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20 and 30 GHz MMIC Technology for Future Space Communication Antenna Systems

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ABSTRACT

The development of fully monolithic gallium arsenide (GaAs) receive and transmit modules is described. These modules are slated for phased array antenna applications in future 30/20 GHz communications satellite systems. Performance goals and various approaches to achieve them are briefly described. The latest design and performance results of components, submodules and modules are presented.

INTRODUCTION

With the expanding utilization of existing frequency and orbital slot resources, the future generation of communications satellites is under increasing pressure to maximize its operating efficiency while minimizing cost. A major factor in achieving these goals has been identified as the implementation of multiple scanning beam antenna systems on future communications spacecraft. The Advanced Communications Technology Satellite (ACTS) scheduled for launch in late 1980's, will be the first satellite to employ scanning beam antenna technology in the 30/20 GHz bands. Future satellite communications systems are expected to use monolithic receive and transmit module technology to better implement this function.

Gallium arsenide (GaAs) Monolithic Microwave Integrated Circuits (MMIC) offer substantial performance advantages in the proposed frequencies of interest. Since entire microwave circuits can be fabricated on a single chip, the resulting circuit is free of parasitics, losses and component value uncertainties normally associated with wire bonds and other external interconnects.

NASA Lewis Research Center has a substantial ongoing program to develop 20 GHz transmit and 30 GHz receive modules for this application.

20 GHz TRANSMIT MODULE

The original transmit module concept is shown in Fig. 1. Although the stated module size and the power output have been modified, the design approach shown still applies. The module performs two distinctly different functions necessary for phased array antenna application. These are phase and amplitude control of the radiated rf energy. Proper phase control of radiating elements results in beam steering while amplitude control of selected radiators defines the beam shape. A basic concept employing MMIC transmit modules in a multiple scanned beam spaceborne antenna application is shown in Fig. 2. Similarly, the receive modules (described later in this report), operating at different frequencies, can be incorporated into the same feed array by use of orthomode transducers. Since a typical feed array will contain hundreds of radiators, both phase and amplitude will be controlled by a computer with capability to adapt to changing beam size and scan requirements.

The phase shifting and the variable power functions of the transmit module are being developed as two separate chips by two separate manufacturers. The phase shifter chip is being developed by Rockwell International while Texas Instruments is developing the variable power amplifier.

VARIABLE POWER AMPLIFIER MODULE

The performance goals of the variable power amplifier are as follows:

rf band	17.7 to 20.2 GHz
rf power out	0 to 0.5 W (variable)
Gain	20 dB max. (variable)
Efficiency	15 percent/6 percent
Amplitude control	Operate on digital input
Mechanical design	Fully Monolithic

While exhibiting high efficiency, the amplitude control provides for five output power states at levels of 500, 125, 50, and 12.4 mW and off. The amplitude control is digital and TTL compatible. The 4 bit D/A converter has been designed, fabricated, and tested.

The variable power amplifier module development approach uses four stages of amplification, with dual gate FET's. A preliminary four stage single-gate amplifier module achieved an output power of 630 mW with 25-dB gain and 21-percent power added efficiency at 18 GHz. The four stage dual-gate FET amplifier (fig. 3) is still in development. So far it has demonstrated a 250-mW output power with 15-dB gain at 19 GHz.

PHASE SHIFTER MODULE

The phase shifter module performance goals are as follows:

rf band	17.7 to 20.2 GHz
rf power out	>200 mW
Gain	$\geq$16 dB
Efficiency	>15 percent
Phase control	Operate on digital input
Mechanical design	Fully Monolithic

Figure 4 shows the fabricated version of the phase shifter module. The module consists of five cascaded single bit phase shifters each employing a switched line approach using FET devices for switches. The digital control circuitry accepts a TTL input signal and provides the signals to switch in or out each of the five phase shifters. A two stage buffer amplifier follows the phase shifters to compensate for their insertion losses. Finally, a three stage power amplifier provides the required output power.

A saturated output power of approximately +21 dBm was measured across the band of interest. The phase shifters operated well although the insertion loss per bit was approximately 3.5 dB, which is about 1 dB above the goal.

Initial investigation of the phased array antenna design disclosed that more efficient antenna operation can be realized by dividing the phase shifter module in two submodules where phase shifting and amplitude control are accomplished at two different physical locations.

20 GHz HIGH POWER AMPLIFIER MODULE

In a related effort, Texas Instruments is developing a monolithic amplifier which exhibits higher power. The objectives of this effort are as follows:

Efficiency	20 percent (Sat)
rf band	19-21 GHz
rf power out	2.5 W (Sat), 1.5 W (Lin)
Gain	>15 dB

With the effort under way for approximately one year, the following results have been achieved:

(1) An output power of 2 W with 12 dB gain and 20 percent power added efficiency has been achieved for the 3 stage amplifier. The linear gain was 14 dB at 1 W output at 17 GHz.

(2) A four-way monolithically combined travelling-wave amplifier has achieved an output power of 2 W at 7 to 8 percent efficiency (not optimized).

(3) A travelling wave amplifier has achieved state of the art results of 0.5 W output power over 2 to 21 GHz frequency range with average gain of 4 dB and 14 percent power added efficiency.

30 GHz RECEIVE MODULE

The 30 GHz monolithic receive module is being developed by two contractors as a parallel effort. The two contractors are Hughes-Torrance Research Center and Honeywell-Corporate Technology Center. The module's performance goals are as follows:

rf band	27.5 to 30 GHz
if center frequency	Between 4 to 8 GHz
Noise figure at room temperature	$\leq$5 dB
rf/if gain	$\geq$30 dB at highest level of gain control
Gain control	At least six levels; 30, 27, 24, 20, 17 dB and Off
Phase control	5 bits; each bit ±3° band center
Module power consumption	250 mW in all states except OFF. In OFF state, 25 mW
Phase and gain control	Operate on digital input.
Mechanical design	Fully monolithic

The receive module consists of the following four basic submodules: Low noise amplifier, phase shifter, gain control and mixer/IF. The approximate module layout is represented by Fig. 5. The dimensions shown are preliminary. The final module dimensions are expected to be smaller. Basically, the design approaches of both contractors are similar with some minor differences. Both contractors have completed approximately 2 years of the scheduled 4 year effort.

Figure 6 shows the Hughes low noise amplifier submodule. It's gain and noise figure are expected to be approximately 11.5 dB and 4.5 dB respectively. Significantly better results are expected in the FET gain and noise performance area in the future.

Honeywell's initial submodule, a 3 bit phase shifter, is shown in Fig. 7. Its measured performance showing the various possible phase states across the band of interest is shown in Fig. 8. A slight phase disturbance just above 28 GHz is due to instrumentation and not the phase shifter itself. The final phase shifter performance goal requires that it operate at five different phase states. The phase shifter design approach is based on switched transmission lines where large gate periphery FET's are used as rf switches.

The remaining submodules are in various stages of development.

CONCLUDING REMARKS

A brief overview of the development of the monolithic microwave integrated circuit receive and transmit modules has been presented. NASA Lewis is pursuing those MMIC developments that promise maximum system impact in areas of efficiency, weight and cost. Initial results indicate that the major goals of the 20 and 30 GHz MMIC module contracts are likely to be met.

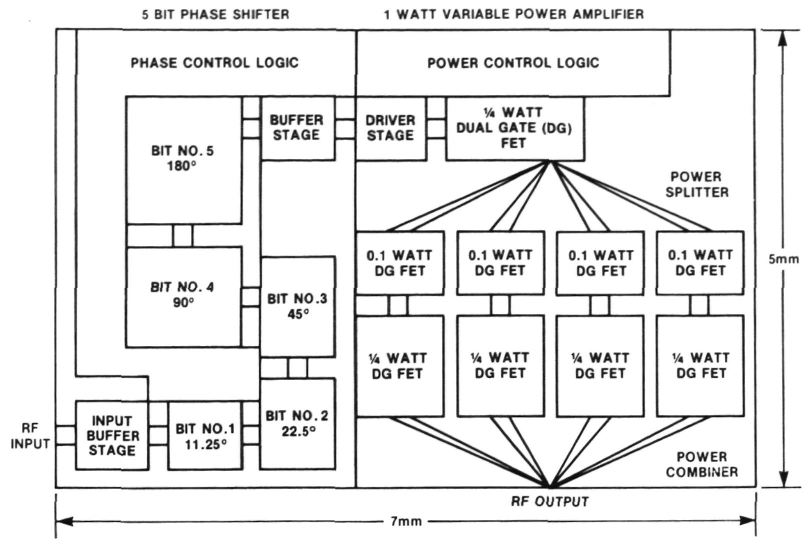


Figure 1. - 20 GHz GaAs monolithic transmit module.

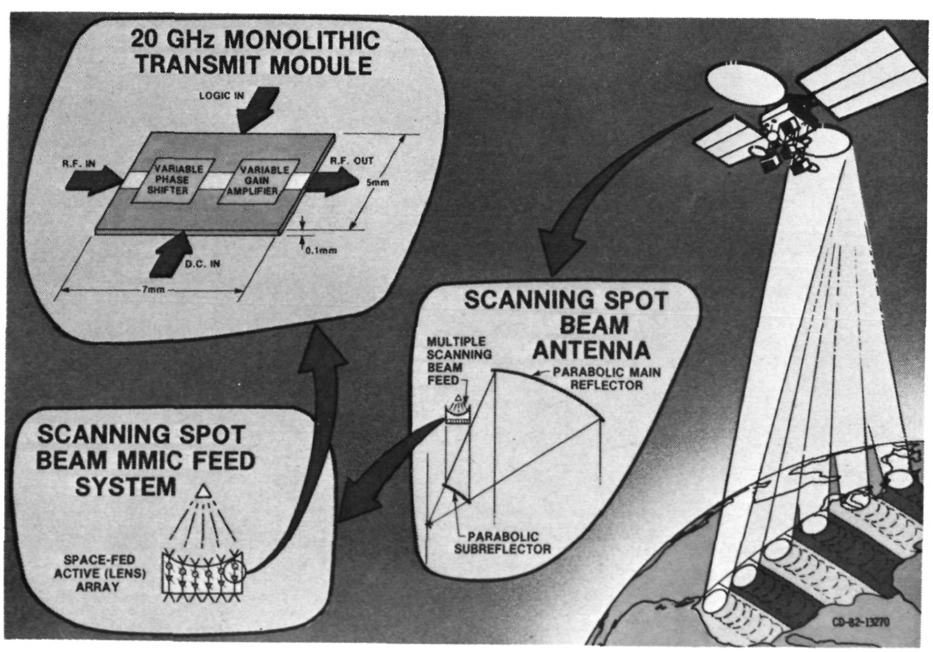


Figure 2. - Multiple scanning spot beam antenna.

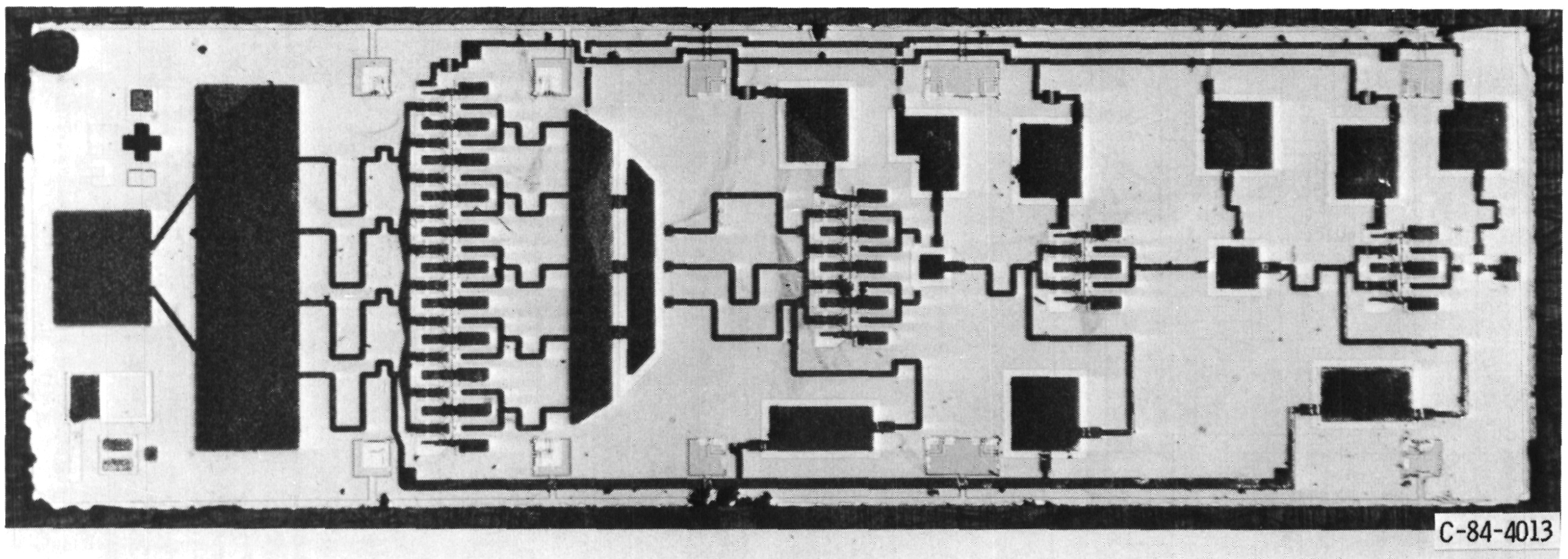
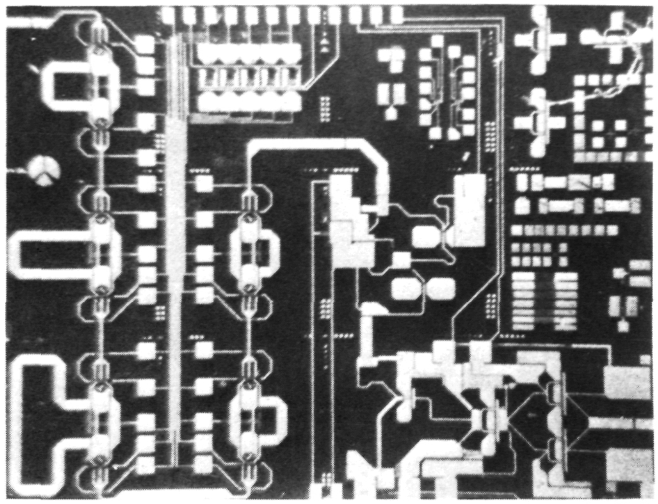


Figure 3. - 20 GHz dual gate amplifier (254 X 48 X 4 mils).



4.8 mm X 6.4 mm X 0.127 mm C-84-1139

Figure 4. - 20 GHz monolithic phase shifter module.

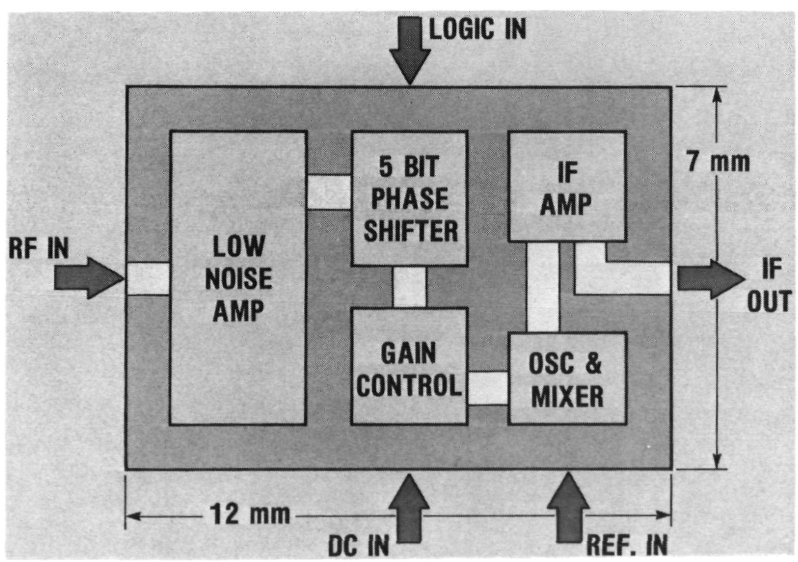


Figure 5. - 30 GHz monolithic receive module.

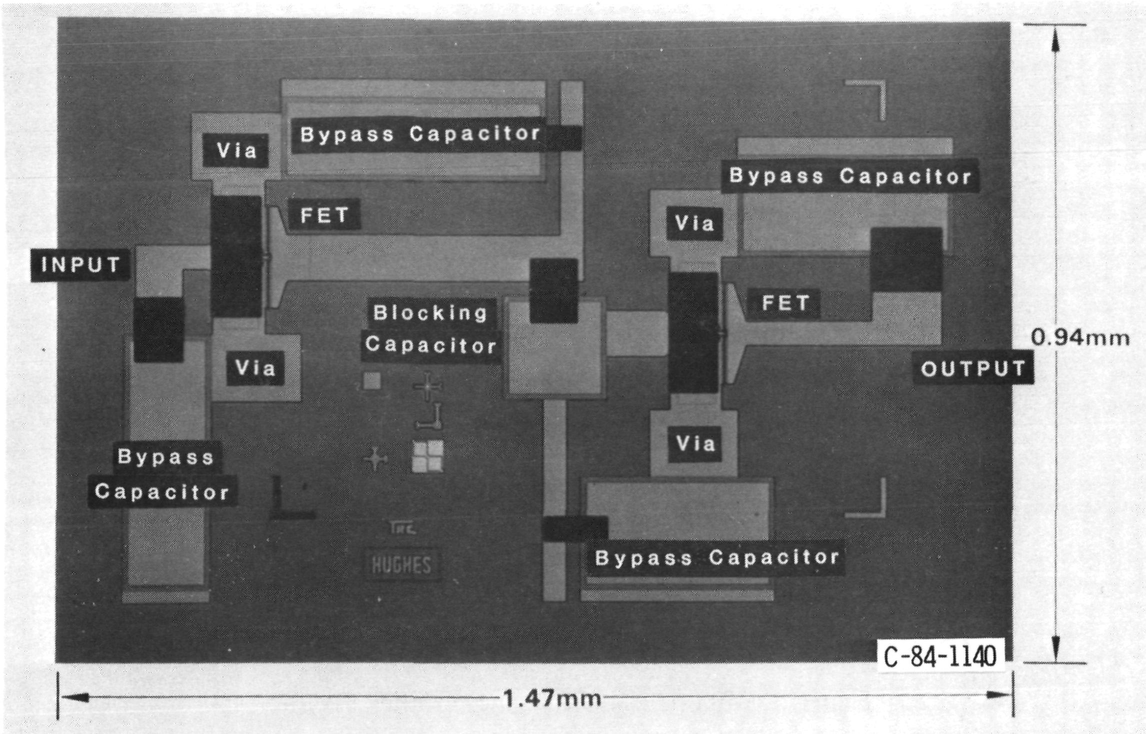


Figure 6. - 27.5 -30 GHz monolithic low noise amplifier.

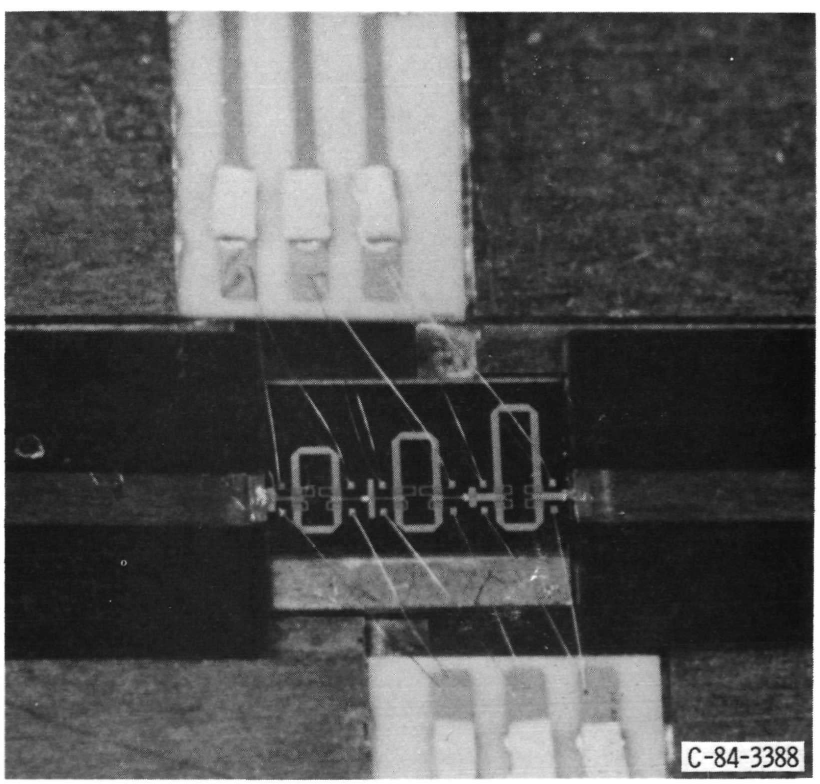


Figure 7. - Three bit 30 GHz phase shifter.

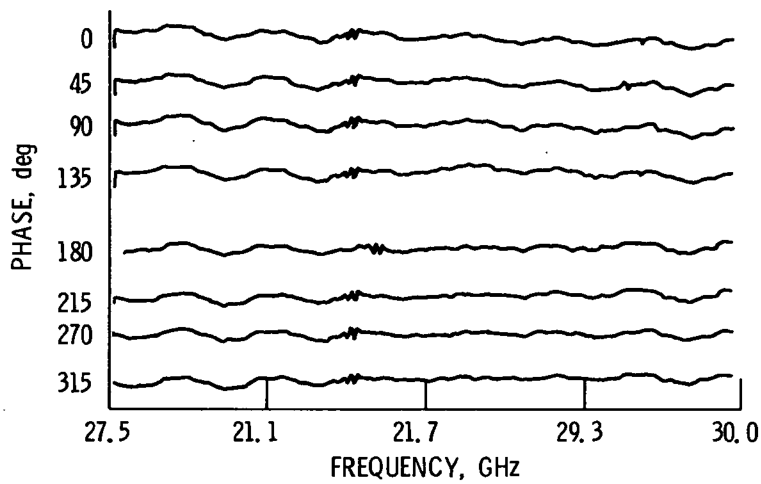


Figure 8. - Insertion phase for 3-bit phase shifter.

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16. Abstract

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