X-band GaInP HBT 10 W High Power Amplifier including on-chip Bias Control Circuit

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Abstract — **A monolithic two stage high power amplifier (HPA) has been developed for X band applications. This amplifier is fabricated on UMS commercially available GaInP/GaAs HBT process. The MMIC HPA provides about 10 W output power from 8.4 to 10.4 GHz with a mean power added efficiency of about 35 % and a mean small signal gain of 16 dB. The HPA was also validated in a wide temperature range (-30 - +80 °C) from small to large input signal and for extensive frequencies. The most significant feature of the new HPA is the use of on-chip bias control circuit allowing a linear control of collector current independently of the temperature.**

INTRODUCTION

In the last 10 years, promising performances of MMIC HPA based on HBTs have been reported [1], [2]. Today, HBT technology associated to high breakdown voltage and high collector current density is a mature technology and a good candidate for power applications up to Ku-band.

This paper presents an X band high power amplifier using UMS GaInP/GaAs HBT process. The new HPA provides 10 W output power over 8.4 – 10.4 GHz with high power added efficiency (> 35 %) and 16 dB small signal gain. This amplifier includes an appropriate bias control circuit resulting in significant advantages such as a linear current control, high impedance interface for pulsed applications and a temperature compensated behavior. Moreover, the high power amplifier was validated in –30 - +80 °C temperature range and is today a UMS catalogue product called CHA7010.

These competitive performances are also due to our design approach based on a deep circuit investigation in terms of linear and nonlinear simulation of HPA stability, temperature behavior and spread analysis taking into account active and passive parameter variation. The HPA design has been performed using accurate nonlinear models of HBTs, which include a transistor thermal effects.

MMIC TECHNOLOGY

UMS has developed an industrial GaInP/GaAs HBT process especially dedicated to high power MMIC amplifiers for applications from C to Ku frequency bands. This process has been optimized for high reliability and includes specific features for reducing the junction temperature and increasing the thermal stability of the device.

The transistors have a traditional multi-mesa configuration. Selective etching steps are used extensively, resulting in excellent uniformity and reproducibility of the critical parameters. The intrinsic excellent reliability is obtained thanks to the use of high quality GaInP/GaAs MO-CVD epitaxies; a depleted ledge layer passivates the extrinsic emitter-base junction. A resistive layer is inserted in the epitaxial structure of the emitter, providing a built in ballast resistance in each emitter finger. The value of this ballast resistance has been optimized to prevent thermal run away (the so-called "current-crunch" effect) and not to degrade the microwave gain of transistors. Finally, a thick gold metal layer is used to interconnect the emitter fingers and plays the role of an efficient thermal drain, which reduces significantly the junction temperature and contributes dramatically to thermal stability of the device (figure 1). The process also includes via holes through the 100 µm thick substrate, MIM capacitors, resistors and air-bridges.

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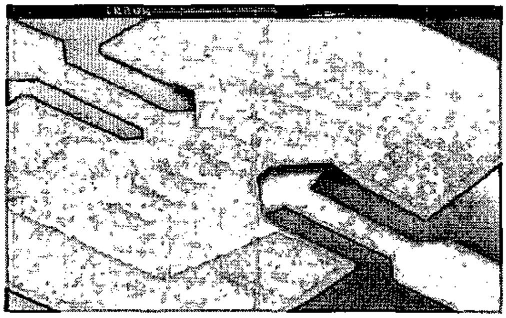

Fig 1. SEM Photo of a multi-finger power HBT featuring the thick gold thermal drain covering the transistor

HIGH POWER AMPLIFIER DESIGN

Figure 2 shows a photograph of MMIC X band GaInP/GaAs high power amplifier. This amplifier is based on two stages using 2 µm 320 µm and 2 µm 400 µm devices as a basic cell. The design includes simple transmission line elements and MIM capacitors to transform the transistor optimum load to moderate impedance value. The key point of our approach is to determine the optimum impedances for the fundamental and the second harmonic frequencies allowing a maximum efficiency with a specified output power. In order to achieve these performances, we have used the load-pull optimization technique. This HPA is fully 50 Ohm matched on both input and output. Furthermore, we have integrated on the chip bias control circuits [3]. This bias system offers the following advantages :

- High impedance interface for pulse mode
- Linear control of collector current
- Current adjustment independently of the ambient temperature

The circuit analysis has been performed by mean of linear and nonlinear simulations using HBT models of UMS library and taking into account active and passive parameter spreads [4]. Amplifier stability was deeply analyzed using linear and nonlinear open loop simulations in a wide frequency band [5]. Moreover, nonlinear model includes a transistor thermal effects trough a circuit composed of thermal resistance R_{TH} in parallel with a thermal capacitance C_{TH}. Thus, the temperature is a command of the device and simulators can compute it and feed back to the model. Using this model, the HPA thermal behavior has been extensively analyzed in small and large signal.

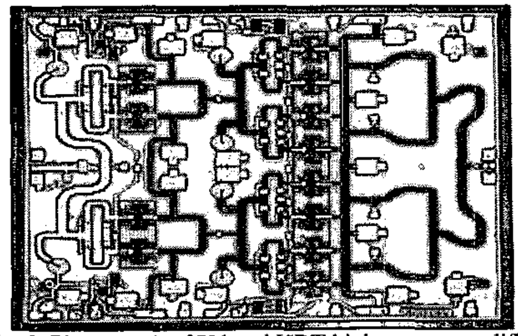

Fig. 2. Photograph of X band HBT high power amplifier

HIGH POWER AMPLIFIER PERFORMANCES

The amplifier was firstly tested for output power as a function of frequency from low to high input signal level using on-wafer pulse power test set-up in the following conditions :

Pulsed control voltage (from 0 to 5 V)
DC collector voltage (Vc = 9 V)
30 % duty cycle (pulse width = 80 µs)
Ambient temperature = 25 °C

After electrical and optical sorting, several samples were assembled in test fixtures and then completely characterized for S parameters as well as for power at different temperatures.

Figure 3 shows S parameter measurements in a wide frequency range. The small signal gain exhibits a mean value of about 16 dB while input and output return losses present a 12 dB mean value in the frequency band (8.4 - 10.4 GHz).

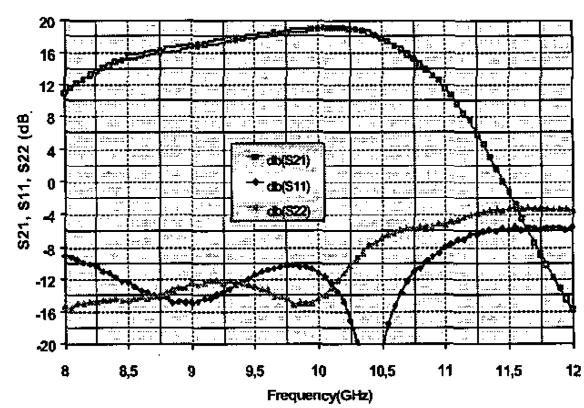

Fig. 3. Measured S parameters of the HPA at 25 °C

Using the same pulsed conditions as on-wafer tests, figure 4 shows measured output power versus input power for different frequencies. The saturated output power is almost constant in the frequency band (39- 40 dBm). This result is also confirmed in figure 5, which illustrates output power versus compression. Moreover, this graph exhibits the high linearity of the amplifier.

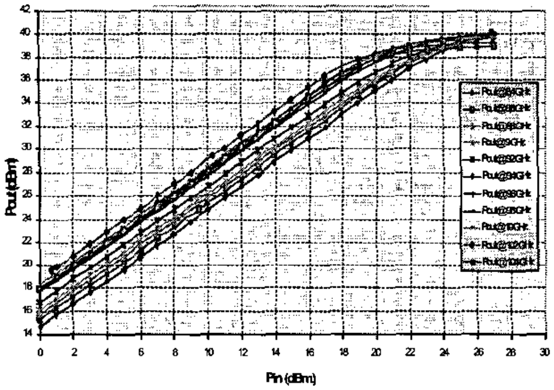

Fig. 4. HPA output power versus input power and frequency

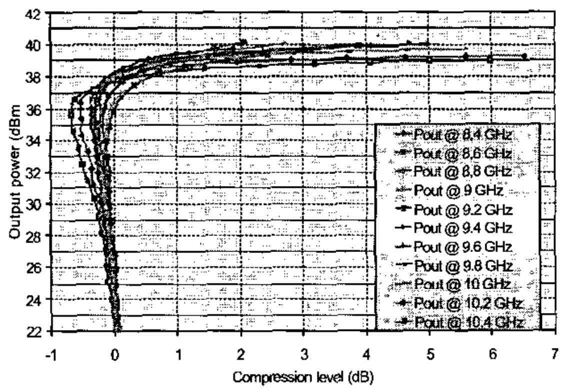

Fig. 5. HPA output power versus compression and frequency

Figure 6 summarizes the high power amplifier performances at a fixed input power (27 dBm) in terms of output power, power-added efficiency, associated gain and output mean current. These results confirm the constant behavior of gain and saturated output power as a function of frequency. The operating class choice leads to a good compromise between high linearity and high efficiency (PAE varies between 33 and 36 % in the frequency band).

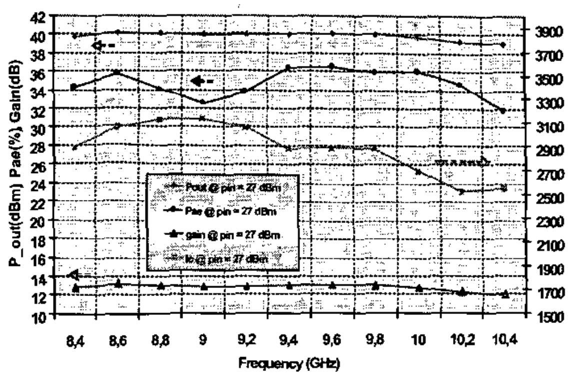

Fig. 6. HPA output power, efficiency, collector current and gain at 27 dBm input power versus frequency

The first temperature validations concern on-chip bias control circuit. Figure 7 shows collector mean current for different frequencies when temperature varies from -30 to +70 °C. The current variation is about 6 % for this temperature range. This result exhibits clearly the successful temperature compensation and the flexibility of DC current adjustment obtained with on-chip bias control circuit. Furthermore, power measurements have been done for different temperature and frequencies. As shown in figure 8, at similar compression, the output power is almost the same for all temperatures in the frequency band.

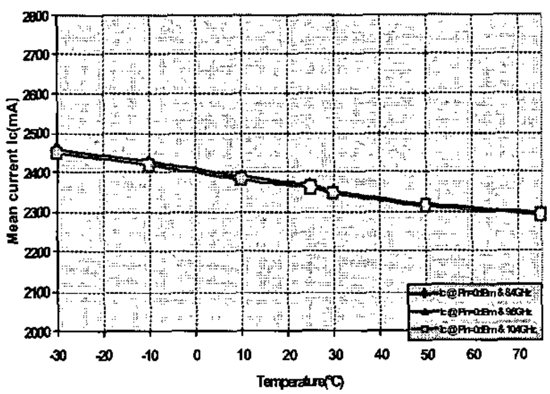

Fig. 7. HPA mean collector current versus temperature

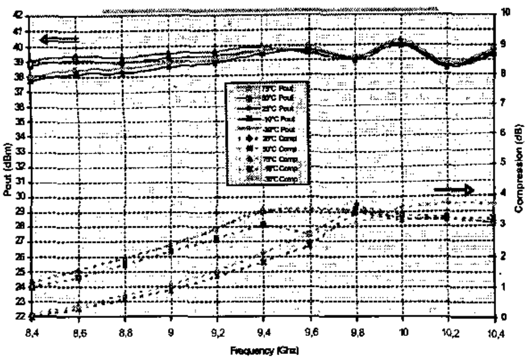

Fig. 8. HPA output power and associated compression versus temperature and frequency

CONCLUSION

This paper has reported the performances of 10 W MMIC high power amplifier based on UMS GaInP/GaAs HBT process. This amplifier is covering 8.4 – 10.4 GHz frequency band. The most significant advantage of this HPA is the use of on-chip bias control circuit allowing a flexible amplifier operation in pulsed mode and in the case of temperature variation. The main performances of the new HPA are summarized in figure 9.

Symbol	Parameter	Min	Typ	Max	Unit
F_op	Operating frequency	8.4	9.4	10.4	GHz
G_lin_1	Linear gain (8.4 to 9.4GHz)	14	16		dB
G_lin_2	Linear gain (9.4 to 10.4GHz)	16	18		dB
G_lin_T	Linear gain variation versus temperature		-0.035		dB/°C
RL_in	Input Return Loss	8	12		dB
RL_out	Output Return Loss	6	12		dB
P_sat_1	Saturated output power (8.4 to 9.8GHz)	39	40		dBm
P_sat_2	Saturated output power (9.8 to 10.4GHz)	38	39		dBm
P_sat_T	Saturated output power variation versus temperature		-0.01		dB/°C
P_1dBc_1	Output power @ 1dBc (8.4 to 9.8GHz)	38	39		dBm
P_1dBc_2	Output power @ 1dBc (9.8 to 10.4GHz)	37	38		dBm
PAE_sat	Power Added Efficiency in saturation	30	35		%
PAE_1dBc	Power Added Efficiency @ 1dBc	27	32		%
Vc	Power supply voltage		9		V
Ic	Power supply quiescent current		2.4		A
Vctr	Collector current control voltage		5.5		V
Zctr	Vctr input port impedance		350		Ohm
Top	Operating temperature range	-30		+80	°C

Fig. 9. MMIC High Power Amplifier Performances

REFERENCES

[1] M. Khatibzadeh, B. Bayraktaroglu and T. Kim, "12 W Monolithic X-Band HBT Power Amplifier", *IEEE 1992 Microwave and Millimeter-Wave Monolithic Circuits Symposium*, June 1992, pp. 47-50.

[2] M. Salib, A. Gupta, A. Ezis, M. Lee and M. Murphy, "A Robust 3 W High Efficiency 8-14 GHz GaAs/AlGaAs Heterojunction Bipolar Transistor Power Amplifier", *IEEE MTT-S International Microwave Symposium Digest*, 1998.

[3] E. Järvinen, S. Kalajo, M. Matilainen, "Bias Circuits for GaAs HBT Power Amplifiers", *IEEE 2001 MTT-S International Microwave Symposium Digest*, Phoenix, AZ, May 2001

[4] J.Ph. Fraysse, D. Floriot, Ph. Auxémery, M. Campovecchio, R. -Quasi-Static Model of GaInP/AlGaAs HBT for Power Applications", *IEEE MTT-S International Microwave Symposium Digest*, vol. 2, pp. 379-382, June 1997.

[5] S. Mons, J.C. Nallatamby, R. Quéré, P. Savary and J. Obregon", A unified approach for the linear and nonlinear stability analysis of microwave circuits using commercially available tools", *IEEE Trans. On Microwave Theory and Techniques*, vol. 47, n° 12, pp. 2403-2409, December 1999.