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MICROELECTRONICS

PROLOGUE

The issues involved in the development of microelectronics technology span a range almost as broad as that of technology itself. The vast number of potential applications and the apparently pervasive nature of their impacts mean that perspectives on developing microelectronic technology quickly become blurred with perspectives on technology itself. Those who have positive feelings about technology have nothing but praise for the marvels of microelectronics. Those who are generally suspicious about the benefits of technology see microelectronics as an open door to a world in which machines control and dominate society.

The near identity which exists between speculations on microelectronics and the conventional wisdom of technology itself easily spills over into assessment of microelectronics technology. American studies, for example, assume technology to be good and therefore they approve of further investment. British studies tend to view the new technology as being threatening to labour but inevitable, so they plan accordingly. French studies emphasize sovereignty. It is important to observe that cultural biases towards technology are the driving force behind all these studies. They are at best conjecture even though some authors have gone to great length and detail to document their cases. Because the foundations of such assessments are essentially unprovable, such extended works give a finer texture to the arguments presented without necessarily bringing them closer to the truth. At least a few such technology assessments amount to science fiction written by bureaucrats who are interested in the area, but feel they must be bored while studying it.

This is not to say such studies have no value. They are, in fact, good expositions of the potentials of technology. Their credibility (or inferred truth content) however, relies on the existence of national "articles of faith" regarding technology. Countries with a strong belief in technology have a microelectronics policy which reflect the strength and form of that belief.

The following report reviews the issues and sorts through the abundant literature dealing with microelectronics. Hopefully it is not done in a boring manner! The main objective of this report is to condense numerous points of view in a small space. The report is a critical view of current thought concerning trends in microelectronics. It includes a few insights which follow from the synthesis.

The report is organised to expose the trends and issues as efficiently as possible. The basic conclusions are presented first. There is nothing surprising about the conclusions. The evidence merely confirms what has long been supposed. The conclusions are elaborated on in the following section. The elaborations briefly qualify and put in context the four basic conclusions. The next section, which gives bulk to the report, contains background material. This material is provided for readers who wish to know what kind of case can be made to support the conclusions. Anyone not familiar with the technical aspects of microelectronics will find them briefly discussed in the appendices.

Organising the report so that it begins with terse statements and gradually becomes more detailed is the reverse of normal documentation which seeks to rationalize conclusions on the basis of evidence. Since the conclusions of this report were indeed arrived at inductively, there did not appear to be a strong need to use a deductive style. The advantage of the method used is that there is a continuously declining marginal utility of effort for the reader. Put another way, what the reader most needs to know comes first.

Put another way, the more you read, the less you want to continue. There is, of course, much more material available on this subject. Any reader wishing to go into this fascinating subject in greater depth is well advised to plan a personal odessey through source materials.

CONCLUSIONS

The four conclusions of this study are:

1. Microelectronics will be the principal growth technology of the 1980's.

2. The development of national microelectronics industries will increasingly become dependent on government involvement.

3. Microelectronics will have a wide range of impacts, both good and bad.

4. Both the opportunities and the threats posed by this new technology are partially manageable.

The following section describes these in more detail.

ELABORATIONS

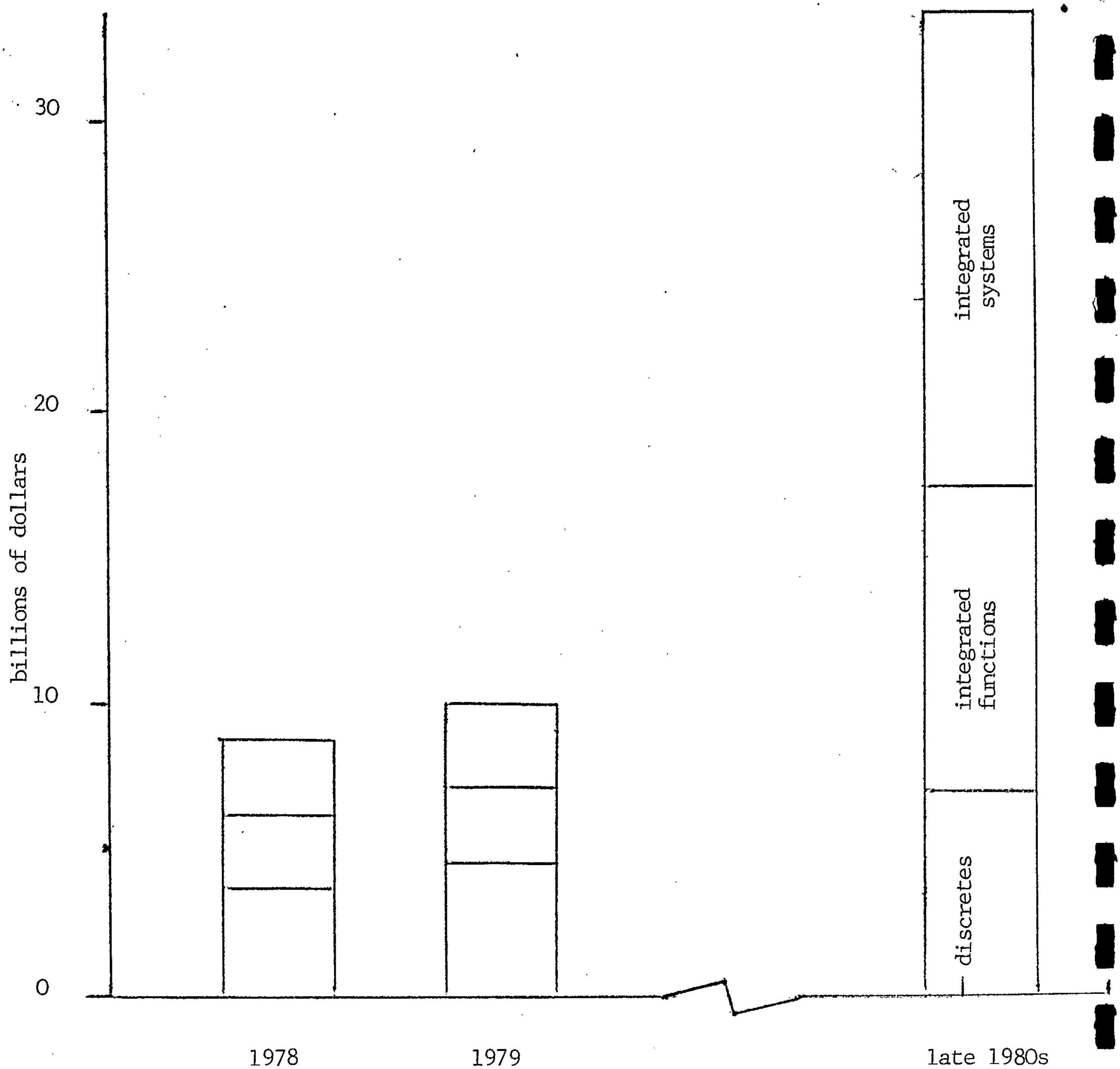
1. FIRST CONCLUSION: Microelectronics will be the principal growth technology of the 1980's.

A prima facie case for the continuing growth of the microelectronics industry can be readily inferred from figures 1 and 2. Figure 1 forecasts the market size in billions of dollars (U.S.) while figure 2 points to a wide diffusion of the technology. The rapid growth illustrated in these trend lines is a typical characteristic of most aspects of the microelectronics industry including capital investment, R & D, and manpower.

By themselves, trend lines do not tell the whole story. The future of any technology is dependent on whether or not it meets certain conditions for survival and evolution. These conditions can be placed in three broad and inter-related classes: technology push; technology pull; and, environmental. The strengths of microelectronics technology lie in its impressive fulfillment of push and pull conditions (cf. background section). The problems, or growth pains, of the industry lie primarily within the class of environmental conditions. In particular, the forward motion of microelectronics is, and will continue to be constrained by three environmental factors: the capital stock barrier; the intellectual stock barrier; and the entrepreneurial barrier.

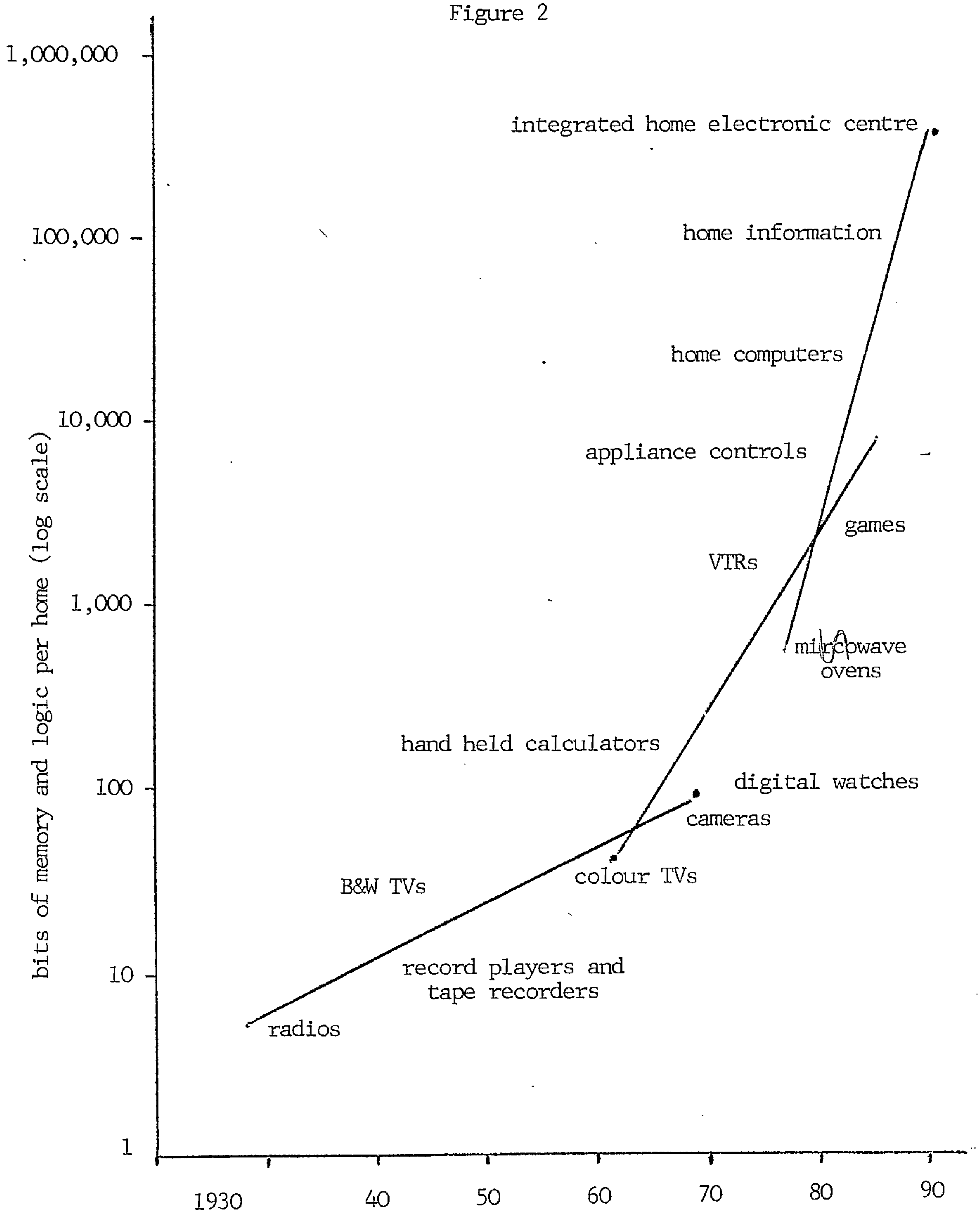
The key to forecasting the growth and impact of microelectronics technology lies in determining where and by how much the barriers to diffusion will slow down development. Most policy-oriented studies of microelectronics overstate the consequences of this technology by underestimating the influence of constraining forces. Industry forecasts tend to consider constraint problems. They consequently produce significantly different projections.

Figure 1



World Semiconductor Market Size

Figure 2



Intelligent electronics in the average American home

One principal difficulty, often overlooked, in impact assessment is that a large part of the semiconductor market is for new products (e.g. electronic games) rather than for substitution goods (e.g. electronic controls replacing mechanical controls). This difficulty has biased a number of assessments which forecast major disruption (especially unemployment) by focusing on technological substitution without adequately considering new growth due to new markets.

2. SECOND CONCLUSION: The development of national microelectronics industries will become increasingly dependent on government involvement.

There are two models for the development of a successful microelectronics industry: that of the U.S., and that of Japan. The former is essentially a "free enterprise" private sector oriented model, the other is a "dirigiste" government directed model. Neither is pure in that they both have elements of free competition as well as elements of government support. Both systems work very well.

In an overall context the "free enterprise" system is clearly superior since it offers the most efficient distribution of goods. Its production most closely matches the perceived needs of consumers. In a game theoretic sense, however, there is no doubt that there are economic rewards for collusion, for the establishment of barriers to competition, and for getting support from the government.

The second conclusion is based on the supposition that in the event of conflict, a team with a co-ordinated strategy and extra resources will win against a group of individuals with normal resource levels. This situation currently exists. Japan, using government purchasing, non-tariff barriers, R & D grants and outright co-ordinating of national efforts, has built up a strong microelectronics industry. Its target market is the industrialized West. The only defence for domestic industries is to develop a national policy with the same strategic advantages of the Japanese model. A number of nations are now doing this, leading to open competition not among individual firms but among competing industrial policies aimed at preserving national electronics industries.

The social costs involved in doing this need to be considered in any complete accounting. The supremacy of any industry is bought for a price. Those countries which promote microelectronics over other industries apparently feel that the price is worth it. The question left for Canada is: Is the social and strategic value of a domestic microelectronics industry high enough to warrant the deflection of government resources away from other social priorities?

3. THIRD CONCLUSION: Microelectronics will have a wide range of impacts, both good and bad.

The power of microelectronic technology can best be understood in a metaphorical way. It has often been said that tools are extensions of man in the sense that they increase man's power. The machines of the industrial revolution were extensions of muscles greatly enhancing man's ability to move large weights, to accomplish repetitive tasks quickly. This resulted in the phenomenal growth of industrial economies with subsequent social impacts.

The complexity of history does not permit one to say without qualification that specific events in the past have caused the world to be what it is today. But if one abandons rigour, broad patterns emerge which show how technological developments have contributed in an important way to forming today's world. To give one example of cause and effect chains, the development of engines resulted in:

a move away from agricultural/rural economies to industrial/urban economies; the rise of capitalism; the consequent rise of Marxism with its notions of "class struggle"; and the polarization of global politics and ideology into capitalist and socialist camps.

More recently, telephone, radio, television, and other communications technologies have provided the tools to extend man's senses. McLuhan and others have devoted much thought to the social and economic impacts of this new capability. This technology has expanded man's ability to know and has tempted him to increase his span of control beyond local concerns. The reduced cost of information collection and transfer has had a number of subtle impacts on social and economic organisation. Among them are: the rise of the service industry (and concomitantly the increasing participation of women in the labour force); the expansion of government and the welfare state; the development of global politics; and the arrival of the multinational corporations.

Microelectronics extends man's mind. It extends mind in the sense that it performs functions previously done only through the use of human intelligence. Some of these functions it performs at speeds many orders of magnitude faster than is possible for the human mind. While there are many mental skills which will not likely be replaced by machines, nevertheless, the impact of intelligent electronics will be extremely wide and deep. There is virtually no area of human endeavour that could not, in principle, be changed by microelectronics.

The benefits do not come without their cost. The new microelectronics industry could devastate the old electronics industry. Productivity gains will cause labour displacement. The use of computers in business and education will sharpen analysis and increase the accessibility of libraries and data banks. But this could create a pool of "computer illiterates" -

people disadvantaged by not having access to an important and necessary tool. In the market place information and allocation will flow better, but the possibility of rapid execution of transactions could result in oscillating and unstable markets.

4. FOURTH CONCLUSION: Both the opportunities and the threats posed by this technology are partially manageable.

Once opportunities and threats are identified, course of action can always be designed so as to maximize returns in some restricted way. Often, however, very difficult tradeoffs have to be made. The problem of unemployment is a good example.

Microelectronics technology shows the promise of creating significant productivity gains. These gains will, in some cases, reduce the need for workers, thus creating unemployment. Assuming there are related jobs elsewhere, the answer to this problem is the retraining of workers for new tasks. This problem is manageable only to the degree that the labour force is amenable to relocation. The feasibility of this solution depends on social and political milieu to which it is applied. The degree to which this impact is threatening is, accordingly, dependent on the society involved. Unemployment due to microelectronics will likely be more of a problem in Britain than in the U.S., not so much because of the nature of the technology but because of the nature of the solutions to the problems.

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What follows is more extensive background information. It has been arranged in four sections, each addressing one of the conclusions. The first digit of the subsection numbers refers to the number of the conclusion being talked about.

BACKGROUND

1.0 The Growth of Microelectronics Technology

1.1 The Place of Technology in Economic Systems

Figures 1 and 2 have served to indicate that the scope and penetration of microelectronics have increased greatly. It is a fairly safe bet to say that this growth will continue into the future. Simple trends cannot, however, be used to forecast the underlying forces which guide and direct the growth. Determining how and where a technology moves requires a different kind of analysis.

There are many subcurrents below this swelling technology. Some are more important than others. Selecting main themes requires some view as to what is important in technological development and what is not. Important in today's world means, by and large, economically important.

Two points need to be made when discussing technology in economic terms. The first point is that mainstream economic thought focuses on balancing supply and demand. Economic theory which describes very well the market mechanisms leading to equilibrium is less successful at describing dynamic, non-equilibrium phenomena. Technological innovation is one such phenomenon. New technology can shift supply and demand schedules around enough to completely thwart the best theoretical predictions. Consequently, "R & D Theory" is difficult to make economically orthodox.

The second point is that economic activity, in both the equilibrium models and the dynamic models, is divided into two distinct activities: production and consumption. Each activity moves technology in a different way.

On the production side the optimizing criterion and main organising principle is efficiency, getting more product for fewer (in terms of factor costs) resources. In the "non-equilibrium" case, something else is happening beyond the simple accommodation of supply and demand schedules. New technology is being created. The producing firm is still organised on an efficiency model, however. Its new technology is accordingly a "natural" extension of old technology. The firm continually refines its own products because this maximizes their R & D effort. They can capitalize on their collective experience. The efficiency model for innovation predicts the form of the familiar "learning curve" and explains why large corporations rarely make bold innovations but concentrate on improving production facilities. When they want new products they generally buy out small innovative firms.

R & D which follows its own logic of efficiency results in low cost innovation. This type of innovation is said to be driven by "technology push" since it follows the lines of existing technology. The positive manifestation of technology push is that it mass produces objects very cheaply. The pathological manifestation of technology push is that it results in unnecessary product differentiation.

The consuming sector (households) also reacts to laws of supply and demand by exchanging labour and ownership of resources for products. But they do so by using an optimization criterion which is distinguished by the fact that it is driven by value rather than price. The consuming sector's organising principle is effectiveness. Its main interest is in maximizing "felicity" or "happiness" while reducing "inconvenience" and "unpleasantness".

The evolution of taste, desires, and patterns of final demand is not well understood. These things do change, however, and the new demand generates new values which eventually become prices to which the producing sector responds. Technology changes in directions to which it might not, if left to its own evolutionary principle - efficiency, go itself. The phenomenon which so draws technology is called technology pull (and sometimes also demand pull).

Technology push and pull are the two forces which move technology through time. The velocity of technological change, or the rate of innovation, depends on the environment in which the forces are exerted. By way of analogy, a motor capable of exerting a fixed force will turn at variable speeds depending on the load put on it, or whether the gears attached to it are oiled or not. So it is that under certain economic conditions, both push and pull may be present, but still the direction and rate of innovation are modified by environmental factors. The push, pull, and environmental factors which apply to microelectronics are discussed later in this background material.

Where does government policy fit in this melange of push, pull and environmental factors? Everywhere. It has crown corporations as firms in the producing sector. As a purchaser, consumer, owner of resources, it behaves like households. It also regulates both the factor and product markets. Government also manipulates environmental conditions to facilitate or reduce the forces of technology push and pull. This it does via taxation, regulation, etc. It often manipulates environmental conditions to selectively modify push or pull forces. This gives rise, under this form of classification, to five categories of government action: (1) direct technology push, in which government acts like a producer; (2) indirect push in which environmental conditions are manipulated to affect mainly producers; (3) direct technology pull, in which government is a consumer; (4) indirect pull in which conditions affecting mainly consumers are manipulated; and (5) purely environmental conditions, which alter very generally both push and pull (e.g., by improving the "economic climate").

Figure 3 summarizes the push/pull discussion.

Figure 3

	Technology Push	Technology Pull
Optimisation Criterion	Efficiency	Effectiveness
Domain of Operation	Producing Sector	Consuming Sector
Positive Aspect	Mass produces related product lines cheaply	Moves R & D to socially needed areas
Negative Aspect	Results in useless product differentiation supported by heavy advertising	Ignores cost of diverting resources away from technically efficient allocation patterns
Factor Markets	Reacts by changing the production function	Causes changes in quantity and quality of factors of production
Product Markets	Causes changes in market basket of "economically" available goods	Reacts by changing vector of final demand

<u>Technology in the Evolution of Economies</u>

1.2 Technology Push in Microelectronics

The microelectronics industry is continually striving to make chips smaller, more integrated and faster. They do this because there are good technical, as opposed to market, reasons for such development. These reasons define the development goals for the industry which are presented below as the "technology push" drive for microelectronics.

All firms have these common goals and the race to achieve them is intense. The rapid changes taking place in the microelectronics field mean that products quickly become obsolete. There are definite advantages to being the first with a new product. The initial design of a microprocessor or memory technology sets de facto standards to which other devices must conform. The first design of a new product can conceivably take up such a large part of the market that subsequent designs, appearing as little as 8 to 12 months later, have to face considerable marketing obstacles.

1.2.1 wafer size and quality

Microelectronic circuits are built on a substrate of silicon. The substrate material takes the form of a thin disc-shaped wafer which is cut off from a large, cylindrical crystal of pure silicon. Early silicon wafers were 4 cm in diameter, and are now more than 3 times that size. Each wafer can hold many copies of one circuit, from 400 for simple devices like watches, to as little as 25 for large charge-coupled device memory arrays.

Since all copies of the same circuit are processed one wafer at a time, there are economies to be gained by making large wafers. There is some progress being made in this direction. Some R & D now being devoted to producing cheap, photo-voltaic cells for solar energy is expected to have as a spinoff larger useable wafers for producing microelectronic circuits.

Quality in wafers is even more important than quantity. As chip size (the area occupied by one circuit) increases, and as density increases, so quality must increase in order to maintain adequate yields. One small flaw in the centre of a wafer used to make only 25 chips will reduce yield by 4% while it will only reduce yield by 1/4% if 400 chips are made from the wafer. Such flaws, coupled with other production problems can mean that a production unit can attain yields of as low as 5%.

Figure 4 shows the trend in silicon chip sizes.

1.2.2 circuit density

Increasing circuit density (number of circuit elements per unit area) has been a consistent goal of the microelectronics industry. There are a number of reasons for wanting to do this. By reducing chip size, less time is needed for signals to travel along it. Small chips have low power requirements which in turn means less heat dissipation and no need for extra circuits to amplify signals to overcome transmission losses. Capacitance of interconnections is reduced as is the electromagnetic noise caused by gates switching on and off. The smaller the circuit and circuit elements, the more efficient the device for processing signals. Figure 5 shows the trend in miniaturization.

Combining forecasts for density and size suggests that it is possible to achieve in 15 years, chips with functional capabilities 2000 times greater than now exists. With only slowly rising costs, prices should decrease by a factor of about 1000.

There are two obstacles in the way of this goal. The first is that, as circuits get smaller, the dimensions involved get close to the wavelength

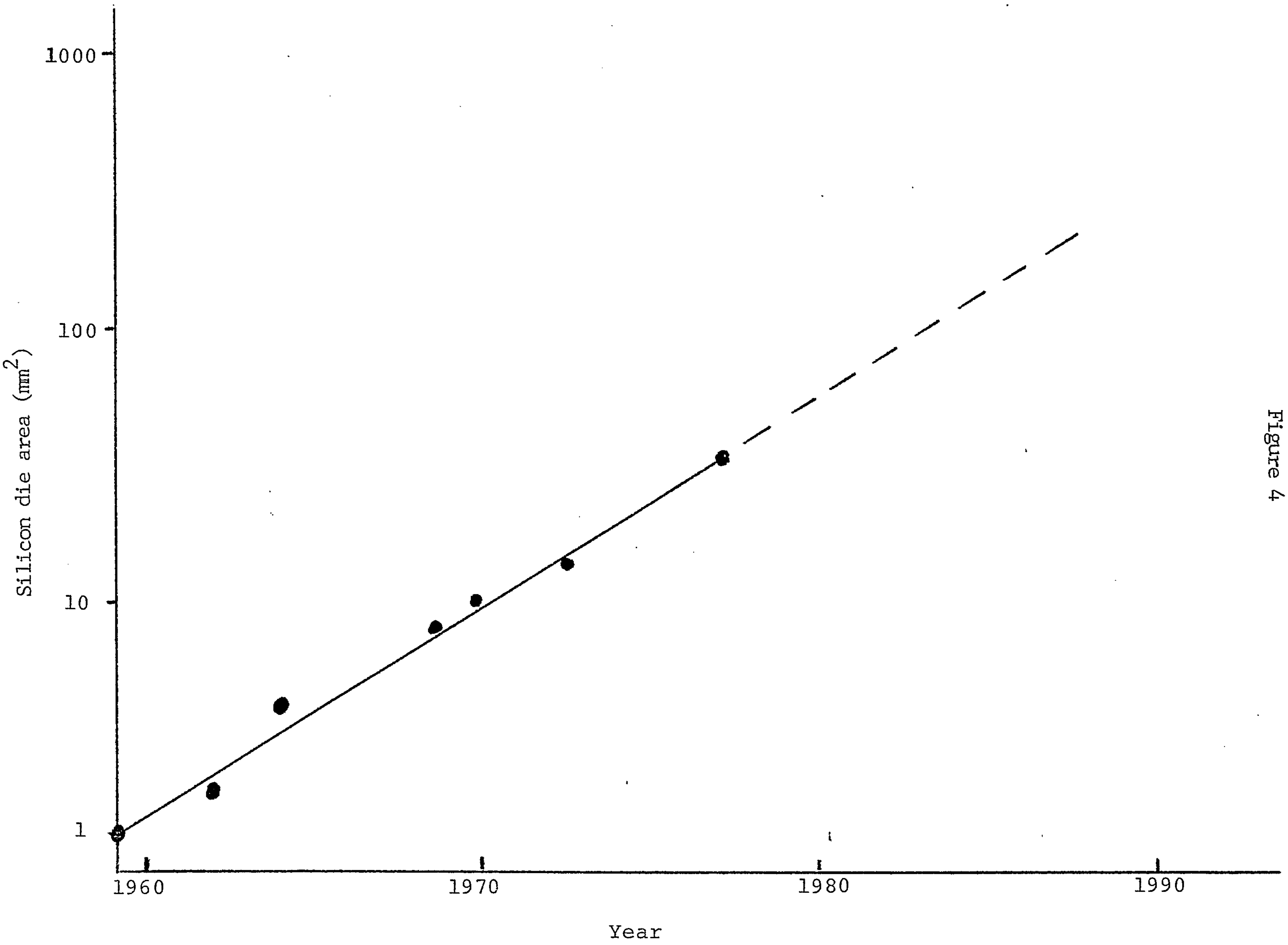


Figure 4

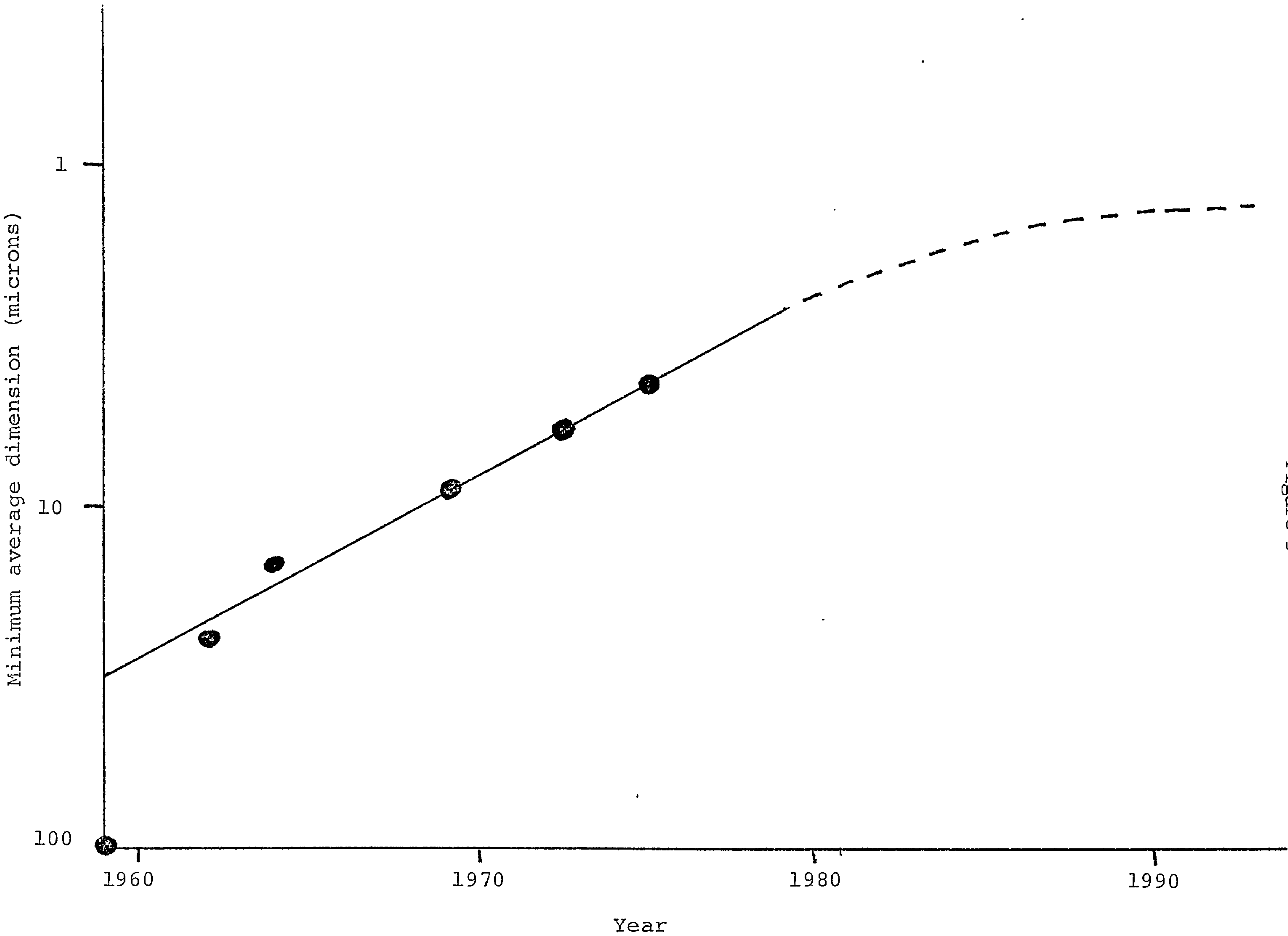

Minimum average dimension (microns)
1
10
100
1960
1970
1980
1990
Year

Figure 5

of light (about 1/2 micron). At this point, visible light can no longer be used in the photolithographic process. It is as if the circuit elements are so close together that light cannot slip between the spaces that separate them. Two techniques are being developed to overcome this problem. One approach is to use X-rays in the photolithographic process. A second method is to use an electron beam scanner to "draw" each chip.

The second obstacle lies in the difficulty in aligning successive masks in the photolithographic process. As successive layers of a microelectronic circuit are built up, photomasks have to be perfectly aligned with work already laid on the silicon base. Realignment more accurate than 3 times the wavelength of light is not currently possible. One approach to overcoming this problem is the development of devices whose critical elements do not depend on photo-engraving. This can be done, for example, by varying individual transistor specifications via amount of solid state diffusion of the doping impurities rather than relying on critical contact areas between parts of the transistor. Electron beam technology will also be helpful in solving the alignment problem.

1.2.3 circuit complexity

Figure 6 shows a trend to integrated circuits having more and more parts, and, consequently being more complex. Optimal levels of complexity vary from technology to technology, but they all contain the features shown in figure 7, i.e. chip cost and testing and assembly cost.

Assembly and test cost is inversely proportional to the number of functions on a circuit. This is because the costs are associated with handling, packaging, and testing the chip itself. It does not really matter how many functions are on the chip.

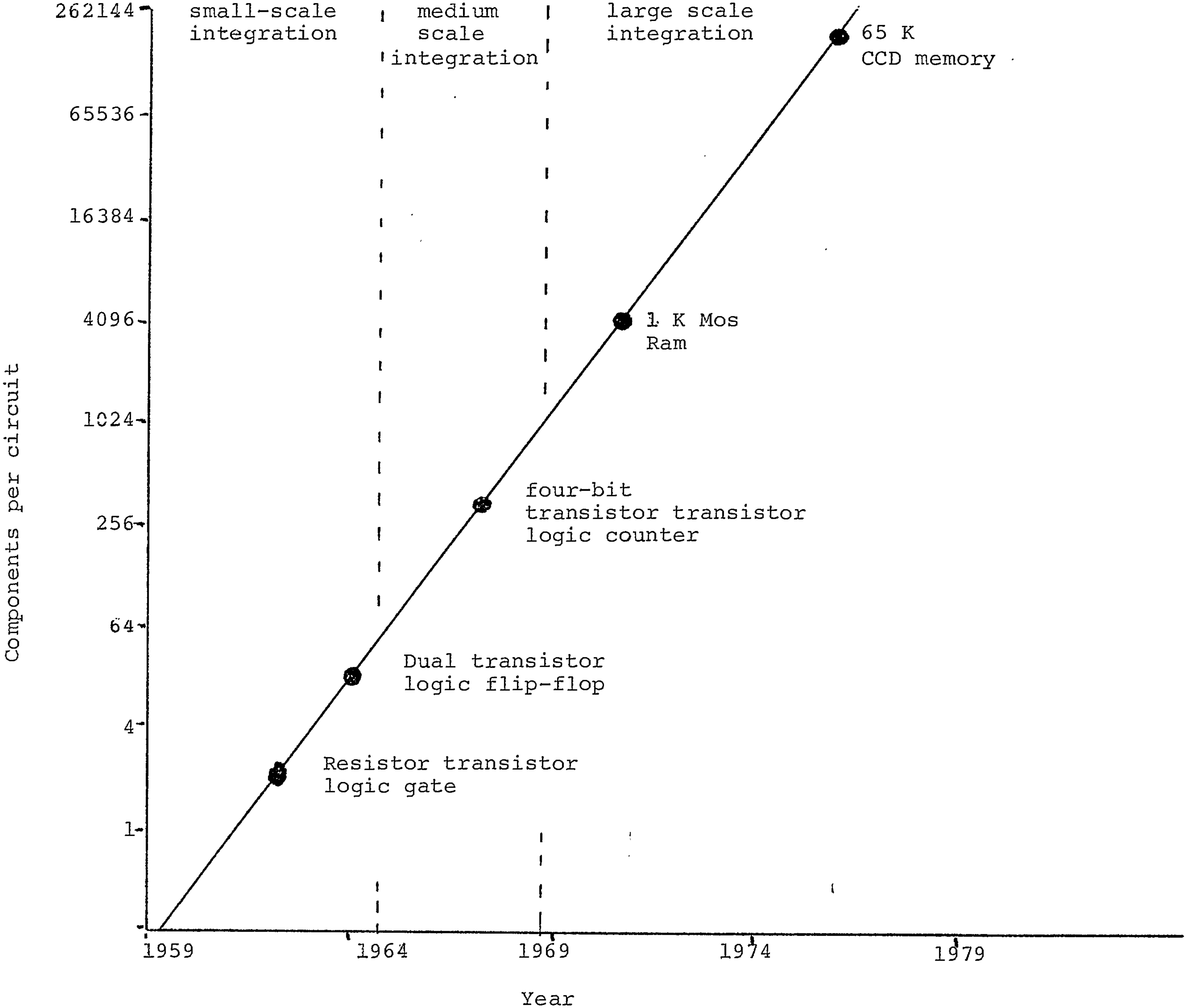
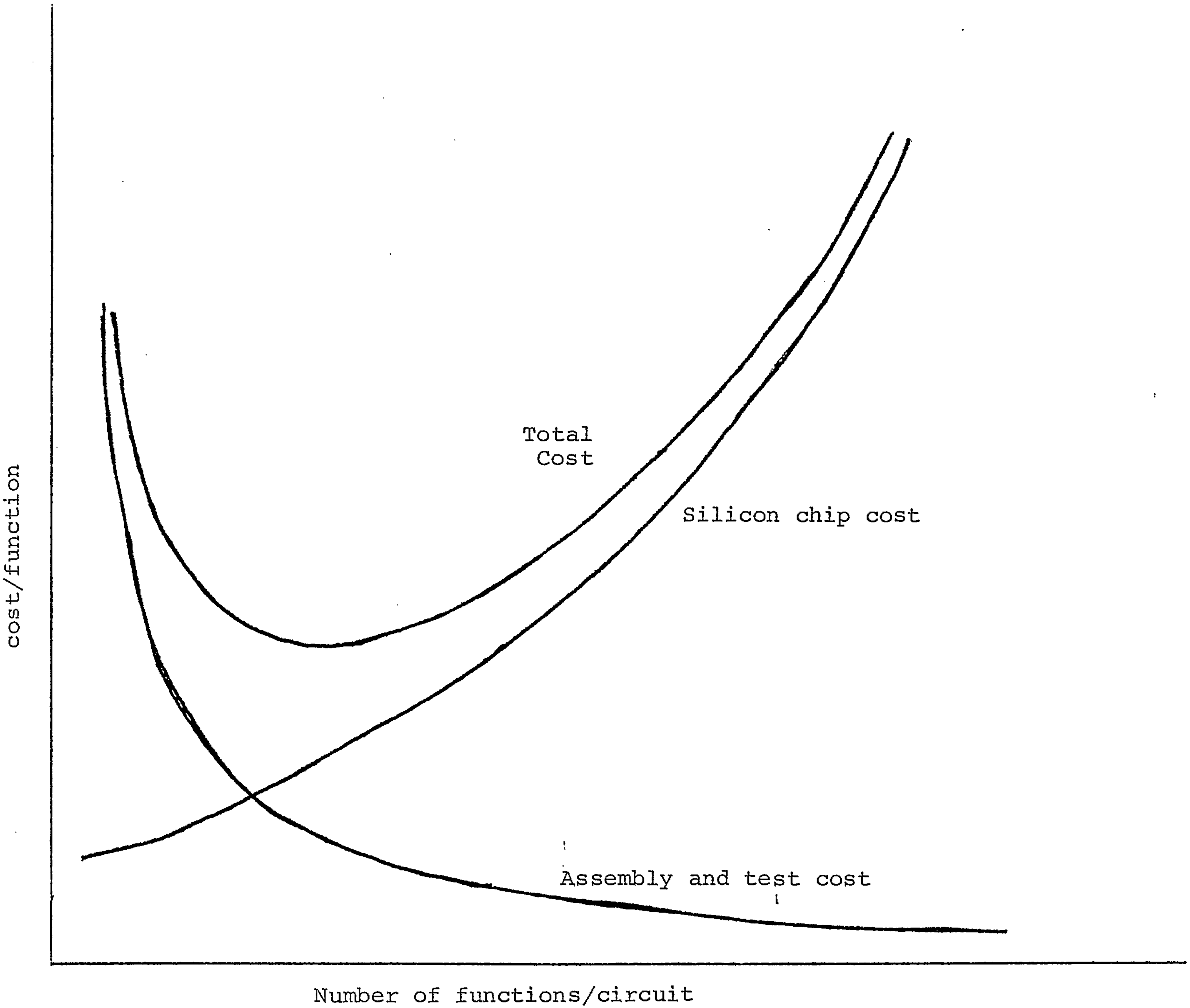

262144
65536
16384
4096
1024
256
64
4
1
Components per circuit
small-scale integration
medium scale integration
large scale integration
65 K CCD memory
1 K Mos Ram
four-bit transistor transistor logic counter
Dual transistor logic flip-flop
Resistor transistor logic gate
1959
1964
1969
1974
1979
Year

Figure 6



Total
Cost
Silicon chip cost
Assembly and test cost
cost/function
Number of functions/circuit

Figure 7

Silicon chip cost on the other hand exponentially increases as the number of functions per circuit increases. This is because each function has a distinct probability of failure and these probabilities are compounded to give a failure probability for the whole chip.

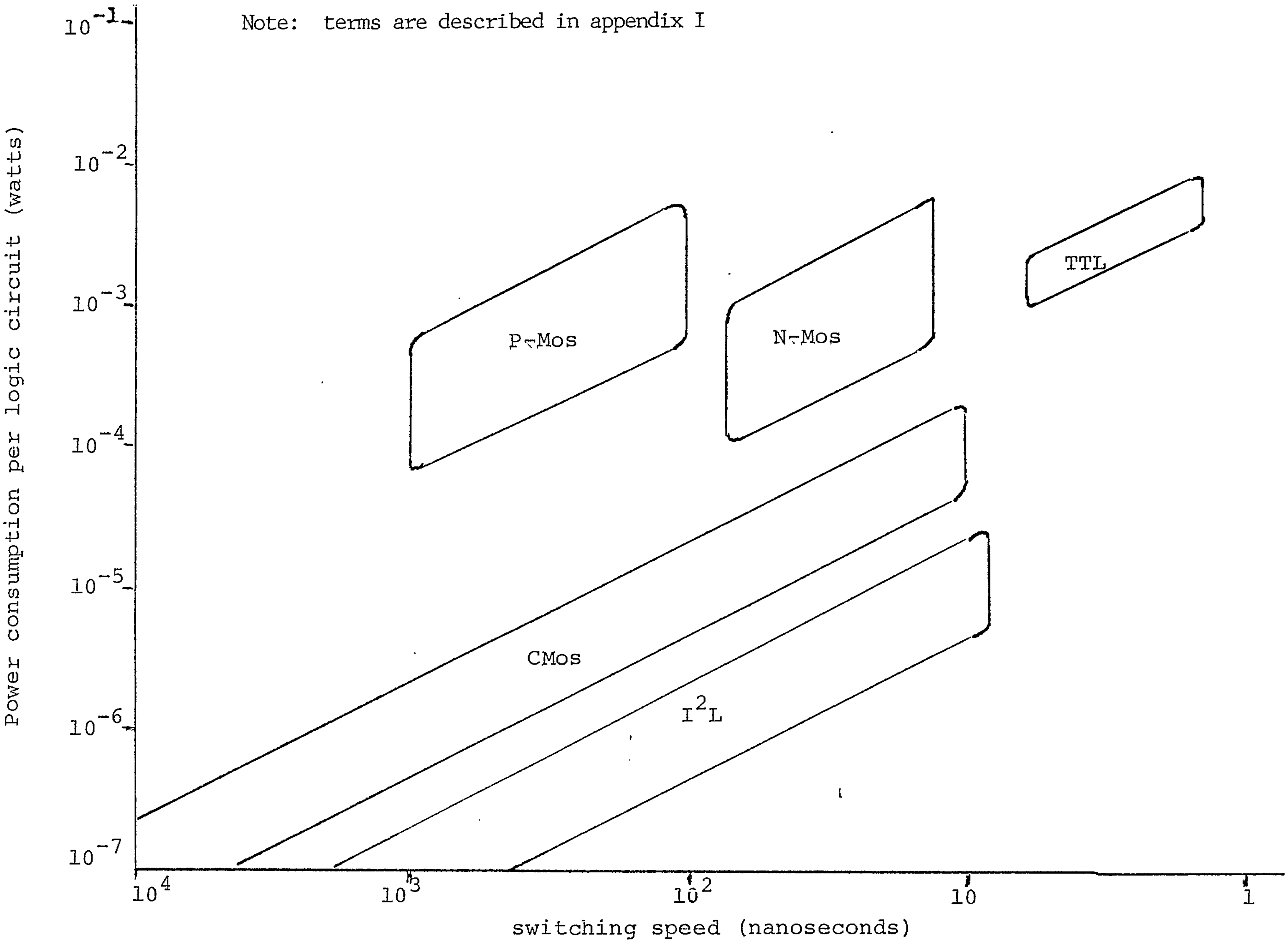
Total cost is obtained by adding chip cost and assembly cost. This gives a cost/function curve with a definite minimum. If circuit complexity is below "optimal" complexity, manufacturers tend to compete on the basis of reducing assembly costs. This, in the past, has meant shipping chips to the Far East, and more recently, Mexico, for packaging and assembly. At high levels of complexity, price competition works through reduction in silicon chip costs. This implies a strategy based on R & D rather than low labour cost.

One of the most interesting developments in increasing circuit complexity lies in the possibilities of circuit redundancy. In such a scheme, if one part of a circuit is defective then another part can take over its function. In the medium term this leads to the possibility of extremely fault-tolerant circuits and in the long term to "self-healing" circuits. Silicon chip costs, in such a case, would no longer increase exponentially as functions/circuit increase, but would likely follow a quadratic cost schedule.

1.2.4 switching speed and power need

A fourth development goal for microelectronics technology is to increase speed of operation. Reducing system size by increasing circuit density and complexity helps achieve this goal by reducing the time needed to move a signal from one part of a chip to another.

The type of technology used determines the other factor in speed of operation. Some technologies simply have higher switching speeds than others. Figure 8 shows how different microelectronics technologies compare with respect to speed and power consumption. Not shown in figure 8 is superconductive tunnel junction technology (STJ). This technology is still in the early research stage. Its power consumption could be 100 to 1000 times less that of I^2L and switching speed 10 to 100 times faster than I^2L. Its need to operate close to 0^o Kelvin means, however, that it will hardly be portable.



Note: terms are described in appendix I
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Power consumption per logic circuit (watts)
P-Mos
N-Mos
TTL
CMos
I^2L
10^4
10^3
10^2
10
1
switching speed (nanoseconds)

Figure 8

1.3 Technology Pull in Microelectronics

Technology pull of microelectronic technology refers to the way in which technical development is drawn towards consumer demands. This force is also known as demand pull.

Pull forces are conceptually different from push forces. The latter trend to be based in known technical problems which have solutions which can be cost estimated. Pull forces are based on human needs and desires. Since a list of such needs is unbounded and since there is no known calculus for trading off one need against others, one can only speculate on which needs, real or perceived, will ultimately have some drawing power for new microelectronics projects.

The analysis of technology pull forces is undoubtedly a weak link in forecasting exercises. This is especially true for forecasts of microelectronic applications. Figure 9 is a list of consumer needs with a corresponding description of microelectronic solutions. Some of these will be developed, others will not. Figure 9 merely illustrates how a demand oriented technology forecast can lead to outlandish predictions.

Figure 10 presents a list of applications which are likely to occur within 5-10 years. The items in this list will come about depending on whether or not they meet three criteria: (1) there must be a need for the product; (2) the market must be able to pay for the product; and, (3) there must be no significant social barriers to marketing the product. Reports in trade literature indicate that the items of figure 10 meet some or all of these criteria enough to justify development work by microelectronics firms.

Figure 9

Some Microelectronic Solutions to Perceived Needs

Need	Solution
control toxic substances in the environment	-develop a data grid to measure and estimate trends in global pollution levels;
	-on line dispersion models to predict flow of industrial pollutants;
cope with complexity of large managerial systems	-improve communications links to collect, move and process data;
	-word processors with robot editors;
	-identification of problems using computers;
increase energy conservation	-fuel control systems for automobiles;
	-sophisticated thermostats for houses;
	-power optimizers for electric motors;
reduce psychological and physical stress on humans	-psychotherapy programs, e.g. ELIZA;
	-personal meters to measure pulse, blood pressure;
identify "life cycle" diseases	-establish cumulative health records including indices of environmental stress.

Figure 10

List of likely microelectronic developments

- dramatic cost reductions for word processors
- fuel control for trucks and autos
- environmental controls for homes
- downward diffusion of computers to small business
- digital telephone and video communications
- some form of electronic funds transfer
- medical diagnostic programs
- private satellite receiving stations
- expanded use of computer assisted instruction
- "smart" weaponry - cruise missiles to computer guided small arms
- cheap, high precision measuring devices for R&D
- some (limited) progress in robotics
- wider use of computer aided design and manufacture

1.4 Environmental Forces in Microelectronics

There are strong technical and demand forces behind microelectronics development. The technical forces will lead manufacturers to smaller, more highly integrated chips at very low prices. Demand forces, in the sense that there is a need to be met, are drawing microelectronics into virtually every area of human endeavour. It appears then that the shape and form of technological applications will be determined by the selective action of negative forces which will slow some developments more than others.

These ambient negative forces are: the capital constraint; the intellectual constraint; and the entrepreneurial constraint.

The capital constraint is a barrier to almost all hardware intensive innovation. This constraint operates when in situ capital (machines, physical plant) still has a long and adequate service life. There is little incentive to replace old technology with new technology when there are only marginal benefits to be gained. This is especially the case when new technology is expensive while the old is already fully amortized and therefore "free". New machines tend to replace old ones only under the following conditions:

(a) when a new plant is being built, but this requires an expanding industry;

(b) when an old machine breaks down or needs extensive regular and expensive repair;

(c) when product markets shift to articles the old machine cannot produce;

(d) when the economic returns of new technology are so great that market pressure forces retooling.

Those advocating government subsidies for the microelectronics industry stress the last point (d). They feel that industry is being forced to retool, but that it cannot finance the additional investment.

The capital barrier is more effective in some areas than others. Innovation in the manufacturing sector is often slowed down because of high retooling costs. Plant engineers are often wary of the reliability of new designs and early production models. It is not a significant barrier in the office equipment area, however. It is interesting to note that the benefits of microelectronics, notably switching and digital coding, are so great that communications firms are installing large quantities. This, even though they have among the highest levels of installed capital of all firms (a close second to the railroads).

The intellectual barrier arises because there is not enough brain power to either develop or use new devices. This barrier manifests itself in a number of ways.

Computer programming, microelectronics design and related technical subjects are intrinsically difficult things to do. In any given society there is a limit to how many people are available for, and inclined towards these tasks. There is currently a shortage of good programmers and systems analysts. While it is not known whether this is as a result of shortcomings in the educational and manpower training systems or whether it is a genuine social constraint, nevertheless, the possibility of a real upper limit exists and will, sooner or later, slow the forces of push and pull.

The intellectual barrier is manifested in another important way. New knowledge and techniques render the old obsolete. A substantial part of the labour force has a vested interest in making certain that their personal intellectual capital is not obsolete. In extreme cases, labour unions resist new technology openly and forcefully. In many other more subtle ways, managers and plant engineers resist unfamiliar processes and favour "tried and true" methods.

These two aspects of the intellectual barrier feed each other. A shortage of good analysts leads to poor programs and systems design. This leads to system failure and a distrust of new systems by managers. These, in turn, thwart the further development and improvement of the system, and so on.

The intellectual barrier will affect some applications more than others. New devices will be rapidly accepted when they enhance a worker's skills and produce a better product. Computer aided design technology is a good example. Applications which make the work environment boring or which threaten workers in some way will be resisted.

The entrepreneurial barrier arises because there are more possible inventions than there are entrepreneurs who can develop and market them. For every 10 devices predicted for the future, perhaps only 4 will ever be produced. Moreover, there is no guarantee that the most valuable devices will be produced. Small, portable microelectronic blood pressure meters, for example, were invented somewhat after T.V. games became widespread. Necessity is not the mother of invention after all, just the maiden aunt. The real mother is economic opportunity and the father is the elusive fast buck. As was the case with the intellectual barrier, there is no way of knowing whether or not the entrepreneurial constraint is currently binding. It does, however, represent a theoretical upper limit to innovation which is definitely lower than estimates made by enthusiastic, demand oriented forecasters.

There are other barriers to innovation which have not been discussed: institutional, cultural, legal. These, by and large, do not appear to be exerting a drag on forward moving forces. (The exception to this being, of course, institutional barriers in the electronic funds transfer systems development).

1.5 Linkage to Rest of Report

The paragraphs immediately above naturally lead to a discussion of applications and their impacts. This natural order will be broken slightly by Section Two which considers the possibilities for government policy. The thread will be picked up again in Section Three which discusses applications.

2.0 The Need for Government Support

2.1 Rationale for Government Involvement

Different governments have different reasons for getting involved in microelectronics. Canada's position, as presented by I.T.& C. makes a case based essentially on improving our balance of payments (current account). Involvement by the U.K. government is primarily spurred by the fear of the impact of microelectronics on employment. The French "technological sovereignty" position assumes that microelectronics is an important industry in which there should be a French presence. Japan sees microelectronics as a low resource, high value added key to expanding its economy. The U.S. views microelectronics as an area in which they have, and wish to maintain technological primacy.

There are two types of arguments used to promote the idea of government aid to the microelectronic industry. The "ceteris paribus" type considers government support for microelectronics only in relation to other national demands on government revenues. The "mutatis mutandis" type uses the same arguments as the "ceteris paribus" type, but further assumes that other national governments are actively involved modifying the rules of the game for the international microelectronics market.

2.2 Mutatis Mutandis

The "mutatis mutandis" arguments paint a bleak picture for the free operation of international markets. It is claimed that effective government aid protects national markets while leaving national firms free to compete aggressively in foreign markets. Ultimately, it is argued, the companies not receiving aid go out of business. The only solution for the foreign firms is to get similar protection in their own countries. Competition is thus between opposing industrial strategies rather than between firms.

Believers in this scenario maintain that Japan has already escalated the conflict and that it is only a matter of time before other semiconductor industries collapse. Representatives of these industries believe that government support is now urgent and necessary.

Certainly the Japanese have singled out microelectronics as a strategically important sector. The electronics industry in Japan has received benefits well over and above the other privileges of belonging to "Japan", Inc." Japanese companies have an aggressive and successful exporting program for electronics. Their strength has been in consumer electronics, but, more ominously, they now show considerable strength in computing devices and semiconductors.

The U.S. semiconductor industry is very edgy. They are all the more annoyed at recent developments which have seen Japanese manufacturers open factories in the U.S. itself. They fear that the cartelization and technology sharing of the parent firms will spill over into the U.S., putting U.S. companies at a further disadvantage.

The Japanese defense is that the economic benefits they give their companies are not greater than benefits U.S. companies get from their government, notably space and defense contracts. They contend that their success is due to high quality output.

Opponents to the mutatis mutandis argument note that only Japan is giving strong support to its industry and that in any event the whole microelectronics field is so big that everyone can get a piece of the action. Japanese aggressiveness, they say, does not warrant a rush to support national industries.

After all points have been weighed, the balance seems to favour those who are concerned about the Japanese offensive. It is expected that Japan will soon dominate the high volume semiconductor market. (Their current drive is in 16K RAMs). This is the bread and butter of the industry. The high volume products pay for R & D into new areas. Without a foothold in this market, national innovation in semiconductor could well slow down. Without offsetting support, other companies would likely weaken and, in some cases, disappear. The question then remains: Is a national semiconductor industry worth saving?

2.3 Ceteris Paribus

A number of countries have gone beyond the hand-wringing stage of policy development. While all of them (except Japan) mention the Japanese threat, they each give other good reasons for public sector investment in microelectronics.

2.3.1 Canada

The Canadian case for the support of microelectronics comes from I.T.& C. It is, quite understandably, based on trade concerns. They show (figure 11) a declining trade balance in electronics. The negative trade balance for electronics is equal to 37% of the negative balance of trade on the current account for 1977. Employment in this sector declined 16% between 1967 and 1977, a loss of 11,441 jobs. An important part of this decline is attributable to the loss of Canada's T.V. industry.

I.T.& C. feels that the continuing decline is guaranteed in the absence of government policy. We are at the stage where threats come not only from the U.S., Japan, and Europe, but also from advanced developing countries such as Korea, India and Brazil. To counter these trends, I.T.& C. has recommended a package of supportive measures designed to: increase R & D performance; increase capital investment; and, improve management and marketing capability.

Figure 11

International Growth of Output and Use of Electronics

(billions of 1971 U.S. $)

	Shipments			Domestic Market			Trade Balance		
	1972	1977	1980	1972	1977	1980	1972	1977	1980
Canada	1.6	2.2	2.5	2.9	3.4	4.0	-1.3	-1.2	-1.5
US	39.6	52.6	66.3	38.8	51.3	64.8	1.8	1.3	1.5
Japan	18.6	28.9	39.2	15.3	23.0	30.3	3.3	5.9	8.9
UK	6.0	8.9	11.3	6.0	8.6	11.4	0	0.3	-0.1
France	4.9	10.2	15.5	5.2	11.4	17.0	-0.3	-1.2	-1.5
W. Ger.	8.3	13.3	17.0	7.2	12.2	15.4	1.1	1.1	1.6

I.T.& C. has advocated a number of measures, including: tax-based investment incentives; development of "core" companies; the use of procurement and chosen instruments; the development of a strong microelectronics industry; and, the continued development of an already healthy communications industry.

The balance of payments and employment arguments may be compelling to some, but not to others. Those more interested in macro economic concerns note that one can't have exports without imports. A poor showing in the electronics trade, in this view, is not due to a lack of ability in electronics, but rather to a preponderance of comparative advantage in other areas. Sorting out these arguments requires defining what is an ideal configuration for Canada's current and capital accounts. This, in turn, leads to the elusive concerns of: technological sovereignty, economic nationalism, national self-reliance, etc.

The absence of a decisive case for support has resulted in a weak program of government assistance to microelectronics in Canada. Little has been recommended and less has been approved.

2.3.2 the U.K.

Britain has had a policy of support for electronics since the early 60s. Financial support of over $1 billion is being provided to stimulate the growth of this industry.

The government of the U.K. has been especially interested in microelectronics and Very Large Scale Integration. They have developed a strategy to: build a state of the art capacity for standard chips; build up a solid base for custom chip work; and, encourage the development of applications of microelectronics.

To do this, they have set up a Microelectronics Industries Support Project. This $160 million, 5-year project provides 50% of research costs and 25% of development costs. These are recovered through levies on subsequent sales.

Additionally, 25% grants are available for investment in production facilities. These funds are over and above the funds (about $11 million annually) given to the microelectronics industry as its share of support for electronics.

The government has also embarked on a program of heavy direct investment. Most notable has been the $115 million investment in INMOS for the production of VLSI chips.

The U.K. has attempted to improve the synergy between users and producers. The Microprocessor Applications Project ($80 million over 2 years) was designed to make potential users aware of the applications of microelectronics. The U.K. has allotted $70 million for educational initiatives and over $50 million for training and retraining.

The decision of the U.K. to move into this area was based on the twin fears of: massive unemployment, and declining competitivity. Alarming forecasts of the use of robotics in manufacturing and the obsolescence of products not using microprocessors has driven the U.K. to the extremes of decisiveness. They have convinced themselves that they have two choices: face large scale labour disruption in a microelectronic economy; or face complete economic ruin by ignoring the field. They see the latter as being only slightly worse. So it is that through radical and precipitious programs the British seek marginal solutions.

2.3.3 France

The French have concluded that microelectronics will be an important technology in the 80's. Their concern has best been stated in a report prepared for the president entitled "L'informatisation de la Société". They therefore feel it appropriate that they have a strong capability in this area. To this end, they have embarked on a support strategy which uses heavy financial assistance, direct investment, and procurement from chosen instruments. They strongly prefer French control, but will permit substantial minority holdings by foreign firms.

The keystone of the strategy is a joint venture between Motorola and EFCIS to build LSI and VLSI. The initial investment is $75 to $100 million, just under half coming from government. They are currently setting up a second joint venture. The French expect to spend $25 million annually in support of the standard integrated circuit industry.

In the custom field, three chosen instruments will spend over $250 million in three years. The government will cover half of this. In addition to these specific measures, the French government offers a range of incentives for R&D and new investments.

2.3.4 Japan

The Japanese long ago identified electronics as a critical industry in which it wanted to achieve a strong position. It felt this to be a "natural" industry for Japan since it used low levels of resources, had high value added, and had a good export market. Since the 1950's the Japanese have used every means possible to support electronics and consequently are now the second largest market and producer of electronic goods after the U.S.

Over the past decade, the Japanese have concentrated their efforts on microelectronics. A 1974 7-year plan put $933 million into computers and $186 million into integrated circuits, components and materials. In 1976 a consortium of four companies spent $375 million to develop VLSI technology. Of that amount, $161 million was a government grant. The Japanese government also condones patent-pooling, raw material control, and other monopolistic practices among electronics companies.

These efforts have paid off. The technology gap between Japan and the U.S. closed very rapidly. In 1978 Fujitsu introduced a 64K RAM at about the same time as IBM and Texas Instruments. Not only are the Japanese producing advanced products but their chips are of higher quality. Japanese workers at TI-Japan are also 20 to 40 percent more productive than their U.S. counterpart.

The concerted and concentrated effort by Japan has shown results in market terms as well. Figure 12 shows the growth of sales of 16K RAM's in the U.S. The data shown demonstrate that Japan has more than just a foothold in the prime semiconductor market.

2.3.5 the U.S.

The U.S. pioneered semiconductor and integrated circuit technology. The microelectronic industry is seen by some as a symbol of the achievement of high technology, of the superiority of American knowledge, and of the ideological correctness of the free market system. Moreover, microelectronics is, and has been good business. Figures 13 and 14 shows sales of semiconductors and integrated circuits. The U.S., in 1977, had 72.9 percent of the market for integrated circuits and 61.9 percent of the market for semiconductors.

These data, while impressive, do not tell the whole story. While the U.S. is increasing its market share in semiconductors, its share is decreasing for integrated circuits. This means that their competitors are gaining in the newer, higher microelectronics technology. There are fears that the U.S. industry is aging, though far from infirm.

The impressive performance of U.S. industry has been accomplished without a deliberate support strategy. Support for the electronics industry has come indirectly through high levels of government procurement and through basic research, especially for space and defense objectives.

Figure 12

Sales of 16K RAM

Company	1977	1978	1979
	millions of units		
Mostek	0.76	4.9	16.6
*Nippon Electric	0.31	3.8	11.1
Texas Instruments	0.04	3.2	8.2
*Hitachi	0.005	1.2	6.8
*Fujitsu	0.26	2.0	6.0
Motorola	0.05	1.8	4.2
Intel	0.56	2.4	3.5

* Japanese companies

Figure 13

total semiconductor market share estimates
(millions of dollars)

	1970	1971	1972	1973	1974	1975	1976	1977
U.S.	1,283	1,373	1,865	2,812	3,358	2,783	3,502	4,040
Japan	712	725	788	1,089	1,092	842	1,420	1,538
Europe	424	432	481	690	881	729	873	934
Others	6	10	14	23	38	10	12	14
Total	2,626	2,540	3,148	4,614	5,369	4,364	5,807	6,526

Figure 14

total integrated circuit market share estimates
(millions of dollars)

	1970	1971	1972	1973	1974	1975	1976	1977
U.S.	625	663	883	1,459	1,875	1,559	2,083	2,577
Japan	143	153	241	343	372	343	599	661
Europe	53	87	107	161	210	204	260	288
Others	6	10	14	23	38	10	8	10
Total	827	913	1,245	1,986	2,495	2,116	2,950	3,536

U.S. firms invest heavily in R&D. American spending on semiconductor R&D, not including that of IBM and Bell Laboratories, was over $200 million in 1977 alone. Industry sources estimate that IBM investment in VLSI from 1977 to 1980 was about one billion dollars.

With all this spending and all those sales it is surprising that U.S. industry should feel threatened, but they do. High technology is high risk. When innovation is rapid, large amounts must be spent on R&D and that investment has to be paid back before it is obsolete. U.S. firms need a high return on investment to find new capital. Foreign companies operating under a government umbrella do not have such difficulties. In 1977, U.S. electronics firms had a return on common stock equity of 16.2 percent while in Japan it was only 9.7 percent.

Increasingly, funding for the microelectronics industry has come through mergers and acquisitions by mature firms. Of the 36 semiconductor startups since 1966 only seven remain independent. Established companies, both foreign and domestic, are vertically integrating to assure sources of supply. The semiconductor industry does not particularly like this, feeling that innovation will be stifled, but in most cases they don't have much choice.

The U.S. government is showing signs of being sympathetic to industry problems but, with the exception of a $150 million DoD project to develop Very High Speed Integrated Circuits, has come up with no firm programs.

2.4 Summary

Countries having some microelectronics capability are protecting them with government support. In the U.S., support has been relatively indirect. In all countries, the support strategy is premised on a strong awareness of the economic importance of the industry combined with a concern for "unfair" foreign competition. Business behaviour has reflected the feeling that microelectronic technology is critical for its survival. Large businesses have, in some cases, sought to guarantee supplies by acquiring semiconductor firms.

3.0 Impacts of Microelectronics

It would be impossible to list the ways in which microelectronics could change society and economics. What follows describes a few applications which are very likely to develop because the first steps have already been taken. It is the nature of this field, however, that new and completely unexpected innovations are developed and put on the market within a matter of only a few years.

3.1 The Office of the Future

The electronics industry has, over the past few decades, transformed information handling in offices. Over that period of time, electro-mechanical and mechanical business machines were gradually replaced with more sophisticated gear. Computer sales have grown at a phenomenal rate. Once relegated only to simple billing and filing functions, computers are now used for more complicated forms of analysis on a routine basis. Associated with this increased use of computing devices has been a new service industry of software and hardware specialists. In two decades a new economic subsector has emerged, complete with new jobs, new skills and a new infrastructure.

The use of electronic data processing will become increasingly widespread in the years to come but the patterns of growth will change significantly. In the past, computer power was dominated by the large, fast mainframe computer. These machines eventually achieved tremendous capabilities which could be accessed at a central location. Keeping these big machines busy required full-time staffs to continually feed it data and programs. While these machines will continue to exist, and perhaps get even larger in the future, it is likely that computing power will decentralize. More and more tasks will be handled by microcomputers and other forms of "intelligent electronics".

Forecasts of the impact of microelectronics on the office generally consider, singly or severally, four new devices: the electronic typewriter; electronic intra-office mail; electronic, or at least machine readable, archive and file registry systems; and the portable computer. The IRPP has conducted research into the impact of microelectronics, and have published a number of occasional papers which look at microelectronics in the office. Titles include: The Electronic Briefcase; and The Impact of the Microelectronic Industry on the Structure of the Canadian Economy.

3.1.1 the electronic typewriter

The term "electronic typewriter" includes such items as: automatic letter-writers, computer based text editors, and memory typewriters. In terms of machine implementation, they range from simple stand-alone typewriters with a small storage capacity and limited editing capabilities to large service bureau networks (such as Alphatext) which offer editing facilities from initial draft to final mock-up ready for printing. Hybrid systems, already in existence, use microcomputers to assemble blocks of text. These are already used in law offices for preparing contracts, deeds and wills. Standard conditions, restrictions and codicils are kept in a "catalogue" in the computer's memory and are added into documents as needed.

The main advantage of such devices has been in the quality of output. Documents prepared on text editors tend to go through more drafts being rewritten until the exact meaning and wording is attained. Visual presentation has also been enhanced. Form letters, in some cases, are no longer necessary since text editors are well equipped to "personalize" correspondence.

It is likely that the electronic typewriter will evolve along two distinct paths, as a stand-alone system, and as part of a larger text network. Stand-alone systems are already with us in the form of memory typewriters. It is expected that these will develop a more sophisticated command structure, increase internal memory, and have secondary output capability such as magnetic tapes. In the near term these machines will resemble ordinary typewriters but in the longer term the print mechanism will be replaced by a screen. These will not likely be the standard T.V. screen now being used but will be solid state devices. These do not need high voltage power supplies, are small and light, and do not have any tiring screen flicker. Hard copy output can be obtained by taking a magnetic record to a central printer, much as one would go to a central area for photocopying. The elimination of print mechanisms will halve the cost of electronic typewriters and greatly reduce office noise levels.

The second development path leads to the text network. In this system, remote terminals are hooked up to a computer which handles all of the text editing and storage functions. The terminals are simply input/output devices. Prototypes of such networks dedicated only to text editing are relatively rare but medium-to-large timeshare computing facilities often have some text-editing software available as part of their service. There are distinct advantages to such text networks. They are faster; have greater memory capacity; utilize space more efficiently; and permit the ready transfer of text fragments between terminals. This last facility is especially useful for documents being simultaneously written by several authors, technical manuals for instance. In spite of these advantages the text network approach will take longer to mature. This slow diffusion is mainly a result of three factors: there are higher initial capital costs; significant benefits come only if many terminals are involved; and, a data base management structure must be set up.

3.1.2 electronic intra-office mail

An electronic office mail system is simply a data link within an office building. It operates much like a private telephone exchange, the only difference being that text-terminals rather than telephones are hooked up and text, rather than voice is transferred. This capability automatically exists in text networks described above.

The advantages of electronic mail are not immediately apparent. It will make for very rapid information transfer, but even in paper mail systems transfer time is a fraction of preparation time. Electronic text can be easily edited and modified at destination. This may, at times, be an advantage but can easily increase incidents of: plagiarism; errors due to modifications by those who did not author and research the originals; no audit trail for insertions and deletions; and so on. In information environments where text is at once the main product and article of consumption, questions of responsibility for production and accountability for use become important.

The immediate advantages of such a system are speed of transfer and an enhanced ability to have more people work on the text of the document. As electronic mail becomes more sophisticated, and it won't take long, the real impact of the system will be felt. The key lies in the communication protocols used by the system.

Protocols are the standard pieces of information (and information handling procedures) which are exchanged at the beginning and end of a transmission. First come the hardware protocols (sometimes known as "hankshaking") which can include such details as acknowledge signals, data transfer rate signals, and parity signals. Software protocols come next. These may include: origin name and address; destination name and address; central registry file number; document type (letter, memo, short report, long report, etc.); security classification and perhaps urgency status.

The appealing thing about the protocols is that they contain information useful to the user. The receiving terminal can be programmed to order incoming messages in terms of their value to the user. When arriving in the morning, the user would find "useful" information listed first and "junk mail" at the bottom of the heap. When the user is busy, incoming messages could be put in a stack. The terminal would interrupt only in urgent cases.

As the mail system matures it will become more useful and will have subtle impacts on organisations. Documents can be given wide circulation simply by changing access codes. Officers will, accordingly, have a wider range of material to work with. This will perhaps, result in a more fluid, more flexible work force. Organisational design could evolve towards the modular system consisting of many task groups which move around from problem to problem.

Faced with this kind of information fluidity it is interesting to speculate on how human behaviour will change in response to an instinct for preserving territory.

It can be expected that security will be a problem in such text networks. Because documents must be retained in memory for a period of time, and because such a system must be capable of having multiple user access to documents, there is a great temptation to try to access other peoples' documents. The same bunch that stays late at night to read in-baskets will be dusting off software manuals to have the protocol management system send them copies of anything officer A may be sending to officer B. Phase II of software evolution will undoubtedly be the proliferation of encryption software to keep documents private. (Phase III? – de-encryption of course).

3.1.3 electronic archives

The long term storage of machine readable documents is the final destination in the evolution of electronic text processing. In its simplest form archives will consist of old documents prepared and kept on a permanent basis at the outer levels of the text system. Important files, policy manuals and internal reference documents are examples of material that would be stored in some form of electronic memory accessible by the text computer.

When such archives become more common, reference texts such as dictionaries will appear. Later, more specialized books and journals will be published in machine readable form. The most obvious economies will be in the reduction of the need for paper. The economics of information will change significantly. The marginal cost of producing text, already low, will vanish. The fixed cost, which will be high, can be justified by widespread use.

The big advantage of electronic archives is that, by the time archives are developed, input/output terminals will themselves be sophisticated microcomputers. This means that they can be programmed to actually read and "understand" the text. One could, for example, instruct a desk-top terminal to: review all internal memoranda and return with file numbers of all documents dated February to March 1985 which refer to XYZ Corporation and their European marketing plan for power turbines. Such terminals will go beyond software protocols and begin some form of text and content analysis.

3.1.4 portable computer

The fourth device to transform the office of the future will be the portable computer. Microcomputers are already reasonably transportable and will get down to briefcase size (including I/O) in a few year's time.

Although the hardware will be with us soon it may be some time before any significant impact is felt. There are just not enough people around to use them in any effective way. This situation will change over a period of 20 years. By then, children who have grown up with computers, who will have used them in schools, will arrive on the managerial scene with a whole new set of data and symbol manipulating skills. New styles of management and problem solving will then develop. What exactly will change is anybody's guess. The important point for forecasting purposes is not whether a computer is portable, but whether it is widely accessible.

3.2 Electronic Funds Transfer (EFT)

EFT system refers broadly to any electronic system used to implement financial transactions. As such, EFT has been with us for some time. Some companies send a magnetic tape containing payroll information to the computer of a designated bank and have the accounts of their employees automatically credited. Multi-branch banking uses an on-line computer to alter in one branch accounts held in another branch. "Money machines" available on a 24-hour, 7-day basis, permit users to make certain transactions without actually going into a bank.

Some forecasters are predicting increases in the prevalence and use of EFT. They go as far as saying that we are entering the era of the "cashless society". Cards, or some other form of identification would be used in all transactions in the place of money. Analysis of these claims suggest that they may be premature. EFT will develop in the directions indicated by technology push, pull, and environmental friction but will do so at a moderate pace.

3.2.1 technology pull - the consumer

EFT technology consists essentially of: point of transaction terminals; data networks; and transaction computers. What, generally speaking, are the advantages to the consumer of such a system? In what way does EFT more effectively meet consumer needs?

The key advantage of EFT lies in the potential integration of the consumer's financial affairs. Anyone wishing to make a purchase would be able to do so instantly, providing that he has the funds, or the credit. The consumer would not have to carry cash and would not have to pay bills on a monthly basis. Payments would be deducted from his account at time of purchase. EFT would also help a consumer manage savings and investments. Funds could easily be transferred between "current accounts" and "savings accounts".

In return for this convenience the consumer would lose control of his cash flow. Bill payments would not be staggered, but would be collected when creditors asked for the money. A highly centralized EFT system could significantly control the consumer's ability to make financial transactions. A poor credit rating, entered erroneously or legitimately, could put individuals in a straight jacket.

An integrated EFT system would also reduce the confidentiality of transactions. This can be an important consideration for those wishing to do business secretly. Cash has always been the preferred mode of payment for criminal activities, tax evasion, kickbacks, and so on. Both the underground and the underworld economies are thriving and the consumer has an obvious interest in keeping them alive.

3.2.2 technology push - the producer

EFT is, however, a natural evolutionary development from the producer's point of view. The producers in this case being those who provide financial and marketing services.

Not only does EFT increase the efficiency of financial transactions, it also enables financial institutions to get more information on the performance of the financial system. This would greatly enhance their cash management capabilities.

Market analysts would also have a field day since they could potentially have access to an information system telling them which consumers were buying what, when, and where. Government policy analysts could easily investigate changes in rates and patterns of consumer expenditure and savings.

The technology push behind EFT is definitely stronger than technology pull. This leads to the conclusion that new developments in EFT will generally evolve in accordance with institutional needs rather than consumer demand.

3.2.3 environmental constraints

The non-technological, environmental constraints which are slowing the forces of push and pull are not those which have already been mentioned: capital, intellectual, and entrepreneurial. The main environmental constraints in the implementation of EFT are institutional barriers.

It should come as no surprise that both the financial institutions and governments are very interested in how EFT is to be implemented. Financial institutions want a fool-proof system that will protect them against fraud. A centralised computer system is not adequate to such a task. What is needed is a data network accessed by multiple computers, each getting only part of the information, each able to check the others. Such a system would also have to have "human windows" which would allow accountants to peer into the inner workings of machine operations as a final check.

The government has three interests: monetary policy; revenue preservation; and consumer protection. There are suspicions, not firmly established, that microelectronics is altering the money supply. Money supply is changed by speeding up the velocity of money and by increasing money exposure. The velocity of money is increased simply as a result of the speed at which transactions can be made. Financial institutions and multinational corporations have greatly enhanced their cash management procedures. Money exposure is increased by using money 24-hours a day rather than only 8 hours a day. This is currently done only by multinationals with global operations. What they do is move their cash from the European, to the American, to the Asian money markets following the time zones. The practice is not yet widespread and its importance is unknown.

In principle, EFT would be helpful in detecting tax fraud. It is important, however, that the EFT system be designed so that government auditors could access individual files in a way that would yield information. This would be easy to do. There is, however, a psycho-social design problem. An EFT system which is not particularly appealing to consumers would lead to a strengthening of the "informal economy" based on cash and barter. Such an economy makes tax evasion easier and therefore more likely.

The government also has a strong interest in consumer protection. This interest includes: maintaining privacy of data; elimination of discriminatory practices; and assurance of fair access to credit, to name only a few. The legislation and regulations needed to protect these interests will no doubt be complex and will evole over time. Accordingly, it is expected that the truly "cashless society" will be a long time coming but that EFT will slowly and inevitably develop through the 1980s.

3.3 Education and Knowledge

The technology of education is rather primitive and has not improved significantly since ancient times. Many contend that it has in some ways regressed, moving away from discipline and the 3 R's to "self expression in drama classes." The past decade has, however, seen some progress in the use of electronics to aid learning. The most notable use has employed T.V. and other audio visual devices. The teaching of language, for example, has benefited from the development of courses in language labs.

3.3.1 technology push

More recently, computers have been used to teach students. Programmed instruction, which gives a student new information only when old material has been mastered, is improving. Programmed instruction is especially useful in areas requiring "memory knowledge" as opposed to areas requiring problem solving skills. A lot of time and money has been devoted to computer assisted instruction (CAI). There have been successes, but failures have been high too. CAI offers no magic solutions to the problems faced in education. Results depend on the instructional design of the curriculum materials, on the manner of implementation, on the nature of the student population, and on the role played by teachers.

CAI has made advances in areas other than programmed instruction. Another important CAI technique is simulation and gaming. In these techniques, real world problems and situations are presented by a computer, with the student supplying a response. The machine randomly alters the presented situation in accordance with likely changes in the real world. Gaming and simulation are becoming popular as training methods within industry.

The other significant application of microelectronics in education is the use of calculators and computers for computation. Students in the 70's typically would solve twice as many problems in science and mathematics as the students of the 60's. Anyone who has solved a multivariate linear regression by hand knows about the value of calculators.

3.3.2 technology pull

Operating separately from the educational industry, consumers are accessing technology directly for the purpose of expanding knowledge. Personal computing has become very popular at the expensive end of the hobby market. The appeal of this hobby lies in the challenge presented by mathematical and other symbol manipulating problems. Hobbyists have been known to spend hours agonising over their programs, even though some of these programs represent the most trivial use to which computers can be put. As the price of consumer computers declines, the market will greatly expand leading, perhaps, to increased "mathematical literacy" in society.

A much greater, but possibly longer term, impact comes from the ultimate consumers of intelligence microelectronics - the mathematicians and computer scientists working in artificial intelligence. Artificial intelligence (AI) is a branch of computer science which attempts to make machines simulate human thought. The adjective "artificial" was applied in the days when it was believed that no machine could ever duplicate human thought.

Since then, machines have become remarkably clever. They play decent chess and can handle many pattern recognition problems. No one is certain what the upper limit to machine intelligence is. AI research has caused considerable interest in determining the nature of human intelligence and in analysing the functioning of the brain.

The intelligence of computers lies in their ability to manipulate symbols. In the past, programming languages were written to handle the manipulation of numeric symbols and computers quickly assumed the role of supreme number crunchers. AI researchers have developed languages which handle other symbols, such as those encountered in symbolic logic. One could conceivably, for example, give a computer all of the axioms of Euclid's elements and have it produce theorems. The stumbling block is that it would produce many trivial theorems in addition to those presented by Euclid. The machine has no way of knowing which theorems are mathematically "interesting". This problem is being worked on.

There are two important long term impacts of AI. The first will be the impact of having thinking machines. The second will be the advance in knowledge brought about by inquiries into the nature of human thought and in the mathematics of symbol manipulation.

Genuine concern is already being raised over the first possibility. Some computers can now solve software problems and write programs. An Australian machine has taught itself to solve a particular chess problem, and has written its own program to play the relevant chess moves. Its own program was 5 times more efficient than a program written by human programmers. Such automatic programming has generated fears that we are creating "technological black holes" in which humans will not be able to understand the reasoning behind computer results that make key decisions.

3.3.3 environmental constraints

There are two constraints to the use of microelectronics in education and the expansion of knowledge: cost and experience. The equipment used as a teaching aid is very expensive, especially video equipment. The same is true of microcomputers, although the costs are declining.

The main problem in using the equipment is that in many ways applications are still experimental. Educational T.V. has made significant progress, but there is not enough experience in the uses of computers, programmed learning, and gaming. It may be that AI research will give insights into how people learn so that computers can be used more effectively in schools.

3.4 Communications

Microelectronics has had and will continue to have a key role in the development of communications technology. Two techniques will be of special importance: digital encoding and "intelligent" switching systems.

Digital encoding works by taking a signal, dividing it into many small segments and then selecting segments at regular intervals, say every tenth segment. This "sample" of segments is encoded in digital form, transmitted, and the signal is reconstituted by a receiving device. The principal advantage of this technique is that 10 encoded signals can be sent down a wire meant only for one signal. The potential savings in copper wire alone make this technique attractive.

A second group of techniques, "intelligent switching" improves the nodes of a communications network. Microelectronic switches are fast, of high quality, cheap, and small. They allow for a more decentralized, evenly distributed, communications network. "Intelligent" switching means that processors at the switching nodes can choose an optimal path for transmitting messages, either in their entirety or in "packets".

These microelectronic techniques, combined with other hardware such as cable, T.V., satellites and fibre optics, has given rise to predictions of a new "information society".

The implications of the information society are almost as widespread as those attributed to microelectronics in this report. Indeed, in current technology assessment literature, three "revolutions" are being discussed: the microelectronics revolution; the computing revolution; and the communications or information revolution. These overlap so much that for most purposes they are one phenomenon. How one chooses to label the revolution depends on which bias is choosen. The first revolution focuses on the hardware of signal manipulation; the second concentrates on signal processing; and the third on signal transmission. GAMMA, a Montreal-based think-tank, has adroitly avoided the possible content/ carrier confusion by using the term "informediation" to mean mediated, or processed, information. A full review of the impact of microelectronics and communication would be almost the same as the discussion of the impact of microelectronics on everything else.

3.5 Other Impact Areas

Areas in which silicon chips will create improvements are too numerous to list in detail. The following is meant only as a glance at some of the more interesting possibilities not already described.

In medicine we can expect: better measuring and monitoring devices; improved computer diagnosis; better data collection for epidemiology; better prosthetics; and, devices that read for the blind, write for the deaf, and speak for the mute.

R & D will benefit through the use of: more accurate and easy-to-use instrumentation; more computing facilities; computer aided design software; and, better dissemination of results.

Industrial process control will improve through the use of better and cheaper instrumentation; improved tools; and robotics. Because these greatly improve the productivity of capital, they pose a threat to labour. *This report does not dwell on the use of microelectronics in industry because it is believed that changes in industrial technology will proceed at a rate sufficiently moderate to allow for labour adjustment.*

Weaponry for defense will continue to improve. New devices for modern arsenals will include: better cruise missiles; radar with built-in pattern recognition; self-targeting guns; and improved field transmitters with automatic encryption.

The development of microprocessors for the optimization of energy usage in automobiles, factories and homes, will be of significant economic importance.

4.0 The Management of Microelectronics: Recommendations

The field of microelectronics presents an embarrassment of riches for those inclined towards the development and implementation of technology policy. There are many potential problems. Some of them could lead to social and economic disruptions on a grand scale. There are also many opportunities for using microelectronics to solve existing problems.

If, on the other hand, one is not inclined towards the wanton development of government policies, one can take comfort in the observation that the semiconductor industry is strong and growing, that new applications of microelectronics are popping up as fast as the industrial system can handle them, and that problems, where they may arise are not so catastrophic that they cannot be handled via normal markets and government operations.

Microelectronics presents a particular challenge for MOSST. This technology is of such fundamental importance to industry, society, and the economy (relative to other technologies) that it cannot be neglected by a technology Ministry. Indeed, observations of the response of other governments to microelectronics shows that there are parallelisms between their microelectronics plan and their technology plan. The former is a reflection of the latter.

4.1 The Socioeconomic Problems

There are three main socioeconomic problems brought about by the microelectronics revolution. The first problem is the potential for unemployment created when machines replace humans. While the scale of this problem has probably been greatly exaggerated, it is likely to become an important issue. It is also an area currently of concern to governments.

The second problem is that of underemployment due to obsolescence of skills. Unlike the first problem which will deeply affect some people (those who lose their jobs) this problem will generally affect many people and could lead to some form of social malaise.

The third problem will be the obsolescence of capital. This means more than just the loss of jobs, it could mean bankruptcy for firms that cannot keep up, or even the demise of a national industry in the face of foreign competition. This problem will likely occur only sporadically at first, and should not be critical in the short term.

4.2 Meeting the Problems

There are a variety of government responses to the above problems. What follows are minimum responses. Minimum levels are chosen to maintain a non-interventionist, non-expansionist stance currently prevalent.

Problem one, unemployment, is of great concern. MOSST should undertake to co-ordinate a committee to review the implications of technological change for employment policy. The committee would be composed of representatives of MOSST, Communications, CEIC, Labour, MSED, and other interested departments. The role of MOSST would be to define the character and depth of technology policy dimensions and to finesse our concerns into the deliberations of line departments. Such a procedure could serve as a model for increasing the emphasis on technology in other departments.

Problem two, underemployment and education, is more within provincial jurisdiction. Some questions of adult education and manpower training could, however, be dealt with in the committee mentioned above.

Problem three, obsolescence of capital, is more difficult to deal with. As a first step, we need to know where, when, and to what extent technology is changing in a way that could adversely affect Canadian industry. A possible response to this information gap would be to begin a cyclical review process which would prepare "sector profiles" of Canadian industry which would indicate: age of existing capital; availability of new technology; technological ability of competing nations; and an assessment of the threat from foreign industry. Such a review should be done in collaboration with I.T.& C., but should review mainly technological considerations.

4.3 Other Problems

Aside from the socioeconomic problems, there are technical (scientific and economic) problems facing the semiconductor industry itself. These include: the development of communications standards and protocols; the availability of test markets; the availability of risk capital; the adequacy of skilled manpower; and others. In many cases, government assistance would be most helpful. The speedy development of regulations governing cable T.V., for example, could hasten technological innovation in this area.

4.4 Opportunities

The opportunities for using microelectronics are there for anyone who wishes to use them. There are two initiatives, however, that could be supported by MOSST to increase the rate of opportunity capture. The first is an "awareness program" which would alert managers in industry to the opportunities presented by the microelectronics revolution. I.T.& C. has already developed plans for such a program.

The second initiative would be a review of the opportunities for using microelectronics in government operations. Word processing is an obvious example. Another could be custom microcomputers for budgeting in accordance with government regulations and Treasury Board formats. Such a review would be concerned with increasing both efficiency and effectiveness, and could be undertaken in collaboration with the Treasury Board and DSS.

4.5 Conclusion

While these suggestions represent minimum activity levels, they will not, if done properly, yield insignificant results. These recommendations all aim at getting better use of scientific and technological resources. The strategy of consultation places an emphasis on placing knowledge in the hands of users. MOSST would play a catalytic role in making technology more universally accepted.

APPENDIX I

Phenomena, devices, and processes

The purpose in this section is to describe very generally some of the more important components of microelectronic technology. An understanding of the phenomena, devices, and processes of microelectronics is important if one is to understand the strong technology push aspects of microelectronics development.

Semiconductors

The entire microelectronics revolution is based on the properties of semiconductors. As the name suggests, semiconductors are materials which are somewhere between conductors and insulators when it comes to the transmission of electrical charge. Generally speaking, insulators will not carry an electrical current. Conductors, on the other hand, carry a current whose magnitude is proportional to the voltage applied to either end of the conductor. Semiconductors carry no current when low voltages are applied, but when voltage is increased beyond a certain threshold, a current can be carried. The threshold limit is dependent on the materials used in making the semiconductor.

Semiconductors are usually made of silicon, an insulator. The silicon is made semi-conductive by adding impurities to a crystal of pure silicon. This process is known as "doping" and has to be done under very highly controlled conditions. Doped silicon is of two kinds: n-type and p-type. Simply put, one kind will release electrons when voltage is applied while the other kind will accept electrons when voltage is applied. Being n- or p-type depends on what kind of impurity is added.

Bipolar Transistor

The bipolar transistor (also known as a junction transistor) was one of the first useful applications of semiconductor. A transistor is simply a "sandwich" made of semiconductor material. There are two types; n-p-n transistors (p-type on the inside, n-type on the outside) or p-n-p transistors. Transistors are used to amplify signals, and were initially a commercial success when they were used to replace the tubes in radios and T.V.'s.

In its microelectronic form bipolar transistors are linked together in a pattern of circuitry called TTL (Transistor Transistor Logic). TTL circuitry using bipolar transistors is a relatively old technology. It has not achieved the same density of circuit elements per chip as have other technologies. It is also relatively power hungry. Its main virtue lies in its fast switching speed and most applications requiring such speed use bipolar transistors. Switching speed refers to the speed at which individual transistors can switch on and off.

A new and more competitive form of bipolar technology is Integrated Injection Logic, usually abbreviated as I^2L. This technology produces a "super integrated" bipolar transistor. This technology will probably not be as fast as TTL but can currently be built to operate faster than MOS technology (described below). Its advantages lie in its low power requirements and potentially high packing densities.

Field Effect Transistor

The field effect transistor is a more complicated device than the bipolar transistor, but paradoxically, is made in such a way that higher circuit densities are possible than with TTL. Field effect transistors control the flow of electrons by means of a variable strength electric field in the path of electron flow.

MOS

Metal-Oxide-Semiconductor technology is used to produce cheap, but complex circuits made of field effect transistors. It is this technology which has brought about the microelectronics revolution. MOS technology is the backbone of the microelectronics industry and it has developed in a number of variations.

All MOS circuits begin with a substrate made of a wafer of doped silicon. Using a photographic process, a pattern of small islands of silicon is laid over the substrate. These islands are made of material doped differently from the substrate material. Thus, an n-MOS circuit has n-type islands and a p-type substrate. This pattern is then covered with a pattern of silicon dioxide, an insulator. A pattern of aluminum connectors is then placed over the insulating material. These three layers of Metal (aluminum), Oxide (silicon dioxide insulator) and Semiconductor, give the name MOS to this technology.

Early MOS technology used p-MOS circuits because these are easier (and cheaper) to make. N-MOS circuits are faster and have consequently achieved wider use where high performance is necessary.

CMOS technology (complementary metal-oxide-semiconductor) uses both n-type and p-type field effect transistors in the same circuit. A typical application has one circuit laid out in n-MOS with an identical "parallel" circuit in p-MOS laid out beside it. The logic status of the circuit (whether individual switches are on or off) is "bounced" back and forth between each circuit. First, the n-MOS carries the information, then the p-MOS does. This oscillation goes on at a very rapid rate. The duplication of circuits in CMOS is more costly than either n-MOS or p-MOS. The advantage lies in the fact that holding a charge constant in ordinary MOS requires far more energy than passing charge back and forth between circuits. The low power requirement of CMOS means that it can be used in watches or constant memory calculators which must operate for long periods on small batteries. In certain applications the extra cost of manufacture is more than justified by the need for low power drain.

VMOS stands for Vertical Metal-Oxide-Semiconductor. This technology allows for greater packing densities on a single chip. This is done by having a circuit pattern run in three dimensions. Circuit connections are made up and down the sides of "canyons" or "V's" cut into the surface of the chip's micro-landscape. The switching properties of VMOS are similar to that of ordinary MOS.

Charge Coupled Device (CCD)

The charge coupled device is a long string of MOS transistors coupled together to form a chain. A charge placed at one end of the chain is passed from one transistor to the next until it reaches the end at which time it is placed back into the beginning of the chain. Information can be stored on such a device by placing (or removing) charge from this endlessly looping cycle of "charge positions". Storage is much like a message written on a loop of paper which is rotated around to be read over and over again. Like CMOS, CCD's work on the principle that a moving charge is maintained with much less power than a static charge. Moreover, CCD's can get extremely high packing densities. The primary application of CCD's is in non-volatile memories for computers. Such memories could be portable (like books) since they could operate from batteries.

Bubble Memory

Bubble technology is one of the few technologies that uses something other than micro-transistors in its design. Bubble memory operates like magnetic tape in that messages are recorded by having regions of opposite magnetic polarity imposed over a background of uniform polarity. These small domains of opposite polarity are called "bubbles".

Bubble memories use a magnetic film on orthoferrite or garnet to get a background of uniform polarity magnetic field. Unlike the field on magnetic tape, the field in bubble memories can flow in closely controlled patterns so that the bubbles move around (they fizz). As they move along in their patterned flow, they can be read by electronic circuits. The main disadvantage of such devices is that they require a permanent magnet, coils, and a controlled magnetic field. This presents serious packaging problems. Their significant advantage is that memory is retained when power is turned off. While CCD's and bubble memory cannot compete with normal semiconductor memories in terms of speed of operation, they may eventually serve as a replacement for tapes and discs in some applications.

Superconductive Tunnel Junction

These devices exploit the ability of electrons, under certain conditions, to penetrate (tunnel) through energy barriers which would stop them under normal conditions. To perform this feat, the circuits using them must operate at temperatures near absolute zero. This requires them to be immersed in liquid helium - a definite operating disadvantage. Their advantage is that they are compact and extremely fast. It is expected that Josephson memory cells, which use superconductive tunnel junctions, will be 10 to 100 times faster than today's fastest memories. Still in early development, such circuits are expected to find applications only in the next generation of large, powerful computer systems.

Linear Technology

While the bulk of microelectronics devices consist of digital switching circuits, linear circuits still are useful in many applications. Linear circuits are microelectronic versions of analog devices (non-digital) such as amplifiers, voltage regulators, oscillators, timers, etc. Such devices are used in T.V's, radios, instrumentation and sensors.

Microprocessor Electronics

Of all the devices manufactured using microelectronic techniques, the microprocessor is expected to have the greatest impact on society. Current microprocessor technology makes possible sophisticated computer systems costing less than $1000 and process control computers costing less than $150. These devices can solve any problem provided that: the initial conditions can be unambiguously stated; and an effective method of solution is known and can be defined. Any process can be controlled given the existence of: effective sensors for measuring process status; and devices for changing process flow.

These conditions are met by a wide range of real world problems and processes and are approximately met by even more.

The microprocessor by itself does not constitute a "computer on a chip". A typical microprocessor contains the following:

- arithmetic logic unit - to perform computations
- control processing unit - to execute instructions
- CPU registers - to store data
- instruction registers - to store instructions
- address bus control - to access external memory
- data bus control - to transfer data

In addition to these elements, a microprocessor needs a few other parts to become a fully operational computer. These include:

- clock - to control signal timing
- power supply
- interface circuits - to access external I/O devices
- external memory
- data peripherals - printers, keyboard, tape recorder, etc.

and, in the case of process control computers:

- A/D, D/A converters - to go from analog to digital signals and vice versa
- sensors and process controllers

In terms of value, a microprocessor today costs $15 to $25. A microcomputer (excluding peripherals) costs $150 to $250. It is possible to get a general purpose computer on one chip, but manufacturers have been reluctant to take the plunge for a number of very practical reasons. The main reason, however, is that it is not clear what kind of general purpose computer is most suitable for the mass market. The following paragraphs describe some of the terms and devices used in the microprocessor field. These devices are the ingredients used by computer manufacturers to provide a wide variety of computers in their search for a place in the mass market.

Memory

Memory technology is one of the critical variants in the design of microcomputers. The basic type of semiconductor memory is known as RAM (Random Access Memory). This type of memory is used to store and modify data and instructions. Any part of it can be accessed quickly and directly. General purpose computers use a lot of RAM, and generally speaking, the more the better. Each microprocessor has an upper limit to how much RAM can be accessed directly. Newer designs of microprocessors tend to raise these upper limits.

ROM (Read Only Memory) is memory that can be read but not erased. Its advantage is that it "remembers" information when power is turned off. It is used mainly to store sets of high level routines so that the computer knows how to do something when the power is turned on. Early microcomputers when first turned on had to be manually programmed, using switches, to read paper tapes, which in turn contained important high level routines. ROM avoids this labourious step. The need for ROM is not nearly as extensive as it is for RAM although process control machines, which may be subject to interruptions in power, will tend to need more ROM than general purpose computers.

PROM (Programmable ROM) can have data written on it, just like RAM, but at some point can have the memory "frozen" for all time. EPROM (Erasable PROM) retains memory when power is off but can be erased if exposed to high intensity ultravoilet light.

Word Length

A word is the smallest unit of data accessed from memory by a microprocessor. Word length is defined by the number of binary digits (or letters) needed to spell the word. A computer which uses 4-bit word has a "vocabulary" of 16 words. An 8-bit computer has a "vocabulary" of 256 words. An n-bit computer has a "vocabulary" of 2^n words.

Large machines tend to use long words. Pocket calculators use 4-bit words, the current generation of microcomputers uses an 8-bit word, mini computers use a 16-bit word, and large mainframes in commercial establishments have a 32-bit word standard. Research computers can go up even higher.

Each application has a different optimal word length which in turn means that word length defines the boundaries of different markets. The significance of word length is discussed in the appendix on development issues.

A/D, D/A Converters

Computers handle digital information. They measure everything in terms of discrete pulses which are either on or off. Sensors and device controllers tend to be analog instruments. Their inputs and outputs tend to be continuous signals which are a function of what they are measuring or doing. An ordinary thermometer, for example, registers temperature on a continuous scale and has the possibility of giving a reading anywhere within its range. A digital thermometer, on the other hand, can only give discrete readings, usually each whole degree.

In order to have computers communicate with sensors and controllers, appropriate devices have to be made which convert digial signals to analog signals (D/A) or vice versa (A/D). The former are easier to design as a rule.

APPENDIX II

Development issues for the microelectronics industry

The border between technology push and pull is not always clear. What follows is a description of some technical and design issues faced by the industry. Dealing with the issues will depend on how the industry sees the market.

General vs. Special Purpose

One of the key decisions to be made by any firm wishing to enter or expand in the microelectronics market is whether it should produce general purpose chips or concentrate its efforts on special purpose devices. Both strategies can be successful. Companies like Mostek and Zilog have done well in the general purpose field while Hewlett-Packard has a good business in special purpose microprocessor controlled scientific instrumentation.

The general purpose field has been dominated by the producers of microprocessors and memory chips. There is room for expansion, however, especially for chips designed primarily for word processing; banking; communications switching; and industrial process control.

Entry into the general purpose field has the advantages of long production runs resulting in more time to write off R & D and the ability to offer low prices. There is also a spinoff market for making a general chip work in specific applications. Entry costs tend to be high both in the design stages and the market analysis stages. The risks are considerable. If another firm produces a similar chip first, by as little as six months, then it could easily dominate the market.

Cost and risk are both lower in the special purpose area, but so are the payoffs. There appears to be a strong market for special purpose chips for: medical technology; scientific instrumentation; production control sensors; automobile technology; and energy control systems.

Word length

Within the general purpose microprocessor field the choice of word length can corner a producer into a specific market. The current standard (8-bit word) is too wasteful for a word processor. A 4 to 6 bit word would make more efficient use of memory for this purpose. The 8 to 16 bit microprocessors are best suited to personal and small business computing. Machines using long word lengths are most efficiently used in analytic and scientific work. Instrumentation can usually get by with 4-bit microprocessors.

Architecture

A computer's architecture is the "organization chart" which links together the computer's functions. Some architectures are suited to being applied to one problem at a time. Others can cope with many different devices all at the same time. Some architectures are better than others for executing high level languages.

The cost of developing new architectures is high. The benefits of copying existing architectures (such as the IBM 360 or the Digital 11) are significant. Using a micro copy of a large computer's architecture means that the software and programming styles appropriate to the original machine can be readily adapted. It is expected that the next decade will see considerable interest in computer architecture design but it is not likely that many companies will make bold moves to implement them.

Support

Microelectronic circuits are extremely complex devices. Learning how to use them can be time consuming. In order to penetrate the market, manufacturers must provide a wide variety of aids such as courses, applications notes and hardware manuals. They must provide a technical service. The costs involved in doing this can be reduced by adhering to industry standards and conventions, by designing around a "family" of related chips, and by keeping complexities internal to the chip leaving only the essential details to the user.

The question of user support can be influential in determining which application area should be pursued. Simple applications, such as toys and T.V. games require little support in relation to volume of sales. Robotics and industrial control systems may need a lot of support. As a general rule, semiconductor manufacturers are hardware specialists and prefer to restrict themselves to production of chips, without dealing extensively with the sale and marketing of applications.

APPENDIX III

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