COMPACT, RELIABLE 70-WATT X-BAND POWER MODULE WITH GREATER THAN 30-PERCENT PAE

James Sweder, G. Austin Truitt, Stephen R. Nelson, and James S. Mason

Texas Instruments Incorporated
Dallas, Texas 75265

ABSTRACT

A compact X-band solid state module with greater than 70 watts and over 30 percent PAE has been demonstrated over 9.5 to 9.9 GHz. A peak power level in excess of 77 watts with an associated PAE greater than 31 percent is reported. Minimum gain is greater than 13 dB over this frequency range. This was accomplished by combining six highly reliable 12-watt HFET MMIC amplifiers.

INTRODUCTION

The availability of affordable and reliable MMIC amplifiers has enabled their insertion in applications that were traditionally realized in vacuum tube technology. The amplifier module shown in Figure 1 provides high power, small size and excellent reliability.

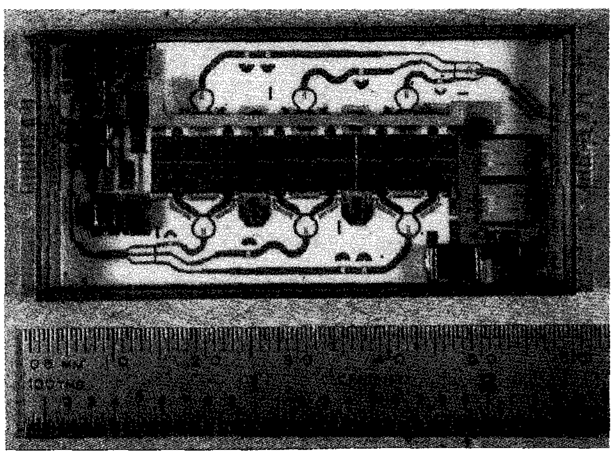

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Figure 1. High Power Module

Figure 2 shows better than 70 watts with a minimum of 30 percent PAE over 9.5 to 9.9 GHz operated in class AB mode. This high efficiency performance provides many system benefits. These include high MTTF, smaller power supplies, and lower weight and system cost. Table 1 shows results for various frequency ranges.

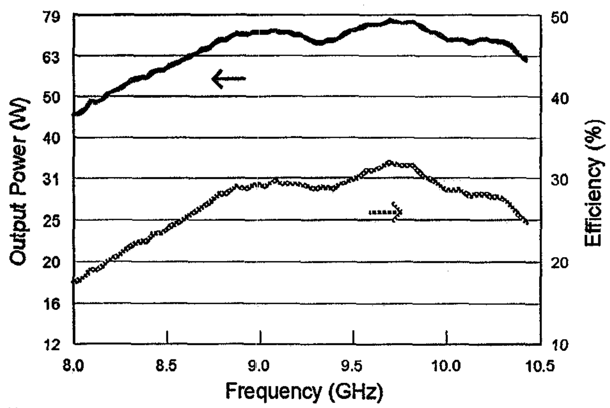

Figure 2. Measured Data for Module

TABLE 1. MODULE PERFORMANCE

Frequency (GHz)	Output Power (W)	PAE (%)
9.7	>77	>31
9.5 to 9.9	>71	>30
8.7 to 10.3	>65	>26
8.6 to 10.4	>60	>24
8.4 to 10.4	>55	>23

This production-ready design is compatible with the high yield automated assembly processes in place in the Texas Instruments module production facilities. Texas Instruments has produced over

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50,000 complex modules using these processes in the Microwave Automated Factory (MAF). The mature HFET MMIC technology provides a highly reliable high power (12 watts per MMIC) amplifier. The choice of standard parts for all other components allows a compact module of less than 2.5 by 1.1 by 0.200 inches. These ingredients provide a highly reliable module over a wide range of environmental conditions.

Versatility comes from the simple construction of this module. The choice of amplifiers can change the power level, efficiency, and frequency range. Although these parameters can be altered, all other circuitry can remain unchanged (i.e., gate regulator, drain modulator, and the six-way combining network).

MODULE PERFORMANCE

The module, when operated in a class AB pulsed mode, is capable of delivering in excess of 70 watts with greater than 30 percent PAE and over 13 dB of gain.

This configuration has been thoroughly tested over temperature. While altering the base plate temperature, the RF pulse envelope and drain current were monitored. No abnormalities were observed. Reducing the fixture temperature to -55°C leads to a 15-percent increase in power and a decrease in PAE of about six points. The gain is increased by roughly 0.8 dB and the drain current increased by about 50 percent. Increasing the temperature to 40°C led to a decrease in output power of less than 0.5 dB with the PAE remaining largely unchanged.

The module was load pulled to verify stability with the RF pulse envelope and the drain current monitored. No signs of oscillation were present. The module was also operated in an open circuit termination without degradation or signs of instability.

The drain modulator is capable of sourcing large amounts of current. In pulsed mode, switching this current in short time periods requires low inductance to avoid large voltage spikes. This is governed by V = Ldi/dt. The Bus Bar concept implemented in this module provides low inductance and low resistance. Measured results have shown with over 20 amps of current switched in less than 50 ns, there is less than a 2-volt spike. In addition, the IR drop is less than 50 mV over the 1.2-inch-long bus bar.

MODULE HOUSING/ASSEMBLY

Proven technologies and assembly processes have been used. The housing consists of a copper molybdenum (CM-15) base for good thermal properties and a good TCE match to GaAs. An Alloy 46 ringframe is brazed to the CM-15. Ceramic feedthroughs provide connections for rf and dc. The power MMICs are solder mounted to CM-15 pedestals. These along with the alumina TFNs are solder mounted to the base. HEXFET switches and the bus bar are solder mounted to the TFNs. All other components are conductive epoxy mounted. Split-tip welding and ball bonding complete the assembly.

Figure 3 shows the module to have four subassemblies; the gate regulator, the drain modulator, the combining network, and the MMIC amplifiers.

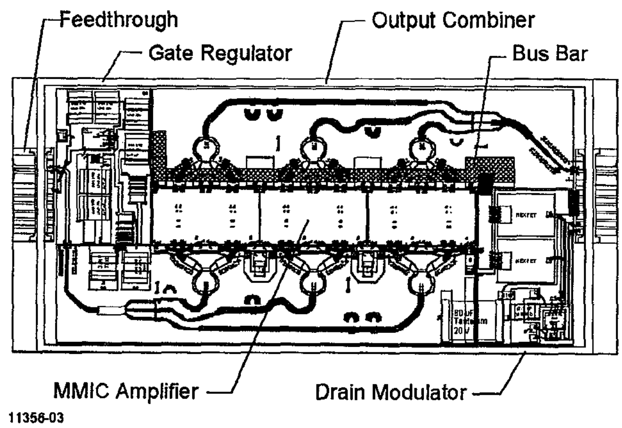

Figure 3. Module Layout

The gate regulator is an adjustable negative regulator. There are a few resistors to provide feedback to set the output level. Capacitors are used for stability and charge storage for pulsed operation. Although temperature compensation is not included, it can easily be incorporated.

The drain modulator consists of two HEXFET switches in parallel (to reduce IR drop through the modulator), a driver for pulsed operation, and some storage capacitance. The output (drain) of the HEXFETs is attached to the bus bar. The bus bar is designed to minimize the inductance and the resistance while maximizing the clearance to all RF lines it must cross.

The six-way corporate combiner network is fabricated on 15-mil alumina. There are two levels of Wilkinson combining with two-section λ/4 transformers to go from 25-Ω MMICs to 50-Ω I/O. Figure 4 shows back-to-back measurements with less than 0.8 dB combining loss over 8.5 to 9.5 GHz. This is a combining efficiency in excess of 83 percent. This indicates the phasing of all paths is properly equalized.

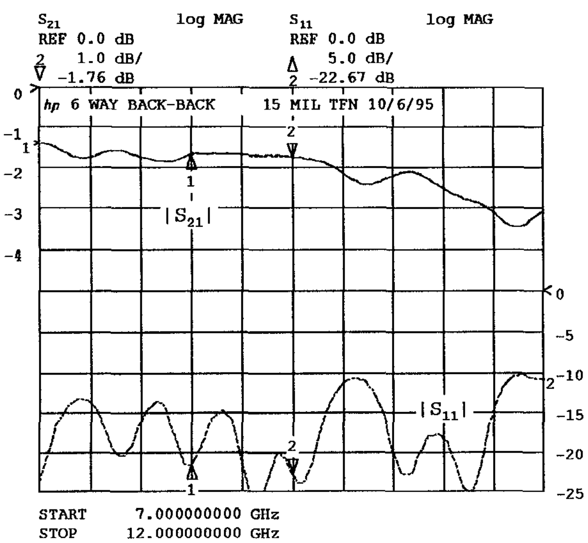

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Figure 4. Six-Way Combiner Back-Back Measurement

MMIC AMPLIFIER

The power amplifier is the TI EG8212. This is a dual-path device. The MMIC has 25 ohms input and output impedance when configured as shown in Figure 5. Test results of the EG8212 configured in this manner are shown in Figure 6. Each half amplifier is capable of delivering in excess of 5 watts at 37 percent PAE over the 8 to 10.4 GHz range while operating at V_{ds} = 8.5 V and I_{ds} = 1.5 to 1.6 amperes.

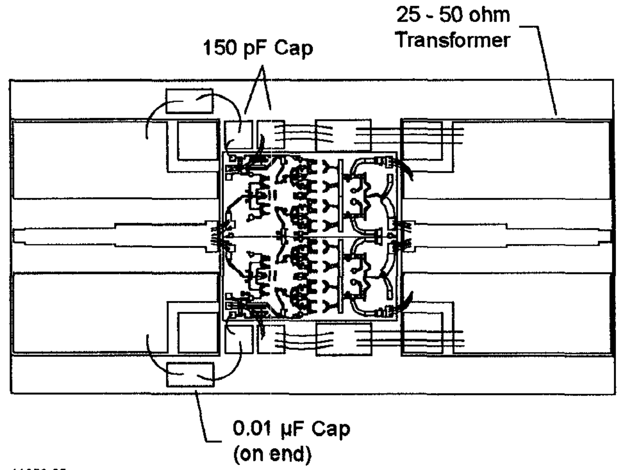

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Figure 5. Single Amplifier Configuration

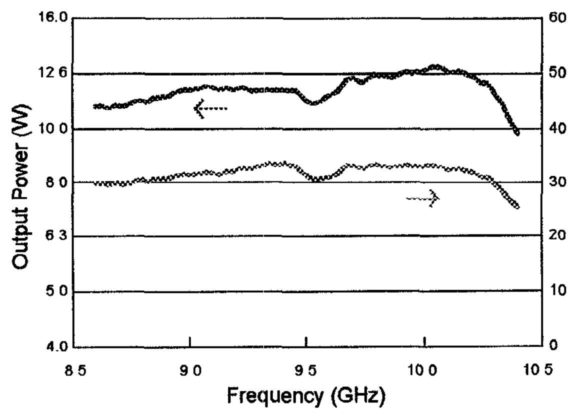

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Figure 6. Single Amplifier Fixtured Response

RELIABILITY

Reliability of the module is driven by the reliability of the MMIC amplifiers. Life test studies on HFET power MMICs have shown the median life in excess of 1E8 hours for junction temperature of 140°C and less[1]. Thermal analysis using finite difference numerical techniques[2] predicts junction temperatures well below 140°C. However, using a serial reliability model and 140°C junction temperature, the MTTF for the module is in excess of 480,000 hours.

CONCLUSION

A power module design utilizing six HFET power amplifiers has demonstrated in excess of 70 watts and 30 percent PAE over 9.5 to 9.9 GHz.

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A power module design utilizing six HFET power amplifiers has demonstrated in excess of 70 watts and 30 percent PAE over 9.5 to 9.9 GHz. Using proven materials and assembly processes leads to a compact, easily produced, reliable power amplifier.

ACKNOWLEDGMENTS

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[1] Decker, K. "Reliability Study of a New HFET Process", Presented at 1993 GaAs Rel Workshop Sponsored by JEDEC JC-50, San Jose CA.

[2] Wilson, J. and Decker, K. "GaAs MMIC Thermal Modeling for Channel Temperatures in Accelerated Life test Fixtures and Microwave Modules", IEEE Tenth SEMI-THERM.