

# 3-WATT Q-BAND WAVEGUIDE PHEMT MMIC POWER AMPLIFIER MODULE

J.A. Lester, J. Chi, R. Lai, M. Biedenbender,  
D. Garske, R. Rordan, and P.D. Chow.

TRW Electronics Systems and Technology Division  
Redondo Beach, CA

## ABSTRACT

Presented is a 3 watt Q-Band PHEMT MMIC power amplifier module with a peak efficiency of 25% at 44.5 GHz, believed to be the highest reported at this power level and frequency. The waveguide power amplifier module features the use of thinned 2-mil GaAs MMICs with off-chip output matching and combining on a 5-mil alumina substrate.

## INTRODUCTION

High efficiency Q-band power amplifiers are a necessity for many EHF SATCOM ground terminal applications. This amplifier module is based on a 2-mil thick PHEMT MMIC amplifier that was presented previously [1]. This work presents a higher level of integration and power combining to yield a power module building block for off-the-shelf transmitter applications. This module features input and output waveguide ports such that higher levels of power can be achieved by simpler combining at the waveguide level. The module has achieved 3 watts of output power with 11.8 dB power gain and a power-added efficiency of 25%, with all data referenced to the waveguide ports.

## POWER AMPLIFIER MMIC DESIGN

The MMIC power amplifier was designed for fabrication using TRW's pseudomorphic InGaAs 0.15  $\mu\text{m}$  T-gate power HEMT process with some key modifications from the previously reported process [2,3]. A single-input, dual-output amplifier design was

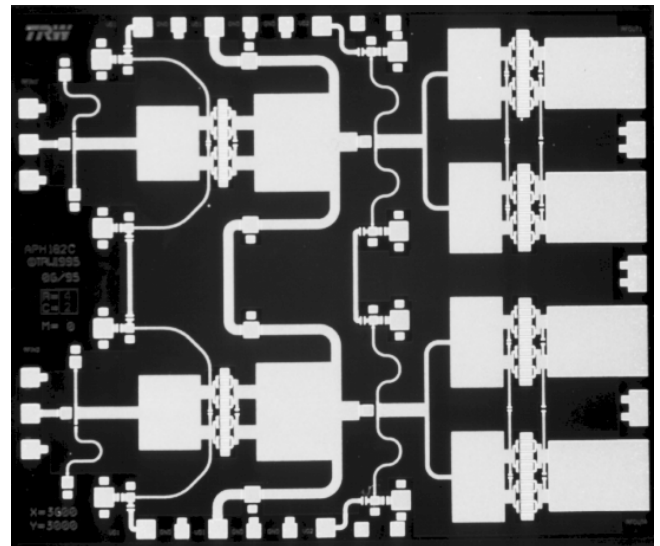


Figure 1. 2-Mil PHEMT Partially-Matched MMIC Power Amplifier

presented previously in [1]. The new amplifier design (a picture is shown in Figure 1) combines two of the previous design into a two-input, four-output MMIC as well as slightly increasing the device periphery of the output stage.

The amplifier is a 2-stage design, with 1.6 mm of device periphery in the first stage driving 4.48 mm in the second stage. The input is matched to a standard 50 ohm impedance, using what is essentially a low-pass matching structure. Gate bias for the first and second stages as well as the first stage drain bias are provided by pads on either side of the chip and contain on-chip bias networks of thin film resistors and MIM capacitors to provide stability. The output of the amplifier is 4 ports

(after an interstage power split), each with 1.12 mm of device periphery. The 4 ports are matched to a real 36 ohm impedance level, to be combined and transformed by the off-chip combiner. The drain bias for the output stages is also provided through the combiner network. By moving the final combining and matching structures and the 2nd stage biasing off-chip, the MMIC size has been greatly reduced and the overall performance of the amplifier improved because of the lower loss alumina substrate.

#### OFF-CHIP COMBINER DESIGN

The microstrip power combiner takes eight 36 ohm ports, combines them, and then transforms them to 50 ohms by means of a quarter-wave transformer. The combiner is a fairly standard Wilkinson, but designed for 36 ohm impedances rather than 50 ohm. The combiner is implemented on 5-mil alumina substrate and also includes dual-sided bias connections for the drain of the second stage devices by means of an RF choke implemented

with microstrip radial stubs. The input power divider is a 4-way design implemented with two levels of Wilkinson dividers and is also fabricated on 5-mil alumina.

#### POWER MODULE DESIGN

The power module (Figure 2) is designed for WR-22 waveguide interface. The waveguide attaches to the backside of the module with 2 - screw flanges for each port. The hermetic transition from the waveguide to microstrip is achieved with a waveguide probe glass bead that is soldered into the aluminum matrix housing. The backshort for the probe transition is machined into the housing. The housing cover is aluminum and is laser-sealed to achieve hermeticity. In addition to the two MMIC power amplifiers and the alumina divider and combiner substrates, the module includes 100 pF chip capacitors for DC bypassing, thin film chip resistors for the setting of gate bias voltages, and DC feed-thru pins that are also soldered in for hermeticity.

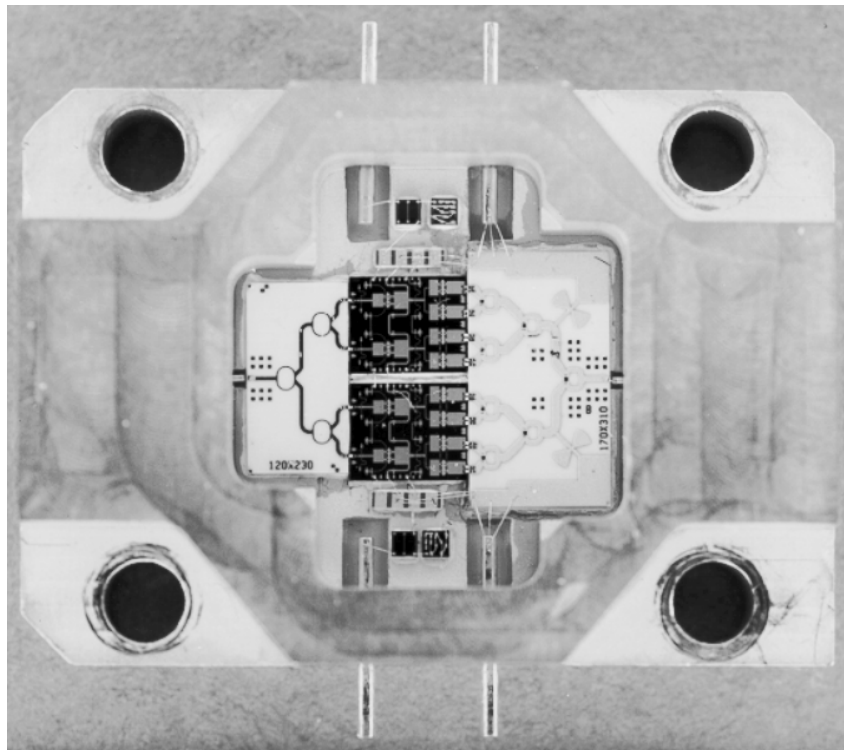


Figure 2. 3 Watt Q-Band Waveguide Power Module with 2 Mil PHEMT MMICs

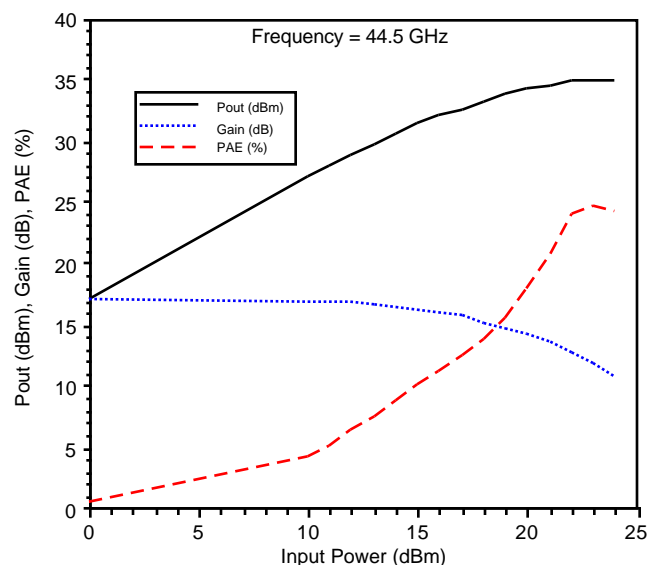


Figure 3. Output Power, Gain, and Power-Added Efficiency of 3 Watt Power Module.

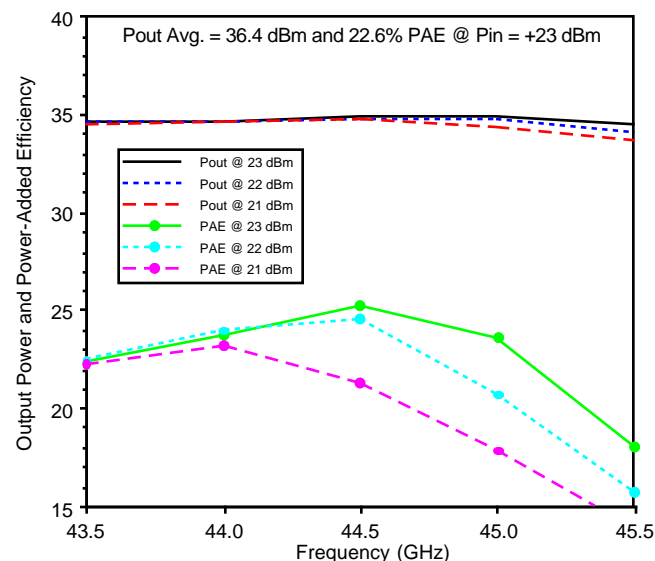


Figure 4. Power Output and PAE vs. Frequency.

## MEASURED RESULTS

Figure 3 shows the measured output power, gain, and power-added efficiency as a function of input power for one of the amplifier modules. At a frequency of 44.5 GHz, the module delivers 34.8 dBm (3 watts) of output power with 11.8 dB gain and a PAE of 25%. Figure 4 shows the output power and PAE from 43.5 to 45.5 GHz for the input power levels of 21, 22, and 23 dBm. At an input power of 23 dBm, the amplifier module achieves an average output power of 2.9 watts and an average PAE of 22.6% across the 2 GHz band. Figure 5 shows the output power performance and Figure 6 the PAE performance for a sample set of 5 modules, showing good repeatability.

## CONCLUSION

We have demonstrated a state-of-the-art high power high efficiency Q-Band MMIC power amplifier module using 2-mil thick PHEMT MMICs and alumina microstrip combiners. The amplifier delivers what we believe to be the best power-added efficiency and output power for a PHEMT Q-Band power-amplifier module, a peak of 3 watts with 25% PAE at 44.5 GHz.

## ACKNOWLEDGMENTS

Thanks to Marshall Huang for his guidance. This work was sponsored by the Air Force Rome Laboratory, Rome, NY under Contract No. F30602-95-C-0037 with funding from the Milstar Joint Program Office. Rome program manager is Capt. Joel Junker.

## REFERENCES

- [1] J.A. Lester, Y. Hwang, J. Chi, R. Lai, M. Biedenbender, and P.D. Chow, "Highly Efficient Compact Q-Band MMIC Power Amplifier Using 2-mil Substrate and Partially-Matched Output," IEEE 1996 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, p. 171-173.
- [2] R. Lai et al., "0.15  $\mu$ m InGaAs/AlGaAs/GaAs HEMT Production Process for High Performance and High Yield V-band Power MMICs," 1995 GaAs IC Symposium Tech. Digest, pp. 105-108.
- [3] M. Biedenbender et al., "A Power HEMT Production Process for High Efficiency Ka-Band MMIC Power Amplifiers," 1993 GaAs IC Symposium Tech. Digest.

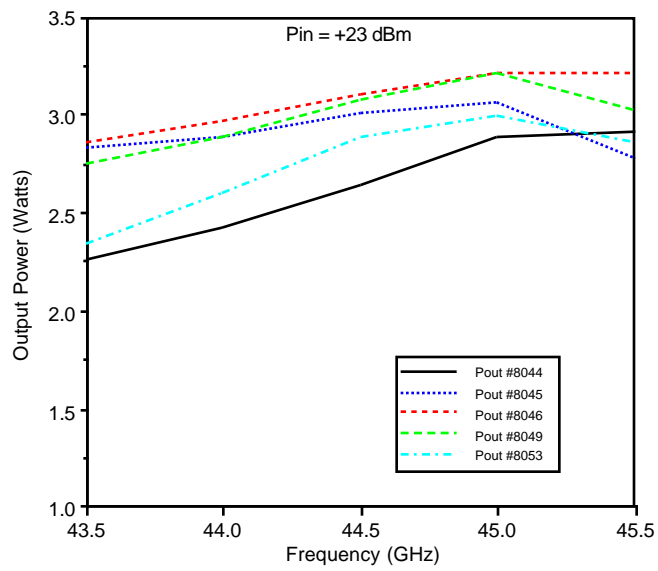


Figure 5. Power Output of (5) Power Modules.

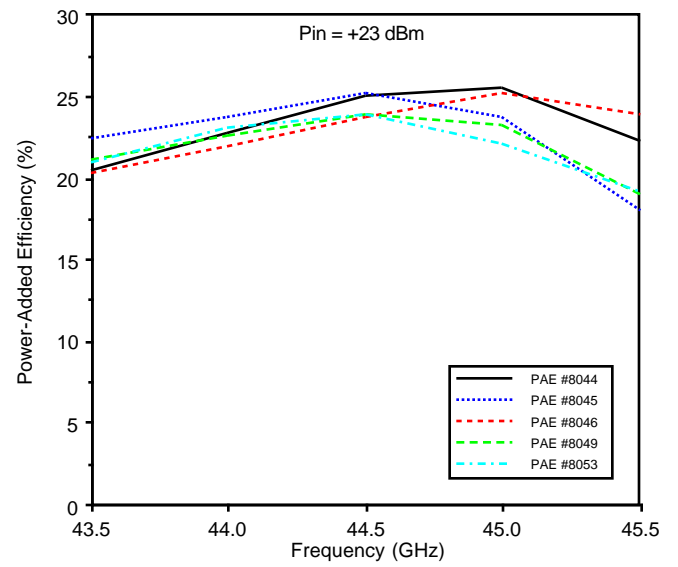


Figure 6. Power-Added Efficiency of (5) Power Modules