EHF SOLID STATE AMPLIFIER

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ABSTRACT

Two 5 watts Q-band solid state amplifiers have been developed. These amplifiers have a minimum of 24 dB gain over a 2 GHz bandwidth. The amplifier can operate from -20°C to +65°C utilizing an electronic temperature stabilization circuit. The experimental test results and the integration of the amplifiers will be presented in this paper.

INTRODUCTION

In today's microwave and millimeter-wave communications systems, great emphasis has been placed on the development of high power and compact packaged solid state transmitters. In order for the millimeter-wave transmitter to be feasible in a system, the reliability and cost of the amplifiers are of main concern. Silicon double-drift high power IMPATT diodes have been chosen as the power source for these solid state amplifiers.

Both of the amplifiers have two separate stages, a preamplifier stage and a high power stage. The electrical specifications for both stages are shown in Table 1. The amplifier must have a minimum of 5 watts output power with 24 dB gain. The frequency band of operation is from 43.5 to 45.5 GHz, over a temperature range of -20°C to +65°C. A schematic diagram of the 5 watt amplifier is shown in Figure 1. All the amplifier modules in both

TABLE I.
EHF SOLID STATE AMPLIFIER SPECIFICATIONS

A. Amplifier Specifications	Preamplifier	Hgh Power Amplifier
1.0 Electrical		
1.1 Frequency (f_0)	43.5 to 45.5 GHz	43.5 to 45.5 GHz
1.2 Bandwidth (f)	2 GHz	2 GHz
1.3 CW output power (P_0)	1 watt	5 watts
1.4 Gain (G)	17 dB ± 1 dB	7 dB + 0.5 dB
1.5 Gain ripple (G)	±0.1 dB/5 mh max	±0.1 dB/5 mh max
1.6 Harmonic output	-21 dB below fundamental	-20 dB below fundamental
1.7 Input and output VSWR	1.3 to 1 max	1.3 to 1 max
1.8 Junction temperature rise (T_j)	225°C max	225°C max
1.9 Operating voltage	50 V_{DC} max	50 V_{DC} max
2.0 Mechanical		
2.1 Cooling	Forced air	Forced air
2.2 Volume	1000 cc	2300 cc
2.3 Weight	1500 gm	3000 gm
2.4 Input/output waveguide	WR22	WR22
2.5 Ambient Temp. (T_A)	-20 to +65°C	-20 to +65°C
3.0 Reliability	20,000 hr	20,000 hr
4.0 Isolation loss of input and output port	20 dB/0.25 dB	20 dB/0.25 dB

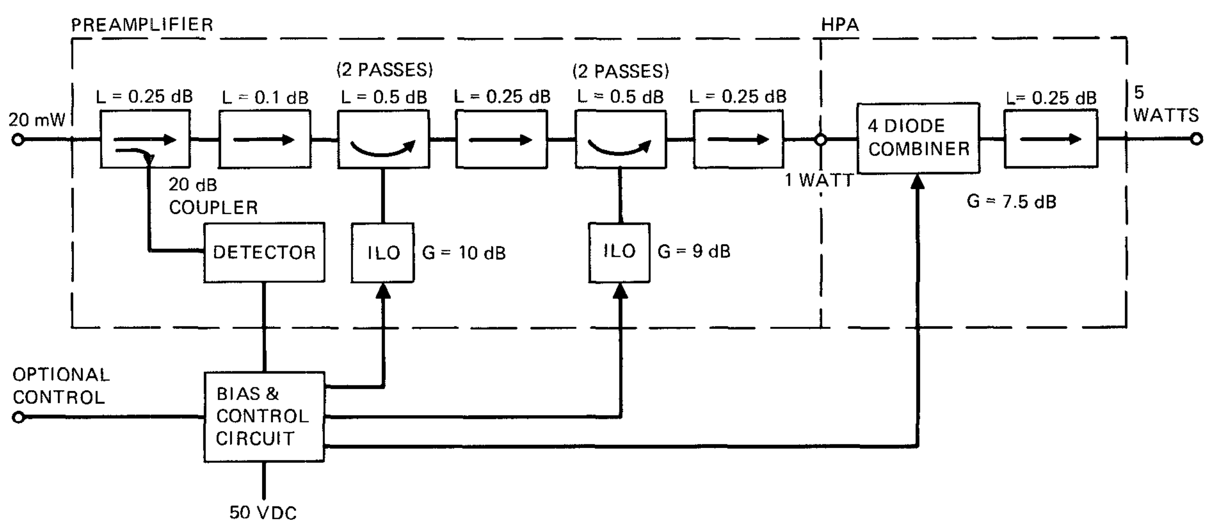

Figure 1. Schematic diagram of the 5W solid state amplifier assembly.

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stages operate in the injection locked oscillator mode. The injection locked oscillators have higher gain compared to the stable amplifiers; therefore, the number of amplifier stages and IMPATT diodes are reduced. A total of six IMPATT diodes are used in each amplifier to meet the output power and gain requirements.

Preamplifier Stage

As shown in Figure 1, the preamplifier section is made up of two driver modules, an integrated 7-port circulator, a crossguide coupler/detector with shutdown circuitry and IMPATT diode bias circuits. In order to meet the size and weight requirements, modular approaches are used in designing the IMPATT diode modules for the amplifier. The IMPATT diode is coaxially coupled to a reduced height waveguide circuit, then it is stepped to a full height Q-band waveguide.

Shown in Figure 2 is a cross-sectional view of the module IMPATT diode module. The circuit impedance can be varied by changing the dimensions of the matching rings, bias chokes, bias pins and reduced height waveguide section. The sliding backshort is used for optimizing the circuit impedance. Unlike the developmental modules, the time consuming and critical alignment of the coaxial shims is eliminated by the matching rings. The bias pin is insulated from the matching rings by a thin dielectric coating around its outer surface. The housings are made out of lightweight aluminum material. Typically, the new modular IMPATT driver module weighs approximately 70 grams as compared to 350 grams for a developmental module. A photo of the IMPATT diode driver module is shown in Figure 3.

Another critical component in the preamplifier stage is the integrated 7-port circulator. This 7-port circulator provides the required interstage isolation between the two driver modules. Three of the ports have been internally terminated with a matched load. The total insertion loss for the 7-port circulator is approximately 1.7 dB or 0.25 dB per pass. By utilizing the integrated 7-port circulator, the overall size and weight of the amplifier are greatly reduced.

The specifications require the output power level to be zero when there is no input power. Since all the amplifier modules are operating in the injection locked

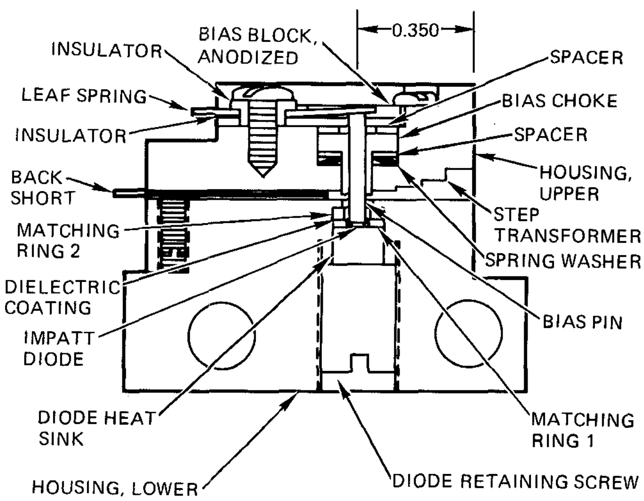

Figure 2. A cross-sectional view of the modular IMPATT diode module.

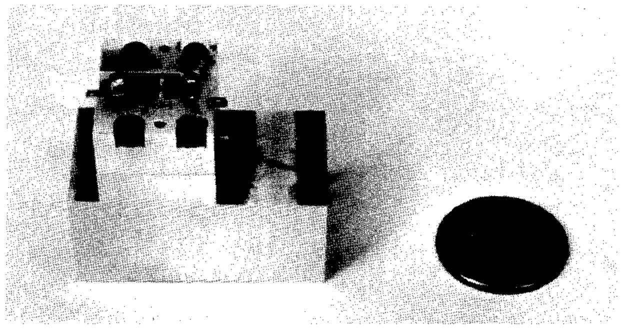

Figure 3. Lightweight modular IMPATT diode driver module used in the preamplifier stage.

oscillator mode, a scheme is required to turn off the RF output power. The crossguide coupler is used for detecting the presence of input power. A small amount of RF power is coupled to a detector diode, the output from the detector is then connected to a bias shutdown circuit. When the input power level drops below the locking range of the ILO, the bias current to each IMPATT diode module is turned off. The amplifier can also be manually shutdown with a TTL input signal. As shown in Table 1, the amplifiers are required to operate in the ambient temperature from -20°C to +65°C. In order for the amplifier to operate spurious free over this large temperature range, temperature bias compensation is required for each module.

A small temperature sensing resistor is used in conjunction with a LM117 voltage regulator in regulating the IMPATT bias currents over the large temperature range. An ideal temperature bias compensation would be to increase the bias current at low temperature, while decreasing the bias current when it is operating in high ambient temperature. By decreasing the bias current at high temperature, the diode's junction temperature is also reduced. By increasing the bias current at the low temperature range, it will not affect the diode's junction temperature as much.

High Power Amplifier Stage

The high power amplifier section consists of four IMPATT hybrid modules, three magic-T hybrids and an output isolator. The output powers from the four IMPATT hybrid modules are combined using three magic-T hybrids. Basically, the four-diode amplifier is made up of two two-diode hybrid power combiners. The output powers from the two-diode combiners are then combined through a center magic-T. The combining efficiency of the magic-T hybrid depends largely on the relationship of phase and amplitude between the modules. In the general case where phase and amplitude of the combining signals are not equal, then combining efficiency can be closely approximated by:

$$\eta_{comb} = \mathrm{Cos}^2 \frac{\theta}{2}\left[1-\frac{1}{2}\left(\frac{\Delta P}{P_{TOT}}\right)\right]$$

where

θ = the phase difference between the signals

ΔP = power difference between the signals

P_{TOT} = total power of the two modules

A plot of combining efficiency of the magic-T vs phase error between the modules is shown in Figure 4A. A lossless circuit and no amplitude mismatch have been assumed. The combining efficiency drops to 90% when the phase error is approximately 37 degrees between the modules. Another plot of combining efficiency vs amplitude mismatch between the modules is shown in Figure 4B. When the amplitude differs by 1.5 dB between the modules, the combining efficiency drops to 90%. It can be concluded that phase error between the modules is more critical in obtaining high combining efficiency.

The size and weight reduction of the hybrid modules and the magic-T hybrids are important in meeting the mechanical specification. The modular IMPATT hybrid module is shown in Figure 5. This module is made out of lightweight aluminum material, and it uses the same piece parts as the driver modules. Each IMPATT hybrid module weighs approximately 47 grams, which is lighter than the driver modules. A set of three magic-T hybrids that are used in the high power amplifier stage is shown in Figure 6. The total combined weight of three reduced size magic-T hybrids is approximately 69 grams, as compared to 440 grams for a single standard magic-T. In volume, the reduced size magic-T hybrid is less than 1/4 of the standard magic-T. In order to utilize all the modular waveguide components, all the waveguide flanges have been changed to a nonstandard pattern.

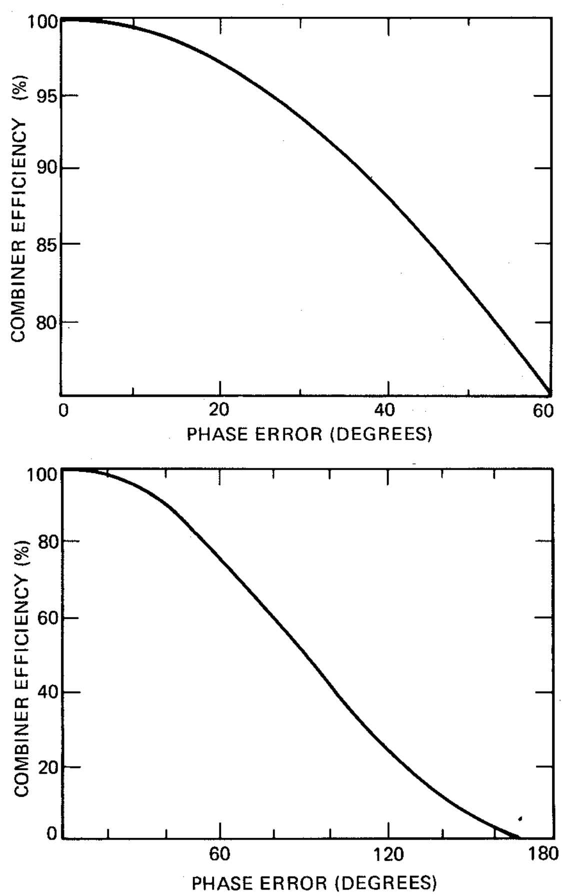

Figure 4a. Power combining efficiency due to phase mismatch between amplifier modules. A lossless circuit and no amplitude mismatch has been assumed.

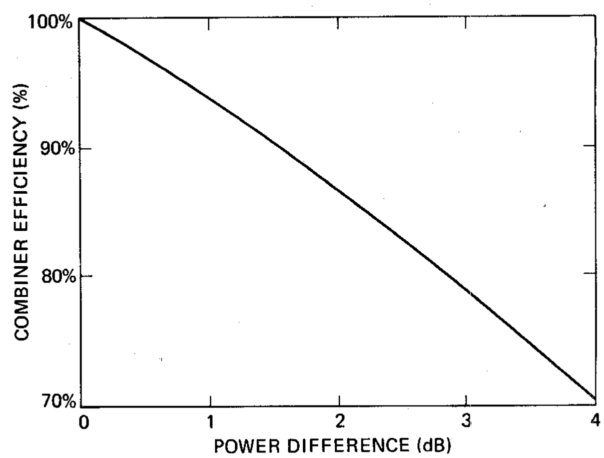

Figure 4b. Combiner efficiency due to amplitude mismatch of amplifier modules versus power difference between modules.

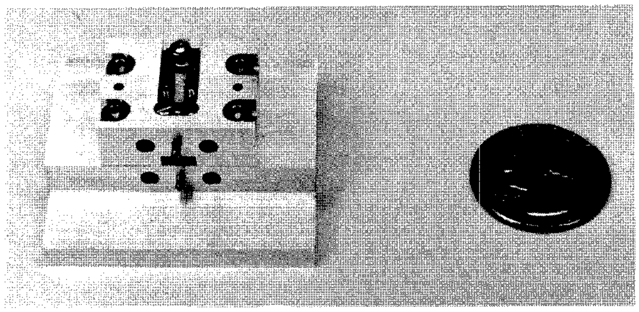

Figure 5. Modular IMPATT hybrid module used in the high power amplifier stage.

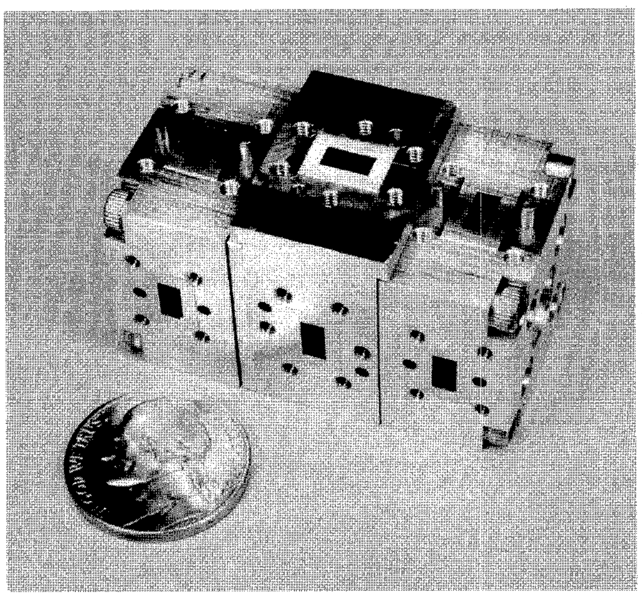

Figure 6. Three reduced size magic-T hybrids used in the high power amplifier stage.

Experimental Results

Both amplifiers have been built and characterized over the temperature range from -20°C to +65°C. With a nominal input power of 13 dBm, both amplifiers have an output power greater than 5 watts and a minimum of 24 dBm gain across the 2GHz bandwidth. The output power levels are also within 0.5 dB of each other as shown in Figure 7. The largest power difference is detected in the upper frequency band. The data were taken at the baseplate temperature of +30°C. With different input drive levels, both amplifiers show negligible variations in the output power level.

The two amplifiers also have been tested at the two extreme temperatures, at -20°C and +65°C. The temperature data for amplifier S/N001 and S/N002 are shown in Figures 8A and 8B, respectively. In order for the amplifiers to operate spurious free at -20°C, temperature compensation has been incorporated into each IMPATT diode bias circuit. It has been experimentally determined that these two amplifiers operate spurious free with a lower bias current at -20°C. As a result of reducing the IMPATT bias current, the output power is approximately 1 dB below their maximum power level. A phot of the two amplifiers is shown in Figure 9, each amplifier weighs approximately 1.74 kilograms and the total volume is less than 1400 cubic centimeters.

CONCLUSION

The electrical performances obtained from these two EHF solid state amplifiers have demonstrated Hughes' capabilities in the millimeter-wave technology. From this R&D program, Hughes has shown its abilities to reproduce lightweight, low cost and state-of-the-art performance in the millimeter-wave solid state amplifier.

Acknowledgements

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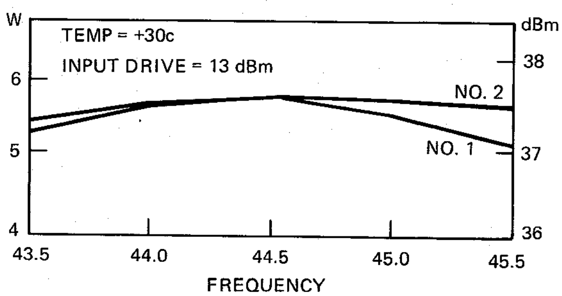

Figure 7. EHF solid state amplifier S/N001 and S/N002, data taken at room ambient temperature.

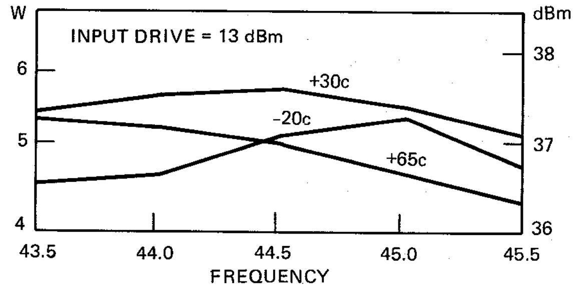

Figure 8a. Temperature data for EHF solid state amplifier S/N001.

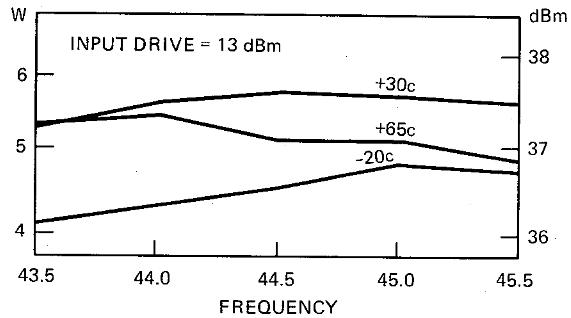

Figure 8b. Temperature data for EHF solid state amplifier S/N002.

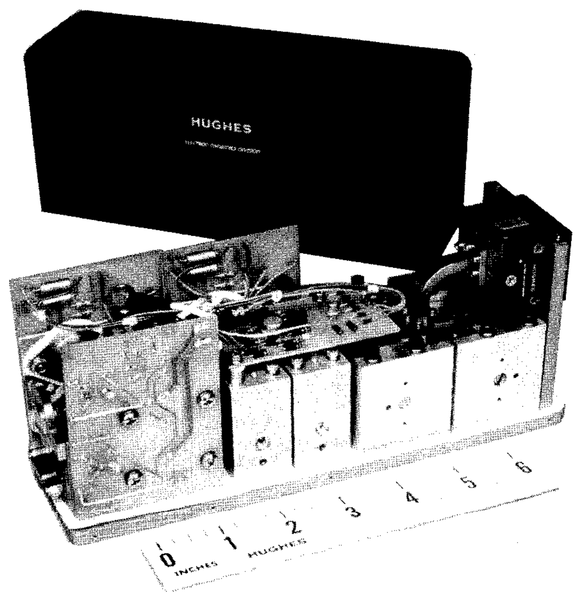

Figure 9. EHF solid state amplifiers, S/N001 is shown in the foreground while S/N002 is in the background.