# Design and Simulation of Ka/Q Dual-Band Doherty Power Amplifier using GaN pHEMT

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**Abstract -** *Modern communication system needs higher data rates and broad bandwidth with minimum power consumption. So novel wideband and energy efficient power amplifiers should be designed. Doherty Power Amplifiers (DPAs) are popular architectures for obtaining high efficiency for large range of output power levels. This paper is concerned with the design of dual band 3-Way Distributed DPA in millimeter-wave (mm-wave) spectrum using Gallium nitride pseudomorphic high electron mobility transistor (GaN pHEMT). The simulation of the work is carried out using Quite Universal Circuit Simulator (Qucs) and it shows that the power amplifier (PA) achieves a peak power added efficiency (PAE) of 30% and 47% at 26/38 GHz and gain of greater than 15 dB. Also output power of larger than 40 dBm is obtained for the defined band. These properties make this design a promising candidate for future fifth-generation (5G) application.*

***Key Words***: *Distributed power amplifier, Doherty power amplifier (DPA), Gallium nitride (GaN), Millimeter-Wave (mm-wave).*

## 1. INTRODUCTION

A power amplifier (PA) is a device that amplifies a low power signal into a better power signal. Typically, Radio frequency power amplifier (RF PA) drives the antenna of the transmitter. Biasing and load modulation are important factors that determines the performance of the RF PA. Millimeter wave (mm-wave) spectrum will be used in the fifth-generation (5G) communication system due to the increasing demand of higher data rate and crowding of frequency band below 6GHz. Spectra around 28, 39 and 45 GHz of mm-wave spectrum have been opened for the 5G development. Doherty Power amplifier (DPA) is a popular architecture used in the design of PA due to its simple structure and enhanced performance when compared to other existing architecture such as envelope tracking (ET) and outphasing power amplifier (OPA).

Without a PA in a system, the receiver of the system cannot receive the full information from the transmit signal. The information signal that transmit by, the transmitter will attenuate itself and the information which is not having the full information that is transmitted to the receiver is known as the loss signal. Thus, the power amplifier can be concluded that it act as a booster for a signal being transmitted to ensure the receiver to receive all the signal information without any loss. One of the important issue that should be considered in designing a PA, is the amplifier linearity. This is because the non-linearity not only distorts the signal in the desired band, it can also damage neighboring channels.

Millimeter wave (mm-wave) spectrum is one of the popular solution to meet the increasing demand of higher data rate and also to overcome the problems caused due to the crowding of frequency band below 6 GHz. Together with the existing wide band antenna a single dual band PA will enable ultra-compact massive input multiple output (MIMO) 5G systems. Also the DPA has the simplest topology and does not need external circuit to control the efficiency, hence it is self-sufficient. So the DPA are attractive choice for PA research. Also improving efficiency while maintaining linearity is an important issue in the amplifier design.

In this paper, we present a high efficiency dual band DPA in mm-wave spectrum using GaN pHEMT. The objective of the project is to design a Dual Band 3-Way Distributed Doherty Amplifier. The simulation of the proposed RF power amplifier is carried out using Qucs studio.

The following sections of this paper are organized as follows. In Section 2, we review the present technology used for amplifier design. In Section 3, we discusses the detailed design of the proposed amplifier. In Section 4, we describe the simulation results. Finally, Section 5 gives the conclusion and discuss possible future research.

## 2. RELATED WORKS

Different architectures have been introduced to overcome the limitations of bandwidth (BW) and efficiency in amplifiers. Some of them are envelope tracking, outphasing and Doherty PA.

The global BW shortage has motivated the exploration of the underutilized mm-wave spectrum for future broadband cellular communication system [2]. The mm-wave carrier frequency allows for larger BW allocations, which translate directly to higher data rate and thus reduce the digital traffic.

Another topology is the concurrent dual band DPA with frequency dependent back-off power ranges [3]. Based on dual band T-shaped network and coupled line network, different dual-band components needed in Doherty PA topology including a 3-dB branch line coupler, an offset line quarter wavelength transformers are developed. Two prototypes with balanced imbalanced back-off power range modes are implemented. For linearization 2D digital pre-distortion (DPD) technique is used to compensate the dual-band distortion. And two two-tone signals were utilized to characterize the non-linearity & verify linearization performance.

Hu et al. [4] presents the first multiband mm-wave linear Doherty PA in Si for broadband application. They introduce a transformer based low loss combiner and a power dependent Doherty PA uneven-feeding scheme. However it require extra control circuits to reconfigure the relative phase between the main and auxiliary PA, also low breakdown voltage and high substrate loss of the SiGe process results in low efficiency and output power.

Wang et al. [5] proposed an efficiency enhanced PA design based on wide bandwidth envelope tracking for the application of OFDM and WLAN. An adaptive time alignment algorithm is also presented for the ET system. It satisfy the OFDM requirement. In order to achieve higher data rate, 5G signal bandwidth will be large as 800MHz. This limit the usage of ET PAs due to the bandwidth limitation.

Huynh et al. [6] explains about the concurrent dual-band impedance-matching filtering methodology together with a 25.5/37-GHz concurrent dual-band PA. This technique facilitates the design of various concurrent dual-band matching networks, each being synthesized from two single-band matching networks. The resultant dual-band matching filtering networks can be used to achieve not only concurrent matching between two arbitrary loads and two arbitrary sources at any dual-band frequencies, but also suppression of unwanted signals like the harmonics and inter-modulation products (IMPs).

Grebennikov et al. [7] describes about the historical aspect of the Doherty approach to the PA design introduced in 1936 and modern trends in Doherty amplifier (DA) design technique using multistage and asymmetric multiway architecture. The DA with a series connected load, inverted, push pull, balanced and parallel Doherty architecture are also described. The Doherty configuration improves the efficiency by 1.5 to 2 times when compared with conventional class AB PA.

In the coming section we will analyze the circuit design of power amplifier.

## 3. CIRCUIT DESIGN

The main aims of this work is to design a high efficiency dual-band PA in distributed Doherty configuration using GaN pHEMT. The dual-band frequency used are 28 GHz and 45 GHz. High efficiency is realized by employing a low loss dual-band output matching network. The PA achieves a gain of 23 dB and 25 dB, peak PAE of 30% and 47% in the dual band. The simulation of the proposed work is carried out using Qucs Studio.

### 3.1 Dual-Band Power Amplifier

It consist of three matching networks input matching, interstage matching and output matching. The output matching network is the most crucial to the realization of high efficiency power amplifier. It should be as simple as possible to achieve a low insertion loss in mm-wave band. It consist of only two inductors and two capacitors. The input matching and interstage matching are almost identical also a parallel RC network is used in series with the gate of the driver stage. The input impedance of which should satisfy equation (1) and (2).

Zin (f1) = Zopt1 (1)
Zin (f1) = Zopt2 (2)

Where Zopt1 and Zopt2 are optimum load impedances at f1 and f2, respectively to ensure unconditional stability across the full frequency band.

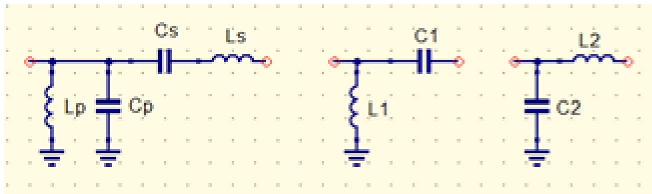


**Figure - 1**: (a) Network for dual-band interstage matching and input matching, and its equivalent circuit at (b) f1 and (c) f2.

The network shown in Fig. 1 is employed in this design, and it consists of only two inductors and two capacitors. The parallel inductor Lp also acts as the drain bias line, while the series capacitor Cs is used to block dc current. The simple circuit results in low loss. The LC parallel network acts as an inductor at f1 and a capacitor at f2 (f1 < f2), while an LC series network acts as a capacitor at f1 and an inductor at f2. As a result, the network in Fig. 1 (a) is equivalent to two different L-type matching circuits at f1 and f2, as shown in Fig.1 (b) and (c). The component values can be synthesized by solving the equations (3-7) with source impedance Rs+jXs and load impedance $R_L$+j$X_L$.

$Zin = (R_L + jX_L + jwL) \,||\, 1/jwC$ (3)

$1/w_1L_p - w_1C_p = 1/w_1L_1$ (4)

$w_2C_p - 1/w_2L_p = w_2C_2$ (5)

$1/w_1C_s - w_1L_s = 1/w_1C_1$ (6)

$w_2L_s - 1/w_2C_s = w_2L_2$ (7)

where,

$w_1 = 2\Pi f1$, f1 = 28 GHz
$w_2 = 2\Pi f2$, f2 = 45 GHz

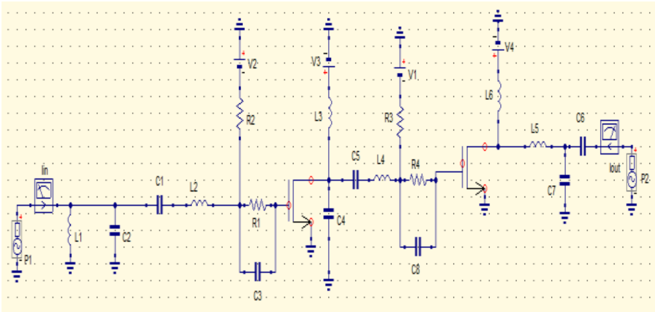

**Figure - 2**: Circuit of dual-band PA

### 3.2 3-Way Distributed Doherty Power Amplifier

Doherty Power amplifier (DPA) is a popular architecture used in the design of PA due to its simple structure and enhanced performance when compared to other existing architecture such as envelope tracking (ET) and outphasing PA. Modern communication system has high peak to average power ratio that considerably affect the PAs peak efficiency and back-off efficiency.

Distributed Doherty power amplifier is a configuration that is used for gain enhancement. The distributed DA uses two individual dual-fed distributed amplifiers (DDA) where these two distributed amplifiers are coupled within the conventional DDA configuration with a $90^0$ hybrid at the input and a quarter wave transmission line at the output.

The distributed Doherty amplifier consists of one main amplifier and two peaking amplifiers. To achieve high efficiency at a high back-off power, the peaking amplifier structure relies on the dual-fed distributed amplifier form.

The desired location of peak efficiency points of a distributed N-way DA can be given in decibels by equation (8)

$P = 20\log_{10}(P/M+1)$ dB (8)

where P and M are the number of the peaking amplifiers and also the main amplifiers, respectively.

The 3-Way Distributed Doherty power amplifier consist of one main power amplifier and two peaking power amplifier. Hence it is called 3-Way Doherty amplifier. The circuit is designed at a center frequency of 36.5 GHz. Here the RF input is provided to a $90^0$ hybrid coupler which equally split the input signal with a resultant $90^0$ phase shift between output ports and also maintain high isolation between the ports. Then it is fed to the main and peaking power amplifier.

The required phase shift is obtained by means of offset lines and phase lines. The peaking amplifier is in dual-fed distributed amplifier form and it is coupled by means of half-wave and quarter-wave transmission lines. It is then fed to the post matching network for impedance matching. The complete circuit is shown in Fig. 3

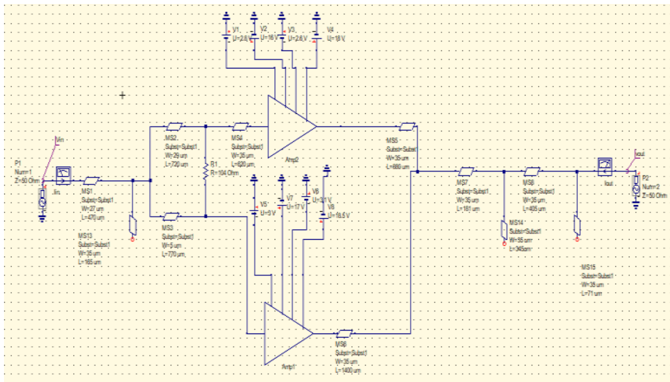

**Figure - 3**: Circuit of 3-Way Distributed DPA

At high frequency, the transistors output reactance should be compensated to provide the required open circuit condition and also it is required to take into account that the transistor input impedance is varied with bias voltage. For this purpose Offset lines with optimized electrical lengths is used. The input impedance of the transmission line is given by equation (9)

$Z_{in} = Z_0\,(Z_L + jZ_0\tan\beta l)/\,(Z_0 + jZ_L\tan\beta l)$ (9)

Where $\beta = 2\Pi/\lambda$ and l is the length of transmission line

## 4. SIMULATION RESULTS AND DISCUSSIONS

The implementation of the proposed DPA is done using Qucs Studio. This section describes the simulation result of the Power amplifier.

### 4.1 Simulation results of Dual-Band PA

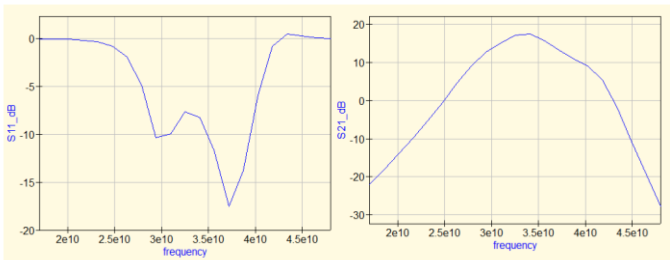


**Figure - 4** S parameter of Dual Band Power Amplifier

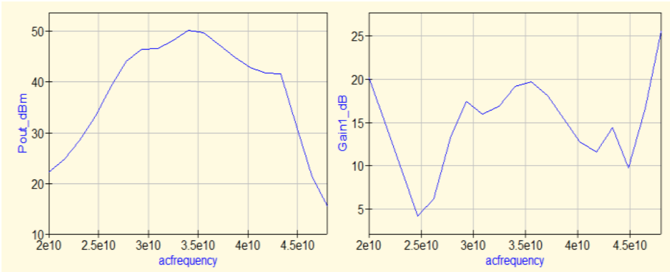


**Figure – 5** Output Power and Gain of Dual Band PA

The circuit is simulated at a center frequency of 36.5GHz. The Fig. 4 shows that the input return loss (S11) of the dual band power amplifier is found to be less than -10dB. Also the forward transmission coefficient (S21) indicate good bandwidth in a frequency range of 25 GHz to 44 GHz. The Fig. 5 shows the output power and gain of the amplifier. It can be observed that the output power increases beyond 25 GHz and maximum of 50 dBm is obtained with an RF input of 30 dBm. And the gain of the amplifier is around 15 dB and maximum gain of 20 dB is obtained at the center frequency.

### 4.2 Simulation Results of 3-Way Distributed DPA

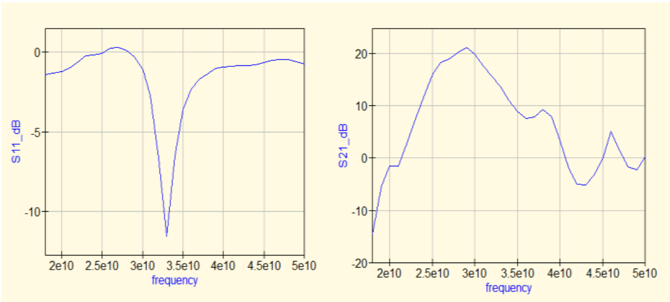


**Figure - 6** S parameter of 3-Way Distributed DPA

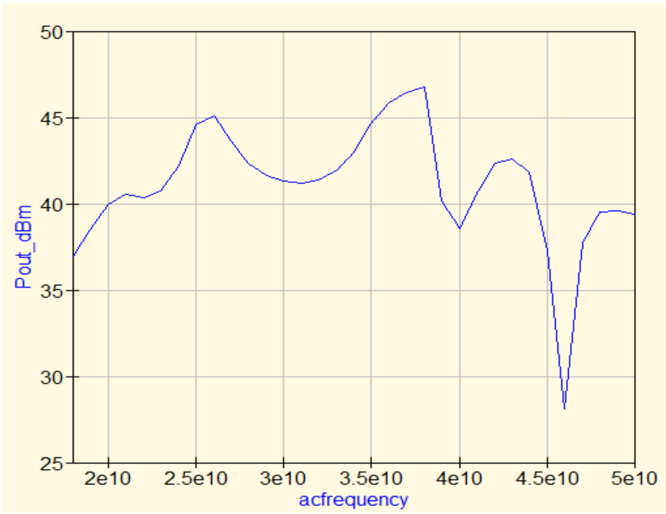


**Figure - 7** Output Power (dBm) of 3-Way Distributed DPA


**Figure - 8** Gain (dB) of 3-Way Distributed DPA

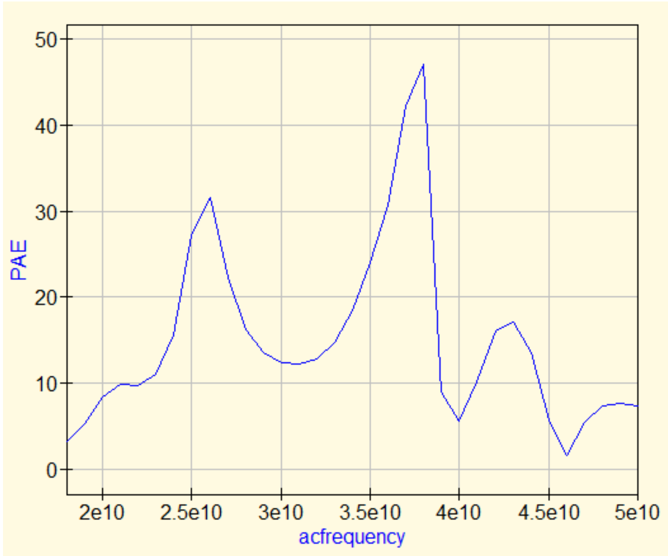


**Figure - 9** Power Added Efficiency (%) of 3-Way Distributed DPA

The Fig. 6 represents the S parameter of 3-Way Distributed DPA with its input transmission coefficient (S11) is found to be less than -10dB. From Fig. 7 it is observed that the peak output power is 46 dBm. Also Fig. 8 represents the gain of the amplifier which is found to be greater than 20 dB. And Fig. 9 shows the power added efficiency of 30% and 47% at 26 GHz and 38 GHz respectively. From these results it is observed that the distributed amplifier is highly frequency selective and operate well in the mm-wave band.

## 5. CONCLUSIONS

In this paper, design and simulation of dual-band distributed Doherty power amplifier is presented. Here the offset lines are realized using simple TLs which satisfied the required phase shift in the dual band. It is observed that the amplifiers provides a reasonable performance in the dual band of Ka and Q. It provides gain of greater than 20 dB and PAE of the amplifier is found to be 30% and 47% in the dual-band. It also provide larger bandwidth with high gain and efficiency.

This result makes this design a promising candidate for future 5G application.

The future works can focus on: 1) fabrication aspects of amplifiers in the mm-wave spectrum; 2) another area is to investigate different circuit topology and Doherty architecture for the performance enhancement.

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## BIOGRAPHIES

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