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## **Dual Segment S-Shaped Aperture-Coupled Cylindrical Dielectric Resonator Antenna for X-Band Applications.**

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## **Dual Segment S-Shaped Aperture-Coupled Cylindrical Dielectric Resonator Antenna for X-Band Applications**

A. H. Majeed, A. S. Abdullah, F. Elmegri, K. H. Sayidmarie, R. A. Abd-Alhameed and J. M. Noras

**Abstract**—A new low-cost dual-segmented dielectric resonator (DR) antenna design is proposed for wideband applications in the X-band region. Two DRs coupled to an S-shaped slot introduce interesting features. The antenna performance was characterized in terms of the reflection coefficient, gain, and radiation pattern, and detailed simulation studies indicate excellent antenna performance from 7.66 GHz to 11.2 GHz (37.5% fractional bandwidth) with a maximum gain of 6.0 dBi at 10.6 GHz while the fabricated prototype has a matched bandwidth from 7.8 GHz to 11.85 GHz (41% fractional bandwidth) and maximum gain of 6dB<sub>i</sub>. The antenna is compact, size 1 x 0.83 x 0.327 time the wavelength at 10 GHz. The two DR segments may be located on the same side or on opposite sides of the substrate, giving respectively improved gain or more uniform field patterns. Experimental testing of the prototype performance showed reasonable agreement with the predicted performance.

**Index Terms**—Dual segment DRA, S-shaped slot coupling, L-shaped feed line, HEM<sub>118</sub> mode, X-band.

### **I. INTRODUCTION**

Dielectric Resonator Antennas (DRAs) have been extensively studied due to their beneficial characteristics: high radiation efficiency, low weight, and small size resulting from the high permittivity of the DR material. One fundamental difference between a dielectric resonator antenna (DRA) and a conventional radiator is that the main loss in the DRA is dielectric loss, and

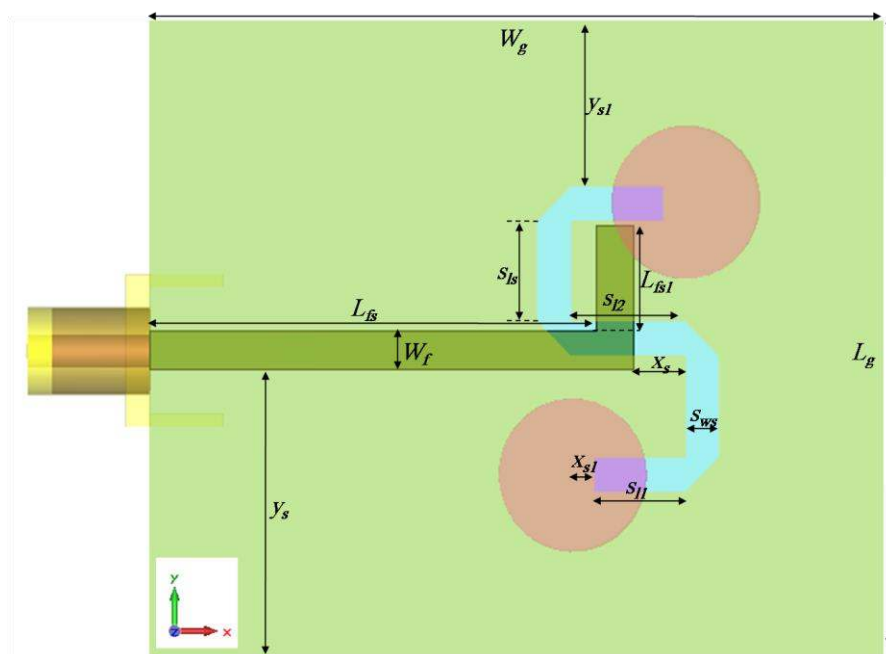
with modern ceramic materials this loss can be made very low [1, 2]. The loss can also remain very small for high permittivity ceramics, so there is not the same penalty for miniaturization that one would expect with metal, or metalized, radiators. Nevertheless, DRAs are still believed to be subject to the fundamental size/shape/bandwidth trade-off [3-16].

The various techniques that have been utilized to obtain larger bandwidths are monopole geometries [4], DRs with multiple segments of different permittivities [5, 6], and DRs using composite shapes such as the letters H, P or asymmetrical T [7, 8 9], and a cylinder with a bowtie-shaped base [10]. While such shapes are tailored in the design stage to give higher bandwidths, designs using DRs of conventional shapes are still competing. A microstrip-fed stepped patch with an intermediate substrate has also been used to increase the bandwidth [11]. The use of dual segments DRs of different permittivities fed by the same line has shown improved bandwidth [12, 15]. Moreover, it has been shown recently that dual similar dielectric resonators (DRs) placed asymmetrically with respect to the feeding aperture can give an increase in the bandwidth as well as offering more design flexibility [3, 16].

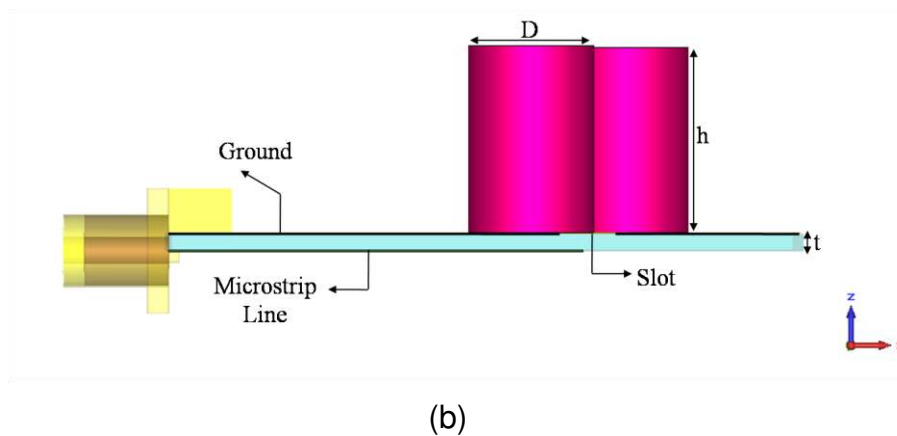
In this paper, a new dual-segmented dielectric resonator antenna with internal S-shaped slot coupling is proposed for use in X-band communications. Most published papers have used short slots (of length comparable to the diameter of the DR) while this design introduces a much longer slot. The folding of the slot into an S shape offers long electrical length at compact size and utilizes its capability of resonating at multiples of the fundamental frequency. The slots used formerly are non-resonating since they are short (less than half the guide wavelength). The bandwidth of the proposed design is thus enhanced by introducing multi-resonant elements such as the S-shaped slot and its coupling structure in addition to the two separated DRs. The design procedure uses several design rules, with analysis and optimization being carried out using CST Microwave Studio [17]. The realization also exploits some well-known techniques developed for physically small, low profile, mobile handset and terminal antenna designs.

## II. ANTENNA LAYOUT AND CONSTRUCTION

The general layout of the DRA assembly is given in Figure 1, with two identical dielectric resonators mounted on a 30 mm × 25 mm substrate-backed ground plane. The resonators are 6 mm (D) × 9 mm (h) cylindrical posts from Dynamic-Ceramic Ltd, Dynalox Al<sub>2</sub>O<sub>3</sub> (99.7% purity, with  $\epsilon_{dr} = 9.4$  and  $\tan \delta = 0.00045$ ), and the substrate is an FR4 ( $\epsilon_{subs} = 4.5$ ,  $\tan \delta = 0.002$ ) of thickness  $t = 0.8$  mm. The antenna thus has a compact size of 1 × 0.83 × 0.327 of the wavelength at 10 GHz frequency. The two DRs are excited by the electric field lines at the outer segments of the S-shaped slot. The excitation is in the dual HEM<sub>110</sub> mode, for which the structure parameters and resonance frequency are related through the curve-fitted equation:



(a)



**Fig. 1:** Schematic diagram for the dual segment S-shaped aperture coupled cylindrical dielectric resonator antenna: (a) top view and (b) side view, with structural parameters.

$$f \text{ (GHz)} = \frac{30}{2\pi a \epsilon_{dr}^{0.42}} (1.6 + 0.513z + 1.392z^2 - 0.575z^3 + 0.088z^4) \quad (1)$$

where  $a = D/2$  (cm) and  $z = a/h$  [1, 13]. This equation can give accurate predictions of the resonance frequency for a wide range of materials and  $0.1 < z < 2.5$  [1].

The antenna assembly is excited using an L-shaped microstrip line that is coupled to an S-shaped slot. The feed line dimensions were  $L_f = 19.5$  mm,  $L_{f1} = 4.2$  mm, and  $W_f = 1.5$  mm, as calculated using the standard formulae [18]. The internal coupling mechanism into the two DR resonators is provided through the S-shaped slot. This configuration serves to influence the resonant structure, and the amount of undesired radiation in the backward direction. It also acts to control the coupling between the radiator and the feed.

### III. THE S-SHAPED SLOT

Most published papers have used short slots of lengths comparable to the diameter of the DR, where rectangular, elliptical, and I-shaped slots were employed. These short slots are non-

resonating. The slot used here is much longer, and thus resonance can occur at more than one frequency across the band of operation. As shown in Fig. 1 the slot length  $S_L$  can be given by:

$$S_L = 2*S_{l1} + 2* S_l + S_{l2} + 4*L_b \quad (2)$$

where  $L_b$  is the length of each of the four bevelled  $90^\circ$  bends. At resonance, the slot length  $S_L$  is equal to  $N$  multiples of half the guided wavelength  $\lambda_g$  i.e.:

$$S_L = N\lambda_g / 2 = \frac{N\lambda_0}{2\sqrt{\epsilon_e}} \quad (3)$$

$$\epsilon_e \approx \frac{\epsilon_{subs} + 1}{2} \quad (4)$$

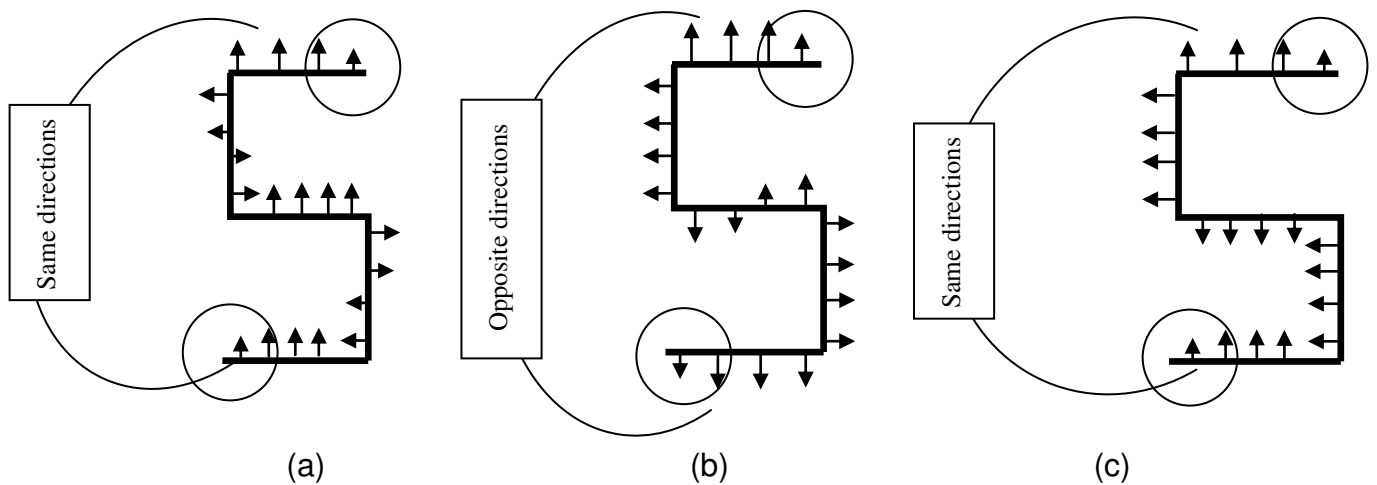
where  $\epsilon_{subs}$  and  $\epsilon_e$  are the permittivities of the substrate and the effective permittivity in the slot respectively, and  $\lambda_0$  is the free-space wavelength. Thus, the resonance frequency  $f$  is given by:

$$f = \frac{Nc}{S_L\sqrt{2(\epsilon_{subs} + 1)}} \quad (5)$$

where  $c$  is the speed of light. Equation 5 can be used either to estimate the resonance frequencies of the slot or to find the proper slot length at a given resonance frequency. The accuracy of this equation depends on the accuracy of estimating the effective permittivity given by equation 4, as well as on proper accounting for the four bevelled  $90^\circ$  bends of the S-shaped slot. The placement of the two DRs on the outer segments of the S-shaped slot pulls more E-field lines from the slot towards the DR, since the DR has larger permittivity compared to that of the substrate. Therefore, the effective permittivity in the whole slot will be slightly higher, which leads to a slightly lower resonance frequency than that predicted by equation 5, which was derived assuming that there were no DRs.

Another interesting feature of the S-slot can be illustrated by looking at the electric field lines across the slot, as shown in Figure 2. Three cases - one at the fundamental resonance frequency  $f_1$  and the two at the next modes  $f_2$  and  $f_3$  (i.e. at slot lengths of 0.5, 1, and 1.5 of the guide

wavelength) are shown. It can be seen from the figure that the E-field lines at the outer segments of the slot (under the two DRs) are in the same direction at the fundamental frequency  $f_1$ , and its third harmonic  $3f_1$  (i.e. when  $S_L = \lambda_g/2$ , and  $1.5 \lambda_g$ ) and hence the two DRs are excited in phase. However, when  $N=2$  (i.e.  $S_L = \lambda_g$ ) the E-field lines will be in opposite directions, and the two DRs are excited in out-of-phase fashion. For the dimensions shown in Table 1 and the FR4 substrate used, it can be shown (from equation 5) that the fundamental resonance frequency of the slot is  $f_1 = 3.768$  GHz, and the next frequencies are 7.536 GHz and 11.304 GHz.



**Fig. 2:** Schematic illustration of the electric field distributions along the S-shaped slot for various operating frequencies; (a)  $SL=1.5\lambda_g$ , (b)  $SL=\lambda_g$ , (c)  $SL=0.5\lambda_g$ .

**Table 1:** Detailed dimensions (in mm) for the proposed antenna

$W_g$	$L_g$	$D$	$h$	$L_f$	$L_{f1}$	$y$	$W_f$	$s_{l2}$	$y_1$	$x_1$
25	30	6	9	19.5	4.2	11.25	1.5	4.5	6.5	0.9

#### IV. SIMULATION AND PARAMETRIC ANALYSIS



A detailed model of the antenna performance is constructed using CST Microwave Studio. Systematic parameter sweeps are made on each of the principal structure parameters governing the S-shaped slot coupling in turn, while the others are held constant; see Table 1. The antenna performance is initially characterized in terms of the reflection coefficient as illustrated in Figures 3 (a to d). The effects of the various design parameters on the reflection coefficient response are discussed in the following.

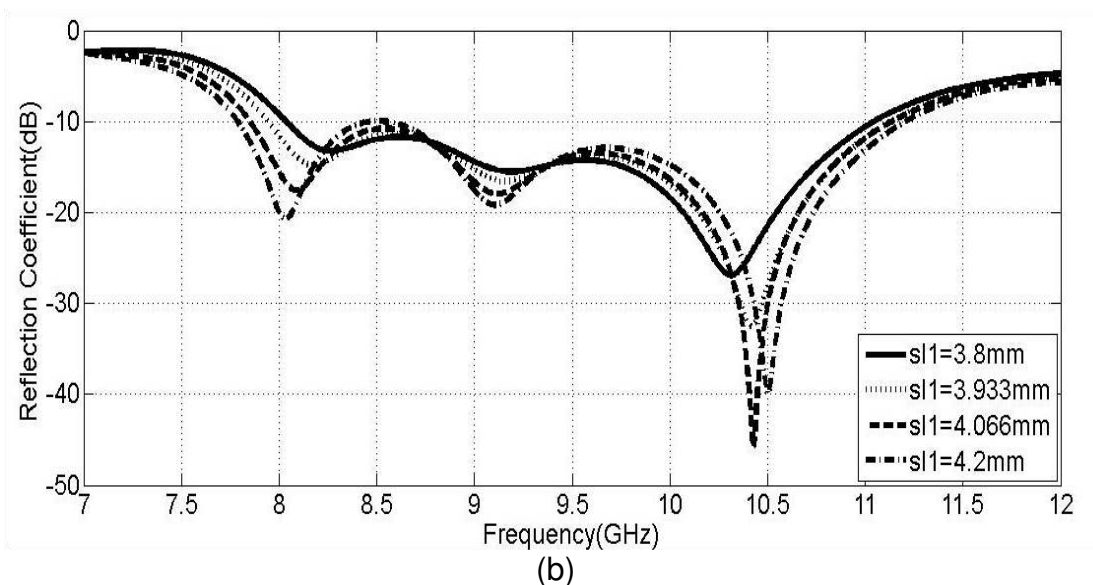
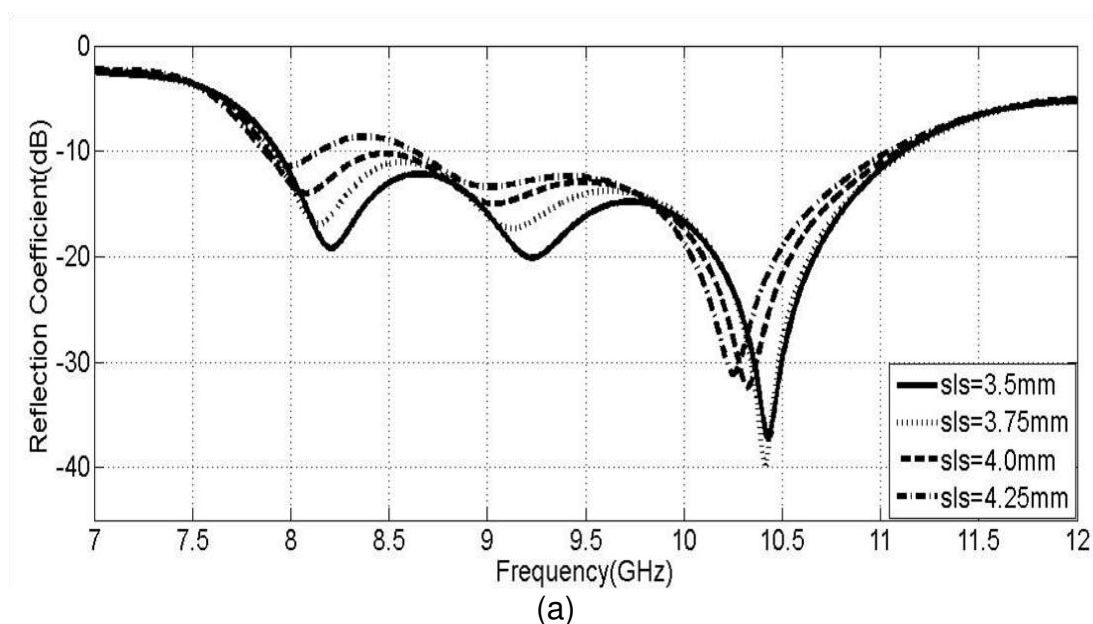
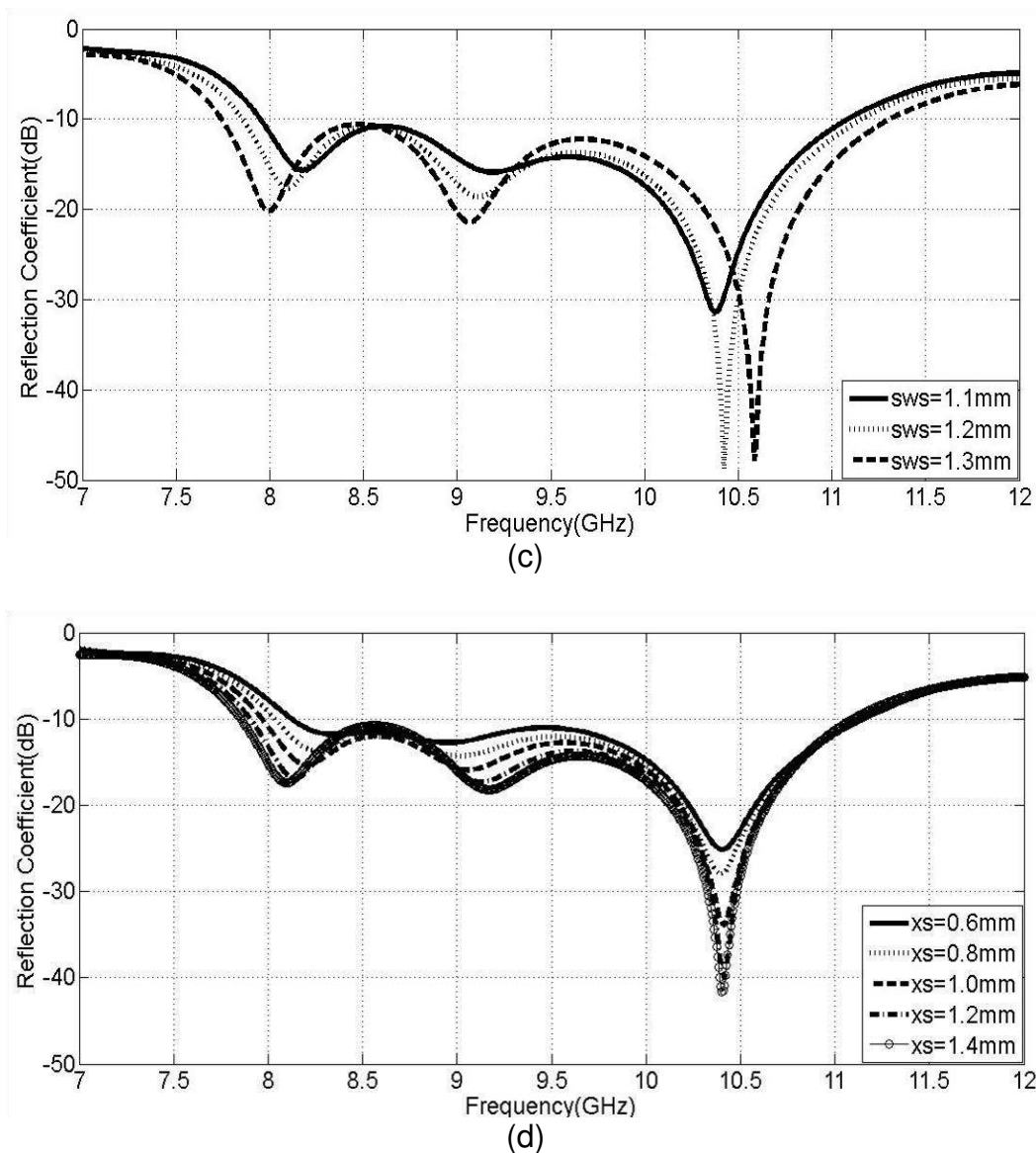


Figure 3

Figure 3 cont.



**Fig. 3:** Simulated reflection coefficients versus frequency for different:

- (a) vertical slot lengths  $s_i$ ;
- (b) horizontal slot lengths of the two slot ends  $s_{l1}$ ;
- (c) slot widths  $s_w$ ;
- (d) position of S-slot along feeding line  $x_s$ ;

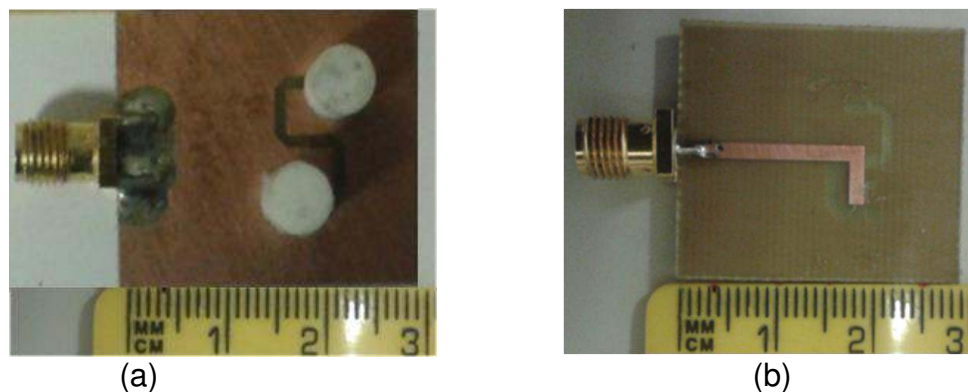
Figure 3a shows the variation in the reflection coefficient ( $S_{11}$ ) with frequency for various vertical slot lengths,  $s_{vs}$ , with  $s_{hl} = 3.5$  mm,  $s_w = 1.1$  mm, and  $x = 1.5$  mm. As the vertical slot length increases, the three resonance frequencies decrease, while the bandwidth and matching change. The optimal value for the vertical slot length appears to be 3.75 mm, as can be seen from the wider impedance bandwidth and minimum reflection coefficient across the frequency range. Figure 3b shows the variation of the reflection coefficient with frequency for different values of the horizontal slot length,  $s_{hl}$ , with  $s_{vs} = 3.75$  mm,  $s_w = 1.1$  mm, and  $x = 1.5$  mm. It can be seen that the three resonant frequencies change in different ways and impedance bandwidth decrease with reducing values of  $s_{hl}$ , and the optimal value for  $s_{hl}$  is 4 mm. Figure 3c shows the variation of the reflection coefficient with slot width,  $s_{ws}$ , with  $s_l = 3.75$  mm,  $s_{hl} = 4.0$  mm, and  $x = 1.5$  mm. The primary effect is on the reflection coefficient, and a slight change in the impedance bandwidth can be observed on the upper band-edge. The optimal slot width appears to be 1.2 mm. Figure 3d monitors the effect of the relative positioning of the S-slot with respect to the feed line on the reflection coefficient, this is the  $x_s$  parameter in Figure 1 (in this case  $s_l = 3.75$  mm,  $s_{hl} = 4.0$  mm and  $s_w = 1.2$  mm). The lower resonance frequency is more affected by the variation, while at the other two resonance frequencies the effect is mainly on matching. The optimum position is given by  $x_s = 1.2$  mm.

Figure 3 shows that there are three resonance frequencies around 8 GHz, 9 GHz, and 10.5 GHz. The first feature of the reflection coefficient results shown in Figure 3 is the large dip at about 10.5 GHz, which indicates best matching. The good matching at this frequency is due to two factors. First, for the DR used, equation 1 estimates a resonance frequency of 10.695 GHz. Referring to section III, it can be seen that the slot resonates in the third harmonic at 11.304 GHz

as estimated by equation 5. Thus the combined effects of the above two factors have resulted in the deep dip at around 10.5 GHz. The second feature of the reflection coefficient results shown in Figure 3 is the large value of  $S_{11}$  (high mismatch) for the 7.0-7.5 GHz range of frequencies. The analysis of section III predicts that there is out-of-phase excitation for the two DRs at a frequency of 7.536 GHz where the slot resonates at the  $\lambda_g$  mode.

**Table 2:** Optimum dimensions (in mm) for the prototype antenna assembly.

$W_g$	$L_g$	$D$	$h$	$L_f$	$W_f$	$L_{f1}$	$x_1$	$y$	$s_l$	$s_{l1}$	$s_{l2}$	$X_s$	$y_1$	$s_w$
30	25	6	9	19.5	1.5	4.2	0.9	11.25	3.75	4.0	4.5	1.2	6.5	1.2

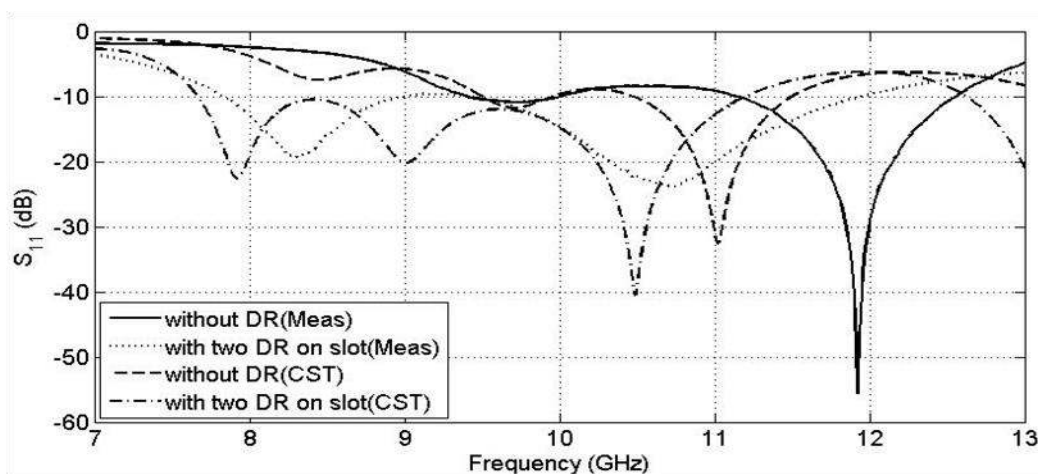


**Fig. 4:** Photographs of the prototype antenna, (a) front view (b) back view

## V. PROTOTYPE MEASUREMENTS

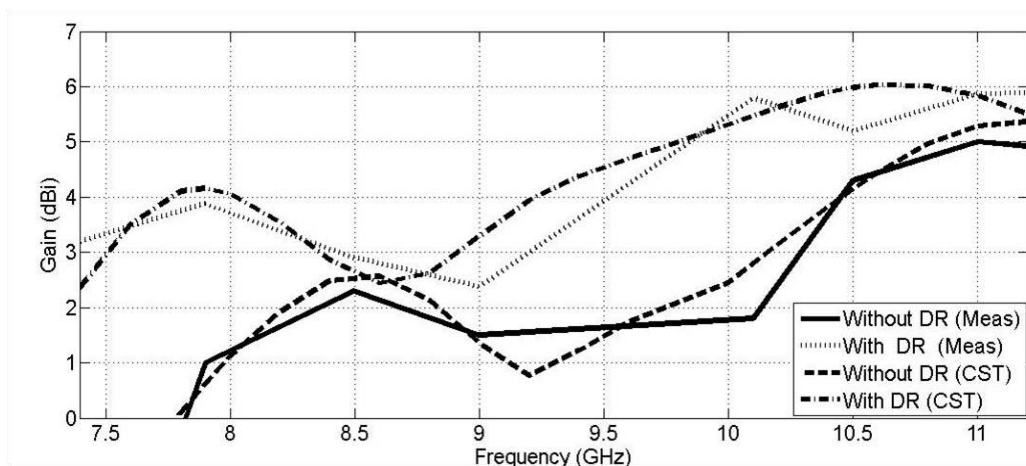
A prototype DRA assembly was constructed using the parameter values derived from the previous section, and these are listed in Table 2. Front and back views of the prototype are shown in Figure 4. The reflection coefficient was measured using a vector network analyser (HP8510C) and results for antenna assemblies with and without DR posts present are

summarized in Figure 5, alongside the corresponding simulation data. When there are no resonant posts on the slot side, the measured impedance bandwidth, for  $S_{11} \leq -10$  dB, is extended from 11.2 GHz to 12.6 GHz, i.e. the fractional impedance bandwidth is 11%. This frequency range confirms the 3<sup>rd</sup> mode resonance of the slot of 11.304 GHz. Introduction of two DR posts on the slot side produces a bandwidth from 7.8 GHz to 11.85 GHz, a fractional bandwidth of 41%. In the simulation, the corresponding values were found to be 9.0% and 37.5%. The addition of the DR posts improves the reflection coefficient and impedance bandwidth. The simulated and measured data show multiple resonances, which can account for this extended wide bandwidth performance. Results measured without the two DRs show good agreement with the simulation results. However, the deep null occurs at 11.91 GHz and 11.062 GHz for the measured and CST results respectively. This resonance frequency corresponds to a slot resonance at  $1.5 \lambda_g$  (11.304 GHz) that was predicted by equation 5, and the prediction errors were found to be 5.4% and -2.1% respectively. With the two DRs the right dip occurs at 10.5 GHz and 10.7 GHz for the simulation and measured results respectively, which are lower than the value predicted by equation 1 by only 1.8% and 0.5% respectively.



**Fig. 5:** Simulated and measured reflection coefficients vs. frequency for the antenna

Figure 6 compares the simulated and measured gain in the broadside direction for the same configurations as above. Good agreements between the measurement and simulation results are noticed both with and without the DRs. The maximum simulated gain with no DR present is 5.3 dB<sub>i</sub> at 11.2 GHz, and with the two DR posts mounted on the slot side it is 6.0 dB<sub>i</sub> at 10.6 GHz. The corresponding measurements are 5 dB<sub>i</sub> at 11.2 GHz and 6.0 dB<sub>i</sub> at 10.6 GHz, respectively. On average, these measurement results are consistent with the values predicted from the parametric modelling. It can also be seen that there is an improvement of approximately 4 dB in the gain across the operational band. This improvement in gain is attributed to the use of the two DR posts, which are fed in phase.



**Fig. 6:** Comparison of simulated and measured antenna gains for the proposed antenna

Desirable design features like high gain, wide radiation pattern, and large bandwidth cannot be achieved easily at the same time. An application may not require all of these desirable features. While [10] and [11] have achieved fractional bandwidths of 50% and 49.4% respectively, and gains of 4 dB to 7 dB, in [11] the two antennas have large sizes, compared to the proposed antenna, due to their large ground planes: a large ground plane increases the front/back ratio of the radiation pattern and enhances the gain. Although higher gains of 5 dB<sub>i</sub> to 7 dB<sub>i</sub> were

achieved in [19, 20] using only single DRA geometries, the proposed antenna with two DRs has 41% bandwidth compared to 3.6% in [19] and 26.8% in [20]. Moreover, the proposed antenna offers much more uniform radiation patterns and smaller size. Further comparison with the published works is presented in Table 3. While some complex shapes are tailored in the design stage to give the desired high bandwidths, designs using readily available DRs of conventional shapes are still competitive. It can be seen that the proposed antenna does have competing gain and bandwidth, while at the same time it has the second smallest size (1 x 0.83 x 0.327 of the wavelength at 10 GHz frequency) among the listed antennas.

**Table 3:** Comparison of the proposed antenna characteristics with those of published works.

Ref.	DR type	Center frequency (GHz)	%BW	Gain (dBi)	Antenna size (mm <sup>3</sup> )
7	H-shaped DR, $\epsilon_r=9.8$	5.23	62	N.A.	55×60×13.5
8	P-shaped DR, $\epsilon_r=10.2$	5.85	80	3.4 - 4.2	17×35×6.7
9	Asymmetrical T-shaped DR, $\epsilon_r=9.8$	6.1	75.1	3.24-7.35	60×60×13.6
10	Rectangle $\epsilon_r=10.2$	10.16	50	N.A.	40×52×4.61
11	Cylinder with bowtie base $\epsilon_r=9.8$	5.569	49.4	4 - 7	60×60×13.5
12	Rectangle, two segments	5.39	76.8	0 - 1	50×50×13
19	Circular disk $\epsilon_r=82$	4.18	3.6	5	140×150×2.8
20	Cylinder $\epsilon_r=12$	10	23.7	6 - 7	80×80×9.8
This work,	Two cylinders, $\epsilon_r=9.4$	9.6	41	4 - 6	25×30×9.8

The other feature that can be concluded from Figure 6 is that the antenna gain drops drastically for frequencies below 7.5 GHz for the case without DRs and 7 GHz with DRs. This

drop is caused by the fact that at a frequency of  $2f_1 = 7.536$  GHz, the E-field lines under the two DRs are in opposite directions (see Fig. 2b) leading to out-of-phase excitation of the DRs. The net effect is a null or reduced radiation in the broadside direction. Even without the two DRs, the segments of the slot have E-field lines that are in opposite directions, causing a reduction in the power radiated from the slot and hence small gain.

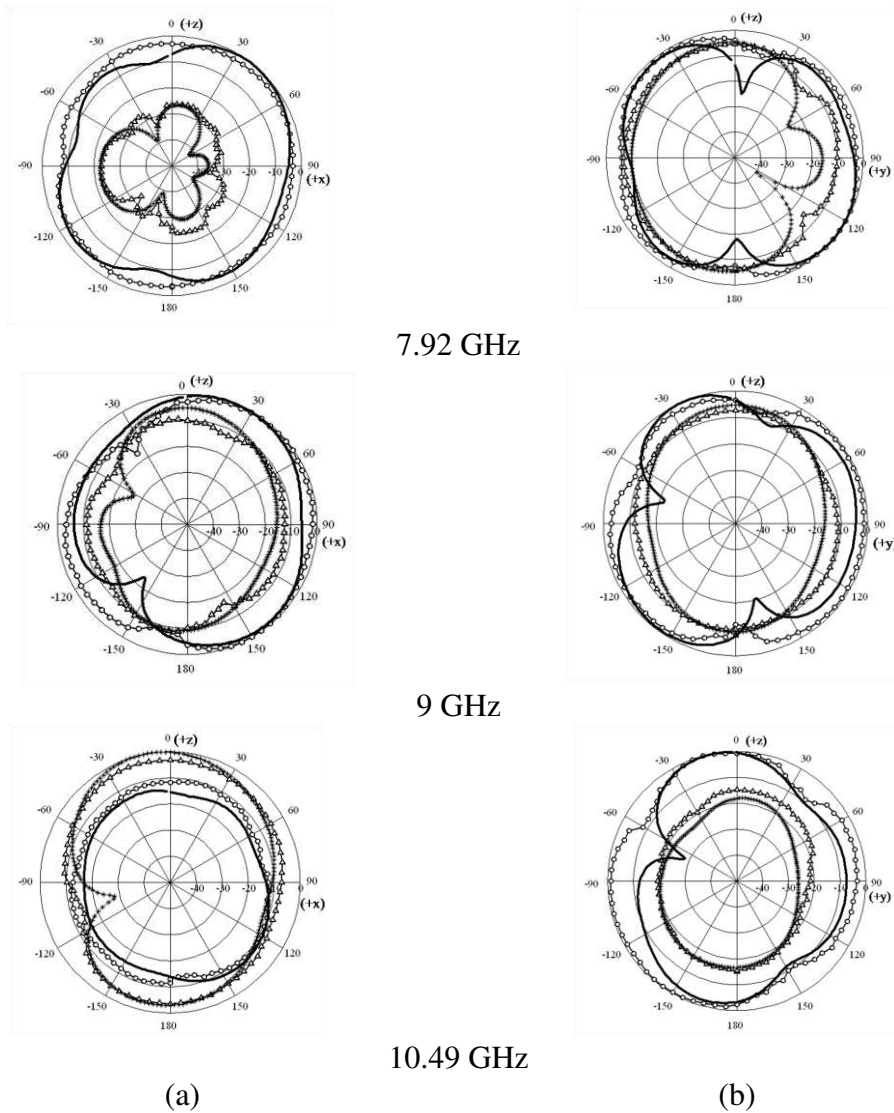
The far-field radiation patterns of the prototype antenna were measured in an anechoic chamber using an elevation-over-azimuth positioner, with the elevation axis coincident with the polar axis  $\theta=0^\circ$  of the antenna-under-test (AUT) coordinate system. The reference antenna was a broadband horn (EMCO type 3115) positioned 3.5 m from the AUT. Two pattern cuts (i.e. the xz and yz planes) were taken at three selected operating frequencies (7.92 GHz, 9.00 GHz, and 10.49 GHz), covering the complete designated bandwidth. The simulated and measured radiation patterns are compared in Figure 7. The patterns show fairly uniform variation in the xz and yz planes, with some ripples that increase at higher frequencies. The patterns look slightly unsymmetrical due to the asymmetry in the layout of the slot and feed line. The cross-polar patterns are low in the xz-plane at lower frequency but relatively high at upper frequencies. The relatively high level of the cross-polar radiation may be caused by the slot being twisted into an S-shape. Although there are two radiating DRs in the yz-plane, the array feature does not appear as the two elements are separated by 0.35 wavelengths at 10.49 GHz frequency. The computed radiation patterns are in reasonable agreement and are consistent with the measurements.

## VI. MAGNITUDES OF ELECTRIC AND MAGNETIC FIELDS

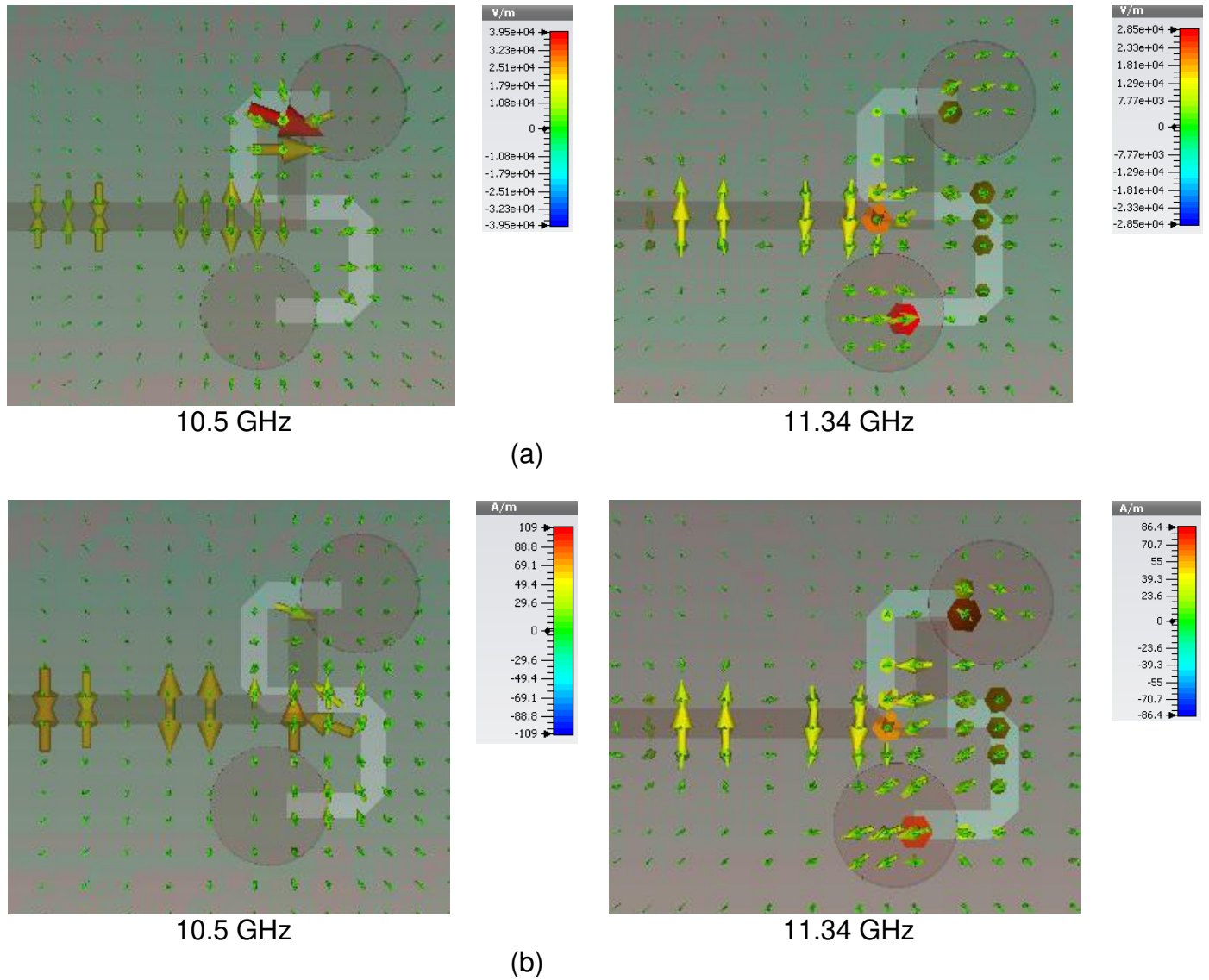
The magnitude variations in the electric and magnetic fields were calculated in the simulation for the optimized antenna model at frequencies of 10.5 GHz, and 11.34 GHz. The E-field and H-field distributions were calculated across the xy-plane that is passing through 1 mm below the upper base of the cylindrical DRs (i.e. at  $z = 8$  mm) and displayed in Figure 8. At a frequency of 10.5 GHz, the E-field and H-field lines are orthogonal, and both are parallel to the cylindrical DR



base. These features are consistent with those of the  $HEM_{110}$  mode [1, 13], whose frequency was predicted by equation 1. Away from resonance frequency (i.e. at 11.34 GHz) the E-field lines are perpendicular to the DR base, while the magnetic field lines are parallel to the base of the DR.



**Fig. 7:** Far-field radiation patterns at (a) xz-plane and (b) yz-plane;  $E_\theta$  Meas. (solid-circles),  $E_\phi$  Meas. (triangle),  $E_\theta$  CST (solid) and  $E_\phi$  CST (solid-\*).



**Fig. 8:** Distributions of the magnitudes of Electric and Magnetic fields of the dual segment antenna across the xy-plane passing at 1 mm below the upper base of the DRs (at  $z = 8$  mm) calculated at 10.5 GHz and 11.34 GHz; (a) Electric fields, (b) Magnetic fields.

Further assessment of the above field distributions shows that the maximum of the E-field is  $3.95 \times 10^4$  V/m at the 10.5GHz resonance frequency of the DR, while it is  $2.86 \times 10^4$  V/m at 11.34 GHz, the slot resonance. The maximum of the E-field at the DR resonance is 1.38 times that found at the slot resonance frequency. The 1.38 magnitude ratio corresponds to a frequency ratio of only 1.08.

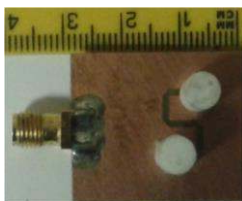
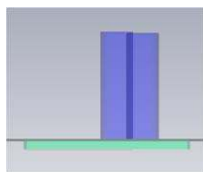
The corresponding ratio for the magnetic field intensities is 1.27. These high peaking in the E-field and H-field responses are usually attributed to a resonance process. These findings are in line with the prediction of the base mode frequency (10.695 GHz) predicted from equation (1), where the dominant mode at this frequency is the  $HEM_{110}$ .

## VII. POSITIONING OF THE DIELECTRIC RESONATORS

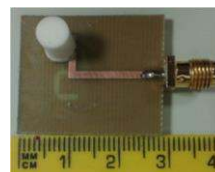
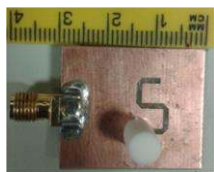
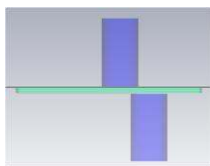
The proposed feed arrangement with the S-shaped slot enables various placements of the two DRs, whose relative positioning needs to be considered in more detail. A refinement of the parametric study in Section IV was made by considering the three configurations shown in Figure 9: (i) both resonators on the slot side, (ii) upper resonator on the slot side and lower resonator on the feed side, and (iii) upper resonator on the feed side and lower resonator on the slot side. It is worth noting that positioning of the DR on the conductor side of the slot is different from when the DR is put on the substrate side of the slot. The latter case introduces a thin layer (0.8 mm of  $\epsilon_{\text{subs}} = 4.5$ ) under the DR, which can be considered as a two-layered DR leading to a slightly different resonance frequency. Therefore, placement of the two DRs on opposite sides can result in slightly different resonance frequencies and a different antenna radiation pattern in comparison with the case when both DRs are on the same side. The performances of the three configurations are shown in Figure 10 for the simulated model and the prototype DRA. In Figure 10, it can be seen that case (i) delivers 41% and 37.5% measured and simulated bandwidth respectively. The corresponding maximum gain values are 6 dB<sub>i</sub> at frequency of 10.6 GHz and 11.2 GHz respectively. The simulation results show that case (ii) gives 31.7% bandwidth and 4.51dB<sub>i</sub> maximum gain at 10.3 GHz, and case (iii) gives 33% bandwidth and 4.92 dB<sub>i</sub> maximum gain at 11.2 GHz. Thus, the largest impedance bandwidth and gain are achieved for case (i), where the two DRs are placed on the same side of the substrate. However, case (ii) and case (iii) indicate a better response for the difference between the maximum and minimum gain states, that means

more uniform patterns but at gain reduced by 1 to 1.5 dB. It should be noted here that when placing the two DRs on opposite sides of the substrates (cases ii and iii) no attempt was made for further optimization of the antenna parameters to achieve better performance. It can also be noted that the dips in the reflection coefficient responses differ slightly for the three cases due to the fact that the resonance frequencies are influenced by the relative placement of the slot and DR.

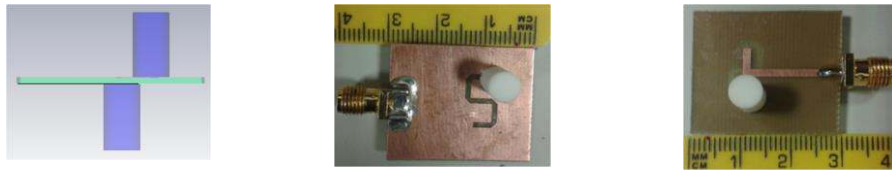
The simulated far field radiation patterns, for the two cases (ii) and (iii) are presented in Figure 11, for two operating frequencies, 9.0 GHz, and 10.5 GHz. Measurements of the radiation patterns were also performed for these two antenna arrangements and plotted on Figure 11 for comparison. The figure shows fair agreement between measured and simulation patterns. The cross-polarized patterns are relatively high, and this may also be attributed to the slot being twisted into the S-shape. The radiation patterns for case (i) are already displayed in Fig. 7, and for brevity they are not repeated. It can also be seen that case (ii) and case (iii) have wider patterns as compared to case (i). This result can be attributed to the displacement of the two DRs on opposite sides of the substrate.



Two DRs on the slot side



Lower DR on the slot side and upper DR on feed side



Upper DR on the slot size and lower DR on feed side

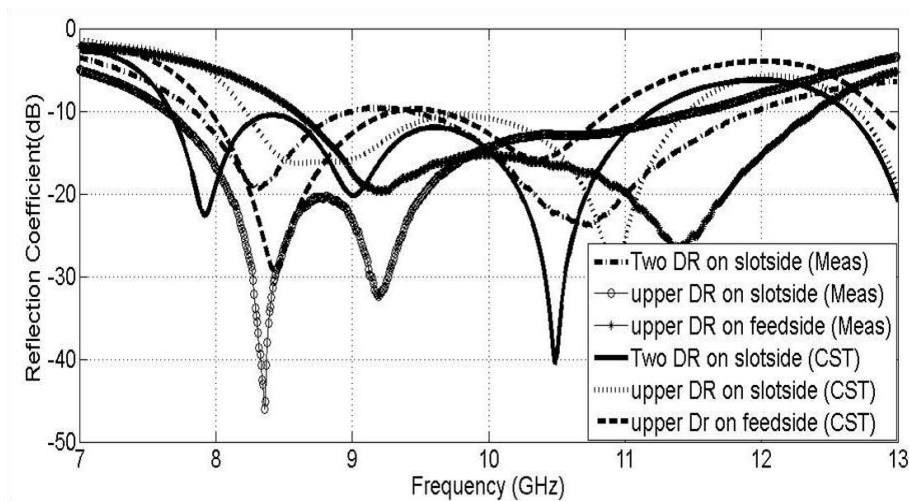
(a)

(b)

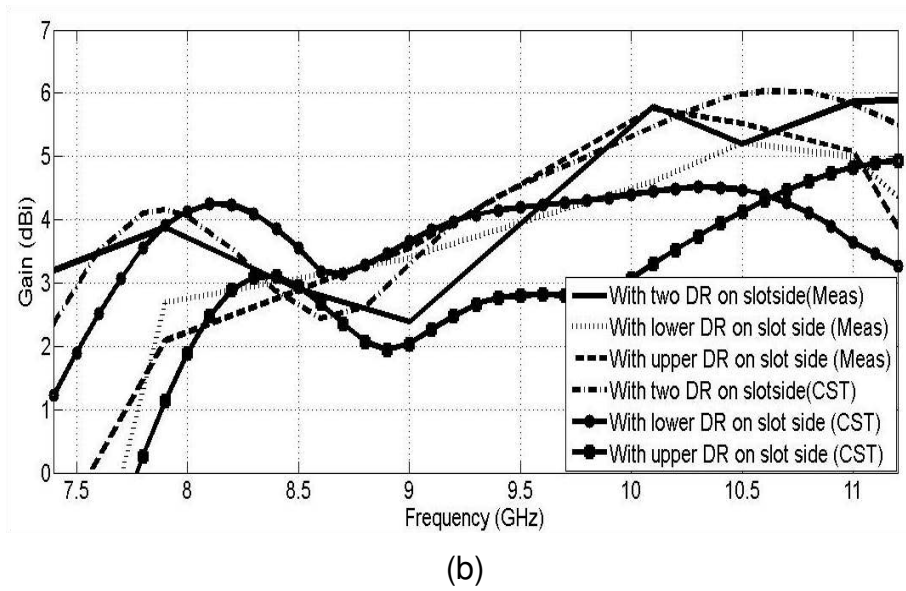
(c)

**Fig. 9:** Investigated positions of two DRs; (a) Simulated model, (b) fabricated antenna showing slot side, (c) fabricated antenna showing feed side.

Figure 10

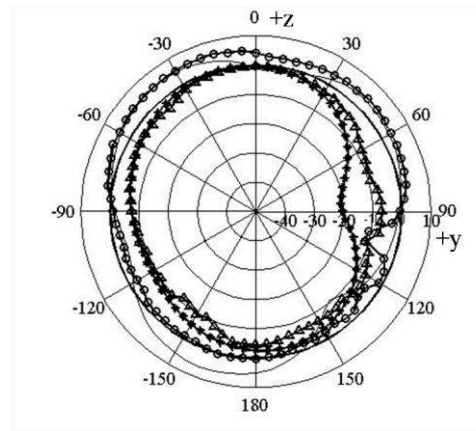
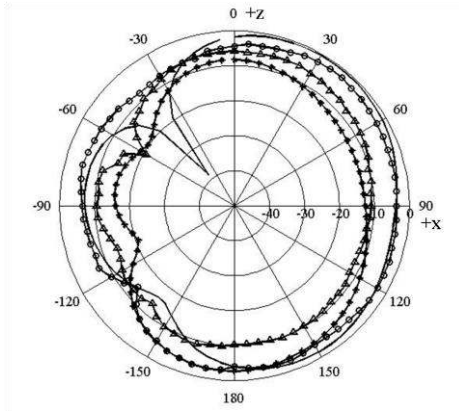


(a)

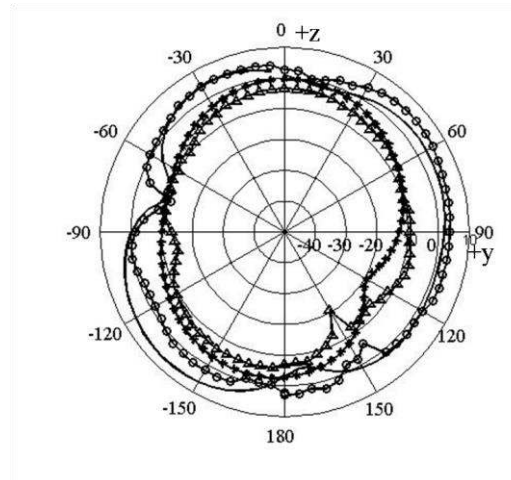
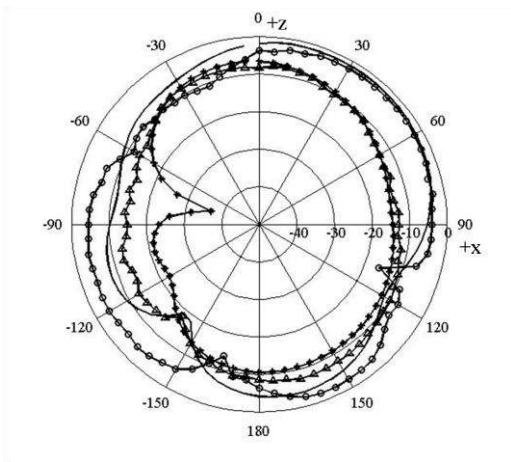


**Fig. 10:** Simulated and measured (a) Reflection coefficient magnitude ( $S_{11}$ ) and (b) Gain (dBi) vs. frequency plots with different DR positions

Figure 11 (a)



Case (ii)

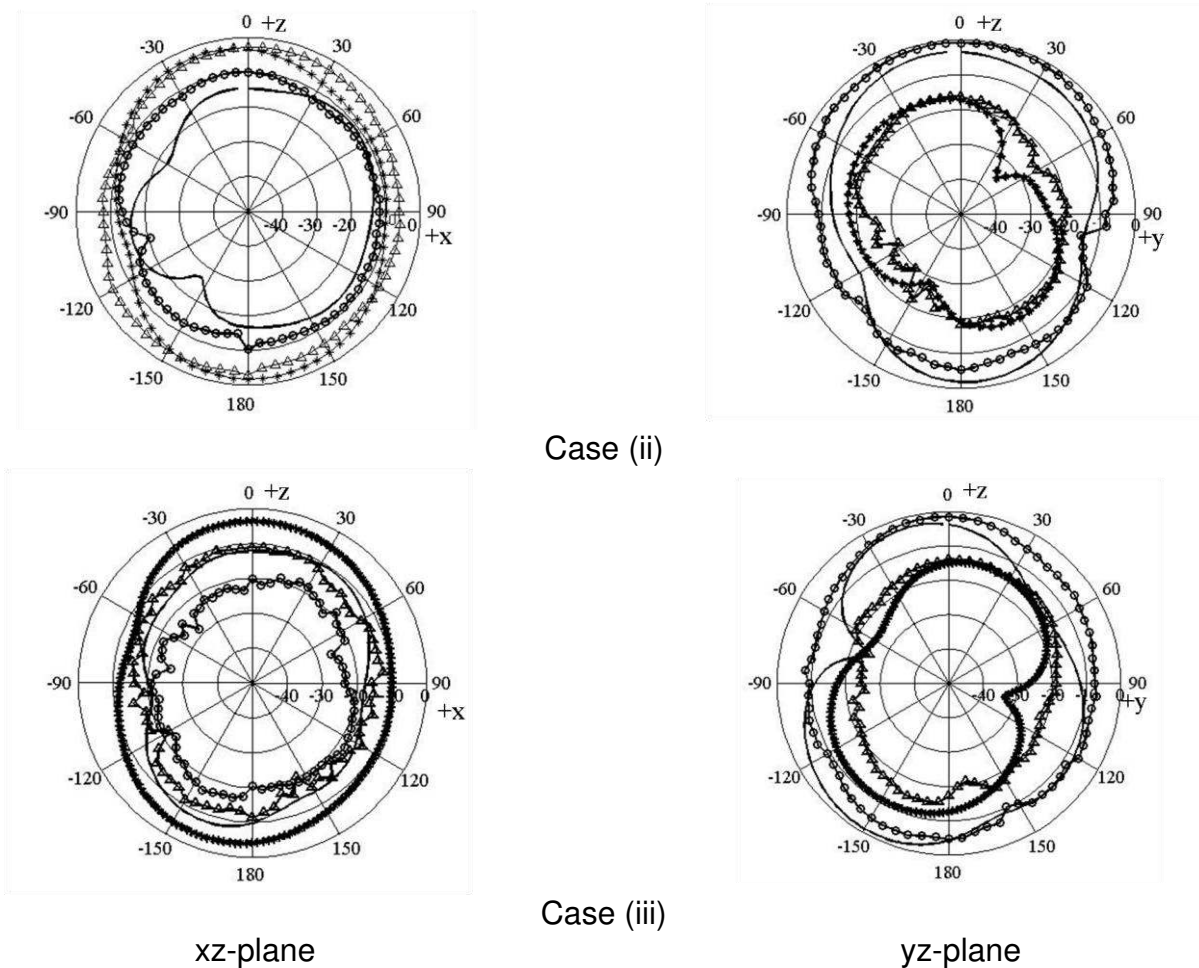


Case (iii)

xz-plane

yz-plane

Figure 11 (b)



**Fig. 11:** Measured and simulated far-field radiation patterns for two antenna arrangements (ii) and (iii) shown in Fig. 9, at (a) 9.0 GHz, and (b) 10.5 GHz;  $E_\theta$  Meas. (solid-circles),  $E_\phi$  Meas. (triangle),  $E_\theta$  CST (solid) and  $E_\phi$  CST (solid-\*).

### VIII. CONCLUSION

A new physically compact aperture-coupled dual-segment DRA has been proposed for use in X-band communications. Identical cylindrical DR posts of permittivity 9.4 are mounted on a substrate-backed ground plane. The antenna is excited using an L-shaped feed line, and internal antenna coupling is achieved using an S-shaped slot. The folding of the slot into an S-shape has offered many interesting features. The measured prototype performance shows a maximum gain



of 6.0 dBi over the frequency range 7.8 GHz to 11.85 GHz (41% fractional bandwidth) while the simulations gave a fractional bandwidth of 37.5% across the 7.66 GHz to 11.2 GHz frequency range. The fabricated prototype has suitable radiation patterns. The DR posts may be arranged in two distinct configurations: (i) occupying a space on one side of the substrate, and (ii) on opposite sides. The first configuration results in higher gain and greater bandwidth, whilst the second one results in more uniform field distribution but at slightly reduced gain. This is an obvious result of placing two DR radiators in same direction as in (i) or in two opposite directions as in (ii). The antenna can suit applications, for example in mobile and fixed satellite, radio location, and UWB OFDM.

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### **References:**

- [1] K. M. Luk and K. W. Leung, Dielectric Resonator Antennas, Research Studies Press, Hertfordshire, England, 2003.
- [2] A. Petosa, Dielectric Resonator Antenna Handbook, Artech House Publishers, 2007.

- [3] A. H. Majeed, A. S. Abdullah, F. Elmegri, K. H. Sayidmarie, R.A. Abd-Alhameed, and J. M. Noras, "Aperture-Coupled Asymmetric Dielectric Resonators Antenna for Wideband Applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, pp. 927-930, 2014.
- [4] O.M. Haraz, A.-R. Sebak, and T. A. Denidni, "A Hybrid Printed Monopole Antenna Loaded with Dielectric Resonator for Wideband and Circular Polarization Applications", *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 22, No. 5, Sept. 2012, pp. 588-593.
- [5] A. B. Kakade, and M. S. Kumbhar, "Wideband Circularly Polarized Conformal Strip-Fed Three Layer Hemispherical Dielectric Resonator Antenna With Parasitic Patch", *Microwave and Optical Technology Letters*, Vol. 56, No. 1, pp. 72-77, 2014.
- [6] D. Guha, B. Gupta, C. Kumar, Y. M. M. Antar, "Segmented Hemispherical DRA: New Geometry Characterized and Investigated in Multi-Element Composite Forms for Wideband Antenna Applications", *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 3, pp. 1605-1610, 2012.
- [7] X-L Liang, and T.A. Denidni, "H-Shaped Dielectric Resonator Antenna for Wideband Applications", *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, pp. 163-166 2008.
- [8] M. Khalily, M. K. A. Rahim, A. A. Kishk, Sh. Danesh, "Wideband P-Shaped Dielectric Resonator Antenna", *Radio Engineering Journal*, Vol. 22, No. 1, pp. 281-285, 2013.
- [9] G. Yang, F. Zhenghe, Z. Li, "Compact Asymmetrical T-Shaped Dielectric Resonator Antenna for Broadband Applications", *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 3, pp. 1611- 1615, 2012.
- [10] L. Z. Thamae and Z. Wu, "Broadband Bowtie Dielectric Resonator Antenna", *IEEE Transactions on Antennas and Propagation*, Vol. 58, pp. 3707-3710, 2010.
- [11] Y. Coulibaly, T. A. Denidni, and H. Boutayeb, "Broadband Microstrip-Fed Dielectric Resonator Antenna for X-Band Applications", *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, pp. 341-345, 2008.
- [12] P. Rezaei, M. Hakkak and K. Forooghi, "Design of Wideband Dielectric Resonator Antenna with a Two Segment Structure", *Progress in Electromagnetics Research, PIER 66*, pp. 111–124, 2006.
- [13] D. Kajfez and A. A. Kishk, "Dielectric Resonator Antenna- Possible Candidate for Adaptive Antenna Arrays", *Proceedings VITEL 2002, International Symposium on Telecommunications, Next Generation Networks and Beyond, Portoroz, Slovenia, May 13-14, 2002*.

- [14] M. Saed and R. Yadla, "Microstrip-Fed Low Profile and Compact Dielectric Resonator Antennas", *Progress In Electromagnetics Research, PIER* 56, pp. 151–162, 2006.
- [15] A. Rashidian and D. M. Klymyshyn, "On The Two-Segmented And High Aspect Ratio Rectangular Dielectric Resonator Antennas For Bandwidth Enhancement And Miniaturization," *IEEE Trans. Antennas and Propagation*, Vol. 57, No. 9, pp. 2775–2780, 2009.
- [16] A.H. Majeed, A.S. Abdullah, F. Elmegri, E. M. Ibrahim, K. H. Sayidmarie, R. A. Abd-Alhameed, "Rectangular Slot-Fed Asymmetric Cylindrical Dielectric Resonators Antenna for Wideband Applications", *Loughborough Antennas and Propagation Conference LAPC 2014*, 8-11 Nov. 2014, pp. 244-248.
- [17] *Microwave Studio Users' Manual*, Computer Simulation Technology AG, Darmstadt, 2011.
- [18] D.M. Pozar, *Microwave Engineering*, 2nd edition, John Wiley & Sons, New York, 1998.
- [19] K.W. Leung, K.Y. Chow, K.M. Luk and E.K.N. Yung, "Low Profile Circular Disk DR Antenna of Very High Permittivity Excited by a Microstripline", *Electronics Letters*, Vol. 33, pp. 1004-1005, 1997.
- [20] R. Chair, A. A. Kishk, and K. F. Lee, "Wideband Simple Cylindrical Dielectric Resonator Antennas", *IEEE Microwave and Wireless Components Letters*, Vol. 15, pp. 241-243, 2005.