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Design and Simulation of Microstrip Bandpass Filter

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Abstract. Practical design techniques are presented for tapped hairpin resonator filters on FR4 laminates. The hairpin filter is one of the most popular low microwave frequency filters because of it is compact and does not require grounding. Its design on FR4 laminates is very difficult to do because of the relatively poor performance of the laminate at the microwave region. The laminate properties of the FR4 become nonlinear unlike more expensive microwave laminates. The motivation to use FR4 in the low microwave frequencies is its cost. The filter is designed using HFSS design software and implemented on FR4 substrate.

Keywords: microstrip, filter, bandpass

1. Introduction

The hairpin resonator filter is one of the most popular microstrip filter configurations used in the lower microwave frequencies. It is easy to manufacture because it has open-circuited ends that require no grounding. Its form is derived from the edge-coupled resonator filter by folding back the ends of the resonators into a "U" shape. This reduces the length and improves the aspect ratio of the microstrip significantly as compared to that of the edge-coupled configuration. There are many substrates with various dielectric constants that are used in wireless applications. Those with high dielectric constants are more suitable for lower frequency applications in order to help minimize the size. [1-3]. In order to increase the bandwidth of end-coupled microstrip bandpass filter parallel coupled microstrip bandpass filter (PCM-BPF) was presented in [4]. In [4] resonators are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators [1]. But this new configuration was too long considering the frequency and the order of the filter. To solve this problem hairpin-line filter using folded $\lambda/2$ resonator structures were developed [5]. A tapped hairpin resonator filter has a smaller insertion loss and better return loss. This is a variant of an edge-coupled filter that contains a matching stub. Varying the length of this stub and the tapping distance varies the return loss and consequently the insertion loss.

2. Design Methodology

A detailed procedure of the design of the edge-coupled filter can be found in [6]. The bandpass filter specifications are given in the following. The filter should have a center frequency of 1 GHz. A fractional bandwidth of 30% with passband ripples 0.1 db. FR4 substrate features are: substrate height 1.6 mm and loss tangent 0.002 and substrate dielectric constant is 4.4. Order of the filter can be determined using (1), (2) and

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(3). From the result of (3), the order of the filter can be determined from [1]. Mathematically, Fractional bandwidth is calculated as:

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \tag{1}$$

Band pass transform is calculated as:

$$\Omega = \frac{\Omega_c}{FBW}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \tag{2}$$

And finally the center frequency is calculated as:

$$\omega_0 = \sqrt{\omega_1 \omega_2} \tag{3}$$

Based on the design specification, a 3$^{\text{th}}$ order filter is required. The element values for a 3$^{\text{th}}$ order is using 0.1dB equal ripple low-pass prototype concept and are determined from (4), (5) and (6) where $g_0 = 1$ [1]

$$g_1 = \frac{2}{\gamma}\sin\left(\frac{\pi}{2n}\right) \tag{4}$$

$$g_i = \frac{1}{g_{i-1}} \frac{4\sin\left[\frac{(2i-1)\pi}{2n}\right].\sin\left[\frac{(2i-3)\pi}{2n}\right]}{\gamma^2 + \sin\left[\frac{(i-1)\pi}{n}\right]} \quad \text{for } i = 2,3,\ldots n \tag{5}$$

$$g_{n+1} = \begin{Bmatrix} 1 & \text{for n odd} \\ \coth^2\left(\frac{\beta}{4}\right) & \text{for n even} \end{Bmatrix} \tag{6}$$

where β , γ are calculated as (7), (8) respectively:

$$\beta = 1n\left(\coth\frac{L_{Ar}}{17/37}\right) \tag{7}$$

$$\gamma = \sinh\left(\frac{\beta}{2n}\right) \tag{8}$$

The element values obtained are shown in Table 1.

Table 1 the low-pass prototype elements values

Low-Pass Prototype Elements	Values
g_0	1
g_1	1.0316
g_2	1.1474
g_3	1.0316
g_4	1

The low-pass prototype elements values obtained can be represented as shown in Figure 1.

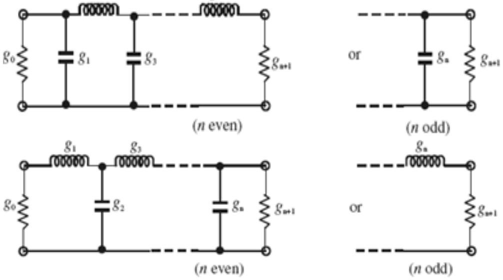


Fig. 1: Low-pass filter prototype

For basic conventional bandpass filter design, *J*-inverter concept is used to convert from low-pass filter to bandpass filter after obtaining the low pass prototype element values. Finally, the characteristic impedances and dimension of the coupled lines can be attained. But for this hairpin design a new electromagnetic (EM) simulation is introduced. After obtaining the low pass prototype element values, external quality factor are computed using (9) and coupling coefficients using (10). The parameters computed are shown in Table 1. Coupling coefficient determines the space required between adjacent hairpins.

$$Q_{e1} = \frac{(g_0 g_1)}{FBW} \quad , \quad Q_{en} = \frac{(g_n g_{n+1})}{FBW} \qquad (9)$$

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \quad , \quad \text{for i = 1 to n - 1} \qquad (10)$$

Table 2 filter parameters

Q factor and Coupling Coefficient	Values
Q_{e1}	3.438
Q_{e2}	3.438
$M_{1,2}$	0.270
$M_{2,3}$	0.270

The length of the U-shape resonator is half wavelength long. The guided wavelength can be calculated using (11). The calculated length of U-shape resonator is 39.3 mm, which is $\lambda/2$. The width of the resonator is 2 mm to match the 50 ohm line. The separation is chosen to be 0.38 mm; a general guideline for choosing the separation is between 1 to 3 times the resonator widths.

$$\lambda_g = \frac{300}{f\left(GHZ\right)\sqrt{\varepsilon_{re}}} mm \qquad (11)$$

After obtaining all the parameters required for designing a three pole hairpin filter, the filter is designed and simulated using HFSS. Figure 2 show the layout of the filter, and Figure 3and 4 shows the simulated result.

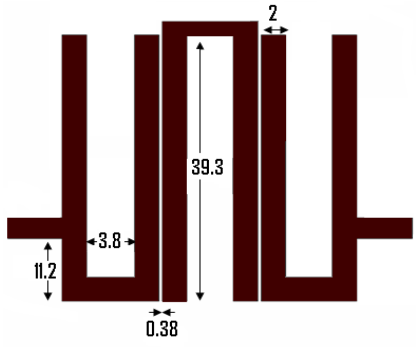
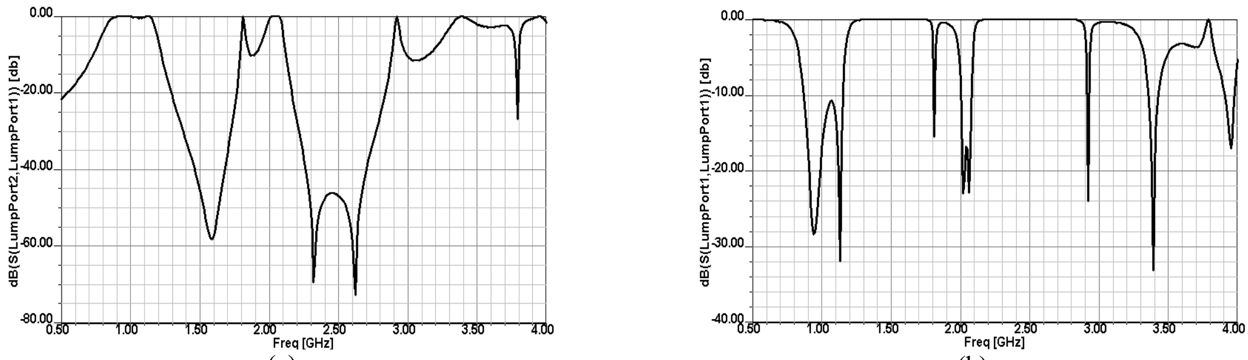
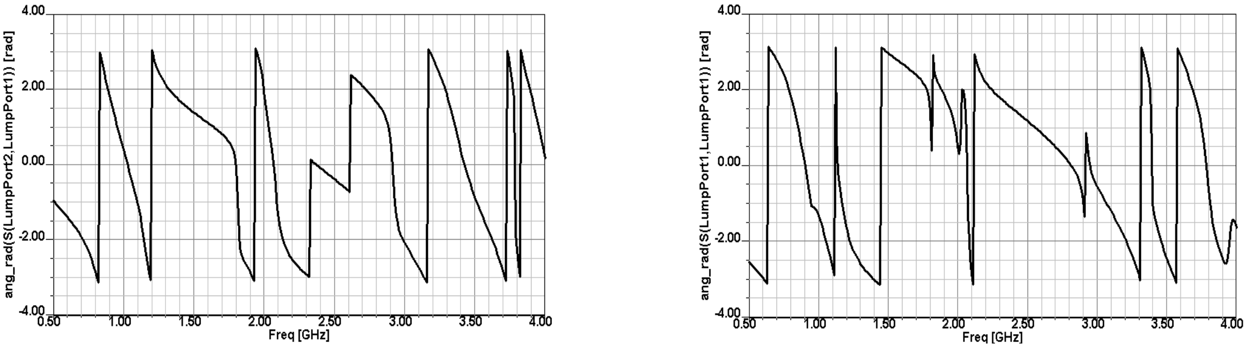


Fig. 2: Layout of the designed hair-pin (millimeter)



(a) (b)

Fig. 3: (a) Simulated S21 (dB), (b) Simulated S11 (dB)



(a) (b)

Fig. 4: (a) Simulated phase S12 (Rad), (b) Simulated phase S11 (Rad)

3. Conclusion

Practical techniques based on design patterns of a tapped hairpin resonator filter on FR4 laminates have been presented in this paper. This motivation is due to the difficulty of designing such filters on FR4 laminates using HFSS. The resonator length was shown to have a significant effect on the center frequency. The resonator spacing generally controls the bandwidth. Tap distance ultimately matches the filter to the rest of the circuitry. A step-by-step method is then presented in order to aid in the filter design.

4. References

[1] J. S. Hong and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications, John Wiley & Sons, Inc., 2001.

[2] Pozar, D. M. Microwave Engg, John Wiley, 2000.

[3] G. Mattaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Norwood, MA, 1980

[4] Cohn, S. B., "Parallel-coupled transmission-line resonator filters," IRE Trans. Microw. Theory Tech., Vol. 6, no. 2, pp. 223-231, 1958.

[5] Cristal, E. G. and S. Frankel, "Hairpin-line and hybrid hairpin line half-wave parallel-coupled-line filters," IEEE Trans. Microw. Theory Tech Vol. 20, no. 11, pp. 719– 728, 1972.

[6] Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*. Boston, MA: Artech House, 1980.