Hindawi Publishing Corporation
Active and Passive Electronic Components
Volume 2007, Article ID 93548, 5 pages
doi:10.1155/2007/93548

Research Article

Design of a Broadband Parallel-Coupled Microstrip Filters without Spurious Resonances

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Received 5 March 2007; Accepted 21 November 2007

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A design of parallel-coupled microstrip bandpass filters without spurious resonance is presented. Two different techniques are used to eliminate this response at twice the passband frequency ($2f_o$). The first one is based on usage of suspended substrate, while the second is carried out by shorting the parallel-coupled lines to the ground plane through two shorting walls. The numerical results show that a broadband filter can be obtained by the suppression of the spurious response. The finite difference time domain (FDTD) with the perfect matched layer (PML) is used in the present analysis. The obtained results are compared with the available published data and good agreements are found.

1. INTRODUCTION

In microwave and millimeter-wave systems, parallel-coupled microstrip bandpass filters are widely used. The conventional design of these filters suffers from the spurious response at twice the passband frequency ($2f_o$) [1, 2]. This is because the inequality of the velocities of the even and odd modes of each coupled sections [1]. This problem could greatly limit the filter applications.

Many techniques have been proposed for avoiding the presence of the spurious response. A defected ground plane is effective in suppressing the spurious response [3]. Microstip filters with ground grooves are used for implementation of harmonic suppression in [4]. In [1, 2], microstrip-coupled lines with a dielectric overlay or a suspended substrate are used, respectively. Recently, shorting walls are used to get a broadband antenna [5].

In the present work, two different techniques are used to suppress the spurious response of broadband parallel-coupled microstrip filters. These techniques based on usage of either suspended dielectric substrates or shorting the parallel-coupled lines to the ground planes through two shorting walls. The effect of the dielectric permittivity as well as the width of the shorting walls is studied.

2. FORMULATION OF THE PROBLEM

2.1. Time domain finite difference formulation

The microstrip transmission line filter is shown in Figure 1 where the strips and the bottom planes are made of perfectly conducting material. The substrate has a relative dielectric constant ε_r. The microstrip line is taken as an open structure. For this structure, Maxwell's equations can be written as

$$\frac{\partial \overline{H}_i}{\partial t} = -\frac{1}{\mu_i}\nabla x\overline{E}_i - \frac{\rho_i}{\mu_i}\overline{H}_i, \tag{1}$$

$$\frac{\partial \overline{E}_i}{\partial t} = \frac{1}{\varepsilon_i}\nabla x\overline{H}_i - \frac{\sigma_i}{\varepsilon_i}\overline{E}_i, \tag{2}$$

where ρ is the magnetic resistivity of the medium in (Ω/m); σ is the electric conductivity of the medium in (S/m); and $i = 1, 2$ represents the substrates and free space, as shown in Figure 1.

To discretize Maxwell's equations (1) and (2), the centered difference approximation is applied to both time and space first-order partial differentiations. This leads to the discretized Maxwell's equations for homogeneous regions [5–7].

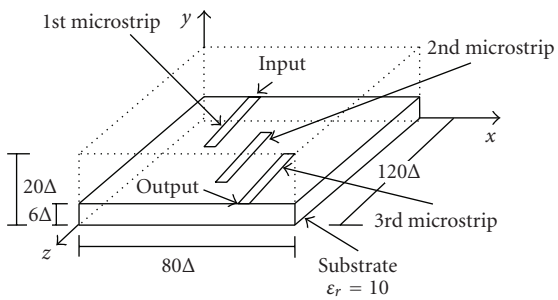


Figure 1: The side-coupled microstrip filter configuration.

For a nonhomogeneous domain, each homogeneous region is treated separately and then the boundary conditions are forced at the interfaces.

2.2. Perfectly matched layer (PML)

The PML is a nonphysical absorber adjacent to the outer boundary of the open structure computational domain. The PML ensures that a plane wave incident at any arbitrary angle or frequency from the free space upon a PML region is totally transmitted into PLM region with a negligible reflections toward the inner structure [8]; that is, total absorption for the outgoing waves. This is carried out by introducing an additional degree of freedom by splitting the field components with anisotropic material properties in the PML region. For this material, the electric conductivity and the magnetic loss are related by [8, 9].

3. NUMERICAL RESULTS

The configuration of the analyzed microstrip filter is shown in Figure 1. The space steps are $\Delta x = \Delta y = \Delta z = 0.212$ mm and the total mesh dimensions are $80 \times 20 \times 120$ in the x, y, and z directions, respectively. At the top and side faces, a PML of width with different number of cells is considered. The microstrip line parameters are [10] as follows:

(i) width of the microstrip conductor $W = 6\Delta$,
(ii) thickness of the substrate $H = 6\Delta$,
(iii) dielectric constant of the substrate $\varepsilon_r = 10.0$, and
(iv) length of each transmission line $= 60\Delta$.

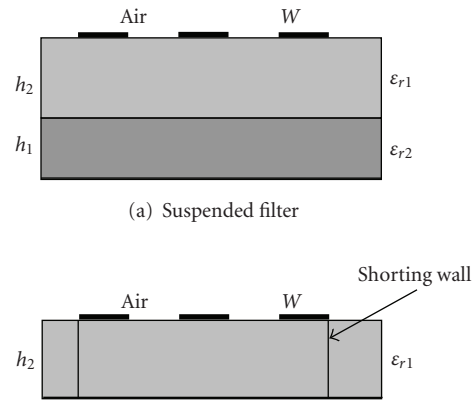
The spaces between the strips and the strip widths are 6Δ, and centered on the substrate.

The time step used is $\Delta t = 0.176$ picoseconds. The input signal is a band-limited cosine pulse of the form

$$\begin{aligned} E_y(t) &= 1 - \cos(2\pi f_{\text{band}} t) \quad \text{for } 0 \le t \le 1/f_{\text{band}} \\ &= 0 \quad \text{for } t > 1/f_{\text{band}} \\ f_{\text{band}} &= 11.8\,\text{GHz}. \end{aligned} \tag{3}$$

This pulse is fed under the microstrip conductor at the plane $z = 0$, and the initial values of the other components are made zero.

The two proposed structures are shown in Figure 2. In Figure 2(a), a suspended microstrip filter is given. Four different dielectric substrates ($\varepsilon_r = 2.6, 3.5, 4.8, 10$) are studied. Figure 2(b) shows a microstrip filter with shorted coupled lines to the ground plane through shorting walls. Three different wall widths are considered. The walls shorted the left- and the right-coupled lines. These lines are shortened a distance equals 30Δ of the plane $z = 0$.



(a) Suspended filter

(b) Shorting walls filter

Figure 2: Geometry of the proposed parallel-coupled filters.

In the first part of the present work, a conventional filter without suspended substrate is analyzed then four different cases of suspended substrate are considered. In these cases, the dielectric constant is changed to study its effect on the rejection level of the spurious response on the upper stopband.

Figure 3 shows a comparison between the results of the conventional and the suspended case of dielectric constant (ε_{r2}) equals 2.6. The scattering parameters show that the suspended substrate rejects the spurious response at 8 GHz by more than 20 dB. On the other hand, the input impedance is almost pure real of 50 Ω over the passband.

Figure 4 shows that the rejection level almost equals 40 dB at passband frequency when using a suspended substrate of ε_{r2} equals 3.5 with input impedance equals 50 Ω.

Figure 5 shows that a suppression of more than 30 dB to the spurious response is achieved at $2f_o$ (8 GHz) for a suspended substrate of ε_{r2} equals 4.8.

In the final case (see Figure 6) a suspended substrate of ε_{r2} equals 10.0 is used in which the spurious response starts to appear again at $2f_o$ and the input impedance is not still have a 50 Ω at that frequency.

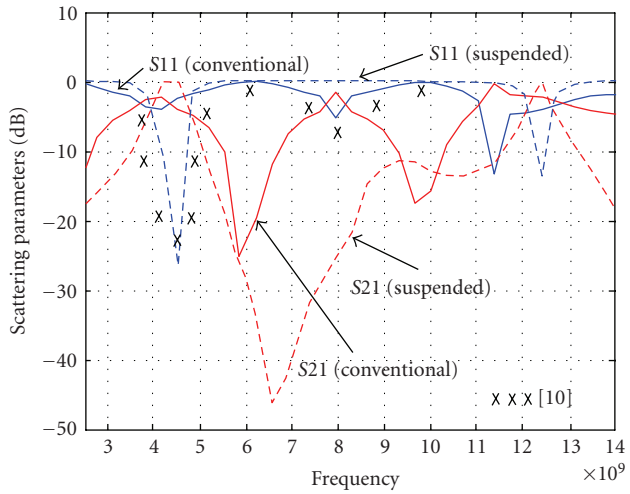
In the second part, the parallel-coupled lines of the filters are shorted to the ground plane through two shorting walls. The effect of the wall width is considered. Three different cases are studied.

Case 1. Shorting wall width $= 3\Delta x$.

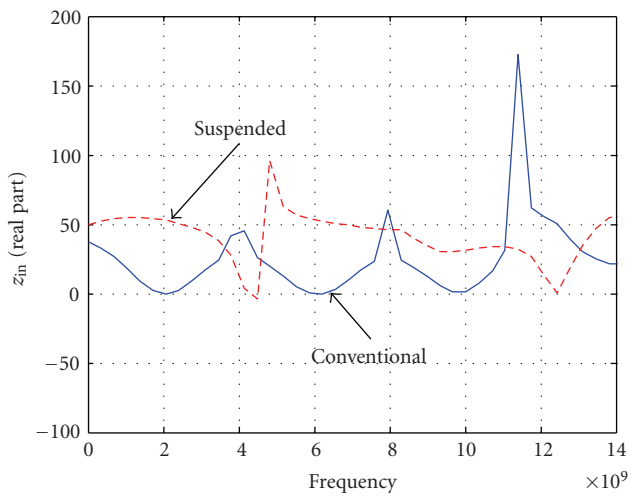
Case 2. Shorting wall width $= 6\Delta x$.

Case 3. Shorting wall width $= 10\Delta x$.

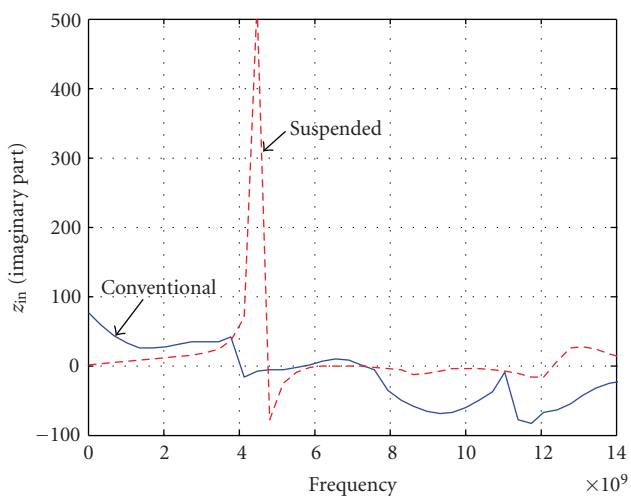
Figure 7 gives a comparison of the scattering parameters for the proposed filter and the three different cases of shorting walls. For the three cases, the spurious at 8 GHz is



(a) The scattering parameters

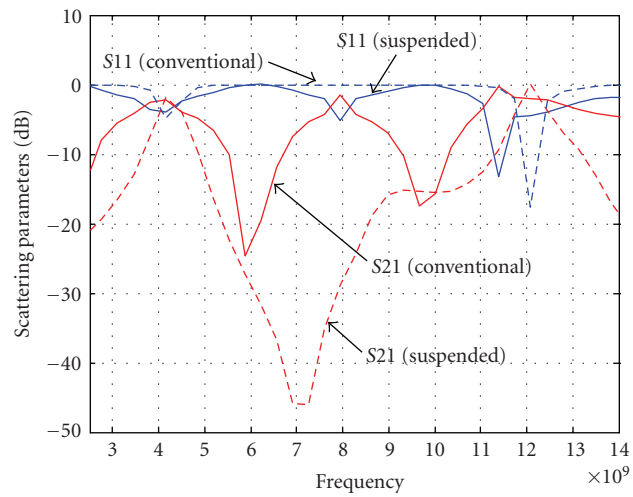


(b) The real part of the input impedance

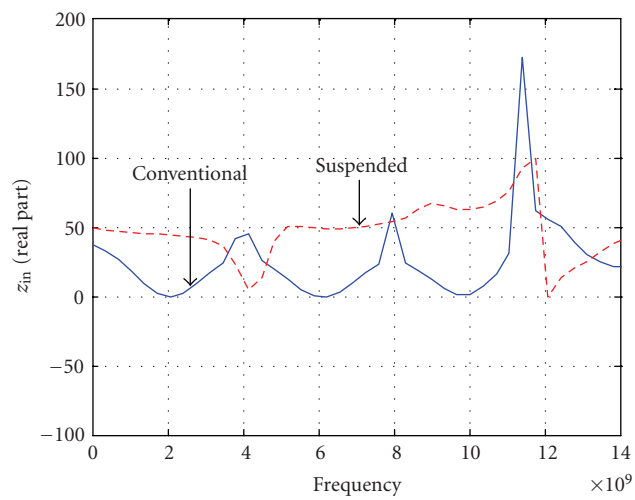


(c) The imaginary part of the input impedance

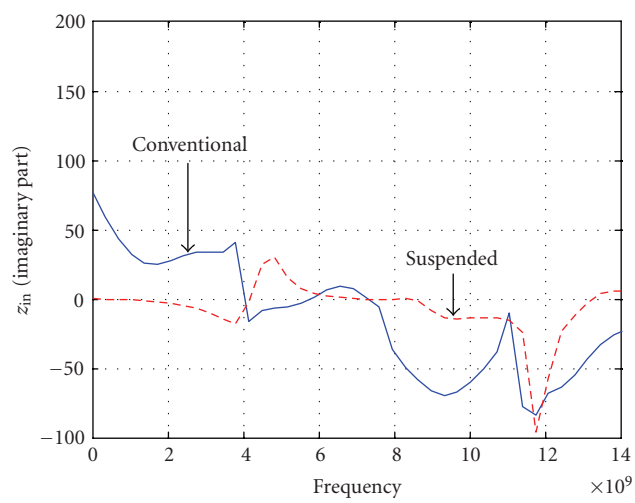
Figure 3: Comparison between the frequency response of the conventional and suspended filter with suspended substrate of ε_{r2} equals 2.6.



(a) The scattering parameters

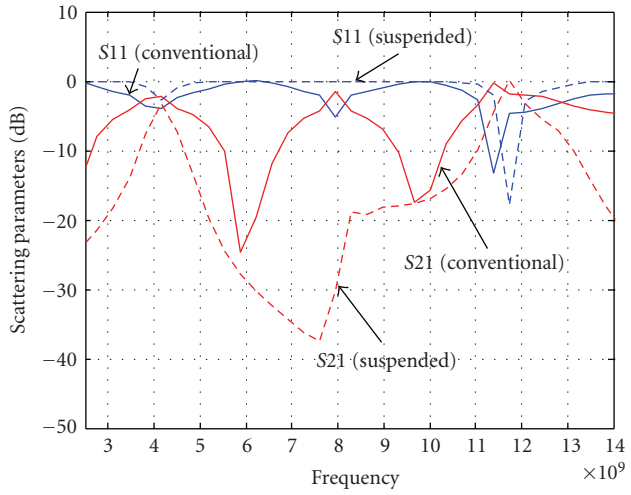


(b) The real part of the input impedance

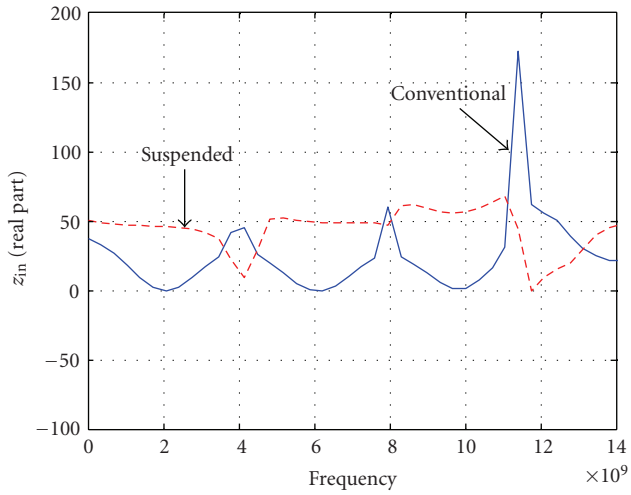


(c) The imaginary part of the input impedance

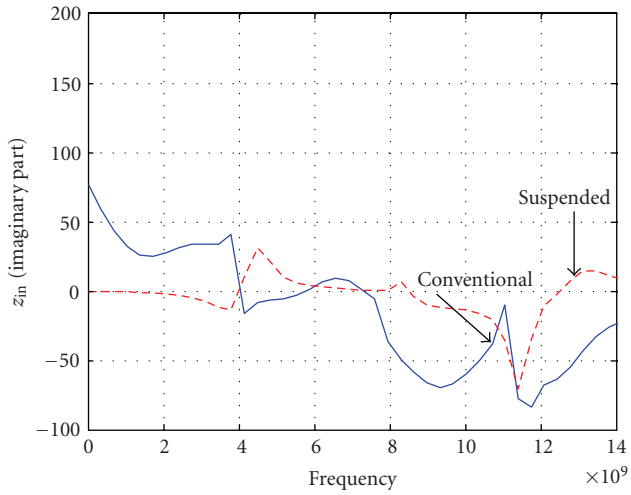
Figure 4: Comparison between the frequency response of the conventional and suspended filter with suspended substrate of ε_{r2} equals 3.5.



(a) The scattering parameters

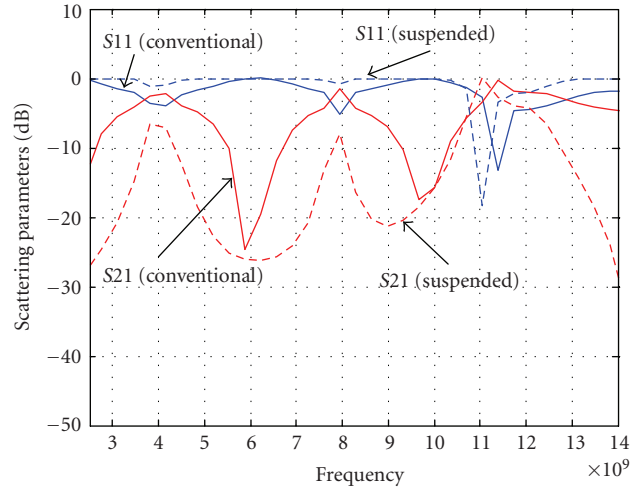


(b) The real part of the input impedance

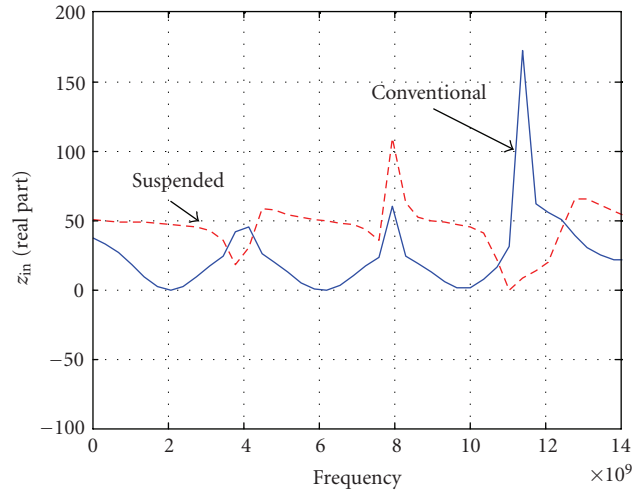


(c) The imaginary part of the input impedance

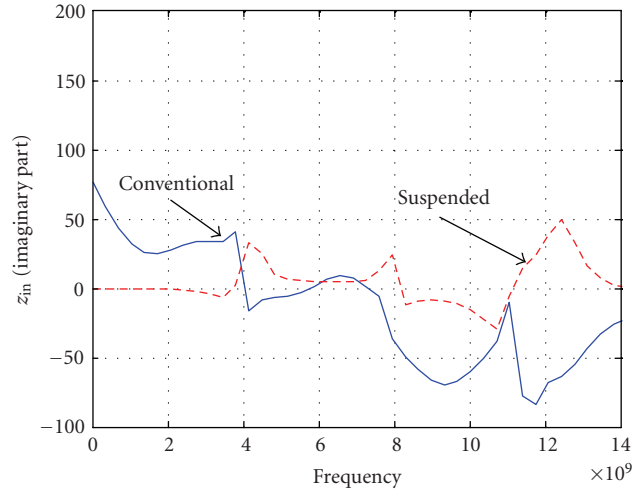
Figure 5: Comparison between the frequency response of the conventional and suspended filter with suspended substrate of ε_{r2} equals 4.8.



(a) The scattering parameters



(b) The real part of the input impedance



(c) The imaginary part of the input impedance

Figure 6: Comparison between the frequency response of the conventional and suspended filter with suspended substrate of ε_{r2} equals 10.0.

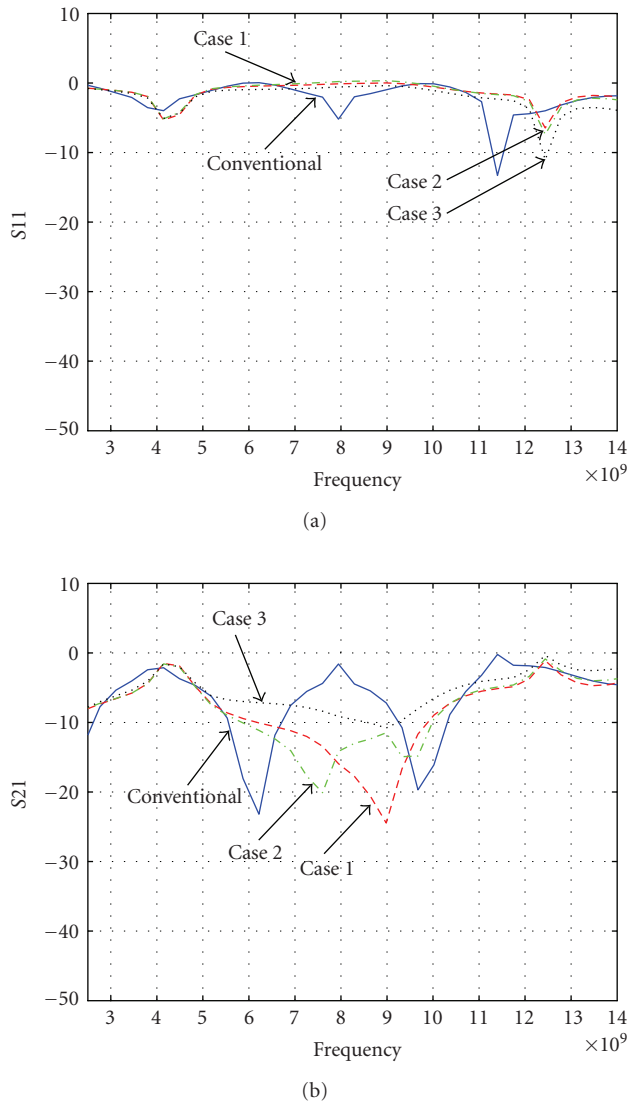


Figure 7: Comparison between the scattering parameters of the proposed filter with and without shorting walls.

eliminated especially for Case 1 as the rejection level of more than 20 dB can be obtained.

4. CONCLUSION

A design of broadband filters is presented. This is carried out by suppression of the spurious resonance at twice the passband frequency ($2f_o$). Suspended substrates and shorting of the coupled microstrip lines are used. The effect of the suspended substrate dielectric constant as will as the shorting wall width is studied. Numerical results show that a rejection level of almost 40 dB at passband frequency can be obtained when using a suspended substrate of ε_{r2} equals 3.5 with input impedance equals 50 Ω. While this level is about 20 dB for a shortened microstrip lines of shorting walls width equals $3\Delta x$. The finite difference time domain (FDTD) with the perfect matched layer (PML) is used in the present analysis. The obtained results are compared with the available published data and good agreements are found.

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