Design and Simulation of 15 W Power Amplifier for 2.4 GHz Applications

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ABSTRACT
This paper presents the design and simulation of Power Amplifier (PA) at 2.4GHz for applications. CREE CGH27015F GaN HEMT (High Electron Mobility Transistor) is used for the design. The designed power amplifier exhibits a gain more than 10dB and input and output return loss better than -10 dB within the operation bandwidth. This PA is designed to achieve the output power of greater than 40dBm. Power amplifier is designed in Class AB and 73.25% Power Added Efficiency (PAE) is achieved. The simulation has been performed using Advanced Design System (ADS) simulation tool. Keywords: GaN HEMT, IMD, PAE, Power Amplifier (PA).

INTRODUCTION
Today, Mobile communications play a central role in voice/data network arena. Development of the cellular mobile communication system recently is very fast. The most important part in transmitting chain of wireless communication system is power amplifier. Before sending the signal it must be amplified, for that power amplifier is the final amplification stage before the signal is transmitted, and therefore must produce enough output power to overcome the channel losses between the transmitter and the receiver. Wide bandwidth power amplifiers are key components in phased-array radars, mobile communication systems, aerospace and military system applications, TV transmission and measurement technique [1]. This paper presents work done on design and simulation of power amplifier for 2.4GHz applications using GaN HEMT device. The active device specified for this design is CREE CGH27015F. Wide band gap technology such as GaN offers the demand of such kind of amplifiers because of its high breakdown voltage, high operating temperature and high power density. Because of this features offered by GaN HEMT the manufacturing of smaller size devices with similar output power is made easier. GaN transistors offer an order of magnitude improved RF output power compared to traditional devices based on silicon and gallium arsenide[2] as well as smaller parasitic capacitances, when compared to silicon LDMOS FETs and GaAs MESFETs of similar output power; this allows relaxed operating conditions, low supply currents, and easy impedance matching which reduce design effort and makes GaN HEMTs the optimum choice to handle high power while exhibiting broader bandwidths than those demonstrated by other technologies[3].

1. DESIGN
1.1 System model
In this design GaN HEMT transistor is chosen because it has a wide band gap and a high thermal conductivity for a reliable high power operation than both Si and GaAs. A wider band gap allows a device to have a higher operating temperature and lower vulnerability to external noise such as shot noise because it requires more energy for the electrons to escape from the valence band to conduction band. It also provides a higher breakdown voltage and higher power density, so that the transistor is able to output higher output power in smaller physical size. The Cree’s CGH27015F is a gallium nitride (GaN) high electron mobility transistor designed specifically for high efficiency, high gain and wide bandwidth capabilities, which makes the CGH27015F ideal for VHF, 3G, 4G, LTE, 2.3-2.9GHz WiMAX and BWA amplifier applications[7].
1.2 DC Analysis
First stage in design of power amplifier is to find out operating point of proposed amplifier using DC analysis. DC biasing circuit isolates RF from DC in the desired bandwidth. Cree’s CGH27015F GaN HEMT is used for design of high power amplifier. The transistor is biased for class AB operation since the maximum efficiency is required, at a bias point of $V_{GS} = -3$ V, $V_{DS} = 28$ V, and $I_D = 68$ mA.

1.3 Stability Analysis
The stability of the transistor amplifier can be measured by using K – Δ test, where it can be shown that a device will be unconditionally stable if the Rollet’s condition are satisfied and it is defined as follows:

\[ K > 1 \text{ and } |\Delta| < 1 \]

Where,

\[ K = \frac{1 + \Delta^2 - S_{21}^2 - S_{22}^2}{2S_{12}S_{22}} \quad (1) \]

\[ \Delta = S_{11}S_{22} - S_{12}S_{21} \quad (2) \]

1.4 Parameters of Power Amplifier
1.4.1 Efficiency
The efficiency of power amplifier can be defined as ratio of output power to dc power taken by device.

\[ \eta = \frac{P_{out}}{P_{dc}} \quad (3) \]

Power Added Efficiency of power amplifier shows how efficient the PA converts DC power to RF power and it is given as,

\[ \text{PAE} = \frac{P_{out}-P_{in}}{P_{dc}} \quad (4) \]

Where the Pout is the output power, $P_{in}$ is input power and $P_{dc}$ is DC power consumption.

1.4.2 1-dB Compression Point
When a power amplifier is operated in its linear region, the gain is a constant for a given frequency. However when the input signal power is increased, there is a certain point beyond which the gain is seen to decrease. The input 1-dB compression point is defined as the power level for which the input signal is amplified 1 dB less than the linear gain. The 1-dB compression point can be input or output referred and is measured in terms of dBm. A rapid decrease in gain will be experienced after the 1-dB compression point is reached. This gain compression is due to the non-linear behavior of the device and hence the 1-dB compression point is a measure of the linear range of operation.
1.4.3 Intermodulation Distortion (IMD)

Intermodulation distortion is a nonlinear distortion characterized by the appearance, in the output of a device, of frequencies that are linear combinations of the fundamental frequencies and all harmonics present in the input signals. If $f_1$ and $f_2$ are the fundamental frequencies then the intermodulation products are seen at frequencies given by $f_{\text{IMD}} = mf_1 \pm nf_2$ Where m and n are integers from 1 to $\infty$. The ratio of power in the intermodulation product to the power in one of the fundamental tones is used to quantify intermodulation. Of all the possible intermodulation products usually the third order intermodulation products (at frequencies $2f_1-f_2$ and $2f_2-f_1$) are typically the most critical as they have the highest strength. Furthermore they often fall in the receiver pass band making it difficult to filter them out. The fundamentals, the second, third, fifth and seventh orders are shown in fig 3.

1.4.4 ACPR

ACPR stands for adjacent channel power ratio and ACLR stands for adjacent channel leakage ratio. It is the ratio of power between the main channel and those channels around the main channel.

\[
\text{ACPR(ACLR)} = \frac{\text{Adjacent Channel Power}}{\text{Adjacent Main Power}}
\]  

(5)
There would be two main reasons why the poor ACPR is bad. The biggest reason would be that the poor ACPR means you have higher unexpected power next to the main channel. If another communication system is using that adjacent area as a main channel, high adjacent channel power of one communication system becomes the high interference to other communication system.

There can be another reason; High ACPR/ACLR means that some that some energy that is supposed to be in main channel spilled over to adjacent channels. It means that the useful energy gets lost in useless form and it reduces the efficiency of transmission.

2. LOADPULL CHARACTERIZATION

Load pull analysis is used to construct a set of contours (typically on a Smith Chart), which determine the maximum power output achievable with a given load impedance. These contours are very useful in assessing the actual impedance a device should see when it is used in an amplifier. It is a technique wherein the load impedance seen by the device under test (DUT) is varied and the performance of the DUT is simultaneously measured. The measured results determine the optimum load and source impedance for which the device gives the best performance. In particular, it is commonly used to give optimum load impedance value for maximum efficiency.

3. MATCHING NETWORK

For GaN HEMTs working on the large signal state, the input and output impedances change when the input power changes. It is appropriate to use the load-pull method based on computer aided design to obtain the input and output impedance of GaN HEMTs. Based on the large signal model of the GaN HEMT and the simulation software, the source impedance \( Z_S \) and the load impedance \( Z_L \) are obtained. In order to obtain the maximum output power, \( Z_S \) and \( Z_L \) are conjugately matched to 50Ω by the designed input and output matching network. Smith chart utility is used for designing matching network. In this we are canceling imaginary part by either adding series and shunt lumped components so that the source impedance \( Z_S \) is get conjugately matched with load impedance \( Z_L \).
3.1 Input Matching Network

Input matching network is used to match the input impedance of transistor to source impedance for minimizing the input return loss (S11) without introducing additional noise. Input matching circuit terminates the transistor to gamma optimum \((I_{\text{out}})\) which represents the input impedance of the transistor for the best noise matches.

3.2 Output Matching Network

Similarly, Output matching network is used to match the output impedance of transistor with 50Ω load impedance. Input and output impedance matching network is used to maximize the power transfer and minimize the reflections. According to maximum power transfer theorem maximum power is delivered to load when impedance of load is equal to complex conjugate of source impedance \(Z_S = Z_L^*\).

4. RESULTS

Following are the results for the designed power amplifier. Stability factor requirement is meet as well as the device is in on state within the required frequency band (2GHz–2.8GHz) as seen from fig.7 and fig.8 respectively.

**Fig 7: Stability analysis**

**Fig 8: Forward transmission coefficient (Gain)**

Designed power amplifier is providing the input return losses better than -10 dB, it can be observed in the whole operation bandwidth (2.220 GHz–2.520 GHz) in fig.9 and fig.10 showing output return loss better than -10 dB at desired frequency.

**Fig 9: Input return loss**
Fig 10: Output return loss

Fig. 11 shows the obtained power added efficiency for designed power amplifier and the output power of 42.24dBm at $P_{in} = 30$dBm at 2.4 GHz. The Output power Vs Input power is shown in Fig 12.

![Output power spectrum](image1)

![Power Added Efficiency](image2)

(a)

(b)

Fig 11: (a) Output power spectrum (b) Power Added Efficiency

Fig 12: Output power Vs Input power

5. CONCLUSION

Design and simulation of GaN solid state power amplifier for 2.4GHz application is presented using the non-linear models of CGH27015F. Designed power amplifier is optimized to achieve 15 W of output power and 73% of efficiency. Designed high power amplifier can be used in 2.4GHz applications for sending signal up to the last mile.
6. REFERENCES


