A HIGH EFFICIENCY 10 WATT HBT POWER AMPLIFIER ASSEMBLY USING COMBINING TECHNIQUES

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Abstract

Six 2 Watt AlGaAs/GaAs Heterojunction Bipolar Transistor (HBT) MMIC amplifiers have been combined using low loss, low temperature cofired ceramic (LTCC) splitting and combining networks. The six MMIC amplifiers were combined in a compact, testable, and producible assembly. The amplifier assembly produced 10 Watts peak output power and 30% peak power added efficiency (PAE) over an 8.0 to 14.0 Ghz bandwidth. This wideband power amplifier has applications in solid state transmitters and transmit/receive (T/R) modules that require high gain, high power, high efficiency, and compact size.

This assembly has demonstrated 10 Watts peak power and greater than 30% peak PAE in the 8-14 Ghz band (> 50% bandwidth). Current HFET and PHEMT based MMIC assemblies are producing 10 Watts over a 20-25% band at X-band with 35% power added efficiency. Continued evolution and refinement of the HBT MMIC and LTCC coupler networks will produce a full band 10 Watts and 40% PAE.

Overview

The rapidly advancing technology developments of the Heterojunction Bipolar Transistor (HBT) and multilayer low temperature cofired ceramic (LTCC) substrates have yielded a compact, wideband microwave power amplifier assembly. This X-Ku band testable assembly was designed to be producible in large volume, (i.e. > 400/month). The overall assembly, shown in Figure 1, includes three testable dual MMIC chip carrier subassemblies with integral constant current bias application specific integrated circuit (ASIC), LTCC splitting and combining networks, D.C. regulation and modulation ASICS, local energy storage capacitance, and a CM15 carrier plate.

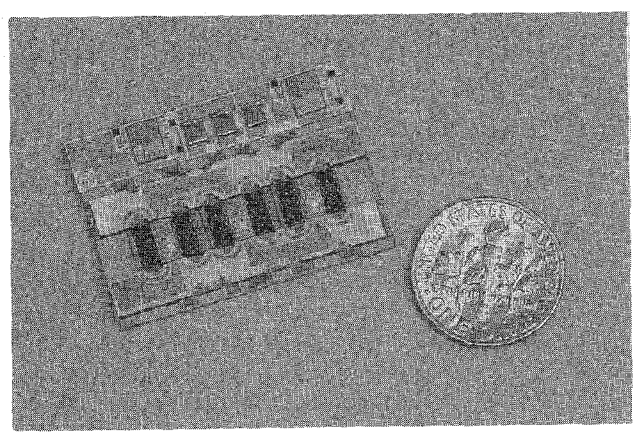

Figure 1. Power Amplifier Assembly

MMIC Power Amplifier

The basic building block of this assembly is the 2 Watt HBT MMIC [1]. This two stage MMIC, comprised of four 0.25 Watt input unit cells driving eight 0.25 Watt output unit cells operates at 7 Volts and produces 2 Watts nominal over the full band with a PAE of 40%. The HBT unit cell structures were grown by MOCVD on 3" GaAs wafers at the Westinghouse Advanced Technology Division's (ATD) foundry. Each unit cell has four 2 um x 20 um emitter fingers with ballast resistance to prevent thermal runaway. The optimum load impedance for the unit cell was determined by using an automated load-pull test set-up. The optimum MMIC load impedance was then determined from the unit cell load-pull test data and used to design the MMIC output matching circuit. The MMIC input matching circuit was determined from small signal input impedance measurements of the unit cell. The MMIC was designed in a 25 Ohm system impedance in order to minimize circuit losses from the eight output unit cells to the output of the power amplifier assembly combining network. The MMIC has > 20 dB of small signal gain. Figure 2 demonstrates the MMIC performance for power and PAE. Excellent repeatability of performance has been demonstrated through multiple wafer runs in the ATD foundry.

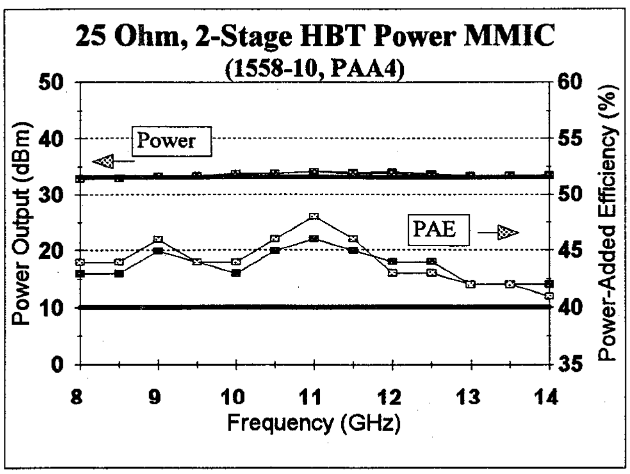

Figure 2. HBT MMIC Output Power and Power Added Efficiency

Splitter/Combiner Network

The 6 way power splitter/combiner was designed in LTCC multilayer stripline using Ferro A6 material with a dielectric constant of 5.9 and a loss tangent of 0.002. The splitter/combiner networks use a serial combination of three paralleled (balanced) pairs. A balanced serial combiner (Figure 3) was used to provide better return loss across the band as compared to a straight serial 6-way combiner [2]. The internal stripline couplers are designed in a 32 Ω impedance and transformed to either the 25 Ω output impedance of the MMIC or the 50 Ω impedance at the assembly interfaces. The balanced/serial combiner was chosen as the best alternative for physical constraint requirements and performance when combined with the 2 Watt HBT MMIC. The splitter/combiner networks were fabricated with results closely approximating prediction and very repeatable from unit to unit. The design, fabrication and test of the combiner are described in separate papers [3],[4].

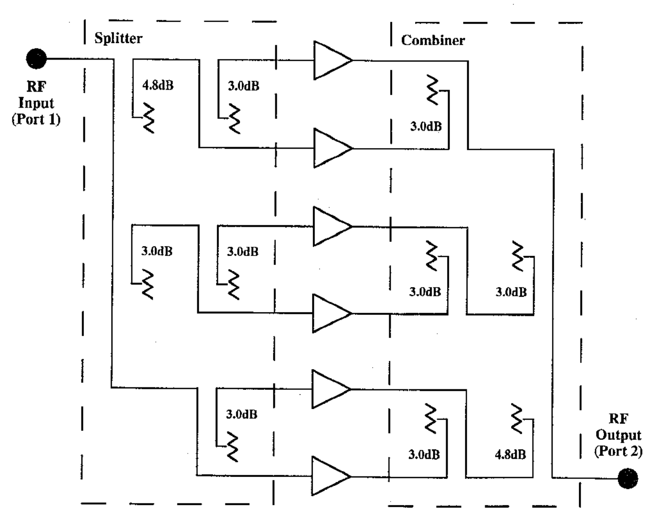

Figure 3. Schematic of Power Combining Network

Power Amplifier Assembly

The layout of the power amplifier assembly is shown in Figure 4. The entire structure is 0.864" W x 1.24" L x 0.110" H. As mentioned earlier, the module assembly includes 6 MMICs, 3 constant current bias ASICs, an LTCC splitter/combiner network, 2 regulator/modulator ASICs, local energy storage capacitance integrated onto a CM15 carrier. Each MMIC chip carrier contains two 2 Watt HBT MMICs and a constant current bias silicon ASIC soldered to a CM15 baseplate. These assemblies are pretested and epoxied into the next higher assembly which includes the LTCC coupler networks, the regulator/modulator ASICs, and energy storage capacitance. The overall assembly is tested prior to installation into the module using ground-signal-ground probes. Large volume processes using automatic pick and place, epoxy attach, and wirebonding are being completed to meet cost objectives.

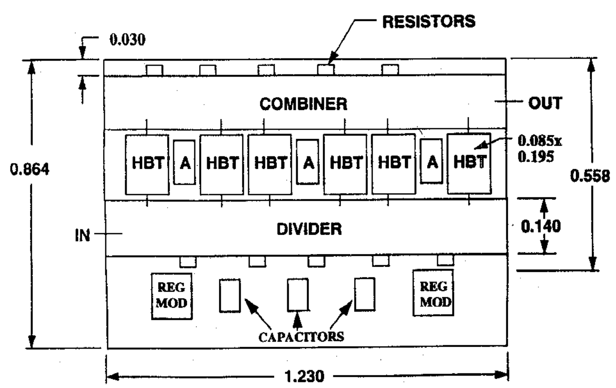

Figure 4. Power Amplifier Assembly Layout

Measured Performance

The measured performance of the full combiner amplifier showed good correlation to the expected results which had been predicted through the use of coupler modelling and measured MMIC chip (S-parameter) data. Figure 5 shows the gain as a function of frequency for a set of stepped input signal levels. Figure 6 shows the full (saturated) output power and associated PAE. The particular MMICs used in this full assembly had a nominal efficiency of 35% over the indicated frequency band.

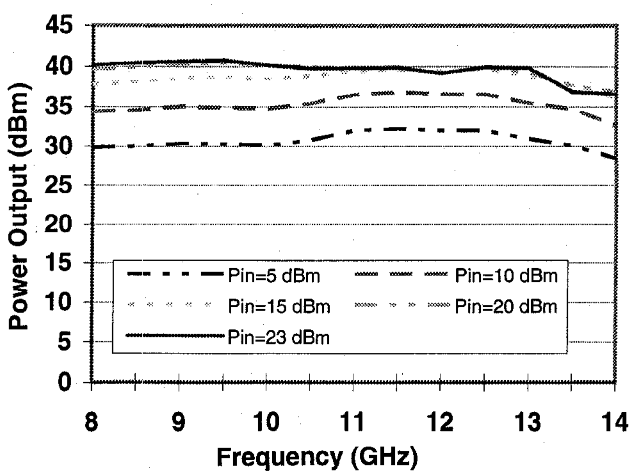

Figure 5. Power Amplifier Performance vs Frequency

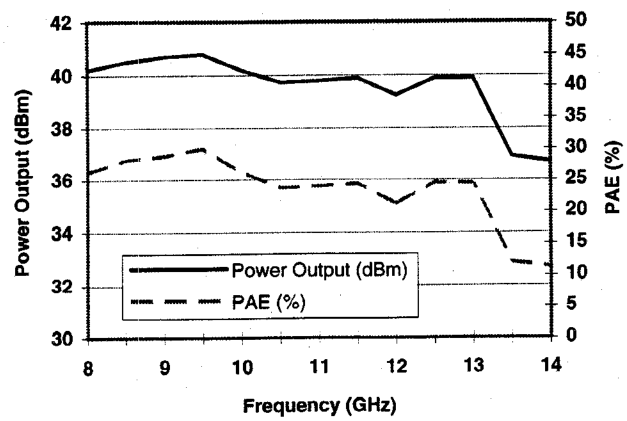

Figure 6. Measured Output Power and Efficiency

Summary and Conclusion

1. Six 2-watt (HBT) MMICs have been combined using low loss LTCC to produce 10-watts of nominal output power and a 30% peak PAE.
2. These results were obtained over an 8-14 GHz frequency band.
3. The assembly is compact, testable and producible. This amplifier is included in a pilot production run of 75-100 units.
4. The high gain, high power, high efficiency, broad bandwidth and compact size make this design highly applicable in modularized solid state transmitter, TWT replacements and transmit/receive (T/R) modules for Electronically Steerable Active Array radars.
5. It is fully expected that the lessons learned through the development of this prototype amplifier will lead to additional state-of-the-art improvements such as higher power, reduced number of components, and higher efficiency through reduced loss of the combiner circuitry.

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