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Suspended Stripline Low-pass Filter Design for Wide Stopband Attenuation Applications**

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ABSTRACT

This paper involves the design of asymmetrical generalized Chebyshev low-pass filter realized with a suspended substrate strip line. The study presents the synthesis and design of an asymmetrical prototype with degree of 11, cut-off frequency of 2.5 GHz, better than 26 dB as passband return loss and a broad stopband rejection of 55 dB. The filter produces 11 transmission zeros (attenuation poles), one at infinity and 5 pairs located at finite frequencies offering better wide stopband attenuation performance as well as sharp selectivity. The filter is built based on suspended stripline structure (SSS) using aluminium as a cavity and with 2mm as a ground spacing. The filter measurements show a reasonable agreement has been achieved with the simulated response.

1 Introduction

The electromagnetic spectrum is getting congested simultaneously with the wide spread usage of communication applications. That significant evolution in wideband wireless communications has led to the need of high performance filters to discriminate between desired and undesired frequencies. Analogue radio frequency (RF) filters are implemented in every part of electronic equipment [1, 2]. Applications extend from various devices such as television through satellite, radio to radar systems for both civil and military purposes. In terms of telecommunications, cellular wireless radio systems are mostly being deployed these days. Microwave and RF filters are considered as key components in cellular systems, base stations and handsets, as they pass wanted frequency bands and reject unwanted signals [3]. Thus, the importance of implementing filters with high selectivity, low passband loss and high stopband attenuation in wireless telecommunication systems is essential.

Ideal LPFs show a transfer function with a mostly constant group delay and immediate transition at cut-off frequency (fc). Practically, in the procedure of microwave filter design, different transfer functions can be used to approximate the response of the lowpass prototype filter. The mostly used transfer functions are Butterworth, Chebyshev, inverse Chebyshev and elliptic [1, 2]. Generalized Chebyshev is a special case of elliptic response which has equiripple passband amplitude characteristics with transmission zeros (TZs) (or attenuation poles) that are placed arbitrarily in

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the stopband [3]. Those TZs are placed at finite frequencies close to the bandedge. Thus, its selectivity is close to that of elliptic function for the same degree but with easier physical implementation [4]. That is because there can be up to 10:1 variation in the impedance value of elements when converting to physical structure in the case of the elliptic filters, and that is problematic. Such possibility of variation can be reduced to 2:1 when choosing a generalized Chebyshev approximation [4]. Also, in prototypes with symmetrical networks, some of transmission zeros are being forced to be placed at the same frequency since the resonator branch is symmetric across a line of symmetry. While in asymmetrical networks, the TZs are spread at different locations so that for a network of order N, there is one TZ at infinite frequency and N-1 at finite different frequencies. This type of networks is synthesized in this paper since it would contribute to a higher filter performance.

In Section 2, the filter design procedure is described step by step by starting with generalized Chebyshev prototype synthesis and distributed-element transformation then realization with suspended stripline, and the simulated and measured responses of the design are presented.

2 Generalized Chebyshev Approximation

The generalized Chebyshev magnitude squared characteristic with multiple asymmetrically located transmission zeros can be formed as [5],

$$A^2_{n,m,k}(\omega) = \frac{1}{1+\epsilon^2 F^2_{n,m,k}(\omega)} \tag{1}$$

where

$$F_{n,m,k}(\omega) = \cosh\left[\sum_{i=1}^{k} l_i \cosh^{-1} y_i(\omega) + m\cosh^{-1}(\omega)\right], \tag{2}$$

$$y_i(\omega) = \frac{1-\omega\omega_{0i}}{\omega-\omega_{0i}}, \tag{3}$$

$$m = n - \sum_{i=1}^{k} l_i, \tag{4}$$

where n is the filter degree, m is the number of zeros at infinity, k is the number of zeros, l_i is the order the unknown transmission zero, and

$$\varepsilon = \sqrt{10^{\frac{-\alpha_{max}}{10}} - 1} \tag{5}$$

in which α_{max} is the maximum attenuation in the passband. The transfer function can be formed as

$$|S_{21}(j\omega)|^2 = A^2_{n,m,k}(\omega) \tag{6}$$

where $A^2_{n,m,k}(\omega)$ is defined in Equation 1. Also, the reflection function is

$$|S_{11}(j\omega)|^2 = 1 - |S_{21}(j\omega)|^2 = \frac{\omega^2 F^2_{n,m,k}}{1+\omega^2 F^2_{n,m,k}(\omega)} \tag{7}$$

S_{11} can be calculated from the left-plane roots of the denominator of Equation 7.

In this paper, the Filpal software is the tool that is used to synthesize the asymmetrical generalized Chebyshev prototype to get the lumped-elements values and simulate the frequency response. An eleventh-order generalized Chebyshev LPF is synthesized with asymmetrical lumped-element network, shown in Figure 1, and the values are in Table 1 to meet the specifications as follows: cut-off frequency is 2.5 GHz, passband return loss is 38 dB, stopband insertion loss is 60 dB, stopband edge frequency is 3.38 GHz, selectivity $(S) = \frac{3.38}{2.5} = 1.35$. The filter has 11 transmission zeros. One of them is at infinite frequency and caused by the series inductors. The other five pairs of transmission zeros are produced by the five shunt resonators and placed at finite frequencies. These resonant frequencies can be determined by using the equation

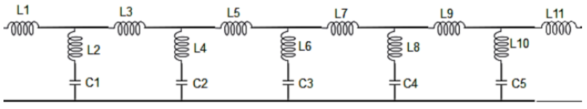


Figure 1. Eleventh-order asymmetrical generalized Chebyshev LPF

Table 1. The lumped-element values

Item	Value (pF)	Item	Value (nH)	Item	Value (nH)
C1	0.71	L1	0.112	L7	5.5
C2	2.08	L2	2.9	L8	0.181
C3	2.14	L3	4.5	L9	4.9
C4	2.08	L4	0.271	L10	0.25
C5	1.51	L5	5.4	L11	1.7
-	-	L6	0.228	-	-

$$f_i = \left(2\pi \times \sqrt{L_{2i}C_i}\right), \quad (i = 1,2,3,4,5) \tag{8}$$

yielding

$$f_1 - 3.4GHz, \quad f_2 = 6.7GHz, \quad f_3 = 7.2GHz,$$

$$f_4 = f_5 = 8.2GHz.$$

This filter design is modelled in order to offer a broadband stopband rejection of 60 dB up to 10 GHz and reasonable selectivity as shown in Figure 2. The wide stopband attenuation is achieved because of producing 11 transmission zeros, 5 pairs of them are at finite frequencies.

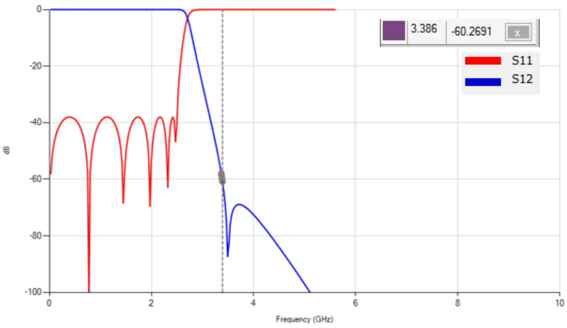


Figure 2. Simulated response of 11th order generalized Chebyshev LPF

Physical Realization

In order to design practical filters that work at microwave frequencies, the lumped-element networks are transformed into distributed-element circuits which are made up of short and open circuited stubs of transmission lines. The preceding asymmetrical prototype network is transformed into distributed-element circuit by using the Richard's transformation [6]. This method enables to transform inductors and capacitors into short and open circuited stubs as following:

$$p \rightarrow \alpha \tanh(ap) \tag{9}$$

Thus, the admittance of shunt resonators and impedance of the of the network in Figure 1 are expressed as

$$Z(p) = L_p + \frac{1}{C_p} \rightarrow Y(p) = \frac{\alpha C}{2} \tanh(2ap), \tag{10}$$

$$Z(p) = L_p \rightarrow \alpha L \tanh(ap), \tag{11}$$

where α in asymmetrical networks is the ratio of the transmission zero frequency location to the passband edge frequency (ω_c), and

$$a = \left(\frac{1}{\omega_c}\right) \times \tan^{-1}\left(\frac{1}{\alpha}\right). \tag{12}$$

From Equation 10 and Equation 11, the shunt resonators can be replaced by open circuited stubs with characteristic admittance of $\frac{\alpha C}{2}$ and the series inductors are replaced by short circuited stubs of characteristic impedance of αL . The lengths of the shunt resonator stubs are $(2l)$ where (l) is

$$l = a \times \nu \tag{13}$$

where is the velocity of propagation and is defined in Equation 12, and the impedance Z is $\frac{50}{Y}$ where Y is the admittance and defined as $\frac{\alpha C}{2}$ according to Equation 10. However, since the series short circuited stubs are unrealisable in practice, they are approximated to an appropriate high impedance lines, in forms of unit elements (UE), with $Z_0 = 120\Omega$ [3]. In a 1Ω system, $Z_0 = 2.4\Omega$. The lengths are obtained as

$$l = \left(\frac{\nu}{\omega_c}\right) \times \sin^{-1}\left[\frac{\alpha L \tan(a\omega_c}{Z_0}\right]. \tag{14}$$

Noting that the value of α that is used in calculations is the ratio of the transmission zero frequency location to the passband edge frequency, and since five pairs of TZs at finite frequencies produced in this design, there are five values of α 1.4, 2.68, 2.88, 3.28 and 3.28 used in calculations of the first, second, third, fourth and fifth shunt resonator respectively. The complete distributed circuit with shunt open circuited stubs and different lengths of stubs is shown in Figure 3 and the values of impedances and lengths of stubs are listed in Table 2.

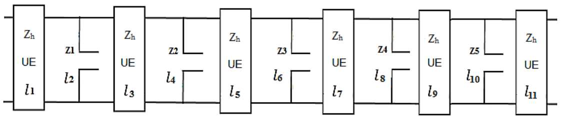


Figure 3. The schematic distributed-element circuit of LPF

Table 2. The stubs distributed values

Item	Value Ω	Item	Value (mm)	Item	Value (mm)
Zh	120	1	0.28	7	15.35
Z1	128.1	2	23.69	8	11.3
Z2	22.84	3	12.03	9	13.3
Z3	20.66	4	13.64	10	11.3
Z4	18.1	5	15	11	4.28
Z5	25.7	6	12.76	-	-

3 Suspended Substrate Stripline (SSS)

Then, the lowpass filter is transformed from short and open circuited stubs into real Transverse electromagnetic TEM transmission line for the purpose of improving the overall filter performance. One of the most effective techniques of implementing this filter is using suspended substrate stripline (SSS). It is a thin printed circuit that is suspended between two ground planes, as shown in Figure 4. Such structure offers potential improvements on filter performance since the majority of electric and magnetic fields are travelling in air cavity. That would lead to minimizing the radiation loss as the electric fields are being terminated at the edges of ground planes.

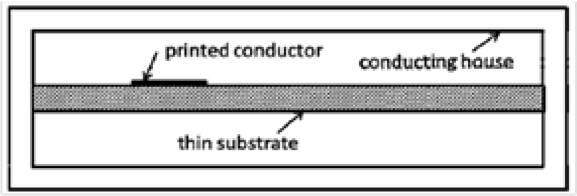


Figure 4. Structure of suspended substrate stripline

The impedance of SSS, which is a TEM transmission line, and its static capacitance are related as following:

$$Z_0\sqrt{\varepsilon_r} = \frac{377}{C/\varepsilon} \tag{15}$$

where ε_r is the medium dielectric constant, $\frac{C}{\varepsilon}$ is the normalised static capacitance per unit length. Since the stripline is suspended, fringing capacitance is considered with the normalised static capacitance as following:

$$\frac{C}{\varepsilon} = 2C_p + \frac{4C_f}{\varepsilon} \tag{16}$$

$$C_p = \frac{w}{(b-t)/2} \tag{17}$$

where b is the space distance between the ground planes and t is the conductor thickness which is assumed to be zero for a printed circuit when doing calculations. Thus, for t = 0,

$$\frac{C}{\varepsilon} = \frac{4W}{b} + \frac{4C_f}{\varepsilon} \tag{18}$$

but the fringing capacitance to ground $\frac{C_f}{\varepsilon}$ for a zero thickness is given by Equation 7 as 0.46. From Equation 15 and Equation 18, with considering is unity, yield the formula of stripline stub width as [3],

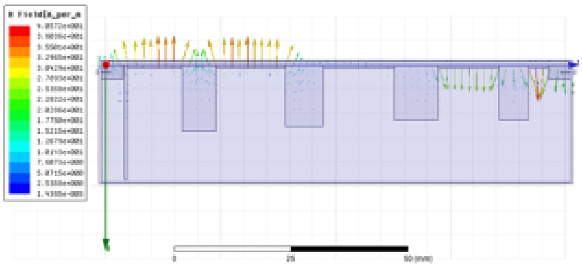
$$w = \frac{b}{4}\left(\frac{377}{Z_0} - 1.84\right) \tag{19}$$

in which the ground spacing b is chosen for the filter design to be 2.027 mm. The complete stripline stubs widths of the design are calculated using Equation 19 and shown in Table 3.

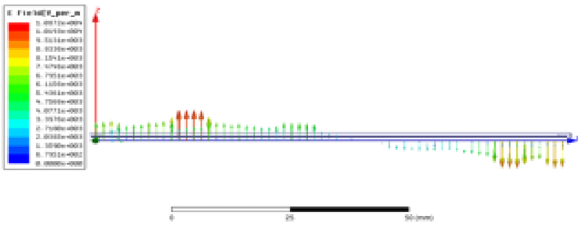
Table 3. Stripline stubs widths

$Z_0(\Omega)$	W (mm)	$Z_0(\Omega)$	W (mm)
120	0.66	20.66	8.314
128.1	0.56	18.1	9.6
22.84	7.432	25.7	6.5

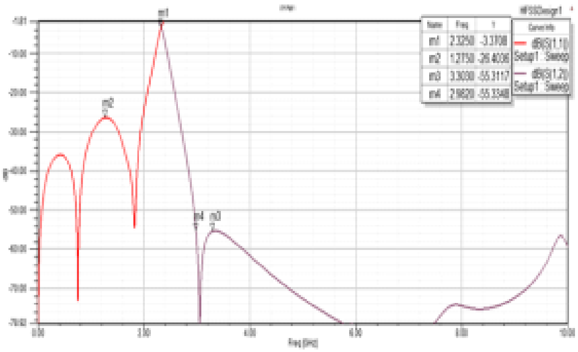
Results Analysis



(a) H-field behaviour



(b) E-field behaviour



(c) Simulated frequency response

Figure 5. 11^{th} order SSS lowpass filter

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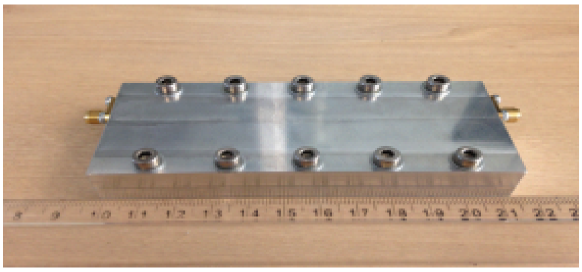
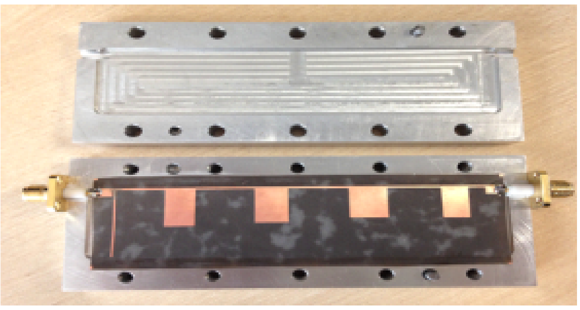
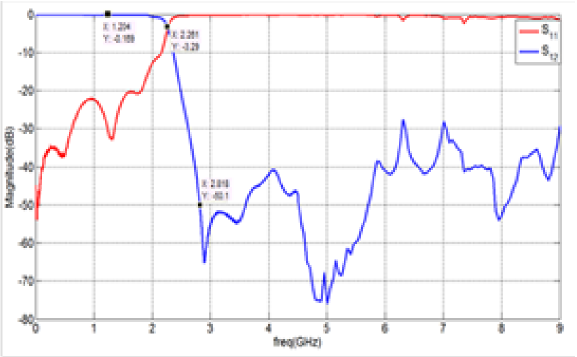
The filter response in Figure 5c shows a good performance by offering better than 26 dB as a return loss, reasonable selectivity of 1.28 and a minimum of 55 dB as a stopband rejection starting from stopband edge frequency up to 10 GHz. Such characteristics are achieved as a result of producing five pairs of TZs placed at finite frequencies, but that at the expense of filter size due to the filter order. On the other side, since this filter design realised using suspended stripline structure, the TEM propagation mode is exhibited. In this mode, the directions of all E-field and H-field lines are perpendicular and restricted to a transverse direction to signal propagation as shown in Figure 5. Such propagation property and suspended substrate structure offer potential improvements on filter performance since the majority of electric and magnetic fields are travelling in air cavity [3]. That would lead to minimising the radiation loss as the electric fields are being terminated at the edges of ground planes. The eleventh-order, generalized Chebyshev lowpass filter has been fabricated using Roger Duroid 5880 substrate with dielectric constant of 2.2 and a thickness of 0.127 mm. Then the filter has been manufactured based on suspended stripline structure (SSS) using Aluminium as a cavity and with 2mm as a ground spacing. Photographs of the manufactured filter are shown in Figure 6. By examining the measured response of the fabricated filter, it can be seen that it has a low insertion loss of 0.17 dB and better than 20 dB as a passband return loss. Also, reasonable filter selectivity of 1.24 has been achieved because of placing a pair of transmission zeros near the stopband edge frequency. A good agreement has been recorded between the simulated and measured responses in terms of passband performance and stopband rejection up to 6 GHz. However, the measured response shows a lower stopband rejection of 30 dB for frequencies higher than 6 GHz.



(a) Structure with lid



(b) Without lid



(c) Measured frequency response

Figure 6. Fabricated 11th order suspended stripline LPF

Conclusion

An eleventh-order lowpass filter satisfying generalized Chebyshev response with asymmetrical topology, a wide stopband rejection and high selectivity has been presented. The filter has a total of 11 TZs, one is located at infinity and 5 pairs located at different finite frequencies contributing response improvements in both passband and stopband regions. The filter has been realized using suspended stripline with substrate dielectric constant of 2.2 and a thickness of 0.127 mm enclosed within aluminum cavity, and experimental results are provided. The filter is usable in wideband wireless communications applications, especially in cellular base stations to clean up the stopband spurious undesired modes produced by dielectric resonator filters.

Future Work

The logical future expansion of this project may be a parallel structure that may be realized either in ASIC or a reconfigurable hardware of FPGA [7–10].

References

[1] Winder S. *Filter design.* Reed Educational and Professional Publishing, 1998.

[2] Hong J. *Microstrip filters for RF/microwave applications.* John Wiley and sons. Inc, New Jersey, 2011.

[3] IC Hunter. Theory and design of microwave filters, stevenage, ed, 2001.

[4] Saod A Alseyab. A novel class of generalized chebyshev low-pass prototype for suspended substrate stripline filters. *IEEE Transactions on microwave theory and techniques*, 30(9):1341–1347, 1982.

[5] Zlatoljub D Milosavljevic. Design of generalized chebyshev filters with asymmetrically located transmission zeros. *IEEE transactions on microwave theory and techniques*, 53(7):2411–2415, 2005.

[6] PAUL I Richards. Resistor-transmission-line circuits. *Proceedings of the IRE*, 36(2):217–220, 1948.

[7] Sami Hasan, Said Boussakta, and Alex Yakovlev. Improved parameterized efficient fpga implementations of parallel 1-d filtering algorithms using xilinx system generator. In *The 10th IEEE International Symposium on Signal Processing and Information Technology*, pages 382–387. IEEE, 2010.

[8] Sami Hasan, Said Boussakta, and Alex Yakovlev. Parameterized fpga-based architecture for parallel 1-d filtering algorithms. In *International Workshop on Systems, Signal Processing and their Applications, WOSSPA*, pages 171–174. IEEE,

2011.

[9] Sami Hasan. Performance-vetted 3-d mac processors for parallel volumetric convolution algorithm: A 256× 256× 20 mri filtering case study. In *2016 Al-Sadeq International Conference on Multidisciplinary in IT and Communication Science and Applications (AIC-MITCSA)*, pages 1–6. IEEE, 2016.

[10] Amjad J Humaidi, Sami Hassan, and Mohammed A Fadhel. Rapidly-fabricated nightly-detected lane system: An fpga-implemented the architecture. *The Asian International Journal of Life Sciences*, 16(1):343–355, 2018.

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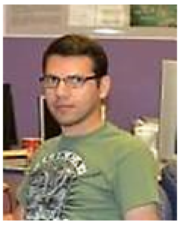

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