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Design of High Efficiency Power Amplifier for 900 MHz GSM Application

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ABSTRACT: In this paper design of a wideband power amplifier is presented. The operating frequency of the power amplifier is from 880 MHz to 960 MHz. The circuit is designed using two 5 W GaN-HEMT. The Wilkinson power divider/combiner is used which is designed using microstrip line. The RF input applied to the power amplifier is divided into two using power divider. The RF signal is amplified in the two amplifier stages and combined. By using linear simulations, a GaN power amplifier circuit was optimized with the input and output return losses obtained as less than -15 dB. Isolation of the PA is approximately -30 dB and the maximum gain is 16.243 dB. The power amplifier is designed in Advanced Design System. The designed power amplifier is useful for GSM application.

KEYWORDS: Gallium Nitride, HEMT, wideband, microstrip line, power amplifier.

1 INTRODUCTION

Mobile phones and other means of wireless communication are getting popular rapidly. The number of cell phone users and amount of data traffic are increasing a much faster rate. The 2.5G networks provide data rates of upto 144 kbps, while 3G networks provide data rate of 384 kbps. The practical speeds for WiMAX and LTE ranges between 4 Mbps to 30 Mbps. In order to meet this increasing demand for communication traffic the next-generation systems are used by cell phone operators to replace old-generation cellular system. However this upgrading from present cellular system to next-generation system has a drawback of an increased power consumption of the equipment caused by increasing data rate and broadened bandwidth. Base stations and other equipments used for communication are the major power consuming components used by cell phone operators [1]. The PA alone consumes more than 50% of total power.

The class AB mode of transistor provides both high linearity and high efficiency. PA designed in class AB mode needs cooler heat sinks than the linear and well-behaved class A mode but this cannot be achieved without some nonlinear effects which can be avoided in some applications [2]. Microstrip resonators are used in both input and output matching networks and a tri-band GaN HEMT power amplifier is designed [3]. For individual frequency of operation two parallel resonators are used in series and a tri-band match network is implemented in similar fashion. A PA is designed using LDMOS employing a tunable matching network design based on varactor [4]. Two power amplifiers namely a class B and a class F are designed using a GaN HEMT device. By employing same bias conditions at 1.7 GHz class B amplifier provided a power added efficiency (PAE) of 69.2%, 39.9 dBm output power and gain of 14.9 dB [5].

The real frequency technique was used for designing output matching network and the bandwidth limitations of a Doherty power amplifier was addressed in [6]. The cascode and basic topology was used for implementing a two stage RF CMOS PA. Use of MOSFET only bias reduces the total dc current [7].The bandwidth limitation of Doherty PA was overcome by using the lower Q of a λ/4 transformer and introducing a phase compensation circuit and an additional offset line into the matching networks [8]. The single input Doherty PA designed in [9] was converted into a dual input Doherty which was found to provide higher efficiency bandwidth. An outphasing PA with improved performance was proposed even when operated in high back off region [10].By using adaptive method for phase adjustment, the efficiency of a dual input Doherty PA was improved [11].

PA is a very important block in the transmitter architecture and it is required to have low power dissipation, small size, high gain and high efficiency. In this paper, we aim at designing a RF GaN PA for 900 MHz GSM base station application. The designing work is done in ADS (Advanced Design System) software from Agilent Systems using the concept of transmission line. This paper proceeds with the design methodology, the actual circuit schematic then simulation results are discussed and finally conclusions are drawn from the obtained results.

2 DESIGN METHODOLOGY

2.1 BLOCK DIAGRAM

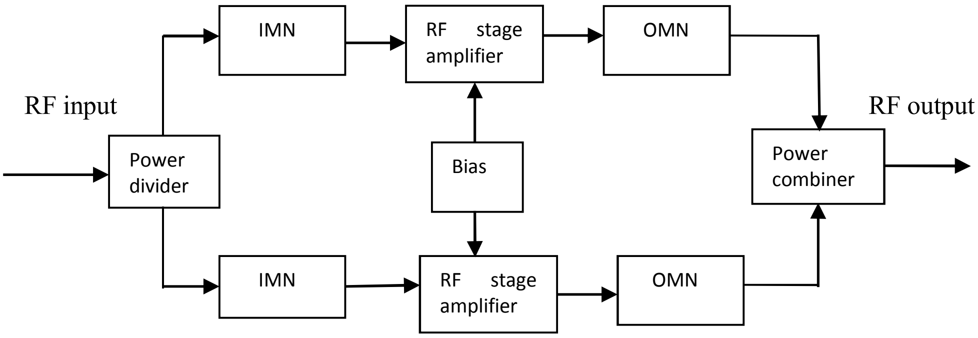

Fig. 1 Block diagram of proposed RF power amplifier

The above figure shows the functional block diagram of the designed Power Amplifier. The main focus is towards providing all the things that are needed for the most critical transistor parasitic which affect microwave performance. Input matching network (IMN) and Output matching network (OMN) are used at input and output stage respectively to reduce return losses. There are two types of return losses namely input return loss and output return loss. Minimising these losses result in improved gain and output power. Input impedance is calculated using the ratio of input voltage and input current. From this ratio input matching is determined. At the input side passive elements with some impedance are connected which forms the input matching network. If the matching is not perfect some loss will occur at the input side. This loss is known as input return loss and it is denoted by S (1,1).Likewise, there is another term called output return loss which relates the loss occurring at the output side because of imperfect matching. It is denoted by S (2,2). IMN, OMN and RF staged amplifier are the main blocks in power amplifier. Here, Wilkinson power divider/combiner is used to to divide/combine the RF power. The complexity of the combining network is kept low. The circuit is operated in 900 MHz GSM (Global System for Mobiles) frequency band.

2.2 POWER DIVIDER

The power divider used in the design is the Wilkinson power divider.It has three ports ,Port 1 is the input port and port 2 and port 3 are the output ports. The two ports (port 2 and port 3) are isolated from each other by a 100 ohm resistor. This power divider provides a 3-dB split without any phase shift meaning the RF signal applied at port 1 will be 3 dB less at output ports. Transmission line is used for implementing the design. The two arms are usually made from λ/4 microstrip lines .The impedance of each arm is 70.7 ohms (i.e.$\sqrt{2}\ Z_0$) in a 50-ohm system. Here, Z_0 is the characteristic impedance. Microstrip line used for each of the three ports has impedance of 50 ohms. The impedance of microstrip line is determined by its width and it is independent of its length.

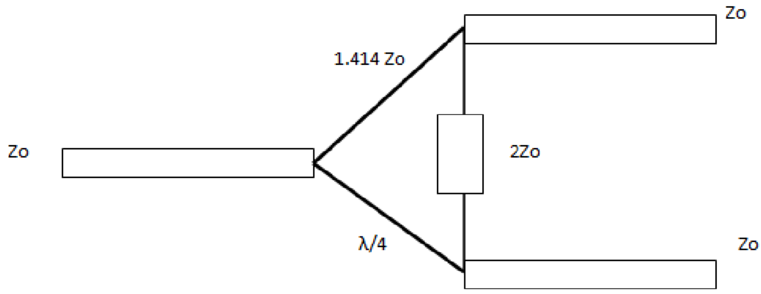

Fig. 2 Wilkinson power divider

2.3 AMPLIFIER STAGE

The transistor used for designing amplifier stage is a GaN HEMT (High Electron Mobility) from MACOM. Silicon Carbide D-Mode Transistor Technology is used for constructing this transistor. It is a wide band RF frequency transistor in which matching is not provided. It is designed for high voltage operation. It is small in size, low cost and light weight. The packaging used is a “true SMT” plastic package. 50V supply is required for its operation and can be used in applications where frequency of operation is from DC to 4 GHz. It is a device with common source configuration biased in class AB mode. Here, we choose class AB transistor as a compromise between the highly linear class A and highly efficient class B devices thereby providing excellent linearity as well as good efficiency.

2.4 INPUT MATCHING NETWORK

Radio Frequency Integrated Circuits (RFICs) cannot be realized without matching networks. Matching is required for amplifiers in order to maximize the output power. Every RFIC has its own input as well as output impedance. Here 50 ohm terminations are used at the input and output side before applying matching networks. The input matching is realized by using two capacitors and two inductors. The low pass filter at the input filters out harmonics. A DC blocking capacitor is also connected before the input matching network. Proper IMN is responsible for reducing input return loss. Ideally there should be no loss meaning no power should be reflected back at the input side .This ensures that matching is perfect.

2.5 OUTPUT MATCHING NETWORK

Output matching Network takes care of output return loss. It is also responsible for controlling the output power and gain of the circuit. Two inductors and three capacitors are used for designing OMN. For a properly designed OMN, there should not any loss. Practically this loss should be as small as possible.

2.6 POWER COMBINER

The RF signals from two stages of amplifier are added by power combiner. Wilkinson power combiner is used which increases the power of amplifier. Signal at the output of the power combiner is the desired RF signal.

2.7 BIAS CIRCUIT

For the simulation of circuit S-parameter model of the transistor is used. This s-parameter model is biased in itself so there is no need of connecting biasing circuit additionally. However, biasing circuit is required when the transistor is to be used in actual hardware. Separate bias needs to be applied to the gate and the drain terminals of the transistor.

3 SCHEMATIC DIAGRAM

Figure 3 shows the schematic of the designed RF power amplifier.

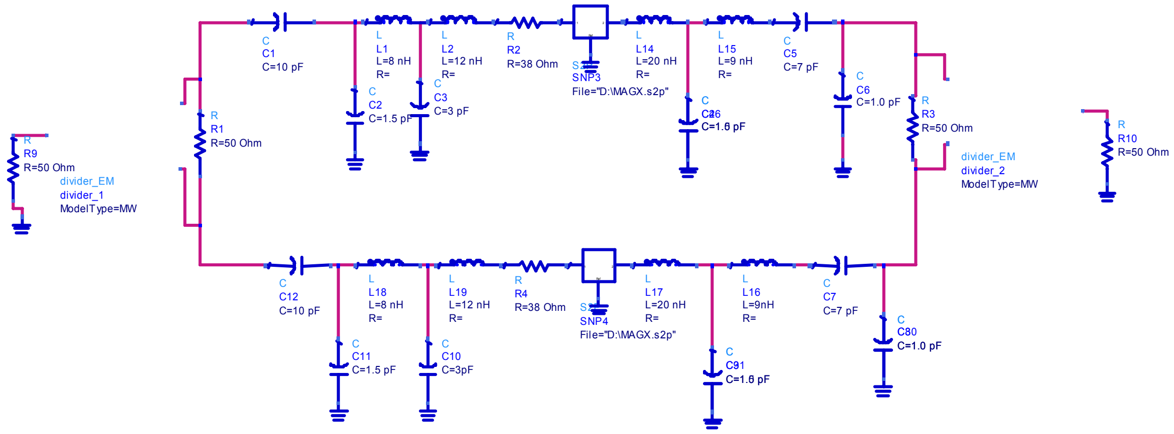

Fig. 3 Schematic of designed power amplifier

4 SIMULATION RESULTS AND DISCUSSION

For a circuit designed to operate at radio frequency, there should be no oscillations in the circuit. Presence of oscillations makes the circuit unstable so stability of the circuit must be ensured before using it in any application. Figure 4 shows the stability graph of the designed PA. The stability factor is 1.757 at 500 MHz. This ensures that the designed PA is stable.

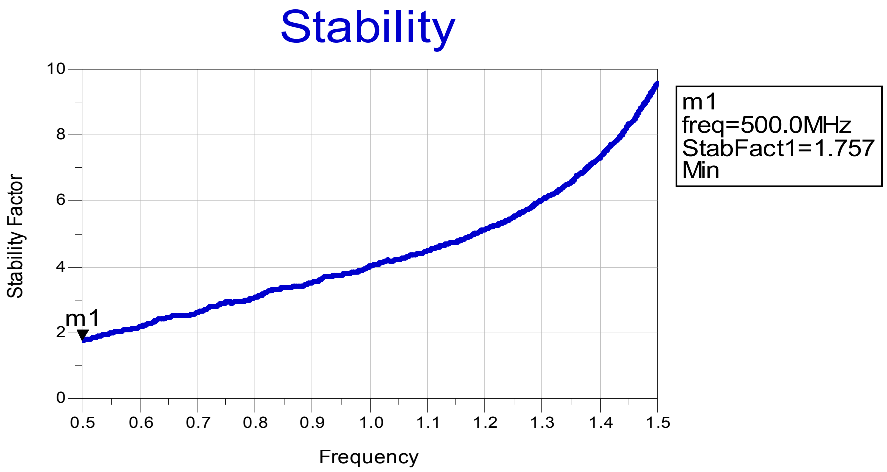

Fig. 4 Stability factor

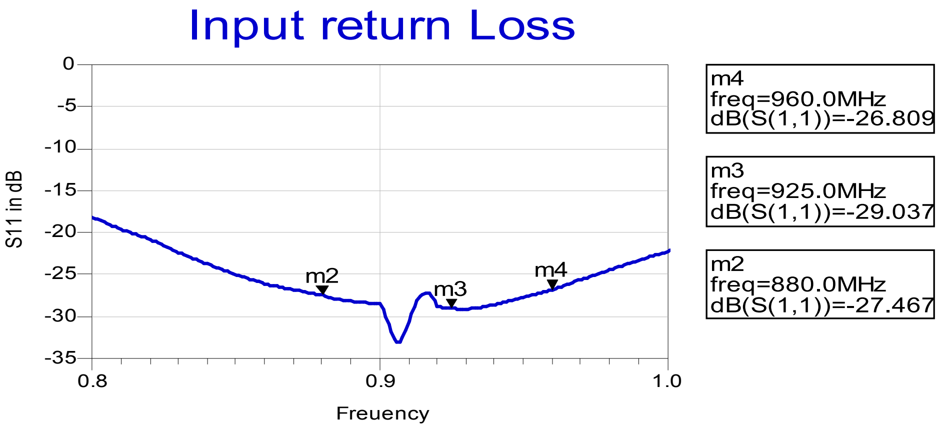

Fig. 5 Input Return Loss

S – Parameters are very useful for analysis of Power amplifiers. There are four s-parameters which are needed to be measured for observing the performance of a power amplifier. They are input return loss S(1,1), output return loss S(2,2), isolation loss S(1,2) and gain S(2,1). Input return loss is defined as the ratio of amount of power reflected back to the amount of power transmitted from the source at the input. It is also known as input reflection coefficient. Ideally we want no reflection of power at the input during transmission. Practically zero reflection is not possible to achieve, however it should be as low as possible. As shown in figure 5, the input return loss of this amplifier at 880 MHz is -27.467 dB which means that 4.23 % of transmitted power is reflected back at the output side and at 960 MHz it is -26.809 dB which means 4.56 % of transmitted power is reflected back. Output return loss is defined as the ratio of amount of power reflected back after transmission from the antenna at the output side. It is also known as output reflection coefficient. In figure 6, the output return loss at 880 MHz -18.296 which means that 12.167 % of transmitted power is reflected back at the output side and at 960 MHz it is -22.421 dB which means 7.566 % of transmitted power is reflected back.

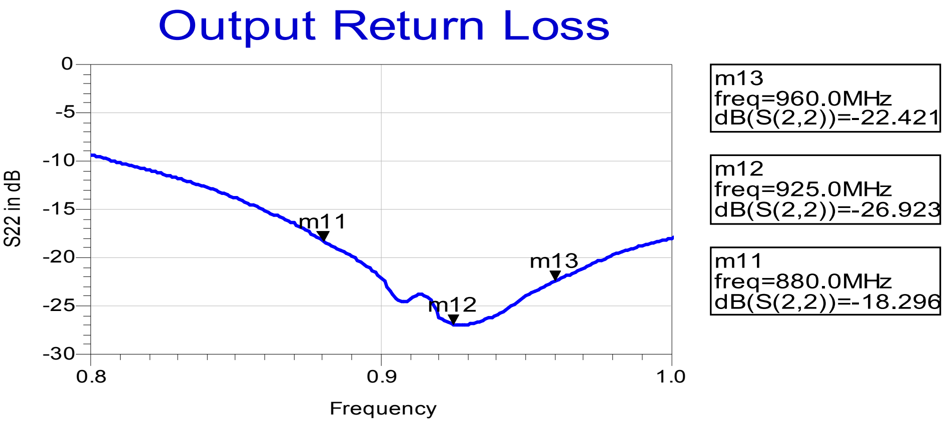

Fig. 6 Output Return Loss

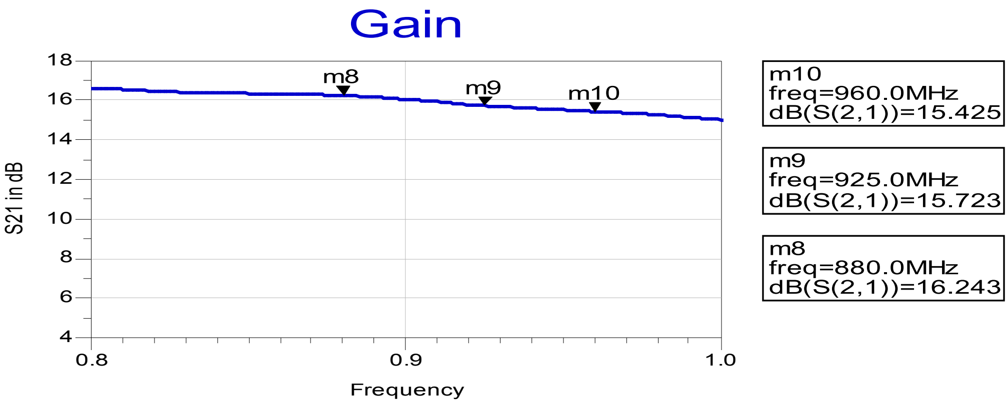

Fig. 7 Gain

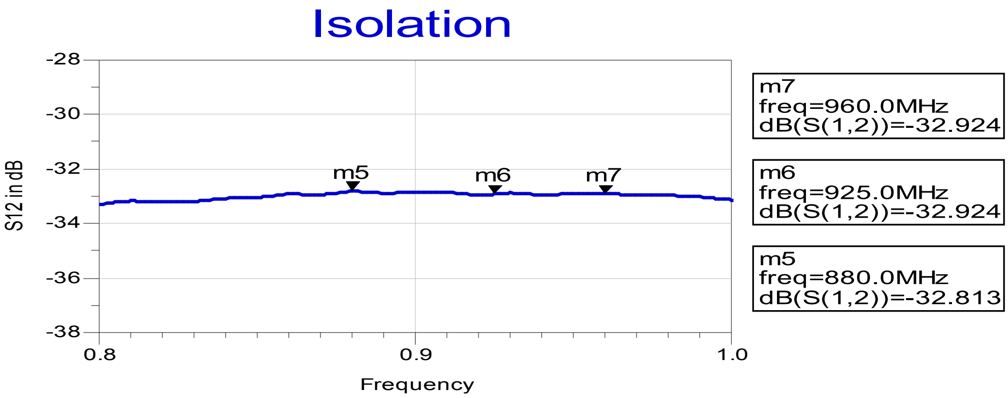

Fig. 8 Isolation

Gain of the PA is defined as the ratio of output voltage to input voltage. It is also known as forward transmission coefficient. It gives the amount of gain obtained at the output with respect to input. In figure 7, the gain is observed to be 16.243 dB at 880 MHz and 15.425 dB at 960MHz. Figure 8 shows the graph of isolation loss and at the desired frequency range it is observed to be less than -32 dB which means that there is approximately 100 % isolation between input and output. Isolation graph tells how well the output of the circuit is isolated from the input. Figure 9 shows the smith chart for input and output matching networks. It indicates how well the input and output are matched. From the smith chart it can be seen that the S(1,1) and S(2,2) graphs are well near the resistive line indicating good matching between input and output. This PA is designed to deliver output power of 10 W. All the simulations were performed using s-parameter palette. The values of frequency sweep goes from 500 MHz to 1.5 GHz with a step size of 1 MHz.

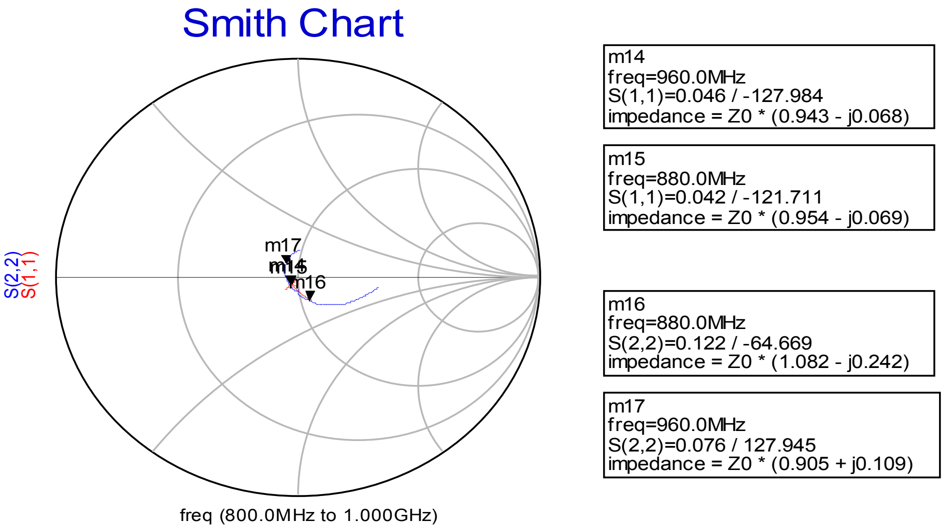

Fig. 9 Smith chart

Table 1: Comparison With Other Published RF Power Amplifiers.

Parameter	Ref.[5]	Ref.[6]	Ref.[7]	This Work
Frequency	1.7 GHz	2.6 GHz	2.4 GHz	0.88-0.96 GHz
Technology	GaN HEMT	GaN HEMT	RF CMOS	GaN HEMT
Stability factor	-	-	-	> 1.757
Input Return Loss (S11)	0.872 dB	~ -18 dB	-11.131 dB	-27.467at 880 MHz, -26.809 at 960 MHz
Output Return Loss (S22)	0.634 dB	~ -8 B	-12.467 dB	-18.296 at 880 MHz, -22.421 at 960 MHz
Gain (S21)	4.017 dB	~ 8 dB	43.745 dB	16.243 at 880 MHz, 15.425 at 960 MHz
Isolation (S12)	0.034 dB	-	-61.889 dB	-32.813 at 880 MHz, -32.924 at 960 MHz

5 CONCLUSION

An RF input GaN HEMT Power Amplifier for 900 MHz GSM application is designed and simulated in this paper. Microstrip transmission line is used for designing the Wilkinson Power Splitter/combiner. The input matching is realized using low pass filter networks. Two small value resistors are needed to make the circuit stable. T-shaped networks are used in output matching networks. Symmetrical design reduces the complexity of the circuit. The designed PA achieved maximum gain of 16.243 dB which is obtained at 880 MHz. Simulation results show that the matching provided by the design is proper and the circuit is unconditionally stable. Future work will provide a more thorough experimental comparison with the actually fabricated PA.

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