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# BST-COC COMPOSITE BASED RECTANGULAR DIELECTRIC RESONATOR ANTENNA (DRA) FOR 2.4 WLAN WRIST APPLICATIONS

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**Abstract**—A rectangular dielectric resonator antenna (DRA) based on Barium Strontium Titanate-Cyclic Olefin Copolymer (BST-COC) composite for 2.4 GHz wrist application is designed and characterized. The dielectric properties of the composite with $\sim$ 57 vol.% BST loading are characterized using microstrip ring resonator structures at 2.45 GHz frequency. The proposed DRA, fixed onto a reverse grounded FR4 laminate, has a very compact size of $19\,\text{mm} \times 10\,\text{mm} \times 5\,\text{mm}$. The impact of the user's body proximity on the radiation performance of the antenna is studied experimentally. The percentage total efficiency and gain of the antenna deteriorated by about 8.5% and 2 dB due to the proximity of the user's body. The proposed DRA showed better performance than that of resonant type of antennas when close to the user's body.

## 1. INTRODUCTION

In recent years the popularity of wireless health care monitoring devices for consumer applications has increased considerably. These devices in general comprise wearable antennas placed in the vicinity of a human torso or arm. The antenna performance, such as total radiation efficiency and the shape of the radiation pattern, can be seriously affected by the presence of the human body, which can be treated as a lossy dielectric medium. The performance of different types of antennas is affected differently by the proximity of the human body. This is because of different coupling mechanisms between the antenna and the body. Lately, many researchers have demonstrated resonant type

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antennas for wearable applications [1–4]. However, the performance of these resonant type antennas is significantly reduced in close proximity to the human body due to the presence of strong surface currents on the ground plane of the antenna. In order to alleviate these adverse effects, these resonant type antennas are usually elevated from the human body by approximately 5 mm, thus increasing the total antenna efficiency [3]. However, this solution increases the overall antenna volume. Owing to their compact size and devoid of conductor losses, dielectric resonator antennas (DRA) have gained much attention [5, 6]. Usually, these DRAs are fabricated using ceramic materials [7–11]. However, these ceramic DRAs are fragile and involves expensive high sintering fabrication processes including metallisation.

Ceramic-polymer 0-3 composites have been attracting considerable interest because they enable the realization of inexpensive 3-D microwave devices and packages. These composites, when using a thermoplastic polymer, have the additional advantage of a simple 3-D fabrication processes, such as injection moulding. The dielectric properties of thermoplastic composites prepared from barium-strontium-titanate $Ba_{1-x}Sr_xTiO_3$ (BST) and different kinds of polymers such as polyvinylidene fluoride-co-trifluoroethylene, polyphenylene sulfide (PPS), cycloolefin copolymer and polypropylene-based polymer alloy have been investigated for radio frequency applications [12, 13].

In this work, a compact rectangular dielectric resonator antenna based on BST-COC polymer composite material for wrist type applications operating in the 2.4 wireless local area network (WLAN) frequency band (2.4 to 2.484 GHz) is designed, fabricated and measured. The antenna performance of the dielectric resonator antenna (DRA) is demonstrated to be less affected by the presence of the human body than that of resonant type of antennas. This can be attributed to the weaker surface currents on the ground plane of the DRA.

## 2. SUBSTRATE PREPARATION

The preparation of the BST-COC composite through extrusion has been reported in detail by Tao et al. [13]. The BST-COC composite with ceramic loading of 57 vol % was extruded through a hot mould of suitable sample size (30 mm × 30 mm × 1 mm) for RF characterization. The DRA was made by hot pressing the BST-COC composite into the desired dimensions. The DRA was soldered onto a ground plane backed FR4 PCB ($\epsilon_r = 4.4$) substrate. A copper foil about 10 μm thick was transferred onto the BST-COC composite substrates using conventional printed circuit board (PCB) technology.

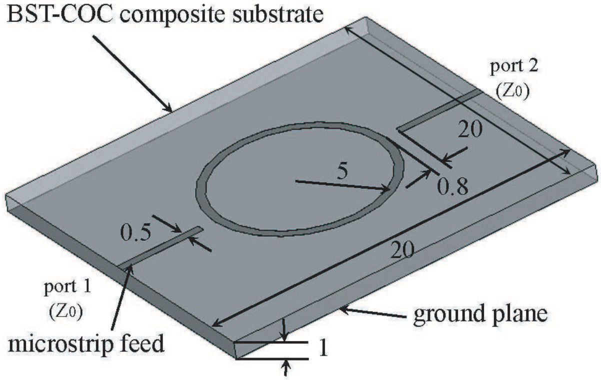


**Figure 1.** Schematic layout of the ring resonator structure for the dielectric characterization of BST-COC composite at 2.45 GHz (dimensions in mm).

## 3. RF CHARACTERIZATION OF BST-COC SUBSTRATE

A microstrip ring resonator structure was chosen for the RF characterization of the BST-COC composite substrate at 2.45 GHz. This structure offers the most accurate and simple method for RF characterization of planar substrates [14]. A schematic layout of the ring resonators operating at 2.45 GHz is presented in Fig. 1. Ansoft HFSS (version 12), a commercial 3-D electromagnetic simulator, was used for the design of the ring resonator structures. The resonance frequency and unloaded Q-factor were measured to be 2.456 GHz and 43.6 respectively. The relative permittivity of the BST-COC composite substrate was calculated from the measured resonance frequency and geometry of the structure [14]. The dielectric loss tangent value ($\tan \delta$) of the composite material was calculated from the measured Q-factor of the ring resonator and estimated conductor losses [15].

## 4. ANTENNA STRUCTURE

Figure 2 depicts the schematic layout of the proposed BST-COC composite based rectangular dielectric resonator antenna operating in the 2.4 GHz WLAN frequency band for a wrist watch type application. The antenna structure proposed by Saed and Yadl [16] and Mohssin et al. [17] was adopted in the design of the DRA. The antenna has a compact structure of 19 mm $\times$ 10 mm $\times$ 5 mm, and is thus suitable for watch type wireless communication devices. Metallisation for the antenna element was done using conventional printed circuit board technology. The DRA was mounted onto a 50 mm × 20 mm reverse-side-grounded 0.83 mm thick FR4 PCB substrate. A 50-Ω microstrip transmission line was used to feed the antenna. The complete antenna structure was simulated using Ansoft HFSS (version 12). The simulated electric and magnetic field vector components of the DRA at 2.44 GHz are shown in Figs. 3(a) and (b). The DRA resonated in the lowest order mode, $TE^x_{\delta 11}$ mode configuration.

The simulated surface currents on the ground planes of the proposed DRA and an inversed-F antenna (IFA) [1] at 2.44 GHz are shown in Figs. 4(a) and (b). The simulation results show relatively weak surface current strengths (∼ 30 A/m) on the ground plane of the proposed DRA compared to those of the IFA (∼ 300 A/m), which makes it more suitable for use in the proximity of the user's body, which is a lossy medium.

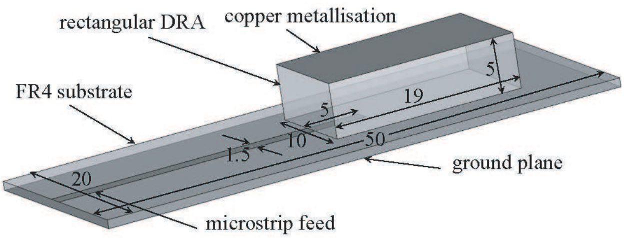


**Figure 2.** Schematic layout of the proposed rectangular dielectric resonator antenna (dimensions in mm).

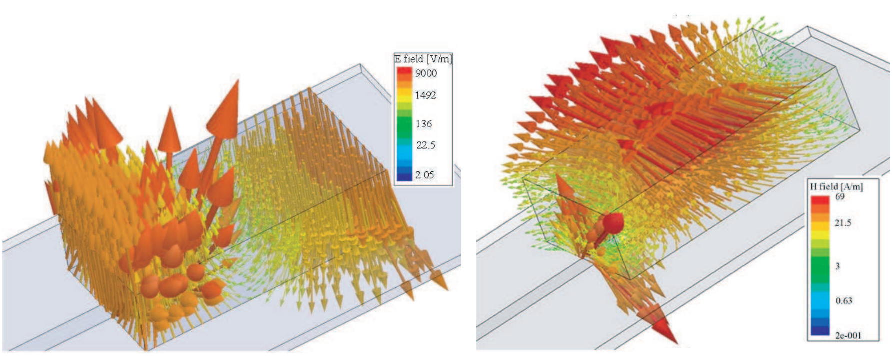


**Figure 3.** Simulated (a) electric field vector component, (b) magnetic field vector component of DRA at 2.44 GHz.

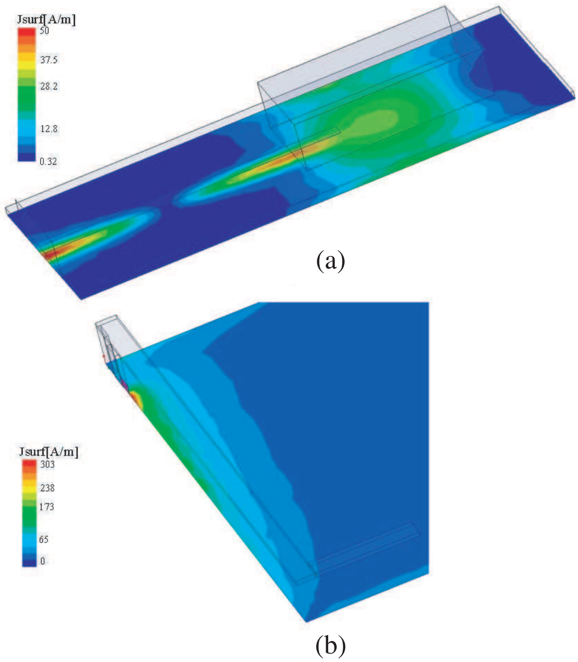


**Figure 4.** Simulated surface currents on ground planes of (a) DRA (b) inversed-F antenna at 2.44 GHz.

The radiation pattern and the total antenna efficiency of the antenna were measured with a Satimo Starlab near field chamber [18]. In order to study the effect of the human body on the antenna performance, a user hand model (Indexsar IXB-060L) [19] was used. In this manner the return loss and radiation characteristics of the antennas as a function of the distance between the hand model and the antenna, $H$, were analyzed.

## 5. RESULTS

The fabricated ring resonator structure is shown in Fig. 5(a). The relative permittivity and dielectric loss tangent values of the BST-COC were 20 and $2 \times 10^{-2}$ at 2.45 GHz frequency, respectively. A photograph of the fabricated DRA is presented in Fig. 5(b). The measured return loss of the DRA in free space and as a function of distance from the users hand model is shown in Fig. 6. The DRA covers the 2.4 WLAN frequency band with better than $-7.36$ dB (1 : 2.5 voltage standing wave ratio, VSWR) return loss in all cases. The resonance frequency of the antenna was 2.44 GHz in free space and was shifted to higher frequencies by about 30 MHz when placed in close proximity ($H = 0$ mm) to the user's body. This frequency de-tuning of the DRA can be attributed to the coupling of the antenna with the user's body. The resonance frequency of the DRA is not significantly affected for $H$ more than 2 mm, as can be seen from Fig. 6. We have reported similar trends in return loss of a monopole antenna and planar inversed-F antennas [1, 4].

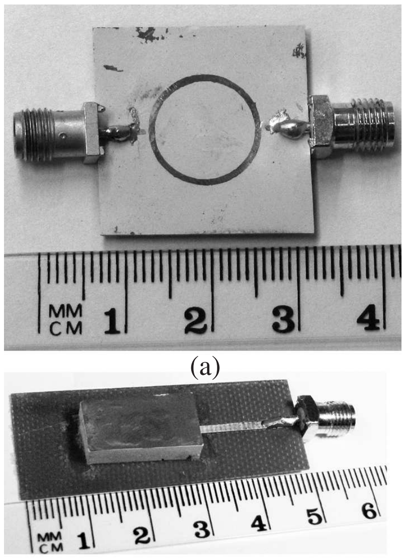


**Figure 5.** Fabricated (a) ring resonator, and (b) DRA structures.

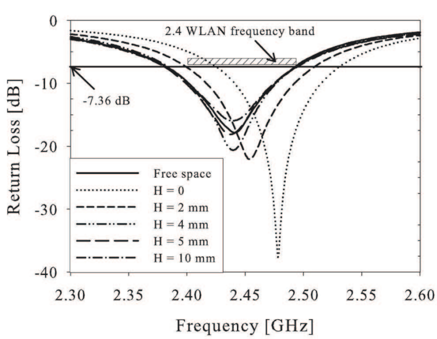


**Figure 6.** Measured return loss of the DRA in proximity to user's body.

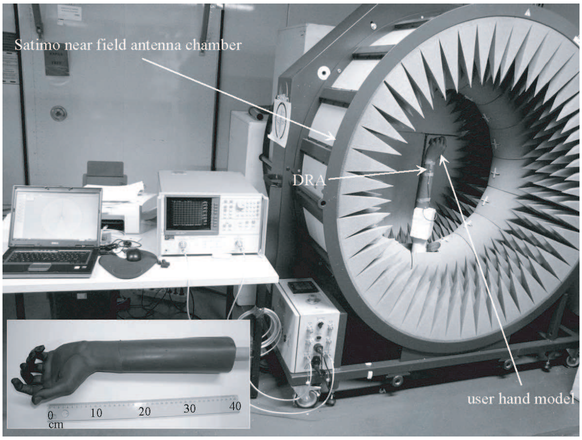


**Figure 7.** Satimo near field antenna measurement chamber with user hand model for the measurement of antenna radiation performance in the proximity of the user's hand model.

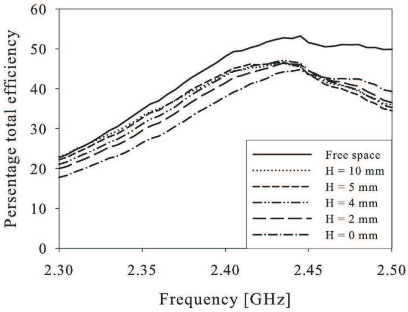


**Figure 8.** Measured total antenna total efficiency of the DRA as a function of distance from the user's body ($H$).

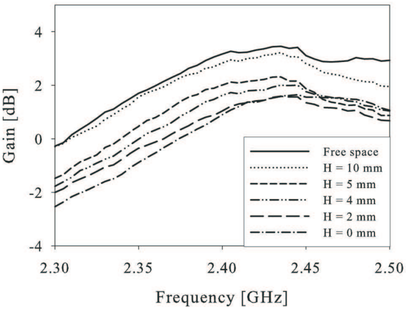


**Figure 9.** Measured gain of the DRA in free space and in proximity of the user's body ($H$).

The measurement setup for the radiation performance of the proposed DRA is shown in Fig. 7 and the user hand model is shown in inset of Fig. 7. The percentage total efficiency ($\eta_{tot}$) and gain in dB of the DRA in free space and in proximity to the user's body are shown in Fig. 8 and Fig. 9, respectively. The DRA has a peak $\eta_{tot}$ of 53.2% in free space and deteriorated to 44.75% when $H = 0$. This 8.45% deterioration in $\eta_{tot}$ of the DRA is significantly less than that of resonant type of antennas ($\approx$ 35%, [1], $\approx$ 48%, [4]). This can be attributed to the relatively weaker surface currents on the ground plane of the DRA. The peak gain of the DRA in free space was 3.41 dB at 2.44 GHz. The gain of the antenna decreased (from 2.95 dB to 1 dB) as the distance from the human body decreased (from 10 mm to 0 mm). The peak gain values of the DRA presented are better than those of the resonant type antennas reported by Palukuru et al. [1] and Wong and Lin [2] when the antenna is placed near to the user's body ($H = 0$ mm).

The measured far-field radiation patterns of the DRA in free space and in proximity to the user's hand are presented in Fig. 10. The radiation pattern of the DRA is directional in the $XZ$ and $YZ$ planes. The shape of the radiation pattern is not significantly affected by the proximity of the user's body. The peak level of cross polarisation ($E_\phi$) of the proposed DRA in free space, and in $XZ$ and $YZ$ planes are about

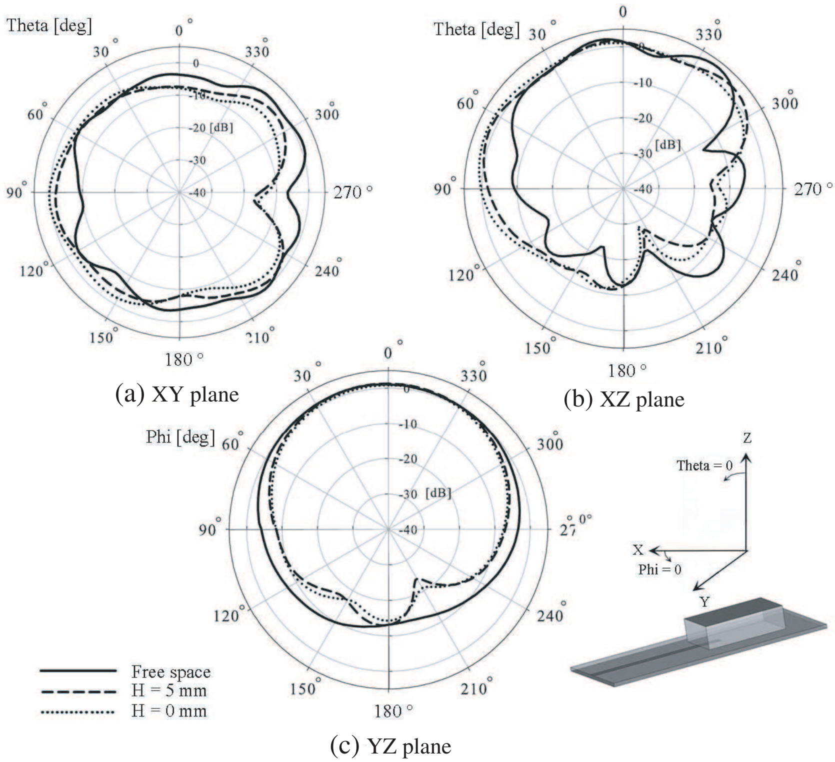


**Figure 10.** Measured radiation patters of the DRA in free space and in proximity of user's body (a) the $YZ$ plane, (b) the $XZ$ plane, and (c) the $XY$ plane.

$-15$ dB. In $XY$ plane, the levels of co-polar ($E_\theta$) and cross-polar ($E_\phi$) electric field components measured to be same. The measured level of cross-polar electric field component is not significantly affected by the presence of the users body.

## 6. CONCLUSION

The dielectric properties of a BST-COC composite with ceramic loading of 57 vol.% at 2.45 GHz are presented and a rectangular dielectric resonator antenna for possible wrist type communication devices is reported. The BST-COC composite has a relative permittivity of 20 and a loss tangent value of $2 \times 10^{-2}$ at 2.45 GHz. The antenna covers the 2.4 WLAN frequency band with better than $-7.4$ dB return loss and 1 dB gain. Additionally, the impact of the proximity of the user's body on antenna performance was studied experimentally with the help of a user's hand model. The DRA shows better radiation performance in proximity to the human body compared with that of resonant type antennas. The antenna can be further miniaturized by the use of a BST-COC composite with a higher value of relative permittivity or by the use of magneto-dielectric composites. Flexible antenna structures with a more conformal nature can be fabricated by choosing flexible polymers for the polymer matrix.

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