SMALL-SIZED MICROSTRIP LOWPASS FILTER USING DEFECTED GROUND STRUCTURE

By

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Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved by:

Prof. Dr. Grant Andrew Ellis
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2009

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 Firdaus Bin Shahrin

ABSTRACT

Microstrip lowpass filter plays important role in many RF or microwave applications. They are used to select the microwave signals within assigned spectral limits. In this project, a conventional stepped-impedance microstrip lowpass filter is designed to have an equal-ripple response with a cutoff frequency of 0.8 GHz. The filter needs to satisfy more than 20 dB insertion loss at 1.2 GHz with the impedance of 50 Ohm. By using the insertion loss method, filter performance is expected to be improved at the expense of a higher order filter. Another filter with the defected ground structure (DGS), having the same physical length, is introduced to investigate the performance of the filter. The simulation is carried out using the Agilent Advanced Design System (ADS) and Sonnet Suite software and in the experimental measurements a vector network analyzer is used. The results taken from the measurement shows that the signal response from the filter with DGS exhibits a wider passband frequency, with sharp cut off frequency. Another filter with defected microstrip structure (DMS) also shows the same behavior. The discontinuities structure proves that it can be used to improve the performance and reduces the size of the filter.

ACKNOWLEDGMENTS

Praise be to Allah s.w.t to Whom we seek help and guidance and under His benevolence we exist and without His help this project could not have been accomplished.

I would like to express my sincere appreciation to my project supervisor, Prof. Dr. Grant Andrew Ellis, for his encouragement, guidance, critics and friendship during the course of studies. Thanks for helping me to kick start and finish this valuable research.

Thanks for my friends especially Regina, Koh Ming Hao, Fatimah Zaharah and others for their help and moral support during the entire research. Without their continued support and interest, this project would not have been realized.

Last but not least, my gratitude also goes to all technicians for their co-operation throughout the critical period of completing this project. Thank you all.

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LIST OF ABBREVIATIONS

ADS	Advance Design System
BW	Bandwidth
dB	Decibel
et al	and others
FCC	Federal Communications Commission
FR4	Flame Retardant 4
GHz	Giga Hertz
IEEE	Institute of Electrical and Electronics Engineers
IL	Insertion Loss
LC	Inductor and Capacitor
LPF	Low pass filter
PCB	Printed Circuit Board
RL	Return loss
R/T	Reflection/ Transmission
RF	Radio frequency
S-parameter	Scattering parameter
SMA	Subminiature version A
VSWR	Voltage Wave Standing Ratio

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Filter circuits are important in communication systems. They are used for frequency band selection, channel separation, noise suppression, and matching. The conventional microstrip lowpass filters such as stepped-impedance is the area of interest for this project.

In general, the design of microstrip lowpass filters involves two main steps. The first one is to select an appropriate lowpass prototype. The choice of the type of response, including passband or stopband ripple and the number of reactive elements, will depend on the required specifications. Having obtained the suitable lumped-element filter design, the next step is to find an appropriate microstrip realization that approximates the lumped-element filter.

1.2 Problem Statement

A stepped-impedance microstrip lowpass filter is to be designed having an equal-ripple response with a cutoff frequency of 0.8 GHz. It is necessary to have more than 20 dB insertion loss at 1.2 GHz. The filter impedance is 50 Ω. The defected structure is introduced on the ground plane to investigate the performance of the filter.

1.3 Objectives

The objective of this project is to design, simulate and fabricate an equal-ripple microstrip lowpass filter. This filter must exhibits a good stopband characteristic with a sharp rate cutoff frequency.

The performance of the filter is investigated when the defected ground structure is introduced in the ground plane.

1.4 Scope of Study

The scope of study for this project is to understand the basic microstrip lines, the microstrip filters and some design implementations of defected ground structure to obtain the required characteristics. The research study may include published papers or journals and books from various sources in the related field.

The proposed microstrip filter design is simulated using Agilent Advanced Design System (ADS) and Sonnet Suites software.

CHAPTER 2

LITERATURE REVIEW

2.1 Microstrip Line

Planar configuration is one of the principal requirements for a transmission structure in microwave integrated circuit. A planar configuration means that the characteristics of the element can be determined by the dimension in a single plane. There are several transmission structures that satisfy the requirement of being planar. The most common structures are microstrip, coplanar waveguide, slotline, and stripline, and many other types of related geometries.

Microstrip is a type of transmission line which can be fabricated using printed circuit board (PCB) technology, and is used to convey microwave-frequency signals. It is the most popular types of planar transmission lines, because it can be fabricated by photolithographic processes and is easily integrated with other passive and active microwave devices.

2.1.1 Microstrip Structure

The general structure of a microstrip is shown in Figure 1 [19]. A conductor of width W is printed on a thin, grounded dielectric substrate of thickness h with relative dielectric constant, ε_r.

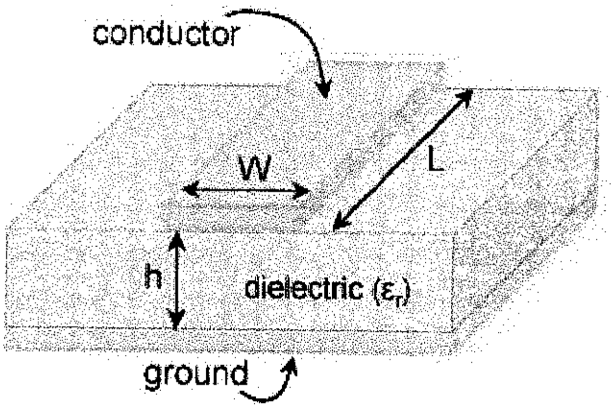


Figure 1 Geometry of a microstrip line

The presence of the dielectric that does not fill the air region above the strip line complicates the behavior and analysis of microstrip line. Microstrip has some of its field lines in the dielectric region, concentrated between the strip conductor and the ground plane, and some fraction in the air region above the substrate. For this reason, the microstrip cannot support pure TEM wave.

2.1.2 Waves Propagation in Microstrip

The structure of microstrip is inhomogeneous where the fields in the microstrip extend within two media – the air region above and the substrate below the microstrip line. With the presence of the two guided-wave media, the waves in a microstrip line will have no vanished longitudinal components of electric and magnetic fields, and their propagation velocities will depend on the physical dimensions of the microstrip besides the material properties. A sketch of the field lines is shown in Figure 2 [20].

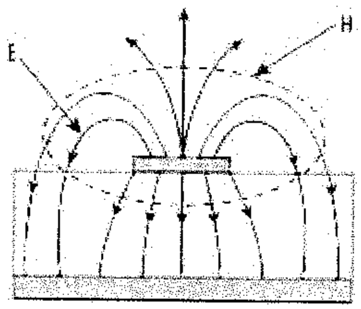


Figure 2 Electric and magnetic field lines

2.1.3 Losses

For lowest cost, microstrip devices may be built on an ordinary FR4 (standard PCB) substrate. Loss components of a microstrip line may include conductor loss, dielectric loss, and radiation loss.

2.2 An Overview of Microwave Filters

Microwave filter is used to control the frequency response of a two-port network in a microwave system. Certain frequencies are allowed to transmit within the passband and others attenuate in the stopband of the filter. There are two methods that can be used to design the microwave filter, which is image parameter method and insertion loss method. Both provide lumped-element circuits.

2.2.1 Filter Design by Image Parameter Method

Filters designed using the image parameter method may consist of a cascade of simpler two-port filter sections to fulfill the desired cutoff frequencies and attenuation characteristics of passband and stopband. Although the procedures are simple, the design of the filters often must be iterated many times to achieve the desired results because this method does not allow the specification of a frequency response over the complete operating range. This method is very useful for simple filters in practical filter design.

2.2.2 Filter Design by Insertion Loss Method

Insertion loss method is a modern procedure, which uses network synthesis techniques with a specified frequency response. The design is simplified with the filters being normalized in terms of impedance and frequency. Transformations are then applied to convert the prototype designs to the desired frequency range and impedance level.

2.3 Filter Response

In insertion loss method, a filter response is defined by its insertion loss, or power loss ratio, P_{LR} :

$$P_{LR} = \frac{Pinc}{Pload} = \frac{1}{1-|\Gamma(\omega)|^2} \tag{1}$$

P_{inc} = Power available from source

P_{load} = Power delivered to load

and

$$1-|\Gamma(\omega)|^2 = \frac{M(\omega^2)}{M(\omega^2)+N(\omega^2)} \tag{2}$$

Substituting this for (2) gives the following:

$$P_{LR} = 1 + \frac{M(\omega^2)}{N(\omega^2)} \tag{3}$$

Thus, for a filter to be physically realizable, its power loss ratio must be of the form in (3). Practical filter response is discussed below.

2.3.1 Equal-ripple Functions

If an equal-ripple function, or Chebyshev function, is used to specify the insertion loss of an N-order lowpass filter, then a sharper cutoff frequency will result, as expressed in the form below:

$$P_{LR} = (1+k^2)T_N{}^2(\frac{\omega}{\omega_c}) \tag{4}$$

The passband response will have ripples of amplitude $1+k^2$. Thus, k^2 determines the passband ripple level.

2.3.2 Lowpass Prototype Filters and Elements

A lowpass prototype filter defined as the lowpass filter whose element values are normalized to make the source resistance or conductance equal to one, and the cutoff frequency to be unity. Figure 3 [14] below demonstrates two possible forms of an N-order lowpass prototype for filter response. Both forms can be used and give the same response:

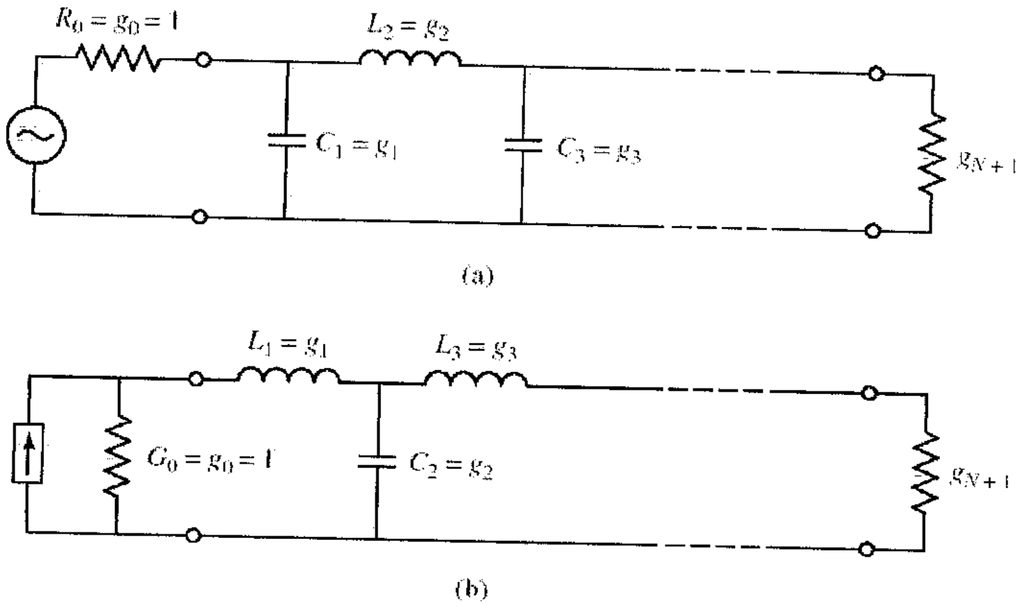


Figure 3 Ladder circuits for lowpass filter prototypes and their element definitions. (a) Prototype beginning with a shunt element. (b) Prototype beginning with a series element.

It is necessary to determine the size, or order of the filter, dictated by a specification on a specified passband ripple level or by the insertion loss of a specified stopband of the filter.

Table 1 [14] lists the element values for normalized lowpass filter prototypes having 0.5 dB or 3.0 dB ripple, for N=1 to 10. If the stopband attenuation is specified, the curves in Figure 4 [14] can be used to determine the necessary value of N for these ripple values.

Table 1 Element values for Equal-Ripple Lowpass Filter Prototypes (g_0=1, ω_c=1, N=1 to 10, 0.5 dB and 3.0 dB ripple)

					0.5 dB Ripple						
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

					3.0 dB Ripple						
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

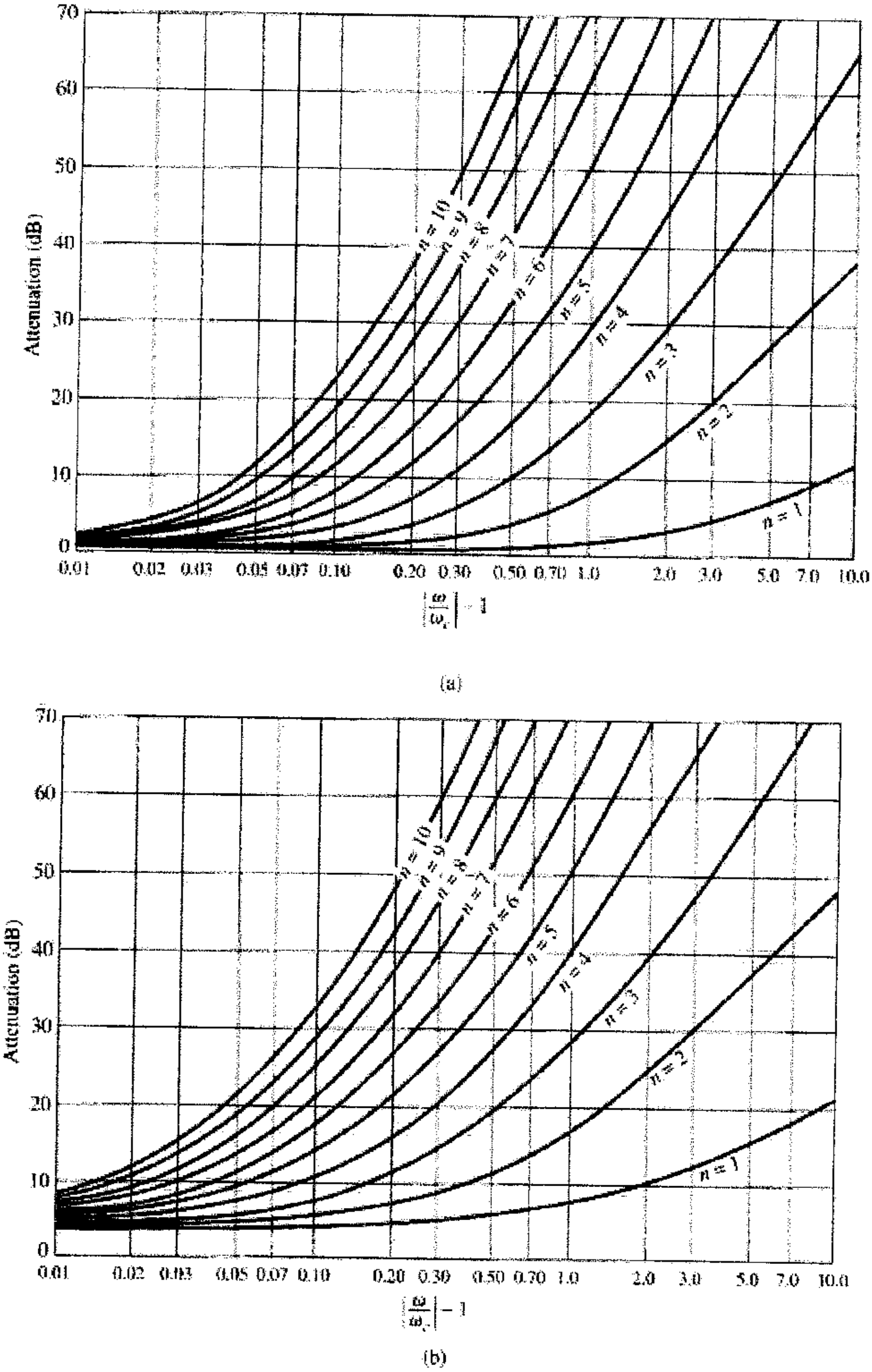


Figure 4 Attenuation versus normalized frequency for equal-ripple filter prototypes. (a) 0.5 dB ripple level. (b) 3.0 dB ripple level

2.4 Filter Transformation Using Impedance and Frequency Scaling

The lowpass filter prototypes of the previous section (2.3) are normalized designs having a source impedance of $R_s = 1\Omega$ and a cutoff frequency of $\omega_c=1$.

Impedance Scaling. The source and load resistance are unity in prototype design. A source resistance R_0 can be obtained by multiplying the impedances of the prototype design by R_0.

$$L' = R_0 L \tag{5a}$$

$$C' = C / R_0 \tag{5b}$$

$$R'_s = R_0 \tag{5c}$$

$$R'_L = R_0 R_L \tag{5d}$$

The primes denote impedance scaled quantities, where L,C, and R_L are the component values for the original prototype.

Frequency scaling. The frequency of the filter scaled by the factor of $1/\omega_c$ to change the cutoff frequency of a lowpass prototype from unity to ω, by replacing ω by ω/ω_c. The new element values are determined by applying the substitution of ω/ω_c to the series reactances, $j\omega L_k$ and shunt susceptances, $j\omega C_k$ of the prototype filter.

$$jX_k = j(\omega/\omega_c)L_k = j\omega L_k \tag{6a}$$

$$jB_k = j(\omega/\omega_c)C_k = j\omega C_k \tag{6b}$$

Then the new element values are given by

$$L'_k = L_k/\omega_c \tag{7a}$$

$$C'_k = C_k/\omega_c \tag{7b}$$

The results of (5) can be combined with (7) to give

$$L'_k = R_0 L_k/\omega_c \tag{7a}$$

$$C'_k = C_k/R_0 \omega_c \tag{7b}$$

2.5 Stepped-Impedance Filter Design

Stepped-impedance lowpass filter, referred as hi-Z and low-Z filter, are alternating sections of very high and very low characteristic lines. They are easier to design and take up less space than a similar lowpass filter using stubs. The high impedance lines act as series inductors and the low impedance lines act as shunt capacitors. Approximation is involved to design this filter.

The electrical lengths of the inductor sections calculated as :

$$\beta_l = \frac{LR_o}{Z_h} \tag{8a}$$

The electrical lengths of the capacitor sections calculated as :

$$\beta_l = \frac{CZ_l}{R_o} \tag{8b}$$

2.6 Defected Ground Structure (DGS)

The use of discontinuities in ground planes is currently employed to improve the performance of different passive circuits, such as the size reduction of filters and the enhancement of filter characteristics. The use of DGS allows an increase in the slow-wave factor (SWF) in transmission lines [2]. These can be used to reduce the size of passive planar circuits like microstrip line lengths, coupling lines, and microstrip antennas. JA Tirado Mendez [2] introduces a very simple and accurate method to describe how defected structures can be used in reducing the size of microstrip structures and predict their new dimension.

2.6.1 *Slow-Wave Factor (SWF)*

SWF is the relationship between the wave number in free space, k_0, and the propagation constant, β of the transmission line. The SWF for loss less microstrip line is

$$SWF = \sqrt{\varepsilon_e} \tag{9}$$

where ε_e is the effective permittivity of the material, and the propagation constant is defined by

$$\beta = (\sqrt{\varepsilon_e})k_o \tag{10}$$

The SWF of a microstrip line is raised when a discontinuity is introduced in the path of the electromagnetic wave, increasing the impedance of the line [2].

2.6.2 *Method to Reduce Dimensions*

The method proposed by JA Tirado Mendez [2] shows that to achieve the dimension reduction, it is necessary to find the electrical length introduced in a microstrip line when a DGS unit-cell or several unit-cells are employed. For microstrip lines, the electrical length is given by

$$\theta = \beta l = (\sqrt{\varepsilon_e})k_o l \tag{11}$$

Microstrip circuits can be separated and their respective electrical length can be calculated. These lines show a resonant frequency, f_r, by themselves.

$$f_r = \frac{c}{4l\sqrt{\varepsilon_e}} \tag{12}$$

where l is physical length of the line and c is the speed of light in free space.

To propose the structure for a unit-cell dimension of DGS, the electrical length, θ_c at f_r is obtained by EM simulation. From here, the SWF will be

$$SWF = \frac{\theta_c(\pi/180)}{lk_o} = \sqrt{\varepsilon_{ec}} \tag{13}$$

After introducing the unit-cell, the substrate employed presents an apparent effective dielectric constant, ε_{ec}, which is larger than the real effective dielectric constant, ε_e. This apparent permittivity provides the tool to explain how the dimensions of microstrip circuits can be reduced. For a higher dielectric constant, the wavelength and the microstrip circuits are shorter.

Since introducing a DGS unit cell into the microstrip line increases the electrical length, a new dimension must be found to keep the electrical length equal to that of the non-defected lines. The new length that gives the original electrical length for the microstrip line with DGS unit cell s obtained from

$$l_c = \frac{c}{4f_r SWF} = \frac{c}{4fr\sqrt{\varepsilon_{ec}}} \tag{14}$$

2.7 Defected Microstrip Structure (DMS)

The defected microstrip structure (DMS) is similar to the structure called spurline, where a defect is made over the microstrip line. DMS can achieve a greater associated inductance and slow wave effect (SWF), since it has more discontinuities, thus providing a longer trajectory to the electromagnetic wave [2].

Same with the DGS structure, the DMS increases the electrical length of the microstrip, and an increment in the associated inductance. With this electrical length increment, the filter size can be reduced.

CHAPTER 3

METHODLOGY

3.1 Procedure Identification

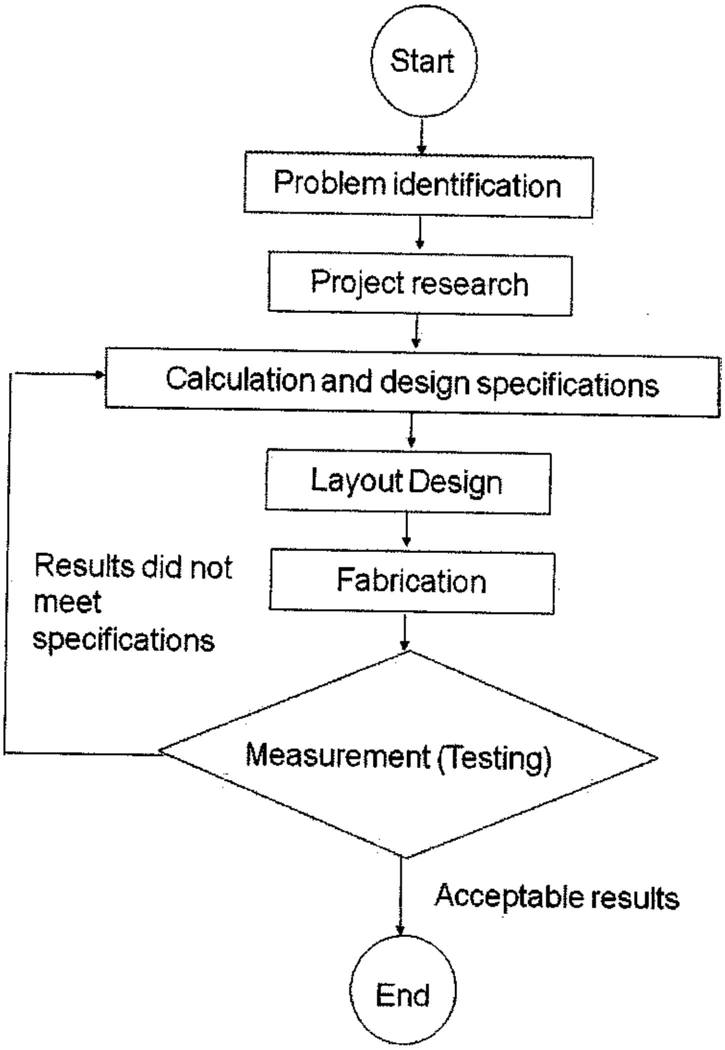


Figure 5 Project flow chart

3.2 Simulation Filter Design

Agilent Advanced Design System (ADS 2008) is used to design and simulate the filter. Based on the requirements of the filter design, the S-parameter for simulation can be set up.

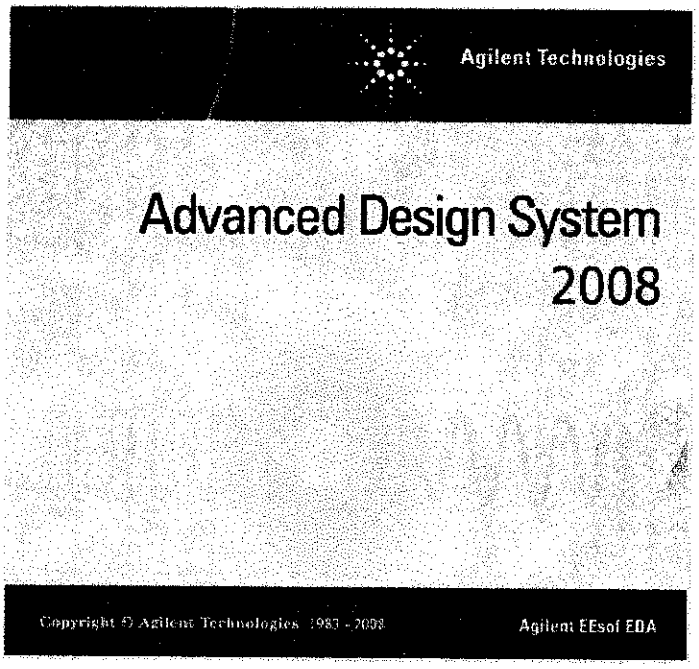
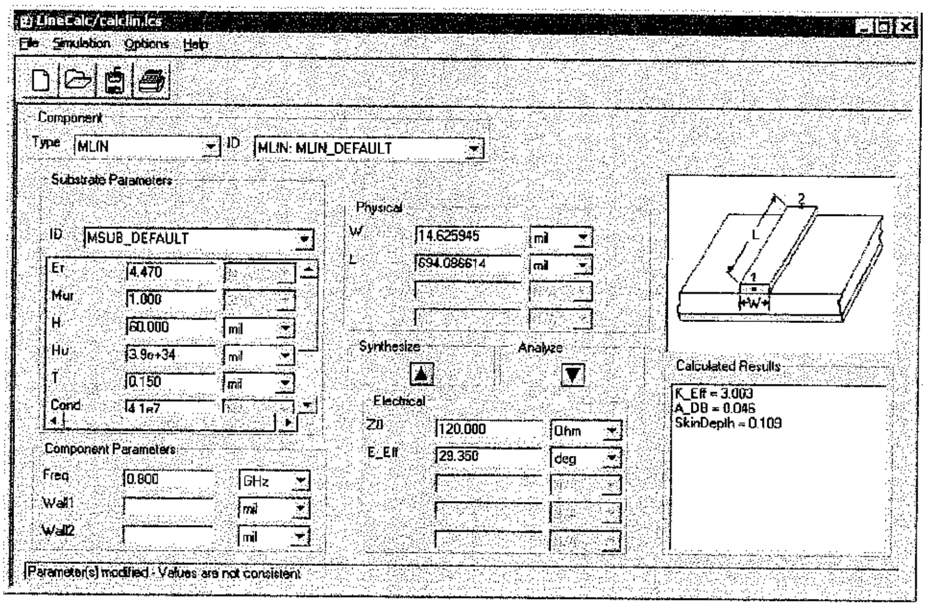


Figure 6 Advanced Design System 2008

ADS provide LinCalc tools to synthesize the physical wide and length of the microstrip filter, given that the electrical length and the impedance line are known.



Type: MLIN
ID: MLIN: MLIN_DEFAULT
ID: MSUB_DEFAULT
Er: 4.470
Mur: 1.000
H: 60.000 mil
Hu: 3.9e+34 mil
T: 0.150 mil
Cond: 4.1e7
Freq: 0.800 GHz
Wall1: mil
Wall2: mil
W: 14.625945 mil
L: 694.086614 mil
Z0: 120.000 Ohm
E_Eff: 29.350 deg

K_Eff = 3.003
A_DB = 0.046
SkinDepth = 0.109

Parameter(s) modified - Values are not consistent

Figure 7 LinCalc tools in ADS 2008

In order to simulate a complex structure like DGS, Sonnet Suite is used to simulate the electromagnetic field of the design filter and show the response in a short time.

3.3 Stepped-Impedance Filter Design

The conventional stepped-impedance microstrip lowpass filter was first designed as a reference.

3.3.1 Design Specifications

From Figure 4, the specified filter order obtained is:

$|\omega/\omega_c| - 1 = |2.6/2| - 1 = 0.3$

$N = 5$

From Table 1, for 0.5dB ripple, at N=5,

$g1 = g5 = 1.7058$; C1 and C5 respectively

$g2 = g4 = 1.2296$; L2 and L4 respectively

$g3 = 2.5408$; C3

$g6 = 1$; R_L

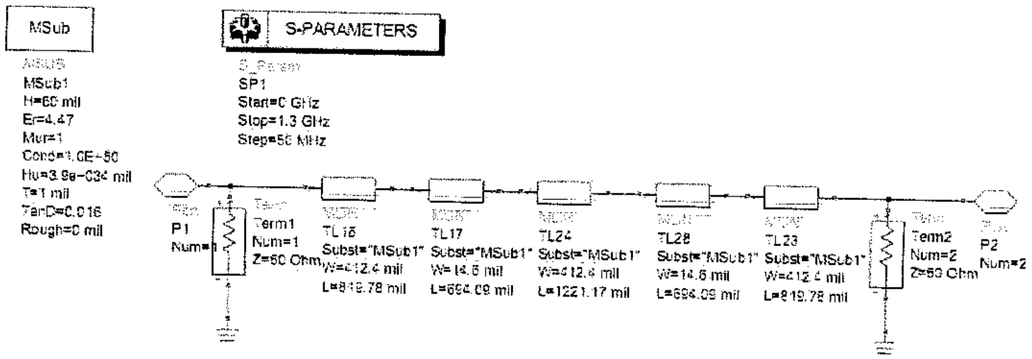
Highest practical line impedance, $Z_h = 120\ \Omega$

Lowest practical line impedance, $Z_l = 20\ \Omega$

The required electrical line lengths, βl_i , along with the physical microstrip line widths, W_i and lengths, l_i are given in the table below:

Table 2 The lowpass prototype filter dimensions

Section	βl_i	W_i (mil)	l_i (mil)
C1=C5	$\beta l = 39.09^\circ$	412.4	819.78
L2=L4	$\beta l = 29.35^\circ$	14.6	694.09
C3	$\beta l = 58.23^\circ$	412.4	1221.17



MSub
MSub1
H=60 mil
Er=4.47
Mur=1
Cond=1.0E+50
Hu=3.9e+034 mil
T=1 mil
TanD=0.016
Rough=0 mil

S-PARAMETERS
SP1
Start=0 GHz
Stop=1.3 GHz
Step=50 MHz

P1
Num=1
Term1
Num=1
Z=50 Ohm

TL16
Subst="MSub1"
W=412.4 mil
L=819.78 mil

TL17
Subst="MSub1"
W=14.6 mil
L=694.09 mil

TL24
Subst="MSub1"
W=412.4 mil
L=1221.17 mil

TL28
Subst="MSub1"
W=14.6 mil
L=694.09 mil

TL23
Subst="MSub1"
W=412.4 mil
L=819.78 mil

Term2
Num=2
Z=50 Ohm
P2
Num=2

Figure 8 Microstrip lowpass filter design in ADS

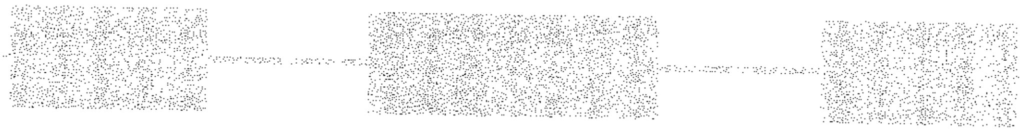


Figure 9 Microstrip prototype of lowpass filter

3.4 Unit Cell DGS

As stated by JA Tirado Mendez in his article in [4], a unit-cell DGS structure shows a band stop frequency response. Figure 8 shows an equivalent LC component when a unit-cell DGS is introduced.

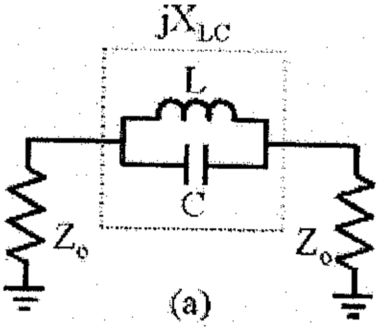


Figure 10 Equivalent circuit of a microstrip line with a unit DGS

3.5 Microstrip Filter with DGS Design

The second filter designed to have the stepped-impedance microstrip lowpass filter on top, and the defected ground structure for the ground plane.

This filter has been designed to have the same physical length as in the stepped-impedance filter design. The defected ground structure will be introduced on the ground plane, and the response obtained through measurement will be used to compare with the reference one.

3.5.1 Design Specifications

3 units of defected ground structure cell are designed on the ground plane, located directly under the low-Z (low impedance line). The designed feature is shown in Figure 11.

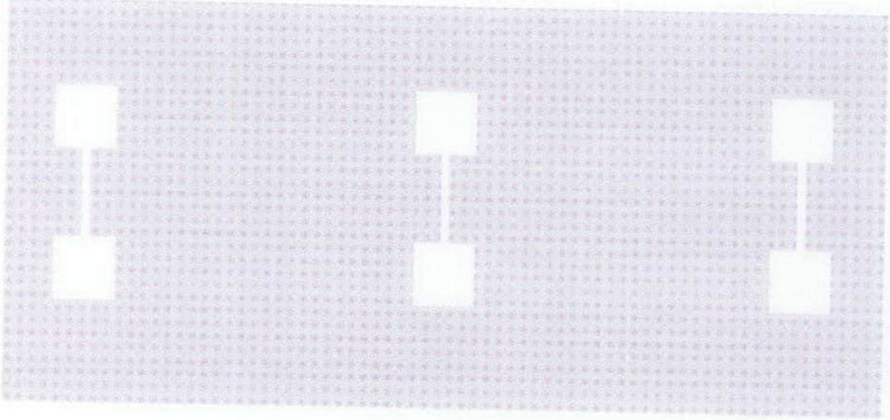


Figure 11 3 units Defected Ground Structure on the ground plane of the microstrip lowpass filter as designed in ADS.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Design Specifications

4.1.1 Microstrip Lowpass Filter

The stepped impedance lowpass filter designed with the specified length will act as a reference filter and is shown in Figure 12 and Figure 13.

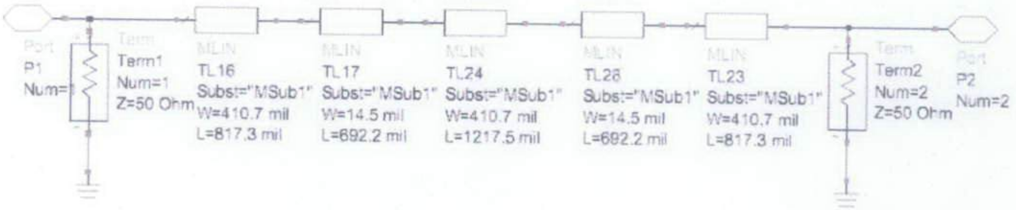


Figure 12 Microstrip lowpass filter design in ADS

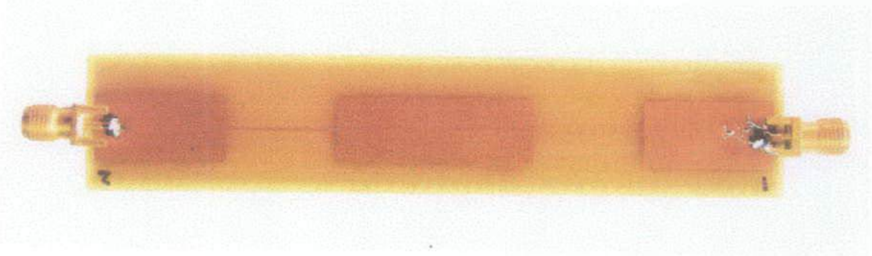


Figure 13 Microstrip realization

The graph in Figure 14 shows that the measured signal exhibits almost the same response as the simulated one. This response shows that the conventional stepped-impedance microstrip lowpass filter work successfully.

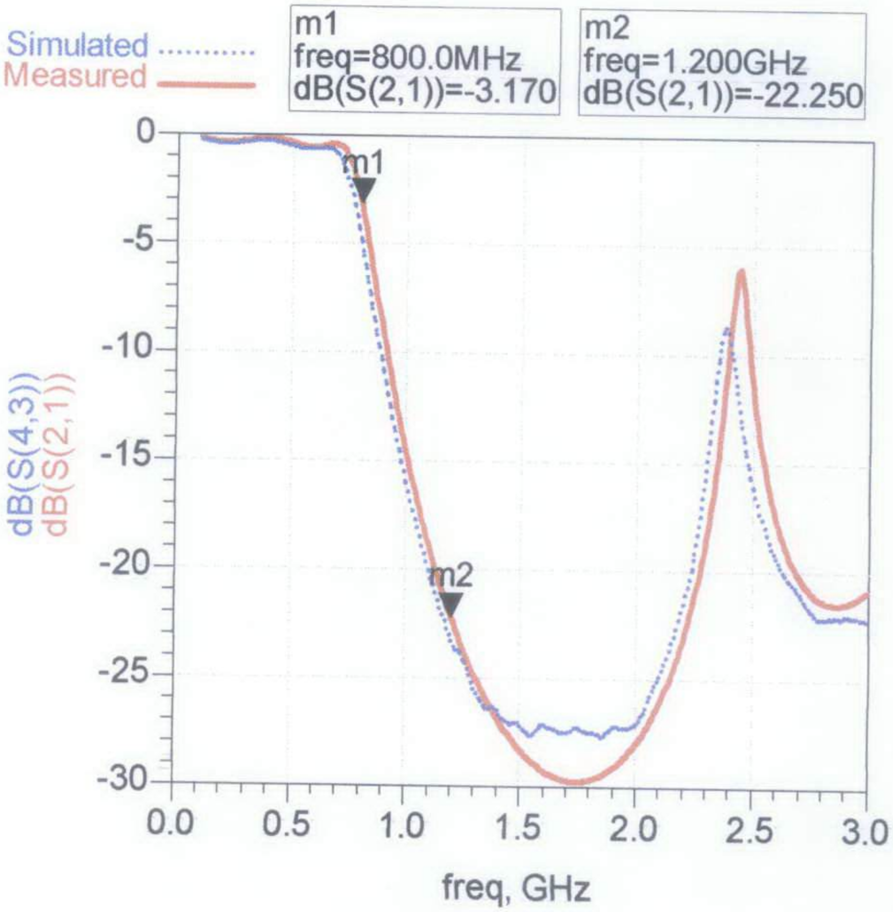


Figure 14 Simulated and measured response of microstrip lowpass filter

4.1.2 Microstrip Lowpass Filter with Defected Ground Structure

Microstrip lowpass filter with DGS has been successfully designed, simulated, and fabricated. Figure 15 shows the microstrip realization for the top and ground plane.

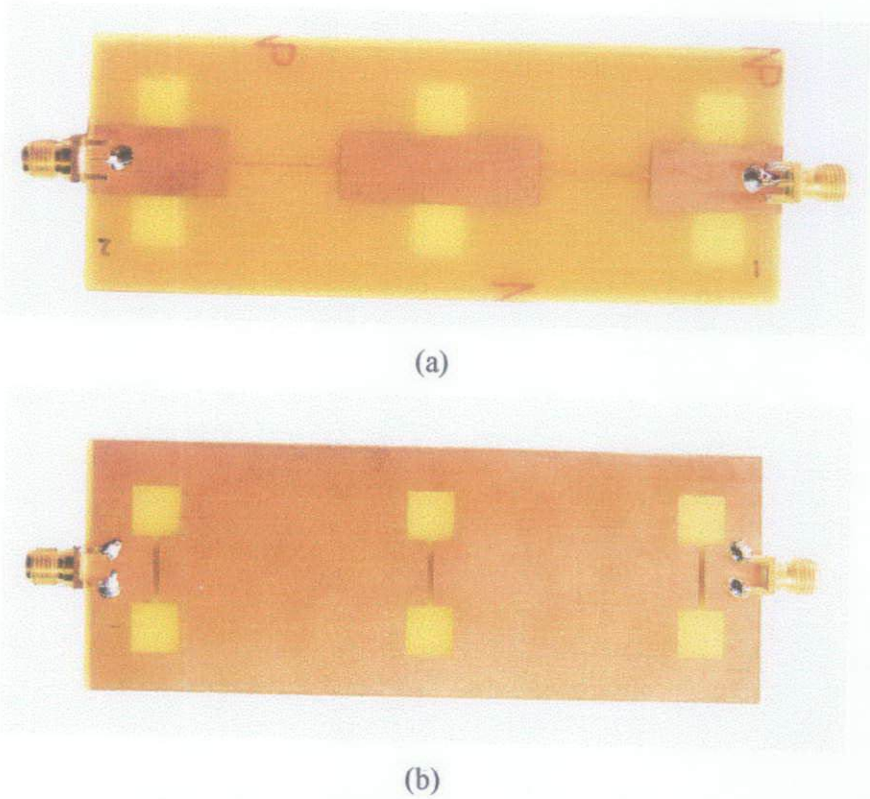


Figure 15 Microstrip realization (a) top design and (b) ground design

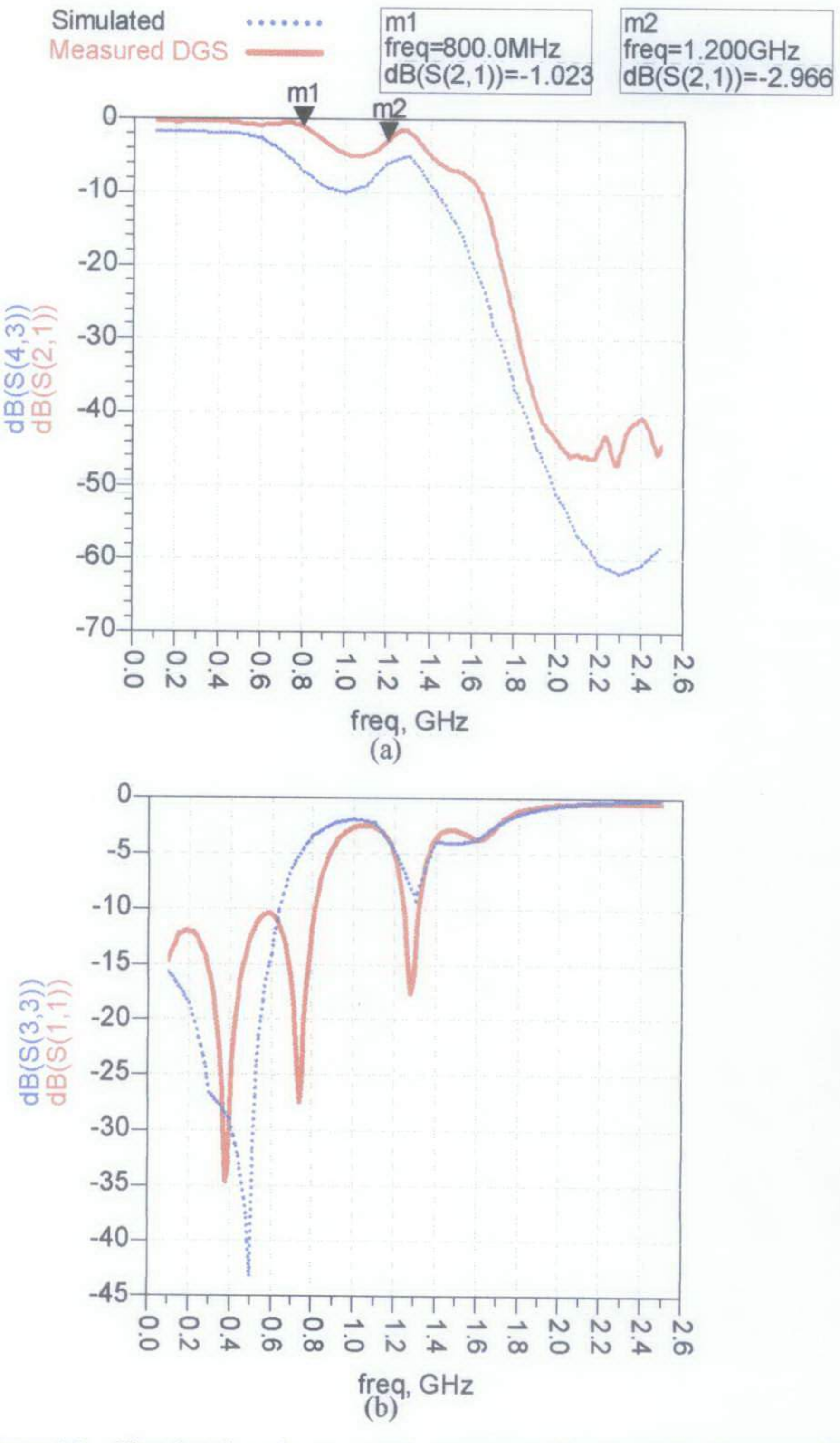


Figure 16 Simulated and measured response of microstrip lowpass filter with DGS (a)S21 and S43 (b)S11 and S33

The simulated and measured graph in Figure 16 below shows that for the designed cutoff frequency of 0.8GHz, and having the same physical length as the reference, the filter manage to have a wider passband, which is about 1.2GHz.

The change in the passband frequency shows that the discontinuities introduced on the ground plane increases the electrical length of the line impedance, which give rise to the resonant frequency.

Thus in order to obtain the same performance of the reference filter, having the same cutoff frequency of 0.8GHz and insertion loss more than 20dB at 1.2GHz, the filter length must be reduced. This would lead to a reduced physical length of the filter.

4.1.3 Filter Comparison - with and without DGS

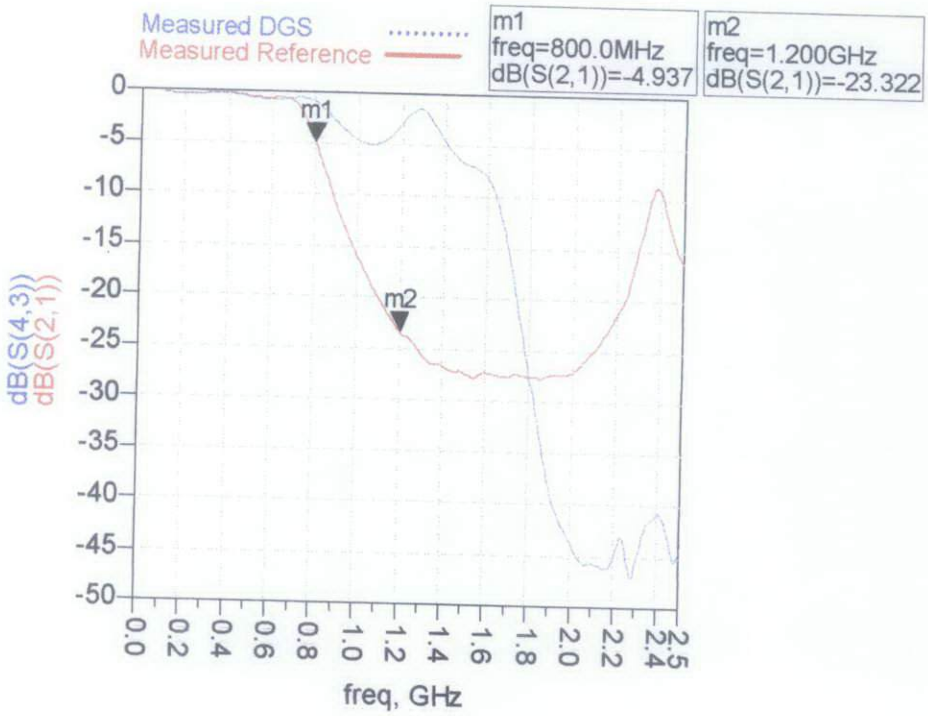


Figure 17 Measured response - with and without DGS

The comparison from both filter (with and without DGS) as shown in Figure 17 above depicted the wider passband frequency for the filter with DGS. A mere important feature can be seen as the filter with DGS shows a very fast response, compared to the filter without the DGS. This enhancement to the filter show that the performance of the filter can be further improved if the defected ground structure is implemented in the filter design.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The introduction of the defected ground structure increases the electrical length of the line impedance and the signal response shows that it exhibits a wider passband frequency, with a sharp and fast response. A new, smaller dimension must be found to keep the electrical length equal to that of the non-defected lines. The discontinuities structure proves that it can be used as a method to improve the performance and reduces the size of the filter.

5.2 Recommendations

Future works can be done to further improve the project. Currently, the implementation of the defected ground structure for this project focused around the improvement that it gives to the filter response.

A smaller sized filter with the defected ground structure, with the specified performance, is expected to be realized, given that the filter can be designed according to the results obtained from this project as a reference point.

Another discontinuities method that can be used to make a small-sized filter is by introducing the discontinuities on the microstrip line, known as Defected Microstrip Structure. As per reference, the microstrip filter with DMS is implemented as a part of further investigation that can be made in the future.

Figure 18 shows the the microstrip realization, and Figure 19 shows the simulated and measured response of the filter. This filter is design to have a cutoff frequency of 450MHz.

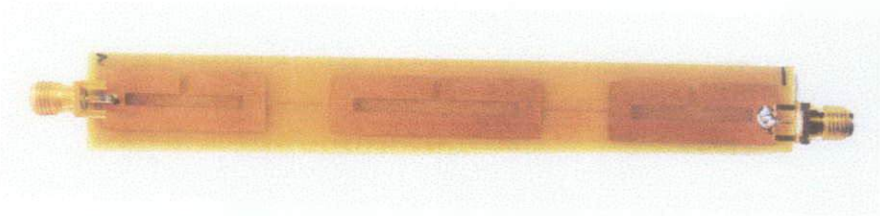
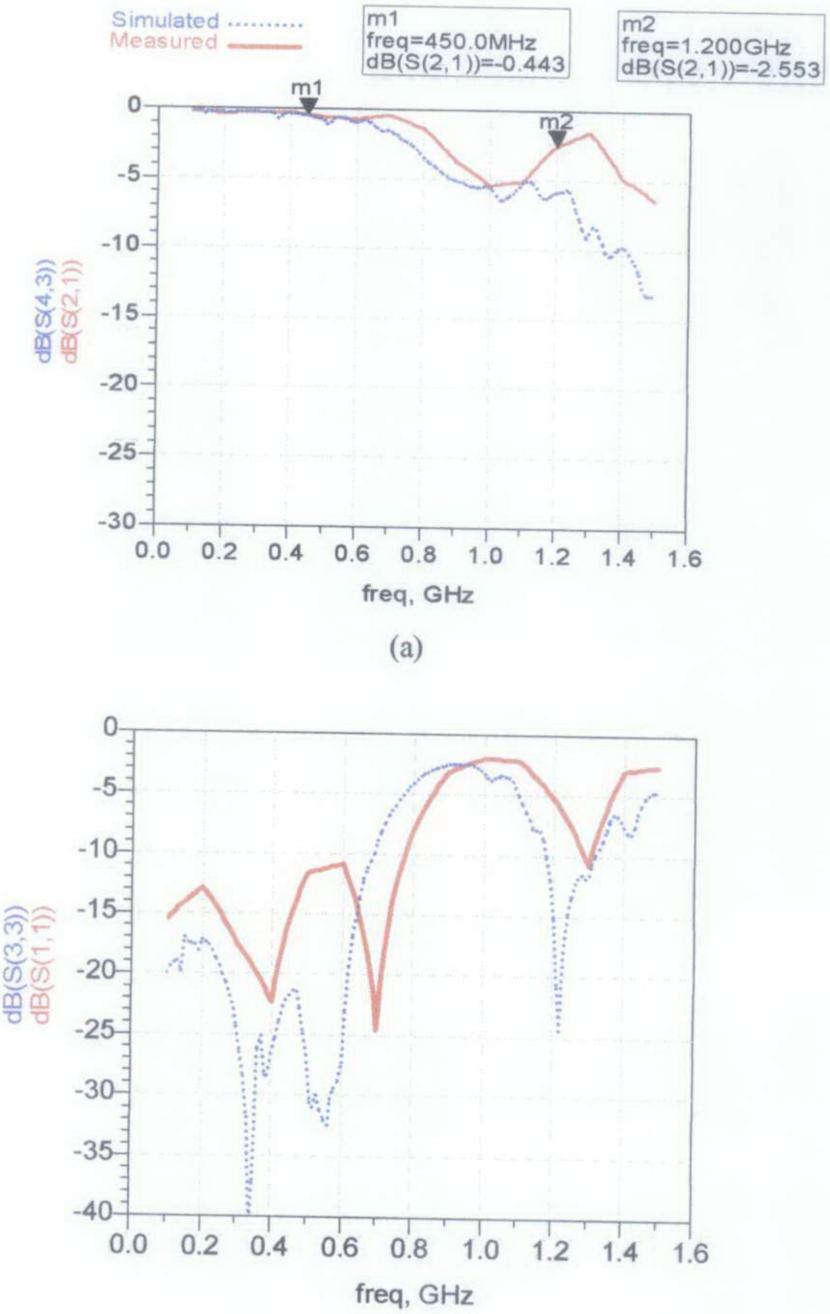


Figure 18 Microstrip lowpass filter with DMS



(a)

(b)

Figure 19 Simulated and measured response of microstrip lowpass filter with DMS (a)S21 and S43 (b)S11 and S33

It is very interesting to investigate the kind of response that we can get by using both methods. This project can be further improved if investigation can be made to compare the performance of a lowpass filter, having the same performance, but with different structures. The kind of structure in interest is the filter with DGS, filter with DMS, and filter with both DGS and DMS combined.

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APPENDIX A
FABRICATION PROCESS

Step 1: Generate mask on transparency

Convert the design from ADS standard gerber file (*.gbr) and print it onto the transparency film. Since the design involves a modified ground plane, the layouts for both sides of the filter are printed.

Step 2: Photo exposure process

The films on the FR4 board are exposed to Ultraviolet (UV) light using exposure machine. It is done to transfer the image of the circuit pattern with a film in a UV exposure machine onto to the photo resist laminated board. When UV light strikes the photoresist, it will harden the resist. The exposure time is set to 30 seconds.

Figure A1: UV exposure machine

Step 3: Drill

PCB board undergoes a drilling process using CNC drilling machine (Figure 3.6) to align the top plane to the ground plane. The machine is controlled by the computer and the hole is drilled based on the drill file provided to it.

Figure A2: Drilling machine

Step 4: Etching in developer solution

To ensure the pattern will be fully developed, the photoresist developer solution is used to wash away the exposed resist. Then the solution removed by spray wash.

Step 5: Etching in Ferric Chloride

Etching process is done using the Conveyorised Etching machine. The solution for etching process is Ferric Chloride. It will remove the unwanted copper area and this process was followed by the removal of the solution by water. The FR4 board is inserted a few times into the machine to ensure proper etching.

Figure A3: Conveyorised Etching machine

Step 6: Cutting PCB Board

PCB board is cut using shear cutter machine available readily at the PCB lab (Figure A4). The low-tack blue plastic film is removed and the films are then synchronized with the drill hole for use during the UV process.

Figure A4: Shear cutter machine

Step 7: Cutting PCB Board

The board is dried and rubbed with sand paper to remove the remains of the unexposed resist pattern area. Upon fabrication, the SMA connector is soldered to the microstrip filter.