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MMIC Technology for Advanced Space Communications Systems

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MMIC TECHNOLOGY FOR ADVANCED SPACE COMMUNICATIONS SYSTEMS

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ABSTRACT

The current NASA program for 20 and 30 GHz Monolithic Microwave Integrated Circuit (MMIC) technology is reviewed. MMIC advantages are discussed. Millimeter wavelength MMIC applications and technology for communications systems are presented. Passive and active MMIC-compatible components for millimeter wavelength applications are investigated. The cost of millimeter wavelength MMIC's is projected.

INTRODUCTION

Advanced space communications systems concepts such as NASA's Advanced Communications Technology Satellite (ACTS), scheduled for launch in the late 1980's, are using electrically steerable phased array antennas for transmit and receive applications. These antennas require arrays of several hundred radiating or receiving elements, with controllable phase and gain for each element. The phase and gain of each array member is adjusted to shape the transmit (or receive) beam and "point" the antenna to the proper location, allowing faster and less bulky control of the beam compared to conventional mechanical pointing. An MMIC transmit or receive module on each array element would offer significant advantages over other methods (1). MMIC's offer advantages in reliability, reduced parasitics, reproducibility, bandwidth, and system efficiency over hybrid approaches. Many functions can be contained on one chip, allowing increased design flexibility, small size, low weight, and low cost, making MMIC's very attractive for communications systems.

CURRENT NASA PROGRAMS FOR 20 AND 30 GHz MMIC TECHNOLOGY

NASA Lewis Research Center is currently managing several contract efforts to develop the technology necessary for MMIC-based transmitters and receivers at 20 and 30 GHz, respectively (fig. 1). A monolithic 20 GHz variable power amplifier (VPA) module (Texas Instruments) and a 20 GHz phase control module (Rockwell International) have been under development since early 1982. 30 GHz receive modules are being developed by Hughes and Honeywell in parallel contracts awarded in late 1982. A short description of each MMIC

development contract and a summary of progress to date follows.

20 GHz Variable Power Amplifier

The 20 GHz VPA is a fully monolithic GaAs module providing 2.5 GHz of bandwidth (17.7 to 20.2 GHz) at five digitally controlled power levels. Contract goals are 500 mW rf output power with 20 dB minimum gain and 15 percent efficiency at the maximum power condition, and 12.5 mW output power with 4 dB minimum gain and 6 percent efficiency at the lowest power "on" condition. In the off state, maximum dissipation will be 50 mW. Intermodulation products are to be 20 dB below the carrier. A TTL-compatible four-bit digital input is used to control the discrete power levels.

The VPA is divided into two submodules; the control submodule and the amplifier submodule (fig. 2). The control module, developed during the first year of the program, is a four-bit TTL-compatible digital to analog converter designed to control the gain of the FET's used in the amplifier submodule. The amplifier submodule uses dual-gate gallium arsenide FET's for the four-stage amplifier. To date, a four-stage, single-gate amplifier has been produced with an output power of 630 mW and 25 dB gain, with 21 percent power added efficiency at 18 GHz. This single-gate amplifier is a preliminary version of the dual gate amplifier which is being worked on now. The dual-gate version promises higher efficiency in addition to providing the power control capability. The D/A converter will be integrated with the dual-gate version. The total chip size will be 1.4 mm x 4.4 mm.

20 GHz Digital Phase Shift Module

The 20 GHz digital phase shift module (also known as the 20 GHz transmit module) is being developed for NASA by Rockwell, International, Thousand Oaks, California. Technology goals for this contract are 200 mW output power with 16 dB gain, 15 percent power added efficiency, and a 2.5 GHz bandwidth (17.7 - 20.2 GHz). Like the VPA, intermodulation products are to be 20 dB below the carrier. A five-bit phase shifter completes the transmit module. Initial goals require the development and delivery of fully monolithic modules.

For development purposes, the 20 GHz transmit module was divided into eight submodules; five phase shifter submodules of 11.25°, 22.5°, 45°, 90°, and 180° bits, a digital control submodule, a buffer amplifier, and a power amplifier (see fig. 3). These eight submodules were developed separately and, in the final version, will be integrated into a fully monolithic transmit module. Recent studies by COMSAT and Harris on 20 GHz phased array transmit antennas indicate that it would be desirable to have a separate phase shift module and amplifier/power module. This corresponds to separating the transmit module between the buffer amplifier and the power amplifier submodule. This is being done under a modification of the original Rockwell contract. An actual phased array antenna is being developed by General Electric's Space Systems Division for NASA's Antenna Section, using Rockwell phase shift and amplifier modules, and TI variable power amplifier modules.

30 GHz Receive Module

30 GHz receive modules are being developed under two parallel contracts awarded to Hughes-Torrance Research Center and Honeywell's Corporate Technology Center in late 1982. The technology goals for the 30 GHz receive are: 2.5 GHz bandwidth (27.5 to 30 GHz), rf to if gain of 30 dB with a noise figure of 5 dB or less, a five-bit phase shifter and a five-level gain control. Block diagrams for both the Honeywell approach and the Hughes approach are shown in Fig. 4. The receive module is made up of four submodules; a Low Noise Amplifier (LNA), phase shifter, gain control and LO to if submodule. A major difference between the two contractor's approaches is that Honeywell performs the gain control at rf and Hughes controls the gain at if.

Both contractors are using sub-half-micron gate length FET's for use in the LNA. The LNA was the submodule Hughes elected to work on first. Preliminary results have produced a FET with a noise figure of 4.5 dB with an associated gain of 11.5 dB across the band.

Hughes' initial phase shifter approach was to investigate an analog phase shifter based on a branch line coupler. Although not a true time delay phase shifter, the analog phase shifter approach promises a higher yield due to the small area it occupies.

The submodule first worked on by Honeywell is the phase shift submodule. A switched transmission line phase shifter using unbiased FET's (300 μm gate periphery) in a shunt mounted configuration. Further work has concentrated on self-aligned gate (SAG) FET's used in a series mounted configuration. To date, an insertion loss of approximately 2.5 dB per bit over the 27.5 to 30 GHz band has been achieved for the 45°, 90°, and 180° bits. A loaded line phase shifter is expected to be used to cover the 11.25°, and 22.5° bits.

MMIC APPLICATIONS AND TECHNOLOGY FOR MILLI-METER WAVELENGTH COMMUNICATION SYSTEMS

A prime candidate for the application of MMIC technology at millimeter wave frequencies is intersatellite links between communications satellites. Frequency bands allocated for intersatellite links are at 23 and 32 GHz, 54 to 58 GHz, and 59 to 64 GHz. Some perhaps obvious benefits of intersatellite links, especially at the high frequencies are the lack of atmospheric attenuation and the immunity from terrestrially based eavesdropping and interference. The low power requirements resulting from low atmospheric losses and increased antenna gain for a given antenna size make solid state MMIC devices a logical choice for intersatellite link applications.

There are some advantages of MMIC's which become more apparent at higher frequencies. Most of these advantages are tied to the inverse relationship between wavelength and frequency. For example, as the frequency of operation increases, the linear size of the circuit element decreases and the number of circuits in a given area increases (fig. 5). This reduction in size for a circuit of a given complexity should result in a potential decrease in cost. Another characteristic that improves with frequency is the attenuation per wavelength (fig. 6); as circuit elements shrink, so does the associated attenuation through the circuit elements. The performance of MMIC passive components tends to decline quite slowly, or in some cases, improve with increasing frequency.

There are many MMIC-compatible millimeter wavelength active devices either in use or under development. Both Schottky diodes and GaAs FET's have been the mainstay of millimeter wavelength MMIC circuits. High mobility materials and new device structures have great potential for use in millimeter wave systems. The High Electron Mobility Transistor (HEMT), Permeable Base Transistor, Opposed Gate Source Transistor (OGST), Vertical FET, and the Planar Doped Barrier Transistor are all under development for use in these high frequencies.

Cost estimates have been projected for complex (10 function) MMIC's for frequencies well into the millimeter wavelength range. Figure 7 shows projected cost versus frequency with yield as a parameter. These estimates assume a pilot line throughput of 10⁵ cm² of GaAs per year and include dc wafer probing and dicing. Further MMIC cost estimates, including packaging and rf testing (yield = 1 percent), predict a cost of \$1000 per 60 GHz MMIC circuit if the rate of testing were one circuit per day. A test rate of one circuit per hour is estimated to bring the per circuit cost down to less than \$300.

CONCLUSION

The current NASA program for 20 and 30 GHz MMIC technology is showing encouraging results in

developing solid state monolithic circuits. The potential for intersatellite links makes 60 GHz a likely frequency range for further MMIC development. The use of monolithic solid state circuits appears both feasible and cost effective in the millimeter frequency range.

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3. D. J. Connolly, G. Anzic, and A. N. Downey, "The Role of GaAs ICs In Future Satellite Communications Applications", in Reliable, Survivable and Affordable Electronics, the 1983 Space Electronics Conf., 1983.

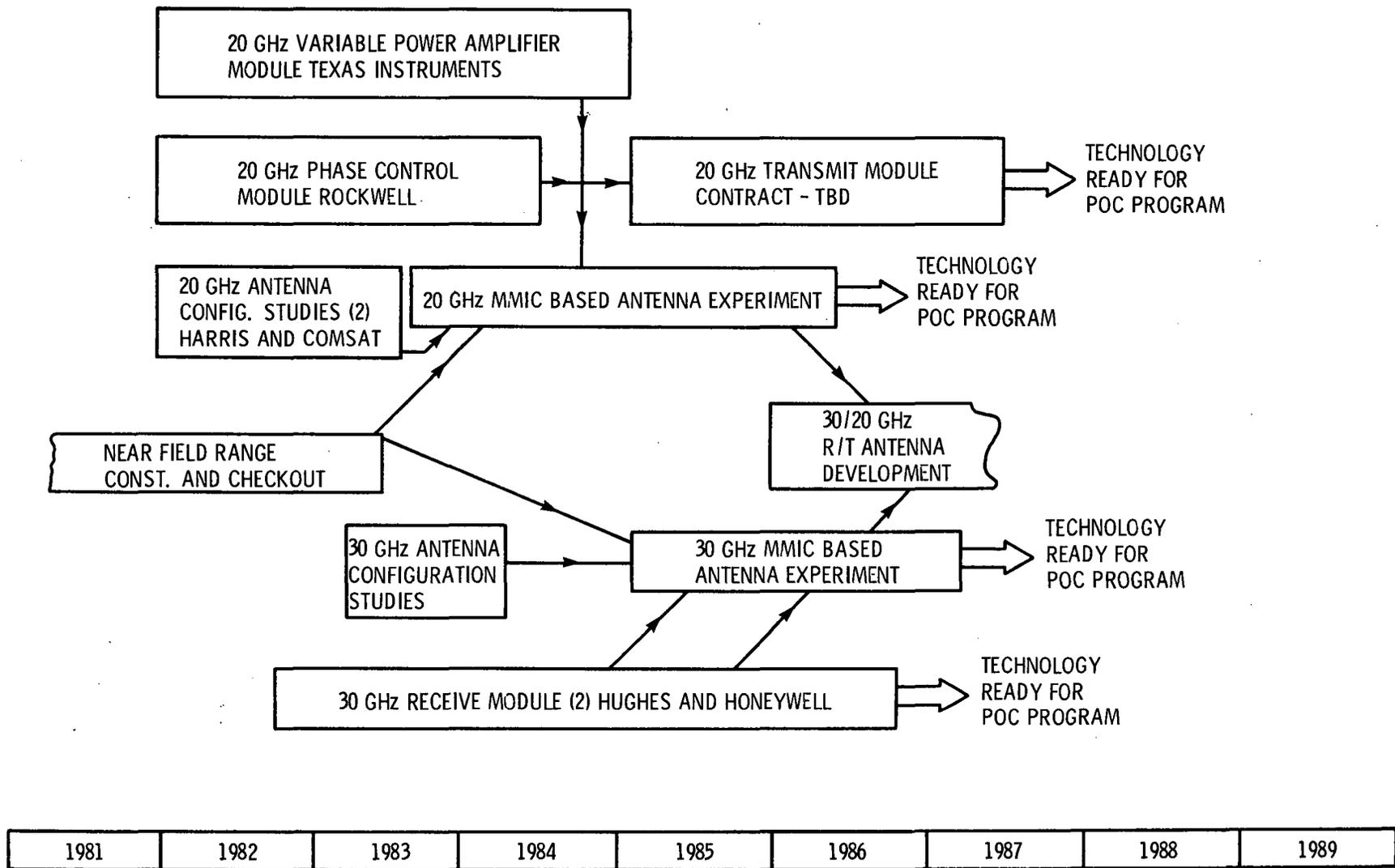


Figure 1. - NASA's program for the application of MMIC Technology.

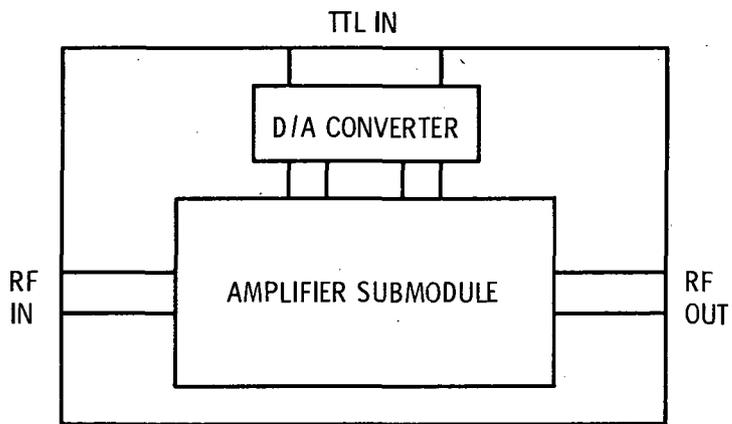


Figure 2. - 20 GHz VPA.

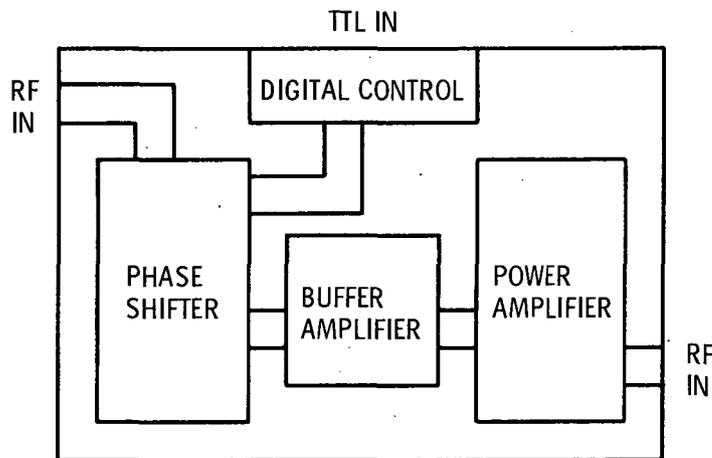
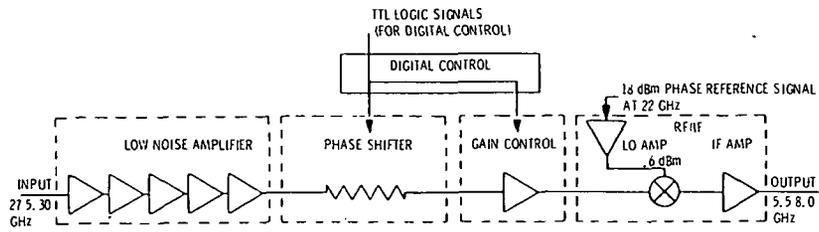
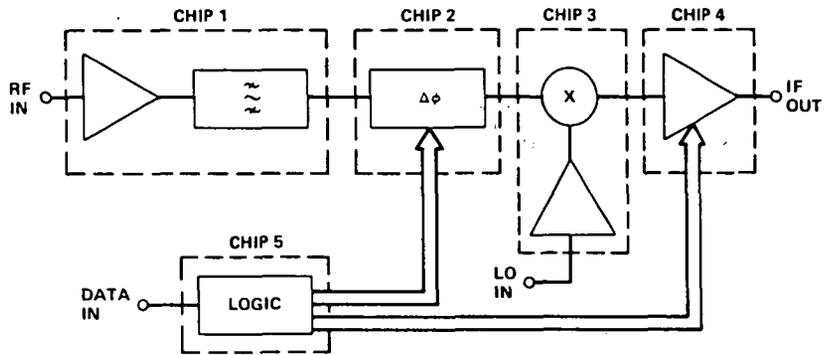


Figure 3. - 20 GHz transmit module.



(a) Honeywell approach.



(b) Hughes approach.

Figure 4. - Block diagram of receiver.

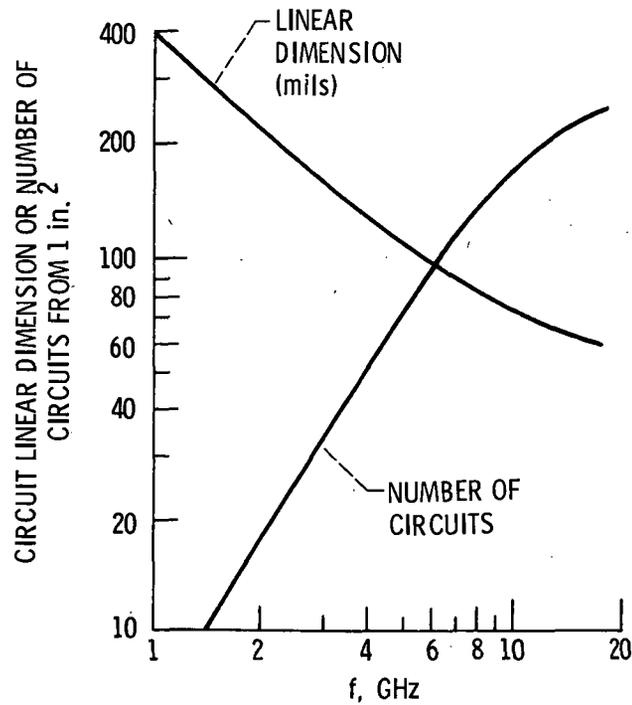


Figure 5. - Estimated linear size and density of monolithic circuits on a one square inch GaAs wafer versus frequency.

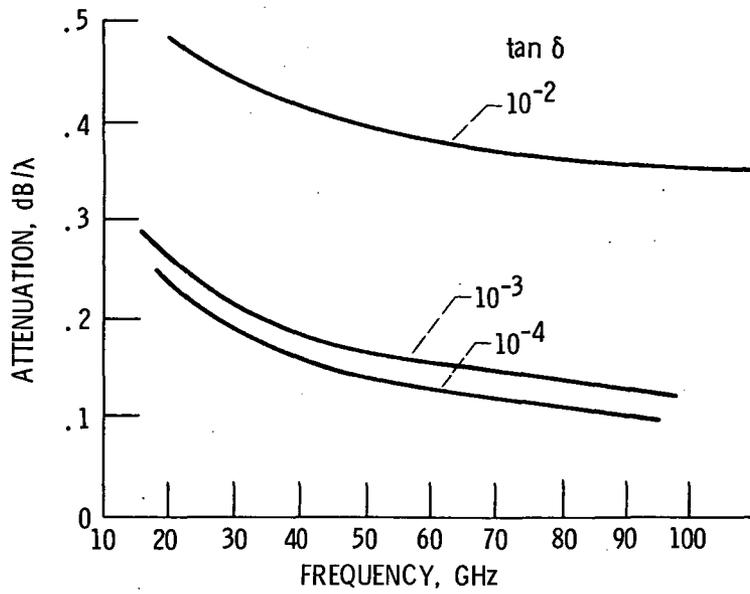


Figure 6. - Loss of 50 Ω microstrip on 4-mil GaAs substrate.

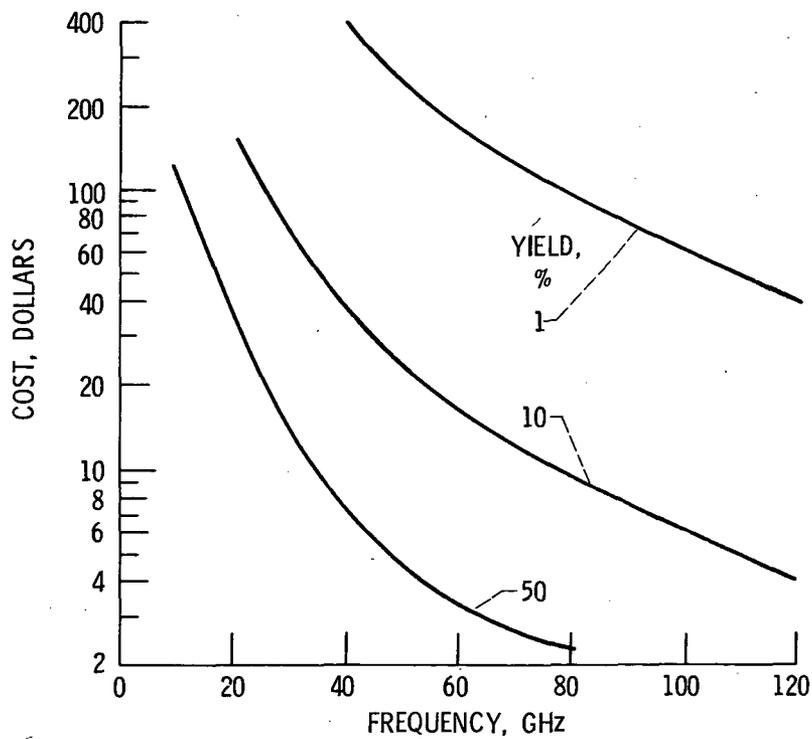


Figure 7. - Projected cost of complex (10 function) MMIC. Assumes 10^5 cm²/yr pilot line - through wafer probe and dicing.

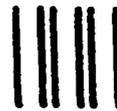
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