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A DUAL BAND FREQUENCY AND PATTERN RECONFIGURABLE DIELECTRIC RESONATOR ANTENNA

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Abstract—A new approach to obtain frequency and pattern reconfiguration in Dielectric Resonator Antenna (DRA) has been proposed. The design consists of two identical aperture coupled DRAs separated by a distance of λ_0. A switchable feed based frequency reconfiguration is discussed in which the feed acts as an ideal switch. This design operates at two frequencies viz., 3.6 GHz and 5.2 GHz. These frequencies are independently tuned using trimmers. Further, the slot length of both the DRAs can be tuned independently using movable shorting pins driven by miniature motors. The shorting pins form a part of the ground plane. By varying the slot length of the DRA, the resonant frequency is controlled which in turn helps in gaining pattern reconfiguration. The structure has been designed for lower and middle band frequencies of WLAN, operating between 5.15–5.25 GHz and 5.25–5.35 GHz, respectively. These types of antennas can be employed in MIMO systems for increasing the capacity through Pattern diversity.

1. INTRODUCTION

The low loss and broadband operational requirements make DRA attractive. Compared to printed antennas, DRA offers better performance for millimeter wave applications [1]. The resonant frequency of the DRA is a function of shape, dimension and permittivity of the dielectric material. Although several shapes of DRAs exist, rectangular DRA is the most widely used since it offers multiple degrees of freedom and is easily fabricated [1]. DRAs have

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become an attractive option in recent years due to their very low losses leading to high radiation efficiencies and their ability to operate over very high frequencies by simply varying the dimensions and dielectric constant [1].

Reconfigurable antennas allow the reuse of the existing volume to operate at different frequency bands [2, 6], permit beam steering [2, 7, 13] and ability to change polarization [2, 8, 9]. Integrating DRA with reconfigurability is a promising technology for high performance wireless communication systems. These reconfigurable antennas can be employed on the transmitter side to overcome changing environmental conditions [2].

There are several feeding methods available to excite a DRA. One such approach is the aperture coupled feeding where in a microstrip line underneath the substrate excites the slot etched over the ground plane of the DRA [1]. Reconfiguration in printed antennas is well explored in literature but not in dielectric resonators though it offers very low losses, frequency stability, and high radiation efficiencies [4, 5]. Reconfiguration requires the change in the antenna dimension which is difficult in DRA as the Dielectric Resonator (DR) used is a single cube placed over the ground plane. In [10, 11], a multi feed based pattern reconfiguration in DRA has been described which makes use of several probe and variable phase excitation. In [12], a manual switch based pattern reconfiguration is discussed. This paper explores the possibility of using an electrical switchable feed based frequency and pattern reconfiguration which eliminates the need for several sources,

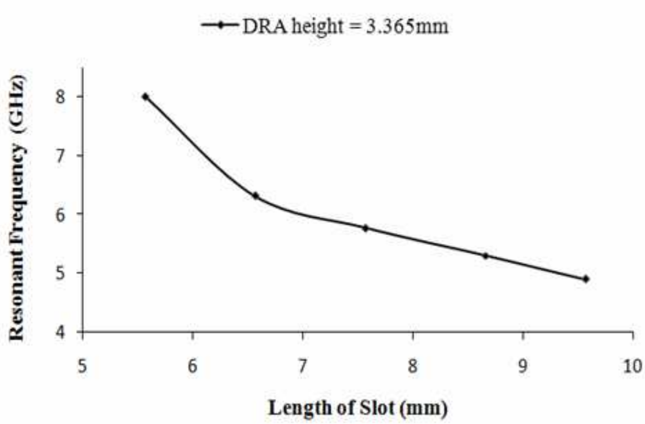


Figure 1. Effect of slot length on resonant frequency.

variable phase requirement and electronic switches.

The frequency selectivity in DRA is accomplished by varying the resonant modes of the slot underneath the DRA rather than varying the dimensions of the DR. The variation of resonant frequency with respect to the change in slot length for fixed DRA height is depicted in Figure 1. The length of the slot (L) corresponding to any DRA height (h) is given by,

$$L = 2h\sqrt{(\varepsilon_r/\varepsilon_{eff})} \tag{1}$$

2. DUAL BAND DR ANTENNA

A single-feed switchable feed network that combines two ports of a dielectric resonator antenna with a quarter wavelengths feed line is presented in this section. The schematic of the switchable feed is shown in Figure 2. The feed consists of two quarter wavelength branch lines with $Z_1 = Z_2 = 2Z_o$ impedance where $Z_o = 50\,\Omega$ and lengths of l_1 ($\approx 5\lambda_g/4$) and l_2 ($\approx 7\lambda_g/4$) operating for $f_1 = 3.6\,\text{GHz}$ and $f_2 = 5.2\,\text{GHz}$. These frequencies fall within IEEE 802.16 standard.

Two dielectric resonator antennas designed to operate at two frequencies are connected to output ports 2 and 3. The operation of the switchable feed can be explained as follows. If f_1 signal is fed into port 1, the DR antenna connected to port 3 will be at off-resonant; the impedance of the slot beneath the antenna is almost reactive ($Z_{L2} \approx jX$). Hence, the input impedance of the lower branch Z_{in2} is given by

$$Z_{in2} = Z_2\left\{Z_{L2} + jZ_2\tan(\beta_2 l_2)\right\}/\left\{Z_2 + jZ_{L2}\tan(\beta_2 l_2)\right\} = -jZ_2^2/X$$

If the input reactance $X \to 0$ then, $Z_{in2} \to \infty$ and hence DR connected to port 3 appears as an open circuit. Hence DR connected to Port 2 will be at resonant while DR connected to Port 3 will be off-resonant and vice versa.

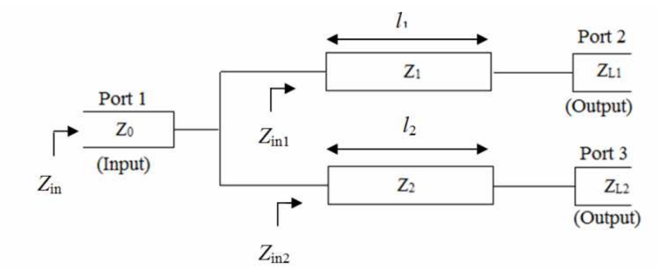


Figure 2. Schematic of a switchable feed.

The geometry of the proposed system is shown in Figure 3. Two identical dielectric resonators are constructed using ceramic material with a dielectric constant of 10 and a loss tangent of 0.0035. The DR is designed as in [1]. The volume of the resonator is $20.84 \times 20.84 \times 3.365\,\text{mm}^3$. The elements are spaced at a distance of $\lambda_{5.2}$. The DRA is constructed over FR4 substrate ($h = 1.6\,\text{mm}$, $\varepsilon_r = 4.3$ & $\tan\delta = 0.025$).

To this dual band model, variable capacitive tuning is provided

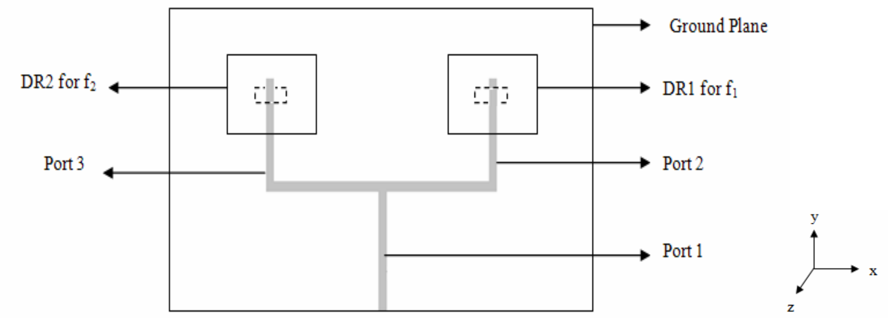


Figure 3. Proposed antenna geometry.

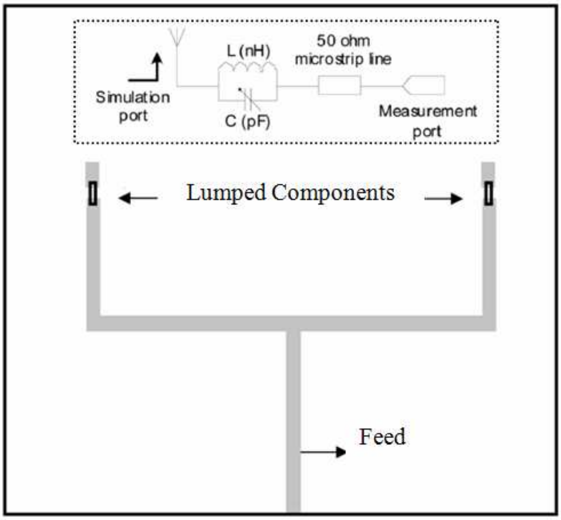


Figure 4. Schematic of capacitive loading.

using a trimmer. This tuning circuitry is placed beneath the proposed structure. The matching frequency of the dual band antenna is varied using the trimmer which can offer capacitance in the range of 0.4 pF through 1.5 pF. The model of trimmer being utilized is TZW4. By adjusting the trimmer, the matching frequency gets shifted from lower to higher frequencies as the capacitance decreases. The schematic of capacitive loading is shown in Figure 4.

The structure is designed and simulated using standard EM simulation software employing FIT (Finite Integration Method) to solve the EM fields of the proposed structure. Further, to ensure the correctness and convergence of the simulation results, simulation is performed by increasing the number of lines per wavelength.

3. RESULTS

The S_{11} characteristic of the simulated structure is depicted in Figure 5. From the results, it is evident that the antenna can operate for both f_1 and f_2 frequencies.

At 4.34 GHz, which is approximately a geometric mean of two operating frequencies, f_1 and f_2, the antenna shows weak resonance. To describe the resonant and off-resonant behavior of the antenna at frequencies f_1 and f_2, the surface current distribution is shown in Figure 6. The surface current is high in DR1 for f_1 and high in DR2 for f_2.

The E-plane co-polarization and cross polarization characteristics are depicted in Figures 7 and 8, respectively. From the results, a maximum co-polarization of 6 dBi is obtained for 3.6 GHz and 8 dBi for 5.2 GHz. In both of these configurations, the orthogonal polarization

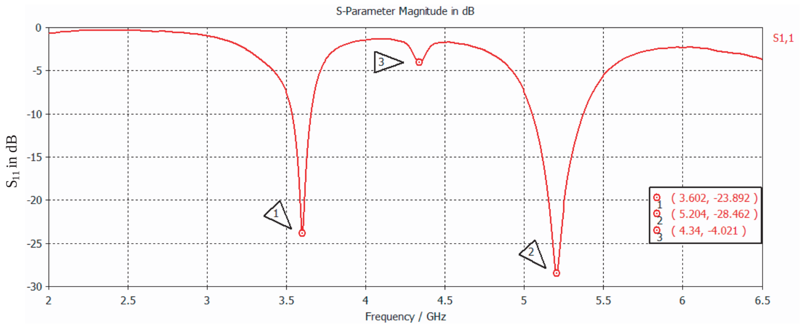


Figure 5. Impedance characteristics of dual band DR antenna.

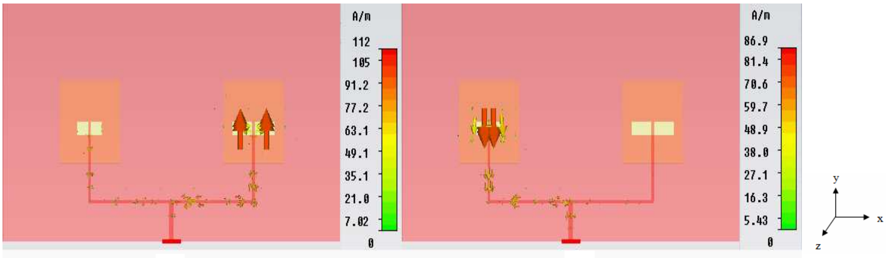


Figure 6. Surface current distribution at (a) 3.6 GHz, (b) 5.2 GHz.

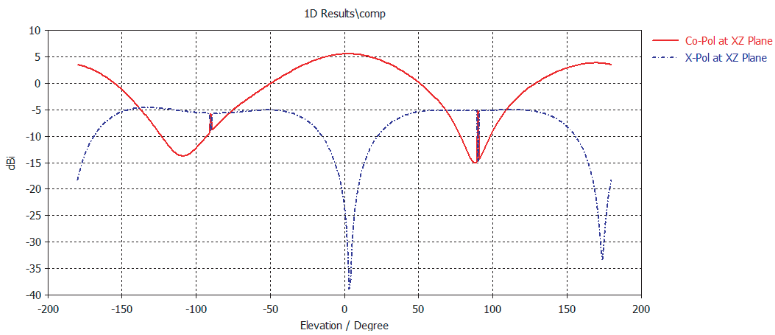


Figure 7. Co and cross polarization at 3.6 GHz.

is minimum, reducing the interference from adjacent DR.

The antenna configuration with trimmer circuitry and corresponding tuning is briefly described in the following Figure 9 and results are summarized.

From the simulated results, it is observed that independent tuning of DR1 can support a tuning range of 100 MHz (3.6 GHz to 3.7 GHz) while DR2 supports a tuning range of 280 MHz (5.2 GHz to 5.48 GHz) without any change in the bandwidth. Further from Figures 10 and 11, it can be seen that tuning one trimmer at one dielectric resonator does not disturb the other dielectric resonator.

4. PATTERN RECONFIGURATION

A two element reconfigurable DRA, simultaneously excited using aperture coupling is presented. The input power to the DRA is split equally using corporate feed. Unlike the previous configuration, here a frequency difference of 0.1 GHz is chosen between two DRs. The

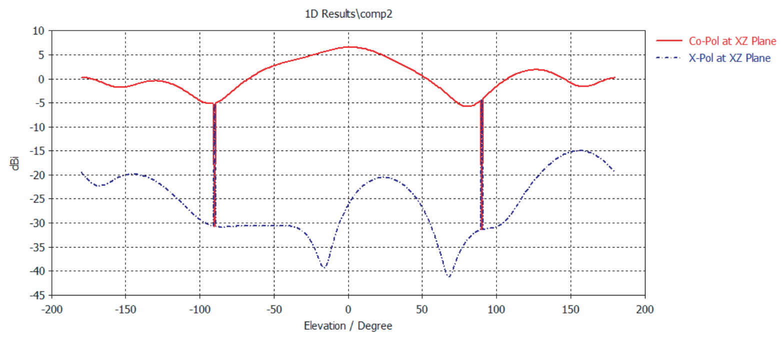


Figure 8. Co and cross polarization at 5.2 GHz.

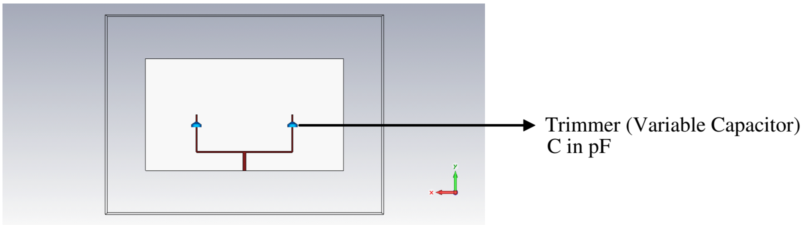


Figure 9. Feed with trimmer circuitry.

spacing between the two DRs is equal to λ_0 of the lowest frequency. The movable shorting pins placed within the slots are used to achieve both frequency and pattern reconfigurations. The ON state of the pin results in a long slot whereas the OFF state results in a short slot. The ON and OFF conditions of the shorting pin, driven using miniature motors, enable four possible configurations of the slot viz., Long-Long, Long-Short, Short-Long, Short-Short.

The Long-Long and Short-Short configurations result in shift in operating frequency; Long-Long results in operation around lower band of WLAN centered around 5.2 GHz; Short-Short configurations extend the operation to mid band of WLAN centered around 5.3 GHz. The radiation and polarization characteristics of the antenna remain the same.

Further the intermediate configurations, viz., Long-Short and Short-Long configurations, allow the operation at 5.25 GHz, along with pattern reconfiguration. The main lobe of the antenna is tilted to some angle about 12° for the proposed system without changing the operating frequency. A minimum of 3% bandwidth requirement is posted for all possible configurations.

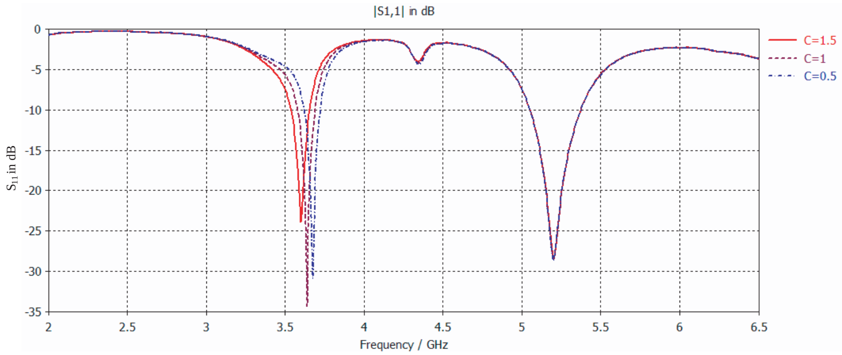


Figure 10. Tuning at DR1.

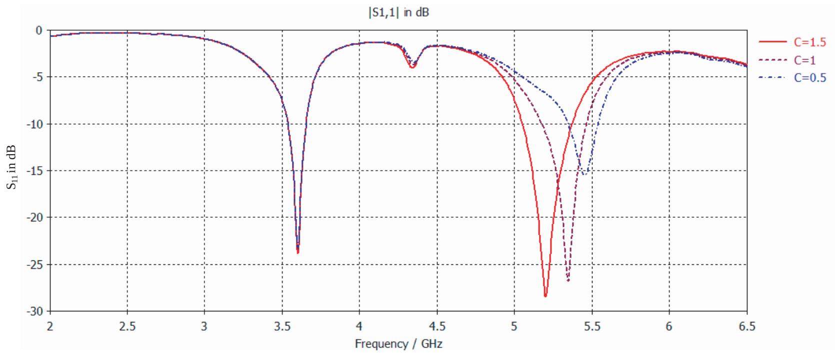


Figure 11. Tuning at DR2.

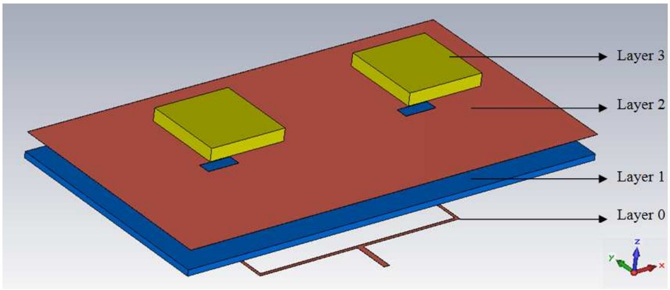


Figure 12. Proposed antenna geometry in layers. [Layer 0 — feed, Layer 1 — FR4 substrate, Layer 2 — ground plane with etched slots, Layer 3 — DR].

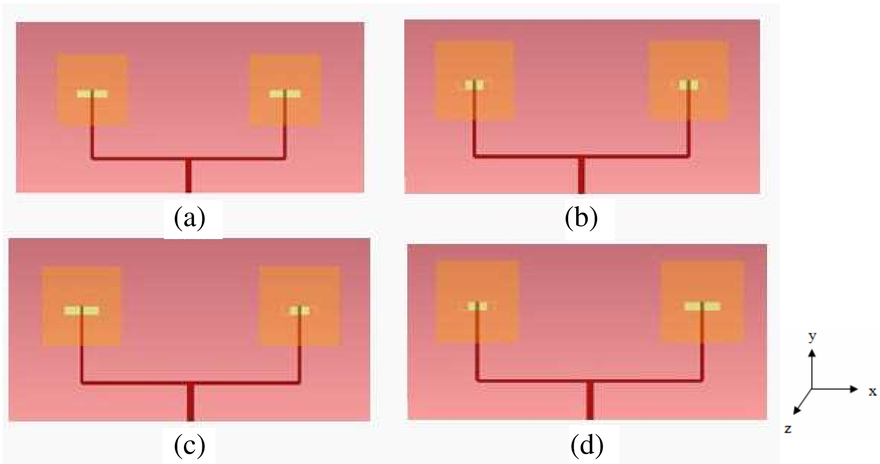


Figure 13. Various configurations of the slot, (a) Long-Long, (b) Short-Short, (c) Long-Short, (d) Short-Long.

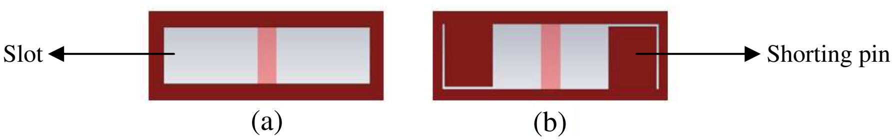


Figure 14. (a) OFF state, (b) ON state of the shorting pin.

5. ANTENNA DESIGN

The geometry of the proposed system is shown in Figure 12. Two identical dielectric resonators are constructed using Taconic CER material with a dielectric constant of 10 and a loss tangent of 0.0035. The DR is designed as per [1]. The volume of the resonator is $20.84 \times 20.84 \times 3.365\,\mathrm{mm}^3$. The elements are spaced at a distance of $\lambda_{5.2}$. The DRA is constructed over FR4 substrate ($h = 1.6\,\mathrm{mm}$, dielectric constant, $\varepsilon_r = 4.3$ and $\tan\delta = 0.025$). A Slot is etched on the ground plane sufficiently offset from the center of each DR to enhance coupling of energy from the feed to the DR. The possible configurations of the proposed system are depicted in Figure 13.

A miniature motor is activated which causes the shorting pin to move within the slot resulting in either a short slot or a long slot as depicted in Figure 14. The slot dimension for the proposed system is 9 mm which causes resonance at lower band of WLAN. Under the ON condition, the slot length is reduced to 5 mm which causes resonance at middle band of WLAN.

The antenna system is fed using a co-axial probe of 50 Ω. Thus Port 1 and Port 2 of the power divider have an impedance of $2Z_o$, equal to 100 Ω. The width of the microstrip feed line is designed accordingly using [3], and the length of the line equals the integral multiple of quarter wavelength. The length of the branch lines is 35 mm ($\approx 5\lambda_{5.2}/4$) and 34 mm ($\approx 5\lambda_{5.3}/4$) for frequencies f_1 and f_2, respectively.

The movement of the shorting pin is controlled using a miniature motor fixed besides the configuration. By varying the slot dimensions through the control circuitry, the length of the slot is varied, resulting in two configurations namely, Long-Long and Short-Short operating at lower and middle band frequencies, respectively. The Long-Long and Short-Short configurations enable frequency reconfiguration without changing the other operational characteristics of the antenna. The Short-Long and Long-Short configurations operate for a fixed frequency of 5.25 GHz and provide pattern reconfiguration. The results obtained for each configuration is detailed in the following section.

6. RESULTS

The impedance characteristics and VSWR characteristics are shown in Figures 15 and 16.

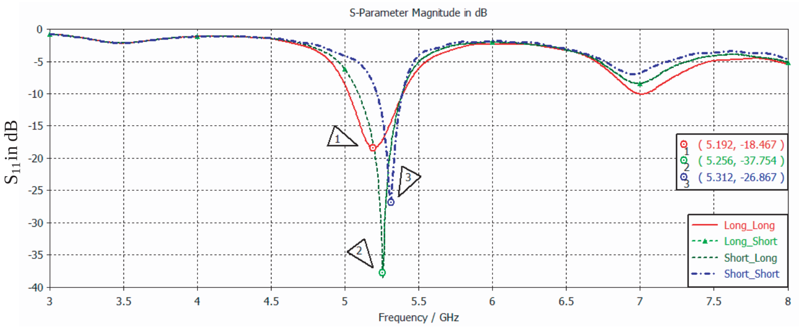


Figure 15. S_{11} characteristics of all four configurations.

6.1. Long-Long Configuration

The state of moving shorting pins in both DRs under OFF condition results in longer slots. The configuration supports a lower band

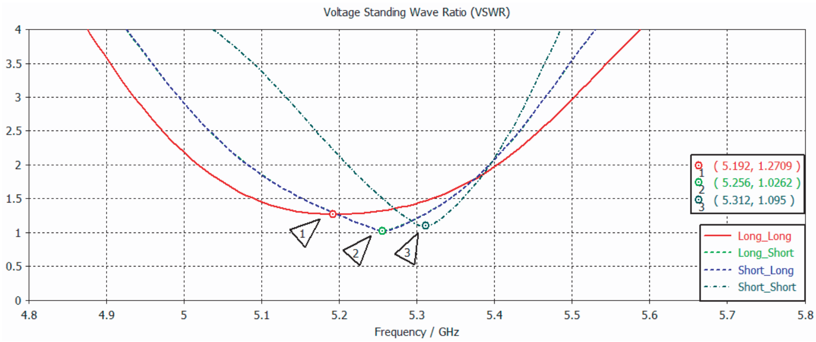
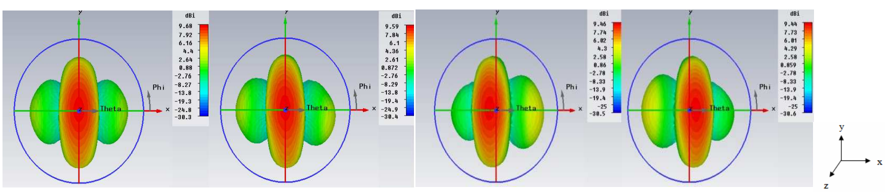


Figure 16. VSWR characteristics of all four configurations.



(a) (b) (c) (d)

Figure 17. 3D plot of far field characteristics, (a) Long-Long, (b) Short-Short, (c) Short-Long (d) Long-Short.

operation centered at 5.2 GHz. As shown in Figure 17(a), the radiation pattern is a narrow beam of HPBW of 28.1° without tilt in the main lobe. Also a bandwidth of 7.126% is realized. Directivity obtained is 9.7 dBi.

6.2. Short-Short Configuration

When the switch state changes from OFF to ON state, a shift in operating frequency is achieved, i.e., the frequency shifts from the lower band to the middle band of WLAN while maintaining the same polarization and radiation characteristics. The main lobe of the radiation pattern is oriented along 0° with an HPBW of 27.5° as shown in Figure 17(b). The resonant frequency is centered around 5.3 GHz. Because of the introduction of the shorting pin, the percentage bandwidth realized is 3.37%. Resultant directivity is 9.6 dBi. Thus this configuration results in frequency reconfiguration compared to Long-Long configuration.

6.3. Short-Long Configuration

The shorting pin state of first DR is ON, and second DR is OFF. The operating frequency shifts to 5.25 GHz which is a geometric mean of the lower band and middle band of WLAN. Change in the direction of radiation pattern is a major characteristic of this configuration. The main lobe gets tilted by 6° towards Left Hand (LH) side and hence Left Hand polarized as shown in Figure 17(c). The directivity is about 9.5 dBi, and 5.56% of bandwidth is supported by this configuration.

6.4. Long-Short Configuration

This configuration is a replica of the previous configuration. The shorting pin state of first DR is OFF, and second DR is ON. The frequency of operation remains same at 5.25 GHz. But, the main lobe is tilted by an angle of 6° towards Right Hand (RH) and hence Right Hand polarized as depicted in Figure 17(d). The directivity is about 9.5 dBi and bandwidth of 5.56%. Thus a total of 12° is achieved using Short-Long and Long-Short configurations.

In summary, beam tilting can be achieved with Long-Short and Short-Long configurations as shown in Figure 17. The main beam tilt can be increased by increasing the frequency difference between two independent DR antennas. Figure 18 depicts the maximum tilt that can be achieved in Long-Short configuration. Within WLAN band, a maximum of 19° tilt along RH side is achieved. Together with Short-Long configuration, a total of 38° tilt in the main lobe is possible. A comparison for the proposed antenna with possible configurations is listed in Table 1.

Table 1. Comparison of system performance.

Parameters	Configurations			
	L-L	L-S	S-L	S-S
Frequency (GHz)	5.2	5.25	5.25	5.3
−10 dB BW (MHz)	370.0	292.1	292.1	178.8
% BW	7.13	5.56	5.56	3.37
$S_{11\,\mathrm{min}}$ (dB)	−18.5	−37.8	−38.6	−26.9
Directivity (dBi)	9.7	9.5	9.4	9.6
Radiation η (%)	87.6	84.6	84.6	80.2
−3 dB Beam width	28.1°	28.3°	28.2°	27.5°
Main lobe direction	0°	$6^{\circ(\mathrm{RH})}$	$6^{\circ(\mathrm{LH})}$	0°

L-Long S-Short

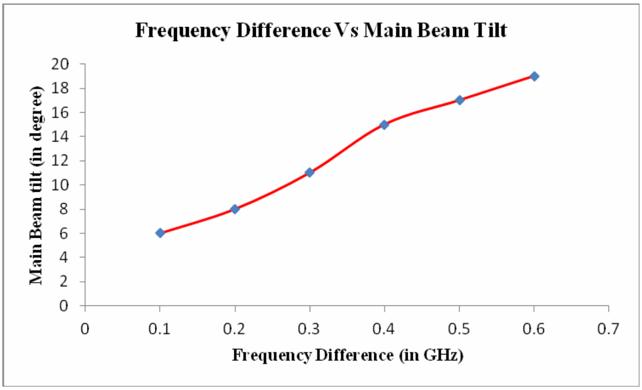


Figure 18. Maximum tilt obtained within WLAN band for long-short configuration. (Minimum frequency: 5.2 GHz and maximum frequency: 5.8 GHz).

The advantages and pitfalls associated with this approach are discussed in detail below.

- When compared to other conventionally available reconfigurable antennas, the one described above overcomes the need for using active elements like PIN diode, FET, etc., which requires a separate DC bias line. Thus the design becomes simpler.
- The movable shorting pin forms a part of the ground plane. Thus fabrication is complex.

7. CONCLUSION

In this paper, a dual band dielectric resonator antenna is proposed. To this proposed antenna, two methods for achieving frequency and pattern reconfiguration are suggested making use of variable capacitor and movable shorting pins. In the shorting PIN based model, for a fixed frequency of 5.25 GHz, the pattern can be tilted to 6° on both sides and hence a 12° shift in pattern is possible. By increasing the frequency difference, a maximum of 38° tilt in pattern can be obtained. As a future scope, the trimmer circuit may be replaced by a voltage variable capacitor for wide tuning range.

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