Substrate Thickness Impact in Ka-Band-Pass Filter Design Methodology

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Abstract. A high performance band pass filter (BPF), with the assistance of the Richards-Kuroda Transformation method, on the basis of the known Chebyshev-Lowpass Filter, is presented. This suggested filter consists of six edge-coupled striplines. The filter operates at Ka-band from 37 GHz to 40 GHz. The proposed circuit is simulated using Laminate R-5785(N) with dielectric constant of 3.34, substrate height of 500um and 750 um and thickness of 17 um. According to the simulation results, the filter is suitable for being integrated within various microwave subsystems.

Keywords: Band Pass Filter, Chebyshev, Edge-coupled, Stripline.

INTRODUCTION

Stripline filters play an important role in many RF applications. As technologies advances, more stringent requirements of filters are required. One of the requirements is the compactness of filters [10]-[11]. For microwave frequencies (>3GHz), passive filter is usually realized using distributed circuit elements such as transmission line sections.

Many research articles have used waveguides for transmission line filter. However, waveguides systems are bulky and expensive. Low-power and cheaper alternatives are stripline and microstrip. These transmission lines are compact [12]. Edge-coupled stripline is used instead of microstrip line as stripline does not suffer from dispersion and its propagation mode is pure TEM mode. Hence it is the preferred structured for coupled-line filters.

Therefore, a fifth order Chebyshev edge-coupled stripline filter is designed and presented in the article. The band pass filter is simulated by using Advanced Design System software.

FILTER TYPES

Several mathematical models and circuits have been developed for the mathematical analysis of the filters, in order to achieve the best possible simulation of an ideal filter behavior. These mathematical models are categorized into the following basic types: Butterworth filters, Chebyshev filters and Bessel filters [1] [3].

The Butterworth filter is a medium-Q filter that is used in designs that require the amplitude response of the filter to be as flat as possible. The Butterworth response is the flattest passband response available and contains no ripple. Since the Butterworth response is only a medium-Q filter, its initial attenuation steepness is not as good as some filters but it is better than others. This characteristic often causes the Butterworth response to be called a middle-of-the-road design.

The Chebyshev filter is a high-Q filter that is used when: (1) a steeper initial descent into the stopband is required, and (2) the passband response is no longer required to be flat. With this type of requirement, ripple can be allowed in the passband. As more ripple is introduced, the initial slope at the beginning of the stopband is increased and produces a more rectangular attenuation curve when compared to the rounded Butterworth response.

The initial stopband attenuation of the Bessel filter is very poor and can be approximated by:

$$A_{dB} = 3\left(\frac{\omega}{\omega_c}\right)^2 \tag{1}$$

This expression, however, is not very accurate above an ω/ωc that is equal to about 2. For values of ω/ωc greater than 2, a straight-line approximation of 6 dB per octave per element can be made. However, the Bessel filter was originally optimized to obtain a maximally flat group delay or linear phase characteristic in the filter's passband. Thus, selectivity or stopband attenuation is not a primary concern when dealing with the Bessel filter.

METHODOLOGY

The requirements for the design of the band pass filter are presented in Table 1. The specification of dielectric material is obtained from Laminate R-5785(N) (Table 2).

Since Chebyshev filter haw steeper initial descent into the stopband than other filter types, this type of filter is chosen in this research work. The filter has been designed by following the five steps: (I) Determining the order and the type of approximation functions to be used (ii) Finding the corresponding low-pass prototype (iii) transforming the low-pass network into bandpass filter (iv) Scaling the bandpass filter in both impedance and frequency and (v) Transforming the lumped elements into distributed realization.

TABLE 1. Requirements of band pass filter

Frequency	Loss
31.3 GHz – 31.8 GHz	>54 dB
31.8 GHz – 35.5 GHz	>30 dB
37 GHz – 40 GHz	<3 dB (passband)
>41.5 GHz	>30 dB

TABLE 2. Specifications of substrate and dielectric material

Dielectric material used	Laminate R-5785(N)
Dielectric constant	3.34
Loss tanget, tanδ	0.003
Substate height	500um / 750um
Copper thickness	17um

TABLE 3. Prototype G values

Order	G[0]	G[1]	G[2]	G[3]	G[4]	G[5]
5th	0.8472	1.3449	1.67	1.34	0.85	1

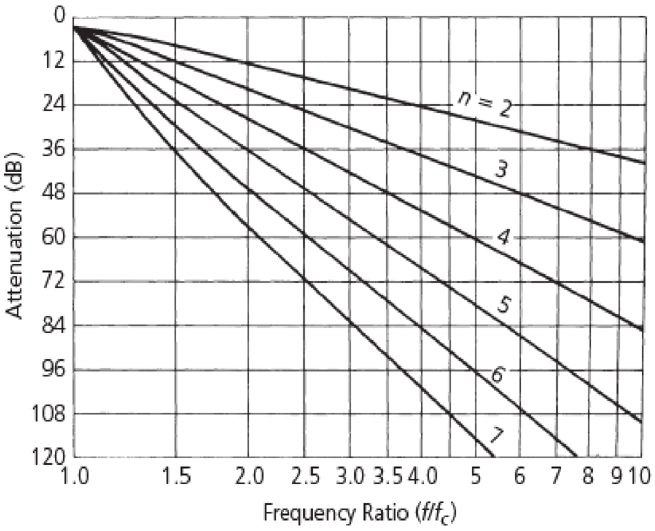

FIGURE 1. Attenuation characteristics for a Chebyshev filter with 0.01-dB ripple

The order of the band pass Chebyshev filter can be determined by using the attenuation characteristics for 0.01dB ripple shown in Fig. 1. In order to find the order of the band pass filter, we have to compute the following expression:

$$\frac{BW}{BW_c} = \frac{f}{f_c} \tag{2}$$

Where, BW is the bandwidth at the required value of attenuation and the BWc is the 3-dB bandwidth of bandpass filter. For the filter of this research work, it is revealed that a 5-element filter will provide more than 54dB of attenuation, which is more than adequate.

The element values for the fifth-order are taken from the Table 3 of normalized values of 0.01dB equal ripple lowpass prototype. The lowpass prototype is presented in Fig.2.

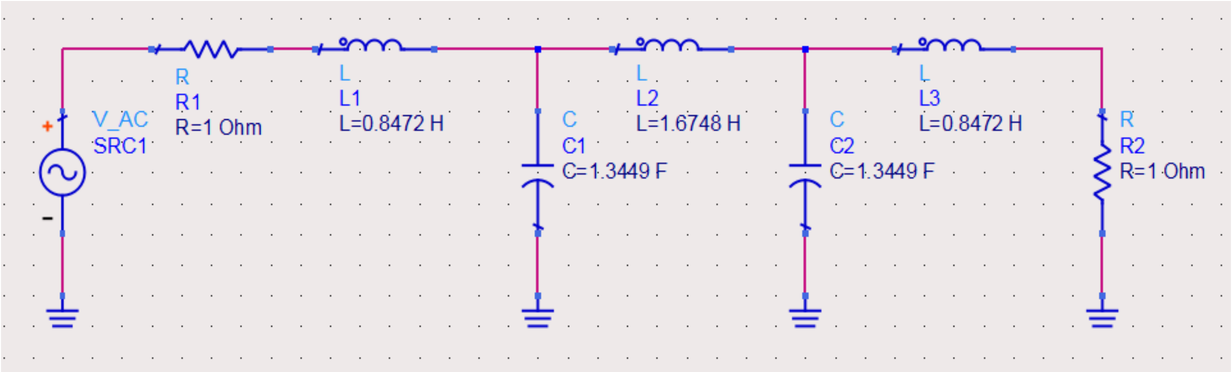

FIGURE 2. Low pass prototype filter 5th order

The actual conversion from the low pass prototype to the bandpass filter is achieved by adding to each branch of the low pass filter an element of the opposite type at the same value. The conversion of the low pass prototype filter into a band pass Chebyshev type filter is shown in Fig. 3.

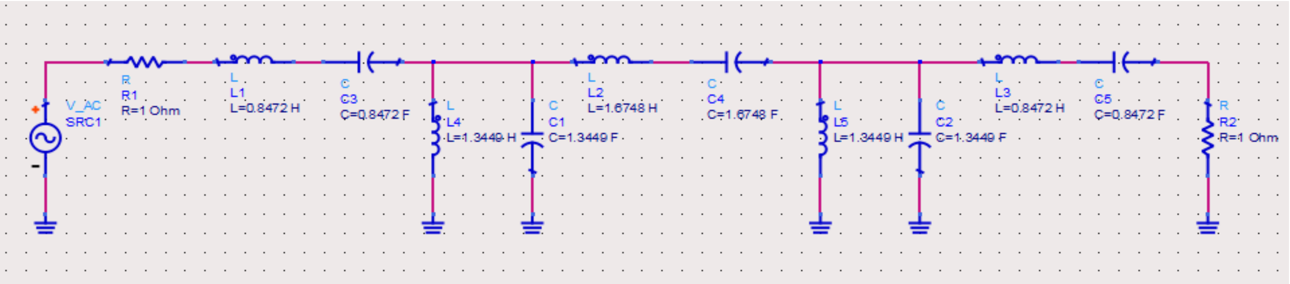

FIGURE 3. Band pass Chebyshev type filter 5th order after conversion

Subsequently, we are scaling the bandpass filter in both impedance and frequency, by using the following mathematical formulas. For parallel-resonant branches,

$$C = \frac{C_n}{2\pi RB} \tag{3}$$

$$L = \frac{RB}{2\pi L_n f_0^2} \tag{4}$$

and for series-resonant branches,

$$C = \frac{B}{2\pi f_0^2 C_n R} \tag{5}$$

$$L = \frac{RL_n}{2\pi B} \tag{6}$$

where,

C=the final capacitor value,
L=the final inductor value,
B=the 3-dB bandwidth,
R=the final load resistance,
fo=the geometric center frequency,
Cn=the normalized capacitor band-reject element value,
Ln=the normalized inductor band-reject element value.

The results are presented in Fig.4.

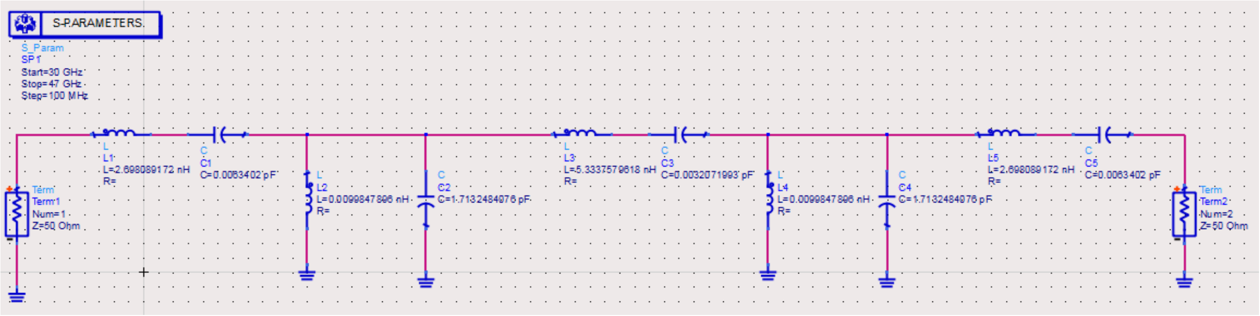

FIGURE 4. Band pass prototype Chebyshev type filter 5th order after scaling the bandpass filter in both impedance and frequency

Richard's tranformation and Kuroda's identities are used to accomplish from the lumped to distributed circuit designs. The explanation of Richard's transformation and Kurada's identities are in [2]. Each section of coupled stripline contains three parameters: S (seperation of two striplines), W (width of stripline) and h (height of substrate). These three parameters are determined from the odd and even mode impendance (Zoo and Zoe) of each coupled-line. Zoo and Zoe are in turn depends on the gain of the corresponding admittance inverter J.

$$J_1 = \frac{1}{Z_0}\sqrt{\frac{\pi\Delta}{2g_1}} \tag{7}$$

$$J_n = \frac{1}{2Z_0}\frac{\pi\Delta}{\sqrt{g_{n-1}g_n}} \tag{8}$$

$$J_{n+1} = \frac{1}{Z_0}\sqrt{\frac{\pi\Delta}{(2g_N g_{N+1})}} \tag{9}$$

$$\Delta = \frac{f_2 - f_1}{f_0} \tag{10}$$

$$Z_{oe} = Z_o(1 + JZ_0 + (JZ_0)^2) \tag{11}$$

$$Z_{oo} = Z_o(1 - JZ_0 + (JZ_0)^2) \tag{12}$$

The values of the parameters W, S and L (Length of stripline) are presented in the Table 4 for two different substrate heights 500um and 750 um.

TABLE 4. Dimensions for striplines for substrate height 500um and 750um

Dimensions	Substrate height 500um	Substrate height 750um
W[1]	186 um	291 um
W[2]	254 um	396 um
W[3]	259 um	403 um
S[1]	48 um	68 um
S[2]	183 um	267 um
S[3]	233 um	343 um
L	1069 um	1069 um

SIMULATION RESULTS

The band pass filter is simulated with ADS software tool in order to predict the performance of the filter. According to the simulation results, the insertion loss is less than 3 dB in passband. Also the response is almost flat over the entire passband. In addition, the simulated response has the attenuation of more than 30 dB at central frequency. The simulation results for both substrate thicknesses (500um and 750u) are presented in Fig.5 and Fig.6. We observe that for higher substrate thickness the results meet the requirements. Finally, the layout of bandpass filter is at Fig.6.

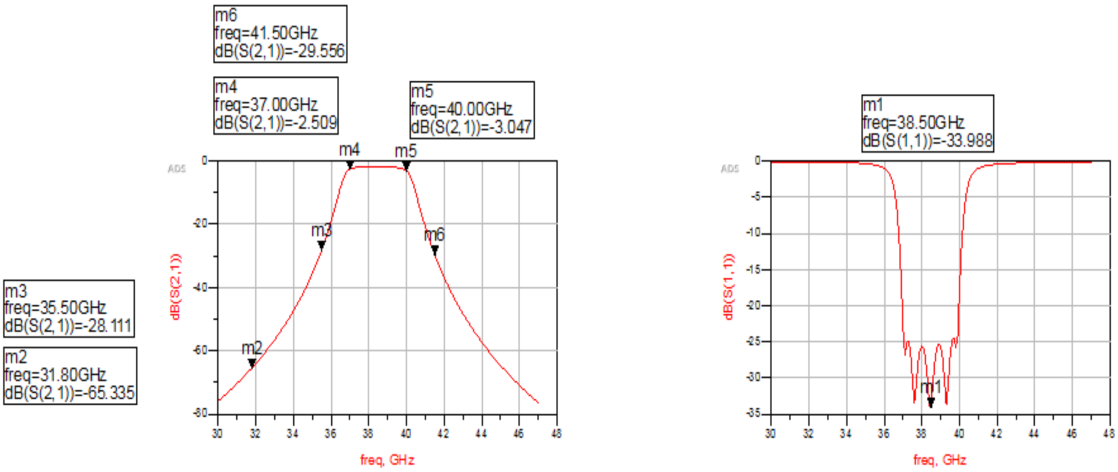

FIGURE 5. Simulation results from ADS for substrate height 500um

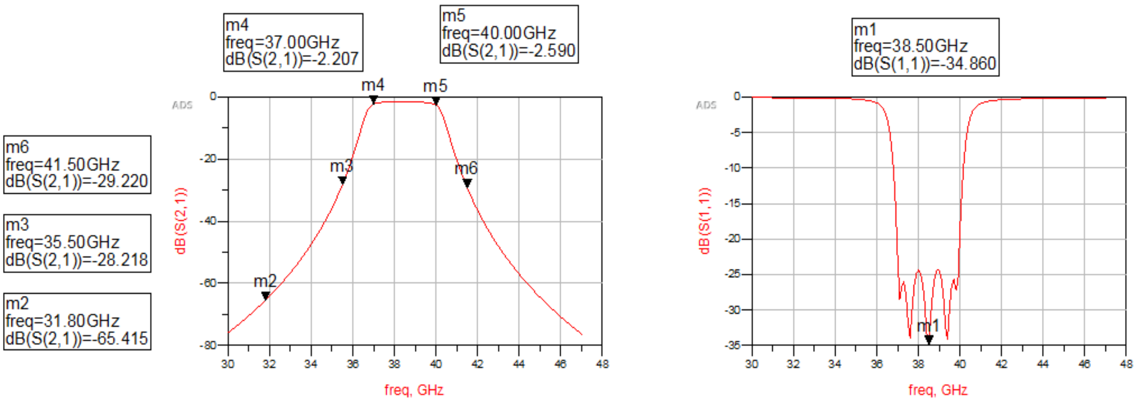

FIGURE 5. Simulation results from ADS for substrate height 750um

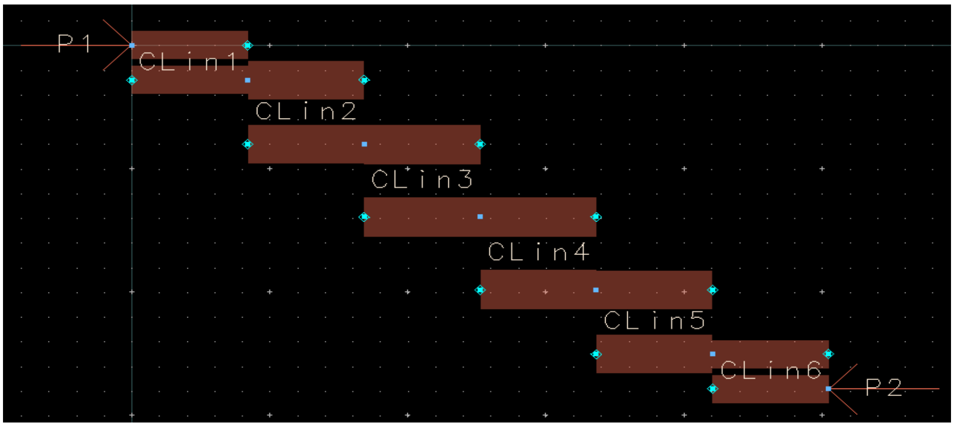

FIGURE 6. Layout

CONCLUSION

This paper describes a procedure for designing a band pass filter with central frequency at 38.5GHz, with 3dB maximum ripple in passband. It was presented step-by-step the construction of the band pass Chebyshev type filter. The requirements for the design of the filter were met in both passband and stopband. Finally, in this article it is proved that the higher the substrate thickness, the better the response of the filter.

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