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# MINIATURE PLANAR UWB BANDPASS FILTERS WITH CIRCULAR SLOTS IN GROUND

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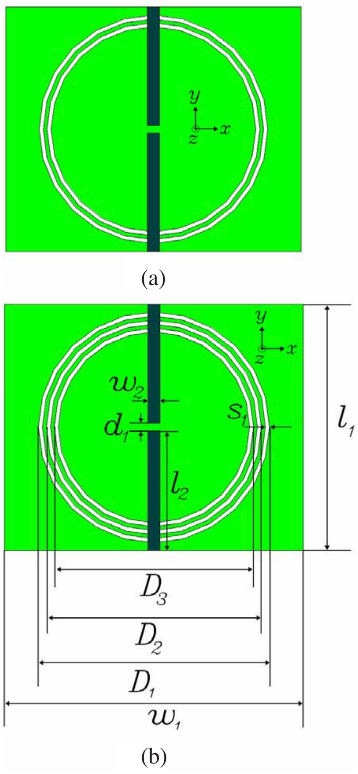
**Abstract**—In this paper, miniature planar UWB filters with circular slots in ground is presented and we are using a new technique by etching a wideband circular-shape slot resonator in the ground plane of the filters. The proposed filters have compact size of $15 \times 12.4\,\mathrm{mm}^2$. Two filters are introduced and the final design achieves flat insertion loss and linear phase of $S_{12}$ throughout the passband (3.14–8.28 GHz) but occasional slight ripple occurs. Two different results are shown and the minimum insertion loss is less than 0.13 dB for both of presented filters.

## 1. INTRODUCTION

Ultra-wideband (UWB) technology has become the most promising solution for future short-range high-speed indoor data communication applications. In 2002, the Federal Communication Commission (FCC) in United States officially released the regulations for UWB technology, and the spectra from 3.1 to 10.6 GHz were allocated for unlicensed UWB indoor medical, measurement and communication applications. Two distinct schemes, the DS-UWB (direct-sequence UWB) and the MB-OFDM (multiband OFDM), have been proposed to compete for the IEEE 802.15.3a Standard [1–3]. The UWB provides the Less susceptible to the effects of multipath interference, Allowable high-speed communications, Applicable to the measurement of positions and distances Streamlined circuit configuration due to the non-use of carrier waves (impulse radio system) [1, 4]. Filters are the particularly challenging aspect of UWB technology. To satisfy such a requirement, various wideband filters have been studied [4–6]. In most common approach to designing UWB filters, the circular resonator isn't use as slot on the ground plane [4–12]. In [13], slotline two pole microwave filter is introduced. The filter has a center frequency of 10.15 GHz, a fractional bandwidth of 9% and minimum insertion loss of 0.5 dB [13].

In this paper, I change the ground plane by subtracting the circular-shape slots from that. These filters are multi-pole microwave filters with additional transmission zeros. The first design consists of two circular-shape slots on the bottom side of the substrate and the microstrip feeding line on the top side. Second design has three circular slots and all other parameter is the same as the first design. The dimensions of filters are $15 \times 12.4\,\mathrm{mm}^2$ and the first design has a 1 dB bandwidth of 4.17 GHz from 3.24–7.41 GHz and minimum insertion loss of approximately 0.13 dB while for the second design, these are 5.14 GHz from 3.14–8.28 GHz and 0.1 dB respectively. The phase of $S_{12}$ is completely linear throughout the passband for both of filters.



(a)

(b)

**Figure 1.** Geometrical parameters of proposed filters, (a) filter with two circular slots, (b) filter with three circular slots.

## 2. FILTERS DESIGN

The filters are shown in Fig. 1(a) and Fig. 1(b). These filters are constructed on Taconic CER-10 substrate with thickness $\sim 0.635\,\text{mm}$ (25 mil), relative dielectric constant $\varepsilon_r$ of 10 and $\tan\delta = 0.0035$ which have a dimension of $15 \times 12.4\,\text{mm}^2$ ($W_1 \times L_1$). The diameter of circular slots are $D_1 = 11.6\,\text{mm}$, $D_2 = 10.8\,\text{mm}$ and $D_3 = 10\,\text{mm}$. The width of transmission line, $W_2 = 0.62\,\text{mm}$ has been designed for approximately $50\,\Omega$ characteristic impedance and $W_2$ has been calculated from (1) and (2) [14] for $\varepsilon_r = 10$, $h = 0.635\,\text{mm}$ and $Z_0 = 50\,\text{ohm}$. Distance between to microstrip feedline, $d_1$ (were then tuned by the commercial software HFSS v10.0) is equal to 0.4 mm. The remaining parameters are: $S_1 = 0.2\,\text{mm}$ and $L_2 = 6\,\text{mm}$.

$$\varepsilon_{\mathit{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\dfrac{h}{w}}} \tag{1}$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{\mathit{eff}}}}\ln\left(\frac{8h}{w} + \frac{w}{4h}\right) \quad \text{for} \quad \frac{w}{h} \le 1 \tag{2}$$

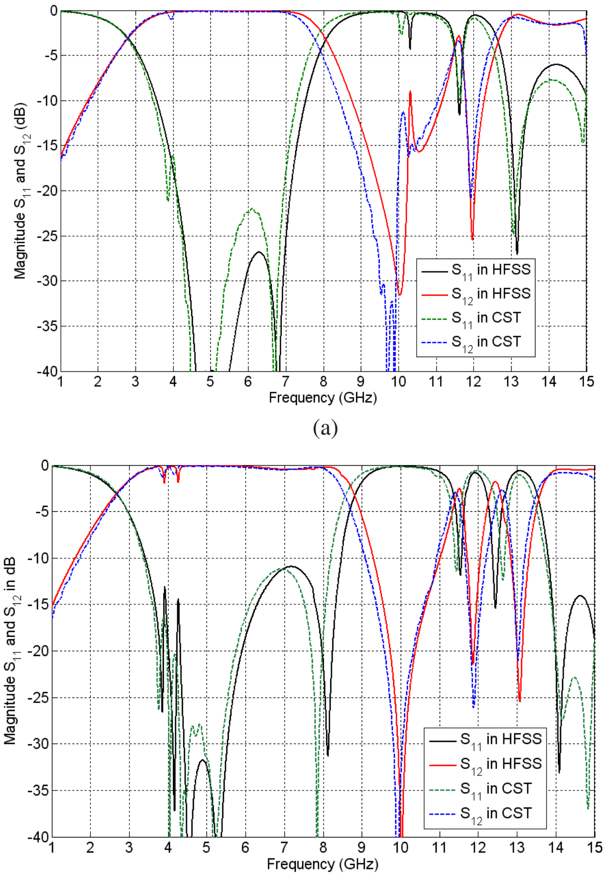
In these circular slots, because there is no variation of the fields along $z$ direction for thin substrates, the modes are designed as $\text{TM}_{nm}$ modes. For $m = 1$, the field across the slot width is constant. For any given frequency, the mode corresponding to $n = m = 1$ ($\text{TM}_{11}$ mode) has minimum mean the circular slot, and is known as the dominant mode [15, 16]. An approximate value of $x_{n1}(x_{n1} = k_{n1}a)$ can also be obtained by using (3). This expression gives a reasonably accurate value of $x_{n1}$ for $n \le 5$ and $(b - a)/(a + b) < 0.35$ [17]. For given values of $a$, $b$, $\varepsilon_r$ and $n$, the start frequency of filters is determined from (1), (3) and (4). For $m = 1$, $n = 1$, $a = 5.6\,\text{mm}$, $b = 5.8\,\text{mm}$ and $\varepsilon_r = 10$ (In (4), $c$ is the speed of light), the start frequency is obtained 3.223 GHz. We will see in next section, the start frequency of filter with two circular slots in ground is 3.24 GHz and for filter with three circular slots in ground is 3.14 GHz. Because propagating of higher modes at higher frequency, the exact theoretical prediction about filter behavior is complicated with analytical formulas at the upper frequency of band. The scope for further research and optimization is noted for better analysis these filters by theoretical prediction.

$$x_{nm} = \frac{2an}{a + b} \qquad \text{for} \quad m = 1 \tag{3}$$

$$f_{nm} = \frac{x_{nm}c}{2\pi a\sqrt{\varepsilon_{\mathit{eff}}}} \tag{4}$$

## 3. RESULTS

I named filter with two circular slots in ground as filter1 and filter with three circular slots in ground as filter2. In Fig. 2(a) and Fig. 2(b), the comparison between magnitude of s-parameters simulation results with Ansoft HFSSv.10 [18] and CST MICROWAVE STUDIO [19] for filter1 and filter2 are shown respectively. Plots show the good match between two simulation results with different commercial software of proposed filters. In general, a good flatness is achieved throughout the passband of filters. However, some occasional slight ripple is observed for filter2. The filter1 has a 1 dB bandwidth of 4.17 GHz



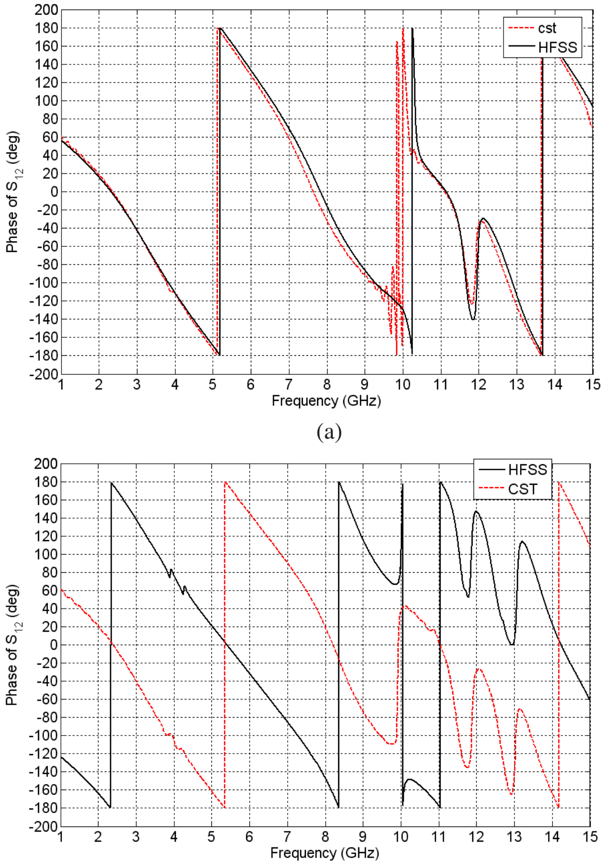
(a)

(b)

**Figure 2.** Magnitude of $S_{11}$ and $S_{12}$ of filters (a) filter1, (b) filter2.

from 3.24–7.41 GHz and minimum insertion loss of approximately 0.13 dB while for the filter2, these are 5.14 GHz from 3.14–8.28 GHz and 0.1 dB respectively (Noted: These results are quotation from CST MICROWAVE STUIDIO results).

In Fig. 3(a) and Fig. 3(b), comparison between phase of $S_{12}$ simulation results with Ansoft HFSSv.10 and CST MICROWAVE STUDIO for filter1 and filter2 are shown respectively. Plots are shown that the phase of $S_{12}$ throughout the passband of presented filters is acceptably linear for UWB applications. Fig. 3(a) show the good match between two simulation results with different commercial software of proposed filters. In Fig. 3(b), the plots have similar behavior but the



(a)

(b)

**Figure 3.** Phase of $S_{12}$ (a) filter1, (b) filter2.

shift of frequency throughout of the passband is noticeable. However, two simulation results shows that the phase of $S_{12}$ is linear throughout the passband.

## 4. CONCLUSION

The results of design and investigation of bandpass UWB filters are presented. Using combination of magnetic coupling between the wideband slots resonator and capacitive source load coupling allows realizing transmission zeros, which improve the selectivity of these filters. Some analytical predictions show good agreement between simulations results. The scope for further research and optimization is noted for better analysis these filters by theoretical prediction. The dimensions of filters are $15 \times 12.4\,\mathrm{mm}^2$ and the first design has a 1 db bandwidth of 4.17 GHz from 3.24–7.41 GHz and minimum insertion loss of approximately 0.13 dB while for the second design, these are 5.14 GHz from 3.14–8.28 GHz and 0.1 dB respectively. The phase of $S_{12}$ is completely linear throughout the passband for both of filters and these filters can apply for UWB applications.

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## REFERENCES

1. Anon., *FCC First Report and Order on Ultra-Wideband Technology*, Feb. 2002.
2. Young, J. and L. Peter, "A brief history of GPR fundamentals and applications," *Proc. 6th Int. Conf. Ground Penetrating Radar*, 5–14, 1996.
3. Daniels, D. J., "Surface-penetrating radar," *IEE Radar Sonar Navigation Avionics Series 6*, 72–93, IEEE Press, 1996.
4. Kobayashi, T. , *UWB Ring Filter and UWB Plane Antenna*, New products, Vol. 23, No. 1, 37–42, 2005.
5. Ishida, H. and K. Araki, "Design and analysis of UWB bandpass filter with ring filter," *IEEE MTT-S THIA-5*, June 2004.
6. Inoue, H., S. Kurashima, M. Yanagi, T. Arita, H. Ishida, and K. Araki, "Development of broad band pass filter for

UWB," *2004 Electronics Society (ES) Conference of The Institute of Electronics, Information and Communication Engineers*, September 2004.

7. Li, J. L., J. X. Chen, J. P. Wang, et al., "Dual-mode microstrip bandpass filter using circular patch resonator with two transmission zeros," *Microwave and Optical Technology Letters*, Vol. 46, No. 1, 28–30, 2005.
8. Weng, M.-H. and H.-D. Hsueh, "A novel compact dual-mode circular-patch bandpass filter with improved second spurious response," *Microwave and Optical Technology Letters*, Vol. 47, No. 3, 203–206, 2005.
9. Chen, Z.-X., X.-W. Dai, and C.-H. Liang, "Novel dual-mode dual-band bandpass filter using double square-loop structure," *Progress In Electromagnetics Research*, PIER 77, 409–416, 2007.
10. Xiao, J.-K. and Y. Li, "Novel compact microstrip square ring bandpass filters," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 13, 1817–1826, 2006.
11. Xue, W., C.-H. Liang, X.-W. Dai, and J.-W. Fan, "Design of miniature planar dual-band filter with 0° feed structures," *Progress In Electromagnetics Research*, PIER 77, 493–499, 2007.
12. Xiao, J.-K., Q.-X. Chu, and S. Zhang, "Novel microstrip triangular resonator bandpass filter with transmission zeros and wide bands using fractal-shaped defection," *Progress In Electromagnetics Research*, PIER 77, 343–356, 2007.
13. Kolmakov, Y. A. and I. B. Vendik, "Microstrip and slotline two-pole microwave filters with additional transmission zeros," *14th Int. Crimean Conference "Microwave & Telecommunication Technology"*, Ukraine, 2004.
14. Jameses, J. R. and P. S Hall, *Handbook of Microstrip Antennas*, Vol. 1, Peter Peregrinus & IEEE, London, 1989.
15. Matthaei, G. L., L. Young, and E. M. T. Jones, *Microwave Filters Impedance-matching and Coupling Structure*, Mcgraw-Hill, New York, 1964.
16. Garg, R., P. Bhartia, I. Bahl, et al., *Microstrip Antenna Design Handbook*, 369–371, Artech House, Boston-London, 2001.
17. Bahl, I. J. and P. Bharita, *Microstrip Antennas*, Chapter 3, Artech House, Dedham, MA, 1980.
18. Ansoft High Frequency Structure Simulation (Ansoft HFSS$^{\mathrm{TM}}$ V 10.0), Ansoft Corporation, 2005.
19. CST MICROWAVE STUDIO v5.0, Computer Simulation Technology, 2003.