

# A trapezoidal microstrip bandstop filter with efficient suppression of undesired stopbands

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A new bandstop filter implemented as a cascade of trapezoidally shaped cells is presented. The proposed bandstop filter suppresses many undesired stopbands at higher frequencies. The cell design is specified by two variables and the initial filter is refined by optimizing the cell variables. The proposed design yields a robust structure suitable for fabrication. The proposed filter is fabricated and measured in a wide frequency range showing more efficient suppression than is reported in literature.

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## 1. Introduction

Microstrip bandstop filter with suppressed undesired bandstops, also refer to as the filter with only the first stopband (marked as  $f_0$ ), was first reported in [1]. The reported filter is implemented as a microstrip line with a sinusoidal pattern etched in the ground plane. The measured results are presented up to  $2f_0$ , showing that the stopband around  $2f_0$  is not fully suppressed. A structure with a sinusoidal variation of the characteristic impedance  $Z_c$  along the microstrip line was reported in [2]. In this structure there is no etching in the ground plane. The variation of  $Z_c$  is between  $Z_{min}$  and  $Z_{max}$  and satisfies  $\sqrt{Z_{min} \cdot Z_{max}} = 50 \Omega$ . The measured results are presented up to  $3.6 f_0$ , showing the first stopband around  $f_0$ , while the stopbands around  $2f_0$  and  $3f_0$  are suppressed. However, in both cases the passband shows ripples in the vicinity of the first stopband.

Another filter, without etching in the ground plane and with only the first stopband around  $f_0$ , is realized in [3]. Its design is based on the spatial Fourier transform, which gives the amplitude of sinusoidal variation of the characteristic impedance  $Z_c$  that decreases going from center of the filter to its ends. The measured results, which are presented up to  $2.5 f_0$ , show that the passband around  $2f_0$  is not fully suppressed. However, the passband does not show ripples in the vicinity of the first stopband.

In this paper, a modification of the structure presented in [2] is introduced. A simple trapezoidal pattern of microstrip line is introduced instead of a much more complicated sinusoidal variation of the characteristic impedance of the line. Design of one filter cell and filter assembling is described in Section 2. Implementation and experimental results are shown in Section 3.

## 2. Cell design and filter assembling

One cell of the proposed structure is presented in Fig.1. The cell contains six sections, marked with numbers 1 to 6. All sections are of equal length. Four sections are tapers: sections 1, 3, 4 and 6. Two sections are uniform lines: sections 2 and 5. The width at the ends of the cell (the beginning of section 1 and the end of section 6) and in the middle of the cell (between sections 3 and 4) is adopted to be that of the  $50 \Omega$  microstrip line. Hence, it will be marked as  $W_{50\Omega}$ .  $Z_{max}$  is the characteristic impedance of the narrow line of width  $W_{min}$  (section 2).  $Z_{min}$  is the characteristic impedance of the wide line of width  $W_{max}$  (section 5).

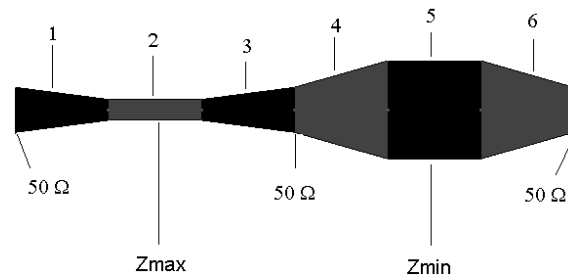


Fig. 1. Proposed cell with 6 sections ( $Z_{max}$  corresponds to  $W_{min}$ ,  $Z_{min}$  corresponds to  $W_{max}$  and  $50 \Omega$  corresponds to  $W_{50\Omega}$ )

Generally, the filter is assembled of arbitrary number of cells of equal length, where  $Z_{max}$  and  $Z_{min}$  of each cell are chosen independently. An example of the filter, consisting of four cells, is presented in Fig.2. If all cells have the same  $Z_{max}$  and  $Z_{min}$  the filter is a periodic structure. As in case of filters proposed in [1], [2], and [3], it can be shown that:

- the center frequency of the first stopband is a frequency at which the cell is half wavelength long,
- the width of the first stopband increases by increasing the ratio  $Z_{\max}/Z_{\min}$  of the cell, and
- the depth of the first stopband increases with increasing number of cells

However, as shown in [1] and [2], the periodicity of the structure results in the passband ripples in the vicinity

of the first stopband. The ripples are suppressed by decreasing the amplitude of impedance variation going from center of the filter to its ends [3]. Hence, to maximally suppress the ripples we propose that cells have arbitrary  $Z_{\max}$  and  $Z_{\min}$ , which are determined by optimization.



Fig. 2. The proposed filter structure with four cells.

### 3. Implementation and experimental results

Based on the design proposed in Section 2, the bandstop filter with the stopband around  $f_0 = 5.8$  GHz, and the depth of 20 dB (20 dB maximum rejection), is optimized for minimum passband ripples. The filter consisting of four cells is fabricated on Cuflon substrate (relative permittivity  $\epsilon_r = 2.1$ , loss tangent  $\tan\delta = 0.00045$ , and thickness  $h = 0.508$  mm). The length of one cell (half-wavelength at  $f_0$ ) is determined to be  $d = 20$  mm. The width of the microstrip line that corresponds to  $50\ \Omega$  is  $W_{50\Omega} = 1.6$  mm.

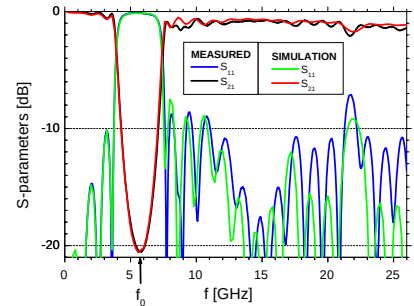
Initial values of cell characteristic impedances are chosen to be  $Z_{\max} = 80\ \Omega$  and  $Z_{\min} = 31.25\ \Omega$  for each of four cells. (These values enable 20 dB maximum rejection in case of sinusoidal variation of characteristic impedance of microstrip line, as shown in [2].) Fast circuit simulation, based on analytical formulas for microstrip components, and optimization of the proposed filter is performed with WIPL-D Microwave Pro [4]. In general case,  $Z_{\max}$  and  $Z_{\min}$  are optimized for each cell, varying widths  $W_{\min}$  and  $W_{\max}$ , thus giving in total of 8 optimization variables. Three optimization criteria are posed:  $S_{21} > -0.3$  dB for  $f < 3.7$  GHz,  $S_{21} < -20$  dB for  $f = 5.8$  GHz, and  $S_{21} > -1$  dB for  $7.9$  GHz  $< f < 26$  GHz. However, it is shown that equally good results are obtained if the fourth cell is equal to the first cell, and the third cell is equal to the second cell. Thus obtained optimal values for widths are:  $W_{\min 1} = W_{\min 4} = 0.98$  mm,  $W_{\max 1} = W_{\max 4} = 3.25$  mm,  $W_{\min 2} = W_{\min 3} = 0.74$  mm and  $W_{\max 2} = W_{\max 3} = 3.5$  mm.

Full wave 3D EM model of the optimized structure was created and simulated in WIPL-D Microwave Pro. The results are in a good agreement with the circuit simulation. The optimized filter is fabricated (see Fig. 3.) and measured.

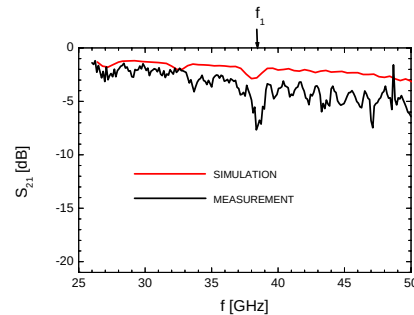


Fig. 3. Photograph of the proposed filter.

Fig. 4 (a) shows  $S_{11}$  and  $S_{21}$  versus frequency up to 26 GHz, in the frequency range for which the filter is optimized. A good agreement between the measured results and those obtained by EM simulation is observed. Figure 4b shows  $S_{21}$  in the frequency range from 26 GHz to 50 GHz, out of the frequency range for which the filter is optimized. A greater deviation of the simulated results from the measured results, in this frequency range, can be mostly explained by the reflection at connectors, which is not taken into account by 3D EM model of the filter. It is seen for Fig. 4 that all undesired stopbands are fully suppressed up to  $f_1 = 6.6 f_0$ .



(a)



(b)

Fig. 4. S-parameters of proposed filter obtained by measurement and 3D EM simulation in the frequency range (a), and out of the frequency range (b), for which the filter is optimized.

#### 4. Conclusions

A new design of bandstop filter, which suppresses higher undesired stopbands, is proposed. The filter is assembled of trapezoidal cells, which are easy for fabrication. Maximum and minimum characteristic impedances of the cells are independently optimized for minimal passband ripples and suppression of undesired stopbands. The filter with the stopband around  $f_0 = 5.8$  GHz is fabricated and measured. The measured results show full suppression of undesired stopbands up to  $6.6 f_0$ , which is much higher than the results previously reported.

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