A V-Band MMIC Power Amplifier with High Gain and Stability

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***Abstract*—Power-added efficiency (PAE), stability and gain are the most important specifications for a power amplifier. And at millimeter-wave frequencies, stability is even more crucial, because the active devices become more sensitive at high frequency. The paper describes a V-band power amplifier with high gain and Stability, coupled with well-established hybrid circuit techniques. The power amplifier is fabricated using 0.13um gate length GaAs PHEMT process, and it includes five stages. At the last stage, in order to improve the circuit stability, the stabilization resistor is used to combine the power. The working frequency is from 57GHz to 63GHz. The measured small-signal Gain is better than 28dB. The output power at 1dB gain compression (P1dB) is above 20dBm at 60GHz.**

***Index Terms*—Gain, stability, GaAs, microwave monolithic integrated circuit (MMIC), power amplifier (PA), V-band.**

I. INTRODUCTION

ALONG with the wide application of millimeter-wave systems for satellite communications, the demand for high frequency power amplifier with good specifications is more urgent than ever. MMIC is the component technology that could be used to manufacture the chip, and the target specifications lead to a decision which foundry process is required. The most commonly used substrate materials are silicon (Si) and gallium arsenide (GaAs). Usually, Si is traditionally used for RF and lower frequencies, and GaAs is used for microwave and millimeter-wave frequencies [1][2]. When the MMIC power amplifier is designed, the first step work is to choose the substrate material and process. The choice of the process is primarily determined by the operating frequency and the required specifications, and it also covers some trade-offs considering several key technique specification [3]-[5].

Stability is the most common problem that power amplifier designer must consider, particularly at millimeter-wave band, which the risk of unstable behavior is not negligible even with a single transistor amplifier. When a V-band power amplifier with high Gain is designed, more attentions must be paid to the stability design of the circuit [6]-[8].

Based on the requirement of millimeter-wave satellite communication, this paper describes a V-band power amplifier designed with hybrid power combiner, which includes five-stages. In the last stage, the stabilization resistors are used to improve the stability of circuit. Design targets are: working frequency from 57GHz to 63GH, gain not less than 28dB, the output power at 1dB gain compression (P1dB) above 20dBm.

II. CIRCUIT DESIGN

In the MMIC design, the first work is the choice of substrate material, which has the greatest influence over the potential performance of the chips. According to the technique specification requirements, the V-band PA is implemented in 0.13μm PHEMT GaAs process, which has a f_T of 100GHz and a f_{max} of 180GHz. And the substrate thickness is 100μm. The process could provide 2.5μm thickness top metal for low loss interconnections and metal-insulator-metal (MIM) capacitor or 49pF/mm^2.

In the V-band PA design, there are several main targets to achieve: the power Gain, the stability, the power added efficiency (PAE), the input impedance matching, the output impedance matching, and the linearity (output 1dB compression point, P1dB). According to the s-parameter simulation result for transistor with different size, five stages could agree with the 28dB gain requirement. The proposed V-band PA is designed as shown in figure 1, which consists of five stages. The first stage, the second stage, the third stage and the fourth stage are the Gain stages to provide enough Gain for the PA. And at the last stage, in order to get high output power 100mW, the power combiner is used. The output of the last stage is matched for maximum output power. The inter-stage matching and input matching network are designed for Gain and input return loss.

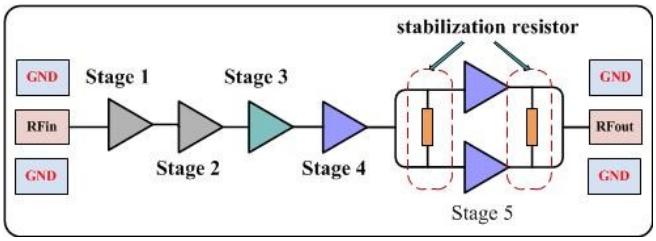


Fig.1. Circuit Block Diagram of V-band power amplifier

When designing an MMIC amplifier, especially a high frequency PA with high Gain, the circuit stability must be considered. The maximum possible Gain of MMIC chip is limited by the chip stable and no oscillation. For the overall chip, this is achieved by keeping the chip Gain lower than any feedback paths, which come from the output RF pads back to the input of the chip. In this design, the circuits have five stages, and there are many possible feedback paths. In order to avoid oscillation, two stabilization resistors are used to improve the stability of circuit.

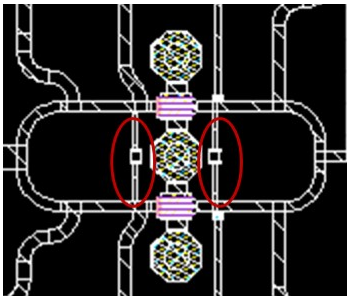


Fig.2. Stabilization resistor at the last stage

Figure 2 shows the layout about stabilization circuit. From the simulation results, the S parameter is similar to the circuit without the stabilization resistors, but the k factor is better, which indicates the circuit more stability. The experimental results show that the resistors are useful to improve the power amplifier stability. If without the stabilization resistors in the power combiner, the circuit is ease to self-oscillate.

After fulfilling the circuit design, the entire layout, including the matching networks, the transmission lines, the MIM capacitors, the inductors, and the pad parasitic capacitance are simulated using full-wave EM simulator. By EM simulation, all the simulation results could agree with the requirements, and the layout then to be manufactured. And the processing of the wafer is fulfilled in a clean room environment, which could prevent dust and moisture from affecting the features.

III. MEASURED RESULTS

Before the MMICs being diced to individual chips, the chips should be measured on wafer. The whole wafer is tested at DC and RF specifications. DC testing results are used to evaluate the process control monitoring (PCM) function to ensure that the process is performed correctly. The RF testing could be used to check the performance of the circuit design. During the RF testing, the RF signal is applied to the chip using a transmission line of known impedance (usually 50Ω), so that the s- parameter of the chip could be recorded.

The designed GaAs V-band PA was measured through on–wafer by the probe station. The gate voltage is -0.2V, the drain voltage is 4 V, and the total current is 260mA. There are 105 chips in one wafer and all be measured on wafer. The measured small-signal gain and input/output return losses are shown in figure 3 and figure 4. The output power versus input power at 60 GHz are shown in Figure 5, a 20.5-dBm P1dB is obtained.

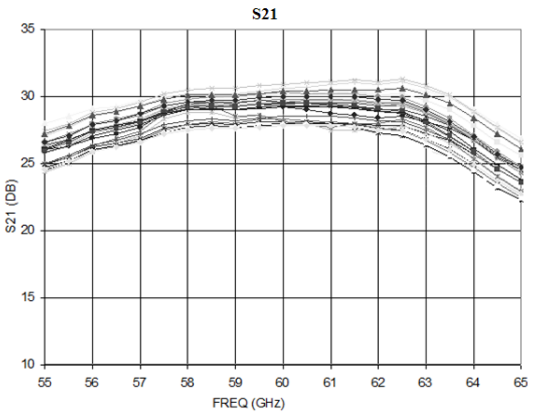
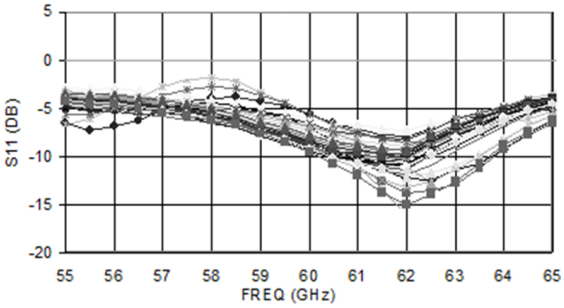
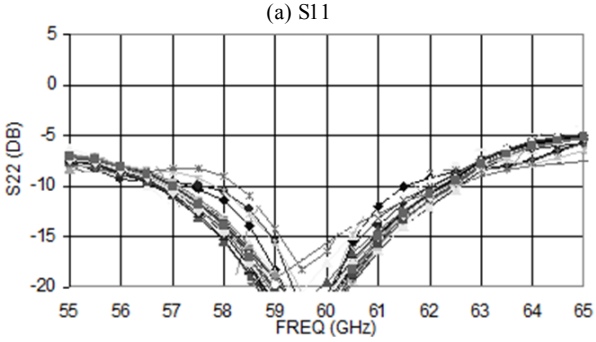


Fig.3. Measured small-signal Gain (105chips)



(a) S11



(b) S22

Fig.4. Measured input/output return loss (105chips)

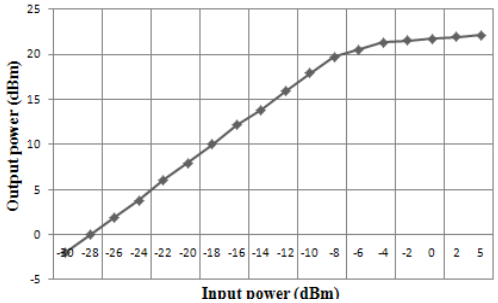


Fig.5. Measured output power versus input power (1 chip sample)

IV. CONCLUSION

A five-stage hybrid power amplifier with stabilization resistor is implemented by 0.13um gate length GaAs PHEMT process. The experimentation results show that the stabilization resistor can greatly improve the circuit stability. It is an effective method to solve the self-oscillation of high gain MMIC power amplifier, especially at high frequency.

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