THE UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

DESIGN OF RF POWER AMPLIFIERS BY USING ARTIFICIAL NEURAL NETWORK METHODS

MASTER THESIS

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I hereby declare that all the information in this study I presented as my Master's Thesis, called "DESIGN OF RF POWER AMPLIFIERS BY USING ARTIFICIAL NEURAL NETWORK METHODS" has been presented in accordance with the academic rules and ethical conduct. I also declare and certify on my honor that I have fully cited and referenced all the sources I made use of in this present study.

Qutaiba Madhat Faris AL-AZZAWI

20. 12. 2017

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS iv
TABLE OF CONTENTS v
LIST OF FIGURES vii
LIST OF TABLES x
LIST OF ABBREVIATIONS xi
ABSTRACT xiii
ÖZET xiv
CHAPTER ONE 1
INTRODUCTION 1
1.1 Power Amplifier Classes 1
1.2 Power Amplifier Performance Parameters 3
1.2.1 Gain 4
1.2.2 Output power 5
1.2.3 Efficiency 5
1.2.4 Drain efficiency 6
1.2.5 Power added efficiency 6
1.2.6 Total efficiency 7
1.2.7 Linearity 7
1.2.8 1dB compression point 7
1.2.9 Noise figure 8
1.2.10 Noise resistor 9
1.3 Design Considerations 9
1.4 Research Problem 10
1.5 Thesis Structure 12
CHAPTER TWO 14
LITERATURE SURVEY 14
2.1 Preface of Power Amplifier Categories 14
2.2 RF Power Amplifiers for Different Applications 15
2.3 Artificial Neural Networks of RF Amplifiers 19
CHAPTER THREE 22
METHODOLOGY BASED ON ARTIFICIAL NEURAL NETWORK 22
3.1 Introduction 22
3.2 Characteristics of Transistor in MATLAB 24
3.3 Stability Testing 24
3.4 The Bode Plot for Design 25
3.5 Analysis Our Circuit Using S-Parameters Method 26
3.6 Matching Impedance and Optimization Method 26
3.7 Output Power and Power Add Efficiency 28
3.8 Artificial Neural Networks 29
3.8.1 Artificial neural cell 31
3.9 Types of Neural Networks 33

3.9.1 Multilayer perceptron neural network 33
3.9.2 Radial based function neural network 35
3.9.3 Generalized regression neural network 36
3.10 Using Different Neural Network Models for Estimation Our Design 38
CHAPTER FOUR 40
SIMULATION RESULT AND DISCUSSION 40
4.1 Design and Modeling RF Power Amplifier with Discussion Results............. 40
4.1.1 Design considerations using MATLAB 40
4.1.2 The design of the RF power amplifier at 450 MHz using MATLAB 40
4.1.2.1 Transistor 41
4.1.2.2 The characteristic of MOSFET in MATLAB.................................... 41
4.1.2.3 Stability test of our circuit 42
4.1.2.4 Amplification test for our circuit 44
4.1.2.5 Frequency response or bode plot 45
4.1.2.6 Matching circuit.. 46
4.1.2.7 S-parameters 49
4.1.2.8 Gain... 53
4.1.2.9 Output Power 55
4.1.2.10 Power add efficiency 57
4.2 Simulation results for test data of an S-parameter using MLP 62
4.3 Simulation Results for Test Data of S-Parameter Using RBF 68
4.4 Simulation Results for 010168 Power Amplifier of S-Parameter Using MLP 74
4.5 Simulation Results for 010168 Power Amplifier of S-Parameter Using RBF 80
4.6 Simulation Results for Input and DC Power Using GRNN............................ 85
4.7 Simulation Results for Input and DC Power Using RBF 88
CHAPTER FIVE.. 91
CONCLUSION AND FUTURE WORK 91
REFERENCES.. 93
APPENDICES 98
APPENDIX A.1 99
APPENDIX A.2 101
APPENDIX A.3 103
CURRICULUM VITAE.. 104
EDUCATION 104

LIST OF FIGURES

Figure 1.1: Characteristics of I-V linear power amplifier [2]............................. 2
Figure 1.2: 1dB compression point for RF amplifier [8]..................................... 8
Figure 3.1: Block diagram for using MATLAB and ADS for design RF amplifier. 23
Figure 3.2: DC load line for NMOSFET transistor [37]. 24
Figure 3.3: The regions of operation for transistor [38]. 25
Figure 3.4: The analysis of frequency response for design 25
Figure 3.5: Scattering method analysis [39]. 26
Figure 3.6: Matching circuit for NMOSFET [40]. 27
Figure 3.7: Artificial neural network representation [42]................................. 29
Figure 3.8: Biological nerve cell [43]. 30
Figure 3.9: Simple sensor model [44].. 31
Figure 3.10: The structure of MLPNN [46].. 34
Figure 3.11: Comparing the result of summing and activation function [46]. .. 34
Figure 3.12: Different types of activation function in MLPNN [46]. 34
Figure 3.13: RBFNN structure [47]. 35
Figure 3.14: The important equations inside hidden layer and output in RBF [47]... 36
Figure 3.15: The structure of GRNN [48]. 37
Figure 3.16: Our procedure for different models of neural network 39
Figure 4.1: The IV characteristics circuit of RF power amplifier 41
Figure 4.2: MOSFET transistor characteristics 42
Figure 4.3: The stability circuit of power amplifier 43
Figure 4.4: The result of stability test 43
Figure 4.5: Test the amplification of our circuit.. 44
Figure 4.6: Amplification result of our circuit... 45
Figure 4.7: The circuit for bode plot (frequency response) for our design........ 46
Figure 4.8: The frequency response result... 46

Figure 4.9: Matching impedance for input, output port 47
Figure 4.10: Noise figure in circuit before optimization method 48
Figure 4.11: Transducer gain in circuit before optimization method 48
Figure 4.12: The magnitude of S_{21} before optimization 49
Figure 4.13: The magnitude of S_{11} before optimization 50
Figure 4.14: The magnitude of S_{22} before optimization 50
Figure 4.15: The magnitude of S_{12} before optimization 50
Figure 4.16: The magnitude of S_{21} after optimization 51
Figure 4.17: The magnitude of S_{11} after optimization 51
Figure 4.18: The magnitude of S_{22} after optimization 52
Figure 4.19: The magnitude of S_{12} after optimization 52
Figure 4.20: Noise figure after optimization method 53
Figure 4.21: The relationship between transducer gain and noise figure during optimization 54
Figure 4.22: The gain of the power amplifier after optimization method 54
Figure 4.23: The circuit with a spectrum analyzer to find the output power..... 56
Figure 4.24: The power spectral density of our circuit..................................... 57
Figure 4.25: Spectrum analyzer took automatically output power 57
Figure 4.26: The final circuit for our design in ADS with the same magnitudes after optimization 58
Figure 4.27: The relationship between input power and output power at 1dB compression point 59
Figure 4.28: Power add efficiency at 1dB compression point........................... 59
Figure 4.29: The final circuit after optimization method in MATLAB 61
Figure 4.30: The MLP model for test data for our proposed work.................... 63
Figure 4.31: The magnitude of S_{11} [dB] 64
Figure 4.32: The angle of S_{11} [deg] 64
Figure 4.33: The magnitude of S_{21} [dB] 65
Figure 4.34: The angle of S_{21}... 65
Figure 4.35: The magnitude of S_{12} [dB] 66
Figure 4.36: The angle of S_{12}... 66
Figure 4.37: The magnitude of S_{22} [dB] 67
Figure 4.38: The angle of S_{22}... 67
Figure 4.39: The RPF model for test data for our proposed work..................... 68
Figure 4.40: The magnitude of S_{11} [dB] 68

Figure 4.41: The angle of S_{11} [deg] 69
Figure 4.42: The magnitude of S_{21} [dB] 69
Figure 4.43: The angle of S_{21} [deg] 70
Figure 4.44: The magnitude of S_{12} [dB] 70
Figure 4.45: The angle of S_{12} [deg] 71
Figure 4.46: The magnitude of S_{22} [dB] 71
Figure 4.47: The angle of S_{22} [deg] 72
Figure 4.48: The MLPNN for 010168 power amplifier testing 75
Figure 4.49: The magnitude of S_{11} [dB] 76
Figure 4.50: The angle of S_{11} [deg] 76
Figure 4.51: The magnitude of S_{21} [dB] 77
Figure 4.52: The angle of S_{21} [deg] 77
Figure 4.53: The magnitude of S_{12} [dB] 78
Figure 4.54: The angle of S_{12} [deg] 78
Figure 4.55: The magnitude of S_{22} [dB] 79
Figure 4.56: The angle of S_{22} [deg] 79
Figure 4.57: The RBF model for 010168 power amplifiers 80
Figure 4.58: The magnitude of S_{11} [dB] 80
Figure 4.59: The angle of S_{11} [deg] 81
Figure 4.60: The magnitude of S_{21} [dB] 81
Figure 4.61: The angle of S_{21} [deg] 82
Figure 4.62: The magnitude of S_{12} [dB] 82
Figure 4.63: The angle of S_{12} [deg] 83
Figure 4.64: The magnitude of S_{22} [dB] 83
Figure 4.65: The angle of S_{22} [deg] 84
Figure 4.66: The model of GRNN for output testing 86
Figure 4.67: The predicted output power using GRNN model 87
Figure 4.68: The RBF model for output testing 88
Figure 4.69: The predicted output power using the RBF model 88
Figure 4.70: Algorithm for our proposed work based on ANN 90

LIST OF TABLES

Table 4.1: Initial magnitudes for all elements for BPF 48
Table 4.2: Magnitudes the input matching circuit elements 49
Table 4.3: magnitudes the output matching circuit elements..49
Table 4.4: The magnitudes of S-parameters for power amplifier before optimization...51
Table 4.5: The magnitudes of S-parameters for power amplifier after optimization......52
Table 4.6: Test our circuit with respect to S-parameters for different frequency 60
Table 4.7: The results test for data using MLPNN 72
Table 4.8: The results for test data using RBFNN..73
Table 4.9: The comparison between MLP and RBF results 73
Table 4.10: Some samples of S-parameters for 010168 power amplifiers 74
Table 4.11: Testing 010168 power amplifier using MLP 84
Table 4.12: Testing 010168 power amplifier using RBF..85
Table 4.13: Comparison of MLP and RBF results..85
Table 4.14: The predicted output power as compared with real output power...............86
Table 4.15: The predicted output power as compared with real output power using GRNN neural network 87
Table 4.16: The predicted output power as compared with real output power using RBF neural network 89
Table 4.17: Comparison between GRNN and RBFNN 89

LIST OF ABBREVIATIONS

PA	: Power Amplifier
RF	: Radio Frequency
GT	: Transducer Gain
GP	: Operation Power Gain
GA	: Available Power Gain
PAE	: Power Add Efficiency
NF	: Noise Figure
SNR	: Signal to Noise Ratio
KNNs	: Knowledge-based Neural Network
MLPNN	: Multilayer Perceptron Neural Network
RBFNN	: Radial Based Function Neural Network
GRNN	: Generalized Regression Neural Network
AM	: Amplitude Modulation
SSP	: Single-Sideband Modulation
QAM	: Quadrate Amplitude Modulation
FM	: Frequency Modulation
FET	: Field Effect Transistor
TWT	: Power Output of Ideal Cycle
MTBE	: Mean Time Between Failures
MACOM	: Company of RF Components
ACLR	: Adjacent Channel Leakage Ratio
ADS	: Advance Design System
ANN	: Artificial Neural Network
FMCW	: Frequency Modulation Continuous Wave
MIT	: Modulated Intermediate Target
CMOS	: Complementary Metal Oxide Semiconductor
LDMOS	: Laterally Diffused Metal Oxide Semiconductor
OFDM	: Orthogonal Frequency-Division Multiplexing
GaN	: Gallium Nitride
RFID	: Radio-Frequency Identification
BICMOS	: Bipolar Complementary Metal Oxide
GaN HEMT	: Gallium Nitride High Electron Mobility Transistor
UHF	: Ultra High Frequency
GaAs HEMT	: Gallium Arsenide High Electron Mobility Transistor
LDMS	: Labour Department Management System
LDCS	: Labour Department Complementary System
ISM	: Industrial, Scientific and Medical
InPDHBT	: Indium Phosphide Double Heterojunction Bipolar Transistor
SiGeHBT	: Silicon Germanium Heterojunction Bipolar Transistor
SS-PPA	: Single Stage Pulse Power Amplifier
PRF	: Pulse Repetition Frequency

TSMC : Taiwan Semiconductor Manufacturing Company
AM/AM : Amplitude Modulation to Amplitude Modulation
AM/PM : Amplitude Modulation to Phase Modulation
RVTDNN : Real-Valued Time Neural Network
FPGA : Field-programmable Gate Array
BP : Back propagation
NMOSFET : N-type of Metal Oxide Semiconductor
MWO : Microwave Office
PSD : Power Spectral Density
S-PS : Convert Simulink Input to Physical Signal
PSS : physical to simulink signal block
RSME : Root Mean Square Error
MAE : Mean Absolute Error
3D GPR : Three Dimension Ground Penetrating Radar
OP AMP : Operational Amplifier
IMD : Intermediation Distortion
TOI : Third Order Intercept Point
PWM : Pulse Width Modulation

ABSTRACT

DESIGN OF RF POWER AMPLIFIERS BY USING ARTIFICIAL NEURAL NETWORK METHODS

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In this thesis, different artificial neural network models for a designed class AB power amplifier are presented. The presented amplifier was designed using MATLAB together with the Advance Design System (ADS) at 450 MHz operating frequency with greater than 10 dB transducer gain and 27.8 dBm of 1dB compression point. The obtained power added efficiency (PAE) was 33.6% under 15 dBm input power. The magnitudes of all elements of the presented amplifier were determined by using optimization methods in MATLAB. V_{DS}, I_{DS} and frequency values were considered as input variables and S-parameters were considered as output variables in the proposed MLP and RBF models. The presented neural network models can perform the task of the proposed class AB power amplifier as a block which can be applied in circuit design. The obtained results show a good agreement between measured and predicted magnitudes especially using the RBF model. Generalized regression neural network (GRNN) is a new method used in this field to estimate the output power using input RF power and direct current (DC) power as input variables. The results using GRNN were found to be promising and can be used instead of Radio Frequency (RF) amplifiers as a block in high frequency circuit design.

Keywords: Artificial neural network, MLP, RBF, GRNN, power amplifier.

ÖZET

YAPAY SİNİR AĞI YÖNTEMLERİ KULLANILARAK RF GÜÇ YÜKSELTEÇLERİNİN TASARIMI

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Bu tezde, tasarlanmış bir sınıf AB güç yükselteci için farklı yapay sinir ağı modelleri sunulmuştur. 450 MHz çalışma frekansında, 10 dB'den daha fazla kazanca ve 1 dB sıkıştırma noktasında 27.8 dBm'lik çıkış gücüne sahip olan yükselteç, ADS programı yardımıyla MATLAB kullanılarak tasarlandı. Yükselteç için güç ekli verimlilik (PAE), 15 dBm giriş gücü altında 33.6 % olarak elde edilmiştir. Sunulan yükseltecin tüm bileşenlerinin büyüklükleri MATLAB'de opitimizasyon metodları kullanılarak elde edilmiştir. Önerilen MLP ve RBF modellerinde V_{DS}, I_{DS} ve frekans değerleri giriş değişkenleri olarak ve S-parametreleri ise çıkış değişkenleri olarak kullanılmıştır. Sunulan sinir ağı modelleri, önerilen AB sınıfı güç yükseltecinin görevini görecek bir blok olarak devre tasarımında uygulanabilir. Elde edilen sonuçlar, özellikle RBF modeli kullanıldığı durumda ölçülen ve tahmin edilen büyüklükler arasında oldukça iyi bir uyum olduğunu göstermektedir. Genelleştirilmiş regresyon sinir ağı (GRNN) RF giriş gücü ve doğru akım (DC) gücünü giriş değişkenleri alarak çıkış gücünü tahmin etmek üzere bu alanda kullanılan yeni bir metottur. GRNN kullanılarak elde edilen sonuçlar ümit verici bulunmuştur ve yüksek frekans devre tasarımında RF güç yükselteçleri yerine blok olarak kullanılabileceği düşünülmektedir.

Anahtar Kelimeler: Yapay sinir ağı, MLP, RBF, GRNN, güç yük

CHAPTER ONE

INTRODUCTION

1.1 Power Amplifier Classes

Although there are diverse classes of power amplifiers, the performance of power transistors can be conveniently evaluated using class A, B or AB. The operational class of the power amplifier depends on the selection of the gate and the drain DC voltage called the quiescent point (Q-point). The selection of the Q- point has a great influence on the linearity, power, and efficiency of the amplifier. The main purpose of the PA is to supply the necessary amount of electric power to the antenna. Most common classes of the power amplifier are briefly described below:

1. Class-A linear amplifiers with Q- point biased near half of the DC load line.

They possess peculiarity the distortion for it if minimal. The strong nonlinear effect (overdrive) happens only when the drain current overrides its saturation point (pinch off) region.

2. In a class-B amplifier, the operation point has to be selected at the threshold voltage to receive maximum power efficiency for class B nearly equal to 78%. In the given case, the linear characteristic is greatly reduced according to the theme that the conduction angle is half that of Class A. Current flows through the class only during half of the input waveform (the positive part of the N-channel transistor). Thus, the input power, the strength of such a model is almost twice as high.

3. The class-AB amplifier gives a resilient solution for a compromise between the linearity and efficiency of the preceding classes. In this mode, the Q-point is located between the A and B points which will correspond to application requirements. Subsequently, the operation angle is typically chosen closer to the

threshold voltage, as shown in Figure 1.1. Thus, the transistor response of class-AB is greater that of

4. class-B due to the operating point. Also, the power efficiency is greater than to class-A. Many communication applications utilize this type [1].

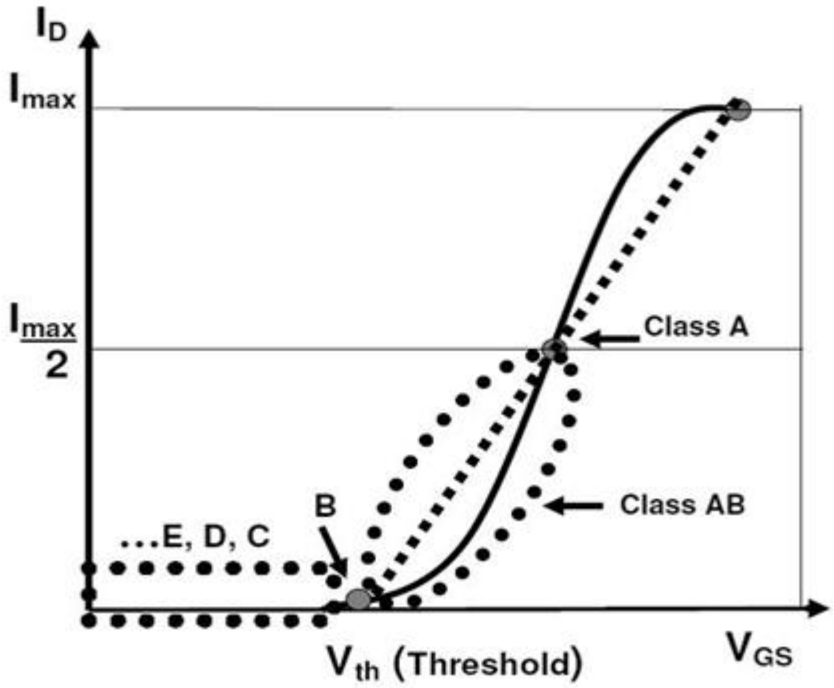

Figure 1.1: Characteristics of I-V linear power amplifier [2].

5. The class C PA is one an important amplifier where the active element works less than one half of the input signal. The operation angle for this type is between 80 degrees and 120 degrees. The serious threats of this kind that we have high distortion in the output. This problem reduced the linearity. According to the operation region for it, efficiency will increase. In theory, efficiency reaches to 90%.

Class C does not prefer to use it for audio implementations. It uses for RF oscillator and RF amplifier where there are some additional toning circuits in order to get back to the natural signal.

6. Class E has switched mode operation with several amendments. Class E PA uses one energetic element as a switch. In the perfect state, the competence of a class-E amplifier is very high. Virtually, the switch has a restricted on-resistance, and the work times from the off-state to the on-state and vice-versa are not low. Both of these approaches cause power dispersal in the switch and diminish efficiency.

7. A class-D PA which may also be recognized as a switching PA or a non-analog amplifier uses output transistors which are either perfectly changed on or completely turned off (switch mode operation).

This class deal with MOSFET to zoom in allusion. The eligibility of class D is more than class AB. The lifetime of battery in this form is longer than class AB.

In AB it is 47.4 hours, but here it is 110.8 hours and that means it is longer by 2.3 times. Class D supports the auditory actions. The same do with PWM techniques to express on the audio signal. Havoc on power produces high heating. In D there is no high heating during its operation.

8. Class G amplifier symbolizes one of the commingled devices. It blends between the merits of class AB and adapter power supply. The structure of class G authorizes to adjust the interior voltage in order to raise the efficiency. The class AB biasing maximizes the fineness of the volume so that it used to support the audio power amplifier.

9. Class F amplifier is one of the largest efficiency amplifiers. It is an addendum to class B and class E outgrowth. Harmonic content is controlled to rebound efficiency. Theoretically, efficiency equal 100%, but in this case, we will need finite the harmonic so that it is not workable. To get half sine waveform for the current, we should get rid of the odd numbers of harmonics. To get the square wave for voltage we get rid of the even numbers of the harmonics. Furthermore, class F boost the output power using the same techniques. There are different implementations for this topic in RF fields [3].

1.2 Power Amplifier Performance Parameters

There are many fundamental parameters in RF Power Amplifier like gain, output power, linearity, stability, efficiency, etc. The requirements of a PA mutate relying on its implementations. When linearity is necessary for some of the PAs, efficiency may be necessary for the others. According to the application, both can sometimes be important. In this part, power amplifier determinates will be elucidated [4].

1. **Gain**
2. **Output power**
3. **Efficiency**
4. **Linearity**
5. **Efficiency**
6. **1dB compression point**
7. **Noise figure**
8. **Noise resistor**

1.2.1 Gain

In appliances, gain is a gauge of the capacity of a device most normally a power amplifier to promote the power or fullness of a signal from the beginning to the end of the circuit as an output, by compounding energy to the transferable energy from the power supply. It may also be introduced on a logarithmic scale, an expression of the decimal logarithm of the same ratio dB gain.

Gain greater than one zero dB, that is, amplification, is the known peculiarity of an efficient ingredient or circuit, However, a passive circuit will have a gain of less than 1. An amplifier's gain may be the voltage, current or power gain. Most often gain refers to, say a voltage gain for audio and common purpose amplifiers, predominantly OP-AMP, but it can refer to a power gain for radio frequency amplifiers.

The small signal power gain can be described by three definitions such as transducer power gain (G_T), operating power gain (G_P) and available power gain (G_A).

$$G_T = \frac{P_{load}}{Available\ P_{source}} \tag{1.1}$$

Where P_{load} is the average power delivered to the load. P_{source} is the maximum available power to the source.

$$G_P = \frac{P_{load}}{P_{input\max}} \tag{1.2}$$

Where P_{load} is the maximum time average power to the load. P_{source} is the time average power that passes on the load.

$$G_A = \frac{P_{load\max}}{P_{source\max}} \tag{1.3}$$

The available gain is the ratio of an obtainable load power to an obtainable source power. This is introduced as the maximum power capable of being received from a source to a load under situations of unifying matching and available gain is only introduced under situations of unifying matching.

1.2.2 Output power

In radio broadcasting, the output for equipment spending is the existing part of the power of radio frequency energy that a transmitter exhibits at its output. A power amplifier's output power is the remarkable resolve item to an amplifier. Its power quantity is described by communication gauges. In some regions, power amplifiers with frequently high output power may be unlawful. Homelands around the world also have various constraints on the ultimate radiated power of the wireless bands so this is always claimed to examine with the domestic organizer company. The RF power varies among industrialist and is typically 13-30 dBm approximately 20 mW-1 W. Some high-power amplifiers are eligible for supplying up to a few watts [5]. The formula for transforming between dBm and milliwatts as obvious [6].

$$dBm = 10\log(mW) \tag{1.4}$$

$$mW = 10^{\frac{dBm}{10}} \tag{1.5}$$

1.2.3 Efficiency

One of the other worthy figures of a trait is the efficiency of a power amplifier. Competence, generally, characterizes the range to which time, effort or cost is well used for the calculated function or aim. It is often used for a special target of moving the capability of a particular application of effort to give a particular result efficiently with a minimum amount or volume of squandering, cost, and needless labor. "Efficiency" has vastly differing significances in different purviews. Power amplifiers are the great power consumers. Due to their exhaustion most of the power, therefore, the overall efficiency is specified by the efficiency of the PA [5]. Overall efficiency can be described frugally as:

$$Overall\ efficiency = \frac{what\ you\ get}{what\ you\ pay\ for} \tag{1.6}$$

1.2.4 Drain efficiency

Drain (or collector) efficiency is the proportion of output RF power to input DC power. It treats with outside of RF circuit. In general, drain efficiency is a little greater than overall efficiency, and is used to portray the device at its substrate [7].

$$Drain\ efficiency = \frac{P_{out}}{P_{DC}} \tag{1.7}$$

In some of the designs, the designer depends on this type of definition, especially when the input is very weak. In the one-stage PA, input power represented fundamental issue because of the gain is weak.

1.2.5 Power added efficiency

The power added efficiency is defined in Equation (1.8).

$$Power\ add\ efficiency = \frac{P_{out} - P_{input}}{P_{DC}} \tag{1.8}$$

Power added efficiency (PAE) is identical to drain efficiency, however, it occupies into its computation the RF power that is increased to the circuit at its input, in the numerator. The propagation of the RF power is increased by the PA to the DC power, thereby giving PAE. The power amplifier with definite gain will get PAE which equalize to drain efficiency. In a fact, PAE ought to constantly be less than the drain efficiency. The diversity of these adequacy idioms spread as the gain of the amplifier boosts. The extreme potential power added efficiency of a system permanently reduces with a frequency [7].

1.2.6 Total efficiency

Total efficiency occasionally named synaptic efficiency as obvious in the adequacy leading title, provides a whole image of the proportion of the output power to both sorts of input power (DC and RF).

$$Total\ efficiency = \frac{P_{out}}{P_{input} + P_{DC}} \tag{1.9}$$

1.2.7 Linearity

In the transistor, there is really influential parameter that effects of its work. All designers want to always ensure work in the safety zone. Linearity indicates that any increase in input is accomplished by an increase in output. Coerce active element to work without any harmonics and shun oscillation. By relying on the mode of the transistor, we can find the best point of operation for biasing. In MOSFET we can find the convenient gate-source voltage to work in amplification territory. There are many criteria to examine the linearity of the transistor such as IMD and TOI [7].

1.2.8 1dB compression point

The 1dB compression point is a very important parameter in an RF amplifier. It can help the designers avoid receiving to this saturation region. The 1dBcompression point refers to the fact that the gain will decrease by 1dB from its signal value according to the input power as shown in Figure 1.2. It is important to notice that the gain is still stable over the bandwidth for the design before receiving to this magnitude of input power.

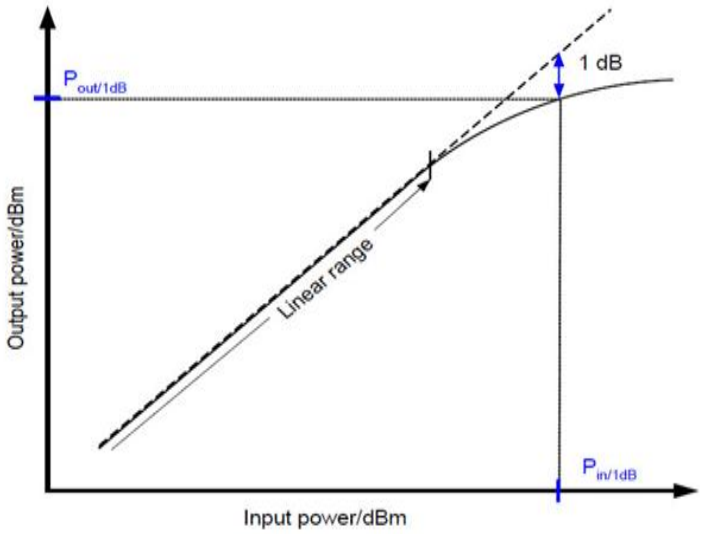

Figure 1.2: 1dB compression point for RF amplifier [8].

1.2.9 Noise figure

The noise figure (NF) represents the relationship between the ratios between signals to noise after passing through the amplifier to the signal to noise for the input signal of the amplifier.

The NF can be calculated using the mathematical equation as shown below;

$$NF = \frac{S_i / N_i}{S_o / N_o} \tag{1.10}$$

Where;

S_i = input power signal

N_i = input noise signal

S_o = output power signal

N_o = output noise signal

From the equation above, if the circuit has clutter, the output noise power is greater than the output signal power. This is how the output SNR will be reduced according to the high output noise power. Once the noise and demand signal are applied to the input of a noiseless circuit, both the noise and signal will be expanded or attenuated by the same degree, that is why SNR will not be changed.

1.2.10 Noise resistor

Noise is an unwanted effect in a resistor. For some applications, the noise characteristics are important, especially in high gain power amplifiers and low noise power amplifiers. Resistor noise is usually known as microvolt per noise for the applied voltage, at 1MHz. Thermal noise is the main source of noise in resistors. It is depended on three variables, resistor, temperature, and bandwidth. The formula the can give us the relationship between these three variables as shown below [9];

$$E = \sqrt{4BTRk} \tag{1.11}$$

Where;

E is the noise volt,

R is the resistor ohm,

K=1. 38×10^{-23}J/K,

T= temperature in Kelvin,

B= the bandwidth in Hz.

From this equation, we can understand that the noise resistor can reduce by reducing these three elements for an RF device [7].

1.3 Design Considerations

Designers have selected the class type to be applied according to the needs of enforcement. Class A, AB, and B amplifiers have been used for linear operations such as amplitude modulation (AM), and single-sideband modulation (SSB). Likewise, it can be used in linear and broadband implementations such as the multi-carrier PA. Classes C, D, E, F, G, and H have done, they wanted for narrow range tuned amplifiers with greater efficiency. These applications contain the expansion of FM signals.

The characterization of power amplifiers in the prior pages has transacted with perfect devices. In fact, solid state amplifiers bear an amount of restrictions that effect amplifier operation and at the end, decrease their efficiency and output power.

Practically FET, there are four essential limitations that impose the operation of FET to distort from the ideal case: the drain-source resistance, the maximum channel current (I_f), the open channel avalanche breakdown voltage, and the drain-source breakdown voltage [9].

1.4 Research Problem

The Power Amplifier is the master component of the transmitting chain of the radar system and it is the final amplification stage before a signal is transmitted. Therefore, it must produce higher output power to avoid channel damages between the transmitter and receiver.

In the previous types of radar, the power amplifier depended on vacuum tubes such as klystron, magnetron, and TWT. They required high input power supplies as a result, there would be high power consumption, heating and very short life spans of these amplifiers. Therefore, engineers would replace them regularly. The mean time between the failures (MTBF) is low in vacuum tube amplifiers.

According to the literature survey (chapter two), practically, transistor amplifier's effect by a number of limitations that limit the amplifier operation and in the end reduce their efficiency and output power.

Due to the assortment of applications, there is a great diversity of requirements for power amplifiers. Some of the most requisite requirements in power amplifier design include the frequency of the operation, output power level, bandwidth, efficiency, gain, linearity, size, and cost. It's not possible to increase all design levels at the same time. Finally, tradeoffs must be made, and only a subset of the requirements can be satisfied. Some of the known tradeoffs comprise gain and bandwidth, operating frequency and output power, linearity and efficiency.

Thereafter, comes a great challenge for a designer to build an RF amplifier. The most important consideration in RF amplifier design is to increase the output power using good matching impedance. In the past, most designers depended on some a number of mathematical statistics or on testing the circuit many times to find the optimal state according to the application. That was caused for much lost time and cost when designing an RF amplifier according to its greatest limitations. For us, we submit an easy method that will contribute as an easy method to select the corresponding matching circuits for an RF amplifier depending on MATLAB.

In addition, there is a very important new technique that can help designers of RF amplifiers. It would be ideal to be able to estimate the outputs of a power amplifier using a number of inputs. In fact, there are many estimation methods to do that. For us, we submit a very new method that can help corporations that produce RF amplifiers for many applications including a radar system. We used the Neural network in different ways to serve the design. For an RF amplifier there are many inputs and outputs that we can use in artificial neural network (ANN). In the active device, there are two important parameters that affect performance of the amplifier represented by drain - source voltage (V_{DS}) and drain- source current (I_{DS}) which we used for our neural network. We add to these parameters the frequency in order to provide high reliability of our model because ANN needs high data to provide to us high imagination about our design. Moreover, there are two input powers for the power amplifier represented by the RF input power and the DC power. We can use these as inputs for our ANN to estimate the outputs.

For outputs, there are many important parameters in amplifiers that we can test, including output power, noise figure, and thermal noise. Because we discussed above the role of matching impedances in amplifier design and the analysis of the circuit using S parameters we therefore used S-parameters as magnitudes and phases in our ANN model. We designed as we will show later different types of ANN to support the point of research, including the multilayer perceptron artificial neural network (MLPNN) and the radial based function neural network (RBFNN) to estimate a number of outputs for our design and some real data for other power amplifiers for RF global companies such as (MACOM) company to show the benefits of this method in the future for all companies that deal with RF components. In our project, we have procedural steps as the following below;

1. Designing a single stage class AB Power Amplifier for operation at the 450 MHz frequency with a wideband frequency range [400 MHz-500 MHz].
2. Unlike the classical design, in our work, a Solid-State Device will be submitted using the new method represented by the optimization method for good matching impedance to our amplifier.

3. The main specifications of Power amplifier design include linearity and output power. Linearity must be maximized in order to reduce signal distortions and minimize adjacent channel leakage ratio (ACLR).
4. Designing an amplifier with a 100 MHz bandwidth, an output power of 27.8 dBm, reliability, better thermal performance and greater than 10 dB gain of the amplifier.
5. Our design depended on the optimization method to find the optimal matching circuit according to the requirements.
6. Design different models of neural networks to estimate the S-parameters for our design and test some global types of the amplifier using the ANN to show the benefits of this method for RF designing.
7. MATLAB and Simulink / Sim power system and RF signal measurements. Additionally, we need some assistance using ADS (advanced design system).

1.5 Thesis Structure

This thesis consists of five chapters to describe the technical specifications and design environments of the system.

In chapter one, we introduced general information for an RF amplifier, the need of power amplifier in radar transmission and their categories. The role that neural networks will take it in the RF power amplifier design. Research objectives and problem definition are also illustrated.

In chapter two, “Literature Survey” presents reviews of the studies and experiments that have been conducted by other researchers and the designs for power amplifiers from different perspectives. Some important information on neural networks presents the benefits of them as an intelligent method that will contribute to the development of the RF amplifier manufacture in the future.

In chapter three, “Methodology” describes the method and the proposed model with all design, technical specifications and all the theories associated with them.

In chapter four, “Simulation and Results” presents the practical model and MATLAB setting environments used for running this model with some help from

ADS program. Additionally, we submit many types of neural network to support our design and take test data for some amplifiers to explain our idea in a very good way.

In chapter five, “conclusion and future work” present the achieved outcomes and the technical interpretation of the work. Also, we submit a number of recommendations for future work to improve our design and how the ANN as an intelligent method will play a necessary role in the future of RF amplifier design.

CHAPTER TWO

LITERATURE SURVEY

2.1 Preface of Power Amplifier Categories

The classes A, B, C and AB are applicable as a constant current source. The obstacle of power dissipation occurs more in these amplifiers. They are used in limited areas of a low- frequency range. These four types of amplifier are classified according to their biasing conditions and the conduction angles.

In any case of conduction angle, the transistors are used as the “Tran conductance” PAs [1].

Included in the switch mode power amplifier classes like E, F and D. The key idea behind switch-mode PA technology is to operate the transistor in the saturation region, according to whether the amplifier class is switched on and off, and whether a waveform exhibits isolated signals of either voltage or current. If the switch is open, only the voltage is present over the transistor while the switch is closed, only the current flows through it. Subsequently, there is no any overlapping for current and voltage waveform, therefore the dispersion of power will be as low as possible. The low power dissipation will provide good efficiency. Theoretically, 100% present efficiency is also possible [3].

The hybrid class of power amplifier has advantages and disadvantages of the combination of two different classes. To overcome these limitations, further improvements will be entered with several classes such as a class BD power amplifier, class EF power amplifiers which are the particular classes of interest. To design this PA, the use of Class EF will give special interest to produce good performance on a low voltage supply. This operating class also has the advantage to achieve high bandwidth with frequency range of 1.5 to 3 GHz [4].

The CMOS RF power amplifier which delivered hundreds of milliwatts of Power was announced in 1997, and was executed in the single-ended configuration with 0. 8 μm CMOS Technology. The power amplifier was able to give 62% drain efficiency of (824 - 849) MHz using the supply voltage of 2.5 V. The first gigahertz range differential power amplifier was reported in 1998, performed using 0. 35 μm CMOS Technology. In 2001, 130 nm CMOS technology was appeared. Today's scientists are now working on 14 nm CMOS technology. In few years, scale will be decreased to 10 nm, which is very small [10].

2.2 RF Power Amplifiers for Different Applications

Researchers have submitted a model for amplifiers that support UHF using the LDMOS class D by using sigma-delta modulation method. This method depends on linear power amplifier design using nonlinear components. The power amplifier operates at 450 MHz. The results show that output power was 100 W and efficiency was 80% and 73% for PAE. For the same design, the researchers used the GaN transistor, however the results were lower than the first case, where output power was less than five times the first state. Both efficiency and PAE were 55% and 38%, respectively. This design corresponds to OFDM and it was executed using the ADS program [11].

In different work, designers employed a GaN transistor with a tunable output matching network in order to increase the output power using varactor diodes. Firstly, they improved the back off efficiency to between (0.9 GHz - 1.0 GHz). The prototype of the power amplifier was tested at 1.4 MHz long time evolution (LTE) signal.

Afterwards, optimization load magnitude results were 33.7 to 35.1 dBm with 33.2 to 47.9% efficiency over 0.6 to 1.08 GHz and <-28.2 dBc of ACPR without any linearization. This design was executed by using Microwave Office (MWO) [12].

Then designer used a two-stage GaN power amplifier for the S band (420 MHz – 450 MHz). The applied voltage for this design was 75 V. All similar commercial types operated at 60 V or less. Increasing the voltage supply increased the load impedance and decreased the load capacitance. Finally, this design proved that it is better than TWT in the same frequency band (420 MHz - 450 MHz). The efficiency of this design was 15 % higher than TWT. It was executed by using the ADS program [13].

The monolithic power amplifier is designed for an RFID reader. The PA is operated with 0.18 um of BiCMOS technology. Moreover, it operates from 860 MHz to 960 MHz. The design was linear and the results were good. The circuit was on a single chip. The dimensions of the chip for this amplifier were 1.1 mm × 0. 9 mm. The small signal gain was up to 21 dB. The S_{11}, S_{22} were -21 dB and -15 dB respectively. The output power at 1 dB compression point was 23. 3 dBm and PAE 27 %. The Power gain was 23 dB and MWO was used for the full design [14].

A broadband power amplifier was implemented in this paper. The designers used lumped elements for the full design. The design depended on a GaN HEMT transistor which was class AB amplifier. The proposed design gave good performance between (200 MHz - 500 MHz). The efficiency was very high at 71%. The design was run using ADS program [15].

The wideband highly efficient class E power amplifier was executed. This amplifier treats the entire bandwidth (470 MHz - 680 MHz). The output power was 10 W for all bandwidths and the PAE was 70%. The practical circuit gave 54% with 10W. This circuit was also tested using pulsed CW signals. The design gave 44 dBm and PAE 89% [16].

The researchers implemented a UHF power amplifier that supports the small satellite. The operating frequency was 435.2 MHz. The main purpose of this power amplifier was to increase the input power in order to increase the output power at the end.

The power gain was good and varied between the 15 dB to 20 dB. The type of amplifier was class A to reduce the distortion [17].

The outfacing transmitter operating at 770 MHz is presented. This transmitter depends on a GaN HEMT technology power amplifier. A load modulation path was used to close the load to an optimal state. A simple lumped elements chireix combiner was also used. The results that were extracted from amplifier were 60% and 7 dB output power [18].

In this paper, we highlighted large-signal stability for the power amplifier. The methodology for this paper depended on studying the poles and zeros from the closed loop transfer function for the circuit around the steady state of the circuit. By using this technique, the designer can select the stability method that corresponds to the amplifier. The model gave 4 W of output power and high stability [19].

The electronically tunable power amplifier is implemented in this paper. The GaN HEMT is used for this type of amplifier which is operated by a class C band. The input gate is tuned using two varactor diodes. The drain output is tuned using three stub tuner that had long controlled on it using pin diodes. The power amplifier delivers between 34 dB to 50 dB with an overall efficiency between 47 % to 65 % [20].

Complementary to the traditional class-E topology, the inverse class-E operation has several characteristics over the class-E parallel, such as lower peak switch voltage and smaller circuit inductance, which are engaged to high power RF design and MMIC enforcement. This method comes with the closed-form design equations that can be used to configure the idealized process of inverse class-E power amplifiers at any switch duty ratio [10].

Calculations of the key design parameters, such as the maximum switch voltage and circuit components magnitudes, carried out and compared with the case of traditional class-E operations. Furthermore, the impractical analysis is proven and verified by numeral simulations performed on a 500 mW, 2.4 GHz idealized inverse class-E power amplifier [21].

A maximum output power of > 20 dBm with the power-added efficiency of 15% is achieved using InP DHBT technology.

As a far as we know, it is the largest output power and efficiency announced for an InP HBT PA in this frequency band. The expected power-added efficiency is greater than that of power amplifiers based on SiGe HBT and GaAs pHEMT technologies. The layout shows the abilities of InP DHBT for power amplifier applications as an alternative to HEMT based technologies in the millimeter-wave frequency range [22].

A study shows the design and nonlinear analysis of a millimeter-wave wideband Doherty PA at a 22 to 29 GHz with 7 GHz bandwidth. The design is carried out using a 0.15 μm GaAs PHEMT active device to support a difference of millimeter-wave applications including a spot to spot digital radio, LMDS/LMCS, Ka-band satellite spacecraft and ISM implementations. The wideband Doherty power amplifier gives more than 21 dBm of output power over a 22 to 29 GHz, with an exactly PAE of 35% and exact gain 15 dB over the frequency band. The proposed Doherty power amplifier also gives agreeable linearity when experimented with the two-tone signal. Analysis results show that the doherty power amplifier significantly provides both efficiency and linearity in the power amplifier in comparison with the master amplifier [23].

The design of the C-Band high-speed pulsed power amplifier for pulsed radar implementations has been explained. The study explaining the design and increase of a narrow range two stage high-speed Solid State Pulsed Power Amplifier (SS-PPA) working at 7.23 GHz frequency has been implemented. The PA is prepared by using commercially packaged PHEMTs. A total pulse card has been developed to allow modulated pulsed bias. At room temperature, the PPA produces 17.58 dB gain yielding a 26.58 dB peak output power for 9 dBm input driving power. The weighted rise and fall time of the final practical circuit are obtained at 25 ns and 19.2 ms, respectively at 90 ns Pulse Width (PW) with 30 kHz pulse repetition frequency (PRF). The study provides a characterization of the design of the power amplifier along with an account of its performance made through a comparison of simulated and practical results with desired object specifications [24].

A high-gain and low-area 77-GHz power amplifier for the long range automotive radar has been submitted. The suggested circuit operates using 0.13 μm RF CMOS (f_T/f_{max}=120/140 GHz) technology. It is also powered by a 1.5 V supply. This circuit uses transmission lines (T-lines) to reduce the total die size and to get accurate line phase shifts instead of real bulky inductors. The layout optimization technique is used to reduce total die size and parasitic capacitances. To improve the power gain of the amplifier, it has a 3-stage cascade scheme. The proposed circuit gave the smallest chip size of 0.152 mm^2 and the highest power gain of 20.3 dB as compared to recently reported research results [25].

The eight high power amplifiers are explained in this work. The designer designed at first a unit amplifier and then using a low loss 1-8 divider with an 8-1 combiner. Finally, combined the eight power amplifiers. The designers used one load pull technique for ADS to find the optimal load and source impedances. The final results were 63.7dBm - 64.3dBm as the output power with a 16.7 - 17.3 dB gain with 50% - 60.4% power added efficiency over 1.2 GHz - 1.4 GHz. This power amplifier serves many application including radar systems [26].

The authors depended on CMOS technology in the following power amplifier. The circuit for the design depended on a 0.18 μm CMOS. The design was a cascade. It consisted of two stages and the results were good. The output power was 19.1 dBm in 1dB compression point. CMOS technology contributed to reducing the size of the power amplifier to be very small. The PAE for the design was 15.6%. The dimensions of the chip for this design were 0.56 × 0.58 mm^2. It represented very small and gave good results. The operation frequency for the design was 24 GHz [27].

In this paper, the researchers presented an HPA that can support the pulse radar system. This design depended on LDMOS FET technology operated at a high voltage and with the high-speed switching circuit. The circuit was better than a GaAs FET due to the good gain and high output power. The output power was 100 Watts. The center frequency was 1.2 GHz. The increased time for this design was 28.1 ns/26.6 ns with pulse repetition frequency 40 KHz [28].

2.3 Artificial Neural Networks of RF Amplifiers

In this article, the researchers focused how we can use the ability of neural networks to linearize nonlinear power amplifiers. AM/AM and AM/PM are used to enhance the work of an ANN and the pre-distortion linearization method. At first BP neural network was modeled to show the nonlinearity state for amplifiers followed by being pre-distortion used in parallel with ANN to operate the linearization amplifier [29].

RF Power Amplifiers are still an important and challenging topic for mobile base stations. Efficiency, linearity, and flexibility are parameters that can be improved. Nonlinearities are some of the most important characteristics that are not yet completely described. They directly impact the performance and efficiency of PA devices. This work has submitted a method to replay the thermal memory effects in a 20 W GaN Class ABJ Power Amplifier by the treating in-situ temperature of the solid-state measured close to its channel. The device temperature is used for a neural network based linearization way [30].

Increasing energy consumption and tools operating value, as well as the parallel issue required to decrease the carbon footprint is a really interesting issue in mobile radio networks. In addition to, the needs to reduce the energy exhaustion. The RF transceiver, especially the Power Amplifier as a component in it, is one of the difficult components. The following paper presents a method for energy efficiency optimization of RF Power Amplifiers with a voltage controllable power supply to control the work point based on Neural Networks. The circuit is essentially standard separate and can adjust itself to a proven standard with its requirements. The system was implemented and simulated [31].

In this paper, the researchers have submitted a structure for the FPGA-implementation of neural network RF power behavioral modeling. The real-valued time-delay neural network (RVTDNN) and the back propagation (BP) learning algorithm were applied to FPGA using the Xilinx System Generator for digital signal processing and the Virtex-6 FPGA ML605 Evaluation Kit. The neural network depended on six layers as a hidden layer. Finally, the performance of the structure was supported the time delay during the operation of the power amplifiers [32].

The researchers used ANN for modeling nonlinear components in this paper. The presented model depended on the MLP model to characterize the memoryless performance of power amplifier. For simulation, they used the feed forword method to normalize input-output conversion. The final results showed that ANN a good tool in modeling for nonlinear components. The difference between test and training data was good [33].

The nonlinearity and memory effect have an important impact on the simulation performance of the PA. In this paper, the designers suggested radial based function neural network utilizing the input and output data extracted from transistor MRF6S21140. After that, design the proposed work using ADS. Simulate two kinds of ANN, back propagation neural network (BP) and radial based function neural network (RBFNN). They computed the error between the real data and predicted data. The final results showed RBF is better than BPNN [34].

In this article, the designers submitted back propogation neural network to simulate nonlinear system. They submitted two kinds of BP, one is cascade BP-RBF ,and the other is practical swarm optimization back propogation (PSO - BP). Then, design power amplifier circuit by using ADS2009 utalizing MRF6S21140 transistor. By comparing the two types of ANN, the designers found BP-RBF method is better than PSO_BP according to RMSE [35].

CHAPTER THREE

METHODOLOGY BASED ON ARTIFICIAL NEURAL NETWORK

3.1 Introduction

RF devices are very critical components in communication systems. Radar represents one notable example RF devices. It consists of two main parts a transmitter and a receiver. Power amplifiers represent interesting points for this work. They amplify the power of a signal before transmitting it in free space. Most designers in the past depended on a number of special programs for the complete design of power amplifiers such as ADS and MWO. For us, we endeavored to improve what we can use in MATLAB with ADS for amplifier design.

There are many factors that can affect power amplifier design, however the most difficult of these designs are the selection of matching impedance. If one can limit which matching impedance corresponds to one’s amplifier. There is another problem of which magnitudes that matches with the requirements. In this thesis, we endeavor to improve using the optimization method in MATLAB is really important, which can help to reduce the time for getting the magnitudes of the elements of our circuit. we present the procedure for using MATLAB with some assistance from ADS for our design [36].

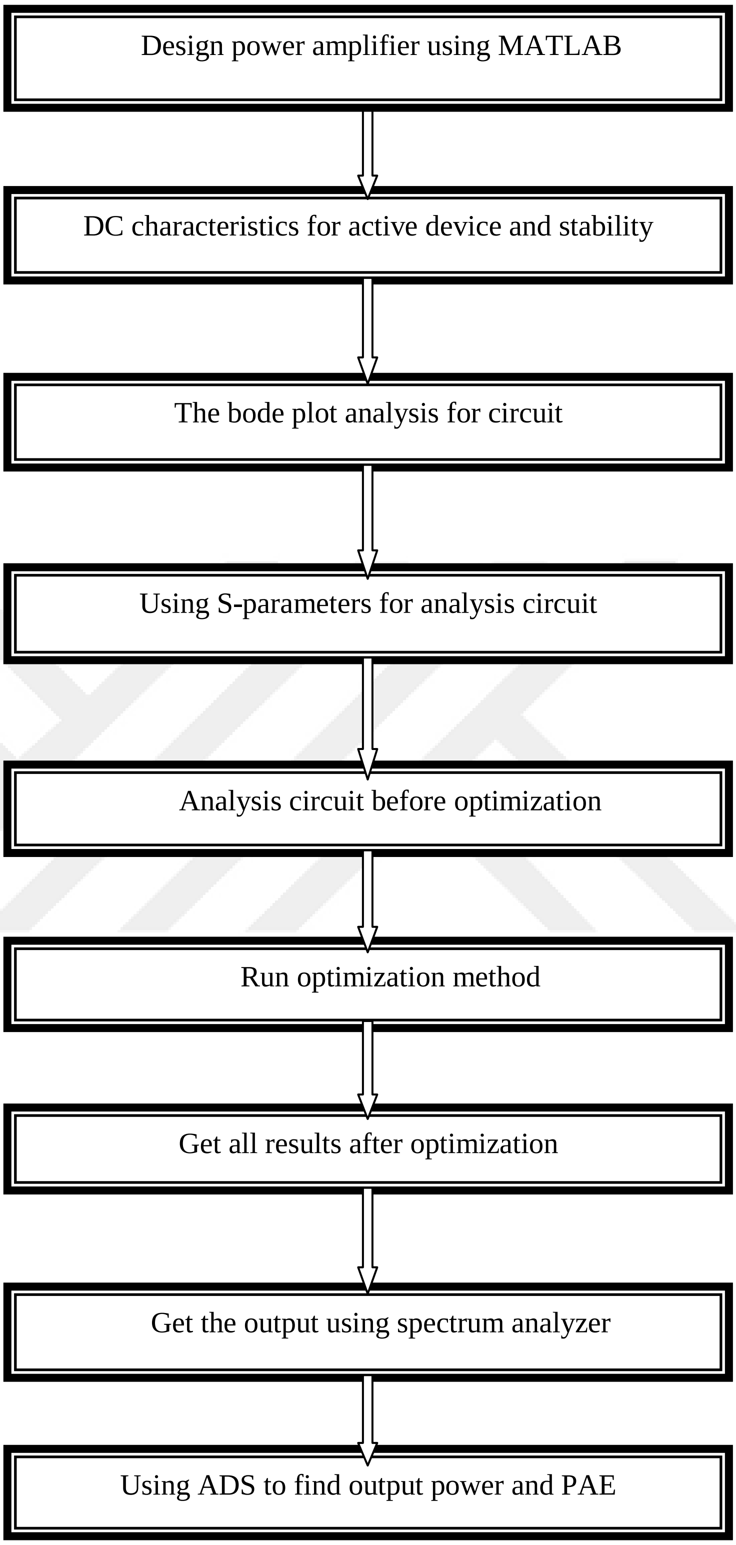

Figure 3.1: Block diagram for using MATLAB and ADS for design RF amplifier.

3.2 Characteristics of Transistor in MATLAB

As already known, the DC characteristic of a transistor is very important to observe the performance of the active device as we are shown in Figure 3.2.

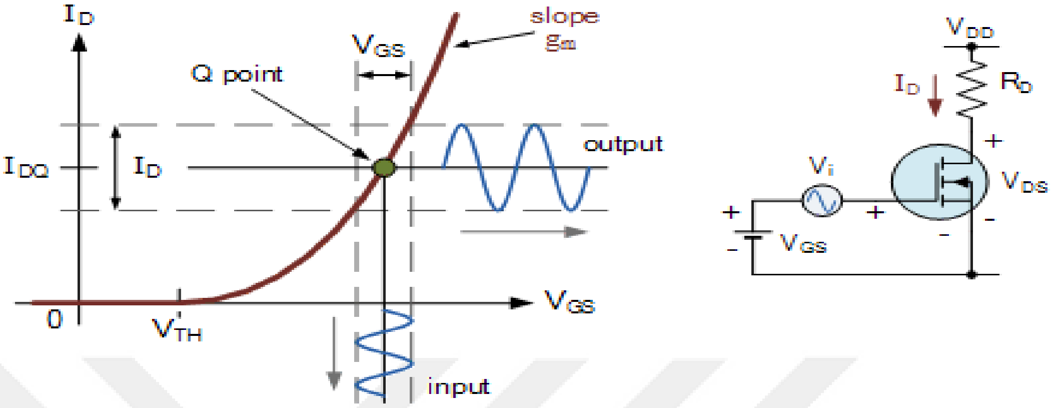

Figure 3.2: DC load line for NMOSFET transistor [37].

In MATLAB program, there is no specific type of transistor. Actually, there is a setting to transistors. Before using the setting for the transistor, we limited the type of general transistor on which we depended for the design of the NMOSFET. The second step limited the operation frequency of our design. By using the setting for the transistor, we limited all of the threshold voltages, the voltage between the drain and source, and current between drain and source. For our design, the operation frequency was 450 MHz. First, we selected a transistor that supports this frequency. We selected the MRF 160 that works from 30 MHz to 500 MHz. We changed the setting for general the NMOSFET transistor to match with the real transistor. We also selected the threshold voltage and the voltage between the drain and source and voltage between the gate and the source and setting all of them. Using the codes that represent the equations between V_{GS}, V_{DS}, and I_{DS}. It is run to show the characteristics of the transistor. Also, we selected the magnitudes for the source and load impedance to be 50 ohms [38].

3.3 Stability Testing

For any RF power amplifier, it is very important to use an active device which should be unconditionally stable. To achieve this, there are many techniques to do that. In this study, we depended on a voltage divider as we show later as presented later in the fourth chapter to achieve unconditional stability and to ensure that the transistor operates in the linear region without effecting different parameters , especially temperature as shown in Figure 3.3 [38].

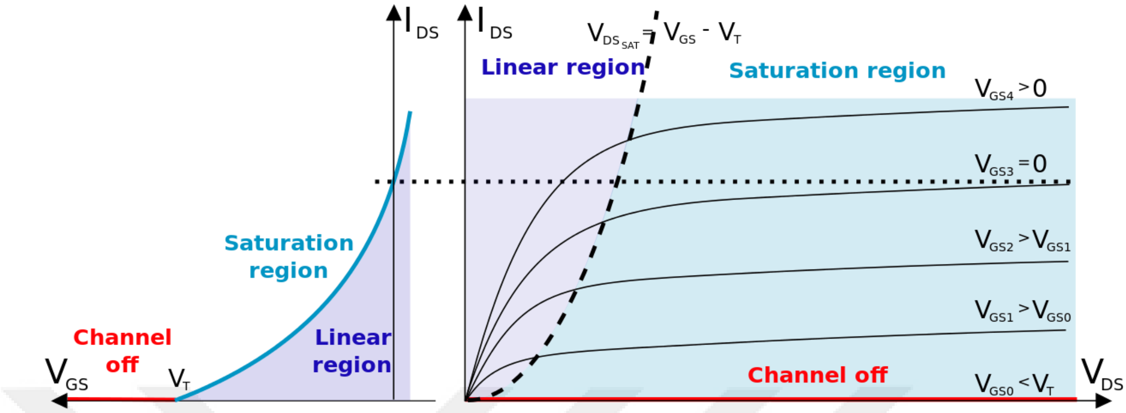

Figure 3.3: The regions of operation for transistor [38].

3.4 The Bode Plot for Design

In this step, we show the behavior of our circuit with respect to the operation frequency. We should know that the frequency in bode plot is implemented in (rad / sec), so we can multiply the operating frequency by (2πf) and show the result in Figure 3.4.

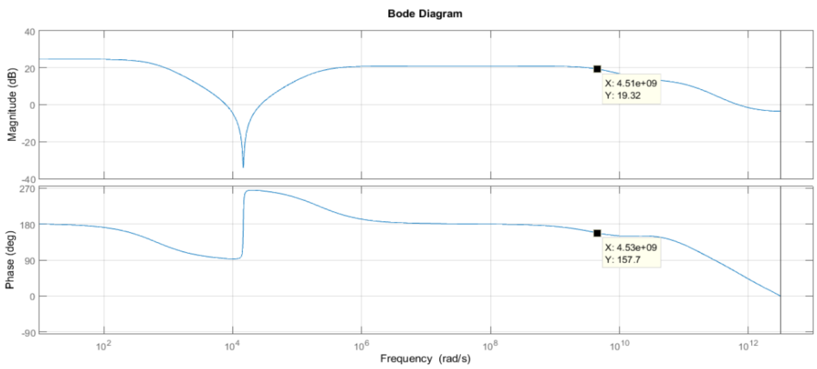

Figure 3.4: The analysis of frequency response for design

3.5 Analysis Our Circuit Using S-Parameters Method

For this design, we depended on the scattering parameters that are one of the important methods for analysis of the RF circuit as shown in Figure 3.5.

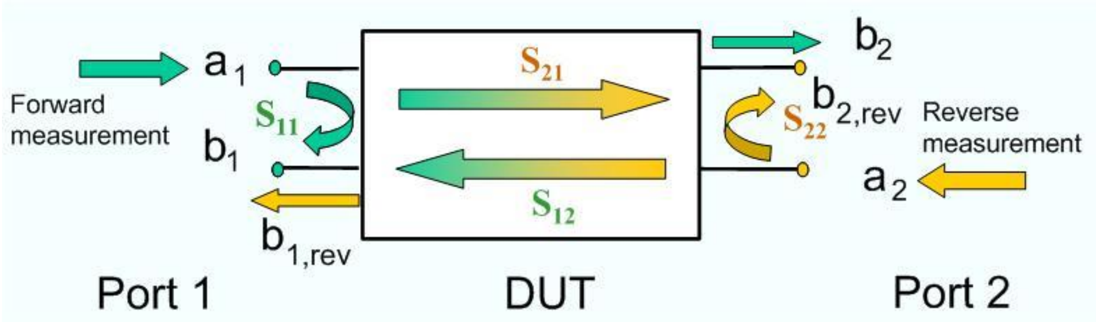

Figure 3.5: Scattering method analysis [39].

$$S_{11} = \frac{b_1}{a_1} \qquad \text{Forward reflection coefficient} \qquad (3.1)$$

$$S_{12} = \frac{b_1}{a_2} \qquad \text{Reverse gain} \qquad (3.2)$$

$$S_{21} = \frac{b_2}{a_1} \qquad \text{Forward gain} \qquad (3.3)$$

$$S_{22} = \frac{b_2}{a_2} \qquad \text{Output reflection coefficient} \qquad (3.4)$$

By extracting the values of the S-parameters, we can know the performance of our design. This method can give a designer a good understanding of the circuit, because of its analysis of both the input port and output port for the circuit and taking all the variables that affect RF circuit.

3.6 Matching Impedance and Optimization Method

A more difficult task for RF power amplifier when designing RF power amplifiers is the selection of matching impedance that matches the requirements of design as we shown in Figure 3.6 [40].

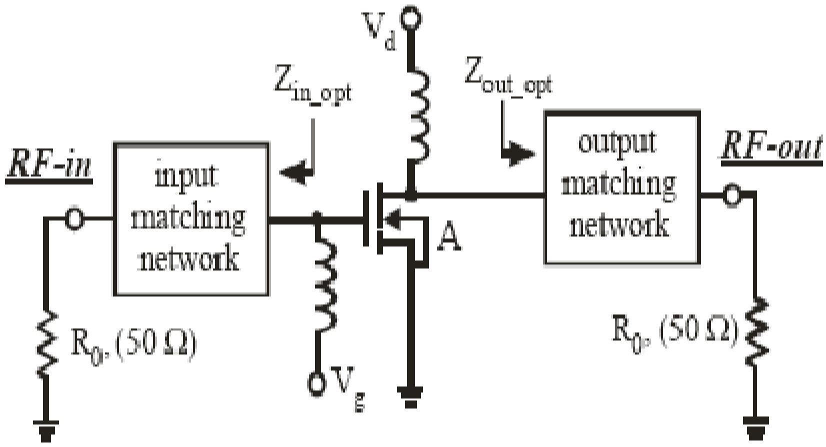

Figure 3.6: Matching circuit for NMOSFET [40].

First of all, we applied the initial values for all elements and got the results. We noticed that all results not as we want, so we decided to use an optimization method to extract the new magnitudes for all elements of our circuit to enhance all results, especially that we limited inside the optimization method gain and noise figure as goals. Actually, there are many steps we should follow them to achieve optimization method as we shown below;

1- The objective function the objective which can be built in different ways. In this design the objective will be;

   Type (' broadband _ match _ filter _ objective _ function. m').

2- Choice of cost function which is a function that is best minimized or maximized in order to achieve the optimal performance. There are many ways to select the cost function. For our design, we have two requirements to satisfy simultaneously gain and noise figure. To create the coat function at first, we find the difference between the current optimized network and the target value for each requirement at each frequency.
3- Optimization variables: In this case, it is a vector of a value for the specific elements to optimize in the matching network.
4- Optimization values: In MATLAB, we used the function "fminsearch" for optimization method.
5- Number of iterations: We try to increase the number of iterations to find the tradeoff between the variables that we want.

6- Tolerance value: This specifies the variation in the objective function value at which the optimization function terminates. We needed to use codes to use codes to express this method.

3.7 Output Power and Power Add Efficiency

One of the important parameters in an RF power amplifier is the output power. There are many methods to produce output power. In MATLAB we used the spectrum analyzer to get the output power. In this method we can extract the power spectral density (PSD) and using the equation that shown below to find the magnitude of the output power. As we know the density is the relationship between mass and volume;

$$Density = \frac{mass}{volume} \tag{3.5}$$

Similarly, we can find the average power for all bandwidths using the below equation;

$$PSD = \frac{dBm}{Hz} \tag{3.6}$$

Therefore, we can find the average power for the design using this equation;

$$Average\ power = PSD \times BW \tag{3.7}$$

$$dBm = \frac{dBm}{Hz} \times Hz \tag{3.8}$$

Moreover, we need to insert all data into our amplifier before running Simulink to extract the average power. The spectrum analyzer according to the data that is inserted inside of it can automatically convert PSD to output power [41]. For power add efficiency, we depended on the ADS program to find the output power for our design. We used one tone load pull in ADS to find the output power and the power add efficiency and the relationship between the input power and the output power as a curve to show at which point the design will enter in saturation region [41].

3.8 Artificial Neural Networks

Artificial neural networks are networks of artificial neurons. They are a research object of neuron informatics and they represent a branch of artificial intelligence. The artificial neural networks, like artificial neurons, have a biological model. They are opposed to natural networks, which form nerve cell networks in brain and spinal cord. However, KNNs are more concerned with the abstraction of information processing and less concerned with the reproduction of biological neural networks, which is the subject of the Computational Neuroscience. The simplified representation of an artificial neural network is shown in Figure 3.7.

From this figure, the ANN represents the mathematical method that can express the outputs. It functions exactly identically to the human brain. We know that if there is any action affecting the body, the neurons in the brain received it and directly make the correct decision that corresponds to it. Therefore, we can say the ANN is the same because it depends on a number of inputs such as the actions to find a number of outputs. Many researchers find that this method is highly accurate and the most reliable.

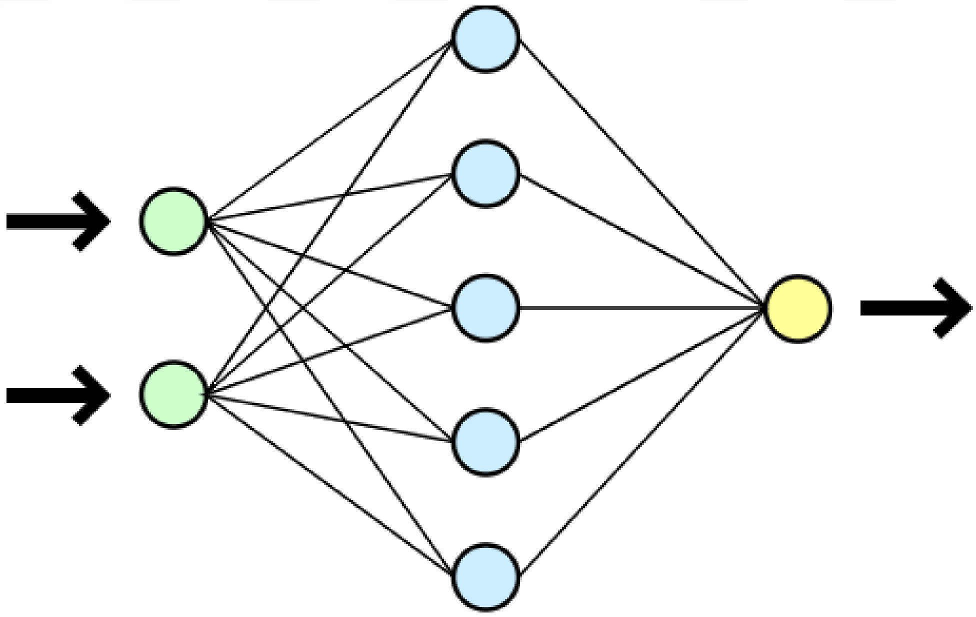

Figure 3.7: Artificial neural network representation [42].

Artificial neural networks are mostly based on the cross-linking of many McCulloch-Pitts neurons or minor modifications thereof. In principle, other artificial neurons can also be used in KNNs, such as the high-order neuron. The topology of a network (the assignment of connections to nodes) must be well conceived depending on the task. After the construction of a network, the training phase follows during which the network "learns". Theoretically, a network can learn by using the following methods:

1. Development of new connections, and deletion of existing connections.
2. Changing the weight (of the weights w_{ij} of neuron i to neuron j).
3. Adjust the thresholds of the neurons.
4. Add or delete neurons.

In addition, the learning behavior changes when the activation function of the neurons or the learning rate of the network changes. Practically speaking, "a network" learns mainly by modifying the weights of the neurons. An adaptation of the threshold value can be completed by an on-neuron.

As a result, KNNs are able to learn complicated non-linear functions by means of a "learning" algorithm, which attempts to determine all parameters of the function by means of the iterative or recursive procedure from existing input and desired output values. KNNs are a realization of the connectivity since the function consists of many simple similar parts. Only in its sum is the behavior complex. Neural networks represent an equivalent model of the Turing machine from the computability.

The human brain consists of approximately 10^{11} account elements called neurons, which comprise the biological neural network, the cell body, the axon, and the dendrite.

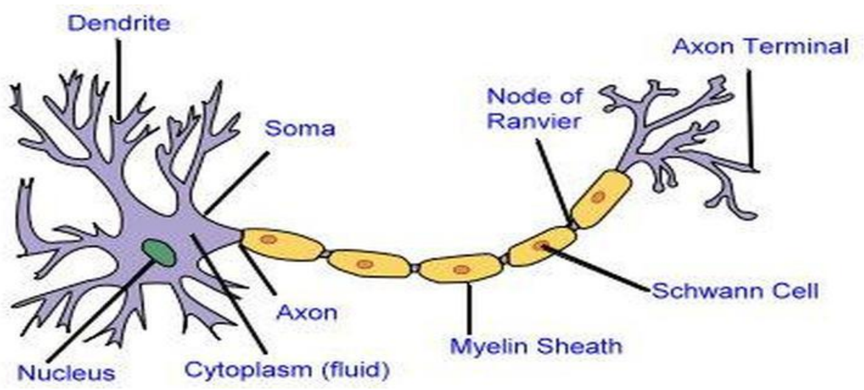

Figure 3.8: Biological nerve cell [43].

The soma (cell body) controls the cell and manages the all cell activity. From the cell body, there are two extensions called dendrites and axons as shown in Figure 3.8. Dendrites pick up from other neurons along the axons of the long fibers used as information transmission lines and carry them to the cell body. The axons are responsible for carrying the information in the body to the dendrites of other neurons. There are small voids called synapses, which are thought to be information storage places where information between axon breaks and dendrites are stored for a long period.

Synapses are the connection points where the neuron introduces its signal to the neighboring neuron. Synaptic connections provide for the transport of messages between neurons. Stimulation, which is achieved via multiple synapses, is ignited or vacated when a certain threshold is reached. Learning in the human brain is accomplished by producing new axons, stimulating axons, and changing the forces of existing axons [44].

3.8.1 Artificial neural cell

The structural components of biological neural networks are nerve cells. Similarly, artificial neural networks have artificial nerve cells as shown in Figure 3.9.

An ANN consists of neurons and connections between them, as in the human neural network. The information is obtained by the network, surrounded by a learning process. Intercellular coupling forces, also known as synaptic weights, are used to accumulate acquired knowledge [44].

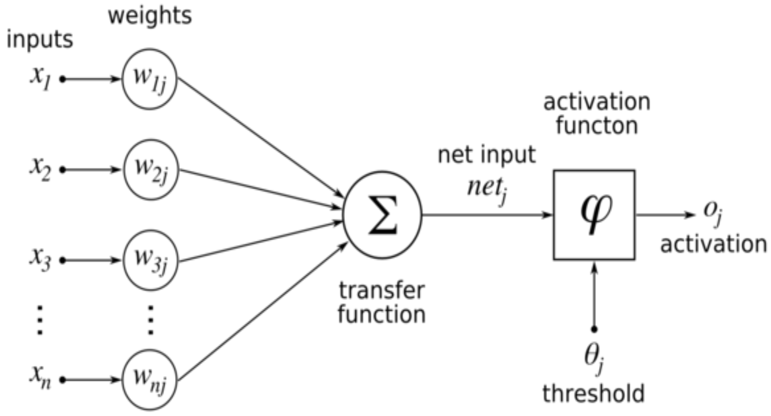

Figure 3.9: Simple sensor model [44].

Information to the ANN can come numerically from the outside world, from other cells, or from it. Information is conveyed through the weights to the cell. Weight values express the importance of the information, which can be variable or fixed values, and can take positive or negative values. Clear information from a nerve cell is commonly calculated by means of the summation function.

Each input value is multiplied by its own weight. The summation function calculates the net cell output by summing these values for all entries. Each cell calculates its net value independently of other cells. The bias-b_k value has the effect of increasing or decreasing the value of the activation function. The information from x_j is used in equation 3.9, where w_{kj} is the weights of each input value, b_k the deviation value, and the output value of the equation is v_k neuron.

$$v_k = \sum_{j=1}^{m} w_{kj} x_j + b_k \tag{3.9}$$

As shown in Figure 3.9, the net information of each nerve cell is passed through an activation function with a threshold value to produce a real output.

Generally, the activation functions being used are a threshold, sigmoid, hyperbolic tangents, and so on. The activation function (φ (x)) Is usually a nonlinear function;

$$y_k = \varphi(v_k) \tag{3.10}$$

The ANN uses training algorithms while being trained with data sets related to any subject. The target output values can be presented to the network while the training set being generated for the event to be learned is presented to the network. Only the input set can be presented to the network, but the system can be self-learning, or the system itself can produce an output for each input set. By generating a signal indicating that the produced output is correct or incorrect, system training can be continued according to this signal. They are grouped as single or multi-layer according to the number of layers in the ANN constructions [45].

3.9 Types of Neural Networks

3.9.1 Multilayer perceptron neural network

The perceptron consists of weights (including bias). The summation process and an activation function [46].

The Perceptron takes a weighted sum of inputs and outputs:

1 if sum > sum adjustable threshold value (theta (θ))

0 otherwise

$$w_1x_1 + w_2x_2 ... + w_nx_n > \theta = 1$$

$$w_1x_1 + w_2x_2 ... + w_nx_n \leq \theta = 1$$

If the input variables are presented to the perceptron, and the predicted outputs are the same as the real outputs. The performance is deemed satisfactory and no change in the weights is made.

However, if the predicted output does not match the desired output, the weights need to be changed to reduce the error.

$$\Delta w = d \times \eta \times x \tag{3.11}$$

Where;

d = predicted output – desired output.

$\eta =$ learning rate usually less than 1.

$x =$ input data.

This model has one or more hidden layer according to the rate of data as shown in Figures 3.10,3.11.

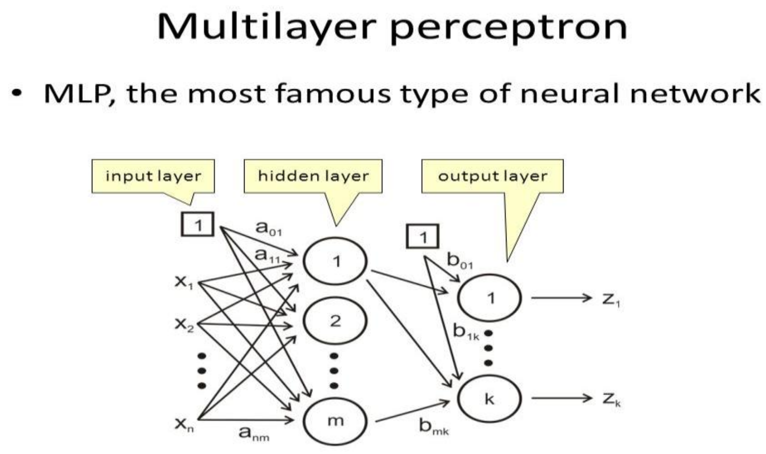

Figure 3.10: The structure of MLPNN [46].

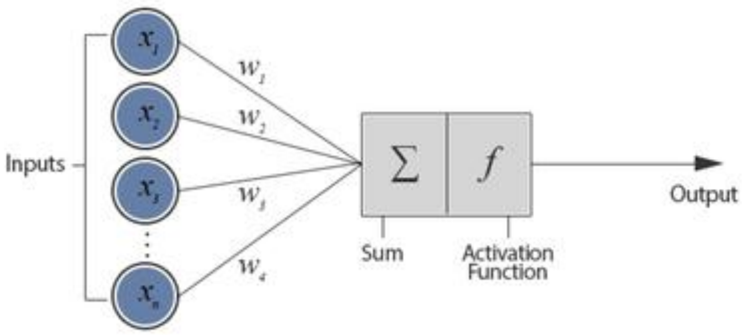

Figure 3.11: Comparing the result of summing and activation function [46].

For the activation function, there are many types as shown in Figure 3.12.

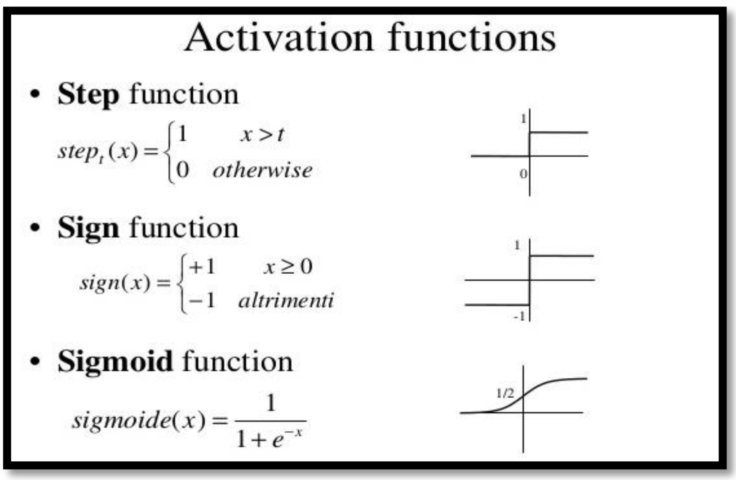

Figure 3.12: Different types of activation function in MLPNN [46].

For MLP, a sigmoid function is very famous for its use to support different models.

3.9.2 Radial based function neural network

This method consists of three-layers: an input layer, hidden layer and output layer. All neurons in a hidden layer consist of a radial basis function (Gaussian function) centered on a point with the same dimensions as the predictor's variables. The output layer has a weighted sum of outputs from the hidden layer to the form of the network outputs as shown in Figure 3.13 [46].

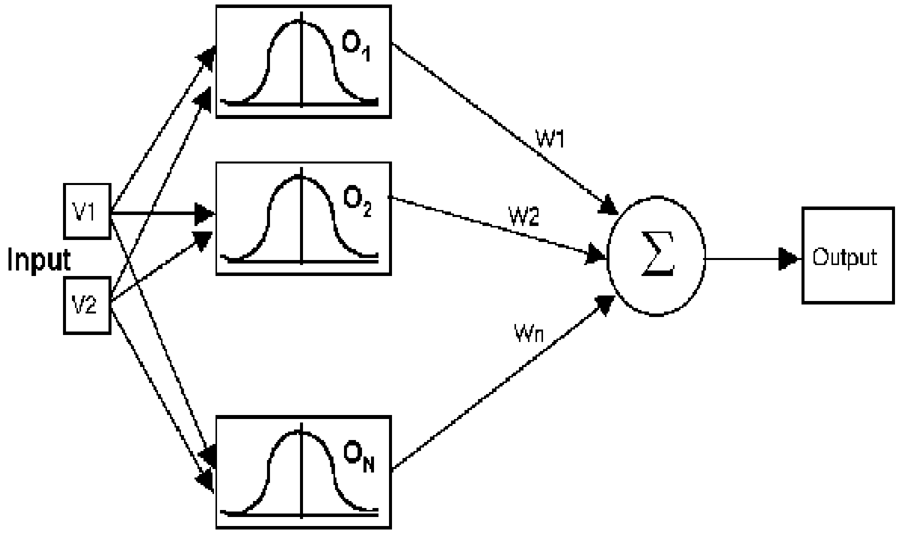

Figure 3.13: RBFNN structure [47].

In this model, the radial basis function for each neuron in the space is described by the predictor variables. The radial basis function is so named because the radius distance is the argument to the function.

According to the diagram below;

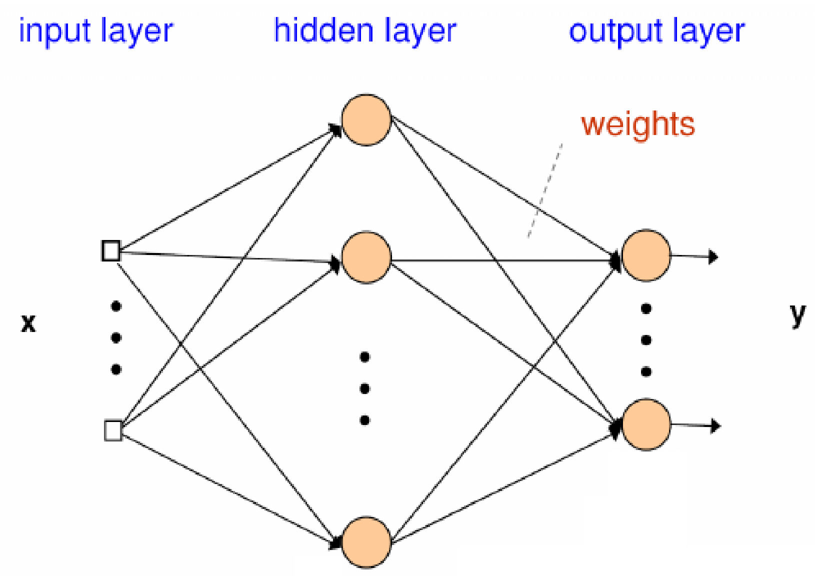

Figure 3.14: The important equations inside hidden layer and output in RBF [47].

If we consider;

$$h_j(x) = \exp\ \left(\frac{\|x - c_j\|^2}{r_j^{\,2}}\right) \tag{3.12}$$

Represents the Gaussian activation function with the parameters r (the radius or standard deviation) and c (the center or average taken from input space) are defined separately at each RBF unit.

When we find $h_j(x)$ we can finally find $y_k(x)$ which represents the output for RBF which is given by the equation below;

$$y_k(x) = \sum w_{kj} h_j(x) \tag{3.13}$$

3.9.3 Generalized regression neural network

This is a new type of neural network that mainly consists of four layers: an input layer, pattern layer, summation layer and an output layer as shown in Figure 3.15.

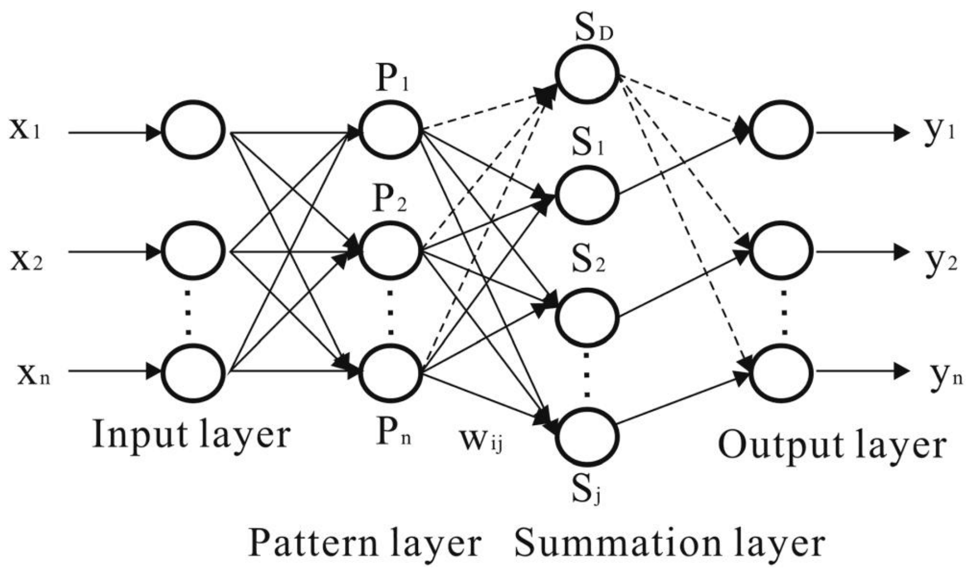

Figure 3.15: The structure of GRNN [48].

A GRNN does not need a repetition training execution as a back-propagation network. It selects any random function between input and output vectors. A depiction of the mission is evaluated immediately from the training data. The estimation error approaches to zero, with only low limitations on the mission.

A GRNN consists of four layers: an input layer, a pattern layer, summation layer and the output layer as shown in the figure above. The first layer is joined to the pattern layer and in this layer, each neuron gives a practice pattern and its output. The pattern layer is connected to the summation layer. The summation layer has two various kinds of collections, which is a single division unit and a combination unit. The summation and output layer together execute an adjustment of the output set. In the training of the network, radial basis function and linear activation functions are used in the hidden and output layers. Each pattern layer unit is linked to the two neurons in the summation layer, the S and D summation neurons. The S-summation neuron calculates the sum of the weighted responses of the pattern layer. On the other hand, the D summation neuron is used to compute the un-weighted outputs of the pattern neurons [46].

The product layer just splits the output of each S-summation neuron by that of each D-summation neuron, thereby producing the predicted value Y_{0i} to an obscure input vector x as below;

$$Y_i = \frac{\sum_{i=1}^{n} y_i . \exp^{-D(x-x_i)}}{\sum_{i=1}^{n} \exp^{-D(x-x_i)}} \tag{3.14}$$

$$D(x, x_i) = \sum_{k=1}^{m} \frac{(x_i - x_k)^2}{\sigma^2} \tag{3.15}$$

Where;

y_i is the weight connection between the neuron in the pattern layer and the S-summation neuron,

D is the Gaussian function,

m is the number of elements of an input vector,

σ is the distance between the input vector and center of neurons,

x and x_k are the arbitrary elements for x and x_i, respectively [46].

3.10 Using Different Neural Network Models for Estimation Our Design

All designers endeavor at all times to discover new methods to serve the technology at the end. There have been many studies on RF power amplifier design. Most of these studies depended on preceding times and on a number of traditional methods such as mathematical statistics and tests. It is known that all of the old methods that followed by RF designing represented the base for this issue. For our endeavors, we present another solution to the RF amplifier design issue. Using neural networks as a novel method is very interesting to estimate outputs using a number of inputs. For RF power amplifiers, there are many inputs on which we can depend as input variables for our models. Biasing components for the transistors V_{DS}, I_{DS} represent important variables for our models. We added very important component represented by frequency (F). The use of three input variables gives our models high reliability.

Because we focused on our proposed work on the importance of matching impedance and by using S-parameters for analysis in our design, so that we represented the S-parameters as the output for our models. It is a really great challenge to model neural network with 8 output variables as most of the old neural networks used only one output.

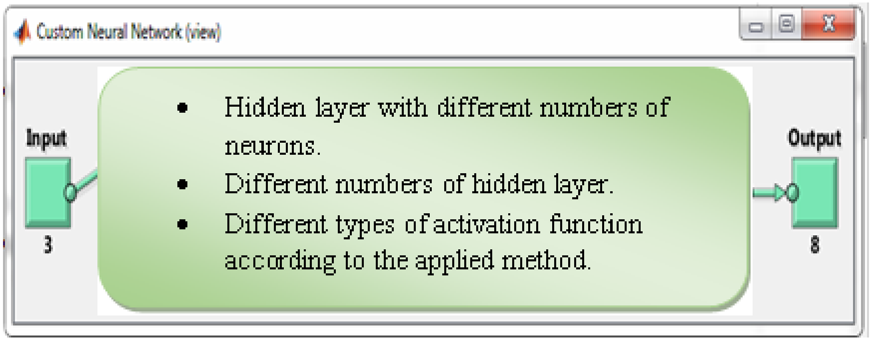

Figure 3.16: Our procedure for different models of neural network

Then we used two methods of the neural network, especially MLP and RBF to express in our proposed work. We designed different models MLP and RBF to implementation of the S-parameters for our design and finding the error between the test data and the predicted data. We made comparisons between both methods using RMSE and MAE as error factors to find which of these methods one yielded high accuracy.

Then we took the test data that are related to the 010168 power amplifier from the MACOM company that is treated with RF components. We designed another type of MLP and RBF to improve the benefits of using this method to RF amplifier design. Then made comparison between the final results.

In the final steps, there are different types of input we can represent them as the inputs to the neural networks. Because we speak about power amplifiers, there is an important input component represented by input power and DC power. We suggested a very new method of a neural network that named generalized regression neural network (GRNN) to support RF amplifier. Then we designed RBF model and made a comparison between them.

CHAPTER FOUR

SIMULATION RESULT AND DISCUSSION

4.1 Design and Modeling RF Power Amplifier with Discussion Results

4.1.1 Design considerations using MATLAB

Many designers depend on a number of special programs that support the high frequencies such as ADS and MWO in order to design RF components. For us, we endeavored to improve by using MATLAB to design an RF power amplifier that can work at UHF according to the final results.

Using MATLAB presents a great challenge for anyone as we need for a number of special techniques to extract the parameters of the circuit. The procedural steps of an RF amplifier in MATLAB differ from the other programs. We will start with RF power amplifier using MATLAB.

4.1.2 The design of the RF power amplifier at 450 MHz using MATLAB

The considerations of our design are;

1. Wideband power amplifier 100 MHz for the bandwidth [400 MHz - 500 MHz],
2. GAIN >10 dB in the center frequency,
3. Output power is 27. 8 dBm,
4. The center frequency is 450 MHz,
5. Power add efficiency.

There are many requirements for our design as shown below;

4.1.2.1 Transistor

In MATLAB there is no specific type of transistor, so we can select the type of active device according to its datasheet depending on the operating frequency of our design. There are many types of transistors that can correspond the frequency of our design such as MRF160 MRF1016HRF, and MRF6VP2600HR6. For us, we selected the MRF160 which has the following consideration as shown below;

a. It has good performance, especially between 30 MHz to 500 MHz,
b. Output power 5 W,
c. Gain 17 %,
d. Operation up to (V_{DS}=28 V),
e. The type is NMOSFET.

4.1.2.2 The characteristic of MOSFET in MATLAB

In MATLAB, there is a method for a build the relationship between V_{DS} and I_{DS} according to V_{GS} values that will apply to the gate of transistor as shown in Figure 4.1.

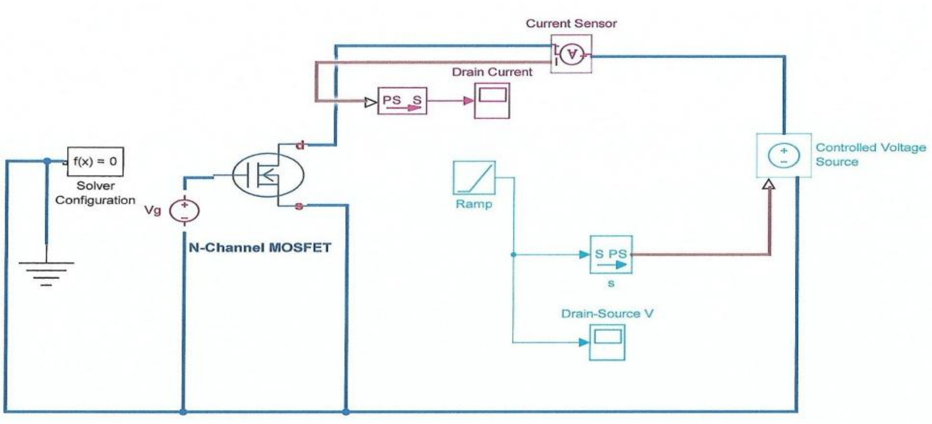

Figure 4.1: The IV characteristics circuit of RF power amplifier

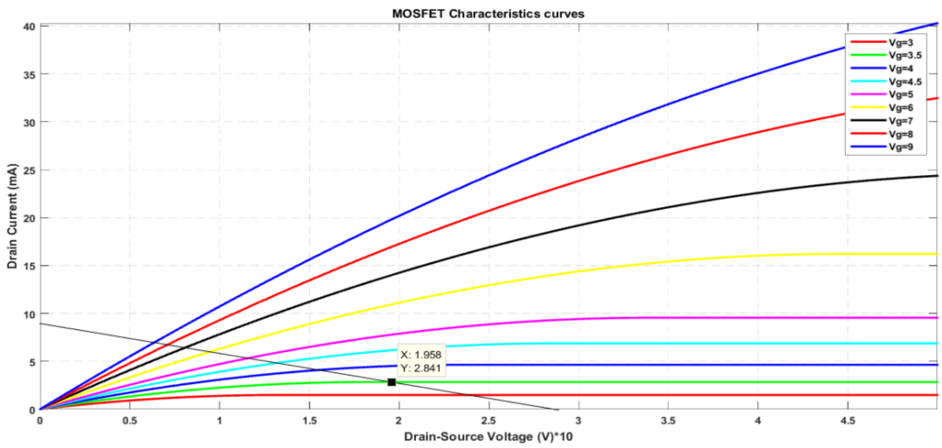

Figure 4.2: MOSFET transistor characteristics

In order to find the IV characteristics for MOSFET in MATLAB, we can connect the circuit as shown in Figure 4.1. We need a DC voltage source for biasing both of the gate and drain of the transistor. There are a number of blocks like solver configurations and S-PS which are so important for Simulink. The solver configuration provides every physical network state that otherwise continues to be implemented as discrete states, while the S-PS converts Simulink into physical magnitudes to be understandable in scope. PSS is used to convert the physical signal to Simulink. After running Simulink, the data that we selected as the input V_{GS} passes through the circuit and uses the codes that give us the relationship between V_{DS} and I_{DS}. According to the datasheet of the transistor, we have V_{th} =3 V for the MRF160. Therefore, we should apply greater than 3 V to overcome the threshold voltage and make the transistor work in the active region. The best option in this case is to select V_{GS}=3.5 V therapy making the power consumption of the transistor very low as shown in Figure 4.2.

4.1.2.3 Stability test of our circuit

The power amplifier should work in the active region. We should ensure that the amplifier works in the stability state under different conditions. We used the plot method to draw Δ and k as a function of frequency to see if the power amplifier is stable. There are many methods that can be used in order to make the transistor work in stability region. For us, we used a voltage divider to do this task as we are shown in Figure 4.3.

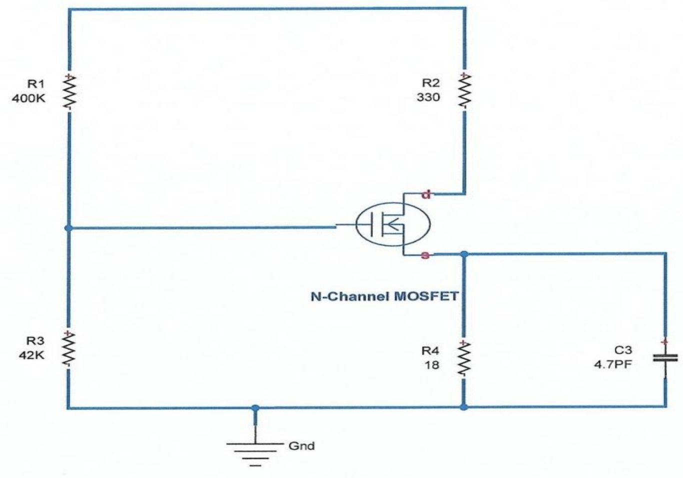

Figure 4.3: The stability circuit of power amplifier

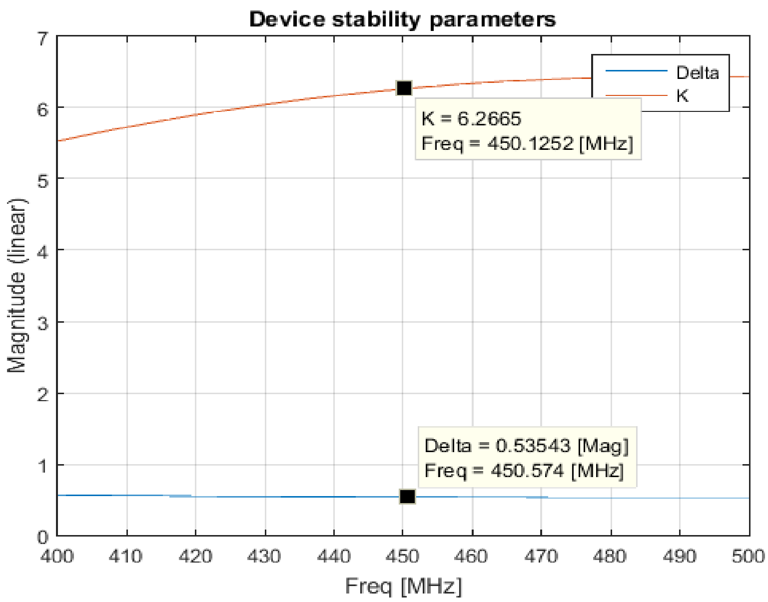

Figure 4.4: The result of stability test

The stability test is dependent on ROLLET's criteria. The formula of stability factor (K) is given below;

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{21}S_{12}|} \tag{4.1}$$

$$\Delta = |S_{11}S_{22}| - |S_{21}S_{12}| \tag{4.2}$$

Where (K) is stability factor and (Δ) is dominant of scattering matrix.

There are two conditions for this equation;

a. If K > 1 and Δ <1 the RF circuit be unconditionally stable.
b. If K > 1 and Δ >1 the RF circuit unstable.

The final result of our design shows that the RF power amplifier circuit is unconditionally stable. The value of K greater than one and Δ is less than one which means that the Q- point in the active region and our circuit can work in this region without being affected by different conditions, especially temperature.

4.1.2.4 Amplification test for our circuit

According to the circuit in Figure 4.5 , we can be noticed that there is an amplification process occurring;

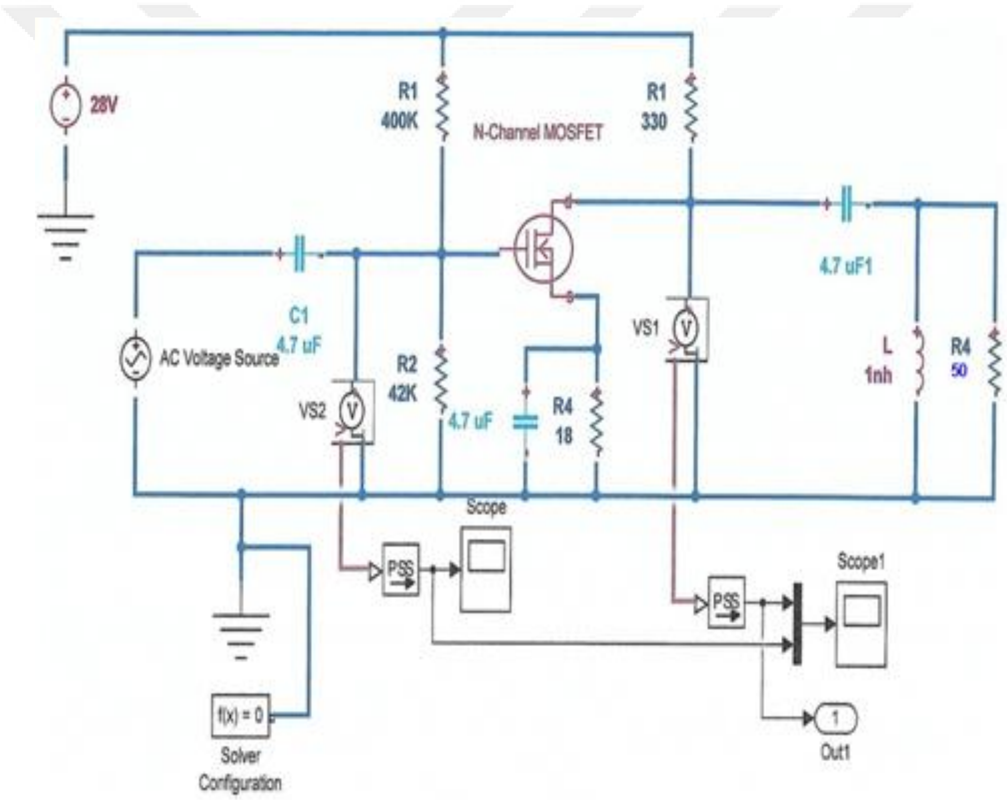

Figure 4.5: Test the amplification of our circuit

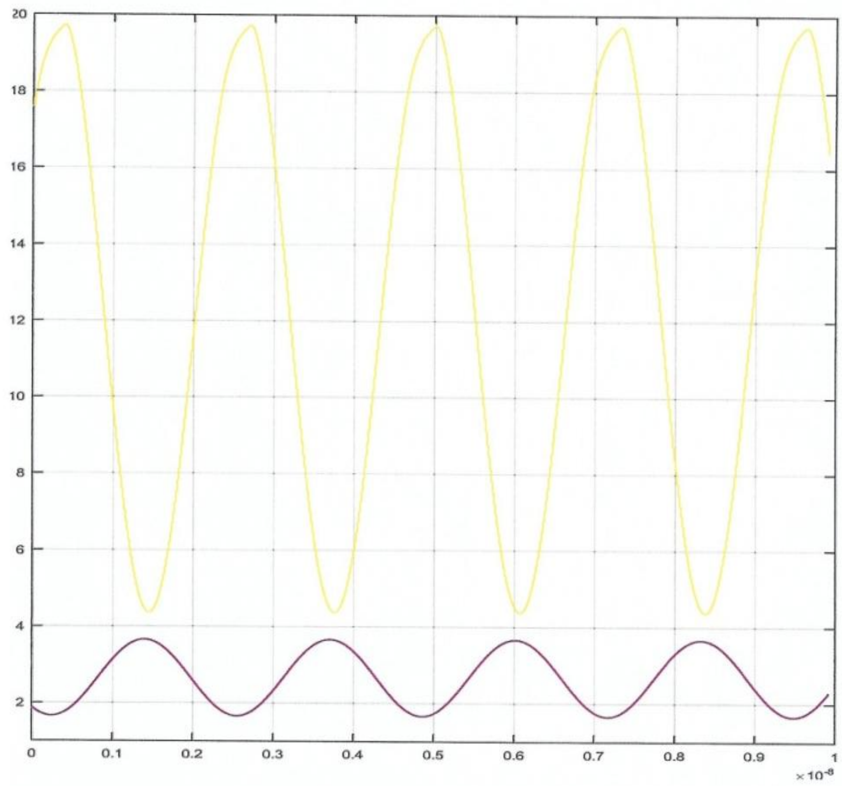

Figure 4.6: Amplification result of our circuit

From the final results, we proved by using MATLAB that this circuit can work as an amplifier. For this circuit, we enter nearly 1.8 volt as an input signal. We noticed that the output was near to 19 volts, which means that there is good amplification for our circuit as shown in Figure 4.6. We can also change the magnitude of the output load to ensure the process.

4.1.2.5 Frequency response or bode plot

As shown in Figure 4.7, we can find the frequency response of our circuit. In this process, we should change the magnitude of frequency 450 MHz to rad/sec accordingly to consider this option in MATLAB. We noticed the 450 MHz equaled $2.826{\times}10^9$ in rad/sec.

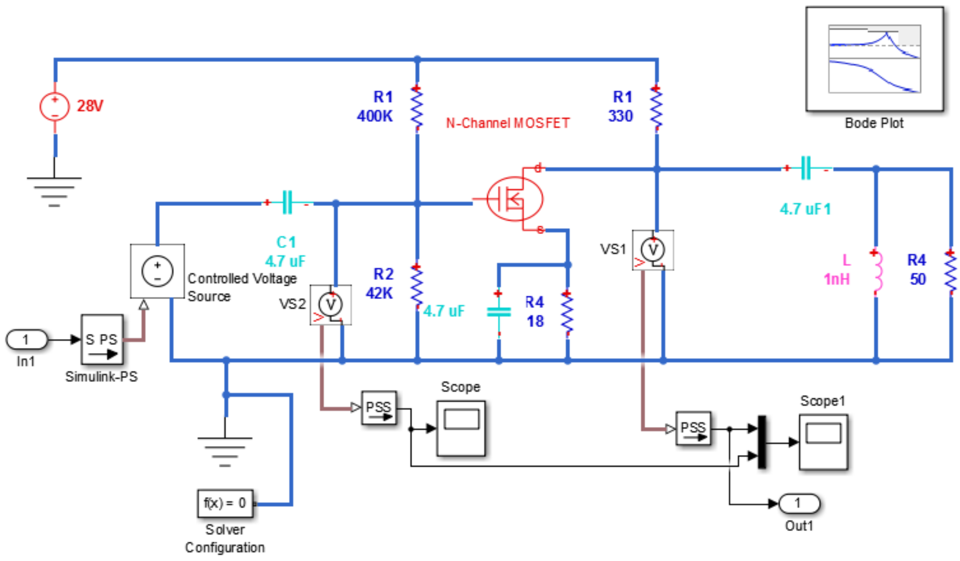

Figure 4.7: The circuit for bode plot (frequency response) for our design

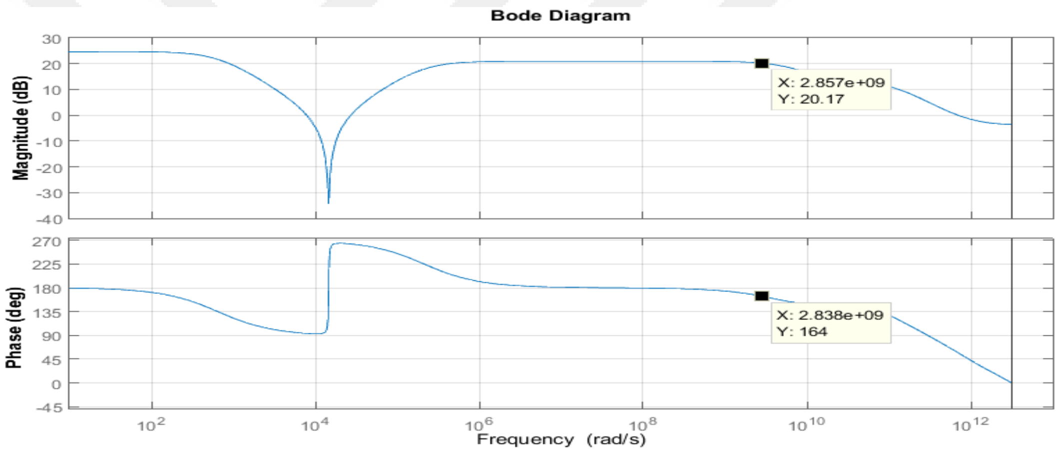

Figure 4.8: The frequency response result

From the figure 4.8, we draw the relationship between frequency and (magnitude, phase) of the output signal from our circuit. We noticed at for the 450 MHz that equaled 2.826×10^9 in rad/sec there is 20.17 dB amplitude of the output signal and 164-degree phase. That means this circuit succeeds of amplification at 450 MHz as shown in Figure 4.8.

4.1.2.6 Matching circuit

From any RF device, we need to use the matching circuit to transfer maximum power from the input port to the output port. As we know, there are many important parameters for power amplifiers such as gain, efficiency, output power, bandwidth, and linearity. According to the requirements of our design, we need to use the BPF for both sides of our circuit as we have shown in 4.9 [28].

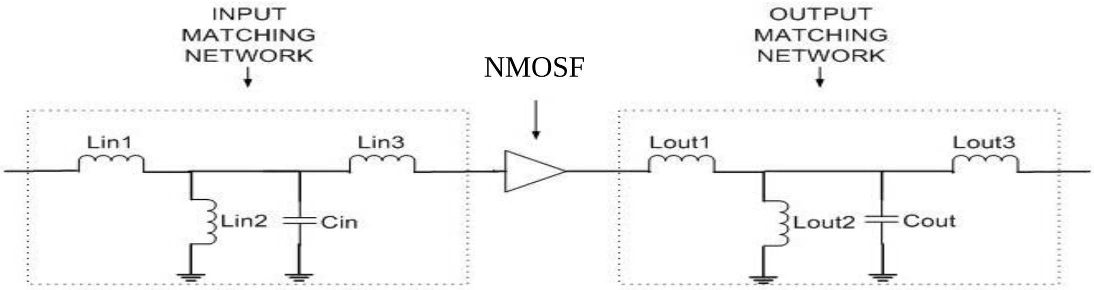

Figure 4.9: Matching impedance for input, output port

As shown above, we used LC lumped elements to allow the frequency band (400-500) MHz pass through this circuit with good magnitudes for all parameters of the power amplifier.

As we know, designers cannot maximize all values for a circuit such as output power, gain, and efficiency, therefore, that designers attempt to make a tradeoff between the magnitudes of all parameters and their focus on some of them as needed by the applications.

In MATLAB, as discussed in the previous chapter, the designer can use the optimization method for RF device design. For our work, in transmitter the signal should have lower noise. According to this information using optimization is important to increase the gain for our design and obtain NF of less than one [29].

According to the requirements of our design, we used BPF and we adjusted the magnitudes of all elements by following the optimization method in MATLAB. Actually, we discussed this operation previously and used the initial magnitudes for elements at first. The final results for all elements of input matching and output matching circuit initially are as below;

Table 4.1: Initial magnitudes for all elements for BPF

The elements	Magnitude
Lin1	10×10^{-6} H
Lin2	10×10^{-6} H
C in	10×10^{-6} F
Lin3	10×10^{-6} H
Lout 1	10×10^{-6} H
Lout 2	10×10^{-6} H
C out	10×10^{-6} F
Lout 3	10×10^{-6} H

And by testing both the noise figure and the transducer gain for our proposed design before the optimization method we obtained the following results;

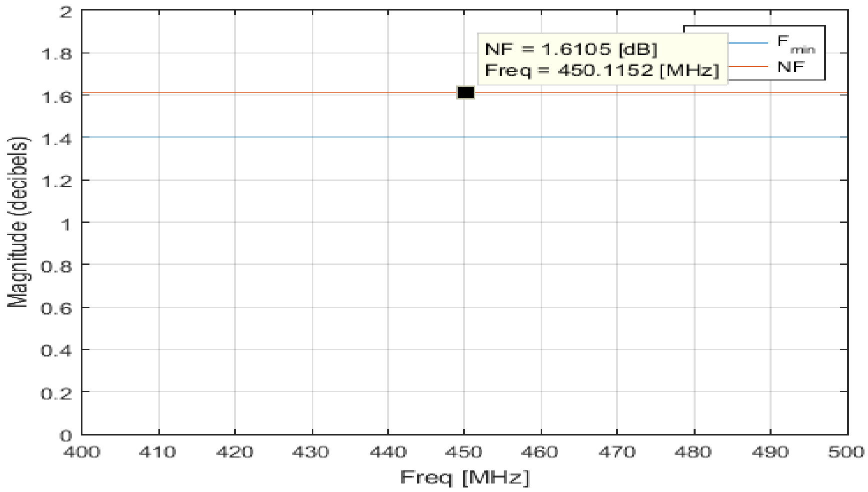

Figure 4.10: Noise figure in circuit before optimization method

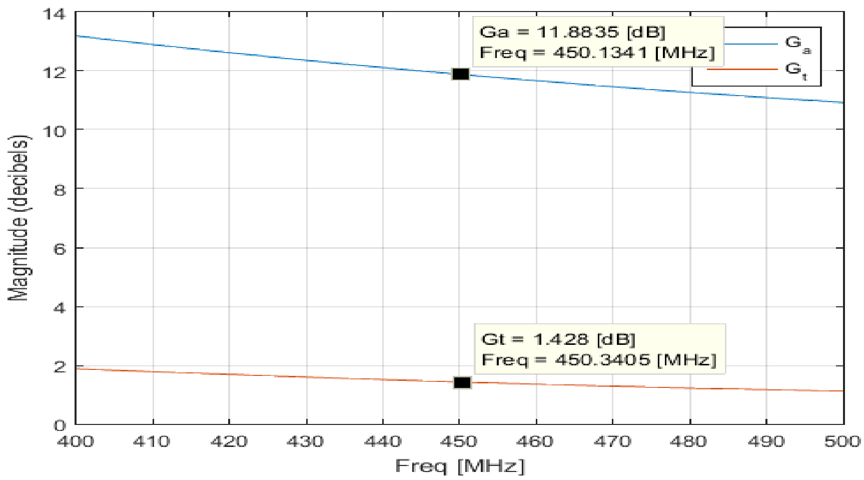

Figure 4.11: Transducer gain in circuit before optimization method

After the optimization we found the following results as shown below;

Table 4.2: Magnitudes the input matching circuit elements

The element	Magnitude
Lin1	1×10^{-6} H
Lin2	0. 01 H
C in	3.7×10^{-12} F
Lin3	0. 17 H

Table 4.3: magnitudes the output matching circuit elements

The element	Magnitude
Lout 1	1×10^{-7} H
Lout 2	0. 63 H
C out	1.25×10^{-12} F
Lout 3	0. 96 H

4.1.2.7 S-parameters

Before the optimization method and depending on the initial magnitudes for all elements of our proposed work we found magnitudes of S-parameters as below;

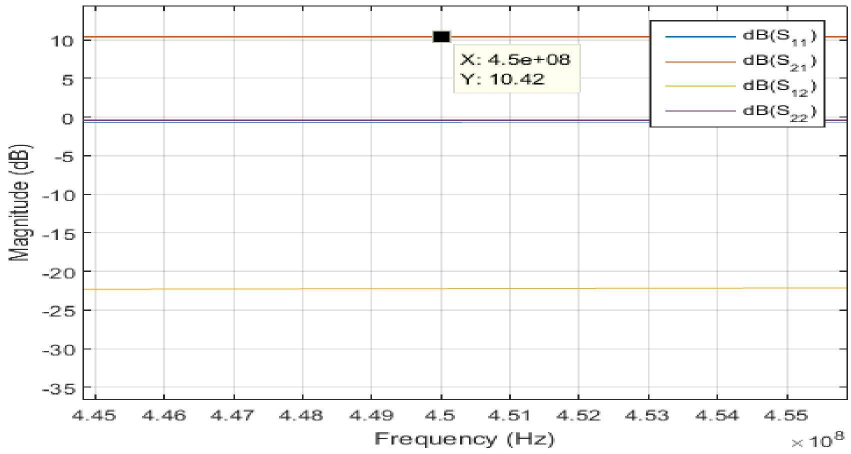

Figure 4.12: The magnitude of S_{21} before optimization

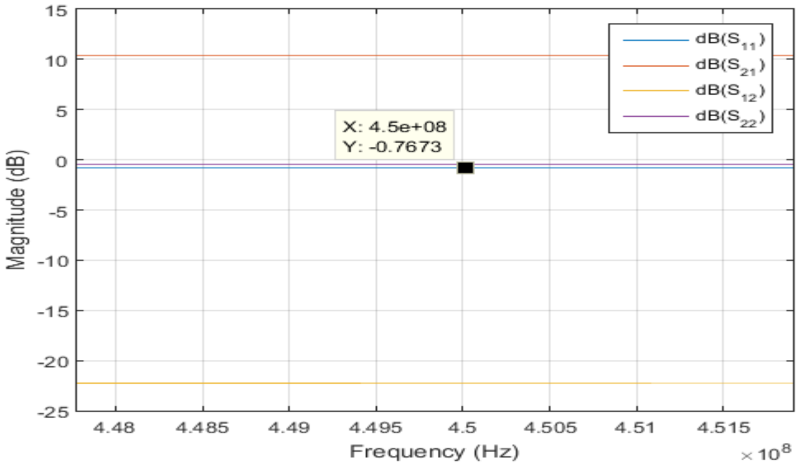

Figure 4.13: The magnitude of S_{11} before optimization

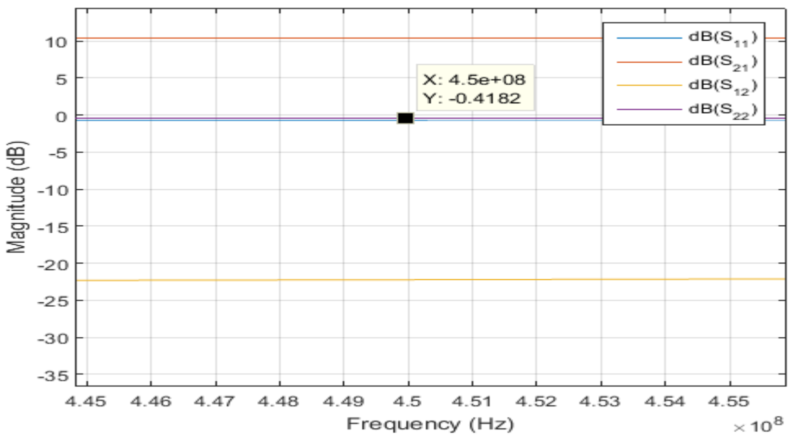

Figure 4.14: The magnitude of S_{22} before optimization

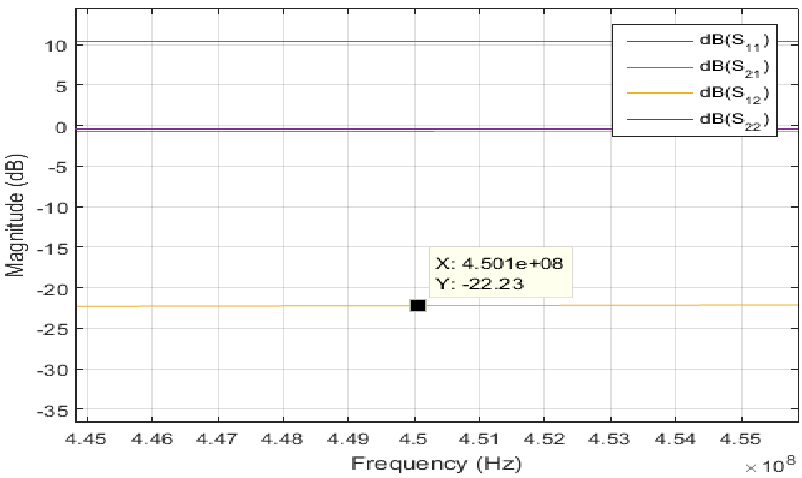

Figure 4.15: The magnitude of S_{12} before optimization

Table 4.4: The magnitudes of S-parameters for power amplifier before optimization

The S-parameters at 450 MHz	Magnitude
S_{11}	- 0.76 dB
S_{21}	10.42 dB
S_{22}	-0.41 dB
S_{12}	-22.23 dB

After matching the impedances and optimizing their magnitudes, we found the S-parameters and others for our power amplifier as shown in Figures 4.16, 4.17, 4.18 and 4.19;

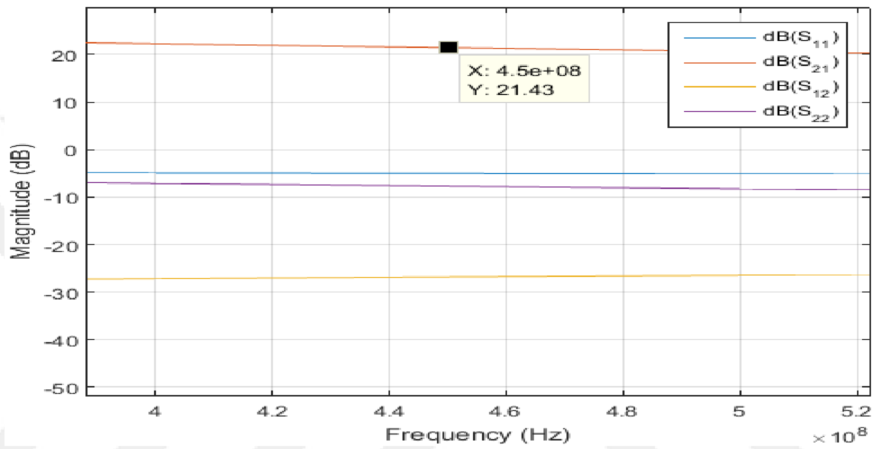

Figure 4.16: The magnitude of S_{21} after optimization

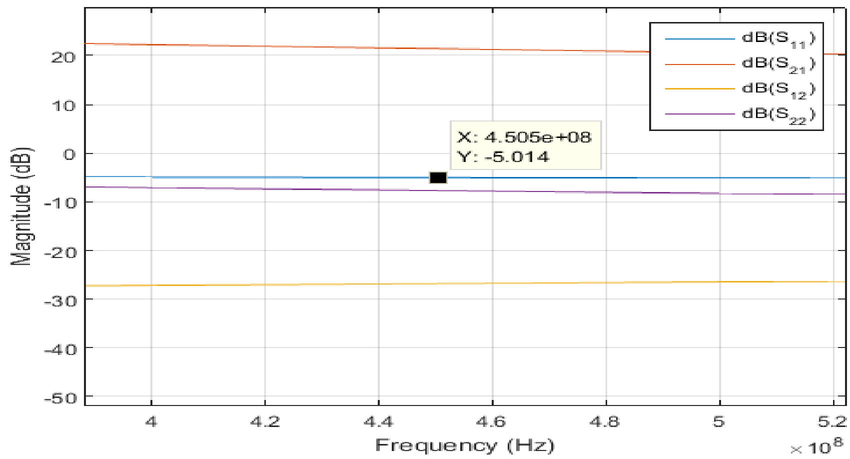

Figure 4.17: The magnitude of S_{11} after optimization

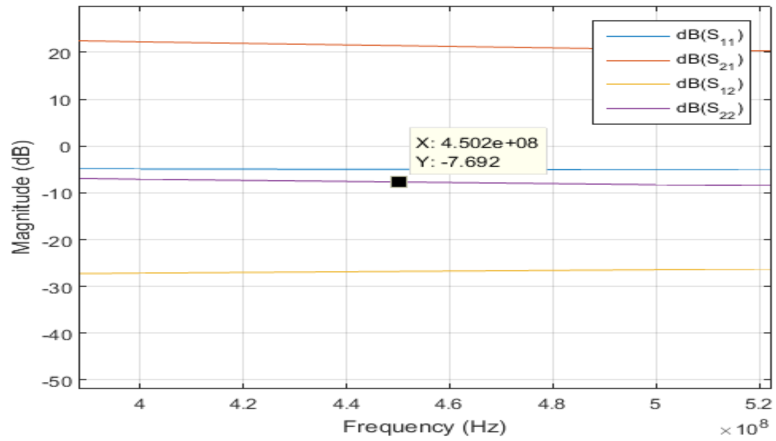

Figure 4.18: The magnitude of S_{22} after optimization

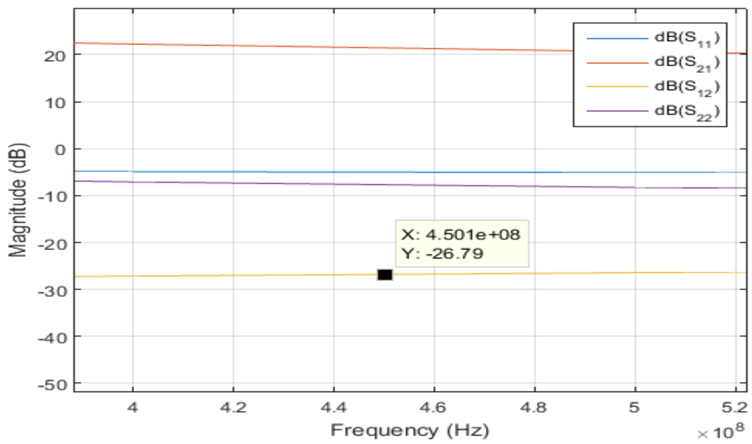

Figure 4.19: The magnitude of S_{12} after optimization

Table 4.5: The magnitudes of S-parameters for power amplifier after optimization

The S-parameters at 450 MHz	Magnitude
S_{11}	-5.01 dB
S_{21}	21.43 dB
S_{22}	-7.69 dB
S_{12}	-26.79 dB

From the schedule above, we have shown that all results after optimization method were good over all the bandwidth. This method will help any designer in the future to select best matching circuit according to the requirements of the design.

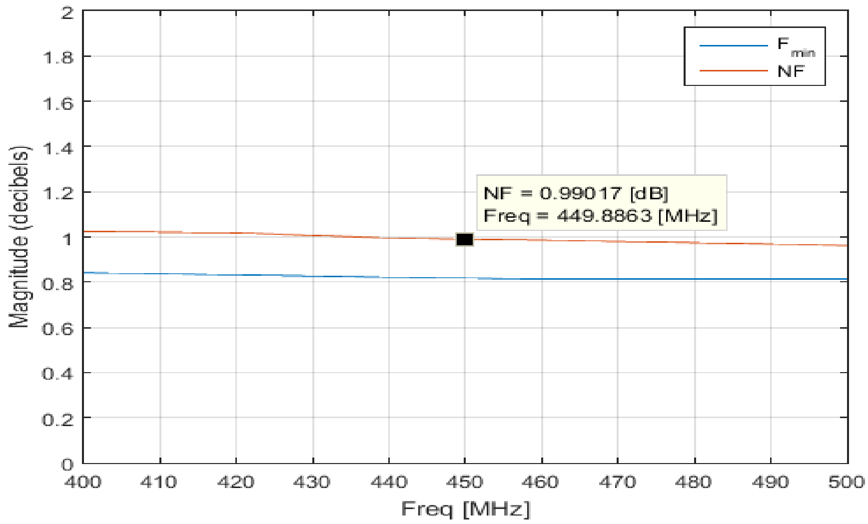

Figure 4.20: Noise figure after optimization method

As shown above, all the results for S-parameters in the 450 MHz were good, meaning that the impedance matching for our design was good. We noticed that the NF prior to optimization method was 1.6 dB, which means that they're high noise in our design which effected on the performance of the amplifier. Using optimization in accordance with the targets of the method, we attempted to increase the magnitudes of the elements and decrease the NF less than 1.

Finally, the NF at an operating frequency of 450 MHz equals 0.99017 dB which represents a good value.

4.1.2.8 Gain

Gain is the output power signal divided by the input power signal, so it is really important parameters. We extracted the gain of our power amplifier according to the matching circuit after optimized it, and the NF should be less than 1.

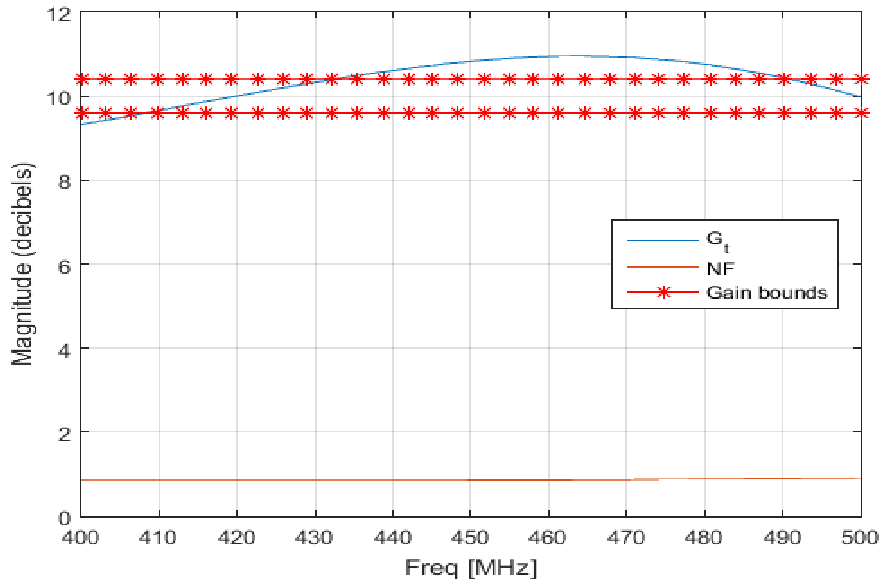

Figure 4.21: The relationship between transducer gain and noise figure during optimization

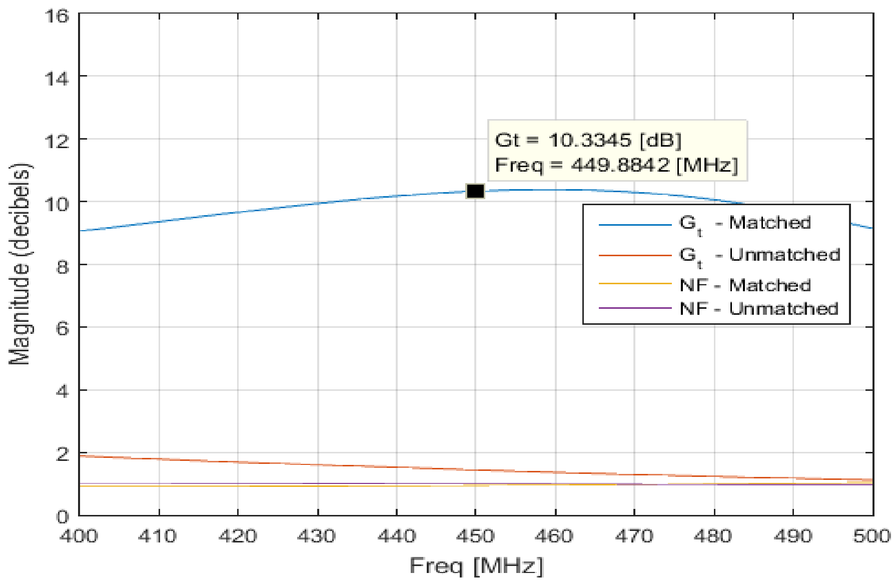

Figure 4.22: The gain of the power amplifier after optimization method

From the results in Figures 4.21,4.22, we can notice that optimization is an important method that can serve the RF devices and according to the requirement of our design. We can limit the target with this method. From the results, we show that the gain was >10dB. The final result was good according to the good matching circuit.

4.1.2.9 Output Power

In MATLAB, there is a good method to find the output power. We used the spectrum analyzer of the circuit and to find the power spectrum density. We set the spectrum analyzer and inserted all the requirements for the circuit. At first, we set the spectrum analyzer to an operating frequency 450 MHz. We ran the optimization method program that represents the relationship between the transducer gain and the noise figure for our design. After finishing optimization method, the magnitudes for all elements of BPF appeared at the end of the operation. Automatically all magnitudes of the lumped elements will go to its locations according to its address. We ran Simulink for our circuit and converted the measurement of the spectrum analyzer at the output power in dBm to calculate the magnitude of it directly.

As we are shown in Figure 4.23, the circuit connected directly with spectrum analyzer at load impedance 50 ohms and read the output power. The output power spectrum analyzer was 27 dB. Because of spectrum analyzer could not support the exact magnitudes of output power in decimal numbers, therefore, we verified the magnitude of output power by using the ADS program to improve our theory and find the difference between the two results.

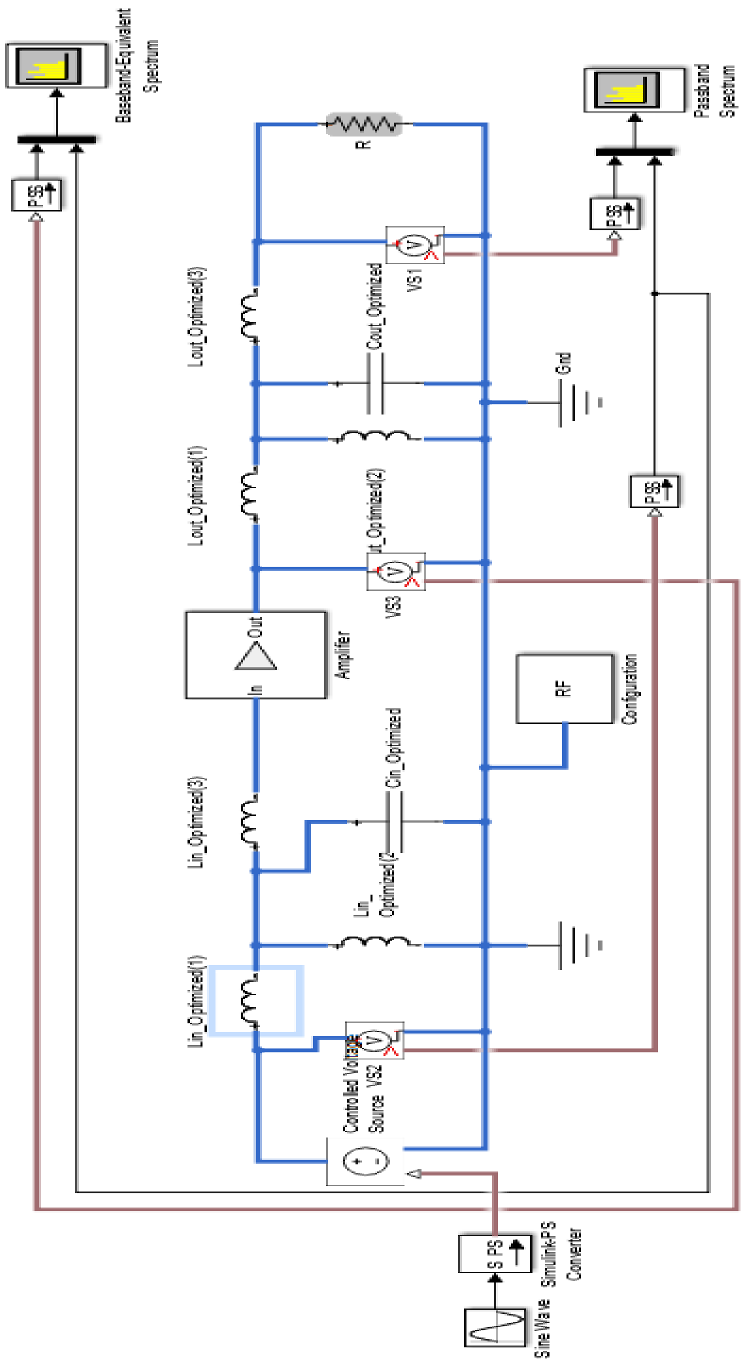

Figure 4.23: The circuit with a spectrum analyzer to find the output power

At first, we ran the optimization method program, then the circuit directly takes all the magnitudes for all elements automatically. Then we run the circuit after setting the spectrum analyzer to work at 450 MHz. The output power for our circuit was as shown in Figures 4.24 and 4.25.

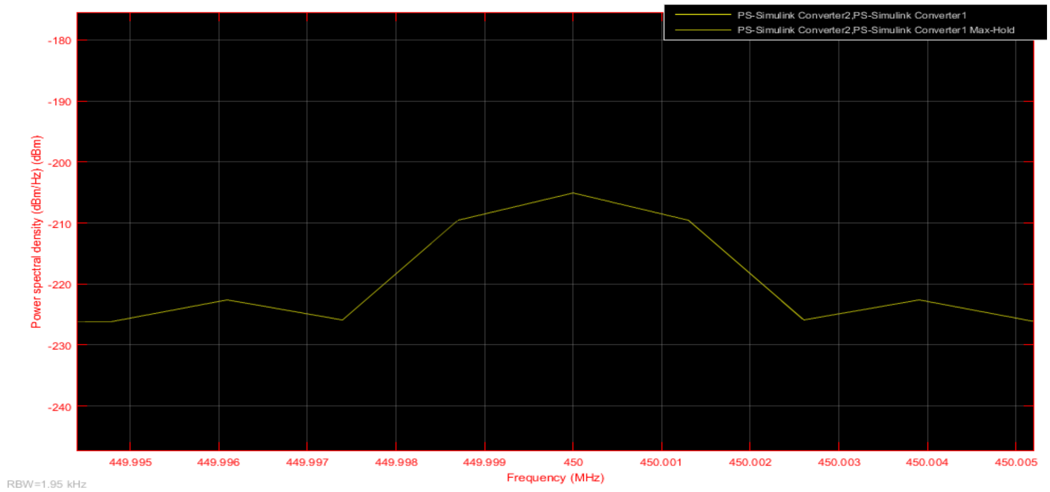

Figure 4.24: The power spectral density of our circuit

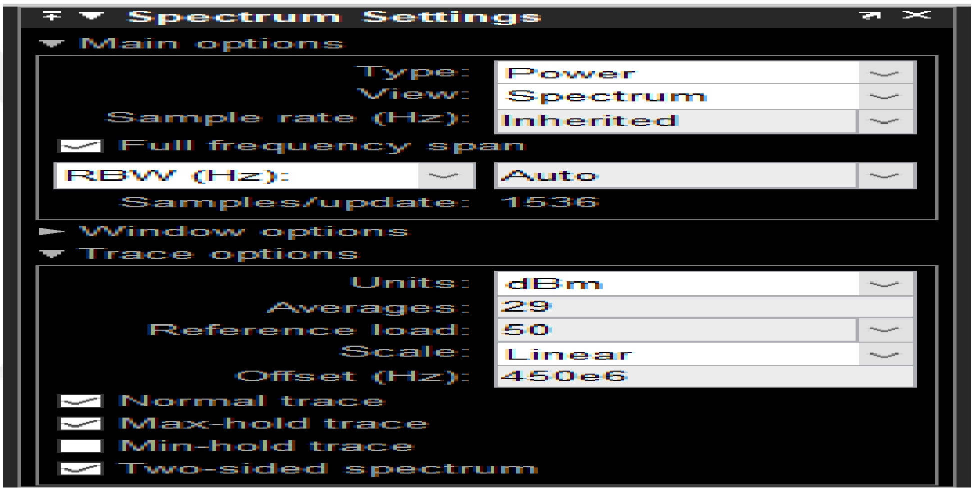

Figure 4.25: Spectrum analyzer took automatically output power

By using the spectral analyzer that automatically converts the power spectral density to output power, we found the output power equaled 29 dBm. We also used the ADS program to verify our output power.

4.1.2.10 Power add efficiency

To find the PAE, we used the ADS program, to ensure our output and find the maximum input power at the 1dB compression point.

We put our circuit into the ADS program with the same magnitudes for every element after the optimization methods by using the one tone load pull method as shown below;

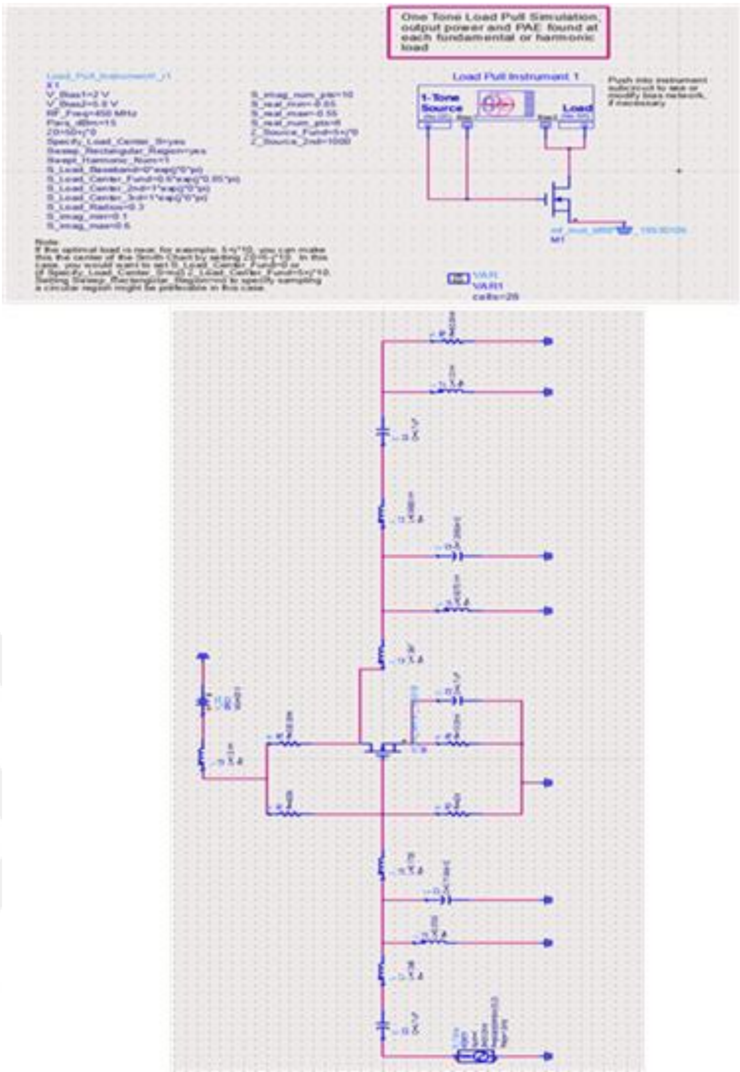

Figure 4.26: The final circuit for our design in ADS with the same magnitudes after optimization

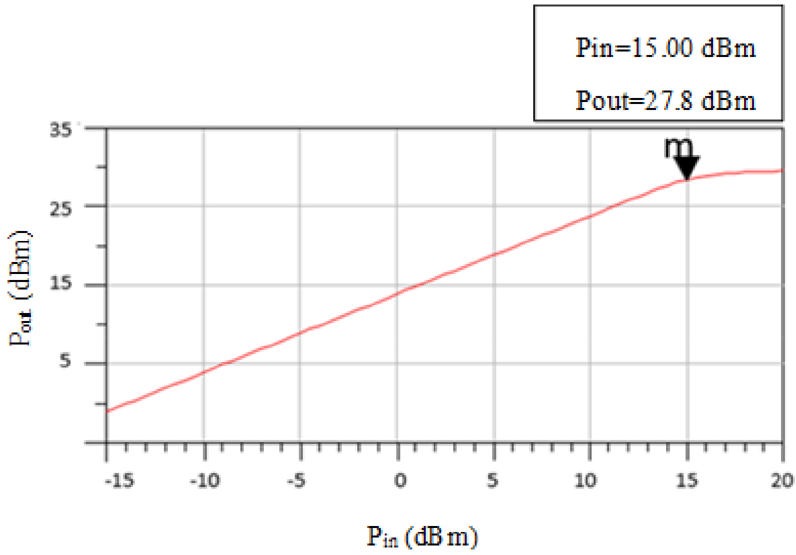

Figure 4.27: The relationship between input power and output power at 1dB compression point

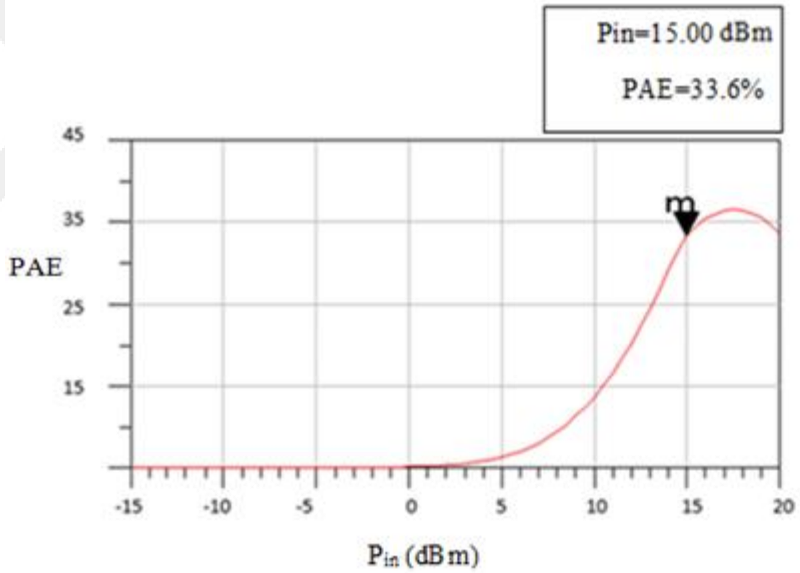

Figure 4.28: Power add efficiency at 1dB compression point

As shown in Table 4.6, after finishing optimization method, we got the table that represents the relationship between the frequency and S-parameters and how the optimization method can be improved all the S-parameters for all the frequency bands [400-500] MHz. After that, we tested our circuit with different frequencies to use inside the neural network. The results were as shown in the Table 4.6;

Table 4.6: Test our circuit with respect to S-parameters for different frequency

Freq-(Hz)	Mag-S_{11}	Angle S_{11}	Mag-S_{21}	Angle S_{21}	Mag-S_{12}	Angle S_{12}	Mag-S_{22}	Angle S_{22}
100×10^6	.753	-49. 4	27.203	148.4	.0213	66.6	.850	-26.1
150×10^6	.722	-51.7	25.303	133.6	0.303	61.0	.760	-30.9
200×10^6	.659	-85.7	21.003	128.3	.0334	53.5	.662	-42.0
250×10^6	.601	-99.7	18.003	120.3	.0355	51.5	.609	-40.0
300×10^6	-42.0	-110	16. 153	115.7	.0396	48.1	.527	-50. 7
350×10^6	.0566	-117	14. 153	110.7	.0404	47.1	.491	-53. 7
400×10^6	.568	-127	12.934	107.4	.0439	46.1	.441	-55.7
450×10^6	.559	-131	11.925	101.4	.0454	46.0	.399	-57.0
500×10^6	. 555	-139.	10.735	101.5	. 0477	45. 8	.386	-58. 9
550×10^6	. 549	-141.	10.723	99.5	. 0478	46. 1	.366	-59. 3
600×10^6	. 543	-147.	9. 109	96. 6	. 0512	46. 5	. 351	-61. 0
650×10^6	. 535	-149.	8. 100	93. 7	. 0522	47. 5	. 339	-61. 3
700×10^6	. 532	-155.	7. 891	92. 8	. 0543	47. 9	. 327	-62. 3
750×10^6	. 531	-157.	6. 944	91. 8	. 0577	48. 9	. 314	-62. 5
800×10^6	.530	161	6. 953	89.4	.0581	49.3	.311	-63.3
850×10^6	.527	162	6. 452	88.3	.0598	49.7	.308	-63.9
900×10^6	.523	-166.	6.221	86.7	.0615	50.3	.298	-64.2
950×10^6	.521	-168.	7.303	87.9	.0688	51.7	.300	-65.3
…	…	...	…	…	…	…	…	…
1.0×10^9	. 522	-171.	5. 676	83. 6	. 0651	51. 3	. 288	-65. 1
1.2×10^9	. 519	-179.	4. 727	78. 5	. 0725	53. 9	. 275	-67. 5
1.4×10^9	. 524	173. 8	4. 072	74. 0	. 0802	55. 4	. 271	-70. 6
1.8×10^9	. 524	163. 3	3. 211	65. 7	. 0959	57. 3	. 276	-74. 8
2.0×10^9	. 528	157. 6	2. 894	61. 9	. 105	58. 5	. 273	-76. 9
2.2×10^9	. 532	151. 9	2. 634	59. 2	. 114	58. 5	. 266	-80. 9
2.4×10^9	. 547	147. 9	2. 423	55. 7	. 120	59. 4	. 267	-86. 3
2.6×10^9	. 544	143. 9	2. 230	52. 0	. 127	59. 8	. 279	-92. 1
2.8×10^9	. 549	140. 7	2. 053	48. 1	. 136	60. 0	. 298	-95. 7
3.0×10^9	. 560	136. 4	1. 957	45. 6	. 145	58. 1	. 308	-97. 6

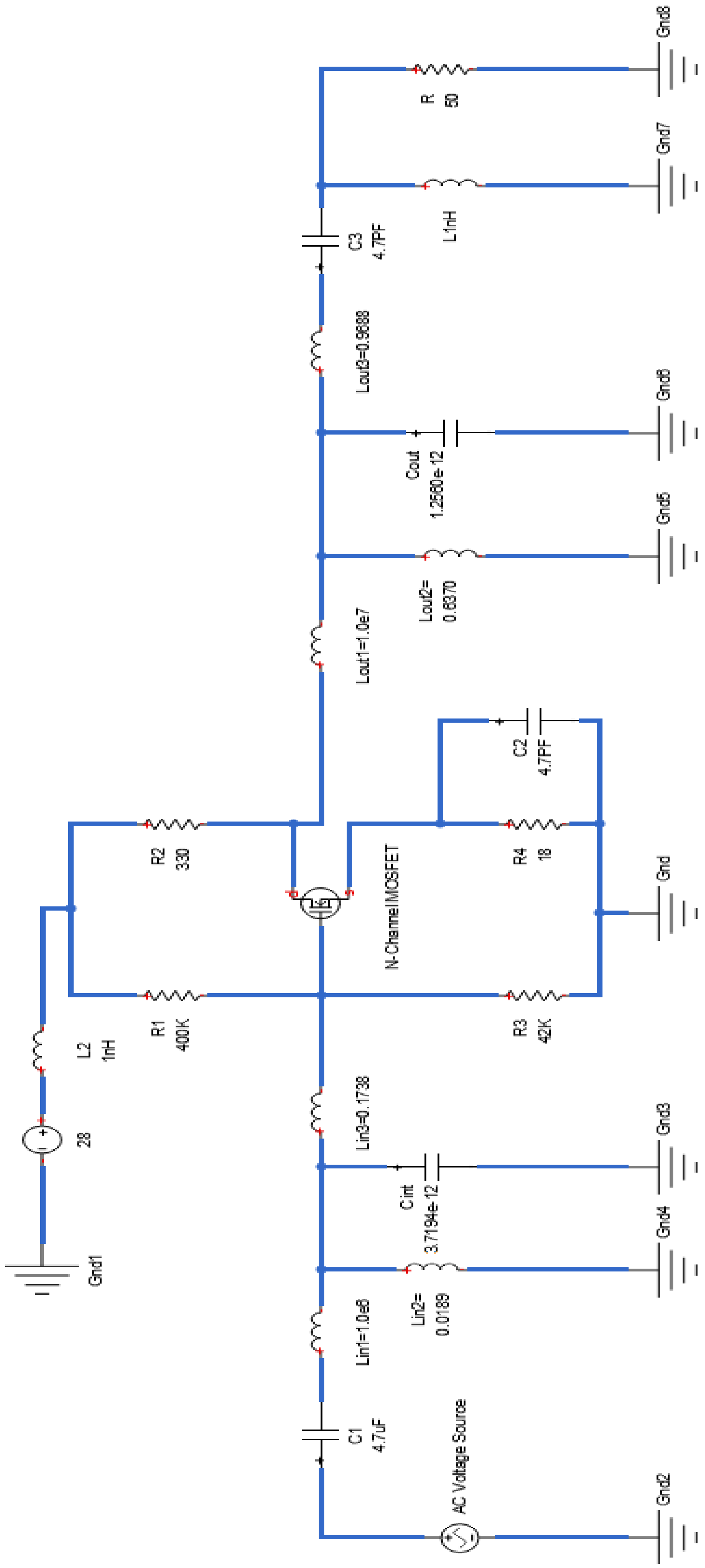

Figure 4.29: The final circuit after optimization method in MATLAB

One of the important parameters in an RF power amplifier is the output power. As shown we need to use a spectrum analyzer to calculate the power spectral density.

The spectral analyzer can automatically find the magnitudes of the output power that we know. The output power was 29 dBm in MATLAB which equals 0.8 W. To verify the output power, we used the ADS Program. We used the same circuit with the same magnitudes for all elements that were found. After optimization method, we found that there was little difference. It was 27.8 dB, which equaled 0.602 W. We found also the power add efficiency at 1dB compression point was 33.6% at an input power equaling 15 dBm. We found the PAE at DC power equaled 32.4 dBm. The drain efficiency equaled 85.8%. We want to say that using the optimization method was a good method for finding the magnitudes of all elements of matching impedance without losing time or complicated mathematical statistics.

4.2 Simulation results for test data of an S-parameter using MLP

The MLP model for the proposed method is shown in Figure 4.30. As seen in this figure the 2-hidden layer is used. For the input, the 3 parameters are selected. These parameters were the drain-source voltage (V_{DS}), the drain-source current (I_{DS}) and frequency. For output, the magnitudes and angles for all S-parameters are selected. For the first hidden layer, 10 neurons are used. Additionally, for the activation function the logarithm sigmoid is used for both hidden layers and for the last layer the linear function was used.

By using the same magnitudes for the S-parameters in Table 4.5 as training data in our model we found according to our model the following results;

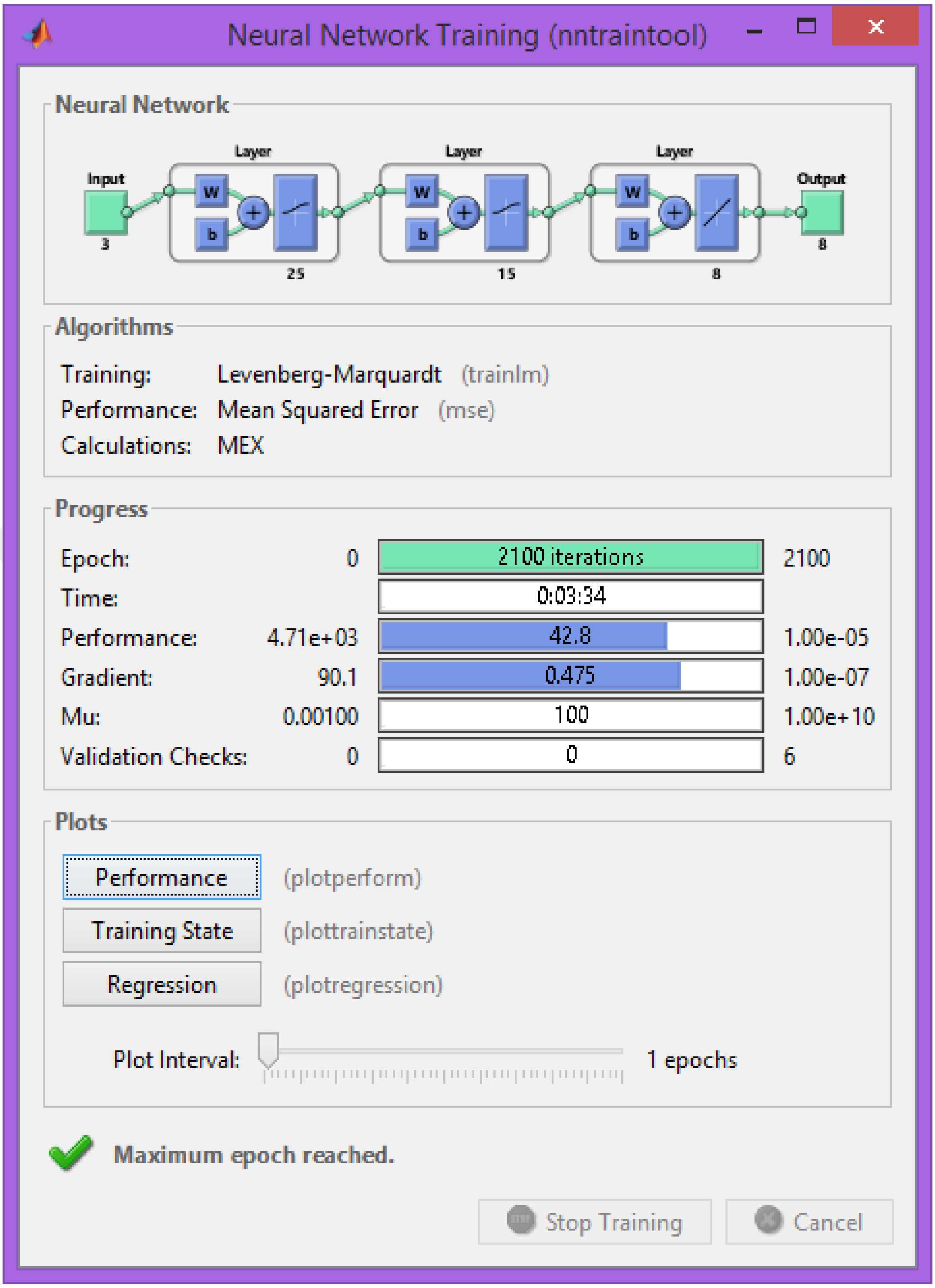

Figure 4.30: The MLP model for test data for our proposed work

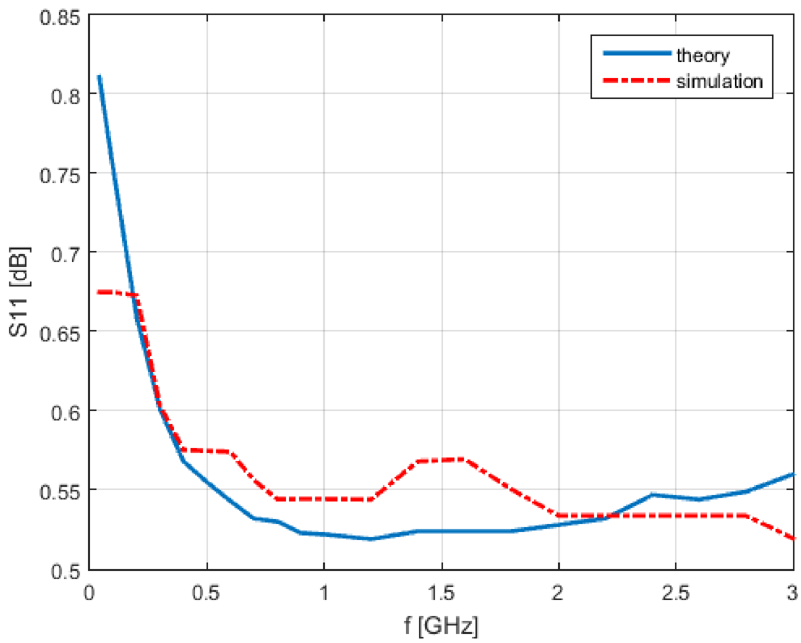

Figure 4.31: The magnitude of S_{11} [dB]

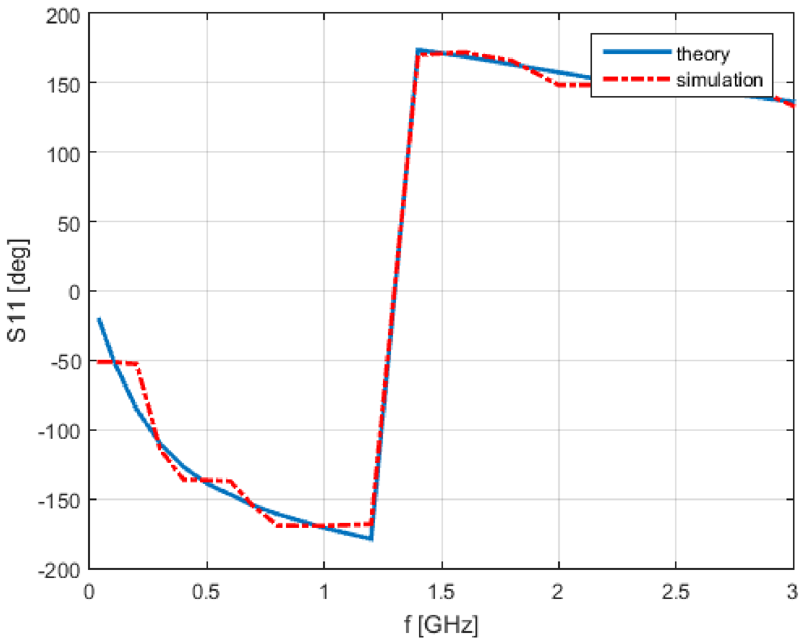

Figure 4.32: The angle of S_{11} [deg]

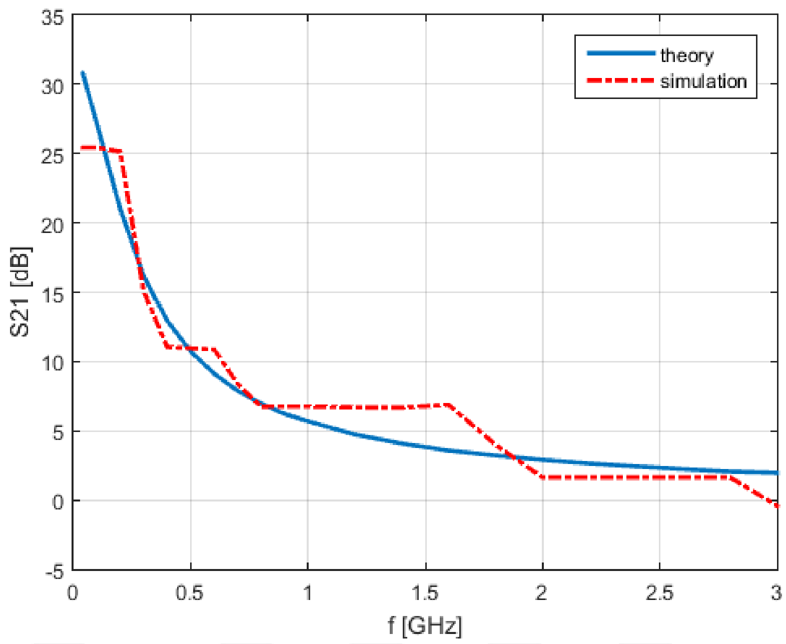

Figure 4.33: The magnitude of S_{21} [dB]

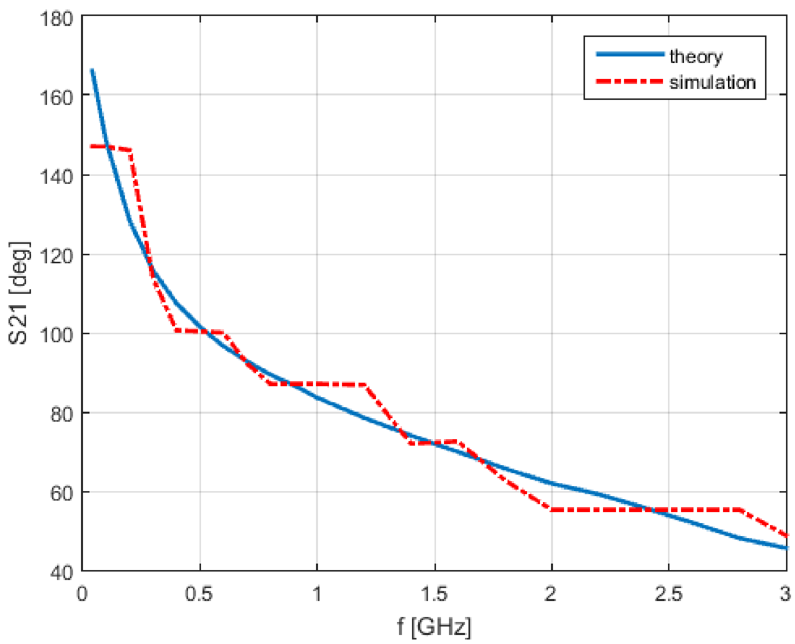

Figure 4.34: The angle of S_{21} [deg]

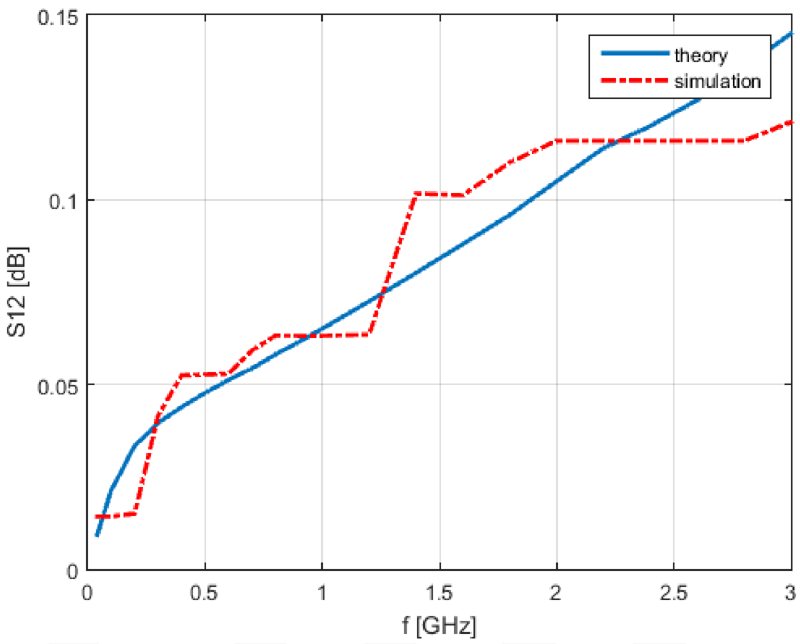

Figure 4.35: The magnitude of S_{12} [dB]

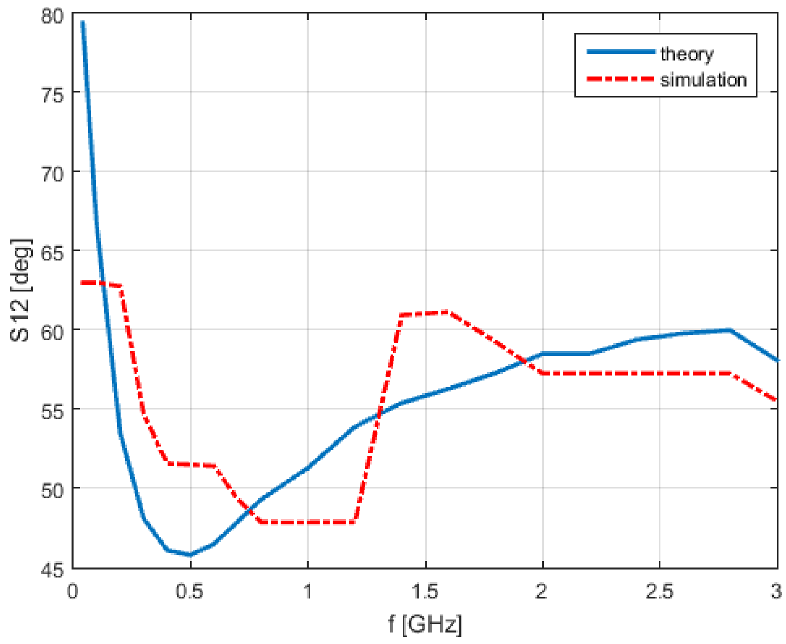

Figure 4.36: The angle of S_{12} [deg]

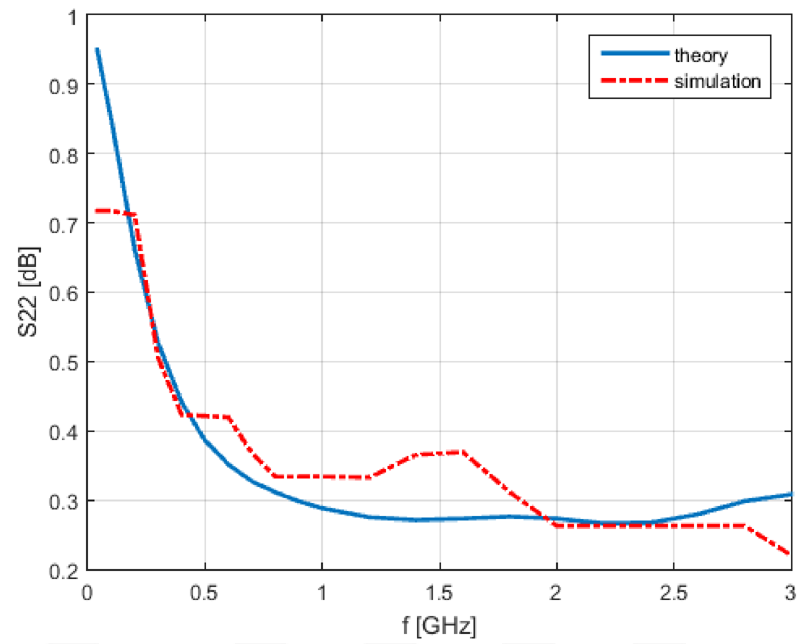

Figure 4.37: The magnitude of S_{22} [dB]

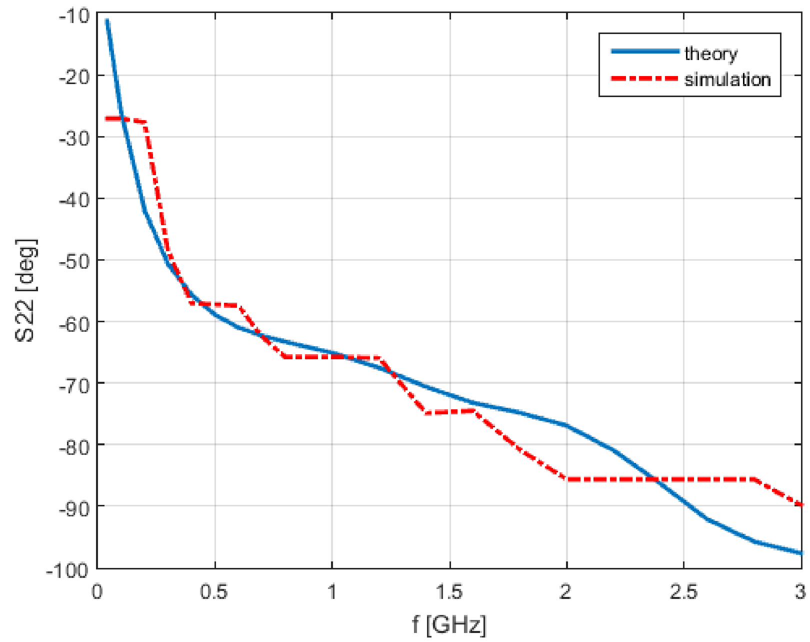

Figure 4.38: The angle of S_{22} [deg]

4.3 Simulation Results for Test Data of S-Parameter Using RBF

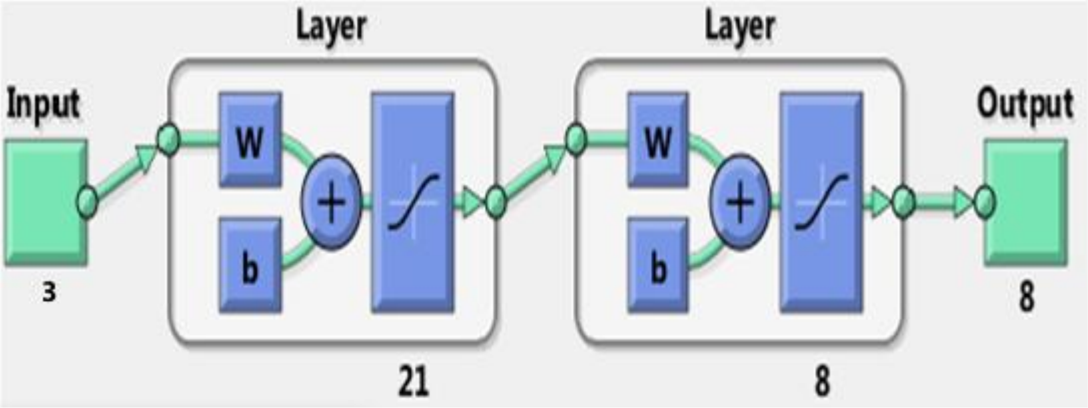

Figure 4.39: The RPF model for test data for our proposed work

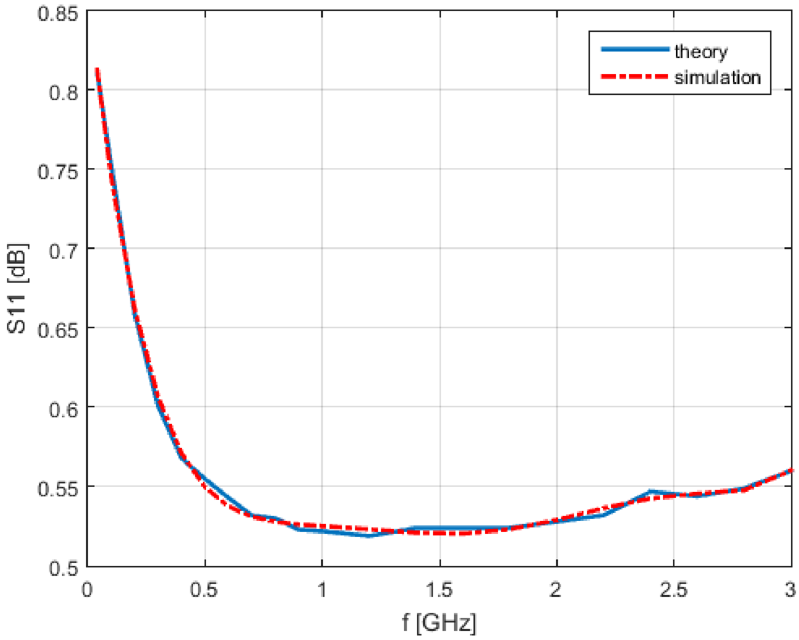

Figure 4.40: The magnitude of S_{11} [dB]

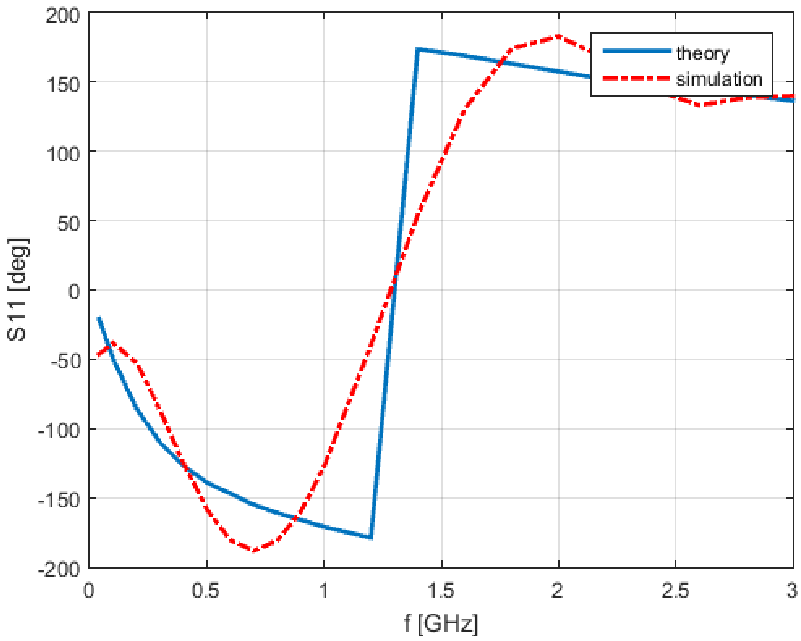

Figure 4.41: The angle of S_{11} [deg]

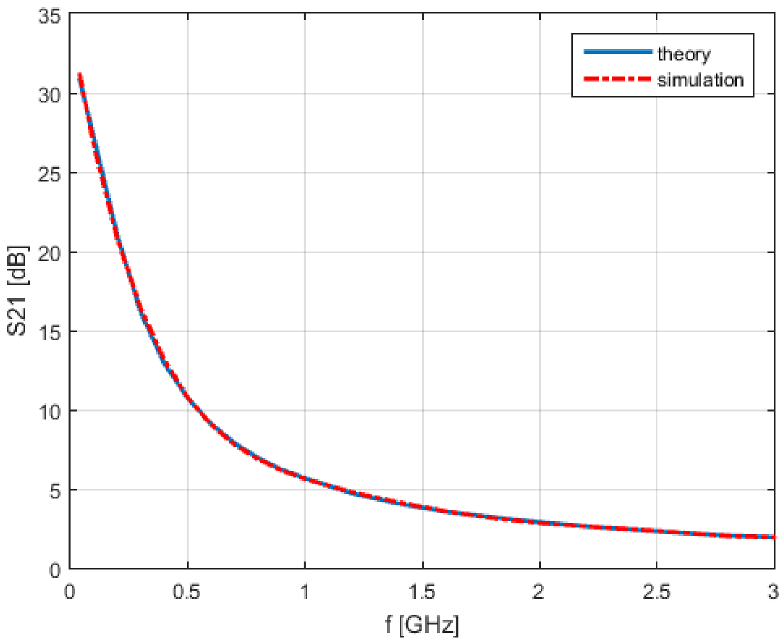

Figure 4.42: The magnitude of S_{21} [dB]

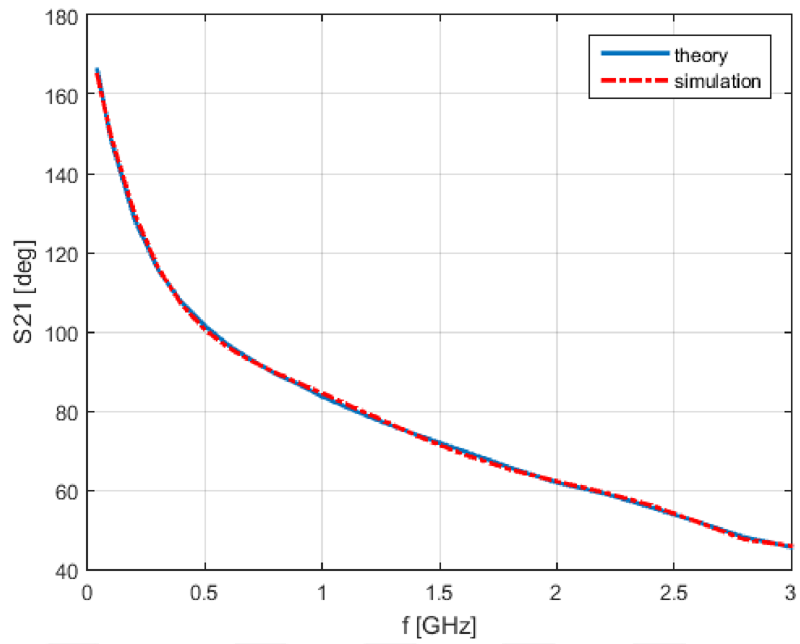

Figure 4.43: The angle of S_{21} [deg]

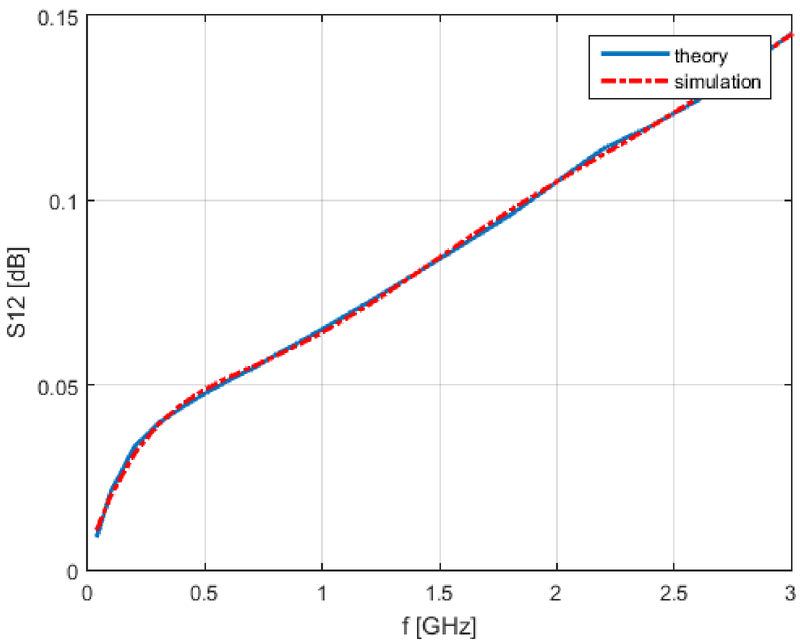

Figure 4.44: The magnitude of S_{12} [dB]

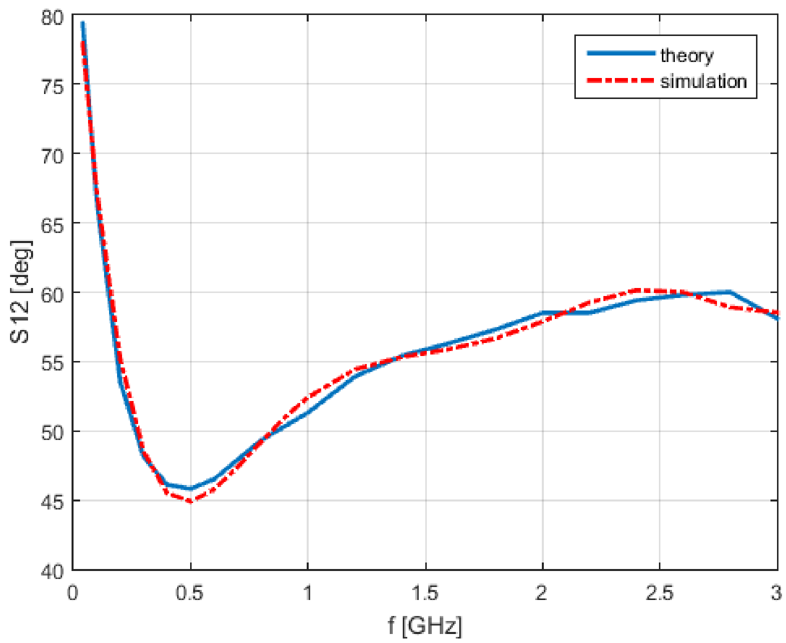

Figure 4.45: The angle of S_{12} [deg]

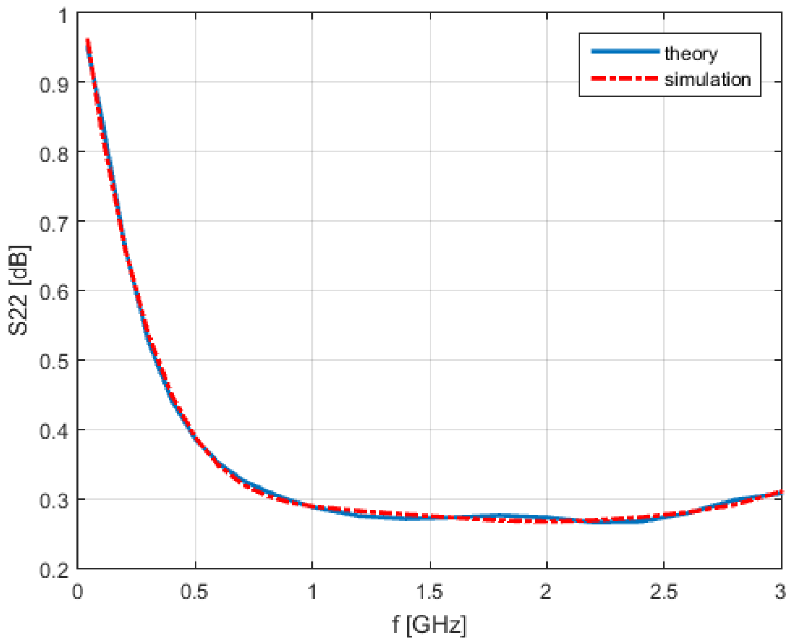

Figure 4.46: The magnitude of S_{22} [dB]

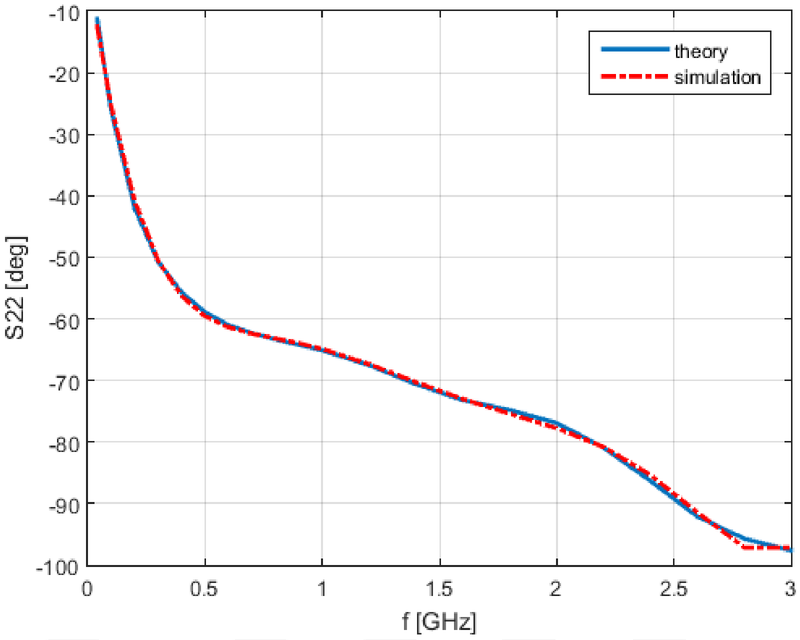

Figure 4.47: The angle of S_{22} [deg]

We selected 8 samples of the S-parameters at center frequency 450 MHz to test the MLP model and shown the difference between the test output and the predicted output. We found the results as shown in Table 4.7;

Table 4.7: The results test for data using MLPNN

Sequence	S-parameters at 450MHz	Test output data	Neural network predicted output
1	Mag- S_{11}	0.56	0.60
2	Ang- S_{11}	-133	-132.7
3	Mag- S_{21}	11.38	13.28
4	Ang- S_{21}	104.5	107.8
5	Mag- S_{12}	0.04	0.04
6	Ang- S_{12}	45.95	53.21
7	Mag- S_{22}	0.40	0.478
8	Ang- S_{22}	-57.31	-55.42

When we repeated the same test for 450 MHz by using RBFNN we obtained;

Table 4.8: The results for test data using RBFNN

Sequence	S-parameters at 450MHz	Test output data	Neural network predicted output
1	Mag- S_{11}	0.56	0.56
2	Ang- S_{11}	-133	-141.70
3	Mag- S_{21}	11.38	11.96
4	Ang- S_{21}	104.5	104.5
5	Mag- S_{12}	0.04	0.04
6	Ang- S_{12}	45.95	45.19
7	Mag- S_{22}	0.40	0.41
8	Ang- S_{22}	-57.31	-57.93

In order to show the accuracy of our models to support RF power amplifier design, we used some error factors like RMSE and MAE which have the following equations;

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} \left| Y_{real} - Y_{pridected} \right|^2}{N}} \tag{4.3}$$

$$MAE\% = 100 \times \frac{1}{N} \sum_{i=1}^{N} \left| Y_{real} - Y_{pridected} \right| \tag{4.4}$$

Where;

RMSE = Root Mean Square Error

MAE = Mean Absolute Error

N = Number of data that used to test

Y_{real} = Real data for design

$Y_{predicted}$ = Predicted data for neural network

By using both of these error factors, we found the following results as shown in Table 4.9.

Table 4.9: The comparison between MLP and RBF results

The model	Error factors	The results
MLPNN	RMSE	5.21
MLPNN	MAE%	1.83%
RBFNN	RMSE	3.35
RBFNN	MAE%	1.18%

As we have shown above, both of the models appeared high performance, according to the low errors for both of them. To compare between them, we found RBFNN gave us high accuracy with respect to MLPNN.

4.4 Simulation Results for 010168 Power Amplifier of S-Parameter Using MLP

The MLP model of the proposed method is shown in Figure 4.48. As seen in this figure the 2 hidden layers are used. For the input, the 3 parameters are selected. These parameters were the drain-source voltage (V_{DS}), the drain-source current (I_{DS}) and frequency. For output, the magnitudes and angles for all S-parameters are selected. For the first hidden layer, 10 neurons are used. For the second hidden layer, 10 nodes are used. Additionally, for activation function the logarithm segment is used for both hidden layers. For the last layer, the linear function is used.

Table 4.10: Some samples of S-parameters for 010168 power amplifiers

Freq-(Hz)	Mag-S_{11}	Angle S_{11}	Mag-S_{12}	Angle S_{12}	Mag-S_{21}	Angle S_{21}	Mag-S_{22}	Angle S_{22}
10×10^6	-1.357	177.339	-78.127	56.325	-87.909	87.11	-0. 614	177.315
20×10^6	-1.381	174.827	-77.163	76.028	-76.425	33.548	-0.638	174.827
30×10^6	-1.391	172.355	-67.505	51.906	-85.824	58. 524	-0. 655	172. 37
40×10^6	-1.402	169. 87	-61. 502	55. 964	-82. 554	-5. 305	-0. 664	169. 91
50×10^6	-1.412	167. 41	-54. 804	51. 262	-79. 813	-7. 848	-0. 672	167. 42
60×10^6	-1.42	164. 92	-48. 61	43. 745	-77. 042	27. 374	-0. 688	164. 97
70×10^6	-1.435	162. 39	-42. 542	33. 598	-76. 802	-6. 852	-0. 7	162. 54
80×10^6	-1.449	159. 92	-36. 646	19. 03	-77. 76	-13. 841	-0. 711	159. 98
90×10^6	-1.46	157. 42	-31. 339	0. 738	-77. 935	22. 733	-0. 725	157. 48
100×10^6	-1.481	154. 93	-26. 813	-20. 722	-73. 322	28. 909	-0. 743	154. 93
...	…	…	…	…	…	…	…	…
7.91×10^9	-0.769	-1909. 6	-55. 366	-2694. 7	-55. 183	-1611. 3	-2. 55	-946. 22
7.92×10^9	-0.776	-1910. 8	-55. 016	-2695. 6	-55. 291	-1614	-2. 557	-948. 19
7.93×10^9	-0.775	-1912. 1	-55. 326	-2696. 4	-55. 307	-1612. 9	-2. 568	-950. 11
7.94×10^9	-0.779	-1913. 3	-54. 977	-2700. 0	-54. 979	-1618. 3	-2. 593	-952. 10
7.95×10^9	-0.782	-1914. 6	-55. 208	-2702. 3	-55. 293	-1621. 7	-2. 617	-954. 07
7.96×10^9	-0.786	-1915. 8	-54. 841	-2704. 2	-54. 868	-1621. 8	-2. 644	-956. 11
7.97×10^9	-0.787	-1917. 1	-54. 856	-2707. 5	-54. 825	-1623. 4	-2. 662	-958. 17
7.98×10^9	-0.793	-1918. 3	-54. 854	-2712. 2	-55. 095	-1628. 0	-2. 676	-960. 22
7.99×10^9	-0.801	-1919. 6	-54. 93	-2709. 0	-54. 948	-1630. 4	-2. 69	-962. 32
8.00×10^9	-0.812	-1920. 8	-55. 009	-2715. 7	-55. 249	-1632. 1	-2. 701	-964. 36

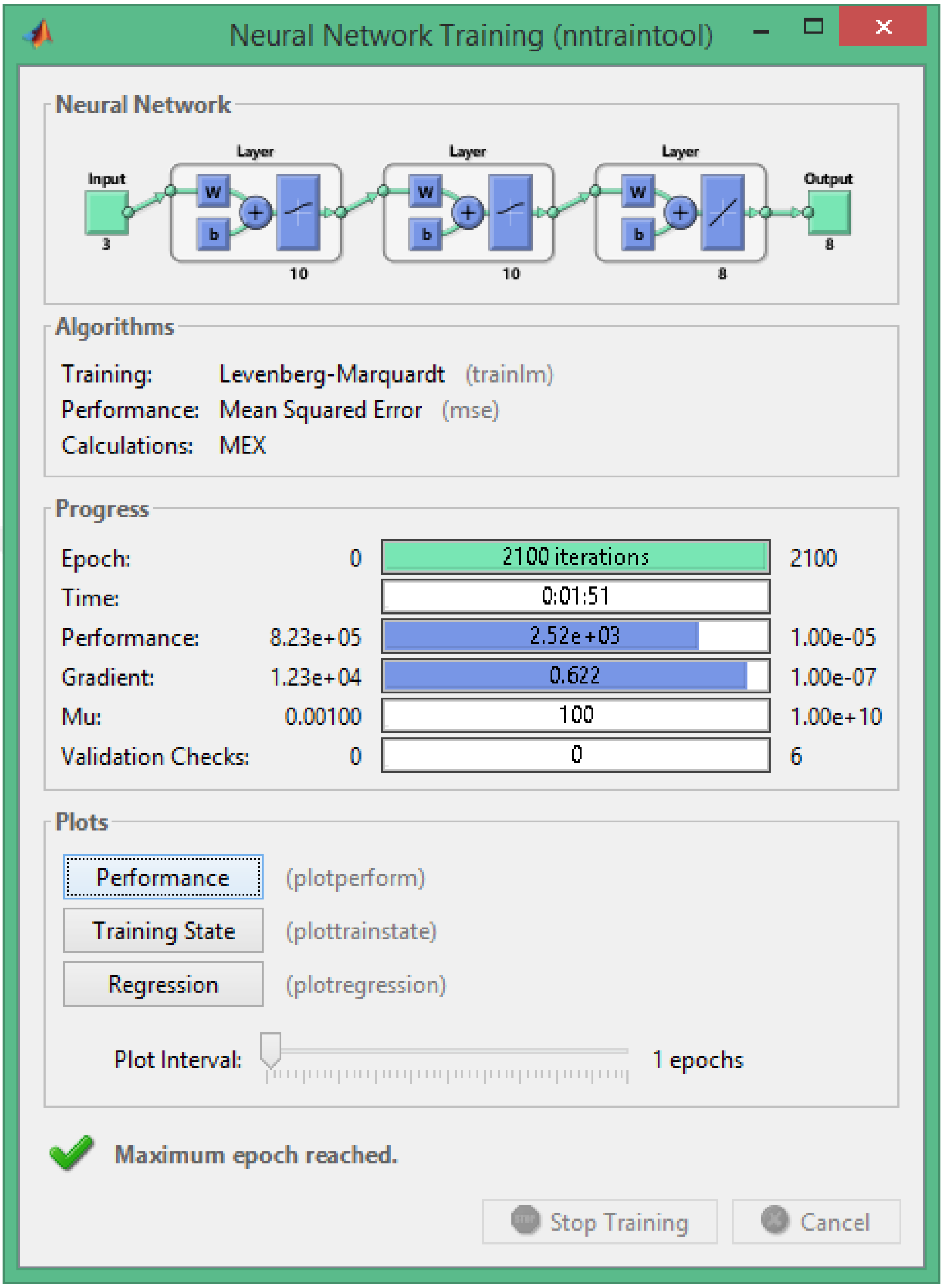

Figure 4.48: The MLPNN for 010168 power amplifier testing

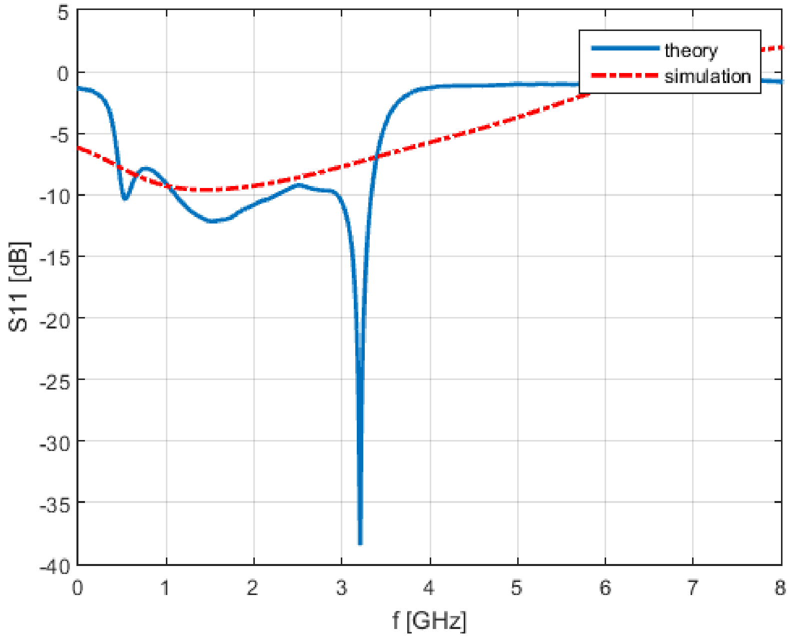

Figure 4.49: The magnitude of S_{11} [dB]

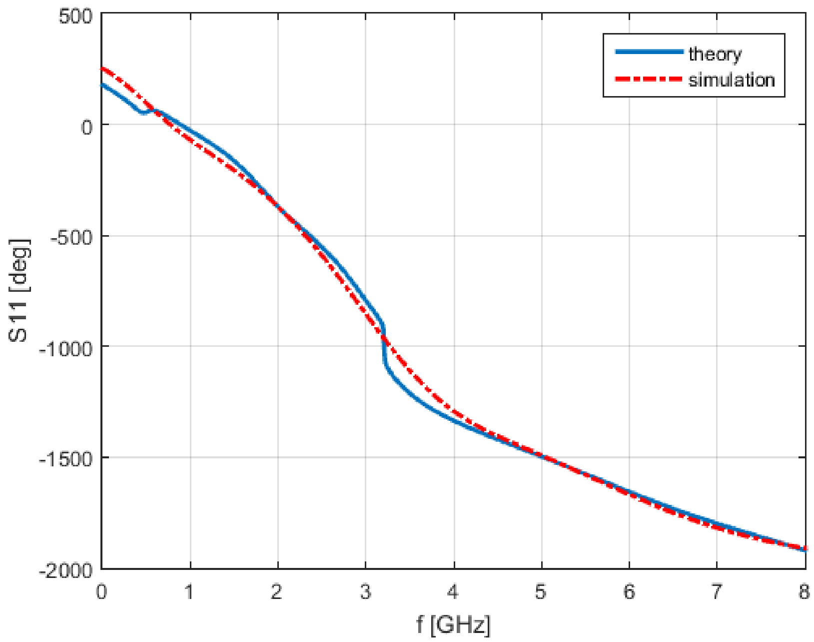

Figure 4.50: The angle of S_{11} [deg]

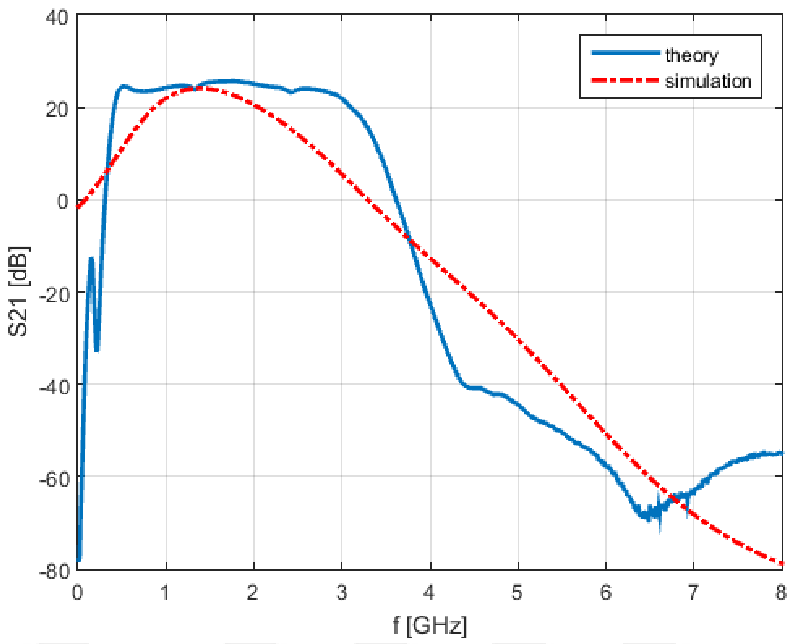

Figure 4.51: The magnitude of S_{21} [dB]

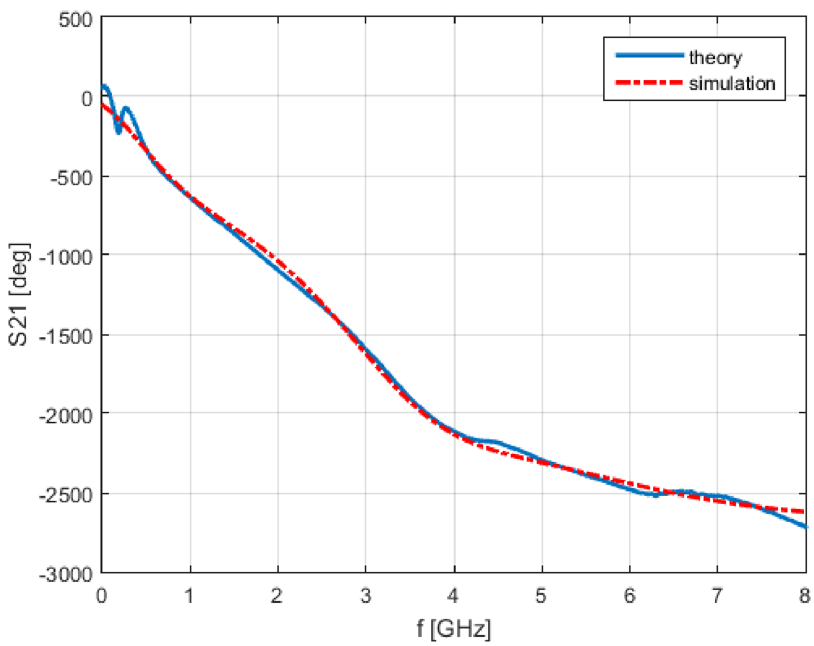

Figure 4.52: The angle of S_{21} [deg]

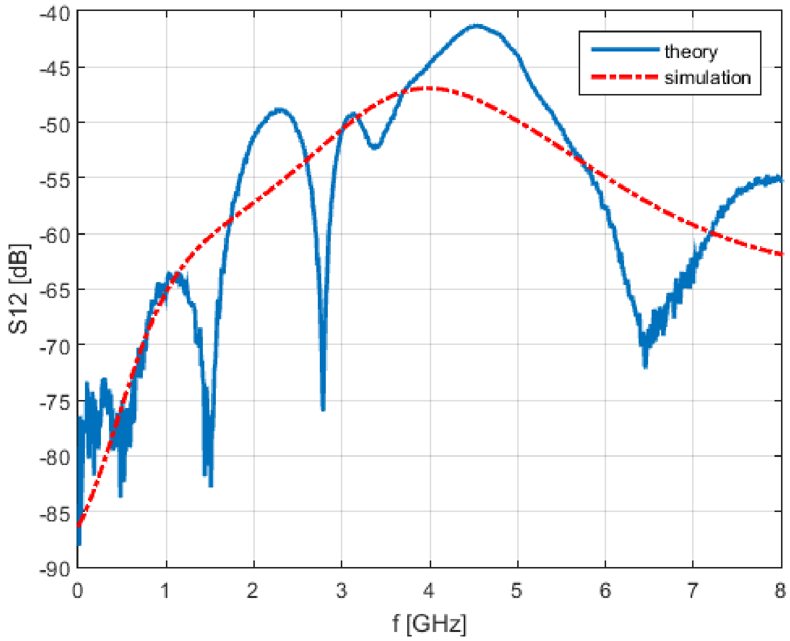

Figure 4.53: The magnitude of S_{12} [dB]

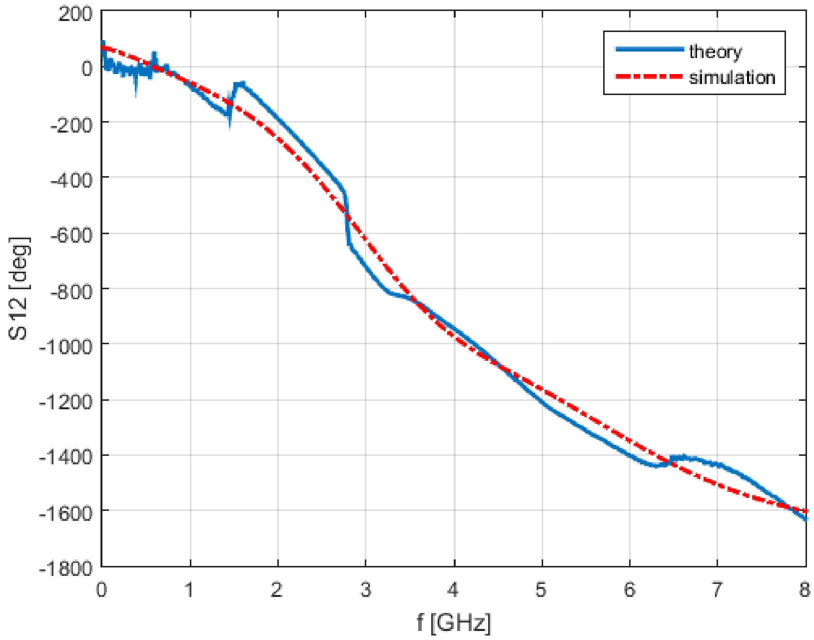

Figure 4.54: The angle of S_{12} [deg]

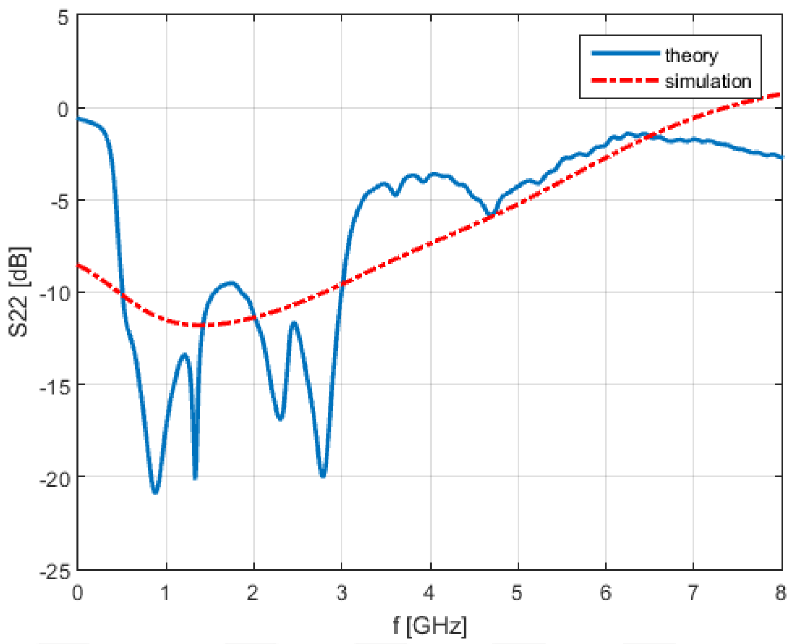

Figure 4.55: The magnitude of S_{22} [dB]

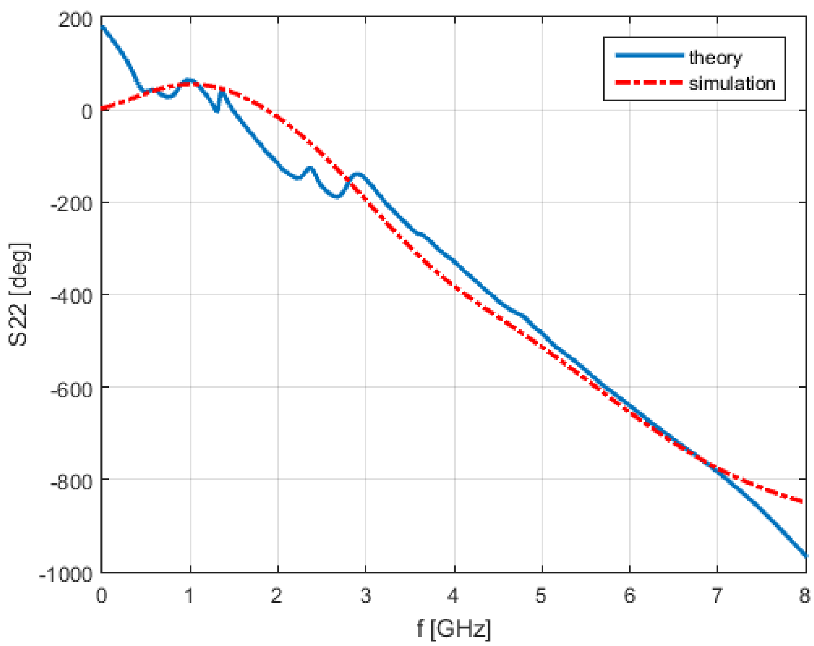

Figure 4.56: The angle of S_{22} [deg]

4.5 Simulation Results for 010168 Power Amplifier of S-Parameter Using RBF

The RBF model of the proposed method is shown in Figure 4.57. As seen in this figure the 2 hidden layers are used. For the input, the 3 parameters are used. These parameters were the drain-source voltage (V_{DS}), the drain-source current (I_{DS}) and frequency. For output, the magnitudes and angles for all S-parameters are selected. For first hidden layer, 25 neurons are used. For second hidden layer, 8 neurons are used. For activation function, the logarithm Gaussian is used for hidden layer. The magnitudes of V_{DS} and I_{DS} were 10 V and 3.5 ms respectively.

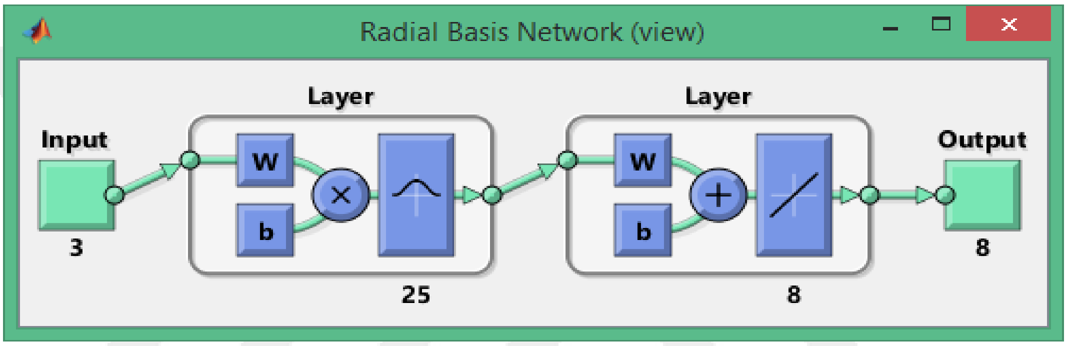

Figure 4. 57: The RBF model for 010168 power amplifiers

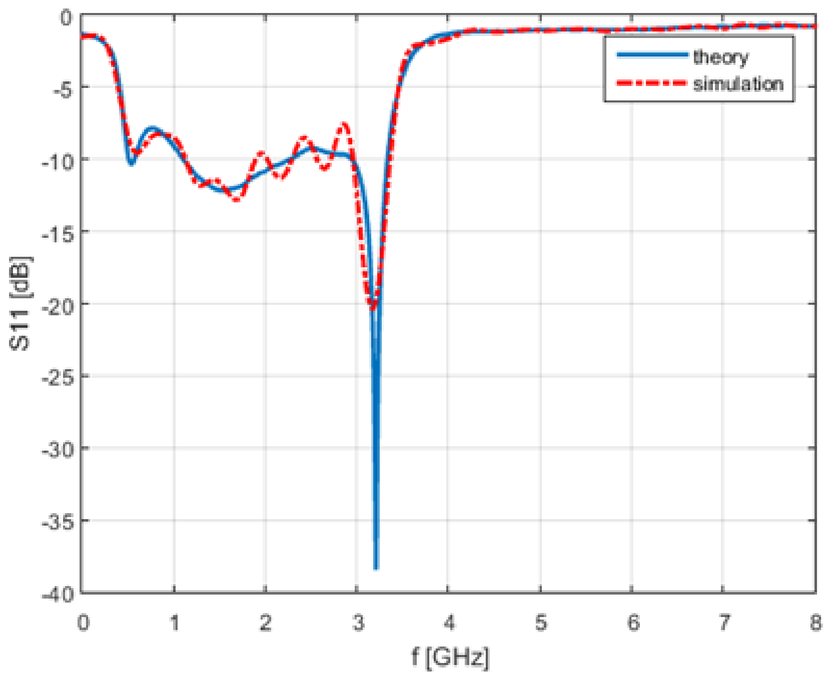

Figure 4.58: The magnitude of S_{11} [dB]

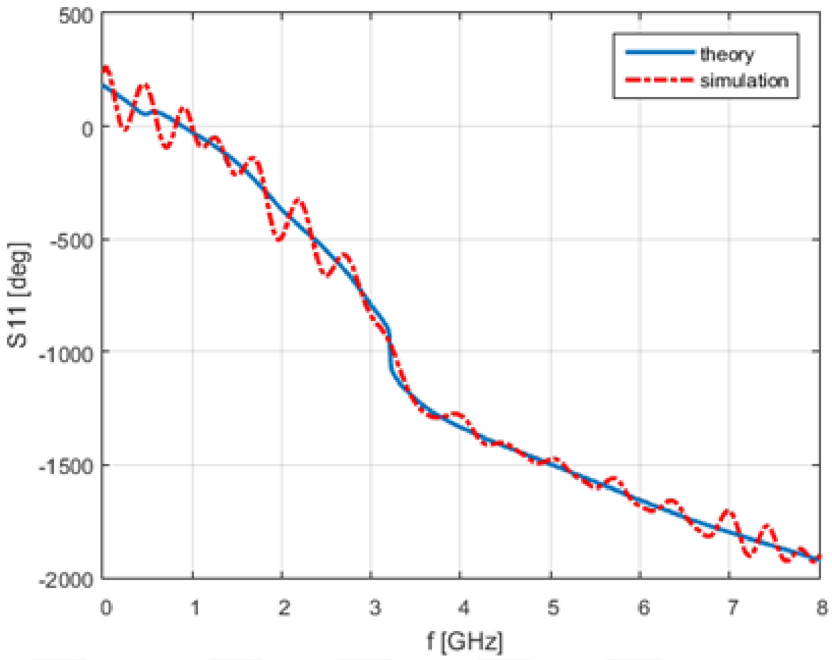

Figure 4.59: The angle of S_{11} [deg]

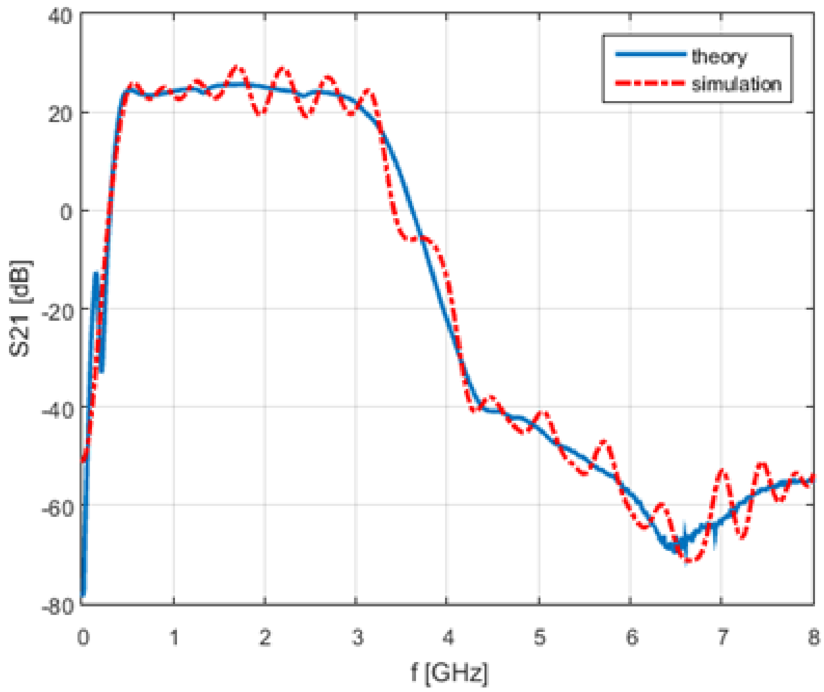

Figure 4.60: The magnitude of S_{21} [dB]

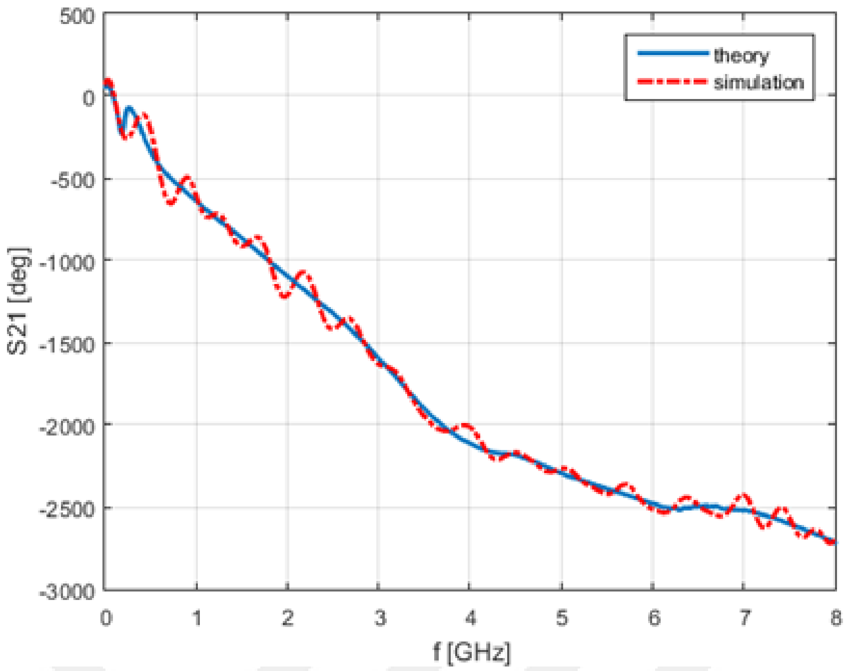

Figure 4.61: The angle of S_{21} [deg]

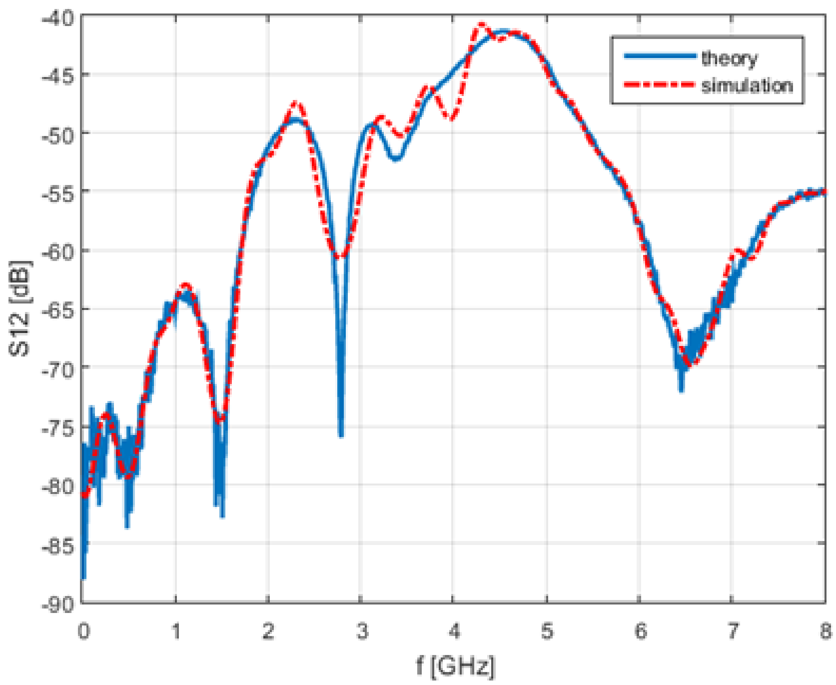

Figure 4.62: The magnitude of S_{12} [dB]

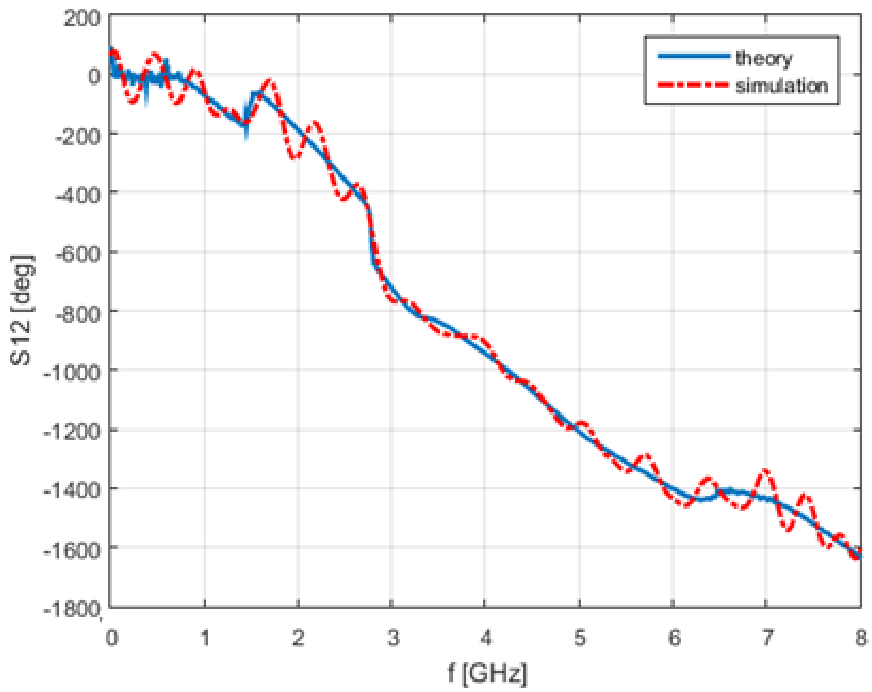

Figure 4.63: The angle of S_{12} [deg]

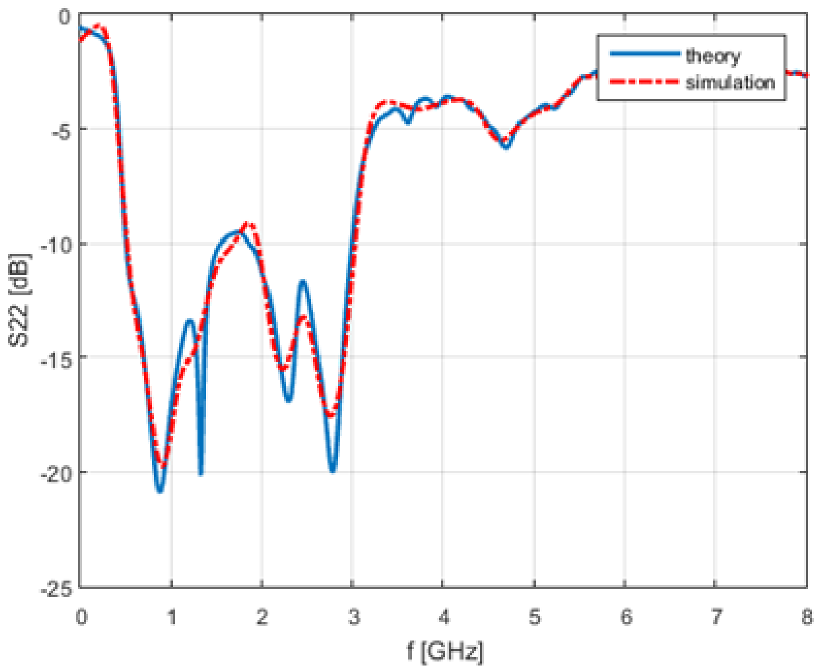

Figure 4.64: The magnitude of S_{22} [dB]

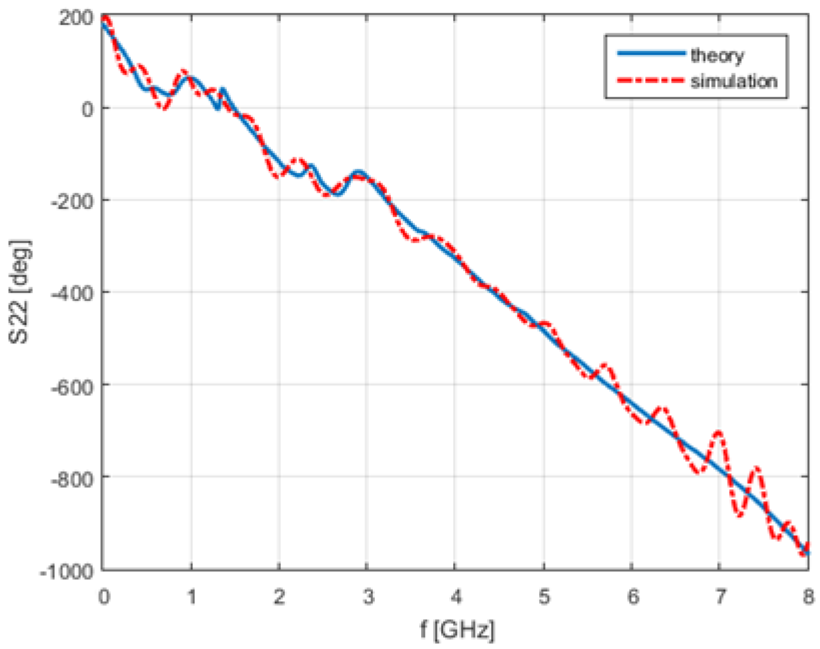

Figure 4.65: The angle of S_{22} [deg]

In order to know the accuracy of our models to support RF power amplifier design, we used some error factors like RMSE and MAE.

We selected 8 samples of the S-parameters at 4.4 GHz to test the MLP model and notice the errors between the test output and the predicted output. The results were shown in Table 4.11.

Table 4.11: Testing 010168 power amplifier using MLP

Sequence	S-parameters at (4.4 GHz)	Test output	MLP output
1	Mag- S_{11}	-1.15	-4.63
2	Ang- S_{11}	-1403.88	-1387
3	Mag- S_{21}	-40.25	-30.23
4	Ang- S_{21}	-2175.59	-2212
5	Mag- S_{12}	-41.71	-43.52
6	Ang- S_{12}	-1043.99	-1051
7	Mag- S_{22}	-4.26	-5.58
8	Ang- S_{22}	-396.29	-403.6

The RMSE=11.065 and MAE%=3.912%.

When we repeated the same test at 4.4 GHz with RBFNN with same magnitudes for both of V_{DS} and I_{DS}, we obtained the results as shown in Table 4.12.

Table 4.12: Testing 010168 power amplifier using RBF

Sequence	S-parameters at (4.4GHz)	Test output	RBF output
1	Mag- S_{11}	-1.15	-1.11
2	Ang- S_{11}	-1403.88	-1403
3	Mag- S_{21}	-40.25	-38.96
4	Ang- S_{21}	-2175.59	-2188
5	Mag- S_{12}	-41.71	-41.53
6	Ang- S_{12}	-1043.99	-1037
7	Mag- S_{22}	-4.26	-4.343
8	Ang- S_{22}	-396.29	-389.8

The RMSE=1.974 and MAE%=0.698%.

Table 4.13: Comparison of MLP and RBF results

The model	Error factors	The results
MLPNN	RMSE	11.06
MLPNN	MAE%	3.91%
RBFNN	RMSE	1.97
RBFNN	MAE%	0.69%

As we have shown above the errors for MLP were a little high, but also MLP was good as compared with huge data that we depended on them in this model. We found the errors for RBF were very few therefore, we can depend on RBF as a good model to implement 010168 power amplifier.

4.6 Simulation Results for Input and DC Power Using GRNN

This model depended on the results that published in paper (design and simulation RF power amplifier using RBF neural network in 2016). This paper was executed using the RPF neural network. We designed a new model that can serve the RF amplifier design in the future. The x-axis represented by using the expression index that refers to both RF input and DC power. The data that we depended here were as shown in Table 4.14.

Table 4.14: The predicted output power as compared with real output power

The Sequence	Input power [dBm]	DC power [dBm]	Output power [dBm]
1	31.98	37.35	36.94
2	26.99	37.01	36.26
3	10.96	33.40	26.40
4	46.99	38.95	40.73
5	38.99	37.76	38.16
6	32.98	37.41	37.08
7	45.99	38.74	40.39
8	44.99	38.58	40.01
9	15.99	34.58	30.46
10	10.00	33.16	25.57

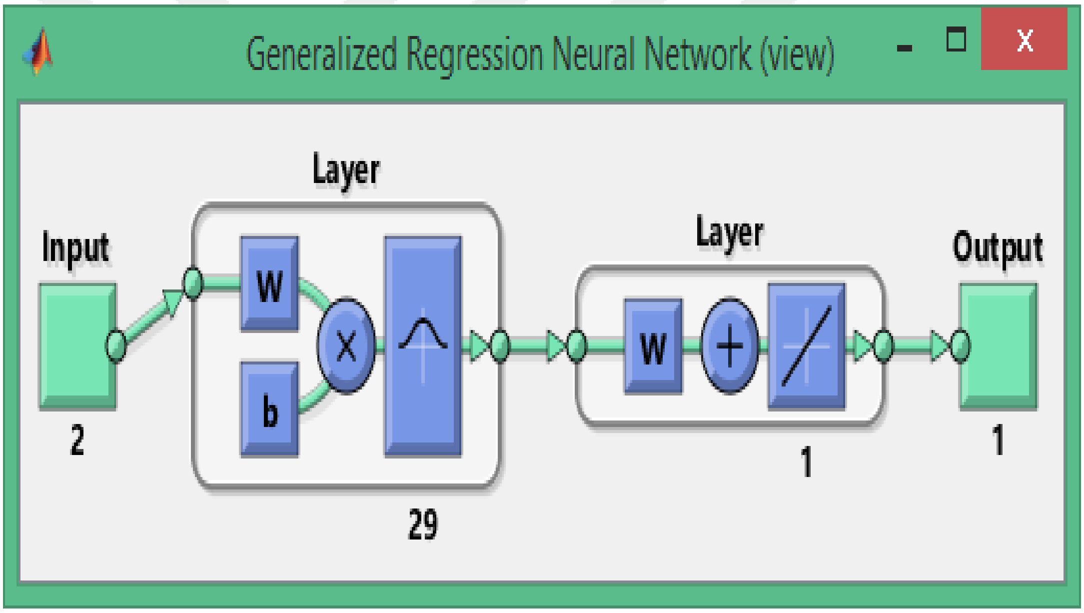

Figure 4.66: The model of GRNN for output testing

After using the model, we found the following results;

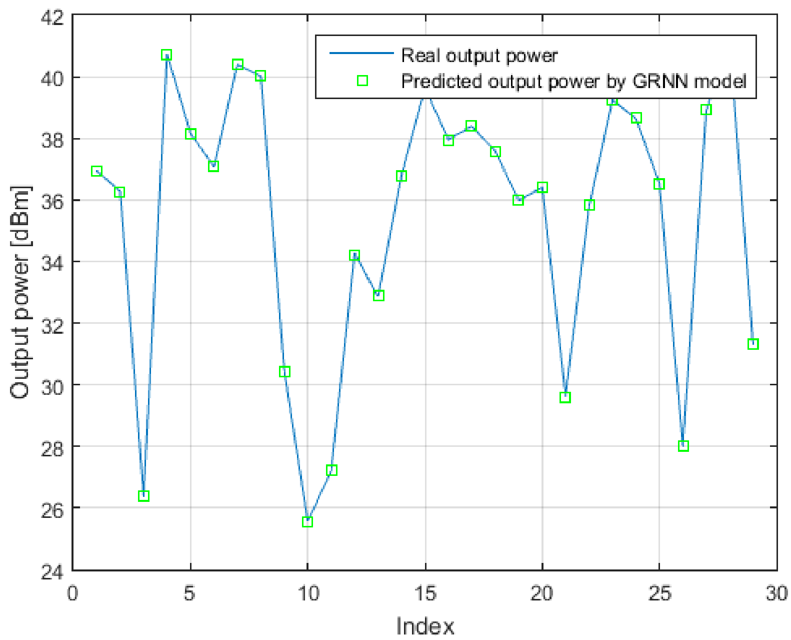

Figure 4.67: The predicted output power using GRNN model

We can find the results depending on Table 4.14 with add the predicted output power shown in Table 4.15.

Table 4.15: The predicted output power as compared with real output power using GRNN neural network

The Sequence	Input power [dBm]	DC power [dBm]	Output power [dBm]	Output network [dBm]
1	31.98	37.35	36.94	36.99
2	26.99	37.01	36.28	36.26
3	10.96	33.40	26.38	26.42
4	46.99	38.95	40.73	40.75
5	38.99	37.76	38.16	38.15
6	32.98	37.41	37.08	37.83
7	45.99	38.74	40.39	40.45
8	44.99	38.58	40.01	40.03
9	15.99	34.58	30.46	30.44
10	10.00	33.16	25.57	25.59

The RMSE = 0.0316 and MAE% = 0.01%.

4.7 Simulation Results for Input and DC Power Using RBF

We designed new RBF neural network model to support the output power using the radial based function neural network as shown below in Figure 4.68.

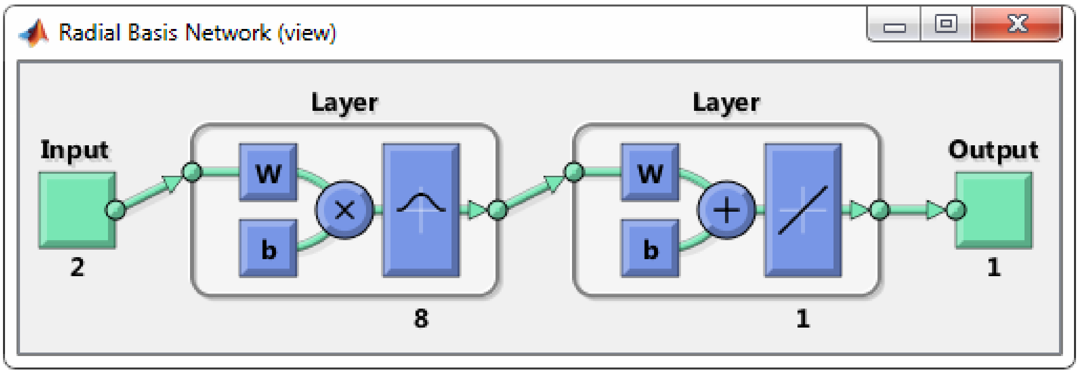

Figure 4.68: The RBF model for output testing

For the same data, we got the following results as shown in Figure 4.69.

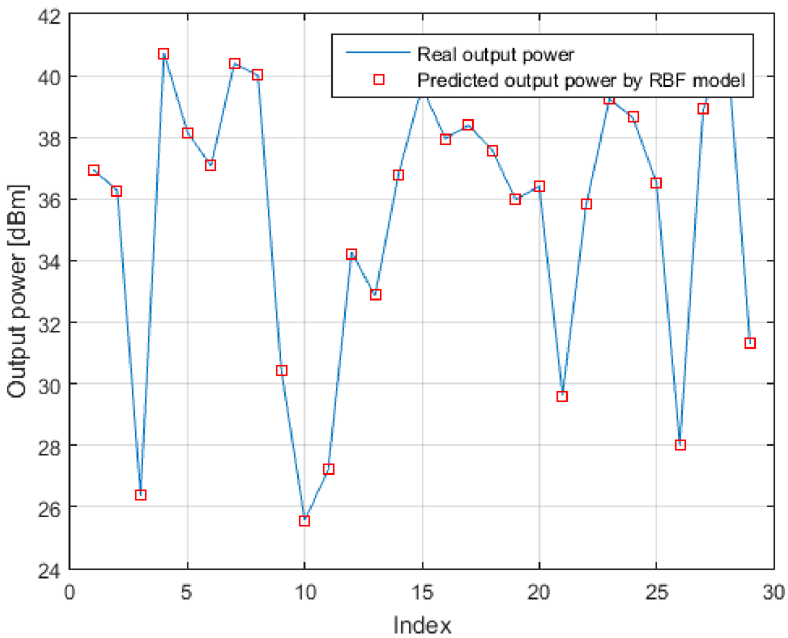

Figure 4.69: The predicted output power using the RBF model

We can find the results depending on the Table 4.14 with add the predicted output power as shown in Table 4.16.

Table 4.16: The predicted output power as compared with real output power using RBF neural network

The Sequence	Input power [dBm]	DC power [dBm]	Output power [dBm]	Output network [dBm]
1	31.98	37.35	36.94	36.94
2	26.99	37.01	36.28	36.27
3	10.96	33.40	26.38	26.41
4	46.99	38.95	40.73	40.73
5	38.99	37.76	38.16	38.15
6	32.98	37.41	37.08	37.08
7	45.99	38.74	40.39	40.37
8	44.99	38.58	40.01	40.03
9	15.99	34.58	30.46	30.44
10	10.00	33.16	25.57	25.53

RMSE = 0.0158 and MAE% = 0.005%.

We compared between these models with respect to RMSE and MAE. We found the results as shown in Table 4.17.

Table 4.17: Comparison between GRNN and RBFNN

The model	RMSE	MAE%
GRNN	0.0316	0.01%
RBFNN	0.0158	0.005%

From this table, we found both of the models had good accuracy, but we found the errors using both the error factors in RBF were less than GRNN. We can represent RBF is the best.

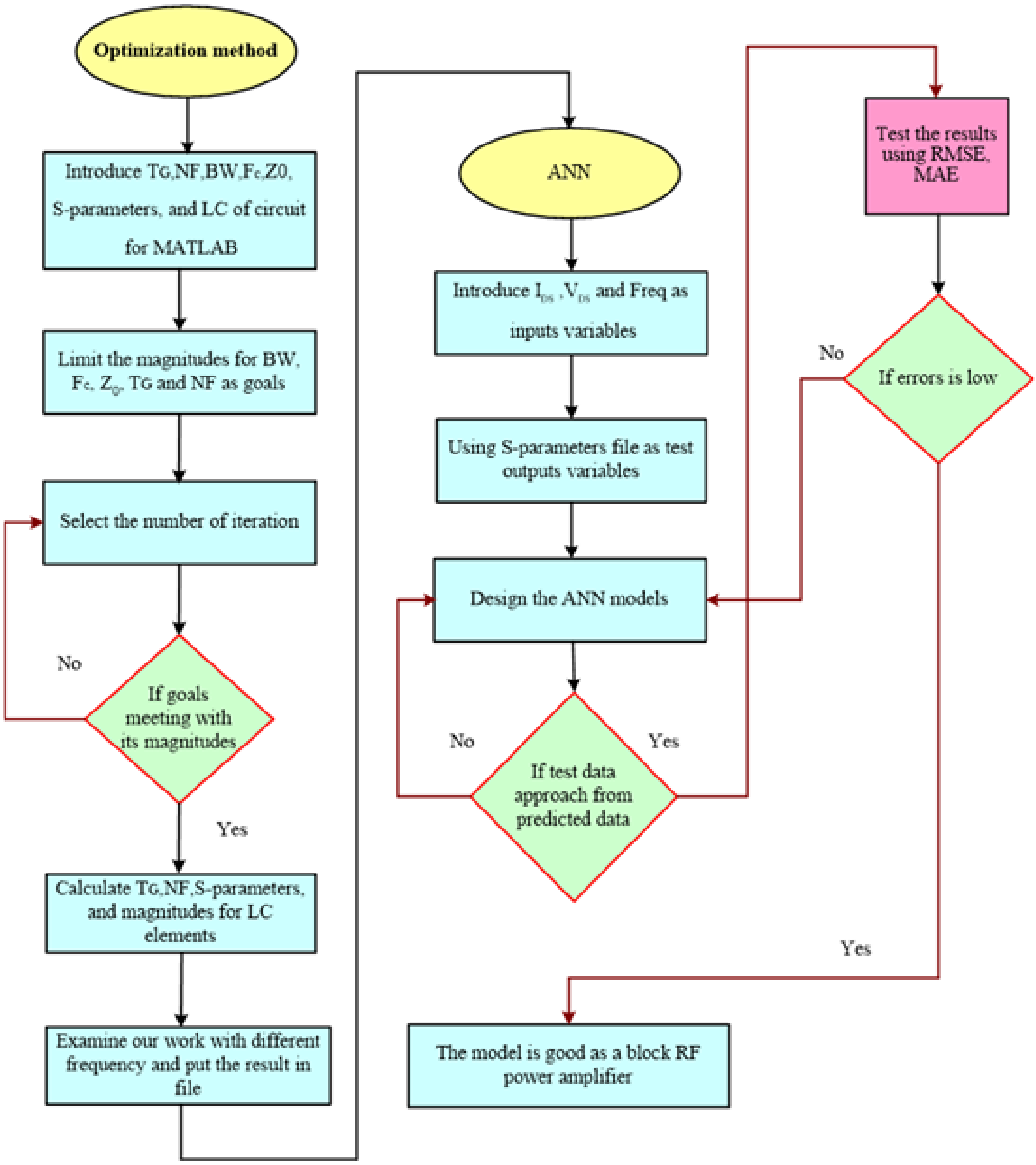

Figure 4.70: Algorithm for our proposed work based on ANN

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

In this work we designed power amplifier using optimization method. Additionally, We designed different types of neural network RF power amplifiers. For our proposed work we focused on matching impedance, because if we can choose the corresponding matching circuit with respect to our requirements, all the other parameters will be good such as output power, efficiency, linearity, and gain. We used scattering matrix as a method to analysis our circuit. By using the optimization method, we got all magnitudes for all elements of our circuit. Also, S_{21}, S_{11}, S_{22}, S_{12} before optimization were 10.42,-0.76,-0.41,-22.23 [dBm], respectively. After optimization the S-parameters became 21.43,-5.01,-7.69,-26.79 [dBm]. The final results after optimization were better for all S-parameters as compared with the magnitudes of all S-parameters before optimization method. The output power was 27.8 dBm and PAE 33.6% when the input power 15 dBm. The design was unconditionally stable. The small signal gain over all the bandwidth (400 MHz-500 MHz) was about 21 dB.

According to the specification of our proposed work, we can use it to support 3D GPR system. This type of radar is so important. There are many types of 3D GPR system. It can work from 30 MHz up to 5 GHz.

Although the optimization method was a practical method for designing, we found another method to design RF amplifier. We found an important method to express about RF amplifier instead of our proposed work or subcircuit using ANN. At first, we tested our proposed work with different frequencies after optimization method and got the values for all the S-parameters as magnitudes and angles. We depended on three variables for our design V_{DS}, I_{DS}, and frequency. We test our design using both MLP and RBF neural networks. The RMSE and MAE of 3.35 and

1.18% of the RBF network are achieved, respectively. The RMSE and MAE were 5.21 ,1.83% in MLP, respectively. According to the final results, the RBF was less error than MLP and that means it is better in its performance. To improve the importance of ANN, we designed two different models of MLP and RBF. We got the results by using the test data for RF 010168 power amplifier. RMSE was 1.974 and MAE 0.698% for RBF model. The RBF was less in error than MLP about six times for both of RMSE and MAE, respectively. The last test in our thesis to increase the attention of ANN method was associated with the components of power in RF amplifier. We used data as input power, DC power, and output power for proposed work in paper 2016. We designed the RBF model and a new type of neural network represented by GRNN. By testing both of them using RMAE and MAE, we found the RBF was better than GRNN because RMSE and MAE were 0.0158 , 0.005% as compared with 0.0316 , 0.01%, respectively. The GRNN treats with the results only as integer numbers, which reduces its accuracy as compared with RBF. Also, we noticed MLP had better performance with the linear system as compared with nonlinear.

The researchers working in RF field try most of the time to find new methods to overcome the difficulties that surrounding by the performance of the RF components. For our design, we want to develop the optimization method to find the magnitudes for all the variables and elements of our circuit such as linearity, output power, and power add efficiency. We suggest in the future using transmission lines or Chebyshev BPF to our matching circuit instead of lumped elements to increase the output power and enhance the S-parameters to be more than what we got.

In the future we can employ the neural network to express on all inputs and outputs for power amplifier instead of using some inputs and outputs. Also, we want to implement ANN to be like physical circuit using one of the smart technologies such as FPGA or synapse circuit using both of analog and digital gates. We suggest to use ANN as a block to be like RF amplifier or to be like the testing circuit for some or all elements of any RF power amplifier design.

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APPENDICES

APPENDIX A.1: The MRF160 datasheet.

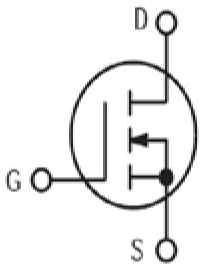
APPENDIX A.2: The 010168 MACOM power amplifier datasheet.

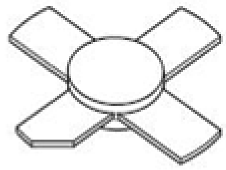
APPENDIX A.3: The RF input power, DC power and output power of paper (design and simulation, RF power amplifier using RBF) 2016.

APPENDIX A.1

MRF160

Designed primarily for wideband large–signal output and the driver from 30–500 MHz.





CASE 249–06, STYLE 3

MAXIMUM RATINGS (T_J = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Drain–Gate Voltage	V_{DSS}	65	Vdc
Drain–Gate Voltage (R_{GS} = 1.0 MΩ)	V_{DGR}	65	Vdc
Gate–Source Voltage	V_{GS}	± 20	Vdc
Drain Current–Continuous	I_D	1.0	ADC
Total Device Dissipation @ T_C = 25°C Derate Above 25°C	P_D	24 0.14	Watts W/°C
Storage Temperature Range	T_{stg}	– 65 to +150	°C
Operating Junction Temperature	T_J	200	°C

THERMAL CHARACTERISTICS

Thermal Resistance — Junction to Case	$R_{\theta JC}$	7.2	°C/W

NOTE — CAUTION — MOS devices are susceptible to damage from electrostatic charge. Reasonable precautions in handling and packaging MOS devices should be observed.

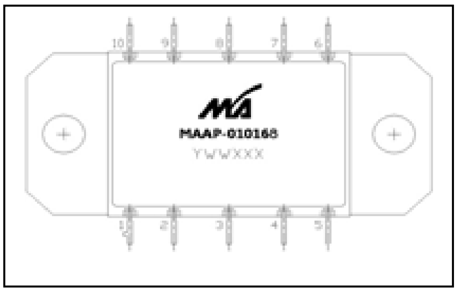
Table A.1: Some specifications of MRF 160 transistor

The RF MOSFET Line: Broadband Power FET 4 W, to 500 MHz, 28

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS					
Drain–Source Breakdown Voltage (V_{DS} = 0 Vdc, V_{GS} = 0 Vdc, I_D = 1.0 mA)	$V_{(BR)DSS}$	65	—	—	Vdc
Zero Gate Voltage Drain Current (V_{DS} = 28 Vdc, V_{GS} = 0 V)	I_{DSS}	—	—	0.5	mA
Gate–Source Leakage Current (V_{GS} = 20 Vdc, V_{DS} = 0 Vdc)	I_{GSS}	—	—	1.0	µA
ON CHARACTERISTICS					
Gate Threshold Voltage (V_{DS} = 10 Vdc, I_D = 10 mA)	$V_{GS(th)}$	1.5	3.0	4.5	Vdc
Drain Source On–Voltage ($V_{DS\ (on)}$, V_{GS} = 10 Vdc, I_D = 500 mA)	$V_{DS(on)}$	—	3.8	—	Vdc
Forward Transconductance (V_{DS} = 10 Vdc, I_D = 250 mA)	g_{fs}	150	220	—	mS
DYNAMIC CHARACTERISTICS					
Input Capacitance (V_{DS} = 28 Vdc, V_{GS} = 0 V, f = 1.0 MHz)	C_{iss}	—	6.0	—	pF
Output Capacitance (V_{DS} = 28 V, V_{GS} = 0 Vdc, f = 1.0 MHz)	C_{oss}	—	6.5	—	pF
Reverse Transfer Capacitance (V_{DS} = 28 Vdc, V_{GS} = 0 Vdc, f = 1.0 MHz)	C_{rss}	—	0.8	—	pF
FUNCTIONAL CHARACTERISTICS					
Common Source Power Gain (V_{DD} = 28 Vdc, P_{out} = 4.0 W, f = 500 MHz, I_{DQ} = 50 mA)	G_{ps}	16	18	—	dB
Drain Efficiency (V_{DD} = 28 Vdc, P_{out} = 4.0 W, f = 500 MHz, I_{DQ} = 50 mA)	η	50	55	—	%
Electrical Ruggedness (V_{DD} = 28 Vdc, P_{out} = 4.0 W, f = 500 MHz, I_{DQ} = 50 mA) Load VSWR = 30:1 at All Phase Angles at Frequency of Test	ψ	No Degradation in Output Power			
Series Equivalent Input Impedance (V_{DD} = 28 Vdc, P_{out} = 4.0 W, f = 500 MHz, I_{DQ} = 50 mA)	Z_{in}	—	6.8 – j21	—	Ohms
Series Equivalent Output Impedance (V_{DD} = 28 Vdc, P_{out} = 4.0 W, f = 500 MHz, I_{DQ} = 50 mA)	Z_{out}	—	21 – j28	—	Ohms

APPENDIX A.2



MAAP-010168

10. **Saturated Output Power: 41 dBm**
11. **Linear Gain: 24 dB**
12. **Power Added Efficiency: 30% at P_{SAT}**
13. **50 W Input / Output Match**
14. **Ceramic Flange Mount Package**

Description

The MAAP-010168 is used as a broadband amplifier. It consists of two MMIC amplifier and used for big power . It is connected with two first and end resistors with 50 ohms for both of them to avoid unmatched state.

Pin No.	Function
1	$V_{GG}2$
2	$V_{GG}1$
3	RF Input[3]
4	$V_{GG}1$
5	VGG2
6	VDD1
7	$V_{DD}2$
8	RF Output[3]
9	$V_{DD}2$
10	$V_{DD}1$

Ordering Information[1]

Part Number	Package
MAAP-010168-000000	Bulk
MAAP-010168-001SMB	Sample Board

TableA.2: Some specifications of 010168 amplifier

Freq = 0.5 - 3.0 GHz, V_{DD} = 10 V, I_{DQ} = 3.5 A, T_A = 25 °C, Z_0 = 50 Ω

Parameter	Test Conditions	Units	Min.	Typ.	Max.
Gain	Small signal	dB	19	24	—
Input Return Loss	—	dB	—	10	—
Output Return Loss	—	dB	—	10	—
P1dB	—	dBm	—	39	—
PSAT	—	dBm	38	41	—
Current	IDQ PSAT	A	—	3.5 5.5	—
PAE	PSAT	%	—	30	—
Gate Bias	—	V	—	-0.7	—
Duty Cycle	—	%	—	—	100

APPENDIX A.3

Design and Modeling of RF Power Amplifiers with Radial Basis Function Artificial Neural Networks**.**

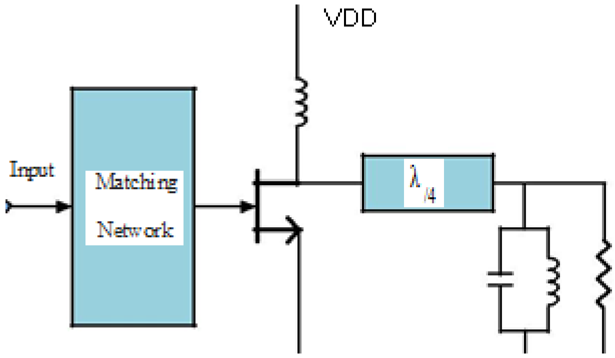


Figure A.3 The proposed work

Table A.3: The input and DC power data for proposed work of paper

The Sequence	Input power [dBm]	DC power [dBm]	Output power [dBm]
1	31.98	37.35	36.94
2	26.99	37.01	36.28
3	10.96	33.40	26.38
4	46.99	38.95	40.73
5	38.99	37.76	38.16
6	32.98	37.41	37.08
7	45.99	38.74	40.39
8	44.99	38.58	40.01
9	15.99	34.58	30.46
10	10.00	33.16	25.57

CURRICULUM VITAE

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