Microstrip Coupled-Line Lowpass Filter with Wide Stopband for RF/Wireless Systems

Vamsi Krishna Velidi, Mrinal Kanti Mandal, and Subrata Sanyal

ABSTRACT—*We present the design of a compact microstrip lowpass filter with a wide stopband which is up to ten times the cutoff frequency. The filter is based on a coupled-line configuration and shunt open stubs. The open stubs create additional transmission zeros, which are used to extend the stopband of the filter without any additional components or cascaded units. A prototype lowpass filter with a 3 dB cutoff frequency of 0.428 GHz and a 15 dB stopband extended up to 4.77 GHz is fabricated to validate the theoretical predictions.*

Keywords—*Microstrip filter, coupled-line, lowpass filter, wide stopband.*

I. Introduction

Recently, compact lowpass filters (LPF) with a wide stopband, low insertion loss, and sharp rejection have been of great interest to suppress undesired broadband signals in many RF wireless applications. Conventional methods suffer from gradual cutoff and narrow upper stopband width [1]-[6]. Several designs have been proposed to address this problem. One technique uses a defected ground structure (DGS) [1], [2]. A variety of DGS shapes are used for this purpose [2]. Another method uses complementary split ring resonators [3]. However, the structures are difficult to fabricate and require a minimum air space between the component and the system ground for the structures to work effectively. In [4]-[6], coupled-line configurations with hairpin resonators are presented for the LPF design. However, the stopband is extended by using two or more cascaded units [4], [5], which increases the overall size.

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In this paper, a simple configuration consisting of two open stubs with a single coupled-line configuration [6] is proposed to obtain a wide stopband without any additional complex structures or cascaded units.

II. Analysis and Design of the Lowpass Filter

Figures 1(a) and (b) show the microstrip layout and the equivalent transmission line models of the proposed LPF, respectively. In the figure, Z_{0e} and Z_{0o} are the characteristic impedances and θ_{0e} and θ_{0o} are the electrical lengths of the coupled section in the even- and odd-mode excitations, respectively; and Z_2 and θ_2 are the characteristic impedance and electrical length of the transmission line section, respectively.

The bandstop filter (BSF) in [6] is used as the basic section which produces three transmission zeros. The structure has the advantage that the variation of the 3 dB cutoff frequencies with the coupled-line width (W) is insignificant for fixed spacing S

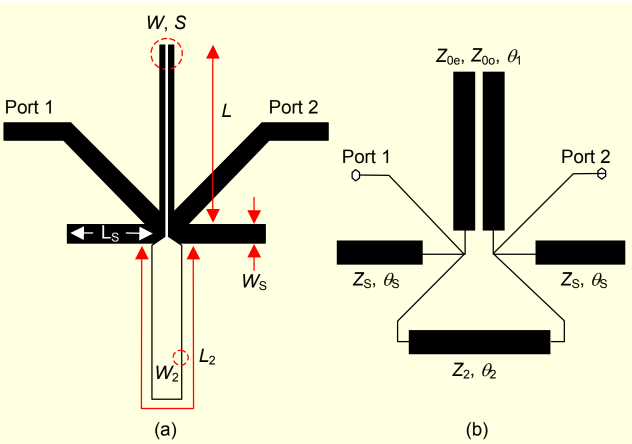

Fig. 1. (a) Proposed LPF layout and (b) its transmission line model.

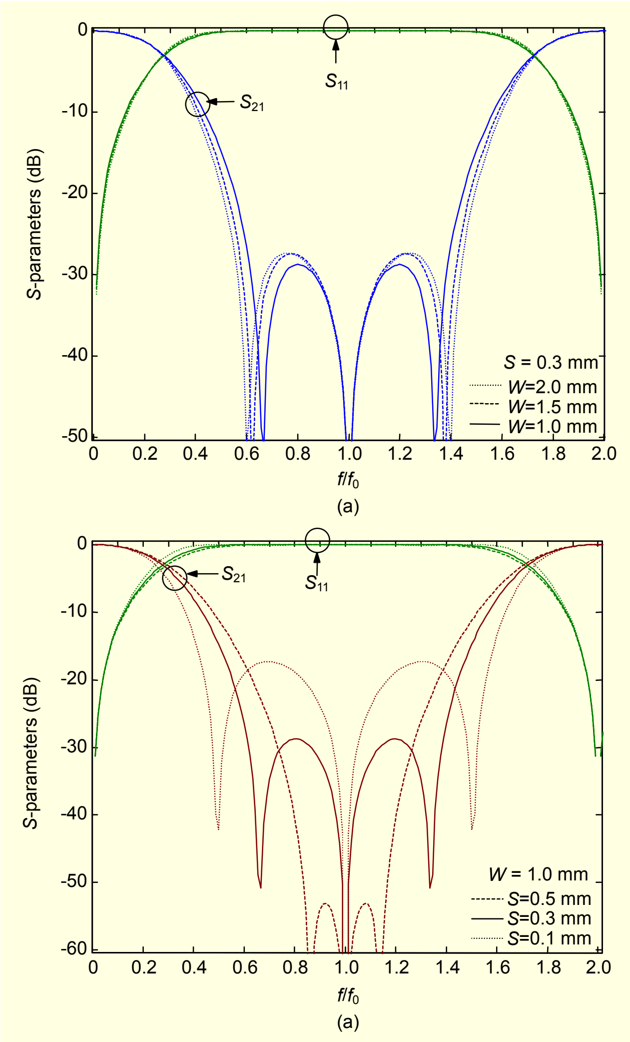

Fig. 2. Circuit computed responses of the basic unit as a function of coupled-line (a) width W and (b) spacing S, (Z_2=120 Ω).

and impedance Z_2 (see Fig. 2(a)).

Thus, the LPF cutoff frequency is almost independent of W. Under the approximation of equal even- and odd-mode velocities, $\theta_{0e}=\theta_{0o}=\theta_1$, the zero condition is

$$Z_2=\frac{2Z_{0e}Z_{0o}}{(Z_{0e}-Z_{0o})\sin\theta_2\tan\theta_1}. \quad (1)$$

The zeros are symmetrically placed near the stopband center frequency (f_0) if the electrical lengths of the coupled-line θ_1 and the transmission line segment θ_2 are quarter-wavelength and half-wavelength, respectively, at f_0. The stopband frequency responses of the basic BSF unit are shown in Fig. 2(b) as a function of S. As S is reduced, the coupling between the coupled lines becomes stronger, which broadens the stopband bandwidth. The 3 dB stopband fractional bandwidth is greater than 150% for S=0.3 mm. However, in many practical applications, the LPF may require a much wider stopband

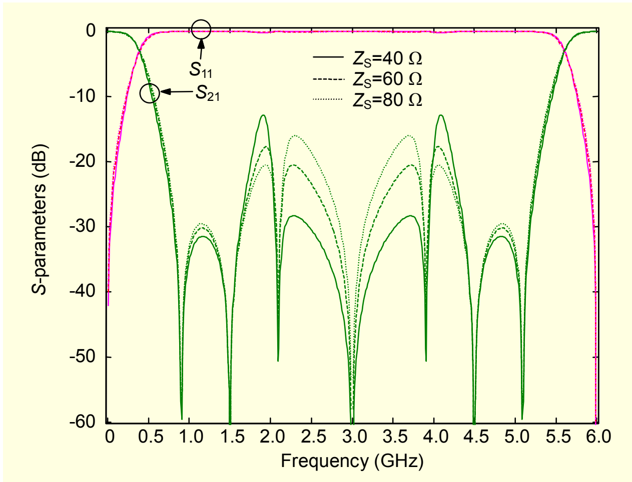

Fig. 3. Predicted wideband response of the proposed lowpass filter as a function of open-stub impedance (Z_S) with $\theta_S=\pi/4$ at f_0=1.5 GHz (Z_{0e}=81.2 Ω, Z_{0o}=40.1 Ω, Z_2=120 Ω, and $\theta_1=\theta_2/2=\pi/2$).

bandwidth. Thus, the basic section has limited application as an LPF due to the harmonic passbands at the odd multiples of f_0, which appear due to the periodic properties of a transmission line section.

To improve the stopband bandwidth limitation, the configuration is modified by introducing two shunt open stubs connected at the feed points (Fig. 1). The shunt open stubs of impedance Z_S and electrical length θ_S produce additional transmission zeros where θ_S equals an odd multiple of $\pi/4$. Therefore, if θ_S is one eighth of the guided wavelength at f_0, the stubs produce an additional transmission zero at $2f_0$ which suppresses the second harmonic passband of the basic section and extends the overall stopband. The advantage of using the stubs is that the stopband bandwidth and rejection level can be simultaneously controlled simply by tuning Z_S without any cascaded unit. The lower 3 dB cutoff frequency of the basic BSF unit is taken as the desired 3 dB cutoff frequency (f_C) of the LPF. It remains almost unaffected by this stub modification. As an example, Fig. 3 shows the computed wideband response of the LPF and the dependence of the stopband rejection level on Z_S. The minimum stopband attenuation also depends on Z_2. An overall rejection better than 20 dB or more can be achieved by tuning Z_S and Z_2 simultaneously.

III. Fabrication and Measurement

A prototype LPF of 3 dB cutoff frequency f_C=0.428 GHz was fabricated on a low cost FR4 substrate (ε_r=4.3, h=1.58 mm, and $\tan\delta$=0.022). The FR4 substrate is a low frequency substrate. The substrate parameters ε_r and $\tan\delta$ approximately maintain the specified values up to 6.0 GHz. Substrate loss

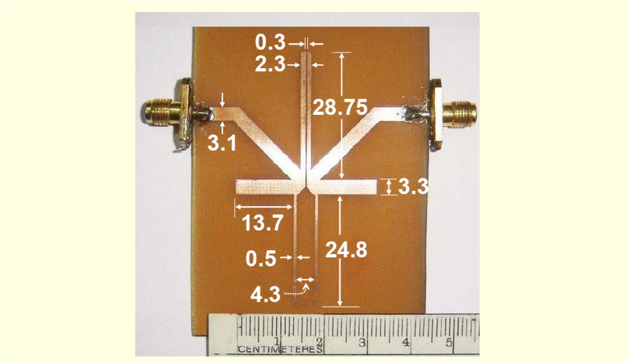

Fig. 4. Photograph of the fabricated LPF.

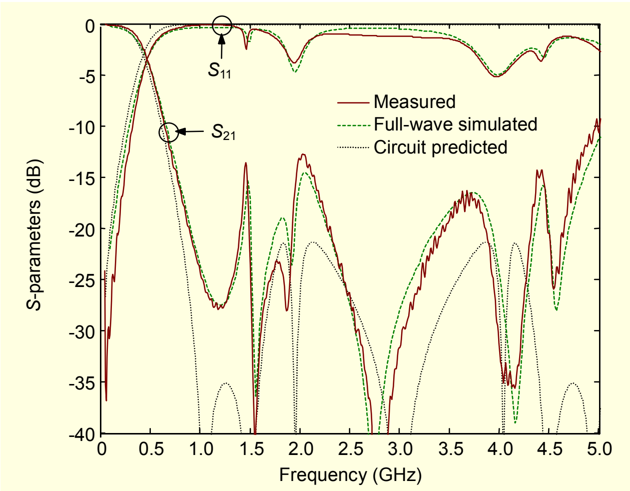

Fig. 5. Measured, full-wave simulated, and circuit predicted responses of the proposed LPF.

increases rapidly beyond this frequency; therefore, a low value of f_C was chosen for the prototype to correctly show the stopband performance on the present substrate.

Considering the previous discussions, the following filter parameters were chosen: Z_{0e}=118.9 Ω, Z_{0o}=50.9 Ω (W=1.0 mm, S=0.3 mm), Z_2=113 Ω (W_2=0.5 mm), and Z_S=48 Ω (W_S=3.3 mm). The electrical lengths are $\theta_1=\theta_2/2=2\theta_S=90^0$ at f_0=1.5 GHz. Figure 4 shows a photograph of the fabricated LPF with physical dimensions. The overall filter size is 53.55 mm × 32.7 mm.

The full-wave simulator IE3D was used to simulate the filter structure. An Agilent 8510C vector network analyzer was used in the measurements. Figure 5 shows the circuit predicted, full-wave simulated, and measured responses of the filter. Note that the basic section provides three symmetrical transmission zeros under the approximation of equal even- and odd-mode electrical lengths, that is, $\theta_e=\theta_o$. However, a microstrip line being quasi TEM in nature, θ_o is always less than θ_e. For a given physical length, the difference in the electrical lengths increases as the frequency decreases. In the worst condition, the number of zeros may decrease to two [7]. The computed responses presented in the figure consider the ideal case, that is, when θ_e and θ_o are equal. Thus, the simulated and measured responses, which consider the actual values of θ_e and θ_o, differ from the computed responses. Equal θ_e and θ_o can be obtained by etching grooves along the inner edges of the coupled-line, by etching a ground plane aperture just below the coupled-line, or by using a dielectric overlay [7].

The measured 3 dB cutoff frequency is 0.468 GHz. Insertion loss is within 1.0 dB up to 0.346 GHz. The measured 15 dB stopband is from 0.770 GHz to 4.772 GHz, which is more than ten times the filter cut-off frequency.

IV. Conclusion

We proposed a simple uniplanar LPF configuration with extended stopband using coupled-line and shunt open stubs. The stopband rejection level can be simply controlled by the impedances. We presented a prototype LPF with a wide stopband which is up to ten times the cutoff frequency. The filter structure is uniplanar and easy to fabricate. It is expected that the proposed configuration will find wide applications in RF/wireless systems.

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