Pattern reconfigurable dielectric resonator antenna using capacitor loading for internet of things applications

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ABSTRACT

This research study presents a cube dielectric resonator antenna (DRA) with four different radiation patterns for internet of things (IoT) applications. The various radiation patterns are determined by the grounded capacitor loading to reduce interference. The DRA is constructed of ceramic material with a dielectric constant of 30 and is fed via a coaxial probe located in the antenna's center. Capacitors are used to load the four parasitic microstrip feed lines. Each pattern of radiation is adjustable by adjusting the capacitors loading on the feed line. The proposed antenna works at 3.5 GHz with -10 narrow impedance bandwidth of 74 MHz.

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1. INTRODUCTION

The internet of things (IoT) enables easy connectivity across a broad range of low-power wireless devices. Intelligent things are constantly detecting and collecting data from their surroundings [1]. Nowadays, increasingly more devices are connecting to the internet [2]. IoT technology enables almost all of these devices to operate wirelessly [3]. Therefore, in order to handle the enormous number of networked devices, it is crucial to design antennas that are effective for IoT applications. A dielectric resonator antenna (DRA) is one of the most efficient antennas being developed by researchers to lower the dissipated power since it requires less metal in the antenna construction [4]. One of its most desirable characteristics is that the DRA has minimal conductor loss or surface wave loss. [5], [6]. With feeding methods including probes, apertures, and microstrip lines, DRA is straightforward to operate. feeding system producing a variety of radiation patterns, including omnidirectional and directional radiation patterns [7]. By aiming the radiation pattern in a specified direction, pattern reconfigurable antennas may decrease interference and the average energy needed for packet transmission, lowering data collisions [8]. Almost all IoT applications work at the S-band frequency range and S-band refers to a frequency spectrum with a range of 2 to 4 GHz. This has several applications like Wi-Fi, industrial, scientific, and medical radio band (ISM band), LTE, and 5G [9]. Especially the channel for band 3.5 GHz for 5G-enabled IoT [10].

There are three types of reconfigurable antennas: polarization reconfigurable [11], frequency reconfigurable [12], and pattern reconfigurable [13]. The aim of a pattern reconfigurable antenna is to reduce interference by controlling the radiation pattern to radiate in desired directions. There are various methods for obtaining pattern reconfigurable in DRA. Some of these methods which researchers use are electrical change such as using a passed antenna array [14], passed array with switch, capacitor loading [15], [16], electrical switch PIN diodes [17], [18], multi-feed [19], [20], multi-port with switches [21], switches on slot in ground plane [22]. On the other hand, some of the researchers used mechanical change, such as liquid material as a dielectric resonator by changing the material inside the dielectric resonator by using a pump to get different radiation patterns [23]–[25], and the other researcher used a motor to rotate the antenna to steer the radiation pattern [26], [27]. The aim of this research study is to design a narrow band pattern reconfigurable dielectric resonator antenna that works at 3.5 GHz for 5G-enabled IoT.

In this research study, the cube shape of the dielectric resonator consists of ceramic martial with a dielectric constant of 30. The dielectric resonator is fed by a probe feed from the middle bottom of the dielectric resonator. The dielectric resonator sits on an FR4 board which has a dielectric constant of 4.3. In addition, four direct microstrip feed lines were added to the dielectric resonator; these feeds are connected to the capacitor loading to the ground. When changing the value of the capacitor will get different radiation patterns.

2. METHOD

In this research, the method to design the antenna is by using the TE_{111} modes of the dielectric waveguide model (DWM) [28]; the equations DWM are (1) to (3).

$$K_z = \frac{\pi}{a}; K_y = \frac{\pi}{b} \tag{1}$$

$$K_z \tan\left(\frac{K_z d}{2}\right) = \sqrt{(\varepsilon_r - 1){K_\circ}^2 + {K_z}^2} \tag{2}$$

$$ {K_x}^2 + {K_y}^2 + {K_z}^2 = \varepsilon_r {K_\circ}^2 \tag{3}$$

$K_\circ$ denotes the wavenumber in free space and the wavenumbers within the three directions x, y, and z inside the dielectric resonator directions K_X, K_Y, and K_Z respectively. On the other hand, ε_r denotes the dielectric constant of the dielectric resonator material. Finally, *a*, *b*, and *d* denote the dimensions of the rectangle dielectric resonator.

2.1. The design of antenna

The form of the suggested DRA is cube. The cube-shaped works the same as a rectangular shape dielectric resonator [29]. The dimensions of DRA are shown in Table 1, with the antenna's complete dimensions and their values in millimeters. The antenna's construction is made up of a dielectric resonator mounted on an FR-4 substrate. The substrate is made of FR-4 material, has a 4.3 dielectric constant, and is 1.6 mm thick. The FR-4 substrate is placed on top of the ground plane, which is 60 mm wide and long. The antenna was fed by a probe feed that was located in the bottom middle of the dielectric resonator. In addition, four microstrip feed lines with grounded capacitor loading are designed as shown in Figure 1. The structure of the antenna from the front view and side view is shown in Figures 1(a) and (b), respectively.

Table 1. The dimensions of the antenna

Parameters Description	Abbreviations	Value (mm)
The width, length and height of the cube-shaped dielectric resonator	Wd, Ld, and Hd	9.3
The width and the length of substrate and ground	Wg and Lg	60
The thickness of ground plane	Hg	0.035
The thickness of substrate	Hs	1.6
The length of parasitic feed line inside the dielectric resonator	Hf	2
Probe feed hole inside the dielectric resonator	Lf	0.65

2.2. Capacitor loaded configurations

Four parasitic microstrip feed lines feed the dielectric resonator from the four sides. Each parasitic microstrip feed line is loaded with a capacitor that is connected to a ground plane, as shown in Figure 1. Changing the values of these capacitors may get four cases. The capacitors configurations of all cases are tabulated in Table 2. Capacitor values for capacitors 1 through 4 in Case 1 are (0.01, 1, 1, 1) pF respectively, Capacitor values for capacitors 1 through 4 in Case 2 are (1, 0.01, 1, 1) pF for capacitors 1 to 4 respectively, Case 3 has capacitors with values of (1, 1, 0.01, 1) pF for capacitors 1 to 4 respectively, and Case 4 has capacitors with values of (1, 1, 1, 0.01) pF for capacitors 1 to 4 respectively.

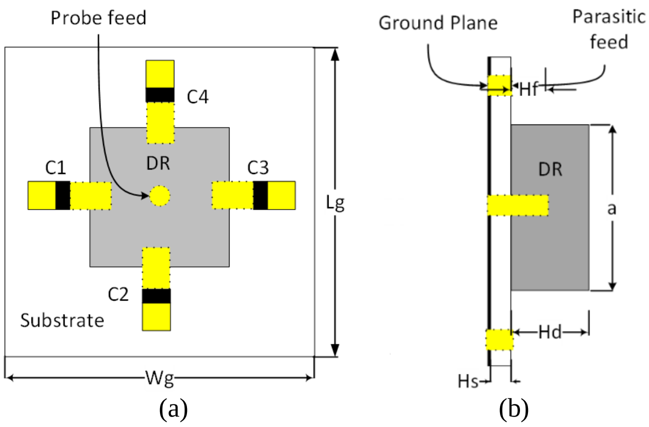

Figure 1. The structure of the antenna (a) front view and (b) side view

Table 2. The dimensions of the antenna

Cases	Capacitor 1 (pF)	Capacitor 2 (pF)	Capacitor 3 (pF)	Capacitor 4 (pF)
Case 1	0.01	1	1	1
Case 2	1	0.01	1	1
Case 3	1	1	0.01	1
Case 4	1	1	1	0.01

3. RESULTS AND DISCUSSION

The proposed antenna has four cases. These cases are changing the values of the grounded capacitor loading. These cases can obtain various radiation patterns. Figure 2 shows that the antenna's reflection coefficient for all cases is -12.24 dB at 3.5 GHz, and the -10 dB impedance bandwidth is 74 MHz, with a frequency range of 3.48 to 3.56 GHz. Figure 3 shows a three-dimensional view of the radiation pattern at the resonance frequency of 3.5 GHz for case 1 in Figure 3(a), case 2 in Figure 3(b), case 3 in Figure 3(c), and case 4 in Figure 3(d). Each case instance thus has its own radiation pattern.

The result shows the direction of the radiation pattern is opposite to the location of the capacitor loading with the value of 0.01 pF. The efficiency for all four cases almost has the same value efficiency as shown in Figure 4. Table 3 shows the comparison between all cases (1 to 4). All cases have the same band, directivity, gain, and efficiency, but each case has different directions of the radiation pattern.

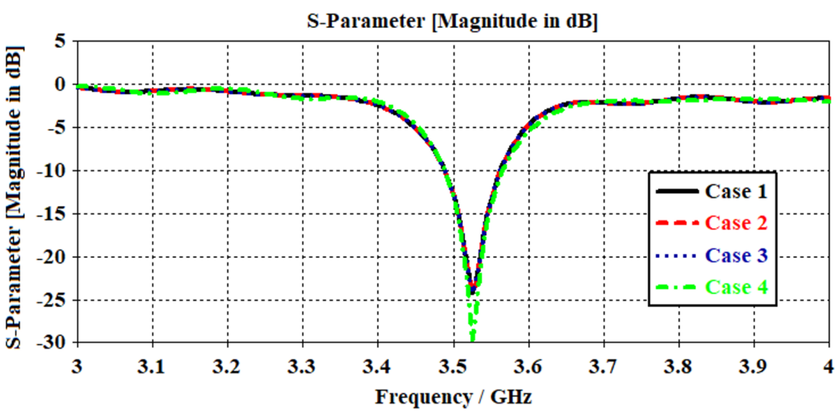

Figure 2. Reflection coefficient of the antennas for all cases

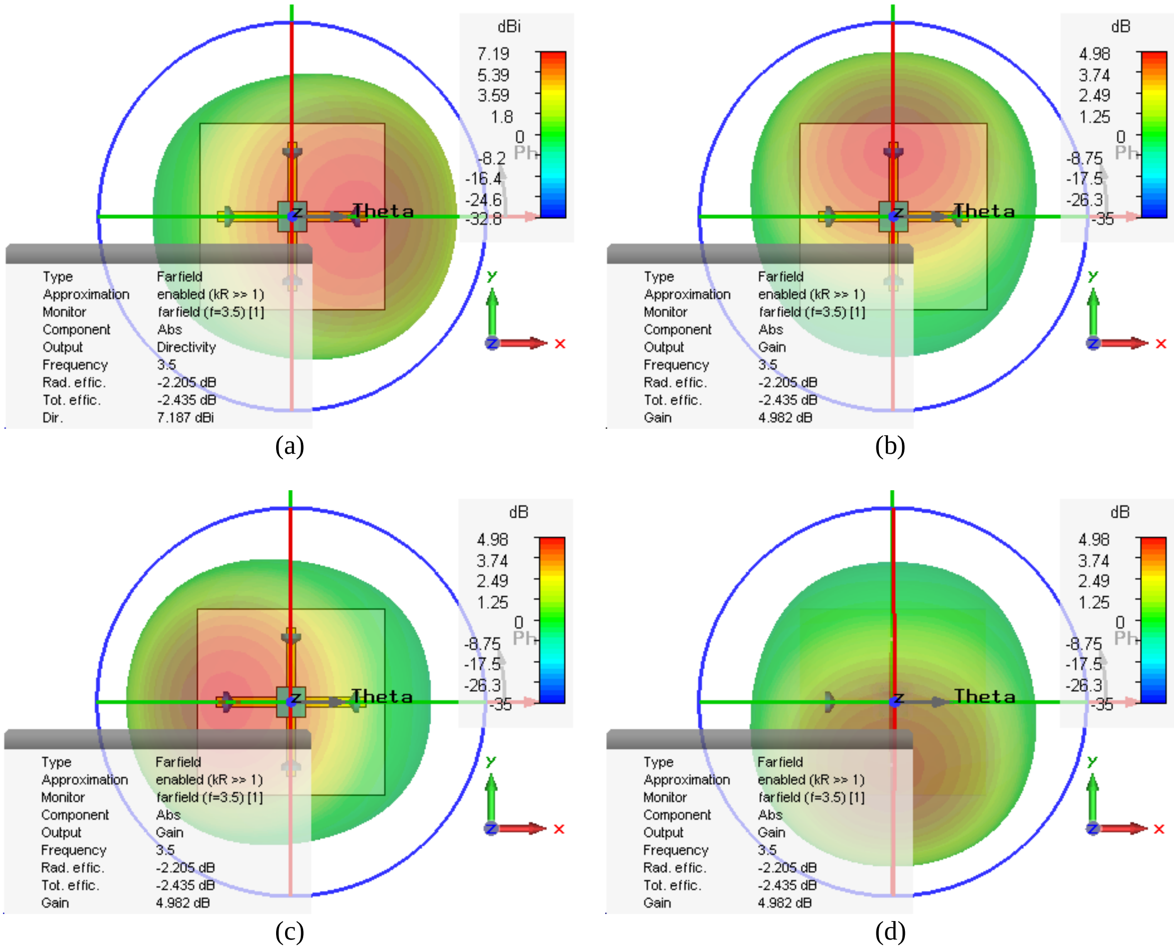

Figure 3. The radiation pattern view of the antenna at 3.5 GHz (a) case 1, (b) case 2, (c) case 3, and (d) case 4

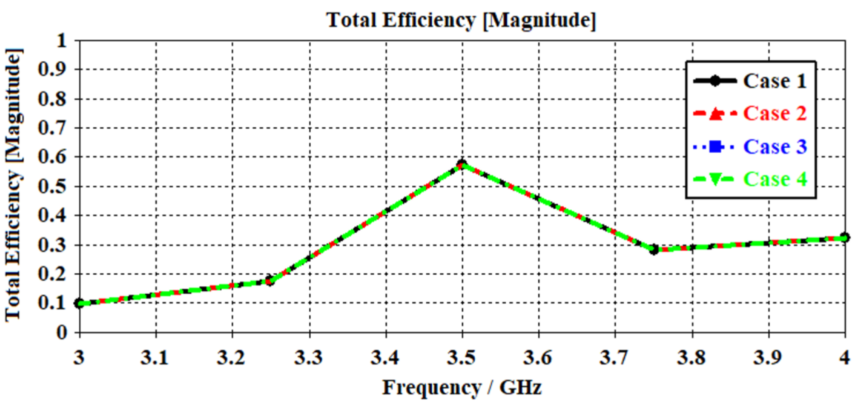

Figure 4. The total efficiency for all the cases

Table 3. The parameter for all cases

Parameter	Case 1	Case 2	Case 3	Case 4
-10 dB impedance bandwidth	74 MHz	74 MHz	74 MHz	74 MHz
Directivity at 3.5 GHz	7.1 dBi	7.1 dBi	7.1 dBi	7.1 dBi
Gain at 3.5 GHz	4.9 dB	4.9 dB	4.9 dB	4.9 dB
Rad. Efficiency at 3.5 GHz	60%	60%	60%	60%
Main lobe direction for Theta at Phi=0˚	19.0˚	0.0˚	-19.0˚	0.0˚
Main lobe direction for Theta at Phi=90˚	0.0˚	19.0˚	0.0˚	-19.0˚

4. CONCLUSION

A four-microstrip feed line loaded with a ground capacitor is implemented to dielectric resonator antenna fed by probe feed are successfully designed. This method yielded four unique radiation patterns. At a resonant frequency of 3.5 GHz, all four cases have a narrow -10 impedance bandwidth of 74 MHz, which is ideal for S-band narrow bandwidth applications such as the channel for band 3.5 GHz for 5G-enabled IoT. In the future, further study will be needed to establish the efficiency of this technique for antenna manufacturing.

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