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Dielectric Resonator Antennas with Band Rejection and Frequency Reconfigurability

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Abstract—In this paper, two types of reconfigurable Dielectric Resonator Antennas (DRAs) are presented. The designs are based on rotating a Dielectric Resonator (DR), placed on the patch of the antenna, using a DC stepper motor connected to the DR to reconfigure the notch frequency, in the first, and the resonance frequency in the second design. The attained results are a UWB DRA with a reconfigurable notch in the 3.2–5.1 GHz range that prevents interference to many narrowband systems in this range, and a DRA with a reconfigurable resonance frequency suitable for microwave and WiMAX applications. The characteristics of the designed antennas are investigated using HFSS and experimentally verified. The computed and measured results are in good agreement, and the antennas meet their design criteria.

1. INTRODUCTION

Recent years have witnessed a great increase in the use of Dielectric Resonator Antennas (DRAs) [1]. They have undergone important development and gained huge attention from researchers all over the world due to their attractive advantages and properties [2]. DRAs, which resonate from their dielectric material, have high radiation efficiency and can radiate in the entire sphere producing a big amount of radiated energy and a larger bandwidth than that of typical antennas, and this makes them a special type of antennas. They have a compact size, light weight, low cost, high versatility concerning their shapes. Moreover, DRAs have several feeding mechanisms (probes, slots, microstrip lines...) and have the characteristic of being excited in various modes producing different radiation patterns [3]. All these important features have involved a big challenge among designers to create new and effective designs. Many techniques have been proposed to achieve DRAs that operate on specific and single frequencies; and UWB and multiband DRAs. For example, in [4], a cylindrical dielectric resonator antenna (DRA) using barium titanate ($BaTiO_3$) is fed with a $50\,\Omega$ microstrip transmission line at frequency around 2.5 GHz and high dielectric constant ($\varepsilon_r = 1000$) resonator samples with different thickness are used. A wideband rectangular dielectric resonator antenna design is created in [5] to obtain wider bandwidth using high dielectric constant material. In [6], a compact dual-band dielectric resonator antenna (DRA) using a parasitic c-slot fed by a microstrip line is designed. The DR resonates at two different frequencies; one from the DRA with broadside patterns and the other from the c-slot with the dipole-like patterns. A compact multiband antenna using dielectric resonator antenna (DRA) is designed is proposed in [7]. This antenna operates at three bands for different wireless applications and accomplished by integrating two antennas side by side on a same PCB card to allow re-configurability of the radiation pattern at all three frequency bands. In [8], a bridge DRA is designed to exhibit multimode operation with broadside patterns and good polarization purity, and is extended to be used in multiband operation. Band-notched DRAs designed to minimize the interference between the UWB system and some narrowband systems such as WiMAX and WLAN are reported in [9]. This is done by adding slots on the patch and maintaining the relationship between the total length and the band-rejected operation. The notched

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frequency can be determined as a function of the speed of light in vacuum, the length of slot, and the relative permittivity of the substrate and the dielectric resonator. In [10], a dual band dielectric resonator antenna is designed to create notches by splitting a rectilinear DR and removing some of the dielectric material.

Reconfigurable antennas have also shown a great increase in use in recent years due to the increasing demands of modern wireless communications applications and devices [11]. These antennas are designed so that they can adapt with different system requirements, operate on different frequencies, and have varying polarizations or different radiation patterns, thus increasing the antenna performance and functionality [11].

In this paper, reconfigurability is added to dielectric resonator antennas, and two types of reconfigurable dielectric resonator antennas are presented. The first is an ultra wideband DRA with a reconfigurable band rejection or notch to help limit interference to different narrowband services operating inside the 3.2–5.1 GHz frequency range. The second is a DRA with reconfigurable resonance frequency suitable for different microwave applications and WiMAX applications. The reconfigurability of the notch and the resonance is achieved by rotation the Dielectric Resonator (DR) placed on the patch of the antenna, using a DC stepper motor connected to the DR. The characteristics of the designed antennas are investigated via HFSS and experimentally verified.

2. DESIGN, SIMULATIONS, AND RESULTS

2.1. DRA with Reconfigurable Notch

The geometry and dimensions of the first proposed DRA is shown in Figure 1. The antenna is designed on a Rogers RO3203 substrate with a dielectric constant $\varepsilon_r = 3.02$ and a loss tangent of 0.016. The board thickness is $h = 1.6$ mm. The dielectric resonator (DR) is a cylinder with a radius of 4 mm and a height of 3 mm. The DR, which is made of TCI Ceramic-K12 material with relative permittivity of 12, is excited by a bevel-shaped patch fed by a microstrip line over a partial ground plane. A rectangular split-ring slot of a width of 0.5 mm is etched on the patch.

The bevel shape of the patch and the partial ground in this antenna lead to UWB operation, whereas the rectangular split-ring slot in the patch is responsible for creating a band notch in this UWB range. The notch frequency depends on the dimensions of the split-ring slot as well as on the DR dielectric constant and its relative position. Figure 2 shows the fabricated antenna with DR rotated by (a) 60°, and (b) 180°.

Notch reconfigurability is attained by rotating the DR to change its position with respect to the

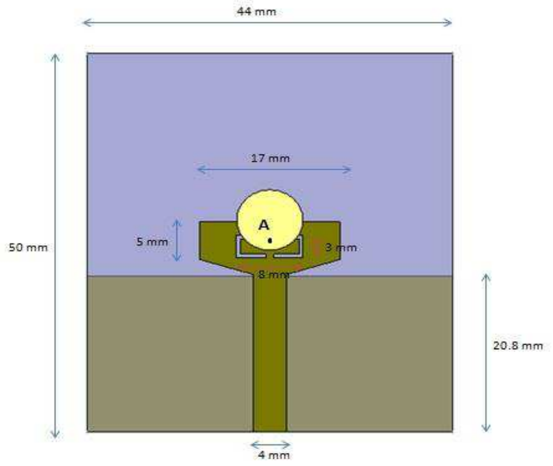


Figure 1. Configuration and dimensions of the DRA with reconfigurable notch.

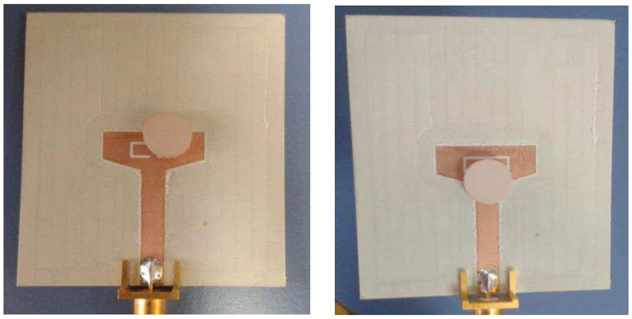

(a) (b)

Figure 2. Fabricated prototype of the DRA with reconfigurable notch, DR rotated by: (a) 60°, and (b) 180°.

patch and the slot. This is achieved by connecting the DR, at point A, shown in Figure 1, to a DC stepper motor placed below the substrate. The stepper motor can be controlled using an FPGA. The idea of rotating parts of an antenna was used in [12], where the authors had to make sure to keep metal contact between feed and radiator. In the design proposed here, only the DR is rotated, so keeping metal-to-metal contact is not an issue. The antenna is designed and simulated using Ansoft HFSS.

The simulated reflection coefficient plots of the reconfigurable band rejection DRA are given in Figure 3 for the indicated rotation angles. It is clear that band-notch reconfigurability has been attained. For example, narrow band rejections at 3.2, 3.4, 3.6, 3.9, 4.2, 4.5 and 5.1 GHz correspond to rotation angles of 0°, 45°, 60°, 135°, 137°, 145° and 180°, respectively. Due to design symmetry, and for the given design parameters, the notch band is limited within the 3.2–5.1 GHz range. A rejection at any frequency

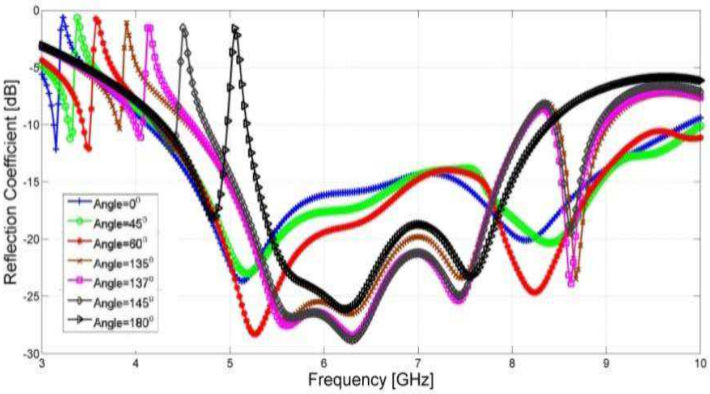
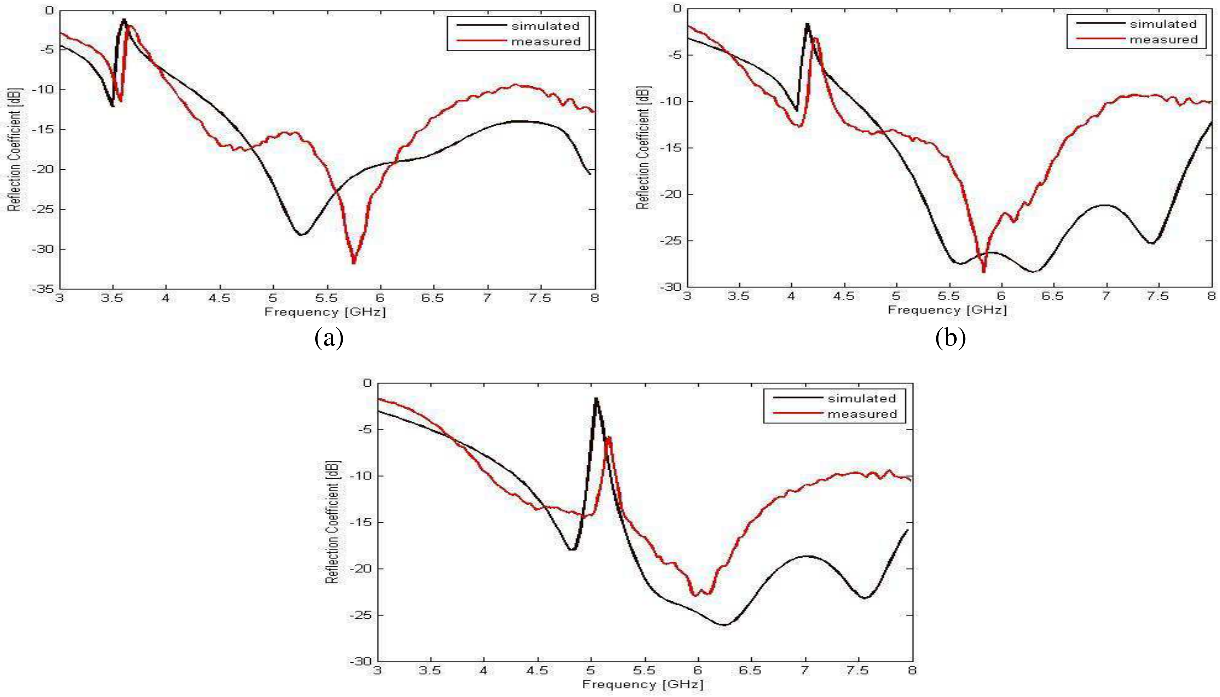


Figure 3. Simulated reflection coefficient of the DRA with reconfigurable notch for different rotation of the DR.

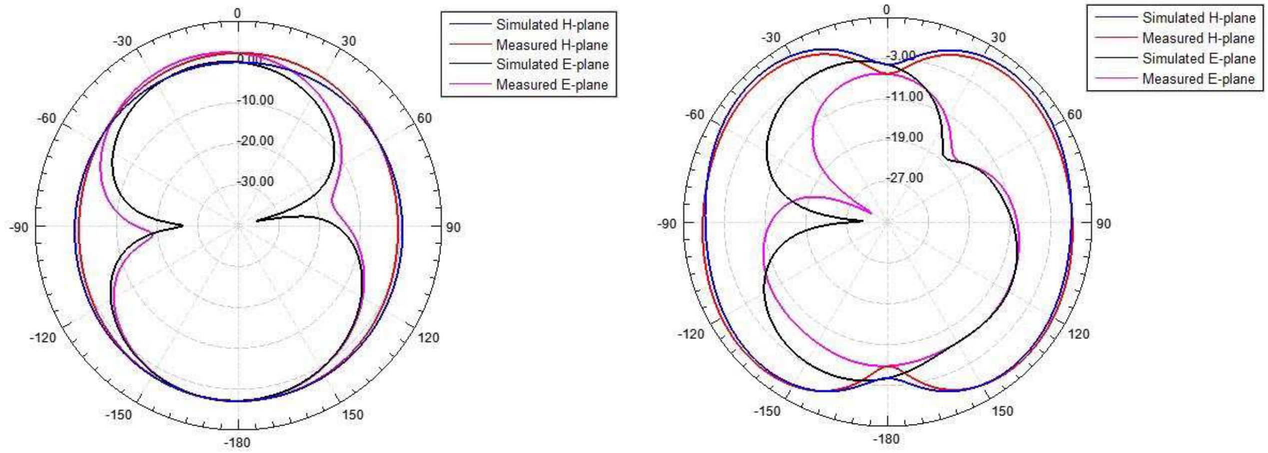


(a)

(b)

(c)

Figure 4. Measured and simulated reflection coefficient of the DRA with reconfigurable notch for: (a) 60°, (b) 137°, and (c) 180°.



(a)

(b)

Figure 5. Simulated and measured radiation patterns of the DRA with reconfigurable notch: (a) at 4 GHz, and (b) at 6 GHz.

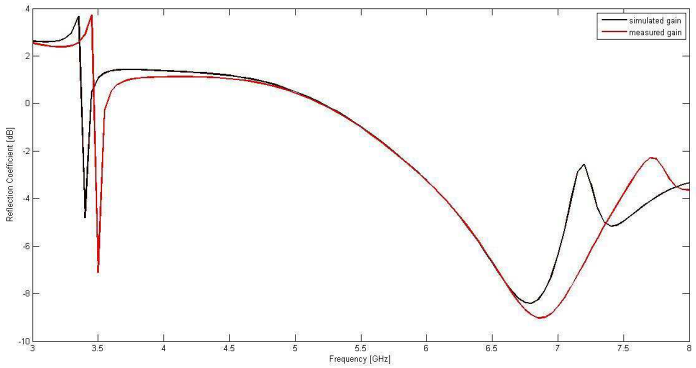


Figure 6. Simulated and measured gain of the DRA with reconfigurable notch.

inside this range is possible, by one corresponding rotation angle. This range is where most narrowband systems operating inside the 3.1–10.6 GHz band are concentrated. The induced band notches help to limit interference to many services such as WiMAX, WLAN, and other wireless applications.

The fabricated prototype has undergone the needed measurements and we rotate the DR in the angles used in the simulation process. It is observed that the simulation results and the measurements results are similar with little difference due to some fabrication issues. Figure 4 shows the reflection coefficients of the simulated and the measured antennas for three rotation angles: 60°, 137°, and 180°.

Figure 5 shows the simulated and the measured radiation patterns at 4 GHz and 6 GHz. It is observed that the radiation patterns are omni-directional, with almost equal radiation in the H-plane, and radiation with the shape of digit 8 in the E-plane.

Figure 6 shows the simulated and the measured gain for the DRA with reconfigurable notch in the frequency range utilized for the rotation angle 60°. It is observed that the peak gain is about 4 dB The simulation results and the measurements results are similar with little difference due to some measurements issues.

2.2. DRA with Reconfigurable Resonance Frequency

The second proposed DRA antenna, which has a reconfigurable resonance frequency, is designed on FR4 epoxy substrate with a thickness of 1.6 mm, a permittivity of 4.4, and a dielectric loss tangent of 0.02. The geometry and dimensions of this DRA is shown in Figure 7. It is based on a symmetrical

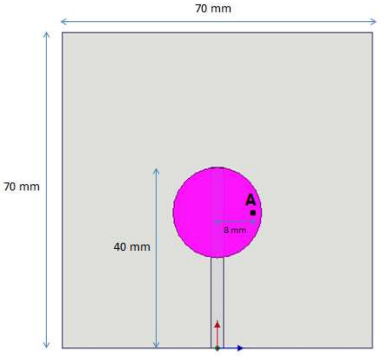
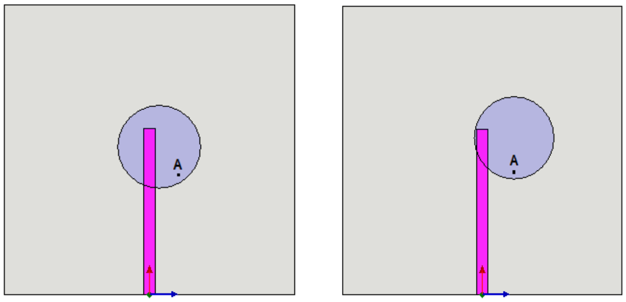


Figure 7. Configuration and dimensions of the DRA with reconfigurable resonance frequency.



(a) (b)

Figure 8. DRA with reconfigurable resonance frequency DR rotated by: (a) 45°, and (b) 90°.

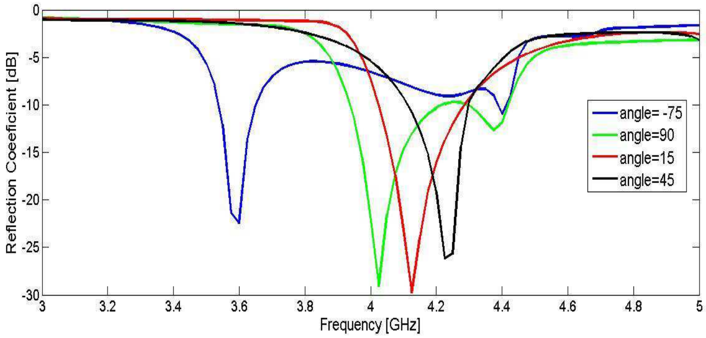


Figure 9. Simulated reflection coefficient of the DRA with reconfigurable resonance frequency for different rotation of the DR.

cylindrical DR with a radius of 10 mm and a height of 3 mm. The DR is made of the Glycerin material, which has a relative permittivity of 42.5, and is excited by a 50 Ω microstrip feed line with a width of 3 mm.

The theoretical resonance frequency of a DRA, where the DR is placed in proximity to the excitation line, as in [6], is calculated using the following equation:

$$f_r = \frac{c}{2\pi R}\left(\frac{1.6 + 0.513x + 1.392x^2 - 0.575x^3 + 0.088x^4}{\varepsilon_d^{0.42}}\right) \tag{1}$$

where $x = R/2h$, c is the speed of light, R is the radius of the DR, h is the height of the DR, and ε_d is the relative permittivity of the DR. For the values given above, but for the same configuration as in [6], the resonance frequency is found to be 4.2 GHz.

For this presented design, resonance frequency reconfigurability is attained by rotating the DR to change its position with respect to the microstrip excitation line. This is achieved by connecting the DR to a DC stepper motor placed below the substrate and controlled using an FPGA. Figures 8(a) and 8(b) show the DR rotated clockwise about point A by 45° and 90°, respectively.

The simulated reflection coefficient plots of the DRA with reconfigurable resonance frequency are given in Figure 9 for the indicated rotation angles. It is clear that resonance frequency reconfigurability has been attained. It is observed that the antenna can operate at 3.6, 4, 4.1, and 4.25 GHz corresponding to rotation angles of $-75°$, 90°, 15° and 45°, respectively. From these results, the antenna can be suitable for microwave applications, radio altimeters, and WiMAX applications.

The proposed antenna has undergone the same simulation in the Computer Simulation Technology (CST) Microwave Studio software with the same rotation angles of the DR. It is observed that the simulation results of HFSS and CST are very close to each other. Figure 10 shows the reflection

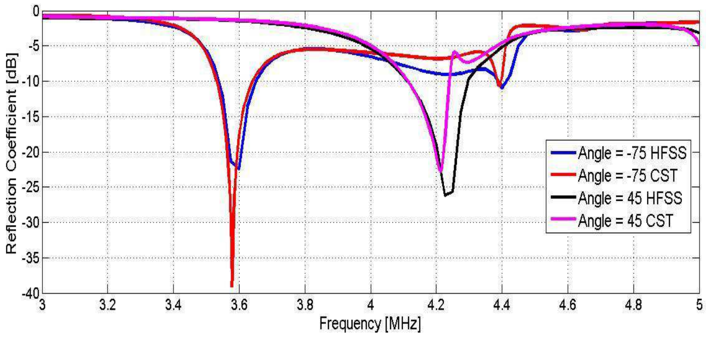


Figure 10. Simulated reflection coefficient of the DRA with reconfigurable resonance frequency in HFSS and CST for the rotation angles: −75° and 45°.

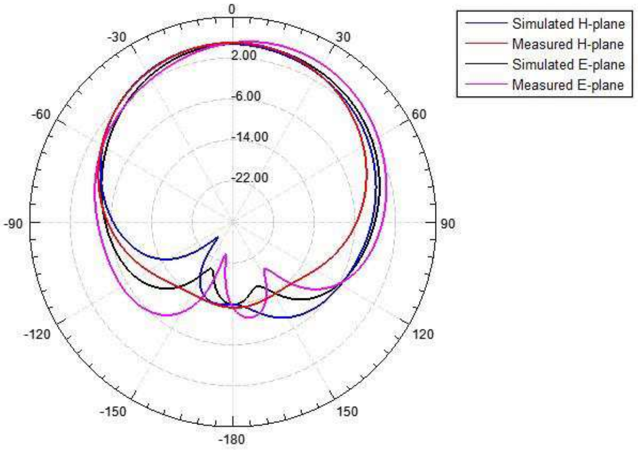


Figure 11. Simulated and measured radiation pattern of the DRA with reconfigurable resonance frequency at 4 GHz.

Table 1. Antenna peak gain of the proposed design.

Frequency (GHz)	Rotation Angle	Gain (dB)
3.6	−75°	4.65
4	90°	4.75
4.1	15°	5.1
4.25	45°	4.1

coefficients of the simulated results in HFSS and CST for the rotation angles: −75 and 45°.

The simulated and the measured radiation pattern plots of the frequency-reconfigurable DRA are given in Figure 11. These patterns are computed at 4 GHz for the case where the antenna resonates at that same frequency. As expected, this antenna has broadside patterns.

The antenna peak gain is given in Table 1. The values are calculated for all the resonance frequencies of this design. We observe that the gain is approximately flat, between 4.1 and 5.1 dB, for all the resonance frequencies.

Figure 12 shows the simulated and the measured gain for the DRA with reconfigurable resonance frequency in the frequency range utilized for the rotation angle 90°. It is observed that the peak gain is about 5 dB and it is relatively high for the resonance frequencies desired The simulation results and the measurements results are similar with little difference due to some measurements issues.

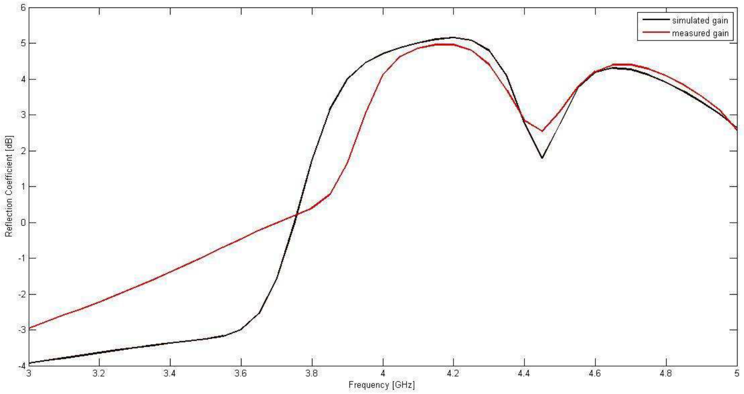


Figure 12. Simulated and measured gain of the DRA with reconfigurable resonance frequency.

3. CONCLUSION

In this paper, two reconfigurable dielectric resonator antennas are proposed. The first is an ultra-wideband DRA with a reconfigurable frequency notch. The induced band notch helps to limit interference to narrowband services operated inside the lower part of the UWB frequency range from 3.2 GHz to 5.1 GHz. This band rejection reconfigurability makes this antenna suitable for UWB applications and UWB Cognitive Radio systems, where interference avoidance is a key requirement. The second DRA has a resonance frequency that is reconfigurable between 3.6 and 4.3 GHz and is suitable for microwave applications and WiMAX applications. For both antennas, a DC stepper motor, placed below the substrate, is used to rotate the DR and change its position with respect to the excitation element.

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