J. of Electromagn. Waves and Appl., Vol. 23, 1235–1243, 2009

ANALYSIS AND DESIGN OF TWO LAYERED ULTRA WIDE BAND FILTER

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Abstract—Design of an Ultra Wide Band (UWB) filter over 3.1 GHz to 10.6 GHz using broad side coupled and spur lines in microstrip medium suitable for UWB communications has been presented in this paper. Parameters of broad side coupled lines have been appropriately chosen to achieve ultra wide band response. Spur lines have been incorporated at the input and output feed lines of the filter to improve the stop band rejection characteristics of the filter. Filter has been analyzed based on circuit models and full wave simulations. Experimental results of the filter designed using the proposed structure has been verified against the results obtained from circuit models and full wave simulations. The results match satisfactorily. Stop band rejection of better than 20 dB was obtained over the frequencies of 13 GHz to 18.2 GHz. Overall size of the filter is $40 \times 18 \times 0.787\,\mathrm{mm}^3$.

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1. INTRODUCTION

Rapid growth of wireless systems requires wide band filter with constant group delay and wide stop band. Extensive work has been reported on the design of wide band filters [1–7]. Besides wide band operation, space constrained modern wireless receivers need compact and high performance circuits. Multi-layer structure such as low temperature co-fired ceramic (LTCC) is one of the potential technologies for designing miniaturized circuits in multi-layered ceramic [8–10]. Multi-layer approach to design miniaturized passive components such as baluns, couplers and filters has been widely used.

This paper reports the design of a two layer compact ultra wide band filter which uses a set of broad side coupled and spur lines as shown in Fig. 1. Analysis of this filter is explained in Section 2. In Section 3, measured results of the filter are compared against full wave simulation results for the validation. Section 4 concludes this paper.

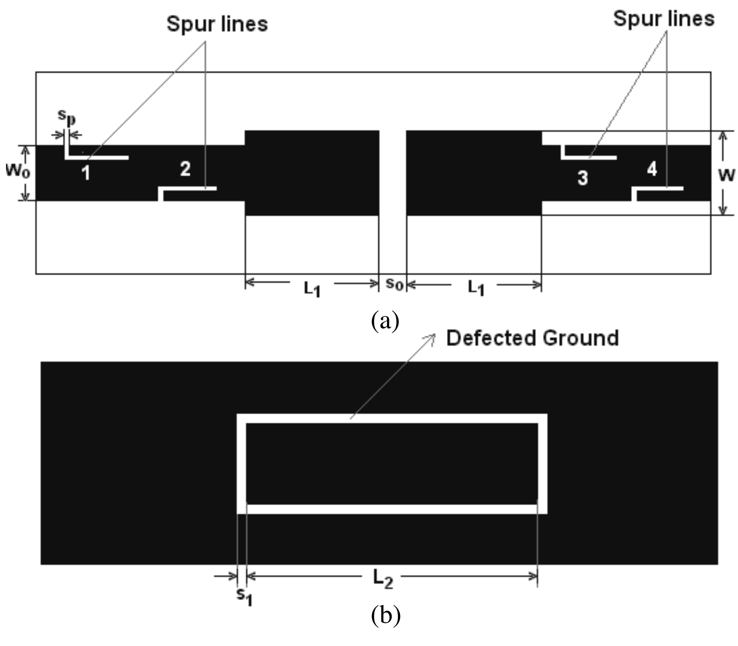

Figure 1. UWB filter. (a) Top layer. (b) Bottom layer.

2. ANALYSIS OF UWB FILTER

Figure 1 shows the designed ultra wide band filter which operates over 3.1 GHz to 10.6 GHz. The filter is designed using broad side coupled and spur lines in two-layer structure. A floating conductor in the slot of the ground plane enhances coupling required for achieving broad band operation. Structural parameters of microstrip medium given in Table 1 are used for the design of filter.

The filter has two attenuation poles out of which one pole is located at DC while the other is located close to the upper stop band region of the filter. Fig. 2 shows the effect of coupled line width 'w' on the bandwidth of the filter. For the present design, coupled line width 'w' is chosen to be 4.4 mm to get the desired response and the design parameters are given in Table 2. Table 3 gives the corresponding electrical parameters of the broadside coupled lines for various widths.

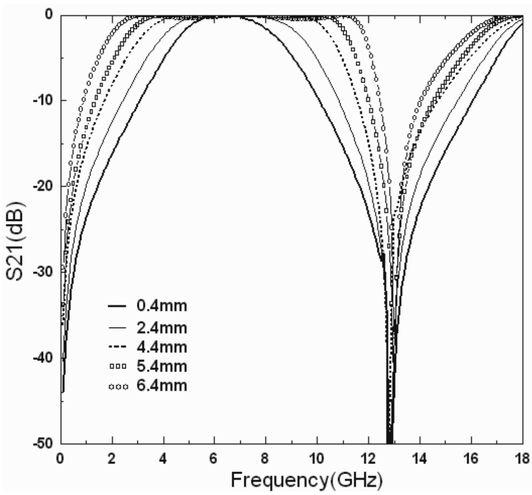

Figure 2. Effect of width 'w' on bandwidth (analytical results).

Table 1. Structural parameters of microstrip.

Substrate thickness 'h'	0.787 mm
Substrate permittivity 'ε_r'	2.17

Table 2. Design parameters of filter.

L_1 (mm)	L_2 (mm)	s_o (mm)	s_1 (mm)	w (mm)	w_o (mm)
6.8	15	1.4	0.4	0.4	2.5

Table 3. Electrical parameters of broad side coupled lines.

Width (mm)	(Z_{oe}, Z_{oo}) Ω	$(\theta_e, \theta_o)^o$ at 6.85 GHz
0.4	(100,50)	(86,93)
2.4	(115,40)	(85,94)
4.4	(130,28)	(84,95)
5.4	(140,23)	(83.3,96)
6.4	(148,20)	(82,97)

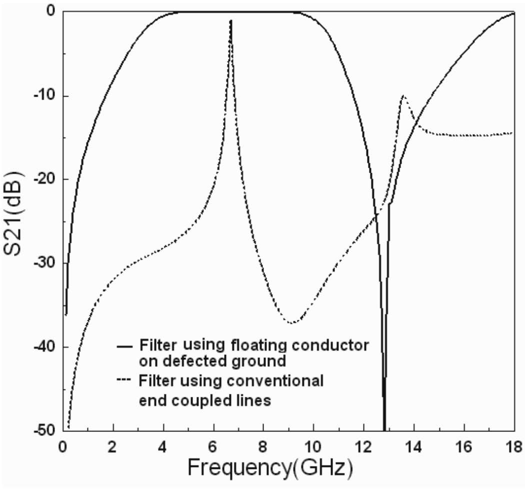

Figure 3. Analytical results of filter with and without defected ground.

Figure 3 compares the performance of the filter with and without slot (conventional microstrip) in the ground. Results of Fig. 3 conform that the coupling was enhanced due to the presence of floating conductor. Coupled line sections of the filter can be characterized using the following $ABCD$ parameters [11]

$$A = D = \frac{Z_{oe}\cot\theta_e + Z_{oo}\cot\theta_o}{Z_1} \tag{1}$$

$$B = \frac{j}{2}\frac{Z_{oe}^2 + Z_{oo}^2 - 2Z_{oe}Z_{oo}(\cot\theta_e\cot\theta_o + \csc\theta_e\csc\theta_o)}{Z_1} \tag{2}$$

$$C = \frac{2j}{Z_1} \tag{3}$$

where $Z_1 = Z_{oe}\csc\theta_e + Z_{oo}\csc\theta_o$, θ_e is even mode phase velocity, and θ_o is odd mode phase velocity. Z_{oe} and Z_{oo} are even and odd mode impedances respectively. Analytical calculations based on the above formulae are done in MATLAB. The calculated $ABCD$ matrix is finally converted into scattering parameters.

Filter's stop band characteristics can be improved by incorporating the spur lines at the input and output sections of the filter as shown in Fig. 1. The length of the spur line shown in Fig. 4 is approximately quarter wavelength at the desired band stop frequency and can be calculated using [12–14]

$$L = \frac{c}{4f_o\sqrt{\varepsilon_{f_o}}} \tag{4}$$

where c is the velocity of the wave; f_o is the band stop frequency and ε_{f_o} is the odd mode permittivity of the coupled lines having widths of 'w_s' and '$w_o - w_s - s_p$' and gap 's_p'. Spur line can be characterized using the following $ABCD$ parameters

$$A = \cos\theta_e \tag{5}$$

$$B = \frac{j(Z_{oe}\sin\theta_e + Z_{oo}\cos\theta_e\tan\theta_o)}{2} \tag{6}$$

$$C = \frac{2j\sin\theta_e}{Z_{oe}} \tag{7}$$

$$D = \cos\theta_e\frac{Z_{oo}\sin\theta_e\tan\theta_o}{Z_{oe}} \tag{8}$$

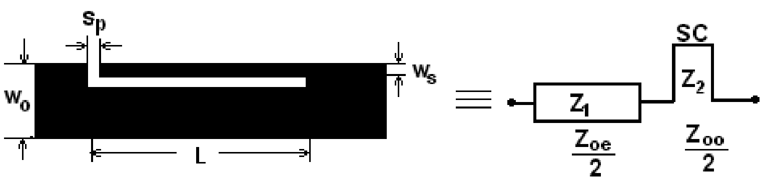

Figure 4. Spur line and its equivalent.

where, θ_e is even mode phase velocity, and θ_o is odd mode phase velocity. Analytical results of spur lines having physical and electrical parameters given in Table 4 are calculated using the circuit model given in (5)–(8), and the results are shown in Fig. 5. The band stop frequencies are chosen to be 14.2 GHz, 15 GHz, 17 GHz and 17.8 GHz for improving the rejection characteristics of the filter. Overall response of the filter obtained from both the analytical calculations (from MATLAB) and EM simulations [15] is shown in Fig. 6. Results show that the embedded spur lines extended the stop band upto 18.2 GHz with minimum rejection of 20 dB.

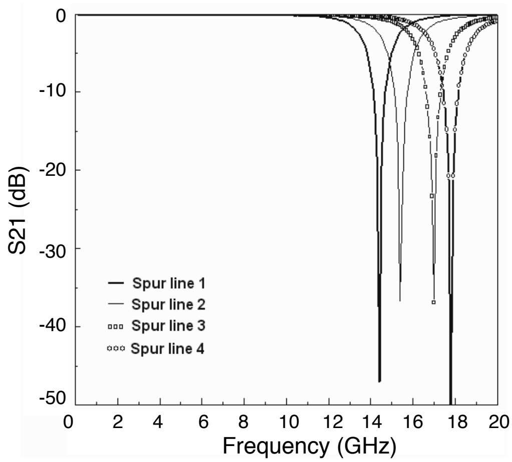

Figure 5. Analytical results of spurlines.

Table 4. Parameters of band stop elements (spur lines, $W_s = 0.4$ mm).

Spur line	1	2	3	4
Overlap Length 'L' (mm)	3.8	3.5	3.2	3.05
Width 'w_o' (mm)	2.5	2.5	2.5	2.5
Spacing 's_p' (mm)	0.4	0.4	0.4	0.4
(Z_{oe}, Z_{oo}) Ω	(94,30)	(94,30)	(94,30)	(94,30)
$(\theta_e, \theta_o)^o$	(86,90) at 14.2 GHz	(86,90) at 15 GHz	(86,90) at 17 GHz	(86,90) at 17.8 GHz

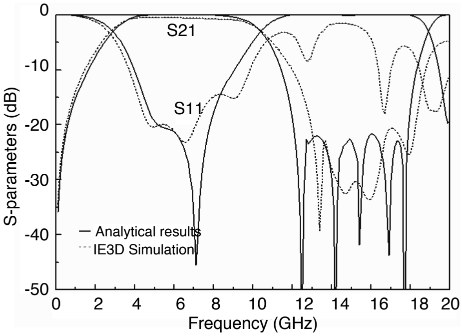

Figure 6. Analytical and EM simulation results of UWB filter with extended stop band region.

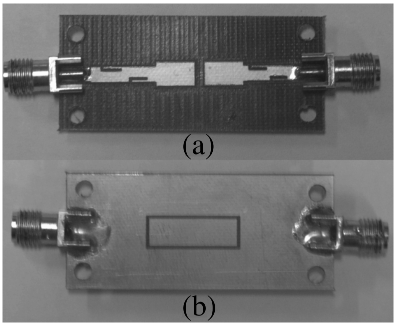

Figure 7. Assembled UWB filter. (a) Layer 1. (b) Layer 2.

3. EXPERIMENTAL RESULTS

Figure 7 shows the photograph of fabricated ultra wide band filter. Fig. 8 compares the experimental scattering parameters of the UWB filter against the results obtained from EM Simulator [15]. Results match each other satisfactorily. Results show that maximum insertion loss is 1 dB, and stop band attenuation is better than 20 dB from 13 GHz to 18.2 GHz. Fig. 9 shows the measured group delay performance of the UWB filter, and group delay is constant with ± 0.02 ns. Overall size of the filter is $40 \times 18 \times 0.787\,\text{mm}^3$.

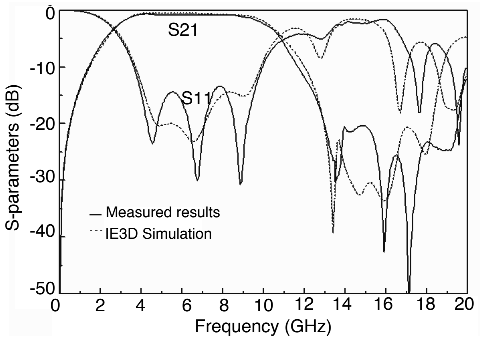

Figure 8. Measured S-parameters of UWB filter.

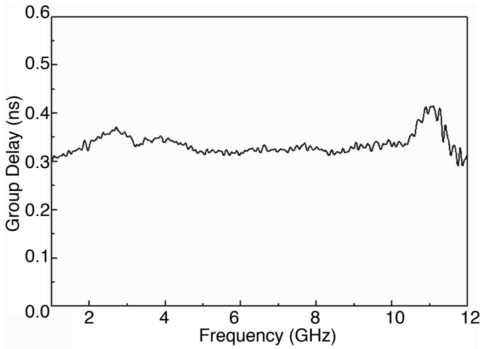

Figure 9. Measured group delay of UWB filter.

4. CONCLUSION

Analysis and design of ultra wide band filter operating on 3.1 GHz to 10.6 GHz with wide stop band using broad side coupled and spur lines in two-layer structure is presented in this paper. Spur lines were applied to improve the stop band rejection characteristics of the filter from 13 GHz to 18.2 GHz with minimum rejection of 20 dB. Proposed filter was analyzed using circuit models and full wave simulations.

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