A Circular Disk Dielectric Resonator Antenna Using a C-Slot, for Dual-frequency operation

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Abstract— The high demand for faster and more reliable services in several applications of modern communications increases the requirements for a large data transmission capacity and hence a wide operational bandwidth. In addition to that, mobile communication set some strict specifications concerning the size, the weight and the efficiency of the RF front-ends, which are responsible for the transformation of the base-band signal to a radiated electromagnetic wave and vice versa. The element of the RF front-end, mainly determines the size and the efficiency of the antenna. In this paper, dual-frequency is obtained, using cylindrical dielectric resonator antenna with a parasitic c-slot fed by a microstrip line. The structure consists of two radiating resonators that are tightly stacked together and resonate at different frequencies. The first frequency is from the DRA and the other from the c-slot. The use of dielectric resonator in feeding circuit requires accurate knowledge of the coupling between the resonator and circuit. So, in order to match the dielectric resonator to the feedline and to excite the $HEM_{11\delta}$ mode in the resonator, the most common method of feeding technique used is aperture-coupled arrangement. The proposed DRA is suitable to be mounted above the system circuit board of the mobile communication devices, and is very suitable for application in mobile communication systems.

Index Terms— Ceramic dielectric material, dielectric Resonator Antenna (DRA), dual band, microstrip feedline.

I. INTRODUCTION

Since the early 1970s dielectric resonators of very high permittivity (relative dielectric constant of the order 100 − 300) were used as resonant cavities for different active and passive microwave components including filters, oscillators, amplifiers and tuners. Van Bladel was the first to examine the properties of these resonators; his work focused on the classification of the excited modes as well as on the investigation of the fields' distributions. This examination was made under the hypothesis that the structures are strictly energy storage devices. For cavities, however, that are not enclosed by metallic walls, electromagnetic fields can also be detected beyond the geometrical boundaries of the resonator. When the dielectric permittivity is very high, the radiation loss is negligible and the unloaded Q factor of the resonator is mainly limited by the dielectric losses. On the other hand, the decrease of the dielectric permittivity value results in an increase of the amount of energy 'lost' in the form of radiation and hence in a degradation of the resonator's operation as a cavity. Long et al. demonstrated in 1983 that dielectric resonators made of low permittivity materials ($8 \leq \varepsilon r \leq 20$) and placed in open environments exhibit small radiation Q-factors if excited in their lower-order modes. The high radiation losses of these resonators make them particularly useful as radiating elements, especially in high-frequency applications where ohmic losses are a serious problem for the conventional metallic antennas. Apart from their low dissipation loss and the subsequent high radiation efficiency, DRAs offer many other attractive features, such as good mechanical and temperature stability, compatibility with MIC's, low mutual coupling in array configurations and most importantly, a small size and weight due to the scaling of the DRA dimensions with the permittivity according to the relation $\lambda\ 0\ /\ \sqrt{\varepsilon}\ r$, with $\lambda 0$ being the free-space wavelength.

Moreover, the DRAs' versatility in terms of their shape and feeding mechanism allows for the efficient control of the excited modes and thus of the input impedance, the bandwidth, the polarization and the radiation patterns. Different DRA modes can be excited through various feeding techniques using conventional transmission lines, while the DRA shape and permittivity can be varied in order to accommodate different design requirements. The most common dielectric resonator geometries are canonical shapes such as the parallelepiped, the cylinder and the sphere/hemisphere, but depending on the application, various noncanonical shapes may also be encountered. Concerning now the electric properties of the dielectric resonators, a large number of suppliers worldwide provide linear, non-dispersive, low-loss materials demonstrating a wide range of dielectric permittivity values.

One of the most important challenges in the design of an antenna is its bandwidth response. Modern communications set the bandwidth requirements very high and the antenna technology needs to keep up with them. DRAs are inherently more wideband than other resonant antennas like for example the microstrip antennas. Hence, DRAs exhibit a higher Radiation Power Factor (RPF), or in other words, a lower Q-factor than microstrip antennas. Since, however, DRAs are resonant structures, they are, in principle, narrowband. Even for a DRA of a low dielectric permittivity ε_r= 10, the bandwidth response does not exceed (10 – 15)%, which is not always enough for many commercial applications. The DRA bandwidth can be increased through the reduction of the dielectric permittivity according to the relation Bandwidth ~ $(\sqrt{\varepsilon_r})^{-p}$, with p being a function of the DRA geometry as well as of the excited mode. A reduction of ε_r will result, however, in an increase of the DRA dimensions, which is also highly undesirable in most of the commercial applications. This trade-off between the DRA bandwidth and size makes the design and the optimization of the DRA a challenging process. Moreover, the DRA designer might have to face additional challenges arising from the requirements for well-behaved Linearly Polarized (LP) or Circularly Polarized (CP) operation with stable patterns and good polarization purity. It is then clear that the thorough investigation of the DRA operation is crucial towards the improvement of its properties and the subsequent enhancement of its practical applicability.

II. METHODOLOGY

A. *Antenna configuration*

The proposed DRA structure is shown in Fig 1. It consists of a circular disk DR and a centre-fed microstrip line which is printed on an FR4 substrate of thickness h=1.6 mm and relative permittivity ε_r = 4.2. The ground plane is printed on the FR4 substrate with a dimension of $L \times W$ (40 × 40) mm2. The DRA has a diameter of D = 14.8 mm, a height of h_d =3.3 mm, and a relative permittivity of ε_d = 25 . Its $\mathrm{HEM}_{11\delta}$ resonance mode can be excited for the aspect ratio ($2h_d$ / D) less than unity. The centre point of DR is placed above the centre line of the ground plane with an offset distance S1 which is used to adjust the coupling energy between the microstrip-fed line and dielectric resonator. The 50Ω feeding line has a length of L_f = 18.5 mm and a width of W_f = 3.0mm. In the figure a parasitic c-slot is etched in the ground plane. The c-slot consists of three parts of a rectangular slot of length L_1,L_2,L_3 , and a fixed width of W_s = 0.5mm. The center point of the c-slot is fixed to half of the ground plane and kept constant S_2 = 20 mm . The total length of the perimeter of the c-slot resonates at approximately one guide wavelength ($\approx\lambda_g$) where λ_g is the guide wavelength of the c-slot with the DR placed on it. In addition, the c-slot dimension was found to be effective in controlling the resonant frequency of the slot mode. By carefully adjusting the c-slot dimension, the proposed antenna can operate in two bands, thereby making the proposed structure work as dual-band dielectric resonator antenna.

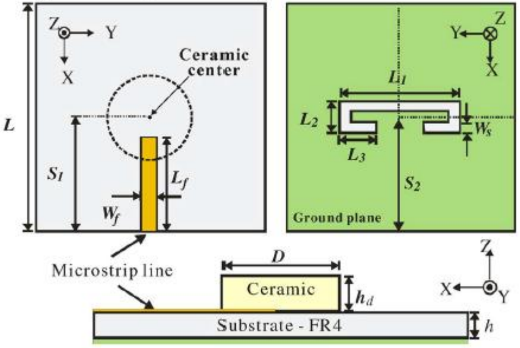

Figure 1: Top view and side view of the DRA.

B. *Parametric Study*

In order to investigate the characteristics of the DR antenna, a parametric study is carried out to achieve optimum antenna performance. The optimal design parameters are h_d =3.3 mm, ε_d = 25, D = W_f = 3.0mm 14.8 mm, S_2 = 20 mm, S_1 =22, W_s = 0.5mm, L_1 =18mm, L_2 = 4mm, L_3 = 6mm, L_f = 18.5. the size of the c-slot is kept smaller than the diameter of the DR, which provides a compact design where the c-slot lies under the DR.

The theoretical resonant frequency of the DRA is calculated [2] by the following equation and is equal to 5.41 GHz (operating in $\mathrm{HEM}_{11\delta}$ mode).

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

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

And for the c-slot the theoretical resonant frequency is given by,

$$f = \frac{c}{(2L_1+4L_2+4L_3-6W_s)\sqrt{\varepsilon_{eff}}}$$

where, λ_g , λ_g being the guide wavelength of the c-slot with DR placed on it. Where c is the speed of light in free space, f is the fundamental frequency of the slot resonator, and ε_{eff} is the effective dielectric constant considering the presence of the different dielectric material on the two sides of the c-slot. In this case, the value of ε_{eff} is about $0.69\varepsilon_r$(~2.9).

III. RESULT AND DISCUSSION

A. *Effect on resonant frequency by varying DR offset distance ‘S_1’.*

Through simulation, the graph between return loss and frequency for a different offset distance S_1 is shown in figure 2. It can be found that the resonant frequency of the c-slot radiator and DRA remains unchanged for S_1 varying from 21 to 24 mm. the resonant length for the c-slot resonance is approximately one guide wavelength λ_g , where λ_g is the guide wavelength of the c-slot with the DR placed on it. So for the c-slot resonator, the resonant frequency is slightly affected by the DR offset distance.

For the dielectric resonator, the resonant frequency is slightly affected by the effective relative permittivity and it is approximately equal to the calculated value (5.41 GHz) of (1).Thus it is evident that the c-slot resonates at lower frequency.

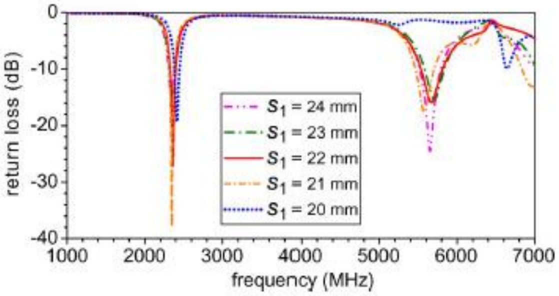

Figure 2: Simulated resonant frequency for the proposed resonator antenna by varying offset distance.

B. Effect on resonant frequency by varying DR Permittivity 'ε_d'.

As it is known that antenna with high dielectric permittivity posses lower resonant mode than antenna with low dielectric permittivity. Fig. 3 shows the simulated return loss versusresonant frequency by varying DR permittivity . It can be observed that by increasing the DR permittivity the resonant frequency of the DRA decreases and there is no change in the resonant frequency of the slot mode. For the $HEM_{11\delta}$ mode of the circular disk DRA, the simulated resonant frequencies for different DR permittivity holds good agreement with calculated results by (1). And, the fundamental resonant mode for the slot resonator occurs at the frequency whose resonant length is approximately one guide wavelength.

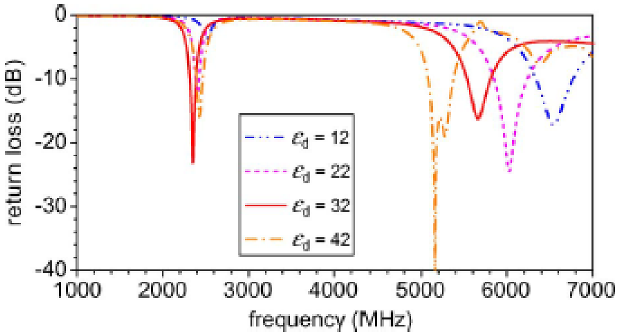

Figure 3: Simulated resonant frequency for the proposed resonator antenna by varying DR permittivity.

C. EFFECT ON RESONANT FREQUENCY BY VARYING SLOT LENGTH 'L_1'.

By varying the length 'L_1' of the slot, there is variation in the resonant frequency of the c-slot. Fig. 4 shows the simulated return loss versus frequency, for different values of slot length 'L_1'. By increasing 'L_1', the total resonant length of the perimeter of the slot increases. And so, as shown in fig.4 , it can be found that the resonant frequency of the c-slot radiator decreases with increasing the slot length 'L_1'.

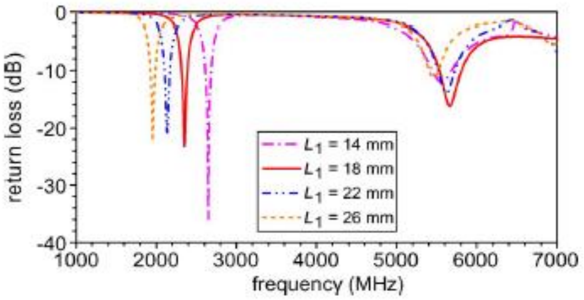

Figure 4: Simulated resonant frequency for the proposed resonator antenna by varying Slot length 'L_1'.

IV. CONCLUSION

In this paper, a parametric study has been done on Cylindrical Dielectric Resonator Antenna, which has dual frequency using parasitic c-slot, with microstrip feedline and the theoretical resonant frequency of the DRA is obtained. The performance analysis of DRA has been carried out by varying design parameters (offset distance, slot length, permittivity) to bring in improvement in bandwidth of the composite dual-band Dielectric Resonator Antenna. Further, in order to excite the resonant mode of the DRA, the microstrip coupling is done with c-slot in the ground plane. The resonant frequency of the c-slot has been derived to be 2.4 GHz and that of the DRA derived to be 5.41 GHz. This antenna has been observed to be compact having smaller dimension. The operational bandwidth observed, to be enhanced from 2.33% - 5.73%, which makes it more useful in mobile communication system applications.

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