Design & Simulation of Radio Frequency Power Amplifiers for High Efficiency and with out affecting Linearity

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Abstract:The purpose of this work is to study and to observe the two important characteristics of Radio Frequency Power Amplifiers, i.e. efficiency and linearity. To provide maximum efficiency, A standard design Procedure is developed and simulated by using Micro Wave Office (Antenna Design Software). Then the Class F Amplifier is designed to Increase the efficiency and simulated by using AWR MWO.
The structure of Doherty Amplifier is introduced to enhance the efficiency without affecting and maintaining the Linearity. The design deals with the Auxiliary device and this device simplifies the circuit. It is able to provide the back-off efficiency and at the same time maintains the linearity.

Keywords: *Class F power amplifier, Introduction of Doherty amplifier, efficiency, linearity, AWR MWO.*

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1. 0 INTRODUCTION

Radio Frequency Power Amplifiers means, it has two major features. RF Power Amplifiers works at Radio frequency, which usually comes under S-band. The output power is relatively large (1 watt). In General the microwaves will be associated with radar systems operating in the band of C and above.

Primarily, the first duty of a power amplifier is to convert DC power most effectively alternating current, which needs little input power possible. Depending on the application, different parameters are underlined. Here we begins with the transfer characteristic of transistors, which is very essential to understand many aspects of the design of the RF power amplifier. Then, the amplifier classes are analyzed, followed by a non-linear analysis. Then load line matching is used inorder to transfer a significant amount of the power to a Load.

2.0 TRANSFER CHARACTERISTIC OF A TRANSISTOR

Field effect (FET) transistors are voltage-controlled current sources (VCCS), the Transfer characteristics of a Transistor is shown in Fig.2.1. When V_{gs} is below the threshold voltage (in this case 2.6 V), the drain current I_{ds} is 0. If there ia an increase in $V_{gs,}$, the transistor enters into turned on region. As soon as the transistor enters into turned on region, I_{ds} increases in a non linear manner. And finally, I_{ds} will remain almost onstant.

In the turned–on region, the non-linearity of the transistor can be read as a linear system , if the gate voltage level is very low, that is known as a small signal analysis.

In case of power amplifiers, the required output power is so high that normally all turned on the region is involved, so small signal analysis becomes inaccurate. So longas the transistor works only in the back region, it could still be

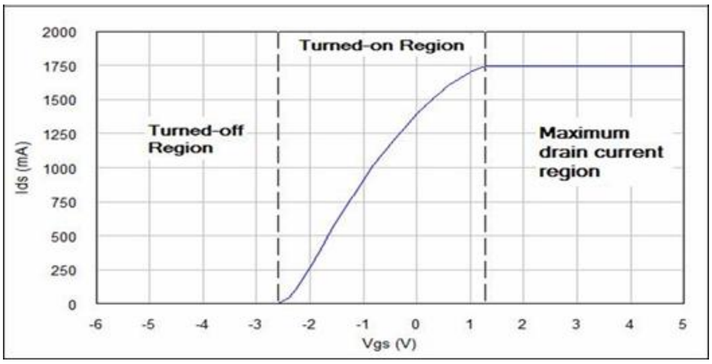
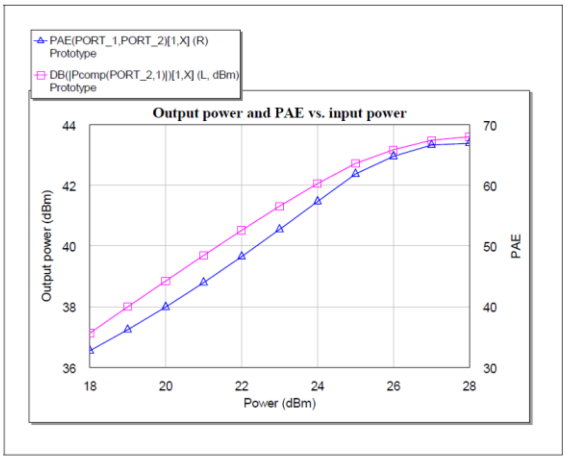


Fig. 2.1 FET VCCS Characteristics

approximated as a linear system. Such is the theoretical basis of the linear power amplifier design.
A practical example is designed to verify the procedure. Class AB amplifier is designed as a examplewith ideal components and analyzed with MWO and it is observed that maximum efficiency of this configuration is 66%.



Simulation results of Class AB Power amplifer

3.0 DESIGN OF CLASS F POWER AMPLIFIER

Due to the high efficiency and the development of linearization techniques, non linear PAs have received more attention over linear power amplifiers. Class E and F are the most common classes of nonlinear power amplifiers. In comparison, Class E power amplifier requires fast switching driver signal that is not required for Class F power amplifiers.

Class F power amplifier is easier to implement.

Class-F power amplifers produces high power capabilities and high efficiency with a limited number of controlled harmonics. The efficiency of an ideal class-F PA is 100% and it is achieved by the second and third harmonic control provided by the output matching network.

In case of conventional amplifiers such as class AB, class B and class C amplifiers, there must be a perfect short circuit for any drain current harmonics. If the load network fails to then the drain voltage will change from a sine wave to other forms due to the presence of harmonic components. It is possible to execute the load network such that a square wave or a similar form of drain voltage signal is generated, finally increasing efficiency. This type of amplifier is termed as Class F amplifier.

Design of the Circuit

A classF power Amplifer is designed at 2.5GHz s is designed and simulated. The transistor is selected Cree GaN HEMT CGH40010.The analysis is performed using AWR Microwave Office. The design uses the load and source impedances provided by Cree, Inc., under the bias condition V_{DD} = 28V and I_{DQ} = 200mA. Since the drain bias voltage is given directly, while the gate bias voltage is not, it is necessary to adjust the gate voltage until IDQ becomes 200mA, as shown in Fig. 3.1.

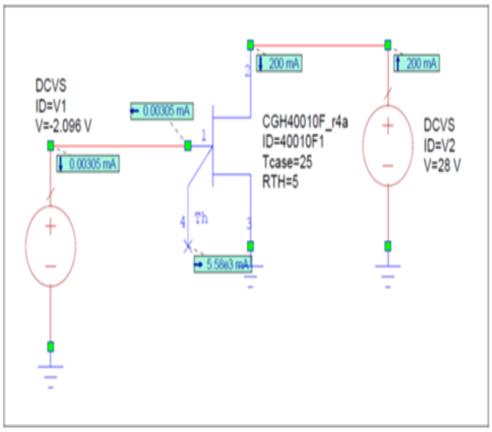


Fig. 3.1 Circuit used to get gate bias voltage.

There are some steps which follows the design

Step 1: Circuit is Designed with Ideal Components

First, the preliminary version of a device is built with the help of the bias voltages and load/source impedance.

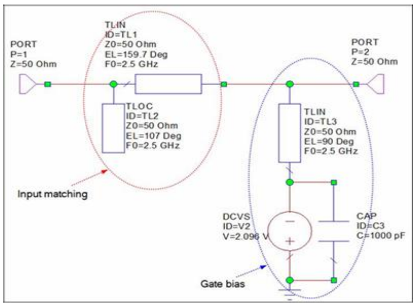


Fig. 3.2 Input matching network designed with ideal componenets

Fig. 3.2 shows the input matching network. It is used to transfer a significant amout of power to a load. In these matching network Transmission lines are used to prevent RF signal from flowing into the DC voltage source.

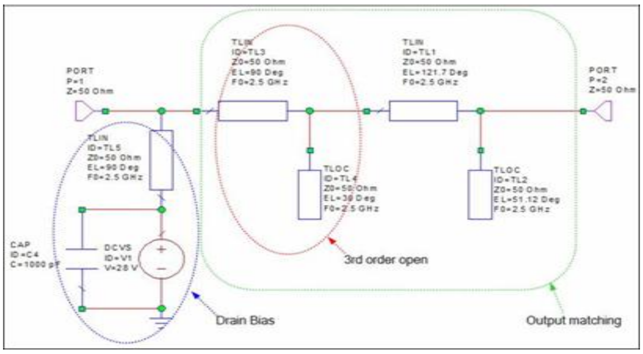


Fig. 3.3 output matching network designed with ideal componenets

Fig. 3.3 shows the output matching network, transmission lines are used. where “TL3” and “TL4” together presents an open circuit to the drain at the 3rd order harmonic of the designed frequency, “TL5” works as the RF choke and also presents a short circuit to the drain at the 2nd order harmonic of the designed frequency.

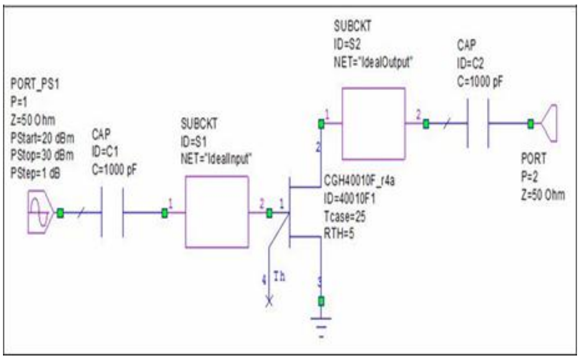


Fig. 3.4 Power Amplifier circuit using ideal components.

The Archetype of the Power amplifier is shown in Fig. 3.4

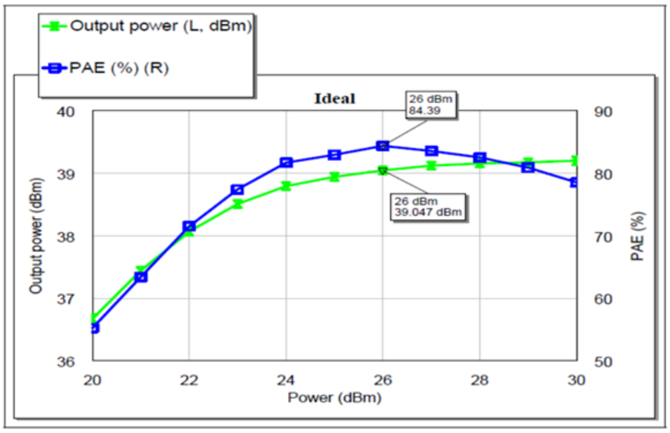


Fig. 3.5 simulation results of class F power Amplifier with ideal components

This schematic is analyzed with Microwave Office. And the output power/PAE vs. input power plot is shown in Fig. 3.5 . It is observed that maximum efficiency of this configuration is 84.34%, with an output power of more than 39dBm.

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Once the Archetype is verified by simulation, the ideal components should be replaced with realistic lossy ones. This would require further tuning and optimization.

Step 2: Convert the Ideal Circuits into Realistic Ones

To convert the ideal components into Realistic ones, microstrip Substrate is used. The parameters of the material used for transmission line is chosen. Taconic ORCER RF-35 is chosen to be the board material with a thickness of 60mils, while the metal is 1oz copper. RF-35 has a stable = 3.5 over a wide frequency band from 2GHz to 10GHz, and a dissipation factor of 0.0018 at 2.5GHz.

With the help of micro strip substrate the ideal lossless transmission line expressed in phase form can be converted into lossy realistic transmission lines.With the help of substrate definition, Here an embedded tool in Microwave Office called TXLine is used (Fig. 3.6). It can be accessed under "Tools->TXLine."

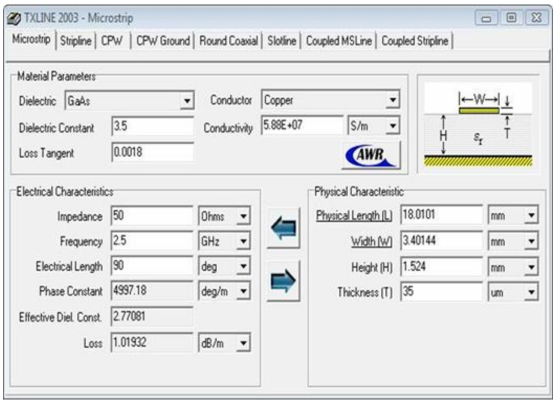

Fig. 3.6 TXLine, used to convert between ideal elements and realistic ones.

Step 3: Tuning and Optimization

It is necessary to do Tuning or optimization after the conversion (or the direct design using lossy components), At GHz frequencies, transmission line length can affect the performance severely for small variations. Using the optimizer in Microwave Office, it is fairly easy to make the matching network present the desired impedance at a certain frequency.

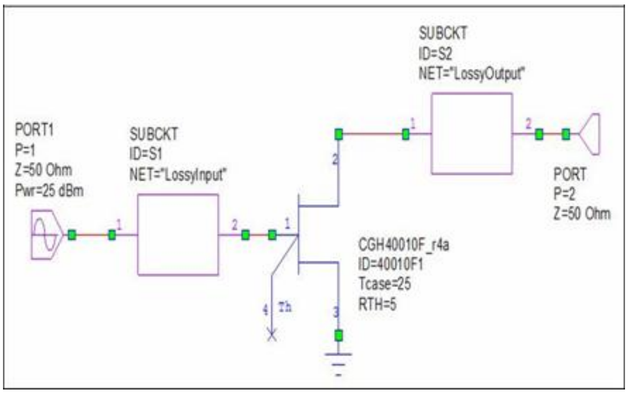

Fig. 3.7 amplifier circuitwith realistic ones.

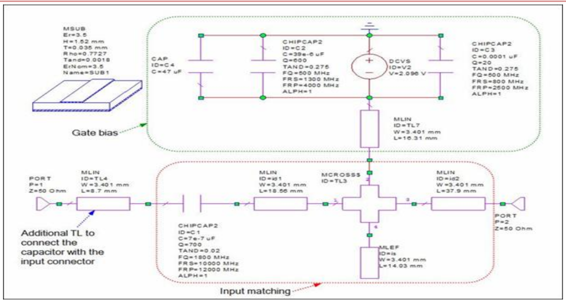

Fig. 3.8 Input matching network with realistic ones.

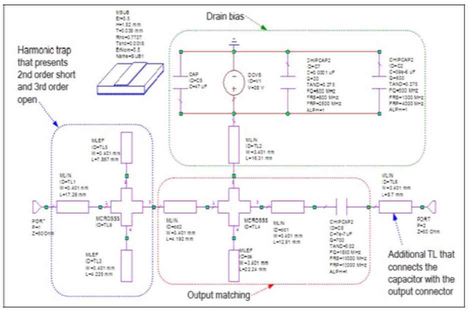

Fig. 3.9 output matching network with realistic ones.

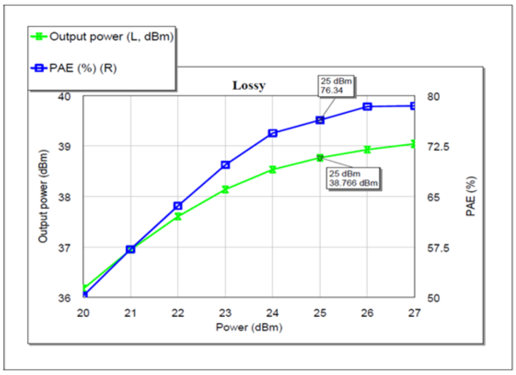

Fig. 3.10 simulation results of class F power Amplifier with Realistic ones

The simulated results of output power and PAE versus input power is shown in Fig. 3.10, It is observed that both power and efficiency are lower compared to the ideal components. The maximum efficiency of this configuration is 75%, with an output power of 38dBm

4.0 INTRODUCTION OF DOHERTY AMPLIFIER

When the input power of a amplifier is constant, the drain current reaches to its maximum value. When the input power is stopped at this level, the efficiency drops significantly. This is a serious problem for power amplifier applications. It is important to maintain high efficiency. The variation of the input power level from a signal source leads to another linearity problem. With wide input drive, a nonlinear amplifier will undoubtedly cause output distortions.

The structure of the Doherty amplifier is the source of the ability to maintain high efficiency in back-off region, and maintains the linearity. The Doherty amplifier is a modified class B Radio frequency amplifier. The principle of Doherty amplifier is to modulate the load of the active device, namely Main (or Carrier) generally biased in Class AB, utilizing the active load pull concept by using a second active device, namely Auxiliary (or Peaking), usually biased in Class C.

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Load-pull concept is the process of varying the impedance presented to a device. Load-pull is required when superposition is no longer applicable, which occurs under large-signal operating conditions

The structure of a typical Doherty amplifier is shown in Fig. 4.1, where an auxiliary amplifier is added to the load. Perfect harmonic trap load is supported and for simplicity not shown in the figure, as well as the fundamental component is considered. The main amplifier of Fig. 4.1, a class-B amplifier. The auxiliary amplifier works only in region 6 dB back-off with twice the trans conductance of principal.

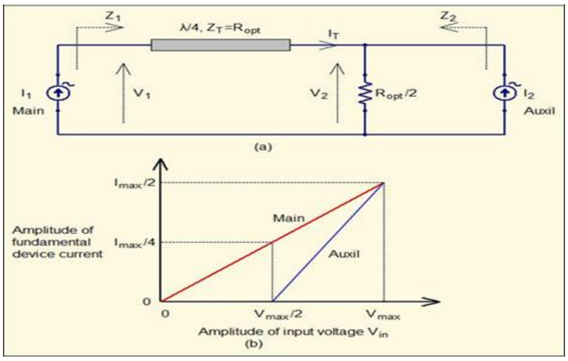

Fig. 4.1 . Doherty amplifier structure

5.0 SIMULATION RESULTS

A Doherty amplifier with 6dB power reverse gear is designed and simulated in Microwave Office.The circuit is designed for the main and auxiliary amplifiers. The simulated results of the Doherty amplifier are shown in Fig.5.1, and shows the distinctiveness of 6 dB back-off high efficiency, and the transfer of moderate linear power.

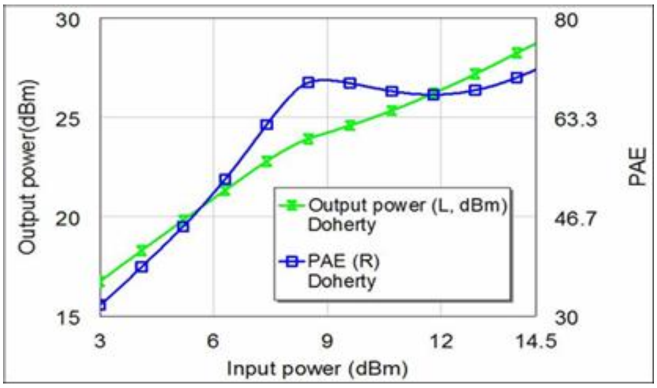

Fig. 5.1 Simulated results of the Doherty amplifier

6.0 Conclusions

In this work, the transistor characteristic was analyzed. The theory of the design pull load power amplifier has been studied and verified. The non-linearity of the amplifier and compression is studied. The maximum power transfer at the amplifier input side produces a maximum gate voltage has been mathematically proved. A practical example is designed to verify the procedure. Class AB amplifier is designed as a example with ideal components and analyzed with MWO and it is observed that maximum efficiency of this configuration is 66%.

The theory of Class F amplifier was studied in detail. A class F amplifier at 2.5GHz has been designed with the GaN HEMT device CGH40010 supplied by Cree, Inc. The design has been implemented and the simulation results show that it delivers 12W output power with an efficiency of 75%, at the input power level of 25dBm.

The design of the Doherty amplifier is discussed as a way of boosting the back-off efficiency and maintaining the high linearity. During the implementation various problems were introduced. A new design of the Doherty amplifier has been developed. This design accepts the insufficient current auxiliary device instead of changing it to meet the prescribed behavior, which simplifies the circuit. Simulation results show that this gives great comparable efficacy without affecting the linearity compared to the Class F RF Power Amplifier.

Comparision table of Efficency for different Amplifiers

Amplifier	Efficiency
Class AB	66%
Class F (with ideal components)	84.3%
Class F (with realistic Lossy ones)	75%
Doherty Amplifier	77%

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