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A COMPACT BANDSTOP FILTER BASED ON TWO MEANDERED PARALLEL-COUPLED LINES

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Abstract—In this paper, a compact wideband high-rejection microstrip bandstop filter using two meandered parallel-coupled lines of different electrical lengths and characteristic impedances in shunt is presented. The transmission and reflection zeros of the filter can be controlled through analytical equations and rulers given. Using this signal interferences technology, this filter obtains a low insertion loss and sharp rejection. Bandwidth and rejection level of the filters of this bandstop filter can be designed by choosing different even- and odd-mode characteristic impedances values of the coupled lines. According to the transmission zeros number, two types of filters are shown in the paper. To validated this topology, a wideband bandstop filter with a 3 dB cutoff frequency bandwidth of 92% centered at 2.6 GHz with sharp rejection characteristics is built to verify the theoretical prediction. The measured frequency response of the filter agrees excellently with the predicted result.

1. INTRODUCTION

With the rapid development of modern wireless systems, compact size, low losses, high selectivity, low cost, and high performance components are the design goals. Filter is an essential component in modern communication system. In response to this need, recently many planar filters with band-pass, low-pass, or band-stop performances have received wide attention [1–7], and many techniques and methodologies used to realize the goals have been investigated.

Bandstop filter (BSF) is one of the key components in modern communication system. It plays a major role of filtering out undesired frequencies and passing the desired signal. Most conventional

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microstrip bandstop filters have open-circuited stubs and shunt stubs of a quarter-wavelength [8, 9]. Filters have high selectivity and low losses, the design procedure is complex. Recently, many reconfigurable bandstop filters have been developed to realize a wideband stopband via different methods and structures. 1. Compact microstrip bandstop filter using open stub and spurline line [10]. 2. Novel U-slot and V-slots sharp which are etched into the ground plane [11]. 3. Compact wideband bandstop filter, with one section of anti-coupled lines with short circuits at one end [12]. Coupled lines have been widely used for implementing filters for a long time. In this paper, the filter has only two meander prototype parallel coupled lines of different electrical lengths and characteristic impedances in shunt. The total circuit layout is based on coupled lines, which is symmetrical and simple. This BSF has only analytical scattering parameters' expressions. But also features compact size and flexible reconfiguration. The design procedure is described in detail. According to the transmission zeros number, two types of filters are shown in the paper. Bandwidth and rejection level of the filters of this bandstop filter can be designed by choosing different even- and odd-mode characteristic impedances values of the coupled lines. Finally, a wideband bandstop filter with a 3 dB rejection bandwidth of 92% centered at 2.6 GHz with sharp rejection characteristics is built to verify the theoretical prediction, and the measured frequency response of the filter agrees excellently with the predicted result.

2. THE CIRCUIT STRUCTURE AND THEORY OF THE PROPOSED BSF

Figure 1 is the structure of meandered parallel coupled lines. The characteristic impendence of the line is Z_e, Z_o. For simplicity, the coupled lines structure is assumed to have the same even and odd mode propagation velocity ($\theta = \theta_e = \theta_o$). The detail of the proposed wideband bandstop filter is shown in Figure 2. It is made up of two meandered parallel coupled lines of different electrical lengths and

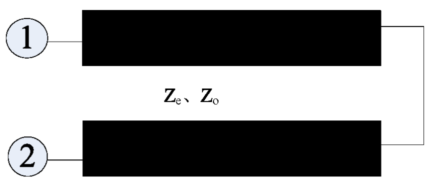

Figure 1. Meandered parallel-coupled line.

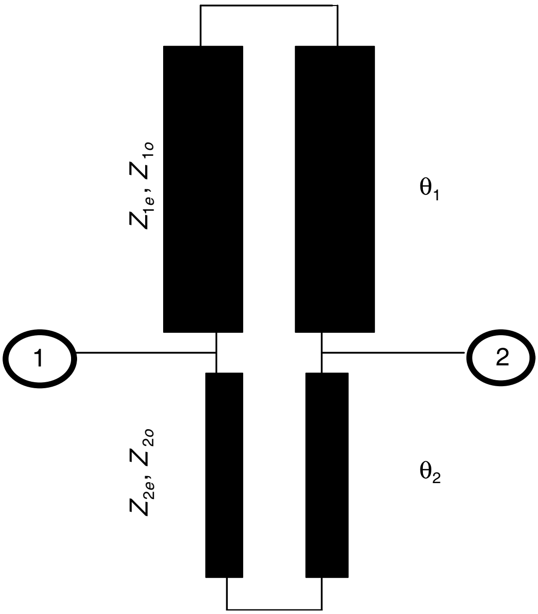

Figure 2. Configuration of proposed bandstop filter.

characteristic impedances in shunt connection. Different from [14], the two meandered lines connected at the end of the structure behave as an all pass filter. When a signal is applied at one end of the structure, it is divided into two components. Different signals after propagating through the structure with different magnitudes and phases can produce different numbers of transmission zeroes [14, 15]. Sharp rejection characteristics can be obtained by higher orders, but it is at the cost of increasing the implementation of area.

The $ABCD$ matrix of this two-port of the measured parallel coupled line [16] is

$$M = \begin{bmatrix} \dfrac{Z_e \cot\theta - Z_o \tan\theta}{Z_e \cot\theta + Z_o \tan\theta} & \dfrac{2jZ_eZ_o}{Z_e \cot\theta + Z_o \tan\theta} \\ \dfrac{2j}{Z_e \cot\theta + Z_o \tan\theta} & \dfrac{Z_e \cot\theta - Z_o \tan\theta}{Z_e \cot\theta + Z_o \tan\theta} \end{bmatrix} \tag{1}$$

Then we can obtain the Y matrix of the line

$$Y = \begin{bmatrix} \dfrac{Z_e \cot\theta - Z_o \tan\theta}{2jZ_eZ_o} & \dfrac{-(Z_e \cot\theta + Z_o \tan\theta)}{2jZ_eZ_o} \\ \dfrac{-(Z_e \cot\theta + Z_o \tan\theta)}{2jZ_eZ_o} & \dfrac{Z_e \cot\theta - Z_o \tan\theta}{2jZ_eZ_o} \end{bmatrix} \tag{2}$$

The characteristic impendences of these line segments are denoted as Z_{1e}, Z_{2o}, Z_{2e}, Z_{2o}. For simplicity, the upper and lower coupled line sections are both designed having the same even- and odd- mode electrical lengths, $\theta_{1e} = \theta_{1o} = \theta_1$, $\theta_{2e} = \theta_{2o} = \theta_2$.

Z_o is the feed line impedance characteristic of port, and the normalized admittance matrix of the filter can be obtained by adding the two coupler admittance matrices [17]

$$[y]_{filter} = [y]_{coupline1} + [y]_{coupline2} \tag{3}$$

$$Y = \begin{bmatrix} \dfrac{Z_{1e}\cot\theta_1 - Z_{1o}\tan\theta_1}{2jZ_{1e}Z_{1o}} + \dfrac{Z_{2e}\cot\theta_2 - Z_{2o}\tan\theta_2}{2jZ_{2e}Z_{2o}} & \dfrac{-(Z_{1e}\cot\theta_1 + Z_{1o}\tan\theta_1)}{2jZ_{1e}Z_{1o}} + \dfrac{-(Z_{2e}\cot\theta_2 + Z_{2o}\tan\theta_2)}{2jZ_{2e}Z_{2o}} \\ \dfrac{-(Z_{1e}\cot\theta_1 + Z_{1o}\tan\theta_1)}{2jZ_{1e}Z_{1o}} + \dfrac{-(Z_{2e}\cot\theta_2 + Z_{2o}\tan\theta_2)}{2jZ_{2e}Z_{2o}} & \dfrac{Z_{1e}\cot\theta_1 - Z_{1o}\tan\theta_1}{2jZ_{1e}Z_{1o}} + \dfrac{Z_{2e}\cot\theta_2 - Z_{2o}\tan\theta_2}{2jZ_{2e}Z_{2o}} \end{bmatrix} \tag{4}$$

The S-matrix of the filter can be readily obtained from $[y]_{filter}$ by the transformation [17],

$$\begin{aligned} S_{11} &= \frac{(Y_0 - Y_{11})(Y_0 + Y_{22}) + Y_{12}Y_{21}}{\Delta Y} \\ S_{21} &= \frac{-2Y_{21}Y_0}{\Delta Y} \end{aligned} \tag{5}$$

where

$$Y_o = 1/Z_o, \quad \Delta Y = (Y_0 - Y_{11})(Y_0 + Y_{22}) - Y_{12}Y_{21} \tag{6}$$

$$Y_{11} = Y_{22} = \frac{Z_{1e}\cot\theta_1 - Z_{1o}\tan\theta_1}{2jZ_{1e}Z_{1o}} + \frac{Z_{2e}\cot\theta_2 - Z_{2o}\tan\theta_2}{2jZ_{2e}Z_{2o}}, \tag{7}$$

$$Y_{12} = Y_{21} = -\frac{Z_{1e}\cot\theta_1 + Z_{1o}\tan\theta_1}{2jZ_{1e}Z_{1o}} - \frac{Z_{2e}\cot\theta_2 + Z_{2o}\tan\theta_2}{2jZ_{2e}Z_{2o}} \tag{8}$$

The condition of transmission zeros can be obtained when

$$|S_{21}| = 0 \tag{9}$$

We normalize the bandstop filter's center frequency at 1 GHz, and it leads to transmission zeros distributed by pairs symmetrically placed around the center frequency f_0. If the line lengths are chosen appropriately, different number of transmission zeros can be created.

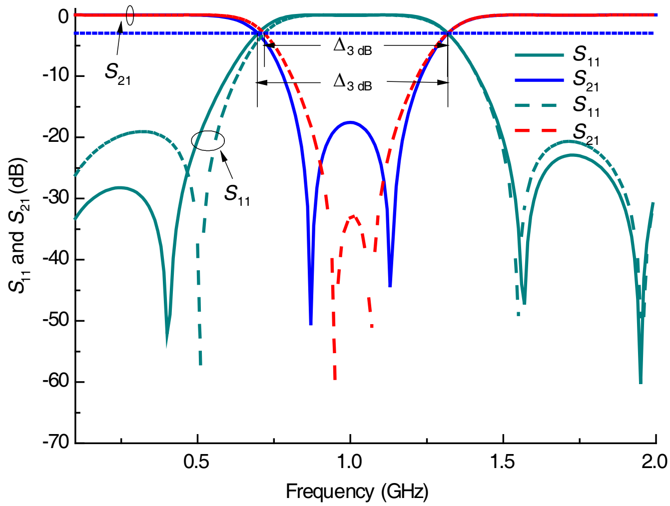

Figure 3. The computed frequency response of filters of case 1, —— with $Z_{1e} = 150\,\Omega$, $Z_{1o} = 100\,\Omega$, $Z_{2e} = 150\,\Omega$, $Z_{2o} = 137\,\Omega$, - - - - with $Z_{1e} = 150\,\Omega$, $Z_{1o} = 129\,\Omega$, $Z_{2e} = 150\,\Omega$, $Z_{2o} = 137\,\Omega$.

According to the transmission zeros numbers, the BSF filter sums up two types:

Case 1: For $\theta_1 = \frac{\pi}{8}$, $\theta_2 = \frac{3\pi}{4}$, this type of filter only has two transmission zeros in the stopband. The computed frequency response of this type of bandstop filter is shown in Figure 3. $\theta_1 + \theta_2 = \frac{7\pi}{8} \angle \pi$, so this type of filter is smaller than that in [13] if fabricated on the same substrate. From Figure 3, we can see that the 3 dB cutoff frequency bandwidth and stopband rejection level are dependent on Z_e/Z_o.

Case 2: Figure 4 shows the circuit transmission responses for $\theta_1 = \frac{\pi}{2}$, $\theta_2 = \pi$, this type of filter has three transmission zeros in the stopband. The number can increase to five or decrease to one if choosing appropriate Z_e/Z_o. The 3 dB cutoff frequency bandwidth is dependent on even- and odd-mode characteristic impedances values of the coupled lines, and adjusting either arm of the two parallel lines can gain it.

3. MICROSTRIP EXAMPLES AND MEASUREMENTS

To verify this design method, a prototype filter was constructed in microstrip on Rogers R04350B with a dielectric thickness of 0.762 mm, relative dielectric constant of 3.48 and loss tangent of 0.0037. The dimensions of the filter are as follows: $L1 = 34.50$ mm, $W1 = 0.27$ mm,

$S1 = 0.32\,\text{mm}$, $L2 = 16.00\,\text{mm}$, $W2 = 0.5\,\text{mm}$, $S2 = 0.55\,\text{mm}$. Figure 5 shows the photograph of the fabricated filter. A full wave simulator HFSS has been investigated to obtain and efficiently tune the physical dimensions. Measurement is carried out using an Agilent N5230C network analyzer. Full wave simulated and measured insertion

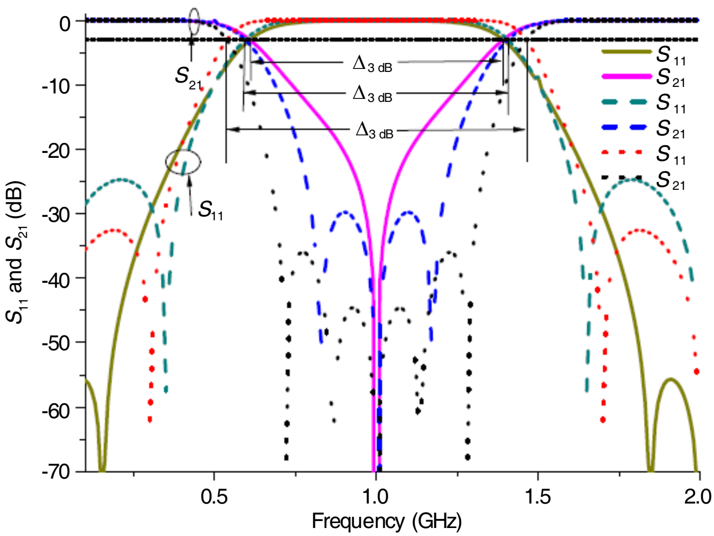

Figure 4. The computed frequency response of filters of case 2, —— with $Z_{1e} = 150\,\Omega$, $Z_{1o} = 147\,\Omega$, $Z_{2e} = 103\,\Omega$, $Z_{2o} = 60\,\Omega$, — — with $Z_{1e} = 150\,\Omega$, $Z_{1o} = 147\,\Omega$, $Z_{2e} = 103\,\Omega$, $Z_{2o} = 83\,\Omega$, - - - - - with $Z_{1e} = 150\,\Omega$, $Z_{1o} = 90\,\Omega$, $Z_{2e} = 150\,\Omega$, $Z_{2o} = 73\,\Omega$.

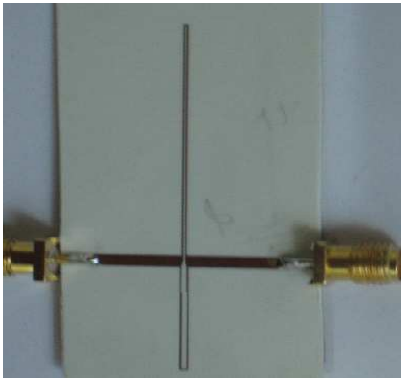

Figure 5. Photograph of the BSF.

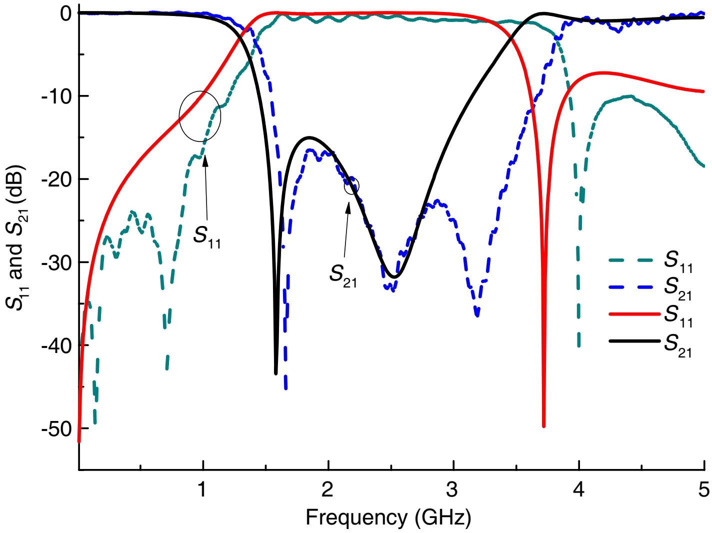

Figure 6. Measured and simulated of the BSF, —— simulated, - - - measured.

losses and return losses are shown in Figure 6. The filter has a center frequency at 2.6 GHz, with 3 dB fractional bandwidth close to 92%, and the 16 dB attenuation is from 1.59 GHz to 3.51 GHz. Both measured insertion and return loss show excellent agreement with the calculated values for the prototype filter. Slight discrepancy between the simulated and measured results is mainly attributed to the substrate, radiation, dielectric loss and two SMA connectors. The slight shift of the frequency might be due to the unexpected tolerance of fabrication and unequal electrical lengths of even- and odd-modes of the coupled lines.

4. CONCLUSION

A novel bandstop filter is composed of a section of two meandered parallel-coupled microstrip lines. Its structure is very simple and compact, but it exhibits good performance. Design equations and rulers for the synthesis of the BSF have been given and investigated theoretically and experimentally. As a result, a wideband bandstop filter with 16 dB rejection bandwidth of 92% centered at 2.6 GHz with sharp rejection characteristics is built to verify the theoretical prediction. The measured frequency response of the filter agrees excellently with the predicted result.

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