UCD School of Electrical &
Electronic Engineering

RF Electronics Laboratory
EEEN40150

Lab 4: Microstrip Filter Design

Introduction

In this exercise, over two laboratory sessions, you will design, build and test a microstrip lowpass filter. In the first session you are required to design the filter using the AWR software. Your filter design will then be fabricated in the workshop and available for measurements in the following session. In the second session you will take measurements on your device using a Vector Network Analyser (VNA) in the RF & Microwave Research Lab.

Three or Four students will work as a team. Each team will only submit one design for fabrication. You are required to **write your own report** on the design process, describing any measurements you made and how they compare with the simulations, and give any explanations/comments you want to make. You must submit your report to **Meng Li in Room 334, no later than Noon 11th November**.

Stepped-Impedance Low-pass Filter

Your task is to design a low-pass, lumped element filter as per your notes. This will then be converted to an equivalent microstrip design using the **stepped impedance** method given in the lecture notes. In this design, you are required to obtain the specification outlined in the table below.

Team Leader Student Numbers (last two digits)	Design Number	Filter Type	Cutoff Frequency	Minimum insertion loss
even, even	1	0.5 dB Ripple	1.75 GHz	20 dB @ 3 GHz
even, odd	2	Maximally Flat	3 GHz	15 dB @ 4.5 GHz
odd, even	3	0.5 dB Ripple	2 GHz	20 dB @ 3.2 GHz
odd, odd	4	Maximally Flat	2.5 GHz	20 dB @ 4.25 GHz

What are the advantages and disadvantages of using a 0.5 dB ripple Chebyshev filter instead of a maximally flat Butterworth filter?

In microstrip lines, the characteristic impedance available is usually limited due to electromagnetic and physical layout constraints. To ensure reasonable results when implemented on TLX-8 microstrip, we shall set a lower limit of $Z_0 = 20\ \Omega$ and a higher limit of $Z_0 = 110\ \Omega$ for our design.

First, use the attenuation figures and coefficient tables in the Appendix to find the order and parameters of the filter. **Note: odd order filters must be used for 0.5 dB ripple designs to ensure matching to 50 Ω.** Now create a new schematic called "Lumped Element Filter", design your lumped element filter, and **plot the forward transmission (S_{21}) and reflection (S_{11})**

coefficients (in dB) to see whether the design specifications are met. The filter may need to be redesigned if the specifications are not met.

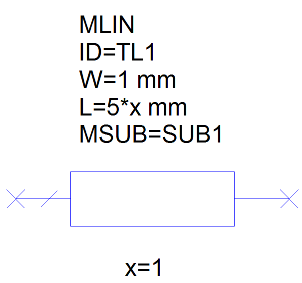
Microstrip Design

Create a new schematic with the title "**Team n xx Design m**" (where n is the team number, xx is the team leader's surname, and m is the design number e.g. Team 1 Doyle Design 2) in Microwave Office. Set the global units for length to 'mm'. In the element browser select the Substrates node find the "MSUB" model and place it on the schematic. The physical parameters of the substrate that will be used for your filter are given in the table below.

Parameter	Value
Relative Permittivity ε_r	2.55
Substrate Thickness h	1.14 mm
Conductor Thickness t	18 μm
Resistivity normalised to Gold ρ	0.7
Loss Tangent	0.001

Under the Microstrip node, find the "Lines" subgroup. Select the "MLIN" model and place it in the schematic. This is your basic transmission line element. Use TXLine to find the width and length of the microstrip lines. Select "Copper" from the Conductor drop-down box. Fill in the relevant parameters from the above table, and by choosing the characteristic impedance and electrical length, calculate the width and length of the line.

The stepped impedance approach is just an approximation and, due to parasitic inductances and capacitances (every high impedance section (inductor) will have some capacitance, and every low impedance section (capacitor) will have some inductance), the lengths given by TXLine may be too long. In order to counteract this we may need to tune the lengths of the lines. Add an equation to your schematic (*Draw – Add Equation* or [Ctrl E]) so that the lengths of the lines can be all adjusted by a parameter, x, as shown in the figure below. For now, assume that the lengths are correct (x=1).



You must connect together a series of high impedance / low impedance sections, ensuring you do not exceed the design constraints for the characteristic impedance of each section. As in the previous lab, a junction element must be placed between each line to model discontinuities. In this case, use MSTEP$.

When the filter is built on microstrip, coaxial connectors with Z_0 = 50 Ω will need to be added to each port. To facilitate this, **add 10 mm of microstrip transmission line of 50 Ω**

characteristic impedance to either end. Add ports to either end, with the standard reference impedance of 50 Ω.

Microwave Office has automatically created the layout of your filter based on the parameters you supplied for each length of microstrip line. To view this layout, right-click on your Microstrip Schematic title in the project browser and select “Open Layout”. The layout does not automatically join each transmission line together (it shows red lines displaying where the connections should be). To do this, select the entire layout (Ctrl-A) and press the “Snap Together” button on the toolbar. You should now see your entire filter layout. **Is it as you expected?** There is a measure tool available on the toolbar, use this to measure the length and width of each section. **Record these values. Are they as designed?**

Add a graph (including some identification in the title), displaying the S_{21} scattering parameters (in dB) versus frequency for your Microstrip filter. Add a marker at your *required* maximum attenuation frequency. **Is it as expected? Does it satisfy the specifications? If not, how can it be fixed?** Adjust your circuit until it meets the specifications.

On the same graph, add your previous lumped filter measurements. Compare the traces. **Are they the same?** Now add a graph of phase versus frequency – Phase(S(2,1)) – for both filters and **compare the results. Print out a copy of the two graphs** and add your comments on the results.

When you are happy with your layout, select the “Export…” option from the Layout menu, save the file in *Gerber* format with the title “Team n xx Design m ” (where n is the number of your team and xx is the team leader’s surname e.g. Team 1 Doyle Design 2). Submit this design **before leaving the lab** by e-mail to **Declan Lehane (declan.lehane@ucd.ie)** in the workshop, as an attachment. In the text of your email you must include the dimensions of each section, the names of your team members, and in the subject include your team name and design number. Declan will fabricate your filters and they will be available for you to measure in the next lab session (which will be held in the **Microwave Laboratory, Room 238, Monday 24th October and Monday 7th November (time schedule will be given later).**

Additionally, you will need to **upload** .s2p files of the chosen design to Blackboard. .s2p is a file format used for storing S-parameter data. To do this, go to the Project tab, right click on Output Files, then select Add Output File > NPORTF. Set the data source to your microstrip file, the parameter type to S Parameters, specify the output file location and name the file “Microstrip.s2p”, and press okay. Repeat this procedure for your lumped element filter, naming the file “Lumped Element Filter.s2p”. **Set the frequency range from 0 to 10 GHz with 0.01 GHz steps and re-simulate the circuit to generate the files.** These files **must** be uploaded to Blackboard prior to **Wednesday 19th October**. Once again, **you must re-simulate your circuit in order to generate the output files.**

Report

The specific details of the laboratory report are left up to you. However, the following information should be included:

- Your name, team number, and the names of your lab partners.
- A copy of the each of the graphs printed during the simulation (Week 1), as well as a copy of the results that you measured on the VNA (Week 2).
- A full top view diagram of your constructed filter, including the dimensions of each section.
- Your description of the design process.
- Comparison of the simulated results from the lumped and microstrip filters.

- Comparisons of the simulated and measured microstrip filter results.

Timeline

- Monday, 17th October: Lab 1 – Filter Design, Room 329, as per usual. All .gerber files must be submitted at the end of the lab.
- Wednesday, 19th October: Deadline for .s2p files submission.
- Monday, 24th October/7th November: Lab 2 – Filter Measurement, Room 238.
- Friday, 11th November: Deadline for report Submission.

Appendix

Table 1. Coefficients for maximally flat low-pass filter (N = 1 to 10)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

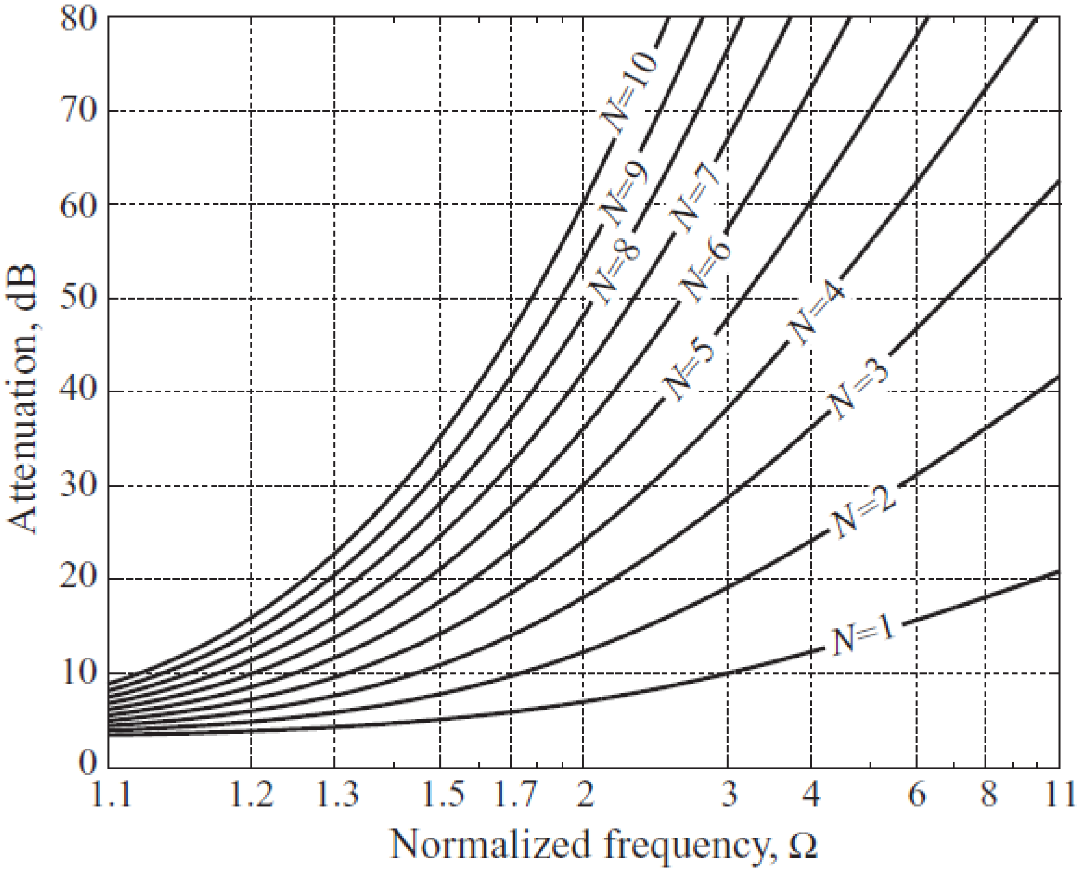


Fig. 1. Attenuation response of maximally flat low-pass filter vs. normalized frequency

Table 2. Coefficients for 0.5dB ripple Chebyshev low-pass filter (N = 1 to 10)

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	1.0000			
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	2.7939	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

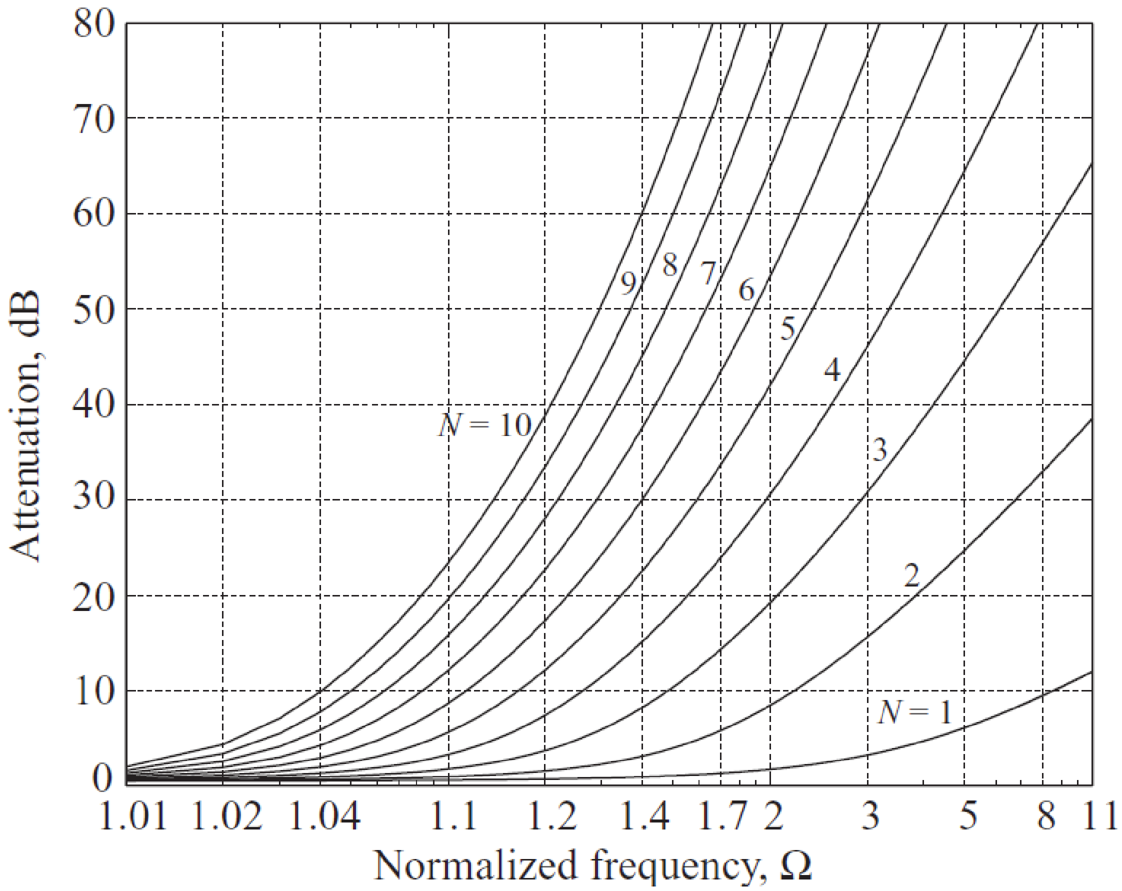


Fig. 2. Attenuation response of 0.5dB ripple Chebyshev low-pass filter vs. normalized frequency