

# A DARPA Perspective on the Future of Electronics

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## **Abstract:**

This paper gives a brief review of the role of the DoD in the development of key electronics technology, offers an assessment of the current role of DoD, and particularly DARPA, in electronics technology development, and gives a view of what could occur over the next 10 years.

## INTRODUCTION

The US Department of Defense (DoD) has always had electronic component and system requirements that far out strip current commercial needs. The requirements are driven by the need to operate in harsh environments (elevated temperature, high radiation, etc), detect small targets at long range, process high rate sensor data in real time, and operate outside of commercial spectrum bands, to name a few. This has led the DoD to often lead the development of high performance electronic components, developments that have in turn sparked large commercial applications such as the personal computer and cellular phone.

With the change in the core structure of the DoD industrial based over the past 10 years there has been a consolidation of component development and production capability. At the same time the Department has experienced a period where "Commercial Off the Shelf" (COTS) technology was deemed sufficient for system requirements. The COTS emphasis was driven largely by cost reduction

objectives, often at the expense of system performance. However, the recent drive to transform the US military appears to require electronic component technology well in excess of that available via COTS. This has led DARPA's Microsystems Technology Office to expand its investment in high risk, high payoff electronics research.

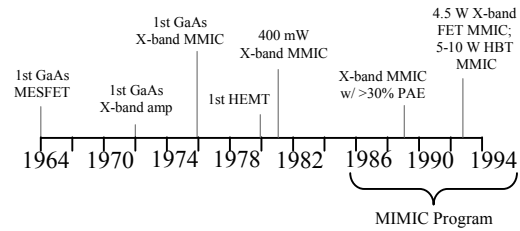
## DoD ELECTRONICS DEVELOPMENTS

After the invention of the transistor in 1948 at Bell Laboratories and the Integrated Circuit in 1959 at Texas Instruments, solid state electronics has seen a steady and increasing level of performance and complexity. In the early 1980's silicon integrated circuits were being commercialized and the DoD needed to insure access to the highest performance digital circuits to maintain their technology advantage. As the level of circuit integration and complexity increased, it was further understood that advanced interconnect technology and design tools were necessary to speed circuit development and optimized performance. At that time, a program on Very High Speed Integrated Circuits (VHSICs) was initiated through the Office of the Secretary of Defense (OSD) to address these issues. The program ran from 1980 to 1990 and established the US as the premier producer of silicon IC's in the world. In a similar time period the Defense Advanced Research Projects Agency (DARPA) initiated the GaAs Pilot Line Program to establish GaAs digital integrated circuits to directly compete with silicon technology. While this effort was technically successful in developing complex, high speed GaAs digital circuits, largely based on ion implanted GaAs

MESFETs, the ever increasing capability of silicon CMOS captured the dominate role in the commercial IC market as it followed Moore's law with a doubling in transistor count every two years.

While GaAs digital circuits did not become a dominant technology, its development, along with another DoD program, established the infrastructure that lead to the wireless revolution. In 1985 DoD initiated a program to transition the basic research progress in GaAs microwave technology funded by the Office of Naval Research, the Air Force Office of Scientific Research, and the Army Research Office to develop manufacturable GaAs high frequency amplifiers under the Microwave/Millimeter Wave Monolithic Integrated Circuits (MIMIC) program.<sup>i</sup> This effort was initially conceived to reduce the cost and increase the reliability of GaAs rf components that were needed for radar, communications, and electronic warfare. To that point, solid state rf components were largely discrete devices fabricated into hybrid circuits with each circuit requiring custom tuning. The MIMIC program, initiated in the OSD and later transfer to DARPA, lead to the first demonstration of a multi-watt monolithic microwave IC. A timeline of GaAs microwave technology development and the MIMIC program showing key technical milestones is given in Figure 1. This program established GaAs MMIC as a viable technology for DoD systems and also directly led to the subsequent explosion of wireless technology. Not only was the device and circuit manufacturing established, but also the design and testing capability was developed that enabled a broad range of circuit developments. Further still, the DoD investment directly, or indirectly, educated a generation of engineers skilled in microwave device and circuit technology. This engineering base carried the US to the forefront of rf/microwave electronics technology.

### GaAs Microwave Amplifier Chronology



**Figure 1:** Chronology of GaAs microwave transistor and monolithic integrated circuit development.

Following the MIMIC program, DARPA initiated the Microwave Analog Front End (MAFET) program that moved on to develop InP technology to extend the frequency of operation for solid state components into the W-band.

### CURRENT DARPA INVESTMENTS<sup>ii</sup>

Currently DARPA, through the Microsystems Technology Office (MTO), is investing in the next generation of compound semiconductor materials (6.1 angstrom materials and wide bandgap semiconductors) and in the frontier of scaled silicon and SiGe technology for DoD unique circuits.

The 6.1 angstrom materials (GaSb, InAs, and AlSb) are expected to enable extremely low noise mm-wave receivers and sub-one-volt mixed signal logic as a result of their extremely high mobility (up to 33,000 cm<sup>2</sup>/Vs at room temperature) and saturated electron velocity (over 4x10<sup>7</sup> cm/s) at low field. The current MTO Antimonide Based Compound Semiconductor (ABCS) program is developing InAs-based HEMTs and HBTs with high speed operation between 0.5 and 1.0 V.

Wide bandgap semiconductors, namely SiC and GaN, are being developed for both power conversion and distribution, and for high frequency amplifiers. A phase I MTO program is focused at establishing the necessary substrate and epitaxial material quality and uniformity to allow large area power devices and complex microwave

circuits to be realized during phase II. These materials offer the potential for ten times higher power densities, with operation at high temperature and higher frequency (for a given power), than conventional solid state devices.

MTO is pursuing efforts in wide bandwidth, high dynamic range mixed signal circuits to establish the components necessary for DoD systems to exploit reprogrammable, multifunction digital RF architectures. Two MTO programs are targeting complex mixed signal circuits such as direct digital synthesizers and analog-to-digital converters. The first, Technology for Efficient Agile Mixed Signal Microsystems (TEAM), is exploiting the integration and processing capability of aggressively scaled SiGe HBTs to exploit this technology for mixed signal circuits with clock frequencies in the 10's of GHz enabled by HBTs with cutoff frequencies over 350 GHz.<sup>iii</sup> The program will explore circuit topologies enable by the integration of mixed bipolar and CMOS circuits for high precision circuits.

A second program, Technology for Frequency Agile Digitally Synthesized Transmitters (TFAST), is developing super-scaled InP DHBT to fully exploit the carrier transport and breakdown properties of this material in increasingly more complex mixed signal circuits. The phase I program is developing the core transistor technology with a bench mark demonstration targeting a 150 GHz static flip flop from DHBTs with  $f_t$  and  $f_{max}$  both greater than 350 GHz and with a breakdown voltage  $\geq 4$  V. The high breakdown voltage and linearity of InP DHBTs is expected to enable higher dynamic range mixed signal circuits at lower power than competing technology. The second phase will demonstrate complex (>20,000 transistors) circuits with clock speeds over 100 GHz.

## INTELLIGENT MICROSYSTEMS

Beyond the development of new materials and device structures, MTO is pursuing a new class of intelligent,

reconfigurable, components whereby the operating conditions (e. g. bias point, efficiency, bandwidth, center frequency, etc.) can be changed in real time in response to autonomous sensors or digital control imbedded in the component. These new "Intelligent Microsystems" that can include aspects of sensing, computation, actuation, and power control, are seeking to exploit the technology overlaps of traditional digital, analog and mixed signal electronic technology with MicroElectroMechanical Systems (MEMS) and other dynamic circuit control techniques.

To realize Intelligent Microsystems the functionality of different materials systems and device types must be seamlessly combined at the device, circuit, and sub-module level. This will require heterogeneous integration and design tools that can model complex interfaces and multiple device models. Increasingly, the core circuit and resulting microsystems will exploit three dimensional topologies to minimize signal and clock paths and optimize the overall performance.

One example in this area is the Intelligent RF Front Ends (IRRFE) program that is seeking to embed digital control in analog RF components for real time control and optimization of RF front ends. This effort requires real time sensing of the analog waveform and dynamic reconfiguration of the input and output matching networks to alter the output for changing environmental conditions or mission requirements.

With the combination of multiple materials and devices in closely spaced Microsystems, heat management and removal will become an ever more critical component. Removal of the excess heat will require the inclusion of advanced thermoelectrical cooling layers, embedded micro-channel cooling, or other advanced cooling schemes.

## CONCLUSION

The transformation of the US military will require extending the

underlying technology well beyond that available from commercial components. In particular, in the area of electronics, or more broadly, Intelligent Microsystems, the DoD will require dynamic, reconfigurable, components that can out performance the adversary in adverse conditions and be adapted to changing mission needs. The Microsystems Technology Office at DARPA is pursuing technology investments to deliver Intelligent Microsystems to the future warfighter and, as occurred with earlier generations of electronics, enable new commercial opportunities for DoD sponsored research.

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Acronyms:

MMIC: Monolithic Microwave Integrated Circuit  
MESFET: Metal Semiconductor Field Effect Transistor  
HEMT: High Electron Mobility Transistor  
HBT: Heterojunction Bipolar Transistor  
MEMS: MicroElectroMechanical Systems  
VHSIC: Very High Speed Integrated Circuits

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- <sup>ii</sup> For details on DARPA/MTO programs see: <https://www.darpa.mil/mto/radprograms.html>
- <sup>iii</sup> J. -S. Rieh, et.al., SiGe HBTs with Cut-off Frequency of 350GHz, IEDM-02, paper 31.4 (2002).