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Simulation and Design of a Temperature Compensation Circuit for a Radio Frequency Power Amplifier

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Abstract: ***Power amplifiers made with the third-generation semiconductor material GaN (Gallium Nitride) are more suitable for 5G technology. However, the turn-on voltage of GaN power amplifiers decreases with temperature rise and has a large variation, showing a significant quadratic characteristic, which leads to the deterioration of the linearity of the static working current. In order to reduce this linear deterioration, this paper achieves the adjustment of the gate voltage VGS at different temperatures through modeling and simulation in software ADS, MATLAB, and reasonable circuit construction in TINA-TI, maintaining the stability of the static bias current. This method has a wide range of applications in GaN RF power amplifiers.***

Keywords: Power amplifier, ADS and MATLAB modeling simulation, TINA-TI design, Temperature compensation circuit.

1. Introduction

In a semiconductor transistor amplification circuit, the circuit is in a DC operating state when the AC input signal is zero; the operating condition of the circuit at this time is referred to as the 'quiescent point'. The purpose of setting the quiescent point is to ensure that nonlinear distortion can be prevented when the AC signal being amplified is added to the circuit, whether it is the positive half cycle or the negative half cycle. However, if the quiescent point is set improperly, a high quiescent point may result in saturation distortion during AC signal amplification; a low quiescent point may lead to cutoff distortion during AC signal amplification. Therefore, an appropriate quiescent point can determine the static values of voltage and current in the amplification circuit, preventing nonlinear distortion and ensuring better amplification performance.

Third-generation semiconductor material GaN (gallium nitride) supports higher data transmission capacity and significantly reduces chip area. It has advantages such as high temperature resistance and superior performance in high-frequency environments. Power amplifiers made from GaN are more suitable for 5G technology. However, the linearity of GaN power amplifiers is greatly affected by changes in the quiescent point. In practical applications of GaN power amplifier tubes, the turn-on voltage decreases with rising temperature, leading to an increase in static operating current and degradation of linearity. To mitigate this degradation, the article proposes a temperature compensation method for the quiescent point of GaN power amplifier tubes, which has extensive applications in GaN radio frequency power amplifiers.

2. Temperature Characteristics of GaN Power Amplifiers

GaN transistors are field-effect transistors specifically designed for RF power amplifiers, typically operating in class AB with negative temperature characteristics near the operating point.

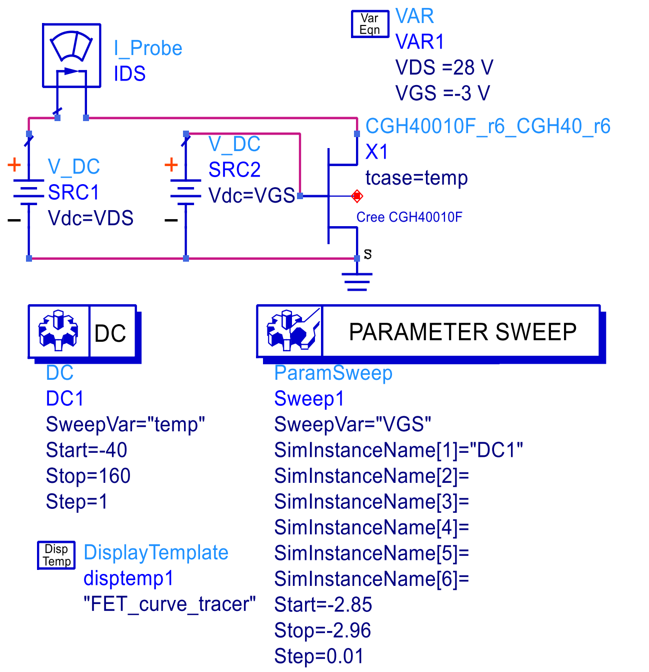

Figure 1: ADS simulation circuit for the Cree CGH40010F GaN model

In the ADS software, simulate the IDS (drain current) and temp (temperature) of the power amplifier with model Cree CGH40010F GaN. The simulation conditions are: VDS (drain voltage) = 28V, temp = [-40:1:160] °C, GaN_VGS (GaN gate voltage) = [-2.96: 0.01: -2.85] V. The simulation circuit is shown in Figure 1.

The simulation results are shown in Figure 2.

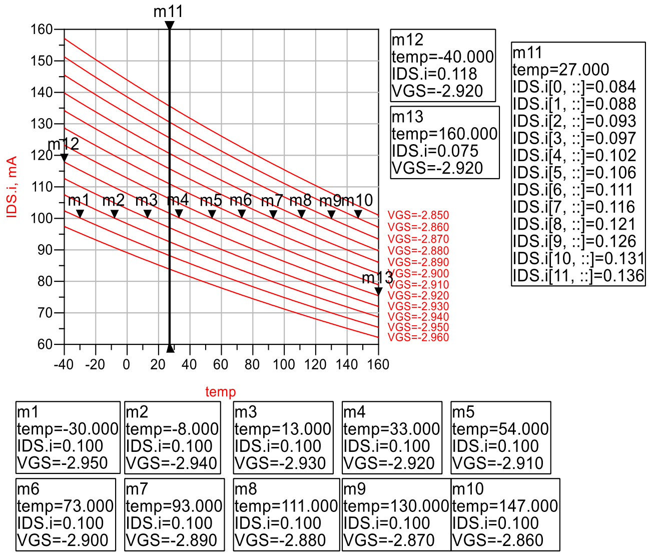

Figure 2: ADS simulation output for the Cree CGH40010F GaN model

From Figure 2, it can be seen that when the VDS (drain voltage) is 28V, under the same temp (temperature) conditions, the larger the GaN_VGS (GaN gate voltage), the greater the IDS (drain current); under the same GaN_VGS voltage conditions, the higher the temp, the smaller the IDS. Based on the above analysis, it can be concluded that when the IDS operating current needs to be the same, the higher the temp, the higher the required GaN_VGS voltage.

3. Curve Fitting of Gate Voltage Versus Temperature for GaN Power Amplifiers

According to Figure 2, extract the relationship between temp (temperature ℃) and GaN_VGS (gate voltage V) when IDS is 100 mA, as shown in Table 1.

Table 1: Relationship between temperature and GaN Gate voltage (GaN_VGS)

Temp(℃)	GaN_VGS(V)
-30	-2.95
-8	-2.94
13	-2.93
33	-2.92
54	-2.91
73	-2.90
93	-2.89
111	-2.88
130	-2.87
147	-2.86

Using the quadratic fitting method based on the relationship table of temp and GaN_VGS, the transfer function is derived as:

$$REF_{VGS} = I * R * [1 + TC1 * (temp\_Tnom) + TC2 * (temp\_Tnom)^2] \quad (1)$$

REF_VGS is the fitted VGS voltage, R is the room temperature resistance, I is the excitation current, TC1 is the first-order temperature coefficient, temp is the temperature variable, Tnom is the room temperature, TC2 is the second-order temperature coefficient.

After simulation in MATLAB, the values of each parameter are as follows:

I=-1mA
R=2923ohm
TC1=-0.0001685
TC2=-0.000000089
Tnom=27 ℃
temp=[-30 -8 13 33 54 73 93 111 130 147] ℃

Based on the simulation results, plot the relationship graph of temp versus GaN_VGS (green line with small circles) and temp versus REF_VGS (blue line) using MATLAB, as shown in Figure 3.

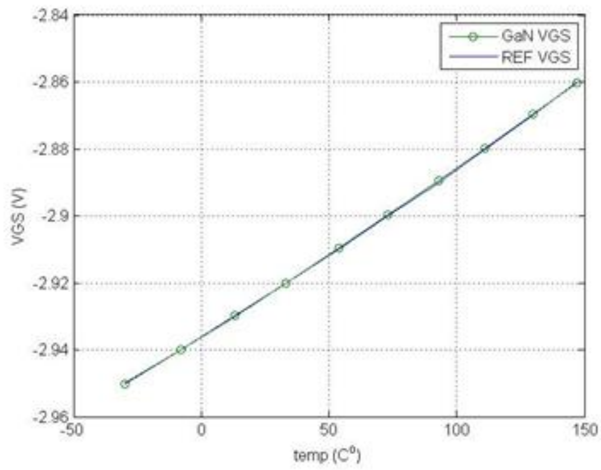

Figure 3: Simulated VGS voltage curve and the fitted VGS voltage curve.

Figure 3 shows that the REF_VGS curve closely aligns with the GaN_VGS curve.

4. The Implementation of VGS Temperature Compensation Circuit for GaN Power Amplifier

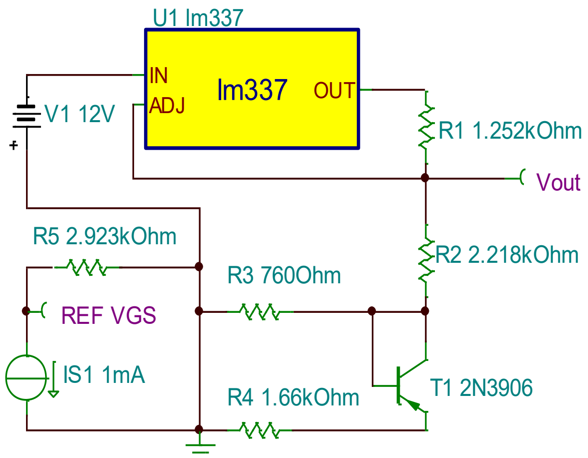

Figure 4: The implementation of VGS voltage temperature compensation circuit for power amplifier

In the circuit design and simulation tool TINA-TI, the simulated circuit model is shown in Figure 4.

In the circuit, IS1 provides a drive current of -1 mA for the reference curve. R5 is a temperature-variable resistor. When Tnom = 27°C, the resistance value of R5 is 2923 ohms, with a primary temperature coefficient TC1 of -0.0001685 and a secondary temperature coefficient TC2 of -0.000000089. The resistance value is:

$$R * [1 + TC1 * (temp_{Tnom}) + TC2 * (temp_{Tnom})^2] = 2923 * [1 - 0.0001685 * (temp - 27) - 0.000000089 * (temp - 27)^2] \quad (2)$$

In the circuit, REF_VGS represents the expected target value after temperature compensation. The constant current source circuit is formed using U1 (LM337 LDO) and R1 resistor, with an output current of -1 mA.

In the circuit, T1, R2, R3, and R4 form a temperature-variable resistor circuit. The resistance of Rbc in TI 2N3906 changes with temperature; the higher the temperature, the smaller the Rbc resistance value. R3 resistor determines the magnitude of the quadratic coefficient, R4 resistor determines the magnitude of the linear coefficient, and R2 resistor adjusts the offset of the voltage curve.

Simulate the power amplifier VGS voltage temperature compensation circuit implemented in Figure 4 using the circuit design and simulation tool TINA-TI. Generate two curves for the expected gate voltage output REF VGS and the actual gate voltage output Vout after circuit compensation, as shown in Figure 5. In Figure 5, it can be observed that the two curves overlap well, indicating that the voltage output from the constructed circuit effectively offsets the effects of temperature changes.

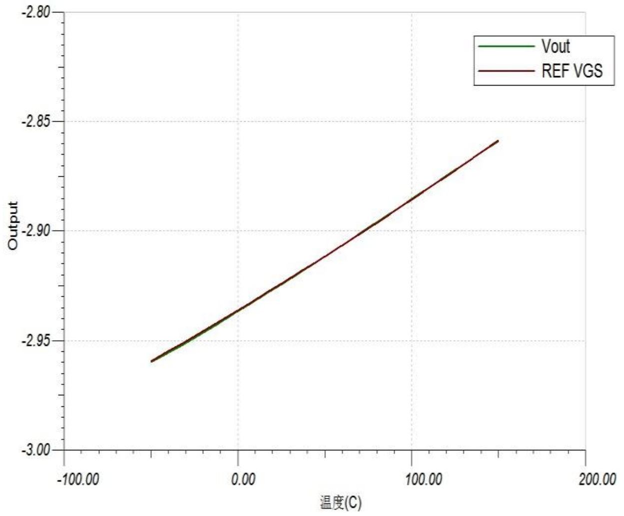

Figure 5: The VGS voltage curve after circuit implementation and the fitted VGS voltage curve

5. Conclusion

The temperature compensation circuit for the GaN RF power amplifier in this paper uses ADS, MATLAB, and TINA-TI software to simulate and implement adjustments of the gate voltage VGS at different temperatures. This compensates for the impact of temperature changes on the linearity of the quiescent point, maintains the stability of the static bias IDS, and ensures that the circuit operates in a better linear state.

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