5.8 GHz High-Power RF Amplifier

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I. Introduction

Power amplifiers (PA's) are used to amplify signals without compromising signal integrity, so that information could be transmitted into the media and recovered by the recipient [1]. They are used in the transmitting chain of a wireless system. The efficiency of power delivered to the load and the output power of the amplifier are the two main design specifications. They are the final amplification stage before the signal is transmitted, and therefore must provide enough output power to overcome channel losses between the transmitter and receiver. PA's are classified according to the circuit configuration and operation conditions into different classes. Power amplifier design includes trade-offs among linearity, power gain, output power and efficiency.

In this work a two-stage class-A high power amplifier (PA) using Mimix GaAs HEMT is fabricated. The amplifier is capable of demonstrating 15 dB of gain across 5.725-5.850 GHz band. The maximum 1 dB compression point output power of the amplifier is 30 dBm. The amplifier is assembled on FR4 and 2 drain biasing strategies are fabricated. The first one includes direct biasing of the PA using power supplies and the second one includes biasing the drains of the PA using a Maxim low-noise bias supply chip.

A. *Key PA specification parameters:*

a) Output power:

Output power is the most important design aspect of the PA. When a supply voltage is given as a fixed value, only the amount of current that provides a required output power can be a design parameter. Assuming a normal output load with resistance R, the PA has an output power that has the following expression (Fig. 1):

$$Pout = \frac{\left(\frac{V_{peak-to-peak}}{2}\right)^2}{2R}$$

Manuscript received July 28, 2010. This work was supported by the Georgia Institute of Technology.

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b) Gain

Transducer gain (G_T) is used for general measurements. Power gain (G_P) is the gain considering input and output matching conditions. This definition is useful when matching condition is not well optimized and the reflections at the input and load are not negligible which is often observed in source/load pull tests. Available gain (G_V) is useful for estimation of the maximum performance assuming perfect matching conditions for the input and the load of the PA.

$$\textit{Transducer Gain } (G_T) = \frac{P_{OUT}}{P_{AVS}}$$

$$\textit{Power Gain } (G_P) = \frac{P_{OUT}}{P_{IN}} = G_T\left(1 + \frac{P_{REFS}}{P_{IN}}\right)$$

$$\textit{Available Gain } (G_A) = \frac{P_{AVO}}{P_{AVS}} = G_T\left(1 + \frac{P_{REFO}}{P_{OUT}}\right)$$

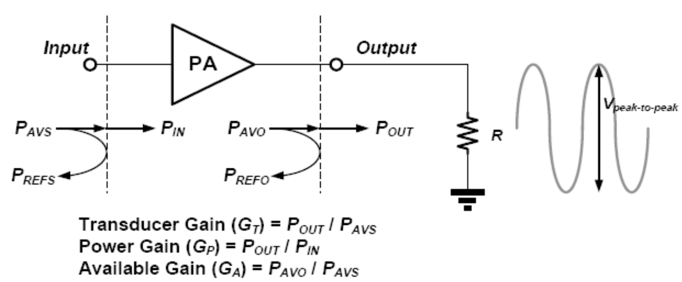

Fig. 1. Definition of power and gain.

II. Mimix GaAs HEMT PA

MiMix Broadband Corp. XP1039-QJ packaged PA operating over 5.6-7.1 GHz band is used in this project [2]. It is packaged in a 24 pin SMT package. The amplifier provides 16.5 dB gain and 49 dBm output third order intercept point (OIP3) with upto 4W of saturated RF power. The chip includes on-chip ESD protection and DC by-pass capacitors. Table I lists the important parameters of the PA. Fig. 2 shows the pinout diagram of the PA. Fig. 3 shows the eagle layout of the board fabricated to measure the characteristics of the PA. it was made sure that the drain traces were thick as they carry a lot of current. Vias were drilled under the PA on the board for the thermal management of the heat dissipated by the PA. The vias were manually filled with conductive lines. Finally during measurements the conductive lines touched a brass board for heat transfer. Op-Amp circuitry was integrated on the board for the reference and detect signals on the PA.

Fig. 4 shows the gain of the PA (at Vd = 8 V, Id = 1.4 A) as a function of frequency. As can be seen the PA provides a good gain of ~ 17 dB over the frequency range. Fig. 5 shows the P1dB of the PA over the frequency range. The P1dB of the amplifier is ~ 35 dBm over the frequency range. The amplifier is highly linear over the desired frequency range for 1-tone operation. Fig. 6. Shows the 2-tone Output third order intercept point (OIP3) of the amplifier. The OIP3 is also very high. Fig. 7 shows the dissipated power (Pdis) of the PA as a function of the package base temperature. The Pdis stays constant till 80 C and then it starts to go down. The Pdis goes down because of the decrease in device currents because of the increased temperature. Another biasing technique in which a Maxim Gate-Drain bias chip is used to bias the gate and drain was fabricated. But here we only discuss the DC supply biasing technique.

Table I.

Parameter	Units	Min.	Max.
Frequency	GHz	5.6	7.1
S21	dB	15.5	19
S11	dB	10	10
S22	dB	8	8
P1dB	dBm	34.5	35.5
OIP3 at 25 dBm	dBm	46	50
PAE at Psat	%	24	24

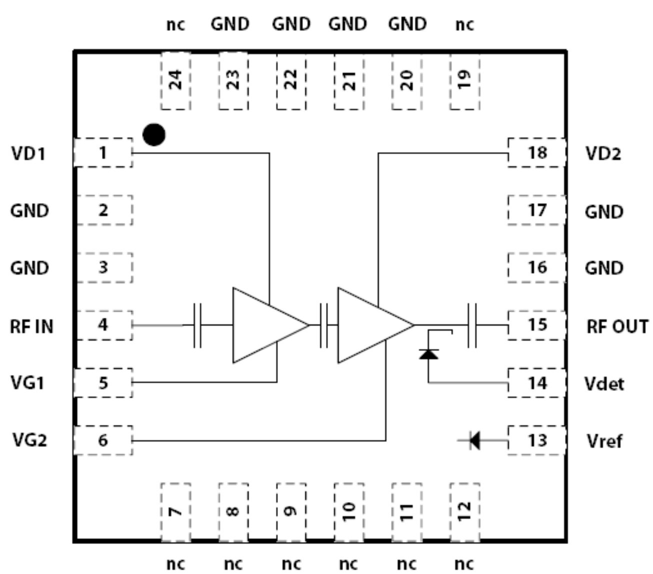

Fig. 2. Schematic diagram of the two-stage PA. The RF supplies are decoupled by DC block capacitors and the DC supplied are decoupled by RF pass capacitors in parallel with supply inputs.

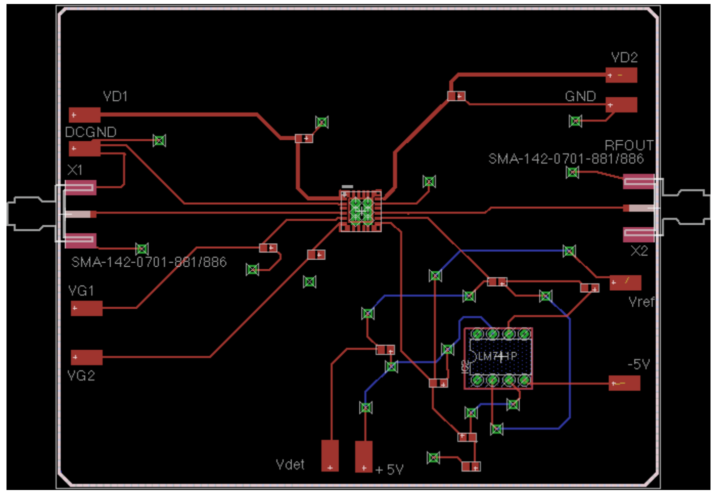

Fig. 3. Eagle layout of the Mimix PA board.

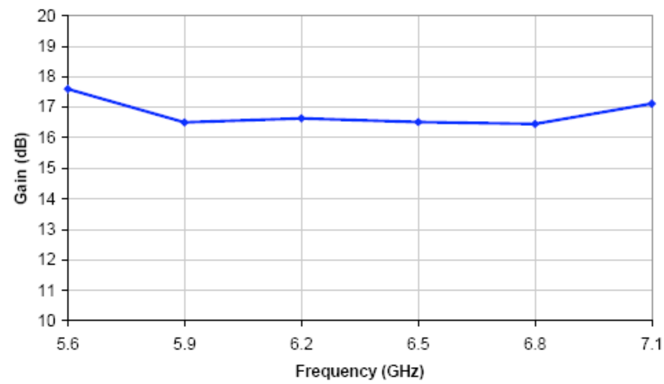

Fig. 4. Gain of the PA (at V_d=8 V, I_d = 1400 mA) over the frequency range. The PA has a gain of 17 dB over the frequency range.

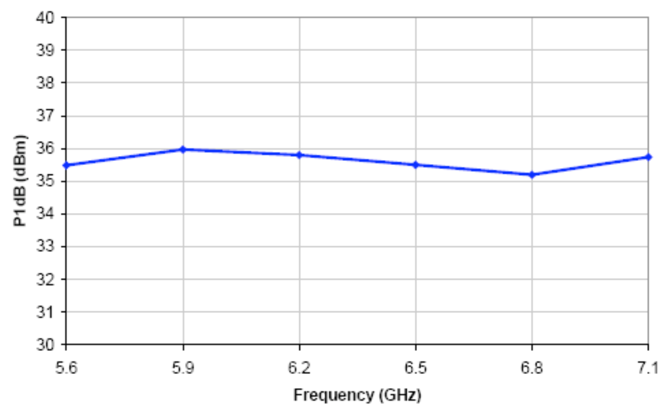

Fig. 5 P1dB of the PA (at V_d=8 V, I_d = 1400 mA) over the frequency range. The PA has a P1dB of 35.5 dB over the frequency range.

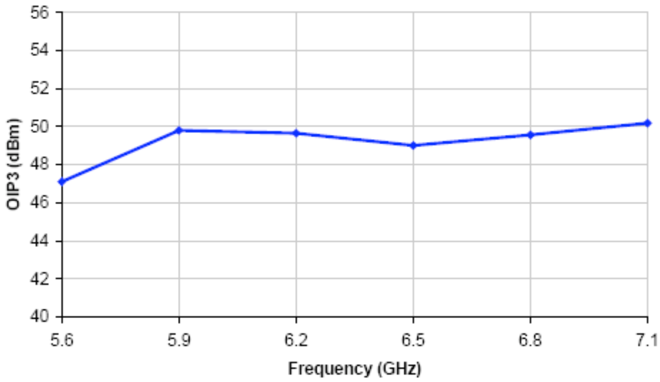

Fig. 6. OIP3of the PA (at P_{total}=28.5 dBm, V_d=8 V, I_d = 1400 mA) over the frequency range. The PA has a OIP3 of 50 dB over the frequency range.

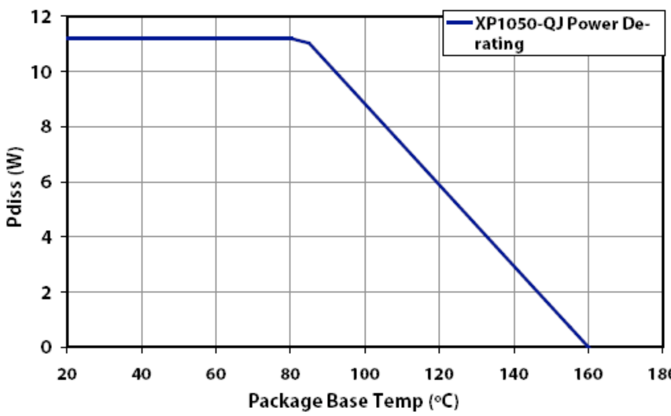

Fig. 7. Dissipated power of the PA as a function of the package base temperature.

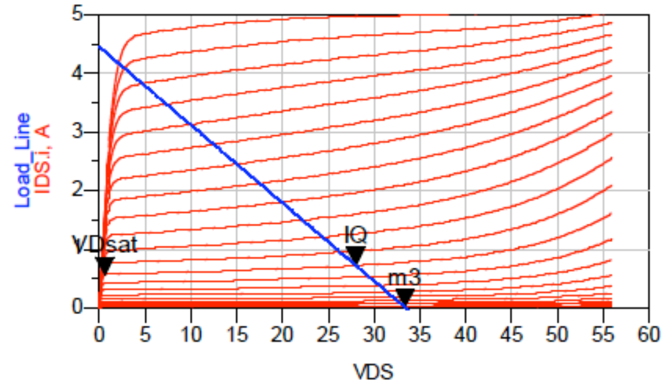

Fig. 8. Output characteristics of a GaAs HEMT device.

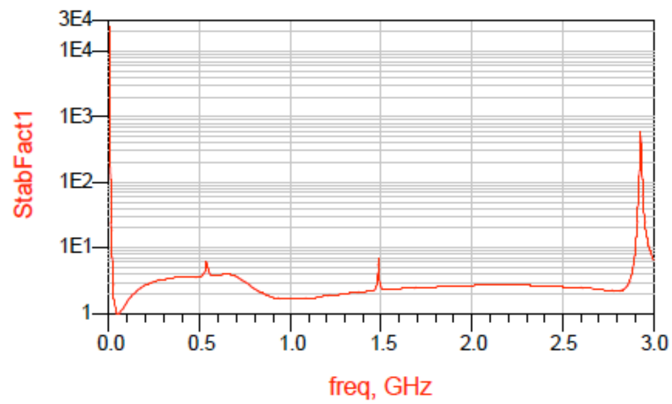

Fig. 9. Stability factor (K-factor) of the PA over the frequency range.

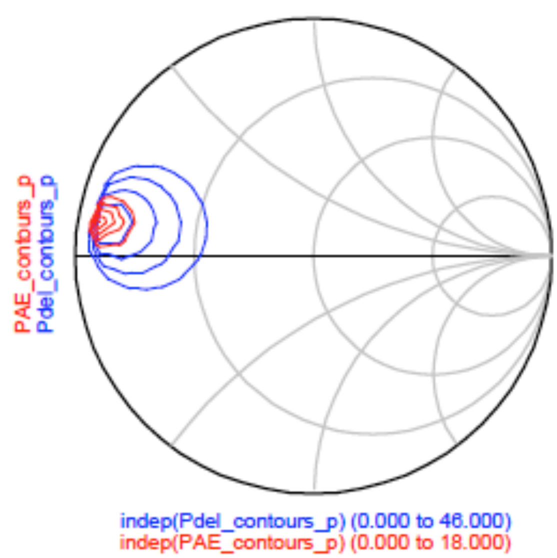

Fig. 10. PAE and Pout contours from loadpull analysis.

III. PA Design

The first step in PA design is to determine the number of PA stages for optimum design. The optimum number of design stages are determined to deliver the required output power and gain. If a high degree of linearity is required, the driver stage should be choosen such that when the final stage is driven into compression, the driver stage is still several dB below its compression point. This may require a slight compromise of PAE. In this work we use 2 stage PA. The first stage is called the driver stage and the second is called the power stage. Power stage should be capable of providing the required output power @ 1dB compression point. Driver stage should be capable of driving the power amplifier stage.

Following steps are followed for a PA design in ADS:

1) DC and loadline analysis-bias point selection:

Goal of this step is to determine the transistor operating point for required output power under class A operation. Transistor bias utility in ADS is used to determine the optimum bias point to deliver the required output power. Fig. 9 shows the output characteristics of a GaAs HEMT. The operating point is selected on this plot.

2) Design of biasing network:

Using the bias utility in ADS the biasing network is designed for the power stage. After the bias network is designed the amplifier is saved as a 3 port symbol.

3) Bias and Stability

The next step is to determine the transistor stability for desired frequency range. The S-parameter simulations are used to simulate the small-signal characteristics. The stability factor of the PA came out to be greater than 1 (Fig. 10). This implies that the PA is unconditionally stable over the desired frequency range. If K-factor is less than 1, a resistor can be connected to the gate of the HEMT to achieve stability. Once the device is stabilized, we measure the Zsource required to achieve maximum available gain.

4) LoadPull analysis

Loadpull simulation is used to determine the output load impedance to deliver the specified output power. The load impedance for which maximum output power is achieved is choosen (Fig. 11).

IV. PA Reliability

Mean time to failure as a function of the package base temperature is shown in Fig. 11. The MTTF decreases as the package temperature increases. This is attributed to the thermal run-away mechanism. Also the MTTF decreases as the dissipated power increases. This is attributed to the higher electric fields present in the transistor for higher dissipated power which result in hot-carrier reliability problems and hence thermal runaway.

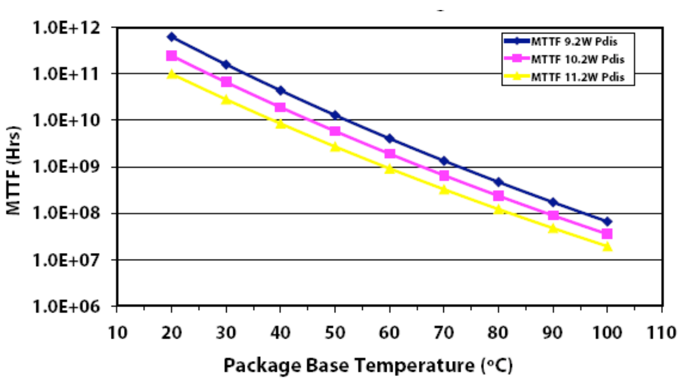

Fig. 11. Mean time-to-failure (MTTF) of the PA as a function of the package base temperature.

V. Design And Discussion

The PA board design was not able to deliver constant RF output power and the PA heated up very quickly. Thus we suggest the following precautions be taken while testing these PA's:

1) Gate bias (V_g) = - 0.7 V should be applied on the PA before applying any drain bias. A zero bias on gate kills the device. Gate bias operating range is from -2.5 V to -0.7 V. Drain bias operating range is from 0 V to 8 V.

2) Drain pin traces should be thick as they carry currents of the order of hundreds of milliamps.

3) Heat sink must be used as the PA heats up for greater than 1 W power dissipation.

VI. Conclusion

A 5. 8 GHz PA was fabricated on FR-4 board. A GaAs HEMT based PA design was also done. The PA was not able to amplify RF input for longer time as the design lacked proper heat flow path. Precautions to be taken while testing these PA's was discussed.

References

[1] B. Razavi, RF Microelectronics, Prentice Hall Communication Engineering, 2004.

[2] P1039-QJ data sheet, Mimix Broadband Corp., 2009.