A Ka-Band HEMT MMIC 1 watt Power Amplifier

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Abstract

A 34-36 GHz , 1 watt 9 dB gain MMIC power amplifier has been developed which utilizes 0.15um pseudomorphic InGaAs/GaAs HEMT process technology. Power amplifier sites across the wafer were fully characterized with an on-wafer pulsed large signal S-parameter test set.

Test results from these amplifier chips showed output powers > 30 dBm , with greater than 9 dB gain, and power added efficiencies > 20%. Overall chip size is 4.8 mm x 2.3 mm. This is the report of a Ka-Band MMIC power amplifier with 1 watt output power. A two-stage power amplifier module was developed using one chip to drive three chips. The resulting amplifier module has achieved 3 watt output power and 17dB gain from 34-36GHz

INTRODUCTION

Monolithic millimeter-wave MMIC power integrated circuits are key components for future communication and Smart munition applications which require components that are light weight, good reliability, high volume, and low cost. Recent developments of High Electron Mobility Transistor (HEMT) technology has made it possible to produce power MMIC's at Ka-Band. Excellent gain and efficiency performance has been achieved by discrete PM InGaAs/GaAs HEMT's at millimeter-wave frequencies [1-2]. MMIC power amplifiers at Q-band been utilizing HEMT technology [3] have also demonstrated with the 300 mw to 400 mw output power. This paper describes the development of a Ka-Band 1 watt power MMIC amplifier which operates over 34-36 GHz, with > 9 dB power gain, and > 20 % power added efficiencies.

The amplifier block diagram is shown in figure 1. This driver,with 1.28 mm total device size driving a balanced output stage with 3.2 mm total device stage. The driver stage uses eight finger 320μm unit cells.The output stage uses eight finger 400μm unit cell , couplers provide excellent VSWR and unconditional stability under all loads conditions.

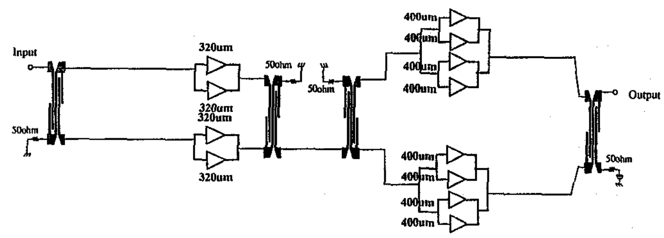

Figure 1. Block diagram of Ka-Band MMIC PA

Figure 2 shows the fabricated chip. The overall size is 4.8 mm x 2.3 mm. This chip was designed to all on-wafer CW/pulse power RF screening.

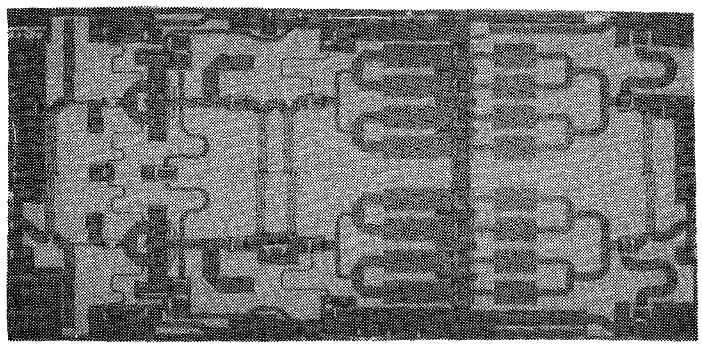

Figure 2. Fabricated MMIC Ka-Band MMIC PA

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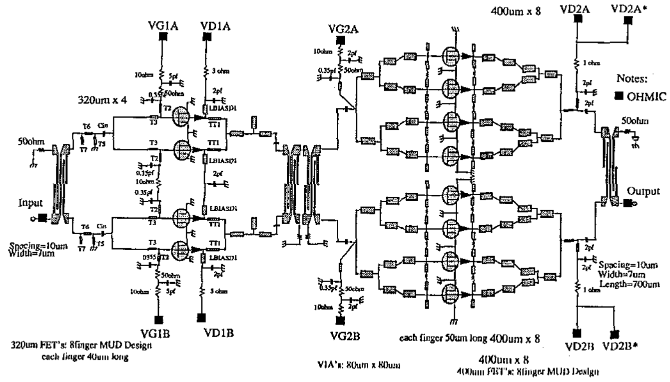
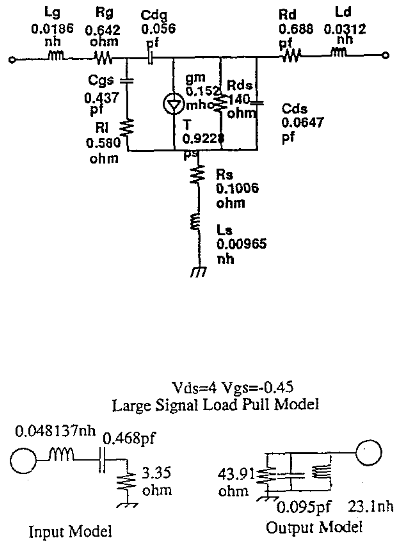


Figure 3. Schematic MMIC Ka-Band MMIC PA

Figure 3 shows the circuit schematic of this balanced amplifier. Bandpass and lowpass distributed matching networks form the desired matching networks. Included in the networks are resistors between cells to provide isolation between each active power cell. This provides a stable design for a cell combing MMIC power amplifier.

DEVICE MODEL

Large signal models were developed via DCIV/S-parameter measurements, in conjunction with Harmonic Balance Computer Aided Design (CAD) techniques to derive equivalent input/output large signal load models for the large signal design. Device and CAD load models were verified with on-wafer load pull measurements. CAD Load-Line Analysis was used to determine the Large Signal Load for maximum output power. Devices are operated at 50% of gm peak to achieve moderate power and efficiency. Figure 4 shows the small signal device model and large signal one-port models for a 400 µm device.

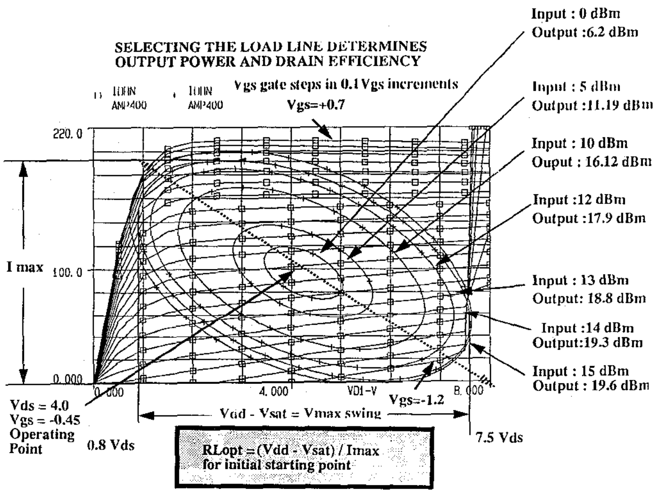


400µm Power Device

Figure 4. Large and Small Signal Models

AMPLIFIER SIMULATION

Figure 5 shows the nonlinear circuit simulation from 32 - 37 GHz with Pin varied from 8 to 20 dBm , the projected Pout and power added efficiency at Ka-Band is 29-30dBm and > 25% with Pin = 20dBm.



CAD Load-Line Analysis derived from Non-Linear Device Model

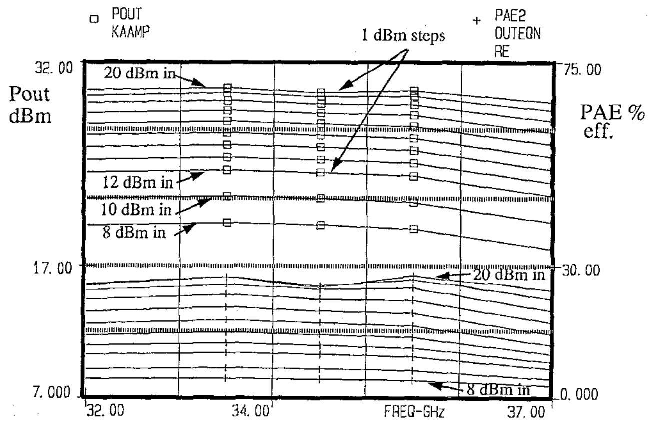


Figure 5 CAD-Simulation of Ka-Band MMIC PA

ON-WAFER PULSE/CW POWER TEST SET

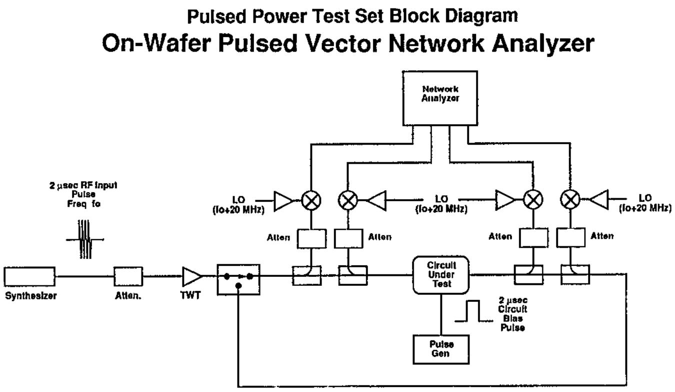


Figure 6. Block diagram of on-wafer Pulsed Vector Network Analyzer

Figure 6 shows the block diagram of the Ka-band on-wafer cw/pulsed large signal S-parameter test set. This test set is fully automated and is connected to TRW MIMIC test data base. For MMIC PA testing , both RF pulse and DC drain current pulse were set to a pulse period of 2 μsec. This prevents excessive device heating during on-wafer circuit test.

Figure 7 shows the measured gain and input return loss for a typical MMIC chip from 32 to 37 GHz. Figure 8 shows the output power and power added efficiency performance as a function of input power at Ka-Band.
With an input power of 20dBm, an output power of 29.9 dBm was achieved , the corresponding PAE is 18%, The saturated output power is 30.5dBm, and associated PAE 20.4%. The chip operates from a +5V supply and draws about 900mA current.

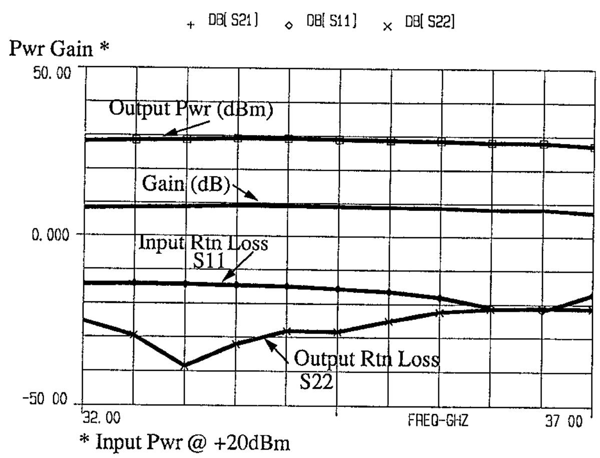


Figure 7. Measured Gain and Input and Output Return Loss for a typical MMIC chip from 32 to 37 GHz

A typical Pin vs Pout plot (Fig.8) shows the saturated output power >30 dBm at Ka-Band for this chip. This chip operates from a +5 V supply @ 900 mA, biased at 50% gm peak for best performance. Power added-efficiencies approached 21% and output powers @ 30.4 dBm at Ka-Band .

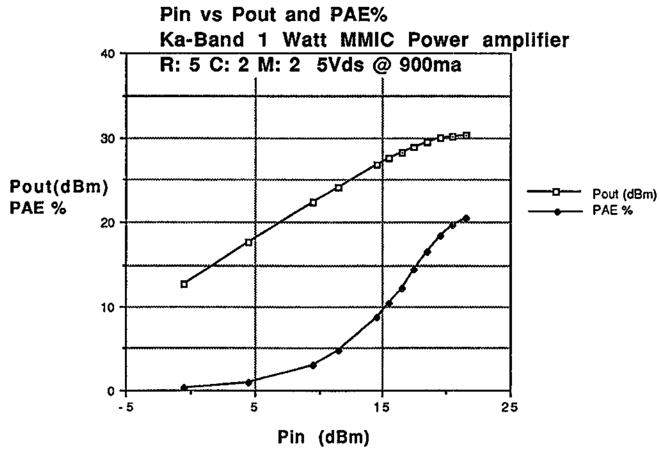


Figure 8. Measured Pin vs Pout of MMIC PA

Figure 9 shows the cumulative yield histogram of MMIC PA measured from 2 wafer lots. A total of 220 sites were measured. The RF yield is about 30% with Pout > 28.5dBm. It increases to > 70% with Pout > 27dBm.

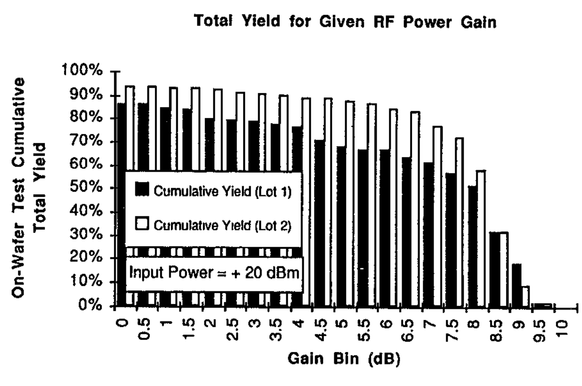


Figure 9. Total yield for on-wafer RF power gain performance

3 WATT OUTPUT Ka-BAND MMIC POWER MODULE

Using this MMIC, a two-stage power amplifier module was developed. The first stage consists of a single MMIC. The second stage consists of 3 MMIC's. Planar 3 way power combiner based on 5 mils Al_2O_3 were used for output stage power combining. Back to back connection of this combiner shows a loss of 0.6dB at Ka-Band.

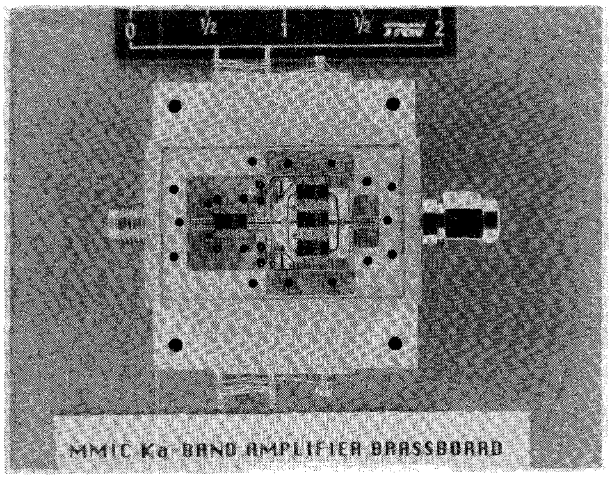


Figure 10. MMIC 3 watt output power module

Figure 10 shows the MMIC 3 watt output power module. In Figure 11, is the Pin vs Pout performance plot of this amplifier. The amplifier has achieved an output power of 34.8 dBm with Pin = 19dBm. The associated power added efficiency is 15%. To our knowledge, this amplifier performance represents the highest output power ever reported at this frequency using MMIC components.

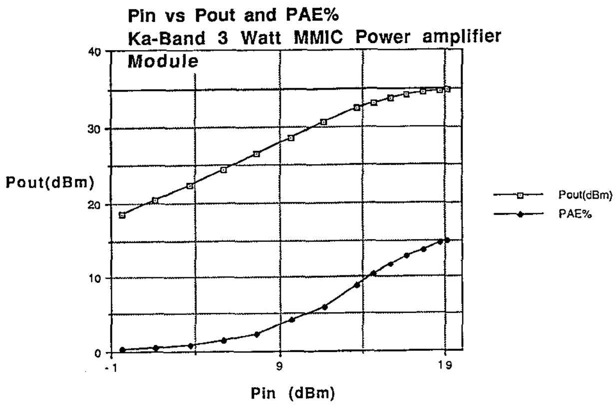


Figure 11. Pin vs Pout plot MMIC 3 watt module

CONCLUSION

A Ka-band 1 watt power MMIC chip was successfully developed. This chip has achieved excellent gain and efficiency power performances. 70% of chips has > 27 dBm output power. The chips were on-wafer tested with a newly developed full-automated on wafer cw/pulse vector measurement power test set. Significant reduction in test cycle time has been achieved. Using this MMIC, a two stage, 3 watt PA was also demonstrated with outstanding performance.

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