Microwave Industry Outlook—Overview

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Invited Paper

***Abstract*—This paper reviews the influences that will shape the future of the microwave industry.**

***Index Terms*—Defense, engineering education, future of microwaves, healthcare, history of microwaves, technology roadmaps, telecommunications.**

I. Introduction

COMPRISING a broad theoretical base and a collection of techniques enabling progress in related disciplines for over a century, microwave practice has become an important discipline of electrotechnology. Influences that give insight into the future of the microwave industry are discussed in this paper and [5]–[7] and [9].

II. History and Corporate Vision

While predicting the future of our industry from past performance evokes familiar disclaimers familiar to investors, there are valuable lessons to be learned from history.

Sobol and Tomiyasu [1] have compiled a collection of milestones in microwave history, which has among its contributors over 25 individuals from two visionary organizations. The first, Bell Telephone Laboratories, incorporated in 1925, directed profits from telephone monopoly AT&T into a research and development (R&D) organization, which provided the environment and vision leading to the transistor, the laser, principles of information theory that revolutionized communications, fundamental contributions to radio astronomy and cosmology, and numerous other significant contributions to microwave theory and applications. The second organization, the Massachusetts Institute of Technology (MIT) Radiation Laboratory, was conceived quickly in 1940 to create technology for the U.S. and allied war effort in 1941–1945. Both organizations had clear purpose, adequate funding, and a relentless insistence on execution and excellence, although one was commercial in nature and the other was driven by national defense needs.

Relying on the technology engine of silicon digital integrated circuits, the computer industry has developed design tools, process control, packaging, and manufacturing techniques that provide an appropriate developmental template for the microwave industry as it participates in high-volume low-cost commercial markets. Microwave technology, in turn, is becoming part of the required knowledge base of the computer chipmakers, as their processor speeds march through L-band and the distributed nature of circuits becomes an important consideration.

Since its inception in 1958, the U.S. Defense Advanced Research Projects Agency (DARPA) has funded research that others either do not or cannot. It has been estimated that DARPA has an annual $2T impact on the business of information technology [2]. While information technology and the Internet will continue to have a large influence on microwave technology, specific microwave technology developments, including the development of GaAs semiconductor devices, improved silicon lithography, and MEMS, were funded by this agency. In the business of funding high-risk high-reward ventures, DARPA experiences many failures, but is responsible for some very big winners.

III. Extrapolating From Technology Roadmaps

The technology roadmaps of the computer-centric semiconductor industry have significant impact on both communications microwave business. Part of the secret of the success of this enterprise is that Moore's law, which projects a doubling of transistor density every 18 months, unifies marketing with R&D and investment. However, projecting this rate of advance over the next 15 years requires significant improvements in materials, processes, and device structures [3].

- Given this progress, silicon, in its various forms, will continue to nibble away at GaAs at the lower end of the microwave spectrum. Functionality in applications where cost and size is key will be transferred from analog to digital as A/D converters replace analog front-end mixers and digital signal processing (DSP)-based filters replace analog varieties.
- The microwave industry will assimilate the developments in three-dimensional (3-D) semiconductor and lithographic manufacturing as the need for size reduction in mobile and portable communications continues. Fuel cell development [4], promising to extend talk time by an order of magnitude, will enlarge portable communications markets, to the benefit of the microwave industry.
- Exotic (compound) semiconductor materials promise extending functionality to even higher frequencies and temperatures; others will allow integration with optical waveguide to create compact opto-electronic integrated circuits. The demand for applications, both commercial and military, will support their development.

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IV. Recent and Emerging Applications Needs

A list of important emerging and continuing applications that requires the microwave industry includes the following:

- terrestrial wireless telecommunications [5]: convergence of the Internet with wireless access requires microwave techniques to provide advances to key system functions of power amplification, sensitive receivers, and smart antennas;
- medical electronics both in therapy and in information transfer [6];
- radar and remote sensing [7], both military and commercial;
- intelligent transportation systems, in which progress to date has been slow, but steady.

V. Industry Response to Major Global Events

Technology may not anticipate, but will respond to global-level cultural, social, political, economic, or environmental threat/disasters. Since the events of September 11, 2001, it is clear that the threat of terrorist attacks was heavily discounted in the U.S. Concepts of target recognition and identification are now radically, perhaps permanently, altered by the asymmetry between terrorism and conventional defense strategies. Microwave technology being developed for deployment in the public safety area includes millimeter-wave holographic radar and RF tags, as Parker [7] indicates, but no longer is radar sufficient to identify hostile forces. The science of information collection, analysis, and dissemination in hostile environments is also under active investigation, including a high-profile program at DARPA that is looking to miniaturize unmanned aerial vehicle ("micro-UAV") technology [7] to supplement future Special Forces intelligence gathering.

VI. Training of Microwave Engineers

Using any of the above measures of future activity, it is evident that the outlook for the microwave industry is rich with opportunity. As we consider our future, it is appropriate to consider the microwave engineer and his or her future as well. Within the IEEE Microwave Theory and Techniques Society (IEEE MTT-S), there is a persistent call for publications and other intellectual property to be *relevant* to the practicing engineer, dating back to a frank assessment of this TRANSACTIONS by one of the giants of our profession, Marion Hines [8]. The final paper [9] of this microwave industry outlook section, asserts that the skill set of the entry-level practicing microwave engineer is woefully lacking and being neglected by both academia and industry. In the field of microwaves, what took weeks of analysis 10–15 years ago is available by a keyboard click today. The obvious caveat is that it must be an informed keyboard click. If there is a uniform theme regarding need for engineer skills in the microwave industry of the future, it is that they be properly trained, in a *multidisciplinary* sense, since microwave practice now touches many other technologies. Knowledge of the wave-like nature of high-frequency devices and/or structures is key, but additional training in photonics, packaging, bioengineering, signal processing, and communications technology are required to properly collaborate with related disciplines.

While responsibility for this training has expanded from academia, the traditional vendor, to industry and third-party trainers, IEEE also offers potential resources. A major board level activity, Educational Activities, in conjunction with the societies within the Technical Activities Board (a society exists for each of the technical specialty areas mentioned above) has the volunteer and staff expertise to offer cross training in these specialty areas. Would you like your IEEE or IEEE MTT-S member benefits to include educational cross training in related disciplines within the IEEE? If so, look inside the front cover of this issue and address your request to the following: your Vice President of Technical Activities; your Vice President, Educational Activities, and your Division Director. They work for you and value your opinions.

VII. Acronyms Used In This Paper and in [5]–[7] and [9]

GPS	Global positioning system.
MMIC	Monolithic microwave integrated circuit.
DOD	(U.S.) Department of Defense.
GaN	Gallium–nitride.
SiC	Silicon–carbide.
MEMS	Microelectromechanical system.
UCAV	Uninhabited combat air vehicle.
DDS	Direct digital synthesizer.
ADC	Analog-to-digital converter.
PA	Power amplifier.
LNA	Low-noise amplifier.
CAD	Computer-aided design.
QA	Quality assurance.
CBT	Computer-based training.
CAE	Computer-aided engineering.
POTS	Plain-old telephone service.
3G	Third generation (digital cellular system).
CDMA	Code-division multiple access.
LMDS	Local multipoint distribution system.
MMDS	Multipoint microwave distribution system.
LAN	Local area network.
TCP/IP	Literally, transmission control protocol/Internet protocol, a suite of networking protocols that have been used to construct the global Internet.
DARPA	(U.S.) Defense Advanced Research Projects Agency.
DSP	digital signal processing.

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In 1972, he joined the MIT Lincoln Laboratory, where he designed microwave devices and circuits and developed measurement techniques for their application to satellite communications. In 1986, he joined M/A-COM, where he developed programs and products in microwave and millimeter-wave technology. In 1992, as Director of Engineering in the Corporate Research and Development (R&D) Center, he helped facilitate the company's transition from government to commercial focus. In 1998, he retired from AMP M/A-COM as the Director of R&D. He is currently a consultant to the RF and photonic industry. He is a member of the Editorial Advisory Review Boards of *Microwave Journal*, *Applied Microwave & Wireless Magazine*, and Artech House.

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