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A Cylindrical Dielectric Resonator Antenna for Wireless Body Area Networks

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ABSTRACT

In this paper, a hybrid dual-band cylindrical dielectric resonator antenna with parasitic slot fed by a microstrip line that is suitable for wireless body area network is proposed. In this configuration, the dielectric resonator performs the functions of an effective radiator along with the feeding structure and the slot in the ground plane. By optimizing the structural parameters, the antenna is made to resonate at two different frequencies; one is from the dielectric resonator antenna (DRA) and the other from the parasitic slot. The design involves a dielectric resonator with the resonant frequency of 2.4 GHz (Industrial, Scientific and Medical) and a parasitic slot with a resonant frequency of 403 MHz (Medical Implantable Communication Service). The physical and geometrical parameters of these elements are tuned to obtain the desired performance parameters. In order to determine the performance of the proposed antenna, functional parameters such as return loss, bandwidth, voltage standing wave ratio (VSWR), and radiation pattern are observed by the simulation of the structure with high frequency structure simulator (HFSS).

Keywords— Ceramic dielectric material, dielectric resonator antenna (DRA), dual band operation, microstrip feedline.

1. INTRODUCTION

In recent years, there has been continuing interest in investigations of dielectric resonator antennas (DRA) [1] due to their advantages such as low loss, high permittivity, light weight, and ease of excitation. In addition, ease of fabrication, low dissipation loss at high frequency, high radiation efficiency due to the absence of surface wave and conductor losses and ease of coupling to commonly used feeding techniques are inherent advantages of DRAs. In the last two decades, much research has been done on the dielectric resonator antenna which also has regained a wider interest in recent years. Its small volume and low profile, together with its lack of metallic surfaces makes it interesting for low conduction losses. The fact that it can be designed for high bandwidths makes it an interesting alternative. The dielectric resonator is widely used in microwave circuits for filters and oscillators but where its resonant modes are confined and narrowband. Now the ambition is to see what this device can achieve as an antenna element. In recent years, theoretic and experimental investigations have been widely studied by many researchers on DRAs of cylindrical, rectangular, and hemispherical shapes [2]-[10]. The use of dielectric resonators [3] in feeding circuits requires accurate knowledge to couple the resonators and circuits. In order to match the DR to the feedline and to excite the desired mode in the resonator, the most common feeding technique is the aperture-coupled arrangement [4]. Recently, hybrid dielectric resonator antennas have attracted extensive attention due to their dual-band as well as wideband operation without increasing antenna volume. The hybrid structure is considered as the combination of a dielectric resonator antenna and another radiating resonator of the resonant feeding structure [5]. These two different radiating resonators are tightly stacked together and resonate at two different frequencies. By arranging for the different radiating resonators' position, a compact dual-band [6] & [7], or frequency tunable [8] & [9] hybrid dielectric resonator antenna can be designed. However, the resonant feeding structure adopted in these reported designs, such as microstrip-fed aperture-coupled, co-axial probe coupling, co planar slot feed and CPW-fed slot arrangement offers more flexibility and is directly compatible with different mounting surfaces.

In this paper, in order to avoid via holes, the microstrip line feed to DRA is proposed [10]. It is the simplest method to energize DRAs. In this method, a microstrip line [11] printed on the same substrate excites a DR that could be placed directly over the microstrip line or nearby over the dielectric substrate. An advantage of microstrip feed is that it is easier to fabricate, match and model.

To demonstrate the idea, the proposed hybrid dual-band antenna [12] is designed for wireless body area networks. It consists of upper (ISM) and lower (MICS) frequencies of the dual band antenna are primarily controlled by the DRA and parasitic slot respectively. The designed dual-band antenna has the maximum radiation directed toward the inside of the human body in the medical implantable communication service (MICS) band [13] in order to collect vital information from the human body [14], and directed toward the outside in the industrial, scientific and medical (ISM) band to transmit that information to a monitoring system. This design has the advantage of compact size, simple structure and can achieve dual band with different radiating patterns. A parametric study of the antenna was carried out, and the effect of the various parameters performance is discussed.

2. ANTENNA CONFIGURATION

The proposed dual band dielectric resonator antenna structure is as shown in Figure 1. The dual band hybrid dielectric resonator antenna with slot [15] is consist of two different resonators one is cylindrical dielectric resonator which is printed on the RT Duroid 6010 substrate and another resonator is parasitic slot which is etched on the ground plane, these radiating resonators are tightly stacked together and resonate at upper and lower frequencies, respectively. The feed line is etched on the substrate at 14.5 mm. The proposed antenna has the dimensions of 36 mm × 36 mm × 9 mm, and a RT duroid 6010 dielectric with a relative permittivity of $\mathcal{E}_r$ = 10.2 and substrate thickness is 1.6 mm. The top resonator is used to suppress the radiation towards the outside of the body in the MICS band and transmit signals to external devices in the ISM band. The bottom patch is designed to communicate with the implanted devices in the MICS band, and to reduce the human body effects of the ISM band.

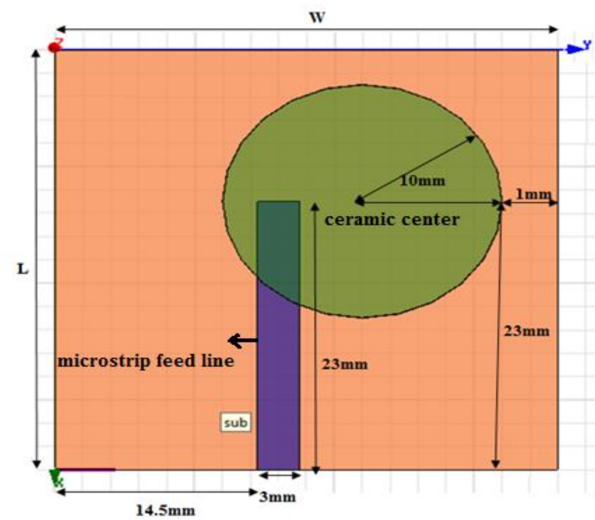
The ground plane is printed on the RT duroid 6010 substrate with a dimension of 36x36(LxW) mm^2. The DRA with ceramic material has a diameter of D=20 mm, height of h_d=7.4 mm, and relative permittivity of $\mathcal{E}_d$ = 42 as shown in Figure 1. The centre point of DR is placed above the centre line of the ground plane with an offset distance 23 mm which is used to adjust the coupling energy between the microstrip-fed line and dielectric resonator. The 50-Ω feeding line has a length of L_f =23 mm and a width of W_f =3.0 mm.

In this letter, a new approach that utilizes a parasitic slot etched in the ground plane is investigated experimentally. The parasitic slot as shown in Figure 1, it is consists of five parts of a rectangular slot of length 15 mm, 35.9 mm, 14.8 mm, 20.8 mm, 20.7 mm and a fixed width of W_s=0.2 mm. In addition, the parasitic slot dimension was found to be effective in controlling the resonant frequency of the slot mode. In order to reduce experimental cut-and-try design cycles, the simulation software HFSS is used to guide fabrication. By carefully adjusting the parasitic-slot dimension, the proposed antenna can operate in two bands, and a good impedance match for the operating frequencies can be easily obtained.

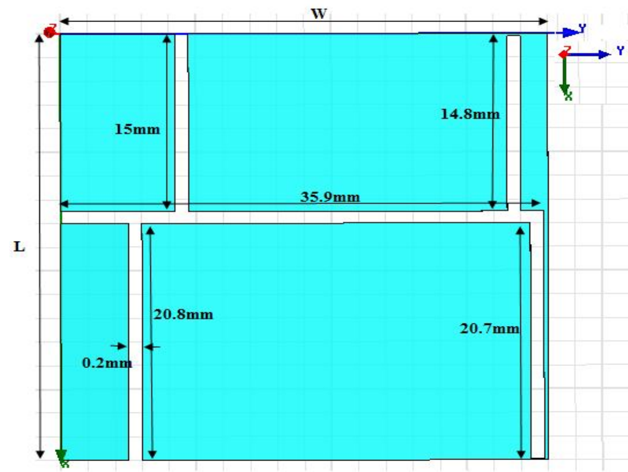
3. PARAMETRIC STUDY

In reference to Figure 1, there are a number of parameters that influence the antenna characteristics. To achieve optimum antenna performance, a parametric study is carried out to investigate the characteristics of the DRA.

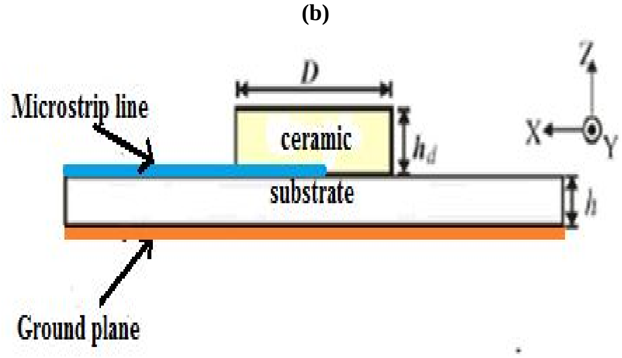
For the design in this study, the cylindrical dielectric resonator is printed on the RT duroid 6010 ($\mathcal{E}_r$=10.2) on the height of substrate is 1.6 mm, initial parameters are chosen dielectric permittivity of the dielectric resonator is $\mathcal{E}_d$ = 42, height of the DRA is h_d = 7.4 mm, offset distance 23 mm. The width and length of the microstrip feed line W_f and S_f are chosen to be 3 and 23 mm, respectively.



(a)



(b)



(c)

Figure 1: Proposed dual band DRA with parasitic slot: (a) Top view; (b) Bottom view; (c) Side view

The theoretical resonant frequency of the DRA is calculated by the following equation [5] and equal to 2.4 GHz which is well suited for industrial, scientific, medical(ISM).

$$f_r = \frac{c}{2\Pi R}\left(\frac{1.6 + 0.513x + 1.392x^2 - 0.575x^3 + 0.088x^4}{\varepsilon_d^{0.42}}\right)$$

Where, x = R/2h_d; c is the speed of light in free space; R, h_d and ε_d are the radius, height, and relative permittivity of the DRA, respectively.

In order to obtain the lowest frequency 403 MHz (MICS), the parasitic slot is designed on the ground plane. The lower excited band is due to the parasitic-slot. It is well-known that by choosing a high permittivity substrate, a greater size reduction can be achieved. For this reason, the substrate selected for the antenna has been RT duroid 6010 (ε_r=10.2). The design consideration for the lower excited parasitic slot antenna is consists of five rectangular slots with different length and fixed width W_S=0.2 mm as shown in Figure 1, the different rectangular slot lengths are 15 mm, 35.9 mm, 14.8 mm, 20.8 mm, 20.7 mm as shown in Figure 1. The parasitic slot on the ground plane is designed to communicate with the implanted devices in the MICS band to collect the vital information from the human body.

4. SIMULATED RESULTS AND DISCUSSIONS

Figure 2 shows the simulated return loss of the proposed hybrid DRA. The lower excited band is due to the parasitic slot while the higher band is due to the DR. As observed in Figure 2, the return loss of the proposed antenna at two different bands is MICS (403 MHz) & ISM (2.4 GHz).

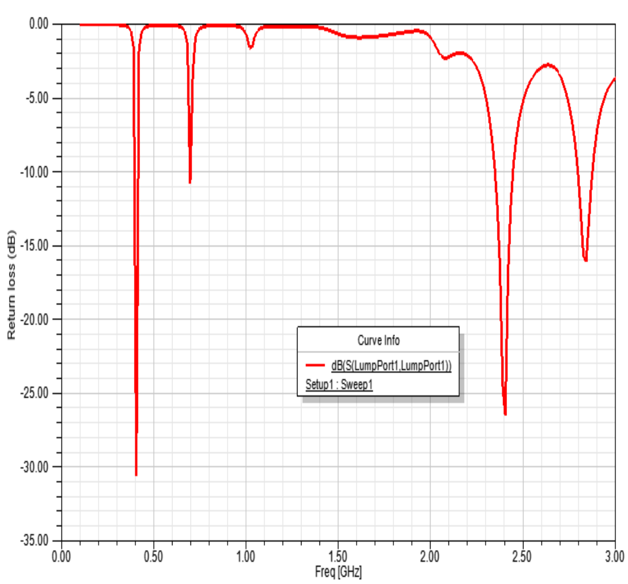
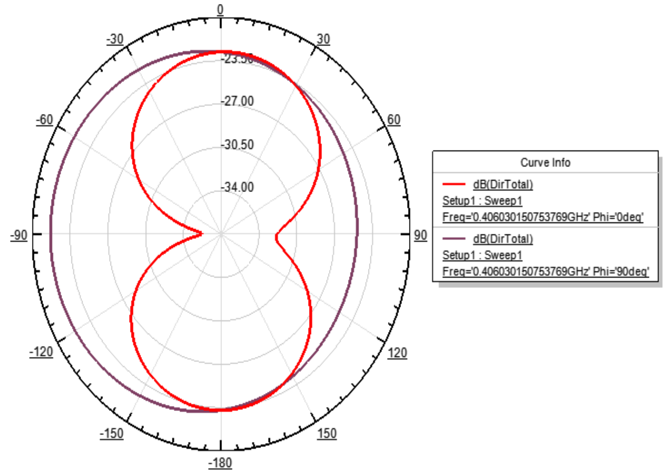
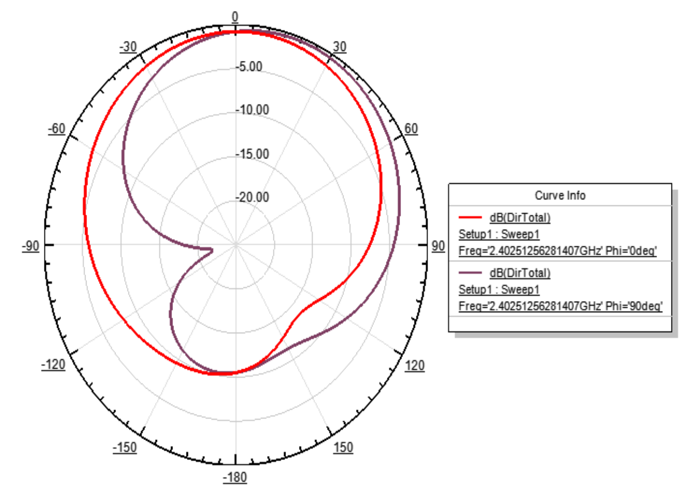


Figure 2: Simulated return loss for the MICS and ISM band

It is observed -30 dB return loss at MICS band and -27 dB return loss at ISM band. As a result, a simulated lower band achieves an impedance bandwidth of 4.12 % (for S_{11} < -10 dB) ranging from 396 to 411 MHz with respect to the centre frequency at 403 MHz and the simulated bandwidth for the higher band reaches about 3.21 % (for S_{11} < -10dB) corresponding to the centre frequency at 2.4 GHz. Note that there are no frequencies to be excited without the presence of dielectric resonator, that is, the resonant slot mode is caused by the DR.



(a)



(b)

Figure 3: Simulated radiation patterns at: (a) MICS band; (b) ISM band

The radiation patterns of the simulated antenna structure for the MICS (403 MHz) and ISM (2.4 GHz) bands with phi=0 (deg) and phi = 90 (degree) are shown in Figure 3. The proposed antenna radiates a maximum in the broadside direction at 2.4 GHz, which corresponds to the far-field radiation from the resonant mode of the DRA and as shown in

Figure 3. It should be mentioned that the radiating patterns in the two planes along the back side have large back radiation, which is because of the effect of bidirectional radiations for the serpentine slot antenna at resonant frequency 403 MHz.

The voltage standing wave ratio (VSWR) of the proposed structure is as shown in Figure 4, than the VSWR of the proposed structure is close to 1.1 in the MICS (403 MHz) band. As it is less than 2 it can be said that the antenna offers good impedance matching characteristics for the MICS band. As well as for the proposed structure simulated VSWR at ISM (2.4 GHz) band is very close to 1.15, as it is less than 2 as shown in Figure 4 and it will said that proposed lower band antenna offers good impedance matching characteristics.

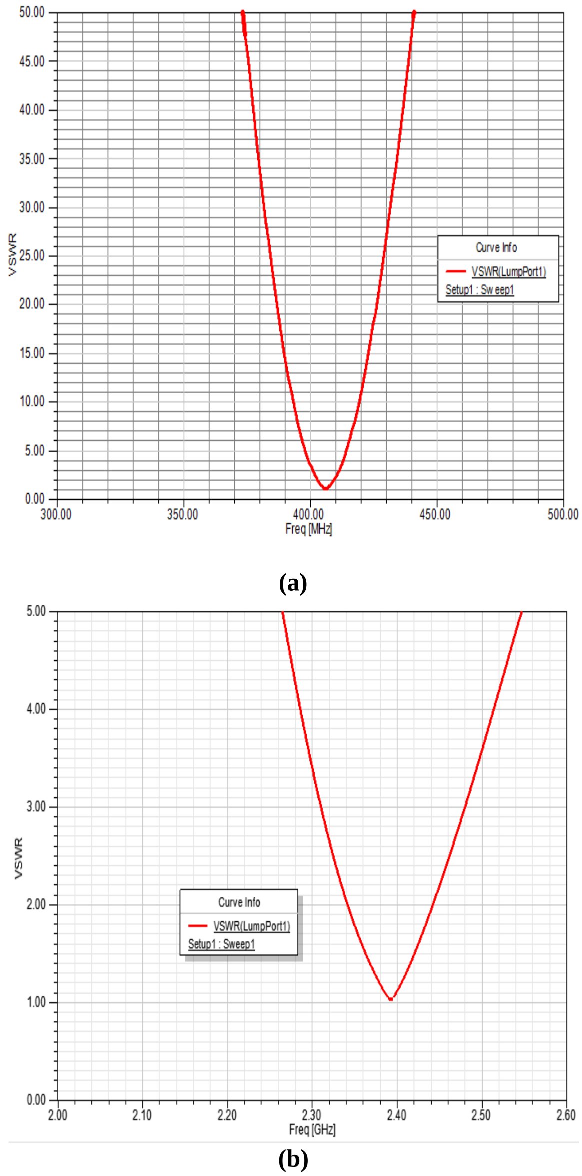


Figure 4: Simulated VSWR at:(a) MICS band;(b) ISM band

5. CONCLUSION

A dual band hybrid dielectric resonator antenna with parasitic-slot fed by a microstrip line has been proposed. The lower and upper bands of the dual-band antenna are provided by the parasitic-slot and DRA modes, respectively. A parametric study is carried out to investigate the antenna functional and design parameters. The prototype has been simulated and it is observed that a bandwidth of 4.12% for MICS and 3.21% for ISM bands, and a return loss of -30 dB and -27 dB respectively. The bandwidths of the proposed antenna were wide enough to cover the MICS (402–405 MHz) and ISM bands (2380–2485 MHz). The radiation pattern of the antenna is advantageous for communication with implant devices in the MICS band and external devices in the ISM band. The proposed structure takes a small volume, and simple shape. The microstrip coupling used in the design is efficient, simple and easy to be implemented and adequate operational bandwidth, such that it is suitable for wireless body area networks.

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