Electronics Industry Study Report:

Semiconductors and Defense Electronics

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Electronics

ABSTRACT: The commercial semiconductor industry is characterized by fierce competition, large fluctuations in demand, increasing performance, and falling prices. Defense electronics has become a miniscule part of the semiconductor industry (less than 1%), but is essential to national security. However, U.S. commercial and defense semiconductor production is losing ground. The industry faces a number of challenges, including: rising capital costs, rapidly evolving technology, future workforce shortages, increasing offshore design and production, infringement of intellectual property rights, and ineffective export controls that hinder U.S. global competitiveness. Furthermore, the defense electronics industry faces significant issues associated with commercial-off-the-shelf components and diminishing manufacturing sources. It is prudent for the U.S. government to recognize the risks of a declining U.S. microelectronics design and production capability, and to plan a course of action to mitigate the emerging risks to national security.

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PLACES VISITED:

Domestic:
Advanced Micro Devices, Austin, TX
BAE Systems, Austin, TX
Defense Advanced Research Projects Agency, Rosslyn, VA
Dell Computers, Austin, TX
Electronics Industry Association, Rosslyn, VA
Fabless Semiconductor Association, Fort Worth, TX
Herley Industries, Lancaster, PA
International Sematech, Austin, TX
Lockheed Martin Aeronautics Company, Fort Worth, TX
National Security Agency, Ft. Meade, MD
Northrop Grumman Electronics Sensors and Systems, Baltimore, MD
Raytheon Network Centric Systems, Dallas, TX
Virginia Semiconductor, Fredricksburg, VA

International:
3M, Madrid, Spain
Advanced Micro Devices, Dresden, Germany
AFARMADE (Asociación Española de Fabricantes de Armamento y Material de Defensa y Seguridad), Madrid, Spain
ANIEL (Asociación Nacional de Industrias Electrónicas y de Telecomunicaciones), Madrid, Spain
CASA – EADS, Madrid, Spain
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INTRODUCTION:

The Electronics Industry Study focused its research on the unique characteristics of the semiconductor and defense electronics industries and their ability to support U.S. national security objectives during peacetime and war. Because the semiconductor is the backbone of the defense electronics industry, the health of the integrated circuit market serves as an indicator of the ability of the U.S. to sustain economic growth and maintain competitive advantage in producing the best technology and products for the nation and the war-fighter.

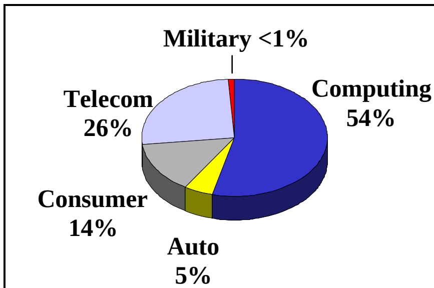
In the course of this study, students visited government organizations, commercial semiconductor and defense electronics companies, and industry associations in Virginia, Maryland, Pennsylvania, Texas, Madrid, Dresden, and Prague. We visited both small niche companies and industry leaders to gain insight into the current condition, challenges, and future of the commercial semiconductor and defense electronics industries.

This report begins by defining the scope of the industry study: semiconductors and defense electronics. Next, it provides a summary of the current state of these industries. The semiconductor industry has seen declining sales, increasing pressures to achieve economies of scale, growing market concentration, and the rise of the Asia Pacific as the largest semiconductor producer and consumer.

The paper also examines key challenges to maintaining a thriving commercial semiconductor industry in the U.S. and assuring that the defense electronics industry is postured to meet national security needs. Next, it discusses future trends for the industries; the outlook is generally positive but it remains volatile. The study presents actions we believe the U.S. should take so that it can benefit from the rapid advances made in the commercial semiconductor sector and to support national security requirements. The study concludes by discussing three major issues in detail and by drawing some overall conclusions.

<u>THE INDUSTRY DEFINED:</u>

Today, the variety of end-use applications for semiconductors is greater than ever. Semiconductors are essential components used in a myriad of end items ranging in complexity from billion dollar satellites to the simple timer on a Brita® Water Filtration Pitcher. Industry analysts generally group semiconductor end-uses into five markets: computing, telecommunications, consumer electronics, automotive electronics, and military electronics. As shown in the adjacent chart, computing and telecommunications are the primary uses for commercial semiconductors. The military – with three-tenths of one percent



Source: Standard & Poors Industry Surveys: Semiconductors, 9 Jan 2003 of the end-use market – is a minor player.

Since every industry from agriculture to transportation uses electronics to conduct its business, we focused this industry study on the *manufacture*, rather the *use*, of electronic devices. In particular, we studied the industry that produces semiconductors and related solid-state devices —what the North American Industry Classification System terms "Semiconductor and Related Device Manufacturing" (code 334413).[1] In addition, we concentrated on the small subset of the electronics industry that integrates semiconductors into defense related products (a.k.a defense electronics).

What is a semiconductor?

The term semiconductor "refers to a class of materials with electrical properties between those of conductors (such as copper and aluminum) and insulators (such as glass or rubber)."[2] Today, silicon is the most commonly used semiconductor material.

A semiconductor – a.k.a. microchip (or just chip), die, or integrated circuit -- is also any "electronic device made from semiconductor material. "[3] Semiconductors are the basic building blocks for electronics devices. Microprocessors, analog circuits, memory device microcontrollers, diodes, transistors, sensors, and optoelectronics (such as solar cells) are examples of semiconductors.

CURRENT CONDITION:

Commercial Semiconductor Industry

Market Trends. Worldwide semiconductor industry revenues and sales began to decline in November 2000. The year 2001 was a particularly difficult year for the semiconductor industry: sales decreased in all major markets. Sales began picking up slowly in 2002, but the industry has not yet fully recovered. At $141.7 billion in 2002, industry sales were still below the 1995 level of $144 billion."[4] The table to the right shows total worldwide semiconductor sales during 2000-2002.[5]

Total Worldwide Sales

Year	Sales ($B)
2000	201.1
2001	138.9
2002	141.7

Source: Semiconductor Industry Association

The United States exported $55 billion worth of semiconductors in 2001, according to the latest figures available from the United States Census Industry Reports.[6] This represented a decrease of 35.6% from 2000 numbers. On the other hand, the United States imported $23 billion worth of semiconductors in 2001. [7]

Industry Leaders and Market Concentration. Intel Corporation remains the world leader, with greater market share than the number two, three, and four ranked companies combined. The following chart depicts further details on sales and market share for 2001 and 2002. As a whole, the semiconductor industry is moderately concentrated. In 2002, the top four-firms captured about 32 percent of the market. The top 10 global semiconductor makers claimed more than a 54% share of the global market in 2002, accounting for $76.6 billion of the industry's total sales of $141.7 billion.

However, barriers to entry have led to *de-facto* oligopolies in two large segments of the semiconductor market -- Dynamic Random Access Memory (DRAM) chips and microprocessors. Samsung, Micron, Hynix, and Infineon control almost three-fourths of the DRAM market,[8] while Intel alone controls more than 80 percent of the microprocessor market.[9]

Worldwide Top 10 Semiconductor Sales Leaders

2002 Rank	2001 Rank	Company	Country	2001 Sales ($B)	2002 Sales ($B)	% Change	% 2002 Mkt
1	1	Intel	U.S.	23.7	24.0	1%	16.9%
2	3	Samsung Semiconductor	S. Korea	6.3	8.7	38%	6.2%
3	2	Texas Instruments	U. S.	6.4	6.5	1%	4.6%
4	4	STMicronelectronics	Switzerland	6.3	6.4	1%	4.5%
5	5	Toshiba Semiconductor	Japan	5.7	5.9	4%	4.2%
6	6	NEC Semiconductor	Japan	5.3	5.5	4%	3.9%
7	9	Infineon Technologies	Germany	4.6	5.4	17%	3.8%
8	8	Hitachi	Japan	4.8	4.9	1%	3.5%
9	7	Motorola Semiconductor	U. S.	4.9	4.8	-4%	3.4%
10	14	TSMC	Taiwan	3.7	4.7	26%	3.3%
		Totals		71.7	76.8	7%	54.3%

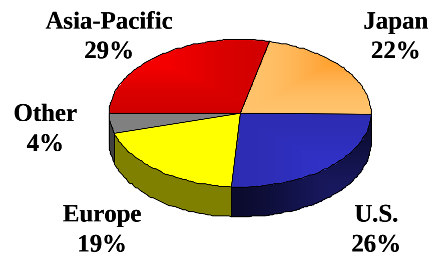
Sources: IC Insights' Strategic Reviews Database[10]/ 2002 market share based on 2002 global total sales of $141.7 billion[11]

Performance. Despite the downturn and slow growth, the semiconductor industry has remained profitable for some producers. In the U.S., the semiconductor production remains profitable for Intel, largely due to their dominance in the microprocessor market.[12] Intel reported earnings of $0.14 per share in the quarter ending March 2003, and $3.12 billion, or $0.46 per share, in fiscal 2002. Other large firms reported losses in 2002: Texas Instruments lost $0.20 per share and Motorola lost $1.09 per share.[13]

International companies also have had mixed performance. The Swiss chipmaker STMicroelectronics has posted consistent profits over the past three years, while the Japanese chipmaker Toshiba lost $0.59 per share in 2002. [14]

Overcapacity. In general, the semiconductor industry generally has excess capacity. According to the Federal Reserve, capacity utilization in the industry reached a nadir of 59.9 percent in July 2001, and subsequently recovered to 67.8 percent in July 2002. In comparison, capacity utilization for American industry as a whole was 76.1 percent in July 2002. Semiconductor companies have taken some measures to correct their excess capacity. Fairchild and National Semiconductors have exited the micro-processor market segment. Fijitsu Microelectronics sold its Oregon fab plant in August 2002 for about 10 cents on the dollar. Other companies, such as Toshiba and Hitachi, merged their direct random access memory (DRAM) operations to achieve cost savings and reduce output.

Globalization and the rise of the Asia-Pacific region. Semiconductor manufacturing has gone global. Manufacturing is located in four major regions: the United States, Europe, Japan, and the Asia-Pacific region (includes South Korea, China, Singapore, Malaysia, Taiwan, and the rest of Southeast Asia.) The year 2001 was a turning point; "the Asia-Pacific region took over the leading role from the Americas,"[15] and now commands the largest share of global semiconductor revenues. In 2002 companies in the Asia/Pacific region had more than 37 percent of global semiconductor revenues, and will likely continue to gain market share.[16]



Source: Standard and Poor's Industry Surveys: Semiconductors, January 2003

Taiwan is successfully developing its semiconductor industry. Taiwan produced an estimated $21.5 billion in semiconductors in 2002, earning it third place among world semiconductor producers, after the U.S. and Japan.[17] Not content to merely produce semiconductor wafers for others, the Taiwanese have aggressively developed skills in chip design. In 2002, Taiwan designers earned $3.6 billion; more than any nation except the U.S.[18]

Primarily because of China's increasing consumer demands for electronic products, the Asia-Pacific region also became the world's largest consumer of semiconductors in 2001. "For all of 2002, Asia-Pacific consumption grew 29% while sales elsewhere shrank. Semiconductor sales fell 13% in the Americas, 8% in Japan, and 8% in Europe."[19] According to Intel CEO Andrew Grove, "China is the most vigorous market for the U.S. and its most vigorous competitor." Firms such as Siemens, General Electric, Motorola, IBM, AMD, Microsoft, and Toshiba are flocking to China to take advantage of low cost production and China's booming internal market.

Rise of "Fabless" Production. As the fixed costs and risks associated with wafer foundries (a.k.a. "fabs") increases, many chipmakers are outsourcing production to third party foundries. An estimated 1000 companies worldwide are using the "fabless" business model; even the largest chipmakers such as Texas Instruments, Motorola, and AMD are contracting out some of their manufacturing to third party foundries.[20] Similarly, Royal Philips Electronics NV plans to outsource as much as 30 percent of its chip production to three Asian foundries. The fabless *production* market is highly concentrated: two Taiwan foundries account for 60-70 percent of the fabless business.

These foundries offer state-of-the art manufacturing capacity. They are able to combine orders from multiple customers to achieve economies of scale. Scale economies also arise from the learning curves associated with their diverse customer base; each customer benefits from lessons-learned on other customers' product.

Technology trends. Steady improvements in the processes used to make chips permit chipmakers to continue to shrink the "circuit linewidths" (and hence chip size). This trend is called "Moore's Law", after Gordon Moore (cofounder of Intel) who in the 1960's predicted that the number of transistors that would fit on a chip would double every 18-24 months. These manufacturing advances, combined with fierce competition between semiconductor manufacturers, reduce the price that consumers pay for a given level of processing.

To retain market share, semiconductor makers must produce chips with the smaller circuit linewidths that allow greater memory/ processing capacity and operating speed (the shorter the path, the faster the circuit). Currently, industry leaders are moving to 0.13 micron (130 nanometers) and even 0.09 micron (90 nanometers) circuit linewidths.

Economies of Scale. Despite declining sales, many firms are achieving profitability through manufacturing technologies that enable meaningful increases in economies of scale. Production costs vary with the number of semiconductor wafers used, so if a firm can produce more usable chips per wafer, costs per *chip* decline. Firms can increase the number of chips per wafer by making smaller chips or by using bigger wafers (or both).

Industry analysts note that chip manufacturers who do not need the speed advantages will still migrate to 0.13-micron chips to achieve the associated cost savings.[21] In addition, switching from the current standard 200-millimeter (mm) wafer to a 300-mm wafer allows considerable economies of scale. Chipmakers can place more than twice as many chips on a 300mm wafer, but the costs of processing that wafer are only 20 percent more.[22]

Defense Electronics Industry

Overview. Semiconductors are found in many defense related electronics components such as computers, sensors, switches and amplifiers. Semiconductors are critical to the way the U.S. military fights and to the functioning of the global economy. Electronics content in military ordnance, fighter planes, bombers, tanks, armored personnel carriers, and a range of other weapons systems is all increasing, according to analysts.[23]

In an interesting paradox, electronics are becoming more important to the Defense Department, while the Defense Department is becoming increasingly *unimportant* to the semiconductor industry. Estimates put electronics as 60% of the cost of new weapons systems, yet defense represents only .3% of the semiconductor market. [24]

Industry Leaders**.** Lockheed Martin, Boeing, Northrop Grumman, and Raytheon were the Defense Department's top four contractors for Fiscal 2002, accounting for $49.3B of the $170.8B, or 28.9% of the prime contracts awarded.[25] These are multi-product defense firms producing more than just electronics components. According to

Lehman Brothers, Lockheed Martin and Raytheon hold 35 percent of the global market for defense *electronics*.[26]

Top Department of Defense Contractors for Fiscal 2002

Rank	Name	Sales ($B)
1.	Lockheed Martin Corp.	17.0
2.	The Boeing Co.	16.6
3.	Northrop Grumman Corp.	8.7
4.	Raytheon Co.	7.0
5.	General Dynamics Corp.	7.0
6.	United Technologies Corp.	3.6
7.	Science Applications International Corp.	2.1
8.	TRW Inc.*	2.0
9.	Health Net Inc.	1.7
10.	L-3 Communications Holdings Inc.	1.7

*On 11 December 2002, Northrop Grumman acquired TRW Inc. for $13 billion.
Source: DefenseLINK, United States Department of Defense News Release, "DoD Announces Top Contractors for Fiscal 2002"

Performance. The profitability of American defense contractors is mixed. In 2002, Lockheed Martin reported earnings of $1.11 per share, Northrop Grumman reported earnings of $0.34 per share, and Boeing reported earnings of $0.59 per share. On the other hand, Raytheon reported losses of $1.57 per share in 2002, the second consecutive year of significant losses for the company.[27]

Across the Atlantic, a RAND study ranked European players in defense electronics and characterized the European defense market as fragmented at both the subsystem and platform levels. The report also portrays European defense electronics as a "European spaghetti bowl" consisting of three big players, a number of smaller ones, with joint ventures and other structural relationships linking them.[28] This structure is somewhat similar to that found in the defense electronics sector in the United States.

Defense Electronics: Ranking of European Companies [29]

Company	Main products	Est. 2000 Revenues (Euro billion)
BAE Systems	Avionics, communications, identification friend or foe, C4I, EW	4.0
THALES	Communications, avionics, C4I, optronics, radar, EW	3.3
EADS	C4I, surveillance, reconnaissance, radar, avionics, EW	1.3
Finmeccanica	Avionics, C4I, communications	0.8
Saab	Avionics, C4I, EW, sensors	0.3

Lack of Defense Influence. The defense electronics share of the total $2 trillion dollar electronics industry is miniscule. Defense was less than 3% in 2000, less than 1%

in 2002, and less than .5% in 2003. Since the military's share of the demand for electronic components has declined to less than 1% of the market, it has little influence over the electronic component manufacturers.

Military electronics systems generally take years to produce and remain in the inventory for decades. Since it comprises such a small portion of the market, the military may not be able to count on commercial electronics vendors to quickly respond to wartime mobilization and surge requirements, particularly with "smart" weapons.

Consolidation and partnerships. The defense electronics sector – like the defense sector overall – has been consolidating to achieve economies of scale and scope. However, the industry is still learning to cope with the defense industrial base consolidations of the last few years, the merger of corporate cultures, and the rationalization of facilities.[30]

At the same time, large contractors are shifting from electronics hardware *production* to the *integration* of semiconductors into defense systems. Furthermore, the large contractors -- unable to influence the commercial electronics industry to meet defense-unique requirements – are turning to smaller niche electronics firms to manufacture military specific components. However, some contractors continue to fill requirements that can't be filled elsewhere by operating organic "fabs of last resort."

CHALLENGES:

Capital Costs

As previously stated, equipment and facilities costs are extraordinarily high. Standard and Poor's calls the semiconductor industry a "'no-limit poker game' in which participants invest enormous sums but have no guarantee of earning adequate return." [31] Today, a state-of-the-art semiconductor fabrication plant currently costs $2-3 billion; in the future, such a "fab" plant may cost as much as $10 billion, making it the most expensive plant of *any kind in the world*. [32]

To produce each new generation of chips, and to take advantages of the cost advantages offered by the larger wafers, manufacturers need new equipment and facilities. Thus, chipmakers must continually reinvest in facilities and equipment. Because only large firms have the revenue and sales volume to keep such an investment cycle going, this drives industry consolidation and the move to the fabless business model.

In addition, the high sunk costs mean that during periods of weak demand, firms may continue to operate even when chip prices fall below average total cost. Because companies cannot easily withdraw their investment or transfer these assets to other uses if profits decline, the high cost of fabs represents a significant barrier to entry and exit.

Technology

Circuit line widths continue to shrink. Industry leaders are producing line widths down to 90nm. Line widths below 90nm push the technological limits of lithography used to make masks and microscopes to observe circuit defects. During the last two years, research laboratories have experimentally demonstrated transistors with gates down to 20nm. With gates no more than 2-3 atomic layers, new materials will also be required to bring gate leakage to acceptable levels.

To stay competitive, manufacturers must drive down defects with reliable and repeatable manufacturing processes. Most are looking for the lowest possible defect rates. Larger wafers and smaller line widths increase the potential for defects. More stringent clean rooms and next generation lithography are required to ensure acceptable defect rates for 90nm and below – and this means more capital.

As circuits become smaller, they generate more heat. One way to help compensate is to reduce voltages. Unfortunately, when voltages change, new semi-conductors are no longer compatible with older, higher voltage components, so one for one replacement becomes difficult if not impossible.

Workforce

The engineers and scientists in the domestic semiconductor industry are a vital, but eroding, national resource. Although there is currently an oversupply of qualified scientists and engineers -- in 2001-2002, the U.S. lost 560,000 jobs in the high-tech industry[33] -- the U.S. will likely see a high-tech worker shortage as the economy recovers. If the U.S. does not produce more qualified workers domestically, U.S. industry has two choices: import workers via the H1-B visa processes or move work offshore.

The looming high-tech worker shortage mirrors trends in the overall workforce. By 2005, over half the workforce will be eligible for retirement. The U.S. Labor Department is predicting an overall worker shortage by 2010, with a workforce that has a deficit of ten million workers. Additionally, U.S. electrical/mechanical/aerospace engineering graduates from 1995 to 2000 have decreased approximately 15%.

Moving Work Offshore

Some foreign governments are reducing the capital costs for firms operating in their territories. Foreign government subsidies, either in the form of tax incentives or direct contributions to plant construction, encourage firms to locate new manufacturing capacity offshore. About one-third of all semiconductor manufacturing is now located in the East Asia/Pacific region - mostly South Korea, Taiwan and China - and the East Asian market share is growing.

There are other obvious cost advantages to moving work overseas. In China, the salary for a person with a master's degree and five years of experience is about

$1,000/month; a person with similar experience would make $7,000/month in the U.S. Microsoft, Intel, Oracle, Phillips, and Texas Instruments are just a few of the electronics companies that are actively outsourcing and expecting to increase their workload overseas. During a recent speech, a Microsoft Senior VP, Brian Valentine, urged managers to "pick something to move offshore today."[34] According to recent reports, electronics outsourcing is quickly escalating with expected double-digit growth in 2003.[35]

However, the U.S. would not want the semiconductor industry to be concentrated in a single area of the world; dependence on Mid-East oil has taught us the perils of a world supply that is concentrated in a single region and depends on that region's geo-political stability. Natural disasters or man-made confrontations could lead to interruptions in semiconductor trade flows. Such interruptions could be devastating to semiconductor consumers that increasingly tend to operate with razor-thin inventories.

Intellectual Capital

The U.S. is losing the "high-tech" ground to Asia. China produces 600,000 engineers a year - 200,000 of them are electrical engineers.[36] By contrast, last year the U.S. granted 70,000 undergraduate and 37,000 graduate degrees in electrical engineering. In addition, 54% of U.S. engineering doctorates went to foreign students, many of whom returned home after graduation or after gaining experience in the U.S.

Offshore movement of intellectual capital has a downside. According to the Pentagon's Advisory Group on Electron Devices (AGED), "off-shore movement of intellectual capital…particularly in microelectronics, has impacted the ability of the U.S. to research and produce the best technologies and products for the nation and the warfighter."[37] In addition, many in the industry are asking if outsourcing domestic work to foreign countries is contributing to layoffs. However, the impact of offshore hiring is hard to measure, since so far, only a tiny portion of U.S. *white-collar* work has jumped overseas.

Intellectual Property Rights

As firms move semiconductor manufacturing and testing operations offshore to countries such as China, Taiwan, and Korea, intellectual property rights have become extremely important within the global market. The protection of intellectual property rights (IPR) is thus a growing concern within the industry, particularly for "fabless" operations. For example, CISCO recently brought a lawsuit against a Chinese electronics firm for duplicating a copyrighted chip. The Chinese chip not only duplicated the exact same design, it also copied the "text strings, file names, and bugs" in the source code.[38]

U.S. Export Controls

Cold War methods of controlling sensitive technologies are no longer effective. Meanwhile, the current export control framework adversely impacts U.S. firms' ability to compete in the global market. This is discussed in greater detail in the essays on major issues.

Commercial Off the Shelf/ Diminishing Manufacturing Sources

Recognizing the DoD's loss of market share and the ever-decreasing costs of commercial products, the Secretary of Defense, William Perry, instructed the services in 1994 to adopt commercial products and standards in order to reduce costs. The services responded by incorporating more Commercial Off The Shelf (COTS) products, particularly electronics, into weapon systems. Mass produced COTS offers tremendous costs savings versus the low quantity, highly specified military components.

However, the use of COTS components offers a unique set of challenges. Defense producers and maintainers must fully understand and test or qualify COTS components before using them. Otherwise, COTS components may not meet the expected requirements such as operating at the extreme temperature ranges that many defense products are expected to operate. In addition, since everyone has access to COTS, the use of commercial chips and processors levels the playing field for allies and adversaries. This means that it could be harder for U.S. systems to retain a competitive advantage.

The electronic content of defense systems is growing. At the same time, technology is evolving in accordance with Moore's law – thus, electronics components generally have very short life cycles. Diminishing Manufacturing Sources and Material Shortages (DMSMS or DMS for short) is the title used to describe when a subcomponent or material supplier stops producing a specific component or material. The growing occurrence of DMS presents an increasing workload for the Defense Department and the defense electronics industry.

The short life cycles associated with COTS requires developers of new defense systems as well as the maintainers of fielded systems to proactively plan and prepare for replacing these components. Development/production for major weapons systems typically takes well over 10 years, yet the average lifecycle of COTS electronic components is 2-5 years. Military specific electronics typically have life cycles exceeding 12 years, so while their replacement is less frequent, it is still a time consuming and demanding process.

<u>A DMS example -- Radiation Hardened Electronics.</u> Electrical components that can survive, and perform reliably, in high-radiation environments (e.g. space) are called "radiation-hardened" or "rad-hard" electronics. According to an Aerospace Corporation study, there were over thirty domestic radiation-hardened foundries in the mid-1980s; by the late 1990s only four firms could produce strategic radiation-hardened systems. [39] In the past few years, two of these manufactures stopped producing DoD-unique integrated circuits. [40] However, several DoD satellite systems require modern "rad-hard" electronics (0.15-0.25-micron). Furthermore, the remaining two manufacturers have

fallen several generations behind. The total rad-hard market is simply too small for these firms to justify the capital investment in new production technology. [41]

OUTLOOK

Commercial Semiconductor Industry

Business. Short term, the semiconductor business cycle may be poised for a modest recovery. East Asia will likely fuel the recovery. The American, Japanese, and European markets are expected to remain flat, but semiconductor consumption in the Pacific Rim is expected to rise dramatically.

Leading semiconductor analysts predict more mergers, acquisitions, partnerships, and consolidations in the next 1-5 years. Slow industry growth rates, weak chip prices, and excess capacity support this prediction. The effects of the recent downturn have devastated the smaller and cash poor companies and caused the industry leaders and those who want to remain in the business to re-examine their business strategies. Increasingly, semiconductor companies will reorganize, right-size, seek partnerships, outsource, merge, and/or spin off portions of their companies to gain competitive advantage.

We have already seen this trend in action. In January 2003, Advanced Micro Devices, Inc. (AMD) ended its partnership with Taiwan's United Microelectronics Corporation to team with International Business and Machine (IBM) to "jointly develop 65nm and 45nm semiconductor process technologies for 300mm wafers." "AMD wants desperately to compete with Intel on process technology and wouldn't necessarily have the means to do it themselves. So, what better way than to partner with someone like IBM," says Cary Snyder, an analyst with Forward Concepts.[42]

We will see more cooperation across borders with design, production and distribution occurring in multiple sites. Furthermore, *more* companies will go "fabless". The current 10% of world semiconductor revenue from fabless firms is expected to grow to 50% by 2010. This will be a major change in market structure.

"Killer Applications." The semiconductor industry sees the wireless revolution as the next "big thing." Also, expanding use of Personal Digital Assistants and other hand-helds will generate a market for advanced chips. Ultimately, semiconductors could be used in a host of applications that haven't yet been envisioned.

Future of Silicon base chips. How far can Moore's Law go with silicon technology? Only time will tell. Some renowned scientists believe we can continue to push the physical boundaries of silicon semiconductors for decades, while others predict that by 2015 transistors will become so small that material thickness will no longer prevent subatomic particles from leaking through the gates!

Defense Electronics Industry

Market Outlook. Rising defense budgets bode well for the defense electronics industry. Overall defense spending will continue to increase. The Bush Administration has requested $380 billion for DoD in 2004, up from $344 billion in 2002. In 2008, the Bush Administration estimates that the budget will increase to $462 billion by FY2008.[43]

Defense electronics is a growing market even though business is slow for the overall electronics industry.[44] "Defense systems are expected to become increasingly complex over the next 10 years. New demands for command and control functions, land, sea and air battle operation, communications and sensors, for a variety of new threats, will drive the continued development of new electronic systems. While the defense electronics market is much smaller than the commercial electronics business market, it is a critically important one."[45] The total U.S. Defense Electronics Market may be worth more than $181 billion over the next decade.[46]

Forecast International (a provider of market analyses in the areas of aerospace, defense, power systems, and military electronics) indicates that Raytheon, BAE Systems, Lockheed Martin, Northrop Grumman, and Boeing will remain the defense electronics market leaders with projected sales, respectively, at $23 billion, $15.94 billion, $12.42 billion, $8.96 billion, and $7.41 billion in the next decade.[47]

GOVERNMENT GOALS AND ROLES:

Government policy can address market failures, but the government should proceed cautiously. Second and third order effects can stifle innovation and economic growth. However, the U.S. government should act to satisfy national security concerns and promote economic growth.

Policy Recommendations

National Foundry. DoD cannot always fulfill its requirements with COTS technology. With more and more production moving offshore, COTS products become especially risky. When defense requirements call for production of classified and application specific parts, the Government must assure leading edge semiconductor production capabilities.

Public and private organizations need to put forward proposals for a national strategy adequate to support the needs of U.S. national security. This strategy could consist of a single U.S. corporate entity or consortium of U.S.-owned companies whose core competency is R&D, production, and sustainment of electronic components that cannot be satisfied through COTS or foreign vendors. Any government investment has opportunity costs; however, such investments should occur only when there is a particularly compelling case.

Government-Industry Partnerships to share high risk R&D. The U.S. wants its weapons systems to retain a competitive advantage. Therefore, the national security community needs to lead, not follow, technology. Furthermore R&D is critical to long-term economic growth. Therefore, the government should promote more experimental R&D within the United States.

The Defense Advanced Research Projects Agency (DARPA) can play a key role in such a public/private R&D effort. Additionally, the Federal Government should harness the innovation potential in the private sector by enacting a permanent incentive for performing experimental R&D in the United States.

Education. The U.S. government should collaborate with universities and industry to align curricula with critical and emerging technologies. The American Society of Engineering Education (ASEE) advocates such an alliance. The desired result is to produce the engineering graduates capable of meeting the professional standards, challenges, and requirements of the modern business environment.

The government should fully support organizations like ASEE, universities, and companies that encourage students to pursue technical interests. Industries like Boeing have fellowship programs that bring in faculty from universities to expose them to engineering, information technology and business practices. The U.S. can provide further educational direction through outreach programs, scholarships, grants, and design competitions in target technology fields.

Tax policy. Today, firms can depreciate semiconductor-manufacturing equipment over five years, but it only has a three-year economic life.[48] The U.S. should assure that depreciation of capital investment for tax purposes is commensurate with actual useful life of that capital. This would lower the after tax cost of capital (and thus entry barriers) and make investment in U.S. facilities more attractive.

Export Controls. The government should continue to take an active role in controlling the export and proliferation of critical electronic technologies used in weapons of mass destruction. However, to counter the advances in computer processing and availability of high-speed processors in the marketplace, the United States will have to turn towards a combination of alternative methods of measuring computer performance and using its sophistication in software development.

COTS. In order to capitalize on the tremendous cost and performance advantages that COTS products offer, Government and defense industry managers must design systems to enable rapid insertion of new COTS parts and establish inexpensive alternatives for providing parts for legacy weapon systems.

ESSAYS ON MAJOR ISSUES

Analysis of Moore's Law

The future of Moore's Law is uncertain. Conflicting industry pronouncements confuses the situation. Some argue that reduction in transistor size and corresponding microprocessor integration issues will soon reach their physical limitations. Others disagree.

Engineers at major semiconductor companies like Intel and Advanced Micro Devices currently continue to prove Moore right. Transistors have shrunk to less than 130 nanometers (nm) and silicon channels to 4 nm, down from 15 nm only last year[49]. Prime manufacturers anticipate cracking the 100nm barrier for transistors this year and surpassing 70 or even 50 nm by 2008**.** [50] In theory, there's little to stop engineers from pushing the envelope down to the atomic limits - 1.4 nm for a molecule of silicon dioxide or .27 nm for a single atom of silicon. Could Moore's Law continue on unchecked for another 50-plus years? Due to associated physical limitations, most industry experts think not.

As the transistor sizes continue to shrink, the increased concentration of dopant atoms will become too great for the silicon's crystalline structure to contain the atoms, resulting in performance-crippling leakage. Another root cause of leakage involves the ever-shrinking size of the transistor gates; reputed projections of 9nm gates, while a potential boon to the speed of the microprocessor, will likely become too thin to prevent electron leakage.[51] Finally, the heat emitted by the energy transfers between billions of electrons associated with sub-50 nm transistors theoretically approaches the heat generated at the sun's surface. [52]

The shear cost of fabs presents another challenge.[53] Based on the technology required to further decrease transistor size, fab costs are estimated to run into the $10 *billion* range – certain to engender caution in the capital investment plans of almost all chip manufacturers.[54] Several industry experts doubt chip manufacturers will be readily able to transition past the current optical lithography process. While experiments in extreme ultraviolet lithography and electron projection lithography show promise for inserting the future generation billion-plus transistors onto chips, engineers must develop new technologies to interconnect them. The infrastructure required to activate these new lithographic processes, including all new plant, equipment, and entirely revolutionized metrology tools, will add to the increasingly exorbitant costs of making a fab.

Engineers are not sitting idly by in the face of these challenges. The world's leading semiconductor manufacturer, Intel Corporation, believes it will continue to shrink transistors, at least to 50nm, merely through a silicon-based process termed hyperthreading. Hyperthreading is a means of splitting the energy of a single transistor without actually dividing the chip, i.e. enabling it to simultaneously burn a CD and edit a video.[55] To get around the heat problem, they have designed (and may soon develop/refine) a family of "terahertz" transistors. The flagship Trigate terahertz transistor will wrap around three sides of the diodes, or gates, as opposed to simply covering them, thereby significantly lessening heat emissions.[56]

Engineers are exploring ways to enable molecular electronics to improve transistor functions. Similar in concept to hyperthreading, the idea involves layering molecule-switch devices onto conventional silicon transistors and boosting their capability.[57] In some respects, this innovation represents part silicon, part synthetic hybrid solution extending the limits of Moore's Law.

More revolutionary strategies replace silicon as the primary transistor component. Gallium arsenide and germanium are equally touted as silicon substitutes for transistors in the 10-nanometer range.[58] Several manufacturers are experimenting in synthetic chemicals[59] and plastics in the hope that they can simultaneously achieve full transistor capability and zero leakage. Uniquely interesting are forays into biotechnology. Some companies are investing in ferritin, a protein found in both plants and animals (to include humans). Their goal is to grow magnetic nanoparticles that will eventually "combine digital, analog, and micro-electromechanical particles all on a single chip,"[60] and thereby increase capability by orders of magnitude.

Of all the proposed initiatives to further shrink transistors, the most revolutionary and risky involve subatomic application. From the previously mentioned molecular transistors to using carbon-based nanotubes as gates in the new chip design, scientists strive to isolate parts of atoms for use in future transistors.[61] But the truly new paradigm of quantum computing as the basis of chip design is wherein lies the greatest potential.

In essence, quantum computing encompasses the theory that split atoms can work as "quantum switches" and simultaneously rest at both on and off, i.e., represented by 1 and 0 (as opposed to conventional switches which can represent *either*, but not both 1 or 0). The practical result would contrast the example of three ordinary switches that could store any one of eight patterns, versus three quantum switches that could hold all eight patterns at once.[62] If this holds true, the theoretical potential for transistor power is staggering. Even further optimistic projections suggest a 0.25 nm size transistors (smaller than a single silicon atom) created through a process called subatomic channeling, where carbon nanotubes found within living systems are configured to ballistically transport almost a trillion electrons across a single chip.[63] If these concepts become reality, new frontiers open and the demise of Moore's Law will be a negligible footnote in the history of electronics.

–By LtCol Greg Burns

<u>Diminishing Manufacturing Sources</u>

Diminishing Manufacturing Sources and Material Shortages (DMSMS or DMS for short) occur when a subcomponent or material supplier stops producing a given part or material. This can create a serious impact to customers who continue to need these parts. It is no surprise that DMS occurs most frequently with commercial electronic parts. The average life spans for many of the commercial electronic devices are less than 5 years while the average life span for military specific microcircuits exceeds 12 years.

The occurrence of the DMS condition is usually the result of the rapid advancement in technology combined with market forces. In accordance with the phenomena called, “Moore’s Law”, the number of transistors that can be placed on a microcircuit doubles every 18+ months creating the short product life cycles of less than 5 years for commercial microcircuits.[64] When newer and better electronic components are introduced to the market, the demand and the prices for older components drop quickly making them unprofitable to produce. Hence, manufacturers quickly delete the older components from production lines.

Since DoD’s share of the demand for electronic components has steadily declined to the current level of less than 1% of the market[65], it has little influence over the electronic component manufacturers. Recognizing the DoD’s loss of market share and the ever-decreasing costs of commercial products, the Secretary of Defense, William Perry, instructed the services in 1994 to adopt commercial products and standards in order to reduce costs. The services responded by incorporating more Commercial Off The Shelf (COTS) products, particularly electronics, into weapon systems.

Unfortunately, the DoD underestimated the major challenge that DMS would present to the producers and maintainers of weapon systems that have long development, production, and operational lifetimes. With development time spans of our newer weapon systems such as the F/A-22 and the AEGIS DDG-103 lasting over ten years, many electronic parts have become obsolete during development prior to becoming operational.

So what are the impacts of DMS? During development and production, a part that becomes obsolete can cause significant delays and cost impacts until replacement parts can be obtained. If a new part has to be designed and tested, this can be very expensive and time consuming. For fielded aircraft, DMS can result in part shortages that can ground aircraft thereby impacting mission capability and readiness.

Program managers and engineers have several alternative solutions to resolve DMS issues. If notified by the supplier prior to shutting down the part line, the program manager can decide to perform a total or partial “life-of-type” purchase whereby all the needed parts can be purchased at one time. Another option is to purchase just enough parts to provide the time required to implement other solutions. There are several “after market” firms who specialize in producing older parts and survive quite well in these niche markets. In other cases, the program manager might be able to find a substitute part or perhaps develop a replacement part (emulation) using state of the art materials that meet the same or similar specifications. The F-15 maintainers have used emulation extensively in creating replacement parts for the radar and other avionics components. Other examples of military systems that are still being produced and supported using DMS replacement semiconductor devices include the AWACS, AEGIS systems, Patriot and cruise missiles, and Vertical Launch systems.[66] And generally the most expensive approach, and therefore the last alternative, is developing a totally new part, and/or electronic system.

Fortunately many of today's program managers and maintainers employ proactive DMS management practices levying design requirements that include selecting components at the front end of their life cycle and using open architectures that support part replacement and system upgrades with less disruption. Pro-active measures also include requiring suppliers to provide advance notification as to when parts will be discontinued, and supporting corporate and industry association databases on DMS parts and possible DMS solutions.

The F/A-22 program office has a comprehensive, proactive DMS management program that has a strong contractor partnership as its foundation. Lockheed Martin, the prime contractor, uses web-based management systems to manage and communicate status and issues and requires its suppliers to provide at least one-year notification before parts are discontinued. As of March 2003, over 100 line replaceable modules (LRM) involving several hundred parts have been identified as DMS requiring product teams to develop and implement DMS solutions. The annual program cost to manage and mitigate DMS issues is approximately $100M per year. Without a proactive DMS management system, defense programs rich in advanced electronics content could not survive.

Commercial companies such as the Boeing Commercial Airplane Group (BCAG) delegates more responsibility to its suppliers than do typical military programs. In the commercial industry the suppliers typically have multiple year contracts and responsibility for providing support for the life of the aircraft. The suppliers have authority to change or upgrade parts that are form, fit, and function compatible thereby reducing the workload of the prime contractor. The DMS management costs for commercial companies is unknown since it cannot be segregated from the suppliers overall product prices. However, it is believed to be less than defense DMS programs.

Defense programs such as the F-35 Joint Strike fighter and the AEGIS program office are taking a commercial approach by developing road maps that focus on periodic insertion of new technologies when older parts and/or systems become obsolete. In addition they authorize and in some cases incentivize suppliers to introduce new parts that are cheaper and better while maintaining form, fit, and function requirements. It is envisioned that this Tech Refresh approach will help reduce DMS impacts and management costs while taking full advantage from the technology advancements that the commercial electronics industry offers.

It is imperative that new program managers and engineers become knowledgeable of DMS issues and management practices and establish proactive DMS management programs to minimize the impacts of DMS. The Air Force, Army, Navy and industry all have DMS focal points who can provide lessons learned and guidance on how to manage DMS as well as share and maintain DMS databases. In addition, the Defense Micro Electronics Association (DMEA) is an organization that has developed many guidance documents for program managers including GEB-1 (Management Practices) that has become well recognized in industry. [67]

–By Mr. William Marks

<u>Export Controls</u>

The nature of military operations has changed from the *weapon centric* warfare of the Cold War era. *Network* and *net centric* warfare characterize military operations of today as command, control, intelligence, surveillance, reconnaissance and target acquisition rely on complex microprocessors, networks, and computing power.[68]

Controlling the export of high-speed microprocessors and computer technologies are a necessary part of ensuring the security and safety of the United States. The goal of U.S. export controls is to deny advanced technologies to adversaries, particularly emerging rouge states and non-state actors. These technologies are enablers for advanced weapons technology. Denying these technologies is a significant challenge since the manufacture of semiconductors has become a global phenomenon. This addendum examines U.S. export controls on computing power[69] and microprocessor technology, as well as the effectiveness of those controls.

Current controls on electronic and information technology are the product of Cold War strategies designed to deny the former Soviet Union access to critical technologies. The Soviet threat motivated allied nations to tightly control sensitive technologies; the fear was that the Soviet Union would obtain these technologies and use them in military applications. Once the Soviet Union collapsed, the floodgates opened and technology began to spread internationally.

Since 1993, the United States government, under the Wassenaar Arrangement has restricted exports of computers with certain computing power, speed, and performance as measured in million of theoretical operations per second (MTOPS). The initial threshold was 2,000 MTOPS. Since 1993, the U.S. government has raised the MTOPS level seven times. The last change, in March 2002, increased the level to 190,000 MTOPS for Tier 3 countries. Currently, however, supercomputers operate in the millions of MTOPS.[70]

Nations do not necessarily need supercomputers to achieve high performance computing levels. Supercomputer performance levels can be attained by assembling computers using mass-market microprocessors, by clustering microprocessors and desktop computers, and by using the Internet to link multiple computers from multiple locations. Technological advances allow powerful computing performance with significantly fewer resources and investments when compared to years past.

The General Accounting Office concluded that current export controls for high performance computers are ineffective - they do not prevent the linking and clustering of low performance computers which achieves the same level of computing power as controlled systems. Another technique for creating increased computing power is through the use of networks. An adversary can exploit the Internet to combine thousands of desktop computers to form a single, high power computing system. As a result, the United States faces the same risks and vulnerabilities from networking strategies as it does from the proliferation of high performance computers. To defend against these threats, the United States must look beyond controlling computing power and towards controlling networks and software applications.

Current U.S. export controls focus on denying our enemies high-speed computers to prevent the development of advanced military technologies. The Center for Strategic and International Studies (CSIS) Panel Report of 2001 suggests that this paradigm does not function well in the 21st century. While supercomputers are currently achieving millions of MTOPS, the U.S. military's most advanced systems operate at the "thousands" of MTOPS range. For example, the F/A-22 is designed around a 958 MTOPS computer and the J-STARS battlefield surveillance aircraft only uses a 240 MTOPS workstation – a mere twenty-five percent of the power in a Pentium chip.

It is important to understand that we do not measure the performance of a weapon system by computing power alone. Rather, the performance and lethality of a weapons system is based on a combination of integration and application of the components. The same can be said regarding the development, design and construction of weapons of mass destruction. Notably, the design and development of the U.S. nuclear arsenal took place without the use of supercomputers. However, it remains imperative to deny supercomputers and high-speed processors from our adversaries. Computing power is critical in the simulation and modeling process. Supercomputers also reduce the run time for complicated mathematical computations.[71] Computing power is a vital element for the future design, development and production of advanced nuclear and conventional weapons.[72] Through the use of supercomputers and high-speed microprocessors, our adversaries can conduct "virtual nuclear testing" thereby evading the Comprehensive Test Ban Treaty.[73]

Measuring MTOPS has its shortcomings. The CSIS Panel provides several alternatives to MTOPS.[74]

- *Power Dissipation*. Measures watts per MTOPS in relation to the size of the microprocessor housing. (Currently in use in Japan to measure environmental effects)
- Linpack *Benchmark*. Algebraic method to determine peak performance. This method is currently an acceptable measure of performance but does not account for associated software.
- *Memory Bandwith*. Measure of systems ability to pass data from processor to memory.
- *Processor Count.* Measures the number of CPU microprocessors.

The MTOP standard addresses a specific measure of computing performance but does not account for the integration of microprocessors, clustering of resources, and networking of computers. To counter advances in computer processing and the availability of high-speed processors in the market, the United States must turn towards a combination of alternative methods to measure computer performance. The U.S. must use its sophistication in software development and systems integration to deny our adversaries the use of advanced microprocessors for weapons proliferation.

–By LTC Michael Bonheim

CONCLUSIONS:

The semiconductor industry and the defense electronics industry are inextricably linked. Every new weapons system in production will rely on semiconductors as its core component. A healthy, robust, and leading edge semiconductor industry is essential for defense needs and indeed for all elements of national security. Several broad conclusions can be drawn from our study.

- The only thing certain about the semiconductor industry is uncertainty. Broad fluctuations in demand, rapid technology refresh periods, escalating capital requirements and falling prices make for unpredictability and instability in the structure of the market and the industry. Semiconductor companies have responded by reorganizing, right-sizing, seeking partnerships, outsourcing, merging, and/or spinning off portions of their companies.

- There is growing concern regarding the offshore flight of intellectual capital and semiconductor production facilities. Some argue that the ability of the U.S. to maintain access to cutting-edge technology will be adversely affected. The decline of technical talent among U.S. students contributes to these concerns.

- In the defense electronics sector, mergers and consolidations are prevalent. The large defense contractors have systems integration as their core competency. Low volume, highly specialized defense requirements in the semiconductor industry marginalize the influence of DoD in the market.

- U.S. semiconductor manufacturing capability is eroding, and DOD risks being over-reliant on foreign suppliers. Offshore movement of intellectual and industrial capability has negatively impacted the ability of the U.S. to research and produce defense electronics. This could give other nations political and military leverage over the U.S. and makes supply less assured.

- It is prudent for the Defense Department and the U.S. government to recognize the risks of a declining U.S. microelectronics design and production capability, and to plan a course of action to mitigate the emerging risks to national security.

The Department of Defense must ask itself a key question regarding the electronics industry as it relates to military and national security issue: *Do we want to lead or to follow?*

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