

2.4 GHz WLAN InGaP/GaAs Power Amplifier with Temperature Compensation Technique

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ABSTRACT—This letter presents a high performance 2.4 GHz two-stage power amplifier (PA) operating in the temperature range from -30°C to $+85^{\circ}\text{C}$ for IEEE 802.11g, wireless local area network application. It is implemented in InGaP/GaAs hetero-junction bipolar transistor technology and has a bias circuit employing a temperature compensation technique for error vector magnitude (EVM) performance. The technique uses a resistor made with a base layer of HBT. The design improves EVM performance in cold temperatures by increasing current. The implemented PA has a dynamic EVM of less than 4%, a gain of over 26 dB, and a current less than 130 mA below the output power of 19 dBm across the temperature range from -30°C to $+85^{\circ}\text{C}$.

Keywords—InGaP power amplifier; wireless local area network (WLAN); temperature compensation technique; dynamic error vector magnitude (EVM).

I. Introduction

Recently, the wireless local area network (WLAN) market has grown rapidly due to the increasing demand for high data rates [1]. It requires a highly linear power amplifier (PA) because of a high peak-to-average ratio. The linearity of an 802.11g PA is generally evaluated through error vector magnitude (EVM) because information is carried on both magnitude and phase of a signal [2]. Therefore, EVM is a key parameter for 802.11g PA development along with gain and efficiency. There has been much effort to improve or optimize

the EVM of power amplifiers at room temperature [3], [4].

EVM measured with a PA continuously turned on is called a static EVM. A dynamic EVM is measured by turning on a PA when the signal is applied to the input of a PA. Interestingly, the dynamic EVM is worse than the static EVM [3]. WLAN applications use a same frequency band for a transmitter (Tx) and a receiver (Rx). Hence, WLAN systems need a switch to perform time domain duplexing (TDD). When a signal is being received through an Rx, it is obviously more efficient if the Tx is off. For this reason, the dynamic EVM should be monitored rather than the static EVM.

To the best of our knowledge, this is the first paper reporting on dynamic EVM with a wide range of temperature variation. In the real market, PA performance, especially EVM, should meet the specification requirements across a temperature range from -30°C to $+85^{\circ}\text{C}$. In this letter, a two-stage PA employing the proposed temperature compensation technique shows huge improvement in EVM performance in cold temperatures.

II. Power Amplifier Design

A simplified schematic of the PA is shown in Fig. 1. The device sizes of the two stages are $240\text{ }\mu\text{m}^2$ and $1280\text{ }\mu\text{m}^2$. Each device includes ballast resistors (R_{b1} and R_{b2}) to avoid thermal runaway [5]. The bias and the RF signal path are separated to preserve gain. The high-pass network is used for input and the inter-stage matching, and the low-pass network is used for output matching. We designed C_1 , C_2 , and L_1 to bring the input impedance to $50\text{ }\Omega$. The values of C_3 and L_2 were chosen to make the gain peak at the center of the band and to maintain linearity decided from the power stage design. The output matching network is implemented externally. Instead of using an inductor, the output trace on the PCB evaluation board of

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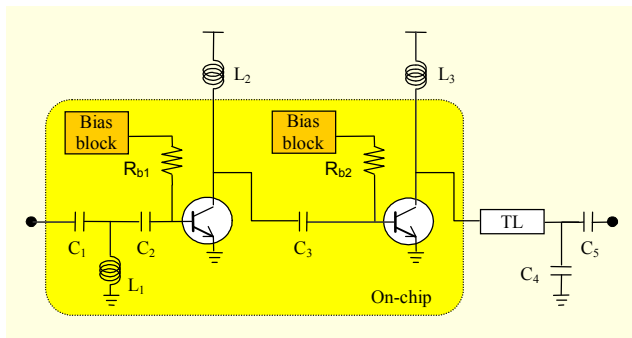


Fig. 1. Simplified schematic of the proposed PA.

50 Ω transmission line (TL) is used. It allows much more accurate output matching impedance to be easily found than the discrete lumped inductor by sweeping the position and the value of the shunt capacitor, C_4 .

III. Bias Circuit with Temperature Compensation

Figure 2(a) shows the common bias circuit for the PA design. It is based on a common current mirror consisting of Q_1 and Q_3 with one more diode (Q_2) stack under Q_1 to hold the base-emitter voltage of the power device constant. This kind of bias configuration for PA design is commonly discussed [6]. However, it is known that the base-emitter voltage (V_{BE}) increases when the temperature decreases. In simulations, when the temperature decreases from 25°C to -30°C, the V_{BE} of the transistor increases by 55 mV. The configuration with a two-diode stack in the bias circuit doubles the increase so that the collector current of the PA is tremendously reduced at cold temperatures. This current reduction pushes the PA operation into the deep class AB mode; thus, EVM performance becomes worse than at room temperature.

Figure 2(b) shows the bias circuit with the temperature compensation technique. Based on the common bias configuration, it employs a temperature compensation resistor R_{TC} (TCR), which connects the supply voltage directly to the base terminal of the power device. At cold temperatures, the TCR makes the direct current path leak from the supply voltage, so that it increases the current of the power device.

There are three candidates in this InGaP/GaAs HBT process to implement the resistor: a thin film resistor (TFR), base layer resistor (BLR), and collector layer resistor (CLR). The TFR is made of NiCr. The BLR and CLR are made of the epitaxial layer of the base layer and collector layer, respectively, so they are called semiconductor resistors. The three resistors have different thermal characteristics as shown in Fig. 3. Each resistor shows resistance variation as a function of temperature from -30°C to +85°C. Although a current increase is needed at cold temperatures, it is not desirable at hot temperatures. The

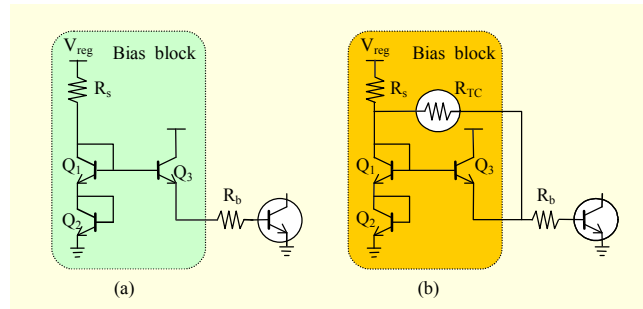


Fig. 2. (a) Common bias circuit and (b) the proposed bias circuit with temperature compensation resistor.

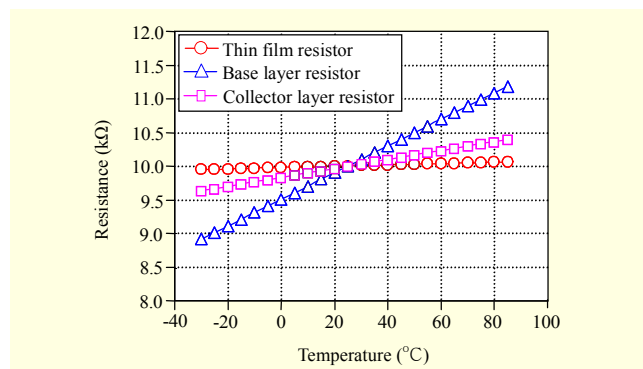


Fig. 3. Temperature characteristics of three resistors: thin film, base layer, and collector layer.

TCR should have lower resistance at cold temperatures and higher resistance as the temperature increases. Based on its thermal characteristics, the BLR was chosen for the temperature compensation technique. In this work, only the TCR was designed with a semiconductor resistor. Both R_s and R_b were designed with the TFR. Before adding the TCR, the values of R_s and R_b were 300 Ω and 200 Ω , respectively. After adding the TCR of 10 k Ω , R_s was chosen to be 500 Ω , and R_b was not changed.

IV. Measurements

Figure 4 shows the EVM performance of the PA with a bias circuit with and without the TCR. The figure plots the EVM results as a function of the output power with three different temperature conditions. The PA was measured at the frequency of 2.45 GHz with a 64QAM OFDM signal for 54 Mbps. The EVM performance at -30°C is very poor. From the output power level of 13 dBm, EVM goes over 6%. On the other hand, the PA employing the bias circuit with the temperature compensation technique shows great EVM improvement at cold temperatures.

Figure 5 shows the gain performance with temperature variation. As the temperature decreases, the PA shows gain expansion indicating that it enters the deep Class AB mode.

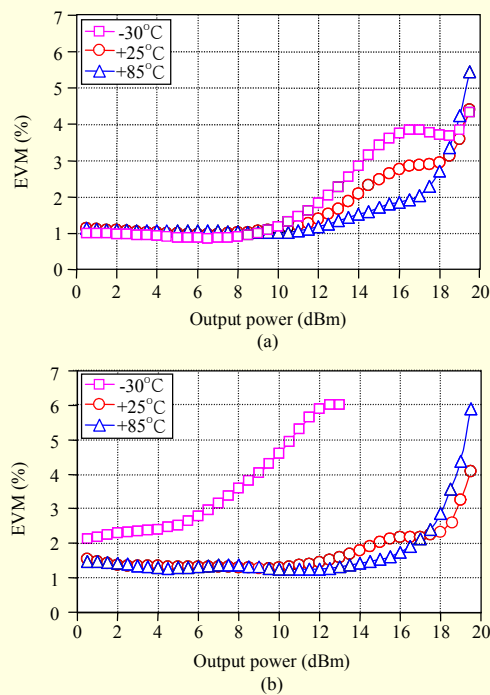


Fig. 4. EVMs with temperature variation of PA with bias circuit (a) with TCR and (b) without TCR.

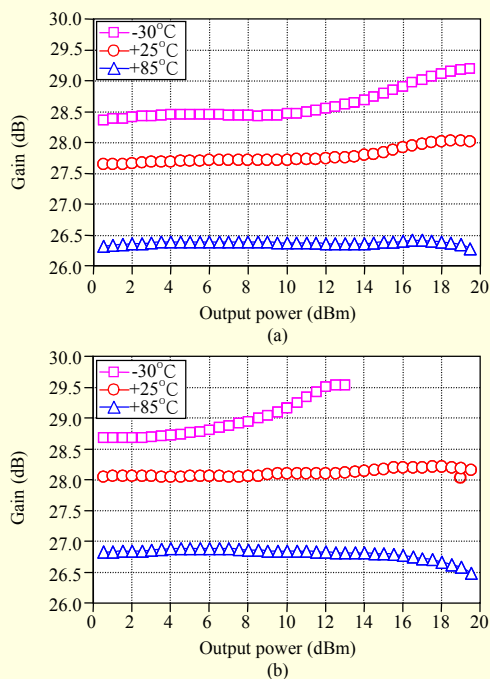


Fig. 5. Gains with temperature variation of PA with bias circuit (a) with TCR and (b) without TCR.

Figure 6 shows the currents with temperature variation with TCR. Note that the current variation across temperatures is reduced by 40% with the TCR.

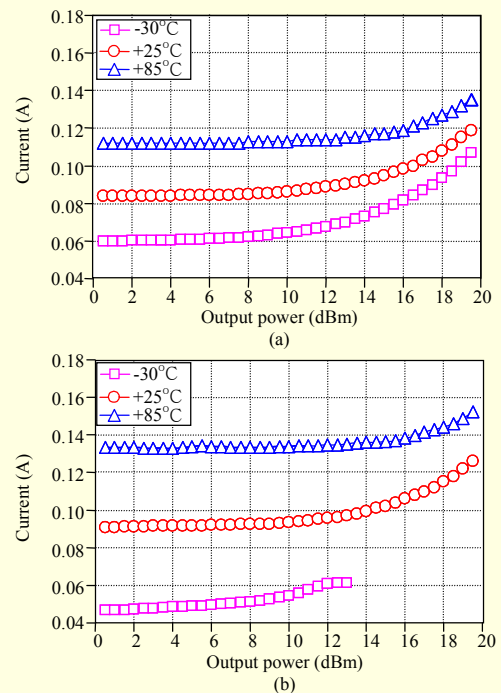


Fig. 6. Current consumption with temperature variation of PA with bias circuit (a) with TCR and (b) without TCR.

V. Conclusion

This letter presents the two-stage PA in InGaP HBT technology with a temperature compensation technique for EVM for IEEE 802.11g application. A resistor is added between the supply voltage and the base terminal to increase the current at cold temperatures. It is made with a base layer of HBT to suppress the current increase at high temperatures.

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