BST-COC polymer composite based Dielectric Resonator Antenna (DRA) for 2.4 WLAN wrist applications

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Abstract— **The dielectric properties of Barium Strontium Titanate (BST) and cyclic olefin copolymer (COC) composite are presented at 2.4 GHz frequency using ring resonator structures. A cylindrical dielectric resonator antenna (DRA) based on BST-COC composite operating in the 2.4 WLAN band is presented. The antenna covers the 2.4 -2.484 GHz WLAN band with a return loss of -8 dB. This antenna can be used for wrist-watch type wireless communication devices. The effect of the proximity of the user on the antenna performance is studied through simulation models. A DRA is suitable for wrist type applications due to its directive radiation pattern away from the user. The antenna shows a peak realized gain of 4.9 dBi in free space and 2.5 dBi in the proximity of the user's hand. These DRA types of antenna are found to perform better in proximity to the human body than do the resonant types.**

***Index Terms*— Dielectric resonator antenna, BST-COC composite material, user's effect.**

I. INTRODUCTION

With the rapid growth in wireless health care monitoring, devices for consumer applications have received much attention in recent years. Usually, these wireless health monitoring devices comprise wearable antennas placed in the vicinity of a human torso or arm. The antenna performance such as antenna bandwidth, total radiation efficiency and the shape of the radiation pattern will be greatly affected by the presence of the human body, which can be treated as a lossy dielectric medium. The performance of different type of antennas might be affected differently by the proximity of the human body. This is because of different types of coupling mechanism between the antenna and the body. Many researchers have demonstrated resonant type antennas for wearable applications [1-4]. However, the performance of these resonant type antennas is significantly affected by the presence of 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 separated from the human body by approximately 5 mm, thus increasing the total antenna efficiency. However, this solution increases the overall antenna volume.

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, using thermoplastic polymer, have the additional advantage of simple 3-D fabrication processes, such as injection molding. 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. [5–6].

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

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II. SUBSTRATE PREPARATION

The preparation of the BST-COC composite through extrusion was reported in detail by Tao *et al.,* [6]. The BST-COC composite with ceramic loading of 45.8 vol % was extruded through a hot mold of suitable sample size (22 mm×43 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 Rogers 4003C (ε_r = 3.38) substrate. A copper foil about 9 µm thick was transferred onto the BST-COC composite substrates using ASPECT additive circuit transfer technology [7].

III. RF CHARACTERIZATION OF BST-COC SUBSTRATE

A microstrip ring resonator structure was chosen for the RF characterization of the BST-COC composite substrate at 2.44 GHz. The ring resonator structure offers the most accurate and simple method for RF characterization of planar substrates [8]. A schematic layout of the ring resonators operating at 2.44 GHz is presented in Fig.1 (a). Ansoft HFSS (version 11), a commercial 3-D electromagnetic simulator, was used for the design of the ring resonator structures. The resonance frequency and unloaded Q-factor of the ring resonator were measured to be 2.456 GHz and 43.6 respectively.

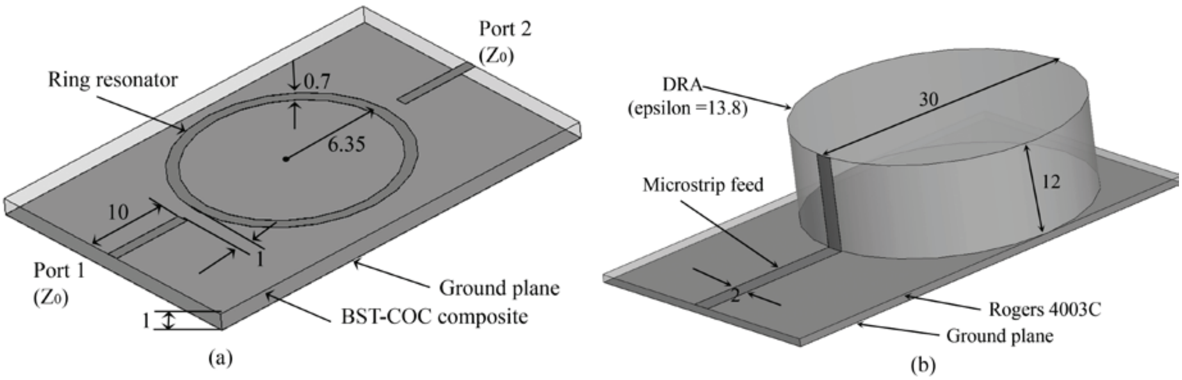


Fig. 1. (a) Schematic layout of the ring resonator structure for the dielectric characterization of BST-COC composite at 2.5 GHz, (b) Schematic layout of a DRA based on BT-COC composite (dimensions in mm).

The effective relative permittivity of the BST-COC composite is extracted from the measured resonance frequency of the ring resonator using the equation (1) [8].

$$\varepsilon_{eff} = \left(\frac{c}{2 \times \pi \times r_m \times f_c} \right)^2 \qquad (1)$$

where r_m , f_c are the mean radius and resonance frequency of the ring resonator, respectively and c is the velocity of light in free space.

The relative permittivity of the composite material is extracted from the effective relative permittivity using equation 2.

$$\varepsilon_r = \frac{2 \times \varepsilon_{eff} + \left[1 + \frac{12 \times h}{w_{eff}} \right]^{-0.5} - 1}{\left[1 + \frac{12 \times h}{w_{eff}} \right]^{-0.5} + 1} \qquad (2)$$

where h is the thickness of the composite substrate and w_{eff} is the effective width of the microstrip line. This is calculated from the physical width, w taking the fringing fields of the microstrip line into consideration:

$$w_{eff} = w + \frac{1.25 \times t}{\pi} \cdot \left(1 + \ln\left(\frac{2h}{t}\right)\right) \tag{3}$$

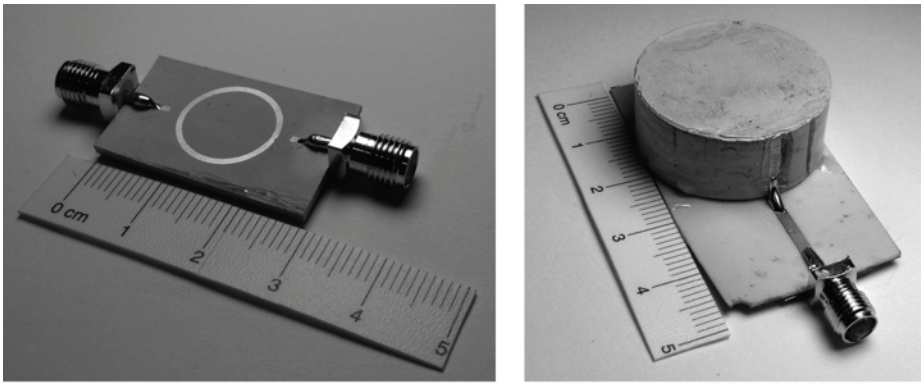
The dielectric losses of the composite material are calculated from the measured total losses and estimated conductor losses [9]. The extracted relative permittivity and loss tangent of the BST-COC composite are 14.5 and 0.00235, respectively.

IV. ANTENNA STRUCTURE

Fig.1 (b) depicts the geometry of a BST-COC composite based DRA suitable for wrist applications. The cylindrical DRA has a diameter of 30 mm and a height of 12 mm. The antenna is excited by an edge microstrip probe feed. The DRA operating at 2.44 GHz provides a compact structure, and is thus suitable for application in wrist-watch type wireless communication devices. A copper foil of about 3 µm was laminated onto the DRA to make the metallization of the edge microstrip feed. The DRA was soldered to a 50 mm x 30 mm reverse side-grounded PCB (Rogers R4003C, ε_r = 3.38, thickness 0.8 mm) with 17 µm thick copper metallization. A 50 Ω microstrip line was used as feed for the antenna. The complete antenna structure was simulated using Ansoft HFSS (version. 11). The radiation pattern and the total efficiency of the antenna were measured with a Satimo Starlab near-field chamber [10]. A user hand model, Indexsar IXB-060L [11], was used for human hand proximity studies. 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, D, were analyzed.

V. RESULTS

The fabricated ring resonator structure is shown in Fig. 2 (a). The relative permittivity and dielectric loss tangent values of the BST-COC were 14.5 and 2.35 x 10^{-3} at 2.45 GHz frequency, respectively. A photograph of the fabricated DRA is presented in Fig. 2 (b). The measured return loss and gain in dB of the antenna in free space and as a function of distance from the user's hand model are shown in Fig.3 (a) and (b), respectively. The DRA covers the 2.4 WLAN frequency band with better than -8 dB return loss in all cases. The resonant frequency of the antenna was not significantly affected by the proximity of the human body. This can be attributed to the weak surface currents on the ground plane of the DRA. The gain of the DRA in free space was 2.7 dB at 2.44 GHz. The gain of the antenna increased (from 2 dB to 2.65 dB) as the distance from the human body increased (from 0 mm to 5 mm). Thus, in all cases, the gain of antenna remained better than 2 dB across the 2.4 WLAN frequency band. The peak gain values of the DRA presented are better than that of the resonant type antennas reported by Palukuru *et al.* [1] and K. L. Wong *et al.,*[2] when the antenna is placed near to the human body (D= 0 mm).



(a) (b)

Fig. 2. (a) Photo of the fabricated ring resonator structure on BST-COC composite, (b) Photo of the DRA fabricated.

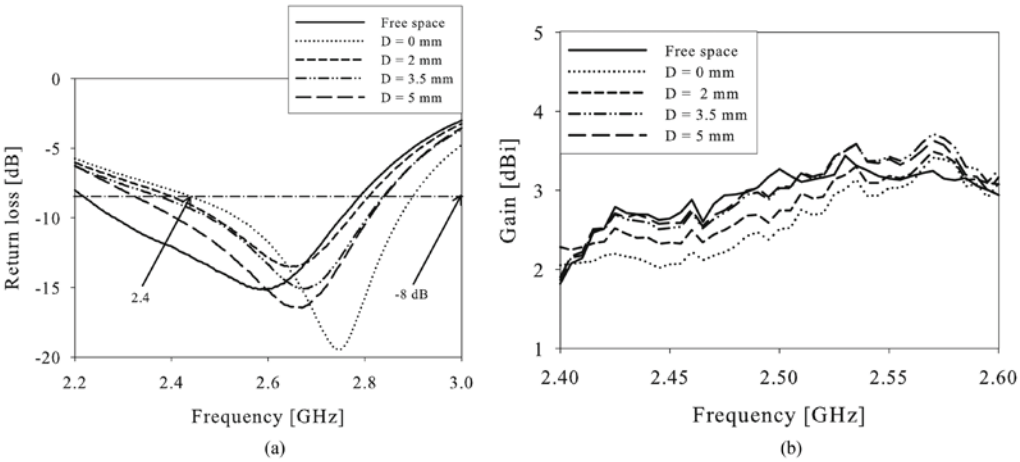


Fig. 3. (a) Measured return loss of the antenna, (b) Measured gain of the antenna with different distances from the human body.

Fig. 4 shows the measured radiation pattern of the DRA in free space and in the presence of the user's hand (D = 0 mm, 5 mm). The shape of the radiation pattern is not significantly affected by the proximity of the human hand.

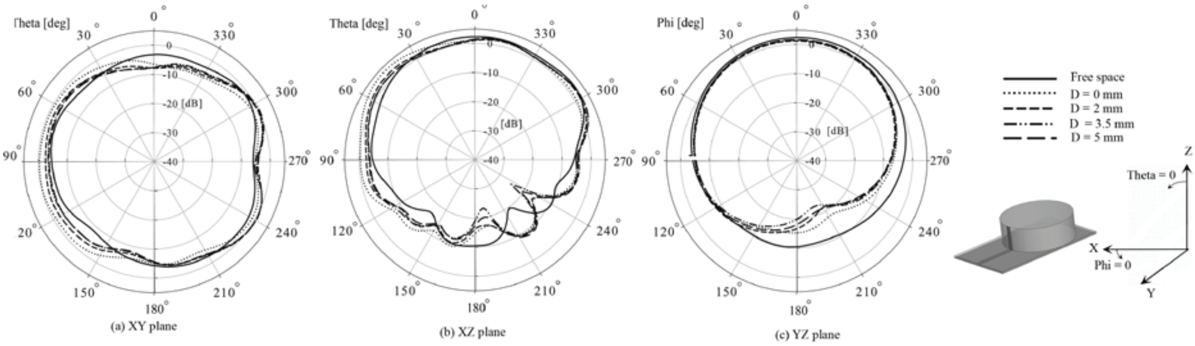


Fig 4. Measured far-field radiation patterns of the DR antenna; a) in the XY plane; (b) in the XZ plane; and (c) in the YZ plane.

VI. CONCLUSION AND DISCUSSION

The dielectric properties of a BST-COC composite with ceramic loading of 45.8 vol % at 2.45 GHz are presented and a cylindrical dielectric resonator antenna for possible wrist applications is reported. The BST-COC composite has a relative permittivity of 14.5 and a loss tangent value of 2.35×10^{-3} at 2.45 GHz. The antenna covers the 2.4 WLAN frequency band with better than -8 dB return loss and 2 dB gain. Additionally, the impact of the proximity of the user's hand on antenna performance was studied experimentally with 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 size can be further miniaturized by the use of a BST-COC composite with a higher value of relative permittivity and by using compact antenna shapes such as rectangular antenna structures.

VII. ACKNOWLEDGEMENTS

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