Design and Realization of a Wideband Microstrip Filter Using Signal-Interaction Techniques

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Abstract **─** The signal-interaction techniques are adopted in this paper to design a novel wideband microstrip filter. The signal is transmitted from input port to the output one through two transmission paths in parallel which is composed of a wideband 180° inverter based on microstrip line and a 3λ/4 transmission line. Besides, two λ/4 shorted-ended lines is employed to improve the passband transmission performance of the BPF (Bandpass Filter). It is demonstrated from the simulation and measurement results of the novel BPF that three transmission zeros leading to the good harmonic suppression performance are achieved for the BPF operating from 0.99 to 2.51 GHz with 3-dB fractional bandwidth of 86.8%.

Index Terms **─** Passband, phase inverter, transmission path, transmission pole, transmission Zero.

I. INTRODUCTION

Recently, it is increasingly demanded for the filters with wide operating band in wireless communication area. In the engineering application, the interference signal is required to be suppressed for the wideband BPF. Various kinds of wideband filters employing parallel-coupled lines, ring resonators, short/open stubs, and composite microstrip coplanar-wave guide structure were designed and analyzed [1-9]. In [1-3], the parallel-coupled lines were observed to be good candidates for wideband systems design because of the advanced features such as simple design, compact size, and good linearity. However, smaller gap between the parallel-coupled lines is needed to achieve wider fractional bandwidth, which is not easy to fabricate. In [4-5], some wideband filters are implemented by cascading a low- and high-pass filter with good out-of-band rejection. However, there are some drawbacks for these structures, such as larger circuit size, and imperfect group delay over passband. In [6-9], filters was achieved by using etched patterns in the ground plane or via holes. Inevitably, the structures with etched patterns in the ground plane both have disadvantages as well, for instance, package problems, sensitivity, In [10-12], the disadvantages referred above is overcome by introducing two parallel transmission paths. Based on the concept of the signal interaction, several improved wideband filters are fabricated. However, for the adoption of another transmission path, the size of BPF is increased. So, in order to realize the miniaturization, 180° phase inverter is added to stand for a transmission line [13-14]. Even through, it is not convenient to adjust the 3-dB bandwidth of the filters.

In this paper, by adopting the signal interaction concept, a compact improved wideband bandpass filter using two shorted stubs and a 180° phase inverter based on microstrip line [15] is proposed. And it fails to be complicated to tune the 3-dB bandwidth of the filter through adjusting the characteristic impedances ratio of two transmission paths. Without other lowpass or bandstop networks, wide upper stopband can be implemented. In the following sections, detailed theoretical analysis, simulation and experimental result are given respectively.

II. THE ANALYSIS OF THE NOVEL WIDEBAND FILTER

The passband performance of the proposed filter is supposed to be improved through shunting one quarter wavelength short stub to the input and output 50 Ω feeding line [2]. Hence, The RF component is adopted here for the designed broadband bandpass filter, as demonstrated in Fig. 1.

In Fig. 1, two different transmission paths, one of which is θ in electrical length and another is 3 θ in electrical length (θ = 90° at the center frequency f_0,), are employed to transmit the signal from input port the output one. The characteristic impedance is denoted as

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Z_1 and Z_2. To realize the miniaturization, an 180° inverter is added in path 1 to replace a transmission line. And two short-ended lines, θ in electrical length and Z_s characteristic impedance, are separately connected in parallel to the input and output transmission line with characteristic impedance of 50 Ω.

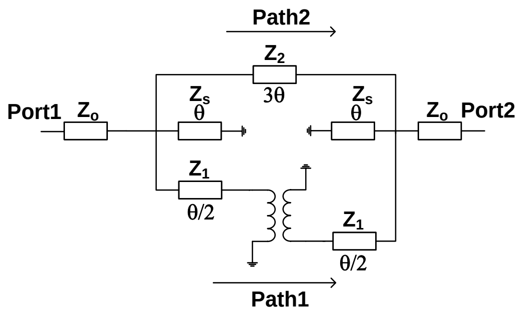


Fig. 1. Circuit of the novel wideband filter in this paper.

It is deduced from the signal-interaction concepts that the passband of the proposed filter can be achieved by the following equation [16]:

$$\theta_1(f_0) = \theta_2(f_0) \pm 2n\pi, \quad (n = 0,1,2...). \tag{1}$$

For the electrical length relationship between two different paths $\theta_1(f_0)=180°+\theta(f_0)=\theta_2(f_0)=3\theta(f_0)=270°$, a passband feature of the novel filter can be easily obtained at f_0 during the propagation of the signal from Port1 to Port2. In addition, at the second harmonic $2f_0$, $\theta_1(2f_0)=180°+\theta(2f_0)=360°=\theta_2(2f_0)-180°=2\theta(2f_0)-180°$, it is supposed to realize a stopband performance owing to the fact that signals from Path1 and Path2 are in the same magnitude but out-of-phase.

The ABCD matrix of the shorted lines, the 180° swap, and the two transmission paths are:

$$Ms = \begin{bmatrix} 1 & 0 \\ 1/\ jZs\tan\theta & 1 \end{bmatrix}, \tag{2}$$

$$M_{swap} = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}, \tag{3}$$

$$M_1 = \begin{bmatrix} \cos\theta/2 & jZ_1\sin\theta/2 \\ jY_1\sin\theta/2 & \cos\theta/2 \end{bmatrix}, \tag{4}$$

$$M_2 = \begin{bmatrix} \cos 3\theta & jZ_2\sin 3\theta \\ jY_2\sin 3\theta & \cos 3\theta \end{bmatrix}. \tag{5}$$

For Path1, the *ABCD* parameter matrix is $M_s \times M_1 \times M_{swap} \times M_1 \times M_s$; for Path2, the *ABCD* parameter matrix is $M_s \times M_2 \times M_s$. After the *ABCD*-, *Y*-, and *S*-parameter conversions, two transmission zeros can be obtained when $S_{21}=0$:

$$\theta_{tz1} = \arcsin\sqrt{(3Z_2 - Z_1)/4Z_2}, \tag{6}$$

$$\theta_{tz2} = \pi - \arcsin\sqrt{(3Z_2 - Z_1)/4Z_2}. \tag{7}$$

It is analyzed from above that one transmission zero appears when $\theta=\pi$. And, based on (6) and (7), another two transmission zeros which are determined by Z_1/Z_2 can be found symmetrically around $\theta=180°$. How the transmission zeros and 3-dB fractional bandwidth is controlled by the ratio of Z_1 and Z_2 is indicated in Fig. 2. It is obvious that through changing Z_1/Z_2, the bandwidth for the filter is able to be adjusted conveniently. Besides, transmission zeros of the bandpass filter fails to be affected by the value of characteristic impedance Z_s, as shown in Fig. 3, where $Z_1=Z_2=80$ Ω. Moreover, when $S_{11}=0$, we can get the following relationship:

$$A\tan^2\theta * \tan 2\theta + B\tan 2\theta - 2C\tan\theta = 0. \tag{8}$$

$$A = Z_1^2 Z_2^2 Z_S^2 - Z_0^2 Z_1^2 Z_S^2 - Z_0^2 Z_2^2 Z_S^2, B = Z_0^2 Z_1^2 + Z_0^2 Z_2^2 - 4Z_0^2 Z_1 Z_2,$$

$$C = Z_0^2 Z_1 Z_2 Z_S + Z_0^2 Z_1 Z_2 Z_S^2.$$

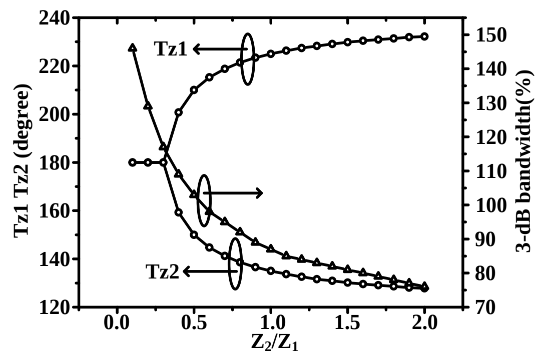


Fig. 2. Transmission zeros and the 3-dB bandwidth.

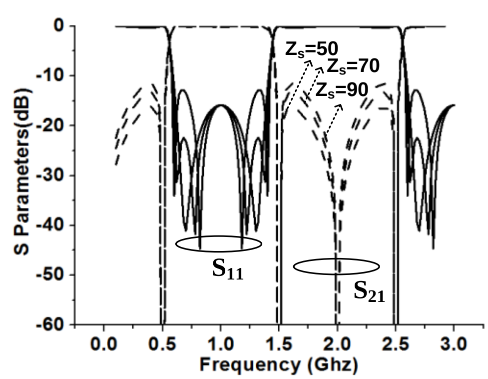


Fig. 3. S_{11} and S_{21} of circuit simulation.

The numbers of the transmission poles in the passband for the bandpass filter are mainly determined by the roots of the Equation (8), and the roots of the Equation (8) depend on the coefficients *A*, *B*, and *C*. Table 1 illustrates the numbers of the transmission poles for two cases in the Equation (8). In addition, the simulated results for the transmission poles are shown in Fig. 4 and Fig. 5, from which we can find that due to the introduction of the two shorted lines with characteristic impedance Z_s, several transmission poles can be realized and thus improving the passband transmission characteristic for the filter.

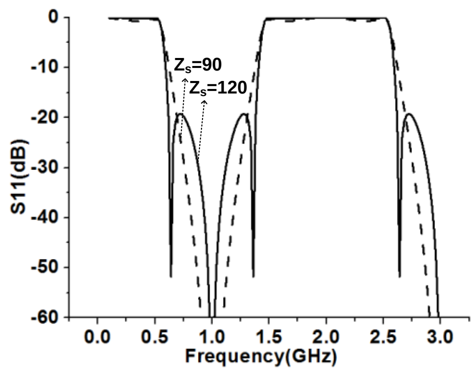


Fig. 4. Transmission pole (Z_1=Z_2=100 Ω).

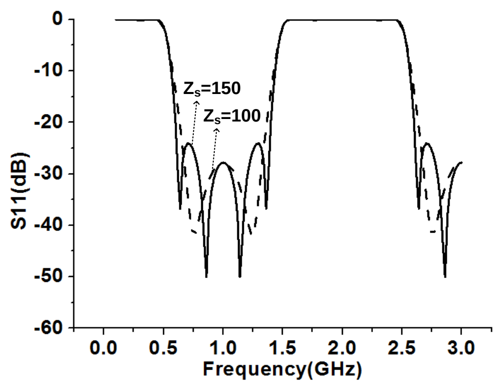


Fig. 5. Transmission pole (Z_1=120 Ω, Z_2=80 Ω).

Table 1: Numbers of transmission poles

Z_1 Z_2 Z_s		Transmission Poles
Z_1=100 Ω Z_2=100 Ω	Z_s>Z_1/2	$\theta_{tp1}<\theta_{tp2}=\pi/2<\theta_{tp3}$
	Z_s<Z_1/2	$\theta_{tp1}=\theta_{tp2}=\theta_{tp3}=\pi/2$
Z_1=120 Ω Z_2=80 Ω	Z_s>max(Z_1,Z_2)	$\theta_{tp1}=\theta_{tp2}<\pi/2<\theta_{tp3}=\theta_{tp4}$
	Z_s<max(Z_1,Z_2)	$\theta_{tp1}<\theta_{tp2}<\pi/2<\theta_{tp3}<\theta_{tp4}$

III. NOVEL WIDEBAND FILTER BASED ON 180o INVERTER

What's is analyzed above is focused on how to select the exact values of Z_1, Z_2 and Z_s, if one is given the design index. Besides, to design the novel wideband filter of excellent performance, one should construct a wideband 180° phase inverter. In this paper, the critical component [15] shown in Fig. 6 based on slot line and short-ended coupling line is employed to produce the 180° phase difference. And, the phase simulation result is given in Fig. 7.

Observing Fig. 7, one is able to conclude that the phase difference between the proposed phase inverter and a length of microstrip line nearly equals 180° from 1 GHz to 4 GHz. All the major parameters including gap width, coupling line width, coupling line length, via diameter, slot line width, slot line length, and slot line diameter are optimized in the software Ansoft HFSS to realize good impedance matching. When a signal is feed into phase inverter, the electrical line is supposed to reverse after it propagates through the slot line which can be seen clearly in Fig. 8.

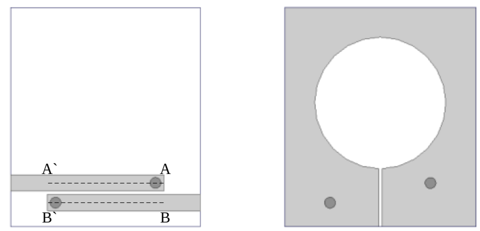


Fig. 6. The structure of the 180° phase inverter.

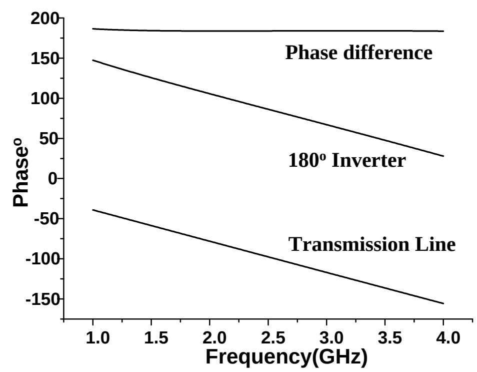


Fig. 7. Phase simulation of 180° inverter.

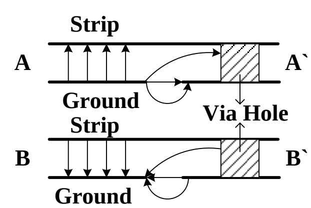


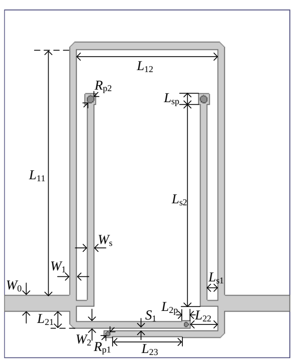
Fig. 8. The change of electrical line.

The initial physical length of each part of the proposed filter can be determined according to Fig. 1, if center frequency f_0 is given. Then, referred to Fig. 2 and Fig. 3, one can fix the ratio of Z_1 and Z_2 as long as the 3-dB bandwidth is given. Finally, Table 1, Fig. 4 and Fig. 5 tell how to find out the Z_1, Z_2 and Z_s.

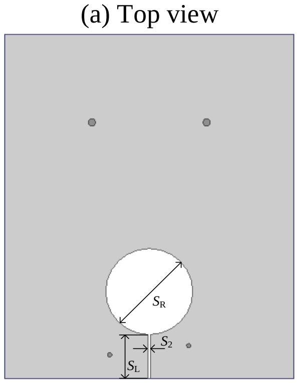
Figure 9 illustrates the geometry of the wideband bandpass filter with a 180° swap, and the detailed circuit and structure parameters is shown below. The simulated results are shown in Fig. 11. Two transmission zeros are located at 0.9 GHz and 2.6 GHz, respectively; while four transmission poles are realized in the passband (3-dB fractional bandwidth is approximate 86.8%). The insertion loss is less than 0.5 dB, while the return loss is over 19 dB (1.07-2.42 GHz). Furthermore, over 20 dB second harmony suppression is achieved.

One prototype of proposed bandpass filter with size of 22 mm×41 mm is fabricated on a substrate with ε_r = 2.55, h = 0.78 mm, and $tan\delta$ = 0.0006. Figure 10 illustrates the photograph of the filter. The measured S-parameters is illustrated in Fig. 11. Two transmission zeros are located at 0.83 GHz and 2.45 GHz; within the passband (0.91-2.34 GHz), the measured insertion loss for the filter is less than 1.0 dB while the return loss is over 11 dB. Furthermore, over 20 dB second harmony suppression is achieved. Good agreement can be observed between the simulation and the experiments. The slight frequency shift between measured and simulated results may be caused by measurement and fabrication errors.

To further demonstrate the performances of this filter, the comparisons of measured results for several transversal signal-interaction wideband filter structures [12-13] are shown in Table 2.



(a) Top view



(b) Bottom view

Fig. 9. Geometry of the proposed filter.
(*W_0=2.2 mm; W_1=0.95 mm; W_2=0.95 mm; W_s=0.9 mm; S_1=0.3 mm; S_2=0.3 mm; S_R=12 mm; S_L=6.1 mm; L_{11}=34 mm; L_{12}=19.8 mm; L_{21}=2.35 mm; L_{22}=3.9 mm; L_{23}=9.8 mm; L_{2P}=1.1 mm; R_{P1}=0.6 mm; L_{s1}=1.55 mm; L_{s2}=27.9 mm; L_{sP}=1.5 mm; R_{P2}=1.0 mm.*)

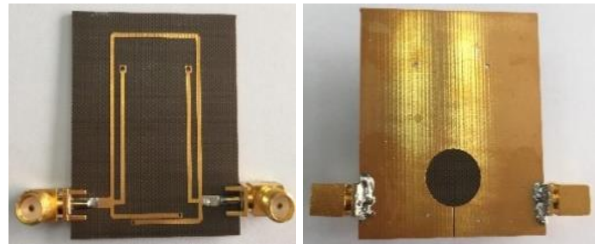


Fig. 10. Photograph of the proposed bandpass filter.

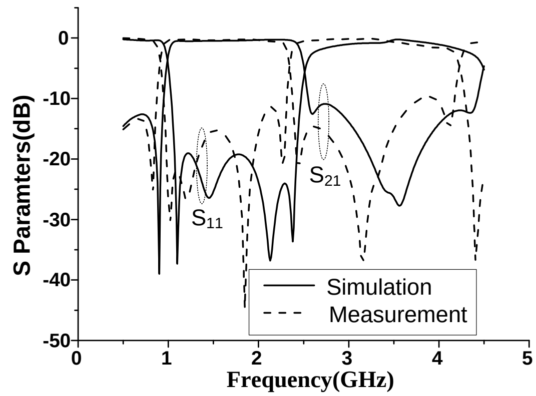


Fig. 11. Simulated and measured results.

Table 2: Comparisons with wideband filters in [12] and [13]

Different Structures	Filter in This Paper	Ref. [13]	Ref. [12]
f_0	1.63 GHz	6.8 GHz	6.8 GHz
Circuit size (λ_o)	0.17×0.32	0.63×0.49	0.62×0.47
Transmission zeros	3	1	1
Transmission poles	4	3	3
Second harmony suppression	20 dB	15 dB	15 dB

IV. CONCLUSION

In this paper, a novel compact wideband filter based on transversal signal-interaction concepts is proposed. Two transmission paths are used to realize the signal transmission from Port1 to Port2. The bandwidth for the bandpass filter can be easily adjusted by changing the impedances of the two transmission paths. Good frequency selectivity and harmonic suppression can be realized for the bandpass filter. Good agreements between simulated and measured responses of the filter are demonstrated, indicating the validity of the design strategies.

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