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Microwave stepped-impedance filter design: a comparative study of Chebychev and maximally-flat filters

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Abstract
This paper reports microwave stepped-impedance filter design: a comparative study of Chebyshev and maximally-flat filters. First, the MATLAB tool was used to observed both filters High-pass/Low-pass response, Cut-off frequency, Percentage of ripple in the pass-band and the Number of poles as the key parameter indicators and the results obtained compared for both filters. Secondly, by setting the maximum insertion loss at 0.5dB, cut-off frequency at 4GHz, attenuation at 15dB for 6GHz and input/output impedance at 50Ω, the ADS software accompanied with some stipulated data was used for the simulation of the two filters by using the same design specifications for both filters and the results obtained also compared for both filters. By setting the frequency range to sweep through 1.0GHz to 15GHz at 1.0MHz intervals with characteristic impedance of 50Ω the design filter characteristics was observed and simulation results of lumped element filter has been presented. These filters were converted into planar filters, which were also simulated and analysed using ADS software. Finally, a number of iterations of end correction was done in order to compensate for the effect of stray capacitance and inductance.

Keywords: Microwave, Filter, Chebychev, Maximally-Flat, Stepped-Impedance

1. Introduction

Microwave signals are signals which operate above 1GHz. Due to this high frequency nature, the filters employed in microwave possess a high frequency and are used in electronic warfare, remote-sensing systems, metrology, satellite and mobile communications. It can only be compared with electrical filters when they exhibit low frequency. These filters execution properties vary due to their dependency in the order of electrical wavelength (Matthaei *et.al.*, 2018). Microwave filters are two-port, passive, linear, reciprocal devices which heavily attenuate unwanted signal frequencies while transmitting wanted frequencies. There are three types of constructions of filters: Reflective Filters which consist of inductive and capacitive elements maintaining zero reflection loss in the pass-band and very high attenuation in the stop-band; Absorptive Filters which attenuate the unwanted signals and pass the wanted signal; and the Lossy Filters which uses lossy materials in the filters to manufacture major losses in the rejected signal but low loss in the wanted signal (Pozar, 2010).

In the microwave system, transmission lines are used instead of inductors and capacitors at low frequency. This establishes important transmission and coupling effects which is impossible at small frequencies. With recent technology development, it is quite easy to determine the insertion loss. Insertion loss (amplitude response of the filter) can be estimated using network synthesis techniques which is used to accommodate microwave distributed circuit elements. This can be done by verifying filter measurements, design of a low pass prototype filter, balancing and converting the filter and conversion of the lumped components to distributed components (Richard *et.al.*, 2016).

Irrespective of all the theory about microwave filters, it could be said that in practice there is small non-zero attenuation in the pass-band and a small signal output in the attenuation or stop-band, since the microwave filter is designed to operate among resistive sources and load impedances of 50 ohm in many microwave systems. In the design of a microwave filter, some of the parameters that should be considered are; pass bandwidth, stop-band attenuation and frequencies, input and output impedances, return loss, insertion loss and group delay. The popular and widely used microwave filters are low-pass, band-pass, high-pass, band-stop and all-pass filters.

Low-Pass Filters: By definition, a low-pass filter is a circuit offering easy passage to low-frequency signals and difficult passage to high-frequency signals. There are two basic kinds of circuits capable of accomplishing this objective, and many variations of each one. The inductive low-pass filter and the capacitive low-pass filter. The inductor's impedance increases with increasing frequency and high impedance in series tends to block high-frequency signals from getting to the load while the capacitor's impedance decreases with increasing frequency. This low impedance in parallel with the load resistance tends to short out high-frequency signals, dropping most of the voltage across series resistor (Jha *et.al.,* 2017). When there is low frequency present in the system, the shunt capacitances have large impedances and the series inductances have low impedance. This will help the signal to emerge from the output of the filter. But when relating to frequencies above the cut-off frequencies it could be said that the shunt capacitances have low impedance and series inductors have high impedances. This will transfer the signal to the load (Jia-sheng Hong *et.al.,* 2011).

Low-pass filters can be manufactured by using micro-strip lines, coaxial lines and strip lines. Since they are small in size, low cost and very light; micro-strip filters are used for airborne communication, satellite communications, EW systems (Bharathi *et.al.,* 2000). High-Pass Filters: A high-pass filter's task is just the opposite of a low-pass filter: to offer easy passage of a high-frequency signal and difficult passage to a low-frequency signal. As one might expect, the inductive and capacitive versions of the high-pass filter are just the opposite of their respective low-pass filter designs. The high-pass filter could be recognized by a series of capacitors and shunt inductances. At large frequencies the capacitors have low impedance and inductors have large impedances. Hence the signal which has a frequency which is large will pass onto the load with a small amount of loss and vice-versa (Komal *et.al.,* 2019). When considering micro-strip lines and coaxial lines; small lengths of large characteristic impedances are T-connected to the main line which almost equalizes the shunt inductors. The shunt inductances could be recognized by an H-plane T-junction (Micro-Strip Version 7, 1999).

Band-Pass Filter: There are applications where a particular band, or spread, or frequencies need to be filtered from a wider range of mixed signals. Filter circuits can be designed to accomplish this task by combining the properties of low-pass and high-pass into a single filter. The result is called a band-pass filter. What emerges from the series combination of these two filter circuits is a circuit that will only allow passage of those frequencies that are neither too high nor too low (Lin-Chuan *et.al.,* 2008).
Band Stop Filter: This is also called band-elimination, band-reject, or notch filters. This kind of filter passes all frequencies above and below a particular range set by the component values. Not surprisingly, it can be made out of a low-pass and a high-pass filter, just like the band-pass design, except that this time we connect the two filter sections in parallel with each other instead of in series (Kuphaldt *et.al.,* 2007). Interestingly high-pass filter is a complement of low-pass filter and band-stop filter is a complement of the band-pass filter. Two frequency bands are being used to transfer the signal to the load. One will be from lower frequency to lower cut-off frequency and the other from upper cut-off frequency to infinite frequency (Darlington, 2009).

Ladder Network Filters: The position of the final reactive element relies on whether the number of elements is odd or even. To do this; a design for a low-pass filter should be developed where the cut-off frequency is 1 rad/s and the terminating resistors are 1ohms. When this is done the impedance level and the cut-off frequency could be adjusted to any value needed. Then the circuit topology is transformed to a high-pass, band-pass and band-stop filters when required. The notation of the low-pass prototype filter, with values of **'g'** is as shown in Figure 1 and is widely used in the world. Filter values could be found by easy recursion equations. For example, the **'g'** near the inductor defines the inductance, the **'g'** near the capacitor defines the capacitance and a **'g'** near the resistor defines the resistance. Interestingly for a normal prototype circuit, **g** = 1 (Young *et.al.,* 2016)

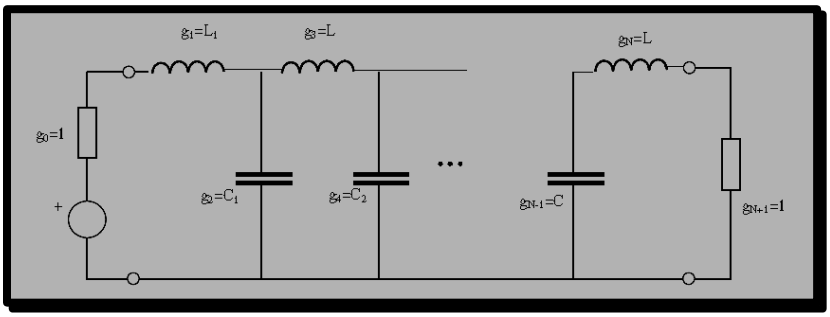


Figure 1: Ladder circuit for low pass prototype (Young *et.al.,* 2016)

Maximally Flat Filter: The Maximally flat filter commonly known as Butterworth filter is said to possess a gradual out-of-band attenuation and a smooth pass-band. It could be designed using the following steps:

a. Determining the appropriate order of the filter, N, for given filter specifications in which for a maximally flat filter characteristic, the order of the filter that satisfies given filter characteristics is given by equation 1.0 (Komal *et.al.,* 2019).

$$N \geq \frac{IL(\omega_C) + IL(\omega_S)}{20\log\left(\omega_S/\omega_C\right)} \quad (1)$$

Where

$$IL = 10\log(1 + \omega^{2N}) \quad (2)$$

IL = Insertion loss, N = Order of the filter

The appropriate order of the filter, N, is determined for given filter specifications.

b. Using formulas and tables. Values for different elements could be found which will create a low-pass filter with a cut-off frequency 1 rad/s, with a load of 1 ohm and above order.
c. Since the above values were normalized values, formulas are used to scale those values to the actual design cut-off frequency and to the actual load and source impedances.

Chebyshev Filter: Chebyshev filters are used to separate one band of frequencies from another. The primary attribute of Chebyshev filters is their speed, this is because they are carried out by recursion rather than convolution. The design of these filters is based on a mathematical technique called the z-transform (Sha Luo *et.al.,* 2018).
Considering a Chebyshev filter, it could be said that it has a steeper out-of-band attenuation and a rippled pass-band response. When small ripples in the pass-band are allowed, the slope of the pass-band for a known number of elements of a filter could be enhanced. This filter function creates a very small pass-band ripple for a known bandwidth or a very large bandwidth for a known pass-band ripple.

2.0 Material and methods

In this paper, comparative analysis will be done using two different methods. First, the MATLAB tool will be used and the behaviours of some key parameter indicators observed and compared for the both filters. Secondly, the ADS software accompanied with some stipulated data will be used for simulation of the two filters and their behaviours also compared.

2.1 The MATLAB tool methodology: For the Chebyshev filter, the four parameters selected in its design are; High-pass or Low-pass response, Cut-off frequency, Percentage of ripple in the pass-band and the Number of poles.
For the maximally flat filter characteristic, the order of the filter that satisfies given filter characteristics is given by equation 3.0 to 6.0 (Lin-Chuan *et.al.,* 2008).

$$N \geq \frac{IL(\omega_c) + IL(\omega_s) + 6}{20\log\left(p + \sqrt{p^2 - 1}\right)} \quad (3)$$

.

The insertion loss of the Maximally flat filter is given by Equation 4.0,

$$IL = 10\log(1 + \omega^{2N}) \quad (4)$$

The insertion loss of the Chebyshev filter is given by Equation 5.0,

$$IL = 10\log\left(1 + \varepsilon T_N^2(\omega)\right) \quad (5)$$

Where N = Order of the filter, $T_N(\omega)$ = Chebyshev polynomial of order N, ε= parameter that defines the ripple of the Chebyshev filter in the passband.

The Chebyshev polynomial is given by Equation 6.0. This is a recurrence formula.

$$T_{N+1}(\omega) = 2\omega T(\omega) - T_{N-1}(\omega) \quad (6)$$

Where $T_0(\omega) = 1$, $T_1(\omega) = 2$ etc.

Using the above equations for the insertion loss of the maximally flat filter and that of the Chebyshev filter, the code was written in MATLAB which implements these equations when simulated to give us our plots of comparison between maximally flat filter characteristic and the Chebyshev characteristics. The graphs of figure 2 to figure 5 represent these comparisons for different orders of N = 3 to N = 6 respectively. The value of epsilon in Chebyshev filter for the whole order was kept constant at 1 throughout this simulation.

2.2 The ADS software simulation methodology: By deploying the ADS design software using the same design specifications for both filters as outlined, the characteristics exhibited by the Chebyshev and Maximally flat filters can be studied and comparisons made.

Maximum insertion loss = 0.5dB; Cut-off frequency = 4GHz; Attenuation = at least 15dB at 6GHz;
Input and output impedance = 50Ω

2.2.1 For Maximally flat filter

Based on above given filter characteristics the appropriate order of the filter, *N*, is first determined for given filter specifications. For the maximally flat filter characteristic the order of the filter that satisfies the given filter characteristics is given by equation 7.0 (Jia-sheng *et.al.*, 2011)

$$N \geq \frac{IL(\omega_c) + IL(\omega_s)}{20\log\left(\frac{\omega_s}{\omega_c}\right)} \quad (7)$$

Where

$$N \geq \frac{0.5 + 15}{20\log\left(\frac{6}{4}\right)}$$

therefore N ≥ 4.4011. So, we choose the order N = 5 being the closest odd number. The order of the filter should actually be either greater than or equal to 4.4011 or smaller than or equal to 7 but this is not met due to some design specifications, hence the order of 5 being chosen.

Table 1 shows the element values for maximally flat low pass Filter Prototypes for order of 5. The normalized low-pass filter prototype values used to obtain the L and C element is given by equations 8.0 and 9.0. Calculations made using these equations to find the maximally flat filter (lumped element).

Element values for maximally flat low pass Filter Prototypes for order N = 5 given in table 1.

Table 1: Element values for maximally flat low pass Filter Prototypes for order N = 5

N	g1 = L_1	g2 = C_1	g3 = L_2	g4 = C_2	g5 = L_3
5	0.6180	1.6180	2.0	1.6180	0.6180

The scaled element values are gotten using equations 9.0 and 10.0 (Sha Luo *et.al.*, 2018)

$$L' = \frac{R_0 L}{\omega_c} \tag{8}$$

$$C' = \frac{C}{R_0 \omega_c} \tag{9}$$

Where: $R_o = 50$, L = values of $L_1 – L_3$, C = values of $C_1 – C_2$ and $\omega_c = 2\pi f$

The calculated values for the corresponding $L's$ and $C's$ are displayed as shown

$$L1' = \frac{R_0 g_1}{\omega_C} = \frac{50 \times 0.6180}{2\pi \times 4G} = 1.2295nH$$

$$C1' = \frac{g_2}{R_0 \omega_C} = \frac{1.6180}{50 \times 2\pi \times 4G} = 1.2876pF$$

$$L2' = \frac{R_0 g_3}{\omega_C} = \frac{50 \times 2.0}{2\pi \times 4G} = 3.9789nH$$

$$C2' = \frac{g_4}{R_0 \omega_C} = \frac{1.6180}{50 \times 2\pi \times 4G} = 1.2876pF$$

$$L3' = \frac{R_0 g_5}{\omega_C} = \frac{50 \times 0.6180}{2\pi \times 4G} = 1.2295nH$$

2.2.2 For Chebyshev filter

The above process is repeated here for a Chebyshev low-pass filter with maximum insertion loss of 0.5dB at a cut-off frequency of 4GHz, at least 15dB attenuation at 6GHz and impedance of 50Ω. To carry out this task based on given filter characteristics, the appropriate order of the filter, *N*, is determined for the given filter specifications. For the Chebyshev filter characteristic, the order of the filter that satisfies a given filter characteristics is given by equation 10.0 (Jia-sheng *et.al.*, 2011)

$$N \geq \frac{IL(\omega_c) + IL(\omega_s) + 6}{20 \log\left(p + \sqrt{p^2 - 1}\right)} \tag{10}$$

Where $p = \omega_s/\omega_c = (6/4) = 1.5$. Therefore,

$N \geq \frac{0.5 + 15 + 6}{20\log\left(1.5 + \sqrt{1.5^2 - 1}\right)}$. Such that, $N \geq 2.5719$. So, we choose an order of N = 3.

It could be said that there were some design specifications which had to be met. It was found that the order of the filter should be greater than or equal to 2.5719 and smaller than or equal to 9. Therefore, the order of Chebyshev filter is taken as 3.

Table 2 shows the element values for Chebyshev low pass Filter Prototypes for order of 3. The normalized low-pass filter prototype values used to obtain the L and C element is given by equations 8.0 and 9.0. Calculations made using these equations to find the Chebyshev filter (lumped element).

Element values for Chebyshev low pass Filter Prototypes for order N = 3 given in table 2.

Table 2: Element values for Chebyshev low pass Filter Prototypes for order N = 5

N	g1= L_1	g2 = C_1	g3 = L_2
3	1.5963	1.0967	1.5963

Using equations 11.0 and 12.0, the scaled element values were calculated.

$$L' = \frac{R_0 L}{\omega_c} \quad (8)$$

$$C' = \frac{C}{R_0 \omega_c} \quad (9)$$

The calculated values for the corresponding $L's$ and $C's$ are displayed in the block

$$L1' = \frac{R_0 g_1}{\omega_C} = \frac{50 \times 1.1963}{2\pi \times 4G} = 3.1757nH$$

$$C1' = \frac{g_2}{R_0 \omega_C} = \frac{1.0967}{50 \times 2\pi \times 4G} = 0.8723pF$$

$$L2' = \frac{R_0 g_3}{\omega_C} = \frac{50 \times 1.5963}{2\pi \times 4G} = 3.1757nH$$

3.0 Results and Discussions

Analysis of the results gotten by using the MATLAB tool

Using the MATLAB tool, the graphical plots of the characteristics of both filters were simulated and their corresponding behaviours analysed

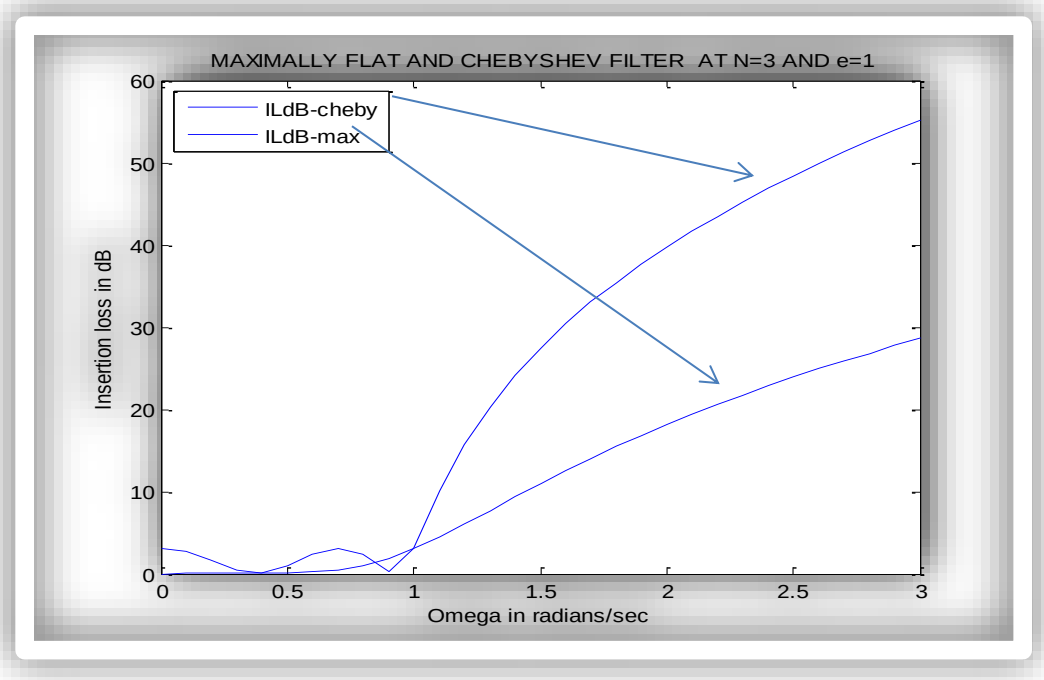


Figure 2: Chebyshev and Maximally flat filter characteristics for N = 3

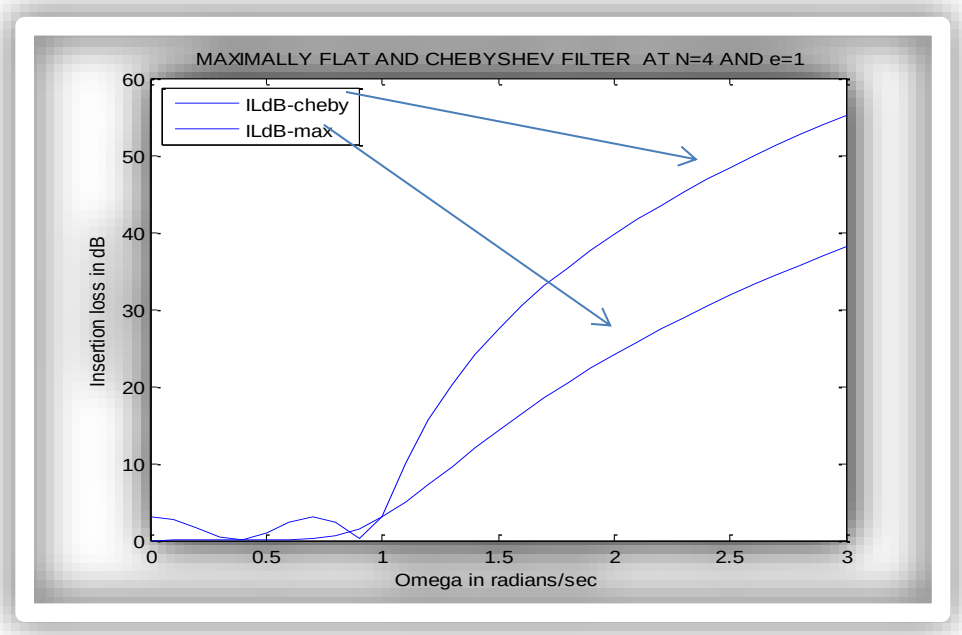


Figure 3: Chebyshev and maximally flat filter characteristics for N = 4

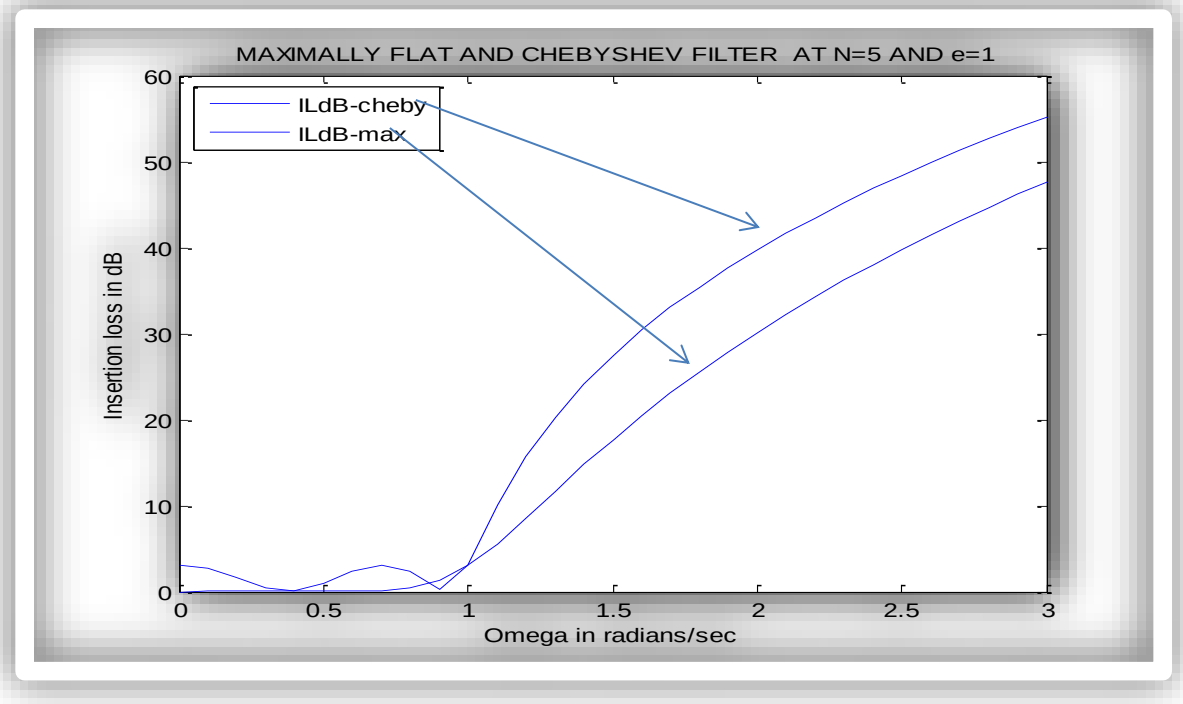


Figure 4: Chebyshev and Maximally flat filter characteristics for N = 5

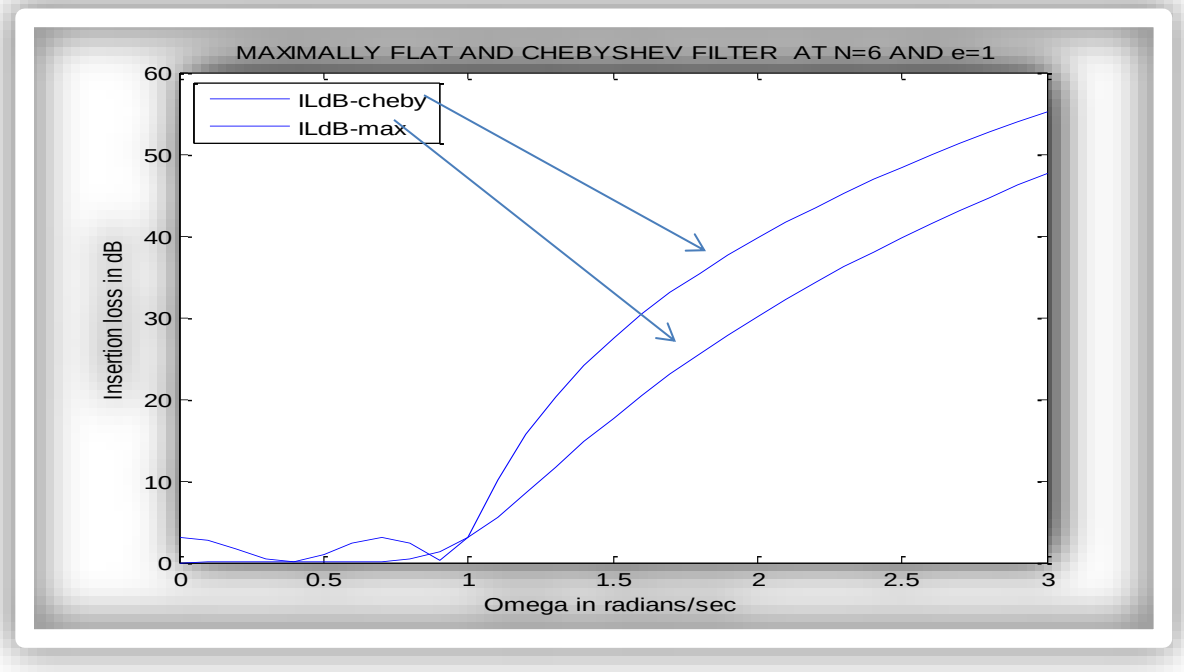


Figure 5: Chebyshev and Maximally flat filter characteristics for N = 6

Observations showed that, the Maximally flat filter exhibited a flat amplitude passband response with a curve of a more gradual slope, while Chebyshev filter exhibited ripples of amplitude in the passband before the cut-off frequency with a steep curve for all the orders.
Also, the Chebyshev filter exhibited a higher insertion loss than the Maximally flat filter, this indicates that it has a better attenuation compare to Maximally flat filter. With respect to the insertion loss exhibited at cut-off frequency by Chebyshev filter, it shows that it possesses good features of low pass filter. However Maximally flat filters have a more linear phase response in the passband than the Chebyshev.
Finally, the insertion loss increased with the increase in the order for both Maximally flat filter and Chebyshev filter characteristic graphs.
In order to check the effect of epsilon, ε its value has been changed to 0.1 and 8 respectively. Then the Chebyshev filter characteristics for N = 3, 4, 5, 6 graphs have been plotted, which are shown in figure 6 and 7.

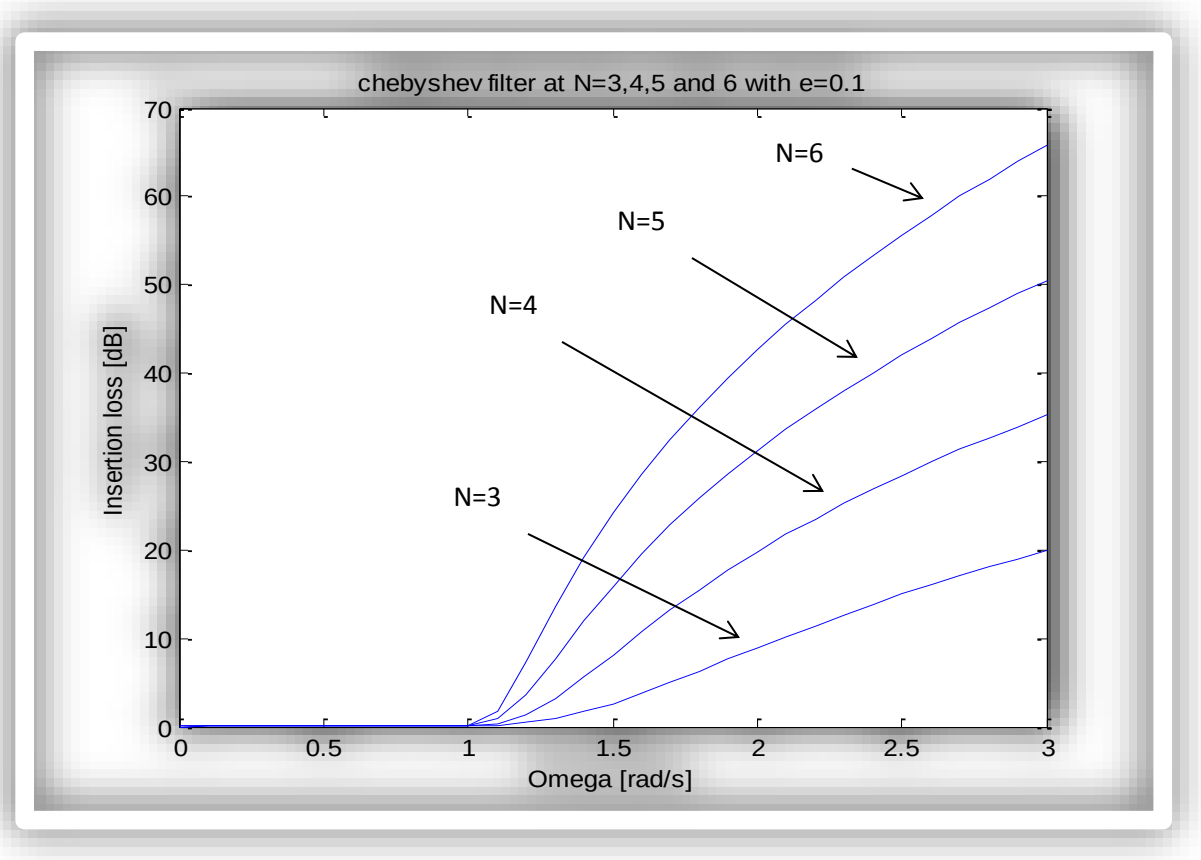


Figure 6: Chebyshev filter characteristics for ε =0.1

Observations show that, when the value of ε = 0.1, the Chebyshev filter doesn't show any ripple and provides the flattest possible passband response in the passband before the cut-off frequency. This characteristics feature is peculiar with the maximally flat filter characteristic. Therefore, at this value both Chebyshev and maximally filters possess the same characteristic feature.

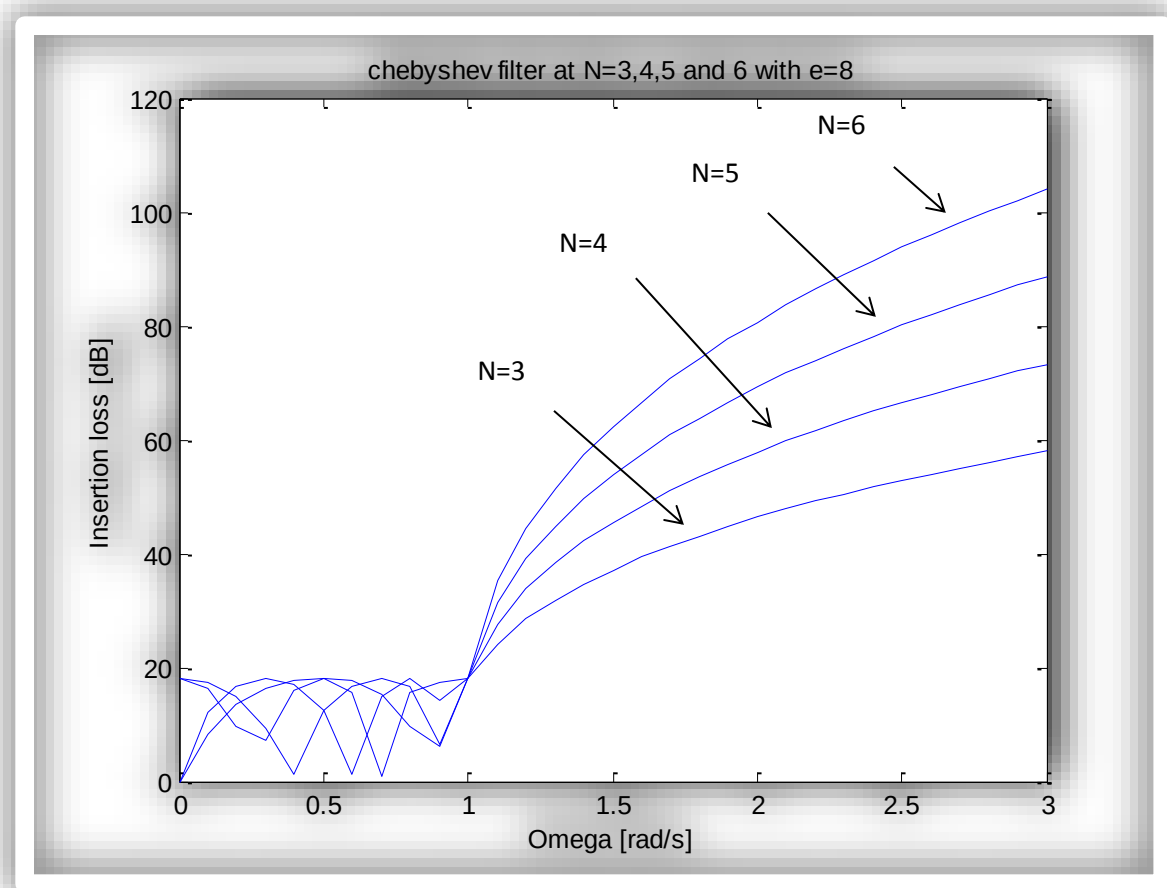


Figure 7: Chebyshev filter characteristics for ε =8

When the value of ε = 8, the amplitude of the ripples increased massively in Chebyshev filter passband before the cut-off frequency. This effect causes the desired signal to be highly attenuated by the filter.

From the above observations, it has been shown that if the value of epsilon is reduced, the Chebyshev filter characteristics are almost similar to the maximally flat filter characteristic, but if the value of epsilon is increased, then filter gives more ripples, which affects the desire signal as it will be highly attenuated.

In order to observe the characteristics of Maximally flat filter and Chebyshev filter with different orders separately, a MATLAB code was developed using the MATLAB tool. Figures 8 and 9 gave us the graphical characteristic behaviours of the Chebyshev and Maximally flat filter respectively.

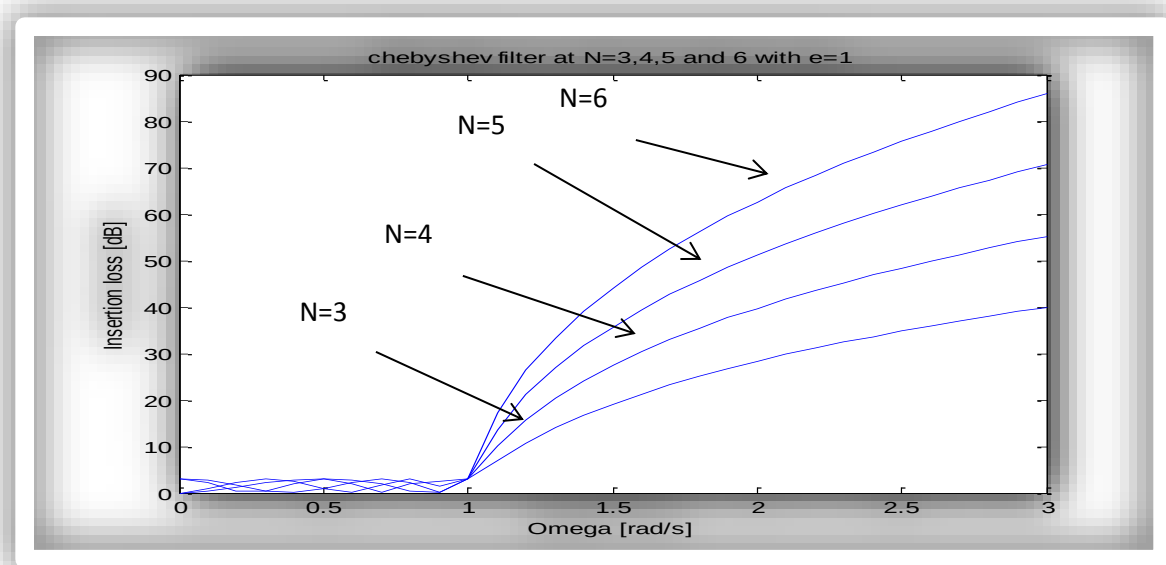


Figure 8: Chebyshev filter characteristics for N = 3, 4, 5, 6

As we increased the order of the filter, the numbers of ripples increased for Chebyshev. This causes the desired signal to be attenuated. Therefore, increase in the order of the filter makes room for increase in attenuation. Also, the filter tends to respond more quickly after the cut-off frequency.

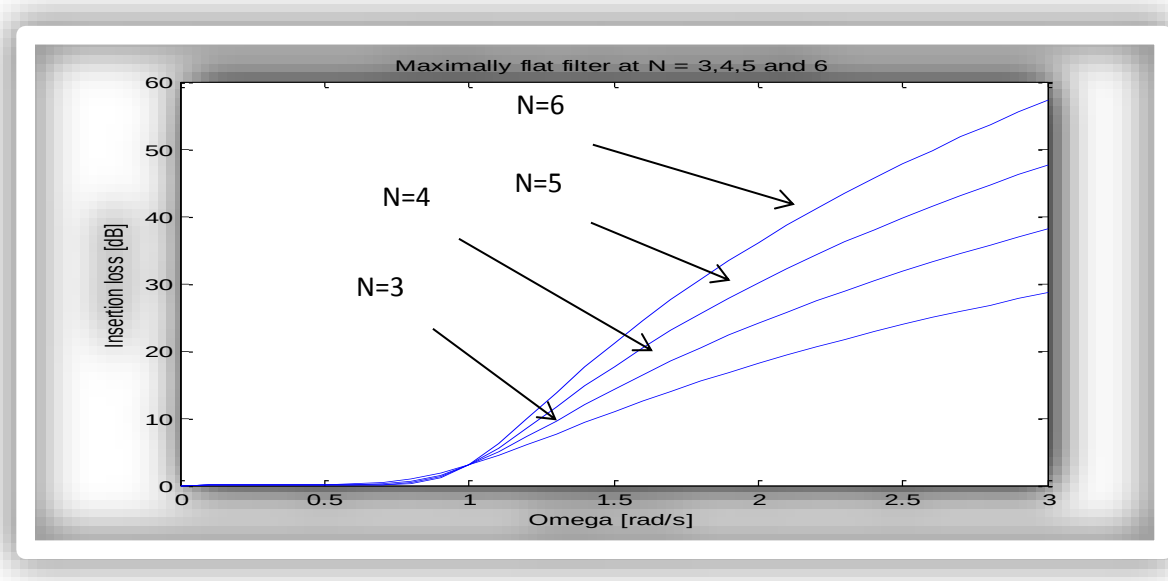


Figure 9: Maximally flat filter characteristics for N = 3, 4, 5, 6.

Observations here showed that the insertion loss increases gradually with the increase in the order of the filter and the filter response indicates that, it doesn't experience any change with its shape. With this, we can conclude that the Maximally filter response for frequency is greater than the cut-off frequency and attenuates rapidly with the higher level of order.

On the side of insertion loss, it shows that insertion loss increases by the increment of filter order at the cut-off frequency and further than it. So, this makes the filter to be a better low pass filter. This indicates that Maximally flat filter will exhibit a better performance for higher order values.

Analysis of the results gotten for the Maximally flat filter by using the ADS software simulation

Using the ADS software, the schematic filter circuit of figure 10 was designed and corresponding values of inductor and capacitors imputed.

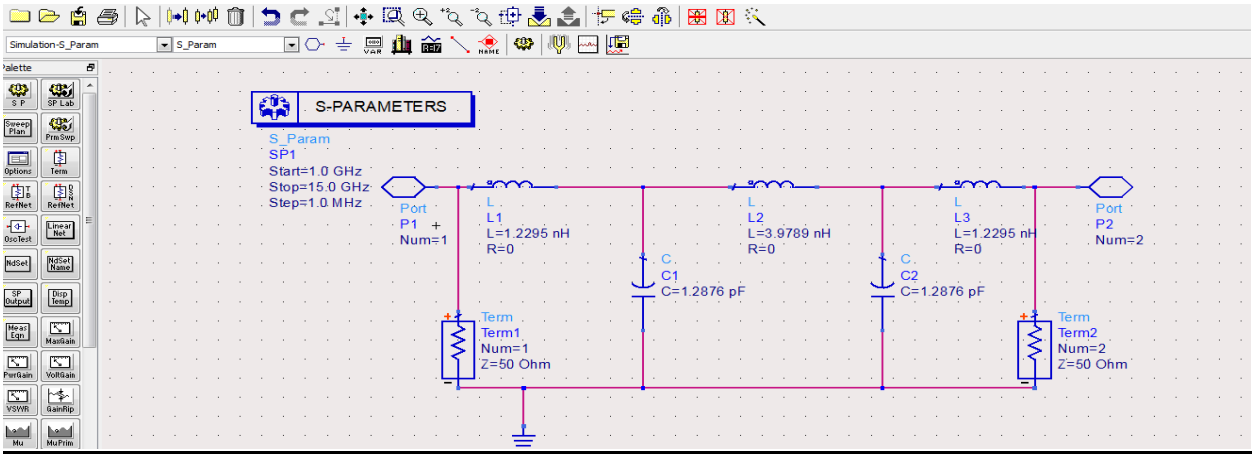


Figure 10: Schematic using ADS when N = 5

Setting the frequency range to sweep through 1.0GHz to 15GHz at 1.0MHz intervals so as to observe the design filter characteristics. It took exactly 2.20sec for the simulation palette to run giving us the result of the circuit design as show in Figure 11.

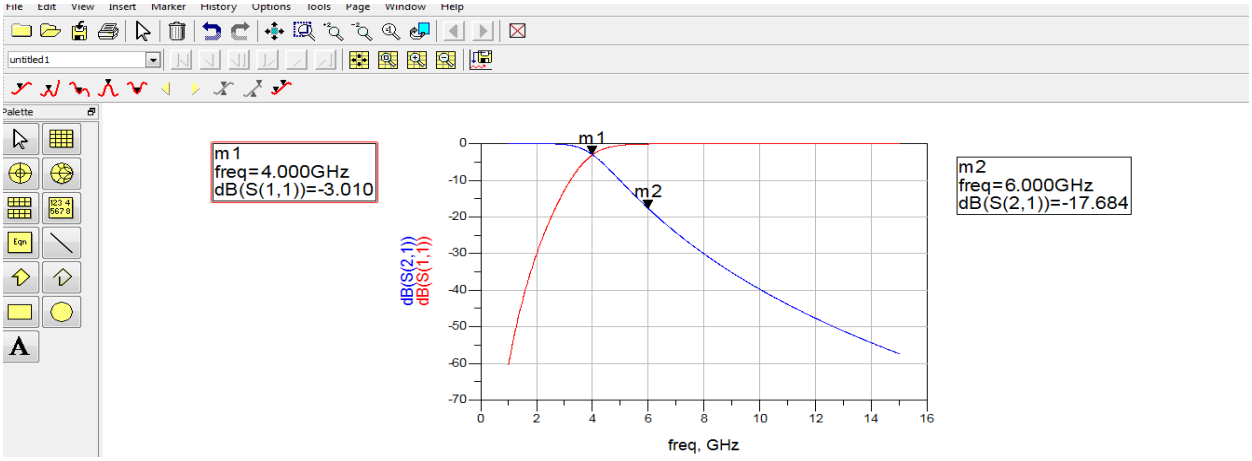


Figure 11: Circuit design schematic window

From the above simulation result, we noticed that the cut-off happened at about -3dB (common definition of cut-off) at 4GHz frequency. It also exhibited 17.684dB attenuation at 6 GHz, whereas the anticipated requirement is expected to be at least 15dB. With this result, we therefore can conclude that the design for the filter satisfies the given requirements and the schematic structure of the filter has been designed correctly. To obtain the equivalent transmission line filter, the capacitors and inductors of the lumped circuit are converted into transmission lines of certain lengths and characteristic impedances. In order to produce a layout of the micro-strip filter structure some assumptions were made which includes:

Substrate has dielectric constant $\varepsilon_r = 4.2$; Thickness of the metal, T = 0.02mm; Micro-strip substrate thickness = 1mm; The tanδ = 0.02 and Conductivity = 10^5.

The ADS LineCalc subroutine as shown in Figure 12 was used to obtain the corresponding values for the widths and lengths of the microstrip lines, so that the micro-strip filter could be designed using the ADS design software.

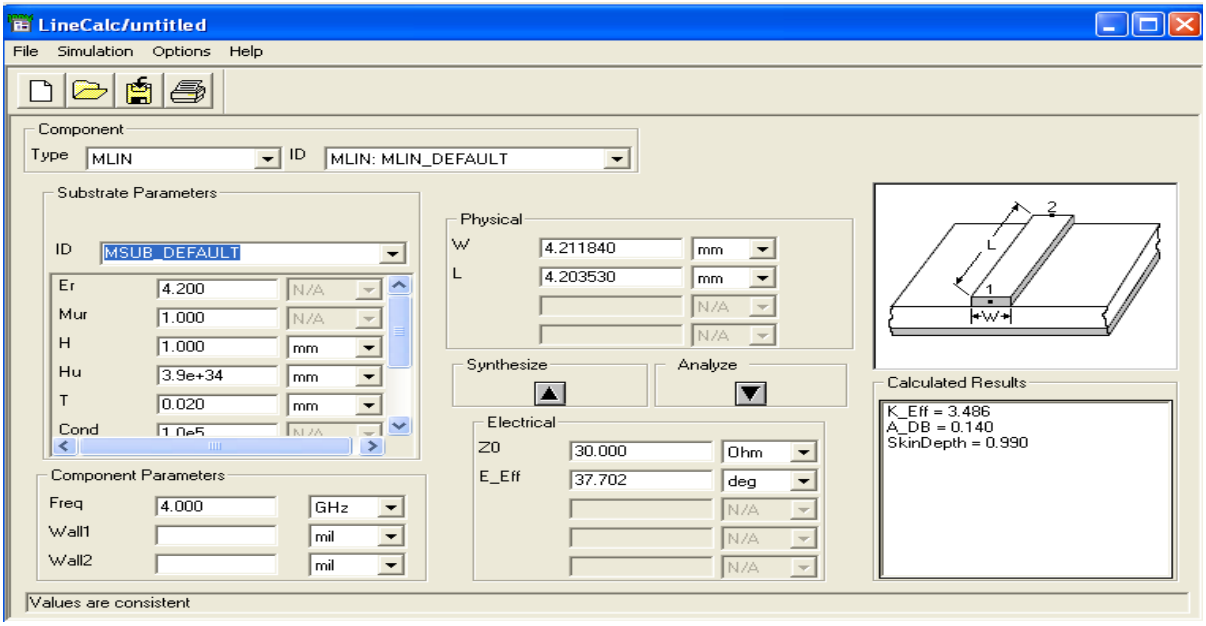


Figure 12: the ADS LineCalc subroutine for calculating the W's and L's of the microstrip lines.

Table 3 shows the width and length as obtained from the LineCalc and electrical length of the capacitors and inductors as previously calculated above, which are required to produce a layout of the microstrip filter structure.

Element	Width (W) mm	Length (l) mm	Electrical Length (degree)
L1'	0.4399	2.1689	17.704
C1'	4.2118	6.2016	55.623
L2'	0.4399	7.0192	57.296
C2'	4.2118	6.2016	55.623
L3'	0.4399	2.1689	17.704
$Z1_0$'	1.9566	41.7052	360
$Z2_0$'	1.9566	41.7052	360

Using the ADS design software, the microstrip filter layout design is shown in Figure 13.

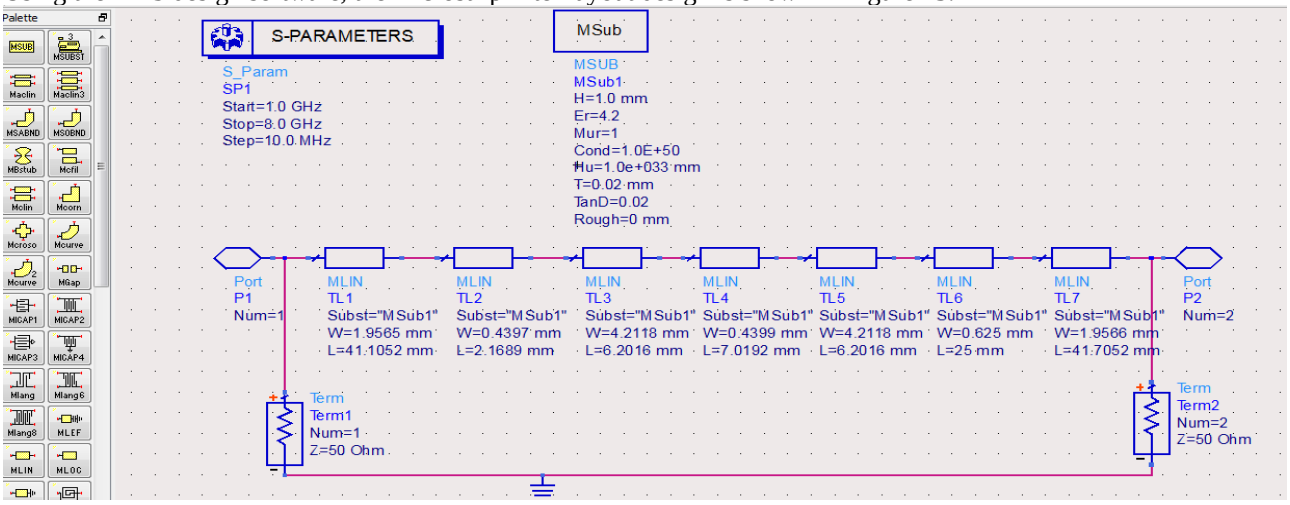


Figure 13: Microstrip layout design

It is observed from figure 11 that the microstrip layout consist of 3 inductors, 2 capacitors and 2 arbitrary microstrip line length of 50Ω MLIN at both input and output of the filter. Imputing the above parameters of width, length and electrical length, the layout design was simulated to observe the design filter characteristic. This took 1min 50 seconds to run. The frequency range has been set from 1.0 GHz to 11.0 GHz sweeping through 1.0MHz. The simulation result given in figure 14.

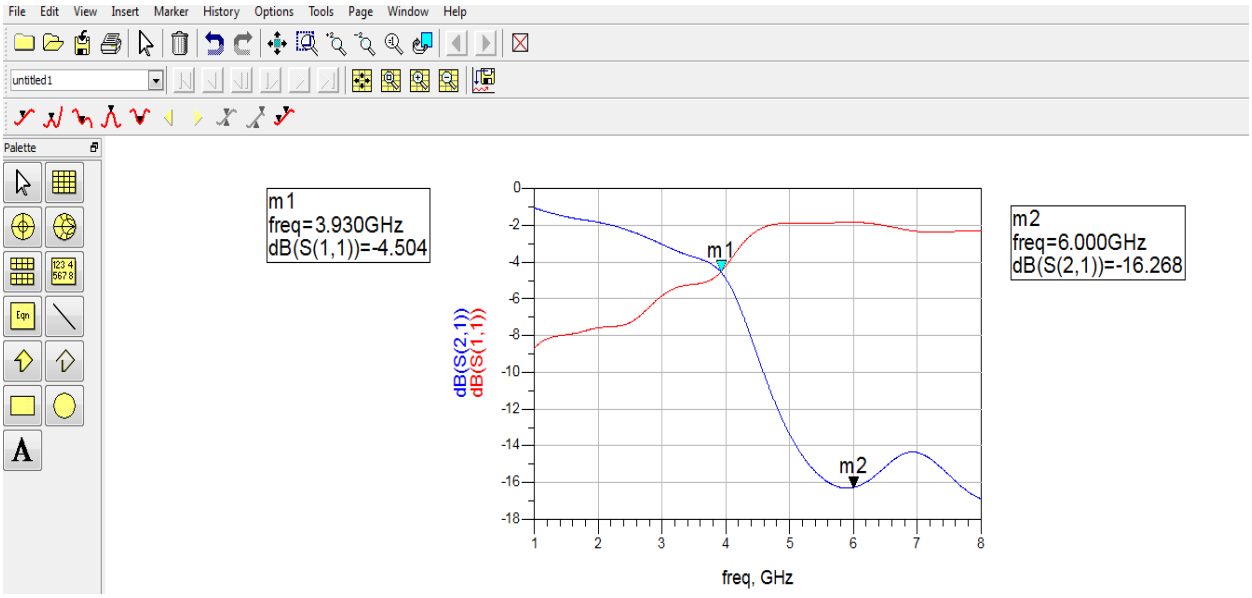


Figure 14: Simulation result for the layout design

Observation showed that the cut-off occurred at 4.504 dB at 3.930GHz frequency. But cut-off has to be at -3 dB and 4GHz frequency. So above shown simulation output values are almost similar to the expected values. Also, it shows an attenuation of 16.266 dB at 6 GHz, which satisfies the requirement of at least an attenuation of 15 dB; this is even closer to the expected value. It is observed that the simulation results that were obtained from the schematic design and simulation results that were obtained from the layout design have the same characteristics graphs. Therefore, we can state that from the simulation results that the design for the filter satisfies the given requirements and the layout design structure of the filter was designed correctly.

Analysis of the results gotten for the Chebyshev filter by using the ADS software simulation

With the ADS software, the schematic filter circuit was designed and is presented as shown in Figure 15.

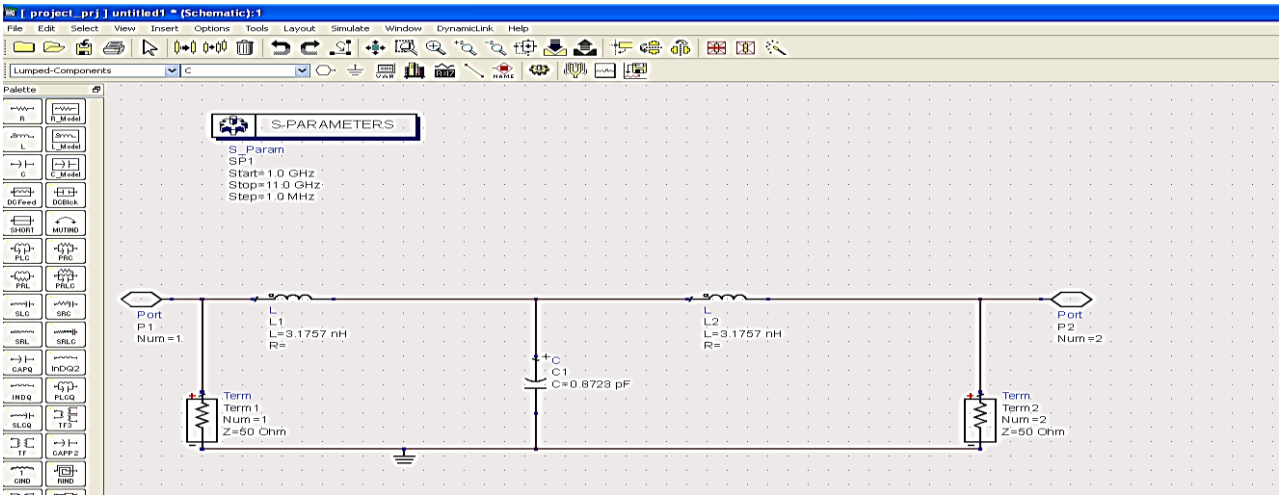


Figure 15: Schematic using ADS when N = 3 for Chebyshev filter.

Setting the frequency range to sweep through 1.0MHz between 1.0GHz and 11.0GHz as can be seen from the design, it took a few seconds and the design filter characteristic window was displayed as shown in Figure 16.

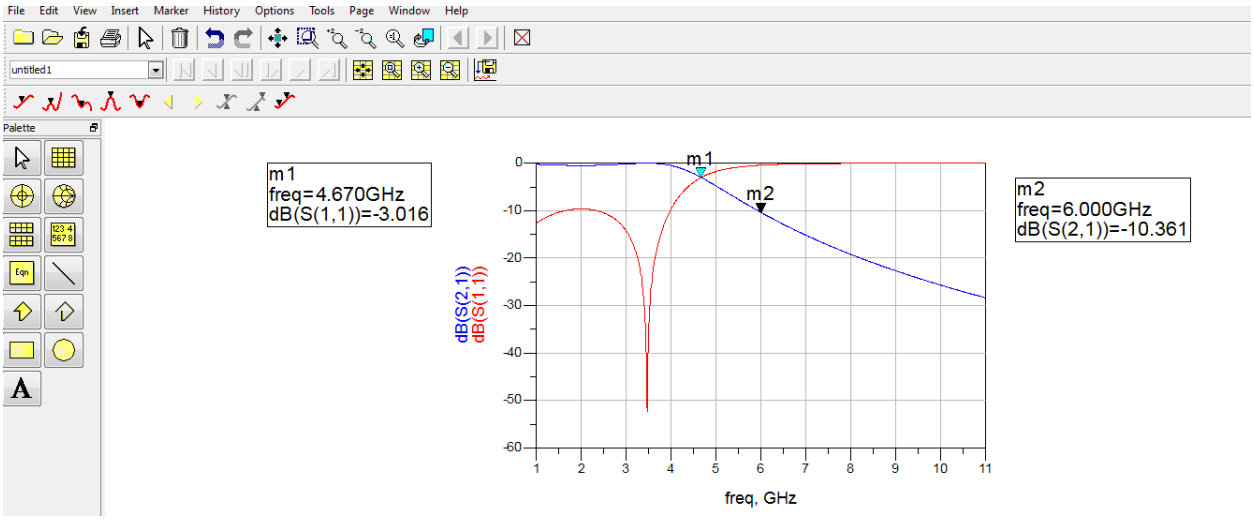


Figure16: Simulation result for the circuit design

Chebyshev filters as a matter of fact do not play by the rules of the common definition of the cut-off frequency at −3dB, this is observed as the cut-off did not happen at this point and at the given frequency, rather we got -3.016dB at frequency of 4.670 GHz as compared with the study carried out by Sha Luo *et.al.*, in 2018 . Also, it shows 10.361dB attenuation at 6 GHz, whereas the requirement is at least 15dB. This is not quite close to the expected value. In addition, figure 14 shows ripple and a steep, which are the characteristics of Chebyshev filter. Therefore, from the simulation results, we can say that that the design for the filter did not really satisfies the given requirements even though the schematic structure of the filter was designed correctly.
Then TXLINE-micro-strip tool has been used to find out the values for width, length and electrical length of the capacitors and inductors as shown in the table 4. These values are required to produce a layout of the microstrip filter structure for the Chebyshev filters.

Table 4: values for width, length and electrical length of the capacitors and inductors

Element	Width (W) mm	Length (l) mm	Electrical Length (degree)
L1’	0.4399	5.6024	45.731
C1’	4.2118	4.2035	37.702
L2’	0.4399	5.6024	45.731

Then ADS design software has been used to design the microstrip filter layout design. The microstrips filter layout design is as shown in figure 17.

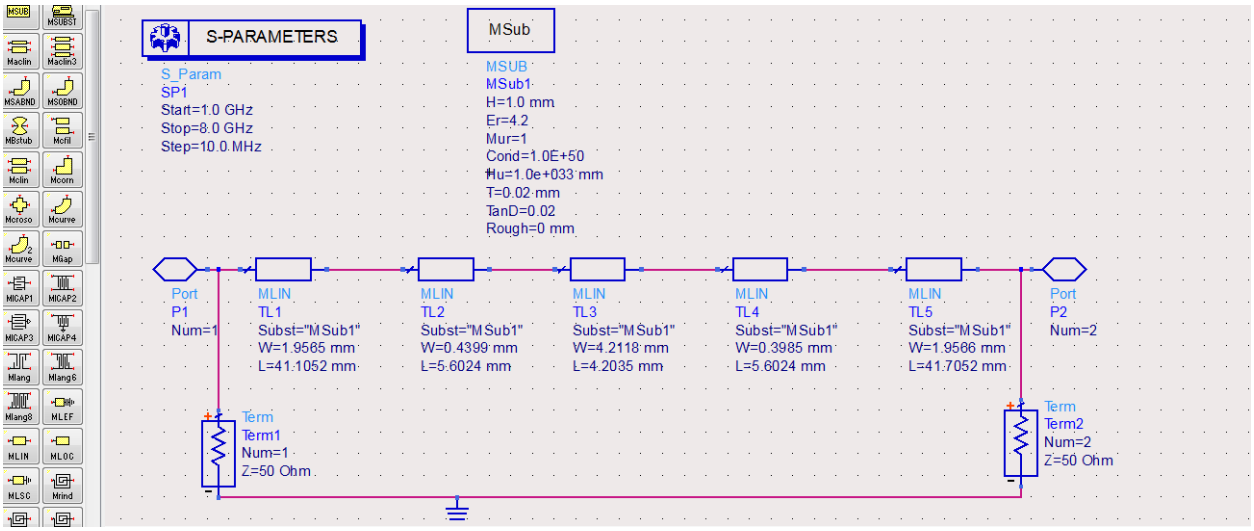


Figure 17: Microstrip layout design

The microstrip layout of figure 17 consists of 2 inductors and 1 capacitor as can be seen from the design. The simulated lengths, widths and calculated electrical lengths were used for the design. The layout design was simulated to observe the design filter characteristic. The frequency range has been set from 1.0 GHz to 11.0 GHz sweeping through 1.0MHz. The simulation result is as shown in figure 18.

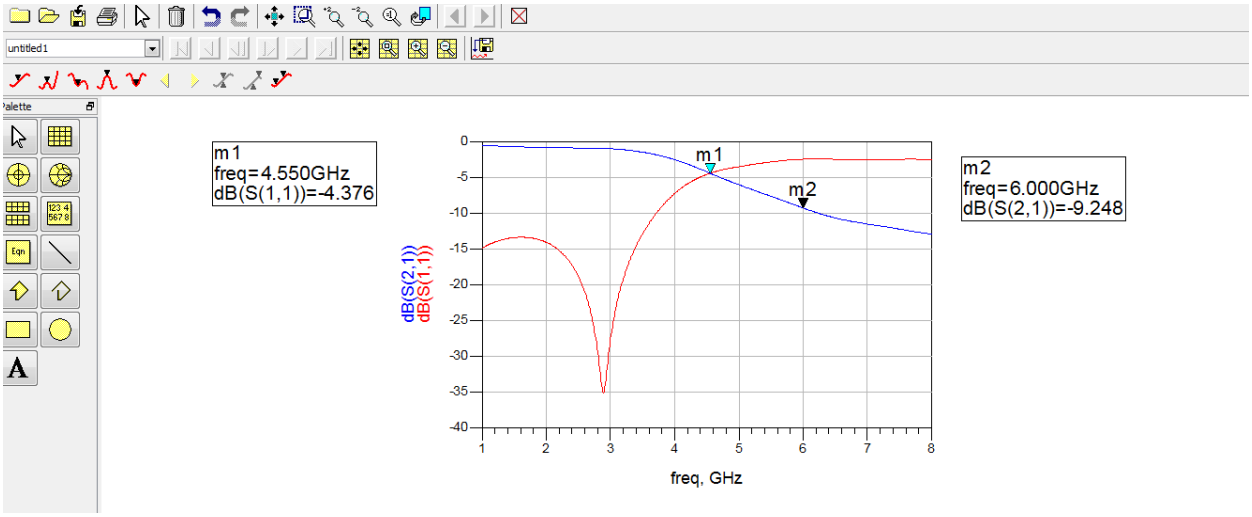


Figure 18: Simulation result for the layout design

Since the common definition of the cut-off frequency to -3dB does not hold for Chebyshev filters, therefore, the simulation result shows the correct output. It shows 9.248dB attenuation at 6 GHz, whereas the requirement is at least 15dB. In addition, figure 16 shows ripple and a steep, which are the characteristics of Chebyshev filter. The simulation results obtained from the schematic design and that obtained from the layout design have the same characteristics graphs. Therefore, we can state that from the simulation results, the design for the filter satisfies the given requirements and the layout design structure of the filter designed correctly.

4.0. Conclusion

The maximally flat filter is completely defined mathematically by two parameters which are the Cut-off frequency and number of poles, while the Chebyshev filter has a third parameter in addition to these two parameters known as Pass-band Ripple. The Maximally flat filter low pass exhibits a maximally flat response within the pass region whereas the Chebyshev filter response is a mathematical function for achieving a faster roll-off by allowing ripple in the frequency response. As the ripple in Chebyshev filter response increases the roll-off becomes sharper. The Chebyshev

response exhibits similar characteristics as the maximally flat filter when the ripple factor is set to 0%. In the transition region, Chebyshev filter response exhibits are somewhat steeper. The Maximally flat filter displays a better phase linearity than the Chebyshev filter. Meaning that, the derivative of phase with respect to frequency is more constant with maximally flat filter. Therefore, the waveform distortion in the maximally flat filter is lower. In dealing with high frequencies, the micro-strip filters are of a better choice. As the order of the filter increased, the insertion loss increased for both Butterworth and Chebyshev filters. However, in the Chebyshev response, when the ripple is set to 0%, the filter is close to a maximally flat filter.

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