41 GHz 10 WATT SOLID STATE AMPLIFIER

Dale W. Mooney and Franklin J. Bayuk
TRW Electronics and Defense Sector
One Space Park
Redondo Beach, California 90278

Introduction

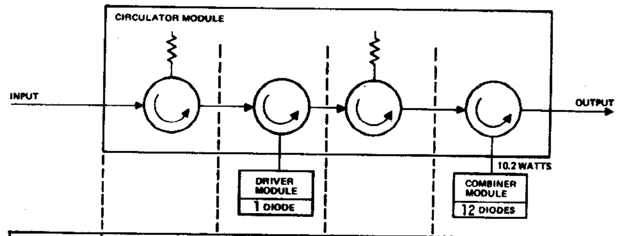
This paper describes the results of the study, design, development and test of a 10-watt, 41 GHz solid state amplifier employing rectangular waveguide resonant cavity mode combining of high frequency diodes. This development effort is of significance because it extends beyond 40 GHz the ability to design high power, broadband, multistage amplifiers with reasonable efficiencies suitable for spacecraft applications. Specifically, an amplifier with a power level of more than 10 watts and gain level of greater than 30 dB and a bandwidth of 250 MHz at 41 GHz was demonstrated. This development offers an alternative to the traveling wave tube amplifier in the millimeter wave spectrum. Such an amplifier has projected high reliability and less complexity, size, and weight than a TWTA and is therefore particularly suitable for space applications.

Amplifier Description

The 2-stage design consists essentially of two modules: a driver module, followed by a combiner module. The driver module contains a single-diode circulator-coupled wideband injection locked amplifier which provides a total gain of 17.7 dB with an output of 400 mW. The driver stage and the power combining stage both incorporate 1-watt silicon double drift diodes. The individual amplifier stages are coupled to the main channel via a cascaded multi-junction circulator module. These circulators show a typical measured insertion loss level of less than 0.3 dB per pass and typical bandwidth of 10 GHz. Typical reverse isolation exceeds 20 dB per junction.

Figure 1 illustrates the amplifier gain and power distribution achieved. The driver stage performance represents an exceptionally low Q_{ext} of 8 resulting in gain and bandwidth achievement far in excess of the design goal Q_{ext} of 20. This performance was achieved through an iterative design procedure of matching device and circuit impedance levels which resulted in unprecedented agreement between measured and calculated results at millimeter wave frequencies. Figure 2 shows a cross-section of the single diode driver stage with the corresponding circuit and a sampling of comparative experimental versus calculated impedance information from the position of the diode for distinctly different bias line conditions. The circuit model determined from the driver stage development was subsequently employed to design the twelve-diode combining amplifier.

The high power second stage combines the output power from the twelve diodes in a rectangular resonant cavity. This design is based on that by Kurokawa[1] and features independently biased peripheral coaxial modules similar in structure to the driver stage bias line design. Coupling between the coaxial modules and the resonant cavity is achieved via the interaction of the magnetic fields, as indicated in Figure 3. This coupling is modeled by an ideal transformer as indicated in the equivalent circuit representation, shown in Figure 4. Also shown are some of the component parts of the combining amplifier.



OVERALL GAIN	17.7 dB						14.3 dB	
GAIN/LOSS	-0.3 dB		+18.9 dB		-0.3 dB		+14.8 dB	
POWER, dBm	+8	+7.7	+7.4	+26.3	+26.0	+25.7	+25.4	+40
POWER, mW	6.3	5.9	5.5	426	398	372	347	10 Watts

Figure 1. 41 GHz 10 Watt Amplifier Gain and Power Distribution

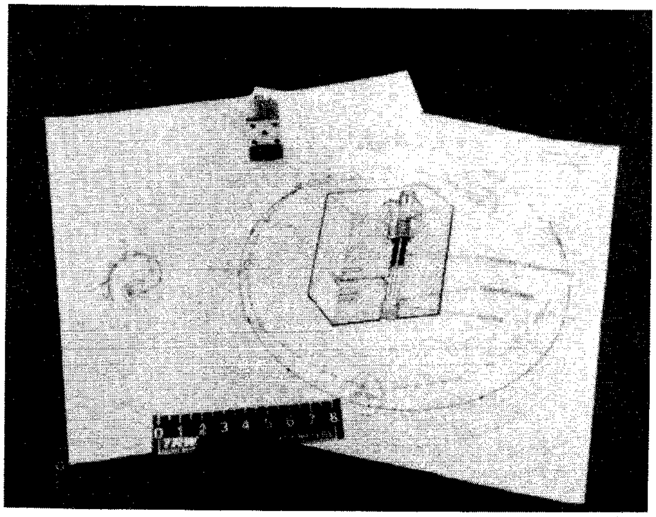


Figure 2. 41 GHz Driver Stage

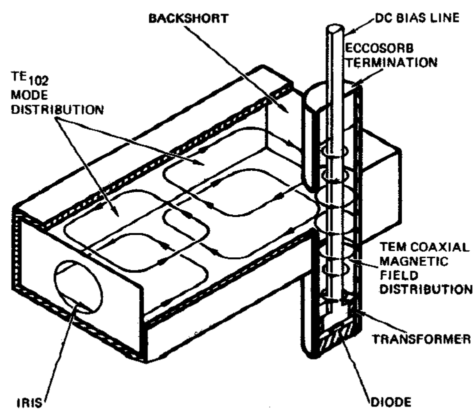


Figure 3. Magnetic Field Line Coupling Between Coaxial Module and Cavity

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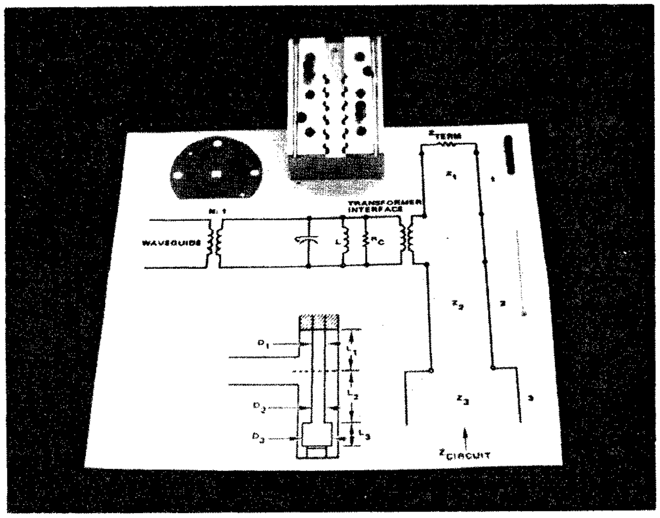

Figure 4. Combining Amplifier Equivalent Circuit and Hardware

The two amplifier stages were integrated with a four-junction circulator module and thirteen current regulator/power conditioning circuit cards onto a common baseplate. This configuration results in an attractive, compact and rugged design. The unit is 10x20x6.25 cm (4x8x2.5 inches) in size, and weighs 2 kg (4.4 pounds). Figure 5 shows the complete amplifier unit.

Figure 5. 41 GHz 10 Watt Amplifier

Amplifier Performance Summary

The performance of the amplifier was evaluated in standard laboratory ambient temperature conditions. The baseplate temperature was allowed to deviate to assess performance with respect to temperature. Figure 6 summarizes this power, frequency and bandwidth performance.

The amplifier was also subjected to a random vibration in three axes to verify spacecraft launch survivability. During vibration, telemetry was monitored to verify bias line continuity. The data acquired gave no indication of interrupted bias current and thus verified the design integrity from a DC perspective. After completion of the vibration test, the amplifier was evaluated in terms of the RF performance. A frequency shift of 120 MHz was noted, however, the power and bandwidth performance was unchanged. The change in frequency was traced to movement in the dielectric sleeve which surrounds the bias line in the driver stage. This sleeve was returned to its proper position, and nominal performance was again observed.

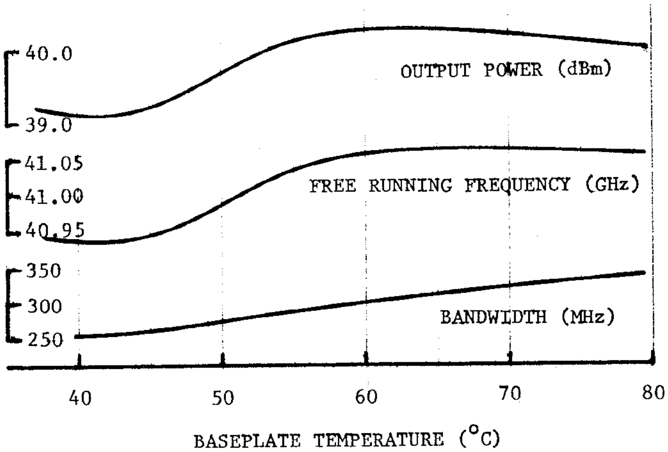

Figure 6. Power, Frequency and Bandwidth Performance versus Baseplate Temperature

Conclusion

Table 1 identifies all of the parameters that were evaluated and presents the requirement versus the capability for each item. These performance figures, in conjunction with a compact design, substantiate a package which represents a major step toward realizing a solid state amplifier suitable for spacecraft applications.

Acknowledgement

This work was sponsored and funded in part by AFWAL, Wright-Patterson Air Force Base, Ohio 45433, under Contract No. F33615-77-C-1185.

Reference

1. Kurokawa, K., "The Single-Cavity Multiple-Device Oscillator," IEEE Trans. Microwave Theory and Tech., Vol. MTT-19, Oct. 1971, pp. 793-801.

Table 1. Summary of EHF Solid State Amplifier Performance Requirements versus Capabilities

Parameter	Requirement	Tested Capability
Center Frequency (GHz)	41	41
Bandwidth (MHz)	100	>250
Amplifier Efficiency (%)	10	>6
Output Power (Watts)	10	>10
Output Power Variation		
Maximum Peak-to-Peak (dB)	0.1	0.6
Maximum w/Frequency (dB/MHz)	0.1	<0.1
With 4 dB Maximum Drive Level Range, over Freuqency and Temperature (dB)	1.2	1.2
Input Power Range (dBm)	8 to 12	8 to 12
Nominal Gain (dB)	30	30
VSWR		
Input, Maximum	1.25:1	<1.1:1
Output, Cold, Maximum	1.5:1	<1.1:1
Thermal		
Baseplate Temperature Range (°C)	+5 to +50	+37 to +82
Maximum Base Plate Power Dissipation (Watts/in.^{2})	10	5.5