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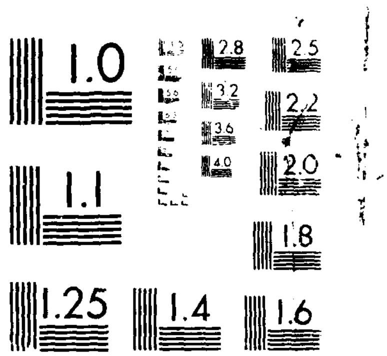

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REPORT SD-TR-88-06

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Voltage-Tunable Microwave Monolithic Integrated Circuits

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Capt Richard J. Young/SD/CWX was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) Program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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The incorporation of voltage-tunable reactive elements in microwave monolithic integrated circuits (MMICs) would increase the performance, yield, producibility, adaptability, and affordability of these devices. These improvements would be very important for both low-volume applications, (e.g., space communications) and high-volume applications, (e.g., space-based radar). The feasibility of this concept will be explored by means of the computer-aided design and simulation facilities at The Aerospace Corporation. It is anticipated that some laboratory experiments in selected tuning concepts will be conducted.

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FIGURES

VOLTAGE-TUNABLE MICROWAVE MONOLITHIC INTEGRATED CIRCUITS

The purpose of this report is to suggest that a large payoff would result from the use of voltage-tunable reactive elements situated at critical stages within microwave monolithic integrated circuits (MMICs). An individual chip could then be tuned by means of externally controlled bias voltages to meet circuit specifications. Given that performance compromises and low yield are possibly the most critical issues at this stage of the rather infant MMIC industry, tunability would improve the performance and increase the processing yield of MMICs. Tunability would also broaden the adaptability of a single design to a wider range of frequency and bandwidth applications.

Yield and adaptability relate to the ability to produce chips at an affordable cost. These issues are critical to the low-volume user, e.g., in space communications, because the requirements are customized and the cost per chip could be prohibitively high if chips adaptable to the user's requirements were not available. These issues are also very important to the high-volume user, because the required number of chips can be so large that the cost per chip could be critical for the acceptance of an overall concept. For example, some space-based radar concepts call for MMIC transmit/receive elements numbering in the hundreds of thousands; a similar number of devices are forecast for expendable smart weapons and decoys. Automation of the tuning sequence in MMIC production is another important issue. The high-volume user would require that the tuning be automated and controlled by microprocessors. Tuning by microprocessors would be accomplished as part of the testing sequence, which by necessity would be automated, regardless of a tunability feature.

Microwave monolithic integrated circuits have, in general, very desirable features for satellite electronics. The anticipated better reliability and lifetimes of MMICs are principal issues. MMICs should be more reliable and have longer lifetimes than circuits fabricated with discrete devices, because the many interconnects are eliminated. Moreover, the reliability and lifetime of monolithic circuits are more predictable, because the reliability variables associated with these interconnects are eliminated. The small size and weight of MMICs are also very attractive attributes, because the reduction in size and weight of a satellite component results in important cost savings.

Consequently, if the principal problems associated with MMICs could be solved, MMICs would be incorporated into a wide variety of future Air Force Space Division (SD) systems. Voltage tunability could be an important technique for solving these problems.

The tunable reactive elements could be passive devices such as Schottky-barrier diodes or hyperabrupt varactor diodes. Both of these devices are voltage-tunable capacitors. Voltage-tunable inductance could be obtained by incorporating these devices with quarter-wavelength impedance transformers.

The voltage tunability of the capacitance C of a uniformly doped Schottky-barrier diode is given by

$$\frac{C}{A} = (q\epsilon N/2V_{bi})^{1/2}/(1 - V/V_{bi})^{1/2} \qquad (1)$$

where A, q, ϵ, N, V_{bi}, and V are the area of the diode, electronic charge, permittivity of the semiconductor, carrier concentration, built-in potential of the barrier, and applied bias voltage, respectively. This expression is plotted in Fig. 1 for various values of N. The voltage V is limited in the positive direction by forward conduction and in the negative direction by reverse breakdown, a doping-sensitive variable. The reverse-breakdown limit is indicated by the dashed line in Fig. 1.

A hyperabrupt varactor is characterized by a capacitance that can be more sensitive to applied voltages than a Schottky-barrier diode. As such, this device could be a better choice as a tuning element in an MMIC. The C-V characteristics of commercial GaAs hyperabrupt varactors manufactured by M/A-COM are shown in Fig. 2. The choice of using the Schottky-barrier diode or the hyperabrupt varactor as the tunable capacitor would depend to a large extent on the signal level at the point in the circuit where the device would be inserted. The more sensitive hyperabrupt varactor would be limited to circuit nodes where the signal levels are low enough not to be distorted by the voltage sensitivity of the diode, i.e., where intermodulation products introduced by the nonlinearity of the varactor are low enough not to be of concern. The possibility of using active devices as voltage-sensitive reactive elements should also be investigated.

In conclusion, the introduction of voltage tunability to MMICs is viewed as an important step in improving the performance, yield, and adaptability of

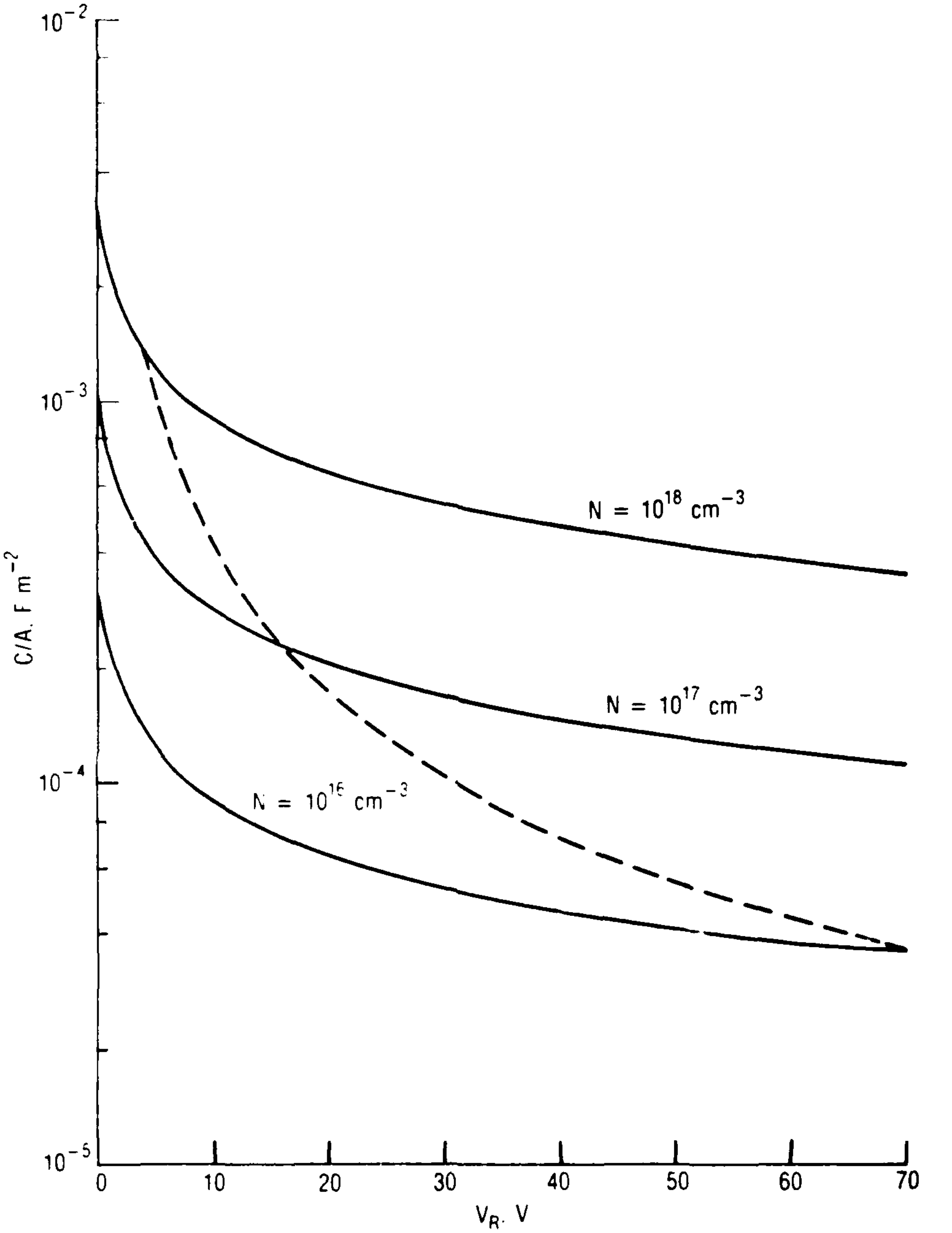

Fig. 1. Capacitance C per Unit Area A of a Uniformly Doped GaAs Schottky-Barrier Diode as a Function of Reverse-Bias Voltage V_R [as Calculated by Eq. (1)]. The reverse-voltage breakdown is indicated by the dashed line.

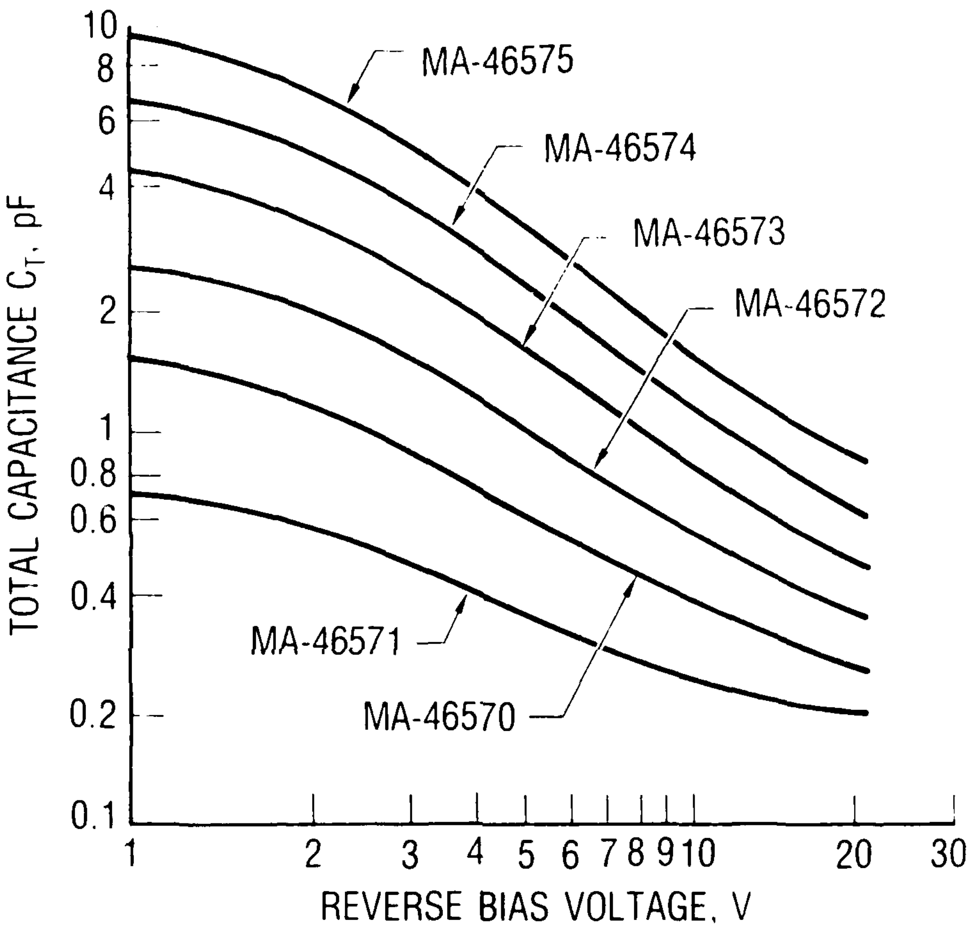

Fig. 2. Capacitance as a Function of Reverse-Bias Voltage for Commercial GaAs Hyperabrupt Tuning Varactors (M/A-COM MA-46570 series).

these devices. The payoff is a lowering of costs for both low-volume and high-volume customers and, as a result, MMICs would be incorporated into a wide variety of future SD systems. A minor disadvantage of the proposed concept is the loss in chip "real estate" that must be devoted to the voltage-tuned devices on the chip. The overall feasibility of voltage tunability will be examined by use of the computer-aided design and simulation facilities at The Aerospace Corporation. It is anticipated that some laboratory experiments in selected tuning concepts will be conducted.

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, chemical dynamics, environmental chemistry, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed chemical and excimer laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, microelectronics applications, communication protocols, and computer security.

Electronics Research Laboratory: Microelectronics, solid-state device physics, compound semiconductors, radiation hardening; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; microwave semiconductor devices, microwave/millimeter wave measurements, diagnostics and radiometry, microwave/millimeter wave thermionic devices; atomic time and frequency standards; antennas, rf systems, electromagnetic propagation phenomena, space communication systems.

Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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