School of Engineering and Technology

Course:	Final Year of Beng/CEE Communications & Electronic Engineering
Names of students:	Ignacio Salan
	Jordi Gutierrez
Assignment title:	Microwave Workshop – Microstrip Filter Design
Supervisor:	Mr. Hugh Ross
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1 INTRODUCTION

This project is concerned with the design, simulation, construction and test of a microstrip filter. The simulation is held with Microwave office that is a powerful software tool; the construction of the filter is made through the Wavemaker.

This is assignment is divided in two different parts as follows:

1.1 Design and simulation

In this part is required to simulate and design a low pass filter with lumped elements. The specifications are to obtain a 3 dB cut-off frequency of 800 Mhz, using three stages low pass filter and the standard designs of Butterworth and Chebyshev.

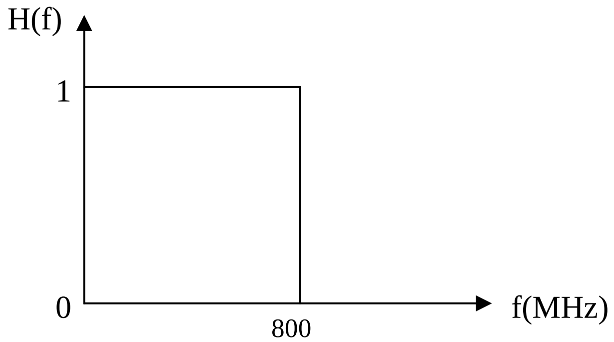


Figure 1. *Ideal frequency response of the filter.*

- **Butterworth:**

In order to meet the previous specification these are the calculations made, first we take the values of the normalised coefficients of the filter from the Butterworth table. We have the following values:

$g_1=1 \qquad g_2= 2 \qquad g_3=1 \qquad g_4=1$

The next formulas have been applied in order to work out the real values of the inductors and capacitors:

$$L_i = \frac{g_i \cdot Z_0}{w_c} \qquad\qquad C_i = \frac{g_i}{w_c \cdot Z_0} \qquad \textbf{(1)}$$

It is shown the circuit implemented with lumped elements in the next figure,

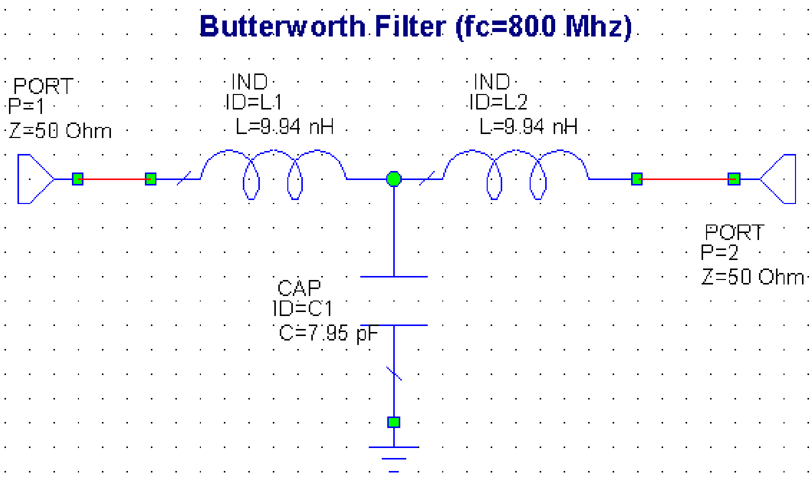


Figure 2. *Butterworth filter with lumped elements.*

Here are the graphs obtained with the software,

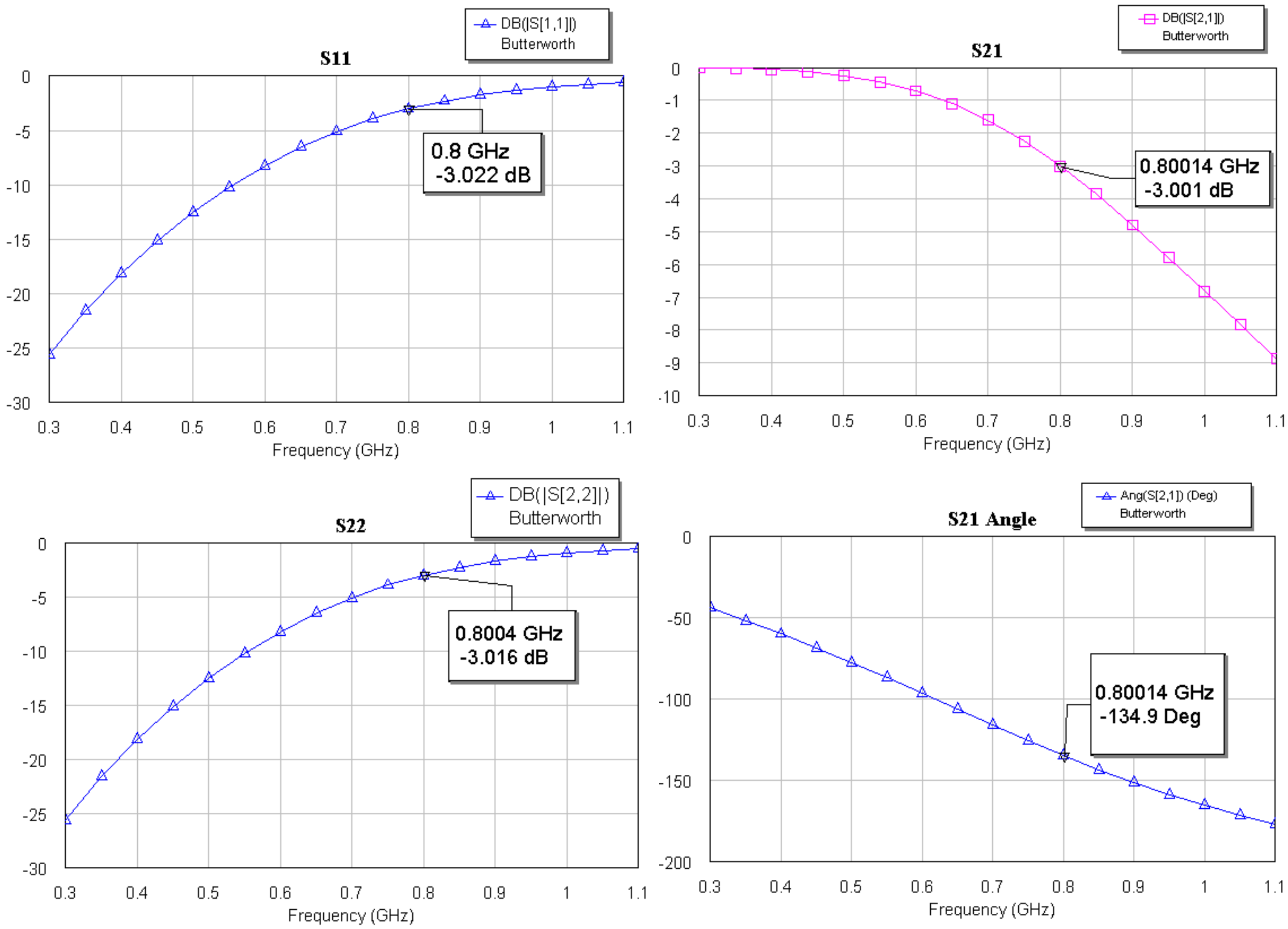


Figure 3. *S parameters of the Butterworth low-pass filter (fc=800 Mhz).*

As it can be seen in the graphs S11 is the same as S22 as it was expected due to the symmetry of the circuit. Another important aspect of these graphs is in the S21 graph as it was expected the form of the frequency response at the band-pass of the filter is flat. This is a characteristic of Butterworth filters, but the decreasing of the frequency response at the cut-off frequency is not very sharp.

- **Chebyshev:**

Like in the Butterworth filter design, the first step is to obtain from the coefficient's table the proper values for a filter with the specifications shown at figure1. We have the following normalized coefficients from the table for a 3 dB ripple:

g_1=3.3487 g_2=0.7117 g_3=3.3487 g_4=1

Then the same formulas **(1)** than in the Butterworth's case are applied to work out the real values for the inductors and capacitors. This is the circuit for the Chebyshev filter:

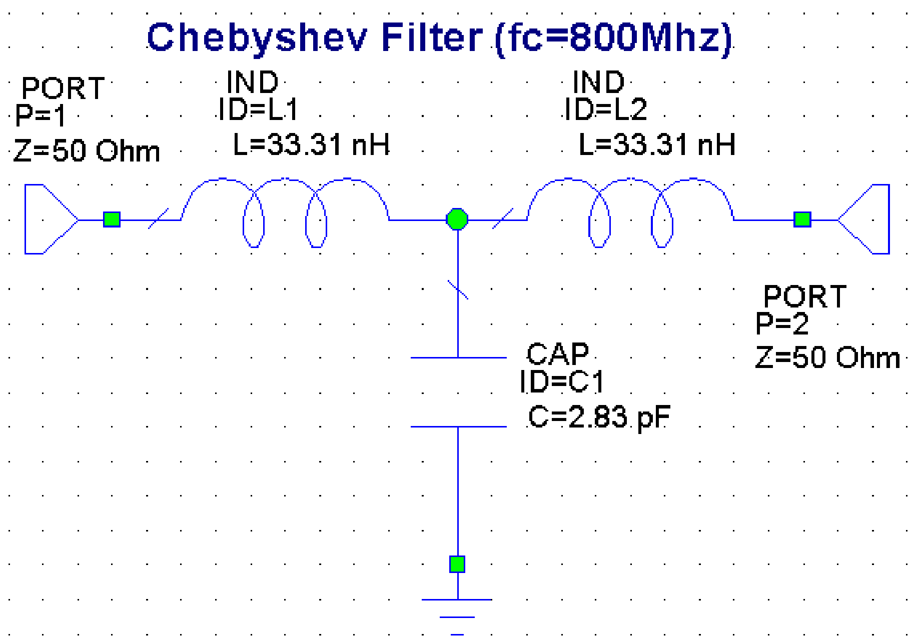


Figure 4. *Chebyshev filter with lumped elements.*

In the next page are represented the four graphs obtained with the simulation of this filter.

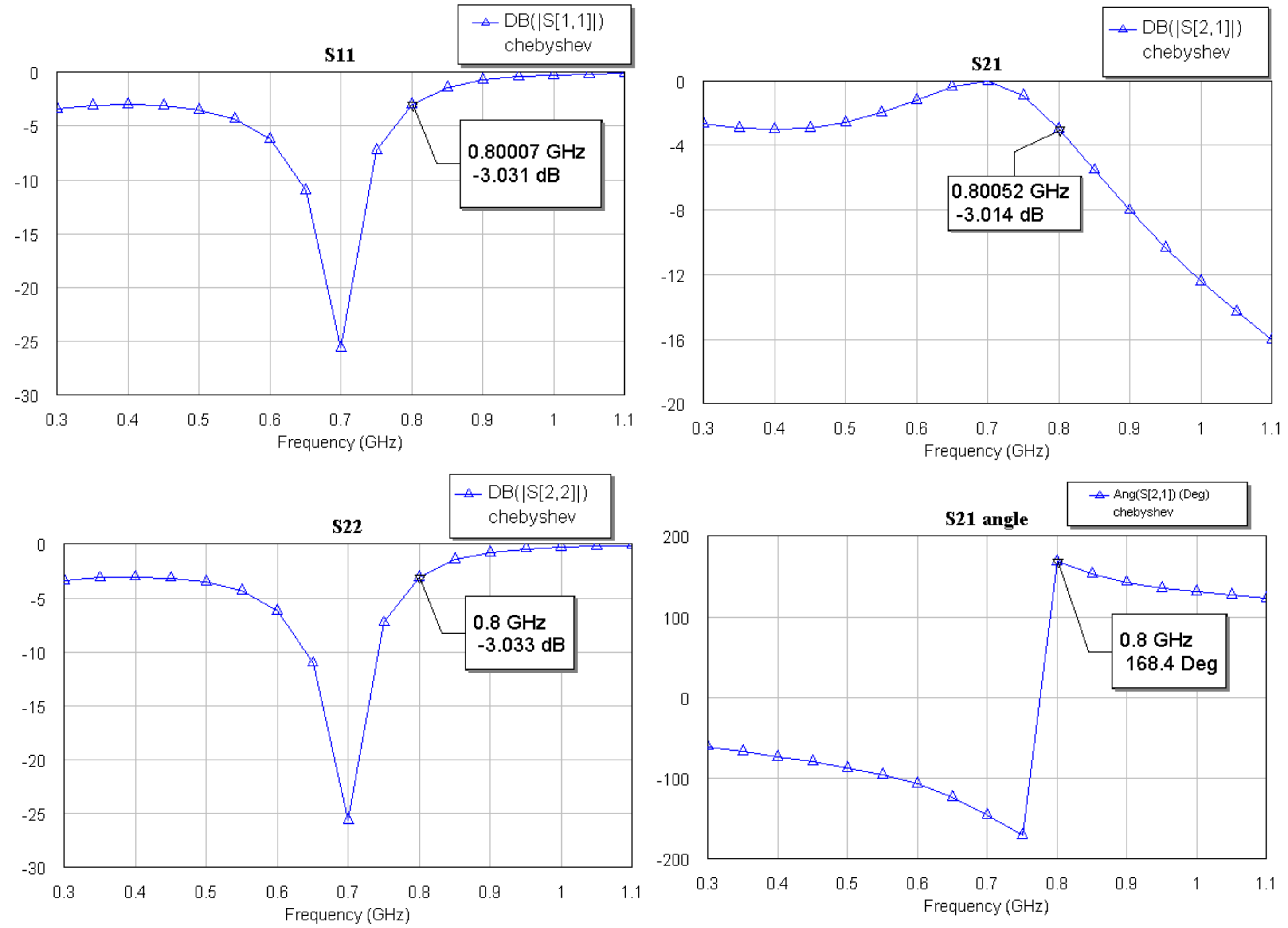
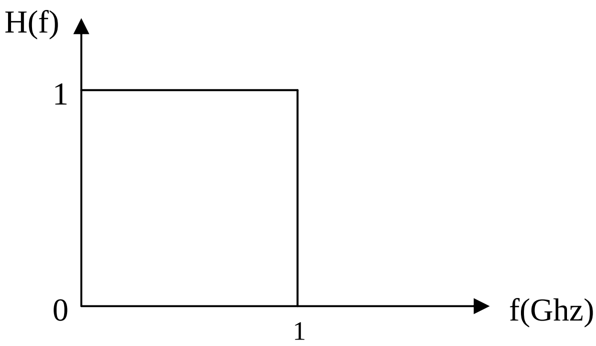


Figure 5. *S parameters of the Chebyshev low-pass filter (fc=800 Mhz).*

Here it is shown again how S11 and S22 are equal because the symmetry of the circuit. It is also important to note that S21 as it was expected has a ripple at the band-pass. Very similar to the Butterworth filter the decreasing (roll-off of the filter) of the response is not very sharp after the cut-off frequency, but the phase of S21 suffered an abrupt change that is very different from the Butterworth. More stages would be necessary to make sharper the roll-off.

1.2 Butterworth Filter

In this part is required to design a 3-stage Butterworth filter using microstrip technology and following the standard procedure design. The next figure shows the frequency response of the filter required.



RT DUROID 5870

ε_r=3.38

H=0.79 mm

Tand=0.0012

Rho=0.068

(Copper) T=0.035 mm

Figure 6. *Ideal frequency response of the filter and the microstrip substrate required.*

The first step is to design the filter with lumped elements following the previous steps as in the first part of this assignment. The different values obtained from the tables are:

$$g_1=1 \qquad g_2=2 \qquad g_3=1 \qquad g_4=1$$

The formulas **(1)** are applied to work out the values for the inductors and capacitors, and this is the circuit designed, the characteristic impedance is 50 Ohms:

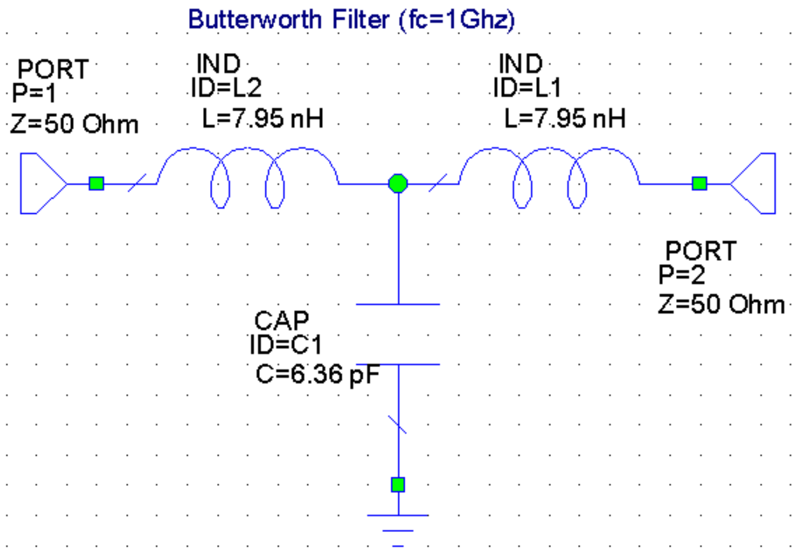
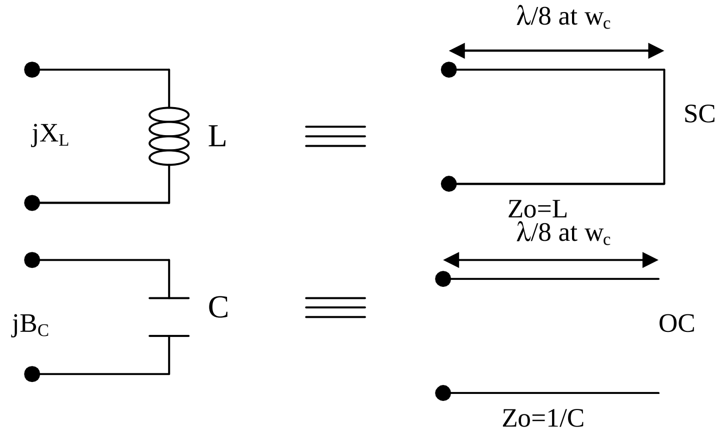


Figure 7. *Butterworth low-pass filter with lumped elements (fc=1Ghz)*

The next step is using the Richards transformations the circuit is converted to a circuit with ideal transmission lines, using the following formulas and transformations; no losses are introduced in this part.

Richards transformations



Following these transformations this is the circuit using ideal transmission lines:

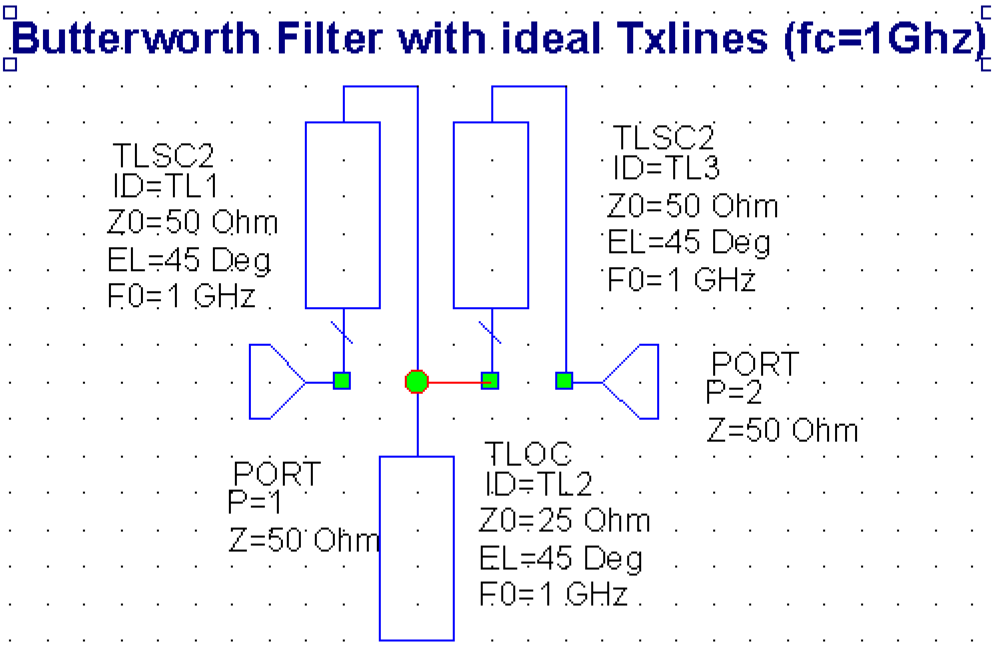
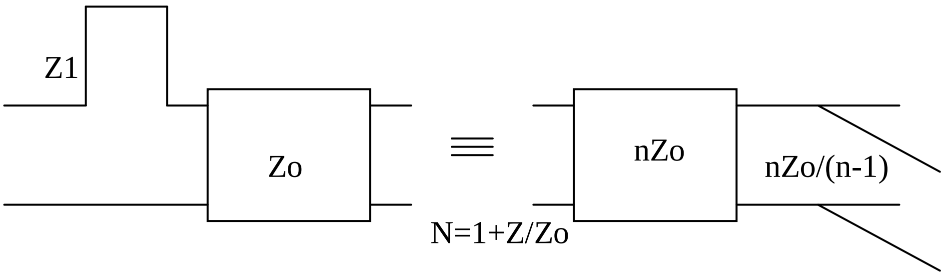


Figure 8. *Butterworth low-pass filter with ideal Transmission lines (fc=1Ghz).*

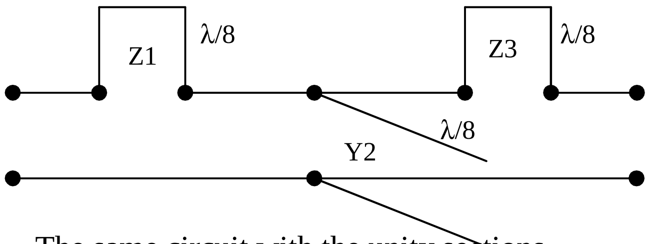
All the Zo have been calculated taking the real values of the capacitors and inductors as shown in the circuit with lumped elements and using the formulas of the impedance for capacitors and inductors.

$$Z_L=jwL \qquad Zc= -j/wC \qquad \textbf{(2)}$$

The next step in design procedure for microstrip filter have been used the Kuroda's identities, it is only noted here the one required for this assignment:

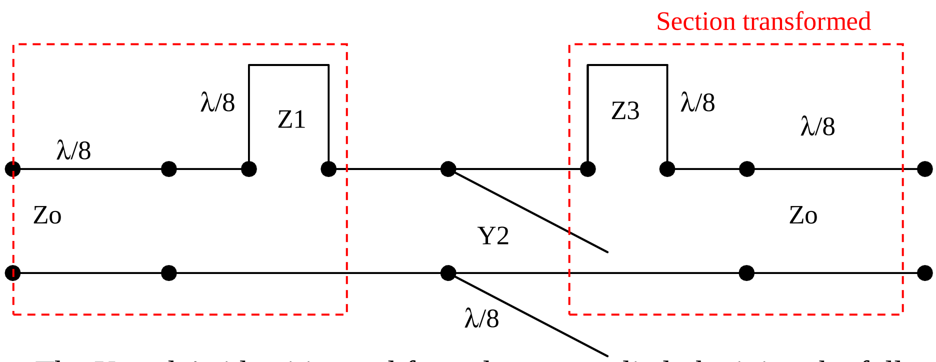


In order to apply Kuroda's identities it is necessary to add two sections at the beginning and at the end of the circuit using transmission lines with characteristic impedance (Zc) of 50 Ohms, they are called unity sections. After this, the previous transformation is direct and is only required to make it at the end of the circuit because the beginning is symmetric. All the time all the calculations are made with the normalized values in function of the Zc=50 Ohms. In the next figures the steps are described graphically:

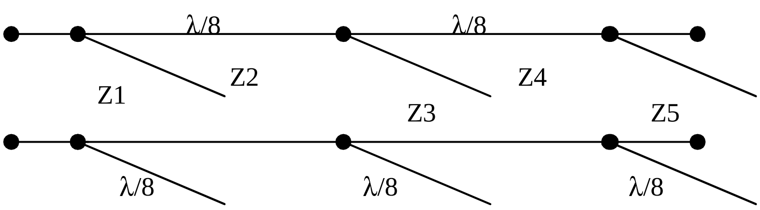


$Z_1=1$ $Y_2=2$ $Z_3=1$

The same circuit with the unity sections,



The Kuroda's identities and formulas are applied obtaining the following values and letting the circuit as follows:



$N=1+(Z_1/Z_0)=2$

$Z_1=Z_5=nZ_0/(n-1)=2$

$Z_2=Z_4=nZ_0=2$

$Z_3=1/Y_2=0.5$

The next step is to renormalize all the impedances in function of Zc=50 Ohms, then the next circuit represents the microstrip filter but without discontinuities and the losses derived from them.

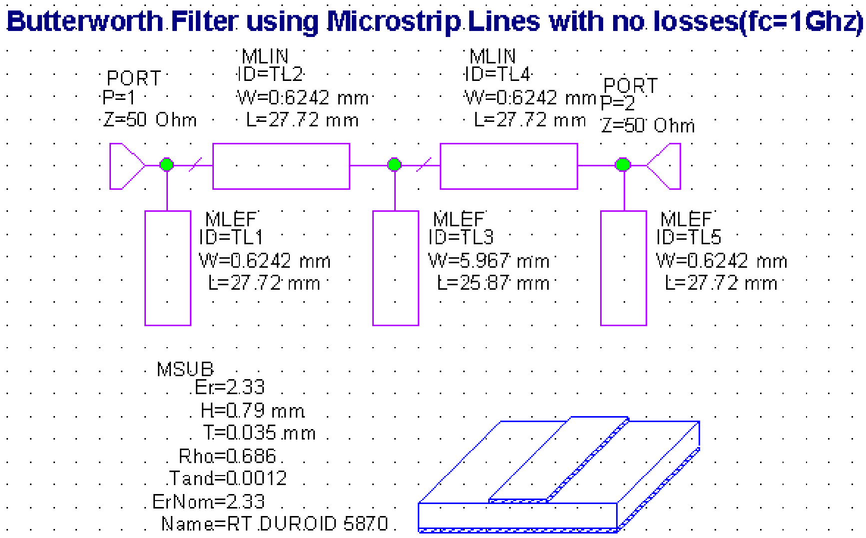


Figure 9. *Butterworth low-pass filter with Microstrip lines with no losses (fc=1Ghz).*

All the lengths and the widths of the microstrip lines have been calculated using the Microwave Office component Txline. Taking in count all the parameters of the microstrip substrate required for this assignment. Then the last circuit is the one with the discontinuities and the proper losses introduced by these, also are needed two sections in order to connect the ports and the real connectors. Both of them of Zc=50 Ohms and 20 mm of length to keep the symmetry of the circuit.

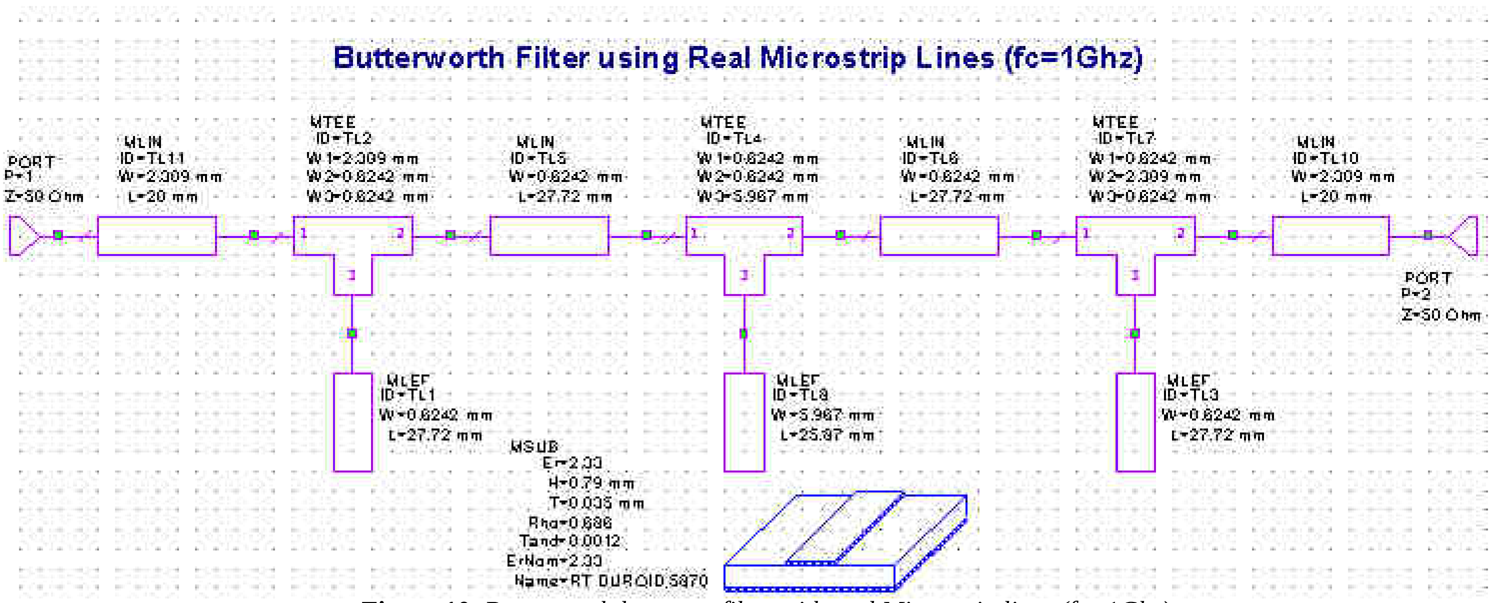


Figure 10. *Butterworth low-pass filter with real Microstrip lines (fc=1Ghz).*

This is the layout of the circuit and very similar to the physical prototype, obtaining using the Microwave Office and the Wavemaker to make a file with extension (EPS).

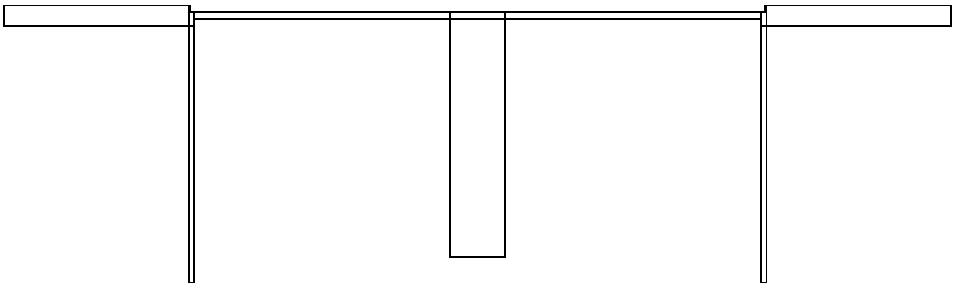


Figure 11. *Layout of the filter.*

The following pages of this report will have the graphs of the S parameters obtained with each circuit in the design procedure. To make easier the comparison between them, they are going to appear as it can be seen in this page.

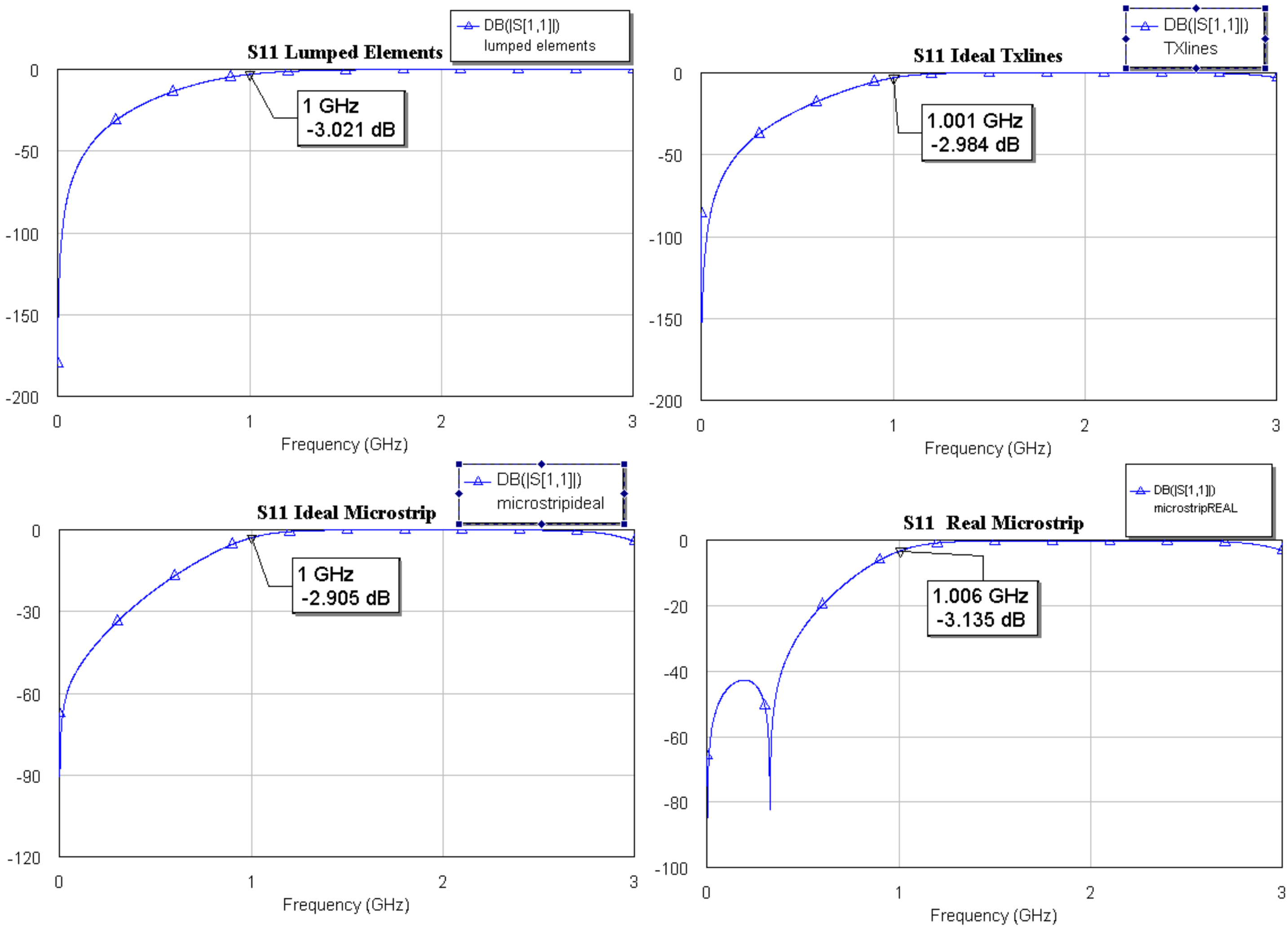


Figure 11. *S11 parameter of each circuit.*

As it was expected the S11 changes from the filter with lumped elements to the real one using microstrip lines.

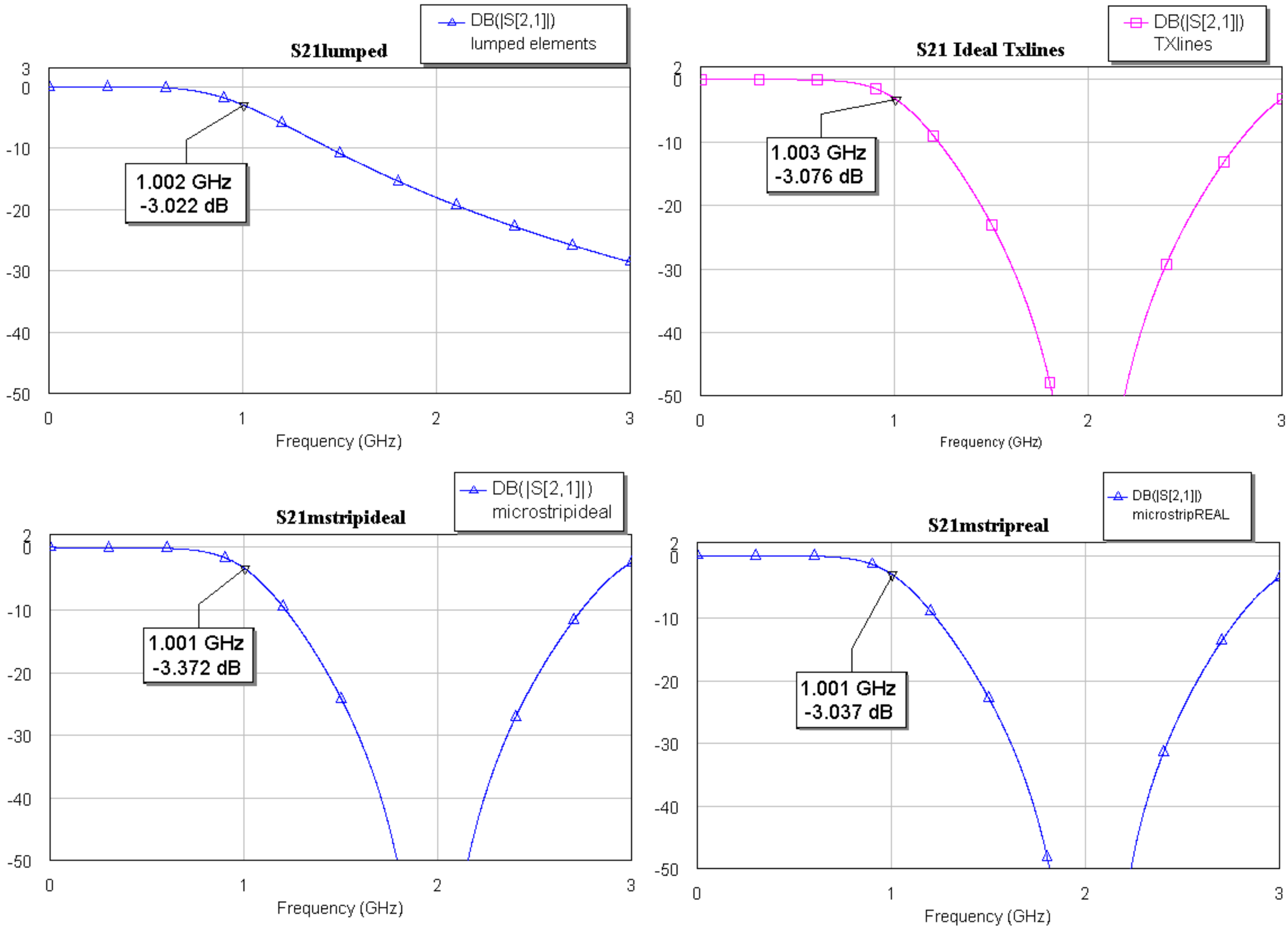


Figure 12. *S21 parameter of each circuit.*

Here it can be seen the differences between the S21 of the circuit with lumped elements and the one using microstrip lines without discontinuities, also is important to notice the abrupt roll-off of the real filter against the soft one of the circuit with lumped elements. The results obtained with the real microstrip lines are enough in order to reach the specifications of this filter. After experimenting with the lengths of the different sections were not found significant changes in these graphs. Now we represent the rest parameters.

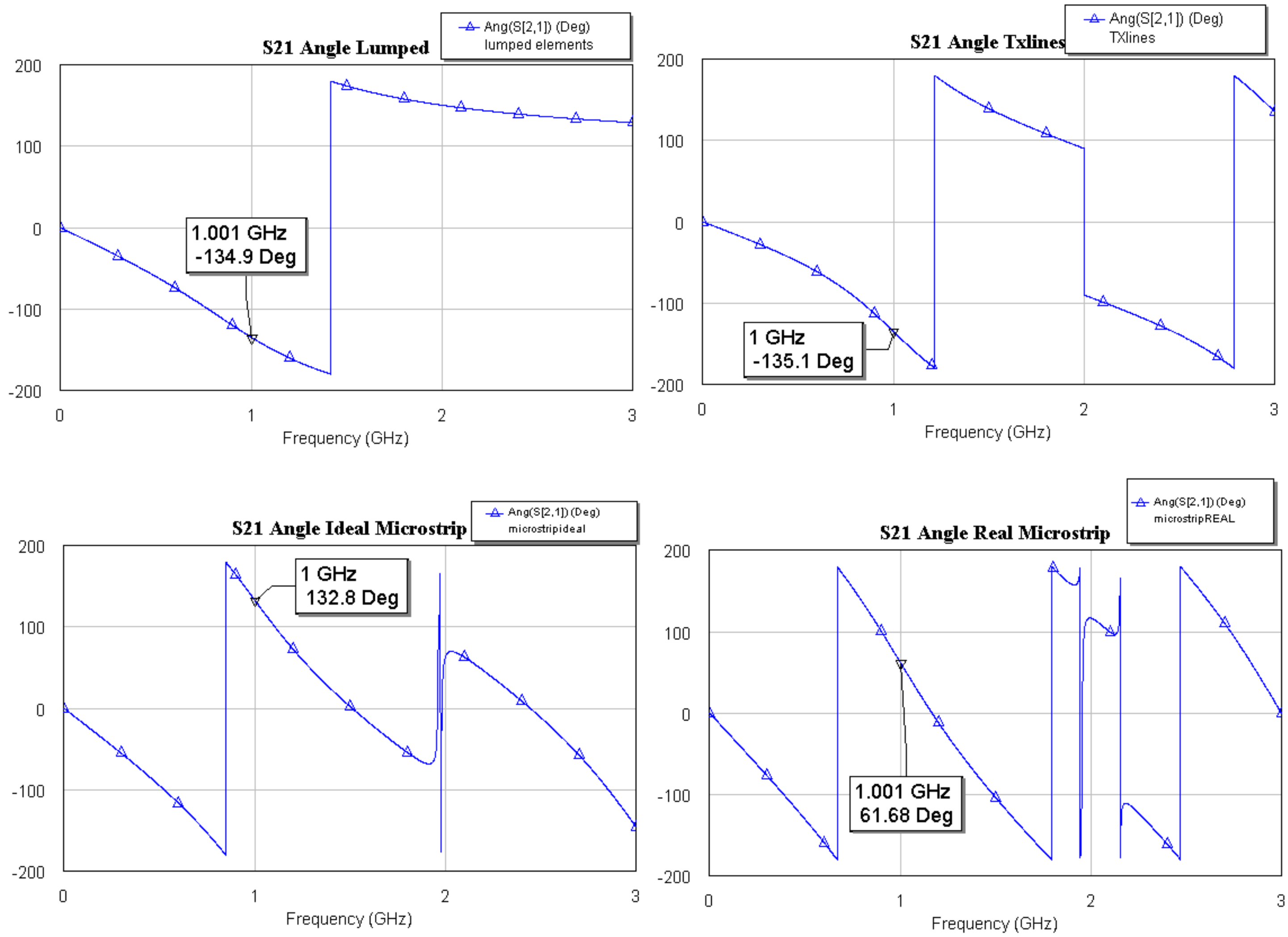
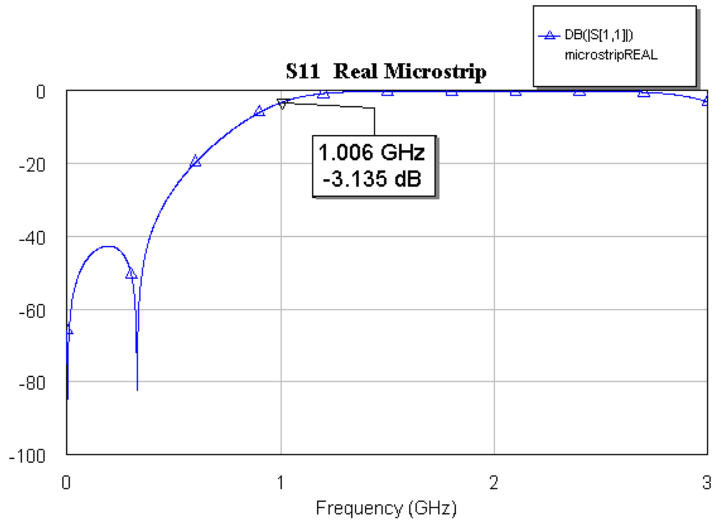
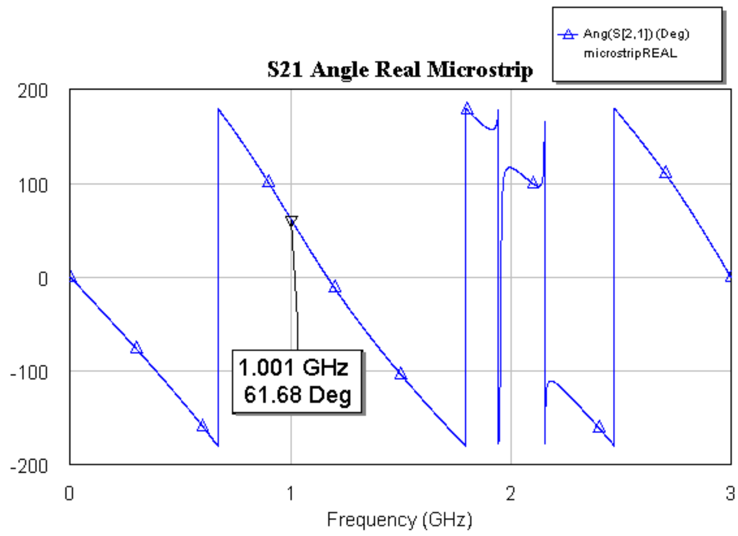
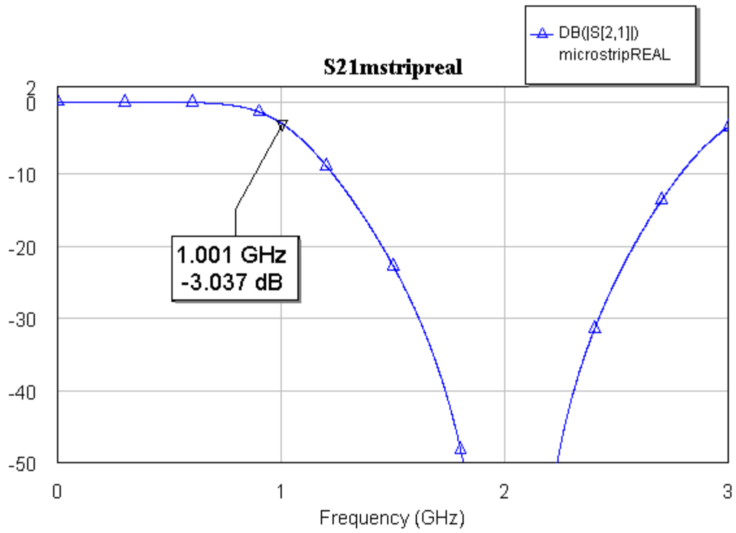


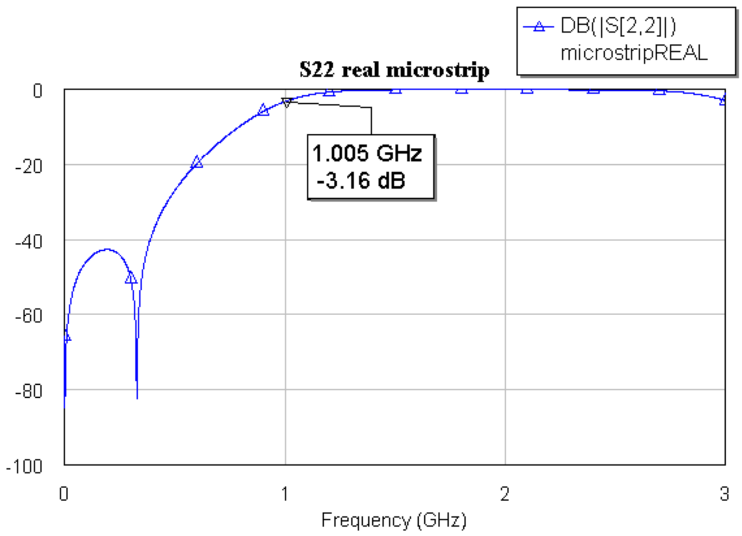
Figure 13. *S21 angle of each circuit.*

The are many differences between the phase of S21 in each circuit, the last one and the real circuit is due to the sections incorporated to make possible the connection of two ports. The S22 parameters have not been represented because they were exactly the same as S11. All the circuits are symmetric, in the next section is represented the S parameters measured with the real prototype and the network analyser. After that page are shown again the S parameters of the real microstrip circuit to make easier the comparisons.


S11 Real Microstrip
DB(|S[1,1]|)
microstripREAL
1.006 GHz
-3.135 dB
0
-20
-40
-60
-80
-100
0
1
2
3
Frequency (GHz)


S21 Angle Real Microstrip
Ang(S[2,1]) (Deg)
microstripREAL
1.001 GHz
61.68 Deg
200
100
0
-100
-200
0
1
2
3
Frequency (GHz)


S21mstripreal
DB(|S[2,1]|)
microstripREAL
1.001 GHz
-3.037 dB
2
0
-10
-20
-30
-40
-50
0
1
2
3
Frequency (GHz)


S22 real microstrip
DB(|S[2,2]|)
microstripREAL
1.005 GHz
-3.16 dB
0
-20
-40
-60
-80
-100
0
1
2
3
Frequency (GHz)

2 CONCLUSSIONS AND DISCUSSION

Different results have been obtained between the real physical circuit and the simulated one with the Microwave Office. The measurements with the network analyser have revealed that all the parameters are different from the ones represented with the simulation. Otherwise the accuracy is not bad for example the S21 has changed in 1.30 dBs and the rest are very similar to the simulation ones. Only the phase has suffered a significant change.

Due to the date of submission of this assignment there is no more time to experiment different solutions in order to get more accuracy but here are described some of them. It is possible that the behaviour of the discontinuities has not been the expected from the simulation and the losses of the microstrip substrate are bigger than the required ones.

In the filter designed with microstrip lines can be observed abrupt changes in the width of the line this discontinuities are distorting the Electromagnetic field, and also are affecting the electrical length of the lines making them shorter or longer. That can be seen in the S21 parameter measured with the network analyser the work frequency has suffered a displacement, the 3 dB is obtained at a different frequency point bellow 1 Ghz as was required.

The most important discontinuity as it has been mentioned before is the Tee Junction; this one is very difficult to work with. This junction can make lines electrically shorter, can introduced effects of multi propagation of the EM waves and the simulation software is not taking all these effects in count. It is very difficult to know exactly the behaviour of this kind of junction, in order to predict the exact effects introduced by them.

It is possible to improve the accuracy of this filter, using the tuning tools provided by the Microwave Office Software, and trying to make softer the changes in the width of the lines. Other point would be to assure the technical characteristics and parameters of the substrate used.