of press coverage both in the technical journals and periodicals as well as some of the more secular magazines and newspapers. If its potential in the early days was well-documented, so too were its problems. Whatever was obvious to the practitioners within their own confines was amplified through the various news media.

Technology

The integrated circuit is one of the most sophisticated technical components ever produced by the U. S. electronics industry--or any industry for that matter. The manufacturers making IC components require personnel capable in a spectrum of skills spanning the physical sciences. The product, although

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[95]Jack Robertson, "Texas Instruments Expects Orderly Semicon Price Cuts," Electronic News, September 3, 1962, p. 14.

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fostered, nurtured, and accelerated to its present high status by a market need created by the military, is basically an evolution of the technology preceding it. The integrated circuit could not have appeared ten years ago; our technical knowledge was not up to it. It is mandatory, therefore, to at least briefly review some of the history of the semiconductor industry in the years prior to the commercialization of the IC product to see how the latter's evolution was both limited and then facilitated by the progress made in the semiconductor art.

The integrated circuit is closely tied to the transistor yet in one aspect it represents a much wider gap between it and the transistor than the transistor to the tube. The transistor is an electronic component; in many applications it can be inserted wherever a tube is, and by changing the value of the other circuit components, the circuit function can be simulated. The integrated circuit, although a direct outgrowth of the semiconductor industry, can incorporate the equivalent of many transistors along with resistors, capacitors, and diodes. The entire circuit is embodied within one silicon chip. This is a critical difference and therein lies the conceptual genius of the integrated circuit.

The spark of inventiveness that suggested to some restless investigator(s) to travel this particular path is difficult to trace. From the industry point of view, the economic utility was only forthcoming when that idea could be translated into a salable product, capable of being reproduced

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in mass volume with identical characteristics and stable over lifetime use. It also had to offer the potential of being inexpensive when volume increased and learning curve improvements were achieved.

These feats are not attributable to any single person or group. Many minds added their singular contributions to the product we know today. Patents have been awarded and others are pending in various areas of the IC technology.

The integrated circuit in its most basic form is the simulation within a small chip of silicon of various electronic elements--diodes, transistors, resistors, and capacitors. The entire chip is covered with a layer of silicon dioxide--glass--that protects the chip from the environment and provides a base on which a metalization pattern interconnects the elements within. When one views the unencapsulated finished product with the naked eye he sees a reflection of himself with striations where the metalization is. The total final product consists of a package encasing the chip and connecting the points of the circuit, through strong leads, to the outside world.

The economically feasible IC product depends upon three factors:

1. The capability to simulate the various electronic elements within the silicon chip with some degree of mutual isolation.

2. The capability of interconnecting them with one another.

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3. The means by which they can be inexpensively produced in quantity if not inherent in 1. and 2.

These three ingredients are essential; they may actually be two in number. For the type of product demanded for high-reliability applications, other criteria may be added.

The diffusion technique enabled the scientist to simulate the electronic elements. This method was developed at Bell Telephone Laboratories in 1955 and was introduced to the world in January, 1956. By using this technique, the elements could be selectively placed within the chip. This selectivity was accomplished by masking techniques. A major contribution of the diffusion process was the allowance of batch fabrication production, i.e., the integrated circuit, or initially the transistor could be fabricated in a batch process in which many units were made at the same time rather than incurring handling for each--the norm before diffusion methods were used.

In tandem with diffusion, oxide-masking techniques were developed. Initial work was also done at Bell Telephone Laboratories, but Diamond Ordnance Fuze Laboratories made valuable additions in photolithography techniques.

The interconnection of elements was achieved through the development of the planar technique. The latter process was originally used by Fairchild Semiconductor for its transistors in the late fifties, and then applied to its integrated circuits. The planar method improved the oxide-masking techniques then achievable and utilized the silicon dioxide layer

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as a base for metalization. These two steps, in the author's mind, were the most valuable contributions to the IC concept.

Another major advance was announced by Bell in 1960. The epitaxial process allowed greater flexibility in obtaining device characteristics. It too has been used for transistors. With this new addition, the performance of the integrated circuit was improved, ultimately leading to increased yield and, in the long run, lower prices.

It is of interest to retrace the steps just described. Working backwards, the epitaxy technique came in mid-1960, and the planar process was developed in late 1959-1960. The next major advance preceding it occurred in 1956 with the announcement of the diffusion technique. There is a hiatus of about four years that bears directly on the chronology associated with the integrated circuit. This point will be discussed in Chapter V.

The various technical achievements cited are the basic building blocks for the IC component as we know it today. Again, the concept of putting the electronic elements into a single monolithic block of silicon is a separate story unto itself. This too will be reviewed in Chapter V. Suffice it to say here that the idea had to wait for the technology to catch up with it.

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CHAPTER IV

THE COMING OF A NEW ELECTRONIC PRODUCT

Before describing the events that led to the introduction and development of the integrated circuit, it is both interesting and appropriate to describe very briefly a similar sequence for that component's electronic ancestors--the vacuum tube and the transistor. The commonality for the three is slight, if any. The fanfare for the integrated circuit is contrasted to the initial indifference and lack of publicity which greeted the latter two.

Vacuum Tube

The three-element vacuum tube, as with so many other inventions preceding it, was the result of an unplanned set of circumstances and not the culmination of a series of experiments based upon theoretical premises. It was achieved after much experimentation, and required the elements of an imaginative mind, dogged persistence, and some degree of luck. With these, Lee de Forest introduced the major component that was to spark and sustain the electronics industry for five decades.

The three-element vacuum tube, simply called the vacuum tube in further discussion, is sometimes referred to as a triode or a valve. Conceived in late 1906, the patent was

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applied for in January, 1907, and was awarded less than thirteen months later. It was the first "active" electronic component; it could amplify electric currents. Herein lay the sine qua non for the then infant radio industry. This single invention more than any other was to revolutionize the communications media of the world and, by so doing, trigger the growth of an industry which is still expanding.

In 1864, Maxwell formulated the electromagnetic theory of light: light and electricity travel in waves at the same speed. Twenty years afterwards, Hertz actually demonstrated these waves. This was the theoretical foundation for radio-wireless telegraphy. Marconi, the innovator, translated the theory into practical reality. He created the British Marconi Company and, in 1899, with $10 million capitalization, he formed the American Marconi Company. In competition with this firm, Lee de Forest established the De Forest Wireless Telegraph Company in 1902 with $3 million backing. This was the spawning ground for de Forest's inventive talents. Wireless telegraphy was struggling not only for economic subsistence but also for technical acceptance. As a new technological innovation, it attracted venture capital and opportunistic would-be capitalists. De Forest found his share of both.

At that time the radio art lacked a sensitive, reliable detector, i.e., a device that could pick up the low-power radio waves and then faithfully reproduce and amplify them. Patents had been issued for devices performing the basic function, but these solutions were far from satisfactory. Combined with

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other deficiencies, radio was still at the stage of basic development; refinement of the art was yet to come. De Forest directed much of his effort to the basic amplification problem, although he was productive in other phases of the technology.

The vacuum tube principle involves electron current control by use of a small voltage to modulate a much larger one. The source of energy is a heated cathode operated at a high enough temperature to emit electrons. The electron had been discovered less than ten years before, in 1897, by J. J. Thomson, a Cambridge professor. Before that time, the smallest particle in the universe was thought to be the atom. The principle of thermionic emission--electrons being "thrown off" a heated element--had been observed by Edison in 1883 while he was working on his incandescent bulb. He noted the phenomenon, which was causing deleterious effects in the operation of his bulb, but did nothing about it. In 1904, J. Ambrose Fleming used this "Edison Effect" to create a diode. He heated a cathode to incandescence and placed it near a metallic plate--all within an evacuated glass tube. When the plate was positive relative to the cathode--thereby allowing it to attract electrons--current flowed from the plate to the cathode (using today's conventions), i.e., electrons were attracted to the more positive plate or anode. No current flowed when the plate was negative. This is the principle in diode and rectifier action which still holds today in all tube devices that must perform the function.

Fleming's device had theoretical and practical

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limitations. Future innovations were to translate the concept into a much more meaningful contribution. Here, however, was the takeoff point for de Forest's work. One deterrent for him was the patent situation which forced him to seek non-infringing techniques for his inventive efforts. Although patent-infringement plagued the radio industry for many years hence and sucked away many dollars which could have been spent in more productive areas, it, nonetheless, had the salutary effect of fostering, if not forcing, new thinking on old subjects. The patent constraint, an ever-present realization for de Forest, was really a disguised blessing. De Forest, who was to know a life of disappointment and seemingly endless, bitter court litigations, was compelled to apply his talents in new directions. This he could do well.

When de Forest worked on a new invention, everything else was forgotten. He burned with an intense flame, and his success seems to have been a product of brilliant imagination and intense application. The pace was so energy-consuming that he could not sustain it for long. During his periods of creative productivity the commercial aspects of his enterprise were completely neglected.[1]

Sparked by a hunch from some previous experimentation, de Forest hit upon the idea of placing a third electrode within

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[1]W. Rupert MacLaurin, Invention and Innovation in the Radio Industry (New York: The Macmillan Co., 1949), p. 250.

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the vacuum tube. This element was called a grid since it was shaped like a gridiron. Situated between the cathode and the plate, electron current between those two electrodes could be regulated by changing the grid's voltage. Dr. I. I. Rabi, Nobel prize-winning physicist, described the discovery as "so outstanding in its consequences that it almost ranks with the greatest inventions of all time."[2] Ironic as it may seem, de Forest did not understand how this creation worked and, more importantly, how he could improve it. He did not realize, as future investigators did, that the better the vacuum in the tube, the better its performance and operating characteristics. The initial triodes that de Forest produced, though inherently superior to other forms of detectors, were poor in construction and reproducibility; the commercial market did not materialize until future developments improved their operation.

De Forest as an inventor and innovator was another in the long line of great achievers who had to resort to their own resources and imagination. He had the strengths and foibles that are typically associated with these types of creator.

Lee de Forest had a keen intuitive sense for significant technical inventions. He was not only a pioneer in the development of the vacuum tube and the feedback circuit (which occurred later), but he was also one of the early inventors of the sound motion picture apparatus. He remained, however, always the

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[2]Dr. I. I. Rabi, "The Physicist Returns from the War," Atlantic Monthly, CLXXVI, No. 4 (October, 1945), p. 109.

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lone inventor, totally incapable of cooperating with others in organized research. In consequence, he never retained any research assistants for long periods. He did not have Marconi's tenacity of purpose. He was too impatient and volatile to remain with any one aspect of a field.

These characteristics applied equally to his business ventures. De Forest was responsible for a succession of companies, all ending in bankruptcy. He did not surround himself with able business associates and had no sense of sound finance. In his business activities he was essentially a promoter, sensing the possibilities for a new commercial venture, eager to obtain funds for new technical experiments, but losing interest very quickly in the commercial aspects of his companies once they had been launched.[3]

There is no doubt that Lee de Forest was motivated by economic stimuli. When he did have money, he spent lavishly. When his fortunes reversed, his activities were impeded by this lack of foresight. His inventiveness was nurtured by his fierce pride and confidence in his own capabilities; these must have been ample, since he rarely had much more to work with. When he invented the triode, he was virtually penniless.

The diode, the starting point for his triode investigations, was also developed for business reasons; it was the property of British Marconi. These two inventions were based

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[3]Maclaurin, p. 246.

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on previous work done by others. Indeed, the entire radio industry which was the fountainhead for all this experimentation could not have been possible had not Maxwell and Hertz laid the initial theoretical groundwork. They were interested in pure science; their only intentions were to gain a greater knowledge of the universe and natural phenomena. As S. C. Gilfillan has suggested, all inventions are derived from previous achievements. The vacuum tube was no exception. Its genesis lies with many for its basic ideas, and much additional work was done after de Forest's initial effort to bring it to fruition.

Nevertheless, de Forest's discovery constituted a supreme invention contributing in a very large measure to the tremendous progress that has taken place in the radio field.[4]

Transistor

If the invention of the vacuum tube gave birth to the electronics industry, then the development of the transistor gave it needed vigor and growth potential after the Second World War. Whereas the vacuum tube fathered a new industry, the transistor accelerated its growth and led it into avenues either impossible or impractical for the tube. The vacuum tube was the undisputed "active" element in electronic circuits for about half a century; the reign of the transistor is to be

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[4]John G. Glover and William B. Cornell, The Development of American Industries (3d ed.; New York: Prentice-Hall, Inc., 1951), p. 956.

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more short-lived. The struggle is now occurring, barely a dozen years after the transistor reached any semblance of volume production and only seventeen years--the lifetime of a patent--since it was originally announced to the world. Its birth was more orderly and refined than that of its predecessor, its parents were well-to-do, and its birthplace, the very paragon of modern-day industrial research laboratories--Bell Telephone Laboratories. It came into being primarily through the efforts of talented scientists--non-entrepreneurs--with access to probably the best research facilities the world had to offer. The new component's assets generated its rapid ascendancy in the industry. As the vacuum tube still has its unassailable niche, so too for the transistor. Its promise of a decade ago has been achieved, but obsolescence in certain applications has also been its fate.

The transistor is a three-element device. (There are variations, but they have not gained great acceptance.) Conceptually, it performs the same type of function as the vacuum tube. Its major attributes relate to its reliability, size, and power requirements. Since the transistor is a solid-state device--unlike the vacuum tube, its operation is based on physical phenomena occurring with the bulk of a semiconducting material--it does not require heating. No warmup time and power are needed to energize a cathode. Its size is considerably smaller than the "bottle" associated with vacuum tubes; its dimensions generally run in the fractions of inches. For many applications--the computer, for instance--the advantages

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are many. It is also generally conceded that there is no inherent time-dependent failure mechanism in today's well-made transistor; its reliability is greatly improved over that of vacuum tubes. Although even today there are areas in which the transistor cannot match the performance of the vacuum tube, e.g., temperature insensitivity, the growth in the electronic components industry for the past decade is due mainly to this component.

An ancestor of the transistor was the crystal rectifier of very early radio days. This rectifier was used in the same manner as the Fleming vacuum tube diode. It had similar properties, although the physical principles were completely different. As detectors in radio equipment, both were superseded by de Forest's triode. Scientists had found that certain materials, such as impure lead sulphide, could conduct electric current in only one direction. At the time--early 1900's--there was no theory to support this observable phenomenon. It was used simply because it worked. The vacuum tube ultimately replaced it, since the triode could not only detect and rectify an electric current but could also amplify. The amplification principle--the basis of the "active device"--was indispensable for radio receivers.

The theoretical base for semiconductor operation was developed during the 1920's when quantum mechanics gained acceptance. In 1931, A. H. Wilson formulated the basic theory later published in book form. It was to take another seventeen years before the implementation of the theory occurred.

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In 1939, William Shockley of Bell Telephone Laboratories began work to determine if semiconductors could amplify current. This establishment, then as now, was known for the quality of its scientific staff and the relative freedom afforded this group. If such a device could be developed, the BTL parent, American Telephone and Telegraph, could put it to good use within the Bell system. Bell used a great many electromechanical devices to perform basic switching functions. These devices presented serious reliability and size problems. If an electronic component could be developed that was small, used little power, had a relatively long life, and could ultimately be produced inexpensively, it had an assured market just within the Bell system, not to mention the numerous other applications for which it could be applied. This was at least one of the major factors advocating the investigation of semiconductors. The work was sidetracked during the war and picked up in the mid-forties along with another major avenue of interest relating to vacuum tubes. Radars, invented during the war, used vacuum tubes that had serious performance limitations at the high radar frequencies. Here too, another possibility for an amplifying semiconductor device beckoned.

In 1946, BTL decided to make an intensive study of silicon and germanium, two of the more common and simpler types of semiconductor materials. Shockley headed a group composed of himself and two other physicists, Walter Brattain and John Bardeen. All received the Nobel Prize in 1956 for

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their work in creating the first transistor. From the efforts of this trio, BTL, on June 30, 1948, announced to the world that the first transistor (which stands for "transfer resistor") had been developed:

> The transistor is of such overwhelming importance because it (and its still smaller successors) makes practical hundreds of electronic devices, which were previously too bulky, too expensive or too unreliable for everyday use.[5]

Transistors are by no means passé. Dollar sales in 1964 were over $320 million and 25 per cent higher in 1965. During the early sixties, dollar revenue remained constant at about $295 million. Under any circumstances, the future lies with the newer innovation which is the main subject of this work. Transistors are regarded now much as the vacuum tube was in the mid-fifties:

> Time hath, my lord, a wallet at his back
> Wherein he puts alms for oblivion,
> A great-sized monster of ingratitudes.
> Those scraps are good deeds past, which are devoured
> As fast as they are made, forgot as soon as done. . . .
> Since things in motion sooner catch the eye
> Than what not stirs.[6]

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[5]Arthur C. Clarke, scientist, "Spark of the Second Industrial Revolution," The New York Times Magazine, December 9, 1962, p. 32.

[6]Ulysses to Achilles in William Shakespeare, Troilus and Cressida, Act III, Scene III, lines 145-150, 183-184.

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Integrated Circuit

Introduction

It is appropriate from the outset to make a few comments on the subject of semantics in the microelectronics area. This field, even now, causes as much chaos as it did six to seven years ago when the various technologies were first being discussed. It will be impossible to do away with all the confusion since quotations from various sources will be referred to, and there is no commonality in such statements.

Two major terms will be used continually. Although they are in no way interchangeable in actuality, they are often used as synonyms. When reference is made to molecular electronics* (molecular circuitry, molectronics, etc.) the intent is to describe a form of electronic component that has no obvious electronic equivalents such as transistors, diodes, resistors, and capacitors.

Integrated circuits* (integrated electronics, integral electronics, silicon monolithic integrated circuits, semiconductor integrated circuits, etc.) are simulated within a chip of silicon and interconnected on the same chip.

The following press documentation of the introduction and subsequent development of the integrated circuit serves only to indicate how this innovation was created and the attendant events which followed. A critical review is part of

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*See Glossary.

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Chapter V. Before the spring of 1959, references to this new technology were sparse. In April of that year, when the first contract for molecular electronics was let, the rumblings increased in volume, spurred on by the participation of the military. When feasibility was proven and actual systems were demonstrated using the new components, the press coverage reached crescendo pitch, and transistors became passé as the bandwagon effect took hold.

This section will be divided into three subsections based on chronological sequence. "Genesis" proceeds up to and includes the first pioneering contract of spring, 1959. "Initial efforts" takes off from that point and continues through 1961. "Continuing momentum" carries the story to the near past.

The press coverage through various periodicals was, to put it conservatively, extensive. Not only was the volume great but the nature of the stories, especially those that included statements from the technology's proponents, was generally one-sided tending to give a somewhat distorted, optimistic view. If the industry, en masse, finally turned to the IC component, the power of the printed word should share part of the credit.

Genesis

A harbinger for an unborn technology was heard at the Institute of Radio Engineers' (IRE) conference of April, 1957, held exclusively on the subject of microminiaturization.

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Radical reductions in size, made possible through basic new knowledge in semiconductor materials, were discussed.

In May of 1958, the Defense Department announced that it had earmarked $13 million in emergency funds for the experimental development of military devices fron new materials using new techniques. This program represented a major stepup in military-supported basic research and technical development for electronic components.

The Micromodule program, the Army's attempt to obtain size reduction for military equipment, received its initial funding in April of 1958. Other agencies were using or thinking of different microelectronic approaches. The Navy had been funding Varo through its Office of Naval Research (ONR). Varo's basis was use of thin-film techniques in conjunction with discrete components. The Air Force introduced a new technology called molecular electronics which had gained adherents within that agency. Its impact would be radical, it was prophesied:

> Molecular circuitry may upset traditional lines of demarcation between electronic component and equipment manufacturers. Because molecular circuitry poses a direct threat to conventional parts, it is logical to expect more component manufacturers to move to protect their position. However, molecular circuitry will require much more research and knowhow than many of the smaller component manufacturers now possess.[7]

The Air Force, after considerable review on its own part, was seemingly prepared to sponsor work in this

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[7]Philip Klass, "Electrochemistry May Cut Circuit Size," Aviation Week, June 2, 1958, p. 66.

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particular field of research.

At about this time, a Bell Telephone Laboratories scientist predicted on the basis of recent laboratory success the future appearance of:

> Solid-state devices capable of performing complex circuit functions within a single physical structure the size of a transistor, with a minimum of external circuitry and very high reliability. . . .[8]

By late 1958, molecular electronics was being touted as the needed technology for future space vehicles and weapon systems. The practical utility forthcoming from devices and systems using this new technology, it was suggested, would be dependent upon how fast military and industrial management accepted the value of molecular electronics.[9]

By the end of 1958, before any formal contract had been awarded to an industrial firm to develop usable components from this new technology, the molecular electronics concept was considered by some to be the answer not only to present problems, but also to those still forthcoming in the future.

In April, 1959, the long-awaited first molecular electronics contract was released by Air Research and Development Center (ARDC) of the Air Force. The aim of this $2 million effort was to develop a fundamentally new approach to avionic equipment design and fabrication of electronic equipment,

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[8]"Semiconductor Devices of Future May Replace Complex Circuitry," Aviation Week, June 30, 1958, p. 23.

[9]Charles Wendel, "Molecular Field Seen Key to Space," Electronic News, November 17, 1958, p. 5.

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structured upon basic building blocks. Reductions of avionic equipment size and weight by factors as much as 1000:1 with significant gains in reliability were among the major objectives. It was noted that electronic equipment design, other than that for the inclusion of the transistor, had been fairly static for an extended period of time. Spurred on by the new space vehicle needs, the problems of size, weight, reliability and power consumption took on added dimensions; this program was clearly aimed at obviating these difficulties, both for the present and the foreseeable future. ARDC believed that the solution lay in the new knowledge of atomic and molecular structure of materials recently emanating from research in semiconductors. One major Air Force official stated it thusly:

> This knowledge [R&D on a microscopic level] should allow proper utilization of every essential atom and molecule, the elimination of unnecessary materials, and consequently great simplification and improvement in life and reliability of future electronic equipments. This technology evolving from this effort is called molecular electronics.[10]

During the length of the two-year contract, Westinghouse in the first year would deliver eight circuits demonstrating the new technology, and the second half of the effort would be devoted to investigating the feasibility of components for representative Air Force equipments. Besides the attributes of reduced size and weight, it was expected that

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[10] H. V. Noble, Technical Director, Air Force Electronic Components Laboratory, "Statement of H. V. Noble," Electronic News, May 4, 1959, p. 18.

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the most critical advantage of the new technology would be the vastly improved reliability it would afford. Single electronic components would replace circuits composed of many discrete electronic devices, thereby reducing the number of interconnections: this latter consideration was a major reliability hazard. It would also allow for the use of redundancy techniques to improve reliability levels.

The contract represented the initial thrust by the Air Force in its molecular electronics program. It triggered an avalanche of activity and soul-searching for the semiconductor components industry. The first flurry of attention was followed by an intensive campaign to insure its continuance.

Initial efforts

The enthusiasm was not limited to only the scientific and engineering communities. Business Week, early in 1960, expressed the following opinion in an article entitled "Electronics Goes Microscopic":

> The electronics business is on the verge of another revolution at least as sweeping as the one which began a decade ago when the transistor cut in on the vacuum tube. The revolution is coming from a new science called molecular electronics, which is just now emerging from the laboratories.[11]

The article continued in laudatory phrases to depict the many advantages of this new technology.

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[11] "Electronics Goes Microscopic," Business Week, July 25, 1959, p. 34.

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The Air Force, meanwhile, through some of its representatives, made its objectives crystal clear:

> During the past decade, Air Force weapon systems have become increasingly complex to accomplish their increasingly difficult mission assignments. . . .
>
> This trend has created a number of major problems for the air/space vehicle designer, including size, weight, and electric power requirements. Perhaps the most critical is the lesser reliability which results from the irrevocable law of nature that the reliability of a system is equal to the reliabilities of each of its individual components. . . . We need a new concept, or breakthrough, in the electronic components field.[12]

In short order, the industry began to heed the message:

> Interest and activity in molectronics and micro-circuitry is spreading through the avionics industry, sparked by the needs of space and missile technology and by a recent major program launched by the Air Force at Westinghouse Electric Corporation.
>
> At least 20 companies, ranging in size from the giants to the smallest, from semiconductor and component makers to equipment manufacturers, are actively engaged in molectronic research and in related micro-circuitry development.[13]

By early 1960, at least one Air Force official felt that the molecular electronics technology was ready for the application stage:

> Operational molecular electronics equipment could be available in 3 to 5 years.[14]

The potential of improved operating characteristics, it was

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[12]H. V. Noble and R. D. Larson, "USAF Investigates Basic Molectronics," Aviation Week, August 17, 1959, p. 17.

[13]Philip Klass, "Space Needs Spur Molelectronics Activity," Aviation Week, September 28, 1959, p. 73.

[14]Col. W. S. Heavner, Chief, Electronic Technology Laboratory, WADC, as quoted in "Molecular Electronics in Applied Stage," Electronic News, January 25, 1960, p. 8.

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suggested, would make electronic equipment using this new technology competitive with substitutes even if initial costs were higher.

By February, Westinghouse had developed nearly twenty different circuits demonstrating the molectronic phenomenon:

> Molecular electronics is feasible and it is here today. . . .[15]

Within two months that feasibility was confirmed by the announcement by Fairchild Semiconductor and Texas Instruments of commercially available components in which a complete circuit may be built into a single small silicon chip. (As discussed in the introduction to this subsection, this component is an integrated circuit; it does not encompass the true molecular electronics concept as originally espoused by the Air Force.) The Fairchild line, called Micro-Logic elements, is housed in a standard transistor-type "can" and provides basic computer functions. The TI products are called Solid Circuit Semiconductor networks. Texas Instruments announced soon afterwards that it was building a new production facility for this product to replace the one that had been previously making the IC components as part of a research and engineering function.

The component manufacturers, now faced with actual IC products from two of their competitors, were warned to

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[15]Col. W. S. Heavner, as quoted in Philip Klass, "Molectronic Developments Demonstrated," Aviation Week, February 8, 1960, p. 79.

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consider molecular electronics "or take the risk of becoming obsolete."[16] Col. Heavner suggested that the Air Force was trying to stimulate interest in this new technology; he underlined his feeling that the state-of-the-art transition had already been passed. He contended that molecular electronics should be considered for all electronic equipment, and the art will some day encompass an even greater span of physical phenomena, e.g., heat, light, magnetism.

Emphasized by the intent of Electronic Technology Laboratory of Wright Air Development Center, Air Force interest lay squarely with molecular electronics and not with conventional techniques; its strong support in this area was clear.[17] Industry reacted cautiously noting that components manufacturers should not panic over the strong statements recently made. One industry spokesman took complete exception to the molecular electronics optimism:

> We'd better set about improving technology before talking about the wild blue yonder of "molecular electronics" where each molecule is in the right place with error below one in a thousand. . . .
>
> I am sure that publicity is well ahead of technology. In my opinion, a manufacturer of microcomponents has several years to enjoy a market for his products before he is superseded by solid-state circuits, to say nothing of molecular circuits.
>
> Solid-state circuits are on their way but they will

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[16]Col. Heavner, as quoted in Donald C. Hoefler, "Heavner Urges Bionics as Next Step in Research," Electronic News, March 24, 1960, p. 34.

[17]"WADC Stresses Moletronics," Electronic News, Sec. 1, March 21, 1960, p. 96.

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not arrive for at least 5 to 10 years.[18]

Like it or not, the industry was on the edge of an upheaval. Earlier, in May, a high official in DOD had commented:

> Development and military application of molecular electronics will be on a considerably shorter time scale than the transistor.[19]

The industry was being forced to reexamine its techniques, materials, and production methods. The technology was acclaimed not only as an asset for military and space systems but for the whole electronics industry as well.

The momentum was maintained into the new year--1961--as the armed services planned to exploit the various microelectronic technologies. Several programs by the Army and Air Force were described documenting their particular interest areas and the planned allocations in each. The total expenditure outlay for the military for microelectronics, including the Micromodule program, was over $20 million.[20] Towards midyear, the Air Force noted that it had been approached by industry for contracts in the molecular electronics field:

> As recently as two years ago many companies were saying that molecular electronics would not have any practical

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[18]Dr. H. Q. North, President, Pacific Semiconductor, Inc., as quoted in Alfred D. Cook, "Slow Progress Cited in Field of Minification," Electronic News, May 30, 1960, pp. 1, 5.

[19]J. Bridges, DDR&E, as quoted in "Views Split on 'When' of Molectronics Usage," Electronic News, May 9, 1960, p. 5.

[20]Barry Miller, "Microelectronics Studies Gain Support," Aviation Week, January 23, 1961, p. 99.

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> applications for 50 to 100 years. Now they're trying to get aboard the bandwagon.[21]

At this time, the Air Force was seeking firms willing to put some of their own funds into new molecular electronics programs. They found one in Motorola which entered into a $1.5 million cost-sharing contract with the Air Force; the company would contribute $0.5 million to the program's work effort.

One company, Westinghouse, was already looking past the immediate military market and predicting the penetration of the consumer sectors with its molecular electronic circuits. Large volumes of these components would allow unit prices to become competitive and then be incorporated into consumer products, it was asserted. Although these claims were met with skepticism in some areas, it indicated that the firm was looking for a broad application for molecular circuitry.

In late 1961, Texas Instruments showed a digital computer utilizing its integrated circuits. Earlier in the year, Westinghouse had exhibited a radio receiver demonstrating the molecular electronic principle. The TI equipment, however, was a digital system and a particularly fine example of the advantages of the new technology. It weighed 10 ounces, was 6.3 cubic inches in volume, and had 587 components. It replaced a predecessor system that had over 14 times as

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[21] H. V. Noble, as quoted in "Molecular Approach Stirs NAECON Interest, Debate," Electronic News, May 15, 1961, p. 53.

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many parts, was 150 times larger, and weighed 48 times as much. The computer was built as a showcase vehicle to confirm the potential utility of the molecular electronic component on the system level:

> We can now convince the system people that here is something to do the job of bridging the gap in the systems cycle.[22]

Business Week concurred in its evaluation of the occasion:

> You can find skeptics who doubt that the problem of meeting tight specifications has been anywhere near solved, who say that yield is still economically low. Some object, too, to the centralizing of end-product design responsibility in the hands of the component manufacturer. Customers may balk at using molectronic circuits under such conditions, the critics say. The answer is that the Air Force will have much to say about that, and the Air Force is apparently sold on molectronics.[23]

The industry, meanwhile, was tooling up for initial product line offerings and was setting up the needed facilities. Texas Instruments announced its initial IC line at the time it demonstrated its digital computer. Motorola disclosed development of IC devices for industrial and military applications, although no specific product line was cited. Fairchild Semiconductor, which had offered its first formal IC component in early 1961, added to its line throughout the year, and, by December, it could boast seven items, all

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[22]Col. W. A. Wallace, Deputy for Technology, ASD, as quoted in "Molectronic Computer Shown by Texas Instr.," Electronic News, October 23, 1961, p. 16.

[23]"Next Step Beyond Transistor," Business Week, October 28, 1961, p. 50.

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digital types. Westinghouse established a semiconductor molecular electronics department, and Philco did likewise calling its group the Microelectronics Department. Even the major aerospace firms were setting up microelectronic research facilities to keep abreast of the fast-breaking developments in the new technologies.

The Navy was also showing interest in microelectronics. Early in 1961, the Bureau of Ships established a program to investigate the potential of microelectronic circuitry. The project was to combine both in-house and outside contracts; the bulk of the dollars would be devoted to electronic firms in the field.

A major contract was awarded to IBM by the Navy to build a high-volume thin-film production facility--the first of its kind to use thin-film techniques for automatic fabrication of advanced electronic components. In December, an all-Navy panel recommended a sharp increase in the Navy's fundings on microelectronics, with major emphasis on thin-film techniques. The program would aim to supply hardware to users capable of maintaining the new equipment. There was to be no duplication of Army and Air Force work in these areas.

Continuing momentum

The technology, going into 1962, had had a very promising beginning. With the help of the military, the industry was preparing for the opening of markets formerly held by discrete component circuits. Also, the creation of

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completely new applications that had no obvious predecessors appeared feasible. Other than the demonstration by Texas Instruments of its miniature computer--which was admitted to be merely a showpiece item to confirm feasibility on a system level--there had been little or no application of the new technology to electronic equipments or systems. In 1962, the first major applications were announced, new firms entered the field, older participants strengthened their positions, and the industry gained increased momentum.

Early in the year, Westinghouse demonstrated an emergency receiver utilizing its molecular electronic circuits. This non-digital application, as compared to the TI equipment shown in the previous fall, weighed 0.5 pounds and had a volume of 9 cubic inches; it replaced an earlier non-IC model which weighed over 5 pounds and occupied 148 cubic inches. This too was designed to show feasibility beyond the device level for the new technology. It was described as "the most complex linear electronic system of its type yet achieved through these principles."[24] At about the same time, Westinghouse announced that it was offering its first line of IC components, a combination of linear and digital types. Soon after, the firm formed a Molecular Electronics Division to market its IC product line.

Texas Instruments introduced its "Master Slice" design

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[24]H. V. Noble, as quoted in "Westinghouse Shows 0.5-lb. Receiver," Electronic News, March 5, 1962, p. 1.

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that would enable customers to obtain custom integrated circuits from the company at a small increase above the price paid for standard off-the-shelf catalog items. This, it was hoped, would add great flexibility to its product line offerings. In order to stimulate the linear portion of the market, the firm introduced, late in the year, a line of linear amplifiers.

New firms were also formed to exploit the new technology. Signetics, a company created in September, 1961, as a spinoff from Fairchild and originally backed by Lehman Brothers, had brought out its first IC component in early 1962 and expanded its line through the year, already introducing price cuts in late December. Corning Glass Works bought a major share in the firm for about "$1.75" million for which it obtained "close to 50% interest." Another new firm, Siliconix, was formed in March, 1962, with backing from Baldwin Piano and Electronic Engineering, and an initial capitalization of $2 million. Molecular Science, also created to take advantage of the new technology, was incorporated in May, 1962. CBS Labs, a division of CBS, Inc., was talking about more advanced IC circuits than those currently available on the market; it suggested that IC devices could be fabricated that used very low amounts of power--millionths of a watt.

The IC movement was given great impetus in mid-1962. The Air Force, through the Aeronautical Systems Division (ASD), devised a comprehensive plan to incorporate molecular electronic circuitry across-the-board into systems, sub-systems,

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and support equipment.

> Molecular electronics, which has been playing a hopeful understudy for several years, will be elevated to stardom in ASD programs over the next three years.[25]

ASD felt that current techniques had advanced sufficiently that great improvements in size, weight, and reliability could be achieved. A multi-million dollar program was envisioned translating the molecular electronics technology from promise to reality. The plan that took shape pinpointed two dozen areas in which the Air Force felt that it could take advantage of the new technology:

> We feel the Air Force has to go this way and that it can really get some profitable use of the technology right now.[26]

A $40 million annual boost for molecular electronic expenditures was to be recommended, and the $10 million current level of support for research in this area would probably be maintained.

The ASD backing, still tentative at that time relative to its funding level outlays, contrasted with the announcement in December, 1962, that North American's Autonetics division had decided to use integrated circuits in the Improved Minuteman, WS-133B. Autonetics was a prime contractor to Ballistics Systems Division, a sister group to ASD. This move

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[25]J. O'Connor, "ASD Programs to Develop Molecular Electronics Use," Electronic News, July 16, 1962, p. 1.

[26]E. Cocper, ASD, as quoted in J. O'Connor, "Integrated Circuit gets $ Impetus," Electronic News, September 24, 1962, p. 1.

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had been rumored earlier in the year by industry sources. It was felt that if this high-reliability program did turn to integrated circuits to attain its objectives, it would be a tremendous boost for the IC industry. Two contracts were let to IC suppliers with more to come. Texas Instruments received initial funding of about $1 million, and Westinghouse was awarded a contract of lesser magnitude. For both firms, it was the largest IC order each had ever received.

Besides the programs mentioned above, other applications were appearing. NASA would use integrated circuits in a telemetry system for its Eccentric Geophysical Observatory (EGO). A prototype guidance computer using the new components was in development at AC Spark Plug Division; its possible application would be in a rocket-launched space vehicle. The Martin Company had already designed a digital computer using the IC devices with the hope of incorporating the new equipment into its Titan programs.

The Navy was also accelerating its interest in the microelectronics technology. One high Navy official said that the technology appears to hold "the promise of an ideal [for the Navy, and offers] just about everything we do not have but want."[27] This thought was echoed by a BuWeps official:

Microelectronics offers us a solution to our

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[27]Rear Adm. B. F. Roeder, as quoted in "Microelectronics Seen Answer to Navy Needs," Electronic News, October 1, 1962, p. 4.

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problems, and this is the way we are going to go.[28]

The Navy was pushing ahead with its own programs to incorporate various microelectronic components into hardware being produced by its contractors. At the outset, replacement would be piecemeal wherever the new devices could be used without incurring an increase in contract cost. A more comprehensive program was outlined aimed at utilizing the full potential of the microelectronic technology by designing the new components into military systems on a broad front. This plan was called MEETAT (Maximum improvement in Electronic Effectiveness Through Advanced Techniques).

The growing acceptance of integrated circuits and other microelectronic components was realized and commented upon in various circles. Business Week put it this way:

> If the transistor and its brothers and sisters shook up the electronics industry, the tiny devices now under development will turn it upside down reshaping the industry along new, unpredictable lines.[29]

The advantages of the IC component would propel it into new applications spanning the electronic equipment spectrum:

> When you combine these factors [the advantages] with others, including current trends in government accelerating the introduction of integrated electronics,

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[28]Col. A. D. Lowell, Chief, Avionics Division, BuWeps, as quoted in Nilo Lindgren, "Navy to Push Microelectronics Development Program," Electronics, October 12, 1962, p. 24.

[29]"The New Shape of Electronics," Business Week, April 14, 1962, p. 161.

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> an orderly progression from today's complex devices into tomorrow's integrated electronics seems inevitable.[30]

The development of integrated circuits, it was noted, was coming along much faster than anticipated. At two major trade shows, numerous vendors were offering IC products; one show was reported to have ten manufacturers offering an IC product line while the other, five months later, listed twelve in its ranks. The outlook was highly optimistic tinged with only the slightest amount of caution:

> When a circuit containing a dozen or more transistors, resistors, and capacitors gets down to the price of a single transistor [which was the avowed aim of at least one major producer], engineering departments will have a harder time justifying continued use of component-assembled circuits that are only marginally superior in performance, if as good. But the outlook is not for a complete takeover of traditional design.[31]

The continued good business health of firms making discrete components (especially those catering to markets where the IC devices were beginning to make some headway) was questioned. Early in the year, one industry spokesman commented on the subject:

> It is becoming increasingly difficult to believe that a large dollar market will materialize [for discrete components in applications where miniaturization is critical]. [The discrete component approach]

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[30] C. H. Knowles, Motorola, Inc., as quoted in "Broadened Use by '65-'66 Seen for Integrated Circuitry," Electronic News, May 28, 1962, p. 10.

[31] "Circuit in a Nutshell," Business Week, December 8, 1962, p. 88.

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is not really growing as some of us anticipated.[32]

One trade magazine for the electronics industry had this to say:

> The impact of new techniques will be felt at all levels of our industry, and the time to prepare for it is now, not five years from now. . . .
>
> The coming year will be the biggest yet for microelectronics in all its forms.[33]

By 1963, there was more activity on the part of the component manufacturers, the users, the armed forces, and NASA.

Texas Instruments, after receiving two major production contracts for integrated circuits, was expanding the capacity of its manufacturing capability for these components. It had plans to increase its floor space by 290,000 square feet and perhaps add on another 140,000 later. A new IC line was being contemplated, its apparatus division was giving greater emphasis to utilizing them in division products, and the overseas English subsidiary, TI, Ltd., was increasing its IC production.

Motorola placed its first IC products on the market in February, but the complete line of digital components was only available some months later. Before the year was out, Motorola had reduced prices up to 50 per cent on some items; this latter

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[32]W. B. Hayes, Vice-President, Thompson-Ramo-Wooldridge, as quoted in Robert Henkel, "Interest Seen Lagging in Discrete Circuitry," Electronic News, January 22, 1962, p. 46.

[33]"Do It Now," Electronics, September 28, 1962, p. 3.

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move was attributed to production economy, increased volume, and widespread acceptance of its IC product line. Motorola's president indicated the position of his firm:

> We're designing and producing integrated circuits on a custom-built basis for military and OEM [original equipment manufacturers] customers, and the technology is progressing far enough to make production of standard integrated circuits in the next few years appear feasible.[34]

This enthusiasm by Motorola's president was in contrast to some illuminating remarks he made later in the year relative to the price of admission in this burgeoning market. Motorola's capital investment in its IC operation in 1963 was $22 million and less than half this sum was to be allocated for 1964. He did not expect any IC profits before 1965.[35]

Westinghouse moved into a completely new IC facility in late 1963. The plant, staffed with 200 persons, was valued at $2 million with about $3 million worth of equipment; it was to be devoted entirely to the IC operation. The company had also planned to strengthen its position in the linear segment of the market and accelerate its marketing program in this area.

Some new entries were also being heard from. General Microelectronics planned to build twelve plants throughout the country within 18-36 months. It was about to initiate a

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[34]R. Galvin, President, Motorola, Inc., as quoted in Al Wrigley, "Motorola Semicon Volume Rises 25-50% for 3d Year," Electronic News, March 18, 1963, p. 80.

[35]J. Lydon, "No Integrated Circuits Profit Seen at Motorola Before '65," Electronic News, December 16, 1963, p. 31.

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ten-year capital expenditure program costing $250 million.[36] It hoped to offer an IC product line directed to all markets. International Resistance Corporation also entered the IC market. General Instrument Corporation, already involved with discrete semiconductor components, was developing a broad microelectronic product line, including integrated circuits. Corning, to capitalize on its strong capability in glass and ceramics, was initiating a development program to meld both thin-film and semiconductor techniques for a new microelectronic component line.

In the spring of 1963, the Department of Defense directed all the military services to use microelectronic circuits wherever possible. At the same time, it urged NASA to do likewise in order to obtain the high reliability needed for the latter's projects. Somewhat later, a DOD official suggested that 77.1 per cent of all military electronic gear will consist of microelectronic circuitry by 1970.[37]

The Air Force continued its strong support for programs in molecular electronics. A $290,000 six-month contract was let to ARINC Research Corporation to extend a state-of-the-art survey which had been started earlier. It was also funding programs directed to the future design and fabrication of integrated circuits using computerized techniques.

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[36] J. Lydon and W. Mathews, "GME Plans Set for Wide Diversity," Electronic News, August 26, 1963, p. 10.

[37] "Micro Gear to Dominate: Defense Aide," Electronic News, September 30, 1963, p. 29.

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NASA, then funding R&D microcircuit programs at a yearly rate of about $1 million, was expected to increase its support in this area. Semiconductor circuits, it was claimed, offered "tremendous potential" for future spacecraft and missile use.[38]

The ascendancy of integrated circuits raised various problems for other firms in industries affected by the new technology. Manufacturers of passive components--namely, resistors and capacitors--in an effort to protect their own markets from further penetration by the integrated circuit were evolving their own IC capability. Meanwhile, the systems firms that bought from the component houses were faced with a different kind of problem brought about by the rise of the IC technology:

> Small sands make a mountain, someone has said, and miniature parts will bring big changes to the industry. The move toward microcircuitry and specifically integrated circuits is accelerating.
>
> Just where the trend will end cannot be seen though many persons have their own opinions. It is evident that some strange moves are taking place. Here and there systems manufacturers are undertaking the production of parts and some components producers are moving in the direction of systems work.[39]

Some systems manufacturers faced with an increasingly larger percentage of their design work being performed through outside procurement were entering the component field

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[38]Philip Trupp, "NASA Stress on Semicon Microcircuit," Electronic News, January 21, 1963, p. 1.

[39]A. D. Cook, "Letter to the Editor," Electronic News, February 18, 1963, p. 2.

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themselves. Components people, in turn, were attempting to thwart such decisions by building even more sophisticated IC circuits. The make-or-buy decision was one that confronted both types of firms--systems and component--with complex alternatives.

Final comment

This documentation of the progress of the IC technology (with little editorial comment by the author) depicts the very wide press coverage given by the press literature to the subject. There is much that has been omitted since a good deal of the material written is basically redundant, as various magazines and other members of the communications media report on the same events.

It is important to mention that the coverage of the technology was not only given considerable space by these publications, but it was often critically located and headlined, so that even the casual reader would have to take notice. Typically, in Electronic News for instance, major advances, events, and commentaries were given front page space, adding to the impact of their reportage.

Some of the editorial staffs not only reported on the news, but made it themselves when they felt that a topic was particularly newsworthy. Besides the editorial page, surveys were frequently initiated to obtain opinions on matters of import. In this way, much of the current feeling was obtained (sometimes anonymously) from the practitioners actually

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involved in, affected by, and making the decisions influencing the forward movement of the IC technology.

It is the combination of all these factors which (the author feels) was very conducive to creating a positive climate for the new technology. Without this publicity, it is highly doubtful if the transition to integrated circuits would have been as rapid. Although its absolute contribution is obviously unknown, it is safe to say that its presence expedited the whole process.

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CHAPTER V

ANALYSIS

Introduction

There are several obvious problems which arise when one attempts to analyze critically a sequence of past events, and then comment upon the various factors that contributed to it. If the subject were one completely rooted in the past, the difficulty would be eased. But this is not the case here. The origins of the IC technology trace back, for the most part, to the late fifties and early sixties, but their impact is very much with us today. The technology represents the area of greatest interest and volatility in the electronics industry today. There is scarcely an application using electronic components which is not in some way being considered for IC usage--at least in part--at present or in the near- or far-future. This circumstance presents the most basic impediment to objectivity, for the laboratory oddity of a half dozen years ago has become today's success story. As was discussed in Chapter I, its acceptance is documented by its sales history over the past few years, and there is no reason to believe that its near-term growth will be dampened. Even now, there are actions being taken within military and industrial institutions indicating that the growth already

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experienced will be relatively insignificant compared to its future prospects.

A success story invariably creates a multitude of "halo" effects, i.e., those who were instrumental in the development are quick to recognize their own contribution--usually placing it completely out of proportion to reality--while those who were not originally enthusiastic for the idea have changed--or been forced to change--their evaluation and are now supporters. Indeed, some of the latter group have since become members of the original crusade that initially favored the now successful and accepted alternative.

There is undoubtedly a great deal of ego involvement in such associations--and this is natural. The inclination to be part of the winning team is a universal one; we are probably all prone to it to some degree. Besides this difficulty, the analysis is aggravated by two other factors which compromise and complicate the task of impartial criticality to exponential dimensions: the passage of the years and the limited span that any person or group always has.

Most of the material discussed by the author during the extensive interviewing related to events that occurred five to ten years ago; a small part of the conversations related to events, decisions, and actions of the past few years. For the vast majority of the cases, the interviewee did not resort to any form of documentation; he extemporized as the questions were posed. Although some of the answers could be cross-referenced, the bulk of the discussions dealt with impressions

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and opinions which were difficult to verify. The problem of cause and effect was apparent. Can a particular event be directly and only attributed to the specific cause suggested by the individual? This is certainly difficult for a listener to confirm, and it is most probable that even the speaker does not know the "whole story." Often there were contradictory reports on exactly the same occurrence.

There is also the uncertainty caused by the passage of time, in which events occurring years ago are muddied by subsequent happenings, including those having nothing to do with the subject of interest. There is the natural tendency to preoccupy our minds with matters which are of current import. Often a question brought a response akin to a derrick dredging a river: the respondent was evidently going deep into his memory to formulate his answer. In a general way, this reaction combined with the aforementioned "halo" effect tend to dilute the value of the interview technique.

Finally, the truism should be cited that any person sees the world through the constraints of his own particular work and interest areas. There were very few people interviewed who were knowledgeable of <u>both</u> the economic and technical considerations that prevailed in the industry during the time in question. The more capable the individual in either discipline, the less his competence in the other. The differences between persons from the various Government agencies and those from industry were marked. The former

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generally had a much more insulated view of the world and the influence of their own actions on particular events. The industry sources, on the other hand, had a more realistic and secular understanding of how and why certain occurrences came to pass. The need for self-praise or ego-enhancement was much less apparent--generally--with this latter group.

Problems notwithstanding, this analysis section combines inputs from interviews, literary research, and the author's own experience. It will review critically the past events of the semiconductor industry and the IC technology development to determine causal motivations. This will serve as the basis for the final conclusions offered.

The Semiconductor Components Industry as an Economic Entity

Introduction

The semiconductor components industry is an economic institution. Whatever other things it may do poorly or well, it must act first as an economic entity. We may associate many other characteristics with the business enterprise but, as Peter Drucker so cogently argues in his The Practice of Management, its economic performance is its first yardstick. Whether profit maximization is its goal will not be argued here; profits are certainly of concern and no firm, except under the rarest of circumstances, is willing to endure a loss for a prolonged period of time. The semiconductor components

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industry of the fifties was, with one major exception, a group of divisions within larger firms. Most of these larger corporate entities may be called systems firms, i.e., companies that sell finished products to a customer as an end-use item. (The differentiation stressed is the realization that these firms did not supply others with product inputs which in turn were used to make a final product.) Although one may argue that having an unprofitable division within a larger corporate body may have other salutary effects for the organization as a whole, this is generally not viewed as a desirable situation, but one that is only tolerated, and probably only for a relatively short time. The corporate management will ultimately have to deal with the problem and make a decision relative to this division, e.g., leave the business in the particular field in which the division is participating. Whatever other myriad of factors may prevail, the business firm must still look to its profitability.

The participants

As mentioned earlier, the semiconductor industry and particularly the transistor segment of that market enjoyed a phenomenal growth rate in the period from the mid-fifties to the very early sixties. Of the three companies which have been the major innovators in the IC technology--Texas Instruments, Fairchild Semiconductor, and Westinghouse Electric--the first has consistently had the largest share of the semiconductor market since the mid-fifties; the second began operations in

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late 1957, and has been a very strong contender since then; and the third had a fairly strong share of a very narrow segment of the market in the late fifties, but was insignificant relative to the overall picture. A further look at these firms--and others--is called for.

Texas Instruments Incorporated

Texas Instruments, formed in 1930, had sales of about $4 million in 1947, all derived from geophysical services. In the fall of 1951, when Western Electric offered transistor licenses to industry, Texas Instruments quickly paid the $25,000 asking fee. It had been contemplating such a move since 1950 and prepared accordingly. It entered the transistor business and was a pioneer in marketing germanium transistors. By persuading Regency Radio to produce a radio receiver using these components--a project which cost Texas Instruments $2 million as its part of the investment--it gained a strong hold in that market.[1] In 1954, it successfully developed a silicon transistor--at a time when the rest of the industry was still working on the germanium type--and had practically no competition in this field until 1958:

> Competition is extremely keen [in the semiconductor market], but in the silicon transistor field, Texas Instruments is the only factor of importance.[2]

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[1]John McDonald, "The Men Who Made T.I.," Fortune, LXIV, No. 5 (November, 1961), p. 224.

[2]Letter from investment firm to client, September 19, 1958.

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The company's sales and profits from 1955 to 1962 are given below:

TABLE 3

TEXAS INSTRUMENTS SALES AND PROFITS: 1955-1962
(millions of dollars)

Year	Net Sales	Net Profit
1955	28.7	1.6
1956	45.7	2.3
1957	67.3	3.8
1958	92.0	6.0
1959	193.2*	14.1
1960	232.7	15.5
1961	233.2	9.4
1962	240.7	8.6

*In 1959, the company obtained Metals & Controls Corporation which was valued at about $50 million.

Source: Standard & Poor's Corp., Standard Listed Stock Reports.

From 1953 to 1959, stockholders' equity multiplied better than eight times to $56.7 million, and from $5 a share the stock price rose to a 1959 high of $191; it was to go even higher.

Table 3 naturally refers to Texas Instruments in toto. Although the exact figures for its semiconductor operation are not publicly released, there are some unofficial estimates that have been made. In a Fortune article, the firm

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was said to have had 16 per cent of its 1955 revenue derived from transistor sales. In 1956, about half of the firm's sales increase came from transistor revenues, and in 1957, the same was true with respect to its silicon transistors.[3] One market analyst, not with Texas Instruments, estimated the company's semiconductor sales to be the following:

TABLE 4

TEXAS INSTRUMENTS
ESTIMATED SEMICONDUCTOR SALES
1955-1961
(millions of dollars)

Year	Sales
1955	4
1956	12
1957	26
1958	50
1959	82
1960	108
1961	98

The Fortune figures substantially agree with those above except for 1961 in which it estimated $126 million to be the sales. (Since the article appeared in late 1961, it was probably written considerably earlier at a time when more optimistic forecasts were being made, i.e., before the 1961

[3]John McDonald, "Where Texas Instruments Goes from Here," Fortune, LXIV, No. 6 (December, 1961), 112.

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debacle was apparent.) The article also mentioned that the company gets half of its sales and more than half its profits from its semiconductor operations. In reviewing its net income statements, from interviewing various TI personnel and other knowledgeable individuals close to the industry--some of its competitors--there is an almost airtight case that Texas Instruments had an extremely profitable semiconductor business in the late fifties; the first dark clouds formed in 1961, when its sales were sharply affected by the general collapse that hit the whole industry. Even then, the transistor operation thrived:

> Despite the price collapse, TI's Transistor Products division moderately increased its percentage share of the millions and millions of transistors produced for this market and in the process turned in both relatively and absolutely the largest profit of any of our divisions [for 1961].[4]

As one TI spokesman said, "TI was making loads of money." This was the consensus of the industry.

Fairchild Semiconductor

Fairchild Semiconductor, a subsidiary of Fairchild Camera and Instrument Corporation, was founded in December, 1957, by a group of scientists that left Shockley Laboratories of Beckman Instruments. The management of Fairchild Camera agreed to underwrite the expenses of the group for eighteen

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[4]Speech by P. Haggerty, President, Texas Instruments Inc., before shareholders meeting, Dallas, Texas, April 18, 1962.

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months in return for an option to buy 100 per cent of the shares of the new operation at the end of the trial period. The group would attempt to fabricate and market an improved high-speed transistor. At the end of the eighteen months, the mother company opted to pick up the shares; each of the original eight members received Fairchild Camera stock which, at the time of the transaction, was worth about $250,000. The stock quickly increased in value.

The semiconductor group did not have a marketable product until late 1958, and full transistor production began in 1959. The 1958 sales were about $0.5 million, 1959--$7 million, 1960--$21 million, and 1961--$27 million. These figures are not official, but are a composite from several sources in which the individual variations were not very great. It is of interest to review the total corporate picture of Fairchild Camera during this period and for the years previous. These figures are shown in Table 5.

The fortunes of the parent corporation track the progress of its semiconductor division so closely that it cannot be attributed to coincidence. From 1955 to 1958, the organization has a less than impressive record both in sales and earnings; in that period, the progress is negative. In 1959, the first year the semiconductor division began to market in earnest, net income as a percentage of sales jumped to nearly 5 per cent from a dismal 1.6 per cent the year before. It continued to climb through 1960 though at a less spectacular rate.

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TABLE 5

FAIRCHILD CAMERA AND INSTRUMENT SALES AND PROFITS
1955-1962
(millions of dollars)

Year	Net Sales	Net Profit*
1955	33.1	0.8
1956	43.0	0.7
1957	37.0	0.8
1958	31.7	0.5
1959	43.4	2.1
1960	67.9	3.8
1961	92.3	5.3
1962	101.5	6.0

*Various tax credits are included in the net profit column.

Source: Standard & Poor's Corp., Standard Listed Stock Reports.

One source close to the industry stated that in a recent period within the past year nearly all of the parent's profits were derived from the semiconductor operation; all the other divisions were either unprofitable or contributed very little to the aggregate. As one analyst said in a Business Week article:

> If I could buy just the Semiconductor Division, I might do it, but I can't see paying a premium for Fairchild's management and all the uninteresting stuff you have to take with Semiconductors.[5]

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[5]"What Made a High Flier Take Off at Top Speed," Business Week, October 30, 1965, p. 122.

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An indication of the success of the semiconductor group is the recent reorganization that took place in the overall corporate management. The marketing manager from the semiconductor operation, who had been in that position since the group's formation, became head of the firm's instrumentation division. The man who had been the only manager of the semiconductor division became a group vice-president with both the semiconductor and instrumentation divisions answering to him.

The same conclusion is reached for Fairchild Semiconductor as for Texas Instruments: the semiconductor operation was very profitable soon after its inception and became a major participant in the industry. This is a general consensus from many persons both inside and outside the firm.

Westinghouse Electric Corporation

The arguments reached for the previous two companies discussed do not hold for Westinghouse. Its revenue from semiconductor products was a totally insignificant portion of the income derived by the industrial giant; 1959 company sales were $1.9 billion. The semiconductor operation was never and still is not a major factor in the overall industry. One estimate of the industry breakdown, in 1960, did not even list Westinghouse explicitly in its rundown of the sales of various firms; the smallest revenue listed was $10 million.[6] It was

[6]"Seven Western Semiconductor Manufacturers," Service to Management -- Electronics Industry (Arthur D. Little, Inc.), December, 1960, p. 30.

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not listed in the firms which comprised the "Other" column. Similarly in 1961, the company was not cited in a group of firms in which the smallest contributor had an estimated sales of $8 million.[7] On the other hand, one observer within the industry listed Westinghouse's semiconductor sales, in millions of dollars, as follows for the years 1958 to 1961: 2, 6, 14, 15. Whatever the exact figures are, it is certain that the semiconductor operation of Westinghouse was not a significant factor within the company or relative to the rest of the industry. It had a small market that specialized in semiconductor power devices. It is exactly because of its lustreless position that this firm became a factor in the IC technology; this will be discussed at length further along.

Motorola, Incorporated

The three firms mentioned above all had some stake in the semiconductor market before integrated circuits came on the scene. Since they were the first ones to participate in the infant IC technology, the center of attention must be placed with them. In today's market, these three and two others command the IC business. With respect to the other two, one (Signetics) was created in late 1961 solely to exploit the IC technology. The other (Motorola, Inc.) entered the market through competitive pressures; its own stake in the

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[7]Barry Miller, "Microelectronics Causes Avionics Turmoil," Aviation Week, March 19, 1962, p. 57.

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industry might have been in jeopardy since two of its major competitors were already entrenched in the new field. The former company will not be discussed at all since it has no direct bearing on the IC innovation process. The latter, however, is of interest since it is now a major factor in the IC market, and because it was a latecomer with a great deal to lose if it could not become a strong competitor in this area.

The semiconductor operation of Motorola was a relatively late starter in the field. It has become, especially in recent years, a major contender reputed in some circles to be second to Texas Instruments in total semiconductor sales. The estimated revenue of the semiconductor division for the years 1956 through 1962, in millions of dollars, was: 3, 4, 5, 9, 24, 30, 40. The picture for the whole organization is as follows:

TABLE 6

MOTOROLA SALES AND PROFITS: 1956-1962
(millions of dollars)

Year	Net Sales	Net Profit
1956	228	8.0
1957	226	7.8
1958	217	7.4
1959	292	14.2
1960	301	12.6
1961	298	9.5
1962	347	13.2

Source: Standard & Poor's Corp., Standard Listed Stock Reports.

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There is no obvious correlation between the division operation and that of the parent. The growing importance of the semiconductor division's contribution relative to the whole is perhaps the most revealing conclusion that can be gathered from review of the data. This has serious implications for a company like Motorola which has a very strong hold in some important equipment markets.

From various industry sources, the impression is obtained that the Motorola semiconductor operation, which was primarily in-house up to 1958, was probably losing money. In 1958, the only semiconductor component in volume production was a power transistor. The semiconductor division supplied devices to its sister divisions, and there was an obvious mutual need. The sharp jumps in the firm's semiconductor sales can probably be attributed to the success it had with its zener diodes and mesa transistors which were introduced into the market in the late fifties. It has also been successful in supplying low-cost semiconductor components for automotive equipment. Combined with the communications work done by the parent, the company has been a leader in these areas.

Transitron Electronic Corporation

Transitron was founded in late 1952 by two brothers who held all the outstanding stock until 1959. It is the only firm of major proportions that was originally devoted exclusively to the manufacture of semiconductor devices; it therefore presents a good study example. Its sales and profits are shown below:

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TABLE 7

TRANSITRON SALES AND PROFITS: 1955-1962
(millions of dollars)

Year	Net Sales	Net Profit
1955	3.9	0.7
1956	7.5	1.2
1957	16.1	2.3
1958	17.1	1.9
1959	30.9	6.5
1960	47.8	8.1
1961	37.1	-1.5
1962	28.8	-0.8

Source: Standard & Poor's Standard Listed Stock Reports.

Transitron has experienced both the peaks and valleys of success. Through the late fifties, it was generally considered to be number two or three in the industry based on semiconductor sales. In December, 1959, 13 per cent of the company's outstanding common stock--one million shares--was sold at $36 per share; this was the equivalent of a market valuation for the firm of about $277 million. Its price-earnings ratio then was over 40:1. Eleven months later, a second offering of 1,250,000 shares sold for $35 each. Within less than one year, the market had paid about $80 million for 30 per cent of the outstanding common.

The company had several strong product lines concentrating on military applications. It contended that its

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semiconductor operation was probably more profitable than that of Texas Instruments since it catered primarily to the military customer--Texas Instruments was active in non-military markets--and the accompanying profit margins were higher. It also attempted to keep its costs down by buying old textile mills rather than constructing new manufacturing facilities.

Transitron was seemingly very successful through 1960, but in the light of future events there should be some eyebrow-lifting relative to the degree of its success. In June, 1961, the company incurred a $7 million inventory write-down. Although write-downs at that time were common, Transitron's was considerably greater than that experienced by any other firm. (It should be added that if the other semiconductor firms did incur write-downs, it would be "buried" in the overall company's statements; since Transitron was basically a semiconductor house, its semiconductor operations were public knowledge.) Still in all, there is very strong feeling that Transitron through the years was particularly flagrant in its accounting techniques and was therefore prone to such a debacle when the proper exogenous conditions arose.

The firm also had a reputation within the industry as being particularly shortsighted in its internal R&D expenditures. There is a consensus that in its desire to buoy up profits it "cheated" on its R&D outlay in an industry which cannot condone such a policy in the long run.

All these considerations included, there still seems to be little doubt that Transitron was quite profitable in the

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late fifties; how much, based on conservative standards, is subject to question. Its later problems were aggravated by the idiosyncrasies of its internal operations, but its fundamental difficulties were experienced by almost all the participants in the industry--at least to some degree.

Radio Corporation of America and General Electric

These two firms, though major factors in the discrete components semiconductor industry, have been very erratic in their policies relative to integrated circuits. Although their semiconductor operations were considerably bigger than those of Westinghouse, the same problems in analysis apply. Their semiconductor business represented a small percentage--probably of the order of 1-3 per cent--of the aggregate sales of each parent. It is extremely difficult to comment on the profitability of these semiconductor groups; there is a considerable disparity of opinion as to whether they were profitable and, if so, how much.

Philco Corporation and Hughes Corporation

The similar kind of division aggregate problem arises again, but it is widely held that the semiconductor operations of both these firms were once highly profitable. Due to varying problems, both suffered turn-arounds. Philco has dropped its discrete semiconductor work and is concentrating its efforts on the IC market; this decision was made in late 1963 or early 1964; Philco is not a consideration in the IC

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innovation history. Hughes, on the other hand, has yet to enter the field, although it seems to have already been on the brink several times. Both firms once had very strong holds on different segments of the semiconductor market.

General Instrument Corporation

This firm, which acquired General Transistor Corporation in 1962, had a good share of the semiconductor market in the late fifties and early sixties--probably running about 5 per cent. It has been in and out of the IC market opting presently to place its major emphasis on a new device called an MOS (metal-oxide-semiconductor). The profitability of its past semiconductor operations is in doubt since this division is also part of a larger firm.

Final comments

There are various answers to the question "Was the semiconductor components industry profitable in the late fifties, early sixties era?" Most observers agree that in the latter part of that time period, the answer is yes. Almost all agree--the author cannot recall any dissension on this point--that several of the firms were extremely profitable. Some of the more observant respondents see an industry that has had a great many participants come and go or just "hang on." The firms that experienced negative, zero, or very low profits tend to offset, in the aggregate, the fine showings of the fewer, very successful competitors. This point is

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extremely difficult to substantiate, one way or the other. Even if it were true, it does not offer much to the argument. The firms that innovated in the IC technology were the successful ones; the broad industry picture is not really relevant for this discussion.

Profit has been referred to more or less in the traditional manner that one views it relative to the economic welfare of a corporation, i.e., as a profit and loss center on its own. But systems firms may carry unprofitable components divisions, since the final products in which these components are used by the systems groups are profitable. This is a good example of an opportunity cost. Although some semiconductor operations were always cited as being profitable, there was no such consensus for General Electric or RCA; if anything, the feeling was that sometimes the systems operations "carried" the components groups. Whatever the validity of these contentions, the subject was not investigated except in the most peripheral manner. There are three reasons for this attitude. First, it is extremely difficult to obtain data about divisions in large multi-divisional firms. Second, the problem of commonality of comparison becomes practically unworkable when some component operations must survive completely on their own merits, while others are buoyed up by sister divisions. Third, we do not look to these companies when IC innovation is discussed. At present, the IC market is dominated by two firms whose livelihood is closely tied to the profitability of their semiconductor and IC operations.

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One veteran observer stated that "80% of the semiconductor manufacturers were making good profits in the late fifties." Whether that number is correct or not is debatable. It seems fairly certain, however, that those who were successful did very well. If the argument has not been proven conclusively, then certainly the weight of the evidence points in one direction.

The industry's view of the future

The previous section dealt with the economic status of the semiconductor industry as an accountant might view it. Since his orientation, by necessity, deals with the past, it is obvious that we are still confronted with perhaps the most critical point in the whole analysis: What did the industry, as well as its single firms, see in the future? Depending upon one's expectations of the future relative to one's own particular firm, the industry at large, and even the economic prospects for the country and for the world, present and certainly future actions will be greatly influenced. Some of the data presented were not available at the time in question, e.g., the status of Transitron did not become public knowledge until 1959 when the company went public; prior to that time, there was no full awareness of the firm's success (although there had been much to indicate that it had been doing well). If a firm fears reduced future profits on its present line, then this may be good cause to look to new products. Here, the reasoning traces back to Schumpeter's basic thesis that

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profits go to the innovator; if one product (line) is expected to become less profitable, then a new one--if the firm can bring forth a new, salable product--can take up the slack. On the other hand, innovation may be encouraged when the firm is doing well and expects to continue to do so. This, in some ways, is the best time to seek innovations since there is a sound financial foundation from which to base one's efforts. Some consider this the best time to move in such a direction, since the action is motivated through strength (expected, at least) rather than fear and the attendant problems. Indeed, the argument can be waged on both sides, and there are cogent reasons that persuade in either direction. Perhaps the basic question resolves to: "If the firm does innovate--and this does not mean to imply that all firms do regardless of what their economic status is, present or expected future--is it motivated by a replacement stimulus, a growth impetus, or perhaps even some other factor?" This difference is most critical since its determination may offer insight into corporate management philosophy: how a firm views the future and decides to exploit it. Different firms faced with identical situations may choose to confront the future in entirely different ways.

First, it is necessary to review what actually did happen to the industry in the early sixties. Through 1960, the industry maintained its phenomenal growth record, as depicted in Figure 2 (page 77). In 1961, based on EIA figures, the transistor revenue ceased rising--1960, $301.4 million to

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1961, $299.5 million--and the non-transistor segment of the semiconductor market decreased slightly--1960, $231.4 million and 1961, $219.2 million. While the total revenue from semiconductor components dropped about 2.5 per cent, the unit volumes were still sharply on the increase. In the same two-year period, unit sales of transistors rose nearly 50 per cent, from 128,000 to 191,000, and the diode and rectifier unit sales increased by just over 50 per cent.[8]

The transistor debacle presented the worst picture when contrasted to its growth in the previous years. Its progress had been more rapid than the other component lines. It was cited previously that the transistor growth rate from 1954 to 1960 was nearly 100 per cent compounded yearly on a dollar basis. The equivalent growth rate for the non-transistor products was about 33 per cent. The movement of the industry, and indeed the image of the industry, was centered around the transistor; if that component fell from favor, its fall would be all-encompassing.

The reasons for this seeming downfall were many and varied. Basically, it was a classic example of an industry and especially a few firms experiencing the fruits of success and then not being able to cope with the ensuing problems. There were also new entries offering no new products but

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[8]The non-transistor sales of the semiconductor industry include more than silicon and germanium rectifiers and diodes. EIA lists other groups for which it gives dollar figures but no units. The dollar sales for the industry are all-inclusive.

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selling older, accepted lines at lower than the previous prices. Overproduction existed due to a combination of increased output from entrenched and newer firms and highly automated assembly lines that raised the throughput, i.e., the number of good items obtainable for a given time. Learning curve improvements had raised the yields and, coupled with other factors, the market was no longer production-limited.

Certain facets of demand were also shifting unfavorably. In 1959, Japanese imports began to have an effect, increasing in both units and dollar value through 1961. Their greatest impact was on the low-quality lines that included the older, high-volume types. The industry, especially in the late fifties, had both high volume, low per unit profit lines and relatively low volume, high per unit profit products. Japanese imports threatened half of this tenuous balance. There was also some decrease in Government orders, as major programs were being phased out and some of the effects of the lower spending rates in the last Eisenhower years were being felt.

Texas Instruments' stock, which had been as high as 256 in May, 1960, fell to below 100 by late 1961. At the same time, Transitron's stock, which had once risen to $60--a common stock valuation of $450 million, not quite ten times its 1960 sales volume--was selling at $18. The earnings of several of the participants dropped sharply; a major contributor to the fall was often the inventory writedown which is inevitable when a firm's products are experiencing radical

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price decline to a less-than-cost valuation.

The inventory problem has received much publicity and perhaps this difficulty, as much as any other, typified the problems of the industry. From the outset, the industry was not overly diligent in its accounting techniques. The firms were generally run by a technical management, both unknowing and indifferent to the subtleties of the accounting art. Also, the managers probably leaned away from conservatism, since they apparently wanted profits to increase and the net worth of the firm to appear as high as possible. There are several obvious reasons for this. They were riding the crest of a wave in which transistors were in high regard, and their industry was the epitome of American technological know-how and ingenuity. Over and above all other factors, inventory had not been a major problem since a sellers market had prevailed. Finished goods in inventory made up a small percentage of the current assets. Moreover, inventory for firms making semiconductor products was basically in finished items rather than in goods-in-process or raw materials. A combination of conditions existed--low inventory, no exact knowledge of costs, no great interest in obtaining precise figures for inventory valuation--to allow the inventory situation to remain as a latent problem. As one observer put it:

> There was practically no real honest-to-God cost control over the manufacturing process.[9]

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[9]Interview with experienced industry participant, November 29, 1965.

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If the industry was less than an accountant's paragon, there are some cogent arguments which help to excuse such a lapse. The problem of exact or even good inventory valuation of semiconductor products is extremely sticky and arbitrary. Although standard off-the-shelf products were offered by vendors, a good deal of the purchases were custom-ordered, since certain variations were usually requested by the purchaser. This was especially true for military work. When a particular lot of items was fabricated, some components were not within the customer's specifications but still capable of functioning. The good products were sold and presented no problems. The difficulty, however, began with properly placing a valuation on the remaining items. First, unless the latter were completely inoperable--dead short or completely open--they were not discarded (and some observers doubt whether this was always the case). Proper accounting insists that these units be carried on the books at cost or market, whichever is lower. As stated, cost accounting techniques were not exemplary, and there is a wide consensus that, except for some of the larger, more competent firms, the business just didn't know what the per unit costs were. One interviewee cited that these fallout items were typically carried at burden loading; he did not state how the burden rate was determined and allocated.

As for market value, the determination was fraught with even more difficulties. New products were being continually introduced, prices were in a constant state of

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transition with very little stability over an extended period of time, and the products offered were very diverse. The homogeneous product of the purely competitive model was non-existent. In the early days, when the manufacturers could sell everything they made, the market price was probably considerably above the actual cost even if the latter was reckoned in a very crude manner with high imprecision. When the inventory levels began to mount--when the market began to favor the buyers--the determination of actual market value took on critical significance. For the reasons cited, this becomes an almost impossible task. The fallout items mentioned above were compatible with no particular customer's need. The lucky vendor might be able to fill another outstanding order with some or all of them. More likely, they went on the shelf, hopefully to be called upon at some future date when their characteristics approximated those of an unfilled order. But at any given point in time, for any particular semiconductor component, the demand for it might be zero. If, for instance, the original specification called for components which had to be operable at 125°C, fulfilling a certain performance capability, and the rejects in question were only satisfactory to 90°C, there may be no specific need for this type of component. Its valuation was, at best, guesswork based upon the prices at which similar units were selling. To aggravate the situation, when the fallout (salvage) rate was high, the number of rejects increased accordingly. The potential selling price of 100 identical devices was not the same as that for 1,000 or

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10,000 of the same type. The same difficulty arose when new products obsolesced older ones sitting on the shelf; what was a salable item a short time ago now might have a very small or no demand. In an industry where fast technological changes are the norm, such an occurrence was very common.

A combination of events forced the semiconductor firms to reevaluate their inventories. Transitron in June, 1961, took a $7 million writedown which helped turn a 1960 profit of $8.1 million into a 1961 deficit of $1.5 million; in that time period its sales dropped about 22 per cent. Pacific Semiconductor suffered an approximate $3 million writedown, and Hughes also took a heavy loss in this manner. All the semiconductor firms were probably affected to some degree, but those that had instituted periodic writedowns were not as adversely struck.

Another misleading technique sometimes employed by firms was the capitalization of R&D expenditures rather than expensing them in the accounting period in which they were incurred. One company applied a five-year straight line amortization of its $180,000 for research in one year and only charged $9,000 to operations.[10] This occurrence was probably not too prevalent. In all the conversations in which this point was raised, the respondents all claimed that their own companies and the overall industry expensed R&D costs rather

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[10]"Glamor Industry Takes Its Lumps," Business Week, November 11, 1961, p. 113.

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than capitalizing them.

From all the information gathered on this subject, there is no doubt that the difficulties encountered by the industry in 1961 were unforeseen. Without exception, observers have concurred on this one point. Some have suggested that a fall was not unexpected, but not so acute as the one actually experienced. Others have mentioned that there was not the slightest inkling of a slowdown, even though the industry was aware of the yearly price declines. If the most pessimistic of observers had predicted an industry sales volume of $600 million for 1961, he would have been labelled as a Cassandra. From 1959 to 1960, transistor sales increased by 39 per cent while the average unit price decreased from about $2.70 to $2.40. Texas Instruments predicted that industry sales would hit $640 million in 1961.[11] Another firm forecast that its 1961 semiconductor revenue would be $36 million; it was actually $29 million.

Some suggest that the first intimations of impending disaster came about the last quarter of 1960. Among other considerations, several new firms, such as Fairchild Semiconductor and Motorola, were becoming very strong competitors. If some sensed faint shadows in late 1960--and very few said they did--no one suggested in the late fifties that the future was anything but positive. In all the conversations, there was not the slightest hint that future growth would be

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[11] McDonald, Fortune, December, 1961, p. 112.

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deterred, notwithstanding the maturing of some lines such as germanium diodes. It is, the author believes, a fair assessment of the mood of the industry to state that it projected a future for itself of unfettered growth.

The best example of the sign of the times relates to some work done by a major consulting firm for an important company in the semiconductor market. This latter company was basically a systems house, but it had a very active semiconductor operation. Throughout the fifties, its semiconductor division had a strong market, although its absolute sales volume had risen unimpressively during that time period. According to the report, in no segment of the market--military, capital equipment, consumer, distribution, export--did it strengthen its hold and, indeed, in some it went from a major position to one of relative insignificance. Over the approximately seven year span ending in March, 1959, the net loss for the division was between $1 and $2 million. This aggregate loss was experienced during a period when some other firms were enjoying large profits on their semiconductor operations.

The recommendation of the consulting firm, written in June, 1959, is perhaps typical of the euphoria which pervaded the industry and those associated with it:

> The semiconductor division [of Company X] serving a growth market is requesting approval of appropriations for additional facilities that would (1) approximately double its present production capacity, and (2) provide new and consolidated quarters for its administration and engineering activities.
>
> Within the scope of the study, we have reached two major conclusions with respect to [Company X's]

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opportunities in the semiconductor field. These conclusions are:

1. The semiconductor field does offer [Company X] attractive profit opportunities because the total market demand in the United States for semiconductor devices should continue to expand significantly during the next several years, and

2. [Company X] has or is actively seeking the resources, facilities, and personnel to enable it to grow at least as fast as the industry.[12]

In the light of the division's poor showing over the years, both in a relative and absolute sense, these final suggestions are of great interest. At first glance, one would expect that the parent should drop its semiconductor operation. In informal discussions with the corporation's top management, this recommendation was made. The firm ultimately decided to stay in the semiconductor market; it heeded some of the suggestions contained in the report. At least two of its reasons for remaining were its optimism for the future of the entire market (and its own potential capability for gaining a greater share of it), and the company's fear lest the financial community react negatively should it drop this operation; i.e., it would be a patent sign of weakness to leave the semiconductor field at a time when the growth potential, by common consensus, was tremendous. There was also an argument made for the division's ancillary value to its sister groups within the corporation; again, an opportunity cost is apparent.

From all indications, the semiconductor operation of

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[12]Letter from consulting firm to president of company, June, 1959.

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this company was in very bad condition. Taking into account other factors not discussed here, there was no facet of its business showing strength. The recommendation to spend several million dollars to make it competitive seems to have been very questionable. The division has remained in this field, continuing to maintain its indifferent performance in integrated circuits and most probably losing money in this area also.

As an interesting epilogue to this incident, the consulting firm also listed its estimates of the future semiconductor market for the subsequent five-year period. Although its forecasts turned out to be relatively conservative absolutely, it contained no hint of a slowdown in growth for the industry. It, too, standing outside the industry and without an "axe to grind," gave an optimistic forecast of the growth rate.

As one head of a major semiconductor firm said:

> It [the 1961 collapse] caught everyone. . . . [It was a] major mess![13]

It is easy to be wise in hindsight and point to weaknesses which augured future problems for the industry. This has not been the purpose of this section. From the industry's standpoint, it is important to establish the mood which prevailed in the late fifties and early sixties relative to the industry's appraisal of its future prospects and prosperity. Although the days of reckoning did come, there were

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[13]Interview on November 5, 1965.

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no harbingers beforehand; quite the contrary:

> The industry is entering into a 30- or 40-year period during which solid-state physics will dominate and point out the course for the future.[14]

In May, 1960, a Department of Defense survey reinforced the optimism which Dr. Noble's statement implied:

> About 60 percent of the companies [manufacturing semiconductor devices] responding . . . indicated that they planned to expand their semiconductor facilities in the next 2 years, in which case semiconductor manufacturing and R & D facilities will be approximately doubled by the end of 1962. . . .[15]

Combined with the documented review of the progress of the industry as described in Chapter III, the evidence clearly indicates that the industry, and those outside including the financial community, were geared for continued growth--price declines notwithstanding. If the industry did turn to integrated circuits, it was not because it feared a future lack of acceptance of its products.

The economic impetus for innovation

The previous two sections endeavored to point out two major factors:

1. Many of the firms within the semiconductor industry were profitable, some very profitable. There is less consensus

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[14]Dr. D. E. Noble, Executive Vice-President, Motorola, Inc., as quoted in Alfred D. Cook, "Letter from the Editor," Electronic News, September 14, 1959, p. 2.

[15]U.S., Department of Commerce, Semiconductors, February, 1961, p. 6.

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for the entire industry, but practically no one suggests that there were not at least several very successful participants.

2. Optimism for the entire industry was the prevailing mood in the late fifties and early sixties. The "haves" expected to remain affluent, and the relative "have-nots" were hopeful for improved status. No one, it seems, saw any dark clouds ahead.

If both these contentions are basically valid, one conclusion becomes evident. The industry and especially its prosperous firms did not seek new products, such as integrated circuits, because of their anxiety for the present and future. As for price declines, these were expected and even welcomed in part:

> Greatly increased production [of germanium transistors] made a 30% cut in price possible accelerating the advent of mass markets in portable, table, and automobile radios, television sets and many other commercial and military products.[16]

This, however, is the negative side of the reasoning. There is, on the other hand, a very powerful motivation impelling the industry to move in the new direction, and, it will be argued, this could only have occurred because of the two considerations just cited. For the innovation that we know as integrated circuits, the firms were seeking increased growth appended to that achievable from their discrete semiconductor products. As will be discussed shortly, this would have

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[16]Texas Instruments, Inc., Annual Report, 1955, p. 4.

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occurred whether or not the military had funded the initial programs as lavishly as they did.

The two most successful firms in the IC business, both with respect to their market position and their acknowledged technical leadership in the new technology, had very similar motives for moving in the new direction, and they both were operating from very successful organizations. There are some major differences, of course, but they lie more with the approach rather than the underlying motivating factors.

Texas Instruments is a firm whose rapid growth has been almost completely predicated upon growing from within rather than by acquisition. Other than a major acquisition made in 1959, there does not seem to be any other significant increase in organization via that route. TI personnel continually emphasized that this policy was and is the corporate philosophy emanating from the very top. The policy and its implementation have apparently been very successful. In 1954, the company's sales were just over $24 million and in 1964, practically 1/3 of a billion dollars--more than a thirteen-fold increase. Its growth plan was pictured as described below:

> Back in 1949 Texas Instruments was a good, small company with sales that year of $5,800,000 and a net profit after taxes of $263,000. In 1949 we decided that we wanted to be a good, big company instead of a good, medium-sized company which had been our expressed goal to that point. We defined a good, big company as one which would do about $200 million per year and earn at least $10 million net on that volume. In pursuing that company goal, we used several strategies

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> simultaneously, although the semiconductor strategy was the most important single one to achieving our goal, as we did in 1960.[17]

Here, from its chief corporate officer, is the avowed company policy of Texas Instruments: rapid growth using the semiconductor capability as its major foil. And, if the above describes the broad strategy, the tactic was described in the same presentation:

> We are convinced that both useful products and services and long-term profitability are the result of innovation and that, as a matter of fact, profitability above the bare fee for the use of assets level results from the innovation advantage and disappears as soon as the innovation has become routine.[18]

Many conversations with industrial and Government persons indirectly confirm the fact that these statements represent the basic TI philosophy.

Whereas with Texas Instruments we refer to a corporate entity dominated by the semiconductor technology, Fairchild Semiconductor has, naturally, always been a semiconductor house and, more recently, its influence both in products and personnel is pervading the mother organization. Here is an operation which from its very inception has been wedded to the frontier of the semiconductor technology. It pioneered the use of silicon for complex semiconductor products, although it was not the first to use this material in semiconductor devices.

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[17]Speech by P. Haggerty, President, Texas Instruments Inc., before shareholders meeting, Dallas, Texas, April 22, 1965.

[18]Ibid.

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The high level of sophistication attained by the industry in the planar process can be attributed to its efforts. From conversations with its major founder, industrial personnel, and Government officials, it is obvious that the Fairchild group has always prided itself on its technical expertise and capability to translate new ideas into profitable returns. This has been evident from its past attitudes on receiving Government R&D support--a point which will be taken up subsequently.

Within the IC market, this company has been the most aggressive marketing force, introducing changes in price structures and packaging configurations to accommodate new markets. It cultivates its product line to attract the industrial and consumer markets rather than the more limited military and space applications. This policy, one source suggests, has been a very conscious "turn-around" decision on the firm's part, since its original clientele were mainly military. In 1960, 80 per cent of its transistors were destined for military equipments. By choosing to concentrate on the non-Government markets--in which the company today has an "IC stranglehold"--the firm has seemingly sought mass volumes.

For Westinghouse, a different set of criteria must be used to explain its original efforts in molecular electronics. Its semiconductor operation, very small relative to the whole market, had pinpointed its activities to applications in which power was a main consideration. Whether this was a direct

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outgrowth of the company's basic orientation to electric power is not readily apparent. It did participate in a small segment of the total market. The division was originally part of the consumer products group. One Westinghouse source contends that the semiconductor operation was not profitable in 1956-1958, but went into the black in 1959-1960. There is no obvious way to determine its profitability; its position in the industry, at best, was probably tenuous. This situation was perhaps its rationale for entering into a new area of high risk and high potential payout. To become a strong contender in the industry, according to one respondent very close to the organization, it decided to enter the low-signal field, i.e., it would attempt to develop a capability in areas where power was not an important consideration. The most profitable members of the industry did not make their successes on power devices. Increasing the power-handling capacity of semiconductor devices was a major objective of industry R&D efforts. Westinghouse, then, was seeking an entree into a market in which several other firms were strongly entrenched. Although some companies entered the discrete semiconductor component market in the late fifties, especially through the introduction of improved high-frequency devices, Westinghouse looked to molecular electronics as its avenue. Whether this particular new technology was originally sought from the beginning, or whether it was a fortuitous happenstance which occurred in the R&D laboratories is unknown. It seems evident, however, that Westinghouse hoped that a strength in the

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molecular electronics technology would add to its present, limited line of semiconductor products, and even eclipse it one day:

> The only semiconductor devices it [Westinghouse] makes now are high power devices. It has never got into the transistor race and doesn't intend to now. So to keep its position in the electronics industry it has decided on the strategy of skipping a generation of technology and going straight to solid-state circuits.[19]

The impetus of the IC technology, both in spirit and deed, is attributable to the three firms cited above. Today's IC product is basically the result of their efforts, with varying contributions from each. This does not imply that other organizations have not helped to improve the IC technology. Nor does it hold to the doctrine that the product as we know it today will be the same in one or five years from now, and the firms that have brought the industry to its present status will be the same ones that will be the major innovators for the IC device of the near future. For today's IC component, there has been very little variation from the basic technology which evolved during the 1959-1961 era. Other firms, some originated by individuals who left these original three, have entered the market; their contributions have related more to circuit techniques rather than the basic technology itself. It is reasonable to contend that the fundamental impetus was attributable to these three companies;

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[19]"Westinghouse Jumps an Electronic Gun," Business Week, July 15, 1961, p. 36.

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the translation of the concept into a salable product was the work of only two of them. All were motivated by a desire for growth via technological innovation. Within this framework, and a separate subject in itself, one must review the reasons why business entities consider growth to be a desirable objective. Certainly profit is part of the answer; higher profits lead to higher earnings per share and, hopefully, a rising market price. It is much more than that, however, and if one imputed the profit motive as the only basis for the growth impetus, he would be far short of the mark in this particular instance. There is much more that is closely associated with the type of individuals who have been the major protagonists in the movement, both originally and since. This will be discussed briefly in Chapter VI.

The Industry-Government Relationship

Without a doubt, the coming of the IC component is an excellent example of an R&D technology which has evolved into product lines serving military, space, industrial, and, eventually, consumer markets. The Government's role in facilitating this achievement has been considerable:

> It is not surprising . . . that the companies which appear best equipped to exploit today's and tomorrow's market for the wafers [from which the IC devices are made] are those which originally got into the business on military contracts and had a large part of their early research paid for by the government.[20]

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[20]"Burning Up the Circuits," Barron's, August 9, 1965, pp. 13, 16.

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Although this citation flagrantly overlooks the case of Fairchild Semiconductor, which originally received no Government R&D dollars in this area, the opinion is widely held. Perhaps an obvious extrapolation is to suggest that the IC product line would not be available today had not the Government taken the actions that it did. This is a reasonable conclusion that can be derived from the literature and from discussing the subject with Government personnel. These conclusions seem valid--but they must be substantially qualified when one considers the IC reality of 1966 relative to the aspirations, objectives, and actions taken in the late fifties by the military. The more one delves into the subject, the clearer the realization that "the hoped for" of 1959 and "the achieved" of 1966 are far apart. The path to the present has been travelled with less than the best, most responsible leadership and with less than optimum use of available resources.

These facts stand out:

1. The concept of molecular electronics as espoused in the original Air Force proposal has not been realized. Its commercial value for any foreseeable application is very limited. For all practical purposes, the IC component of today is totally alien to the device conceptualized by the original molecular electronics proponents.

2. The material originally selected for use by the two firms that received initial fundings in this area is not

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used at all.

3. The present techniques now being applied are attributable to a company that perfected the methodology without any support from Government-sponsored R&D contracts.

4. The company that first demonstrated the IC concept did so as part of an internally-funded project.

5. The company to which the Government has given the greatest R&D support is definitely not the market leader and is not considered to be the technical leader either.

6. The Government's very aggressive R&D funding has not been matched by a similar zeal to incorporate the IC components into equipments and systems. Perhaps this is the most damning contention of all. The ultimate objective of the military is not to create new devices, but to supply the armed forces with systems and equipments best suited to secure the country's defense and military commitments. Therefore, the utility forthcoming when the components are applied to support these objectives is the overall desideratum; anything less than this may be suitable for other tasks but not for military criteria. If the IC technology, especially beyond the device level, is examined on this much broader plane, the results are less than reassuring.

The objective analysis of the industry-Government relationship in this particular area must divorce itself from the publicity which has attended the IC component since its infancy. This will be attempted here fully realizing that the

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wisdom of hindsight may sometimes not be very constructive; it will, however, lead to some conclusions which could be pertinent for certain kinds of future work which the Government might seek to undertake. The objective of this review will be to formulate, where possible, very specific conclusions and broader-based generalizations that may have applicability for future actions and policies.

Idea initiation

One of the major considerations taken up in the review of the literature and the lengthy interview schedule was a determination of the origin of the IC concept as we know it today. A very clear differentiation is made between the idea and its implementation for actual use. These are two separate steps. Even if the idea is impossible to fulfill at a given time, it may still serve as a stimulus for future work. It is important to trace the idea sequence, and see if there is any obvious correlation between the initial conceptualization and today's practical product.

In 1952, an English scientist made the following observation:

> With the advent of the transistor and the work in semiconductors generally, it now seems possible to envisage electronic 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

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out areas of the various layers.[21]

These words were spoken before the transistor was even commercially available, and the new semiconductor technology was still struggling for acceptance. Thirteen years afterwards, the realization of Dummer's vision is still left for the future. It augurs the molecular electronics idea, although, depending on one's interpretation of particular terms, e.g., electrical functions, it may be closer to today's IC component. Regardless, the idea of an electrical function being performed without connecting wires is very apparent. The semiconductor technology was to be the modus operandi, and a first-rate knowledge of solid-state physics may be inferred as an indispensable prerequisite. In this respect, Dummer very accurately predicted the major subsequent development in electronics.

In the same year, an Air Force memorandum described a project in which the miniaturization of electronic equipment was the prime objective, but considerations of reliability, power consumption, and cost ultimately entered the picture. In discussing the problems, it stated:

> As power is reduced and both active and passive components are made smaller, new integral circuit construction techniques will be needed.
>
> In the past, layout and assembly of electronic circuits with conventional components have been considered

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[21] G. W. A. Dummer, "Electronic Components in Great Britain," Proceedings of the Symposium--Progress in Quality Electronic Components (Washington, D.C., May 5-7, 1952), p. 19.

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> relatively minor problems. . . . In the future, assembly problems will probably present the major difficulties in translating the potential benefits of the new electronics into effective airborne equipment. For proper utilization of the components discussed above, various electronic devices, it is believed that revolutionary new integral construction and assembly techniques must be developed. . . . As many of the components as possible must be fabricated "in situ" and connected by operations that are done simultaneously . . . rather than by consecutive operation.[22]

In a more oblique manner, the possibility of an IC circuit was implied. Although the emphasis on the semiconductor technology was not nearly as great here as in Dummer's comments, it still urged a radical departure from the fabrication techniques of that time. Its suggested means of achievement were less specific.

The idea of an integrated circuit need not be relegated only to semiconductor devices. Much of the work in the past few years has been directed to the fabrication of a thin-film circuit that can be manufactured using only variations of the thin-film technology; to date, this work has not yet left the laboratories. Some of the efforts described in the section on miniaturization were directed toward this end, although the motivation was generally smaller size and lower manufacturing costs rather than the realization of an integrated circuit for its own sake. All these techniques fell short with respect to size reduction of the active components--vacuum tubes--although there was good progress made relative

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[22]C. E. Ryan, "Microtonics Project." Internal Air Force memorandum, April 14, 1952.

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to the passive components, such as resistors and capacitors. Undoubtedly, these attempts helped to "fertilize the ground." It was the coming of the transistor, as Dummer said, that was to be the means of accomplishment.

The question of idea genesis was posed to all the individuals interviewed. There was no consensus. The idea in a very nebulous amorphous state was probably conceived by many persons. As one major industry leader put it, there were two very basic problems that had to be overcome: isolation and interconnection. The solution to both was necessary before a practical IC component could be achieved. Both difficulties were obviated, to a large extent, with the refinement of the planar process; isolation, however, is still a very basic limitation to the performance of the devices, although various new methods are being used to improve electrical characteristics.

The IC concept cannot be attributed to any one person or agency, industrial or Government. Through the years there has been an interchange of ideas and information in which Government agencies were apprised of new findings emanating from industrial R&D laboratories, and Government personnel, more sensitive to needs rather than their exact means of solution, tried to stimulate industry thinking via contract support. Although various persons have claimed at least partial credit for the molecular electronics concept--again, the idea and not the implementation is the emphasis--it can definitely not be linked to any single individual or group.

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To place the role of the military and especially the Air Force in the proper context, one must credit the latter for creating a climate in which such an idea could be brought forth and ultimately developed. As amply documented in the sections on miniaturization and reliability, the military had very urgent problems which received a great deal of publicity. The industry was periodically chided for its failure to develop better electronic components that would ameliorate or (hopefully) eliminate the difficulties. By continually hammering the same theme over and over again, and backing up potentially feasible solutions with R&D funding (as with molecular electronics), the Air Force played a powerfully persuasive role. Also, if industry could develop the appropriate components, the Air Force would probably be a most ready customer for them. This incentive is critical since R&D work, in and of itself, is not very profitable. The resultant products hold the promise for future profits. The Air Force, for instance, periodically reviewed its future plans and tried to correlate the device technology with them, i.e., the planned military electronic system of the future should be compatible with the capabilities of the electronics industry. By distributing to industry documents containing these plans, it tried to encourage private firms to move in a direction which would be complementary to the Air Force's needs. One major Air Force official stated that there was an "open door" policy maintained, in which representatives of private companies could be briefed by officials relative to military

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requirements, and industry, in turn, could invite Air Force personnel to the plant to obtain a first-hand impression of an advanced project on which the firm was working. By so doing, the possibility of cross-fertilization would be increased.

Therefore, the genesis of the molecular electronic or IC concept, disregarding the arguments as to the similarity or difference, cannot be associated only with the military; there is no one point of origin. The critical consideration here is how the idea was transformed into usable electronic products.

Research and development sponsorship

The Air Force awarded its first molecular electronics contract in the spring of 1959. It was worth $2 million and was given to Westinghouse Electric Corporation. The timing of the decision, the nature of the contract, and the industrial firm that was to do the work present an interesting case history.

This contract had the avowed purpose of fostering a radical jump in the electronics technology--a quantum jump. The electronic circuit of that time--a conglomeration of discrete components, each with its own inherent limitations, and all connected by one of many possible techniques--was to become the industry's dinosaur. The realization of molecular electronic components, it was hoped, would completely change this picture and usher in a new era of electronic sophistication that had no antecedent. There is no doubt that just an improvement of the technology was not the objective. This note

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of radical technological progress was repeated by all the Air Force personnel interviewed and generally agreed to by the industrial observers. The press literature also gives strong concurrence to the feeling. Why this particular attitude was assumed may be attributed to any or all of several reasons.

In the fall of 1957, the success of Russia's Sputnik had a severe impact on the thinking of the scientific agencies of the Air Force. (It is quite possible that it had similar effects on other military groups, but only the Air Force reaction is noted here.) In December of that year, one Air Force official relates, several special meetings were called. Scientific breakthrough was the recurrent theme; impressive extensions in capability were being sought rather than relatively simple state-of-the-art improvements which were more the norm. The Air Force was told to encourage the extraordinary--to create the needed climate and be sensitive to any potential breakthroughs which might be forthcoming. The impression is that the mandate was broad in scope and not particular in detail. But, the spokesman suggests, it generated a different kind of orientation, one that would be very receptive to the huge payoff which could be obtained if a molecular electronic concept could be brought to practical fruition. There is, of course, no way directly to correlate this awareness to the events in question, but it is not unreasonable to assume that it helped create a conducive climate.

It is impossible to divorce the relative timing of the

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initiation of the Army's Micromodule program from that of the Air Force's molecular electronics effort. The former had its first funding in the spring of 1958, and the latter began almost exactly a year later. Each received a great deal of attention, and each had its individual proponents pronouncing it as the key to a new age in electronics. Admittedly, the major objective of each varied. The Army was mainly concerned with miniaturization and the Air Force with reliability. Although the basic aim of each was at variance, there was commonality also. Both hoped for long-run equipment cost reduction using the particular technique advocated. The Air Force, naturally, sought size and weight reductions through its program; this was suggested at the outset and continually emphasized when the first demonstration IC equipments were shown--as for the TI computer in October, 1961. Whatever the differences, each was backing a major program which, it was hoped, would bring important changes for electronic equipments and the industry supplying them.

The Micromodule idea, rooted in the Tinkertoy precepts, was seriously considered in 1957, and its initial funding, in early 1958, was $5 million to RCA. Such an aggressive move at that funding level must have had some influence on the Air Force R&D laboratories chartered to improve the electronic capabilities of the devices used in Air Force equipments. Air Force officials have been free to admit that the Micromodule concept was inadequate for their purposes. Overall, this seems reasonable, but such an attitude was probably flavored

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by other motives. The main one, suggested by several observers, was the need for the Air Force to come up with an idea on its own, not one that was similar or comparable to what the Army had. Therefore, the Air Force's program had to not only be different but, since it was coming a year later, it had to be more impressive. The molecular electronics project satisfied on both counts.

The intent of the above discussion is not to suggest with dogmatic certainty the motivations which then prevailed. To attribute such decisions only to impersonal objective scientific rationality is far from realistic. When reviewing the Micromodule program itself in a later sub-section, the same type of influence seems to hold there also. It is sufficient to stress the truism that scientists are people prone to the pulls and pushes of non-scientific stimuli as are all other individuals--a point that C. P. Snow has repeated in outstanding fashion in his many books, e.g., The Affair.

On the other side of the coin, the requirements of the Air Force, including any missiles and space vehicles that were then considered, were more demanding than those of the Army, since basically the tasks of the two military agencies are carried out in such different media: the Army on the ground and the Air Force in the sky. Without belaboring those areas in which the needs are common, it is most obvious that a broad-based electronics program for each had to emphasize different major criteria. The need and dependence

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of the Air Force upon electronic systems, especially the highly sophisticated kind, are considerably greater than those of the Army. Reliability demands take on extremely high priority. This consideration itself was urgent enough to suggest that the Air Force look in directions other than the Micromodule.

If there had been no Micromodule program, it is quite likely that the Air Force might still have taken the same route and followed the molecular electronics path in the way it actually did. Yet, it is probably a fair assessment to suggest that the presence of the Army's program immediately precluded certain possible solutions for the Air Force when the latter was seeking projects to ease its own problems. It probably indicated those avenues that should definitely not be travelled and put a lower limit on the potential payout that any chosen solution may have offered. Its effect was both in kind and degree. A completely separate question is whether this influence in the long-run, with the aid of hindsight, had a positive effect on the development of the IC component; this will be touched upon afterwards.

Whatever the exact motives were and however they came about, some time in 1957 the Air Force and Westinghouse began an inter-relationship which was to be capped with the 1959 contract award. The exact nature of how this came to pass is not without its points of contradiction. One fact does appear to be uncontested: there seemed to be no other company interested in pursuing the type of program desired by the Air Force.

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Perhaps any other programs suggested by other companies were deemed inadequate. It is this latter factor which leads to a particularly sensitive and critical point. Was the Air Force dissatisfied with the inputs, if any, that it received from the other firms in the industry, or was it simply a case of nobody else in the industry being interested in pursuing a course similar to the one espoused by Air Force personnel? There are persuasive arguments for both sides of the question, but the latter alternative would appear to carry the greater weight.

Of the other major IC firms today--besides the firm just mentioned--two were non-existent in 1957 (Signetics was formed in 1961 and Fairchild Semiconductor in late 1957), one was basically a supplier of semiconductor components for in-house purposes (Motorola), and one was the leading company in the industry (Texas Instruments). In the late fifties, the successful semiconductor houses were mainly preoccupied with increasing sales, expanding into new markets, developing manufacturing expertise; concern prevailed for all the problems associated with a business intent on exploiting a new market which apparently offered great opportunities, in the near- and far-term future. For those already enjoying success in this market and hopeful of continued prosperous times and for those who were desirous of sharing some of the semiconductor cornucopia, the idea of molecular electronics or any concept as revolutionary would have been a tremendous distraction. For a management to enter into an extremely high-risk area--even

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if it were coupled with a long-run high potential payout--when the profits in discrete semiconductors were a reality (or at least their achievement was a relatively low risk venture) would have been extremely ill-advised even in the eyes of a most farsighted observer. Even with large financial backing from the Air Force, such a decision could only be justified in terms of the needs of a company like Westinghouse. As cited previously, Westinghouse was not a major factor in the industry and was seeking an entree which would catapult it into contention. Molecular electronics offered such a possibility.

To broaden the discussion, any firm must always choose to allocate its resources among various alternative purposes. The semiconductor industry puts a disproportionate priority upon the scarcest and most irreplaceable of these assets: the human resource. A management would have to divert this scarce commodity from presently and potentially profitable activities into ventures where the outcome was considerably more uncertain. This argument takes into account the probability of heavy R&D outlays by the military and even the prospect of future sales for military systems if the component could be successfully developed. Westinghouse did not have this decision to make, but Texas Instruments did. Initially, the latter firm was reluctant to take R&D contracts for integrated circuits, presumably for the reasons just cited.

As it turned out, the first Westinghouse contract amounted to $2 million, and the work was scheduled for completion within ten to twelve months. If it is assumed that

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engineering and scientific personnel cost an average of $40,000 per year per person--which is probably high even when all loading costs are included--this implies that fifty persons would be involved in the effort:

> Approximately 50 professional personnel are working on the program with others to be added as rapidly as they can be obtained.[23]

The required talent, moreover, would have to be high calibre. If a firm, even a large one, diverted that number and type of personnel from other activities, it would have to have extremely strong justification. Very few firms could have done this, and an even fewer number would have even considered it. This reasoning ultimately leads to at least one partial conclusion as to why Westinghouse was chosen for this pioneering contract: it was interested. Air Force officials often repeated that Westinghouse showed an interest in the type of far-reaching work being advocated, whereas other firms could only offer indifference. Without deeper probing, the initial impression might be gained that such companies were not forward-looking and could not see the validity of seeking electronic innovations. The evidence does not bear out such a conclusion. The industry, and especially its more competent participants, would probably have shown a keener interest in a less ambitious project. Probably the greatest problems realized in translating the potential of the IC component into

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[23]P. V. Horton and T. D. Smith, Survey of Micro-miniaturization of Electronic Equipment. AFBMD-TR-60-57, December 31, 1959, p. 29.

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actual, improved electronic systems can be assigned to the Air Force's desire to obtain a radically new and different device, far superior to its predecessors and requiring new understanding on the part of the potential users.

Interest from Westinghouse, important as that might have been, would still not have been sufficient to warrant the backing that it ultimately received. It had to show some capability in this new field of molecular electronics. It did, at least enough to convince the Air Force and Department of Defense that it was worth funding to a $2 million level. Several devices demonstrating the molecular electronics principle were shown. There have been varying interpretations as to the origins of these devices. Did Westinghouse fabricate them at the request of the Air Force to show a capability in an area in which the latter was interested? Did they originate in the R&D laboratories at Westinghouse and then were they brought to the attention of the Air Force because Westinghouse officials surmised that such devices, knowing the publicized needs of the Air Force, might be of interest to the military? One observer who was close to the events then taking place suggests that the latter sequence was the way it actually occurred. The molecular electronics concept, he contends, was born in the firm's laboratories, partially from pure research efforts and partly from a response within Westinghouse to develop a new product to fill its semiconductor void. Afterwards, when possible applications and sponsors were considered, the firm approached the Air Force with the idea. On the other

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hand, representatives of the military agency state that the original Westinghouse molecular electronics efforts were impelled by Air Force requests. Although it is impossible to confirm, it is most probable that the idea was born out of some pure research effort, independent of the particular needs of the firm or the outside world, and then, sensing a good idea, the company sought ways to capitalize commercially on its creation. From there, the interchange began between the military and Westinghouse.

To carry the narrative through to its first contract award, ultimately a close rapport between the two groups evolved. The type of funding required to give the concept the needed impetus was beyond the financial resources of the Air Force R&D laboratories that normally would sponsor such activity. Other on-going programs required support; the Air Force had to seek funds through avenues contrary to the normal allocation for such projects. Also, the very conscious decision was made to invest a large amount of dollars in Westinghouse in order to vault that firm into a leading position, which would then force other companies in the industry to enter into this new field. (In the long run, this came to pass but not for the reason just stated.) Therefore, the Air Force went to Department of Defense personnel concerned with the electronics area and requested, in late 1958, an amount between $6.5 and $7 million; it is not clear what the accompanying contract time period was to be. The intended program was broad-based and ambitious; molecular electronics on both the

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device and systems levels was to be investigated. Ultimately, the scope of the program was narrowed, and the initial emphasis was directed to developing molecular electronics devices.

The Westinghouse contract of $2 million, it should be added, was devoted not only to molecular electronics, but included an effort on a relatively new technique for making semiconductor material called dendritic growth. The formal contract title was "Dendritic Approach to Molecular Electronics." The proposed molecular electronic circuits were to be fabricated using this technique. The puzzling part of this coupling, then and now, is that the two ideas can be completely divorced, and each still maintains its total identity and direction. The dendritic method, which would have been applicable to discrete semiconductors also, does not add anything to the molecular electronics concept itself. One knowledgeable industrial observer who participated in these events when they occurred suggests that the reason for the coupling was the radical nature of the new technology being proposed, viz., molecular electronics. The latter revolutionary concept would not be able to sell itself, so it had to be tied in with an activity that had less risk, it was contended. An important Government official working in the electronics miniaturization area concurred with this hypothesis. Then, it may be reasoned, if the dendritic technique was not appropriate for molecular electronic components, it could still be used for transistors and other semiconductor devices. The implication was that the Air Force and

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Westinghouse realized the extremely ambitious nature of the proposal and were attempting to ensure the latter's funding by tying it to a more palatable, less radical project. To the author's knowledge, the dendritic technique has never been used for IC components, by Westinghouse or anyone else. To date, it has had about as much application and utility as the original molecular electronics concept--practically none.

It was this contract nonetheless which triggered the events to follow. The proper understanding of its background and the sequence that led to its award offer an excellent case history of how Government actions through R&D contract support can induce a tremendous response from industry. This is not a power that can or should be taken lightly. Its great significance is derived not only from the amounts of money which ultimately poured into this work, but because it set the pace for events that were to occur years afterwards. The original molecular electronics proponents were hoping for more than just a new product development. A new electronics era was about to commence. Through its funding as an R&D sponsor, through its power as a buyer of electronic equipments from the electronics industry, through the wide access that it has to the various communications media, and generally, through its influence as an indispensable force in a tense world, the impact of Air Force decisions such as the one just described was, is, and will be great. The effects of that original contract have had a far-reaching impact.

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Follow-through

As stated at the outset, today's IC component bears little resemblance to the type of device that was conceptualized by the Air Force or Westinghouse in 1959. Besides the similarity that basic electronic functions--switching, amplifying--are performed within a small piece of material, there is nothing in common. The techniques and ideas that have come to prominence are derived from two other companies: Texas Instruments and Fairchild Semiconductor.

The first integrated circuit--electronic elements indivisibly combined within a sliver of semiconductor material--was demonstrated by Texas Instruments in mid-1958. Compared to today's IC component, it was a crude unsophisticated device. Conceptually, however, there is no difference between that component and the current one in use today. It differs in material, manufacturing techniques, interconnection scheme; functionally, it is the same. It resulted from a TI effort to evolve an improved approach to electronic circuitry based on the semiconductor technology. The project under which it was developed had a very broad charter with no specific, well-defined objective. The person in charge had had experience with Centralab, a firm that pioneered in early efforts to miniaturize electronic components. Later that year--1958--the Air Force was given a demonstration of the new device. At this time, contract negotiations between the Air Force and Westinghouse were far along, probably too far to alter the later contract award even if the Air Force did have a change-of-

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heart--of which there is no indication.

The TI invention evoked mixed reactions from Air Force representatives. At least one major official in a key position felt that the TI device was not enough of a stride forward. It still depended upon the fabrication of recognizable electronic elements--transistors, resistors--whereas the molecular electronic component was to have no such counterparts; the latter would simply depend upon the interactions induced within the small bit of material. Although the final components achievable using either method might be identical, the means of attainment were critical. To harken back to a previous theme, the jump was not large enough and the means of obtaining it lacked the ingredient of the spectacular.

There were others, however, within the Air Force who recognized the potential of the TI device. If they could convince the company to take an R&D contract to continue and augment the work effort in this direction, it would serve a twofold purpose. First, the TI program would be a parallel approach for solving the same problems that were besetting avionic electronic equipments, i.e., it offered higher reliability and size and weight reductions that were not obtainable via current techniques. Second, and perhaps even more important, it would bring the major company in the industry into the fray. Now the rest of the industry would have to take notice, since this organization's great success was basically predicated upon its competence in the semiconductor field. If the firm chose to pursue this approach, it was certain to have a

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contagious effect upon other competitors, thus accomplishing the Air Force goal to persuade the rest of the industry to begin similar work, preferably with company funds. The project still was referred to as molecular electronics even though the TI work was really not compatible with the original concept.

The initial attempts to coax the company into the new project were futile. Perhaps the TI management was averse to Government funding as a matter of policy--it developed the silicon transistor on its own--or it felt that it did not need the support since it had already performed the basic work, or, as mentioned earlier, it was not about to divert its best men from working on the present product line for the vagaries of an R&D program that contained an indefinite future. Timing was important, both with respect to Texas Instruments as a maturing corporation and the point at which the company welcomed Government support for an R&D project. Finally, after numerous meetings between top officials of the company and the Air Force, the firm accepted a contract of relatively modest proportions compared to the Westinghouse funding. In June of 1959, it began work on a 2½ year effort aimed at developing IC devices; there was no systems work involved. The funding level was $0.5 million per year.

In early 1961, the TI participation was considerably increased. The company contracted with the Air Force to (1) construct a pilot line within eighteen months that would be capable of turning out 500 integrated circuits per day for ten days, (2) build a computer using IC components within nine

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months, and (3) build a second computer using pilot line circuits. This last task was eventually changed. The value of the contract was about $2.8 million. It is to be especially noted that the work was both device- and system-oriented. It was deemed necessary that the IC devices be incorporated into a particular equipment to convince the systems users and manufacturers that the technology was capable of producing components which could be used in electronic equipments. By so doing, it was hoped that the systems people, both Government and industrial, would also join the "IC bandwagon" and accelerate the movement from a different direction. The results of this effort have been documented in a previous section.

Texas Instruments, therefore, saw fit to change its attitude on Government funding for its IC work. What began as an in-house project, impelled by the direction of a very technically-oriented top management, was translated into a program of close association with the military. To date, the greatest success of the firm in its IC marketing efforts has been derived from its participation in the Minuteman program--the first major program to use integrated circuits. The firm had and still has the largest share of the funding for IC devices. Through the years the company has changed its policy relative to accepting Government R&D contracts and has probably profited as a result. The next company to be described has seen fit, until recently, to fund its R&D programs for integrated circuits through internally-generated dollars.

In 1958, Fairchild Semiconductor (Fairchild) moved from the research to production stage on its transistor product

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line. As described previously, it was backed by Fairchild Camera and Instrument for eighteen months, beginning in December, 1957. At the end of the period, the parent would either absorb the semiconductor division completely or, presumably, drop it in toto. The founders were confronted with a very real problem: develop a capability in a short time. Even if the company were so disposed--which it wasn't--the type of program advocated by the Air Force would be completely untenable for this young operation. The problem of scarce human resources was obvious. The devices being worked on had a sure market if they could be successfully developed. The original group was fairly certain that it could fabricate the device and successfully bring it to market. Undoubtedly, it was an all-consuming task. Representatives of the Air Force did approach the Fairchild management and could evoke no interest for a Government-sponsored R&D program. The Fairchild top management was particularly strong in its belief that it should fund its own R&D ventures without resorting to outside assistance. It might have also felt at this particular point in time that the need for outside funding was slight, since it already had the needed techniques to turn out a salable product with a ready market. Whatever the motivation, it developed its basic IC product line completely "on its own." Throughout its entire corporate lifetime, the author knows of only one Government contract that it took to advance its IC capability.

Whether Fairchild was influenced by the TI or

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Westinghouse work, or whether it envisioned the integrated circuit as an extension of its product line, or whether the idea was independently conceived in the R&D laboratory is uncertain. What is certain, however, is the Fairchild contribution. By its development of the planar process, the IC concept was translated from unfeasible idea to economic reality. All the other firms, including the two originally funded with Government contracts, have adopted the Fairchild process. Inextricably associated with the technique is the use of silicon material rather than germanium with which both the other firms had begun their programs.

The influence of the military on the Fairchild IC development was the power of the market. The firm saw the military as a very obvious--and probably only--first customer willing to pay the relatively high prices that would be charged for a new, low-volume product. Since it has been the forerunner in cultivating the industrial market, one could surmise that it looked to the military or space agencies as the means by which volume would be increased to the point that learning curve efficiencies and improved skills, combined with the higher volumes, would bring the costs and associated prices to the lower levels that could entice the industrial-consumer customer. If this was its plan, the firm has been eminently successful in its fulfillment.

Westinghouse meanwhile, in spite of its own internal problems, extravagant Air Force claims, and outside criticism, continued to receive heavy financial support from the Air

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Force. In 1960, it received additional funding for $2.6 million.

According to at least one DOD official and from the implications of industrial observers, Westinghouse was beset with internal management problems soon after it received its initial funding. The exact nature of these difficulties is not known--at least to the author. Perhaps the greatest indication of its internal weakness was its apparent need to go outside its own organization to obtain a man to head up the division that was formed to work exclusively upon Westinghouse's IC line. To this day, there is a general feeling that Westinghouse is a firm with good IC technical expertise supported by an organization weak in the marketing aspects of the business.

As is evident from the many press articles referred to in the chronology of the technology in the late fifties and early sixties, the claims made for the IC components were ambitious at best and terribly exaggerated at worst. It is conceded that the task of the various R&D arms of the military agencies is to encourage new developments and to spur industry to greater accomplishments which will have salutary results for military systems. It is apparent that the Air Force was greatly concerned with furthering the IC technology, not only for the sake of improved electronics but to safeguard its own rather large stake in this radical departure. Even a cursory review of the press clippings gives one the impression of a problem-free program, undiluted success, and a clear confirmation of actions already taken. The most disquieting inputs,

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however, are the reactions from other agencies of the military, including the Air Force, whose responsibility it was to supply the electronic systems destined for the military inventory. To this day, with only one major exception, Air Force personnel concerned with systems have apparently shown the same degree of indifference relative to IC usage as the R&D groups evinced in encouraging its development.

Normally, research projects of the type awarded to Westinghouse are reviewed by a group known as the Advisory Group on Electron Devices (AGED). This is an assemblage of the top scientific talent in the country, paid to advise the Department of Defense in matters relating to research topics in electronics. The AGED has only staff authority with no power to fund contracts itself. When the first Westinghouse contract was awarded, it was not passed on by this group since emergency funds were being solicited. When it came time to review the contract and choose future directions for a renewal, the program came in for some sharp criticism. There were some who did not feel that the molecular electronics concept was feasible. Others doubted the wisdom of funding only one company; whether it was because that one company was Westinghouse was not clear. Still others were critical of the program objective of applying the young untried technology to equipment application. This may have seemed like a too-ambitious step. The final outcome: the Westinghouse contract was renewed for another $2.6 million.

Besides the three firms cited, the Air Force also

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launched a major R&D program for integrated circuits with Motorola in mid-1961. This was a cost-sharing program in which the firm contributed $0.5 million and the Air Force three times that amount. It undoubtedly was aimed at setting up Motorola as another vendor of IC devices. By this time, Motorola was successful with its discrete semiconductor line, and its future stake in the industry was dependent upon its building up a capability in a field in which three of its competitors already held strong positions. This is most probably the explanation for the cost-sharing aspect, since none of the previous R&D contracts for IC work let by the Air Force had that feature. The basic objective of the program--the combining of both the semiconductor and thin-film technologies into one IC component--has not yet been achieved commercially.

Other considerations

If the Air Force role has been emphasized, there is good reason. Figure 5 depicts the funding for R&D development of the IC device. Especially when published material was used as a source, it was sometimes difficult to determine the exact application of a given contract. Therefore, the data has been divided into two categories: Direct and Indirect. The former covers contracts which are associated with IC work for component firms. The Indirect listing refers to work of a broader nature that may be applicable in part to integrated circuits and to work performed by consulting-type firms. The division between the two categories sometimes required an "educated" evaluation

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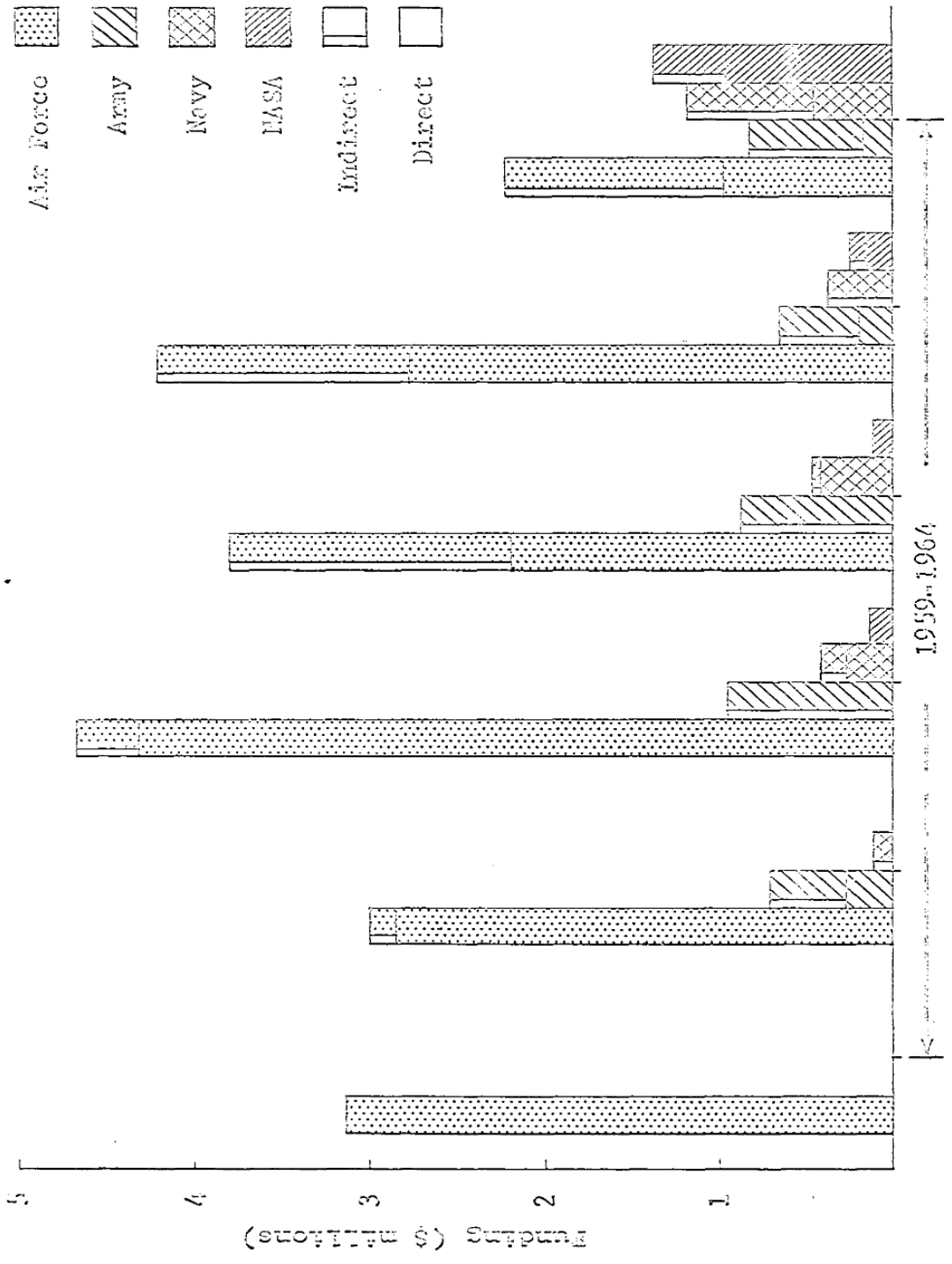


Fig. 5.--Integrated Circuit Research and Development Funding

Source: Commerce Daily, NASA files, USAEC, press literature, interviews

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by the author.

The IC funding is overwhelmingly top-heavy with the Air Force contribution. There is no doubt that it is this arm of the military which has given the greatest support to the technology. It is of interest to review what other branches of the military establishment and the space agency have contributed to the development of this new electronic component and note the Air Force's participation in a non-R&D capacity.

Army

The Army has probably had an indirect effect. Its role has to be examined not only with respect to its impact on Air Force thinking but also relative to industry.

The Army, through its Signal Corps group, had spearheaded the tri-service efforts to develop transistors for military applications. From 1952-1964, the funding for improved manufacturing techniques for transistors and diodes--as differentiated from R&D work--amounted to about $50 million, according to one Army source.

As cited earlier, the Micromodule program received its initial funding a year before the first Westinghouse contract. Its last formal contract award was let in fiscal 1963. Over the approximate five-year time span, it allocated $26 million to this program. Therefore, industry was faced with two military agencies simultaneously funding new approaches to the electronics art with large contracts. How much the Army outlays for its Micromodule effort affected the thinking of

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the Air Force relative to its molecular electronics program is completely dependent upon the validity of the previous discussion, i.e., inter-agency coupling. It would depend on whether there was any mutual influence at all and, if so, how tight it was. One was not totally independent of the other. Other than through military channels, there must have been feedback through industrial firms serving both agencies. Besides the more obvious conclusion that the Army spent a reported $26 million on a non-IC activity--which it certainly was not obliged to do--did its attention to and support of the Micromodule program distract industry from applying its efforts to the IC technology? Generally, the response from observers interviewed was negative. The major reason given as to why this occurred was simple: private firms did not support the Micromodule concept and did not believe that it was the direction to take for miniaturization purposes, although many did supply components for the program. This kind of response could naturally be expected today now that the integrated circuit is in the spotlight, and the Micromodule must be content with the shadows. The response, however, was almost unanimous. There was no industrial representative interviewed who felt, even in the late fifties, that the Army project would be successful. There were equally strong opinions on the subject from various Government personnel. Although the Micromodule approach was not held in high esteem, some suggest that it had fallout value which aided the integrated circuit cause. It helped create a climate, this argument goes, that stressed

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the interest of the military in miniaturization--a major asset of the IC device. It articulated the military's need for smaller electronic components thereby creating a greater receptiveness for the IC technology. This interpretation was not widely held.

In the early sixties when the IC concept received increasing attention and industry was offering several product lines, the Micromodule program was subjected to growing criticism. The Army was forced into a position of defending its approach in the wake of the success of its sister agency's program; it sought to reconcile the two. The success in so doing has been dubious. To bolster its faith in the Micromodule project, the Army allocated $8 million to the program in fiscal 1963. This amount was about twice as much as the 1962 allocation--greater than the outlay for any single year of the effort. Fiscal 1963 was the last year that the program was formally funded.

If the two programs--Micromodule and molecular electronics--were highly interdependent in their effects, one upon the other, than several serious questions are raised relative to the events which transpired. If they were independent in their mutual impact--which is very unlikely--then other questions arise concerning the sponsorship of R&D funds by the military agencies. The background support accrued in this study is not adequate to answer knowledgeably on either question. There is a great deal here that requires further study.

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Navy

Within the microelectronics area, the Navy has generally been associated with its advocacy of the thin-film approach. Whether this attitude resulted from its belief that the technique was better for the needs of the Navy or because it did not want to duplicate the efforts of the Air Force is unknown. Many believe, including the author, that the IC product of the future will in some way be a melding of the two technologies, selecting the best from each.

In many ways, the needs of the Navy relative to its electronic equipments are similar to those of the Air Force, but the degree of urgency is probably not as keen. Improved reliability, reduced size and weight, and lower power consumption all are important to the Navy, but the Air Force puts a higher priority on these objectives. It is from the ranks of the Navy, however, that the most vigorous supporter appeared for incorporating the IC devices into electronic systems. The outstanding application of their use has been by an Air Force agency--the Ballistics Systems Division used the components in the improved Minuteman. Along with NASA's Apollo guidance computer, this purchase has been the largest experienced by the industry, and both were the first major programs to use them in large numbers. The latter two, important as they have been, are conspicuous simply because of their size. The IC technology has the most to offer when used in those electronic equipments produced in the hundreds and thousands. When the military exert a pressure to have their contractors use them

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in the typical, less spectacular applications which make up the great bulk of the military's electronics inventory, then the IC technology will truly be capable of offering the improvements which its original proponents hoped would some day come to pass. The most ambitious beginning in this direction was taken by the Avionics Laboratory section of the Bureau of Weapons in 1962. In no uncertain terms, this group declared its intention to move the IC device into Navy equipment as soon as possible. Where feasible, these devices would replace discrete components on programs currently under contract but not yet into the production phase. The intention was to retrofit these unfinished electronic equipments, gain some of the improvements offered by the technology--but not all since the equipments were not being designed from the outset using these devices--and obtain some experience with the new components. For new equipments and systems using electronic equipments, the emphasis was very clear in its mandate to the potential contractor: look to integrated circuits or have a good reason why not. This overall philosophy was the first of its kind that emanated from an agency with the responsibility and power to have an impact. Although, in the long run, these ambitious intentions have been met with less than unqualified success, there have been very important ancillary effects. The publicity attendant to the Navy's intentions very obviously told the industry that another service was interested in the IC technology and was looking to this innovation for at least a partial easing of its problems. It not only said this, but it

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also began to put some of its contracting weight behind the move. This is probably the greatest persuader to which the military can resort.

NASA

The role of NASA in the introduction of the IC device is very negligible, if any. Its influence in the development of the technology, however, has been considerable both directly and indirectly. There are three major categories in which the space agency has made a positive contribution to the IC cause: climate, R&D sponsor, customer.

Climate--The role of space in our national thinking went from insignificant to imperative in late 1957. The United States, always prideful of its technological prowess and innovative expertise, had been bettered by its cold war adversary. The Soviet Union, ravaged by a World War, had only joined the "modern world" in the second decade of the twentieth century and had achieved one of the most magnificent scientific feats known to man. It cast a long shadow on our own national and international prestige. Its initial conquest could not be erased, but the United States could become superior in space technology and accomplish even greater achievements before the Russians; maybe we could even perform some space feat that the Russians couldn't duplicate. There is no doubt that these objectives became a very real part of our national purpose, initiated in the late Eisenhower years and raised to an almost chauvinistic plateau during the Kennedy Administration. NASA

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officials, capitalizing on this nationalistic fervor, could translate the intangible feeling into very real objectives for the electronics industry and those serving it. Electronic equipment, it was emphasized, was indispensable to the space mission, and the electronic equipment wasn't good enough for the task. There was no reason why it should have been, since the needs of a space age were unprecedented. Both in kind and degree, the requirements for space had no predecessor. A new look was called for, and the semiconductor components industry, so vital to the electronics function, had to lead the way since the equipment generally is no better than its component parts. On another level, the military was repeating the same theme. Reliability must be improved not only because of the importance of the military mission which might depend upon the required electronic equipment, but also for the long-run reduction of supporting costs. The NASA motivation was not translated into a dollars and cents issue. The economic cost of unreliability is great, as has been obvious in several of the more recent space failures. Even now, however, with the increased awareness to cost considerations, failure is stressed relative to its effects on a scheduled timetable and the possible consequences if that schedule falls very far behind. Undoubtedly, the NASA influence had and still has a reinforcing effect for the military exhortations that preceded it. It has also raised these urgings to a level and degree of critical importance which the military could not duplicate. Military problems are more insulated and restricted to the agencies involved and

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their contractors. NASA's problems are more all-pervasive, simply because of the importance accorded it and the publicity which has always accompanied its mission. The general public has been involved.

R&D sponsor--This area, of the three cited here, has probably been the one in which the space agency has had the least impact upon the advancement of the IC technology. This is attributable to two reasons: the level of the funding and the nature of the programs being sponsored.

NASA's role as an R&D sponsor compared to that of the Air Force has been insignificant, as shown in Figure 5 (page 201). In the late fifties, there was no NASA support at all; NASA was founded in late 1958. In the early sixties, it began some modest funding, and in recent years it has become a much more active R&D participant. Generally, however, other than the normal advantages which a company may gain from Government support of its R&D programs--increased income, greater experience in the device technology, encouragement to venture into new areas not normally supported by non-Government applications --the NASA influence in the R&D area has been slight.

Secondly, NASA's needs are very special and particular to its own tasks. Besides reliability improvement, it puts a high premium on reduced size and weight and lower power consumption. These are characteristics desired by the various military agencies to a lesser degree; they have very little priority in industrial-consumer applications. Even within the military establishments, there are very few programs that can

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approach the NASA needs in their high priority on these aspects of electronic performance. Therefore, the type of IC work supported by the R&D programs of NASA may be relegated to a very limited spectrum of applications and, as a result, limited interest beyond these areas.

Customer--The Apollo guidance computer will use integrated circuits on its trip to the moon. Other parts of the Apollo vehicle and other programs of the space agency have used IC components, but this project has, for several reasons, carried the greatest impact.

In fall of 1962, when the decision was made to use IC devices in the prototype computers for the Apollo mission, these new components had not been designed into any major program for any application. (The Minuteman contract was announced in December of that year publicly stating that the advanced version of the missile would use integrated circuits.) Although the Apollo decision did not necessarily mean the devices would be incorporated into the actual computers, it did definitely imply that NASA and its contractors thought enough of these components' potential to consider their use. This was a major accomplishment. The new technology had gained an adherent who had enough faith in it to consider it for the most important mission of the whole space program and to use the IC devices in a critical area where electronic failure was probably equivalent to mission failure or at least a diminution of mission effectiveness. The influence of this decision, impossible to measure, must have been a powerful

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stimulus on systems designers who were still "on the fence" whether to include the IC device in their own designs. Needless to say, it probably gave the semiconductor industry a tremendous lift, since this was the first indication of a justification of the great effort and expenditure which had gone into the technology up to that point. If members of the industry, either those already committed to integrated circuits or those considering such a move, were hesitant about the future of the technology, NASA's decision should have done a great deal to allay such fears. To complete the story, NASA more recently made the definite decision that IC components will be used in the Apollo guidance computer.

In a much more immediate and tangible sense, the NASA action meant that the industry was to have its first volume purchase. In late 1964, one reporter noted that 200,000 integrated circuits had been purchased to that date for the Apollo manned spacecraft project (which includes more than the computer).[24] Considering the time when these devices were being sold, $20 per item would probably be a low figure. If this was the true average price, the revenue would have been $4 million. When one considers the importance of this amount of dollar income and unit volume, it is easy to realize the salutary effects which this purchase conveyed for the other IC products being offered by the firms involved. In the spring of 1964,

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[24]Barry Miller, "Microcircuitry Production Growth Outpaces Applications," Aviation Week, November 16, 1964, p. 79.

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Fairchild Semiconductor, which supplied the major share of the IC devices for the Apollo computer program, was the first to offer an off-the-shelf IC product line that was directly aimed at stimulating the non-military, non-space market. It is highly unlikely that the firm could have made this move if it did not have the NASA support for its higher-priced integrated circuits. At the least, the firm's capability to move in this direction was facilitated by the significant NASA support it had. Soon after, two of the other major IC vendors followed Fairchild's example; now all the major participants supply low-cost devices compatible with the needs of industry and, hopefully someday, the consumer market.

The actions and policies of NASA accelerated the acceptance of integrated circuits, although its greatest activity as a customer is yet to come. Space efforts of the future will use an increasing number of these devices, and the impact of NASA as an R&D sponsor and as a customer should be considerably more important than it has been in the past.

Air Force

It is appropriate to end this analysis with some brief comments on the role of the Air Force as a user of IC devices rather than as a proponent for their development. As was mentioned earlier, the degree of enthusiasm displayed by those members of the Air Force advocating the IC technology on the device component level has seemingly been matched by the

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indifference displayed by those Air Force members whose responsibility it is to supply equipment for the inventory. Other than the Minuteman project, the Air Force has not followed through to ensure that the IC component is used to good advantage by that agency.

The reasons for this apparent cleavage are several. From the outset, the R&D advocates of the IC device were alone in their convictions. Repeatedly, from many sources, interviewees said that those individuals who did promote the new idea were not backed by sister groups; the movement did not have an across-the-board consensus. Certainly the R&D arm of the military must be more sensitive to change than any other group, but it was apparent from the beginning that both industry and the rest of the military had to be convinced that the new approach was worthwhile. Efforts to solicit the support of such systems-oriented agencies were in vain. The sponsorship of the TI digital computer demonstrated in late 1961 is a case in point. Normally such a project would be undertaken by a group chartered to further equipment development, such as building prototype models using new devices. This effort was sponsored by the same groups that were involved in the original device development work. The action was well-intentioned, but it illustrated the dichotomy that existed. In short, the R&D branch felt obliged to prove the device's feasibility on the equipment level. This is not a very typical procedure.

A much more basic problem arises which is by no means

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experienced only within the Air Force or the military; it is quite frequent in industry. Simply stated, it is this: the more radical the device innovation, the more difficult its implementation on the equipment or systems level. If we were to hypothesize a scale labeled "receptiveness to innovation" that had "most receptive" and "least receptive" as its two end points, the R&D groups would be situated at the former station and the systems people at the latter. One observer commented on this problem with relation to the industrial scene, but it has its exact analogues for a military function:

> Any process of innovation must continually work against the instinctive hostility of those who fear they will be adversely affected--in particular, the operating managers. Their hostile attitude is not necessarily overt; it often manifests itself in subtle, but destructive ways. Let us recognize that the basis for such hostility is not entirely irrational. Innovation can really rock the boat. To the operating manager, it can mean loss of equipment, disruption of schedules, loss of immediate profit, and expense of new machinery. Don't tell the operating manager that innovation is a "good thing." He sees innovation as an array of costs. And he wants those costs tallied before anybody talks about going ahead.[25]

Perhaps another cause of the slow transition from device to equipment is strictly a human reaction. The fanfare that accompanied the initial IC work; the very positive statements which soon followed that <u>this</u> was the way to go; and the covert, and sometimes overt, contention that electronic equipment not looking to the IC technology was doomed for

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[25]Sumner Myers, "Attitude and Innovation," <u>International Science and Technology</u>, XLVI (October, 1965), 92, 94.

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obsolescence probably did not ingratiate the IC advocates to those who would ultimately be responsible for the needed follow-through. It is obvious that industry felt as if it was being "squeezed," and one can only conjecture if the Air Force systems groups did not feel that someone else was doing their work for them and also making their decisions. The definitive support for this conclusion is non-existent, but the circumstantial evidence exists.

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CHAPTER VI

CONCLUSIONS

At the termination of this study, two types of conclusion are considered. The first category consists of those findings which are strongly supported by the present investigation. From the author's viewpoint, the evidence arguing for these particular conclusions is very strong; there is little doubt as to their validity. They deal primarily with past events and are totally predicated upon this study of the IC technology. In contrast, the second set of findings is offered with less certainty. It is closely related to the study, yet it involves policies and occurrences regarded as being tangential to the major task; considerations of the present and future were not generally pursued.

The first set of conclusions is labeled Specific and the second is General.

Specific

1. The innovating firms within the semiconductor industry developed the IC product line for its growth potential; there were no apprehensions relative to the profit potential of their present product lines.

The IC innovators looked to the new component as an addendum to a presently profitable product line and not as a

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replacement for it. Absolute growth was the objective. There were no indications in the late fifties that the semiconductor market would encounter the problems that combined to cause the 1961 slowdown. On the contrary, optimism and confidence in the future, both for one's own firm and the industry as a whole, were the signs of the times. The price declines of the late fifties were treated as "normal"; they caused no great anxiety within the industry.

2. The IC technology eventually would have been developed by the industry on its own.

There is no doubt that there were forces within the industry in the late fifties which would have ultimately induced the introduction and development of the integrated circuit. The most important movement was the forward progress of the semiconductor technology. Combined with the industry's affinity for rapid change, the desire for growth products, and the nature of the men who were the major protagonists, the technological progress allowed for and urged the creation of a new electronic component. It was, to some degree, an idea whose time had come.

3. The major IC advances were not attributable to Government support.

The important technological innovations associated with today's IC product were not achieved as the result of the Government-funded R&D programs; one could almost argue that they occurred in spite of them. The major advances were

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generated by the in-house internally-funded projects of private firms. However else the Government may have contributed to the continuing development of the IC component, its formal R&D programs were not the source of the critical breakthroughs.

4. Those firms with a large stake in the semiconductor and IC business have been most successful in the market place and have the best technical capability.

The most successful participants in the IC market, with respect to dollar revenue, unit volume, and acknowledged technical know-how are those corporations whose economic sustenance greatly depends upon the well-being and profitability of their IC component operations. Although there are some major competitors for which this thesis does not hold, it is certainly true for those at the top controlling about 75 per cent of the market. For other than Westinghouse, there is no current IC vendor with a significant share of the market who does not have a major interest in the electronic components market. Similarly, there are no important manufacturers in the IC business from multi-divisional firms--again, other than Westinghouse--who have developed their own IC capability and who also do not depend greatly upon their semiconductor operations. A differentiation is made between the latter type of company and those that have set up an operation through individuals "spun off" from other companies already established in this field.

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5. The advance of the IC technology and its subsequent market growth have been greatly influenced by a few, strategically-placed individuals.

This applies to various persons within industry and the Government.

In the major IC firms, the influence and importance of certain individuals cannot be minimized. The particular technical innovation may not have been directly forthcoming from these particular persons--generally, it wasn't--but the strong support for the programs in which the advances were made is attributable to the aggressive thinking and project implementation of a few driving personalities. In some organizations, the IC operation is inextricably associated with one or two individuals; in others, the activity is relegated to the anonymity of bureaucratic titles. Both within the particular firms and the industry itself, and from those on the outside, this theme was continually repeated, and always the same persons were mentioned.

Within Government circles, the IC technology is also closely associated with just a few persons who have been its champions from the beginning. The participation of the Government can be directly traced to their efforts. Their task has always been double-pronged: convince industry and the other agencies within their own military organizations of the worth of the IC component. Within the military, the coupling is even more definite and particular than it is in industry.

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6. The major Government contribution in advancing the IC technology was the establishment of a "conducive climate."

The Government's main contribution to the introduction and development of the IC component lay in its ability to "fertilize the ground" rather than "plant the seed." The various Government agencies by their insistent demand for electronic components that were more reliable and smaller continually maintained a pressure on the industry to move toward these goals. The military services and NASA created an atmosphere of urgency which carried a double meaning. For those firms who could develop the desired devices, the Government would be a very obvious first customer; for those who did not generate improved components, the Government might not be a customer at all. With NASA, the message took on an air of national importance which could not wholly be translated into pecuniary motivation. This "carrot and stick" theme had its effects both on the components and systems houses and especially upon those companies that greatly relied upon military procurement for their livelihood. For a firm less dependent upon the military and NASA as a purchaser, it saw a first customer willing to pay the higher initial prices--assuming the right product could be developed--that would facilitate the offering of a product line to non-military, non-space clientele.

7. The Government accelerated the development of the IC component.

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The Government role as R&D sponsor greatly accelerated the oncoming of the IC device; as stated above, it did not initiate the movement in that direction. By its dollar support of R&D projects for IC improvements it reinforced in very tangible specific terms what it had been advocating in a more general way: the Government is interested in improved electronic components offering particular advantages. Most probably, the initial contract efforts could not have been funded except on a "cash-on-the-barrelhead" basis, and even this approach had limited or no attractiveness for some firms. The Air Force, however, was willing to back up its words with direct dollar support. This policy not only stimulated the companies contracted to continue in this direction, but it had a similar effect on the others who either could not or would not obtain R&D contract awards. In such a manner, the Government accomplished one of its major objectives: it "persuaded" the industry to allocate its own funds toward the same goals. Although impossible to quantify, the industry has most definitely spent a great deal more for IC development than the Government. This has been one of the Government's prominent contributions to the IC cause: its expenditures have induced even greater outlays by the industry itself thereby creating a multiplying effect. The combination of heavy R&D spending and the attendant publicity constituted a steamroller mechanism which the industry found difficult to ignore; it wouldn't and couldn't.

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8. The Government failed in its initial intent relative to molecular electronics.

Molecular electronics, the original goal of the Air Force contracts, is probably as significant in the market place today as it was seven years ago. As emphasized previously, today's IC component is far removed from the hoped-for molecular electronic device of yesterday. If the Government programs were helpful in other respects, they were fruitless in developing the molecular electronics concept and translating it into useful products. If the term is still used in today's parlance, it should refer to a potential development of the IC future. The present IC concept is not a result of Government funding--development, yes; conception, no.

General

1. The more advanced the device innovation and the greater the gap between it and the best components presently being offered, the less its chances of rapid development and perhaps the less the probability of its feasibility.

There are two major forces within the electronic component operation continually urging for change and the development of new products. The first derives from the economic needs of the business enterprise. New products can result in the innovator's profit. The top management of capable companies has a sensitive antenna to this corporate need. This has been obvious in the IC instance. Secondly,

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there is that branch of the industrial organization existing only on change. The R&D group, both by mandate and personality, continually seeks new approaches. The advanced R&D groups are basically not task-oriented, and the applied R&D operations are harnessed to very particular needs of the organization relative to its present and near-future product line. The former groups are generally motivated by scientific and technological stimuli rather than the realities of the business enterprise, e.g., profits, growth.

For the IC case, when the coupling between these two forces--economic and scientific--has been greatest, the results have been most rewarding. Where top management is closely tied, by past experience or by preference, to the technological aspects of the business, the probability of full implementation from idea to finished product is a maximum.

When the Government chooses to support a new program which is far ahead of industry's thinking on the subject, it is cause for questioning. The business man is naturally heavily influenced by economic factors, but the industry also has its crusaders and prophets who look and work for technological progress. For these individuals, motivation is greatly influenced by non-economic factors. Therefore, when a Government agency feels that a radical change is needed, motives should be reviewed and the probability of success--relative to absolute and opportunity costs--should be seriously considered.

2. <u>The more radical the device innovation, the more difficult its transition to final equipments and systems</u>.

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Change, especially radical change, breeds its own set of converts and non-believers. There are those whose functions are jeopardized by revolutionary innovation, and they therefore see not the promise but the problems. The difficulties are both human and mechanical.

Extreme change demands new thinking. Whatever was being done before is no longer adequate. To some degree at least, the old must be discarded and newer techniques and approaches learned. Many do not like to experience this transition; others cannot. There is a certain safety in doing the job the "tried and true" way. Perhaps the newer method does have advantages, but it also has its costs, human and otherwise. The greater the change required, the greater the inertia force to retard it.

Organizations, both Government and industrial, are also not institutions well-adapted to innovation. The Government, especially, with its unique set of problems, is not geared for rapid change. The bridge between device development and its implementation for final use is less than perfect. For certain special cases where the need is great, such as a Minuteman, the transition may be rapid. But for the vast bulk of equipments, changeover must occur through more tortuous routes. Since major changes have serious ramifications for many years to come, any decision that is a radical departure from the past is a momentous one. Therein lies the dichotomy. Parts of the military organization are, and to some degree must be, extremely conservative in their thinking. Other

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factions, such as the R&D groups, are receptive to change--usually, the more, the better. The totality must somehow reconcile these opposing polarities. A radical innovation, even one with much merit, makes the rapprochement more difficult. It may even raise the painful question: Is a revolutionary change, such as molecular electronics or integrated circuitry, destined for extended problems in the follow-through simply because it is so much better than its substitutes?

3. The efforts of the various Government agencies performing similar R&D tasks should be examined to determine their impact, both pro and con, upon each other and the industry.

The three services and NASA all have a great deal in common in their electronic component work. All would like electronic devices offering higher reliability, reduced size and weight, lower power consumption, and, if possible, lower initial costs. The differences lie in the urgency placed on each of these needs and how much the customer is willing to spend to get them. An improved component for one generally has utility for the others.

Each has its own R&D establishment sensitive to what industry and its counterparts are doing. The feedback may be direct via Government channels or indirect through industrial firms. Since most of the major R&D work is performed in industry's laboratories, the latter path is an obvious exchange medium. Important R&D contract decisions, critical because of

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the funding levels and the emphasis placed upon them by the authorizing agencies, induce reactions from industry and other interested parties in the Government. The effects may be positive or negative depending upon one's outlook. For the Government in toto, duplication and unnecessary spending may result. Perhaps, on the other hand, there may be a salutary fallout for all.

No blanket evaluation can be made. It is axiomatic that organizations, both formal and informal, do react when stimuli work upon them. The objective is to optimize the aggregate of the efforts to maximize the total utility obtainable.

4. Companies have varying motives for accepting Government R&D funding, and some see more overall disadvantage than good in work done under Government support.

Some firms are reluctant to accept Government support for R&D work while others are more than anxious. For the latter group, the motives are quite diverse ranging from the obvious defrayment of costs on high-risk ventures to more subtle criteria far transcending the immediate contract in question. For those in the former category, there are a multiplicity of considerations why a firm would opt to fund its R&D work in-house, e.g. patent retention. The Government should deploy its R&D funds so that, if possible, the impact of expenditures affects more than just the particular firms under contract. The IC case is an excellent example. Since

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an expenditure in one area necessarily precludes funding for a host of alternative programs, the overall impact may be positive or negative in its totality.

Government R&D spending is probably most efficient when it complements work that the particular firm itself is interested in advancing. By so doing, the chances of the multiplier reaction occurring are increased. By espousing programs divorced from the company's normal interest area, the chances of success dwindle. There should be some obvious commonality.

5. <u>For companies or an industry serving both Government and non-Government markets, overdependence upon the Government as an R&D sponsor and eventual customer nurtures latent dangers</u>.

The industrial-consumer market is fickle. Any participant must accommodate his product line to a volatile demand. Risk is high and an assured market does not exist. The marketing skill is therefore at a premium.

The Government market, however, may be just the reverse. New components, especially those developed under Government R&D sponsorship, often have an assured customer. The customer may have specified what he needs; if the device is successfully produced, compatible with the constraints and performance requirements, then the firm's risk may be relatively slight. As Theodore Levitt has said:

> If a team of consultants had been assigned specifically to design a business situation calculated to prevent

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> the emergence and development of a customer-oriented marketing viewpoint, it could not have produced anything better than the conditions just described.[1]

To date, two of the major IC firms have dominated the Minuteman IC procurement. This volume has been a mainstay to these companies; any profits from their respective IC operations have probably been attributable to these purchases. If and when the Minuteman program concludes its IC procurement, these firms may be faced with harsher market realities which previous experience has not prepared them for.

6. New product lines for industrial-consumer applications are sometimes dependent upon the existence and success of the component lines offered to the various military and space agencies.

Although the function per se of Government research and procurement is not to facilitate the offering of new product lines for industrial-consumer applications, the dependence is often great upon Government participation with respect to the appearance of new electronic components. If the Government had not sponsored the original R&D contracts for IC programs or if the military had been less enthusiastic in its statements, the IC component would still have eventually been developed. If the Government, however, had not been the initial customer willing to buy high-priced products, the previous conclusion is in much greater doubt. The Government is considered by many to be the means by which certain non-Government markets are penetrated. The present low-cost IC

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[1]Theodore Levitt, "Marketing Myopia," Harvard Business Review, XXXVIII, No. 4 (July-August, 1960), 54.

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lines probably would not have been available had this condition --Government purchases--not prevailed. In turn, once the firm can cater to the non-Government market, there are salutary returns for the military-space products being offered; lower prices and better quality may be forthcoming.

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GLOSSARY

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GLOSSARY

Active component--component capable of performing electronic functions, e.g., amplification, oscillation

Capacitor--component capable of storing electrical charge

Dendrite--method of growing pure semiconductor material in long strips

Diffusion--physical-chemical technique used in manufacture of semiconductor components

Diode--component capable of passing electrical current in only one direction

Discrete component--single elemental components that together perform electronic circuit functions

Epitaxy--method of growing semiconductor material

Integrated circuitry--indivisible electronic circuits comprising the equivalent of many discrete components within a chip of silicon material

Mesa transistor--transistor type with a mesa (raised) configuration

Microelectronics--techniques directed toward miniaturizing electronic circuitry, generally employing variations of either or both of the thin-film or integrated circuit methodologies

Molecular electronics--indivisible electronic circuits performing their functions within a piece of material not having any recognizable discrete component elements (as in the integrated circuit)

Oxide-masking--technique used in diffusion process to obtain selective masking

Passive component--electronic circuit components not capable of performing electronic functions, e.g., resistor, capacitor

Planar process--fundamental technique used in fabrication of integrated circuits and certain other semiconductor components

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Resistor--component capable of impeding the flow of electrical current

Semiconductor--material exhibiting electrical properties of conduction better than an insulator but not as well as a metal

Solid-state component--component whose operation occurs within a solid, e.g., transistor, rather than a gas or vacuum, e.g., vacuum tube

Thin-film technology--method of simulating electrical/electronic components using very thin layers of material

Transistor--active component made from semiconductor material

Vacuum tube--active component whose operation occurs within a high vacuum

Zener diode--diode capable of serving as a constant voltage source (battery) in electronic circuits

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INTERVIEWS

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