Wideband Coupled-Line Microstrip Filters With High-Impedance Short-Circuited Stubs

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***Abstract*—There have been difficulties in realizing wideband coupled-line filters with microstrip technology due to tight couplings demanded at input and output ports. To solve the problem, a realization method using high-impedance short-circuited stubs is proposed. To verify it, a coupled-line microstrip filter with more than 65% bandwidth is fabricated at 3 GHz and measured. Measured results are in good agreement with prediction, showing that the measured return and insertion losses are better than 18 and 0.85 dB, respectively, within more than 65% bandwidth.**

***Index Terms*—High-impedance short-circuited stubs (HISSs), wideband coupled-line microstrip filters.**

I. Introduction

CONSIDERABLE interest in wideband bandpass filters (BPFs) is on increase which are used for diverse microwave and millimeter wave applications [1]–[8]. Most wideband BPFs are implemented with microstrip and other structures combined to drag into wideband performance. Other structures may be coplanar wave guides [1], slot lines located on the ground plane, or strip lines realized with overlays [2], [3]. The design tools and information for the uniplanar structures or strip lines are, however, relatively poorer than those of the microstrip technology, and intensive optimization process is therefore inevitable. Wideband BPFs may be fabricated only with microstrip technology, or, easy process with low cost but seemingly non-systematic design approach [5]–[8]. The coupled-line microstrip filters may be designed systematically but realizable fractional bandwidth is generally up to 50% [3] due to high couplings required at input and output ports. In this letter, a fabrication method for the wideband coupled-line microsrip filters is presented to have more than 65% bandwidths. For this, high-impedance short-circuited stub consisting of coupled transmission-line sections is introduced, and a way to realize such a wideband filter is to be discussed.

II. Wideband Parallel Coupled-Line Filter

A parallel coupled- line filter consists of n resonators [9]. Each resonator is short-circuited at both ends and a half-wavelength long at a design center frequency. The filter may be viewed as $n+1$ pairs of parallel coupled transmission-line sections with a quarter wavelength connected in cascade. The even- and odd-mode impedances of each set of the parallel coupled transmission-line sections are $(Z_{0e}, Z_{0o})_{n,n+1}$. For a bandwidth more than 65% having 0.1 dB ripple, $n = 6$ is required for which the even- and odd-mode impedances are calculated. The calculated even-mode impedances are $(Z_{0e})_{0,1} = (Z_{0e})_{6,7} = 176.05\ \Omega$, $(Z_{0e})_{1,2} = (Z_{0e})_{5,6} = 240.38\ \Omega$, $(Z_{0e})_{2,3} = (Z_{0e})_{4,5} = 200\ \Omega$ and $(Z_{0e})_{3,4} = 196.07\ \Omega$ [9], which are almost impossible to fabricate in microstrip technology. To realize the filter with microstrip techonlogy, a set of 90° coupled transmission-line sections with two short-circuited terminations is modified using its equivalent circuit [9], [10]. Then, the resulting filter configuration is obtained as shown in Fig. 1, consisting of 90° transmission-line sections and 90° short-circuited stubs. In this case, the characteristic impedances of the transmission-line sections and the short-circuited stubs are listed in Table I, where $Z_{i\ i+1}$ (i; from 0 to 6) and Z_{sj} (j; from 1 to 8) are those of the transmission-line sections and the short-circuited stubs, respectively. Based on the data in Table I, the filter in Fig. 1 was simulated at a design center frequency of 3 GHz, and the simulation results are plotted in Fig. 1 where the bandwidth is about 67.67%.

The transmission-line sections with $Z_{23} = Z_{45} = 142\ \Omega$ and $Z_{34} = 147\ \Omega$ (Fig. 1, Table I) may be realized with microstrip format if a substrate is thicker than 0.78 mm and the dielectric constant of the substrate is lower than 2.33 like RT/Duroid

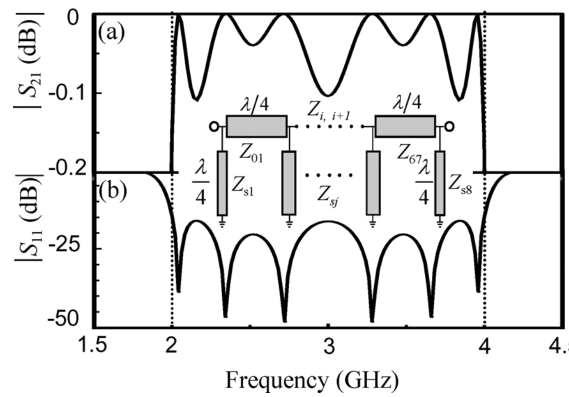

Fig. 1. Frequency responses of the filter. (a) $|S_{21}| = |S_{12}|$. (b) $|S_{11}|$.

TABLE I
CHARACTERISTIC IMPEDANCES OF THE FILTER IN FIG. 1

$Z_{01} = Z_{67} = 69.8\ \Omega$	$Z_{12} = Z_{56} = 107\ \Omega$
$Z_{23} = Z_{45} = 142\ \Omega$	$Z_{34} = 147\ \Omega$
$Z_{s1} = Z_{s8} = 176.05\ \Omega$	$Z_{s2} = Z_{s7} = 101\ \Omega$
$Z_{s3} = Z_{s6} = 109\ \Omega$	$Z_{s4} = Z_{s5} = 99\ \Omega$

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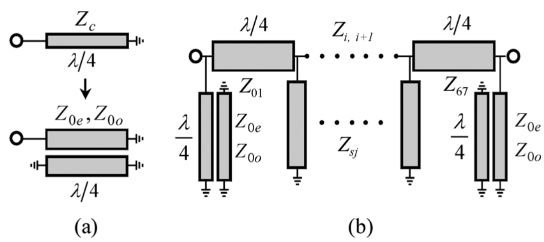

Fig. 2. (a) HISS. (b) Proposed filter.

5870 ($\varepsilon_r = 2.33$, $H = 0.787$ mm). Characteristic impedance $Z_{s1} = Z_{s8} = 176.05\ \Omega$ of the short-circuited stubs is, however, almost impossible in conventional PCB technology. How to realize such high-impedance short-circuited stubs without any fabrication problem will be discussed.

III. HISSs and Measurements

A single short-circuited stub with a high characteristic impedance Z_c may be equivalent to a set of coupled transmission-line sections with three short circuits as depicted in Fig. 2(a). To distinguish the two short-circuited stubs, the one with a set of coupled transmission-line sections is designated as high-impedance short-circuited stub (HISS). In this case, the even- and odd-mode impedances of the HISS [10] are

$$Z_{0e} = Z_c \frac{C}{1-C}, \; Z_{0o} = Z_c \frac{C}{1+C} \tag{1}$$

where C is coupling coefficient of the HISS in Fig. 2(a). In this case, the equivalent characteristic impedance Z_c of the HISS is

$$Z_c = \frac{2Z_{0e}}{\frac{Z_{0e}}{Z_{0o}} - 1} = Z_{0e}\frac{1-C}{C} = Z_{0o}\frac{1+C}{C}. \tag{2}$$

If the ratio of Z_{0e} to Z_{0o} is close to unity or the coupling coefficient becomes very small in (2), very high characteristic impedance of Z_c may be obtained. To realize the short-circuited stubs with $Z_{s1} = Z_{s8} = 176.05\ \Omega$ in Fig. 1, the HISSs may be replaced with those in Fig. 1, resulting in the filter configuration in Fig. 2(b). To see the influence of HISSs on the frequency responses, those of $|S_{11}|$ of the filter in Fig. 2(b) were simulated by fixing Z_c at 176.05 Ω and varying C. The frequency variations are plotted in Fig. 3(a) where only half performance is illustrated.

When the coupling coefficient C is from -1 to -3 dB, the frequency responses are about same as the original one. As the coupling coefficients become smaller, the first and second pole locations are shifted gradually toward the lower frequencies (Fig. 3(a)). With $C = -8$ dB, the frequency response is still acceptable, but the cases with $C > -8$ dB may be difficult to fabricate on the substrate (RT/Duroid 5870) without any wire bonding. When $C = -12$ dB, the fabrication is possible with the substrate but the frequency response is deviated from the original filter performance. To see the changes in frequency responses under the realizable HISSs, the coupling coefficient is fixed at -12 dB and the characteristic impedance of Z_c is

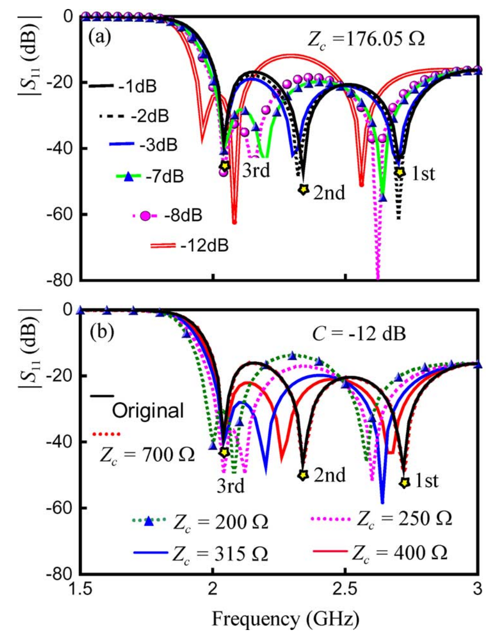

Fig. 3. Frequency responses of $|S_{11}|$. (a) The characteristic impedance of Z_c fixed at 176.05 Ω and the coupling coefficients varied. (b) The coupling coefficient fixed at -12 dB and the characteristic impedance of Z_c varied.

TABLE II
Even- and Odd-Mode Impedances With $C = -12$ dB

Z_c	Z_c (Ω)				
	200 Ω	250 Ω	315 Ω	400 Ω	700 Ω
Z_{0e}	67.09	83.86	105.67	134.18	234.8
Z_{0o}	40.15	50.19	63.24	80.30	140.5

varied. The resulting even- and odd-mode impedances of the HISSs are calculated in Table II.

The frequency responses due to Z_c variations are plotted in Fig. 3(b). When $Z_c = 200\ \Omega$, the third pole of the filter is located outside of that of the original filter and the matching performance is not better than that of the original one. When $Z_c = 250\ \Omega$, the third pole is located slightly outside of that of the original filter, and the general performance is not better than that of the original one. When $Z_c = 315$ or 400 Ω, the location of the third pole is about the same as that of the original one, and both of the return losses are better than that of the original one. As the characteristic impedance of Z_c becomes higher, the locations of the other poles become closer to those of the original ones, which results in the performance close to that of the original one. When $Z_c = 700\ \Omega$, the frequency response of the filter is the same as the original one. Even if the frequency performance with $Z_c = 700\ \Omega$ is the same as that of the original one, the even-mode impedance for $Z_c = 700\ \Omega$ is 234.815 Ω when $C = -12$ dB, which is not easy to be realized. Instead of $Z_c = 700\ \Omega$, the HISS with $Z_c = 315\ \Omega$ may be used, because the whole frequency response of the filter is better than that of the original one, and the HISSs may be completely realizable. For $Z_c = 315\ \Omega$ of HISS with $C = -12$ dB, the even- and odd-mode impedance are 105.67 and 63.24 Ω (Table II). In this case, the physical dimensions are width $w = 0.885$ mm and gap

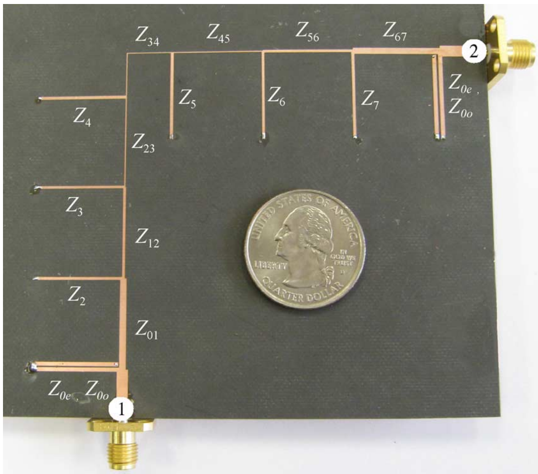

Fig. 4. Fabricated filter.

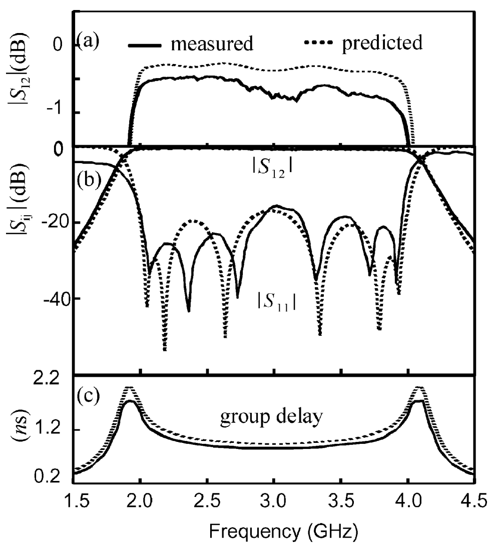

Fig. 5. Results measured and predicted are compared. (a) $|S_{12}|$ only. (b) $|S_{12}|$ and $|S_{11}|$. (c) Group delay.

size $s = 0.409$ mm on the substrate (RT/Duroid 5870) and the fabricated filter is illustrated in Fig. 4.

The results measured and predicted are compared in Fig. 5 where the scattering parameters of $|S_{11}|$ and $|S_{12}|$ are described in Fig. 5(a) and (b) and the group delay in Fig. 5(c). The measured pole locations are slightly different from those predicted but the measured bandwidth is more than 65%. The measured insertion loss is less than 0.85 dB and the return loss greater than 18 dB in whole bandwidth (from 2 to 4 GHz). The measured results are in good agreement with the predicted ones as demonstrated in Fig. 5.

IV. Conclusion

In this letter, a fabrication method for the wideband coupled-line microstrip filters is suggested using HISSs. The HISS each consists of a set of coupled transmission-line sections with three short-circuited circuits and the characteristic impedance of the HISSs can be theoretically as high as possible depending on the requirements. In this letter, only one example of the wideband coupled-line filters is demonstrated but various applications may be expected using the HISSs.

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