# Microwave Industry Outlook—Defense Applications

Don Parker, *Life Fellow, IEEE*

*Invited Paper*

***Abstract*—Microwaves will play a vital role in future defense systems. They will enable the integration and interdependent operation of military ground, surface, air, missile, and space-based radar and communication systems for enhanced overall defense effectiveness. Microwave component, subsystem, and systems engineers will find new challenges in meeting the requirements for extremely high data rates and very low cost that are critical to the development of these systems of systems. The need for multidisciplined microwave engineers will provide new opportunities in the future.**

***Index Terms*—Communication systems, MEMS, military systems, Milstar, MMICs, radar systems, UCAV.**

IN DESCRIBING the role of microwaves in the development of radar, Skolnik emphasized that microwaves and radar were a great match [1]. Microwaves, radar, and communication systems will continue to be great matches in future defense systems. Microwaves and millimeter waves will enable the operation of military ground, surface, munitions, air, missile, and space-based radar and communication systems to become more integrated and interdependent as depicted in the Fig. 1. Instead of autonomous platforms, future collector systems, processors, and users will share information via networks. During operations, the engagement systems will have the ability to reach back for information that will enable them to provide more adaptable quick-reaction forward "footprints" (presence). Ground forces will also contribute to the total situation awareness with improved communications and sensor systems. Solders' positions will be known accurately via global positioning system (GPS) satellite receivers, and they will be able to access secure spread-spectrum cellular-like systems with voice and data links. Data from night-vision, spectrum-scanning, and video sensors will be linked back to headquarters over cellular systems or directly to satellites. Throughout the entire system configuration, many images per second will be collected, processed, and the information shared in real time. In addition to improved radar and communication capabilities, this environment will demand significantly increased signal and information processing capabilities. Processing speeds in excess of ten tera-operations per second will provide new frontiers for microwave engineers.

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D. Parker, retired, was with Raytheon Electronic Systems, El Segundo, CA 90245 USA. He is now at 1728 Seven Oaks Lane, Ogden, UT 84403 USA (e-mail: dcjparker@earthlink.net).

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Fig. 1. Battlefield scenario of the future shows a highly integrated and interdependent system of systems. (courtesy of Tim Kemerley, Air Force Research Laboratory, Wright-Patterson AFB, OH).

Performance has been the overriding design criterion for military systems. Since development times (∼15 years), costs and system complexity have increased dramatically, and the emphasis of the Department of Defense (DoD) is shifting to low cost. Acquisition strategies are changing to take advantage of commercial technologies wherever possible. However, there will still be some unique military requirements like performance to counter stealth, form-fit-and-function, and severe operating environments.

The military has relied on RF vacuum electronics (VE) for high-power amplifiers (PAs) for radar, electronic warfare (EW), and communications systems. As a result, the capability of VE to generate and amplify high-power coherent radiation at high frequency ($f$), as measured in terms of average output power density ($P_{\mathrm{avg}}f^2$), has doubled every two years for the past six decades [2]. Due to constant technology advances, modern electronic amplifiers and oscillators provide reliable long-life operation. Rapid advances in VE will continue with emphasis on small size, light weight, and low cost without sacrificing performance. For example, the low-gain high-power VE approach implemented in microwave power modules (MPMs) with helix traveling-wave tubes (TWTs) will be extended across a range of VE device types for the final amplifier stage of improved radar, EW, and communication systems. The increasing demand for high data rates and bandwidth will drive the development of VE high-PAs to high microwave and millimeter-wave frequencies. Microfabrication techniques like microelectromechanical systems (MEMS) may be used to develop new high-frequency high-efficiency VE tile architectures.

It is likely that monolithic microwave integrated circuits (MMICs) will be a dominant technology, but military requirements will demand the development of new materials and microwave devices (like GaN and SiC) capable of providing lower noise and increased power, efficiency, bandwidth, and reliability in stressing thermal environments. Small ultra-stable oscillators will be required to enable detection of small slow moving targets. Very low-loss low-cost components for switching and phase shifting like MEMS will be required, especially for extremely large space-based arrays and lightweight uninhabited combat air vehicles (UCAVs).

There will be higher levels of integration of microwave devices with mixed-signal components for more compact and adaptable sensor front-ends. Innovative packaging technology and integration techniques will be required to meet performance, volume, weight and cost constraints. For example, UCAVs require conformal antennas. Microwave components mounted on flexible substrates could satisfy these needs, as well as those of satellite systems that must be stowed for launch and deployed in space. Due to array size or quantities of arrays, devices on flexible RF substrates may be assembled on "roll-like" machines at high rates to achieve cost goals.

In future multifunction arrays and ubiquitous radar, the signal-processing functions will be moved forward to the high-PA and low-noise amplifier at each element of the array and beamforming performed digitally [1], [3]. Such systems will require development of advanced adaptable direct digital synthesizers (DDSs) and analog-to-digital converters (ADCs) that work at gigasamples per second with 12-bit resolution and low-power dissipation.

For missile seekers, millimeter-wave frequencies will be preferred because apertures are small. For example, at 35 GHz, the aperture in a 7-in missile would have about 700 elements. To meet cost goals, the cost per element would be between $20–$30—a tremendous challenge for electronically scanned arrays. MMICs and packaging costs would have to be drastically reduced. MEMS or reflect arrays offer some potential solutions.

The need for wide-band communications will lead to the use of millimeter-wave frequencies in future satellite systems. Milstar is the newest fielded military satellite system and operates with a downlink in the 20-GHz band and an uplink in the 44-GHz band. The next-generation communication systems, i.e., Advanced EHF and Advanced Polar, will operate in these same frequency bands with crosslinks between satellites in the 60-GHz band. These future satellite systems will utilize multicarrier signals and multibeam antennas for both transmit and receive. For satellite terminals, PAs at 45 GHz with output powers of 100 W with very good linearity will process multiple carriers and low noise amplifiers (LNAs) with noise figures less than 1.5 dB at 20 GHz will be required. Low-power integrated phase shifters that operate from 18 to 45 GHz will be needed. High-speed (sample rates over 1 GHz) and high-resolution (10–14 bit) A/D and D/A devices as well as a wide range of DDS devices (over 1 GHz) must be developed. Some specialized communications applications will require PAs, oscillators, mixers, and LNAs that operate at 60 and 94 GHz.

Platforms for satellite terminals continue to decrease in size, UCAVs being an example; yet performance comparable to larger terminals will be required, leading to the development of low-profile steerable antennas, high-efficiency PAs, and very LNAs in the 18–50-GHz frequency range.

In the future, microwave engineers with multidisciplined experience in RF, mixed-signal devices, photonics, and packaging technologies will be highly valued. Broad-band signal processing will also require engineers who are skilled in both RF and digital signal processing. Experts in advanced modulation techniques, spread-spectrum techniques, error-correction coding, and digital signal-processing techniques will be needed. Increasingly, microwave engineers will use improved computer-aided design (CAD), modeling, and simulation tools. By creating accurate and reproducible models with user-friendly design tools, design cycle times and costs will be significantly reduced.

Recently, rapidly expanding commercial markets have lured away microwave engineers from defense. This fact, coupled with the design challenges generated by large complex systems, may dictate that virtual teams of engineers from both defense and commercial companies in various geographical locations be organized in order to adequately address the design, fabrication, and testing of microwave components and subsystems. Military security requirements will pose interesting problems for the implementation of virtual teams. In this new business environment, there is an opportunity for industry, universities, and the government to rethink all aspects of recruiting, training, and retention of microwave engineers. Perhaps the technical challenges that are offered by future microwave and millimeter-wave defense systems will entice many engineers to address the unique design and manufacturing problems.

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**Don Parker** (S'61–M'63–SM'73–F'82–LF'94) was born in Ogden, UT, on January 14, 1933. He received the B.E.S.E.E. degree from Brigham Young University, Provo, UT, in 1956, the M.S. degree from Harvard University, Cambridge, MA, in 1957, and the Sc.D. degree in electrical engineering from the Massachusetts Institute of Technology, Cambridge, in 1964.

From 1957 to 1961, he was an MIT Lincoln Laboratory Staff Associate. After serving three years as a lieutenant in the U.S. Air Force, he returned to the MIT Lincoln Laboratory in 1964 as a Staff Member. In 1969, he joined the Stanford Research Institute, initially as a Senior Research Engineer and then Director of the Electromagnetic Techniques Laboratory. In 1976, he joined the Hughes Aircraft Company as Manager of the Microwave Department in the Missile Systems Group. He was then Manager of Radar Laboratory and then Assistant Manager of the Radar Laboratories. In 1986, he transferred to the Radar Systems Group within Hughes and became Manager of Active Array Programs in the Engineering Division. In September 2000, he retired from Raytheon Electronic Systems, Dallas, TX, nearly three years after Raytheon purchased Hughes in December 1997.

Dr. Parker is a member of Phi Kappa Phi and Tau Beta Pi. He was secretary in 1972 and a member of the IEEE Microwave Theory and Techniques Society (MTT-S) Administrative Committee (AdCom) from 1973 to 1982. He served as vice president and president of the IEEE MTT-S AdCom in 1978 and 1979, respectively. He was editor-in-chief of the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES from 1975 to 1978. He was chairman of the Technical Program Committee, for the 1981 IEEE MTT-S International Microwave Symposium (IMS), vice chairman of the 1989 IEEE MTT-S IMS, and chairman of the 1994 IEEE MTT-S IMS. He was the recipient of the 1984 IEEE Fellow Award, the 1985 IEEE Centennial Medal, and the 2000 IEEE Millennium Medal. He was also the recipient of the 1989 Distinguished Service Award of IEEE MTT-S. He was an ABET program evaluator for the IEEE Educational Activities Committee on Accreditation Activities in 1992, 1993, and 1995. From 1992 to 1997, he served as a panel member for electronics and electrical engineering of the National Research Council Board of Assessment of the National Institute of Standards and Technology (NIST) Programs. He was also a member of the Electronics Technology Area Review and Assessment (TARA) Sub-panel of Sensors, Electronics and Battlespace Environments (SEBE) Reliance Panel for the Department of Defense (DoD) Science and Technology Office in 1997, 1998, and 1999.