U.S. LEADERSHIP LOSS IN MICROELECTRONICS

COULD SERIOUSLY IMPACT AEROSPACE APPLICATIONS

Albert S. Jackson, Ph.D., Motorola, Inc., Orange, CA
Elaine S. Jackson, Electronic Marketing Consultant, Irvine, CA

ABSTRACT

This paper is a report on the extension of the study of current and future microelectronic products originally presented at the 1988 IEEE Aerospace Applications Conference. The initial study, performed in 1987, covered both the U.S. and Japanese semiconductor manufacturers and included the results of in-depth interviews with major Japanese semiconductor manufacturers during a three-month visit to Japan. The results of that study showed that, compared to Japanese firms, the U.S. microelectronics companies were lagging in production technology and there were indications that they were starting to lag in some areas of technical expertise as well. This paper considers how changes in the industry over the past two years have affected, and will continue to affect, aerospace design engineers.

U.S. firms, historically the world leaders in microelectronic technology, have continued to lose their leadership position in the industry. In 1987, the total production of Japanese semiconductor firms surpassed that of North American companies for the first time. In 1989, Japanese firms made almost 50 percent of worldwide semiconductor sales, compared to less than 40 percent for all North American companies. Furthermore, 90 percent of all dynamic random access memory (DRAM) chips are now made by Japanese firms -- and these DRAM chips are a very critical component in many aerospace electronic systems. The Japanese are also ahead of the U.S. in some of the critical microelectronic R&D areas such as gallium arsenide (GaAs) radiation hardened (rad-hard) devices. These developments could seriously impact U.S. aerospace applications.

This paper discusses some of the major changes during the past two years in the microelectronics industry, summarizes the present state of the industry and explores the ramifications of those events upon aerospace design engineers. The emphasis in this study is placed on the advanced microelectronic products. Attention is focused on the High Reliability (Hi Rel) and extended temperature range devices, as well as on the full Military Specification (Mil Spec) and rad-hard parts.

INTRODUCTION

Microelectronic products are made from a semiconductor material, usually silicon, but gallium arsenide (GaAs) is growing in use. The present semiconductor technology started with the invention of the transistor at Bell Laboratories in 1948 and in the early '50s the transistor emerged from the laboratory as a viable product that replaced the vacuum tube in electronic circuitry. At first, transistors and diodes were packaged and sold with a single unit per package; such devices became known as *discrete* devices.

By 1960, multiple transistors were being created and interconnected on a single semiconductor die (often called a *chip*), ushering in the age of the *integrated circuit (IC)*, again an American invention. During the past thirty years, the number of transistors per die has grown rapidly from just a few to in excess of one million transistors on the latest DRAM and microprocessor devices. These dice with tens of thousands of interconnected transistors are known as very-large-scale integrated (VLSI) circuits.

In 1970, a two-year old company, Intel, introduced a semiconductor memory device which could store 1,024 bits on a single die; two years later they introduced the first microprocessor, the 4004. The U.S. News and World Report's 1982 ranking of technology breakthroughs listed the microprocessor as one of the "12 Milestones of American Technology." The list included the light bulb, the telephone and the airplane. Semiconductor memory and microprocessor products now account for about one-half of all microelectronic products made.

For thirty years, during the '50s, '60s and '70s, U.S. firms have dominated the fields of electronic products, computers and the semiconductors from which they are made. This picture, however, has changed. During the '60s, the Japanese industry, under the guidance of the Ministry of International Trade and Industry (MITI), aggressively attacked the consumer electronics market in the U.S. Within a few years, all but one U.S. television manufacturer quit the business, very few audio firms were left and the Japanese firms completely dominated the radio, VCR and video camera markets.

MITI next focused on the computer and communications markets -- and upon the semiconductor market as a necessary stepping stone. Japanese firms are now posing a grave threat to the U.S. semiconductor industry; during the past five years they have overtaken the U.S. semiconductor suppliers and now dominate the worldwide market, as seen from Figure 1. The term *merchant*, in the sense of merchant supplier, refers to a company that sells its products on the open market; measures of a merchant market do not include products made by such companies for their own internal use. IBM is an example of a non-merchant manufacturer of semiconductors. Figure 1 shows that the American firms' share of the market is declining very rapidly.

Other basic U.S. industries, such as the steel and shipbuilding industries, have earlier fallen prey to competition from Japan, and the automobile industry has been badly mauled. As a result of Japan's industrial successes, Japan has amassed an awesome economic power during the last 20 years. All ten of the world's ten largest banks (ranked by deposits) are now Japanese. [Burstein pg. 37] The U.S. economy would be devastated if Japanese investors suddenly quit buying government bonds that are used to finance the U.S. government's huge deficit spending.

From an overall viewpoint, the conflicting macroeconomic policies of the two countries provided a vast incentive to export products from Japan to the U.S. This created an enormous trade imbalance between the U.S. and Japan during the '80s. As a result, Japanese firms have a surplus of capital funds, and these funds are being used to buy American firms and real estate as well as to increase production capacity. Japan's current capital investment per capita is more than double that of the U.S. It is estimated that in 1990, the capital investment by Japanese firms will be $100 billion more than that of all U.S. firms. (Electronic News, Nov. 6, 1989, pg. 12)

It is quite evident that we in the U.S. have a problem! The aerospace industry has not been strongly affected by these events as yet, but it certainly will be if the present trends continue. Loss of the U.S. microelectronics industry could strongly impact aerospace applications.

STATE OF THE SEMICONDUCTOR INDUSTRY

We have seen that there has been a significant decline in the market share of the U.S. semiconductor firms, while the Japanese companies have steadily increased their share. American semiconductor firms are up against formidable competition from very large firms. The sum total of corporate-wide sales of the three U.S. manufacturers who place in the top ten in worldwide merchant semiconductor production is less than 72 percent of the third ranking Japanese firm in the semiconductor business. Figure 2 shows the total sales of the three top Japanese firms and the three top U.S. firms who are in the merchant semiconductor market. An exchange rate of 135 yen to the dollar is used in this figure and other figures throughout this paper.

The American semiconductor firms are not only losing market share worldwide -- they are rapidly losing market share even in the U.S. as shown in Figure 3, where data is shown for the top six U.S. firms. The combined market share of the top six U.S. firms has dropped from 55 percent in 1983 to 44 percent in 1988. If this fast-paced decline continues, the U.S. firms may soon be forced to forfeit the semiconductor business entirely, as did most of the consumer electronic firms earlier. Figure 4 shows the top five Japanese semiconductor manufacturers' share of the U.S. market. All but Hitachi are rapidly gaining on their U.S. counterparts.

The U.S. firms are caught in a double bind by the fact that the Japanese semiconductor market is growing at a much faster rate than that of the U.S. and breaking into the Japanese marketplace has proven to be very difficult for the U.S. firms. The market in Japan surpassed that of the U.S. in 1986, as shown in Figure 5, and was 40 percent of the total world market in 1989. In this large market, all the U.S. firms combined had less than 10 percent of market share in 1989 -- in fact, this percentage has not changed for years, despite the pressure from the U.S. government for Japan to open up its markets to foreign competition.

Figure 6 shows the 1989 ranking of the top 10 suppliers in the world semiconductor market. Only three American companies are left in the top 10 and six of the top 10 firms are Japanese. Philips, the large Netherlands firm ($29 billion sales), is the only European firm in the top ten. The semiconductor sales figures for Philips includes that of Signetics, a U.S. company purchased several years ago, but Philips has fallen behind both Mitsubishi and Intel during the past two years. Other rankings have remained the same, although NEC and Toshiba have widened the gap between them and the others, as seen in Figure 7. Intel, Mitsubishi and Fujitsu are on the same growth path as Motorola, with TI falling behind.

It is evident that, if the current trends continue, the margin between Japan and the U.S. will continue to widen. One of the keys to understanding what is happening is reflected in capital expenditures; judging from the figures given in annual reports, the top ten U.S. semiconductor firms are spending only half of the amount spent by the top ten Japanese firms to increase their production capacity.

Another danger sign is that the Japanese firms have been rapidly taking over the market for semiconductor production equipment; the top three suppliers world-wide are now Japanese (Nikon, Tokyo Electron and Advantest); those three firms plus Canon enjoy close to 50 percent of the total market. (Electronic Business, May 1989, pg. 42) In late 1989, one of the major remaining U.S. firms in this market, Perkin-Elmer, announced plans to sell their semiconductor equipment division, a group that has developed an advanced lithography system with funding from both IBM and the Defense Advanced Research Projects Agency (DARPA). Sources for the basic silicon material used in the production of semiconductors have became another potential problem area as a result of recent acquisitions of three major U.S. suppliers by foreign firms. Siltec and the silicon wafer factories of Cincinnati Milacron and Monsanto were sold to Mitsubishi, Osaka Titanium and Huels, respectively. The first two are Japanese firms and Huels is a West German conglomerate.

The leaders of Sematech and the Semiconductor Equipment and Materials Institute (SEMI) recently reported to Congress that the U.S. semiconductor equipment and materials infrastructure is on the verge of collapse. Sematech is a consortium of U.S. firms and SEMI is an international organization with strong, active Japanese, European and U.S. members. Sematech president Robert Noyce, in referring to their study of the situation, said, "We saw a steady deterioration in America's ability to compete effectively in leading-edge equipment and materials. Clearly, without a competitive infrastructure the American semiconductor industry is squarely in harm's way." (Electronic Eng. Times, Nov. 13, 1989)

Unless some major shifts are made in our trade policies and in our overall approach to the competitive problem, the U.S. semiconductor industry may cease to exist for all practical purposes. This poses a grave threat to the aerospace industry. Two consortiums have been formed to help stem the tide: the Sematech Corporation and U.S. Memories, Inc. Both are discussed in a later section.

MARKET HISTORY IN BRIEF

There are several factors that brought about the current state of affairs. Perhaps, the most significant factor is that the Japanese firms gained significant market share when they began selling large numbers of DRAMs and erasable programmable read-only memories (EPROMs) at very low prices into the U.S. electronic market. This resulted in all but two of the U.S. semiconductor companies withdrawing from the DRAM business entirely after having suffered huge losses. Some of the firms also exited the EPROM field. The following is a chronological list of some of the major events that occurred between 1985 and 1989:

- 1985-1986 - The U.S. semiconductor industry as a whole lost money every quarter from the second quarter of 1985 through the fourth quarter of 1986. Major Japanese semiconductor manufacturers were accused of dumping DRAMs and EPROMs.

- June, 1985 - A Section 301 case, citing unfair pricing of Japanese semiconductors in the U.S. and restricted market access of American firms to the Japanese market, was filed with the U.S. Trade Representative.

- July-August, 1985 - Intel, AMD and National filed cases against the Japanese, this time for EPROM-dumping.

- The U.S. Department of Commerce, in preliminary determinations in all of the cases and in the final determination in two cases, declared that the Japanese companies were dumping.

- By the end of 1985, all major U.S. manufacturers had resorted to layoffs and plant closings. As U.S.-based DRAM plants closed, only small Micron Corp. continued to produce DRAMs in the U.S. TI closed their DRAM plants in the U.S., but continued limited production at their plant in Japan. Motorola exited the EPROM business as well, but Intel tenaciously hung on to its leadership in that market.

- Jan. 10, 1986 - The Japan-U.S. market-oriented sector-selective (MOSS), negotiations were held in Washington, D.C. The final agreement required Japan to open its market in four sectors including those of electronics and telecommunications.

- July 3, 1986 - Japan and the U.S. reached an agreement on the semiconductor trade in Washington, D.C. The U.S. agreed to refrain from invoking an anti-dumping law, while Japan agreed to watch export price trends and to ensure increased imports of U.S.-made semiconductors.

- Sept. 1986 - a Japanese/American trade agreement was signed which stipulated that all dumping of DRAMs and EPROMs in the U.S. and third-country markets would cease, and that full market access would be provided to foreign firms in Japan.

- April 17, 1987 - The U.S. government accused Japan of violating the bilateral semi conductor trade agreement. A presidential statement announced a decision to impose a 100 percent retaliatory tariff on power tools, color television sets and personal computers. Tariffs were imposed on $300 million worth of Japanese goods (semiconductor imports were not targeted).

- 1987 - Sematech, a consortium of U.S. semiconductor and electronic firms, was formed to bolster U.S. semiconductor production capability.

- 1986-1988 - Prices of DRAMs soared as supplies from the U.S. firms were depleted. The Japanese firms quickly regained the losses incurred during their struggle for the market. DRAMs became scarce on the U.S. market and many computer and systems manufacturers experienced "line-down" problems for lack of sufficient DRAM devices.

- Dec. 1988 - Japanese firms had captured 87 percent of the worldwide DRAM market and it was estimated that they would surpass 90 percent in 1989. (Semiconductor Inter-national, May, 1989, pg. 18 (ICE))

- March 1989 - Congress passed a resolution citing Japan for Super 301 trade barrier infringements in the areas of communications and supercomputers, but not in semi-conductors. The 1988 Omnibus Trade Act requires that action be taken by the offending nation to permit greater access of U.S. goods within one year of being cited.

- 1989 - U.S. Memories, Inc., a consortium of U.S. firms, was formed to produce DRAMs for member firms.

- November, 1989 - According to news sources, the Bush administration plans sharp cuts in Defense Department programs that sponsor high-technology research and development, including those for high definition television (HDTV) research, x-ray lithography (a sophisticated manufacturing technology that will be needed to make semiconductors in the '90s) and the Pentagon's Manufacturing Technology program, which is intended to develop robots and other advanced manufacturing equipment. White House officials also indicated that the administration may end all support for Sematech.

SOME VIEWS OF THE PROBLEM

The problems caused by competition from Japanese firms have not gone unnoticed. It is helpful to consider what some leaders in both the U.S. and Japan have been saying.

- A 1987 Defense Department report found that America is dependent on Japanese suppliers for eight electronic devices that are crucial to certain U.S. weapons systems. According to Clyde Prestowitz, in his revealing book *Trading Places*, no fewer than 21 of our critical military systems include chips available only from foreign suppliers, primarily the Japanese.

- "Semiconductors are the core technology of electronics," said W.J. Sanders III, chairman and chief executive officer of AMD at the ground breaking of AMD's new Submicron Development Center on October 28, 1988. He continued, "Electronics is the single most important industry to the national security and economic well-being of America." (1988 AMD Annual Report, pg. 6)

- Shintaro Ishihara, a member of Japan's Diet, stated in a recent book *The Japan That Can Say "No"*, co-authored by Akio Morita, Chief Executive of Sony, "If, for example, Japan sold chips to the Soviet Union and stopped selling them to the U.S., this would upset the entire military balance. Some Americans say that if Japan were thinking of doing that, it would be occupied." (Business Week, Oct. 23, 1989, pg. 78)

- "The Japanese have consistently and methodically targeted U.S. industries. The important lesson is that once an industry becomes extinct, it is gone forever. I assure you that a phoenix will not rise from these electronic ashes," said Wilfred J. Corrigan, CEO of LSI Logic Corp., speaking of the loss of the consumer electronics industry. Mr. Corrigan went on to say "U.S. semiconductor manufacturers already are largely dependent upon the Japanese for packaging, advanced steppers and testers. The computer sector relies keenly upon the Japanese for everything from disk drives to DRAMs. The United States must ask itself where the next generation of technology is coming from. For example, flat panel displays, HDTV and 4 Mbit DRAMs all are coming from Japan. Can we afford to let that happen?" (Electronic Engineering Times, Oct. 9, 1989, pg. 35)

- The Japanese MITI has singled out DRAMs as strategically critical components for two major reasons: they are the pacesetter for all other high technology semiconductors -- and they are vital to all computers. As Sanford L. Kane, a former IBM technology vice president and president of U.S. Memories has said, "Now, it's their intention to move up the technology food chain." (Business Week, Oct. 23, 1989)

- "Today, remaining competitive with so many rivals may no longer be a matter of national pride, but of national survival; military and economic competitiveness depends totally on the state-of-the-art technology, that is semiconductors." (IEEE Spectrum, Sept. 1988)

- "Something must be done to halt the deteriorating relationship between the two countries. 'Japan-bashing' which characterizes many debates in the U.S. Congress threatens to undermine the basic security and economic links which are vital to the maintenance of world peace and prosperity." (Journal of Japanese Trade & Industry, No. 4, 1988)

- Many Japanese sincerely believe that they have been misunderstood by Americans, but Japan has done very little to create fundamental improvements in the U.S.-Japanese relations, according to the Journal of Japanese Trade and Industry. "The fact is that the relationship between the U.S. and Japan is a very important one and necessary for the stability of their economies as well as of the world economies as a whole." (Journal of Japanese Trade & Industry, No. 1, 1989)

- "The United States still maintains a market share lead over Japan in 32-bit microprocessors, largely because of proprietary devices from Intel Corp. and Motorola Inc. In addition, the United States still has a leg up on its Japanese competitors in the linear IC industry," said William I. Strauss, president of Forward Concepts Co. (Electronic Buyers, Jan. 23, 1989)

- "In the absence of any policy turnarounds in Washington, by 1992, much of the U.S. microelectronics industry will have been overtaken -- or taken over -- by Japanese companies, leaving nothing more than a fossil," said John Stern, director of the U.S. Electronics Industry Office in Japan. (Electronic Eng. Times, Nov. 20, 1989, pg. 14)

There are various organizations such as the American Electronics Association, the Ministry of International Trade and Industry (Japan) and the joint efforts of the Aspen Institute for Humanistic Studies of the U.S. and the Japan Economic Foundation that are currently heavily involved in trying to resolve the many problems between the two economic powers.

It is widely felt that the U.S. is not investing enough in education, in R&D and in making the vast improvements in manufacturing facilities necessary to compete with Japan. Many people feel that the emphasis in the U.S. seems to be on "get rich quick" schemes, with the emphasis on short term financial gain rather than development of superior products and production capability. It would seem that, in many instances, well executed leveraged buy-outs and subsequent dismantling of one firm after another have replaced the more traditional goals of developing and manufacturing quality products. Some experts state that the basic underlying problem is the continuing huge U.S. federal budget deficit, but a general lack of direction, of long range goals and of commitment to produce quality goods are all basic problems.

TECHNOLOGY

General

The transistor was invented only 40 years ago, introducing a new era in electronics. It is now possible to produce ICs with over one-million transistors on a single silicon die less than one-half inch square, approximately the size of a fingernail. These VLSI products are essential to aerospace designs. The bulk of ICs (95%) are made on wafers of pure silicon sliced from large crystal ingots, with an increasing number of products being made from gallium arsenide (GaAs) wafers.

Most silicon-based ICs are of the metal-oxide-silicon (MOS) type, but circuits that must drive more current use either discrete bipolar transistors or bipolar ICs. The most common type of MOS ICs utilizes complementary pairs of n-p-n and p-n-p type transistors to reduce power consumption, a technology known as complementary MOS or CMOS. Another silicon technology, known as emitter coupled logic (ECL), exhibits greater speed but requires an order of magnitude more area and consumes much more power. Circuits made from gallium arsenide exhibit properties similar to ECL parts, but require less power. A growing trend is to utilize both bipolar and MOS transistors on the same die, a process known as BiCMOS. This technique combines the low power and density of CMOS with the current drive capability and speed of bipolar.

Both ECL and GaAs ICs are more easily radiation hardened than CMOS, a consideration that is important to aerospace designers, especially for equipment that is to be used in space. The Pentagon sponsored studies for building hardened static RAMs have concentrated on the use of bulk silicon, silicon-on-insulator (SOI) and silicon-on-sapphire (SOS). Texas Instruments (TI) and Harris Semiconductor have been competing against non-merchant semiconductor firms such as IBM and GM/Hughes Electronics for these contracts.

Product Mix

Figure 8, 1988 Worldwide Semiconductor Mix, shows MOS memory products are the largest market category (25.1 percent). This is the key to the strategy used by the Japanese firms to dominate the semiconductor market. Furthermore, the design and production of DRAMs are at the leading edge of semiconductor technology. DRAM production is used as the driving force to develop the production capability to produce all of the other VLSI circuits, such as microprocessors. DRAMs are the keystone of the computer industry and will become a major component of future consumer products such as HDTV.

High Speed Circuits

Applications that require ultra high speed logic have traditionally used emitter coupled logic (ECL) rather than transistor-transistor logic (TTL) or CMOS circuits. ECL circuits are fast, but they are also very power hungry. Typical ECL gate array or standard cell circuits have a power dissipation per chip of 20 to 30 W, an unacceptable amount for many aerospace applications. Fewer than five companies offer ECL products of greater than 10,000 gates with the capability to operate at 250 MHz. The leaders are Motorola, Plessey, National Semiconductor, Fujitsu and Raytheon/Bipolar Integrated Technology; the latter firm specializes in relatively low power ECL circuits for workstation and military applications.

Use of GaAs rather than silicon for semiconductor devices has been researched for a long time, but the difficulty of fabricating large integrated circuits in GaAs has limited its use to small scale integrated and discrete components such as light emitting diodes (LEDs). Recently, a number of breakthroughs have led to the production of promising VLSI circuits in GaAs having densities close to that achievable with ECL and with higher speed/power ratios. Firms such as Vitesse Semiconductor, Gigabit Logic, Tri Quint Semiconductors, Raytheon and Gazelle Microciruits. A number of Japanese firms are also doing R&D on GaAs technologies. Japan's National Space Development Agency (NASDA), the Japanese equivalent to our NASA, has let several contracts for development of GaAs rad-hard ICs. Japanese firms plan to add eight GaAs fab lines and 26 silicon fab lines during the period 1989-1990. (Dataquest Report, June 1989)

Quality of Product

It has become painfully obvious to most U.S. semiconductor firms that they must improve their production methodology, particularly with regard to control of quality. Of all of the U.S. electronic manufacturers, Motorola has been perhaps the most vocal about the efforts of Japanese companies trying to dominate the electronics and semiconductor industries. Motorola has done much more than talk and has been extremely active in improving their product lines and quality of manufactured goods.

A major Motorola corporate goal is to achieve six sigma quality -- near-perfect manufacturing with a defect rate of 3.4 defects per million (PPM) -- by the year 1992. Motorola has done surprisingly well at doing at what the Japanese firms do best; they slashed their defect rates from nearly 3,000 PPM in 1983 to less than 200 in 1988 and to even much lower rates in 1989. "Such improvements were a major reason that Motorola won last year's Malcolm Baldrige National Quality Award." (Business Week, Nov. 13, 1989, pg. 114)

National/Fairchild has also been honored for sharp improvements in quality control. They claim defect rates of less than 80 PPM across all product lines in 1989. They have won a number of customer awards for quality and service, including the Q1 Preferred Vendor Status from Ford and supplier excellence awards from Chrysler, Bosch, Siemens and Unisys.

Military and Hi Rel Parts

Harris Semiconductor, Inc., with the acquisition of GE's semiconductor division and of Intersil, has become the number one supplier of military semiconductors, integrated circuits used in space and rad-hard devices. Harris uses SOS and SOI processes in addition to CMOS and bipolar for their military and Hi Rel parts.

TI and Intel are both strong in the military market; TI with a broad line of products and Intel with microprocessors, EPROMs and their new flash EPROMs. AMD always has been a strong supplier to the military and Hi Rel markets with their specialization in bipolar parts such as their 2900 bit-slice processor family. Some of the smaller firms, such as Integrated Device Technology (IDT), target the military market with high speed and/or rad-hard parts. In 1988, IDT completed a military qualified assembly and test facility in Malaysia.

Motorola, the largest of the U.S. semiconductor firms, has recently reorganized their military products group and have become very aggressive in the Hi Rel and military markets. Their goal is to introduce all microprocessor products in military qualified versions within one quarter of commercial production of the part. Extended temperature range Hi Rel parts for prototype and industrial systems are included in the product mix.

ORGANIZATIONS FORMED TO HELP THE INDUSTRY

Semiconductor Research Corporation (SRC): SRC was founded in 1982 for the purpose of cooperatively funding research. It plans and implements an industry-sponsored program of American university research in integrated circuit technology. With an annual budget of $30 million, it is the main source of university support for silicon device-related research.

Sematech: A consortium of 14 U.S. semiconductor manufacturers that sponsors and conducts research in semiconductor manufacturing technology. Formed in 1987 and located in Austin, Texas, Sematech (**SE**miconductor **MA**nufacturing **TECH**nology) is devoted to providing the U.S. industry with the domestic capability for world leadership in semiconductor manufacturing.

A number of universities and the U.S. government are also involved. A Sematech brochure states "Competitive analysis shows that Japan's greatest advantage comes from two factors: an approach that successfully applies technology in manufacturing and an environment that encourages dumping of electronic products on the American market." Sematech's objective is to increase the capability of U.S. firms in the high technology manufacturing area.

Sematech has set aggressive goals in terms of circuit line widths for factory-scale production:

- Phase 1 at 0.8 micron in 1990, using AT&T and IBM-shared production processes
- Phase 2 at 0.5 micron by the end of 1991 (to achieve parity with Japan)
- Phase 3 at 0.35 micron by the middle of 1993 (to reclaim worldwide leadership)

The 14 member companies include all of the major merchant semiconductor suppliers plus AT&T, Digital Equipment Corp., Hewlett-Packard, IBM, National Cash Register and Rockwell; they account for 80 percent of the semiconductor manufacturing capacity in the U.S. The Department of Defense (DOD) is represented by the Defense Advanced Research Projects Agency (DARPA). Sematech established University Centers of Excellence in 1987 at six universities and added three more in 1989, all in different areas of the technology. Sematech's budgets for 1989 and 1990 are $278 and $224 million, respectively.

Semiconductor Equipment Technology Center (SETEC): Formed in 1989 through a technical assistance agreement between Sematech and Sandia Labs at Albuquerque, N.M. SETEC will develop models and methodologies that will lead to enhanced semiconductor manufacturing equipment.

U.S Memories, Inc. (USM): A consortium formed in 1989 to manufacture memory devices. It was started with seven members: Advanced Micro Devices, Digital Equipment Corp., Hewlett-Packard, IBM, Intel, LSI Logic and National Semiconductor, with full memberships costing $5 million. The immediate goal is to raise $500 million in venture capital and an equal amount from debt funding. Initial production will utilize IBM's 8-inch wafer technology for 4 Mbit DRAMs, provided sufficient capital is raised.

Many U.S. executives have argued that in markets faced with substantial foreign competition, cooperation of any type, including manufacturing, should be exempt from antitrust laws. This would pave the way for consortiums such as U.S. Memories. " It needs to be done," says Robert N. Noyce, cofounder of Intel and Chairman of Sematech, "for the sake of national security and the national economy." (Business Week, Nov. 13, 1989, pg. 111)

USM faces an uphill battle to obtain more members and the funding needed to get started. The smaller computer and workstation manufacturers have been reluctant to join, perhaps because of fear of alienating their Japanese suppliers of DRAMs. USM president Sanford Kane continues to look for members and stated, "I think U.S. Memories still has a good chance, but it's unfortunate that the U.S. companies don't support America -- they support their stockholders." (Electronic Eng. Times, Nov. 20, 1989, pg.8)

CONCLUSIONS

The U.S. microelectronics industry is in serious trouble from foreign competition, particularly that from Japan. This is ironic, for the microelectronic technology was invented and developed in America. Unless the present trends are reversed, many -- perhaps most -- of the microelectronic firms in the U.S. will be forced out of the business in the foreseeable future. This would have serious consequences, not only for the aerospace industry, but for the nation as a whole.

Microelectronics is a rapidly advancing, high technology industry and it can be argued that a "critical mass" of both R&D and volume production must be maintained by any firm which hopes to produce state-of-the-art devices. Only small niche suppliers will be left if the commercial, high volume semiconductor firms in the U.S. are driven out of the business. It is doubtful, under such circumstances, that aerospace engineers would be able to design superior systems using only microelectronic parts available from U.S. firms.

The thought that proper functioning of our defense, telecommunication and computer systems might some day be dependent upon the availability of parts from foreign countries is very disturbing. Equally disturbing is the possibility that, without a viable merchant semiconductor industry, aerospace engineers might have to design systems with microelectronic parts that are inferior to those available from other countries.

On a positive note, due to the intense competition from the Japanese firms, U.S. firms have substantially increased the cost-effectiveness of their manufacturing and the quality of their products. A number of U.S. semiconductor firms have also increased their involvement in Hi Rel and Mil Spec products during the past two years, in an effort to decrease America's dependence upon foreign products.

Another positive aspect of the struggle for dominance of the microelectronics industry is the emergence of cooperative arrangements among the fiercely independent firms in the industry. Especially heartening is the appearance of consortium such as Sematech and U.S. Memories. The global nature of the industry has produced a situation in which the relatively small U.S. firms are at a decided disadvantage if they continue to play by the old set of rules and "go it alone".

If the U.S. microelectronics industry disappears or loses its technological edge, our aerospace and defense systems will surely suffer, for their operation will either be dependent upon supplies from foreign sources or they will be inferior to those of other countries. In order to prevent that from happening, a number of things must take place -- and soon. Of primary importance is the substitution of long range objectives for U.S. industry's traditional short-term, profit oriented goals. We need strong, national objectives and goals along with more cooperation between the government agencies, contractors and the semiconductor firms.

Some of the more obvious steps that the federal government must take have been mentioned, such as reduction of the huge federal deficit, relaxation of the anti-trust laws where needed, increased support for the semiconductor industry via R&D funds and stricter anti-dumping measures. Something must also be done to increase the quality of education in the U.S. It is urgent that the problems be recognized before it is too late.

In conclusion, the microelectronics industry in the U.S. faces an uncertain future and the question is not whether it will become less profitable or suffer some cutbacks -- but whether it will survive.

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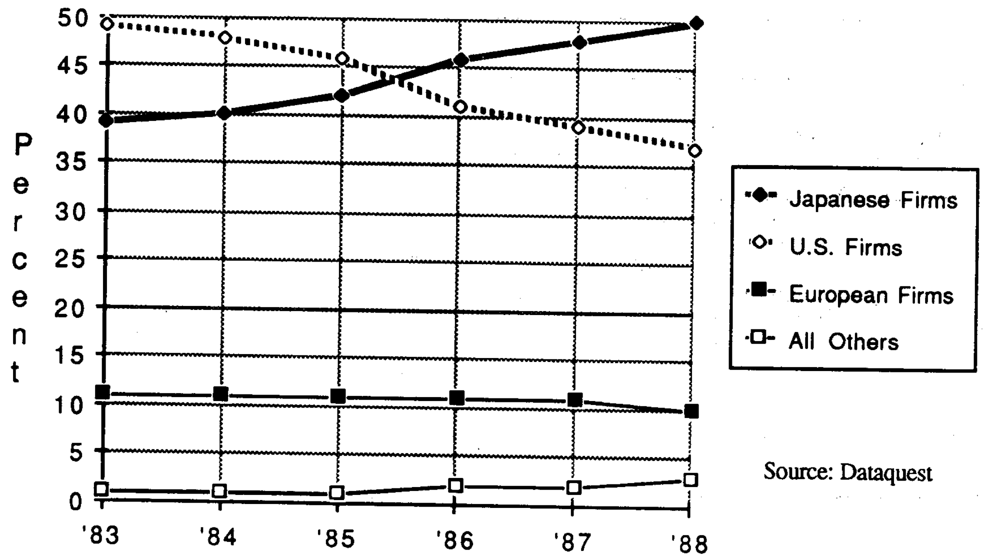

Figure 1 Market Share of Worldwide Merchant Semiconductor Market

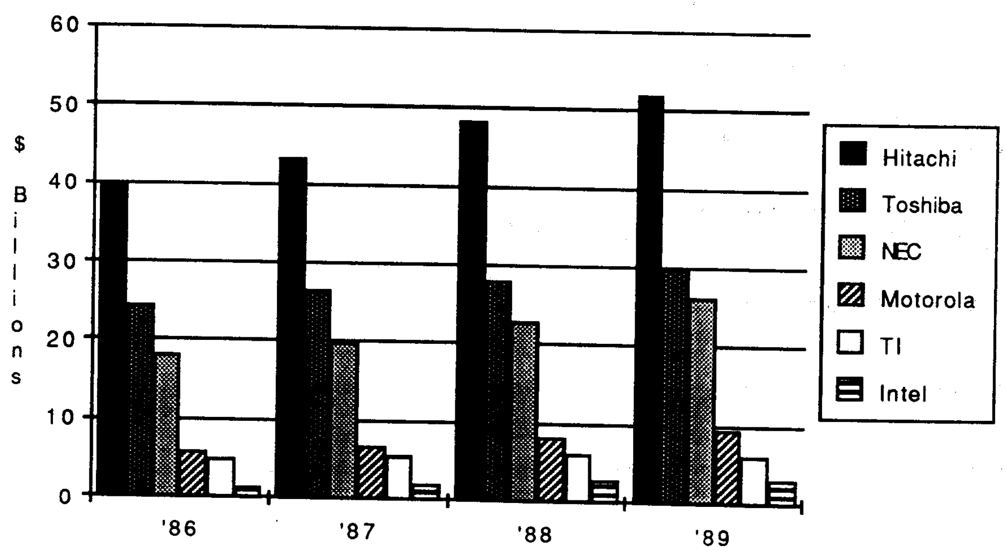

Figure 2 Total Sales of Six Firms Which Rank in Top Eight of Worldwide Semiconductor Production (Data from Annual Reports projected for 1989)

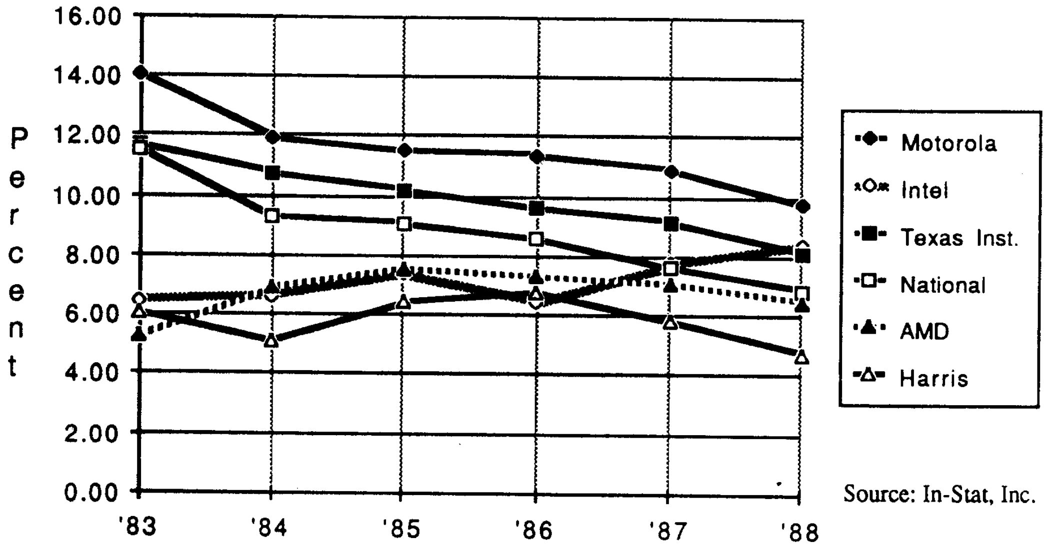

Figure 3 Top U.S. Semiconductor Companies' Share of the U.S. Market

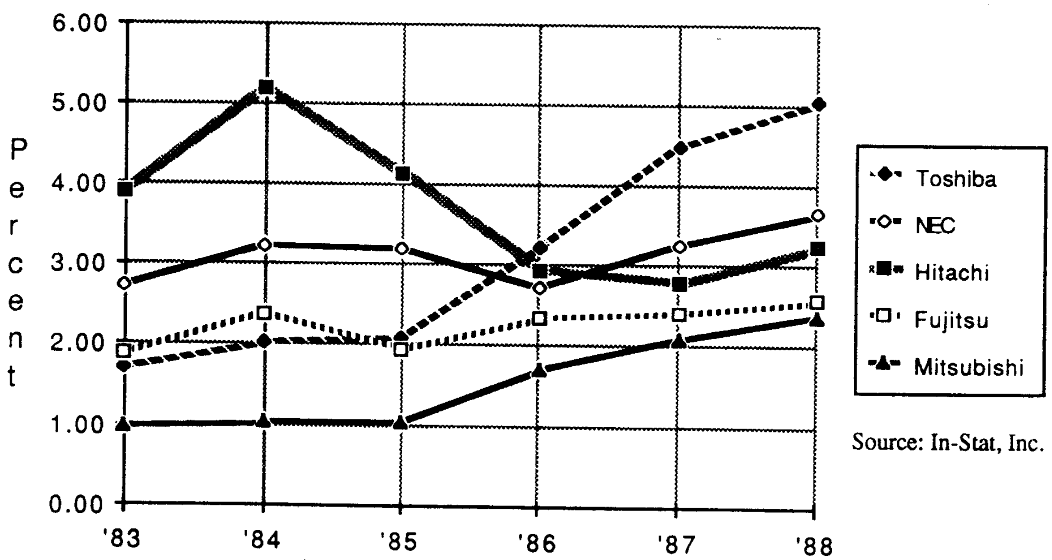

Figure 4 Top Japanese Semiconductor Companies' Share of the U.S. Market

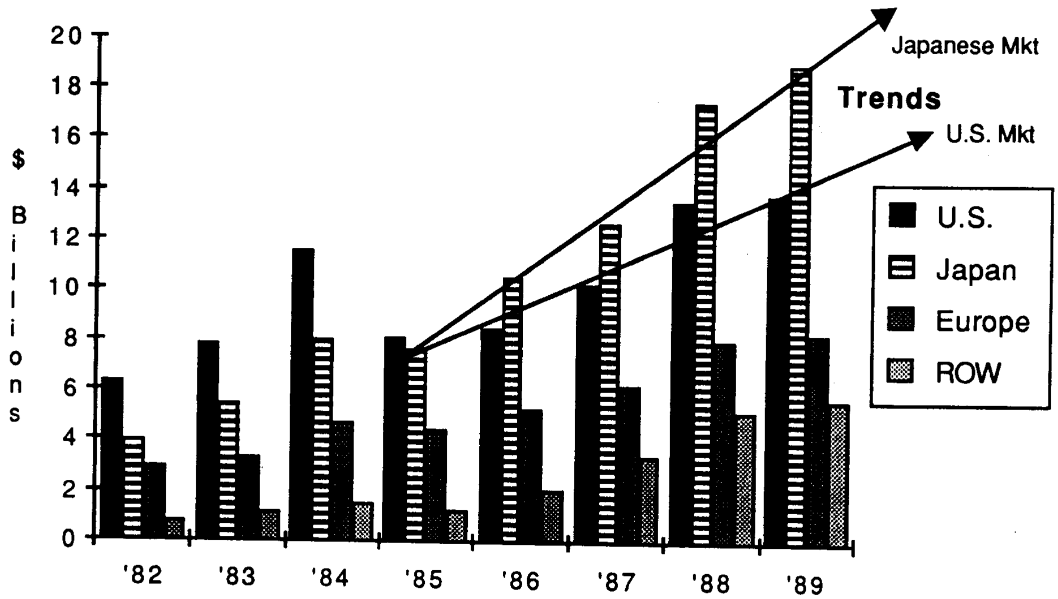

Figure 5 Worldwide Merchant Semiconductor Markets
Source: Montgomery Securities

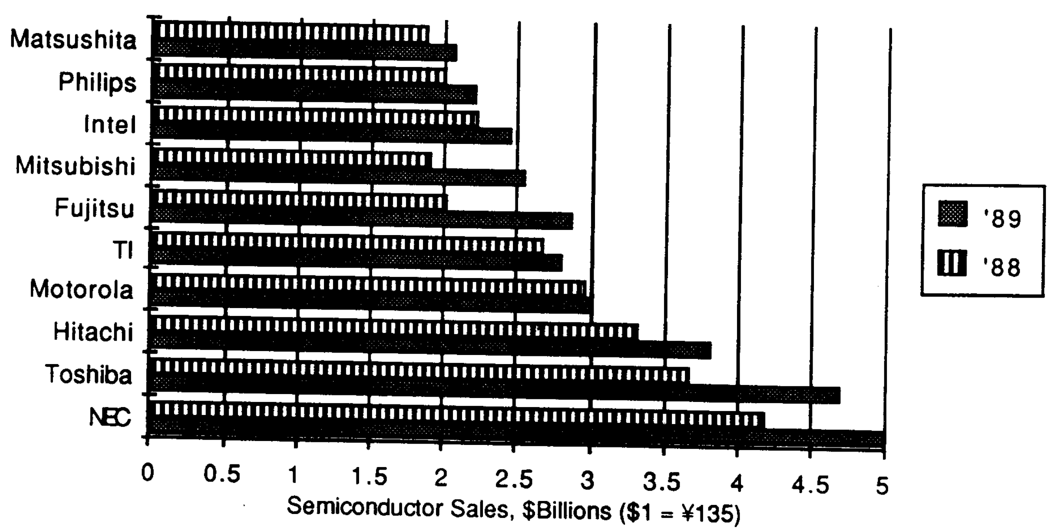

Figure 6 Worldwide Semiconductor Sales of Top Ten Firms ($1=¥135)
(Data from Annual Reports of firms shown)

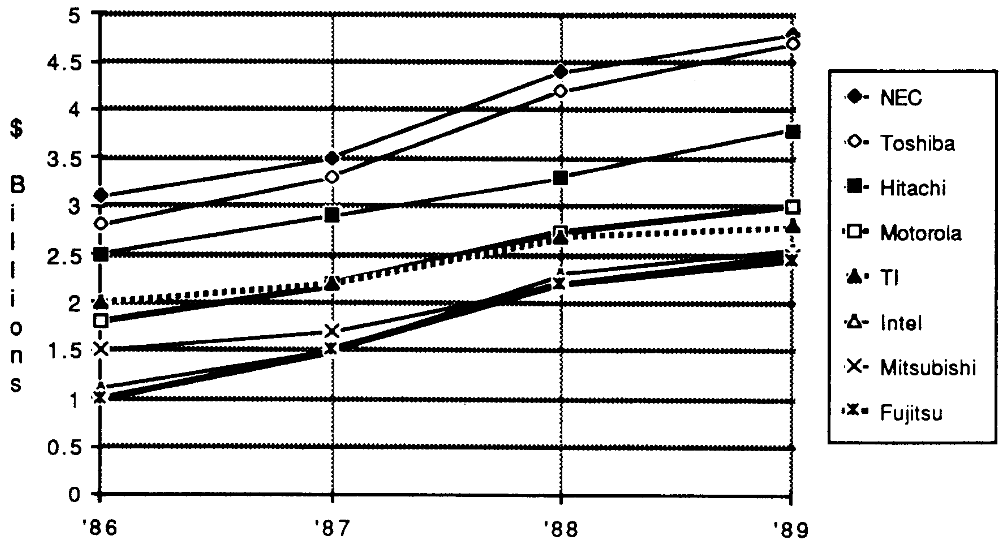

Figure 7 Worldwide Semiconductor Sales Trends of Top Eight Firms ($1=¥135)
(Data from Annual Reports projected for 1989)

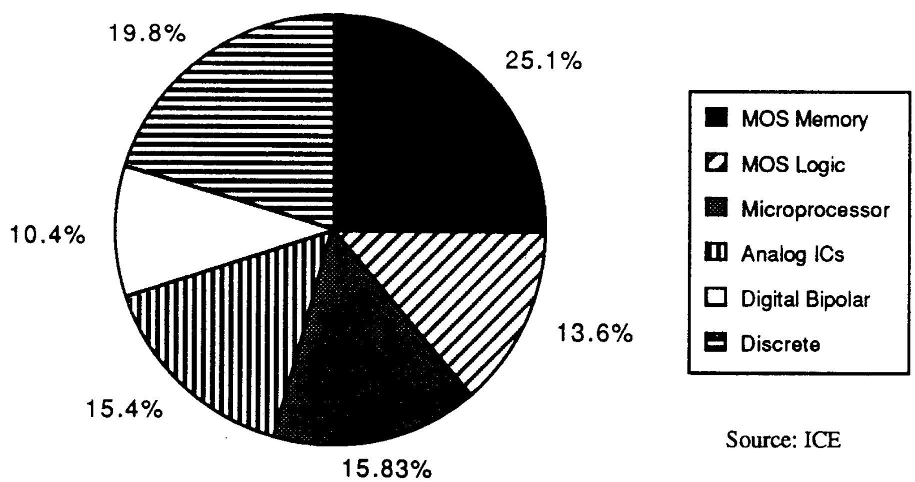

Figure 8 1988 Worldwide Semiconductor Mix

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The following includes the main organizations responsible to resolve the problems between the two countries:

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- International Trade Administration (ITA)
- Very High Speed Integrated Circuits (VHSIC) program of DOD
- National Advisory Committee on Semiconductors
- American Chamber of Commerce in Japan (ACCJ)

U.S. Private Sector

- American Electronic Association (AEA)
- Electronic Industries Association (EIA)
- International Trade Association (ITA)
- Semiconductor Research Corporation (SRC) (a research cooperative founded in 1982)
- Sematech (a consortium founded in 1988)
- U.S. Memories, Inc. (a consortium founded in 1989)
- Microelectronics and Computer Technology Corp. (MCC) (a consortium of 21 firms)
- World Trade Association (WTA)
- Aerospace Industries Association (AIA)
- Aspen Institute for Humanistic Studies

Japanese Government

- Japanese Foreign Ministry
- Japanese External Trade Organization (JETRO)
- Ministry of International Trade and Industry (MITI)
- National Space Development Agency of Japan (NASDA)

Japanese Private Sector

- Electronics Industries Association of Japan (EIAJ)
- Japanese Electronic Products Importer's Association (JEPIA)
- Japan Economic Foundation

International

- Semiconductor Equipment and Materials Institute (SEMI)

APPENDIX II THE FIRMS STUDIED

Applied Micro Devices, Inc. (AMD): Merged with Monolithic Memories, Inc. in August, 1987. 1989 sales = $1.2 billion. 14,800 employees, down from 18,933 in 1984. R&D = 18.5% of sales in 1988; capital expenditures have been cut in half from '84-'85 levels to 11.8% of sales.

AMD specializes in microprocessors and related peripherals, high-performance memories and programmable logic devices. Their present core businesses include the 80286 and 29000 microprocessors, EPROMs and programmable array logic (PAL) products.

AMD just completed their Submicron Development Center; this $100 million facility is seen as the core to AMD's future. It will utilize the advances of Sematech and should enable the firm to build devices with 0.35 micron feature sizes by 1993.

Analog Devices, Inc.: 1989 sales = $450 million. R&D = 14% and capital investment = 11% of sales. They have seven manufacturing facilities: three in the U.S. and one facility each in Japan, Ireland, the U.K. and the Philippines. Sales in Japan = 17% of their total revenue.

Analog Devices specializes in analog (linear) ICs such as analog-to-digital converters and operational amplifiers, and recently has branched out to digital signal processors and a line of application-specific ICs (ASIC) parts designed from a proprietary standard cell library. Analog Devices has developed an advanced bipolar/CMOS process (BiCMOS) optimized for precision linear circuits and is in the process of qualifying a rad-hard version of the process for military applications.

Harris Semiconductor, Inc: 1989 sales = $2.2 billion, with $542 million in semiconductors. Net income = $21 million, down 79% from 1988. 35,100 employees. R&D = 4.7% and capital investment = 5% of sales.

Harris has four divisions: Electronic Systems, Semiconductors, Communications and Office Equipment (Lanier); their percent contribution to sales in 1989 were 41%, 25%, 20% and 14%, respectively. Harris acquired GE Solid State in 1988 and GE's Microelectronics Center in 1989; these acquisitions dramatically increased the firm's semiconductor operations, with annual sales now approaching $900 million. Their portfolio now includes the brand names of GE, RCA and Intersil.

Harris is the largest U.S. semiconductor supplier to the military, with 33% of their sales going to that market. They are also the leader in rad-hard devices for space applications. Harris semiconductor operations focus on signal processing and control, with emphasis on Hi Rel products. International sales of semiconductors = 33% of their total and they are aiming for 50%.

Hitachi, Ltd.: 1989 sales will be close to $50 billion, with semiconductor sales = $3.8 billion. Overseas sales in 1988 = 23% of sales; 21% of overseas sales came from plants there. International procurements during 1988 = $1.85 billion, up 38%. "At Hitachi we have a vigorous program of international procurements that is designed to help correct trade imbalances with our trading partners ...." according to the 1989 Hitachi Annual Report. Hitachi installed a wafer fab in the U.S. for the first time in 1989.

1988 R&D = 5.8% and capital investment = 8.3% of sales. Electronics received special attention in R&D efforts, including the field of neural computing. New fabrication techniques for ultra large scale integrated circuits (ULSIs) include use of phase shifting masks for alternating between ordinary and phase-shifted light in the fabrication of adjacent patterns.

In 1988 started production of 4 Mbit DRAMs fabricated in 0.8 micron CMOS and 1 Mbit SRAMs with access time of 9 nanoseconds. Hitachi entered into an exchange agreement with VLSI Technology for ASIC designs and has announced arrays with 250,000 gates, also fabricated in 0.8 micron CMOS. They produce the H32/200 32-bit TRON microprocessor and the H8/532 8-bit microcontroller chip. Hitachi is developing a BiCMOS version of the HP RISC chip under a joint venture agreement.

Future: 16M DRAM in lab at 0.5 micron, ISDN, color liquid crystal displays and a 70 MHz microprocessor. Technology to enable a thin film of oxide superconducting material to be deposited at a low temperature is being actively pursued

Integrated Device Technology, Inc. (IDT): 1988 sales = $181 million. Founded in 1980, they now have 1,880 employees. 16% of sales to Europe, 7% to Japan. 1988 R&D = 17% of sales.

IDT specializes in SRAMs, microprocessors, specialty memories, first-in-first-out (FIFO) buffers, logic products and ECL interface products. Most of production is CMOS, but the firm has some BiCMOS capability. Production began, in 1988, of the industry's fastest cache-tag SRAM (12 nanoseconds) using a new 0.6 micron effective channel length CMOS process and of the fastest 16K x 4 ECL SRAM using a new BiCMOS process. All new products will be based on these new technologies. IDT makes the MIPS R3000 RISC microprocessor under a license agreement with MIPS.

In 1988, IDT completed a military qualified assembly and test facility in Malaysia.

Intel Corp.: 1988 sales = $2.88 billion, with semiconductor sales = $2.23 billion. 1988 R&D = 11% and capital investments = 16.6% of sales. Intel has 20,800 employees, down from 25,400 in 1984.

Intel, known as an innovator and leader in microprocessor technology, has traditionally served the Hi Rel and military markets well. They offer a broad line of microprocessors ranging from 8- to 32-bits, including the new 80486 and 80860, the latter being a reduced instruction set computer (RISC). Their 80960 RISC-like microcontroller chip has been selected by DOD as one of the 32-bit standard central processing units (CPUs) for airborne use.

Sales to Japan have grown from $108 million in 1986, $170 million in 1987 to $326 million in 1988 (11% of total sales). Growth in Japan from 1986 to 1988 was 300 percent while overall sales grew by 230%. The firm introduced flash memories in 1988, a nonvolatile memory reprogrammable in the socket. All Ford cars and light trucks have used Intel microcontrollers since 1984 (20 million units shipped by the end of 1988).

LSI Logic: Founded in 1981. 1988 sales = \$379 million. 3,600 employees. 1988 R&D = 9.8% and capital investments = 26.6% of sales. New plants were constructed in Japan, Europe and Canada. The plant in Japan is called Nihon Semiconductor, located in Tsukuba near the NASDA Space Center. R&D was for process development in the BiCMOS area and in CAD tools.

LSI Logic claims to be the world's leading supplier of CMOS ASICs and the fastest growing semiconductor firm in the U.S., up 45% in '88. Distribution of sales: 88% in U.S., 14% in Japan and 16% in Europe. LSI Logic, like most U.S. firms, has found it difficult to penetrate the Japanese market. They have sustained losses = 20.5% of sales over the last three years in Japan.

The firm is licensed to make both the SPARC™ and the MIPS™ RISC microprocessors. LSI Logic is a member of U.S. Memories, Inc.

Micron Technology, Inc.: Started in 1979. 1988 sales = \$301 million. 2,230 employees. 1988 R&D = 3% and capital expenditures = 2.7% of sales.
Micron makes only memory products, mostly DRAMs, but also some SRAMs and video RAMs. The firm completed a new 6 inch wafer fab in 1989; their older two fab lines use 4 inch wafers. An agreement between Micron and Intel allows Intel to sell their DRAMs with an Intel label. They started shipping 1 Mbit DRAMs in 1987 and fast 256 Kbit SRAMs and VRAMs in 1988.

Matsushita Electric Industrial Co.: An Osaka-based consumer electronics giant, Matsushita is the world's second largest electronics company, after IBM. 1988 sales = \$46 billion with semiconductors sales of over \$2 billion. They consume an additional \$1 billion of their semiconductor production internally for their electronic products. Exports = \$10 billion. 100,000 employees. Plans include a major plant expansion in the U.S. for office automation and telecommunications products. Matsushita has developed a GaAs technology, combining bipolar and field-effect transistors, that exhibits 200 ps propagation delays while requiring much less power than ECL circuits.

Motorola, Inc.: 1988 sales = \$8.25 billion, with semiconductor sales = \$2.74 billion. Over 100,000 employees. R&D has varied from 7.6% to 8.4% of sales and was 8.1% in 1988. 1988 capital expenses = 9.5% of sales; for the semiconductor group, the figure was \$435 million or 15.9% of semiconductor sales. Sales to federal government agencies = 12.7% of total sales.

Motorola has three major divisions (sectors): Communications, Semiconductor Products and General Systems (includes computers and cellular radios). The Semiconductor Products Sector has the broadest line of products of any firm in the field. In worldwide competition, Motorola ranks 4th overall, vies for first place with Intel in microprocessors, ranks 3rd in bipolar and is 1st in ECL devices.

Motorola's 68000 family of microprocessors includes the inexpensive 16-bit MC68000, the CMOS MC68C000, the 32-bit MC68020 workhorse, the MC68030 with built-in memory management unit (MMU) and the new high speed MC68040 with MMU and floating point capability. Motorola claims to lead in the production of microcontrollers, computer microchips with built-in input and output functions, such as the MC68HC11 and MC68HC05 families. In the super speed area, Motorola offers the MC88100/200 RISC chip set, the 24-bit DSP56001 and the 32-bit DSP96002. Most of these microprocessors and microcontrollers are available in Mil Spec versions. Motorola has become very quality conscious and has greatly increased its efforts to meet the demands of the military and Hi Rel markets.

Forced out of the DRAM market five years ago, Motorola has re-entered via an agreement with Toshiba that includes joint ownership of a plant in Japan and exchange of Motorola's microprocessor technology for Toshiba's 1 Mbit and 4 Mbit DRAM technology. Motorola has also aggressively attacked the static RAM market and has become a leader in high speed static RAMs.

Motorola has been a leader in high speed ECL gate arrays, with up to 14,000 gates per VLSI circuit. They plan to push the density to 20,000 gates with multiple metal levels, 100 ps gate delays and up to 512 pinouts while keeping per package power dissipation in the 15 W to 20 W range.

National/Fairchild: 1988 sales = $1.65 billion. 1988 R&D = 16% and capital expenditures = 16.9% of sales. National's performance during 1988 was rather dismal, with only a 15% increase in sales and a net loss of $23 million. Fairchild Semiconductor Corp. was purchased in 1987 for $121.8 million. During 1988, National closed three plants and sold off two systems subsidiaries; NAS to an Hitachi - Electronic Data Systems joint venture ($366 million) and Datachecker to Britain's STC PLC ($126 million). A new BiCMOS facility was completed in 1989.

In 1987, National entered into a technology agreement with Canon to develop embedded controllers; the first co-developed product is the NS32CG16 processor, optimized for advanced printers and related peripherals. A 32-bit version, the NS32GX32, was introduced in 1988. The company is developing ASIC products under a technology exchange agreement with Xerox.

NEC: 1988 sales = $ 22.8 billion, with $4.19 billion in semiconductors. 104,000 employees. NEC started in 1899 as joint venture with Western Electric Co. 1988 R&D = 16% and capital expenses = 9.2% of sales. NEC is betting on the future with their huge R&D expenditures. "... we will continue to stress R&D as the key to future growth and .... we will focus on further globalizing our production, marketing, and procurement activities and strengthening our financial position." (NEC 1989 Annual Report)

Electron Devices is running 19% of sales, up from 17% in '86 and '87. 25% of overall sales are overseas. Established NEC Research Institute, Inc. in New Jersey in 1988 and NEC Tsukuba Research Labs in 1989. Big in supercomputers and neural networks. Major product groups are: Communications Systems, Computers and Industrial Electronic Systems, Electron Devices (the fastest growing, up 22% from '87) and Home Electronics Products. Average interest rate on short term bank loans = 4.98%. 6% of stock is owned by foreign investors. Licensed to build the MIPS™ RISC microprocessor, they will soon produce the R6000 version in ECL.

Philips/Signetics: N.V. Philips, a Netherlands firm, is the 22nd largest industrial company in the world and the 12th largest outside the U.S. 1988 sales = $28 billion, including $2.01 billion in semiconductors, a decline from 1987 sales = $29.8 billion. 22% of sales are in the U.S. and Canada. 336,700 employees. Investment in capital improvements for component group = 23% of component sales.

Philips plus Signetics ranks among the top semiconductor manufacturers in the world. Discrete semiconductors are a large part of their line. The Mega project was started in 1987 to develop submicron technology; they plan to first produce 1 Mbit SRAMs with this technology.

Philips USA has 52,000 employees and includes Signetics, Norelco, Sylvania Audio/Video, Magnavox, Philco, SMD and Amperex. Signetics has 9,000 employees and is the world's second largest supplier of Programmable Logic Devices (PLDs) and bipolar PROMs.

SGS-THOMSON Microelectronics Inc. of America (a subsidiary of SGS-THOMSON Microelectronics B.V.): 1988 sales = $23 billion, with $1 billion in semiconductors. They have 18 factories, 8 R&D centers and 13 Design Centers in 22 countries. Their standing in semiconductors: 13th in world, 2nd in Europe, 14th in U.S. Change in location of sales from '82 to '87: 6% to 18% in Asia, 13% to 20% in U.S. and 81% to 62% in Europe. From 1983 to 1988, their compound annual growth rate was 22.4% compared to an industry growth of 17.1%. R&D plus capital expenditures were normally 15% of sales, but jumped to 17% in '85, 19.7% in '86 and 22.3% in '87.

SGS specializes in smart power devices and their unique VIPower™; the latter technology mixes high voltage, high current power devices with low voltage logic on the same die. They also make EPROMs and are shooting for 16Mbit devices. They make cache tag RAMs, FIFOs, EEPROMs, telecom chips and second source the Motorola 6804, 6805 and 68000 families. SGS also makes power ICs, standard logic, PLAs, linear ICs, RF and ASIC devices.

Texas Instruments, Inc. (TI): 1988 sales = $6.3 billion, with $2.7 billion in semiconductors. 1988 R&D = 7.8% and capital expenditures = 10.4% of sales. TI plans on capital expenditures of $750 million (12%) in 1989, with a significant portion going to new sub-micron-class wafer fabrication facilities for memory and logic devices.

TI is a broad line supplier and active in the Hi Rel and military markets. In 1988, TI's HCMOS family of logic chips were the first to win JAN-S qualification for use in space systems. In 1988, TI was a leading supplier of CMOS EPROMs and 256 Kbit DRAMs and began sampling of 4 Mbit DRAMs. TI entered into an agreement with Hitachi, Ltd., for joint development of 16 Mbit DRAMs. They are building a dedicated line for prototyping advanced CMOS products, including the 16-Mbit DRAM, and plan a $250 million plant in Italy to serve Europe. TI is implementing their version of Sun's SPARC™ RISC microprocessor.

For the future, TI is stressing PLAs, DSP, floating point processors and advanced linear devices. They plan to lead in the transition to BiCMOS for general purpose logic.

TI's basic microchip patents, filed in Japan, have finally been declared valid by the Japanese government. TI has received $350 million in royalty income on their DRAM litigation-related patent agreements since 1986 and presently receives approximately $80 million annually.

TI's focal-plane array technology was responsible for their selection on the team to develop the Army's next-generation man-portable antitank weapon and award of a development contract for the potential replacement of the Army's TOW (tube-launched, optical guided anti-tank) missile.

Toshiba: 1988 sales = $28.2 billion, with $3.68 billion in semiconductors. Information/Communication Systems and Electronic Devices accounted for 49% of sales in 1988, up 22% from 1987. This reflects the success of Project I, the company's grand strategy for enhancing its capabilities in the business areas of information and communication systems. The I stands for Information, Intelligence and Integration. 19% of their business is in heavy electrical equipment, 32% in consumer products.

Toshiba is the world's number one producer of 1 Mbit DRAMs, with 30% of the worldwide market. They were producing 1 Mbit DRAMs at the rate of 9 million units/month by 3/89. Toshiba was early to market with their 4 Mbit DRAMs, and are shipping them at the rate of 100,000 units/month with plans for 1 million units/month by March 1990. Production of 16 Mbit DRAMs is planned for 1992.

Toshiba is constructing a new plant in Japan for 4 Mbit and 16 Mbit DRAMs. Toshiba has an agreement with Siemens A.G. of Germany for joint development of standard cells, giving Siemens the right to manufacture and market ASICs designed by Toshiba. A leader in high-density gate arrays, Toshiba recently announced a sea-of-gates array that uses triple-level metal interconnects to deliver 100,000 useable gates with 0.4 ns typical gate delays. Toshiba has a balanced emphasis on MOS memories, MOS logic ICs, bipolar ICs and discrete devices.

Toshiba recently introduced their TX1 32-bit TRON microprocessor. They are developing a 4 Mbit EEPROM to replace floppy disk drives in PCs; it uses only 10 transistors to represent 8 bits of data compared to the conventional 16 transistors, with a read time of 1.6 microseconds and a write time of 1.0 microseconds. R&D of neural network computers includes a 16 microprocessor system for optical character recognition.

Toshiba has become a very aggressive international corporation. "In the future, every Toshiba enterprise must operate as part of a closely linked global network, in which business decisions at the local level are indispensable to enable us to swiftly meet changes in the diverse needs of the international market." (Toshiba 1989 Annual Report)

Vitesse Semiconductor Corp.: Financial data was not available. Founded in 1984 to manufacture high performance digital GaAs large scale integrated circuit components, they have focused their efforts to date on the development of ultra high speed devices for telecommunications, computer and military applications. Vitesse provides gate array products with up to 20,000 gates, TTL and ECL compatible RAMs, a 29G00 family of bit slice microprocessors and standard cell offerings. They claim a four-time improvement in the speed/power product over standard ECL circuits at about ECL prices. Of key importance to the aerospace industry is the fact that their products are inherently radiation hardened. Vitesse uses a proprietary circuit design, known as VML™ (Vitesse MESFET Logic), that combines both enhancement and depletion mode FETs in the same circuit, resulting in fewer elements per logic function.

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Motorola, Inc.: 1988 sales = $8.25 billion, with semiconductor sales = $2.74 billion. Over 100,000 employees. R&D has varied from 7.6% to 8.4% of sales and was 8.1% in 1988. 1988 capital expenses = 9.5% of sales; for the semiconductor group, the figure was $435 million or 15.9% of semiconductor sales. Sales to federal government agencies = 12.7% of total sales.

Motorola has three major divisions (sectors): Communications, Semiconductor Products and General Systems (includes computers and cellular radios). The Semiconductor Products Sector has the broadest line of products of any firm in the field. In worldwide competition, Motorola ranks 4th overall, vies for first place with Intel in microprocessors, ranks 3rd in bipolar and is 1st in ECL devices.

Motorola's 68000 family of microprocessors includes the inexpensive 16-bit MC68000, the CMOS MC68C000, the 32-bit MC68020 workhorse, the MC68030 with built-in memory management unit (MMU) and the new high speed MC68040 with MMU and floating point capability. Motorola claims to lead in the production of microcontrollers, computer microchips with built-in input and output functions, such as the MC68HC11 and MC68HC05 families. In the super speed area, Motorola offers the MC88100/200 RISC chip set, the 24-bit DSP56001 and the 32-bit DSP96002. Most of these microprocessors and microcontrollers are available in Mil Spec versions. Motorola has become very quality conscious and has greatly increased its efforts to meet the demands of the military and Hi Rel markets.

Forced out of the DRAM market five years ago, Motorola has re-entered via an agreement with Toshiba that includes joint ownership of a plant in Japan and exchange of Motorola's microprocessor technology for Toshiba's 1 Mbit and 4 Mbit DRAM technology. Motorola has also aggressively attacked the static RAM market and has become a leader in high speed static RAMs.

Motorola has been a leader in high speed ECL gate arrays, with up to 14,000 gates per VLSI circuit. They plan to push the density to 20,000 gates with multiple metal levels, 100 ps gate delays and up to 512 pinouts while keeping per package power dissipation in the 15 W to 20 W range.

National/Fairchild: 1988 sales = $1.65 billion. 1988 R&D = 16% and capital expenditures = 16.9% of sales. National's performance during 1988 was rather dismal, with only a 15% increase in sales and a net loss of $23 million. Fairchild Semiconductor Corp. was purchased in 1987 for $121.8 million. During 1988, National closed three plants and sold off two systems subsidiaries; NAS to an Hitachi - Electronic Data Systems joint venture ($366 million) and Datachecker to Britain's STC PLC ($126 million). A new BiCMOS facility was completed in 1989.

In 1987, National entered into a technology agreement with Canon to develop embedded controllers; the first co-developed product is the NS32CG16 processor, optimized for advanced printers and related peripherals. A 32-bit version, the NS32GX32, was introduced in 1988. The company is developing ASIC products under a technology exchange agreement with Xerox.

NEC: 1988 sales = $ 22.8 billion, with $4.19 billion in semiconductors. 104,000 employees. NEC started in 1899 as joint venture with Western Electric Co. 1988 R&D = 16% and capital expenses = 9.2% of sales. NEC is betting on the future with their huge R&D expenditures. "... we will continue to stress R&D as the key to future growth and .... we will focus on further globalizing our production, marketing, and procurement activities and strengthening our financial position." (NEC 1989 Annual Report)

Electron Devices is running 19% of sales, up from 17% in '86 and '87. 25% of overall sales are overseas. Established NEC Research Institute, Inc. in New Jersey in 1988 and NEC Tsukuba Research Labs in 1989. Big in supercomputers and neural networks. Major product groups are: Communications Systems, Computers and Industrial Electronic Systems, Electron Devices (the fastest growing, up 22% from '87) and Home Electronics Products. Average interest rate on short term bank loans = 4.98%. 6% of stock is owned by foreign investors. Licensed to build the MIPS™ RISC microprocessor, they will soon produce the R6000 version in ECL.

Philips/Signetics: N.V. Philips, a Netherlands firm, is the 22nd largest industrial company in the world and the 12th largest outside the U.S. 1988 sales = $28 billion, including $2.01 billion in semiconductors, a decline from 1987 sales = $29.8 billion. 22% of sales are in the U.S. and Canada. 336,700 employees. Investment in capital improvements for component group = 23% of component sales.

Philips plus Signetics ranks among the top semiconductor manufacturers in the world. Discrete semiconductors are a large part of their line. The Mega project was started in 1987 to develop submicron technology; they plan to first produce 1 Mbit SRAMs with this technology.

Philips USA has 52,000 employees and includes Signetics, Norelco, Sylvania Audio/Video, Magnavox, Philco, SMD and Amperex. Signetics has 9,000 employees and is the world's second largest supplier of Programmable Logic Devices (PLDs) and bipolar PROMs.

SGS-THOMSON Microelectronics Inc. of America (a subsidiary of SGS-THOMSON Microelectronics B.V.): 1988 sales = $23 billion, with $1 billion in semiconductors. They have 18 factories, 8 R&D centers and 13 Design Centers in 22 countries. Their standing in semiconductors: 13th in world, 2nd in Europe, 14th in U.S. Change in location of sales from '82 to '87: 6% to 18% in Asia, 13% to 20% in U.S. and 81% to 62% in Europe. From 1983 to 1988, their compound annual growth rate was 22.4% compared to an industry growth of 17.1%. R&D plus capital expenditures were normally 15% of sales, but jumped to 17% in '85, 19.7% in '86 and 22.3% in '87.

SGS specializes in smart power devices and their unique VIPower™; the latter technology mixes high voltage, high current power devices with low voltage logic on the same die. They also make EPROMs and are shooting for 16Mbit devices. They make cache tag RAMs, FIFOs, EEPROMs, telecom chips and second source the Motorola 6804, 6805 and 68000 families. SGS also makes power ICs, standard logic, PLAs, linear ICs, RF and ASIC devices.

Texas Instruments, Inc. (TI): 1988 sales = $6.3 billion, with $2.7 billion in semiconductors. 1988 R&D = 7.8% and capital expenditures = 10.4% of sales. TI plans on capital expenditures of $750 million (12%) in 1989, with a significant portion going to new sub-micron-class wafer fabrication facilities for memory and logic devices.

TI is a broad line supplier and active in the Hi Rel and military markets. In 1988, TI's HCMOS family of logic chips were the first to win JAN-S qualification for use in space systems. In 1988, TI was a leading supplier of CMOS EPROMs and 256 Kbit DRAMs and began sampling of 4 Mbit DRAMs. TI entered into an agreement with Hitachi, Ltd., for joint development of 16 Mbit DRAMs. They are building a dedicated line for prototyping advanced CMOS products, including the 16-Mbit DRAM, and plan a $250 million plant in Italy to serve Europe. TI is implementing their version of Sun's SPARC™ RISC microprocessor.

For the future, TI is stressing PLAs, DSP, floating point processors and advanced linear devices. They plan to lead in the transition to BiCMOS for general purpose logic.

TI's basic microchip patents, filed in Japan, have finally been declared valid by the Japanese government. TI has received $350 million in royalty income on their DRAM litigation-related patent agreements since 1986 and presently receives approximately $80 million annually.

TI's focal-plane array technology was responsible for their selection on the team to develop the Army's next-generation man-portable antitank weapon and award of a development contract for the potential replacement of the Army's TOW (tube-launched, optical guided anti-tank) missile.

Toshiba: 1988 sales = $28.2 billion, with $3.68 billion in semiconductors. Information/Communication Systems and Electronic Devices accounted for 49% of sales in 1988, up 22% from 1987. This reflects the success of Project I, the company's grand strategy for enhancing its capabilities in the business areas of information and communication systems. The I stands for Information, Intelligence and Integration. 19% of their business is in heavy electrical equipment, 32% in consumer products.

Toshiba is the world's number one producer of 1 Mbit DRAMs, with 30% of the worldwide market. They were producing 1 Mbit DRAMs at the rate of 9 million units/month by 3/89. Toshiba was early to market with their 4 Mbit DRAMs, and are shipping them at the rate of 100,000 units/month with plans for 1 million units/month by March 1990. Production of 16 Mbit DRAMs is planned for 1992.

Toshiba is constructing a new plant in Japan for 4 Mbit and 16 Mbit DRAMs. Toshiba has an agreement with Siemens A.G. of Germany for joint development of standard cells, giving Siemens the right to manufacture and market ASICs designed by Toshiba. A leader in high-density gate arrays, Toshiba recently announced a sea-of-gates array that uses triple-level metal interconnects to deliver 100,000 useable gates with 0.4 ns typical gate delays. Toshiba has a balanced emphasis on MOS memories, MOS logic ICs, bipolar ICs and discrete devices.

Toshiba recently introduced their TX1 32-bit TRON microprocessor. They are developing a 4 Mbit EEPROM to replace floppy disk drives in PCs; it uses only 10 transistors to represent 8 bits of data compared to the conventional 16 transistors, with a read time of 1.6 microseconds and a write time of 1.0 microseconds. R&D of neural network computers includes a 16 microprocessor system for optical character recognition.

Toshiba has become a very aggressive international corporation. "In the future, every Toshiba enterprise must operate as part of a closely linked global network, in which business decisions at the local level are indispensable to enable us to swiftly meet changes in the diverse needs of the international market." (Toshiba 1989 Annual Report)

Vitesse Semiconductor Corp.: Financial data was not available. Founded in 1984 to manufacture high performance digital GaAs large scale integrated circuit components, they have focused their efforts to date on the development of ultra high speed devices for telecommunications, computer and military applications. Vitesse provides gate array products with up to 20,000 gates, TTL and ECL compatible RAMs, a 29G00 family of bit slice microprocessors and standard cell offerings. They claim a four-time improvement in the speed/power product over standard ECL circuits at about ECL prices. Of key importance to the aerospace industry is the fact that their products are inherently radiation hardened. Vitesse uses a proprietary circuit design, known as VML™ (Vitesse MESFET Logic), that combines both enhancement and depletion mode FETs in the same circuit, resulting in fewer elements per logic function.