DESIGN OF A COMPACT WIDEBAND BANDPASS FILTER

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Received 26 August 2009

ABSTRACT: *This article presents the analysis and design of a compact multi-layer layer, high selectivity wideband bandpass filter using stub loaded and 'U' shaped resonators over a slotted bottom ground plane. While the resonators with folded open circuit stub loadings create the desired bandpass characteristics, the 'U' shaped resonators reduce the size of filter. The slotted bottom ground plane is used to enhance the coupling to achieve the desired bandwidth. The proposed filter has been analyzed using circuit model, and the results were verified through full wave simulations and measurements. The fabricated filter is compact and measures a size of 18 mm × 25 mm × 1.6 mm.* Microwave Opt Technol Lett 52: 1387–1389, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25206

Key words: *filter; coupled line; multi-layer; 'U' shaped resonator*

1. INTRODUCTION

Rapid growth and deployment of wireless systems require compact wideband filters with low loss and sharp rejection characteristics. Multi-layer structures incorporating low temperature co-fired ceramic (LTCC) and stacking several layers of standard microwave laminates are some of the useful technologies for realizing compact microwave circuits and systems [1–3]. Wideband filters using metallization on both sides of suspended stripline substrate are realized in Ref. 4. A compact filter has been realized in multi-layer ceramic substrate using LTCC technology [5]. Stacked broad side coupled lines have been used in multi-layer environment to achieve compact and wide band operation [6].

This article proposes a compact three-layer wideband high selectivity filter using resonator loaded with folded open circuit stub and 'U' shaped resonators over a slotted bottom ground plane. The proposed filter uses coupled lines with a quarter wavelength open circuit stub loading at one end to achieve high selectivity characteristics. This filter finds applications in wireless communications such as WiMax and OFDM based ultra wide band terminals. Design and analysis of the proposed filter is explained in Section 2. Measured and simulated results are validated against analytical calculations in Section 3. Section 4 concludes the present article.

2. ANALYTICAL DESIGN OF THE FILTER

The exploded and cross sectional views of the proposed multilayer wideband bandpass filter are shown in Figure 1. The filter is designed using an open circuit stub loaded quarter wavelength resonator and 'U' shaped resonators over slotted ground plane. The slotted ground plane enhances the bandwidth of the filter. Figure 2 shows the performance of typical coupled line section with and without the open circuit $\lambda_g/4$ stub loading (short circuit loading). It can be observed that the open circuit loading improves the selectivity. In the proposed filter, input and output coupled line sections are terminated with quarter wavelength open circuit stubs to improve the selectivity of the filter. The layers of the filter have been arranged as follows. Layer 0 is slotted ground, Layer 1 contains 'U' shaped resonators and Layer 2 contains co-planar waveguide (CPW) feed lines and the ground.

As shown in Figure 1, three-layer filter is designed by stacking two patternized 0.787 mm Arlon substrates of dielectric constant 'ε_r' of 2.17. The filter is designed to have a center frequency of 3.4 GHz with 23% fractional bandwidth, which can find applications in IEEE 802.16 transceivers.

Analysis is carried out by splitting the filter into four coupled line sections namely CI, CII, CIII, and CIV as shown in Figure 3. Sections CI and CIV (or CII and CIII) are mirror images of each other.

The 4 × 4 Impedance matrix [7] of each coupled line in Section 1 can be reduced to a 2 × 2 impedance matrix by taking the loading effect. As the 'U' shaped resonator arms are spaced far away, coupling between them is neglected in the present analysis.

$$Z_{11} = Z_{22} = Z_{33} = Z_{44} = -j0.5\,(Z_{oe}\cot\,\theta_e + Z_{oo}\cot\,\theta_o) \quad (1a)$$

$$Z_{12} = Z_{21} = Z_{34} = Z_{43} = -j0.5\,(Z_{oe}\cot\theta_e - Z_{oo}\cot\theta_o) \quad (1b)$$

$$Z_{13} = Z_{31} = Z_{24} = Z_{42} = -j0.5\,(Z_{oe}\cos ec\,\theta_e - Z_{oo}\cos ec\,\theta_o) \quad (1c)$$

$$Z_{14} = Z_{41} = Z_{23} = Z_{32} = -j0.5\,(Z_{oe}\cos ec\,\theta_e + Z_{oo}\cos ec\,\theta_o) \quad (1d)$$

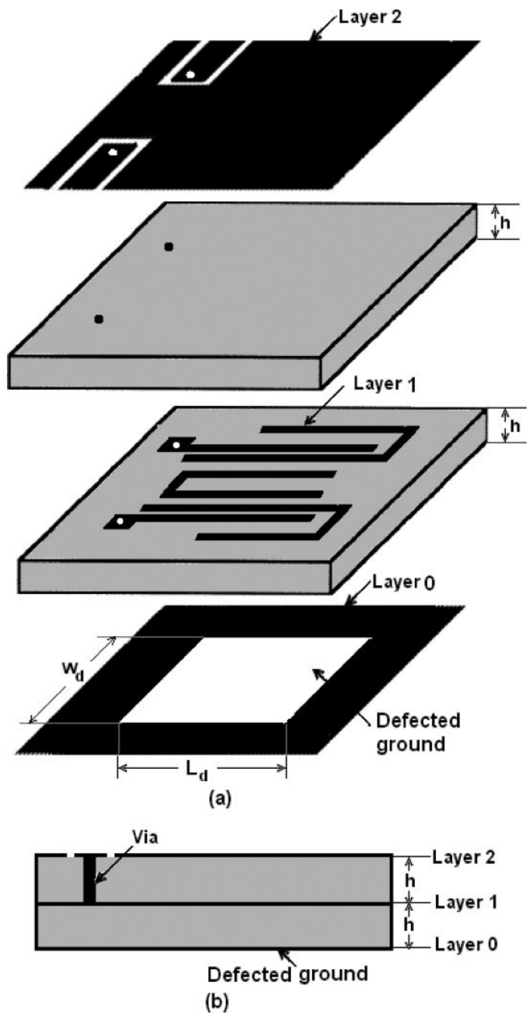

Figure 1 Wide bandpass filter. (a) Exploded view of different layers. (b) Cross sectional view of the complete device

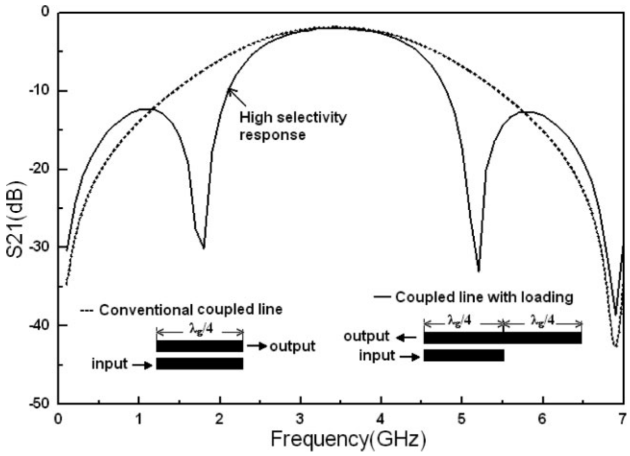

Figure 2 Coupled line responses

Loading of the open circuit stub on the resonators in the coupled line section is taken into account by using

$$Z_{\text{open}} = -jZ_{\text{stub}} \cot(\beta L_{\text{stub}}) \tag{2}$$

where Z_{stub} is the characteristic impedance and L_{stub} is the length of the open circuit stub. Even and odd mode parameters of the coupled line sections (over the slotted ground plane) were extracted using differential (positive and negative ports) and common mode (positive ports) excitation features (as shown in Fig. 4) of commercial EM simulator IE3D [8]. Scattering parameters of the overall filter were estimated by calculating impedance matrices in MATLAB.

Physical and electrical parameters of the coupled line sections are given in Table 1. All resonators have a width and length of 0.5 mm and 30 mm, respectively. Length of the loaded open circuit stub is 15 mm, which is approximately $\lambda_g/4$ at the center frequency of the filter. Effect of slotted bottom ground plane on bandwidth is shown in Figure 5. As slot dimension increases, fractional bandwidth of filter varies from 17% to 24%. There was no significant change in bandwidth beyond the slot dimension of 5.8 mm × 15 mm. Analytical results of proposed filter (with slot dimension '$W_d \times L_d$' of 5.8 mm × 15 mm) are compared against the results of filter without slot in the bottom ground plane in Figure 6.

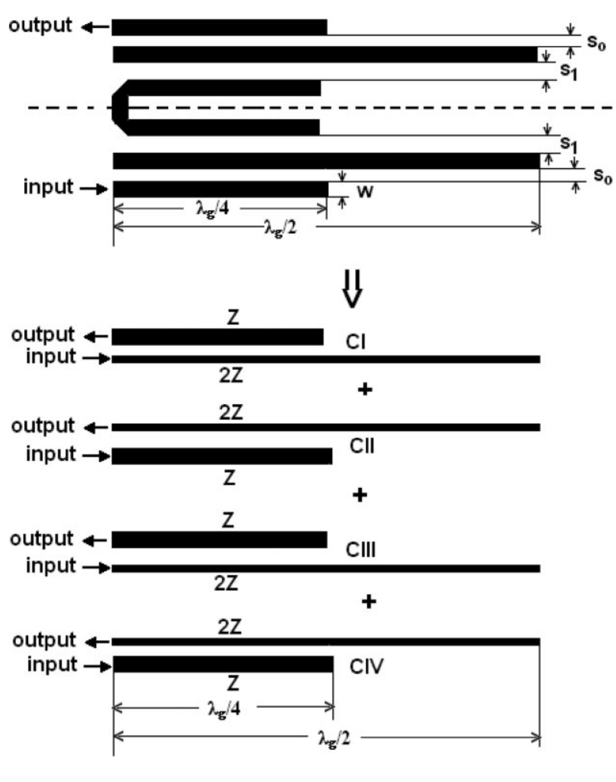

Figure 3 Coupled line sections in Layer 1 and their equivalence

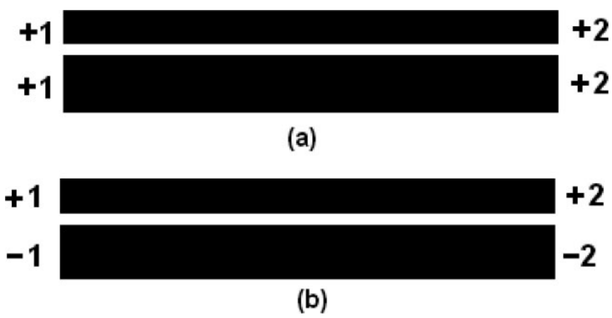

Figure 4 Coupled line excitations for EM simulation

3. EXPERIMENTAL RESULTS

The filter is assembled using two printed circuit boards (PCBs) which have been fabricated using a PCB prototyping machine. The PCBs were held together with the help of screws. The filter is fed using coplanar waveguide (CPW) lines of width 2.6 mm on Layer 2. The feed lines use via transition to connect the coupled line sections in Layer 1. The diameter of via is 1 mm. Figure 7(a) shows the top view of the assembled while Figure 7(b) shows the bottom view with a slot of 5.8 mm × 15 mm in the bottom ground plane. Measured results along with circuit modeling and full wave EM simulation results are shown in Figure 8. Comparison shows a good agreement between them except for a deviation in stop band characteristics of circuit modeling. This could be either due to the air gap in assembly or due to discontinuity of ground plane in Layer 0, which could not be taken into account accurately in circuit simulations. Furthermore, the circuit model assumes an ideal transition from the CPW.

Measured results show that the center frequency of filter is 3.38 GHz with a 23.9% fractional bandwidth. Maximum insertion loss of the filter is 1.1 dB and return loss is better than 11 dB. The dimensions of the developed compact filter are 18 mm × 25 mm × 1.6 mm (0.3 λ_g × 0.4 λ_g × 0.0267 λ_g) and this occupies 45% reduced area compared to a conventional parallel coupled line filter of the same order [7].

4. CONCLUSIONS

A compact three-layer wideband filter at 3.4 GHz has been designed and analyzed. High selectivity has been achieved by

TABLE 1 Parameters of Coupled Lines

Parameters	Coupled Line Section (CI, CIV)	Coupled Line Section (CII, CIII)
Width of coupled line (w)	0.5 mm	0.5 mm
Spacings	$s_o = 0.18$ mm	$s_1 = 0.4$ mm
Even and odd mode impedances (Z_{oe}, Z_{oo})	(176.5 Ω, 66.9 Ω)	(149.6 Ω, 80.1 Ω)

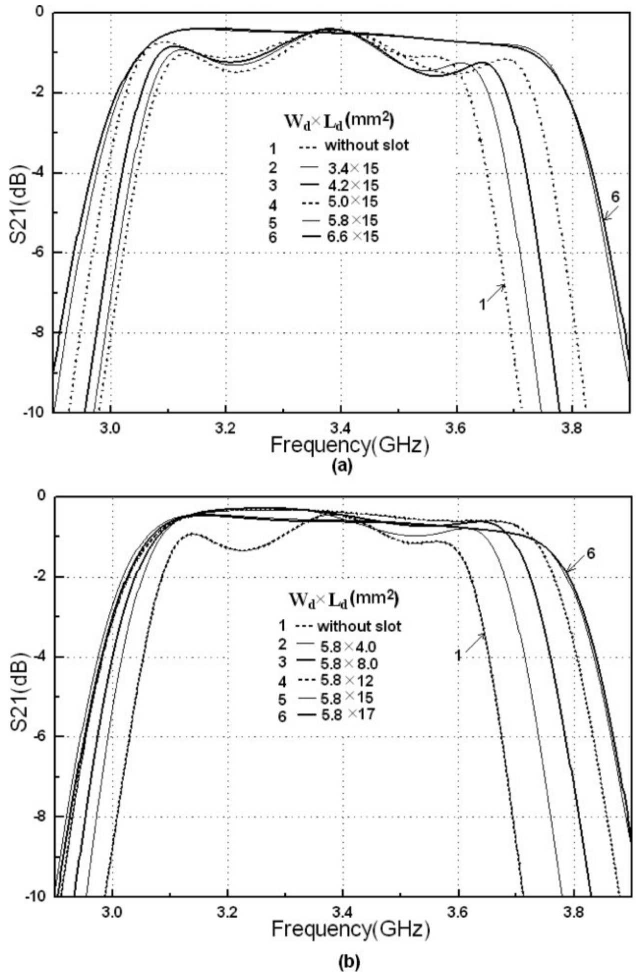

Figure 5 Effect of slot in bottom ground plane on bandwidth: (a) Change in width 'W_d'; (b) Change in length 'L_d'

using open circuit stub loaded coupled lines. Vias have been used to connect the feed lines into the filter structure. Overall dimensions of the filter are 0.3 λ_g × 0.4 λ_g × 0.0267 λ_g. The measured results are in close agreement with the simulation results.

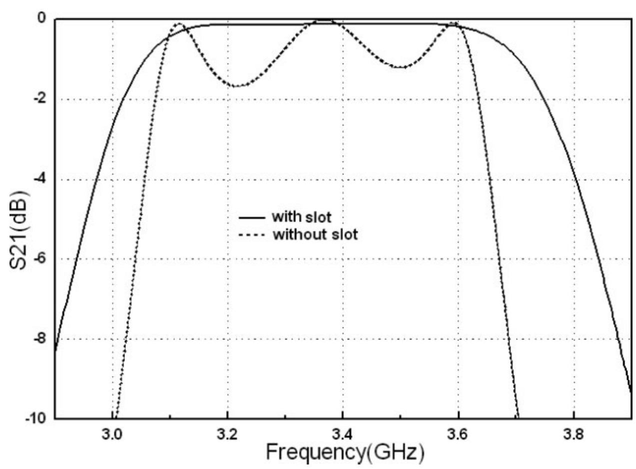

Figure 6 Analytical results of filter with and without slot in the bottom ground plane

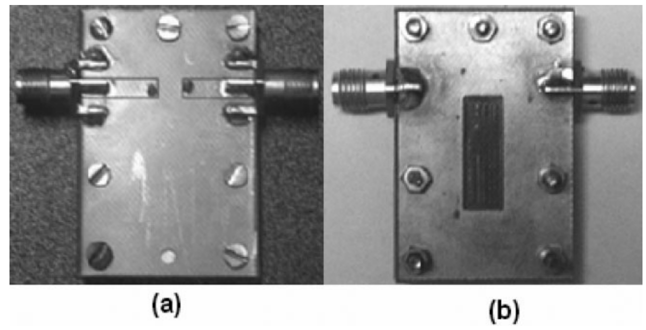

Figure 7 Photograph of assembled wideband bandpass filter: (a) Top view; (b) Bottom view

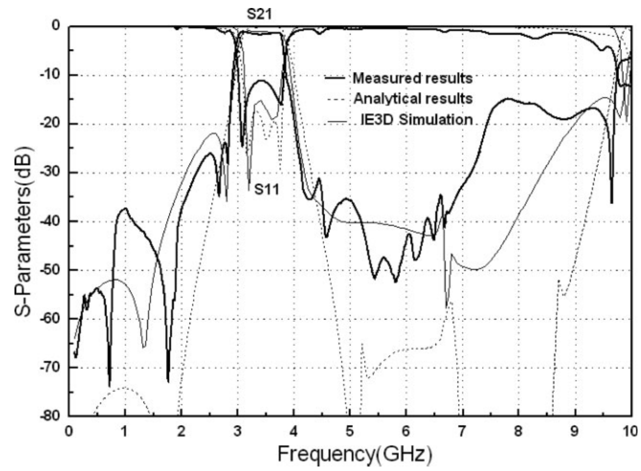

Figure 8 Measured results of wideband bandpass filter

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