

DESIGN OF ULTRA WIDEBAND FILTER

By

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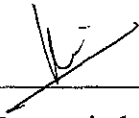
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



Mohd Nooramin bin Mohamad Yusoff

ABSTRACT

Ultrawideband (UWB) filter is one type of filter that has been developed since several years ago. The frequency band released by Communications Commission (FCC) of the United States in 2002 for UWB commercial communication is 3.1-10.6 GHz. Having wide bandwidth frequency of 7.5 GHz, it provides several advantages like capability to support a high transmission data rate up to 500 Mb/s. Several techniques have been discovered during past years to develop this system. However, the problem that we face today there is no analytical model has been developed so far. Therefore, my project is aiming to develop analytical model for Ultra Wideband filter that come out with MMR. To achieve this objective, I am using even and odd mode analysis. This even and odd mode analysis is realized based on symmetrical network circuit of microstrip, which in this case we use multi-mode resonator (MMR). The purpose of doing even and odd mode analysis is to find the Yeven and Yodd, hence the equations of scattering parameter S_{12} and S_{11} can be determined later on. After done mathematical analysis, the ideal plots of S-Parameter for UWB are simulated in both ADS and Matlab. The simulations in both ADS and Matlab will be compared to prove the mathematical analysis. If same result produced, means that the mathematical analysis done is valid and the design of microstrip is continued in AWR or ADS for fabrication purpose. Otherwise, the results then will be analyzed and further investigated.

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TABLE OF CONTENTS

LIST OF FIGURES	ix
LIST OF ABBREVIATIONS.....	xi
CHAPTER 1 INTRODUCTION	1
1.1 Background of Study	1
1.2 Problem Statement.....	1
1.3 Objective	2
1.4 Scope of Study	2
CHAPTER 2 LITERATURE REVIEW	3
2.1 Ultra-Wideband Background	3
2.2 Characteristic and Application.....	3
2.3 Benefits of UWB.....	3
2.4 Challenge.....	4
2.5 Techniques has been Developed in the Past	4
2.6 Problem	5
2.7 Analytical Design Approach Using Even and Odd Mode Analysis	5
2.8 Even and Odd Mode Analysis Review	7
CHAPTER 3 METHODOLOGY	9
3.1 Phase of Project.....	9
3.2 Tools/Software	11
3.2.1 Matlab Software	11
3.2.2 AWR Office.....	12
3.2.3 ADS Software.....	14
3.3 Multi-Mode Resonator	14
3.4 S-Parameter and Relationship with Even and Odd-Mode Analysis	15
3.5 Flowchart	19
CHAPTER 4 RESULTS AND DISCUSSIONS.....	20
4.1 Analytical Description	20
4.2 Mathematical Analysis: Even and Odd Mode Analysis	21
4.2.1 Odd Analysis	21
4.2.2 Even Mode Analysis.....	23
4.3 S-Parameter Equation.....	26

4.4 Matlab Plot.....	27
4.5 AWR Simulation.....	28
4.5.1 Ideal Plot in AWR	28
4.5.2 K1, K2 and Z_0 Calculation Method.....	29
4.5.3 Verify Ideal Plot of AWR in Matlab	29
4.6 Comparison AWR and Matlab Plot	30
4.7 Alternative (Reducing the Bandwidth)	30
4.8 Results Analysis.....	33
CHAPTER 5 CONCLUSION AND RECOMMENDATION	37
5.1 Conclusion	37
5.2 Recommendation.....	38
REFERENCES	39
APPENDICES	40
Appendix A GANTT CHART FYP 1.....	41
Appendix B GANTT CHART FYP 2.....	43
Appendix C MATLAB CODING.....	44

LIST OF FIGURES

Figure 1 Cascaded circuit of two port network.....	6
Figure 2 Phase of Project	9
Figure 3 M-file editor in Matlab	11
Figure 4 UWB design in AWR for ideal transmission line	12
Figure 5 Microstrip design in AWR	13
Figure 6 Physical converter tool	13
Figure 7 Ideal schematic of UWB in ADS	14
Figure 8 Microstrip layout consist of two coupled lines [14].....	14
Figure 9 Line of symmetrical at the center of circuit.....	15
Figure 10 Symmetrical network.....	16
Figure 11 Flowchart of the Project	19
Figure 12 General microstrip layout.....	20
Figure 13 Two port network circuit with line of symmetrical at center	20
Figure 14 Open stub impedance and electrical length of two port network circuit [13].....	21
Figure 15 Network circuit for odd mode analysis (short circuit).....	22
Figure 16 Even mode analysis circuit (open circuit)	24
Figure 17 Matlab simulation plot.....	27
Figure 18 Schematic for ideal transmission line and coupled lines.....	28
Figure 19 Ideal plot of UWB in AWR.....	28
Figure 20 Circuit having K1 and K2 impedance	29
Figure 21 Matlab plot.....	30
Figure 22 Tune parameter for Z_{even} , Z_{odd} and Z_0	31
Figure 23 Ideal plot for new frequency bandwidth.....	31
Figure 24 Matlab plot for reduced bandwidth	32
Figure 25 Equivalent circuit of a coupled-line pair	33
Figure 26 Equivalent circuit of a parallel coupled line-pair	33
Figure 27 (a) Unit element, (b) Equivalent circuit Of unit element.....	34
Figure 28 Schematic design for equivalent circuit in Figure 27 (b)	34

Figure 29 Schematic design for transmission line of unit element..... 35

Figure 30 S- Parameter plot for transmission line and equivalent circuit of unit element..... 35

LIST OF ABBREVIATIONS

UWB	Ultra Wideband
FCC	Federal Communication Commission
MMR	Multi Mode Resonator
EBG	Electronic Band Gap
S-Parameter	Scattering Parameter
AWR	Applied Wave Research
ADS	Advanced Design System
S_{11}	Reflection Coefficient
S_{12}	Transmission Coefficient
Y _{even}	Even-Mode Admittance
Y _{odd}	Odd-Mode Admittance
Z _{oe}	Impedance Characteristic for Even Mode
Z _{oo}	Impedance Characteristic for Odd Mode
UE	Unit Element

CHAPTER 1

INTRODUCTION

1.1 Background of Study

This project focuses on the developing analytical model for UWB filter that come out with MMR. In order to come out with a valid design, the research on the topic needs to be done so that the mathematical analysis can be done. Since several years ago, UWB technology has gain great development with intensive researches on UWB components and systems have been done to meet the U.S Federal Communication Committee (FCC) requirements as defined in [1]. In 2002, the FCC has authorized the unlicensed use of UWB frequency spectrum for short range and high speed wireless communication in 2002 [1]-[3]. In fact, the various applications of UWB and the benefits it provide encourage engineers to do research on UWB. UWB system has been used in many application such as positioning, rescue radar system for rescuing survivors buried under collapsed buildings in many emergency situations, imaging, short range high-data-rate communication systems, and wireless personal area networks (WPANs) for personal computer and electronic devices [4].

1.2 Problem Statement

The Ultra-wideband technology is familiar known used in communication system, radar and sensor. This technology has been the subject of research and development over the past several years. For example, the design of UWB using Multiple Mode Resonators technique has been developed in the past which was originally propose in [5] and further developed in [6]-[10]. Until now, there are many ongoing efforts worldwide in order to optimize this technology that will lead to more applications in the future. Even though this technology was already developed in the past, but there is no analytical model that come out with MMR has been done for UWB. Therefore, this project will focus on designing a valid analytical model of

UWB filter by using MMR technique that consists of its proper mathematical analysis.

1.3 Objective

The main objective of this project is to design Ultra-Wideband filter by developing and representing a valid mathematical analysis for MMR. To fulfill this objective, a better understanding about this technology and its mathematical analysis are needed. The steps taken to fulfill this objective will be shown clearly in methodology part and its mathematical analysis and simulations will be shown in result part.

1.4 Scope of Study

The scope of study will be covering the deep research on UWB filter design. After going through the research and literature review, the following study will be included in this project.

1. Developing mathematical analysis of UWB filter
2. Matlab Simulation
3. Designing and simulation using Computer Aided Design (CAD) software (AWR and ADS office)
4. Prototype fabrication (if successful in mathematical analysis and simulation)
5. Results Analysis

CHAPTER 2

LITERATURE REVIEW

2.1 Ultra-Wideband Background

Based on [1], Ultra wideband (also known as UWB or as digital pulse wireless) can be defined as wireless technology for transmitting large amounts of digital data over a wide spectrum of frequency bands with very low power for a short distance. Ultra wideband is not only can carry a huge amount of data over a distance up to 230 feet at very low power (less than 0.5 milliwatts), but has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and a higher power. Ultra wideband can be compared with another short-distance wireless technology, Bluetooth, which is a standard for connecting handheld wireless devices with other similar devices and with desktop computers.

2.2 Characteristic and Application

The main characteristic of UWB filter is having a wide spectrum of frequency bandwidth which is 7.5 GHz [1]. This wide frequency range is favorable for various modern transmission system applications such as through-wall imaging, medical imaging, vehicular radar, indoor, and hand-held UWB system. For the indoor and hand-held UWB systems, the U.S Federal Communication Commission (FCC) required that UWB bandwidth must be strictly contained between 3.1 and 10.6 GHz [1]. To meet these requirements on the emission level, special research interests in the microwave society have been recently aroused on the development of UWB bandpass filter.

2.3 Benefits of UWB

Having wide spectrum of frequency, UWB filter can support a high transmission data rate (up to 500 Mb/s). In fact, they have low energy density over a

wideband spectrum generated by short pulse excitation, which not only makes the UWB system difficult to intercept but also minimizes interference by other radio systems. Besides, they have extremely low transmission energy (less than 1.0 mW), which is favorable for hand-held radio systems [4].

2.4 Challenge

Even though the UWB filter have many attractive benefits such as transmitting higher data rates and requiring lower transmit power, the big challenges to design filter for UWB is it's difficult to construct the UWB for such high bandwidth in order to meet its requirement. To design the UWB filter that having high performance and compact size is not an easy task for the microwave engineers. There are many techniques has been used over the past few years and some technique will have their own designing challenge.

In the past, various UWB filters used the ring resonators, short/open stubs, and multiple mode resonators (MMR) technique for the design [4]. One of the problem as stated in [11] is when using parallel couple lines with high impedance and strong coupling to achieve larger fractional bandwidth for conventional wideband BPFs, it is very difficult to realize the coupled lines of high impedance and a tight coupling gap due to the limitation of the fabrication process.

Besides, as explained in [11], the MMR-based filter for example, usually suffers from a high insertion loss of about 2.0 dB in the upper UWB passband and a narrow upper stopband of 11.0 to 14.0 GHz. The former is mainly caused by parasitic radiation from the central part with wide strip conductor at high frequencies, while the latter is due to the 4th resonant mode in this stepped-impedance MMR [9].

2.5 Techniques has been Developed in the Past

In [4], there are explanations of several techniques that been used to develop UWB filter over the past years. These techniques can be classified as Multiple-Mode-Resonator (MMR), Hybrid Microstrip/Coplanar-Waveguide (CPW) techniques, Optimum Short-Circuited Stubs, the Cascaded Highpass/Lowpass filter

techniques that proposed to design in and techniques that use Electronic-Band-Gap-Loaded (EBG) structures.

The MMR technique aims to deploy multiple resonant modes in a composite resonating structure to design a UWB filter. The original design uses a similar physical topology as the stepped-impedance resonator (SIR) structure [4]. The EBG structured is implemented using capacitive-loaded transmission lines. The UWB filter is implemented using an optimum short-circuited-stub structure. Using optimum short-circuit stub structure, it can yield a wide passband, and the EBG structure can suppress the harmonic response, a wide upper stopband can be implemented using this technique [4].

While for Cascaded High/Low Pass Filter, it is designed using cascaded single-layer highpass and low-pass filter or cascaded bandstop and bandpass filters. The drawbacks by using this technique are large circuit size and higher insertion loss produced, but realizable to produce wide stopband with flexible design [4].

2.6 Problem

Even though this technology already been developed in recent year, but there is still no analytical model that come out with MMR for UWB. For this technology, it should come out with valid analytical model. To come out with this analytical model, we should use two port networks. There are few methods that can be used to analyze the two port network circuit such as Z parameter, Y parameter, S parameter and ABCD parameter [12].

2.7 Analytical Design Approach Using Even and Odd Mode Analysis

However, in this case, we are interested in doing Even and Odd mode analysis based on symmetrical two port network. This is due to less complexity of mathematical analysis compared to two port analysis using ABCD parameter even though it is also structured with cascaded network. At the end of mathematical analysis, we can find out the equation of reflection coefficient S_{11} and transmission

coefficient S_{12} based on the *Yeven* and *Yodd* obtained. The formula to find out the S_{11} and S_{12} is given by [13];

$$S_{12} = \frac{Yodd - Yeven}{(1 + Yeven)(1 + Yodd)} \quad (2.1)$$

and

$$S_{11} = \frac{1 - YevenYodd}{(1 + Yeven)(1 + Yodd)} \quad (2.2)$$

Then, the graph of S_{11} and S_{12} equations can be plotted using matlab, and the value of variable k and Z_o are varied in order to get the ideal graph of UWB.

The value of k and Z_o later must be multiplied with 50 ohm when simulating in AWR Office software since it used 50ohm system. These values are also important so that the value of Z_{even} and Z_{odd} can be calculated later on. It can be calculated by using the formula below where k_1 and k_2 are the stub impedance as shown in Figure 1 below.

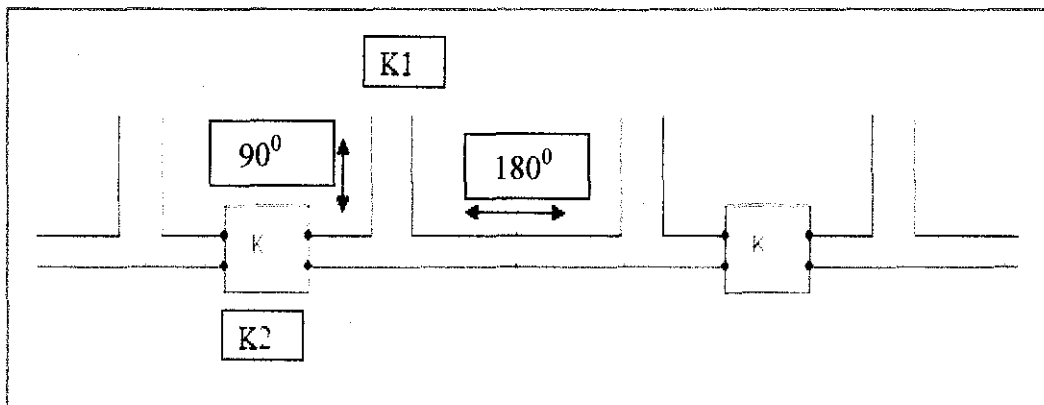


Figure 1 Cascaded circuit of two port network

$$k_1 = \frac{Z_{oe} + Z_{oo}}{2} \quad (2.3)$$

$$k_2 = \frac{Z_{oe} - Z_{oo}}{2} \quad (2.4)$$

2.8 Even and Odd Mode Analysis Review

In doing even and odd mode analysis, it is important to know how to get the equation of Z_{1a} first (refer Chapter 4), then the other calculation can be done. In general, it can be analyzed through two port network. The transfer matrix of two port network is represented by [13].

$$[T] = \begin{pmatrix} \cos \theta & jz_0 \sin \theta \\ jY_0 \sin \theta & \cos \theta \end{pmatrix} \quad (2.5)$$

Consider the equation below for Z_{in} ,

$$Z_{in} = \frac{AZ_L + B}{CZ_L + D} \quad (2.6)$$

For odd mode, the symmetrical network will be short circuit. Therefore the value of Z_L will become zero. When Z_L is zero, the equation will become as below:

$$Z_{in} = \frac{B}{D} \quad (2.7)$$

$$Z_{in} = \frac{jZ_0 \sin \theta}{\cos \theta} \quad (2.8)$$

$$Z_{in} = jZ \tan(\theta) = IZ \tan(x) \quad (2.9)$$

Note that the Z_{in} is equal to Z_{1a} in this analysis.

Meanwhile, for even mode, the network will become open circuit. In open circuit, the value of Z_L will become infinity. Hence the equation will become as below:

$$Z_{in} = \frac{A}{C} \quad (2.10)$$

$$Z_{in} = \frac{\cos \theta}{jY_0 \sin \theta} \quad (2.11)$$

$$Z_{in} = \frac{Z}{j \tan \theta} \quad (2.12)$$

$$Z_{in} = Z_{1a} = \frac{-jZ}{\tan(x)} \quad (2.13)$$

CHAPTER 3

METHODOLOGY

3.1 Phase of Project

The phases of the project will be divided into:

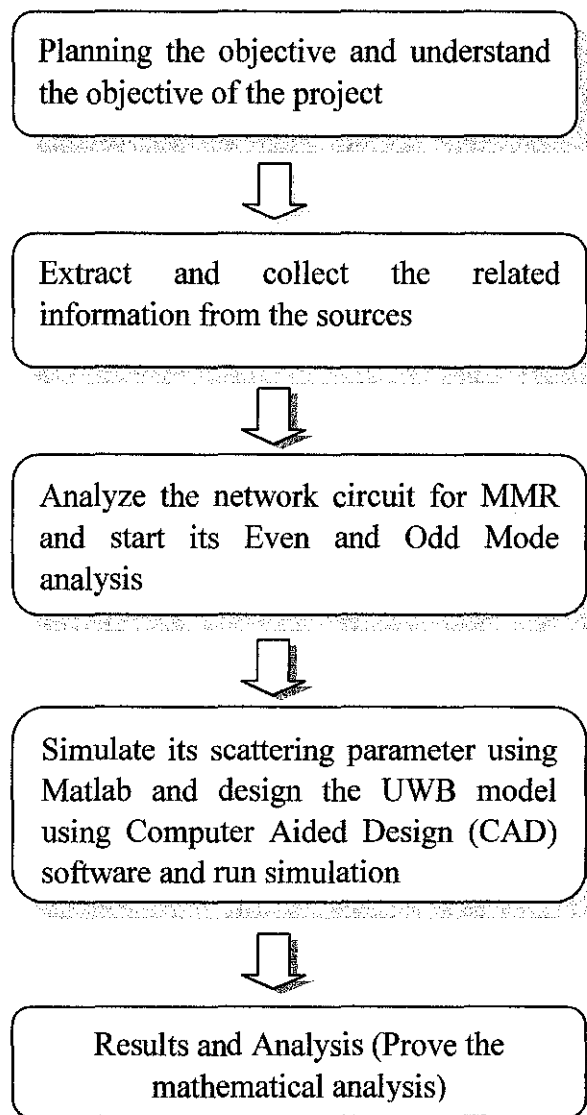


Figure 2 Phase of Project

For the first stage of the project, the good understanding about the project is important in order to fulfill the objective at the end of the project. Therefore, the initial research and study about the project need to be done by gathering all the information that related to this project. Information are gathered from journals, books, technical reports, and also case studies that have any relevance to the topics.

Based on the data gathering, the related topics that focus on microstrip circuit of MMR are emphasized since they will be used to develop the mathematical analysis. After equivalent circuit of MMR is achieved, the mathematical analysis will be done by using the Even and Odd mode analysis. This Even and Odd mode analysis is used to find the S-parameter (S_{12} and S_{11}) [13] which are the transmission and reflection coefficient for this UWB.

After done the mathematical analysis, the results which are S_{12} and S_{11} will be plot in the Matlab by using m-file tool. In Matlab, the variable value of k_1 , k_2 and Z_0 need to be determined first. In this project, these variable values are determined by calculation from the Z_{even} , Z_{odd} and Z_0 that we get from AWR and ADS simulation for ideal transmission line. In Matlab, the ideal plot for this UWB which is the gain (dB) versus electrical length (degree) should produce five transmission poles in the passband and having equal ripples.

Apart from Matlab, the UWB filter model is designed by using CAD software which is Applied Wave Research (AWR) office or Advance Design System (ADS) to get ideal graph of S_{12} and S_{11} . To get that, the Z_{even} , Z_{odd} , and Z_0 need to be tuned. From this value, the k_1 , k_2 and Z_0 can be determined that later will be used in Matlab to plot the same scattering parameter in order to prove the mathematical analysis. Both of this software are available at the UTP laboratory and can be used to design this type of filter.

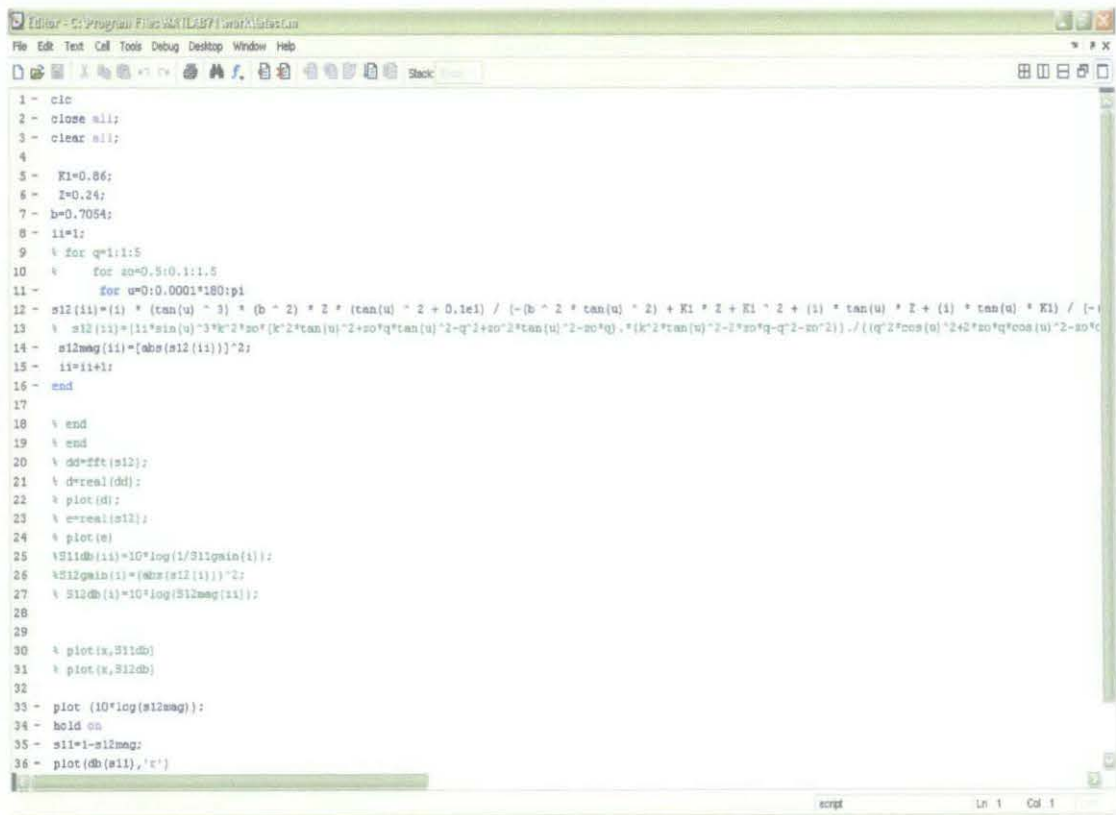
If both simulation in Matlab and AWR/ADS produce the same graph, it means that the mathematical analysis that has been done is proven valid and match with the simulation. If everything is valid, the microstrip design will be proceed to fabricate the prototype.

3.2 Tools/Software

1. Matlab software (to plot graph of S-Parameter of UWB)
2. AWR office and ADS (to design and simulate the UWB filter)

3.2.1 Matlab Software

Matlab simulation will be done after the S-parameter for transmission and reflection coefficients are determined from the mathematical analysis of even and odd mode analysis. In the equation, we have three variables value that are K1, K2 and Z0 which need to be varied to get the ideal plot of UWB filter. These values can be obtained from the ideal plot by CAD software that later on will be used in this Matlab to compare the result of both simulations to prove the mathematical analysis that has been done. In this case, the coding is written in m-file editor and the plot of gain (dB) versus electrical length will be generated after running the coding.



```
1 - clc
2 - close all;
3 - clear all;
4
5 - K1=0.86;
6 - Z=0.24;
7 - b=0.7054;
8 - i1=1;
9 % for q=1:1.5
10 %   for ao=0.5:0.1:1.5
11 %     for u=0.0001:180:pi
12 - s12(i1)=(i * (tan(u) ^ 3) ^ (b ^ 2) * Z * (tan(u) ^ 2 + 0.1e1) / [-(b ^ 2 * tan(u) ^ 2) + K1 * Z + K1 ^ 2 + (i) * tan(u) * Z + (i) * tan(u) * K1] / [-(i)
13 %   s12(i1)=(i1*sin(u)^3*k^2*so*(k^2*tan(u)^2+so*q*tan(u)^2-q^2+so^2*tan(u)^2-so*q) * (k^2*tan(u)^2-2*so*q-q^2-so^2) ./ ((q^2*cos(u)^2+so*q*cos(u)^2-so^2)
14 - s12mag(i1)=(abs(s12(i1)))^2;
15 - i1=i1+1;
16 - end
17
18 % end
19 % end
20 % dd=fft(s12);
21 % d=real(dd);
22 % plot(d);
23 % c=real(s12);
24 % plot(c);
25 % S11db(i1)=10*log(1/abs(s11(i1)));
26 % S12mag(i1)=(abs(s12(i1)))^2;
27 % S12db(i1)=10*log(S12mag(i1));
28
29
30 % plot(i1,S11db);
31 % plot(i1,S12db);
32
33 - plot(10*log(s12mag));
34 - hold on;
35 - s11=1-s12mag;
36 - plot(db(s11),'r')
```

Figure 3 M-file editor in Matlab

3.2.2 AWR Office

AWR microwave office is a one of the design software that can be used to design the microwave filter. Its unique AWR high-frequency design environment platform with unique unified data model enables the filter designer to use this software to design their filter model. For this project, the UWB filter design for ideal transmission line can also use this AWR to simulate the S_{11} and S_{12} parameter. In this project, we use one transmission line section at the center, and two parallel couple lines at both sides and two ports as shown in the Figure 4 below.

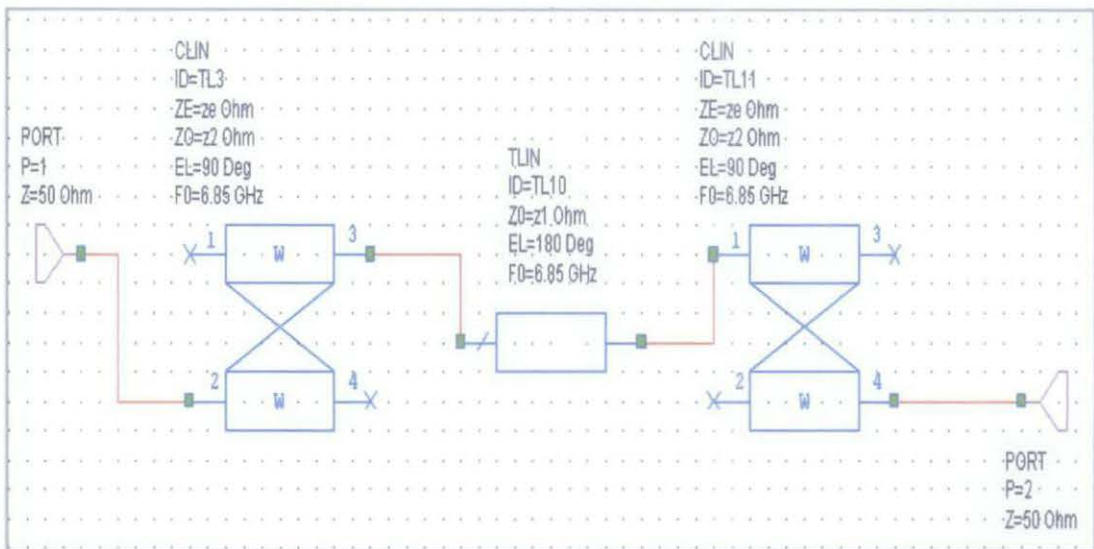


Figure 4 UWB design in AWR for ideal transmission line

As shown in figure, the Z_e and Z_o at the couple lines are the characteristic impedance for even mode and odd mode while Z_0 the impedance of the transmission line at the center. These three values can be calculated either based on the K_1 and K_2 value from the Matlab or by tuning tool to get the ideal graph. Another way if we tune all these characteristic impedance value until ideal graph produced, these values also can be used to calculate the K_1 and K_2 value to put in the Matlab editor to plot S-parameter. Both generated plot in AWR and Matlab should be the same.

If successfully obtaining the same in both Matlab and AWR/ADS, we can continue to design the microstrip in AWR. To convert the ideal design into microstrip, we use

the physical converter to convert the ideal electrical characteristics of the filter into its physical characteristic based on substrate datasheet.

Figure 5 and Figure 6 below shows the microstrip design and the physical converter tool (under option >> TX Line) in AWR

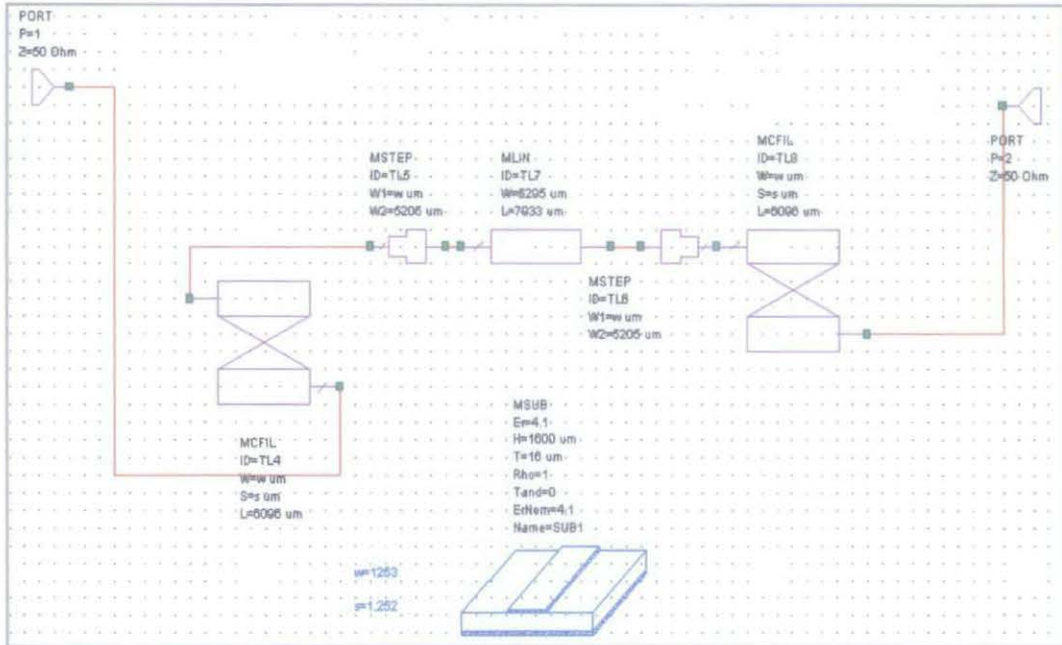


Figure 5 Microstrip design in AWR

The screenshot shows the 'TXLINE 2003 - Microstrip Coupled Line' interface. The 'Material Parameters' section is set to:

- Dielectric: GaAs
- Conductor: Copper
- Dielectric Constant: 4.1
- Conductivity: 58.8 S/um
- Loss Tangent: 0.013

 The 'Electrical Characteristics' section shows:

- Impedance: 101.908 Ohms
- Frequency: 6.85 GHz
- Electrical Length: 90.0405 deg
- Phase Constant: 14976.8 deg/m
- Effective Diel. Const.: 3.31508
- Loss: 14.2319 dB/m
- Mode: Even Mode, Odd Mode

 The 'Physical Characteristic' section shows:

- Physical Length (L): 6011.99 um
- Width (w): 1500.71 um
- Gap (S): 250 um
- Height (H): 1.6 mm
- Thickness (T): 16 um

 A schematic diagram of the microstrip line is shown on the right, with labels for width (w), gap (S), height (H), and thickness (T).

Figure 6 Physical converter tool

3.2.3 ADS Software

Apart from AWR, ADS is another software that can be used to design the filter. We can choose either one since both software will produce the same result but the difference is only the method of use. The Figure 7 below shows the schematic design of UWB. The Z_{even} , Z_{odd} and Z_0 need to be tuned to get an ideal plot.

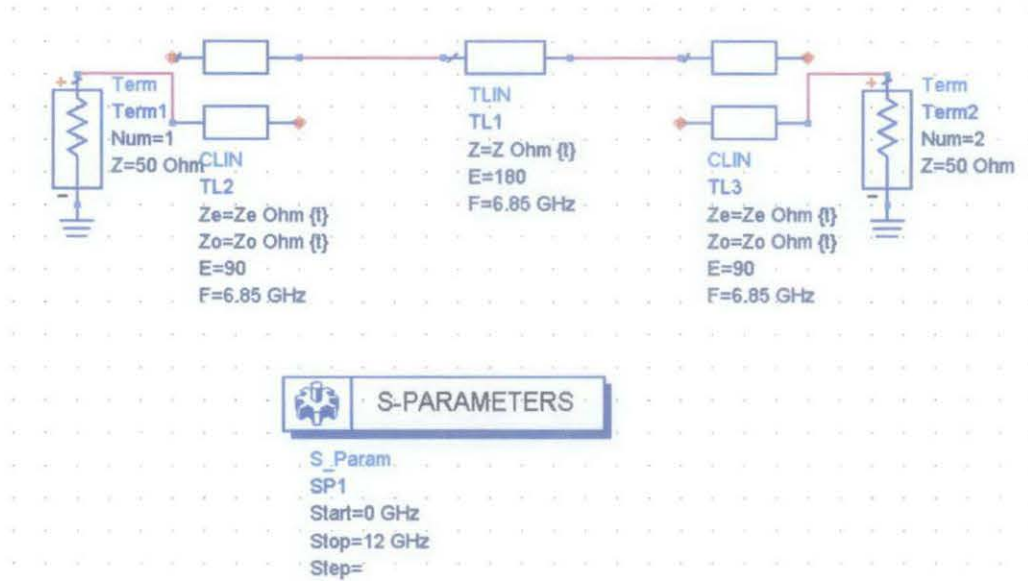


Figure 7 Ideal schematic of UWB in ADS

3.3 Multi-Mode Resonator

For this project, the technique of MMR is employed. As stated in theory, this technique was originally proposed in [6]. This method aims to deploy multiple resonant modes in a composite resonating structure in order to design UWB [4]. At the simulation, it is aimed to produce five transmission poles in the passband.



Figure 8 Microstrip layout consist of two coupled lines [14]

Figure 8 above shows the general layout for MMR. Basically the MMR technique is implemented by having a center low-impedance line section and two identical high-impedance line sections at both sides. The multiple desired resonating modes can be designed in the passband by properly tuning or adjusting the impedance of high and low impedance microstrip transmission line sections.

Based on the Figure 8 above, when we consider a symmetrical line at the middle, the network circuit will become as shown in Figure 9 below. This network circuit in then will be analyzed through Even and Odd Mode analysis in which its mathematical analysis steps will shown clearly in result and discussion part in the next chapter.

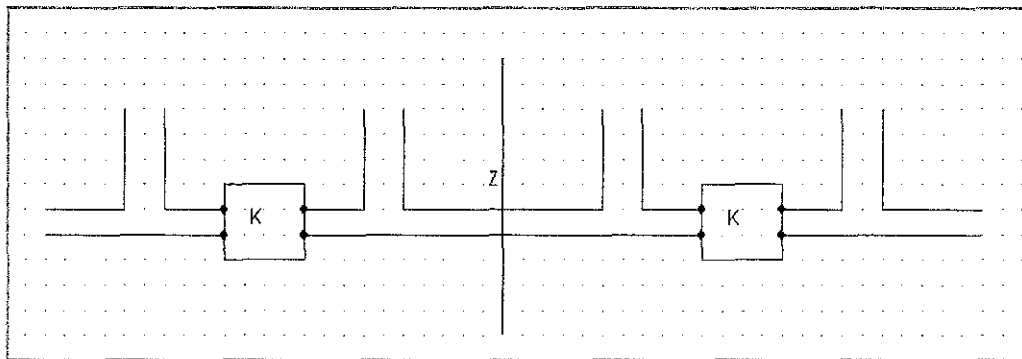


Figure 9 Line of symmetrical at the center of circuit

3.4 S-Parameter and Relationship with Even and Odd-Mode Analysis

As mentioned in literature review, the purpose of doing even and odd mode analysis is to find the admittance of Y_{odd} and Y_{even} that eventually can be used to determine the S-parameter of S_{12} and S_{11} . Below is the step to derive the S_{12} and S_{11} formula based on [13];

Consider the symmetrical network in Figure 10 below;

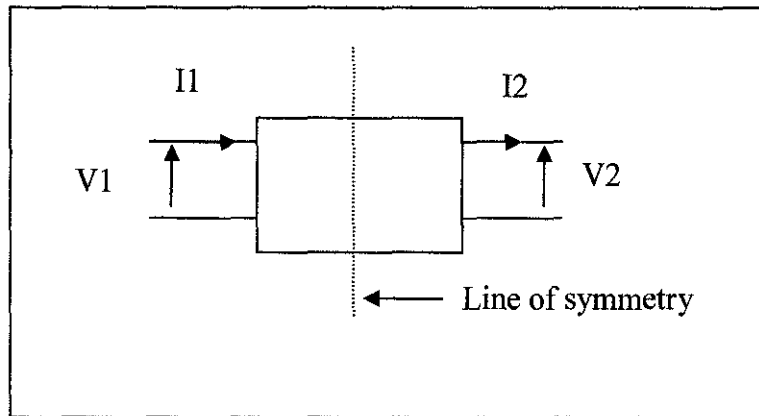


Figure 10 Symmetrical network

For even-mode excitation, it means that equal potentials are applied at each end of the circuit, hence cause open circuit along the symmetrical line. The matrix form for the V_1 and I_1 will become as below;

$$V_2 = -V_1 \quad (3.1)$$

$$I_2 = -I_1 \quad (3.2)$$

Then,

$$\begin{pmatrix} V_1 \\ I_1 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} V_2 \\ I_2 \end{pmatrix} \quad (3.3)$$

hence

$$V_1 = AV_1 - BI_1 \quad (3.4)$$

and solve for Yeven;

$$Y_e = \frac{I_1}{V_1} = \frac{A-1}{B} \quad (3.5)$$

While, for odd-mode excitation, the opposite potential are applied at each end of circuit, hence there is short circuit along the symmetrical line. Therefore;

$$V_1 = V_2 \quad (3.6)$$

$$I_2 = -I_1 \quad (3.7)$$

and solve for Y_{odd} ;

$$Y_o = \frac{1+A}{B} \quad (3.8)$$

now;

$$Y_o + Y_e = \frac{2A}{B} \quad (3.9)$$

and;

$$Y_o - Y_e = \frac{2}{B} \quad (3.10)$$

hence;

$$A[= D] = \frac{Y_e + Y_o}{Y_o - Y_e} \quad (3.11)$$

and;

$$B = \frac{2}{Y_o - Y_e} \quad (3.12)$$

From reciprocity;

$$A^2 - BC = 1 \quad (3.13)$$

Therefore;

$$C = \frac{Y_e Y_o}{Y_o - Y_e} \quad (3.14)$$

The transfer matrix of a symmetrical two-port network, in terms of its even and odd-mode admittance is given by [13];

$$[T] = \begin{bmatrix} \frac{Y_o + Y_e}{Y_o - Y_e} & 2 \\ \frac{2Y_e Y_o}{Y_o - Y_e} & \frac{Y_o + Y_e}{Y_o - Y_e} \end{bmatrix} \quad (3.15)$$

From the transfer matrix above, now we can find the S-parameters since

$$S_{12} = \frac{2}{A + B + C + D} \quad (3.16)$$

Therefore;

$$S_{12} = \frac{Y_{odd} - Y_{even}}{(1 + Y_{even})(1 + Y_{odd})} \quad (3.17)$$

And similarly;

$$S_{11} = \frac{1 - Y_{even}Y_{odd}}{(1 + Y_{even})(1 + Y_{odd})} \quad (3.18)$$

Since we already get the equation of S-parameter, the S_{12} and S_{11} can be determined later on once we have done the mathematical analysis of finding Y_{even} and Y_{odd} . The results of mathematical analysis will be shown in result and discussion part.

3.5 Flowchart

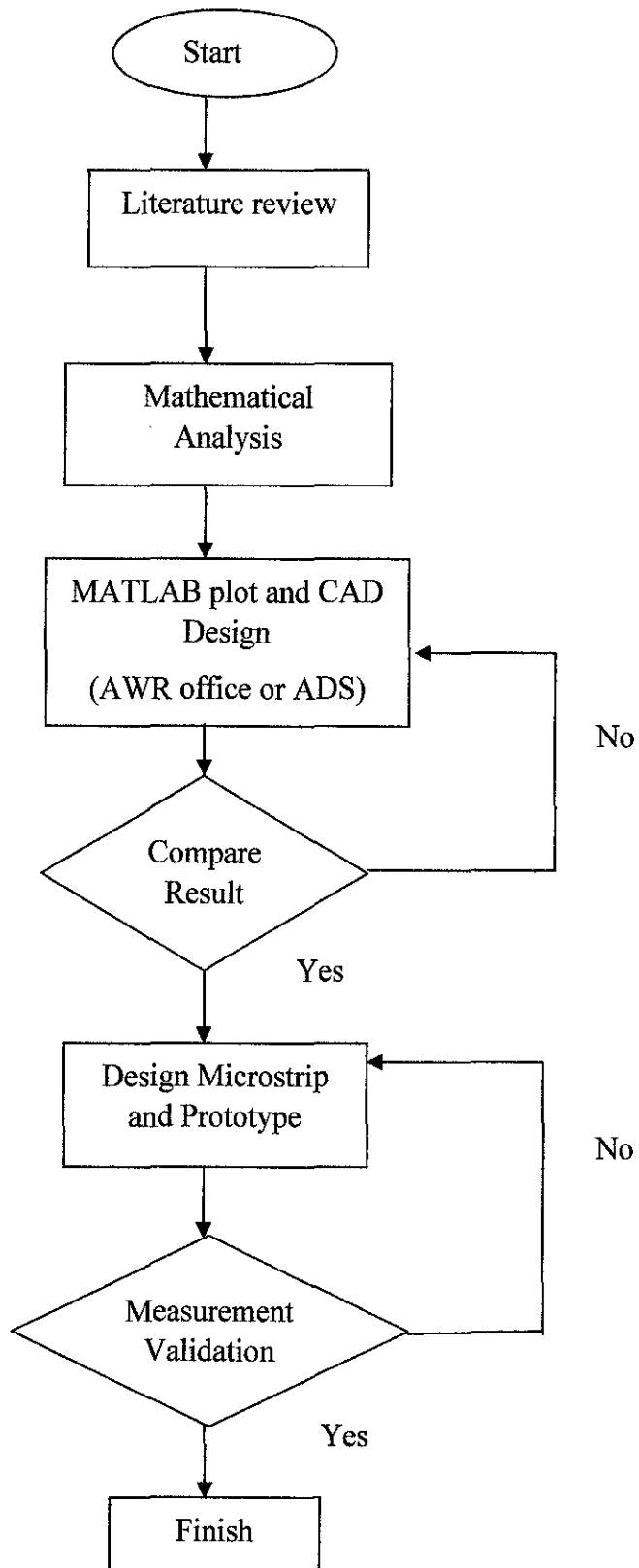


Figure 11 Flowchart of the Project

CHAPTER 4

RESULT AND DISCUSSION

4.1 Analytical Description

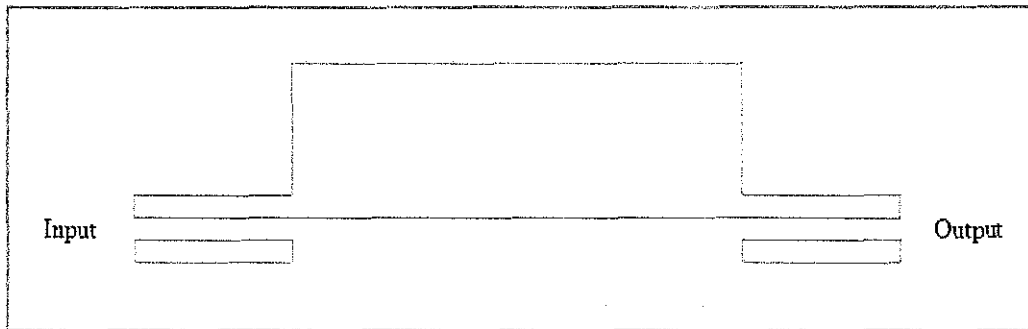


Figure 12 General microstrip layout

Microstrip layout in Figure 12 above shows the MMR technique of UWB. The cascaded network circuit for the MMR above can be shown in Figure 13 below [13]. Referring to the its symmetrical network, the mathematical analysis of the UWB can be performed in two ways either using two port analysis or even-odd mode analysis.

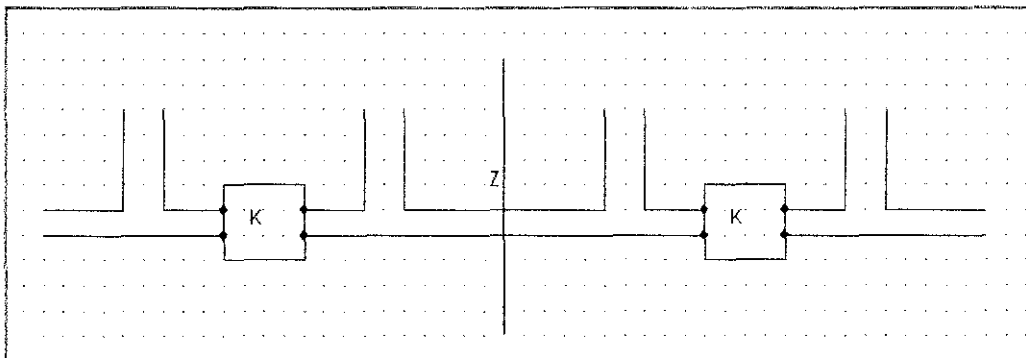


Figure 13 Two port network circuit with line of symmetrical at center

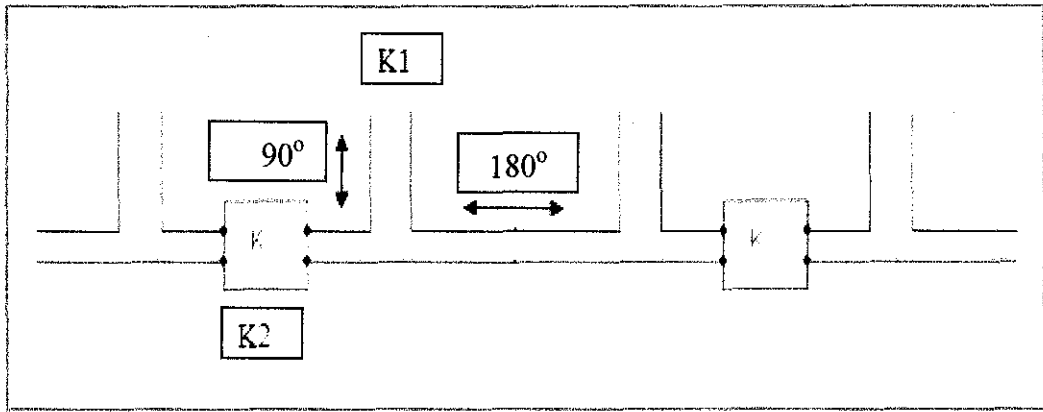


Figure 14 Open stub impedance and electrical length of two port network circuit [13]

In this project, the even-odd analysis is used to perform the analytical model since it is less complicated to simplify the equation rather than two port analysis.

4.2 Mathematical Analysis: Even and Odd Mode Analysis

4.2.1 Odd Analysis

As discussed in methodology part, for odd-mode analysis, the opposite voltages potential were applied at each end of the network circuit. Therefore, the symmetrical network will become short circuit which cause the Z_L becomes zero. As mentioned in literature review, when the Z_L becomes zero, the equation for Z_{in} will become:

$$Z_{in} = jZ \tan(\theta) = jZ \tan(x) \quad (4.1)$$

Referring to the Figure 15 below, the Z_{1a} is equal to Z_{in} . Once we know this equation, we can start doing analytical analysis for odd mode.

The purpose to perform odd-mode analysis is to find the odd-mode admittance, Y_{odd} of the network circuit below in term of odd-mode, since Y_{odd} equation can be used to calculate the S-parameter later. Based on Figure 15 below, the Y_{odd} for the circuit is the inverse of Z_3 . Therefore, the Z_3 need to be determined.

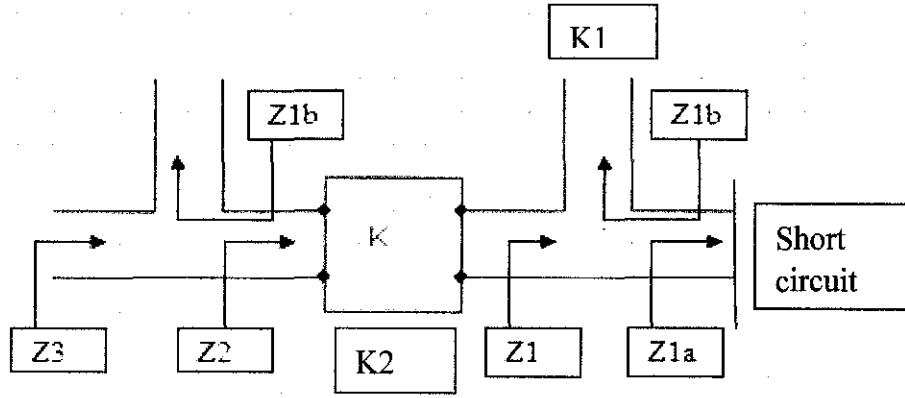


Figure 15 Network circuit for odd mode analysis (short circuit)

To find the $Z3$ which is the summation of $Z2$ and $Z1b$, $Z2$ need to be calculated beforehand. In order to get $Z2$, it is important to determine the $Z1$ first since the formula for $Z2$ is $K2^2/Z1$ where $K2$ is the impedance at K in the figure above.

For $Z1a$, it is equal to the Zin that we obtain earlier which is given by $IZ \tan(x)$ in odd mode. Below is the overall calculation step for odd analysis.

First, $Z1a$ and $Z1b$ are determined first;

$$Z1a = IZ \tan(x) \quad (4.2)$$

$$Z1b = \frac{K1}{I \tan(x)} = -\frac{IK1}{\tan(x)} \quad (4.3)$$

Then, calculate $Z1$;

$$Z1 = Z1a + Z1b \quad (4.4)$$

$$Z1 = IZ \tan(x) - \frac{IK1}{\tan(x)} \quad (4.5)$$

Hence $Z2$ can be obtained;

$$Z2 = \frac{K2^2}{Z1} \quad (4.6)$$

yields;

$$Z2 = \frac{K2^2}{IZ \tan(x) - \frac{IK1}{\tan(x)}} \quad (4.7)$$

Now, Z_3 can be calculated where the formula for Z_3 is;

$$Z_3 = Z_2 + Z_{1b} \quad (4.8)$$

yields;

$$Z_3 = \frac{K_2^2}{IZ \tan(x) - \frac{IK_1}{\tan(x)}} - \frac{IK_1}{\tan(x)} \quad (4.9)$$

Lastly, the Yodd can be determined which is the inverse of Z_3 ;

$$Y_{odd} = \frac{1}{Z_3} = \frac{1}{\frac{K_2^2}{IZ \tan(x) - \frac{IK_1}{\tan(x)}} - \frac{IK_1}{\tan(x)}} \quad (4.10)$$

The Yodd can be simplified as;

$$\frac{I(-Z \tan(x)^2 + K_1) \tan(x)}{-K_2^2 \tan(x)^2 - K_1 Z \tan(x)^2 + K_1^2} \quad (4.11)$$

Let assume K_2 as variable b , the equation of Yodd becomes;

$$Y_{odd} = \frac{I(-Z \tan(x)^2 + K_1) \tan(x)}{-b^2 \tan(x)^2 - K_1 Z \tan(x)^2 + K_1^2} \quad (4.12)$$

4.2.2 Even Mode Analysis

For even analysis, the symmetrical network is being open circuit due to the same potential is applied at each end of circuit which leads the Z_L become infinity. When open circuit, the impedance of Z_{1a} and Z_{1b} become series, therefore the Z_1 can be calculated as sum of the Z_{1a} and Z_{1b} . As mentioned in literature review, the

Z_{1a} is equal to Z_{in} which is given by $-\frac{IZ}{\tan(x)}$

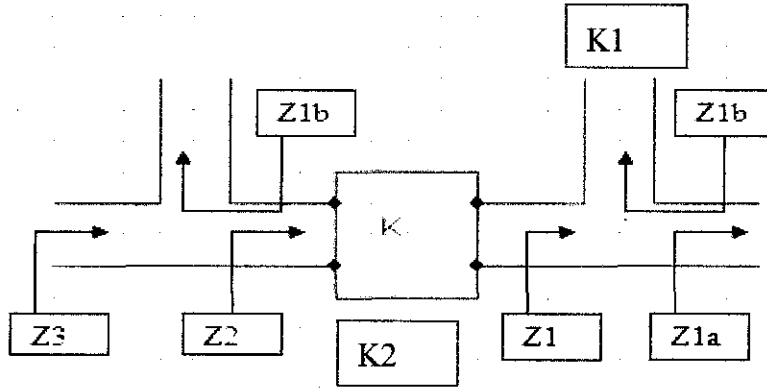


Figure 16 Even mode analysis circuit (open circuit)

Similarly like odd analysis, the step to find admittance, Y_{even} is the same. But the results will be different since it is open circuit for even mode. Below is the mathematical analysis for even mode.

Determine Z_{1a} and Z_{1b} first;

$$Z_{1a} = \frac{Z}{i \cdot \tan(x)} = -\frac{IZ}{\tan(x)}; \quad (4.13)$$

$$Z_{1b} = \frac{K1}{i \cdot \tan(x)} = -\frac{IK1}{\tan(x)}; \quad (4.14)$$

Find Z_1 which the formula is;

$$Z_1 = Z_{1a} + Z_{1b}; \quad (4.15)$$

$$= -\frac{IZ}{\tan(x)} - \frac{IK1}{\tan(x)} \quad (4.16)$$

Then, Z_2 can be determined when Z_1 is obtained;

$$Z_2 = \frac{K2^2}{Z_1}; \quad (4.17)$$

$$= \frac{K2^2}{-\frac{IZ}{\tan(x)} - \frac{IK1}{\tan(x)}} \quad (4.18)$$

Next, Z_3 is determined once Z_2 is known;

$$Z_3 = Z_2 + Z_1 b ; \quad (4.19)$$

$$\frac{\frac{K_2^2}{IZ} - \frac{IK_1}{\tan(x)}}{\tan(x)} \quad (4.20)$$

Finally, can find Y_{even} which is the inverse of Z_3

$$Y_{even} = \frac{1}{Z_3} ; \quad (4.21)$$

Assumming $K_2=b$;

$$Y_{even} = \frac{1}{\frac{\frac{K_2^2}{IZ} - \frac{IK_1}{\tan(x)}}{\tan(x)}} \quad (4.22)$$

Now, Y_{even} can be simplified as;

$$\text{simplify}(Y_{even}) = \frac{I(Z + K_1) \tan(x)}{-b^2 \tan(x)^2 + K_1 Z + K_1^2} \quad (4.23)$$

Now , we have already obtained the equation of Y_{odd} and Y_{even} by using even and odd mode analysis for multi mode resonator. Hence we can determine the S-parameter equation (refer to part 4.3) .

4.3 S-Parameter Equation

The last part is to obtain the S-parameter for transmission and reflection coefficient S_{12} and S_{11} that has been derived in the methodology part since the equations for Y_{even} and Y_{odd} are already known.

The equation of Y_{odd} and Y_{even} will be substituted in the S-parameter equation below. Note that;

$$S_{12} = \frac{Y_{odd} - Y_{even}}{(1 + Y_{even})(1 + Y_{odd})} \quad (4.24)$$

and

$$S_{11} = \frac{1 - Y_{even}Y_{odd}}{(1 + Y_{even})(1 + Y_{odd})} \quad (4.25)$$

The summation of gain S_{12} and S_{11} is equal to 1.

$$|S_{11}(j\omega)|^2 + |S_{12}(j\omega)|^2 = 1 \quad (4.26)$$

After substituting all the value, the gain equation was obtained as shown below:

$$S_{12} = \frac{I \tan(x)^3 Z b^2 (\tan(x)^2 + 1)}{(-b^2 \tan(x)^2 + K1Z + K1^2 + I \tan(x)Z + I \tan(x)K1)(-b^2 \tan(x)^2 - K1Z \tan(x)^2 + K1^2 - I \tan(x)^3 Z + I \tan(x)K1)} \quad (4.27)$$

This equation later can be used to gain the plot of gain versus electrical length using the matlab where x is the electrical length. Since this equation is in imaginary, we can state this equation as $S_{12} = [\text{abs}(S_{12})]^2$ in the Matlab to eliminate the imaginary part.

4.4 Matlab Plot

In MATLAB plot, the value for K_1 , K_2 ($=b$) and Z_0 ($=Z$) need to be varied or tuned to get the ideal plot for UWB filter. To get the ideal plot, the value for $K_1=1.039$ Ohm, $K_2=1$ Ohm and $Z_0=0.69$. Figure 16 below shows the ideal plot of UWB which is the gain versus electrical length.

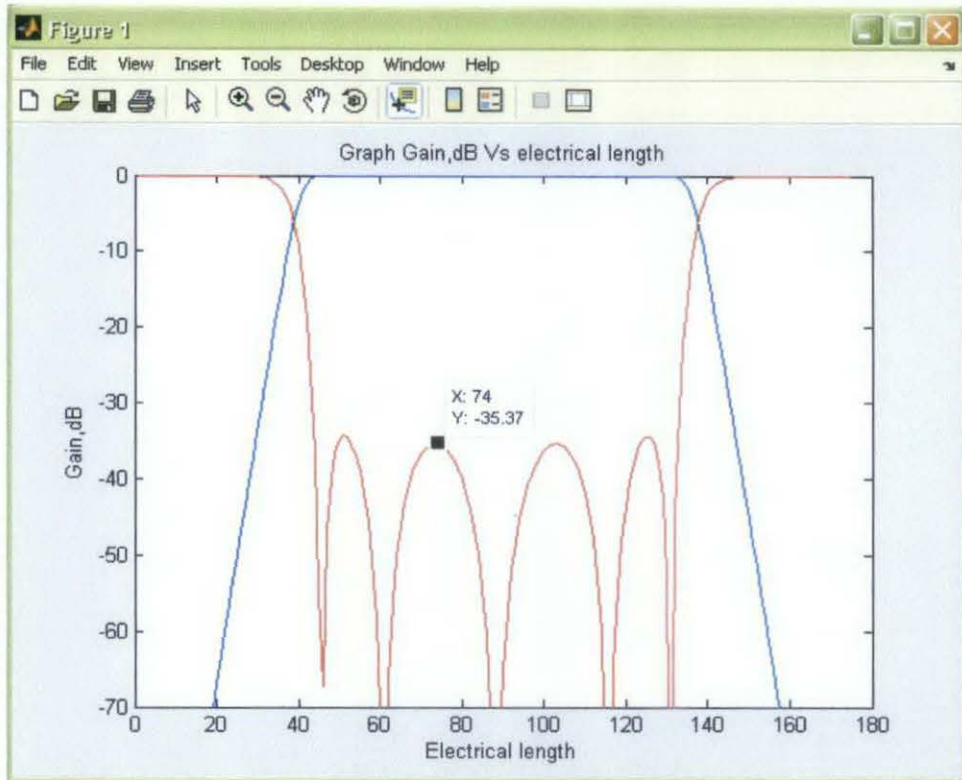


Figure 17 Matlab simulation plot

The line with ripples indicates the gain of S_{11} parameter while the another one is indicating the gain of S_{12} parameter. The gain value for S_{11} in this plot is approximately -35.37dB.

However, in this project, the value of K_1 , K_2 and Z_0 are determined based on the ideal plot in AWR or ADS simulation (refer to part 4.5 for detail explanation).

4.5 AWR Simulation

4.5.1 Ideal Plot in AWR

In AWR or ADS design (refer to schematic diagram in methodology part), the Zeven, Zodd and Z_0 are tuned to get the ideal plot of UWB filter, then these values will be used to calculate the variable value of K1, K2 and Z_0 for S_{12} equation that will be used in MATLAB simulation to verify the mathematical analysis. Figure 18 and Figure 19 below shows the schematic diagram and ideal plot of S_{11} (blue line) and S_{12} (pink line) for UWB.

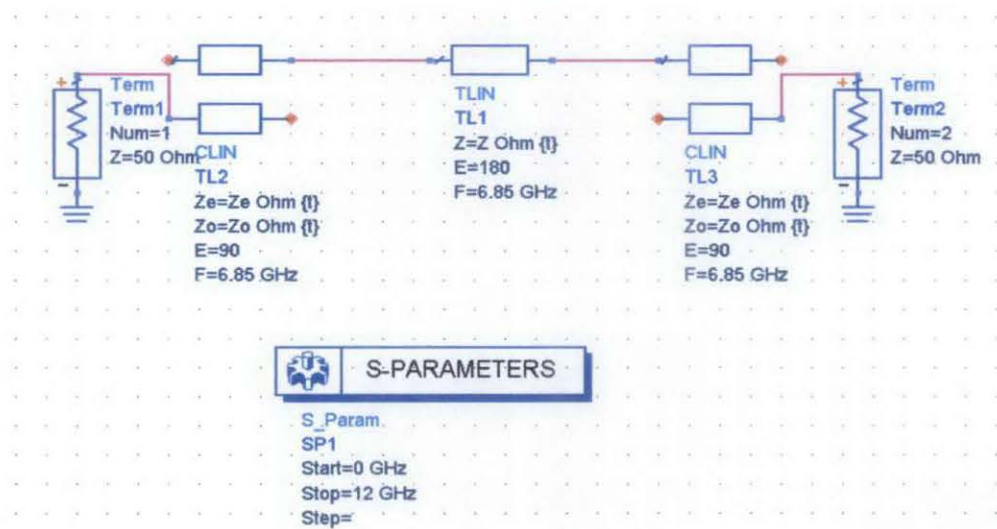


Figure 18 Schematic for ideal transmission line and coupled lines

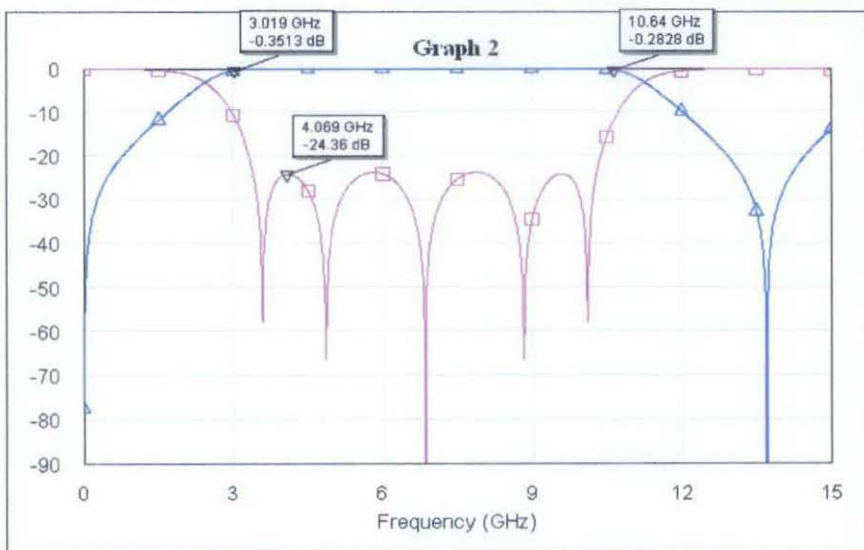


Figure 19 Ideal plot of UWB in AWR

In this case the value of Z_{oe} , Z_{od} , and Z_0 are 116 Ohm, 17.6 Ohm and 38.5 Ohm respectively. Solving for K_1 , K_2 and Z_0 give 1.336, 0.984 and 0.77 respectively. The figure in the next page show there is difference in Matlab Plot compared to AWR plot.

4.5.2 K_1 , K_2 and Z_0 Calculation

The value of K_1 and K_2 can be determined by using the equation below since the Z_{oe} and Z_{oo} are already known [13]

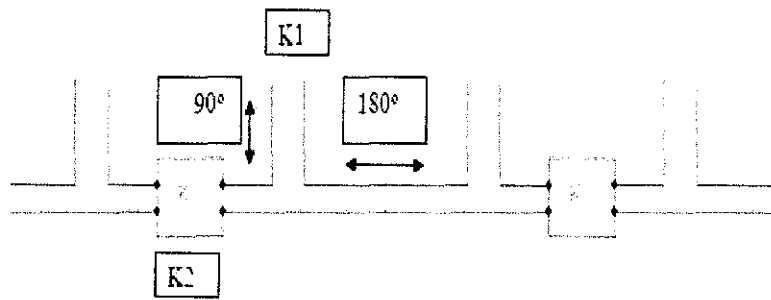


Figure 20 Circuit having K_1 and K_2 impedance

$$k_1 = \frac{Z_{oe} + Z_{oo}}{2} \quad (4.28)$$

$$k_2 = \frac{Z_{oe} - Z_{oo}}{2} \quad (4.29)$$

From the value of Z_{oo} and Z_{oe} in the ideal simulation in AWR, the K_1 and K_2 value can be solved which we get 1.336 Ohm and 0.984 Ohm respectively. While for Z_0 , we can directly take from the Z_0 value in AWR which we get 0.77 Ohm. (Note that all these values are obtained after divided by 50 Ohm since AWR uses 50 Ohm system).

4.5.3 Verify Ideal Plot of AWR in Matlab

Substituting the value of K_1 , K_2 and Z_0 above into m-file editor in Matlab, its simulation plot is obtained as shown in Figure 21 below.

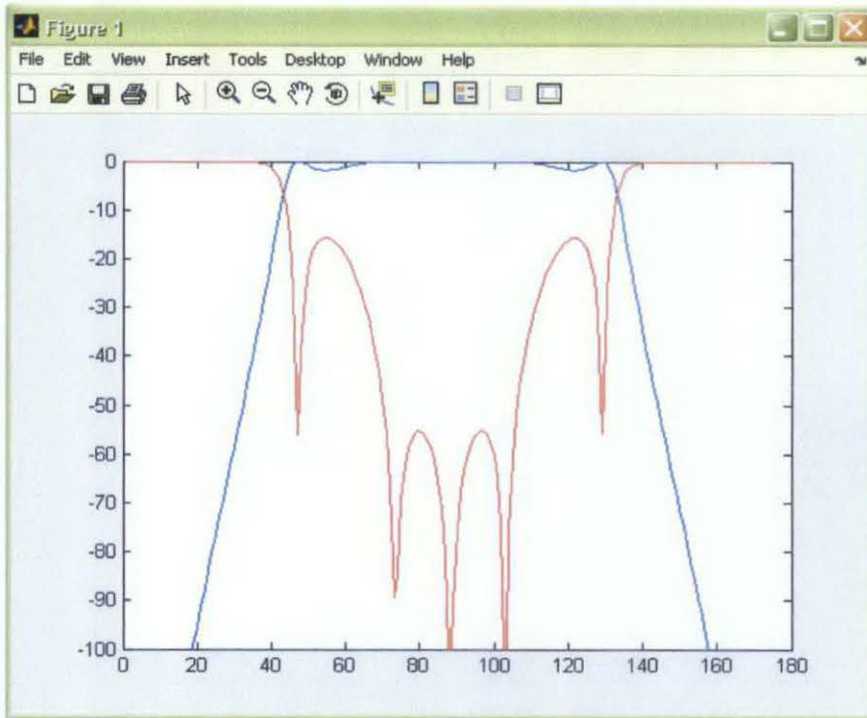


Figure 21 Matlab plot

4.6 Comparison AWR and Matlab Plot

Based on result in part 4.5, the plot of S-parameter in AWR and Matlab are having difference between each other in term of gain, location of transmission poles, and position of ripples which are not equal are obtained in Matlab. Next, the bandwidth of UWB is reduced by 50 percent to see whether there are still differences for both simulations in Matlab and AWR/ADS for narrow bandwidth.

4.7 Alternative (Reducing the Bandwidth)

Reducing the bandwidth to 50 percent might be a solution to this problem. Therefore, the new ideal plot of S_{11} and S_{12} for UWB need to be simulating again to get new bandwidth. Hence, to get ideal plot for reduced bandwidth of 50 percent, the Zeven, Zodd and Z_0 are adjusted to new values, which in this case the new Zeven, Zodd, and Z_0 are 136.9 Ohm, 55.84 and 16.2 Ohm respectively.

Figure 22 below shows the tune parameter used to get adjust the value of Zeven, Zodd and Z_0 and Figure 23 shows its new ideal simulation plot for S-parameter of S_{11} and S_{12} which the bandwidth reduced to 49.7 percent.

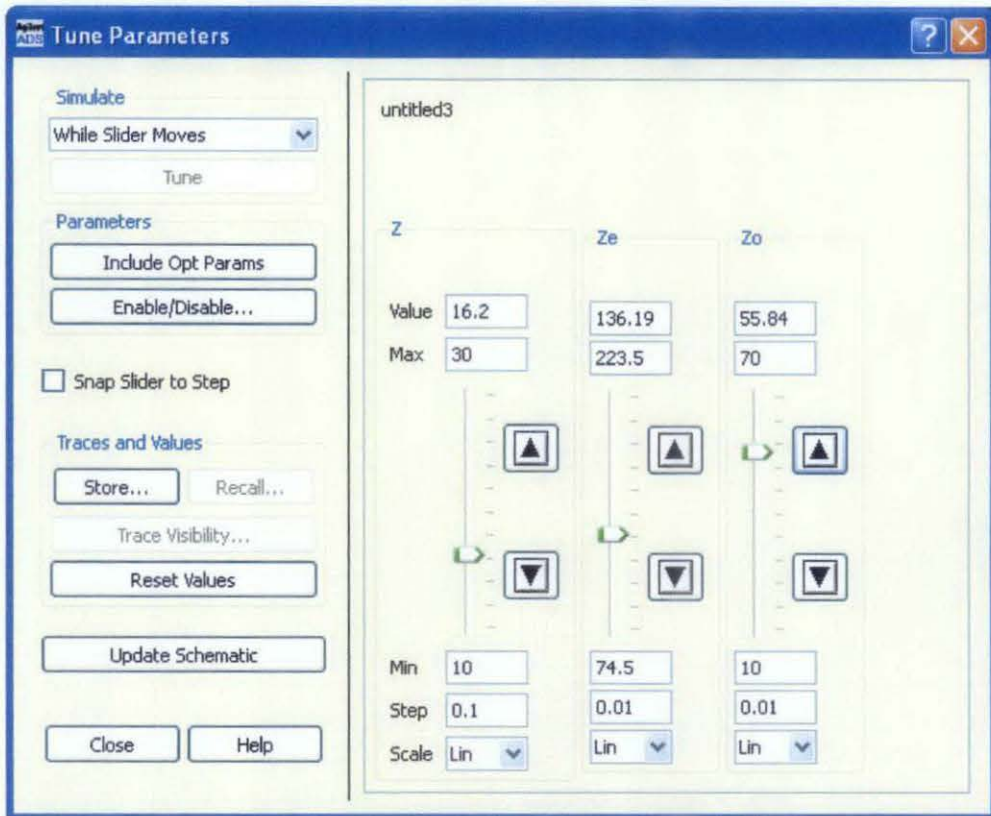


Figure 22 Tune parameter for Zeven, Zodd and Z_0

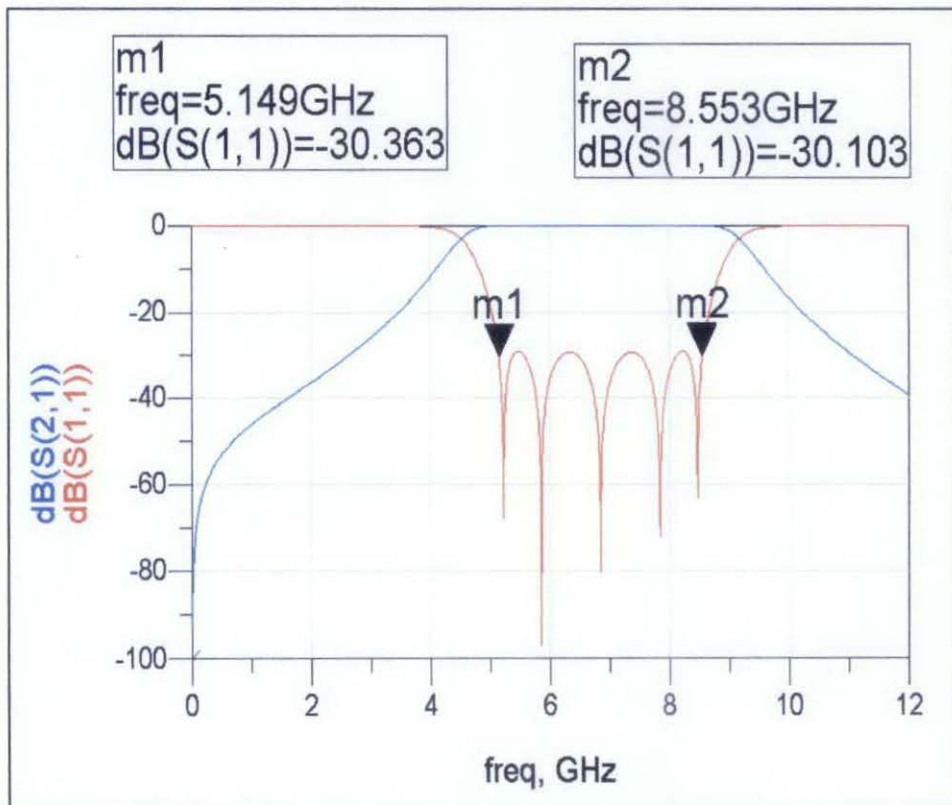


Figure 23 Ideal plot for new frequency bandwidth

Now, the percentage frequency reduced is;

$$\text{percentage} = \frac{8.553 - 5.149}{6.85} = 49.7\% \quad (4.30)$$

Again, solve for K1 and K2 using the formula below (refer *part 4.5.2*);

$$k1 = \frac{Zoe + Zoo}{2} \quad (4.31)$$

$$k2 = \frac{Zoe - Zoo}{2} \quad (4.32)$$

Yields $K1=96.37 \text{ Ohm}$, $K2= 40.53 \text{ Ohm}$ and Z_0 remains as 16.2 Ohm .

However, in mathematical analysis, we use 1 Ohm system instead of 50 Ohm in AWR/ ADS, therefore the value of K1, K2 and Z_0 above must be divided by 50 Ohm.

Hence $K1=1.9274 \text{ Ohm}$, $K2=0.8106 \text{ Ohm}$ and $Z_0=0.324 \text{ Ohm}$

Substituting this new value of K1, K2 and Z_0 into Matlab m-file editor, the simulation result shows in Figure 24 below.

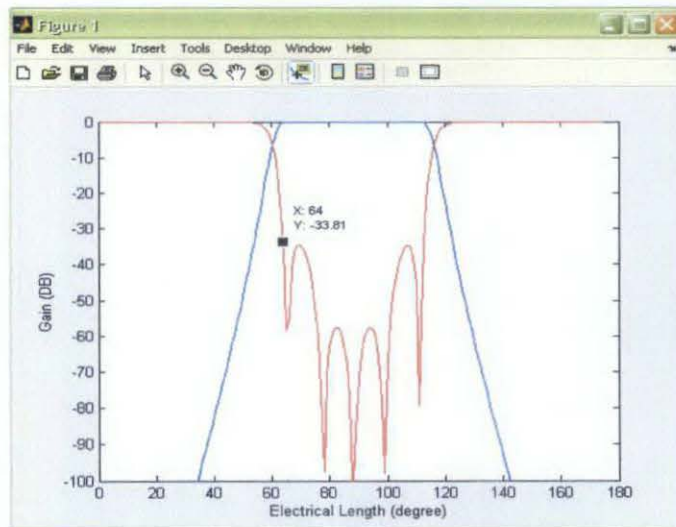


Figure 24 Matlab plot for reduced bandwidth

4.8 Results Analysis

Based on the results above, we can see that the Matlab plot and ADS simulation is not exactly the same to prove the mathematical analysis. For broad band and reduced bandwidth, both results have differences even though five transmission poles are generated in the passband. It supposed to give the same plot both in Matlab and ADS or AWR simulation, but in this case it did not.

Now by referring back to the mathematical analysis for even and odd mode, the analysis are made based on the equivalent circuit consisting of series open circuit stubs separated by inverters as proposed by IC Hunter as shown in Figure 25 below [13].

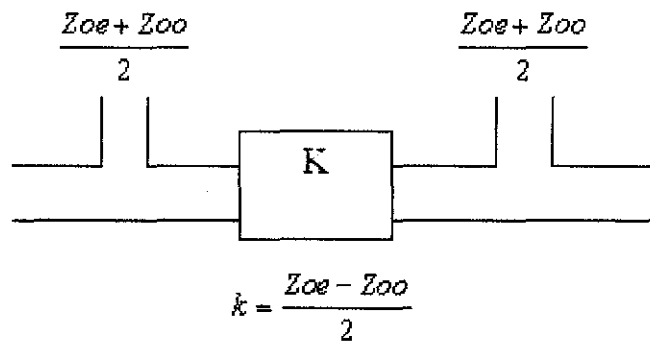


Figure 25 Equivalent circuit of a coupled-line pair

Generally, based on IC Hunter book, the equivalent circuit in Figure 25 above is the final equivalent circuit as a result from combination of equivalent circuit of a unit element (UE) in Figure 27 with the equivalent circuit of a parallel couple line-pair in Figure 26 [13].

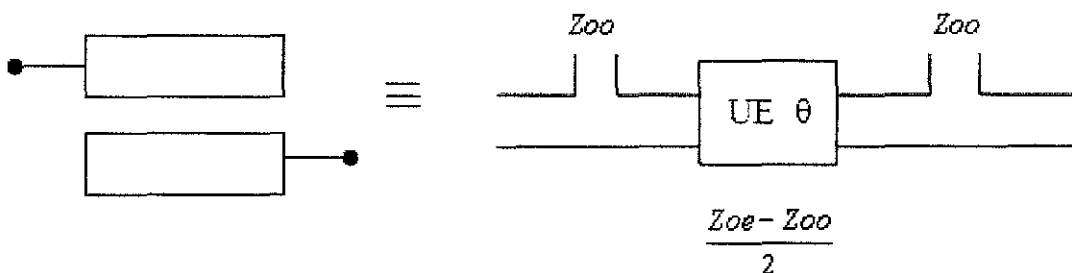


Figure 26 Equivalent circuit of a parallel coupled line-pair

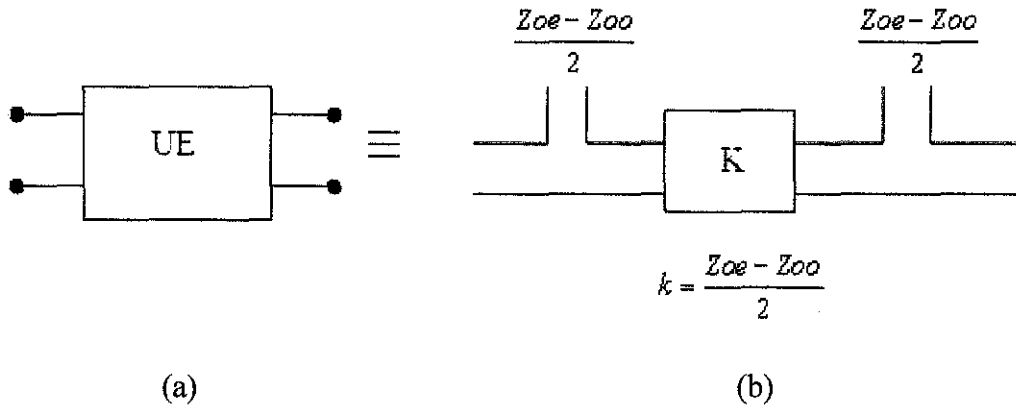


Figure 27 (a) Unit element, (b) Equivalent circuit Of unit element

In this project, the final equivalent circuit in Figure 25 is used to generate mathematical analysis without acknowledging that its approximation only limits for narrow band. The problem is from the theory in [13], it did not state that they the final equivalent circuit (Figure 25) is obtained to achieve narrow band of UWB. It might be during the time that this theory is proposed in 2001, the broad bandwidth for UWB is still new, and not too practical or realizable, unlike in modern technology nowadays which many types of filter are possible to realize and develop.

To prove that this approximation only limits for narrow wideband, the circuit from Figure 27 is designed in ADS as shown below to plot the S parameter to prove this assumption.

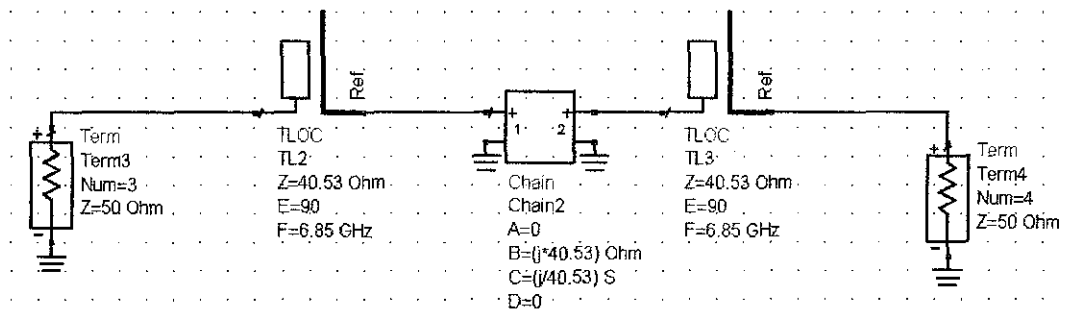


Figure 28 Schematic design for equivalent circuit in Figure 27 (b)

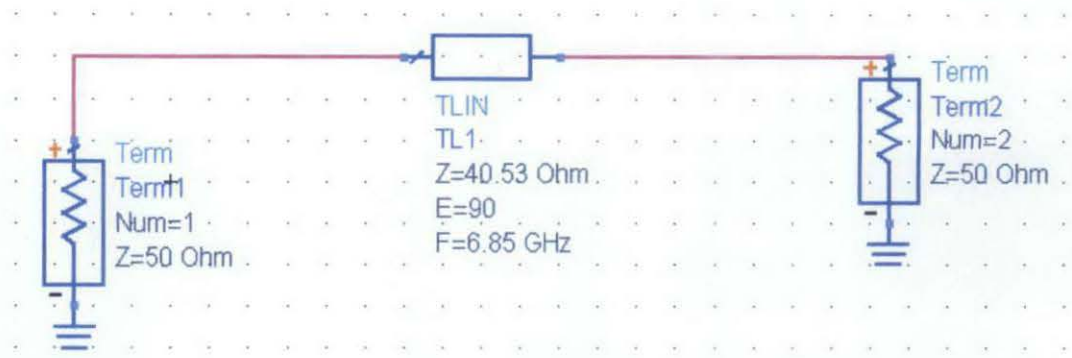


Figure 29 Schematic design for transmission line of unit element

Figure 30 below shows both simulations result for the transmission line and equivalent circuit of unit elements above. S_{11} and S_{12} are the plots for schematic in figure 26 and S_{33} and S_{43} are the plots for schematic in figure 25.

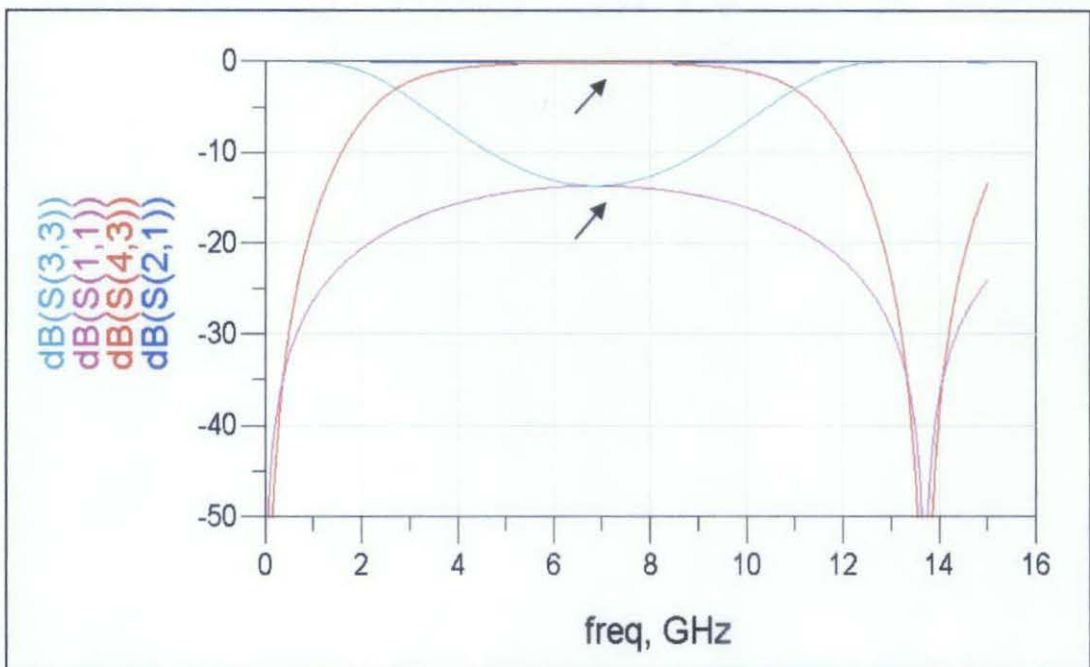


Figure 30 S- Parameter plot for transmission line and equivalent circuit of unit element

As shown in the simulation result above, it is proven that this approximation is limit for narrow band only. The arrows in the Figure 30 show that the region where the signals are slightly overlap is bandwidth for narrow band which is less than 20 percent compared to ideal bandwidth of ultra wideband which is 7.5 GHz. Therefore, the mathematical analysis that has been done before can be only used to design filter with limited bandwidth which is below 20 percent of UWB fractional bandwidth.

The design of microstrip can be continued in ADS, however in this case, the microstrip design of UWB is not proceed since the mathematical analysis done is only valid for narrow bandwidth.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

For this project, designing analytical model required a deep understanding about ultra wideband technology. Since there is no analytical model has been developed in the past, it would be a challenge to come out with such analytical model. In this project, the MMR technique is used. Therefore, the study about Multi Mode Resonator (MMR) is becoming crucial in order to complete this project since the mathematical analysis is based on MMR. Generally, MMR is one type of structures that are able to realize an ultra-wide passband.

However, in this project, even though the fabrication process for UWB is not proceed since the mathematical analysis done is limited for narrow band only, but the new thing is successfully discovered in this project which is the assumption for mathematical analysis done based on the equivalent circuit of a parallel coupled line pair in Figure 25 is only limit for narrow band, which in this case, this assumption is not mentioned in [13].

In a nutshell, generally UWB technology is one of the important achievement of communication engineering since 2002 which the Federal Communication Comision FCC has unlicensed the use of UWB filter that set in range 3.1 to 10.6 GHz. Since that, the UWB filter has become popular among microwave engineers and the researches were continuously done to come out with compact size, simple structure, good frequency performance and flat group delay.

5.2 Recommendation

As planned in the Gantt chart, at the end of this project, it should come out with the prototype fabrication. To produce the prototype of this filter, the schematic design of microstrip need to be done first based on ideal transmission line of UWB. However, in this project, the ideal transmission line simulation result for S-parameter in AWR/ADS is not the same as in Matlab which means that the mathematical analysis need to analyzed and revised back to get the same ideal plot in both simulations.

Therefore, after analyzing the result, it is finally successful to detect what is wrong with the mathematical analysis which leads to the true assumption that the equivalent circuit for parallel coupled line that has been used in the mathematical analysis before is only limit for narrow band only. For ultra wideband, we should use the original equivalent circuit as shown in Figure 26 in part 4.8 which the UE is not decomposed yet into a pair of open circuited stubs separated by K inverter [13].

By analyzing this circuit, the new mathematical analysis can be developed which will give the same plots in AWR/ADS and also Matlab since this equivalent circuit is ideally can produce ultra wide band in the passband. The new transfer matrix needs to be used in the analysis since this circuit has Unit Element instead of K inverter.

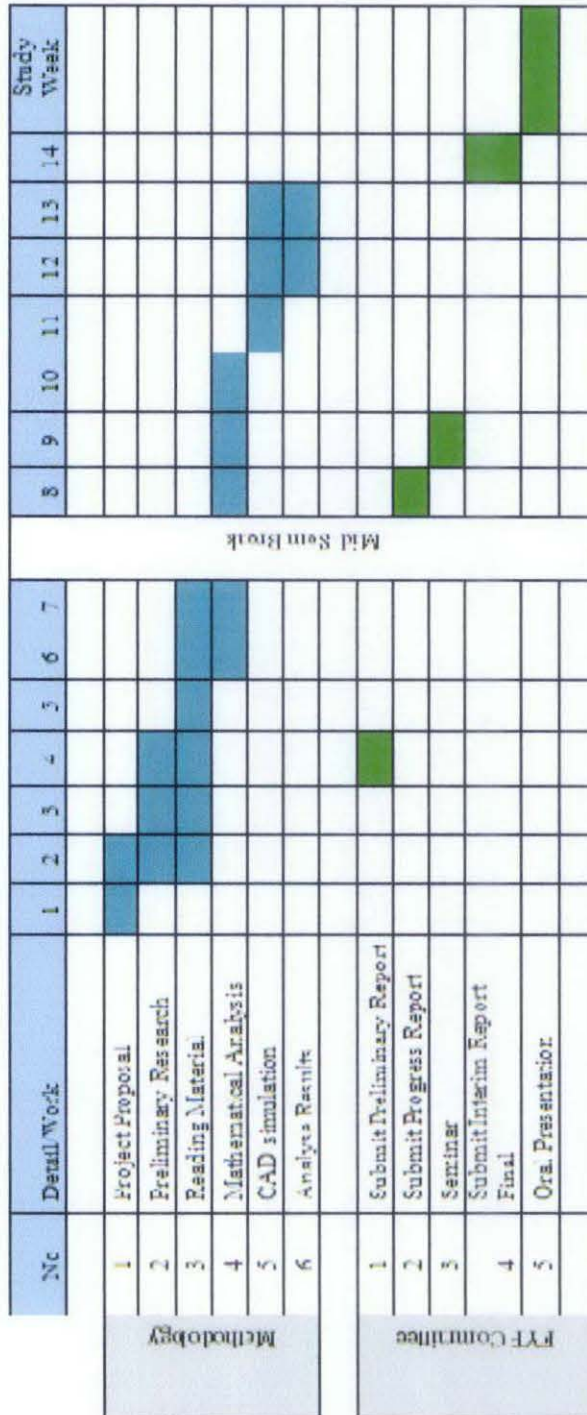
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APPENDICES

APPENDIX A

GANTT CHART FYP 1



APPENDIX B
GANTT CHART FYP 2

	No	Detail of Work/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Exam Week	
Methodology	1	AWR simulation of Microstrip																
	2	Prototype fabrication (if simulation success)																
	3	Measurement Validation (if done fabrication)																
	4	Analyse Results (from simulation fabrication)																
FYP Committee	1	Submit Progress Report																
	2	Pre-EDX																
	3	Submit Draft Report																
	4	Submit Final Report and Technical Paper																
	5	Final Oral Presentation																

APPENDIX C

MATLAB CODING

```
clc
clc
close all;
clear all;

K1=1.039;
Z=0.69;
b=1;
ii=1;

for u=0:0.0001*180:pi
s12(ii)=(i) * (tan(u) ^ 3) * (b ^ 2) * Z * (tan(u) ^ 2 + 0.1e1) / (-
(b ^ 2 * tan(u) ^ 2) + K1 * Z + K1 ^ 2 + (i) * tan(u) * Z + (i) *
tan(u) * K1) / (-(b ^ 2 * tan(u) ^ 2) - (tan(u) ^ 2) * Z * K1 + K1 ^
2 + (-1*i) * (tan(u) ^ 3) * Z + (i) * tan(u) * K1);

s12mag(ii)=[abs(s12(ii))]^2;
ii=ii+1;
end

plot (10*log(s12mag));
hold on
s11=1-s12mag;
plot(db(s11),'r')
hold off
axis([ 0 180 -100 0])
```