DESIGN AND ANALYSIS OF MICROWAVE POWER AMPLIFIER AT 5G SUB-6 GHZ APPLICATION

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronics and Computer Technology and Engineering
Universiti Teknikal Malaysia Melaka

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
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Tajuk Projek : Design and Analysis of Microwave Power Amplifier at 5G sub-6 GHz Application

Sesi Pengajian : 2023/2024

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DEDICATION

I wholeheartedly dedicate this thesis to my most beloved and supporting parents, to my dearly boyfriend, my best friends, my supervisor, all my lecturers, and above all to our Almighty Allah S.W.T. Their encouragements and guidance have always inspired me along this educational journey.

ABSTRACT

A power amplifier is an electronic circuit that increases the power of a signal. For 5G sub-6GHz applications, this project describes a detailed analysis, design, and simulation approach for PA at 3.5 GHz. Higher frequency communications are typically more prone to interference than lower frequency ones. Because it is a lower frequency band than 6 GHz, the 2.4 GHz frequency band can be more prone to interference. The objective of this project is to design and simulate a microwave amplifier for a 5G sub-6 GHz application specifically on 3.5 GHz. This project is comparing the performance between Gallium-Nitride (GAN) High-Electron Mobility Transistor (HEMT), CG240025 and Gallium Arsenide (GaAs) Pseudomorphic High-Electron Mobility Transistor (pHEMT), AM030WX-BI-R to design the matching network and DC biasing network by using Advanced Design System (ADS) software. Hence, AM030WX-BI-R has a better performance because of the high gain (17.799 dB) and a low noise figure (1.223 dB). To conclude, power amplifier projects in 5G are essential to improving healthcare accessible, enhancing well-being, and supporting programs aimed at strengthening people's health and safety because they enable dependable, high-speed communication.

ABSTRAK

Penguat kuasa (PA) ialah litar elektronik yang meningkatkan kuasa isyarat. Untuk aplikasi 5G sub-6GHz, projek ini menerangkan analisis terperinci untuk PA pada 3.5 GHz. Komunikasi frekuensi tinggi biasanya lebih terdedah kepada gangguan daripada komunikasi frekuensi rendah. Oleh kerana ia adalah jalur frekuensi yang lebih rendah daripada 6 GHz, jalur frekuensi 2.4 GHz boleh lebih terdedah kepada gangguan. Objektif projek ini adalah untuk mereka bentuk dan mensimulasikan penguat gelombang mikro untuk aplikasi 5G sub-6 GHz khususnya pada 3.5 GHz. Projek ini membandingkan prestasi antara CG240025 dan AM030WX-BI-R untuk mereka bentuk rangkaian padanan dan rangkaian pincang DC dengan menggunakan perisian ADS. Oleh itu, AM030WX-BI-R mempunyai prestasi yang lebih baik kerana gandaan yang tinggi (17.799 dB) dan angka hingar yang rendah (1.223 dB). Sebagai kesimpulan, projek penguat kuasa dalam 5G adalah penting untuk meningkatkan kebolehcapaian penjagaan kesihatan, meningkatkan kesejahteraan dan menyokong program yang bertujuan untuk mengukuhkan kesihatan dan keselamatan orang ramai. Penguat kuasa sedia melebihi semua elektronik lain dan pemprosesan digital dari segi penggunaan kuasa, yang secara amnya memerlukan tahap kuasa penghantaran yang agak tinggi.

ACKNOWLEDGEMENTS

First and foremost, I am grateful to Almighty Allah for the continuous blessing and giving me strength, good health, well-being, and an opportunity to complete this study. I would like to express appreciation to my parents for their willingness to send me to UTeM, to pursue my studies and always supports and gave me encouragement along my journey as a student in UTeM.

In addition, I want to thank my supervisor, Ts. Dr. Azahari Bin Salleh, for his guidance during this final year project, from the beginning until the end. Dr. Azahari was always willing to share her thoughts and teach me a lot of extra knowledge, which helped this study. Although he is full of schedules as a lecturer and many other final year students' supervisors, Dr. Azahari always makes her time to follow up with my progress. I am very thankful to have Dr. Azahari as my supervisor.

Finally, thanks to all my friends, who supported me through ups and downs to complete my final year project. Without them, it is difficult for me to complete this report.

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LIST OF SYMBOLS AND ABBREVIATIONS

PA	:	Power Amplifier
ADS	:	Advanced Design System
GaN	:	Gallium-Nitride
GaAs	:	Gallium Arsenide
HEMT	:	High-Electron Mobility Transistor
pHEMT	:	Pseudomorphic High-Electron Mobility Transistor
MMIC	:	Monolithic Microwave Integrated Circuit
ADSL	:	Asymmetrical Digital Subscriber Line
FDSOI	:	Fully Depleted Silicon-On-Insulator
RF	:	Radio Frequency
NF	:	Noise Figure
G_T	:	Transducer Gain
K	:	Rollet's Stability Factory
Hz	:	Hertz
dB	:	Decibel
dBm	:	Decibel Milliwatts
C	:	Capacitor
L	:	Inductance

R	:	Resistor
Z	:	Impedance
I	:	Current
V	:	Voltage
G	:	Giga
n	:	Nano
p	:	Pico
mm	:	Millimeter

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

In this chapter, an introduction with motivations and objectives of this project are present. Thus, this chapter is focusing on the project background, problem statements, project objectives, scope of works and thesis outline.

1.1 Introduction

A power amplifier (PA) is an electronic circuit that increases the power of a signal. Its primary function is to amplify the power of a weak input signal to a level suitable for driving a load such as a speaker or antenna. These amplifiers play a critical role in strengthening signals to cover longer distances or to drive speakers or antennas effectively. They come in numerous forms, each built for specialized applications, whether it is for audio amplification in consumer electronics, amplifying radio frequency signals in telecommunications, or raising the power of signals in scientific equipment.

In Malaysia, the development and acceptance of 5G technology, notably in the sub-6 GHz spectrum, have been essential in altering the country's telecommunications landscape. The deployment of 5G within the sub-6 GHz frequency band has been a focal point due to its balance between coverage and capacity, offering improved speeds and connectivity compared to previous generations. Telecommunication companies in Malaysia have been actively investing in infrastructure and spectrum auctions to prepare the way for 5G networks. Higher frequency communications are typically more prone to interference than lower frequency ones. Because it is a lower frequency band than 6 GHz, the 2.4 GHz frequency band can be more prone to interference. Many distinct wireless technologies, including Wi-Fi, Bluetooth, and some cordless phones, share the frequently used 2.4 GHz frequency range. This can result in interference problems and congestion. The 6 GHz frequency range, on the other hand, is a less-used frequency band that has just lately been made available for unauthorized use in some areas. This suggests that compared to the 2.4 GHz frequency band, the 6 GHz frequency band may experience less interference.

The technologies used in this project are GaN for CG2H40025 transistor and GaAs for AM030WX-BI-R transistor. These technologies will determine which transistor will give a better performance for the required specifications such as gain, noise figure and stability in order to design the PA by using ADS software. The expected result for designing a power amplifier is to create an amplifier that can amplify a signal to desired power level with minimal distortion or noise. The PA readily exceeds all other electronics and digital processing in terms of power utilization, which is generally quite high transmit power levels necessary.

1.2 Problem Statement

As the early 5G deployments are mostly in the sub-6 GHz frequency range, which covers frequency bands like 3.5 GHz, RF power amplifiers are created at sub-6 GHz frequencies. These frequencies have favorable propagation properties, including broader coverage areas per base station and better signal transmission over barriers like walls and buildings. At sub-6 GHz, interference is less likely to happen than it does at 2.4 GHz. The design of high frequency of PA is a difficult and challenging problem which is in active network theory of great practical importance [1].

The 2.4 GHz band's reduced bandwidth might result in greater interference and worsened signal quality, which could impact how well the RF power amplifier performs [2]. Because the 2.4 GHz band is a commonly used frequency band, interference from other devices that operate in the same frequency band may be very intense. It may be challenging to achieve a low noise figure and high gain due to this interference's effects on the PA's performance. The 2.4 GHz band has a limited bandwidth, which may affect the PA's performance. This can make it difficult to maintain a sufficient bandwidth while obtaining the required gain and noise figure [3].

Hence, the technologies of GaN and GaAs that used in this project will enhance the performance of the transistors and proved that the 5G sub-6 GHz band is the best frequency range for building PAs for 5G communication since it has a wider bandwidth, better penetration, and less interference than the 2.4 GHz band.

1.3 Objectives

The objectives of this study comprise of the following:

i. To design and simulate the microwave Power Amplifier at 5G sub-6 GHz application.

ii. To compare the performance analysis of Power Amplifier based on different technologies.

1.4 Scope and Limitation

In order to achieve the objectives of this project, there are following scopes will be covered:

a. To study the concept of the power amplifier design.

b. All parts of design are operating at 3.5 GHz band.

c. Advanced Design System (ADS) is used to perform the simulation.

d. Selecting the suitable technologies which are GaAs and GaN that will be used for the design.

e. The analysis of design is based on PA parameters such as gain, noise figure and stability.

1.5 Thesis Outline

Accordingly, there are five chapters in this thesis. Chapter 1 is an introduction to the Power Amplifier, which includes background research; including the general overview of the design using theoretical and experimental approach. This chapter presented the problem statement, objectives, and scope of work.

Chapter 2 provides a relevant background study which consists of an overview of the power amplifiers and 6 GHz application. This literature review also explained about the parameters and technique involved in designing power amplifier. Moreover, there is also a summary of power amplifier design using theoretical and experimental approach.

Chapter 3 described about the research methodologies that consist of step of designing power amplifier and details about the specification involved.

Chapter 4 mainly is for the result and analysis of power amplifier after designing using ADS software and compare the type of two transistors that have been selected which are CGH40025 and AM030WX-BI-R.

Chapter 5 concludes the achievements of the study. Several recommendations are also included at the end of this chapter for the purpose of improving the quality of this study in the future.

CHAPTER 2

BACKGROUND STUDY

Chapter two is about literature review regarding to the previous research done about power amplifier (PA). It contains the method and some results that had been used by the previous research and so on.

2.1 Introduction

Generally, an amplifier or simply amplifier is any device that changes, usually increases, the amplitude of a signal. The relationship of the input to the output of an amplifier, usually expressed as a function of the input frequency is called the transfer function of the amplifier, and the magnitude of the transfer function is termed the gain.

In popular use, the term usually describes an electronic amplifier, in which the input signal is usually voltage or current.

The PA, a critical element in transmitter units of communication systems, is expected to provide a suitable output power at a very good gain with high efficiency and linearity. The output power from PA must be sufficient for reliable transmission. High gain reduces the number of amplifier stages required to deliver the desired output power and hence reduces the size and manufacturing cost. High efficiency improves thermal management, battery lifetime and operational costs. Good linearity is necessary for bandwidth efficient modulation.

However, these are contrasting requirements and a typical PA design would require a certain level of compromise. There are several types of power amplifiers which differ from each other in terms of linearity, output power and efficiency. Parameters which quantify the various aspects of amplifier performance such as output power, gain, intermodulation distortion, efficiency and are discussed in this section.

2.2 Overview of Power Amplifiers

There are specifications parameter should be considered in PA design. The gain of an amplifier is the ratio of output to input power or amplitude, and is usually measured in decibels. RF amplifiers are often specified in terms of the maximum power gain obtainable, while the voltage gain of audio amplifiers and instrumentation amplifiers will be more often specified since the amplifier's input impedance will often be much higher than the source impedance, and the load impedance higher than the amplifier's output impedance.

The bandwidth (BW) of an amplifier is the range of the frequencies for which the amplifier gives satisfactory performance. The satisfactory performance may be different for different applications. Efficiency is a measure of how much of the input power is usefully applied to the amplifier's output. Class A amplifiers are very inefficient, in the range of 10% - 20% with a maximum efficiency of 25%. Class B amplifiers have a very high efficiency but are impractical because of high level of distortion. In practical design, the result of a tradeoff is the class AB design. Modern class AB amplifiers are commonly 35% - 55% efficient with a theoretical maximum of 78.5%. in RF power amplifiers such as cellular base station and broadcast transmitters, specialist design techniques are used to improve efficiency.

An ideal amplifier would be a totally linear device, but real amplifiers are only linear within certain practical limits. When the signal drive to the amplifiers is increased, the output also increases until a point is reached where some part of the amplifier becomes saturated and cannot produce anymore output; this is called clipping, and results in distortion. Noise is an undesirable but inevitable product of the electronic devices and components. The metric for noise performance of a circuit is noise factor. Noise factor is the ratio of input signal to that of the output signal. Output dynamic range is the range, usually given in dB, between the smallest and largest is limited most often by distortion. The ratio of these two is quoted as the amplifier dynamic range.

The applications of PA include many products in the field of microwave communications. One of the important applications of this power amplifier is the output stage of the transmitter where a signal needs amplification before it is transmitted. A high PA is needed for transmitting a signal through an antenna medium.

The PA amplifies the input signal after the signal has been modulated in the transmitter. The high-power amplification step is necessary for every application of antenna transmission.

2.3 Overview of Amplifier Technology Types

The construction of microwave PA for 5G sub-6GHz applications often employs an array of transistor technologies. Several factors including as noise performance, linearity and manufacturability, influence the optimum transistor choice. Using low noise transistors, which are made with a focus on reducing noise and delivering high gain, is a different approach. Based on the summary of the most typical microwave PA technologies, the best transistors/technologies often used in the construction of microwave PAs for 5G sub-6GHz applications are Gallium Arsenide (GaAs) and Gallium Nitride (GaN) transistors. GaAs and GaN technologies are commonly chosen for PA design due to their unique advantages and characteristics.

GaAs technology refers to the use of Gallium Arsenide as the semiconductor material in electronic devices and integrated circuits. GaAs is an alternative to Silicon (Si) and is known for its superior performance in high-frequency and high-power applications. GaAs devices can handle higher power levels than Silicon devices. They are commonly used in power amplifiers for applications such as cellular base stations and satellite communications. GaAs technology finds applications in various fields, including telecommunications, wireless communication systems (such as cellular phones and Wi-Fi), radar systems, satellite communications, optoelectronic devices, and aerospace.

While GaAs offers certain advantages over Silicon in specific applications, it also has some limitations. GaAs technology is generally more expensive compared to

Silicon technology, and it may not be as suitable for large-scale integration due to challenges in manufacturing and compatibility with existing fabrication processes. However, in specialized applications that require high-frequency performance and power handling capabilities, GaAs technology continues to be widely used.

GaN technology refers to the use of Gallium Nitride as the semiconductor material in electronic devices and integrated circuits. GaN is a wide-bandgap semiconductor that offers several advantages over traditional materials like Silicon (Si) and Gallium Arsenide (GaAs). It has gained significant attention and adoption in various applications, especially in power electronics and high-frequency devices. GaN devices can operate at high frequencies, enabling faster switching speeds and efficient power conversion. This makes GaN technology suitable for applications such as power amplifiers, high-speed switching devices, and high-frequency communication systems. GaN devices have lower conduction and switching losses compared to Silicon-based devices. This results in higher power efficiency, reduced heat generation, and smaller form factors for power electronics applications.

While GaN technology offers numerous benefits, it also has some challenges. The manufacturing processes for GaN devices are more complex and expensive compared to Silicon-based devices. However, as the technology continues to mature and economies of scale are achieved, the cost is expected to decrease. Overall, GaN technology has the potential to revolutionize power electronics and high-frequency applications with its high performance, efficiency, and compact size. It is being actively researched and developed to further advance its capabilities and broaden its range of applications.

Two distinct semiconductor technologies that are frequently utilized for power amplifiers are GaAs and GaN. Although all technologies have benefits and drawbacks, it is important to note some significant performance variations. Table 2.1 below shows the comparison between GaAs and GaN technologies.

Table 2.1: Comparison between GaAs and GaN Technologies

Parameters	GaAs	GaN
Frequency Range	Capable of operating at high frequencies, but GaN offers extended frequency capabilities.	Can operate at higher frequencies due to their superior electron mobility and higher saturation velocity.
Noise Figure	Known for its low noise characteristics, making it suitable for applications that require low noise amplification.	Have slightly higher noise figures due to their higher operating voltages and associated noise sources.
Linearity	Offers less better linearity compared to GaN.	GaN devices exhibit improved linearity due to their high breakdown voltage and higher power handling capabilities.
Cost	Less expensive compared to GaN technology.	More expensive due to the complexity of manufacturing processes and lower economies of scale.

2.4 Review of Previous Research

Moreno Rubio *et al.* (2022), presented a strategy to design ultrawideband power amplifiers with a fractional bandwidth of approximately 200% [4]. It exploited a simple output matching network, which consists of a series transmission line together with a shunt stub, to compensate the output parasitic network of the device. Several output matching networks were designed for two different size GaN HEMT devices. One of these examples was implemented and characterized and a drain efficiency from 52% to 70% and an output power between 40dBm were obtained, over 67% of the 5G sub 6 GHz band (0.1 t0 4 GHz). The mentioned results, represented the state of the art in broadband power amplifier.

According to M. Shahmoradi *et al.* (2023), the main PA was designed using an accurate approach that took the loading effect of the auxiliary amplifier on the main amplifier during back-off into account [5]. A symmetric DPA is designed, made, and tested as a proof of concept. According to the measurements, the device's operating frequency range is between 3.3 and 3.9 GHz, its minimum peak output power is 36 W, and its drain efficiency is between 48 and 53.2% at peak and 34.6% to 44.5% at 6 dB back-off.

Lv Guansheng *et al.* (2019), implemented a dual-band power amplifier with hybrid operating modes for 5G mobile communication and vehicle network using 0.25 μm gallium nitride (GaN)-HEMT process [6]. The measurements show that between 3.3 and 3.8 GHz, a saturated power of 41.8 to 42.6 dBm, a saturated drain efficiency of 56% to 64%, and a 6-dB back-off DE of 42% to 51% are achieved, whereas at 5.8 GHz, a saturated power and DE of 41 to 55% are attained. This is the initial hybrid operating mode dual-band GaN monolithic microwave integrated circuit PA. The same (GaN)-HEMT technology was used in publication by Liu R-J. *et al.* (2019), albeit with a different frequency range [7].

Xiong H. *et al.* (2018), proposed an Asymmetric Doherty Power Amplifier using Symmetric Devices (ADSD) for 5G base-station application to improve the back-off efficiency and bandwidth. The primary and secondary elementary power amplifiers (PAs) in this study are built to attain the best back-off efficiency and saturated power, respectively [8]. By doing so, the limitations brought on by the usage of asymmetric devices in traditional asymmetric Doherty Power Amplifier (DPA) can be overcome while the overall performance is improved.

This research proposes a wideband power amplifier constructed in 28nm FDSOI technology by R. Quéheille *et al.* (2020) with regulated efficiency based on second harmonic matching [9]. The class-J harmonic processing technique was employed by the output network to regulate the Power Added Efficiency (PAE) over Bandwidth (BW). In this essay, the efficiency control theory was examined. The papers that have been reviewed is summarized in term of several parameters to distinguish between each other as in the Table 2.2.

Table 2.2: Existing PA Design Comparisons

Research Papers	Operating Frequency (GHz)	Gain (dB)	Output Power (dBm)	Method/ Technology
[4]	0.1-4.0	9-14	40-42.5	Ultra-Wideband
[5]	3.3-3.9	NA	45.6	Broadband
[6]	3.5-5.8	12	41.8-42.6	Dual-Band GaN MMIC
[7]	4.8-5.0	6.1	40-40.3	GaN MMIC
[8]	3.4-3.6	7.5	39	Broadband ADSL
[9]	2.4-5.1	3.0	18.5-20.9	FDSOI
[10]	3.5	NA	30.0	GaN
[11]	4.5-5.2	8.6-11.6	40.4-41.2	C-Band GaN MMIC
[12]	5.8	12.9	37.0	GaN HEMT
[13]	0.41-7.1	15.0	35.0	In-Band
[14]	24-30	19.8	32.2	GaN-on-Si

CHAPTER 3

METHODOLOGY

The methodology of this power amplifier (PA) is discussed in this chapter. This chapter included the types of transistors chosen for the PA. Also, will discuss about the flow chart of the design process and software that is being used for simulation.

3.1 Methodological Flowchart

Figure 3.1 shows the flow chart of the project that will be designed.

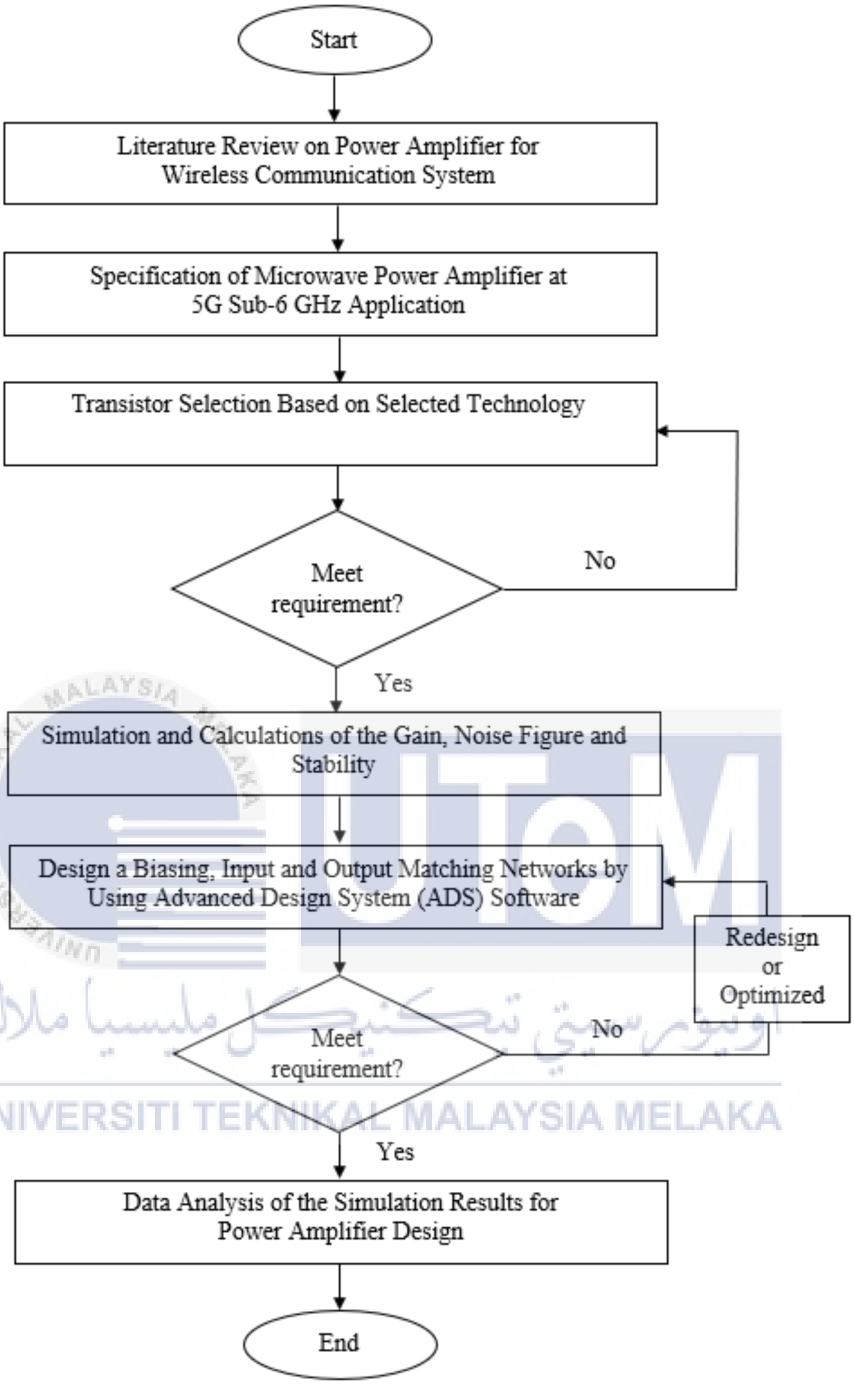


Figure 3.1: Flowchart for Methodology Framework of PA Design

To design the PA by using ADS software, there are few steps needed to make sure the required parameters can be achieved. Hence, more details on how to do the methodology will be explained in this section based on the flowchart created:

3.2 Design Methodology

In this section, it will briefly explain about the steps taken to design the PA. The topology of the PA is examined first, followed by a discussion on specifications, selection of transistor, stability, biasing on transistor, matching network, optimization, and finally analyzing the simulation.

3.2.1 Power Amplifier Design

This following section presented the general procedures of PA design. The design based on a single stage microwave transistor amplifier which be modeled by the circuit of Figure 3.2. The matching network is used on the both sides of the transistor to transform the input and output impedance, Z_O to the source and load impedances, Z_S and Z_L. The input matching circuit, including the bias circuit gives an important impact on the operation of the RF power amplifiers [15]. From the matching networks it will show the different in optimization which is the maximum gain, best linearity and highest efficiency can be measured.

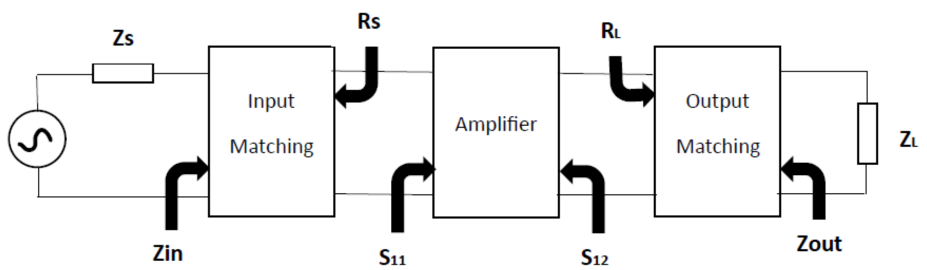


Figure 3.2: General Transistor Amplifier Circuit

3.2.2 Specifications of Power Amplifier

Table 3.1 shows the specifications of the PA design. The operating frequency of amplifier is at 3.5 GHz. The target of this project is that design microwave PA.

Table 3.1: Power Amplifier Specifications

Parameters	Values
Operating Frequency	3.5 GHz
Gain, G	>15 dB
Noise Figure	< 3 dB
Stability	K>1
Input/Output Impedance	50 Ω
Technology	GaAs/GaN

The specifications of PA for the 3.5 GHz frequency band needed ahigh gain and low noise figure. Moreover, the stability must be more than one which K>1 for it to be in an unconditional stable state. Also, the technologies that will be used in this project are GaN and GaAs. The performance of these technologies will be compared based on the S-parameters for both transistors.

3.2.3 Selection of Transistor

The first step involved on designing the power amplifier is the selection of the transistor. Therefore, transistor will be selected based on the requirements for the target specifications. The requirements for the target specifications are the combination of high gain and low noise. Details of the transistor can be referring based on the datasheet. For this project, a type of transistor chosen is the GaAs pHEMT since it is suitable for the high frequencies.

The first step involved in the selection of the transistor of the amplifier is by observing details about the transistor specification due to the amplifier specification design. Initially, the different parameters were compared to each transistor and the suitable transistor are CG2H40025 and AM030WX-BI-R which both transistors satisfying the requirements for the specification needed. Then, the stability of each transistor needed to be checked to ensure that it can fulfill the required frequency range at 3.5 GHz.

For CGH40025 transistor, it is a specific model number of GaN (Gallium Nitride) High Electron Mobility Transistor (HEMT) manufactured by Cree, Inc. Here are the key features and specifications of the CGH40025 transistor:

(a) High linearity performance
(b) Low noise figure
(c) High power gain
(d) High cost but it is still competitive with other GaN HEMTs that offer similar performance

The specifications for the transistor CGH40025 are the target output or results for the design of the amplifier. The specifications are:

(a) 15 dB at 2 GHz and 13 dB at 4 GHz associated gain (typically)
(b) 30 dBm third-order intercept
(c) 1.5 dB noise figure

The GaAs pHEMT AM030WX-BI-R is a high-performance transistor that offers excellent noise figure, linearity, power gain and cost. It is ideal for a variety of RF and microwave applications, such as cellular infrastructure, test instrumentation, and broadband amplifiers. Here are some features of the GaAs pHEMT AM030WX-BI-R in terms of its parameters:

(a) High linearity performance
(b) Low noise figure
(c) High power gain, making it suitable for applications where high-power output is required.
(d) Low cost, which making it a cost-effective option for many applications.

The specifications for the transistor AM030WX-BI-R are the target output or results for the design of the amplifier. The specifications are:

(a) 17 dB at 2 GHz and 13 dB at 4 GHz associated gain (typically)
(b) 35 dBm third-order intercept
(c) 2.5 dB noise figure

3.3 Design Parameter

To design power amplifier, it is required to identify the right parameter that need to be used [16]. In designing power amplifier, there are several parameters such as gain, noise figure and stability.

3.3.1 Stability

In power amplifier design, single power transistor is the method to provide amplification at the desired frequency and the desired linearity. The amplifier must be stable because with unstable amplifier, the signal will not transmit out from the transmitter but will oscillate inside the transmitter. The stability of power amplifier can be determined by using K test. In K test, the will also a Rollet's Condition that need to be satisfied. If the K factor is greater than unity, at the frequency and bias level in question, the expressions for matching impedance at input and output can be evaluated to give a perfect conjugate match for the device. The set of unconditional stability can be expressed in formula below.

Auxilary Condition

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad (3.1)$$

$$K = \frac{1+|\Delta|^2-|S_{11}|^2-|S_{22}|^2}{2|S_{12}S_{21}|} \quad (3.2)$$

The above equation is referred to Rollet's Criteria for Unconditional Stability which is the important condition. The value of K also can be found by using the simulation.

The amplifier design naturally will be in stable state. However, it is difficult to determine either an amplifier it is conditionally stable or unconditionally stable. Insuring stability in an amplifier, especially an amplifier with substantial gain over a wide frequency range requires more attention on the designing of the amplifier [17].

3.3.2 Noise Figure

In theoretical, noise figure is not so important in linearity of power amplifier, but it must be used to design the power amplifier. Noise figure is defined as noise input power corresponding to kTB from the passive device (no gain) held at 290k, where k is Boltman constant and B is noise bandwidth in Hertz.

$$NF = 10 \log (F) \quad (3.3)$$

3.3.3 Gain

There are different definitions of the gain. The most useful is transducer gain, which is the ratio between the power delivered to the load and the power available from the source [18]. Transducer gain can be expressed by:

$$\eta = \frac{P_L}{P_S} \quad (3.4)$$

where P_S is the R_F drives power and P_L is the output R_F power. The typical value of the transducer gains for a R_F PA is 10 – 15 dB (assumed one-stage structure).

The other useful definition is maximum available gain (MAG). Available gain is a ratio between the power available from the output of the transistor and the power available from the source. The maximum value is occurred when the input of the PA is conjugate-matched to the source [19]. The MAG is the highest possible value of transducer gain in case when both the input and output ports are conjugated-matched. MAG can be defined only if the transistor unconditionally stable. It is also useful to evaluate the MAG versus swept frequency. It gives, so called, maximum frequency of oscillation (f_{max}), which shows the frequency when MAG reaches magnitude of 1 (0 dB).

3.3.4 Input and Output Matching

In designing power amplifier, it is essential to design the input and output matching network of the amplifier. There are several numbers of matching technique that can be used such as single stub matching, double stub matching, lumped elements matching, quarter wave transformer matching and many more. The matching network is use to provide maximum power delivered to the load. Matching network is usually place between the transistor which is in the source and the load. Input and output matching network is illustrated as Figure 3.3.

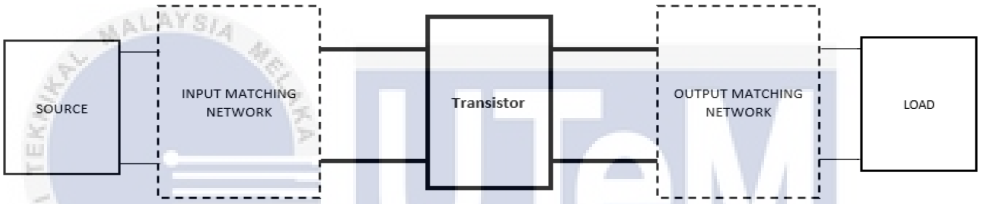


Figure 3.3: Input and Output Matching Network

For this project, single stub tuning is used for matching network. The important factors in the selection of a particular matching network include complexity, bandwidth, implementation, and adjustability. In the single stub matching that uses a single open circuited or short circuited of transmission line (stub), connected either in parallel or in series with the transmission feed line at the certain distance from the load. The shunt tuning is especially easy to fabricate in microstrip or strip line form. The matching network can easily be determined using Smith Chart. For the shunt-stub case, the basic idea at d from the load is form $Y_O + jB$. Then the stub susceptance is chosen as $-jB$, resulting in the matching condition.

The main steps to perform single stub matching are needed in order to design the PA. The impedance mismatch needed to determine the characteristic impedance of the transmission line and the impedance of the load that needs to be matched. Moreover, the stub length also will be calculated and the stub can be open-circuited or short-circuited and is usually a fraction of a wavelength at the operating frequency. If the match is not perfect, small adjustments to the stub length or location might be necessary. Repeating measurements and fine-tuning can help achieve the desired impedance match.

3.3.5 Optimization

The aim of optimization is to improve the performance of amplifier such as the gain, input, and output return loss. For example, in the simulation using ADS, tune parameter is used to tune the input matching (magnitude of S_{11}) and output matching (magnitude of S_{22}). Both magnitudes are referred to the reflection coefficient, Γ which for the perfect matching, the value of Γ should be equal to zero. Optimization of the component values and microstrip line geometries is necessary to achieve the required performance in a fabricated amplifier. Optimization and goals were selected under the component pallet list of ADS. The input and output matching network were separately optimized based on the optimum load and source impedances. The width and length of the microstrip transmission lines and component values were both tuned to achieve the required impedances.

3.3.6 Advanced Design System (ADS)

ADS is a powerful electronic design automation software system. It offers complete design integration to designer of products each as cellular and portable phones, pagers, wireless network, radar and satellite communication systems, and high-speed digital serial links. The Agilent ADS software provide every step to design in form of schematic design, layout design, frequency and time domain circuit simulation and electromagnetic field simulation. The advantage of ADS software is it allowing optimizing entirely the RF designs without changing tools. The ADS also provide a complete, integrated set of accurate and easy to use.

In ADS software section, the simulation firstly is based on 2 – port network which is to find S-Parameters for the transistor at desired frequency, noise figure, stability, source and load impedances, several type of gain such as power gain, available power gain, transducer gain and maximum conjugate gain. After all the needed parameters are achieved and the value is suitable for designing power amplifier based on the standard, the circuit of DC biasing, input and output matching and single stage power amplifier is simulated on ADS software.

3.3.7 Parameter Identification Using Advanced Design System (ADS)

Firstly, the step to use the ADS software is to identify the stability of the transistor. Avago Technologies provide 2 type of files that can be run by using ADS software which is ZAP file and S2P file. ZAP file containing the model of the transistor and the characteristics of the transistor while S2P file contain the S-Parameters for the transistor at specific frequencies. The value of S-Parameters also can be determined inside data sheet of the transistor as seen in Appendix A. First, the ZAP file needs to be unachieved into the ADS so that it could create a workspace along with the transistor model. To determine the stability of the transistor, the circuit in the Figure 3.3 can be used.

From the simulation, the graph of stability, noise figure and available gain with automatically designed inside the graph file. The desired frequency can be selected by sweeping the value of the frequency inside the graph file. For other parameters, the step will be stated in next chapter.

3.3.8 Analyzing Simulation

A careful analysis was performed to understand the operating frequency of 3.5 GHz and observation done on the measured parameters of amplifier. The analyzing should be concerned on the matching elements and review of the power amplifier circuit design on the ADS. Comparison from the simulation results to the expected results will be analyzed. From the analysis, if the obtain results is not satisfied to the expected results, it can be tune at optimization to obtain the best and closed to the expected results. Once all the parameter's measurement obtained nearly to the aim results, this project can move to the next steps.

CHAPTER 4

RESULTS AND DISCUSSION

In chapter four, the calculation, simulation, and analysis of the result of Power Amplifier for 6 GHz application is presented. The simulation of this power amplifier is fully used with Advanced Design System (ADS) software.

4.1 Basic Power Amplifier Design

The maximum achievable gain, input and output matching, stability, noise figure, and bias point simulation must all be considered while designing a power amplifier. At the first step of PA design, simulation is necessary to determine whether a transistor is suitable for use in a power amplifier. To optimize the power amplifier design, every relevant parameter will be contrasted between the two transistors. Because of its intuitive interface, the ADS software was utilized for the simulation.

4.2 Transistor Device Testing

The transistors must first be tested to ensure their stability and gain before beginning the design of the power amplifier [20]. The conditional and unconditional stability of the transistor needed to be examined. To verify the transistor's stability, the S-parameter must be chosen. Transistor S-parameters can be compared with simulations using the data sheet available in the Appendix.

4.2.1 Comparison of S-Parameters for 2.4 GHz and 3.5 GHz Performances

Interference is less common at sub-6 GHz than it is at 2.4 GHz. The narrower bandwidth of the 2.4 GHz band may lead to increased interference and worsened signal quality, which could affect the RF power amplifier's performance. Table 4.1 shows the comparison of S-parameters for 2.4 GHz and 3.5 GHz performances based on the datasheet of selected transistors which are CG2H40025 and AM030WX-BI-R.

Table 4.1: Comparison of S-Parameters between 2.4 GHz and 3.5 GHz Based on Selected Transistors

Transistor	**CG2H40025 (GaN HEMT)**		**AM030WX-BI-R (GaAs pHEMT)**	
Frequency	**2.4 GHz**	**3.5 GHz**	**2.4 GHz**	**3.5 GHz**
S_{11}	0.929∠170.65°	0.934∠161.36°	0.855∠175.51°	0.830∠146.78°
S_{12}	0.013∠-2.99°	0.012∠8.26°	0.024∠8.13°	0.032∠1.01°
S_{21}	2.51∠45.57°	1.65∠26.26°	5.207∠55.76°	3.276∠20.61°
S_{22}	0.611∠-172.71°	0.681∠-179.44°	0.387∠-171.83°	0.398∠172.43°

4.2.2 Calculation Results of S-Parameters for 2.4 GHz Application

4.2.2.1 Transducer Gain, G_T

Calculation of transducer gain for CG2H40025:

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2}{|1-\Gamma_S\Gamma_L|^2|1-S_{22}\Gamma_L|^2}$$

= 21.6 dB

Calculation of transducer for AM030WX-BI-R:

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2}{|1-\Gamma_S\Gamma_L|^2|1-S_{22}\Gamma_L|^2}$$

= 16.84 dB

4.2.2.2 Noise Figure

Calculation of noise figure for CG2H40025:

NF = 10 log F

= 1.08 dB

Calculation of noise figure for AM030WX-BI-R:

NF = 10 log F

= 0.842 dB

4.2.2.3 Stability

Calculation of stability for CG2H40025:

$$K = \left(\frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|}\right) > 1$$

$= 0.927 < 1$

Calculation of stability for AM030WX-BI-R:

$$K = \left(\frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|}\right) > 1$$

$= 0.807 < 1$

The comparison of the calculation's results for the gain, noise figure, and stability of 2.4 GHz and 3.5 GHz for both transistors (CG2H40025 and AM030WX-BI-R) based on the S-parameters are tabulated in Table 4.2.

Table 4.2: Comparison of Calculation's Result between 2.4 GHz and 3.5 GHz Based on Selected Transistors

Transistor	**CG2H40025 (GaN HEMT)**		**AM030WX-BI-R (GaAs pHEMT)**	
Frequency	**2.4 GHz**	**3.5 GHz**	**2.4 GHz**	**3.5 GHz**
Gain, dB	21.6 dB	17.8 dB	16.84 dB	17.71 dB
Noise Figure, NF	1.08 dB	1.30 dB	0.842 dB	1.20 dB
Stability, K	0.927<1	1.35>1	0.807<1	1.15>1

The results show that the performance of 3.5 GHz is much better than 2.4 GHz. This is because 3.5 GHz has a high gain, low noise figure and in unconditional stable state.

4.2.3 Calculation and Simulation Results of S-Parameters for 3.5 GHz Application

The S-parameters from the simulation circuit, as shown in Figure 4.1, are used to determine the stability for the transistors CG2H40025 and AM030WX-BI-R.

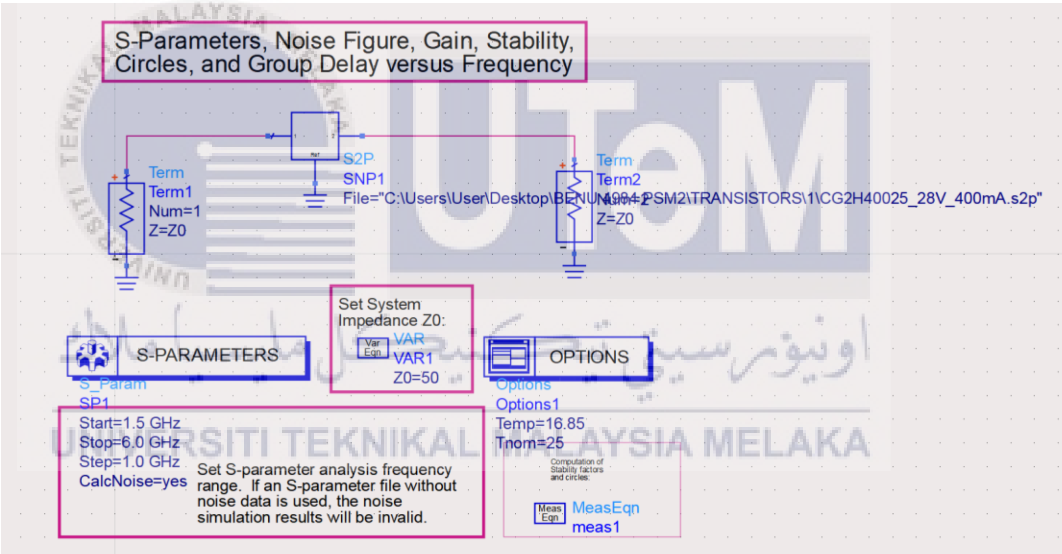


Figure 4.1: S-Parameter Simulation Circuit

4.2.3.1 Transducer Gain, G_T

Calculation of transducer gain for CG2H40025:

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2}{|1-\Gamma_S\Gamma_L|^2|1-S_{22}\Gamma_L|^2}$$

= 17.8 dB

Calculation of transducer for AM030WX-BI-R:

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2}{|1-\Gamma_S\Gamma_L|^2|1-S_{22}\Gamma_L|^2}$$

= 17.71 dB

4.2.3.2 Noise Figure

Calculation of noise figure for CG2H40025:

NF = 10 log F

= 1.30 dB

Calculation of noise figure for AM030WX-BI-R:

NF = 10 log F

= 1.20 dB

4.2.3.3 Stability

To investigate the stability of the transistor by identifying the stable and unstable regions, the S-parameters are required. The input matching network that maximizes the owner gain is also found using the transistor's S-parameters. A circuit simulation must be run to ascertain the S-parameters. The values of K and Δ can be used to determine the stability.

The stability factor calculation result is derived from the simulation outcome. The result is obtained by applying equations (4.1) and (4.2). The Rollet's Condition is obtained using equation (4.2), and the Auxilary Condition is obtained using equation (4.1).

Auxilary Condition,

$$\Delta = S_{11} \,.\, S_{22} - S_{12} \,.\, S_{21} \quad (4.1)$$

Rollet's Condition,

$$K = \left(\frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}||S_{21}|}\right) > 1 \quad (4.2)$$

Calculation of stability for CG2H40025:

$$K = \left(\frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|}\right) > 1$$

$= 1.35 > 1$

Calculation of stability for AM030WX-BI-R:

$$K = \left(\frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|}\right) > 1$$

$= 1.15 > 1$

The calculation result for stability factor obtain from the simulation above are as below. The calculations were calculated by using equation (4.1) and (4.2).

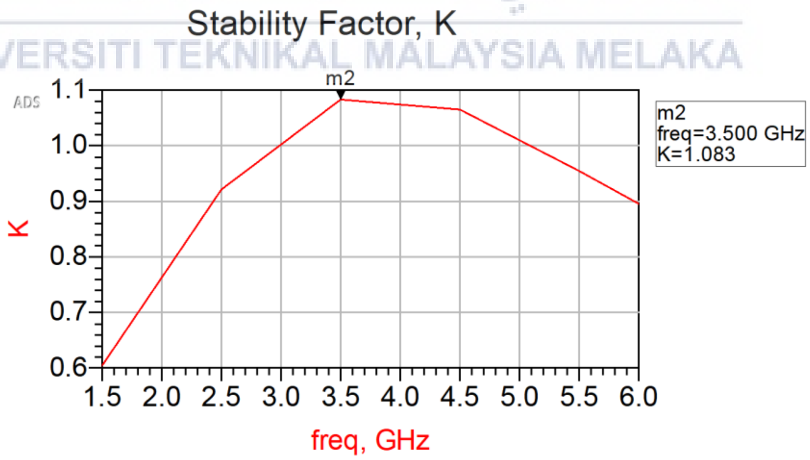


Figure 4.2: Simulatiation of Graph Stability Factor for CG2H40025

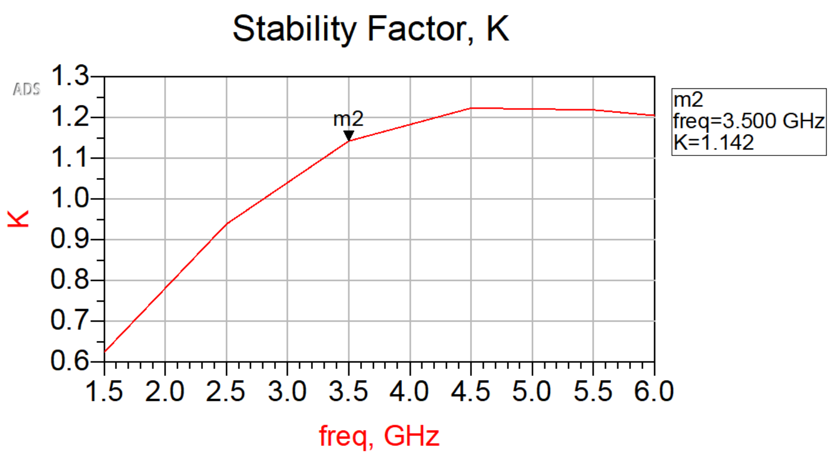


Figure 4.3: Simulation of Graph Stability Factor for AM030WX-BI-R

Table 4.3 shows the results of the calculation and simulation for both transistors by comparing the S-Parameters that included the transducer gain, noise figure and the stability.

Table 4.3: Comparison of S-Parameters between Calculation and Simulation Results for Both Transistors

Transistor	**CG2H40025 (GaN HEMT)**		**AM030WX-BI-R (GaAs pHEMT)**	
Parameters	**Calculation**	**Simulation**	**Calculation**	**Simulation**
Transducer Gain, G_T	17.8 dB	17.091 dB	17.71 dB	17.799 dB
Noise Figure, NF	1.30 dB	1.299 dB	1.20 dB	1.223 dB
Stability, K	1.35>1	1.083>1	1.15>1	1.142>1

Therefore, to meet the transistor's stability requirements, K needs to be bigger than 1 (K > 1). The simulation and calculation results shown that both transistors had reached the stable state, where K values are greater than 1.

However, the results for the transducer gain show for both transistors meet the requirements for the power amplifier specification but the GaAs pHEMT transistor (AM030WX-BI-R) has the most similar results for both calculation and simulation. Hence, the most suitable transistor for 3.5 GHz power amplifier design is GaAs pHEMT transistor (AM030WX-BI-R).

4.3 Input and Output matching Network

Every power amplifier design must include a matching network since it is crucial to avoid unnecessary power loss. Matching networks are often made to ensure that the impedance they look at is equivalent to the characteristic impedance, $Z_o = 50\Omega$. Consequently, to maximize the design circuit's power transfer, the input and output matching networks are crucial.

To determine the length and distance of the stub from the load, stub matching was employed in the amplifier design. A certain amount of calculation is required to determine the length and distance. It is necessary to determine the stub's length, l and distance, d from the load to construct the stub matching. Only the focal frequency, which is 3.5 GHz, will be used for calculation.

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \quad (4.3)$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \quad (4.4)$$

$C_1 = S_{11} - \Delta . S_{22}^*$ (4.5)

$C_2 = S_{22} - \Delta . S_{11}^*$ (4.6)

The Table 4.4 summarized the value of calculation for reflection coefficient, distances, and lengths of the stub at input and output matching for both transistors.

Table 4.4: Reflection Coefficient, Length and Distance of Stubs for Both Transistors

Transistor	**CG2H40025**		**AM030WX-BI-R**	
Parameter	Input Matching	Output Matching	Input Matching	Output Matching
Reflection Coefficient	1.501-j10.536	3.523+j1.345	2.159-j13.498	7.988+j7.599
Distance of Stub	2.7 mm	2.5 mm	2.5 mm	2.3 mm
Length of Stub	5.49 mm	5.9 mm	5.3 mm	5.6 mm

The value from the calculation is implemented in the circuit as in the Figure 4.4. The circuit is for single stub matching.

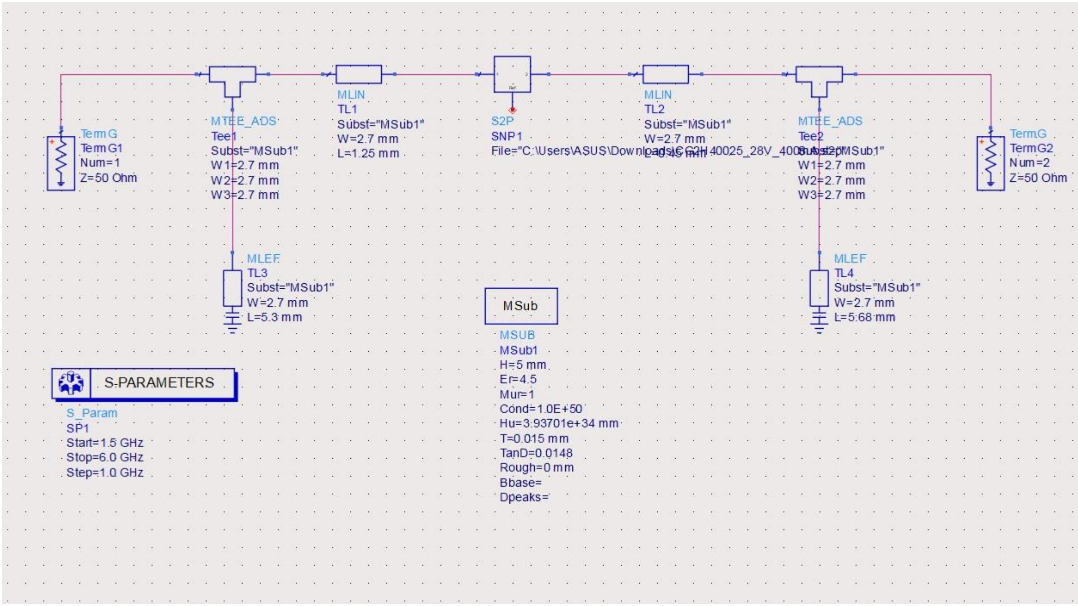


Figure 4.4: Schematic for Input and Output Matching Single Stub

4.4 DC Biasing

Finding the biasing point by using the ADS software's simulation is the first stage in constructing a single-stage power amplifier. Passive DC biassing will be used on both transistors because this project has a single stage architecture. To finish the biassing process when building the power amplifier, use the voltage divider consisting of R_1 and R_2. The voltage divider, which is derived from the drain voltage, creates a form of voltage feedback when R_3 is used. The power supply voltage (V_{DD}) for each design was set at 5.5V. As shown below are the values of R_1, R_2, and R_3:

where; $V_{DC} = 5.5V, V_{DS} = 4V, V_{GS} = 0.34V, I_{DS} = 60mA, I_{BB} = 2mA$

$$R_3 = \frac{V_{DC} - V_{DS}}{I_{DS}} = 25\Omega \qquad (4.7)$$

$$R_1 = \frac{V_{GS}}{I_{BB}} = 170\Omega \qquad (4.8)$$

$$R_3 = \frac{(V_{DS} - V_{GS})R_1}{V_{GS}} = 2170\Omega \qquad (4.9)$$

The following values and functions of the various elements that are added to the design to aid improve the PA are as follows (Table 4.5): Without these parts, the PA would not function correctly and will have a very high noise figure and extremely low gains. Examples of these elements are resistors and capacitors.

Table 4.5: Summary of DC Biasing Component

Component	**Value**	**Function**
C_2 and C_5	3.3 pF	Supply the matching network with a low impedance RF bypass
C_3 and C_6	10000pF	RF bypass capacitor with low frequency for R3 and R4 resistors
R_1	170Ω	Resistance used in voltage dividers
R_2	2170Ω	Resistance used in voltage dividers
R_3	25Ω	Maintain a constant drain current
R_4	50Ω	Boost stability at low frequencies
R_5	10000Ω	Enhance low frequency stability and give the gate current limitation

Figure 4.5 shows the design of a single stage PA with input and output matching and DC biasing. The SNP1 will put the S-parameter files (CG2H40025 and AM030WX-BI-R) in the circuit based on the transistors that are used.

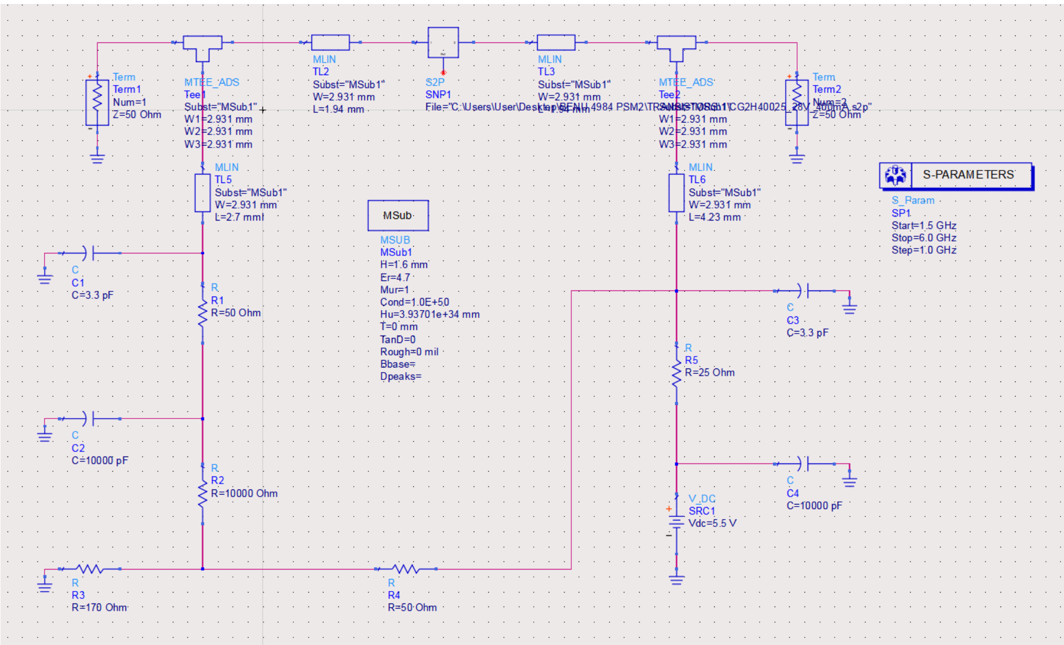
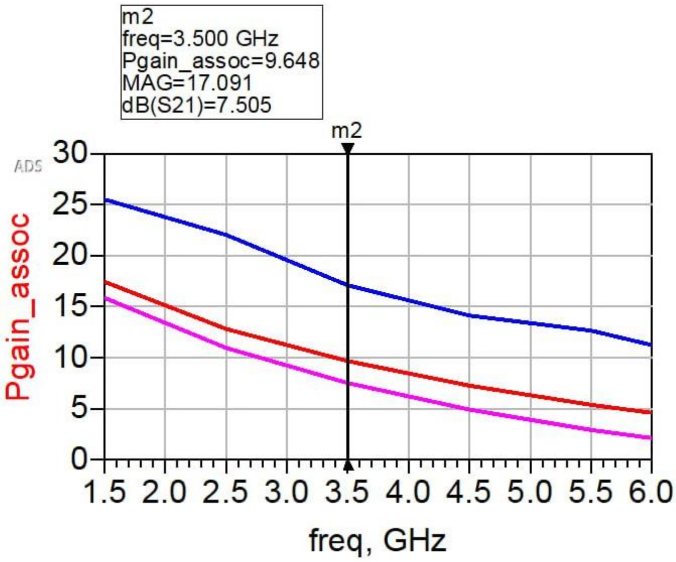
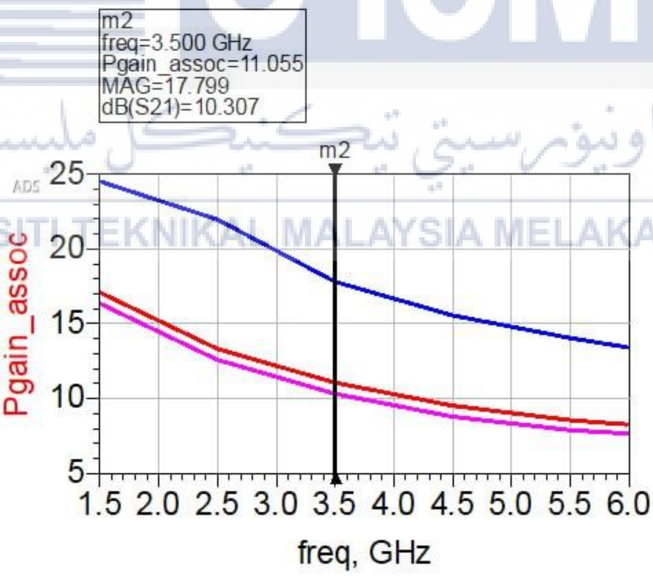


Figure 4.5: Single Stage Power Amplifier Design

Two transistors, CG2H40025 and AM030WX-BI-R, were used in this project. To construct the single stage PA, the DC biassing circuit will be added to the input and output matching circuit [21]. The design of the single stage PA is finished after the DC bias is added. To compare the gain and noise figure, the DC biasing was devised. Figure 4.6 below shows the single stage PA's (gain) for CG2H40025 and AM030WX-BI-R. For CG2H40025 and AM030WX-BI-R, the gain values are 17.091 dB and 17.799 dB, respectively.



(a) Transistor CG2H40025

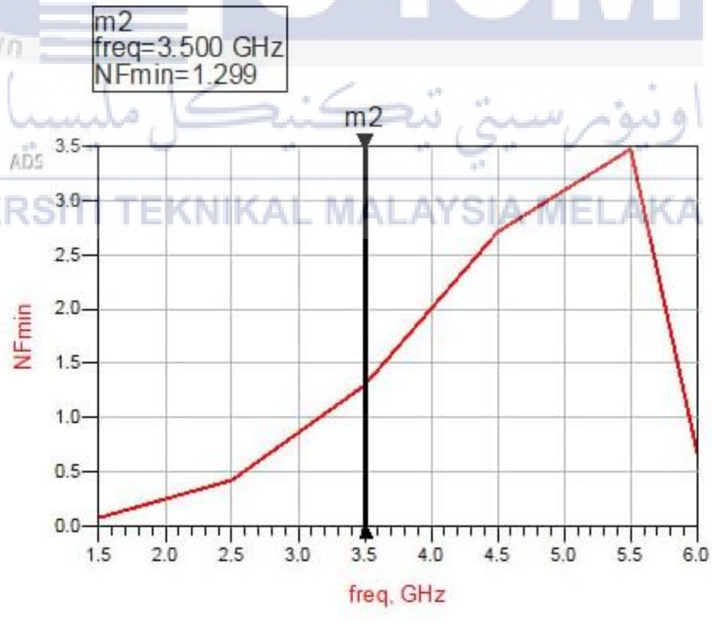


(a) Transistor AM030WX-BI-R

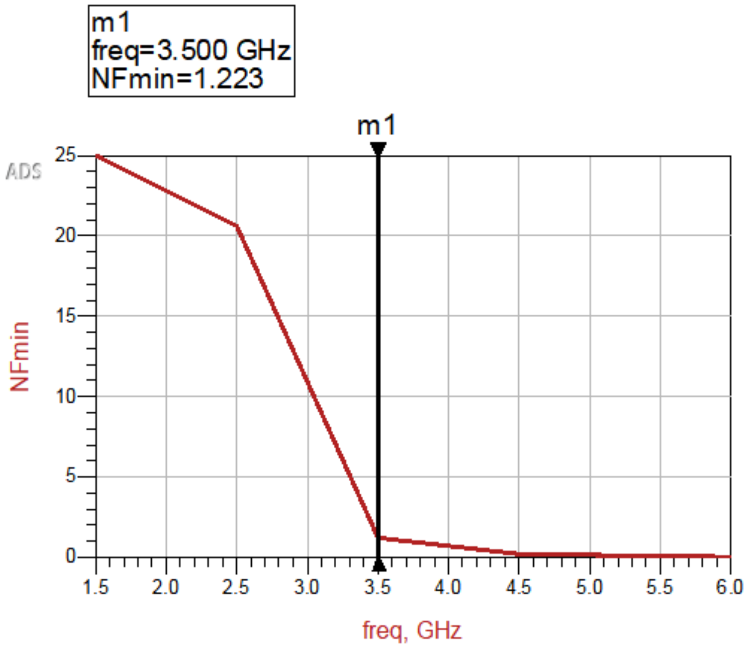
Figure 4.6: (a) Gain Analysis CG2H40025 (b) Gain Analysis AM030WX-BI-R

The results for the gain that obtained from the DC Biasing analysis show that transistor AM030WX-BIR-R I much greater than CG2H40025 which are 17.799 dB and 17.091 dB, respectively. As we know, the PA design need a high value of gain for it to give a better performance and well-functioning. A high gain PA also can boost the signal power significantly without distortion or degradation. Higher gain also enhances the signal level compared to any noise or interference that might be present. Hence, transistor AM030WX-BI-R has a better gain than CG2H40025.

Figure 4.7 shows the noise figure for the single stage PA (CG2H40025 and AM030WX-BI-R). The single stage CG2H40025 has a noise figure of 1.299 dB and AM030WX-BI-R with a noise figure of 1.223 dB.



(a) Transistor CG2H40025



(b) Transistor AM030WX-BI-R

Figure 4.7: (a) Noise Figure Ananlysis CG2H40025 (b) Noise Figure Analysis AM030WX-BI-R

The values for the gain will decrease while the values for noise figure will increase after DC bias are inserted in the design. This is normal because the added elements in DC Biasing will affect the overall performance of the transistor. The value of the noise figure for AM030WX-BI-R is lower which is 1.223 dB compared to CG2H40025 which is 1.299 dB. A low noise figure can give a better performance since PA is usually situated towards the end of the signal chain. It amplifies the signal that has already been processed and optimized. At this stage, the signal has ideally been amplified while keeping the noise figure level as low as possible.

Table 4.6: Comparison of S-Parameters between Calculation and Simulation Results for Both Transistors

Transistor	Parameters	Calculation	Simulation
CG2H40025 (Gan HEMT)	Transducer Gain, G_T	17.8 dB	17.091 dB
	Noise Figure, NF	1.30 dB	1.299 dB
	Stability, K	1.35>1	1.083>1
AM030WX-BI-R (GaAs pHEMT)	Transducer Gain, G_T	17.71 dB	17.799 dB
	Noise Figure, NF	1.20 dB	1.223 dB
	Stability, K	1.15>1	1.142>1

To meet the transistor's stability requirements, K needs to be bigger than 1 ($K > 1$). The simulation and calculation results shown that both transistors had reached the stable state, where K values are greater than 1.

However, the results for the transducer gain show for both transistors meet the requirements for the power amplifier specification but the GaAs pHEMT transistor (AM030WX-BI-R) has the most similar results for both calculation and simulation.

Transistor AM030WX-BI-R achieved high gain for both calculation and simulation which is 17.71 and 17.799 dB. The stability for transistor AM030WX-BI-R also reached the stable state, where K values are greater than 1 and has a low noise figure.

4.5 Project Significant/Impact

This proposed project is relevant to sustainability and environmentally friendly as for the sustainability impact, it develops more energy-effective amplifier designs that still match the performance standards of 5G networks. This project considers utilizing sustainable materials and manufacturing techniques.

For the environmental impact, the main goal should to create more power-saving amplifier designs that nevertheless match the performance specifications of 5G networks. It is also can limit the number of hazardous materials used in the production of PA and incorporate the usage of recycled resources.

Here is a summary of the project significance of power amplifier (PA) design for sub-6GHz at 3.5GHz for 5G applications, relating it to sustainability, environmental effects, and societal impacts:

1. **Sustainability Aspects**
    - The PA designed for high efficiency helps limit power consumption in 5G base stations, aligning with sustainable infrastructure goals by reducing electricity usage and enabling greener 5G networks.
    - Optimizing the PA design to efficiently utilize sub-6GHz bands like 3.5GHz facilitates widespread 5G coverage reach to drive inclusive connectivity - a key sustainable development priority.
2. **Environmental Effects**
    - High-efficiency PA design leads to lower overall power requirements in 5G networks. This helps reduce associated carbon emissions, minimizing the environmental footprint.

- Enabling wider 5G coverage reach with optimized sub-6GHz PA means less infrastructure and associated raw material usage. This leads to lower pollution related to setting up 5G base stations.

3. **Societal Effects**

- The reliable and low-latency connectivity enabled by efficient 5G PAs can empower several sectors like education, healthcare, agriculture and smart cities to enrich quality of life.
- Wider 5G coverage driven by optimized utilization of 3.5GHz band can bridge the digital divide by providing affordable connectivity options to underserved communities.

In summary, the advanced PA development contributes to sustainable 5G networks, reduces environmental impact, and enables social progress - highlighting the immense significance of this project across sustainability, ecological and social dimensions.

4.5.1 Sustainable Development Goals (SDG)

The Sustainable Development Goals, also known as the Global Goals, are a set of 17 goals that aim to address the global challenges and guide global development efforts to achieve a more sustainable and equitable world by 2030. For this project, there are some SDGs that involved such as:

(a) SDG 7: Affordable and Clean Energy

Increasing the power amplifiers energy efficiency can assist to lessen the infrastructure's carbon imprint and facilitate the switch to more cheap, clean energy.

(b) SDG 9: Industry, Innovation, and Infrastructure

Encourage industry innovation and contribute to the construction of more durable and sustainable infrastructure by creating more effective and environmentally friendly power amplifiers for 5G applications.

(c) SDG 11: Sustainable Cities and Communities

Reducing the energy consumption of various applications and promoting the growth of sustainable cities and communities can both be accomplished by increasing the energy efficiency of power amplifiers.

(d) SDG 13: Climate Action

Creating more effective and environmentally friendly power amplifiers for 5G applications.

(e) SDG 17: Partnership for the Goals

Government, business, and civil society must work together to build sustainable power amplifiers for 5G applications.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

Chapter five conclude all the information contains in this report and for the whole project. Besides, the future works to improve this project are explained clearly.

5.1 Conclusion

By the time the project ends, students ought to have gained experience and knowledge from it. They can also demonstrate their expertise and project-producing ideas. The learner should be able to comprehend the fundamentals of power amplifiers and how they are used. A PA’s primary purpose is to boost a signal's power level to a level appropriate for the intended use.

Consequently, the most important aspect of designing a PA is choosing the transistor. From there, stability, maximum gain, and matching network are found using the S-parameter at the operating frequency of 3.5 GHz. The findings of the gain, noise figure and stability were presented considering various characteristics of the PA.

When all the simulation work for both transistors was completed using the ADS, the results obtained by both transistors demonstrate that, in terms of gain, noise figure, and stability, transistor AM030WX-BI-R is performing better than transistor CG2H40025, which achieved high gain for both calculation which is 17.71 dB and simulation which is 17.799 dB. Moreover, the noise figure for the AM030WX-BI-R is lower which is 1.223 dB than CG2H40025 which is 1.299 dB. The stability for transistor AM030WX-BI-R is also had reached the unconditional stable state, where K value is greater than one (1.142>1).

Hence, the most suitable transistor for 3.5 GHz PA design is GaAs pHEMT transistor (AM030WX-BI-R) because it has a high gain, low noise figure and unconditional stable. To conclude, GaAs pHEMT transistor (AM030WX-BI-R) has a better performance compared to GaN transistor (CG2H40025).

5.2 Future Work

Theoretical research and practical domains are the two categories of future work pertaining to the issues and innovations covered in this project. The first covers all modelling, analysis, and extraction-related concerns, as well as certain simulation-related ones. On the other hand, the load pull technique can be used in PA design to find the load impedance needed to maximize efficiency. Moreover, the performances with other technologies also can be compared.

A practical test and fabrication of the power amplifier design will follow. The measurement's outcome and the simulation's outcome will be compared. It could be necessary to make certain design changes for manufacturing. The substrate type and biasing arrangement, for instance.

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APPENDICES

APPENDIX A

Wolfspeed. | A CREE COMPANY

CGH40025

25 W, RF Power GaN HEMT

Description

Cree's CGH40025 is an unmatched, gallium nitride (GaN) high electron mobility transistor (HEMT). The CGH40025, operating from a 28 volt rail, offers a general purpose, broadband solution to a variety of RF and microwave applications. GaN HEMTs offer high efficiency, high gain and wide bandwidth capabilities making the CGH40025 ideal for linear and compressed amplifier circuits. The transistor is available in a screw-down, flange package and solder-down, pill packages.

Package Types: 440196 & 440166
PN: CGH40025P & CGH40025F

Features

- Up to 6 GHz Operation
- 15 dB Small Signal Gain at 2.0 GHz
- 13 dB Small Signal Gain at 4.0 GHz
- 30 W typical P_{SAT}
- 62% Efficiency at P_{SAT}
- 28 V Operation

Applications

- 2-Way Private Radio
- Broadband Amplifiers
- Cellular Infrastructure
- Test Instrumentation
- Class A, AB, Linear amplifiers suitable for OFDM, W-CDMA, EDGE, CDMA waveforms

Large Signal Models Available for ADS and MWO

RoHS COMPLIANT

Rev 4.1 – March 2020

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Absolute Maximum Ratings (not simultaneous) at 25˚C Case Temperature

Parameter	Symbol	Rating	Units	Conditions
Drain-Source Voltage	V_{DSS}	120	Volts	25˚C
Gate-to-Source Voltage	V_{GS}	-10, +2	Volts	25˚C
Storage Temperature	T_{STG}	-65, +150	˚C	
Operating Junction Temperature	T_J	225	˚C	
Maximum Forward Gate Current	I_{GMAX}	7.0	mA	25˚C
Maximum Drain Current[1]	I_{DMAX}	3	A	25˚C
Soldering Temperature[2]	T_S	245	˚C	
Screw Torque	τ	40	in-oz	
Thermal Resistance, Junction to Case[3]	$R_{θJC}$	4.8	˚C/W	85˚C
Case Operating Temperature[3,4]	T_C	-40, +150	˚C	

Notes:
[1] Current limit for long term, reliable operation
[2] Refer to the Application Note on soldering at wolfspeed.com/RF/Document-Library
[3] Measured for the CGH40025F at P_{DISS} = 28 W
[4] See also, the Power Dissipation De-rating Curve on Page 6

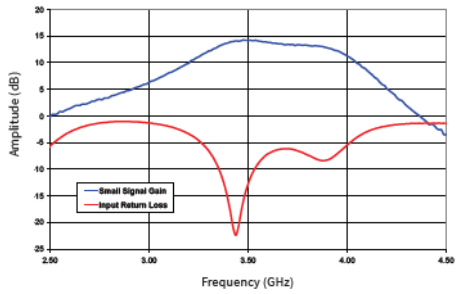
Electrical Characteristics (TC = 25˚C)

Characteristics	Symbol	Min.	Typ.	Max.	Units	Conditions
DC Characteristics[1]						
Gate Threshold Voltage	$V_{GS(th)}$	-3.8	-3.0	-2.3	V_{DC}	V_{DS} = 10 V, I_D = 7.2 mA
Gate Quiescent Voltage	$V_{GS(Q)}$	–	-2.7	–	V_{DC}	V_{DS} = 28 V, I_D = 250 mA
Saturated Drain Current	I_{DS}	5.8	7.0	–	A	V_{DS} = 6.0 V, V_{GS} = 2.0 V
Drain-Source Breakdown Voltage	V_{BR}	84	–	–	V_{DC}	V_{GS} = -8 V, I_D = 7.2 mA
RF Characteristics[2] (T_C = 25˚C, F_0 = 3.7 GHz unless otherwise noted)						
Small Signal Gain	G_{SS}	12	13	–	dB	V_{DD} = 28 V, I_{DQ} = 250 mA
Power Output[3]	P_{SAT}	20	30	–	W	V_{DD} = 28 V, I_{DQ} = 250 mA
Drain Efficiency[4]	η	55	62	–	%	V_{DD} = 28 V, I_{DQ} = 250 mA, P_{SAT}
Output Mismatch Stress	VSWR	–	–	10 : 1	Ψ	No damage at all phase angles, V_{DD} = 28 V, I_{DQ} = 250 mA, P_{OUT} = 25 W CW
Dynamic Characteristics						
Input Capacitance	C_{GS}	–	9.0	–	pF	V_{DS} = 28 V, V_{gs} = -8 V, f = 1 MHz
Output Capacitance	C_{DS}	–	2.6	–	pF	V_{DS} = 28 V, V_{gs} = -8 V, f = 1 MHz
Feedback Capacitance	C_{GD}	–	0.4	–	pF	V_{DS} = 28 V, V_{gs} = -8 V, f = 1 MHz

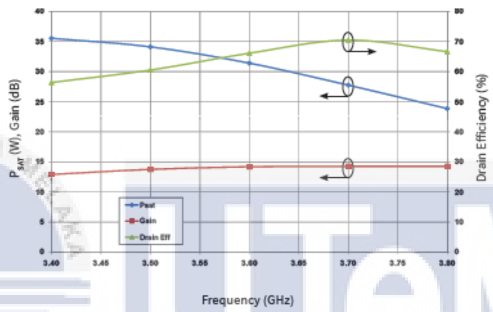
Notes:
[1] Measured on wafer prior to packaging
[2] Measured in CGH40025-AMP
[3] P_{SAT} is defined as I_G = 0.72 mA
[4] Drain Efficiency = P_{OUT} / P_{DC}

Typical Performance

Small Signal Gain and Return Loss vs Frequency
of the CGH40025F in the CGH40025-AMP

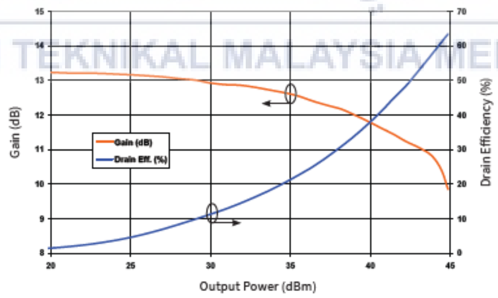


P_{SAT}, Gain, and Drain Efficiency vs Frequency of the
CGH40025F in the CGH40025-AMP
V_{DD} = 28 V, I_{DQ} = 250 mA

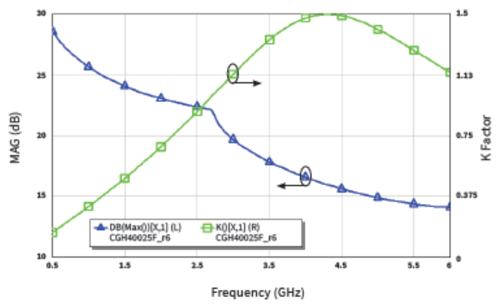


Typical Performance

Swept CW Data of CGH40025 vs. Output Power with Source
and Load Impedances Optimized for P_{SAT} Power in CGH40025-AMP
V_{DD} = 28 V, I_{DQ} = 250 mA, Freq = 3.7 GHz



Maximum Available Gain and K Factor of the CGH40025
V_{DD} = 28 V, I_{DQ} = 250 mA



Typical Package S-Parameters for CGH40025
(Small Signal, V_{DS} = 28 V, I_{DQ} = 400 mA, angle in degrees)

Frequency	Mag S11	Ang S11	Mag S21	Ang S21	Mag S12	Ang S12	Mag S22	Ang S22
500 MHz	0.924	-159.12	12.64	91.13	0.015	8.27	0.485	-163.72
600 MHz	0.923	-163.56	10.58	87.23	0.015	5.84	0.491	-165.34
700 MHz	0.923	-166.92	9.08	83.86	0.015	3.96	0.497	-166.41
800 MHz	0.923	-169.60	7.95	80.83	0.015	2.43	0.502	-167.13
900 MHz	0.923	-171.82	7.06	78.03	0.015	1.16	0.508	-167.65
1.0 GHz	0.923	-173.72	6.34	75.40	0.015	0.08	0.514	-168.05
1.1 GHz	0.923	-175.39	5.75	72.89	0.015	-0.84	0.520	-168.36
1.2 GHz	0.924	-176.88	5.26	70.48	0.015	-1.62	0.526	-168.63
1.3 GHz	0.924	-178.24	4.84	68.15	0.015	-2.29	0.533	-168.88
1.4 GHz	0.924	-179.50	4.48	65.89	0.015	-2.85	0.539	-169.13
1.5 GHz	0.925	179.33	4.17	63.68	0.014	-3.31	0.546	-169.38
1.6 GHz	0.925	178.22	3.89	61.52	0.014	-3.67	0.553	-169.65
1.7 GHz	0.926	177.17	3.65	59.41	0.014	-3.93	0.560	-169.94
1.8 GHz	0.926	176.16	3.43	57.34	0.014	-4.09	0.568	-170.26
1.9 GHz	0.927	175.18	3.24	55.30	0.014	-4.16	0.575	-170.60
2.0 GHz	0.927	174.24	3.07	53.29	0.014	-4.13	0.582	-170.97
2.1 GHz	0.928	173.32	2.91	51.32	0.013	-4.00	0.589	-171.36
2.2 GHz	0.928	172.41	2.76	49.38	0.013	-3.76	0.597	-171.79
2.3 GHz	0.929	171.53	2.63	47.46	0.013	-3.43	0.604	-172.24
2.4 GHz	0.929	170.65	2.51	45.57	0.013	-2.99	0.611	-172.71
2.5 GHz	0.929	169.79	2.40	43.71	0.013	-2.44	0.618	-173.22
2.6 GHz	0.930	168.93	2.30	41.87	0.013	-1.79	0.625	-173.75
2.7 GHz	0.930	168.08	2.20	40.05	0.012	-1.04	0.632	-174.30
2.8 GHz	0.931	167.24	2.12	38.26	0.012	-0.18	0.638	-174.87
2.9 GHz	0.931	166.40	2.04	36.48	0.012	0.77	0.645	-175.47
3.0 GHz	0.932	165.56	1.96	34.73	0.012	1.82	0.651	-176.08
3.2 GHz	0.932	163.88	1.82	31.28	0.012	4.18	0.663	-177.37
3.4 GHz	0.933	162.20	1.70	27.91	0.012	6.83	0.675	-178.72
3.6 GHz	0.934	160.51	1.60	24.60	0.012	9.69	0.686	179.86
3.8 GHz	0.934	158.80	1.51	21.35	0.012	12.64	0.696	178.39
4.0 GHz	0.935	157.07	1.42	18.16	0.013	15.58	0.706	176.88
4.2 GHz	0.935	155.32	1.35	15.01	0.013	18.40	0.715	175.31
4.4 GHz	0.935	153.53	1.29	11.91	0.014	21.01	0.723	173.70
4.6 GHz	0.935	151.70	1.23	8.84	0.014	23.33	0.730	172.05
4.8 GHz	0.935	149.84	1.17	5.80	0.015	25.32	0.737	170.36
5.0 GHz	0.935	147.93	1.13	2.79	0.016	26.96	0.743	168.63
5.2 GHz	0.935	145.98	1.09	-0.20	0.017	28.24	0.749	166.86
5.4 GHz	0.935	143.97	1.05	-3.19	0.018	29.16	0.754	165.05
5.6 GHz	0.934	141.91	1.01	-6.16	0.020	29.75	0.759	163.20
5.8 GHz	0.934	139.78	0.98	-9.14	0.021	30.02	0.763	161.30
6.0 GHz	0.933	137.58	0.96	-12.12	0.023	29.99	0.767	159.35

To download the s-parameters in s2p format, go to the CGH40025 Product page and click on the documentation tab.

Product Ordering Information

Order Number	Description	Unit of Measure	Image
CGH40025F	GaN HEMT	Each	
CGH40025P	GaN HEMT	Each	
CGH40025F-AMP	Test board with GaN HEMT installed	Each	

APPENDIX B

AMCOM COMMUNICATIONS
The RF Power House

Ceramic Packaged GaAs Power pHEMT
DC-10 GHz

AM030WX-BI-R
AM030WX-BI-G-R
December 2014
Rev 2

DESCRIPTION

AMCOM's AM030WX-BI-R is a discrete GaAs pHEMT that has a total gate width of 3.0mm. It is in a ceramic BI package for operating up to 10 GHz.The BI package uses a specially designed ceramic package with bent (BI-G) or straight (BI) leads in a drop-in mounting style. The flange at the bottom of the package serves simultaneously as DC ground, RF ground, and thermal path. This part is RoHS compliant.

FEATURES

- High Frequency Operation up to 10 GHz
- Gain=14dB, P_{1dB}=33dBm, Eff = 46% @ 4GHz
- Surface Mountable
- Bottom ground for Effective Heat Removal

APPLICATIONS

- Wireless Local Loop
- Driver Amplifier
- Cellular Radio
- Repeaters
- C-Band VSAT
- Radar

RF PERFORMANCE

Load pull @ 4 GHz, (V_{ds} = 8V, I_{ds} = 450mA)

Parameters	MIN	TYP
P_{1dB}* (dBm)	32	33
Eff @ P_{1dB}	-	46%
P_{3dB}* (dBm)	33	34
Eff @ P_{3dB}	-	51%
Small Signal Gain (dB)	12	14
IP3 (dBm)	-	41

* Power typically remains the same as frequency changes.

ABSOLUTE MAXIMUM RATING

Parameters	Symbol	Rating
Drain-Source Voltage (V)	V_{ds}	10
Gate-Source Voltage (V)	V_{gs}	-5
Drain Current (mA)	I_{ds}	1080
Continuous Dissipation At Room Temp. (W)	P_t	5.5
Operating Temp. (°C)	T_A	-55 to +85
Max. Channel Temp. (°C)	T_{ch}	+175

DC PARAMETERS

Parameters	Conditions	MIN	TYP	MAX
Saturation Current I_{dss} (mA)	V_{ds}=3V, Vgs=0V	720	900	1080
Pinch-off Voltage V_p (V)	V_{ds}=3V, Ids=2.5% Idss	-1.6	-1.2	-0.8
Drain to Gate Breakdown Voltage BV_{gd} (V)	I_{dg} = 3mA	15	20	
Thermal Resistance (°C/W)			28	

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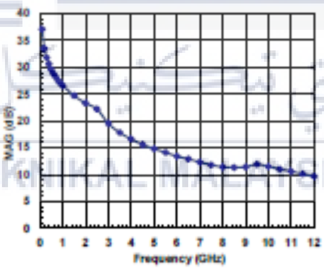
http://www.amcomusa.com
Tel. (301) 353-8400 Fax. (301) 353-8401
401 Professional Drive, Gaithersburg, MD 20879

S-Parameters for AM030WX-BI-R. Vds = 8V, Vgs = -0.8V, Ids = 450mA *

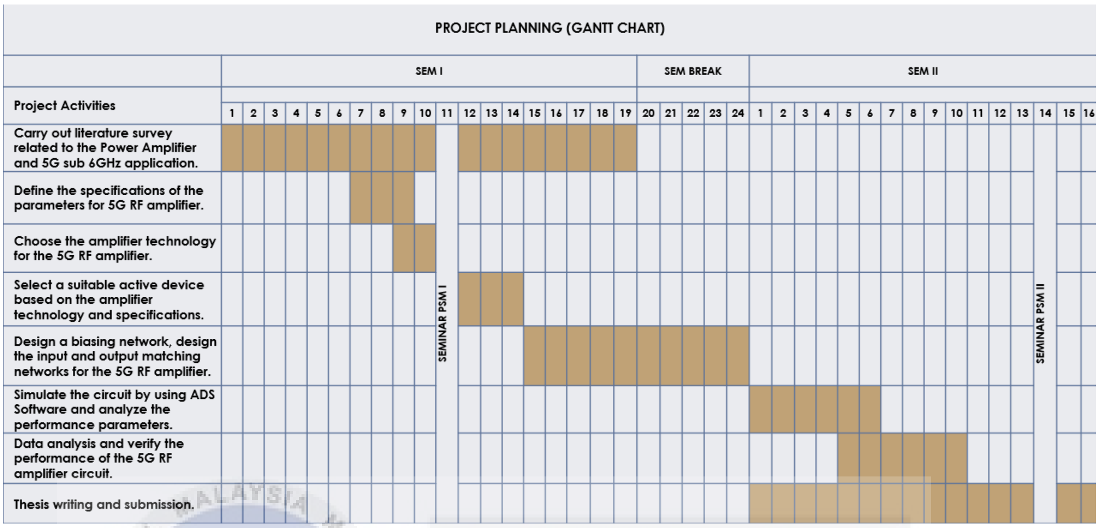
Freq(GHz)	MAG(S11)	ANG(S11)	MAG(S21)	ANG(S21)	MAG(S12)	ANG(S12)	MAG(S22)	ANG(S22)
0.1	0.977	-41.89	36.728	154.48	0.007	62.93	0.196	-82.52
0.2	0.941	-69.87	30.709	139.22	0.014	51.87	0.246	-104.28
0.3	0.913	-93.26	25.573	126.17	0.017	42.37	0.287	-122.13
0.4	0.895	-112.08	21.32	115.31	0.018	34.43	0.318	-136.08
0.5	0.884	-126.32	17.95	106.67	0.02	28.04	0.34	-146.12
0.6	0.883	-135.98	15.463	100.23	0.02	23.22	0.352	-152.26
0.7	0.88	-143.5	13.549	95.03	0.021	20.24	0.359	-156.87
0.8	0.875	-149.81	12.043	90.35	0.021	17.59	0.369	-160.43
0.9	0.874	-155.34	10.795	86.04	0.022	15.23	0.378	-163.31
1	0.871	-159.83	9.767	82.27	0.022	13.9	0.381	-165.46
1.5	0.864	-175.35	6.623	66.44	0.023	8.37	0.39	-171.57
2	0.855	175.51	5.207	55.76	0.024	8.13	0.387	-171.83
2.5	0.845	166.16	4.309	43.63	0.026	5.83	0.39	-175.58
3	0.837	156.67	3.727	31.72	0.029	3.75	0.394	179.82
3.5	0.827	147.27	3.327	19.87	0.031	1.35	0.395	175.34
4	0.819	137.57	3.01	7.86	0.035	-1.91	0.399	169.88
4.5	0.809	127.57	2.782	-4.21	0.039	-5.94	0.396	164.69
5	0.797	117.71	2.603	-16.32	0.043	-10.21	0.396	159.11
5.5	0.78	106.91	2.485	-29.1	0.049	-15.91	0.387	153.54
6	0.759	94.76	2.413	-42.5	0.057	-23.4	0.373	147.32
6.5	0.736	80.17	2.373	-57.23	0.066	-32.48	0.353	140.14
7	0.712	62.41	2.345	-73.35	0.076	-43.58	0.325	130.64
7.5	0.7	42.02	2.289	-90.82	0.086	-56.07	0.293	117.24
8	0.707	20.97	2.201	-108.48	0.096	-69.81	0.259	98.83
8.5	0.734	0.67	2.078	-126.54	0.104	-84.08	0.233	72.6
9	0.77	-17.13	1.927	-144.34	0.109	-98.9	0.228	39.4
9.5	0.812	-32.99	1.767	-161.93	0.112	-113.58	0.261	4.73
10	0.848	-48.45	1.593	-179.26	0.113	-127.76	0.322	-24.11
10.5	0.879	-63.55	1.408	163	0.111	-142.16	0.402	-47.41
11	0.902	-78.83	1.217	145.34	0.107	-156.72	0.494	-67.63
11.5	0.924	-93.53	1.027	128.3	0.1	-171.76	0.58	-84.19
12	0.938	-106.81	0.852	112.9	0.092	174.6	0.657	-98.32

* S2P file downloadable from the web : http://www.amcomusa.com/products/rftrans.html

Maximum Available Gain (8V,450mA)



APPENDIX C


PROJECT PLANNING (GANTT CHART)
SEM I
SEM BREAK
SEM II
Project Activities
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Carry out literature survey related to the Power Amplifier and 5G sub 6GHz application.
Define the specifications of the parameters for 5G RF amplifier.
Choose the amplifier technology for the 5G RF amplifier.
Select a suitable active device based on the amplifier technology and specifications.
Design a biasing network, design the input and output matching networks for the 5G RF amplifier.
Simulate the circuit by using ADS Software and analyze the performance parameters.
Data analysis and verify the performance of the 5G RF amplifier circuit.
Thesis writing and submission.
SEMINAR PSM I
SEMINAR PSM II