A 2.4 GHz GaAs HBT stacked power amplifier with inductance compensation

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Abstract: A stacked power amplifier (PA) using 2- μm GaAs HBT process is presented for 2.4 GHz application. The stacked configuration can increase the output power by raising the supply voltage of the circuit. Additionally, a novel inter-stage matching technique with series RC is proposed to suppress the efficiency degradation caused by the parasitic capacitance. The measurement results show the compensation technique improves PAE by more than 6%, while the error vector magnitude (EVM) is enhanced. And the fabricated PA shows a gain of 23.7 dB and a saturated output power of 32 dBm with PAE of 50%, while the EVMs are lower than 3% up to 26 dBm of OFDM/64QAM output power.

Keywords: heterojunction bipolar transistors (HBTs), power amplifier, stacked structure

Classification: Integrated circuits

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1 Introduction

Wireless local area network (WLAN) has been widely used in modern life, especially the 2.4 GHz WLAN based on IEEE 802.11g/n which employs orthogonal frequency division multiplexing (OFDM) modulation for high data rate. OFDM modulation possesses a very high peak-to-average power ratio (PAPR) and requires high linear power amplifier to avoid signal distortion. The linearity can be achieved by setting the amplifier operate at power back off condition. High power and high efficiency PA is demanded for wide area wifi networks.

In order to obtain the maximum output power, rather than for an optimum gain, the device is matched to a load that allows the maximum voltage and current swings. However, the required output matching impedance is usually much lower compared to the system impedance, making the matching circuit design complicated. Stacked power amplifier is an output power enhancement circuit based on voltage multiplication rather than current increasing. Increasing current swing by means of increasing the active devices size or connecting more devices in parallel will decrease the optimum load impedance, and make it difficult to match. The voltage swing increasing technique through connecting the active devices in series can get a higher impedance [1].

There have been reports of the implementations of stacked power amplifier at low frequency [2, 3, 4, 5, 6]. But at high frequency, the parasitic capacitance effect of an active device becomes obvious. Conventional structure cannot fulfil the inter-stack matching. An inter-stack inductor was adopted in [7, 8] to complete the inter-stack matching circuit at high frequency. However, this inductor will occupy a large area and bring some ohmic loss that decreases the output power. In this letter, we present a novel inter-stack matching structure without inter-stack matching inductor at high frequency, which improves PAE and linearity of stacked power amplifier.

2 Circuit design

The proposed stacked power amplifier architecture is shown in Fig. 1 using a stack of two GaAs HBT transistors which have the same emitter area. The HBT Q1 collector and Q2 emitter are connected. The base of HBT Q2 is connected to a series resistor R_b and capacitor C_b . The topology of the amplifier allows a maximum collector voltage to be $2 \times BV_{ce}$, where BV_{ce} is the breakdown voltage between collector and emitter of an HBT. The supply voltage V_{CC} is set to 8 V. Both bottom and top transistors of the stacked structure are biased in the same condition. The difference between this structure and classic cascode structure is the inter-stage optimum power

Fig. 1. Schematic of dual stacked power amplifier with series RC at the base of the upper transistors.

match. Unlike in a classic cascode structure where the base of the upper transistors is at RF ground, a relatively small external base capacitance in series with a resistance is introduced to allow an RF swing at the base of the upper transistors. The dual stacked amplifier doubles the voltage swing, and the series devices share the same current swing. To obtain high output power, the output voltage swing and current swing must be large enough.

At low frequency, the input impedance and the optimum load impedance of each device in the stack are purely resistive. The optimum output load impedance of each stacked device is $R_{opt} = V_{swg}/I_{swg}$, where V_{swg} and I_{swg} are the maximum voltage and current swing respectively. The optimum load resistance of the dual stacked devices can be assumed to be two times of R_{opt} . The load impedance of the bottom transistors, which is the input impedance of the top transistors, can be adjusted through altering the value of capacitance C_b connected to the base terminal of the top transistors. The impedance is calculated as [2]

$$Z_{emitter} \approx \left(\frac{1}{g_m} \right) \left(1 + \frac{C_{be}}{C_b} \right). \quad (1)$$

Where g_m is the transistor transconductance, and C_{be} is the base to emitter capacitance.

But for high frequency design, considering the parasitic capacitance effect, the optimum load impedance of the device needs some inductance. The small signal equivalent circuit of Fig. 1 is shown in Fig. 2.

According to Kirchoff's law, the input impedance of the top transistors is calculated as

$$Z_{e2} \approx \frac{C_b + C_{be2} + C_b R_b / r_{be2}}{C_b g_m} + j \frac{R_b \omega^2 C_{be2} C_b - 1 / r_{be2}}{\omega C_b g_m}. \quad (2)$$

In Eq. (2), if $R_b \omega^2 C_{be2} C_b > 1 / r_{be2}$, the impedance shows some inductive. There are two degrees of freedom to alter the input impedance of the top transistors, and it is easy to obtain an inductive impedance equal to the optimum load impedance of the bottom transistors. To achieve the maximum output power of the PA, the capacitor C_b and resistor R_b connected

Fig. 2. Small signal equivalent schematic of the dual stacked power amplifier.

Fig. 3. Simulated gain and PAE versus output power at 2.4 GHz.

to the base terminal of the top transistors are properly designed to assure the maximum power transfer to the top transistors. This design suppresses the parasitic capacitance effect, improves PAE and linearity of the power amplifier.

Fig. 3 shows the comparison of simulated PAE between the stacked amplifier with and without inductance compensation. The results show that the PAE can be enhanced by more than 10% at 1-dB output power with inductance compensation design.

3 Measurement

The power amplifiers with and without inductance compensation are fabricated with $2\ \mu\text{m}$ InGaP/GaAs HBT technology. The die photo is shown in Fig. 4. And the chip is mounted in the center of a test board with wires

Fig. 4. Die photo of dual stacked power amplifier.

Fig. 5. Test PCB board.

Fig. 6. Measured S-parameters of dual stacked power amplifier.

Fig. 7. Measured gain and PAE versus output power at 2.4 GHz.

bonded to the board, shown as Fig. 5. The measured small signal gain and return loss are plotted in Fig. 6. The small signal gain is 23.7 dB at 2.4 GHz, and the input return loss is better than 17 dB from 2.4 GHz to 2.5 GHz with inductance compensation. Fig. 7 shows the measurement results of power gain and PAE as a function of output power at the design frequency of 2.4 GHz. The PAE is improved by more than 6% with inductance compensation at 1-dB output power. With inductance compensation, the 1-dB output power is 32 dBm with 50% PAE. Fig. 8 shows EVM measured with the 802.11g OFDM/64QAM signal. The EVMs are lower than 3% up to 26 dBm output power, but increase dramatically beyond this power. And the EVM

Fig. 8. Measured EVM as a function of output power at 2.4 GHz.

is improved by 0.7% with inductance compensation at 26 dBm output power.

4 Conclusion

In this letter, a novel stacked power amplifier structure has been proposed. It is targeted for high frequency application without the need for lossy and bulky inter-matching inductors. The measurement results show that PAE and EVM are improved with this technique. And a power amplifier with this inductance compensation technique is demonstrated to deliver 32 dBm output power with 50% PAE at 2.4 GHz with 8 V voltage supply. The OFDM/64QAM modulation stimulus for the PA test yields 3% EVM under 26 dBm output power.

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