X-band MMIC Power Amplifier with an On-chip Temperature Compensation Circuit

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***Abstract* — An X-band MMIC power amplifier with an on-chip temperature compensation circuit has been presented. The temperature compensation circuit is composed of a diode and a resistor. The compensation circuit is applied to a 4 stage X-band MMIC power amplifier. The gain variation is improved from 5.5dB to 1.3dB in the temperature range between -10deg and +80deg.**

I. INTRODUCTION

In recent years, there have been increasing demands for power amplifiers with small variation of gain and output power with temperature. However, it is known that GaAs FET power amplifiers are seriously affected by temperature variation resulting in gain spread of several dB for amplifiers. Therefore it is necessary to improve temperature characteristics of the power amplifier.

In order to compensate gain variation with temperature, drain current and input power of the amplifiers are controlled by off-chip regulators with temperature sensors in transmitter modules. As a result, the modules become larger. To realize the small modules, the preferable design solution is the amplifiers with an on-chip temperature compensation circuit [1,2].

In this paper, we present an X-band MMIC power amplifier with an on-chip temperature compensation circuit. The compensation circuit is composed of a diode and a resistor. The presented compensate circuit utilizes the temperature characteristics of the diode, that is, the decreasing threshold voltage of the diode with the increase of temperature. The gain variation is compensated by controlling gate voltage of the power amplifier. It has be noted that the presented circuit is the one of the most miniature temperature compensation circuits. Such a circuit can be easily integrated into a single GaAs MMIC chip. The compensation circuit is applied to a 4 stage X-band MMIC power amplifier with a small gain of 32dB at 25deg at center frequency. By making use of the circuit presented, the gain variation is improved from 5.5dB to 1.3dB in the temperature range between -10deg and +80deg.

II. GAIN OF POWER AMPLIFIER WITH TEMPERATURE

The gain of a GaAs FET amplifier decreases with the increase of temperature, while the gain of the FET amplifier whose drain current is at class AB increases with the increase of the gate voltage. To compensate gain variation of an amplifier with temperature, controlling gate voltage of FET with temperature can be used. Fig.1 shows the measured small signal gain of the amplifier at the three temperature points, -20deg, +25deg and +70deg, as a function of gate voltage. The single stage amplifier employs a MESFET with gate width of 900um. Fig.1 shows that the gain can be kept constant in the temperature range between -20deg and +70deg by adjusting gate voltage of the amplifier when the gain of the amplifier is less than 7dB. The gain is expected to be as high as possible. The gate voltage is necessary to be varied from -3.4V to -3V to achieve constant gain of 7dB in the temperature range between -20deg and 70deg as shown in Fig.1. Therefore the compensation circuit is demanded that the gate voltage of the amplifier is varied from -3.4V to -3V in the temperature range between -20deg and +70deg.

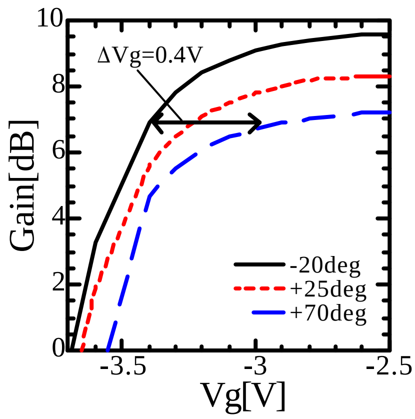

Figure 1 Measured small signal gain of the amplifier with temperature

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III. TEMPERATURE COMPENSATION CIRCUIT

The gain variation of the amplifier can be compensated by increasing the gate voltage with the increase of temperature as mentioned in previous section. Therefore, the circuit providing the increase of gate voltage with temperature is required to compensate gain variation. In this chapter the temperature compensation circuit which is composed of a diode and a resistor is presented, and the operation principle of the compensation circuit is explained. Fig.2 shows the schematic diagram of the temperature compensation circuit. The compensation circuit realizes an on-chip circuit configuration. It has to be noted that the presented circuit is the one of the most miniature temperature compensation circuits. Value of gate voltage Vg is determined by reference voltage Vr and gate control voltage Vgc as shown in Fig.2.

The compensation circuit shown in Fig.2 utilizes the temperature characteristics of the diode, that is, the decreasing threshold voltage of the diode with the increase of temperature. To verify the increase of gate voltage under the varying temperature, the gate voltage with temperature has been measured in a wide temperature range as shown in Fig.3. The MESFET connected drain with source is employed instead of the diode. The gate voltage becomes larger with the increase of temperature and the rate of increasing gate voltage is 1mV/deg as shown in Fig.3. To achieve the variable range of 0.4V presented in Fig.1, the 4 diodes should be connected in series.

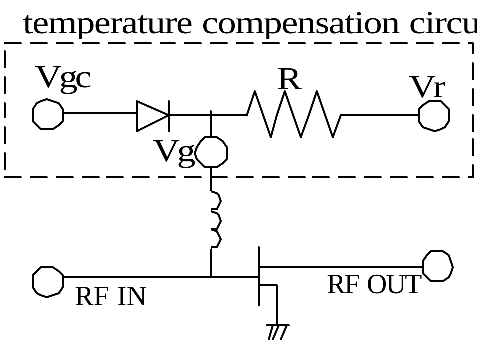

Figure 2 Schematic diagram of the temperature compensation circuit

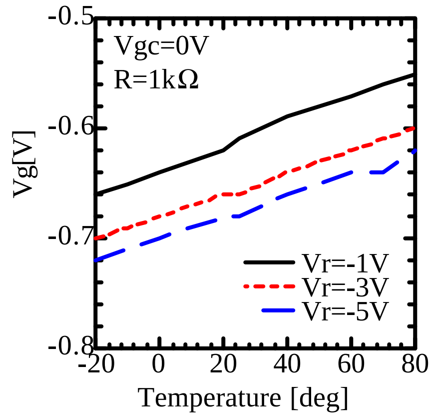

Figure 3 Measured gate voltageof the temperature compensation circuit

IV. APPLICATION TO AN X-BAND POWER AMPLIFIER

The presented temperature compensation circuit is applied to an X-band power amplifier. Fig.4 shows the schematic diagram of the 4 stage MMIC amplifier with the temperature compensation circuit. It is required for the MMIC amplifier to simultaneously achieve both low power consumption and high gain. 4 stage MMIC configuration is used to provide high gain. To achieve low power consumption, the drain circuit is operated at class AB. Further, more it is required for the MMIC amplifier to achieve good gain flatness in broad frequency band. Every inter-stage of the MMIC amplifier is matched to achieve a good gain flatness in broad frequency band. To miniaturize the chip size, matching circuit with short stubs are employed at each stage. The short stubs can be useful as both matching circuits and dc feed lines. Gate width of each FET is chosen to achieve low distortion and low power consumption simultaneously. The X-band MMIC amplifier with the compensation circuit has been developed. Fig.5 shows the photograph of the MMIC amplifier. The compensation circuit is integrated with the X-band MMIC aplifier on a sigle GaAs chip.

To demonstrate the capability of the temperature compensation circuit, temperature characteristics of the MMIC amplifier is measured. The measured small signal gain of the MMIC amplifier with and without temperature compensation circuit at -10deg, 25deg and 80deg are shown in Fig.6. The bias of the MMIC amplifier is fixed at 25deg. It is clearly shown in Fig.6 that the designed circuit compensates the gain variation with temperature. The amplifier achieves the small signal gain of 32dB at 25deg at the center frequency. The measured gain variation with temperature at center frequency is shown in Fig.7. It demonstrated in Fig.6 and Fig.7 that the gain variation of the MMIC amplifier is improved from 5.5dB to 1.3dB in the temperature range between -10deg and +80deg by using the compensation circuit. Therefore, the compensation circuit is suitable to compensate gain variation of a microwave power amplifier within wide temperature range.

Fig.8 shows the measured gain, phase and output power with temperature at center frequency with and without temperature compensation circuit. Variation of gain, phase and output power with temperature are reduced in wide range of input power by using the presented temperature compensation circuit.

The MMIC amplifier has achieved saturation power of more than 22.7dBm and gain of more than 29.7dB in the temperature range between -10deg and +80deg.

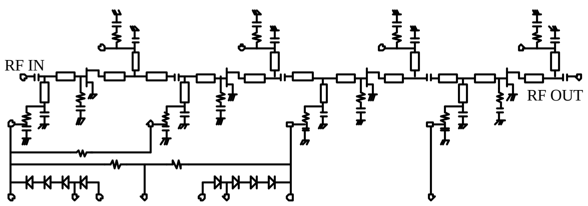

Figure 4 Schematic diagram of the 4 stage MMIC amplifier with the temperature compensation circuit

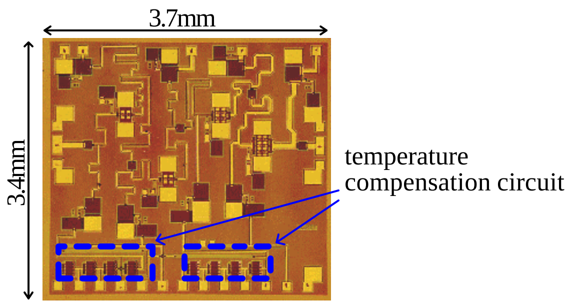

Figure 5 Photograph of the X-band MMIC amplifier with the temperature compensation circuit

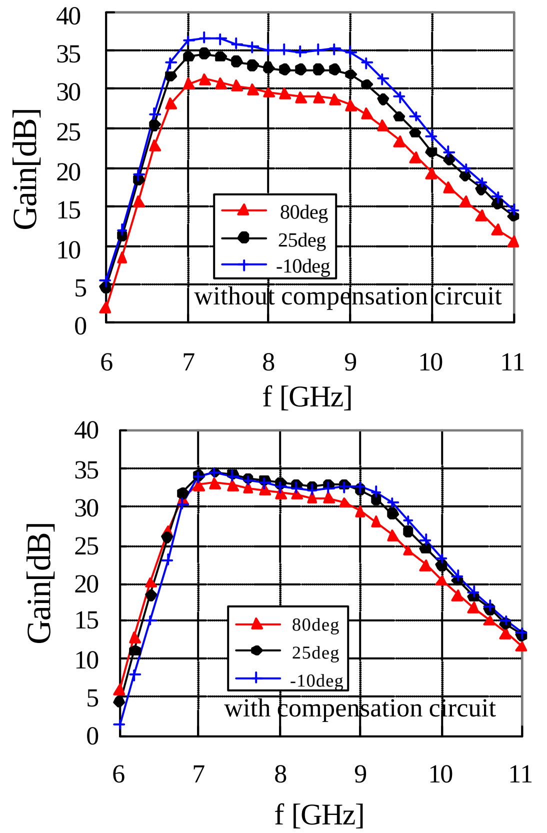

Figure 6 Measured small signal gain of the MMIC amplifier

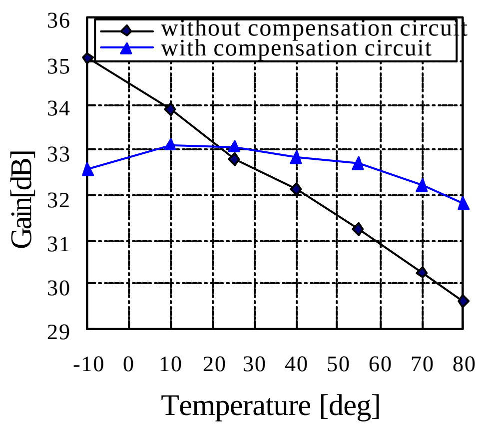

Figure 7 Measured gain variation of the MMIC amplifier with temperature

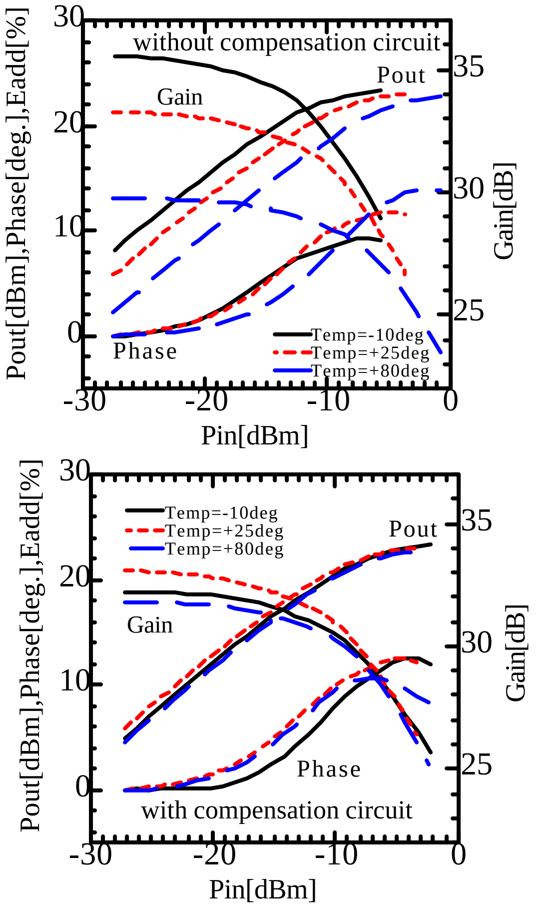

Fig.8 Measured gain, phase and output power with temperature

V. CONCLUSIONS

An X-band MMIC power amplifier with an on-chip temperature compensation circuit has been presented. The temperature compensation circuit is composed of a diode and a resistor. The compensation circuit utilizes the temperature characteristics of the diode. The variation of the amplifier is compensated with temperature by increasing the gate voltage with the increase of temperature.

The compensation circuit is applied to a 4 stage X-band MMIC power amplifier with a small gain of 32dB at 25deg at center frequency. The gain variation is improved from 5.5dB to 1.3dB in the temperature range between -10deg and +80deg by making use of the circuit presented. The compensation circuit is suitable to compensate gain variation of a microwave power amplifier within wide temperature range.

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