TRIPLE-PASS-BAND, DUAL-STOP-BAND UWB ANTENNA WITH SUBSTRATE-INTEGRATED WAVEGUIDE RESONATORS

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ABSTRACT: A coplanar-waveguide fed ultra-wideband (UWB) antenna with substrate-integrated waveguide (SIW) stop-band resonators is introduced for the 3–10 GHz band. The symmetrically placed SIW cavities provide dual-stop-band characteristics due to their $\text{TE}_{101}$ and $\text{TE}_{102}$ resonance modes. Thus, the entire UWB is divided into three pass-bands which cover the frequency ranges 4.23–4.62 GHz, 6.6–8.175 GHz, and 9.39–10.7 GHz. Measurements of a prototype show good agreement with simulation results with a minimum measured return loss of 9 dB in any of the three pass-bands.

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Key words: ultra-wideband antennas; coplanar waveguide; substrate-integrated waveguide; stop-band filter

1. INTRODUCTION

With the release of the 3.1–10.6 GHz band for ultra-wideband (UWB) communication, a number of diverse applications have been proposed and implemented such as systems related to imaging, medical monitoring, surveillance, ground penetrating and vehicular radar, communications, measurements and many more. Portable handhelds for short-range and large bandwidth communications will be required in future UWB systems. Thus, there is a demand for the implementation of UWB antennas in printed-circuit technologies.

Over the last decade, a variety of printed-circuit UWB antennas have been proposed. They use either microstrip, for example, [1–4] or coplanar-waveguide (CPW) technologies, for example, [4–7]. Although CPW has the advantage of requiring fabrication on only a single side of the substrate, microstrip is more versatile as antenna elements may be printed on both substrate sides [8].

To avoid interference with existing wireless networks, UWB antennas are in need of band-rejection capabilities. Instead of adding new circuits to the communication system, stop-band techniques can be applied directly to the UWB planar antenna, for example, [9–12]. However, common practice is to realize the integration of notch circuits with microstrip or slot-line resonators. Their relatively low quality factor usually results in broadband notches with low attenuation and mediocre selectivity [13].

Therefore, this article introduces substrate-integrated waveguide (SIW) resonators to improve the selectivity of stop-bands in UWB antennas because $Q$ factors of SIW cavities are an order of magnitude higher than those of microstrip resonators [14]. A similar approach is presented in Ref. 15 for the 1–7 GHz band where a microstrip feed line is placed on top of a single SIW resonator. However, the return loss values within some of the pass-bands are only 4 dB and thus not that much different...
from the stop-bands. This article demonstrates that pass-band return losses of close to 10 dB are possible in three different pass-bands and that the two stop-bands provide rejection in the order of 10 dB.

2. DESIGN

The design of the CPW-fed UWB antenna element is adapted from Ref. 4, where RT/Duroid 6002 substrate was used with \( \varepsilon_r = 2.94, \) \( \tan \delta = 0.0012, \) substrate height \( h = 508 \mu m, \) metallization thickness \( t = 17.5 \mu m, \) and conductivity \( \sigma = 5.8 \times 10^8 \) S/m. Figure 1 depicts the layout of the UWB antenna with SIW band-stop resonators and outlines all dimensions as well as the coordinate system used in this work. To maintain a reasonable center conductor to slot width ratio (0.7 mm/0.2 mm), the impedance of the feeding CPW is selected as 70.8 \( \Omega \). Note that the 50 \( \Omega \) coaxial connector is included in all simulations and, therefore, this impedance mismatch (VSWR = 1.4) is fully taken into account.

The band-stop filter is designed with two identical SIW resonators to maintain symmetry. For pattern symmetry and group delay performance, symmetric SIW resonators assure that the UWB antenna is fed with the fundamental (even) CPW mode as opposed to a combination of even and odd modes. According to design guidelines presented in Ref. 16, the equivalent waveguide width, \( a_{\text{equ}} \), is given as

\[
a_{\text{equ}} = \frac{c}{2f_c \sqrt{\varepsilon_r}}
\]  

where \( c \) is the speed of light and \( f_c \) is the cutoff frequency which is set to 4 GHz via diameter \( d \) and center-to-center spacing \( p \) are chosen according to Ref. 17, leading to \( p = 1 \) mm and \( d = 1.4 \) mm. Thus, the \( d/p \) ratio is 0.71 which is well within the recommended range between 0.5 and 0.8. After the equivalent waveguide width, \( a_{\text{equ}} = 21.855 \) mm is obtained from (1), the actual width \( a \) of the SIW resonators is extracted from Ref. 16 and is found as \( a = 22.626 \) mm, compared to Figure 1. The distances between the SIW resonators to the antenna and to the coaxial feed have been determined in parametric studies which are not shown here. The same holds for the CPW-to-SIW transitions.

The guided wavelength in a SIW structure is given as

\[
\lambda_g = \frac{c}{\sqrt{\varepsilon_r \sqrt{f^2 - f_c^2}}}
\]  

such that a half-wavelength resonator at 6 GHz is 19.5 mm long. The next harmonic of the resonator falls inside the band and theoretically appears at 9.8 GHz. However, due to the CPW-to-SIW transitions used to excite the resonators, the resonances shift slightly downward and appear at 5.2 and 8.7 GHz. Note that unless a single stop-band is desired in the upper UWB spectrum, waveguide-based resonators will always demonstrate a second pass-band within the UWB range. However,
Figure 6  Normalized radiation patterns in the first pass-band at 4.3 GHz—simulated (solid line) and measurements (dotted line): (a) co-pol $H$-plane, (b) x-pol $H$-plane, (c) co-pol $E$-plane, and (d) x-pol $E$-plane

Figure 7  Normalized radiation patterns in the first stop-band at 5 GHz—simulated (solid line) and measurements (dotted line): (a) co-pol $H$-plane, (b) x-pol $H$-plane, (c) co-pol $E$-plane, and (d) x-pol $E$-plane
Figure 8  Normalized radiation patterns in the second pass-band at 7 GHz—simulated (solid line) and measurements (dotted line): (a) co-pol $H$-plane, (b) x-pol $H$-plane, (c) co-pol $E$-plane, and (d) x-pol $E$-plane

Figure 9  Normalized radiation patterns in the second stop-band at 9 GHz—simulated (solid line) and measurements (dotted line): (a) co-pol $H$-plane, (b) x-pol $H$-plane, (c) co-pol $E$-plane, and (d) x-pol $E$-plane
within limits, the position of the second stop-band can be adjusted by changing the cutoff frequency $f_c$ of the SIW cavities. For instance, if the cutoff frequency of the SIW resonators had been chosen as 4.8 GHz instead of 4 GHz and if the first stop-band remained at 6 GHz, then the second stop-band of the SIW resonator would occur at 8.65 GHz instead of 9.8 GHz.

Figure 2 shows photographs of the fabricated prototype and depicts the connection of ground planes by the coaxial connector.

3. RESULTS

Figure 3 compares the measured reflection coefficient with that obtained from the time-domain solver of CST Microwave Studio. Good agreement is observed with a minimum measured return loss of 9 dB in the three bands that range from 4.23 to 4.62 GHz, 6.6 to 8.175 GHz, and 9.39 to 10.7 GHz.

Figure 4 depicts the simulated co- and cross-polarized field components $E_\phi$ and $E_\theta$ (cf., Fig. 1), respectively, with a probe located in the far field at $\theta = 90^\circ$ and $\phi = 90^\circ$. The copolarized fields are predominant in the pass-bands and similar to the cross-polarized ones in the stop-bands.

For the same scenario, Figure 5 shows the simulated group delay performances of the two polarizations. As the signal is dominated by the copolarized field, the group delay in copolarized direction is the main focus. Its variation is less than 80 ps in the three pass-bands.

Figures 6–10 compare the simulated and measured normalized radiation patterns for frequencies of 4.3, 5, 7, 9, and 10 GHz. The first two plots in each figure [(a) and (b)] are the $H$-plane, (c) co-pol $E$-plane, and (d) x-pol $E$-plane.

Figure 11 Simulated gain performances of UWB antenna with SIW resonators: maximum gain in the $E$-plane ($\Phi = 90^\circ$) and $H$-plane ($\Theta = 90^\circ$).
plane, and the last two [(c) and (d)] are the E-plane radiation patterns. In addition, the plots on the left side of each figure [(a) and (c)] are the copolarized, those on the right side [(b) and (d)] the cross-polarized radiation patterns. Figures 6, 8, and 10 show the radiation patterns in the pass-bands, whereas those in Figures 7 and 9 are in the stop-bands.

Good agreement between simulations and measurements is demonstrated. It is observed that in the pass-bands, the copolarized radiation levels are at least 10 dB above the cross-polarized ones. In the stop-bands, the copolarized fields have similar low power levels as the cross-polarized ones. This is in reasonable agreement with the amplitude responses as shown in Figure 4.

Figure 11 depicts the simulated gain performance of the UWB antenna with SIW resonators. (Note that calibrated gain could not be measured.) Because the direction of maximum radiation changes with frequency according to Figures 6–10, two gain curves are presented in Figure 11: the E-plane plot is the maximum gain obtained when varying angle $\theta$ at $\phi = 90^\circ$, that is, the yz plane in Figure 1. The H-plane plot is the maximum gain when varying angle $\phi$ in the H-plane at $\theta = 90^\circ$, that is, the $xy$ plane in Figure 1. It is observed that both E-plane and H-plane gains have notches at the stop-band frequencies of around 5 and 9 GHz.

4. CONCLUSION

Using SIW cavities in printed-circuit UWB antennas is a viable option to create dual-stop-bands for the purpose of alleviating signal interference in UWB systems. Because a half-wavelength SIW resonator designed for the 6 GHz band will produce a second notch within the UWB due to the next harmonic resonance, three pass-bands separated by two stop-bands are produced. The design that uses a CPW-fed UWB antenna with two symmetric SIW resonators is experimentally verified with respect to input reflection coefficient and pass- and stop-band radiation patterns. In the three pass-bands, amplitude responses, group delays, and gains are reasonable and compared well with other printed-circuit UWB antennas. The pass-band return loss is significantly better than a previous attempt to utilize an SIW cavity within a UWB antenna setting.

REFERENCES


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COMPARISON OF PERFORMANCE OF COMPACT RING PRINTED MONOPOLE AND LOOP ANTENNAS FOR WIRELESS-IMPLANTABLE BODY AREA NETWORK APPLICATIONS

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ABSTRACT: Human bodies have a variety of tissues and organs, and so it needs to be characterized as a radio-wave propagation medium to create a reliable wireless communication link. The radiation characteristics of printed monopole antenna and printed loop antenna for wireless-implantable body area network (WiBAN) applications are presented in this article. The two antennas are submerged into canola oil to mimic an implanted antenna in the human tissue. The tissue is considered a lossy environment and hence, it adversely degrades radiation characteristics of both antennas. Therefore, the RF transmission attenuation, dB