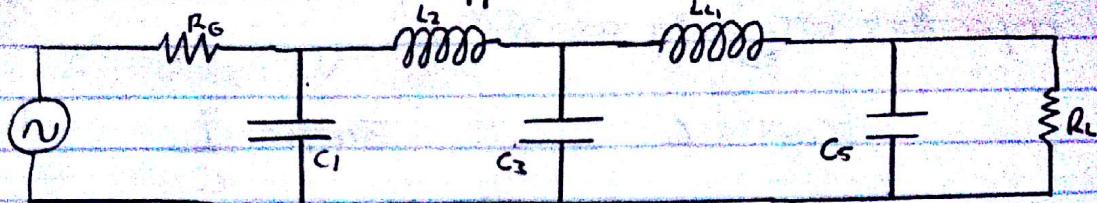


RF ELECTRONICS Homework 1 FERGAL LONERGAN

DESIGN NUMBER 3 0.5dB Ripple 2GHz 20dB@3.2GHz



Element	Normalised value
$R_G$	1
$C_1$	1.7058
$L_2$	1.2296
$C_3$	2.5408
$L_4$	1.2296
$C_5$	1.7058
$R_L$	1

The filter that satisfied our specifications was the  $N=5$  Chebyshev 0.5dB ripple filter.

our denormalised element values are:

Element	denormalisation equation	denormalised value
$R_G$	$1 \times 50$	$50 \Omega$
$C_1$	$\frac{1.7058}{2\pi(2 \times 10^9) \cdot 50} = 50 \cdot 1.2296$	$2.714 \text{ pF}$
$L_2$	$\frac{1.2296}{2\pi(2 \times 10^9)} = 50 \cdot 2.5408$	$4.892 \text{ nH}$
$C_3$	$\frac{2.5408}{50 \cdot 2.714 \cdot (2 \times 10^9)}$	$4.044 \text{ pF}$
$L_4$	same as $L_2$	$4.892 \text{ nH}$
$C_5$	same as $C_1$	$2.714 \text{ pF}$
$R_L$	same as $R_G$	$50 \Omega$

As our circuit had to match our  $50\Omega$  LOAD AND INPUT IMPEDANCE we had to choose an odd ordered filter.

Now we have a lumped element filter design we can use Richard's Transformation to convert it to a microstrip implementation. For this we use our normalised values for our capacitors and inductors and resistors.

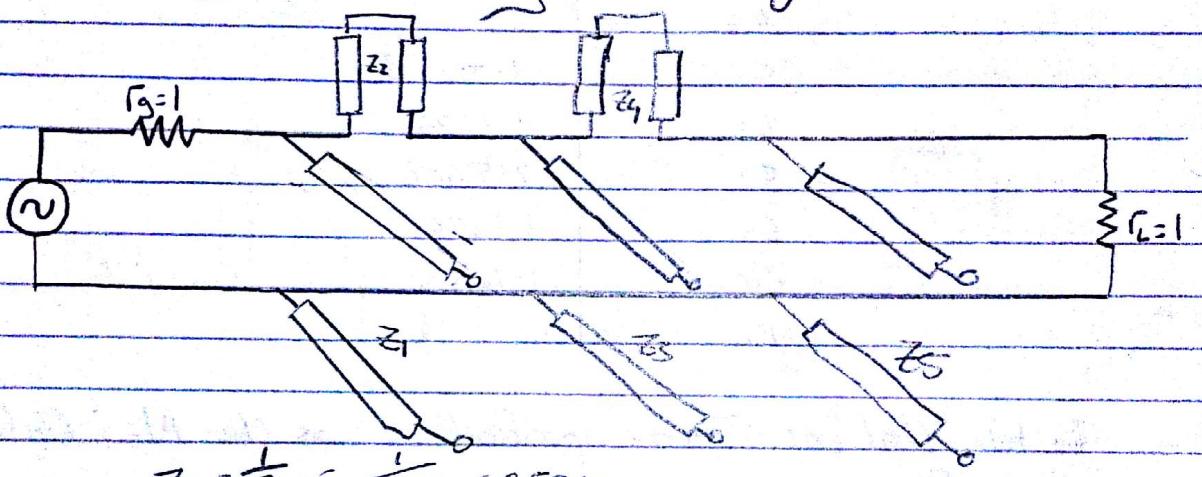
We replace inductors with shorted stubs of length  $\frac{\lambda}{8}$  and capacitors with open stubs of length  $\frac{\lambda}{8}$ .

Our normalized characteristic impedances for our inductors and capacitors are given as follows:

$$Z_{\text{ind}} = L$$

$$Z_{\text{cap}} = \frac{1}{C}$$

Now redrawing our circuit using stubs we get:



$$Z_1 = \frac{1}{C_1} = \frac{1}{1.7058} = 0.5862$$

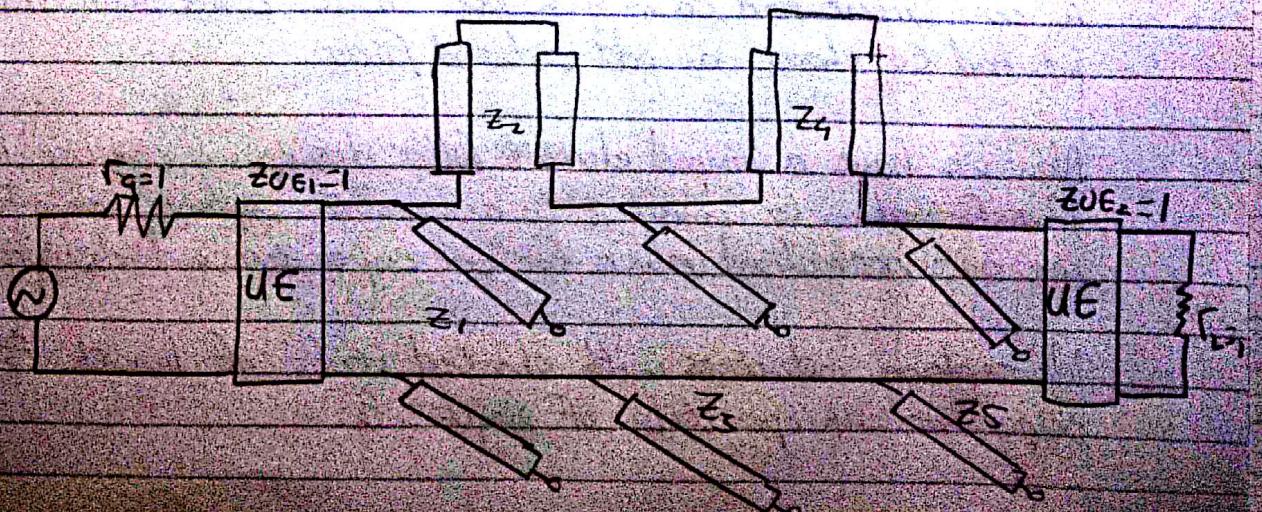
$$Z_2 = L_2 = 1.2296$$

$$Z_3 = \frac{1}{C_3} = \frac{1}{2.5408} = 0.3935$$

$$Z_4 = L_4 = 1.2296$$

$$Z_5 = \frac{1}{C_5} = \frac{1}{1.7058} = 0.5862$$

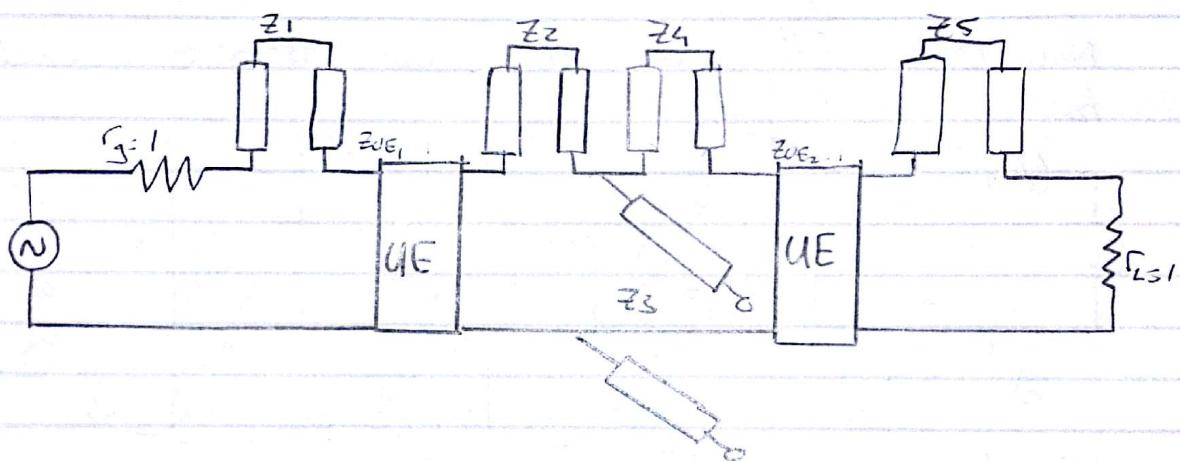
We use Kuroda Identities to convert our short circuit stubs into open circuit stubs as short circuit stubs are difficult to manufacture. To do this we must also introduce two unit elements at the input and output of the filter.



We can now transform our design using the following two identities.

$$n^2 = 1 + \frac{z_2}{z_1} \quad \Rightarrow \quad \boxed{z_1} \quad \Rightarrow \quad \boxed{\frac{z_1}{n}} \quad \boxed{\frac{z_2}{n}}$$

$$\boxed{z_1} \quad \Rightarrow \quad \boxed{\frac{z_1}{n}} \quad \boxed{\frac{z_2}{n}}$$



$$n^2 = 1 + \frac{z_1}{z_{UE1}} = 1 + \frac{1}{1.7058}$$

$$z_{UE1} = \frac{z_1}{n^2} = \frac{1.7058}{1 + \frac{1}{1.7058}} = 0.3696$$

$$z_1 = z_{UE1} = \frac{1}{1 + \frac{1}{1.7058}} = 0.6304$$

$$z_2 = 1.2296$$

$$z_3 = \frac{1}{2.5408} = 0.3936$$

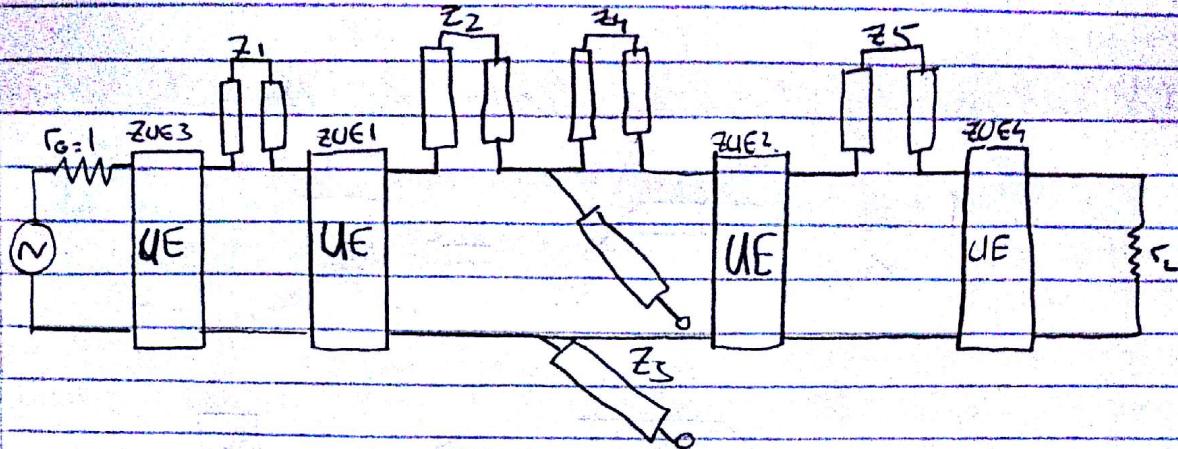
$$z_4 = 1.2296$$

Similarly as above

$$z_{UE2} = \frac{z_5}{n^2} = \frac{1.7058}{1 + \frac{1}{1.7058}} = 0.3696$$

$$z_5 = z_{UE2} = \frac{1}{1 + \frac{1}{1.7058}} = 0.6304$$

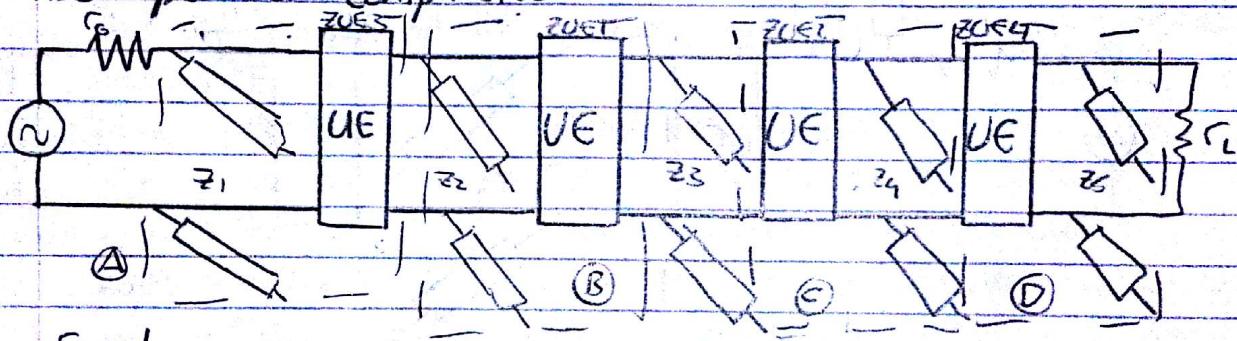
Again we add in unit elements to our circuit, at the input & output



$$Z_{UE3} = 1$$

$$Z_{UE4} = 1$$

Now we can fully convert our circuit design so it exclusively has open stub components



$$Z_{UE3} = 1$$

$$Z_L = 1$$

$$Z_3 = \frac{1}{Z_{UE3}} = 0.3936$$

$$(A) n^2 = 1 + \frac{Z_{UE3}}{Z_1} = 1 + \frac{1}{0.6304}$$

$$Z_1 = Z_{UE3} \times n^2 = (1)(1 + \frac{1}{0.6304}) = 2.5863$$

$$Z_{UE3} = Z_1 \times n^2 = 0.6304(1 + \frac{1}{0.6304}) = 1.6304$$

$$(B) n^2 = 1 + \frac{Z_{UE1}}{Z_2} = 1 + \frac{0.3696}{1.2296}$$

$$Z_2 = Z_{UE2} \times n^2 = 0.3696(1 + \frac{0.3696}{1.2296}) = 0.4807$$

$$Z_{UE1} = Z_2 \times n^2 = 1.2296(1 + \frac{0.3696}{1.2296}) = 1.5992$$

(A) is the same as (D) and (B) is the same as (C)

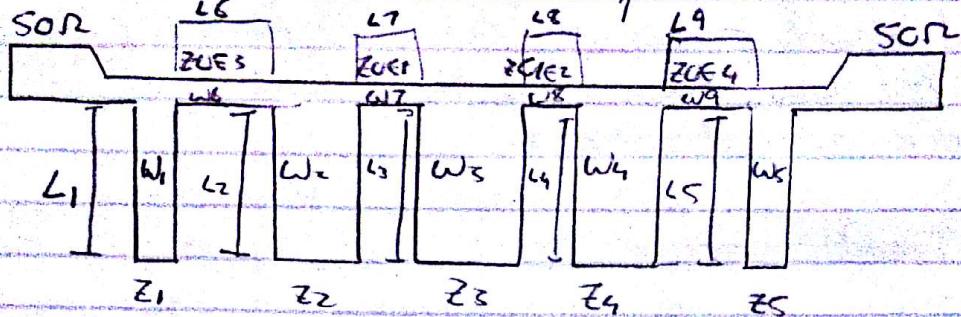
$$\Rightarrow Z_4 = 0.4807$$

$$Z_{UE2} = 1.5992$$

$$Z_5 = 2.5863$$

$$Z_{UE4} = 1.6304$$

Now we can denormalise these impedances:



$$R_G = 50 \Omega$$

$$Z_1 = 129.32 \Omega$$

$$Z_2 = 24.04 \Omega$$

$$Z_3 = 19.68 \Omega$$

$$Z_4 = 24.04 \Omega$$

$$Z_5 = 129.32 \Omega$$

$$Z_{UE1} = 79.96 \Omega$$

$$Z_{UE2} = 79.96 \Omega$$

$$Z_{UE3} = 81.52 \Omega$$

$$Z_{UE4} = 81.52 \Omega$$

$$R_L = 50 \Omega$$

$$W_1 = 0.43276 \text{ mm}$$

$$W_2 = 8.6283 \text{ mm}$$

$$W_3 = 10.9827 \text{ mm}$$

$$W_4 = 8.6283 \text{ mm}$$

$$W_5 = 0.43276 \text{ mm}$$

$$W_6 = 1.35389 \text{ mm}$$

$$W_7 = 1.40516 \text{ mm}$$

$$W_8 = 1.40516 \text{ mm}$$

$$W_9 = 1.35389 \text{ mm}$$

The electrical lengths of all lines is:  
 $\frac{\lambda}{2} \cdot \frac{2\pi}{\lambda} = \frac{\pi}{4}$

We use TXLINE TO find the widths (From MICROWAVE OFFICE)

Relative Permittivity  $\epsilon_r = 2.55$

Substrate thickness  $h = 1.14 \text{ mm}$

Conductor thickness  $t = 18 \mu\text{m}$

Conductor: Copper

Loss Tangent  $\epsilon \cdot \text{copper}$

Cutoff frequency  $\omega_c = 26 \text{ GHz}$

$$L_1 = 13.5425 \text{ mm}$$

$$L_2 = 12.3974 \text{ mm}$$

$$L_3 = 12.2997 \text{ mm}$$

$$L_4 = 12.3974 \text{ mm}$$

$$L_5 = 13.5425 \text{ mm}$$

$$L_6 = 13.2091 \text{ mm}$$

$$L_7 = 13.1949 \text{ mm}$$

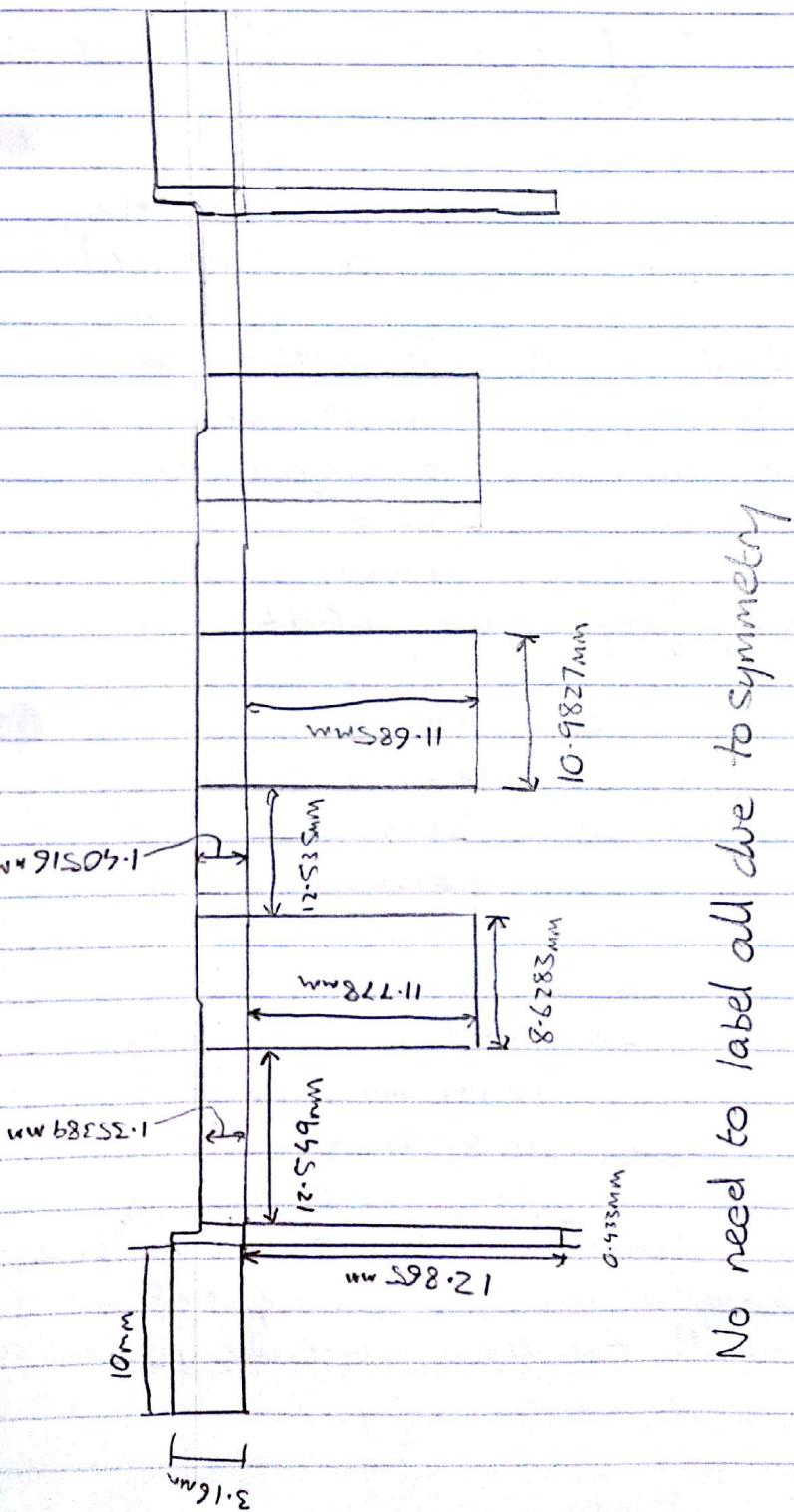
$$L_8 = 13.1949 \text{ mm}$$

$$L_9 = 13.2091 \text{ mm}$$

As in our Lab design we add 10mm of microstrip transmission line of SOR characteristic impedance at the input and output of our filter. Using TXLine the width for these sections is  
 $3.16 \text{ mm}$

I then ran my microstrip circuit and compared it to my lumped element circuit in AWR. I tuned all the lengths, apart from the two 10mm TLs, by a factor of 0.95 to give a more accurate match.

New Lengths are



My First graph shows the frequency response. It doesn't match well enough so we scale our lengths by 0.95.

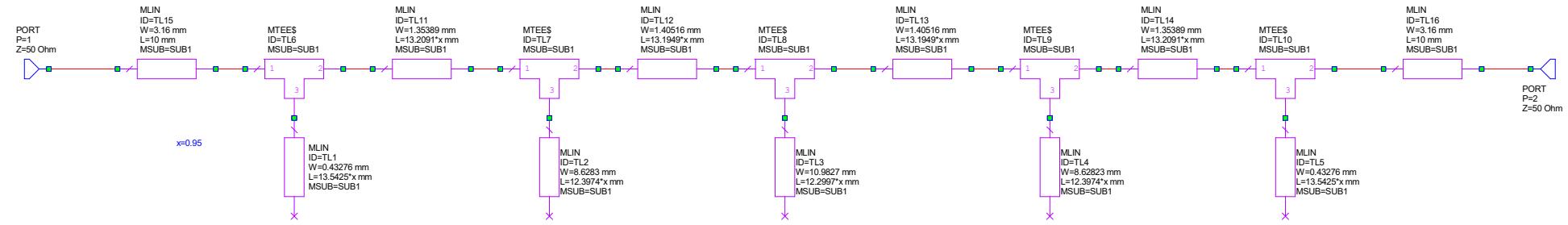
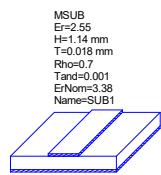
The second graph confirms our design matches our filter specifications. We see our cut-off frequency is at 2 GHz and the insertion loss at 3.2GHz is around 43dB. We were asked to design a circuit with a minimum insertion loss at 3.2GHz of 20dB so our filter fulfils the specifications.

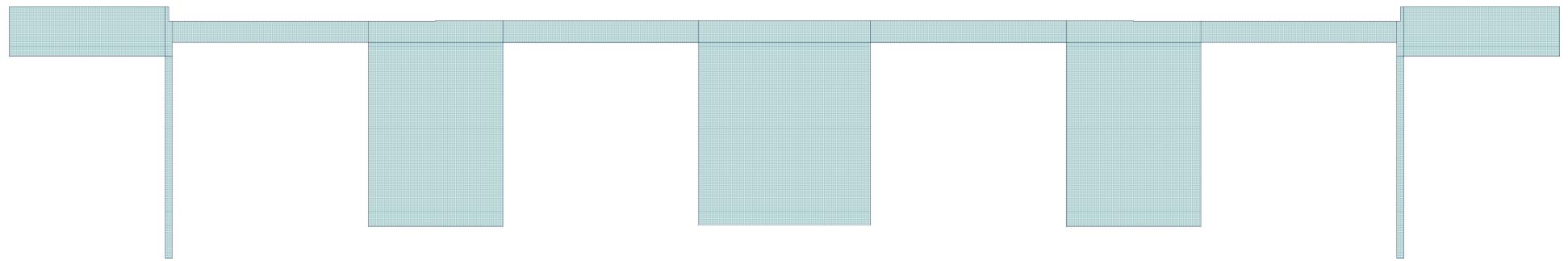
My third figure compares our filter to the stepped impedance implementation filter we designed for last weeks lab. Both filters had to fulfil the same specifications.

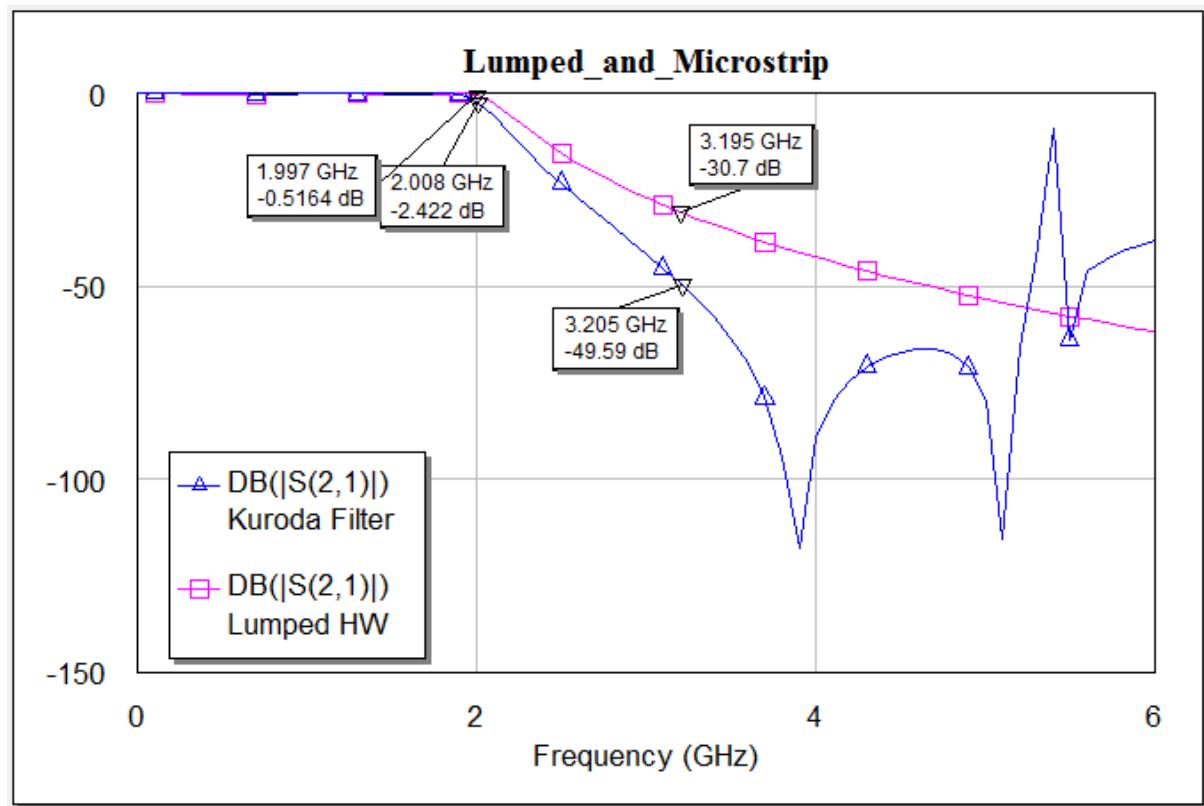
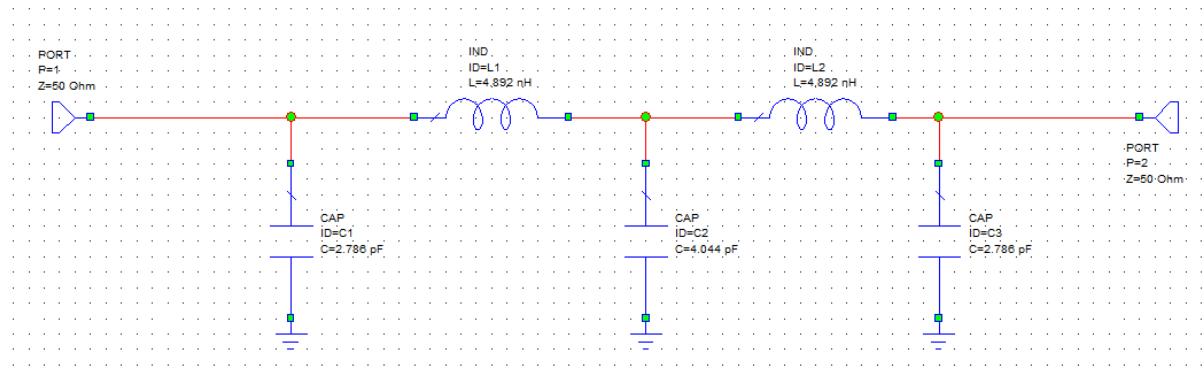
We see both circuits fulfil the specifications however our stepped impedance implementation filter gives a much lower insertion loss of 16 dB, in comparison to the  $\sim 43$ dB we get using the Richard transformations. This is due to us using a lot of simplifying assumptions in our stepped impedance implementation filter that we didn't use in our Richard's Transformation Filter. Therefore the Richard's transformation filter is much more accurate.

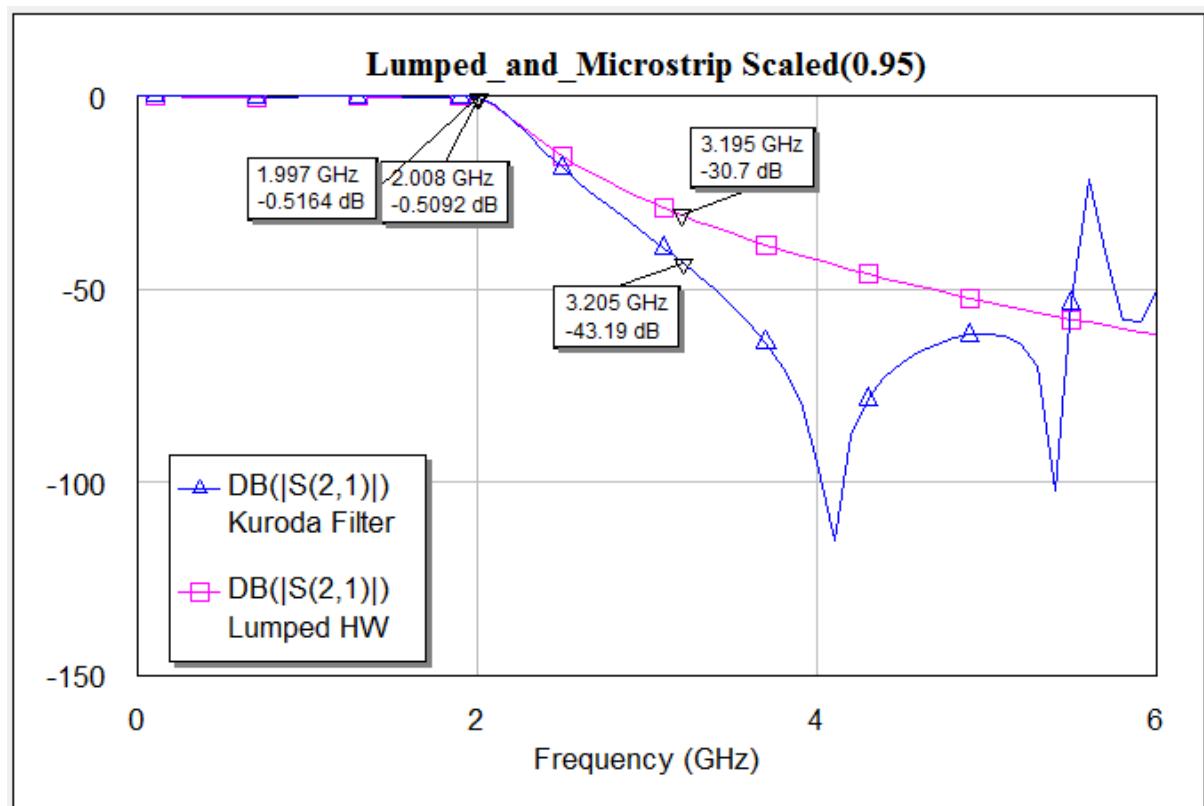
Implementing the stepped impedance design of our filter is a lot more straightforward to manufacture than our Richard's transformation filter.

I would conclude in saying that a far more practical solution than using the Richard's transformation design would be to design a higher order stepped impedance filter. As the 43dB insertion loss is really quite excessive and not merited for these specifications.









Graph 2

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|3.2e+009 -0.043342227 92.712917 -26.699061
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Figure 3

From our .s2p file from lab. We see the stepped response filters insertion loss is 26 dB @ 3.2GHz just satisfying our specifications