Pattern Reconfigurable Dielectric Resonator Antenna Using Parasitic Feed Elements for LTE Femtocell Base Stations

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Abstract**—**An initial cuboid shape dielectric resonator antenna is made from a ceramic compound with a high dielectric constant of 30. A feeding mechanism that consists of a coaxial probe in the middle of the antenna is installed underneath, Parasitic feed elements are used to guide the flow of the surface current into the desired direction. Each parasitic feed possesses a switch to control the surface current flow and obtain a reconfigurable pattern. The impedance bandwidth of the proposed antenna is 320 MHz from 2.45–2.72 GHz with a total efficiency exceeding 96%, which is suitable for long-term evolution (LTE) of bands 7 (2,500–2,570 MHz, 2,620–2,690 MHz) and 38 (2.57–2.62 GHz) femtocell base stations. The proposed antenna is fabricated, and results indicate satisfactory agreement between simulated and fabricated antennas.

Index Terms**—**pattern reconfigurable, dielectric resonator antenna, LTE, Femtocell base stations

I. Introduction

For the past two decades, dielectric resonator antennas (DRAs) have received considerable interest owing to their multiple advantages, such as low loss, compact size, and high degree of flexibility [1]. Moreover, present wireless communication devices require reconfigurable antennas because of various features in terms of frequency, polarization, and radiation pattern that these antennas can provide to improve the overall system performance [2]. However, a significant interest in the study of reconfigurable radiation patterns is noted in the field of reconfigurable antennas because the radiation pattern of an antenna can prevent interference and noise source. Moreover, reconfigurable antennas can also improve security and save power by directing signals to the desired direction [3], thus resulting in a large demand for pattern-reconfigurable antennas in the field of wireless communication.

Reconfigurable pattern is defined as any change in radiation pattern without changes in operating frequency. Researchers have developed numerous techniques to achieve reconfigurable pattern; one such pattern is the phased array antenna, which has been used for pattern reconfiguration in dielectric resonator antennas [4]. The phased array antenna is sometimes too large and complex and thus may not be suitable in meeting the requirements of simple applications. A reconfigurable pattern is obtained by using electrical changes, such as reconfigurable feeding network using electronic components, such as switches [5], using mechanical changes, such as material change [6], or by multi-feed techniques [7]. In such cases, different methods are used to reconfigure the radiation pattern

The basic shapes of DRA can be hemispherical, cylindrical, or rectangular. For this study, the researchers used a cuboid shape antenna because of its simplicity, flexibility, and single degree of freedom. However, cylindrical and hemispherical antennas may yield more radiation patterns because all sides are symmetric.

The authors presented the simulation results of the prop feed cuboid shape of dielectric resonator antenna in an earlier conference paper [8].

The present research study has successfully achieved pattern-reconfigurable cuboid-shaped dielectric resonator antenna which is suitable for long-term evolution (LTE) femtocell base stations. The design uses a high dielectric constant of $\varepsilon_{\mathrm{r}} = 30$ based on FR-4 substrate with a dielectric constant of 4.3. The antenna is centered by coaxial probe feeding, which is matched with 50 Ω and present four parasitic feed elements touching the four sides of the cuboid. Meanwhile, the parasitic feed elements use grounded switch technique.

This paper is organized as follows. Section 2 describes the theoretical analysis of the antenna design. Section 3 describes the configurations of the antenna. The results and discussions are detailed in Section 4, followed by the conclusion in Section 5.

II. Theoretical Analysis

The rectangular geometry of the DRA presents a significantly complex electromagnetic field problem in the analysis of the operation. Numerous methods for analysis, such as method of moments (MoM) and finite difference time domain(FDTD), can be used to analyze these fields. However, these methods require time and memory and are unsuitable for design and optimization. For avoiding these issues, simple models, such as dielectric waveguide model (DWM), have been developed to approximate resonant frequency.

The DWM of the TE_{111} mode is used to obtain resonant frequency [9] based on the equations below:

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

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

where $K_{\circ}$ is the free space wavenumber; the wavenumbers are $K_x = \pi/L$ at *X*-direction, $K_y = \pi/W$ at *Y*-direction, and K_z at *Z*-direction. *W*, *L*, and *H* denote the width, length, and height of dielectric resonator, respectively. The DWM equations of the TE_{111} mode are used.

III. Antenna Configurations

Fig. 1 and Fig. 2 illustrate the proposed cuboid-shaped DRA, which was made of a high-dielectric-constant ceramic (ε_r=30). The dimensions of the cuboid shape of the antenna were as follows: the width and length were of the same dimension of *W*=*L*= 24, and height *H*=16. The DRA is fed with a 50-Ω probe feed, and the height of the probe is H_f=4 mm. The height of the parasitic feed elements was H_p=5. Each parasitic feed possessed a grounded switch for four cases as listed in Table I. The DRA was placed on a 1.6 mm FR4 board with 35 µm of single-sided copper. The dielectric constant of the substrate was 4.3, and the dimensions of substrate board were 60 mm × 60 mm.

TABLE I: SWITCH CONFIGURATION FOR ANTENNA

Cases	Switch Up	Switch Down	Switch Right	Switch Left
Case 0	Off	off	off	off
Case 1	On	off	off	Off
Case 2	Off	on	off	off
Case 3	Off	off	on	Off
Case 4	Off	off	off	On

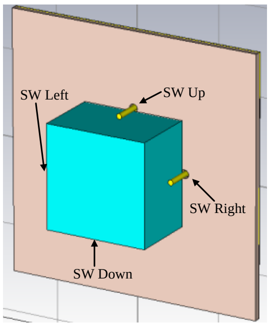


Fig. 1. Structure of cuboid DRA 3D model

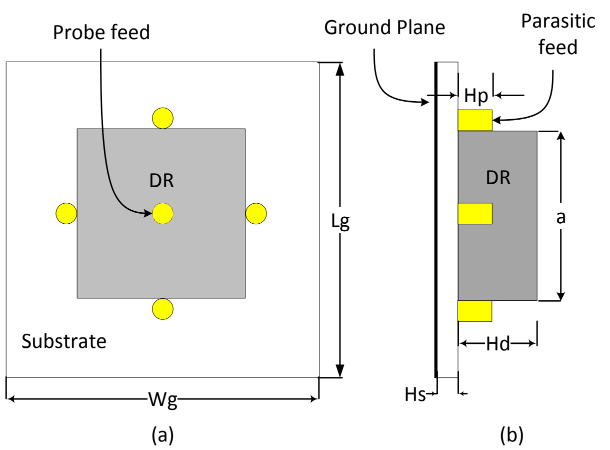


Fig. 2. Structure of cuboid DRA, (a) top view, (b) side view (*a*=24, H_d=16, H_f=5, H_p=6, and W_g=L_g=60 mm)

IV. Results and Discussions

The proposed antenna was simulated using CST Microwave Studio with the optimized parameters. The simulated return losses for all cases mentioned in Table 1 are shown in Fig. 3. The -10 dB impedance bandwidth exceeds 200 MHz and the ranges from 2.45 GHz to 2.72 GHz, which is suitable for the LTE band 7 and 38. Fig. 4 shows the surface current distribution for Case 1. The surface current flows toward the on switch, meaning that the maximum radiation pattern is toward the current flow. Fig. 5 shows the polar linear scale of gain radiation pattern for the five cases (Figs. 5a, 5b, 5c, 5d, and 5e indicate Cases 0, 1, 2, 3, and 4, respectively). In Fig. 6, the 3D radiation pattern with the structure observed at 2.6 GHz for all cases shows that the main lobe is in the same direction as the on switch. The maximum gain at 2.6 GHz is 0.74 dB for Case 0 and 1.447 dB for Cases 1 to 4 (Fig. 7).

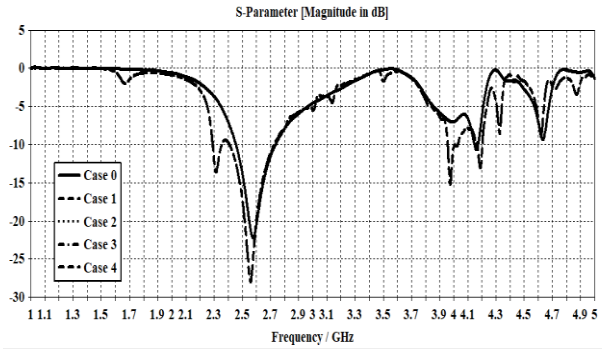


Fig. 3. S-Parameter for all cases

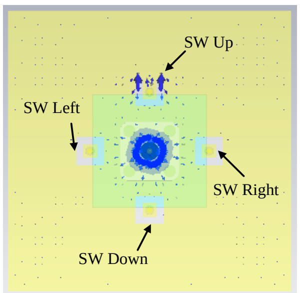
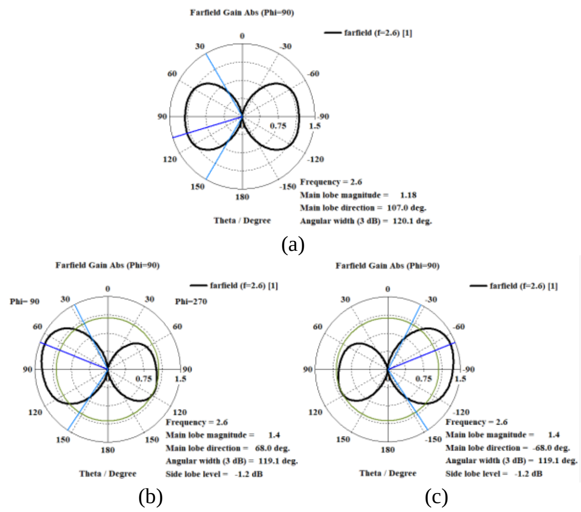
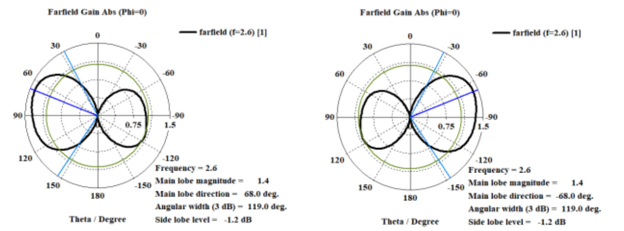


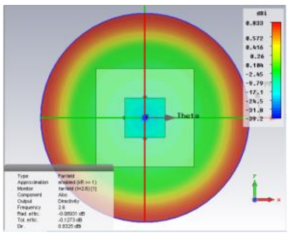
Fig. 4. Surface current distribution for Case 1



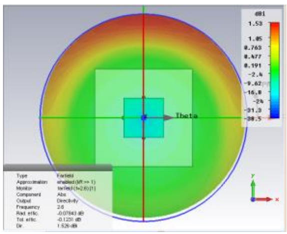


(d) (e)

Fig. 5. Linear scale gain pattern of the proposed antenna at 2.6 GHz, (a) Theta of Case 0 at phi=90 °, (b) Theta of Case 1 at phi=90 °, (c) theta of Case 2 at phi=90 °, (d) theta of Case 3 at phi=0 °, and (e) theta of Case 4 at phi=0 °.



(a)



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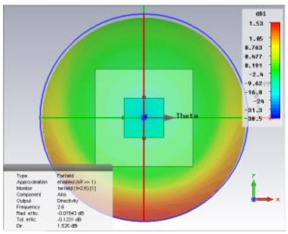

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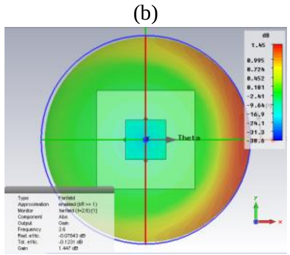
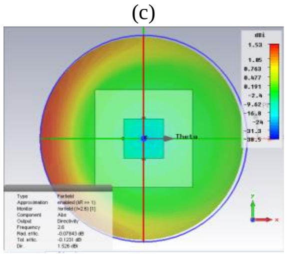


(d)



(e)

Fig. 6. 3D radiation pattern with structure shown at 2.6 GHz for (a) Case 0, (b) Case 1, (c) Case 2, (d) Case 3, and (e) Case 4.

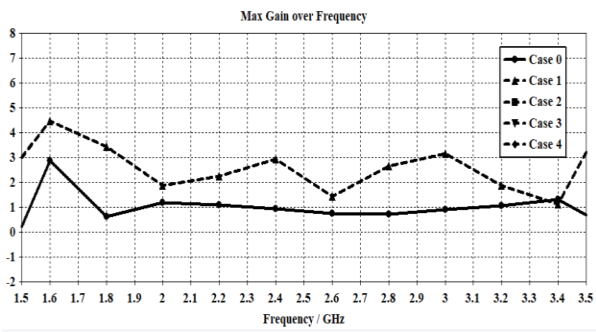


Fig. 7. Maximum gain over frequency

Agilent N5227A PNA network analyzer was used to curry out the measured S parameters results. Fig. 8 shows the measured and simulated return loss for Case 1. The simulated and measured results indicate good agreement.

Satimo near field wave measurement system was used to curry out the measured radiation pattern and gain. Fig. 9 shows the measured and simulated radiation pattern for Case 1 of the polar plot for theta while phi=90 at 2.6 GHz in dB. Fig. 10 shows the measured and simulated gain over frequency. Fig. 11 shows the measured and simulated total efficiency over frequency. Fig. 12 shows the proposed antenna in the measurement laboratory.

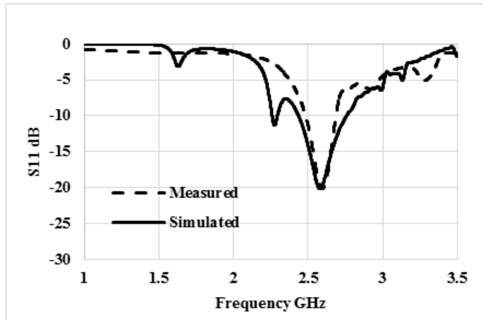


Fig. 8. Measured and simulated return loss of the antenna for Case 1

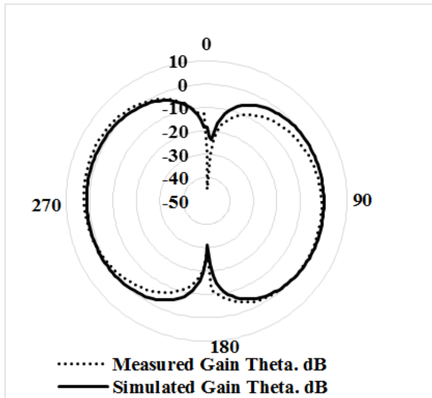


Fig. 9. Measured and simulated gain pattern of theta in Case 1 at phi=90 °

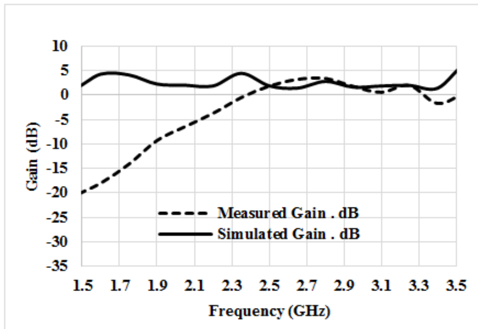


Fig. 10. Measured and simulated gain over frequency

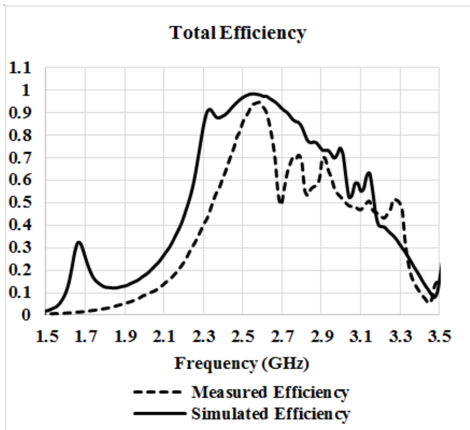


Fig. 11. Measured and simulated total efficiency over frequency

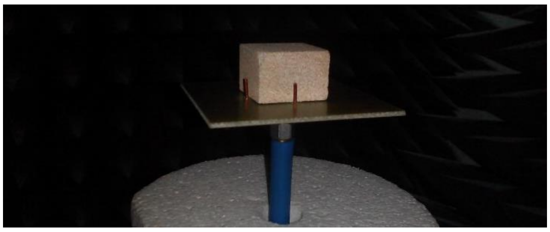


Fig. 12. Image of the fabricated antenna

Table II shows the number of elements, the number of radiation pattern, the frequency band (bandwidth), the antenna size and the techniques that used to obtain pattern reconfigurable for the proposed antenna compared with those in selected publications. The criteria for selecting the published papers are reconfigurable radiation pattern DRA, use of switch technique, and IEEE standard for S-band [10]. The proposed antenna presents one feed and one element. Moreover, the proposed antenna is smaller in size than the others. However, the gain for this technique is minimal compared with those of other DRAs. Finally, the comparison between all cases as described in Table III at 2.6 GHz for main lobe direction, Side Lobe Level (SLL), antenna gain, directivity and total efficiency. The directivity for Case 0 is 0.8278 dBi at 2.6 GHz, whereas the directivity for Cases 1 to 4 is 1.466 dBi at 2.6 GHz. Case 0 is different from other cases.

TABLE II: COMPARISON BETWEEN THIS WORK AND PUBLISHED WORKS REGARDING RECONFIGURABLE RADIATION PATTERN IN DRAS USING SWITCHES

Ref.	No. Ele.	No. pat.	F(BW)	Gain	Size mm	Technique
[11]	4	6	1.95 GHz (500 MHz)	7 dB	292 × 184	4 grounded switches on parasitic patch and feed switches
[5]	4	4	2 GHz (700 MHz)	6.96 dB	130 × 130	20 grounded switches on parasitic patch and feed switches
This Work	1	5	2.6 GHz (320 MHz)	1.44 dB	60 × 60	4 grounded switches in parasitic feed

TABLE III: COMPARISON BETWEEN ALL CASES AT 2.6 GHZ (THETA AT PHI=90 °FOR CASES 1 AND 2 AND THETA AT PHI=0 °FOR CASES 3 AND 4)

Cases	Main Lobe Direction	Side Lobe Level (SLL)	Gain	Directivity	Total Efficiency
Case 0	107 °	N/A	0.74 dB	0.832 dBi	96.6%
Case 1	68 °	1.2 dB	1.447 dB	1.526 dBi	96.7%
Case 2	−68 °	1.2 dB	1.447 dB	1.526 dBi	96.7%
Case 3	68 °	1.2 dB	1.447 dB	1.526 dBi	96.7%
Case 4	−68	1.2 dB	1.447 dB	1.526 dBi	96.7%

V. CONCLUSION

This study investigated the reconfigurable pattern of cuboid dielectric resonator antenna by using four parasitic feeding elements touching one small-size dielectric resonator element. The finding return loss indicates that the proposed antenna is suitable for LTE bands 7 and 38 because of the impedance bandwidth of 320 MHz, which is from 2.43–2.75 GHz. The proposed antenna is based on the low-order mode DWM of TE_{111}. In addition, the feeding mechanism of the proposed antenna is excited by the probe feed. For obtaining four reconfigurable patterns, the use of grounded switches on each parasitic feed element is necessary. This research studied the effects of using parasitic feeding elements. The results show that this technique exerts marginal effect on the radiation pattern. The directivity increases from 0.83 dBi for Case 0 to 1.52 dBi for Cases 1 to 4. The gain increases from 0.74 dB for Case 0 to 1.526 dBi for Cases 1 to 4.

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