A Balanced 2 Watt Compact PHEMT Power Amplifier MMIC for Ka-band Applications

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ABSTRACT — **A balanced form, compact power amplifier MMIC operating at Ka-band was designed and developed using TriQuint's 3MI 0.25μm gate length pHEMT technology. This balanced three-stage power amplifier, with chip size of 6.16mm^2 (2.8x2.2mm), on 100μm GaAs substrate achieved 32.8dBm (1.9Watt) P_{1dB} output power and saturated output power above 2 Watts with higher small signal gain than 18dB at 30GHz. This chip provides a high power and low cost benchmark solution for Ka-band radio market.**

I. Introduction

The recent growth of the emerging commercial wireless communication market required high power and low cost Ka-band power amplifiers. A fully monolithic PA with compact design is a preferred solution.

In this paper, we present a compact 2 Watt power amplifier MMIC with balanced approach at Ka-band, which was developed to meet this requirement. TriQuint's three metal interconnection (3MI) 0.25μm MMW power pHEMT production process on 100μm GaAs substrate was used for the fabrication. The nominal DC characteristics for this process are listed in Table I.

TABLE I
MMW-PHEMT DC CHARACTERISTICS

Peak Transconductance	375 mS/mm
Pinchoff Voltage	-1.0 V
Breakdown Voltage	-17 V
I_{dss}	285 mA/mm
I_{max}	510 mA/mm

With these device characteristics and the use of an etch stop layer which results in uniformity and high yield, our amplifiers could be designed for high output power and high reliability operating at Ka-band. Meanwhile, the 3MI process makes a major contribution to achieving the compact chip size presented in this paper.

II. Circuit Design

The design of this amplifier was based on an accurate small signal FET model and the optimum power load target obtained from load pull measurement. The appropriate matching networks for output, inter-stage, and input networks were selected and designed by considering small signal response and maximum power transfer to the desired load target. To achieve a compact die size design, extensive EM simulations were applied to the most critical areas and components, such as tee-junctions, cross-junctions, spiral inductors, MIM capacitors over via, power combiners and Lange coupler, to take into account of coupling effects between circuit components at Ka-band frequencies. Also, this design takes advantage of lumped elements matching topologies, MIM capacitor over via, to achieve compact die size. The photograph of the 2 Watt power amplifier chip, TGA4513, is shown in Fig. 1 with die size of 6.16mm^2 (2.8x2.2mm). The half single ended power amplifier demonstrated greater than 1 Watt P_{1dB} output power over 27-32GHz is also shown in Fig. 2 (TGA4509) with die size of 2.8mm^2 (2.44x1.15mm).

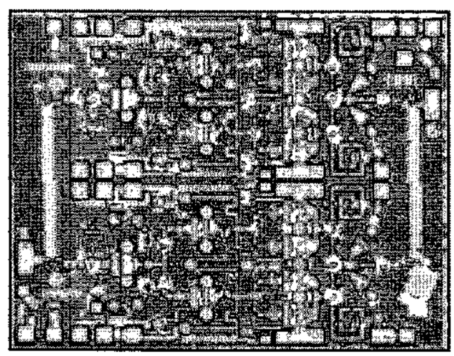

Fig. 1. Photograph of 2 Watt Ka-band pHEMT MMIC (TGA4513) with chip size of 6.16mm^2 (2.8x2.2mm).

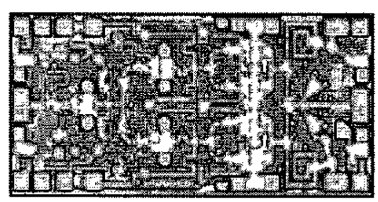

Fig. 2. Photograph of the half TGA4513 1 Watt Ka-band pHEMT PA MMIC (TGA4509) with the chip size of 2.8mm^2 (2.44x1.15mm).

The balanced power amplifier design begins with a half amplifier that formed a building block for the whole circuit. The half PA consists of 3 stages and uses a 600 μm FET cell with 10 gate fingers biased at 6V-drain voltage and 100mA/mm quiescent drain current. The output stage of this half amplifier required 4 FET cells (2.4mm gate periphery) in order to meet the output power objective of greater than 1 Watt output power at Ka-band. After examining the Ka-band power gain characteristics of this unit FET cell, an inter-stage ratio of 2:1 was selected in order to provide enough power drive margin between the stage and good linearity without excessive power consumption. Load pull data at 30 GHz for this FET cell was used for the load target selection. By applying the Cripps method [1] the output matching network was designed to achieve maximum output power and power bandwidth. The inter-stage was also designed to provide a good power match to the selected load target and maximize the drive margin. Non-linear simulations were performed to verify the power output estimated by the Cripps method. The goal of this half PA design is aimed to be less than $3mm^2$ of GaAs area with exceeding 1 Watt P_{1dB} output power over 27-32GHz bandwidth based on the cost target estimated for the Ka-band radio market. The whole PA MMIC, TGA4513, attempted to maximize bandwidth and good return loss. Therefore, the Lange coupler power combining scheme was adopted. Measured back-to-back Lange coupler performance from 20-40GHz bandwidth is shown on Fig. 3.

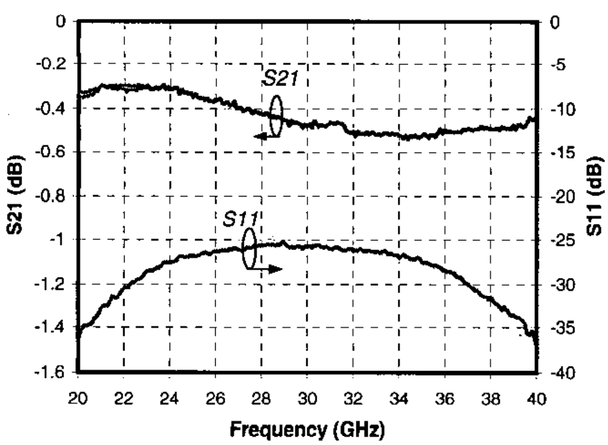

Fig. 3. Measured S-parameters of a back-to-back Lange coupler used for TGA4513.

Amplifier stability under all load conditions was a primary concern during the design of this amplifier. This design used several circuit techniques with the necessary on wafer elements to suppress the both drain and gate bias loop feedback gain, out-of-band gain, f/2 parametric oscillation, and odd mode instability, as well as thermal and reliability management. Both S-probe [2] and loop gain analysis was used to verify linear stability from DC to above the device f_{max}. Additionally, de-coupling capacitors and resisters were incorporated on wafer and fixtured test setup to further prevent low frequency instability generated from drain and gate bias lines.

III. Measured RF Results

Both chips were evaluated in a fixture environment, where they were mounted on CuMo carrier plates and RF input and output pads were then wire-bonded to microstrip lines on a 250μm thick alumina thin-film network (TFN) substrates. The reference plane for all measurements was de-embedded to the end of the alumina TFNs and the measured response included effect of the wirebond interconnection. External bypass capacitors were needed on the chip assembly, although each power supply was bypassed with a 1μF capacitor where the leads were attached.

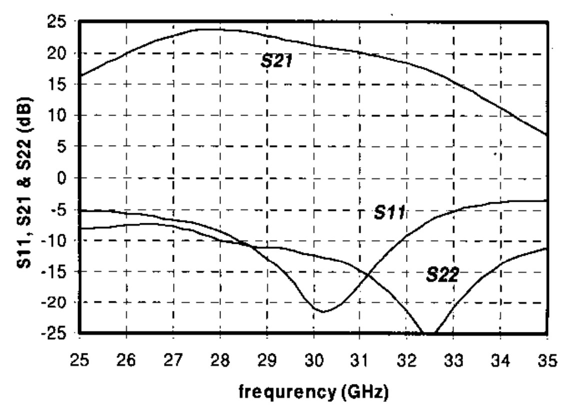

Fig. 4. Measured small signal S-parameters of single ended 1 Watt PA (TGA4509) at Vds=6V, Ids=420mA.

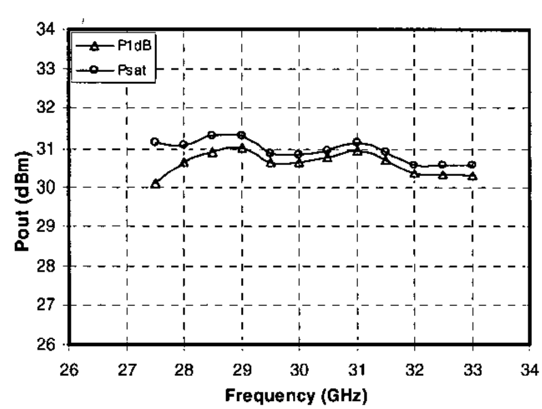

Fig. 5. Measured P1dB and Psat vs. Frequency of single ended 1 Watt PA (TGA4509) at Vds=6V, Idq=420mA.

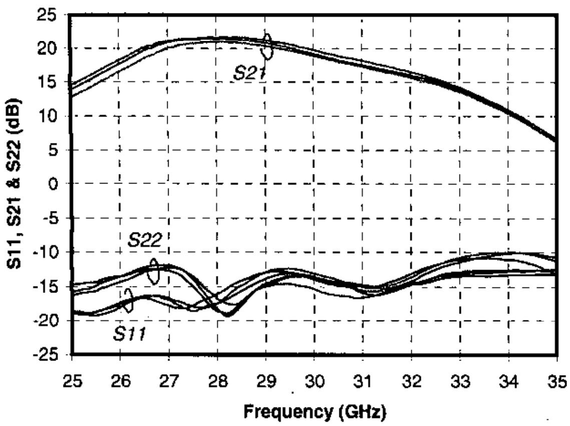

Fig. 6. Measured small signal S-parameters of balanced 2 Watt PA (TGA4513), Vds=6V, Ids=840mA.

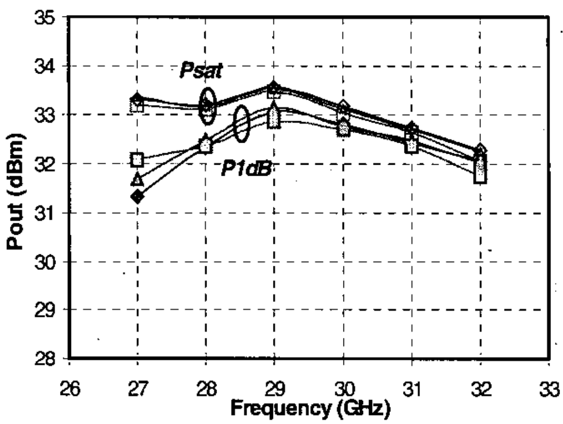

Fig. 7. Measured TGA3513 P1dB and Psat vs. Frequency at Vd=6.5V, Idq=840mA

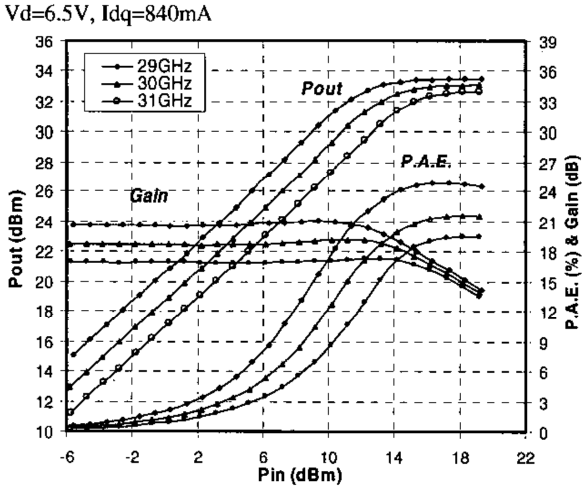

Fig. 8. Measured TGA4513 Pout, Gain and PAE vs. Pin at Vd=6.5V, Idq=840mA

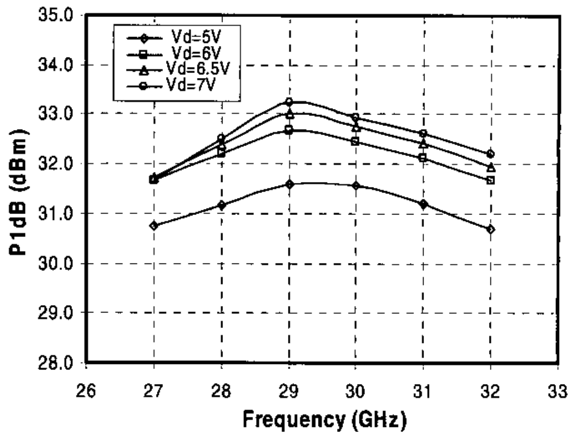

Fig. 9. Measured TGA4513 P1dB vs. Vds at Idq=840mA

Fig. 4 shows the typical small signal response of the half amplifier MMIC, TGA4509, at Vds=6V and Idq=420mA. The small signal gain is typically greater than 20dB at 30GHz, while input and output return losses are typically better than –10dB. Output power performance of this half power amplifier is shown in Fig. 5. Typically, P_{1dB} is greater than 1 Watt over 27.5- 33GHz band. These results are very consistent for several lots tested.

Fig. 6 shows the typical gain and input/output return losses of the balanced 2 Watt power amplifier which was built based on TGA4509. The small signal gain is typically greater than 18dB at 30GHz, while input and output return losses are typically better than –12dB over 27-32GHz. This superior return loss is the result of taking the advantage of Lange coupler at the input and output of the amplifier and also benefits the module designer. Output power performance of balanced power amplifier (TGA4513) is shown in Fig. 7 to Fig. 10. Typically, in Fig.7, an average output P_{1dB} is greater than 32dBm across 28-31.5GHz band for several typical devices. This PA MMIC demonstrated 32.8dBm (1.9 Watts) output P_{1dB}, and its saturated output power is over 2 Watts with small signal gain higher than 18dB at 30GHz when biased at Vds=6.5V and Idq=840mA. The amplifier attained peak output power of 33.5dBm (2.24 Watts) with 25% power-added efficiency (PAE) at 29GHz. Fig. 8 shows the output power, power gain and power-added efficiency vs. input drive power at 29, 30, and 31GHz. At the peak power level, the amplifier exhibited power density of 467 mW/mm at Ka-band. The output power can be pushed higher when devices operated at 7V drain voltage. Fig. 9 demonstrates the output P_{1dB} vs. drain voltage from 5V to 7V across frequencies of interest for a selected device. Fig. 10 illustrates the output P_{sat} vs. drain voltage from 5V to

7V across frequencies for the same device. At the 7V bias condition, the peak output power reaches 33.8dBm (2.4 Watts) with power density of 500 mW/mm at 29GHz.

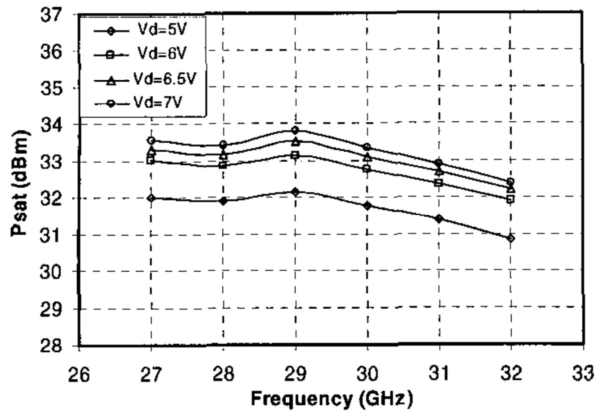

Fig 10. Measured TGA4513 Psat vs. Vds at Idq=840mA

IV. CONCLUSION

In this paper, the design and performance of balanced and single ended compact power amplifiers operating at Ka-band has been presented. The high performance of TriQuint's 3MI 0.25μm MMW power pHEMT technology, combined with the extensively applied EM simulation, has made the design of these compact Ka-band power amplifier MMICs successful in the first pass. These two chips provide a high power and low cost benchmark HPA solution for Ka-band radio market, as illustrated in TABLE II.

TABLE II
BENCHMARCK OF Ka-BAND HPA

Reference	Technology	Freq (GHz)	Psat (dBm)	Die Area (mm^2)
[3]	0.15μm pHEMT	29-33	36.5	14.89
[4]	0.15μm pHEMT	24-38	26.6	3.83
[5]	0.15μm pHEMT	29-32	33.0	12.10
[6]	0.20μm pHEMT	28.5-30	31.6	3.88
[7]	0.25μm pHEMT	27-32	30.5	3.69
[8]	0.25μm pHEMT	27-31	35.3	12.88
[9]	0.25μm pHEMT	28-31	30.1	2.25
This work	0.25μm pHEMT	27.5-33	31.0	2.80
This work	0.25μm pHEMT	27-32	33.1	6.16

ACKNOWLEDGEMENT

The authors wish to thanks the management at TriQuint Semiconductor Texas for IR&D support of this effort, the colleagues from the Millimeter-wave Radio Design Group for their on-going suggestions and comments during the design phase. Especially, the authors would like to thank Dr. G. Brehm, Dr. J. Carroll, S. Brown, L. Howard, and B. Nguyen for their support and encouragement.

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