UNIVERSITI TEKNOLOGI MARA

PROSIDING



Seminar INSIGHTS 2002
Universiti Teknologi MARA

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DESIGN AND SYNTHESIS OF MICROWAVE FILTERS

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ABSTRACT

Design and synthesis of microwave filters presented in this paper consist of three classes of filters. They are the short circuit stubs bandpass filter based on the conventional Chebyshev rational function, the lowpass filter and combline bandpass filter are based on the Generalized Chebyshev rational function.

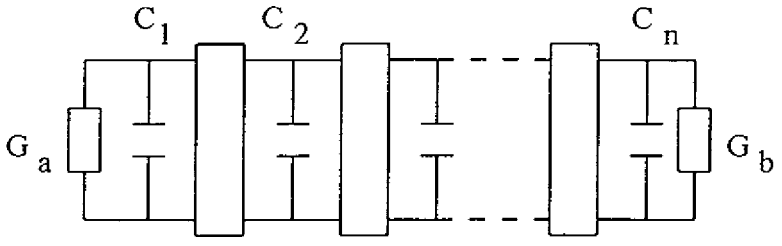
The design technique for the short circuit stub filter is based on an approximate design method, using close form equations, whereas for the lowpass filters and the combline bandpass filters, they are based on an exact synthesis technique, which involves the solving for roots, forming Hurwitz polynomial and element extraction. All the design and synthesis procedure were implemented using Mathcad version 8.

INTRODUCTION

Filters are devices which selectively transmit signals according to their frequency. Filters are widely used in communication, radar systems, satellite systems, field test unit and in laboratory measuring instrument. They can be used to separate or combine different frequencies, as in multipliers and multiplex communications.

Short Circuit Stub Filters

An approximate design procedure for short circuit stub bandpass filters due to Matthaei [1] uses a low pass lumped-element prototype filter, inverters, and image-parameter techniques. The prototype low-pass lumped filter consist of a shunt capacitor with impedance inverters on either side of them as illustrated in figure 1. The design equations were programmed and written in Mathcad. By inserting the required specification for the filter, the program will calculate the necessary element values to build the filter.



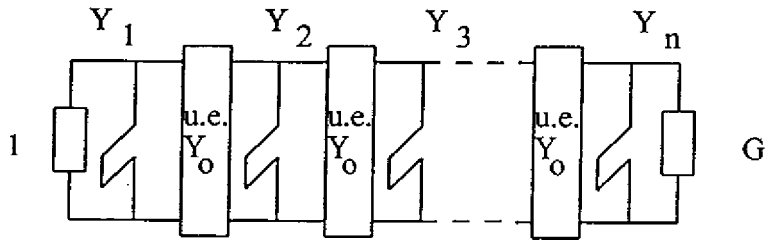


Figure 1: Basic lumped element and distributed band-pass filter

The Amplitude Response. [2]

The Chebyshev approximation exhibits an equiripple pass band and maximally flat response in the stop band. The amplitude squared transfer function is given by

$$|S_{21}(j\omega')|^2 = \frac{1}{1+\varepsilon^2 T_n^2(\omega')} \qquad (1)$$

The transfer function of the Chebyshev low-pass filter can be specified in terms of insertion loss, α

$$\alpha\,(\mathrm{dB}) = 10\log_{10}[1+\varepsilon^2 T_n^2(\omega')] \qquad (2)$$

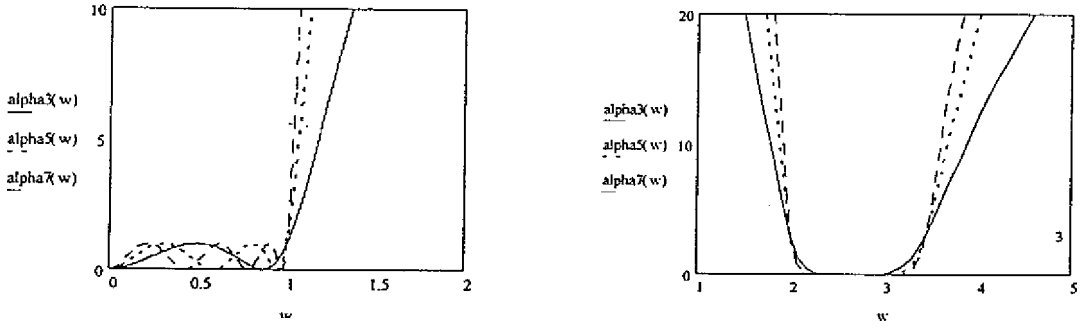


Figure 2: Normalised Chebyshev lowpass transfer function and its transformation into a bandpass response

Designing the Microwave Short Circuit Stub filters. [3], [4]

The filters were designed having an equal percentage bandwidth, to fill the frequency band between 2 GHz to 18 GHz, using 4 filters to function as a multiplexer. Two prototype filters were initially designed and tested [5], [6], they were built on RT Duroid 6010.2, with its substrates relative permittivity of $\varepsilon_r = 10.2$ and thickness 0.635 mm.

The filter layout drawn from the element values are shown below.



(a) (b)

Figure 3: (a) Example layout of a short circuit stub bandpass filter with a stepped ground rail and (b) 10 - 18 GHz fabricated filter.

Generalized Chebyshev Lowpass Filter. [7], [8]

A Generalized Chebyshev filters have an equiripple passband response with **m** transmission zeros at infinity and an even multiple of transmission zeros at finite frequency close to the bandedge. Generalized Chebyshev insertion loss response is shown in figure 4. A Generalized Chebyshev low-pass prototype filter having 1 transmission zeros at infinity and (N-1) at finite frequency is shown in figure 5 and a prototype filter with having 3 transmission zeros at infinity and (N-3) at finite frequency is shown in figure 6.

The transmission zeros are order (**N-m**) at □ = □$_o$ and **m** at infinity.
N is an odd number degree network. RL is the minimum return loss level (dB) in the passband.

$$IL = 1 + \varepsilon^2 \cosh^2\left[(N-m)\cosh^{-1}\left[\omega\left(\frac{\omega_o^{\,2}-1}{\omega_o^{\,2}-\omega^2}\right)^{1/2}\right] + 3\cosh^{-1}\omega\right] \qquad (3)$$

$$\varepsilon = \left[10^{RL/10} - 1\right]^{-1/2} \qquad (4)$$

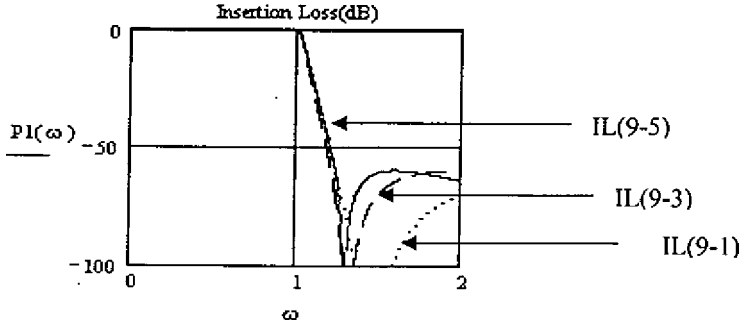


Figure 4: The response with m = 1 transmission zeros at infinity (IL(9-1)) and m = 3 transmission zero at infinity (IL(9-3)) for a circuit with 9 elements.

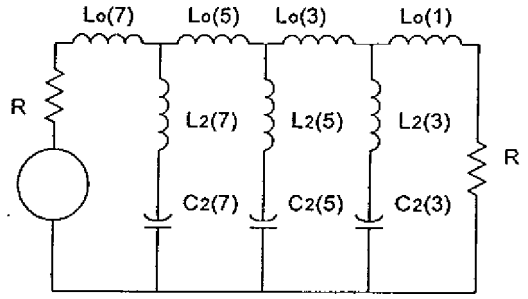


Figure 5 : Circuit for N = 7 and **m**=1 transmission zero at infinity.

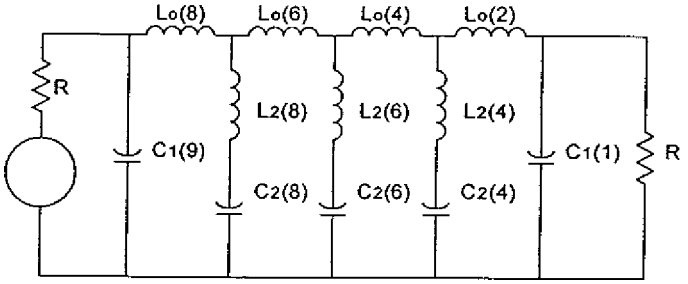


Figure 6: Circuit for N = 9 and **m** = 3 transmission zero at infinity.

Designing The Microwave Generalized Chebyshev Lowpass Filter. [9], [10]

The filter was design with a cutoff frequency of 4 GHz, stopband attenuation of 60 dB and a return loss of 20 dB. It was synthesized using alternating pole synthesis technique, due to its simplicity and high accuracy. It was then fabricated on RT Duroid ε_r = 2.35 and thickness 0.8 mm.



(a)



Figure 7 :(a)Generalized Chebyshev lowpass filter layout and (b) the fabricated filter.

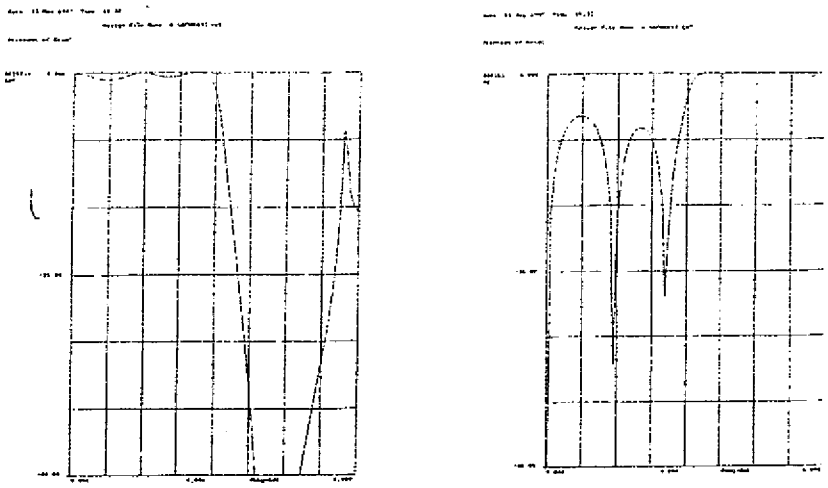


Figure 8 : The Generalized Chebyshev lowpass filter simulated response, using Libra.

Microwave Combline Bandpass Filters

The combline filters was first introduced by Matthaei [1], who gave an approximate design method based on lowpass prototype but suitable for narrow bandwidth. Broadband design method was introduced by Pregla [11] and later Wenzel [12] presented an exact synthesis method for combline filters.

Exact Synthesis Method for Lumped Bandpass Prototype. [13]

Microwave combline filter satisfying a generalized Chebyshev response is given by

$$|s_{12}(j\omega)|^2 = \frac{1}{1+\varepsilon^2 F_N{}^2(\omega)} \qquad (5)$$

where $F_N(\Gamma)$ is a generalized Chebyshev function defined by the prescribed transmission zero and may be written as

$$F_N(\omega) = \cosh\left\{(N-1)\cosh^{-1}\left[\frac{\omega^2-a^2}{1-a^2}\right]^{\frac{1}{2}} + \cosh^{-1}\left[\frac{1}{\omega}\left(\frac{\omega^2-a^2}{1-a^2}\right)^{\frac{1}{2}}\right]\right\} \qquad (6)$$

where

N is an even number equal to the total number of transmission zeros. The transmission zeros are of order (N-1) at $\Gamma = \infty$ and one at $\Gamma = 0$. And α is a bandwidth factor, its value is always less than unity when the upper bandedge frequency Γ_2 is normalized to one as shown in figure 9.

The synthesis cycle of the network shown in figure 10, is given elsewhere [13].

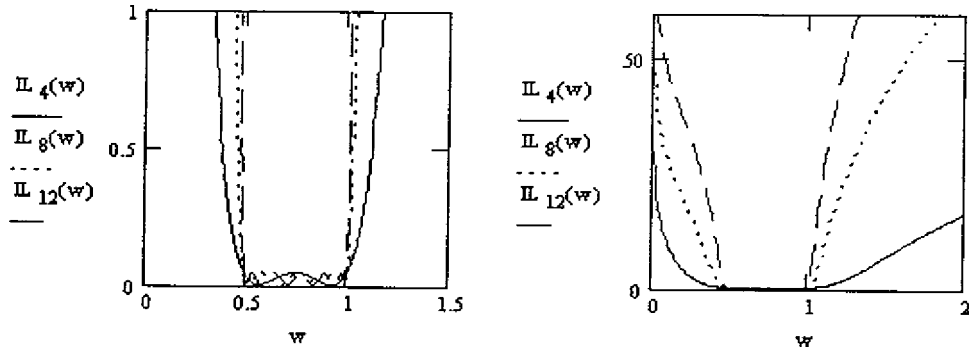


Figure 9 : The response curve from equation (6), with the number of filter elements

N = 4, 8, and 12. The selectivity of the filter improves as the number of element increases.

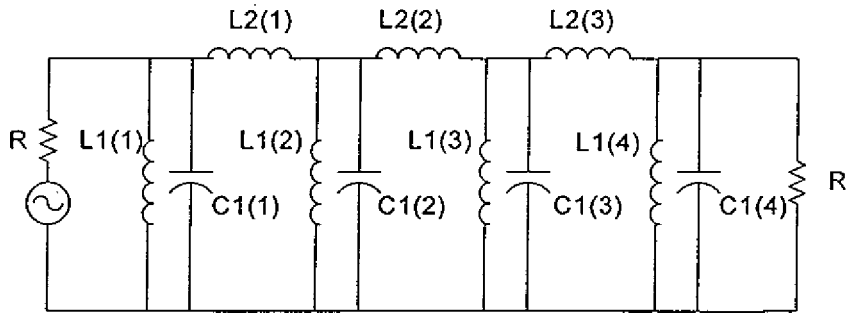


Figure 10 : Prototype network of order 8 combline filter. In this design example the capacitances C1 are made equal, for ease of fabrication in the stripline form.

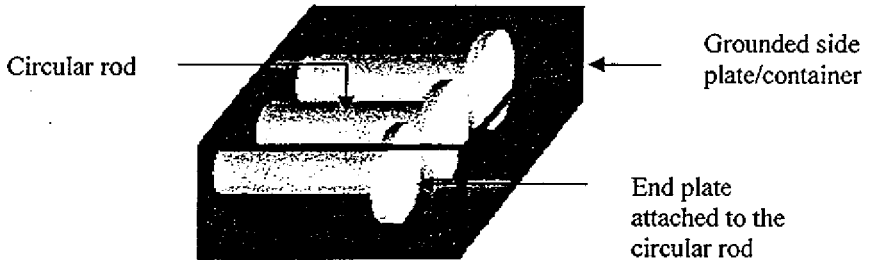


Figure 11: An example of a microwave combline filter fabricated in stripline form using circular rod. It consist of a rod with a plate attached at the end, between this end plate and the grounded side plate forms the capacitive elements in the design. The length of the rod is one-eighth of a wavelength at the designed frequency.

CONCLUSION

In this paper, design examples [4], [7], [13] are given for the three classes of filters, the Conventional Chebyshev bandpass filters, the Generalized Chebyshev Lowpass filters and the Combline bandpass filters. The technique presented can be adapted to design and fabricate many other filters in similar class. It is hoped that the transparency in the design technique presented would make the understanding of this technology available to non specialist and undergraduates.

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