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Compact Band-Notched UWB Dielectric Resonator Antennas

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Abstract—Novel compact ultra-wideband (UWB) rectangular stacked dielectric resonator antennas (DRAs) with band-notched characteristics are proposed. The DRAs are designed to cover the FCC band (3.1–10.6 GHz) and have very compact sizes, due to the shorting conductor. Printed dipoles that are placed on one side of the dielectric resonator will resonate and generate band notches within the ultra-wide operating band. Simulations and measurements confirm the validation of the design principle.

1. INTRODUCTION

UWB technology has experienced a blooming growth in recent years since the US Federal Communication Commission (FCC) permitted the authorization of using the unlicensed frequency band of 3.1–10.6 GHz for commercial communication applications. Various UWB antennas [1–5] and band-notched UWB antennas [6–9] were developed for UWB systems, and most of them are based on the printed monopole antenna technology. Dielectric resonator antennas (DRAs) have received much attention for the past two decades due to their inherent advantages such as small size, high radiation efficiency, wide impedance bandwidth and ease of integration to the system. Recently, DRAs have been demonstrated [3–5] to have the potential for UWB applications.

In this paper, two compact band-notched UWB rectangular DRAs are proposed. The printed dipole and loop are proposed to combine with the compact UWB DRAs in [5] to generate single- or dual-notched bands, which can be slightly moved within the operating band of 3.1–10.6 GHz. Good agreements are achieved between the simulated and measured results. Compared with other UWB antenna designs, the proposed band-notched DRAs show a very compact size, only $0.13\lambda \times 0.08\lambda \times 0.16\lambda$ at 3.1 GHz, without compromising the radiation performance over the FCC band of 3.1–10.6 GHz.

2. ANTENNA DESIGN WITH A SINGLE BAND NOTCH

Printed band-notched UWB antennas have been implemented in recent years [6]. Two techniques are normally applied to design such antennas. One is cutting slots in the radiators. The other is adding resonators on the feedline, or putting resonators close to the feedline. The later will be applied to the UWB DRA to generate band notches, without compromising the other performance of the antenna.

The proposed band-notched UWB DRAs are based on the design presented in [5]. The basic configuration is shown in Figure 1. It is a stacked DRA and composed of a dielectric resonator (DR, $l \times w \times h_2$), a thin dielectric segment ($l \times w \times h_1$), a PEC ground, a shorting conductor ($w \times (h_1 + h_2)$) and a coaxial feeding probe. The thin dielectric segment has a lower permittivity (ε_1) than that (ε_2) of the DR and is placed between the PEC ground and the DR, to reduce the Q-factor of the DRA and broaden the operating bandwidth. A rectangular groove ($a \times w \times b$) is cut on the lower part of the DR, to improve the impedance matching of the DRA [5]. The probe that passes through the thin dielectric segment and has a length of d1 inside the DR is used to feed the DRA. A rectangular metallic patch

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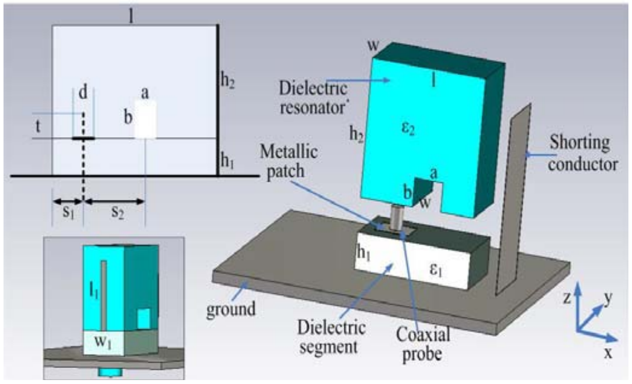


Figure 1. Schematic views of the proposed UWB band-notched DRA.

is printed on the upper surface of the dielectric segment and connected with the probe, to broaden the bandwidth of the DRA [5]. The shorting conductor is attached to one side of the DRA, to reduce more than half volume of the DRA, without compromising the radiation performance [4]. To generate a notched band within the bandwidth of the DRA, a printed dipole ($l_1 \times w_1$) is attached to the DRA, opposite to the side of the shorting conductor. The dipole will resonate at a frequency that will cause a notch in the operating band of the DRA. The length (l_1) of the dipole can be approximately evaluated by

$$l_1 = \frac{\lambda}{2\sqrt{\varepsilon_2}} \tag{1}$$

where λ is the free space wavelength at the frequency at which the band notch is located. The dipole acts as a resonator on the DRA. When the resonator is close to the feedline of the DRA, the probe together with the rectangular patch, a band notch will be generated at the resonant frequency of the dipole. Due to the strong mutual coupling between the printed dipole and the probe as well as the feeding metallic patch on the upper surface of the dielectric segment, the length l_1 should be slightly modified. The closer the dipole is to the probe, the shorter the length l_1 is.

The proposed DRA was investigated and optimised using commercial software Ansys HFSS. A UWB DRA for the FCC band application was first designed [5], and then the band-notched technique described above was applied. The materials selected for the DR and the thin dielectric segment are Rogers TMM10 and RT/Duroid 5880, respectively, whose dielectric constants are 9.2 (ε_2) and 2.2 (ε_1), respectively. The dimensions of the designed UWB DRA are: $l = 13\,\text{mm}$, $w = 8\,\text{mm}$, $h_1 = 3.5\,\text{mm}$, $h_2 = 12\,\text{mm}$, $a = 5\,\text{mm}$, $b = 3\,\text{mm}$, $d = 2.3\,\text{mm}$, $t = 3.5\,\text{mm}$, $s_1 = 2.5\,\text{mm}$, and $s_2 = 5\,\text{mm}$. The ground size is $100 \times 100\,\text{mm}^2$. The total DRA size is $13 \times 8 \times 15.5\,\text{mm}^3$, or $0.13\lambda \times 0.08\lambda \times 0.16\lambda$ at 3.1 GHz, much smaller than those of UWB DRAs with other configurations [3, 7–9]. The simulated VSWR is plotted in Figure 2. As can be seen, the operating band, determined by VSWR < 2, is from 2.95 GHz to 11.1 GHz, covering the UWB FCC band of 3.1–10.6 GHz. The band-notched technique was then applied to obtain a notch within the UWB FCC band. In the investigation, the parameter w_1 is 1 mm and l_1 is varied. The simulated results are also shown in Figure 2. It can be seen that the notch peak varies with the change of l_1. Parameter l_1 can be used to control the location of the band notch.

The fields and current on the dipole for the DRA case of $l_1 = 10.5\,\text{mm}$ have been studied. The current on the dipole of the DRA at 5.75 GHz is plotted in Figure 3. It can be seen that strong current is generated at 5.75 GHz, due to the strong resonance of the dipole at the frequency, and hence a band notch around 5.75 GHz is generated.

A prototype was fabricated, and the VSWR was measured using the vector network analyser Agilent E8363C. In the prototype, the value of l_1 is 10.5 mm. The measured and simulated VSWRs are plotted in Figure 4. It can be seen that the agreement is very good. The measured bandwidth, determined by VSWR < 2, is from 2.9 GHz to 12 GHz, with a band notch from 5.2 GHz to 6.1 GHz. The radiation patterns of the prototype were measured in a far-field anechoic chamber. Figure 5 shows the measured radiation patterns at 3.3 GHz, 6 GHz and 10.2 GHz in E- (XOZ plane) and H-planes (YOZ

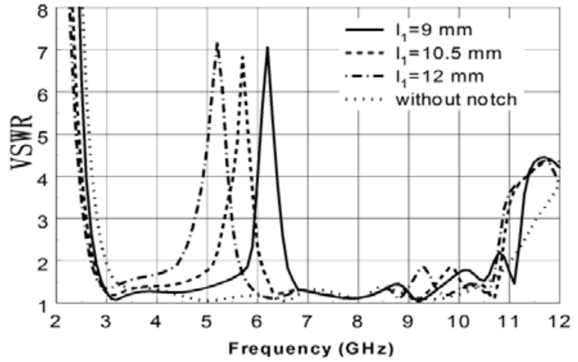


Figure 2. Simulated VSWR for DRAs with various l_1 and that without applying the band-notched technique.

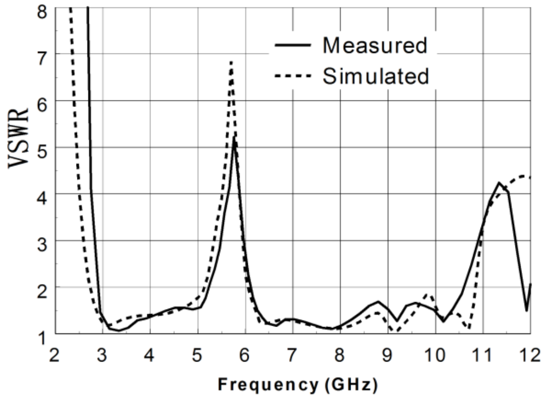


Figure 4. Simulated and measured VSWRs of the prototype DRA.

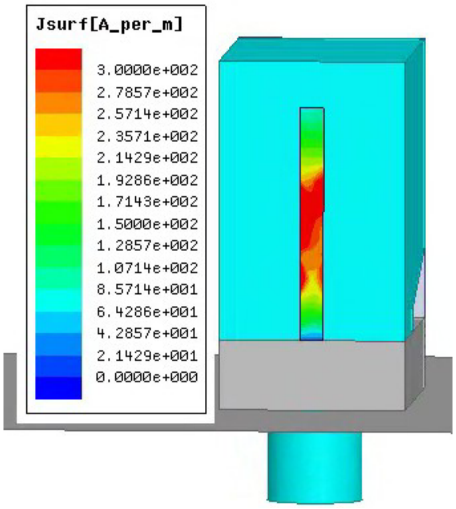
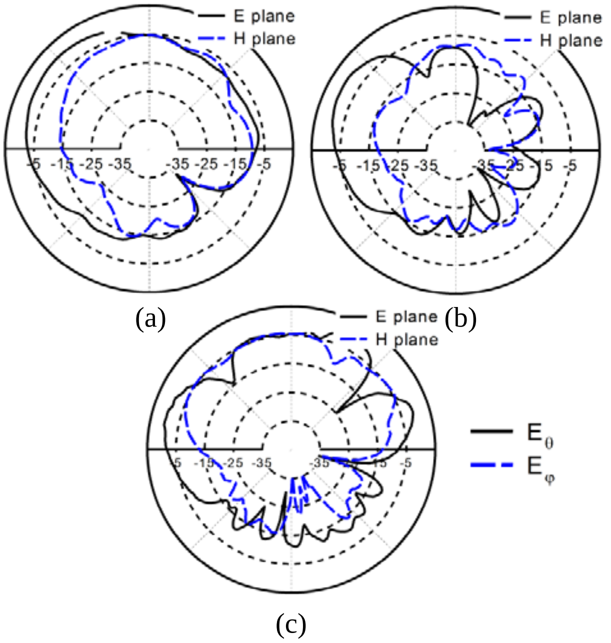


Figure 3. The current density on the printed dipole on the DRA at 5.75 GHz.



(a) (b) (c)

Figure 5. Measured radiation patterns: (a) 3.3 GHz; (b) 6 GHz; (c) 10.2 GHz.

plane). Symmetrical and non-symmetrical patterns are obtained in *H*-plane and *E*-plane respectively for all the three frequencies. The gain of the antenna was also measured and shown in Figure 6. The simulated gain is also plotted in Figure 6, for comparison. The agreement between the simulation and the measurement is not good enough at some frequencies. The reason is that the ground size in measurement is 100 × 100 mm^2, while that of 40 × 40 mm^2 is used in simulations. A reasonable low gain is obtained at the notched band, which can be used to reject the unexpected frequency within the UWB FCC band.

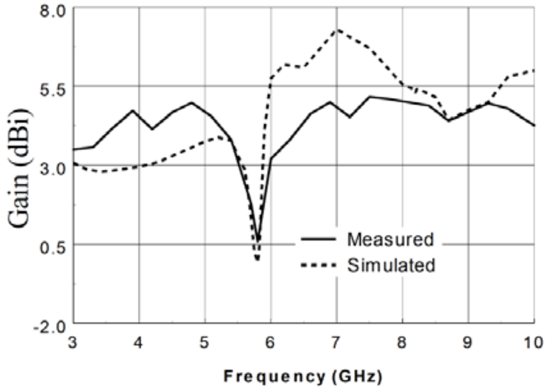


Figure 6. Measured and simulated gains.

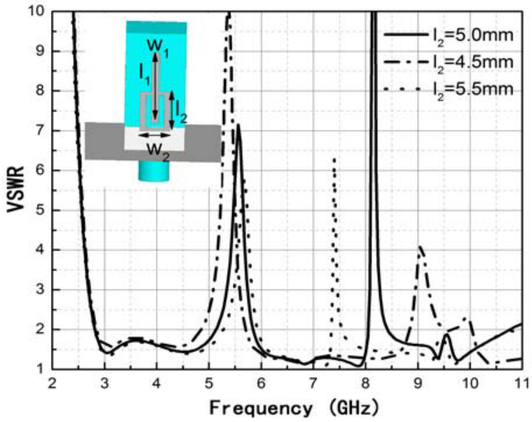
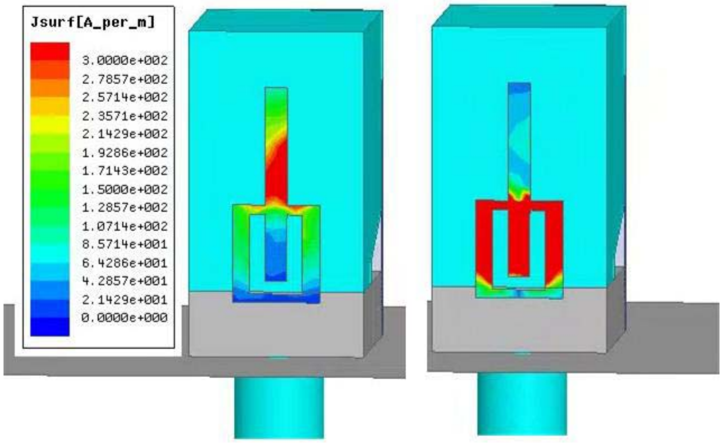


Figure 7. Simulated VSWRs for the proposed dual band-notched UWB DRA with varied l_2.



(a) (b)

Figure 8. Current densities on the modified printed dipole and loop on the DRA at 5.75 GHz and 8.1 GHz.

3. ANTENNA DESIGN WITH DUAL BAND NOTCHES

The band-notched technique for UWB DRAs can be further extended to generate dual band notches within the operating bandwidth. If the resonator close to the feedline were able to resonate at two frequencies, two band notches would be generated. The design principle has been validated in printed dual-band-notched UWB antennas and will be applied to design a UWB DRA with dual band notches. As shown in the inserted DRA in Figure 7, a rectangular metallic loop together with a dipole, which is applied to generate a single band notch in the above section, is printed on the side of the DRA close to the feeding probe. The dimension of the dipole is $l_1 \times w_1$ and that of the rectangular loop is $l_2 \times w_2$. The combination of the printed dipole and loop will resonate at two different frequencies, corresponding to the two band notches desired. In the extended technique, the printed dipole will generate the first band notch, like that obtained above. A second band notch can be generated by the rectangular loop together with the dipole. By changing the dimensions of the dipole and the loop, the positions of the two notches can be controlled.

A design example is presented in Figure 7. The WLAN band (5.15 GHz–5.8125 GHz) and ITU

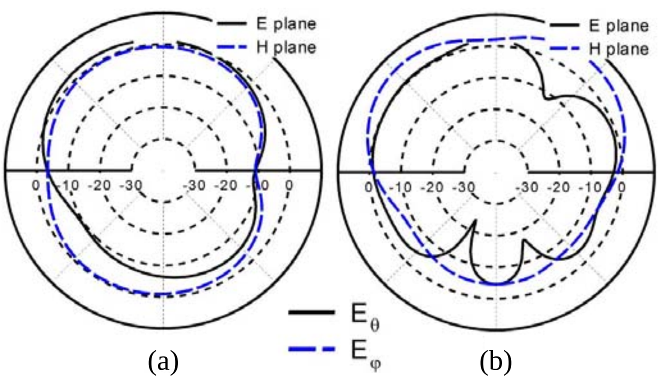


Figure 9. Simulated radiation patterns: (a) 4 GHz; (b) 10 GHz.

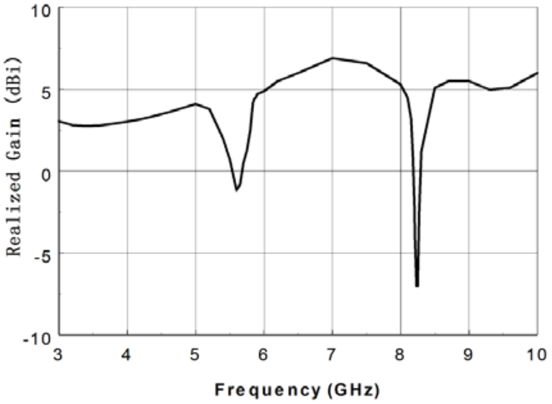


Figure 10. Simulated realized gain of the UWB dual band-notched DRA.

band (8.025 GHz–8.4 GHz) will be rejected in the UWB FCC band (3.1 GHz–10.6 GHz). The design parameters l_1, w_1 and w_2 are 9 mm, 1 mm and 4 mm, respectively. When changing parameter l_2, as shown in Figure 7, the position of the lower band notch is minor changed, while that of the second notch will vary with l_2. Therefore, parameters l_1 and w_1 can be used to control the first band notch and l_2 and w_2 will mainly affect the second notch, and the mutual effect of the two controls is minor. It can be seen in Figure 7, the second notch at ITU band is obtained when $l_2 = 5$ mm.

The current densities on the printed dipole and loop on the DRA at 5.75 GHz and 8.1 GHz are plotted in Figure 8. It can be seen that strong current density is mostly on the dipole at 5.75 GHz, while that is mainly on the loop and the part of the dipole inside the loop at 8.1 GHz, demonstrating how the two band notches are generated at the two frequencies.

Figure 9 shows the simulated radiation patterns of the UWB dual band-notched DRA design at 4.0 GHz and 10 GHz in E- (XOZ plane) and H-planes (YOZ plane). Symmetrical and non-symmetrical patterns are obtained in H-plane and E-plane respectively for both frequencies. Simulated realized gain is plotted in Figure 10. It can been seen that the lower gains are obtained at WLAN and ITU bands, as expected.

4. CONCLUSIONS

It is possible to generate band rejections in the operating band of a UWB rectangular stacked DRA by placing printed dipoles on the side of the dielectric resonator that is close to the feeding probe. Due to the application of the shorting conductor, the stacked DRA has a very compact size, only $0.13\lambda \times 0.08\lambda \times 0.16\lambda$ at 3.1 GHz. A thin dipole printed on the side of the DRA can generate a band notch and two notches can be obtained by printing a thin dipole and a printed loop on the side of the DRA close to the probe. The peak positions of the band notches can be moved by changing the length of the printed dipole or that of the printed loop. Measurements of the prototype with a printed dipole show that the bandwidth of VSWR < 2 covers the frequency range of 2.9–12 GHz, with a band notch of 5.2–6.1 GHz, while simulations demonstrate that two band notches can be generated using a printed dipole and a printed loop. Reasonable gains and radiation patterns are also obtained both in the measurements and simulations.

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