good parity with simulated results. It is also observed that to achieve best performance a stable experimental setup is highly needed. This new technique will be immensely useful to prepare FSS structures in smart building, laboratory, etc. to minimized electromagnetic interference. More over tedious curved FSS theoretical investigation can be validated by practical experiments very easily. Aluminum foil is a very common and low cost material. During these experiments laser cutting machine is used to achieve high precision. For in-house experiments foil paper made FSS can be designed without laser cutting machine too. This can decrease the manufacturing cost even more. This process can revolutionized the whole existing FSS fabrication technique.

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A compact sixteenth-mode substrate integrated waveguide bandpass filter with improved out-of-band performance

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Abstract

This article presents a compact sixteenth-mode substrate integrated waveguide (SMSIW) bandpass filter operating at fundamental mode TM01. The filter size is reduced by introducing SMSIW circular cavity. It occupies only 6.25% of the conventional substrate integrated waveguide (SIW) circular cavity with same resonant frequency. The higher-order mode TM02 of the circular cavity is suppressed by etching two slots on the ground plane to improve out-of-band performance. Measured results show that an out-of-band rejection better than 18 dB is obtained from 2.5 GHz to 8 GHz. The in-band and out-of-band performance obtained from simulation and measurement are presented and they are in good agreement. The filter exhibits good stopband performance and compact size.

KEYWORDS

bandpass filter, circular cavity, improved out-of-band performance, sixteenthmode substrate integrated waveguide (SMSIW), substrate integrated waveguide (SIW)

1 | INTRODUCTION

High-performance, low-cost, and compact-size components are required due to advancements in the field of wireless communication systems. Substrate integrated waveguide (SIW) is a suitable candidate to design microwave and millimeter-wave components due to its attractive advantages.[1] Various microwave filters have been realized using

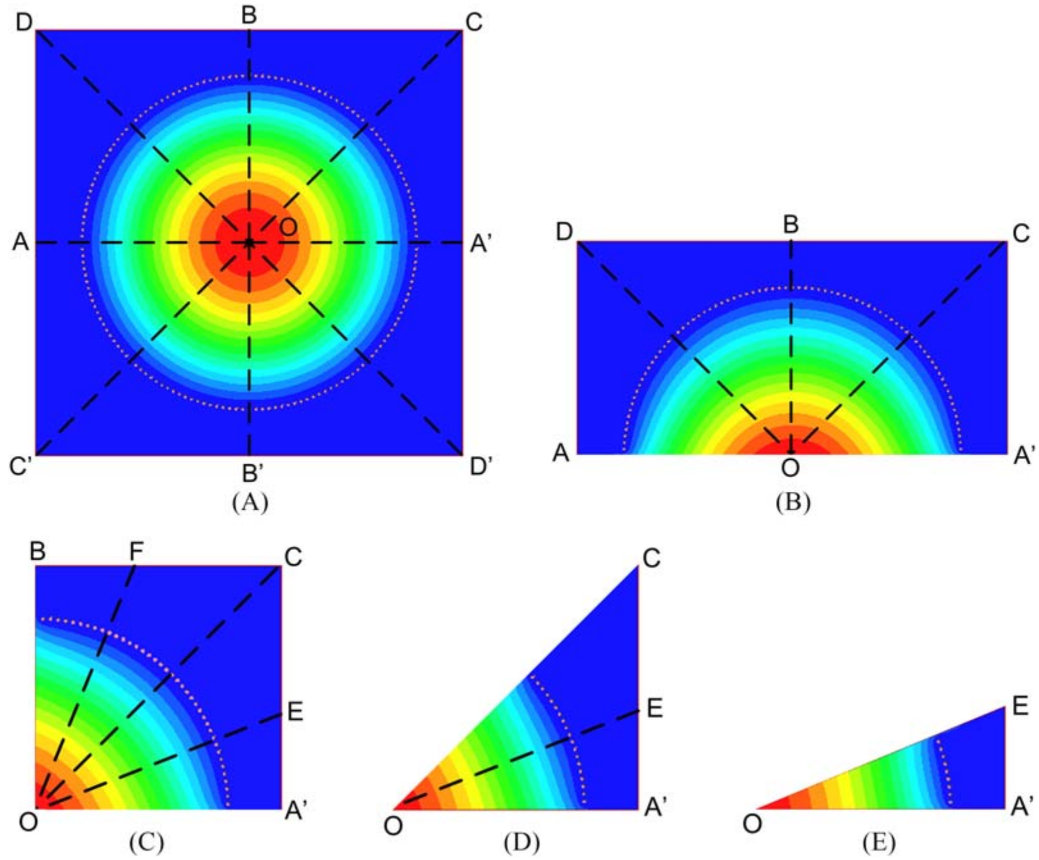

FIGURE 1 Simulated electric field distributions: (A) Full-mode SIW; (B) Half-mode SIW (HMSIW); (C) Quarter-mode SIW (QMSIW); (D) Eighth-mode SIW (EMSIW); (E) Sixteenth-mode SIW (SMSIW). [Color figure can be viewed at wileyonlinelibrary.com]

SIW structures. The presence of undesired higher-order modes of SIW structure degrades the stopband performance of the filter. Several SIW structures have been reported to eliminate the higher-order modes.[2–8] The reported structures are based on full-mode, half-mode, one-third mode, folded waveguide, and multilayer geometry.

This letter presents a compact two-pole bandpass filter based on sixteenth-mode substrate integrated waveguide (SMSIW) circular cavity operating at fundamental mode TM01. The size of the SMSIW cavity is reduced to a factor of 1/16 compared to the conventional SIW cavity while maintaining an identical resonant frequency. The out-of-band rejection deteriorates due to existence of higher-order mode TM02. An approach is presented to suppress higher-order mode in order to improve out-of-band performance. The proposed SMSIW filter is compact in size and shows good out-of-band performance.

2 | SMSIW CAVITY

The magnitude of the electric field distributions in a conventional SIW, HMSIW, QMSIW, EMSIW, and SMSIW cavity of the TM010 mode are presented in Figure 1. Figure 1A shows the magnitude of the electric field of a conventional SIW circular cavity. When the SIW is cut along the perfect magnetic wall A-A′, the half-mode SIW (HMSIW) is obtained, as shown in Figure 1B. The size of the HMSIW is nearly half of the size of the SIW for the same resonant frequency. Further size reduction of the HMSIW is performed by bisecting it along fictitious magnetic wall O-B, which is called a quarter-mode SIW (QMSIW), as shown in Figure 1C. Half-reduction of QMSIW along O-C gives the eighth-mode SIW (EMSIW), as shown in Figure 1D. The sixteenth-mode SIW (SMSIW) is generated by bisecting the EMSIW with another fictitious magnetic wall O-E, as shown in Figure 1E. The overall size can be reduced to a factor of 1/16 of the conventional SIW while it has almost same resonant frequency. In our work, the SMSIW structure has been used to design a compact microwave bandpass filter operating at 2 GHz. It is designed on Rogers RT/Duroid 5880 substrate with dielectric permittivity $\varepsilon_r = 2.2$, substrate thickness $h = 0.787$ mm, and loss tangent $\tan\delta = 0.0009$. Figure 2 shows the structure of SMSIW circular cavity where r is the radius of the cavity and d is the diameter of metalized via-holes. In our experiment, r and d are taken as 38.5 mm and 0.6 mm, respectively.

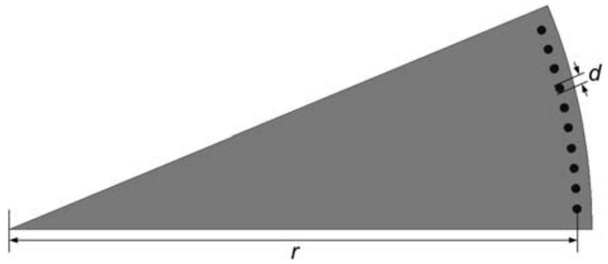

FIGURE 2 Configuration of SMSIW circular cavity

3 | RESONATOR ANALYSIS

Figure 3A shows the structure of the single SMSIW resonator fed by two 50 Ω. microstrip lines. The frequency response analysis has been carried out by full-wave simulator Ansys HFSS. The simulated frequency response is presented in Figure 3B. The stopband performance degrades due to presence of higher-order mode TM02 at 4.8 GHz, as shown in Figure 3B.

In order to eliminate the higher-order mode TM02, two slots are etched on the ground plane located below input and output feedlines, as shown in Figure 4, where l is the length of the slot, w is the width, and s is the separation of the slot from the resonator. The resonant frequency of the slot is 4.8 GHz. The slot on the ground plane generates a stopband at its resonating frequency and suppresses the higher-order mode TM02. The dimension and location of the slot can be chosen such that it provides wide out-of-band rejection. The simulated frequency responses of the single resonator with ground slots are shown in Figure 5. It can be observed that the higher-order mode (TM02) is eliminated by applying the proposed approach and an improved stopband performance is obtained while the desired mode (TM01) is not affected. Figure 5A shows the frequency response when l is varied from 23.5 mm to 25.5 mm, whereas w and s are kept constant at 0.2 mm and 0.2 mm, respectively. It is observed that $l = 24.5$ mm gives slightly better performance. Figure 5B shows the frequency response when w varies from 0.2 mm to 0.8 mm, whereas l and s are kept fixed at 24.5 mm and 0.5 mm, respectively. It can be seen that $w = 0.2$ mm exhibits the lowest insertion loss. Figure 5C presents the response when s is varied from 0 mm to 0.5 mm, whereas l and w are 24.5 mm and 0.2 mm, respectively. The frequency selectivity increases with increase in s, as shown in Figure 5C. In our work, the slot dimensions are as follows: $l = 24.5$ mm, $w = 0.2$ mm, and $s = 0.5$ mm, as suggested by the analysis presented in Figure 5.

4 | EXTERNAL AND INTERNAL COUPLING

The SMSIW resonator is excited with a 50 Ω microstrip feedline to determine the external quality factor (Q_e). The external quality factor can be calculated by using the following relation[9]:

$$Q_e = \frac{f_0}{\Delta f_{\pm 90s^\circ}} \tag{1}$$

where f_0 is the resonant frequency and $\Delta f_{\pm 90s^\circ}$ is the two frequencies obtained by the phase shifts of $\pm 90°$ with respect to the absolute phase at f_0. Q_e can be controlled by adjusting the position of the feedline (t). Figure 6 shows the calculated Q_e against t. It is seen that Q_e increases if t is increased.

The coupling coefficient can be determined by using the following relation[9]:

$$k = \frac{f_1^2 - f_2^2}{f_1^2 + f_2^2} \tag{2}$$

where f_1 and f_2 are the high and low resonant frequencies, respectively, and k is the coupling coefficient between two coupled SMSIW resonators. The coupling can be controlled by adjusting the separation (g) between the two SMSIW resonators. Figure 7 shows the variation of coupling coefficient

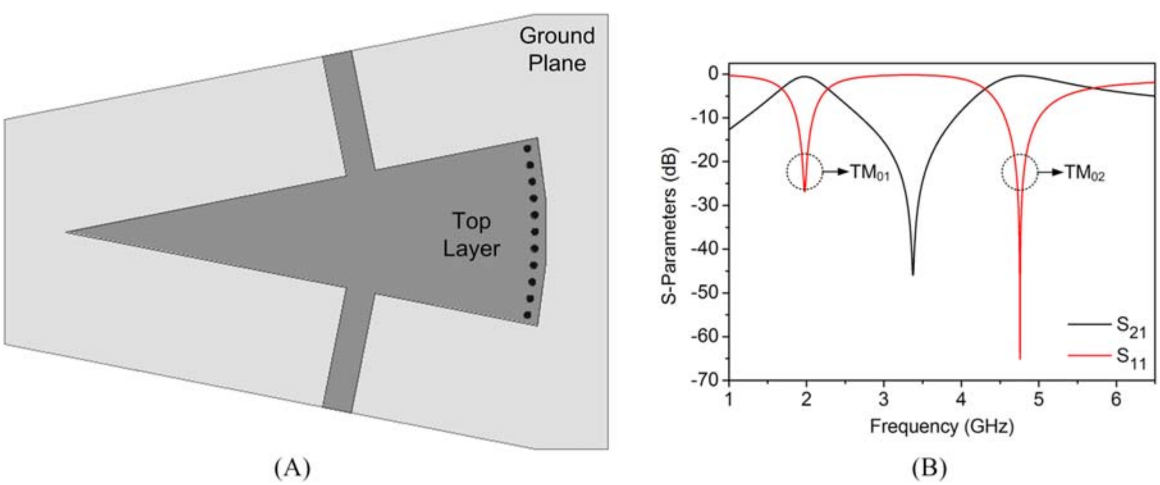

FIGURE 3 (A) Single cavity structure; (B) Simulated frequency response. [Color figure can be viewed at wileyonlinelibrary.com]

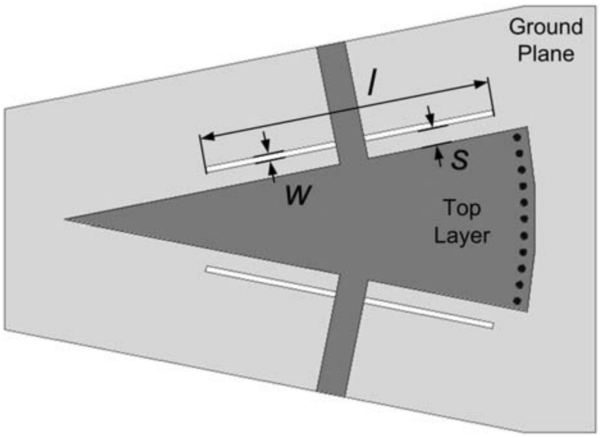

FIGURE 4 Single cavity with ground slots

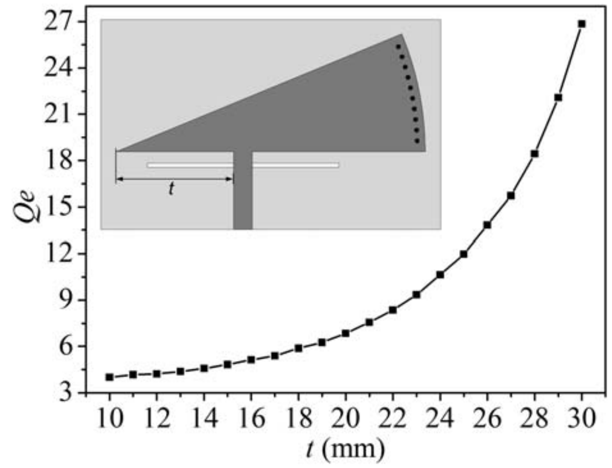

FIGURE 6 External quality factor Q_e against position of the feedline t

against g. It is observed that the coupling coefficient decreases if g is increased.

5 | FILTER DESIGN

To demonstrate the proposed approach, a two-pole bandpass filter exploiting SMSIW circular cavity with two ground slots is designed. The configuration of the filter is presented in Figure 8A. The filter is centerd at 2 GHz with a bandwidth of 8%. The coupling coefficient and the external quality factor are as follows: $k = 0.11$ and $Q_e = 10.5$. The dimensions of the filter satisfying the above requirements are: $r = 38.5$ mm, $w_{feed} = 2.4$ mm, $t = 23.5$ mm, $g = 0.55$ mm,

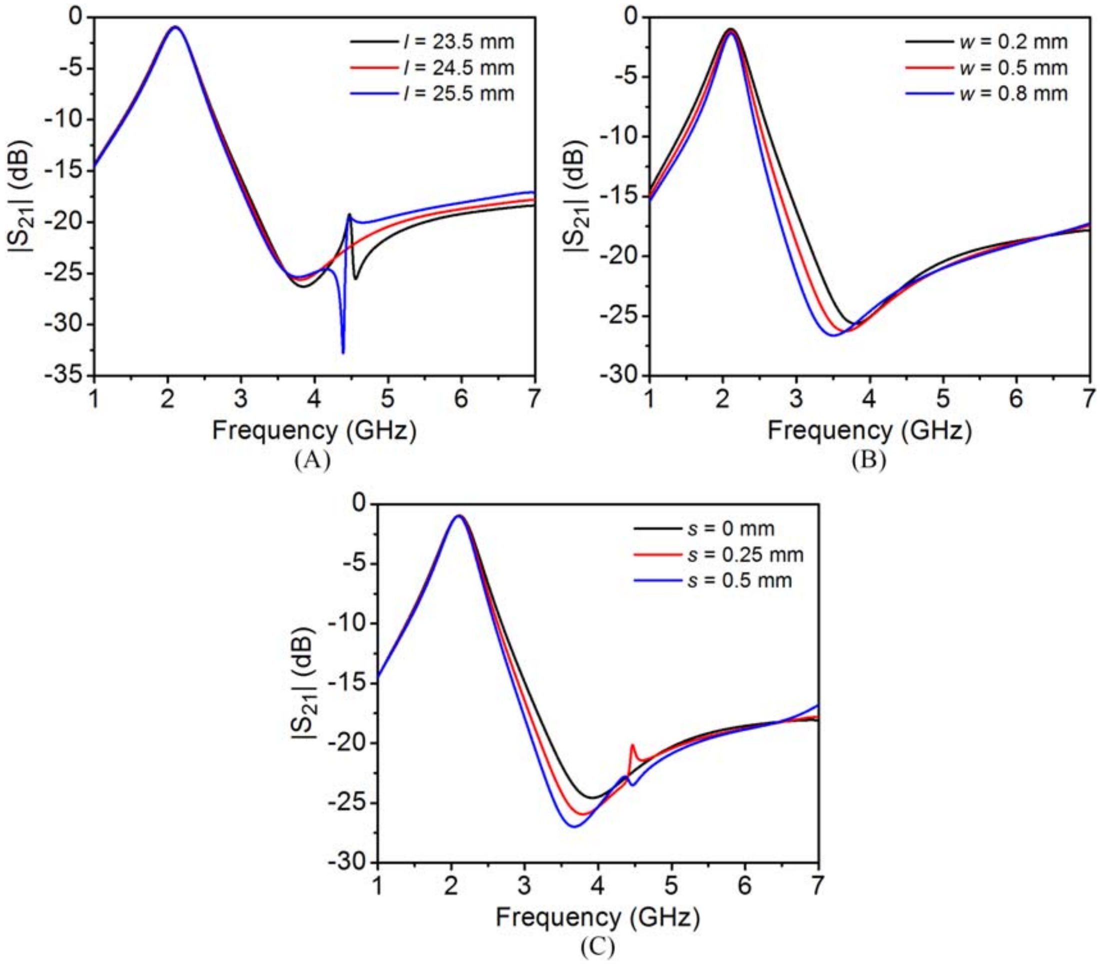

FIGURE 5 Simulated frequency response against (A) l; (B) w; (C) s. [Color figure can be viewed at wileyonlinelibrary.com]

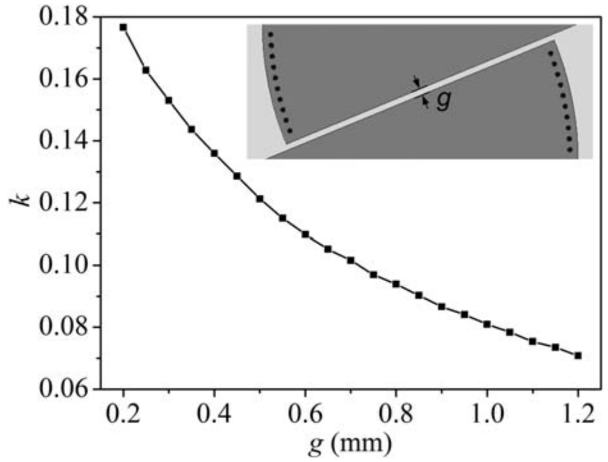

FIGURE 7 Coupling coefficient against g

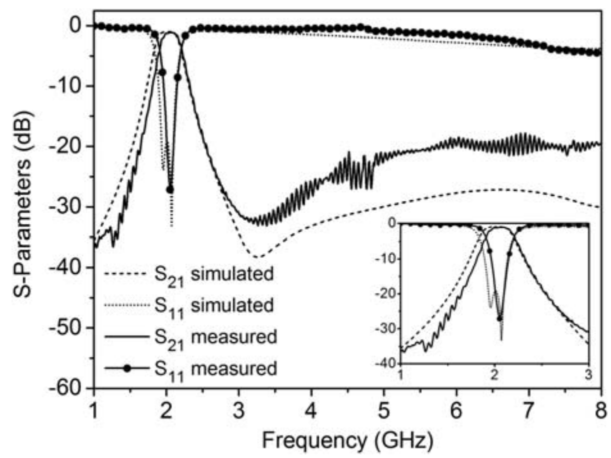

FIGURE 10 Simulated and measured filter response

$l = 24.5$ mm, $w = 0.2$ mm, and $s = 0.5$ mm. The simulated S_{21} (dB) of the designed filter is presented in Figure 8B and it is compared with the filter without ground slots. It can be observed that the proposed approach significantly improves the out-of-band performance by suppressing the higher-order mode TM_{02}.

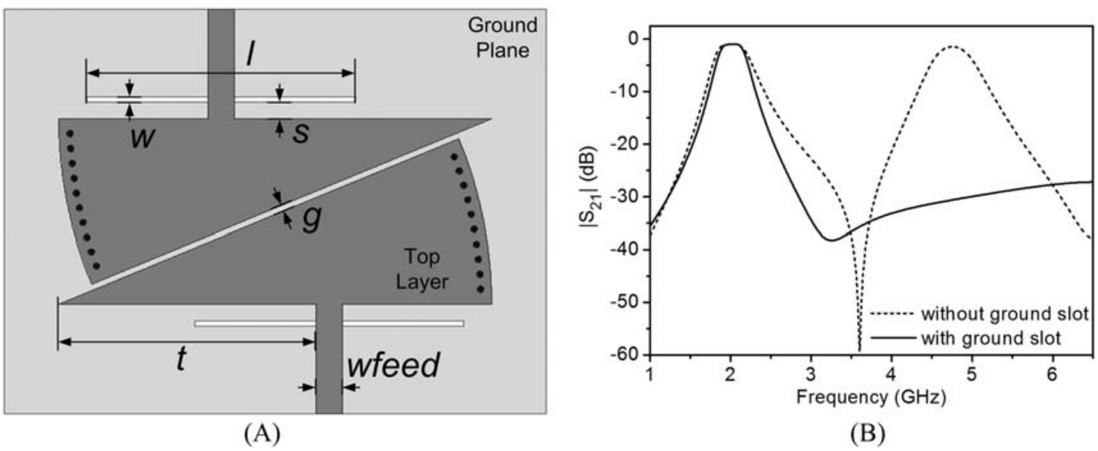

FIGURE 8 (A) Two-pole bandpass filter with slots on ground plane; (B) Comparison of $|S_{21}|$ (dB) of bandpass filters with and without slots on ground plane

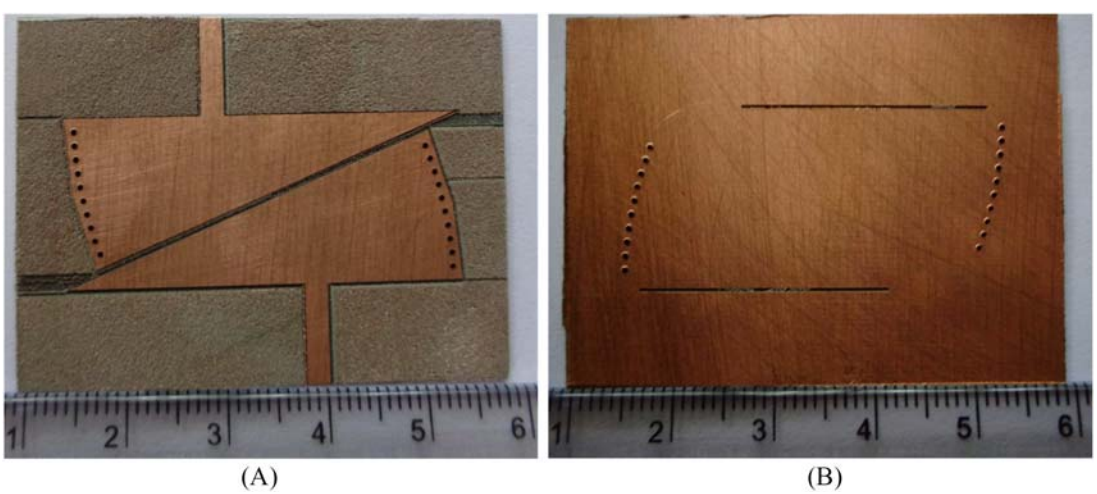

FIGURE 9 Photograph of fabricated filter: (A) Top view; (B) Bottom view. [Color figure can be viewed at wileyonlinelibrary.com]

6 | MEASUREMENT RESULTS

The photograph of the fabricated filter is shown in Figure 9. The simulated and measured results are presented in Figure 10. The filter is centered at 2.05 GHz with a bandwidth of 7%. The measured minimum insertion loss is 1.2 dB and passband return loss is better than 16 dB. An out-of-band rejection level below 18 dB is obtained from 2.5 GHz to 8GHz ($4f_0$), where f_0 is the design center frequency. Some discrepancies have been observed between the simulated and measured results, which can be attributed to fabrication error and losses due to connectors. The demonstrated filter is of compact size and exhibits wide out-of-band rejection.

7 | CONCLUSIONS

A compact bandpass filter based on SMSIW circular cavity is presented in this letter. The SMSIW cavity occupies only 6.25% of the convention SIW cavity while maintaining the same resonant frequency. An approach is presented to suppress higher-order mode in order to improve stopband performance. The filter operates at 2.05 GHz with wide out-of-band rejection up to $4f_0$. Simple structure, compact size, and ease of fabrication are the attractive advantages of the filter.

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Investigation of a notched UWB antenna with opening and shorting resonators

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Abstract

In this article, a planar ring monopole UWB antenna with two kinds of resonators are presented and investigated. The half wavelength opening resonator and quarter wavelength shorting resonator are coupled with the feed line capacitive to obtain notched characteristic. The contrast of current distribution demonstrates this novel method, and experimental results show that the proposed antennas meet the requirement of ultra-wide bandwidth (3.1–10.6 GHz), while avoiding the interference from WLAN band. Some important models and parameters, such as the transmission line model, equivalent circuit model, VSWR, radiation pattern antenna gain, and transfer function are also studied to evaluate notched characteristics.

KEYWORDS

half wavelength resonator, quarter wavelength resonator, notched monopole, UWB antenna