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# 31W Linear Broadband 3.4 to 4.4 GHz High Power Class-J GaN HEMT Amplifier

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**ABSTRACT**

***The increased demand for high-power amplifiers in transmitters deployed in numerous wireless communication applications such as electronic warfare (EW), RADAR, Satellite and optical communications has further underscored the importance of linear broadband high-power Class-J power amplifiers. This paper proposes a 31W linear broadband 3.4 to 4.4 GHz high-power Class-J GaN HEMT (gallium nitride high electron mobility transistor) amplifier. The power amplifier was designed based on Cree's commercially available 10W GaN HEMT power transistor device (CGHV40010F) using Keysight Advanced Design System (ADS) software and simulated. The transistor was biased with a drain supply voltage of 48V at a quiescent drain-to-source current of 0.58A which makes the power transistor suitable for high voltage transmitter operations and foreclosed the need for voltage upgrade, thereby reducing the cost of operation. The power amplifier (PA) operates from 3.4 to 4.4 GHz with a centre frequency of 3.9 GHz. The PA has an output power of 31W, drain efficiency of 36.3%, power added efficiency of 35.3% and power gain of 12.9 dB at an input power of 32 dBm. The PA small signal gain stood at 10.6 dB at a centre frequency of 3.9 GHz. The PA maintained a peak envelope power of 56.2W at an input power of 31 dBm at a two-tone Frequency of 3.895 GHz. The PA will find applications in wireless communications, military and aviation transmitters.***

## INTRODUCTION

The quest for increased signal power for the numerous wireless communication systems requires the deployment of linear high-power Class-J PA in transmitters used in such areas as electronic warfare, RADAR, optical and satellite communications (Ishda, 2011; Pengelly *et al*., 2012). Mishra *et al*. (2008) investigated that wideband gap gallium nitride (GaN) high electron mobility transistor (HEMT) with semi-insulating silicon carbide (SiC) substrate has high electron saturation drift velocity, high operational voltage and high thermal conductivity, which provides it with the capability to deliver high power. The high output power ability of GaN HEMT justifies the use of a commercially available 10W GaN HEMT device (CGHV40010F) in this work. The power and efficiency of PAs are often overwhelmed by device parasitic capacitance at Giga Hertz frequencies, especially the output parasitic capacitance (drain-to-source capacitance). The power transistor output parasitic capacitance controls the PA output power available to the fundamental load. Cripps (2006) first proposed using reactive termination to mitigate the effects of power transistor output parasitic capacitance on the fundamental load and referred to the PA mode as Class-J. Class-J PA topology effectively improves the output power and efficiency of Class AB and Class B PAs without limiting the amplifier's bandwidth. This is achieved by applying reactive termination at the fundamental and biasing the power transistor in deep Class AB or Class B.

Reactive termination changes the fundamental load from a resistive regime to a reactive regime. Reactive termination mitigates the effects of the second harmonic component of output power and enhances output power and efficiency. Wright *et al*. (2009), Guan *et al*. (2012), Preis *et al*. (2012), Moon *et al*. (2010), Fu *et al*. (2012), Tuffy *et al*. (2011), *Ma et al*. (2013) and Ture *et al*. (2014) have all proposed Class-J PA with different stability network and frequency of operation from the one proposed in this paper. Moreover, the proposed PA has a stability network of two parallel capacitors and a resistor, forming a parallel RC network in its input matching network. This ensures that the PA is unconditionally stable. To the authors' knowledge, a Class-J PA operating from 3.4 to 4.4 GHz frequency with a similar stability network and 31 W output power has yet to be reported.

## MATERIALS AND METHODS

### Class-J Theory

In Class-J power amplifier, reactive termination applied to the fundamental changes it from resistive to reactive regime thereby mitigating the effects of power transistor output parasitic capacitance on the fundamental load. Wright et al. (2009) reported that in Class-J PA mode, even higher-order harmonics than the second harmonic is non-existent, while the third harmonic impedance component is assumed to be short-circuited out. In Class-J PA, the fundamental, second and third harmonic components of impedance denoted by $Z_{f0}$, $Z_{2f0}$ and $Z_{3f0}$ are respectively given by

$$Z_{f0} = R_L + jR_L \quad (1)$$

$$Z_{2f0} = 0 - j\left(\frac{3\pi}{8}\right)R_L \quad (2)$$

$$Z_{3f0} = 0 \quad (3)$$

### Design

The PA circuit was designed with Keysight Advanced Design System Software (ADS) based on Cree CGHV40010F high voltage transistor biased at deep Class AB drain supply voltage of 48 V and quiescent drain-to-source current ($I_{DSQ}$) current of 0.58 A. The drain-to-source current ($I_{DS}$) versus the drain-to-source voltage ($V_{DS}$) characteristics of the GaN HEMT power transistor with load-line are shown in Figure 1. The PA was subjected to Source Pull and Load Pull simulations to determine the source and load impedances required to synthesize the Microstrip input and output matching network for maximum output power at the fundamental frequency. The matching networks consist of quarter-wave transmission lines and open circuit stubs. The dimensions of the width and length of the transmission lines are in millimeters (mm). The PA schematic circuit is shown in Figure 2. The PA schematic circuit contains DC Feed inductors, DC blocking capacitors and by-pass capacitors. An RC Stability network forms part of the PA input-matching network. The stability network maintains the PA unconditional stability across the 1 GHz bandwidth from 3.4 to 4.4 GHz with a maximum gain of over 16 dB at 3.9 GHz centre frequency, as shown in Figure 3. The Class-J PA was subsequently subjected to one-tone and two-tone harmonic balance simulations. One-tone harmonic balance simulation was used to determine the drain efficiency, Power added efficiency (PAE), output power and power gain at 3.9 GHz centre frequency. The power available to the source was swept from 0 to 32 dBm. Two-tone harmonic balance simulation was used to determine the output power at first harmonic ($P_1$), second harmonic ($P_2$), third harmonic ($P_3$) and the transducer power gain at first harmonic ($G_1$). Quadrature phase shift keying (QPSK) modulation was also carried out on the PA using the Advanced Design System (ADS) PTlomey setup. This was aimed at determining the adjacent channel power ratio (ACPR). The signal data was sampled at a bit rate of 100 MHz at ten samples per symbol at a temperature of 0ºC and RF fundamental frequency of 3.9 GHz at an input power of 32 dBm.

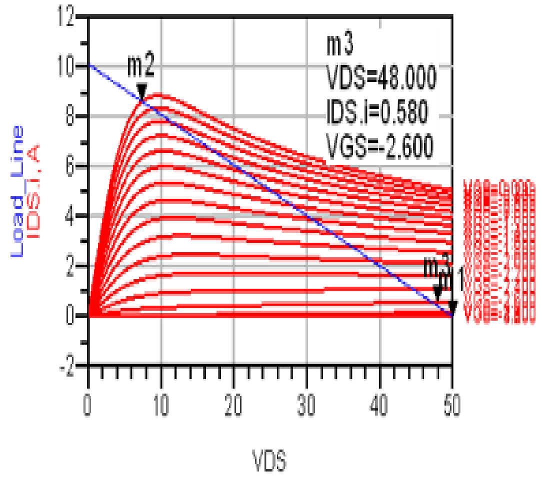


Figure 1. DC $I_{DS}$ versus $V_{DS}$ characteristics bias points.

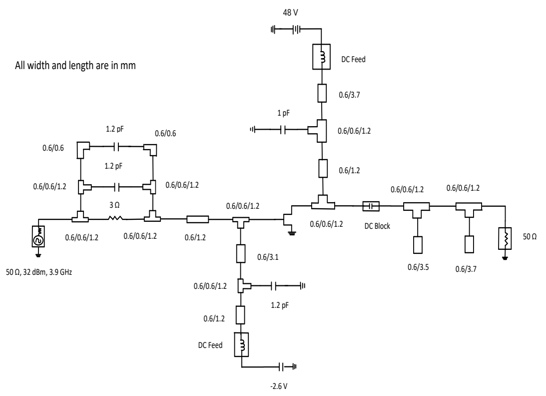


Figure 2. PA schematic circuit

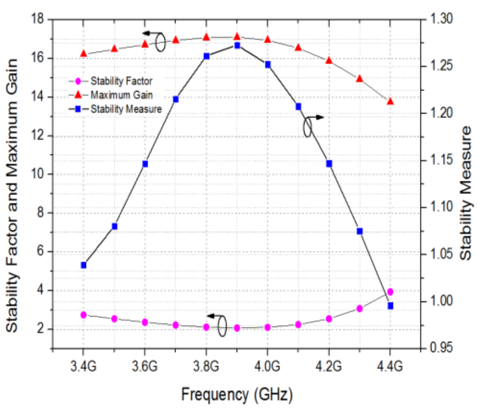


Figure 3. Stability factor, stability measure and maximum gain

## RESULTS AND DISCUSSION

The results following harmonic balance simulation and quadrature phase shift keying (QPSK) modulation will be discussed.

### Harmonic Balance Simulation

The result of the one-tone harmonic balance simulation is shown in Figure 4. The result indicates that the PA has an output power capability of 44.93 dBm (31.1W), drain efficiency of 36.3%, PAE of 35.3% and power gain of 12.9 dB. The result of the two-tone harmonic balance simulation indicating the first harmonic ($P_1$), second harmonic ($P_2$), third harmonic ($P_3$) and the transducer power gain at the first harmonic ($G_1$) is shown in Figure 5. The two-tone harmonic balance simulation was used to determine the peak envelope power (PEP) of the PA. The output power delivered to the load at fundamental, second and third harmonics stands at 44.9 dBm, 2.7 dBm and -11.9 dBm respectively. The transducer power gain at fundamental stands at 12.9 dB. A peak envelope power of 56.3W was obtained at 3.895 GHz.

### Quadrature Phase Shift Keying Modulation

The adjacent channel power ratio (ACPR) spectrum obtained from quadrature phase shift keying

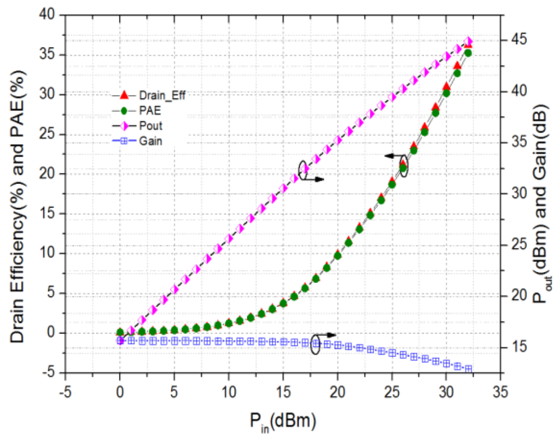


Figure 4. Output power, drain Efficiency, PAE and power gain

modulation from 3.65 GHz to 4.15 GHz and centre frequency of 3.9 GHz indicates that the adjacent lower channel from 3.75 GHz to 3.85 GHz and adjacent higher channel from 3.95 GHz to 4.05 GHz, were used to obtain the Lower ACPR Power of 41.273 dBm and Upper ACPR Power of 39.492 dBm, respectively. The ACPR spectrum is shown in Figure 6.

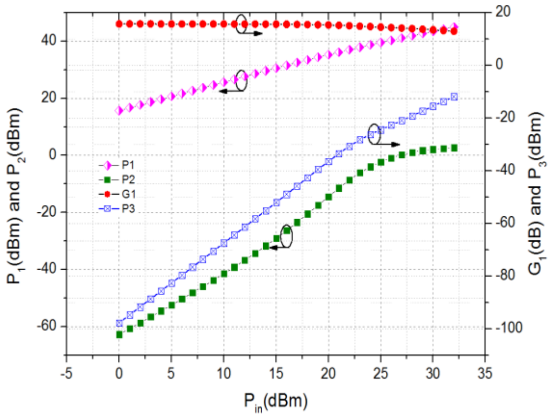


Figure 5. Power at first harmonic ($P_1$), second harmonic ($P_2$) and third harmonic ($P_3$) and Power Gain at Fundamental ($G_1$).

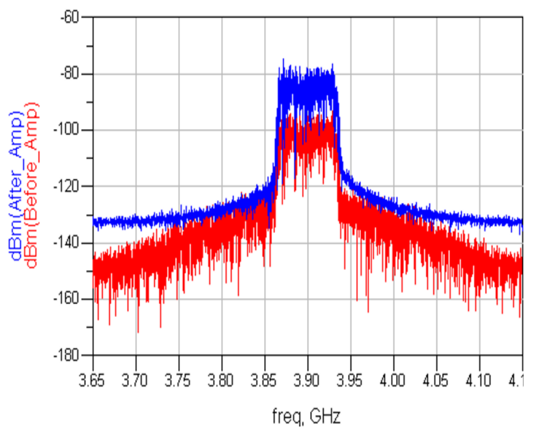


Figure 6. ACPR Modulated Signal Channel Spectra

## CONCLUSION

A 31 W linear broadband 3.4 to 4.4 GHz high power Class-J GaN HEMT amplifier using Microstrip distributed transmission line components has been proposed, designed and simulated. The power amplifier has the novel uniqueness of an RC input stability network and a high operational drain supply voltage of 48V at a quiescent drain to a source current of 0.58A. The high output power of 31W, peak envelope power of 56.2W and power gain of 12.9dB make the PA suitable for high-power wireless applications such as transmitters used in Electronic Warfare (EW), RADAR and Satellite communication systems in S- and C- band frequencies.

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Charies Nwakanma Akwuruoha was born in Abia State, Nigeria. He became a member of the Nigerian Society of Engineers (NSE) in 2005 and a registered member of the Council for the Regulation of Engineering in Nigeria (COREN) in 2009. He received his Bachelor of Engineering (B.Eng) degree in Electrical and Electronic Engineering from the Federal University of Technology Owerri, Nigeria in 2000. He received his Master of Engineering (M.Eng) degree in Electronics and Telecommunication from the University of Port Harcourt, Nigeria in 2006 He also received his Doctor of Philosophy (PhD) degree in Electrical and Electronic Engineering from The University of Manchester, United Kingdom in 2018. His area of specialization is microwave engineering.