A 5 W High Efficiency Class AB Power Amplifier for LTE Base Station Application

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***Abstract*— This paper presents the design of a Class AB power amplifier operating at a frequency band of 3.4 GHz - 3.7 GHz for LTE base station applications. The proposed design is targeted for a compact, low cost, high efficiency, and good linearity features. It based on GaN HEMT CGH40006P device manufactured by Wolfspeed/Cree. The design procedure and assessment of the presented power amplifier are described in this paper. The proposed input and output matching networks with stepped tapered microstrip transmission line have enhanced the transmission coefficients of the power amplifier, resulting in improvement of overall performance. The drain voltage and current waveforms are demonstrated to ensure the appropriate biasing point of class AB. At 1dB compression, the simulated results of the proposed class AB power amplifier with one tone input signal delivers power added efficiency of 59%, and 38 dBm output power. With code division multiple access (CDMA) signal, the power amplifier delivers a 51.9% of PAE, adjacent channel power ratio (ACPR) of below than -28.5 dBc at 2.25 MHz offsets, and delivers 37 dBm (~5 W) output power.**

Keywords*— *Power amplifier; GaN-Based; Class AB; High efficiency;

I. Introduction

High efficiency and linearity power amplifiers are extremely desirable by wireless telecommunication equipment manufacturers to meet the requirements of new technology of wireless communication systems. Power amplifiers play a significant role in wireless communication system performance. Its features strongly effect the entire system performance as it serves to enhance the signal to competently cope with varying its characteristics while ensuring efficient transmissions, and cost effectiveness [1]. The linearity of the power amplifier is also very important for transmitting complex modulation schemes that provide high data rates. As the modulated signal often has non-constant envelope modulation with with high Peak to Average Power Ratio (PAPR) such modulation schemes are realized in CDMA and OFDM systems [2-4]. Therefore, power amplifiers must be appropriately designed to ensure efficiency and linearity [5].

Designing a power amplifier involves numerous challenges such as the trade-off between linearity, efficiency, gain, output power, stability, input and output reflections and device selection [6]. Class AB power amplifiers are compromise between Class-A and Class-B modes in terms of linearity and efficiency [1], [7]. Typically, the device is biased to a quiescent point, which is somewhere in the region between the cut-off point and the Class A bias point. In this case, the device will be conducting current for more than half cycle, and less than a full cycle which results in an efficiency between 50%-78% and better linearity than class B [8].

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Transistor selection is an important step in designing power amplifier [5]. There are many device technologies such as laterally diffused metal oxide semiconductor (LDMOS), gallium arsenide (GaAs), and gallium nitride (GaN) [9,10]. Each device has its advantages and limitations. In this design, a Gallium Nitride (GaN) High Electron Mobility Transistor (HEMT) is chosen due to its superior performance at microwave frequencies [11]. GaN HEMTs are promising devices, as they ensure large bandwidth, high power density, high breakdown voltage, high gain, and provide high level of robustness, stability thermal conductivity and heat capacity [12,13].

In this paper, a 5 Watt high efficiency class AB power amplifier based on GaN HEMT device is designed using Advanced Design System (ADS2016) software. It operates at 3.4 GHz-3.7 GHz for LTE base station application. Section II discusses the design methodology including biasing networks, input and output matching networks, decoupling, and stability circuit to achieve optimal trade-off between efficiency, linearity and reflection coefficients. In Section III, the power amplifier is characterized, the simulation results include transmission coefficients, small signal gain, PAE, output power, and ACPR with different input signals. This work is concluded in Section IV.

II. Design Procedure of Class AB Power Amplifier

Table I presents the specification of the proposed Class AB power amplifier. A GaN HEMT from CREE, the CGH40006P, is selected. For the board substrate RO4350B, from Rogers Corp., with relative permittivity of ε_r = 3.8, dielectric loss tangent of $\tan_\delta$ = 0.0031, and thickness of 0.762 mm is chosen for the proposed design due to its promising features such as reliability and low dielectric losses.

TABLE I. The proposed Class AB power amplifier specifications

Parameters	Specification
Operating Frequency	(3.4-3.7) GHz
Bandwidth	300 MHz
Output power	37 dBm
PAE	> 50%
Gain	>15 dB
Return loss	<-15 dB

To ensure class AB mode operation, a DC simulation for the nonlinear device (CGH40006P) model was performed using ADS 2016 software to obtain the I-V curve and selecting a proper Class AB basing point. Fig. 1 shows the I-V characteristics of the selected device. By observing the device's I-V characteristics, the operating point for Class AB mode is chosen at drain current I_{DS} = 308 mA, gate voltage V_{GS}=-2.2 V. It is located below the Class A, and above the pinch-off point (Class B). The chosen operating point ensures that the device's conduction angle is higher than 180° and less than 360° resulting in a compromise between linear and efficient operation.

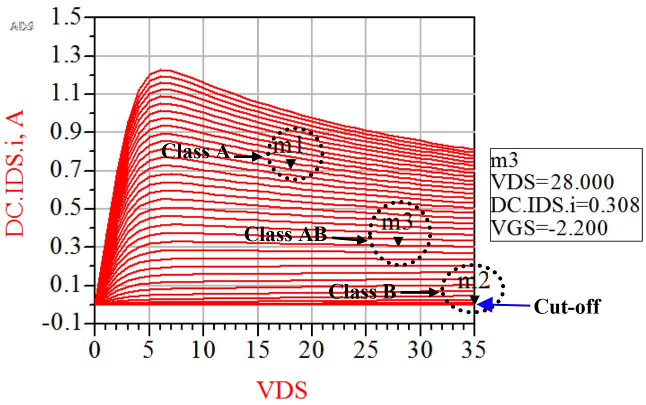
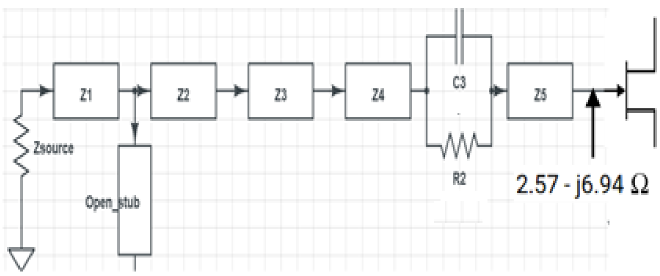


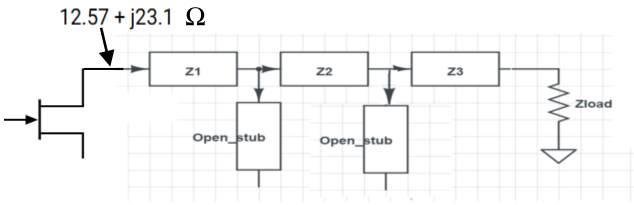
Fig. 1 I-V curves for CGH40006P device biased at Vgs= 2 V to 3 V to -3.5 V and Vds = 0 V to 35 V.

The input and output matching networks of the proposed Class AB power amplifier are designed using stepped impedance and open stubs matching filter to match the typically 50 Ω input and output impedance to the given transistor's source and load impedance for optimal performance. The input matching network is designed to match a 50 Ω to transistor's source impedance 2.57-j6.74 Ω within the operating frequency band (3.4 GHz-3.7 GHz), see Fig. 2 (a). A single stub and stepped transmission line is used to filter out all unwanted harmonic components while pass signals within the desired frequency band. To improve the stability of the device, parallel RC circuit is placed before the gate of the transistor as shown in Fig. 2 (a). Similar to the input matching network, an output matching network is designed with stepped tapered microstrip line and two open stubs to match a 12.5 + j 23.1 Ω output impedance to the customary 50 Ω output impedance as shown in Fig. 2(b). The input and output match response of the proposed design for 3.4 GHz-3.7 GHz is shown in Fig. 2 (c).

Drain and gate voltages feed the transistor by similar DC biasing networks through high reactance RF choke (L_1,and L_2), and RF decoupling and voltage stabilizing capacitors (C_5-C_{11}) as can be seen in Fig. 3.



(a)



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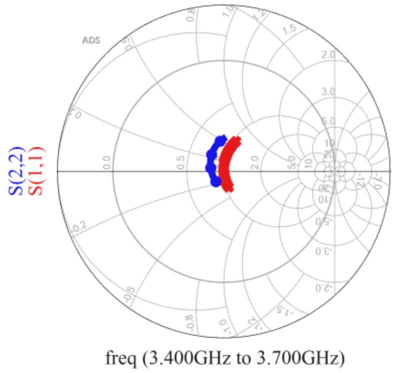
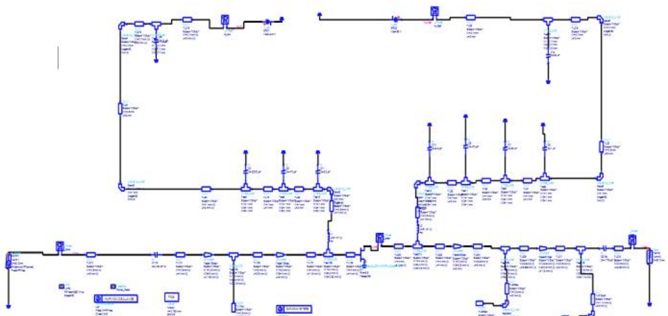


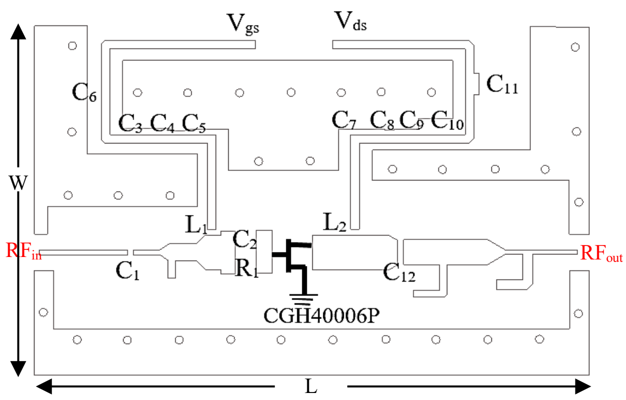
(c)

Fig. 2 Input and output matching networks, (a) Input matching network, (b) output matching network, (c) simulated input and output match response seen at the input (S11) and output (S22) of the proposed power amplifier within operation band (3.4 GHz-3.7GHz).

Fig. 3 (a), and (b) illustrates the full design schematic and layout of the proposed class AB power amplifier, respectively. Parameters values are demonstrated in Table II.



(a)



(b)

Fig. 3 Schematic and layout of the proposed design, (a) schematic, (b) layout.

TABLE II. THE PROPOSED CLASS AB POWER AMPLIFIER PARAMETERS

Parameters	Value	Parameters	Value
C_1, C_{12}	4.7 pF	W	40 mm
C_2	2 pF	L	56 mm
C_3, C_4	8.2 pF	V_{gs}	-2.2 V
C_4, C_8	470 pF	V_{ds}	28 V
C_3, C_9	0.33 uF	R_1	4.7 Ω
C_6	10 uF	-	-
C_{11}	33 pF	-	-

III. RESULTS AND DISCUSSION

Fig. 4 (a) and (b) illustrates the simulated small signal S-parameters of the presented Class AB power amplifier. It can be observed that the input and output reflections (S_{11} and S_{22}) are lower than -10 dB within the operating frequency band results, indicating better load matching and efficient transmitting capability. A small signal gain (S_{21}) of 15 dB is achieved as can be seen in Fig. 4 (b).

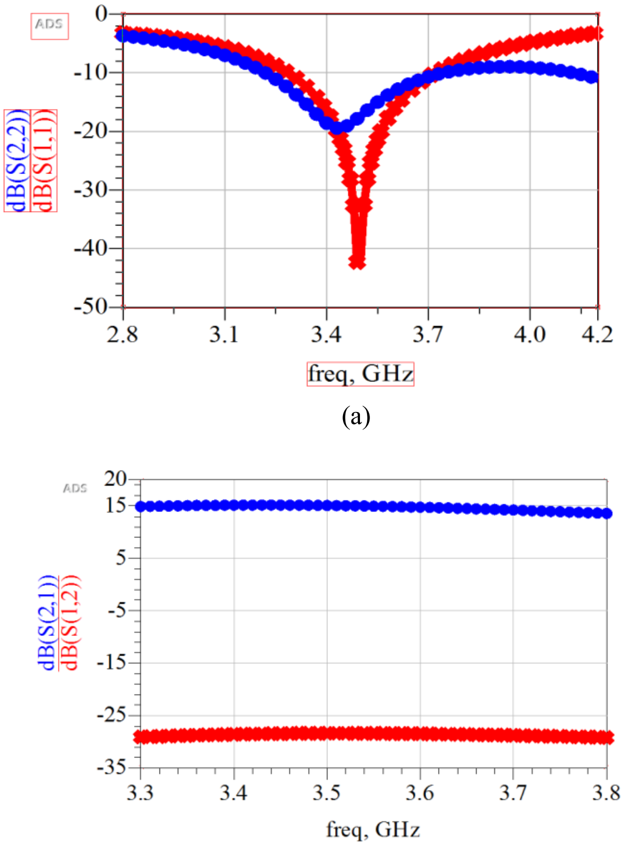


Fig. 4 Simulated S-parameters of the proposed design, (a) S_{11} and S_{22}, (b) S_{21}, and S_{12}.

First, performance of the proposed power amplifier is evaluated using a one tone input signal. A center frequency 3.55 GHz is selected and input power levels (RFpower) swept from 0 dBm to 30 dBm to assess the power added efficiency (PAE), gain and output power. The simulated output power and PAE with one tone signal are illustrated in Fig. 5 (a) and (b), respectively. A 59% of PAE is achieved at 1 dB compassion point as can be seen in Fig. 5 (b).

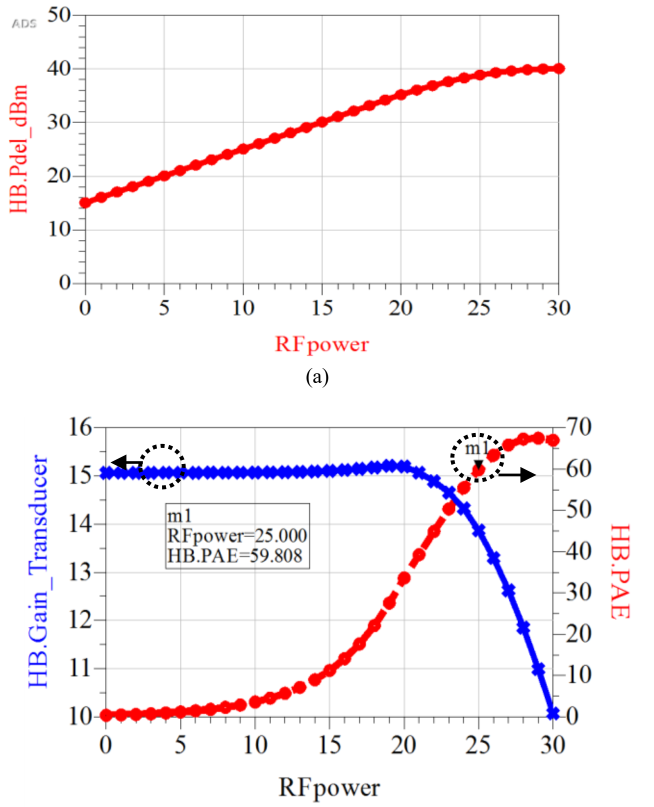


Fig. 5 One tone input signal results, (a) output power, (b) transducer gain and PAE.

Fig. 6 shows the simulated drain current and voltage waveforms at higher input power (23 dBm to 25 dBm). As can be observed from Fig. 6, the waveforms of drain voltage at high input power (23 dBm to 25 dBm) are sinusoidal, thus indicate a linear operation. Waveforms of drain current indicate class AB mode operation since its conduction angle is greater than 180° and turned-off before completing a full cycle.

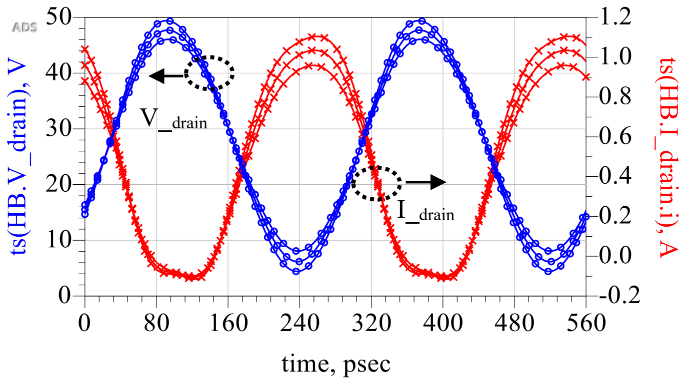


Fig.6 Drain voltage and current waveforms of the proposed power amplifier.

The non-linearity of the power amplifier creates difficulties in wireless communication systems as the RF modulated signal is distorted and recovering the transmitted information becomes challenging [9]. One of the most popular techniques to evaluate non-linearity behavior of power amplifier is by finding its carrier to intermodulation ratio (C/I). Defined her to be, the ratio of useful component output power to the intermodulation distortion (IMD) output power [1]. In this technique, two tone signal with more than one carrier frequency is applied at the input of the power amplifier resulting in intermodulation distortion products of side bands. Third-order intermodulation product (IM3) is the most critical source of distortion provided by two tone signals [14]. It appears at near or inside the desired signal band.

Fig. 7 shows the simulated results of upper and lower sides IM3, and IM5 of the proposed Class AB power amplifier. The input of the power amplifier is excited using two tone signals, both have the same amplitude with 5 MHz tone spacing. The frequency is wept from 3.4 GHz to 3.7 GHz and input power also swept from 0 dBm to 30 dBm. At 37 dBm output power, the upper and lower sides of IM3 are below -20 dBc, and IM5 is below -40 dBc, respectively as can be observed from Fig. 7.

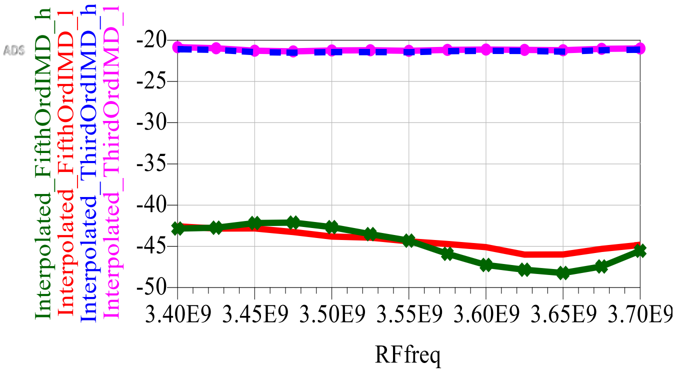
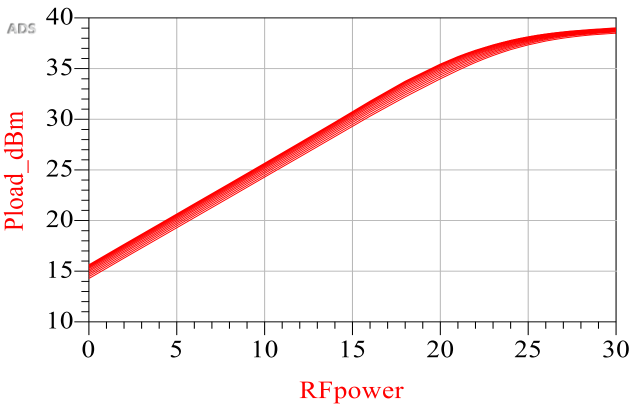
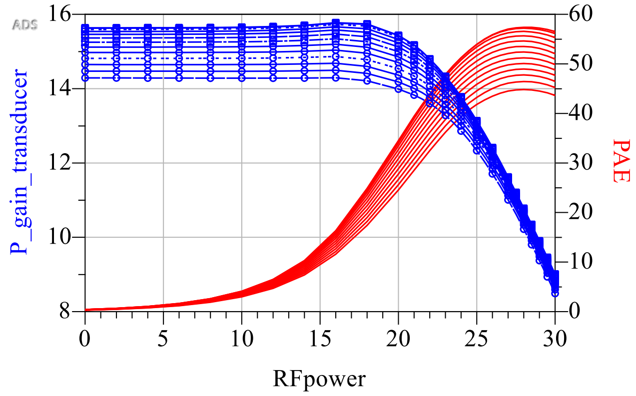


Fig. 7 Upper and lower sides third-order IMD (dBc), and fifth-order IMD (dBc) of the proposed amplifier at 37 dBm output power and two tone input signal.

Fig. 8 (a) and (b) shows the output power, PAE, and transducer gain versus input power (0 dBm to 30 dBm) at frequency band 3.4 GHz to 3.7 GHz with two tone signal. At 1 dB compression, output power varies with frequency as can be seen in Fig. 8 (a). However, the output power is constantly greater than 36 dBm for all frequencies within desired band at 1 dB compression. The PAE is greater than 47% within desired frequency band, see Fig. 8 (b).



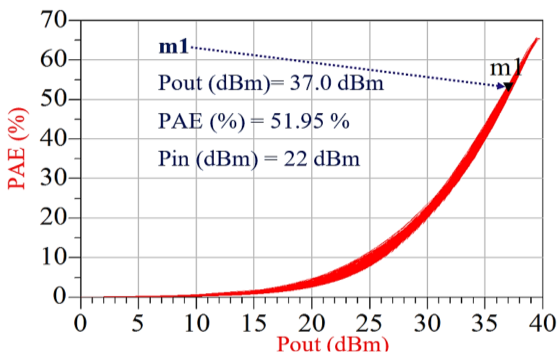
(a)

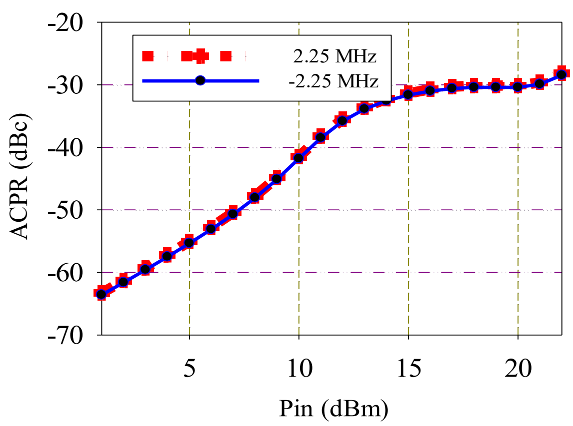


(b)

Fig. 8. Two tone input signal results, (a) output power, (b) transducer gain and PAE.

A modulated signal reverse-link CDMA with a bit rate of 1.2288 Mcps at center frequency 3.55 GHz is evaluated using ADS2016 software to verify the operation of the proposed design. Fig. 9 (a) and (b) illustrates the simulated results of the power amplifier with CDMA signal. The simulated result of PAE is 51.95% at output power of 37 dBm, and 22 dBm input power. Fig. 9 (b) demonstrates the Adjacent Chanel Power Ratio (ACPR) of the power amplifier. ACPR is less than -40 dBc at the offsets of 2.25 MHz for 33 dBm (average output power) and it is below -28.5 dBc for the maximum output power 37 dBm (~5 W).





(b)

Fig.9 Simulated results of the proposed power amplifier with CDMA signal, (a) PAE, (b) ACPR.

IV. Conclusion

In this paper, a 5 W high efficiency Class AB power amplifier operates at 3.4 GHz- 3.7 GHz for LTE base station applications is presented. The design procedure includes DC basing, input/output matching networks, extracting S-parameters, stability and small signal gain are discussed. One tone signal, two tone signal and CDMA signal are used to evaluate the performance of the presented power amplifier. A 51.95 % of PAE, less than -28 dBc of ACPR, and 37 dBm output power are achieved with CDMA signal.

Acknowledgment

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