A High Power Density, 6W MMIC for Ku/K-Band Applications

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Abstract — **A Ku/K-Band very small size MMIC high power amplifier (HPA) providing 6W of CW output power, 23dB of gain and 30% power added efficiency for application in the Ku/K-Band is presented. It is produced on a low cost, commercially available 0.25um pHEMT process. This MMIC is composed of three stage pHEMT and chip size is 3.5 x 3.0 mm^2. The HPA achieved 570 mW output power per 1 mm^2 die area. This value is the highest power density at Ku/K/Ka-Band reported to date.**

I. INTRODUCTION

Recent emerging Ku/K-Band applications have significantly increased the need for high power amplifiers at low cost. Internally matched FETs (IM-FETs) has been used as a final high power output device for these systems. But, since IM-FETs are hybrid devices, bonding-wires are used as matching elements and it is difficult to keep a small distribution of transmission phase (S_{21} Angle) from device to device and achieve high gain especially at K/Ku-band. IM-FETs also needs tuning on each device, an obvious disadvantage from a cost point of view. High power MMICs is the solution instead of IM-FETs for Ku/K-band applications. A good 50 ohm MMIC does not required external tuning and has small distribution of transmission phase from device to device. Besides, the multi-stage MMIC can achieve high gain, eliminating the need for driver amplifier contributing to lower costs.

A three stages 6W output power MMIC was developed for Ku/K-band applications.

II. DEVICE STRUCTURE

Figure-1 shows the cross-sectional view of power pHEMT that was used for Ku/K/Ka-band high power MMIC. This power pHEMT is composed of buffer layer, n-AlGaAs/i-InGaAs/n-AlGaAs double hetero-structure, n-AlGaAs Schottky layer and n-GaAs cap layer.

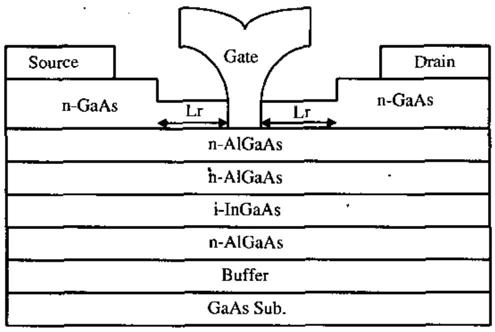

Figure-1 Cross sectional view of pHEMT used Ku/K-Band high power MMIC

These layers were grown by metal-organic vapor phase epitaxy (MOVPE), on top of 4-inch GaAs semi-insulating substrate. The thickness of GaAs substrate was thinned down to 28 μm to reduce the thermal resistance. The gate metal is WSi/Au for high reliability. The gate is recessed with n-GaAs cap layer in order to reduce the influence of surface depletion. The fabricated pHEMT exhibited a maximum drain current (I_{MAX}) of 480mA/mm, saturated drain current (I_{DSS}) of 120mA/mm and a maximum transconductance (gm) of 300mS/mm.

A good RF performance was achieved at Ku/K/Ka-band by optimizing the recess length (Lr). Figure-2 shows the typical RF performance of Wg = 600 μm pHEMT biased on VDS = 7 V at 18GHz[1]. This pHEMT achieved a 68% peak power-added efficiency with 23.5dBm (225mW) output power.

The long term reliability test of this pHEMT has already been completed and shows a MTTF over 10^6 hours, if the channel temperature is below 125 °C and drain bias voltage is below 8V.

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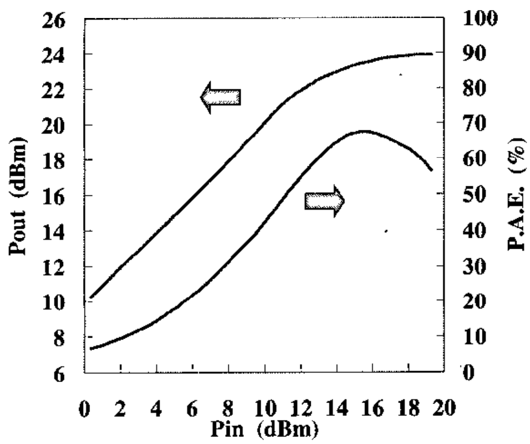

Figure-2 Pin-Pout characteristic of Wg=600um pHEMT at f=18GHz, VDS=7V.

III. CIRCUIT DESIGN

An original accurate distributed small signal equivalent circuit model was developed from S-parameter measurements carried out on a Wg = 1200 μm pHEMT test cell. This model is composed of lumped elements for the active transistor and distributed elements based on realistic device layout. By using this accurate distributed model, we can scale pHEMT size up to Wg = 2400 μm with very small errors. For large signal pHEMT operation we extracted "Load Pull" information for maximum power from a Wg = 1200 μm pHEMT test cell.

This MMIC comprises three FET stages with the following gate widths: 1600um x 2 at the 1st stage, 1600um x 4 at the 2nd stage and 2080um x 8 at the output stage. We also developed models for the passive elements taking fringing effects into account for capacitors, resistors, bonding pads, via holes and so on.

The difficulty of designing Ku/K/Ka-band, high power MMICs comes from larger gate widths at high power, and the relatively long dimensions of wavelength even at Ka-band. Therefore, a large area is required to accommodate the distributed elements used to match the devices, which is not suitable for chip size reduction. Our approach was to use lumped elements to reduce the size of matching networks, consequently the chip area.

The output matching network was designed for maximum output power condition using load impedance extracted from active load pull measurement. A special care was dedicated to minimize combiner losses. The inter-stage network between second and output stage was also designed for the aforementioned maximum power load. In this case, the power splitting losses had to be minimized. The input network and inter-stage network between first and second device were tuned for high gain and good gain flatness condition. Stability was accomplished using resistors inserted into the gate and drain bias networks. Extensive EM simulations were utilized in the MMIC design to reduce the chip size.

Figure-3 shows the top of view of Ku/K-Band 6W MMIC high power amplifier. The chip size of this MMIC is 3.5 x 3.0mm^2.

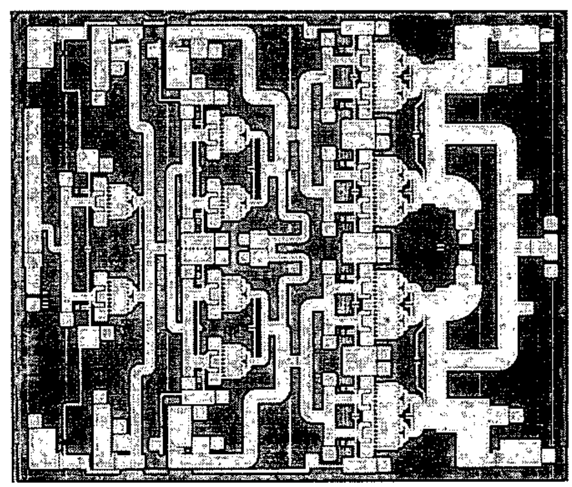

Figure-3 The top of view of developed Ku/K-band high power MMIC.
The chip size is 3.5mm x 3.0mm.

IV. MEASUREMENTS

The MMIC was mounted on Cu-based heat sink and evaluated with RF-probes. All measurements were carried out under CW conditions.

Figure-4 and Figure-5 show the small signal performance of this MMIC in wide band and tuned band respectively. In figure-4, there was no gain except within the desired frequency-band, a sign the stability networks in gate and drain bias circuitry are effective. Figure-5 demonstrates an excellent agreement between simulated and measured gain performance.

Figure-6 shows the output power at the 1dB gain compression point (P_{1dB}) and the respective power gain (G_{1dB}) for a drain bias voltage of 8V and drain bias current of 1600mA, without applied RF. At the targeted Ku/K-band frequency range, we achieved 6W output power with over 23dB gain.

The reasons why we achieved such high power is: reduced thermal resistance by using thin GaAs substrates, 28 μm, and the use of a high efficiency pHEMT technology. The power density per die area is 570 mW/mm^2.

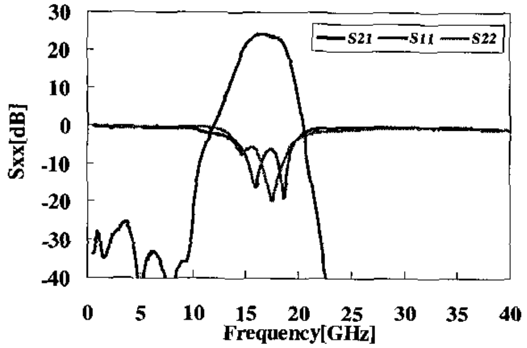

Figure-4 Small-Signal performance of developed Ku/K-Band high power MMIC.

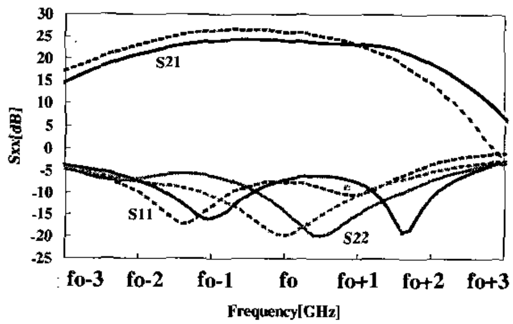

Figure-5 The comparison between simulation and measurement of developed Ku/K-Band high power MMIC.

(Solid line : Measurement, Dash line : Simulation)

Figure-7 shows the output power and Power Added Efficiency (P.A.E.) versus input power characteristic of this MMIC. There was no discontinuous condition in Pout-Pin curve a property of stable large signal operation. This MMIC achieved about 30% P.A.E. at P_{1dB} point.

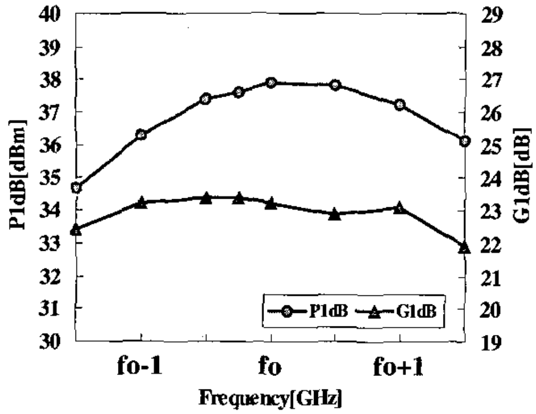

Figure-6 P1dB and G1dB performance of developed Ku/K-band High power MMIC.
Test Condition : VDD=8V, IDD(DC)=1600mA, CW

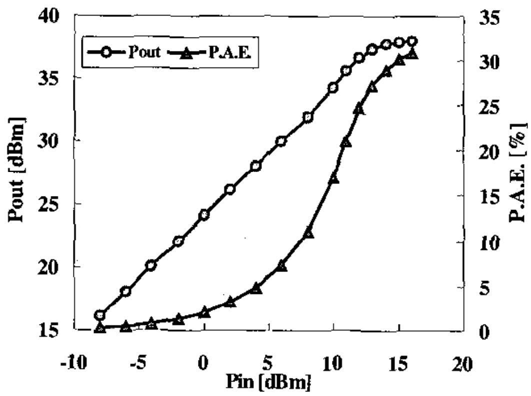

Figure-7 Pout and P.A.E. characteristic of developed Ku/K-band high power MMIC.
Test Condition : VDD=8V, IDD(DC)=1600mA, CW

Figure-8 shows the third order inter modulation distortion (IM3) and the third order intercept point (IP3) versus output power per single-tone characteristic of this MMIC. An IP3 of 44 dBm was obtained for a single tone output power of 26 dBm. This value satisfies the needs of point to point or point to multi-point SDH system.

Table-1 compares various Ku/K/Ka-band power amplifier MMICs in terms of output power density per die area. It is clearly seen that the power density of 570 mW/mm^2, presented in this paper, is the best power density compared with recent reports [2]-[5].

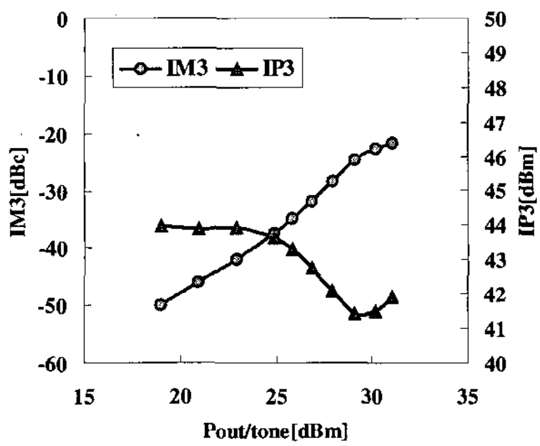

Figure-8 IM3 and IP3 characteristic of developed Ku/K-band high power MMIC.
Test Condition : VDD=8V, IDD(DC)=1600mA, Delta frequency=10MHz

V. CONCLUSION

We have demonstrated a very small chip size, high-power, and high-gain MMIC for Ku/K-band applications. The developed MMIC provides a CW output power of 6W and a gain of nearly 23dB at Ku/K-band.

The overall performance of this MMIC, estimated from the figure of merit output power per die area is 570 mW/mm^2 and is nearly two times higher than best previously published reports. This MMIC is adequate for Ku/K-band applications.

REFERENCES

[1] T.Satoh et.al., "A 68% P.A.E. Power pHEMT for K-Band Sattelite Communication System", 1999 MTT-S IMS Digest

[2] J.J.Komiak et.al., "Fully Monolithic 4 Watt High Efficiency Ka-Band Power Amplifier", 1999 MTT-S IMS Digest

[3] M.K.Siddiqui. "A High Power Broadband Monolithic Power Amplifier for Ka-Band Grand Terminals", 1999 MTT-S IMS Digest

[4] R.Emrick, "Monolithic 6W Ka-Band High Power Amplifier", 2001 MTT-S IMS Digest

[5] C.Grondahl et.al., "Wideband 5.5W Ka-Band Low-Cost MMIC High Power Amplifier with 30dB of Gain", 2002 European Microwave Digest

Table-1 Comparison of Ku/K/Ka-Band High power MMIC.

Author	Organization	Year / Conference	Freq.	Pout	Gain	P.A.E.	Chip Size	Po/mm^2	Ref.
			[GHz]	[W]	[dB]	[%]	[mm^2]	[mW/mm^2]	
This Work			**Ku/K**	**6**	**23**	**30**	**10.5**	**570**	
J.J.Komiak	Sanders	1999 MTT IMS	29-31	4	14	31	14.9	268	[2]
M.K.Siddiqui	TRW	1999 MTT IMS	29-32	2	16	27	12.1	166	[3]
R.Emrick	Motorola	2001 MTT IMS	25-31	6	21.5	-	26.3	228	[4]
C. Grondahl	US Monolithics	2001 EUMW	28-32	5.5	32	-	25.1	219	[5]