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Microstrip Stepped-Impedance Low-Pass Filter Design of Chebyshev Filter Using Advanced Design Systems

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Abstract: Advanced design systems (ADS) technique was used to design a stepped impedance microstrip low pass filter design with Chebyshev responses.The cut-off frequency is 4 GHz with source and load impedances of $\mathbf{50\ \Omega}$. The insertion loss at passband is $\mathbf{0.5\ dB}$ and stopband is $\mathbf{20\ dB}$. In this filter design, an order $\boldsymbol{N = 5}$ was used for computation of the lumped elements of Chebyshev low pass filter prototype. Substrate properties such as relative dielectric constant $\in_r = \mathbf{4.2}$, loss tangent $\boldsymbol{tan\delta = 0.02}$, height of dielectric material $\boldsymbol{h = 2.0\ mm}$ and conductor thickness of $\mathbf{0.01}\ \boldsymbol{mm}$ were used in calculation of the length and width of the transmission line.Design of lumped circuit for microwave filter prototype scaled in frequency and impedances is discussed. Equivalent transmission line was obtained by converting lumped circuit into certain lengths and characteristic impedances. ADS simulation software was used to plot filter characteristics Chebyshev filter. The plots show variation of incident wave $\boldsymbol{S(1,1)}$ and forward gain $\boldsymbol{S(1,2)}$ with frequency in $\boldsymbol{GHz}$. It also fabricates microstrip structural layouts for Chebyshev filter.

Keywords: Stepped impedance, Low-pass filter, Chebyshev filter, Advanced design systems

1. Introduction

Microwave filters mainly comprised of two-port network utilized for frequency response control at defined points in a microwave system through transmission of signal at frequencies within the passband of the filter and attenuation within the stopband of the filter. The ever-growing demand and specification levels of microwave filters for application in advanced communication systems have necessitated research interest in both industry and academia [1]-[6].Mason, Sykes, Darlington, Fano, Lawson, and Richardsdevelopedfilter theory and practice in the early years before World War II. The image parameter method of filter design was developedin the late 1930sand became popular for low-frequency filters in telephony and radio. you submit your paper print it in two-column format, including figures and tables [1]. G. Mattaei, L. Young, E. Jones, S. Cohn, and other researchers at Stanford Research Institute contributed immensely towards the development of microwave filter and coupler in the early 1950s.Today, microwave filters are designed based on insertion loss method using cutting-edge and state-of-the art computer-aided design (CAD). Recent advances in network analysis with distributed elements, deployment of low-cost temperature semiconductors and other materials, and the connection of active devices in filter circuits makes microwave filter design an active area of research.

Filter theory and design have frequency characteristics with periodic structures, which comprised of a transmission line or waveguide periodically loaded with reactive elements. Periodic structures are of interest in filter design due to their use in slow-wave components and travelling-wave design, and also as they display basic passband-stopband responses that give rise to the image parameter method of filter design. Design of filter by image parameter method comprises a cascade of simpler two-port filter sections which gives the desired cut-off frequencies and attenuation characteristics but rejects the specification of a particular frequency response over the complete range. The relatively simple procedure in the design of filters by the image parameter method do not affect the many times iterations required to achieve the desired results [1]-[3].The insertion loss method is a more modern procedure that uses network synthesis techniques to design filters with a completely specified frequency response. Here, low-pass filter prototypes that are normalized relative to impedance and frequency. The prototype designs are converted to the desired frequency range and impedance level by applying transformations. Insertion loss and image parameter methods of filter design develop circuits using lumped elements such as capacitors and inductors. These designs are usually modified for microwave applications to employ distributed elements comprising transmission line sections. Richard transformation and the Kuroda identities helps to convert lumped networks to distributed networks [4].

Due to the incessant demand to meet ever-growing telecommunication challenges faced by microwave systems due to size, cost and performance of microwave devices, there is need to design microstrip low-pass filters that transmit signals at microwave frequency. In this project, a microstrip stepped impedance low-pass filter with insertion loss of 0.5 dB at cut-off frequency 4 GHz and attenuation of 20 dB at stopband frequency 6 GHz, with given substrate properties such as relative dielectric constant $\in_r = 4.2$, loss tangent $tan\delta = 0.02$, height of dielectric material $h = 2.0\ mm$ and conductor thickness of 0.01 mm was designed for order $N = 5$ Chebyshev low pass filter prototype.

N	g_1	g_2	g_3	g_4	g_5	g_6
5	1.7058	1.2296	2.5408	1.2296	1.7058	1

2. Design of Chebyshev Low-pass Filter

The stepped impedance microstrip low-pass Chebyshev filter was designed using advanced design system (ADS). The design was carried out with a cut-off frequency or passband frequency of 4 GHz and stop band frequency of 6 dB with input and output impedance of 50 Ω. The following filter design procedures were implemented.

1. Calculate lumped circuit elements C and L, obtain its equivalent circuit for Chebyshev filter with order $N = 5$.
2. Design of Chebyshev low pass filter prototypes.
3. Design of their corresponding distributed transmission line circuit by frequency and impedance scaling of the lumped elements and conversion into lengths and characteristic impedances.
4. Implementation of stepped impedance microstrip low pass filter by ADS to provide layout structures for Chebyshev filter.

To select the appropriate low-pass prototype network, it is necessary to calculate the appropriate order N for the Chebyshev filter:

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

where $p = \frac{\omega_s}{\omega_c} = \frac{6}{4} = 1.5$

$$N \geq \frac{0.5 + 20 + 6}{20\log\left(1.5 + \sqrt{1.5^2 - 1}\right)} \qquad (2)$$

$$N \geq 3.17 \qquad (3)$$

It is better to choose a higher order chebyshev filter as it gives better frequency response at high frequency and odd number filter is better than even number. Hence, an odd number order of 5 is used.

Table 1: shows element values for chebyshev low pass filter prototype ($g_o = 1, \omega_c = 1, N = 5$)

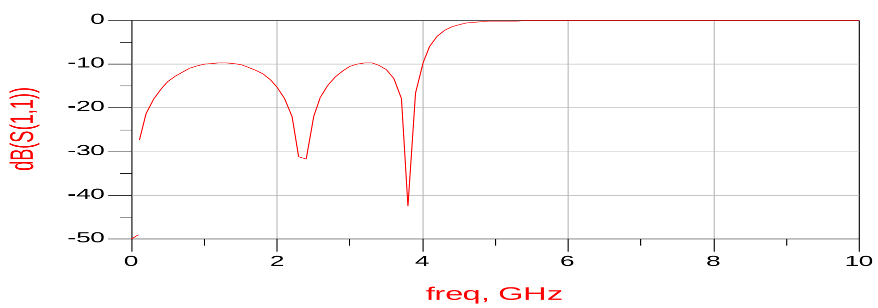

Figure 1: The characteristic of the chebyshev filter showing variation of incident wave with frequency

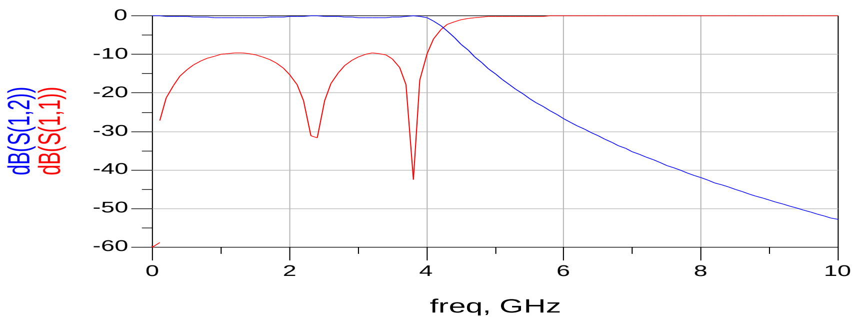

Figure 2: The characteristic of the chebyshev filter showing variation of both incident wave and the forward gain with frequency

The Chebyshev filter provides a slightly faster roll-off in the transition band than the maximally flat gain filter. The maximally flat filter has wide transition band. A higher order Chebyshev filter is required to meet the same filter specification as maximally flat filter.

2.1 Design of Chebyshev Filter Prototype (L and C Elements) Scaled for the given Frequency Band and 50Ω Input/Output Impedance.

The coefficients were converted into a microwave prototype network by impedance and frequency scaling utilizing the equations as follows:

$L' = \frac{R_o L}{\omega}, C' = \frac{C}{R_o}, \beta l = \frac{L'}{Z_{OL}}$, given that $R_O = 50\ \Omega, \omega_c = 2\pi f_c$, f_c= 4 GHz

Table 2: Shows lumped element values of the capacitor and inductor for Chebyshev low pass filter prototype ($g_o = 50\Omega,\ g_6 = 50\Omega$)

g_o	$g_1 = L_1$	$g_2 = C_1$	$g_3 = L_2$	$g_4 = C_2$	$g_5 = L_3$	g_6
50 Ω	3.394 nH	0.978 pF	5.055 nH	0.978 pF	3.394 nH	50 Ω

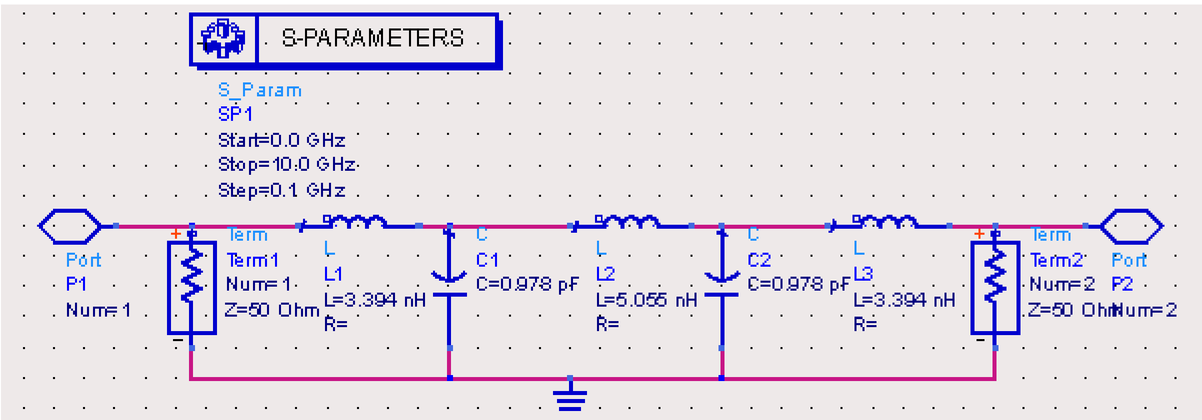

Figure 3: Lumped Circuit for Chebyshev Low-Pass Filter Prototype

2.2 Equivalent Transmission Line Filter obtained by Converting the Capacitors and Inductors of the Lumped Circuit into Transmission Lines of Certain Lengths and Characteristic Impedances

To obtain the equivalent transmission line filter we have to convert the capacitors and inductors of the lumped circuit into transmission lines of certain lengths and characteristic impedances. This is obtained by the equations below;

$L' = R_0 L,\ C' = \frac{C}{R_0},\ L = Z_{0L}\beta l, C = \frac{\beta l}{z_{oc}}$, where $R_0 = 50\Omega$

From these calculations the above transmission line parameters were obtained as shown in Table 3.

Table 3: Shows distributed element values of the capacitor and inductor for Chebyshev low pass filter prototype.

Low pass prototype		Impedance scaling	Electrical length (βl) in degree
L1	1.7058	85.29	40.72
C1	1.2296	0.0246	28.19
L2	2.5408	127.04	60.66
C2	1.2296	0.0246	28.19
L3	1.7058	85.29	40.72

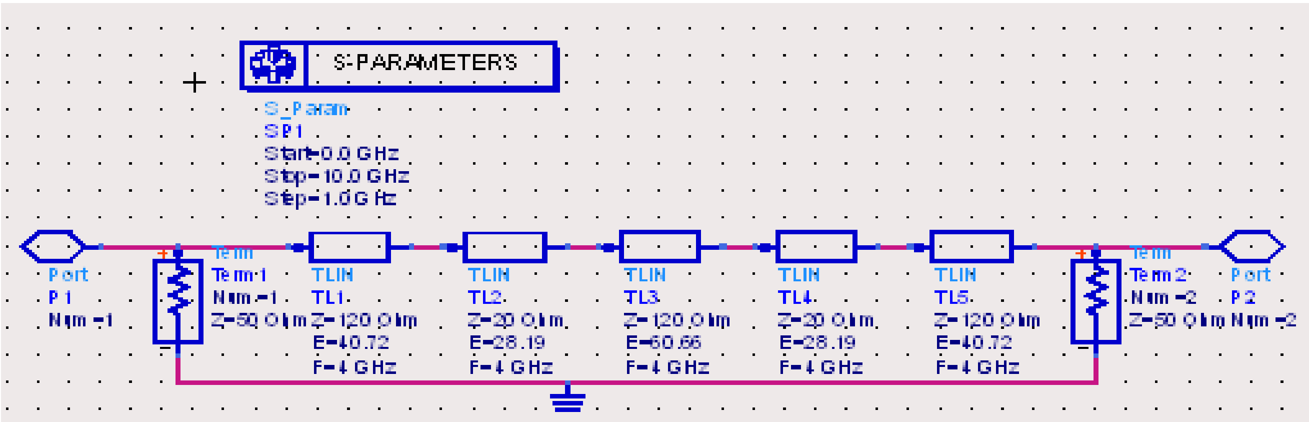

Figure 4:ADS representation of the distributed transmission line circuit

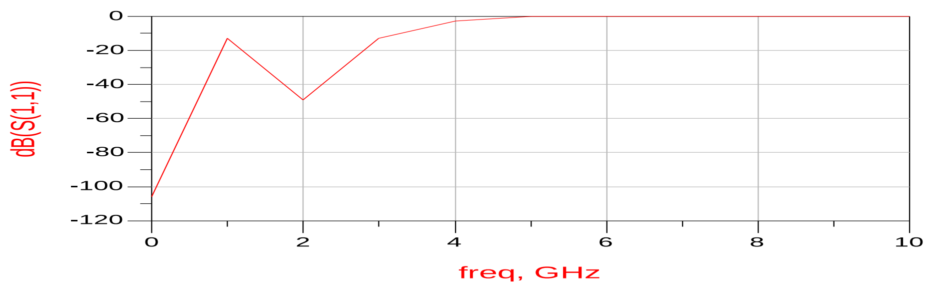

Figure 5: The characteristic of distributed transmission line showing variation of incident wave with frequency

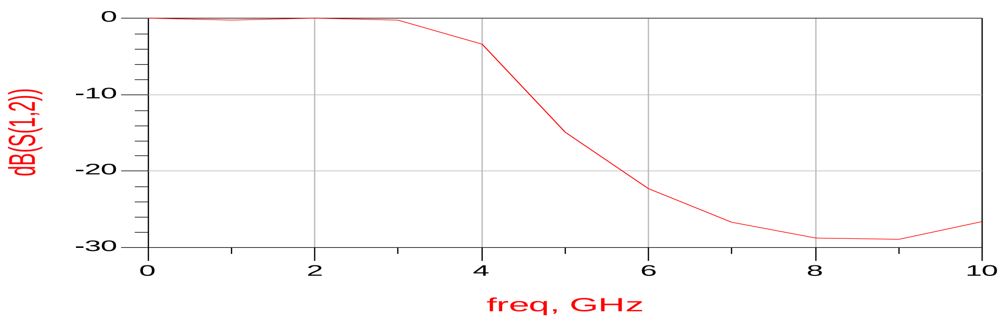

Figure 6: The characteristic of distributed transmission line showing variation of reversed gain with frequency

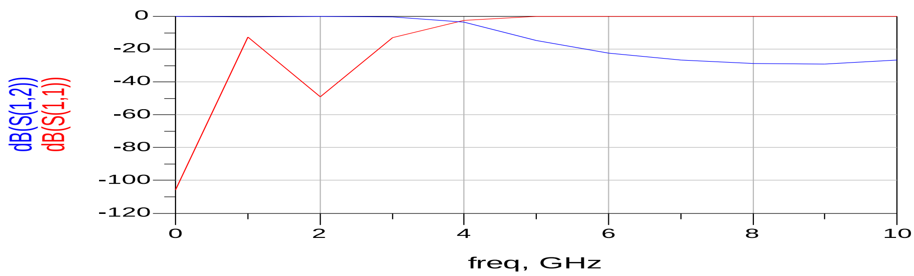

Figure 7: The characteristic of the distributed transmission line showing variation of both incident wave and the forward gain with frequency

The Chebyshev filter provides fast roll-off in the transition band (**Figure 5**). From **Figure7**, it is apparent that the S(1 2) attenuates at high frequency. The chebyshev experiences greater attenuation at high frequency. In order to resolve this problem a higher order should be used at high frequency.

3. Layout of The Microstrip Filter for Chebyshev Filter

Based on the assumption that all transmission lines are realized in microstrip technology and the substrate has dielectric constant $\varepsilon_r = 4.2$, rough = 0mm, mur =1, H =2.0 mm, Hu =1.0, cond =1.0e+5, tanδ = 0.02, T = 0.01mm and using the above equations;

$L^{'} = R_O L,\ C^{'} = \frac{C}{R_O}, L = Z_{OL}\beta l, C = \frac{\beta l}{z_{oc}}\ , where\ R_O = 50\Omega$

Table 4: Calculated width, length and electrical length of the individual microstrip line

Sections	Z	βl	W(mm)	*l(mm)*
1	120	40.72^o	0.5352	4.939
2	20	28.19^o	14.56	3.0183
3	120	60.66^o	0.535	7.424
4	20	28.19^o	14.56	3.018
5	120	40.72^o	0.536	4.939

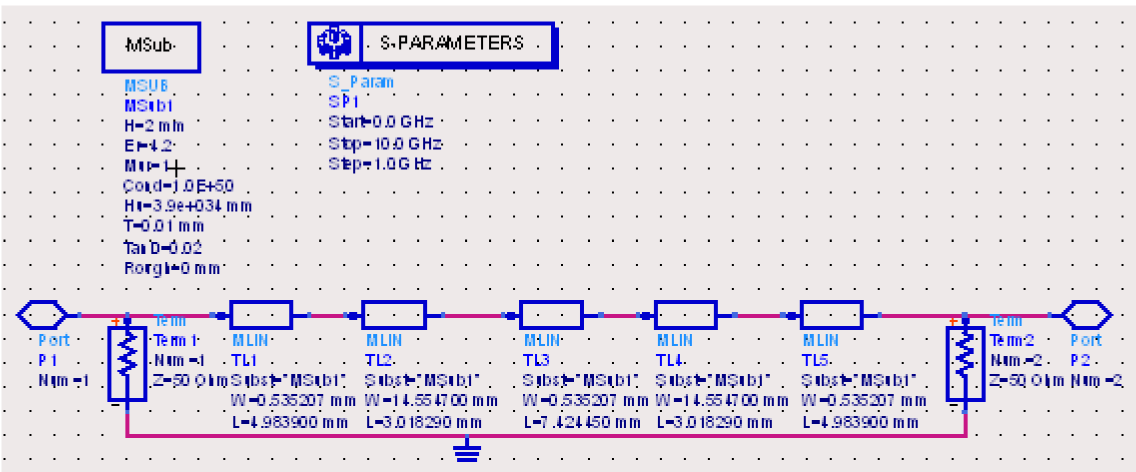

Figure 8: ADS representation of the Chebyshev microstrip filter.

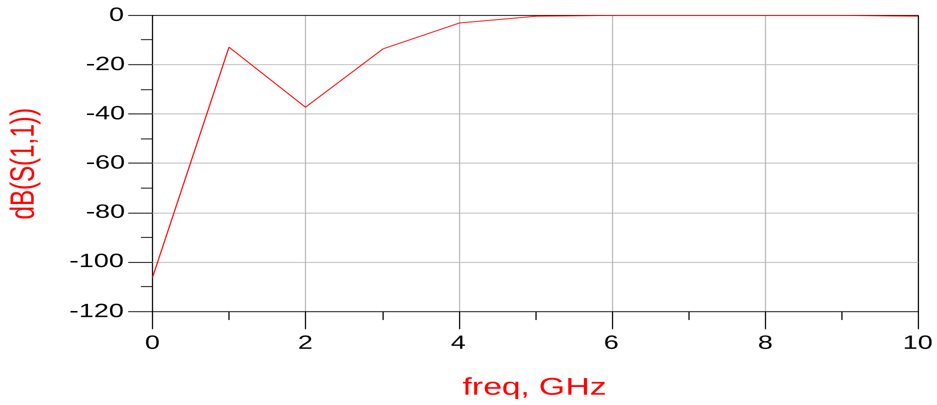

Figure 9: The characteristic of microstrip structure showing variation of incident wave with frequency

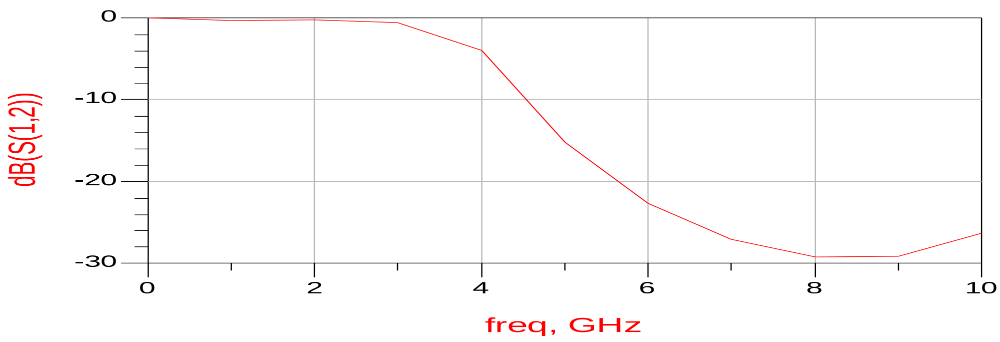

Figure 10: The characteristic of microstrip structure showing variation of reversed gain with frequency

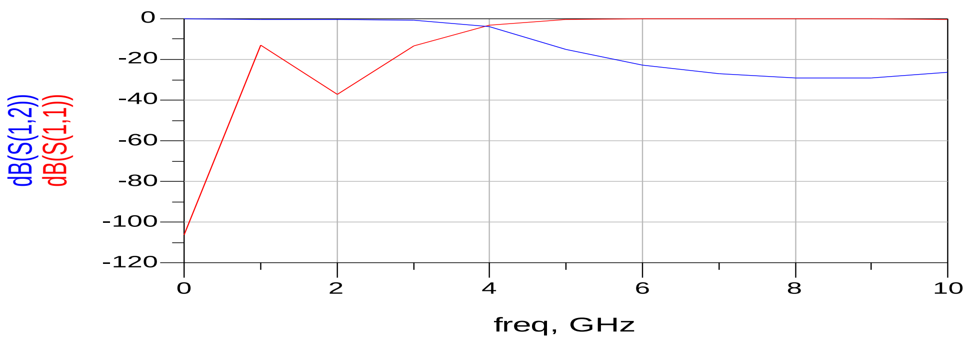

Figure 11: The characteristic of the distributed transmission line showing variation of both incident wave and the forward gain with frequency

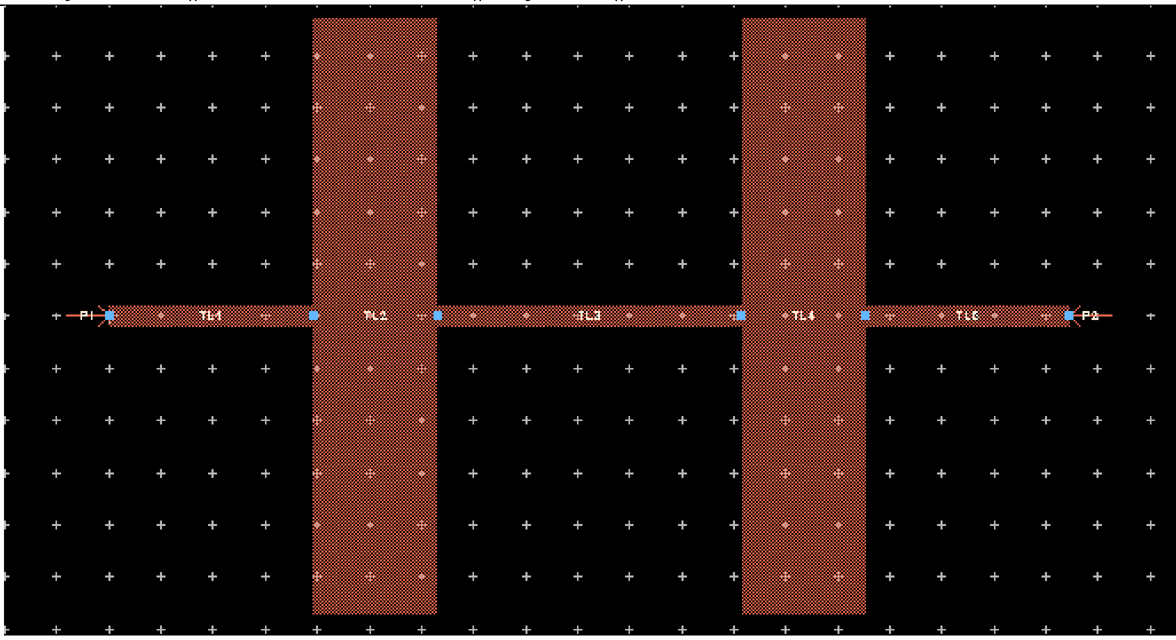

Figure 12: The microstrip filter structure for the Chebyshev Low-Pass Filter

4. Conclusion

Microwave filter provide frequency selectivity in satellite and mobile communications, radar, electronic warfare, meteorology, and remote sensing systems operating at microwave frequencies ($1\ GHz$) and above. These filters perform similar function as electric filters at lower frequencies.

The difference in microwave filter implementation is that its circuit dimensions are on the order of the electrical wavelength at microwave frequencies. At microwave frequencies, the lumped-element capacitors and inductors are replaced with distributed circuit elements such as transmission lines. This is a major challenge faced by microwave filter designers, but it also provides several useful coupling and transmission effects that are not achievable at lower frequencies.

The microwave filter design specification was achieved as the Chebyshev low-pass filter incident wave and forward gain intercept at 4 GHz. In Figure 5 and Figure 6 the cut-off frequency of 4 GHz was obtained. The characteristic of the distributed transmission line circuit was obtained by simulating the circuit using the ADS software and we were able to obtain similar frequency response as compared to the lumped maximally flat low-pass filter prototype. We obtained a cut-off of 4 GHz for both s_{11} and s_{12} against frequency. It is of great importance to note that, s_{12} and s_{21} $are\ symetrically\ equal$. It was observed that when s_{11} and s_{12} was plotted on the same axis against frequency there was an interception at 4 GHz which proves the fact that the design specification was achieved. Finally, microstrip impedance low-pass filter forChebyshev filter was designed using ADS simulation software based on the assumption that all transmission lines are realized in microstrip technology and the substrate has dielectric constant $\varepsilon_r = 4.2$, rough= 0 mm, mur=1, H = 2.0 mm, Hu =1.0, cond=1.0e+5, tanδ=0.02, T=0.01mm $Z_l = 20\ \Omega$, and$Z_h = 120\ \Omega$.The cut-off frequency is 4 GHz with source and load impedances of $50\ \Omega$. The insertion loss at passband is $0.5\ dB$ and stopband is $20\ dB$. In this filter design, an order $N = 5$ was used for computation of the lumped elements of Chebyshev low pass filter prototype. Figure 9 and Figure 10 show variation of incident wave $S(1,1)$ and forward gain $S(1,2)$ with frequency in GHz. ADS simulation software was used to fabricate microstrip structural layouts for Chebyshev filters.

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