A Hollow Stacked Rectangular Dielectric Resonator Antenna with High Gain for Ultra Wide-band Applications

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This research article presents a small wide-band stacked rectangular dielectric resonator antenna (HSDRA) for ultra-wideband applications. The antenna is made on a Glass epoxy FR4 substrate with a hollow rectangular Dielectric resonator of FR4 (εr=4.4). The antenna structure overall dimensions of 70 X 70 X 8.87 mm3. The antenna structure has an FR4 substrate; on which a metallic ground layer is deposited from which an aperture slot tilted by 450 is cut out. On top of the aperture coupled ground, a hollow ring of FR4 of height 3.2mm is pasted and above this ring an rectangular alumina substrate of height 4mm is pasted. This makes the antenna an aperture coupled stacked DRA. On the bottom of this epoxy substrate, a metallic feed line is printed to supply power to the antenna for radiation. By arranging the hollow stacked structure such that low permittivity (εr=4.4) substrate ring lies below a high permittivity substrate (εr=9.8) with an air gap between them allows the antenna to show an UWB behaviour (3.7 to 5.7 GHz). The antenna shows a simulated impedance bandwidth of 42.55% (3.7 to 5.7 GHz) at the centre frequency of 4.7 GHz and a maximum simulated gain of 9.2 dBi at 5.1 GHz frequency

Keywords: Dielectric resonator antenna, Ultra-wideband applications, Gain, Impedance Bandwidth

I. INTRODUCTION

In past two decades, Ultra-Wideband (UWB) has been greatly in demand as it is an unlicensed wireless band and offers a high data rate for 4G/5G applications. Its demand is growing day by day, as it consumes low power or low energy level and is available for applications like RADAR, imaging etc. The handy devices in the today’s communication world require small sized and portable antennas operating over the UWB to support high speed multimedia applications. Many such antennas have been proposed by researchers in the literature for UWB applications [3-10]. Dielectric Resonator Antennas are an advantage over the existing Microstrip antennas as they offer low metallic losses, better gain and a 3D antenna structure radiates as a whole for these antennas.

The DR antennas (DRAs) have many advantages as small size, light weight, broad bandwidth, low profile, less production cost, ease of fabrication and offer high radiation efficiency [2]. These have more versatility and higher degree of flexibility as compared to linear and planar antennas, allowing for various applications in handy wireless communication devices [3]. DRAs have been explored by many researchers, as a DRA 3-D structure can be made easily and a structure like rectangular, cylindrical, conical, triangular, cylindrical ring, hemispherical and a 3D structure with more height as compared to MSA can radiate more effectively [4-7].

Since the hollow DRA has a wider bandwidth as compared to its solid counterpart [8], the hollow structure design is preferred in this research article. Therefore the Multi-layered hollow DRAs have been proposed in this research article to widen the impedance bandwidth of the antenna’s operation with good gain properties [10-13]. The current article proposes a multilayer DRA made on a FR4 sheet with feed network printed on the FR4 sheet. The ground layer has a slot 45 degrees tilted and cut out from it. A hollow FR4 layer of 3.2mm height is pasted on the ground and then a DRA rectangular sheet is pasted on the hollow layer to provide the required impedance bandwidth of antenna’s operation. The antenna structure has been chosen with an annular ring to provide the required operational characteristics of high gain. The proposed DRA reports a simulated impedance bandwidth of 43.22% (3.7 to 5.74 GHz). An average gain of 8.52 dBi and a maximum gain 9.2 dBi at 5.1 GHz allows it to be suitable for the handy devices used in near range wireless communications specifically for WLAN (IEEE 802.11b) applications. A wide bandwidth supported by the antenna allows it to support high data rates and hence be able to be used for multimedia applications.

The next sections of the article present the antenna configuration, its simulated results and the conclusions of the research article.

II. ANTENNA DESIGN AND CONFIGURATION

The snapshots of designed stacked dielectric resonator antenna are presented in figures 1(a) and (b) respectively. The antenna is made up of two materials; a high permittivity (εr=1) pasted over a lower dielectric layer with low...
permittivity (\(\varepsilon_{rd2}\)). The antenna is designed in CST MWS V16, it has a lower layer of commercially available FR4 (with dielectric constant of 4.4 and height of 1.57mm) and has a metallic ground layer deposited on its top with a thickness of 0.035mm. The feedline made of copper is deposited at the bottom of substrate (height =0.035mm). An aperture slot shifted by 45 degrees is etched out from the ground layer to allow better coupling to the DRA. On the top of the aperture coupled ground layer, a rectangular annular ring with a thickness of 2 mm is placed. A rectangular DR of Alumina (Al2O3) with a higher dielectric constant of 9.8 is then pasted on this hollow annular ring to allow the antenna to exhibit the required bandwidth of operation. Figure 1(a) shows the view of Annular ring and an aperture slot in ground, figure 1(b) shows the DR pasted over the annular ring structure with thickness of hs and a size of Ls × Ws, the slot or aperture length Isand ws is cut from the ground. Equation 1 is used to design the rectangular stacked DRA for the dominant mode resonant frequency at 4.7GHz

\[
f_{\text{TE}_{mn}} = \frac{v}{2\pi\sqrt{\varepsilon_{s}}} \sqrt{k_x^2 + k_y^2 + k_z^2}
\]

\[
k_x = \frac{l\pi}{D_{14}}, \quad k_y = \frac{m\pi}{D_{w5}}, \quad k_z = \frac{m\pi}{2h_{\text{DR}}}
\]

Here, \(k_x, k_y, k_z\) are the wave propagation number in x, y, z direction, where \((k_x)^2 + (k_y)^2 + (k_z)^2 = \varepsilon_{\text{DR}} (k_0)^2\).

Also wave propagation numbers should satisfy (2), where \(D_{14}, D_{w5}, h_{\text{DR}}\) are the length, width and height of rectangular shape DR shown in figure 1(b).

where \(k_0\) is denoted by free space wave number.

All the dimensions of different parts of the antenna are as follows. The variables value of the prototype antenna are given by \(\varepsilon_{rd1} = 9.8, h_1 = 4 \text{ mm}, \varepsilon_{rd2} = 4.4, h_2 = 3.2 \text{ mm}, \text{LDRmax} = 40 \text{ mm}, \text{LDRmin} = 36 \text{ mm}, L_s=W_s=70 \text{ mm}, \varepsilon_s=4.4, h=0.8 \text{ mm}, L_g=W_g=70 \text{ mm}, l_s=37.5 \text{ mm}, w_s=2.4 \text{ mm}, l_f=1.8, w_f=44.5 \text{ mm}, \) aperture tilted with 450 angle

![Figure 1](image_url)

**Figure 1:** Fabricated antenna (a) with hollow DRA on ground layer h2(b) With Alumina sheet pasted on the hollow DRA (c) Perspective view of the multilayer antenna structure

### III. SIMULATED AND MEASURED RESULTS

The current research article presents a hollow stacked Dielectric Resonator antenna with high gain for UWB applications. The antenna was designed using CST MWS V16 with open boundary conditions for simulations. The antenna parameters optimization was carried out using parametric sweep option in the software wideband HSRDR antenna operating in frequency 3.7 to 5.8 GHz was designed and simulated. In this antenna, the high permittivity dielectric material with \(\varepsilon_{\text{DR1}}=9.8\) is chosen as by Al2O3 and low permittivity dielectric material layer with \(\varepsilon_{\text{DR2}}=4.4\) is chosen as FR4.
Figure 2 shows the simulated $S_{11}$ with respect to frequency of HSRDR antenna, with reasonable agreement between two software results obtained. The measured and simulated less than -10 dB impedance bandwidth are 43.22% (3.7 to 5.74 GHz) HFSS and 42.24% (3.79 to 5.82 GHz) CST respectively. Figure 3 shows the E-field of the DRA is observed at 4.1GHz and 5.5 GHz. This resonant behaviour is observed by the fundamental mode of transverse electric mode (TE) because of maximum E-field near location of slot.
Figure 4 shows the simulated far field 3-D isometric radiation pattern at 4.1 GHz resonant frequencies in both softwares HFSS as well as CST. A gain of 7.88 dBi and 8.01 dBi at 4.1 GHz frequency is obtained in CST and HFSS respectively.

Figure 5 shows the simulated SDRA antenna gain of designed antenna. According to the figure, the simulated gain and radiation efficiency of twosoftware’s are approximately equal. The antenna shows a maximum gain in both softwares; CST and HFSS as 9.21 dBi and 9.12 dBi (8.5 dB and 8.2 dB) at 5.1 GHz frequency and average gain in band of operation as 8.5 dBi (7.8 dB). A maximum radiation efficiency 92.12% and 91.12% at 5.1 GHz frequency and average 82.5%, respectively is also exhibited by the antenna.

Figure 5: Simulated gain results as radiation efficiency, isotropic gain (dBi), and total gain (dB) (a) CST (b) HFSS

IV. CONCLUSION

A stacked hollowDRA consisting of two dielectric layers with distinct permittivity has been presented in this letter. The hollow structure has low permittivity and solid structure has high permittivity. The HSRDR antenna have a simulated impedance bandwidth of 43.22%, average gain ~ 8.54 dBi, maximum gain 9.2 dBi at 5.1 GHz. The small size and good operational characteristics allow this antenna to be successfully used for UWB applications. The work can be extended to make an array for MIMO applications.

V. REFERENCES