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Full paper

Generalized Chebyshev Highpass Filter based on Suspended Stripline Structure (SSS) for Wideband Applications

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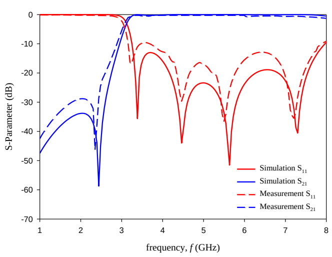
Graphical abstract



Abstract

This paper presents the method to transform generalized Chebyshev lowpass filter prototype to highpass filter based on Suspended Stripline Structure (SSS) technology. The study involves circuit analysis to determine generalized Chebyshev responses with a transmission zero at finite frequency. The transformation of the highpass filter from the lowpass filter prototype produces a cutoff frequency of 3.1 GHz with a return loss better than -20 dB. The design is simulated and measured on a Roger Duroid RO4350 with a dielectric constant, ε_r of 3.48 and a thickness of 0.508 mm. The experimental results are in good agreement with the simulated results. This class of generalized Chebyshev highpass filter with finite transmission zero would be useful in any RF/ microwave communication systems particularly in wideband applications where the reduction of overall physical volume and weight as well as cost very important, while maintaining its excellent performance.

Keywords: Microwave filter, highpass filter (HPF), Suspended Stripline Strucutre (SSS), transmission zero

1.0 INTRODUCTION

With the fast development of wireless communication, microwave filters with characteristics of high performance, low-cost, low insertion loss (IL) and compact are highly desirable for the next generation wireless communication system. Filter design starts with a classical lowpass lumped-element equivalent circuit or prototype. The equivalent circuit consists of series and shunt inductance and capacitor and their combination to form either series or parallel resonators [1-2]. The advantage of generalized Chebyshev is this response can mathematically place the transmission zeros at finite frequency. Therefore, it produces good selectivity, enhances the filter's performance and reduces the overall physical volume [3]. The suspended stripline structure (SSS) can be used as an interesting medium for all types of filters due to its structure preventing leakage or radiation from other signals [4].

A microstrip ring resonator with stubs is studied in to design a wideband filter by utilizing its first three resonant modes [5]. However, a lack of strength in capacitive coupling between the feeding-lines and ring, made the filter unable to produce a good response with wide bandwidth. The compact suspended stripline resonator is presented in which produces a microwave filter by using resonator [6]. This design has increased the capacitive loading of the resonator but it is difficult to control the return loss. The filter is designed using optimum distributed short circuited stubs method. However, this design did not produce narrow curve rejection at insertion loss [7].

In this paper, the transformation of generalized Chebyshev from the lowpass filter prototype to highpass filter is presented. As proof of concept, the highpass filter is designed at a cutoff frequency of 3.1 GHz with minimum stopband insertion loss of 40 dB at 2.5 GHz and minimum passband return loss of -20dB. The performance of generalized Chebyshev characteristic is better than the conventional Chebyshev particularly in term of its selectivity due to the transmission zeros that can be placed at desired finite frequency. Thus, the generalized Chebyshev reduces the number of elements used in prototype and subsequently reduces the overall circuit dimensions. The filter design is designed based on suspended stripline structure (SSS) to exhibit a pure transverse electric-magnetic (TEM) mode of propagation and resulting in very low loss characteristics and excellent selectivity. The design has very sharp rejection which easier to determine the minimum stopband insertion loss.

2.0 DESIGN OF HIGHPASS FILTER

2.1 Transformation Lowpass Filter Prototype to Highpass Filter

In this section, a systematic filter development using the lowpass filter prototypes as a starting point will be demonstrated. A dual type of the generalized Chebyshev lowpass prototype filter is used. This dual type of lowpass prototype will satisfy the generalized Chebyshev with three transmission zeroes. The transformation to highpass filter is as follows [8]:

$$\omega \rightarrow -\omega_c/\omega \tag{1}$$

where ω_c is cutoff frequency

This maps the lowpass filter prototype cutoff frequency to a new frequency. The transformation is applied to inductors and capacitors, where

$$C' = 1/\omega_c L \tag{2}$$

$$L' = 1/\omega_c C \tag{3}$$

Hence the inductors are transformed into capacitors and the capacitors are transformed into inductors as shown in (Figure 1). The component values of the prototype highpass filter are shown in Table 1.

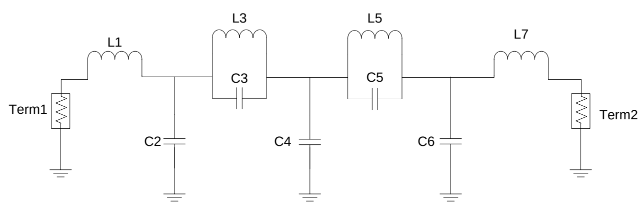


Figure 1 Seventh-degree generalized Chebyshev highpass filter prototype network

Table 1 Component value for prototype lumped elements

Elements of LPF	Value	Elements of HPF	Value
$L_1 = L_7$	1.02647	$C_1 = C_7$	0.97421
$C_2 = C_6$	1.08027	$L_2 = L_6$	0.92569
$L_3 = L_5$	0.541922	$C_3 = C_5$	0.90904
$C_3 = C_5$	1.10006	$L_3 = L_5$	1.84528
C_4	0.984147	L_4	1.01610

2.2 Impedance and Frequency Transformation

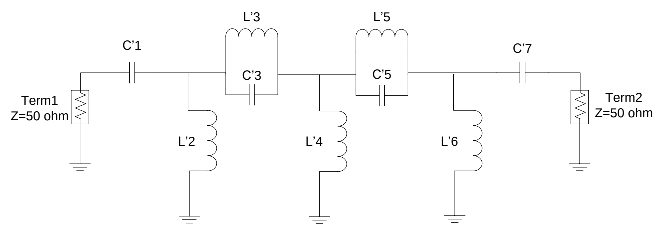
To verify the theory, the device is constructed using Roger RO4350 with relative dielectric constant, ε_r=3.48, substrate height, h = 0.508 mm. The thickness of copper 0.035 mm and the loss tangent is 0.019. The highpass filter with cut-off frequency of 3.1 GHz with the degree, N = 7, the minimum stopband insertion loss of -40 dB at 2.6 GHz and minimum passband return loss of -20 dB. The values of elements for the lowpass prototype network are shown in Table I with its corresponding ω_0 = 1.29516 rad/s which can be obtained in Alseyab [9].

The next step is to perform the impedance scaling with 50 Ω. After scaling to 50 Ω, the values of the equivalent circuit for each lumped component are shown in Table 2.

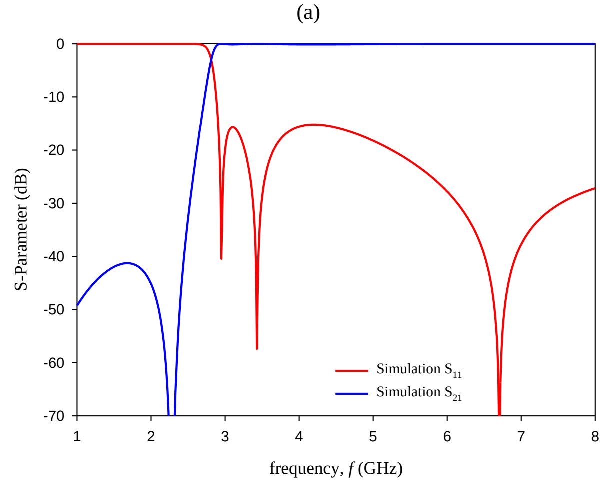
Table 2 Component value of lumped elements

Elements	Value
$C_1'=C_7'$	1.0003 pF
$L_2'=L_6'$	2.3763 nH
$C_3'=C_5'$	1.02619 pF
$L_3'=L_5'$	4.7368 nH
L_4'	2.6084 nH

The highpass filter circuit can now be simulated using the Advance Design System (ADS) as seen in (Figure 2a) and the response is shown in (Figure 2b). It is observed that the filter has a cutoff frequency of 3.1 GHz which are in excellent agreement with the design specification.



(a)



(b)

Figure 2 (a) Seventh-degree generalized Chebyshev highpass filter (b) Simulated frequency response of the generalized Chebyshev highpass filter

2.3 Transformation of Lowpass Filter Prototype to Highpass Filter

The lumped element highpass filter is then transformed to open- and short-circuit transmission line segments by applying Richard's transformation. Generalized Chebyshev highpass filter distribution can be constructed by applying Richard's transformation to the highpass filter prototype in (Figure 1). Under this transformation, the inductor is transformed into an open-circuited stub with admittances:

$$Y_0 = \alpha / L_r \tag{4}$$

and the resonator in the prototype has an impedance:

$$Z(j\omega)= j\omega L_r - j/(\omega C_r) \quad (5)$$

The Richard's transformation allows replacing lumped inductors with short circuited stubs of characteristic impedance $Z_0=L$ and capacitors with open circuited stubs of characteristic impedance $Z_0=1/C$. The resonator impedance can be represented as admittance of an open circuited stub by characteristic admittance $\alpha C/2$.

The length of the stub is one quarter wavelength at ω_0. Constant a can be obtained by applying Richard's transformation at the band edge. The structure of distributed element after applying the Richard's transformation is shown in (Figure 3). The values of short- and open-circuit stubs are shown in Table 3. The electrical length of 30° is decided to obtain a broader passband bandwidth.

Table 3 Element value of stub

Elements	Value	Elements	Value
Z1	29.4 Ω	Z4	63.045 Ω
Z2	290.68 Ω	Z5	62.37 Ω
Z3	42.12 Ω	E1	30°

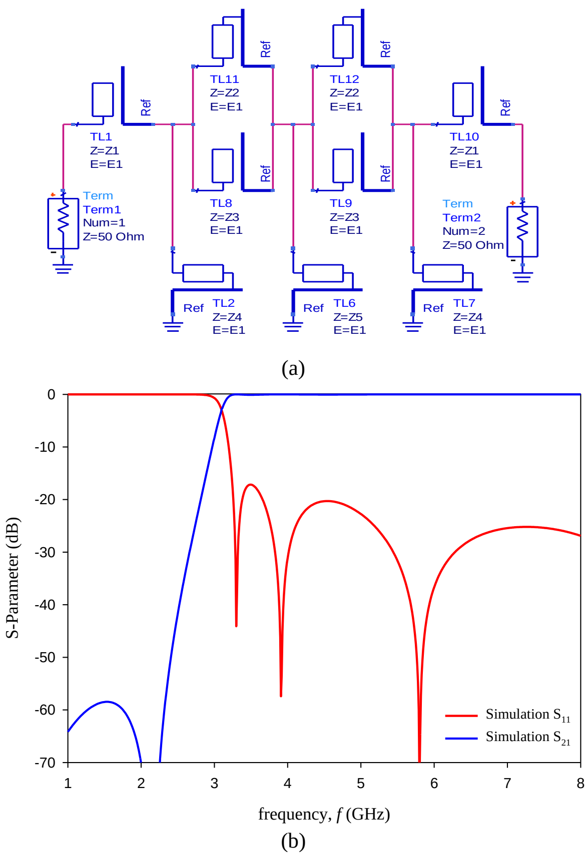


Figure 3 (a) Generalized Chebyshev highpass distributed filter (b) Simulated frequency response of the generalized Chebyshev lowpass distributed filter

The simulated results show an insertion loss (S_{21}) is almost 0 dB and return loss (S_{11}) better than -20 dB are obtained in the passband. A transmission zero at finite frequency of 2.1 GHz is observed.

2.4 Suspended Stripline Structure (SSS)

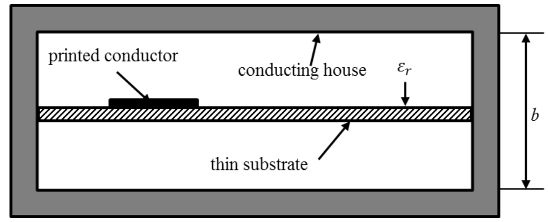


Figure 4 Suspended stripline structure

This highpass filter is simulated using SSS (as shown in (Figure 4)) in order to improve the overall filter performance. The impedance of the SSS which is based on Transverse Electromagnetic (TEM) transmission line is related to its static capacitance to ground per unit length as the following [10]:

$$Z_0\sqrt{(\varepsilon_r)}=377/(C/_\varepsilon) \quad (6)$$

where ε_r is the dielectric constant of the medium and $C/_\varepsilon$ is the normalized static capacitance per unit length of the transmission line. If a transmission line is suspended, the normalized static capacitance would include fringing capacitance:

$$C/\varepsilon=2C_p+(4C'_f)/\varepsilon \quad (7)$$

and

$$C_p=w/((b-2)/2) \quad (8)$$

For a printed circuit, t is assumed as zero and hence

$$C/\varepsilon=4w/b+1.84 \quad (9)$$

Therefore the line width can be obtained as:

$$w=b/4(377/Z_0-1.84) \quad (10)$$

where b is a ground plane spacing in mm and Z_0 is characteristics of impedance line.

In order to realize the highpass filter layout, series capacitors and resonators can be approximated by inhomogeneous couple lined realized in suspended substrate. A series capacitance can be realized in the form of parallel coupled structure, overlapping of strips on the top and bottom layers of the substrate as shown in (Figure 5).

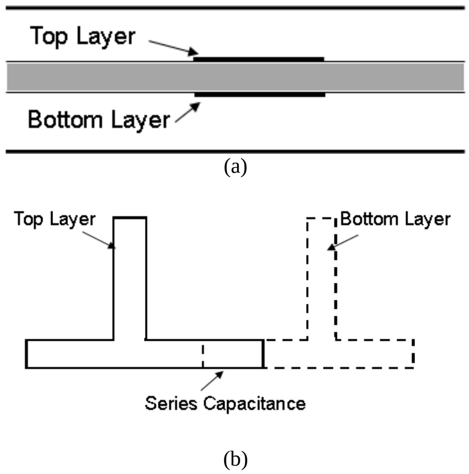


Figure 5 Layout of highpass filter using series capacitance and open circuited shunt stubs (a) cross section (b) top view

To produce a wider bandwidth, the value of necessary impedance became too small to fabricate effect of line separation. This limitation can overcome in suspended stripline where the larger impedance can be produced by using broadside-couple lines.

$$Z_0=h_0/\sqrt{(\varepsilon_e)}[w/h+1.393+0.667\ln(w/h+1.444)]^{-1} \quad (11)$$

where

$$\varepsilon_e=1/2[\varepsilon_r+1+(\varepsilon_r-1)F] \quad (12)$$

and

$$F=(1+12h/w)^{-1/2} \quad (13)$$

ε_r is the relative dielectric constant of substrate and h_0 is the wave impedance which is 377 Ω.

The series capacitors are represented by an overlapping line possessing capacitance C_s. The length overlaps is given by

$$l=(1.8uZ_{00}C_s)/\sqrt{(\varepsilon_e)} \quad (14)$$

where u is the phase velocity and Z_{00} is the odd mode impedance and is given by replacing h in (11) by $h/2$.

For the series resonators, the capacitance too can be represented by the length of overlapping lines and can be calculated from (11) and (14). The nearer distance between them means tighter coupling results in a better selectivity. The 3-D physical layout of the highpass filter is shown in (Figure 6a). The air gap between substrate and lid is 2 mm from bottom to top of the aluminium box. The current flow visualization of the physical layout is shown in (Figure 6b). The current flow of highpass filter is focused at 3.1 GHz where the high concentrated occur in the middle of the stub. The SSS highpass is modeled, simulated and optimized using ADS Momentum. The structure of fabricated product for the highpass are shown in (Figure 7a) and (Figure 7b). The comparison of the simulated and measured response is shown in (Figure 7c). The measurement results show the promising result with simulation where the transmission zero is sharp at 2.1 GHz and the selectivity is similar with the simulation result. The results show an insertion loss (S_{21}) is almost 0 dB and return loss (S_{11}) better than -20 dB are obtained in the passband. There is a noted transmission zero occurs at around 3 GHz.

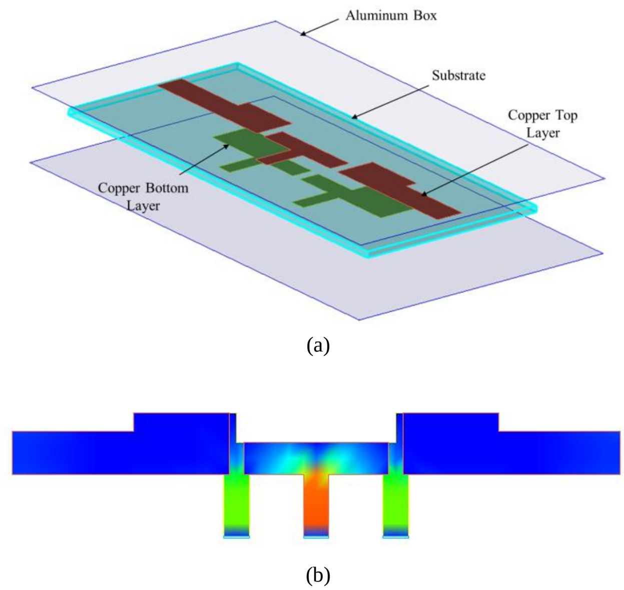


Figure 6 (a) 3-D view of generalized Chebyshev highpass filter and (b) current flow visualization of highpass filter at 3.1 GHz

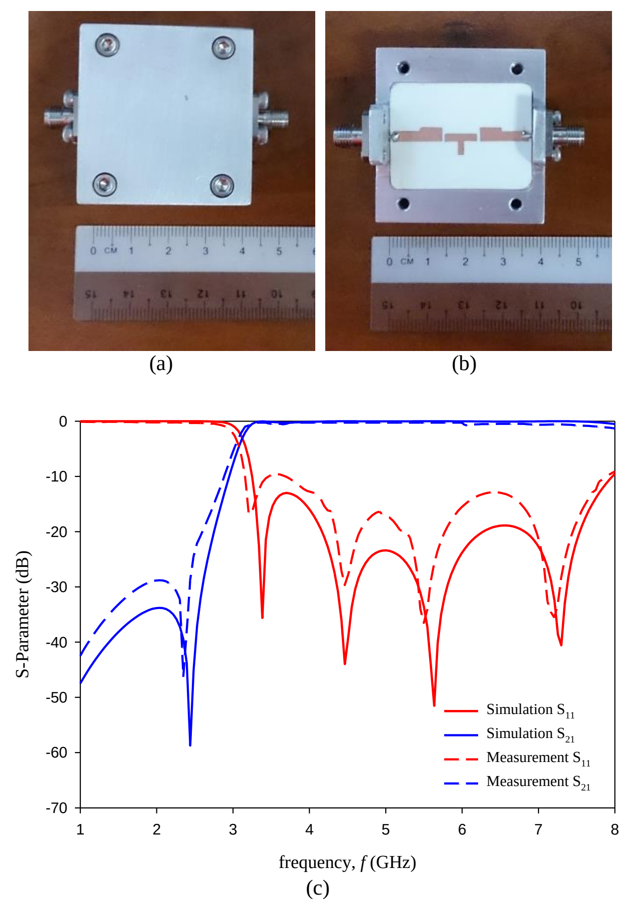


Figure 7 Photograph of suspended stripline structure highpass filter (a) overall filter structure with lid (b) inside (base – without lid) and (c) comparison simulation and measurement result S_{11} and S_{21}

3.0 CONCLUSION

The measurement result of the compact highpass filter with wide bandwidth produces an excellent agreement with simulation results from EM simulation with return loss, S_{11} better than -12 dB and insertion loss, S_{21} better than -0.5 dB. This work can be simulated and fabricated in future work by cascading the lowpass filter and highpass filter to produce a bandpass filter characteristic. In addition, a defected stripline structure (DSS) can also be proposed to exhibit a sharp notch response in the integrated lowpass and highpass filter in order to remove the undesired signals in the wideband applications. The number of elements can be reduced by using this type of generalized Chebyshev in order to produce good selectivity and minimize the overall filter size. Therefore, this new class of microwave filter would be useful in any microwave communication systems where the reduction of overall physical volume is very important while still maintaining the good performance such as in ultra wide band (UWB) and radar applications.

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