K-1

SOLID STATE RADAR'S PATH TO GaAs

David N. McQuiddy, Jr.

Texas Instruments Incorporated
P. O. Box 226015
Dallas, Texas 75266

ABSTRACT

Significant advances have been achieved recently in the field of solid-state active modules. It is now possible to project improved radar system capabilities for meeting the operational requirements of the next generation aircraft. The active element phased array radar can provide an interdiction/strike aircraft with the ability 1) to terrain sense for low level flight, 2) to detect and counter both air and ground threats, and 3) to navigate and acquire targets for improved weapon delivery. The beam scanning rates and beam shape agility necessary for interleaving these functions are not achievable with conventional mechanically scanned antennas or with phase scanned passive arrays. High performance, low cost solid-state active transmit/receive modules are key to the successful implementation of an active element phased array radar (solid-state radar).

Introduction

The application of solid-state technology to airborne phased array radar was visualized nearly twenty years ago. The MERA (Molecular Electronics for Radar Applications) program initiated the technology development activities that ultimately will result in the production of tactical/strategic aircraft equipped with active element phased array radar. The MERA program started in 1964 with the initial objective of simply advancing the state-of-the-art in microwave integrated circuits. After the program was underway, but still in its infancy, the emphasis was expanded to include a demonstration of this new technology. The expanded effort led to the development and demonstration of a laboratory model X-band all-solid-state phased-array radar in 1968. The RASSR (Reliable Advanced Solid-State Radar) program followed MERA and had two major objectives. First, the program was to demonstrate that a practical system could be built that would meet operational requirements. Second, the program was to demonstrate that the reliability improvements promised by the technology was achievable.

This paper will describe the technology limitations identified as a result of the MERA and RASSR programs and will project the promise GaAs microwave semiconductor technology offers as a solution.

Background

The MERA program provided an early stimulus for the application of microwave integrated circuits in advanced systems. This program, covering the 1964 to 1968 time period, was the first major effort to extend integrated circuit technology into the microwave region and to apply high density microelectronics in phased array radar. The program was sponsored by the Air Force Avionics Laboratory, Wright-Patterson Air Force Base and executed by Texas Instruments, Incorporated.

The MERA system was an all solid-state, electronically scanned X-band radar with an active aperture consisting of 604 identical transmit/receive modules. A photograph of the module including the radiating element (dipole) is shown in Figure 1. The microwave integrated circuits were fabricated on high-density alumina and high resistivity silicon, using thin-film hybrid techniques. Each module in the array transmitted a peak power of 0.6 W at 9.0 GHz. The module receiver, centered at 9.0 GHz, provided a module noise figure of 12 dB at a gain of 14 dB.

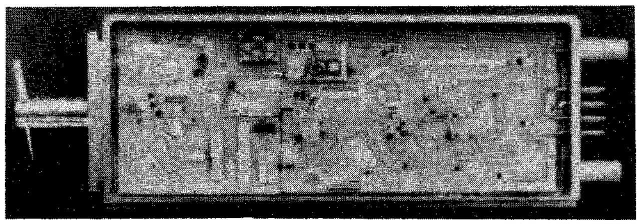

Figure 1. Photograph of MERA Module

Transmitter exitation and local oscillator power at S-band were uniformly distributed to the modules by a corporate manifold. Frequency multiplication was accomplished in the module to generate the transmit signal. Similarly, the local oscillator signal was multiplied to X-band to allow the receive signal to be down-converted to a 500 MHz intermediate frequency. A photograph of the completely populated array face is shown in Figure 2.

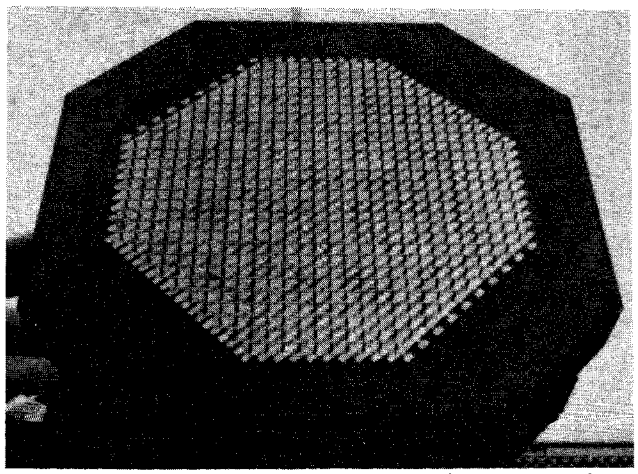

Figure 2. Completed MERA Array (604 Modules)

The RASSR program was awarded to Texas Instruments by the Air Force Avionics Laboratory in 1969 and completed in 1974. A follow-on 18-month program evaluated the unique aperture characteristics through suitable ground testing.

The primary objective of the RASSR design was to use state-of-the-art microwave integrated circuit technology to demonstrate a reliable all solid-state, active element, radar array. The configuration of

0149-645X/82/0000-0176 $00.75 © 1982 IEEE

the array was derived from considerations of the system requirements such as aperture gain, pattern shapes, scan volume, polarization and techniques to be used to generate the transmit and collect the receive energy.

The array, Figure 3, consists of the X-band module, a three-part corporate-feed manifold, a liquid-cooled coldplate, a ground plane for the aperture's front face, a support structure, and a shroud. (Note that the front ground plane is removed from the array shown.)

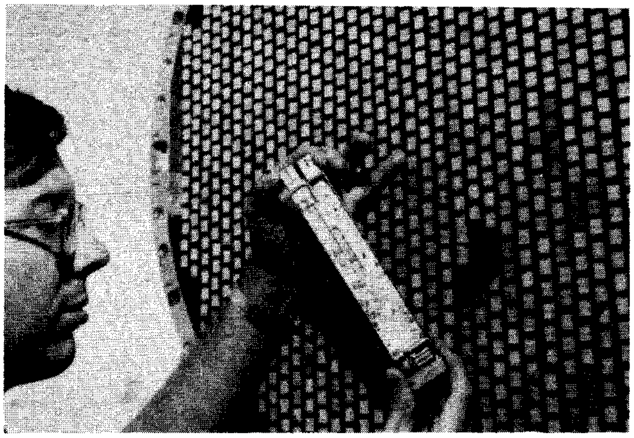

Figure 3. Front View of RASSR Array With Ground Plane Removed

The aperture is formed with 1,648 elements located within a 32-inch diameter area. An equilateral triangular element grid is implemented with 824 dual-element modules. Figure 3 also shows a dual-element module with one of its covers removed to expose the circuitry. Figure 4 shows the element functional block diagram. The complex design was dictated by the silicon bipolar transistor technology limitations. Specifically, x 4 multipliers and the resultant additional amplifier requirements were needed to allow X-band radiation and reception. Each of the elements had an output power of approximately 1.6 W peak and a 10 dB receive noise figure. The element bandwidth was 3 percent.

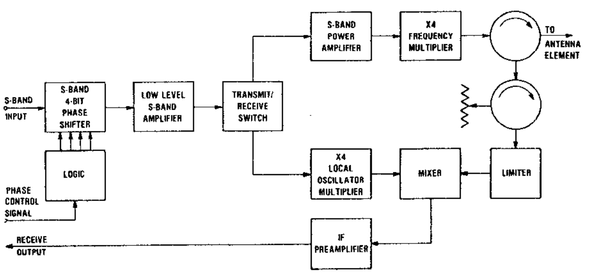

Figure 4. RASSR Module Functional Block Diagram

The success of the RASSR program is best demonstrated by the fact that the aperture accumulated over 1,000,000 module hours during its evaluation. A module MTBF of 18,000 hours was observed. In addition to utility and reliability demonstrations, the program also documented the fact, recognized early in the program, that the combined obstacles of microwave power generation limitations and module cost would prevent RASSR from leading to an operational system in the original time frame. The need for technology development focusing on solid state power generation and low noise amplification directly at X-band was an obvious conclusion.

GaAs FET Technology

The discovery of the GUNN effect in 1963 resulted in a major GaAs materials research and development effort. By the late 1960's, microwave quality GaAs consisting of high purity epitaxial layers was becoming available in useful quantities. During this same time period, the first microwave frequency field effect transistors were fabricated and tested using GaAs as the semiconductor medium. Laboratory demonstrations of X-band low-noise amplification were made as early as 1971.

The X-band power generation capability of GaAs FETs was initially demonstrated in 1973. Increased government and industry sponsored research and development, in large part motivated by solid-state radar needs, advanced the technology such that, by 1978, medium-power amplification (1 to 2 W) with DC-to-RF efficiencies greater than 25 percent and bandwidths greater than 10 percent had been demonstrated. The technology (GaAs FET) was ready for application to the solid-state active module. The electrical performance deficiencies identified on the RASSR program could be overcome.

X-Band Active Element Module

Both the Air Force and the Navy initiated module development programs in the 1979-1980 time period. Both programs apply GaAs FET technology to achieve a module implementation represented by the functional block diagram shown in Figure 5. The reduced design complexity resulting from the application of GaAs FETs is readily apparent by comparison with Figure 4. An engineering model version of the Navy (Naval Research Laboratory) module developed by Texas Instruments is shown in the photograph of Figure 6. A four-stage transmit amplifier provides a net module gain of 20 dB with an output power of 4 W at 5 percent duty. Five packaged power GaAs FETs are used in the amplifier. A balanced two-stage receive amplifier provides a net module gain of 9.2 dB at a module noise figure of 4.3 dB.

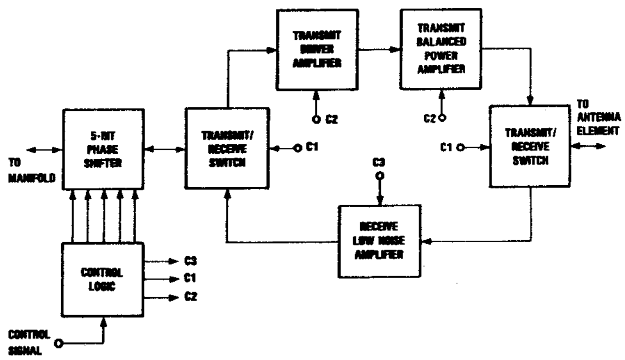

Figure 5. Solid-State Module Functional Block Diagram Made Possible by GaAs FET Technology

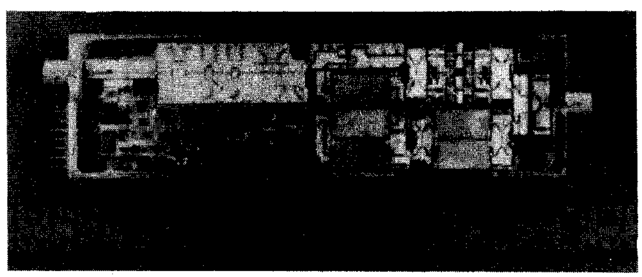

Figure 6. X-Band Solid-State Module Using GaAs FET Technology

Figure 7 is a photograph that portrays nearly 20 years of technology advancement, covering three generations of development, in X-band, solid-state, active module design.

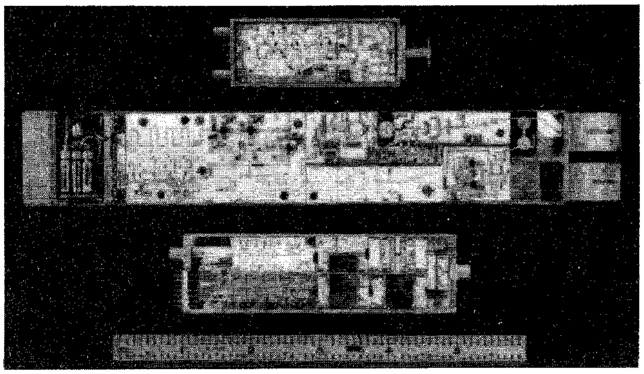

Figure 7. Photographs of the MERA, RASSR, and X-Band Modules

GaAs Monolithic Microwave Integrated Circuits

Although GaAs FET technology and microwave hybrid circuits allow a significantly less complex module implementation than achieved in the RASSR design, cost analyses including optimistic learning curve projections indicates module costs will exceed affordability limits. Additional cost analyses, factoring in the positive impact of GaAs FET technology in microwave monolithic circuit form, shows with a good probability that module cost can support a solid-state radar implementation competitive in cost to conventional radar on a life cycle cost basis. Monolithic circuits extend GaAs FET technology into circuit level functions and offer significant advantages over discrete designs in the areas of lower assembly labor, fewer parts, smaller size and lower weight.

Both low noise (<4 dB) and medium power (>1 W) multistage monolithic amplifiers have been demonstrated at X-band. A breadboard X-band module has been assembled using monolithic low noise and medium power amplifiers in the receive and transmit paths, respectively. A hybrid 5-bit phase shifter and T/R switches from the Navy 4W module design were used to complete the breadboard (Figure 8). The module has demonstrated a noise figure less than 5 dB with a net gain greater than 17 dB over the frequency band from 8.7 to 10.7 GHz. The module transmit channel provides 0.5 W output with 20 dB gain. The relative size can be obtained by scaling from the phase shifter hybrid circuit (0.5-inches by 1.2-inches).

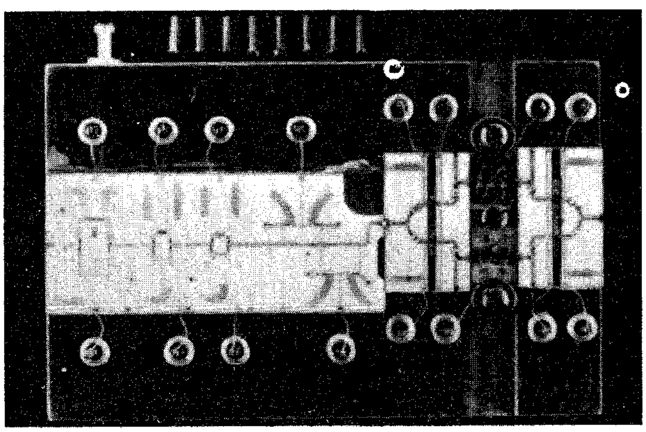

Figure 8. Hybrid/Monolithic X-Band Module

A DARPA/Air Force solid-state module development program has as its principal objective the implementation of all solid-state module RF functions on a single semiconductor substrate. To date, all four key module functions have been individually demonstrated and present effort is focused on integration of the functions on a common substrate. Figure 9 shows a photograph of the individual GaAs monolithic circuits "mocked-up" as they would possibly appear when integrated. A functional block diagram of the module is included. Conservative projections predict the integrated module chip will be contained within a 0.25-inch by 0.5-inch area. Control logic and energy storage will be located off-chip.

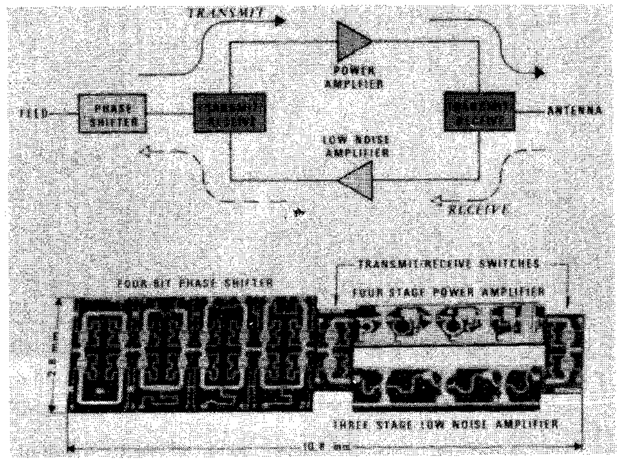

Figure 9. Monolithic X-Band Module Mock-up

Outlook

The emergence of GaAs FET technology during the decade of the seventies has renewed interest in solid-state radar. The application of GaAs monolithic circuits offers to provide module realization at an acceptable cost and enhanced reliability. The production of solid-state radar systems will require large volume production of electrically identical GaAs monolithic circuits. The technology is relatively immature. It is not clear that volume production can be achieved. A significant industry/government investment is required and is being made to prove that producibility constraints can be eliminated. A positive outlook can be forecast for solid-state radar.