Chapter Three

COMMERCIAL TECHNOLOGY TRENDS RELEVANT TO MILITARY RADARS

INTRODUCTION

A fundamental assumption made by the advocates of CMI is that commercially derived technologies, products, and processes increasingly are at least equivalent and often superior to those developed in the military sector. Skeptics, however, accuse CMI advocates of "cherry picking" a few obvious technology areas such as integrated circuits or microprocessors where great advances have been made in the commercial sector over the last few decades, and ignoring many other crucial technology areas where the military sector remains far ahead. Clarification of this question is critical. CMI cannot be viewed as a desirable strategy that will bring significant benefit if advanced technologies directly relevant to military applications do not exist in the commercial sector.

A definitive all-inclusive assessment of this issue is far beyond the scope of this research. Instead, we examine commercial market trends in a critical military technology area that traditionally has been dominated by military R&D and that is rarely used as an example by CMI advocates: defense-related microwave technologies. We seek to shed light on the following question:

- Is the commercial market in military-relevant microwave electronics large enough to encompass an adequate range of technologies, parts, and components required to support a comprehensive CMI strategy for military-specific subsystems such as fighter fire-control radars?

Questions on the performance capabilities and potential cost and schedule benefits of commercial microwave electronics technologies are explored in Chapters Four and Five.

RADAR AND THE NEW COMMERCIAL MARKET IN MICROWAVE TECHNOLOGIES

The development and deployment of radar is one of the great historical achievements of the military industrial base. Although the first practical use of radar can be attributed to American physicists conducting scientific experiments in 1925, most of the major technical and engineering innovations that made the widespread use of radar possible were developed by the military R&D establishments of the United States, the United Kingdom, and Germany before and during World War II. After the war, radar began to be used in many civilian applications, including weather avoidance, navigation, and maritime surveillance. Later, radar was used for high-resolution area mapping and for many civilian space applications. Nonetheless, the major technology developments in radar continued to be driven by the demanding performance and environmental requirements of military systems. This was particularly true in the 1950s and 1960s with the introduction of extremely sophisticated multirole fighter fire-control radars for air-to-air and air-to-ground operations.

Until recently, the vast majority of radio-frequency consumer products operated well below the 1 Gigahertz (GHz) frequency range on the electromagnetic spectrum. Fire-control radar, however, typically operated much higher up the electromagnetic spectrum in the X-band (8–12.5 GHz) and lower Ku-band (12.5–18 GHz) frequency ranges, thus requiring substantially different—and more demanding—hardware and technical and manufacturing techniques for parts and components.[1] Throughout most of the Cold War era, therefore, military radar and other military electronics requirements drove most of the technology developments in the microwave fre-

[1]For the development of radar in the 1930s and 1940s, see Buderi (1996) and Stimson (1983).

quency range (about 1 GHz to 30 GHz) and millimeter-wave (MMW) frequency range (30–100 GHz).

Phased-array radars, based on electronically scanning antennas populated with transmit/receive (T/R) modules that employ GaAs MMIC chips, are on the cutting edge of military radar technology. They provide numerous advantages over conventional radars, particularly for fighter aircraft, including lower radar cross-section (greater stealthiness), simultaneous multiple-target engagement capabilities, extended target-detection range, higher survivability, greater reliability, and reduced weight and size. All the original T/R module and electronically scanned array technologies were developed by military contractors using government money.

By 1990, however, a technology revolution appeared to be under way in the commercial sector regarding microwave and MMW technologies. As the decade of the 1990s comes to a close, the fundamental assumption of CMI advocates for our technology area of inquiry seems to be increasingly true: Many defense-critical RF microwave/MMW technologies directly relevant to military radars, CNI, EW, intelligence gathering, and other sensors appear increasingly likely to be driven by civilian market demands. If this is true, then military systems developers must efficiently exploit technology developments in the commercial sector to gain access to the most advanced technologies available.

There are four particularly active product areas in the emerging commercial microwave market relevant to military microwave products that exhibit great technological dynamism:

- Land-based wireless communications
- Television Direct Broadcast Satellites (DBS), and High Definition TV (HDTV)
- Automotive sensors
- Mobile communications satellite systems.

Their relative positions on the electromagnetic spectrum are shown in Figure 3.1.

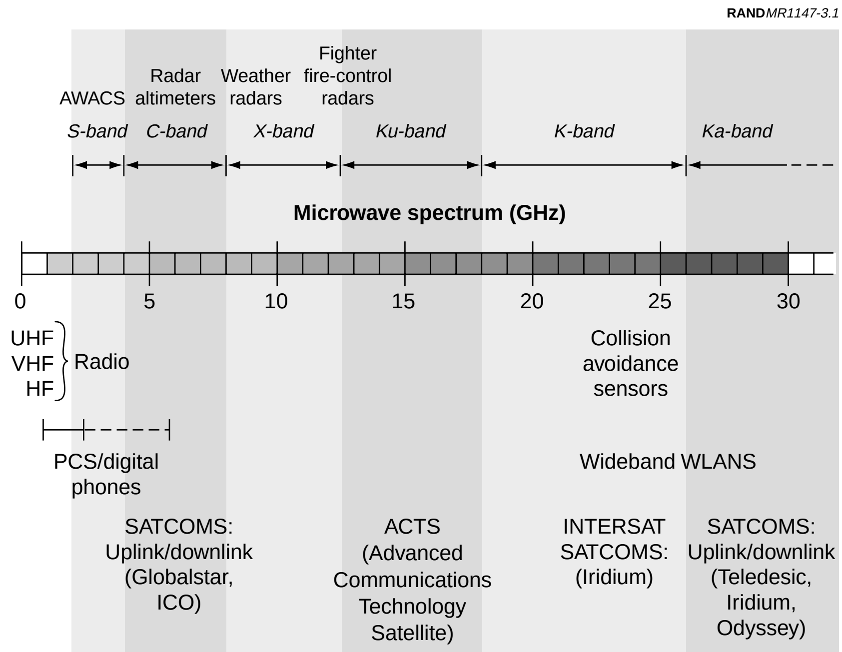

Figure 3.1—The Dual-Use Microwave Spectrum

Two highly active technology areas in land-based wireless communications are (1) cellular phones, cellular/fax-data modems, personal communication systems (PCS), and RF identification sensor systems, and (2) wireless local-area networks (WLANs). Automotive sensors include radar T/R modules being developed for vehicle collision avoidance or adaptive cruise control (ACC) systems. The new generation low-earth orbit (LEO) and medium-earth orbit (MEO) mobile communications satellite antennas and transceiver systems are extremely important for the commercial development of low-cost, high-capability T/R modules. Finally, the tuners and antenna receivers used in television DBS and HDTV are prominent in the commercial microwave revolution. Rapid market growth is projected for many of these defense-relevant RF/microwave commercial products.

WIRELESS COMMUNICATIONS

Dramatic growth is expected to continue in the wireless communications sector. High growth in the demand for cellular phones and PCS is expected to drive this increase. As shown in Figure 3.2, worldwide cellular phone subscribers are projected to rise from under 90 million in 1995 to almost 700 million in 2003. At the end of 1997, the worldwide digital subscriber base outnumbered the analog subscriber base for the first time. By 2003, digital technologies are expected to account for over 91 percent of the market.[2]

Whereas conventional cellular phones employ analog technology and operate in the 800 MHz frequency range and below, PCS use digital technology and operate at higher frequencies in the 1.8 GHz range and above. Higher-frequency broadband-width digital technology permits the transmission of far more information on the same

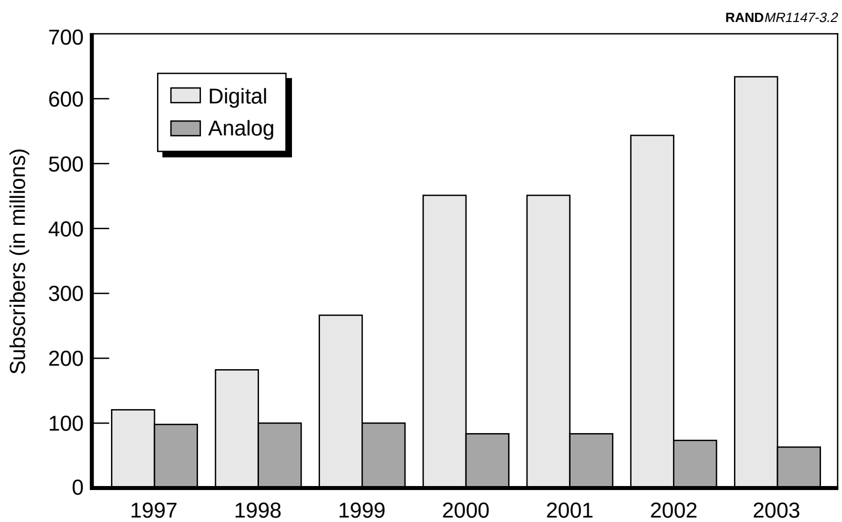

Figure 3.2—Projected Worldwide Cellular/PCS Subscribers by Technology

2 Data from the Strategis Group, Washington, D.C.

channel. Thus PCS carriers will be able to offer many services in addition to the standard voice transmission available with current analog cellular phones, including wireless access to the World Wide Web, fax services, voice mail, electronic mail, paging, and traffic and weather reports. The growing demand for such expanded services is anticipated to push digital phone technology into even higher frequency ranges in the microwave spectrum.

The greatly expanded services offered by digital PCS compared to cellular require the use of broader bandwidth in order to increase to acceptable levels the rate and quantity of information that can be transmitted. Current silicon-based technology cannot always support the necessary microwave technology requirements. Although they historically have been much more difficult and expensive to process and manufacture, GaAs-based MMIC devices are necessary for most microwave transmission applications. The new PCS data-transmission requirements therefore are encouraging widespread commercial development of GaAs MMIC devices for the first time.[3]

Many other new commercial products are increasingly making use of higher-frequency broadband microwave technologies. These include DBS, cable television receivers (cable boxes), "wireless" cable TV systems (28 GHz band), fiber optic communication systems, and many wireless applications. While smaller than the PCS/digital phone market, WLANs make up an extremely important and rapidly expanding commercial sector that is relentlessly driving commercial wireless technology higher into the microwave spectrum.

WLANs permit the interconnecting of personal computers (PCs) without the necessity of additional wiring or cables. WLANs appeal primarily to niche markets where there is a need for networking in a mobile situation where wiring is difficult. Growing market demand for WLAN technology from retail stores, restaurants, medical service providers, warehouses, and other commercial businesses has led to an expected increase in worldwide connections from 1.8 million in 1996 to over 3 million in 1997.

As in the case of PCS/digital phones, the key factor driving LAN technology is the need for higher bandwidth to increase data transmis-

[3]See, for example, Hardy (1996) and Arnold (1996).

sion. This factor pushed LAN technology from the 900-MHz range in the early 1990s up to the 2.4-GHz range by the middle of the decade. By the end of the decade the technology is expected to push further up the microwave spectrum to 5.8 GHz (Hostetler, 1996).

AUTOMOTIVE SENSORS

The emergence of automotive ACC and collision warning systems, as well as the projected new generation of LEO and MEO mobile communications satellite systems, are of particular relevance to the future of commercial defense-related RF/microwave technologies. Both these products are promoting the development for the first time of high-technology commercial radar T/R modules that are planned for large-scale, low-cost commercial production. Almost every major automobile manufacturer is investigating a variety of new automotive sensors for ACC, the most interesting of which for our purposes are T/R radar modules that are mounted on front and rear bumpers. Most of the so-called “Big LEOs” are projected to have many communication satellites equipped with up-link/down-link and intra-satellite communication antennas that will be heavily populated with GaAs MMIC-based T/R modules.

Automotive electronics companies and defense microwave component vendors are developing collision warning systems. For example, Delco Electronics Systems, a division of Delphi Automotive Systems, is marketing the Forewarn collision warning systems and developing other integrated ACC systems for passenger cars.[4] Working closely with HE-Microwave, a joint venture between Delphi and Raytheon, a dual-use T/R module facility has been developed that produces products for both the civilian and military markets. The Forewarn systems integrate emerging low-cost microwave and millimeter-wave radar sensors, developed in part from military and aerospace applications, with existing automotive electronics. The Forewarn object detection system has already been widely marketed for school buses. Various technologies have also been tested and integrated on two test passenger vehicles, a Lexus LS 400 and Cadillac Seville. A forward-looking millimeter-wave radar that op-

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[4]Prior to May 1999, Delphi was majority-owned by General Motors Corporation.

erates in the 77-GHz range has been developed to operate in conjunction with a laser radar. Engineers have experimented with both mechanically scanned antennas and switched-beam radar sensors. The rear detection system is based on sophisticated GaAs MMIC technology and operates in the 24-GHz range, well up in the microwave spectrum. Radar signal-processing techniques are used to discriminate among different categories of targets (Olney et al., 1996).

LOW-EARTH ORBIT MOBILE COMMUNICATIONS SATELLITES

Although the commercial future of many of these systems appears to be in doubt, the new generation of MEO and LEO mobile communications satellite systems are pushing commercial microwave technology up the microwave spectrum closer to technology areas of interest for fire-control radars. If successful, these satellite systems could open up a major new commercial market for active phased-array radar technologies. Unlike automotive collision avoidance systems that use only a few T/R modules per vehicle, next-generation communication satellites will mount large phased-array antennas populated with almost as many T/R modules as on antennas on phased-array fire-control radars.

Most existing communication satellites systems are based on a small number of large geostationary satellites in high-altitude orbits that broadcast a single beam that covers large portions of the world's surface. These satellites are well suited for television transmission and fixed telephone communications. In the mid 1980s, however, engineers began envisioning satellite communication systems that could provide global mobile cellular phone and data transmission capabilities. This concept required much larger numbers of smaller, low-altitude satellites with directional antennas that could transmit many "spot beams" to specific small areas on the earth's surface.[5] This proposed capability required antennas populated with many T/R modules based on GaAs MMIC technology (Kuznik, 1996). In addition, by the early 1990s, market pressures for more data-carrying

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[5]Geostationary communications satellites are located 22,300 nautical miles above the earth, while LEOs will orbit at altitudes ranging from 420 to 750 nautical miles.

capabilities, combined with growing demand for more broadcasting frequencies, had already been pushing communication satellite transmitters further up the electromagnetic spectrum, from C-band frequencies (4–8 GHz) beyond the X-band into the Ku-band (12.5–18 GHz) (see Figure 3.1). Launched in September 1993, the National Aeronautics and Space Administration's Advanced Communications Technology Satellite (ACTS) provided one of the first successful demonstrations of broadband Ku-band satellite communications (Kuznik, 1996).

Among the most important of the new and projected systems are ICO Global, Globalstar, Iridium, and Teledesic.[6] These are all nongeostationary mobile satellite communications systems intended to provide global real-time voice and data transmission ranging from basic electronic mail to videoconferencing, interactive multimedia and real-time two-way digital data flow. Although several of these systems are now in financial jeopardy—Iridium and ICO Global each filed for bankruptcy protection in August 1999, and Globalstar is now finding it difficult to raise financing—all either do or will deploy advanced active radar antennas. Iridium satellites each have three side panels with multibeam array antennas providing a total of 48 spot beams for mobile users. Feeder uplinks and downlinks operate in the Ka-band. Globalstar satellites each carry planar phased-array antennas for mobile users with 16 spot beams for L-band and S-band coverage. Teledesic satellites will have a multipanel system with many active-element phased-array facets on each panel. Teledesic will operate entirely in the Ka-band. These three systems alone, if fully deployed, will require the design and manufacture of thousands of low-cost, high-performance T/R modules to populate scores of antenna arrays.

Drawing in part on its extensive recent experience in developing military phased-array T/R modules for such programs as the ground-based radar for the U.S. Army's Theater Missile Defense program,

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[6]Among the major partners on ICO Global are Deutsche Telekom, Ericsson, and Digital Voice Systems, Inc. Globalstar is majority-owned by Loral; other partners include Qualcomm and Alcatel. Raytheon, Siemens, Lockheed Martin, Sprint, Korean Mobile Telecom, and 11 other companies are teamed with Motorola on Iridium. Teledesic was first founded by Microsoft chairman Bill Gates and cable/cellular phone entrepreneur Craig McCaw; Boeing, Motorola, and Matra Marconi Space joined in 1998.

Raytheon has already developed T/R modules for the satellite antennas on the Iridium and Globalstar systems. Raytheon is also deeply involved in the Multifunction Integrated Radio Frequency System (MIRFS) program for development of the next-generation phased-array fire-control radar for the U.S. Air Force/Navy Joint Strike Fighter (JSF) (*The Economist*, 1996).

CONCLUSION

The broader bandwidth requirements of PCS/digital cellular phones, WLANs, DBS, mobile communications satellite systems, and other new consumer broadband technology products have led to an explosion of commercial parts and components development in exotic microwave areas that previously were almost entirely dominated by the military. A dramatic case in point is the widespread commercial development of whole new families of GaAs MMIC and application-specific integrated circuits (ASICs) for the new commercial applications. GaAs MMIC RF power amplifiers and other RF analog devices developed for PCS and other mobile communications may be particularly relevant to future military RF applications, as are some of the manufacturing processes for the T/R modules developed for automotive sensors and mobile communications satellites. Highly specialized GaAs device vendors, such as M/A-Com, Anadigics, and Triquint—companies that for the most part focused heavily on the development of military microwave GaAs devices in the 1980s—have become predominantly commercial foundries for consumer products in the 1990s. They have been joined by commercial giants such as Motorola and Raytheon.

As a result, for the first time, commercial applications are becoming increasingly important in the development of new technologies, especially in lower-cost manufacturing processes for RF/microwave devices. For example, the development of affordable new packaging approaches such as Bump Grid Arrays, Ball Grid Arrays (BGAs), and solder-bumped flip chips for high-frequency MMIC packages are being driven largely by the commercial market for applications in

PCS, WLANs, DBS satellites, and automotive collision-avoidance systems.[7]

Commercial demand for these sophisticated RF/microwave parts and devices is likely to far outstrip military demand. For example, the Teledesic system alone is projected to use many millions of gallium arsenide microchips in its satellites to support RF functions (*Red Herring*, 1996). If ACC and collision avoidance systems become common on passenger cars, automotive T/R module production could rise into the millions.

Many of the parts and components being developed for consumer products may not be directly applicable to or usable in military fire-control radars, nor do they necessarily possess the performance capabilities, ruggedness, and reliability required for the harsh environment in which fighters must operate. Nonetheless, the commercial marketplace is clearly becoming increasingly dominant in broad sectors of RF/microwave technologies and manufacturing processes in a way that could benefit defense applications. Design methodologies, process technologies, and many other areas that have direct relevance to military radar system design and development are likely to be increasingly driven by the commercial market. Commercially developed parts and components will be available for incorporation in military systems, but will such items developed for consumer products possess the high-performance capabilities required for incorporation into weapon systems?

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[7]An example is the product line being developed by Micro Substrates Corporation.