Compact Cylindrical Dielectric Resonator Antenna for MSS Handheld Terminals

Abhishek Shukla
Satellite Communications Antenna Division
Antenna Systems Group
Space Applications Centre, ISRO, Ahmedabad, India
abhisheks@sac.isro.gov.in

*S. Sravan Kumar**, *M. B. Mahajan***
Satellite Communications Antenna Division
Antenna Systems Group
Space Applications Centre, ISRO, Ahmedabad, India
*sravan@sac.isro.gov.in **mb_mahajan@sac.isro.gov.in

***Abstract*− This paper presents a compact cylindrical Dielectric Resonator Antenna [39 X 39 X 12mm³] for Multipurpose MSS Ground (Handheld) Terminal Application. DRA is realized using Ceramic material having low Loss Tangent and dielectric constant of 20. The Right Hand Circularly Polarization has been achieved using dual feed (two orthogonal modes) lateral excited by Wilkinson Power divider (fabricated on Low dielectric constant substrate) beneath the ground plane. A Novel idea of grooved ground plane is implemented in order to ensure proper adhesion of DR Block to the Ground plane so that air gap does not exist in the realized hardware, which would cause frequency shift in DRA is negligible. The Gain of the Antenna is better than 2.5 dB up to (± 45°) over the desired frequency band (2.56 – 2.69 GHz.), while Axial ratio is less than 0.3 dB in the range (θ ± 45°) in the entire band. Antenna is having wide return loss bandwidth (better than 20 dB in the desired Band, while 17dB return loss Bandwidth is around 15%. The antenna was characterized with terminal itself and met all performance requirements.**

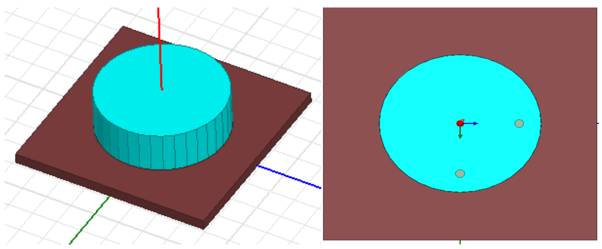
Keywords- circular polarization; minituarized; ground ; SMR; power divider; wide bandwidth

I. INTRODUCTION

DRAs are good candidates to replace traditional radiating elements at lower as well as higher frequencies. This is actually attributed to the fact that DRAs don't suffer from conduction losses and characterized by high radiation efficiency, if excited properly. DRA are generally realized by using of high dielectric constant based ceramic material(usually ε_r ・ 10).Advantage of DRA comes in to picture because of its size. Size of DRA is proportional to (・o/・εr) with ・o being the free space wavelength where εr denotes the relative permittivity of the material forming the radiating structure. In order to decrease the size of DRA, a material of high ε_r can be chosen; however, This should be carefully done since Impedance bandwidth can be affected negatively by the choice of dielectric material. These Antennas are normally constructed from a low loss ceramic material, mounted on a ground plane. When DR is placed in an open environment and properly excited (either by coaxial probe, inserted in DR or microstrip under the ground plane with an aperture through it), power is lost in radiating field and become DR to DRA. Fields are excited inside the resonator when excited in a resonant mode, It is this field which radiate. Earlier Experimental measurements had been made on several Dielectric cylinders with varying aspect ratio (Radius/Height of cylinder), dielectric constants & Feed probe lengths. DRA provides a flexibility in terms of various shapes (cubic, cylindrical, hemispherical etc.). Cylindrical shape provides less challenge in terms of fabrication, ability to excite different modes as well as sensitivity to dimensions. In this paper, Cylindrical shape DR is placed above the conducting ground plane, excited by two coaxial probes, placed at locations (perpendicular axis in order to get Circular polarization). There are various approaches to achieve Circular polarization(CP) in DRA of different-2 shapes (corner truncated, Hemispherical, elliptical, nearly square/cubic) using single feed. Various Research and study have been carried out also to enhance the axial ratio Bandwidth in a single feed itself. CP-DRAs supporting degenerate modes and excited with dual point inputs, are capable of larger Impedance as well as Axial ratio(AR) Bandwidth.

II. ANTENNA CONFIGURATION

DR consists of cylindrical disk of having dielectric constant 20, above a conducting ground plane (38mm X 38mm X 01mm) as shown in Fig.1. HEM(11・) mode is the fundamental mode of DR cylinder. It radiates like a horizontal magnetic dipole, exhibiting broadside radiation pattern, low X-Pol level & largest possible bandwidth. Lateral of DR is placed against a coaxial probe, which excites the desired HEM(11δ)mode. In order to get CP characteristics dual point feed configuration is implemented.



(a) (b)

Fig.1 (a) DRA-3D View(b) DRA with orthogonal dual point inputs

If DR has radius a, height h and dielectric constant εr, Using the Conventional Dielectric Wave-guide Model(CDWM) and Dielectric –air Boundaries (which are considered as Perfect magnetic conductors (PMC)), Resonant Frequency of HEM(11δ)can be approximated by Equation [3] :

$$Fr= \frac{2.997}{20*\pi*\sqrt{k}} sqrt[\left(\frac{1.841}{a}\right)^2 + (\pi|2h)^2] \qquad (1)$$

Equation 1 is obtained with hypothesis that the lateral and upper surface of DR are PMCs, Because These assumption is verified only for infinite permittivity.

The Equation for resonant frequency for HE(11δ)Mode can be approximated by extensive numerical simulations & curve fitting ( ) by equation (2):

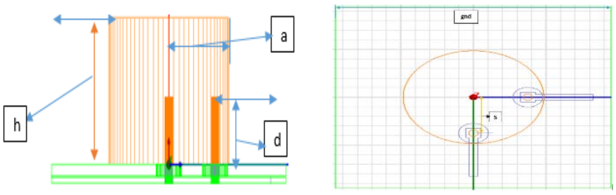
$$Fo = (1.007)\times\left(\frac{1}{sqrt(\varepsilon r+2)}\right)\times\left(\frac{300}{a}\right)\times P \qquad (2)$$

$$\text{Where } P = \left(0.27 + 0.36\times\left(\frac{a}{2h}\right) + 0.02\times\left(\frac{a}{2h}\right)^2\right)$$

In Equation 2, a is the radius of cylindrical DR in (mm.)

III. DESIGN APPROACH & DETAILED ANALYSIS

The Cylindrical DRA shown in Fig 2(a)&(b) is dimensioned for the centre frequency 2.625 GHz using design equation 1 & 2, To make this design to be applicable for wide band Tx Rx (2.56 – 2.69 GHz), the antenna is excited by Wilkinson power divider. The DRA radius a, height h, Probe location s, probe insert depth d are optimised for the minimum total reflected power (good Return Loss in the desired Band, Broadside radiation pattern)



(a) (b)

Fig.2(a) & (b) Dual Point Feed DRA by Two orthogonal probe excited by Micro strip Lines

For a defined ground plane size, design and analysis has been carried out for optimum performance. To make it compatible to Wilkinson power divider, it is earlier designed to excite DRA at Two orthogonal points through metallic pins/probes, feeded by Micro strip lines of desired width (50 Ohm Impedance). Micro strip line is on bottom side of the substrate material Rogers RO3003, while Top side is fully etched. For the Ground Plane a copper plate of 1mm thickness is used (on which DRA is placed) between DRA & substrate.

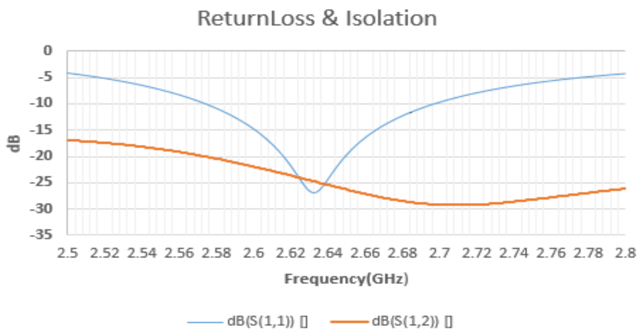


Fig.3 Simulated Return loss & Isolation

From Fig. (3) it is evident that the antenna resonates at 2.625GHz, while at the desired band th return loss is ≤-10 dB & Port-Port Isolation is better than 17dB.Antenna simulated Radiation pattern (Ø: 0°,45°,90° plane) at 2.625 GHz.is also shown in Fig.4. Simulated Peak Gain value is better than 5 dB at Bore sight, while at (θ ± 45°), Gain is ≥ 2.5 dB in all plane. Fig4 clearly expresses the difference between Co-Pol & Cross Polar level is better than 15dB, exhibiting AR ≤ 3dB.

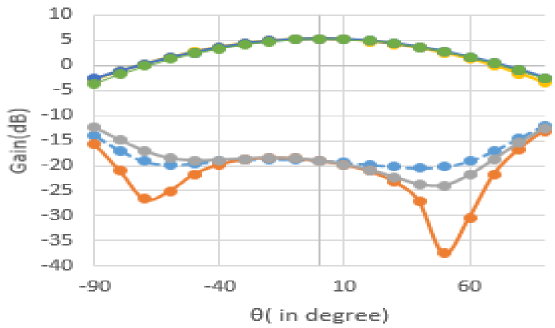


Fig.4 Simulated Radiation Pattern at 2.625 GHz

Once Probe locations are fixed, to provide exact equal amplitude & relative Phase difference of 90° between desired points Wilkinson Power divider(WPD) on substrate RO3003 of thickness 0.508mm is designed, In [6], it has been proved that the antenna CP bandwidth is frequency independent, while the phase and magnitude of the quadrature signals are frequency dependent, therefore WPD is chosen. The Power divider achieves not only equal power division but also impedance transforming between input and output ports. As it is shown in layout in Fig.5(a), that the input signal at Port 1 is split into two paths through a pair of quarter-wavelength transformers, and then they transmit along the paths generating 0° phase difference at output ports 2 and 3.

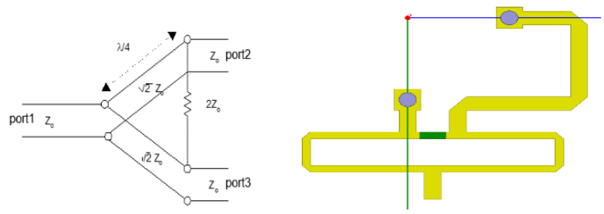


Fig.5 (a) Fig.5 (b)

Equivalent Transmission line ckt Fig.5(a) & An equal-split Wilkinson power divider in microstrip form Fig.5(b)

While in Fig.5(b) It is clearly shown that to achieve dual-feed-type circular polarization, a pair of orthogonally-orientated vertical probes connected to the WHC is employed to excite the DR at the furthest point from the DR axis, and the corresponding two quadrature signals are then generated. Good impedance matching can be achieved by adjusting the probe dimensions — the diameter (rp) and depth (d).

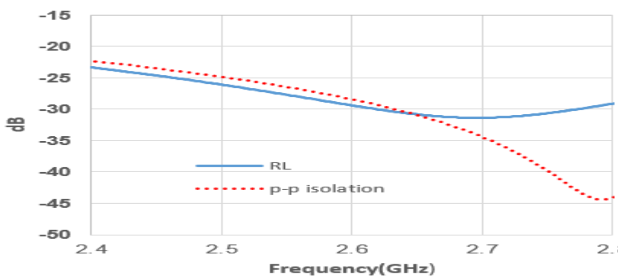


Fig.6 Simulated Rloss & P-P Isolation of WPD

Simulated Return loss is better than 20 dB and Port to Port Isolation is better than 25 dB over the desired Band as shown in Fig.6.

Once the individual design of DR element and WPD is completed, theyare integrated to realize the Antenna. As earlier discussed DR is placed on metallic ground plane of thickness 1mm, To bond DR on a metallic surface, Proper adhesive is required to make a proper contact between dielectric – metal interface. The detailed information about adhesives are not reported. To bond DR with gnd plane Adhesive of Thickness (0.06mm) & Dielectric constant (2.65) having loss tangent of 0.005 is used in this proposed design. There are various adhesives such as cynate ester, Araldite, 3M adhesive, silver epoxy etc.

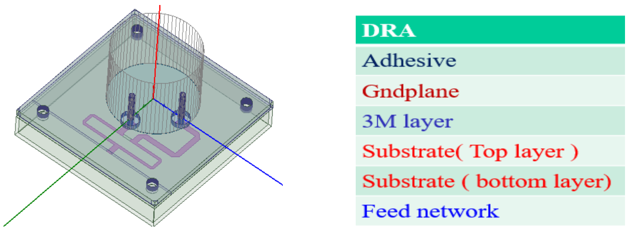


Fig.7(a) & (b) 3-d View of Antenna on flat gnd plane & Stack up configuration layer wise

As shown in Fig7, Ground plane can be of copper/aluminum etc. In the Proposed design the antenna was connected to the terminal using a SMA cable.

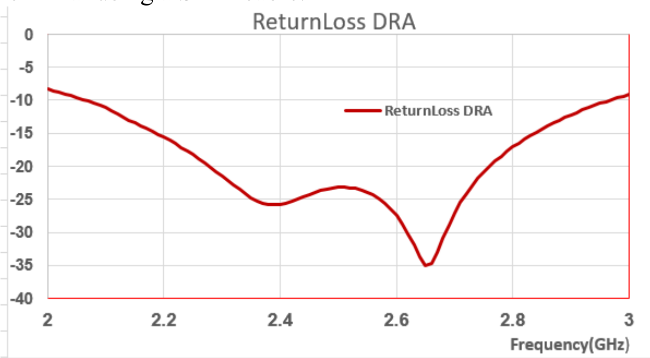


Fig. 8(a) Simulated Return loss of Complete DRA

Fig.8 shows the simulated Return loss of the DRA along with the feed and exhibits 17dB return loss over 22 % Bandwidth..

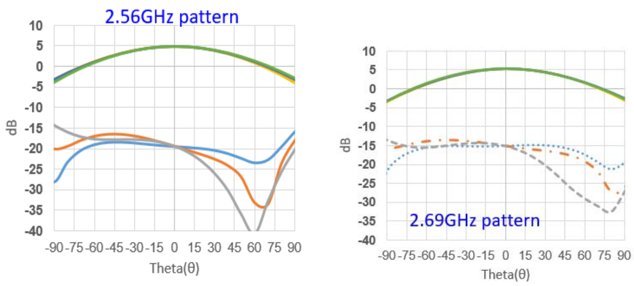


Fig. 8(b) Simulated Pattern of DRA

Simulated pattern at Edges Frequency of Tx & Rx Band (2.56 & 2.69 GHz) is shown in Fig.8(b). At both Frequencies Gain ≥ 2.5 dB (θ ± 45°), in All Phi plane, Difference between Co & Cross Pattern also signifies, AR better than 3dB over All phi plane.

The challenge comes in realization of DRAs. After the machined ceramic block, I s to be bonded on metallic ground surface. To make this optimum surface roughness of Both Ceramic & Metallic ground plane should be good, otherwise at the time of adhesion air gap can be formed between DRA & Ground plane.

Parametric study has been carried out with respect to air gap between DRA bottom side & ground plane as shown in Fig.9.

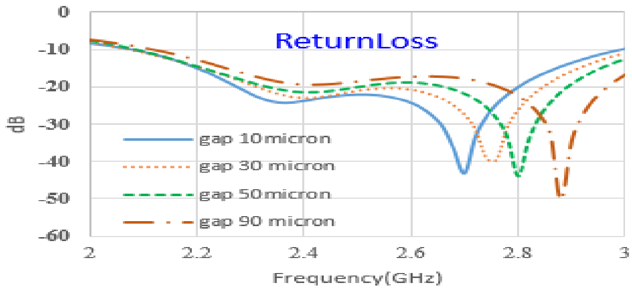


Fig.9 Parametric return loss variation

Due to air gap created, Net effective dielectric constant get lower than actual εr of DRA, as per formulae:

$$\varepsilon r(\text{eff}) = \left(\frac{h1+h2}{x}\right), \text{ where } x = \left(\frac{h1}{\varepsilon r1}\right) + \left(\frac{h2}{\varepsilon r2}\right)$$

Due to net effective dielectric constant getting lower, frequency get shifted to higher side asper relation in equation [2] mentioned above. This problem becomes severe in single Feed narrow band DRA schemes, while in wideband ones, margins are incorporated in design stage.

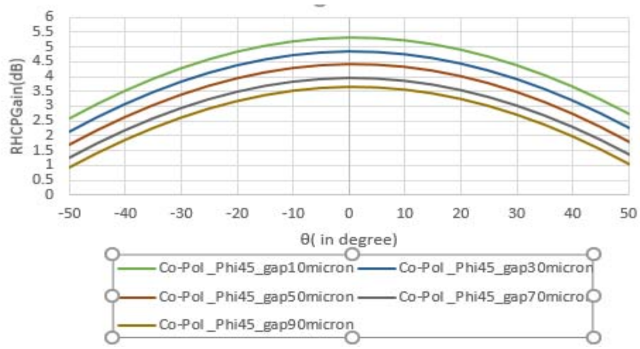


Fig.10(a) Gain Variation with gap b/w DRA and gnd plane

Due to this air gap, gain also decreases with increase in gap. At desired centre frequency, in D-Plane RHCP pattern (gain) Vs θ, has been plotted in Fig.10(a) with gap variation (10μ - 90μ). Peak Gain at Bore sight drops from (5.4dB up to 3.6dB), which in turns also affects desired gain of 2.5dB at (θ ±45°).AR vs θ is also plotted with gap variation as shown in Fig.10(b).

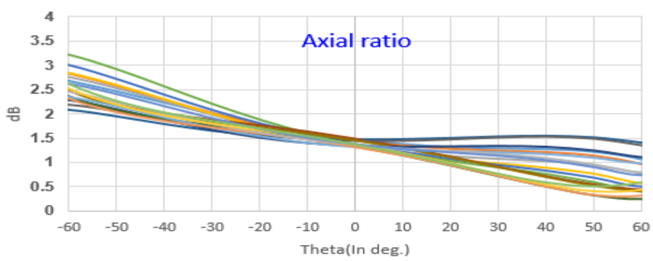


Fig.10(b) AR Variation with gap b/w DRA and gnd plane

In order to minimize the frequency shift problem that commonly occurs in the realized hardware, a novel practical solution has been proposed in this paper, which is also incorporated in design and simulation. A cylindrical groove of certain depth has been incorporated in the ground plane as shown in Fig.11(a)&(b), Then DR can be kept inside it & bonded with either Cynate ester or Silver epoxy.

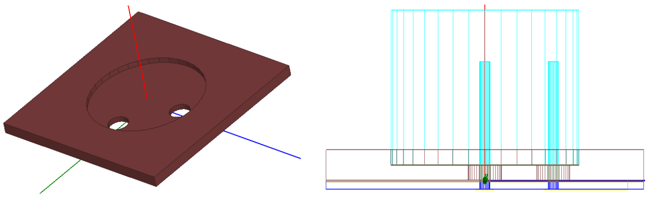


Fig.11(a) & (b) DRA inside grooved gnd plane

It is essential to implement / incorporate adhesive (With Its electrical properties) in design itself. As Adhesives properties are different so it may result in dimensional change in DR block (radius a, height h, dia of probe inserted in DR Block, depth of probe insert inside DR block , desired location of probe inserted), for a particular centre resonant frequency. Thickness of ground plane does not have a significant impact as seen in simulated performance shown in Fig12.

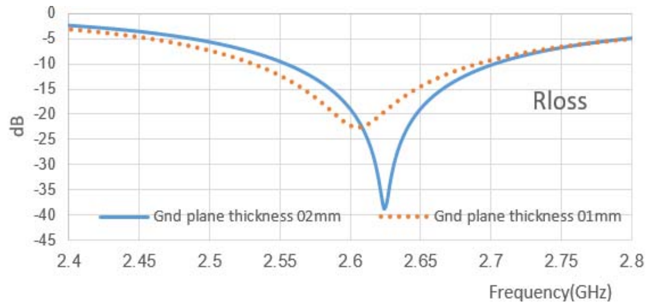


Fig. 12 Simulated parametric Return Loss (dB) with variation in gnd plane thickness

For A Fixed dielectric constant based ceramic material and desired resonant frequency analyzed & optimized dimensions are tabulated as mentioned in Table1.

S.N.	a		h	posn	depth	Condition
1.	11.5		10.0	8.4	6.67	Groove gnd plane, Cynatyster adhesive
2.	11.2		10.0	8.0	6.57	Groove gnd plane, silver epoxy
3.	12.5		9.00	9.1	9.00	Groove gnd plane, Cynatyster adhesive
4.	11.3		10.2	8.1	6.60	Without any kind of adhesive

Table 1. DR Dimensions wrt different conditions

Most preferred approach is to insert the DR block inside Grooved gnd plane and bond it with Cynatyster/silver epoxy. Both the approach of bonding has been found good enough practically, in order to match the simulated & measured results. As antenna is to be placed at some platform in the desired location at terminal. As feed network is etched at bottom side of substrate (RF Interface – coaxial cable (SMA)), Rohacell foam of thickness 4mm & Cavity fixture has been made to hold the antenna, which has been incorporated in design/analysis/simulation itself as shown in Fig.13.

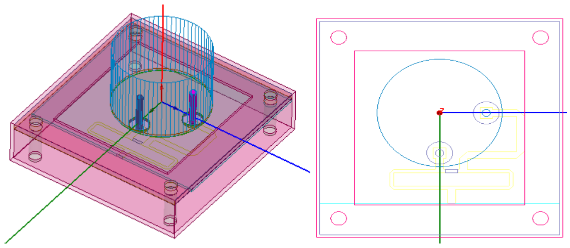


Fig 13. DRA bonded in grooved gndplane (3-d& Top view)

Simulated return loss of Antenna (shown in Fig13) is shown in Fig 14(a)

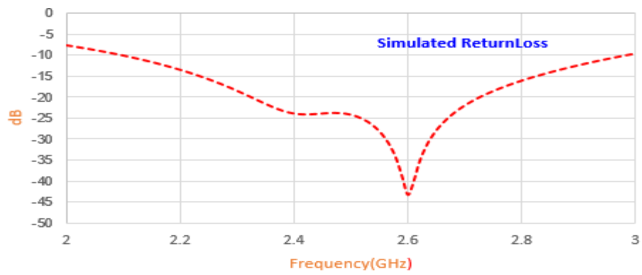


Fig 14(a). Simulated Return loss

Simulated Radiation pattern at edges frequencies (2.56,2.69 GHz.as well as centre frequency 2.625 GHz) are shown in Fig.14(b), Simulated Gain (desired RHCP-CoPattern) is >2.5 dB for all frequencies over all phi cuts.

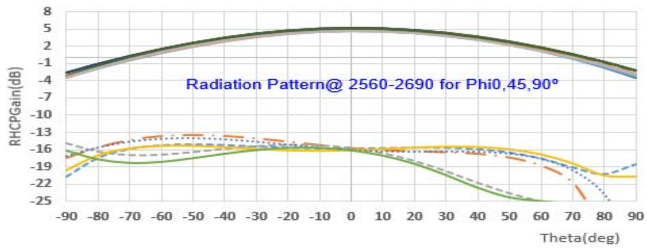


Fig 14(b). Simulated pattern

Simulated Axial ratio is shown in Fig.14(c), Axial ratio Beam width is too wide, Axial ratio < 04dB Over (-80º<θ<80º) in all phi plane (0 to 337.5º, all 16 cuts @ step size of 22.5º).

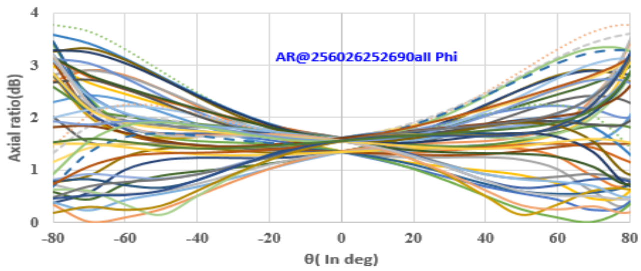


Fig 14(c). Simulated AR

IV. PARAMETRIC STUDY

Detailed parametric analysis has been carried out in this section, As DRA is more sensitive with respect to fabrication point of view, dimensional tolerance study has been carried out. To insert the probe inside DRA, a Via (Hole of certain Dia is required up to a depth). Parametric Return Loss

Variation with respect to of probe height is shown in Fig.15(a).

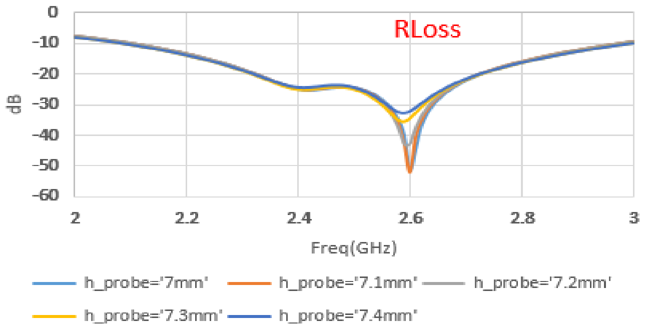


Fig 15(a). Return Loss Vs Frequency with respect to probe height variation

From Fig 15-a, it is very clear that there is not much significant change in Return loss with respect to Probe height/depth variation with in (±200μ tolerance), which is a good number from DRA Fabrication point of view.

In same way Position(location) of probe inserted in to DRA also matters, As it effects upon the impedance matching, there is not much impact in performance for a tolerance of ±200μ, as shown in Fig 15(b).

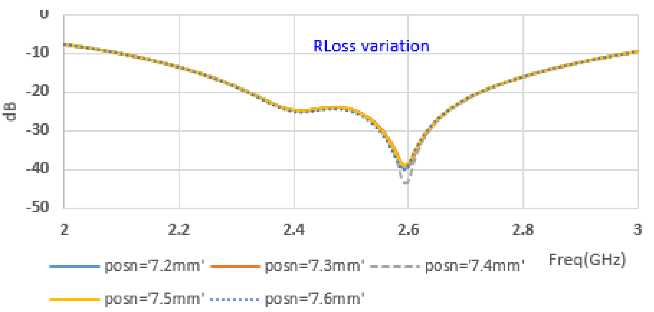


Fig 15(b). Return Loss Vs Frequency with respect to probe position/location variation

In order to remove the any kind of ambiguities regarding commonly seen frequency shift, impact on RF performance due to variation in Dielectric constant (with in ±200μ) has been studied. Simulated return loss with respect to variation in DK is shown in Fig15(c).

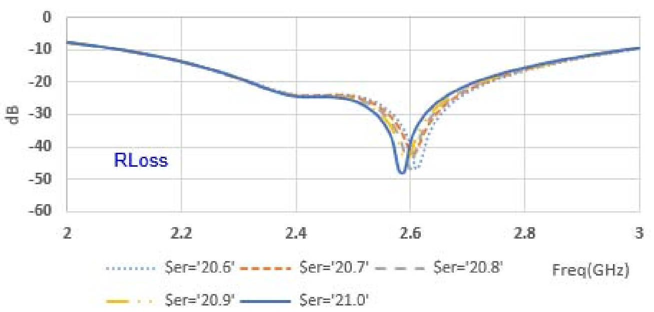
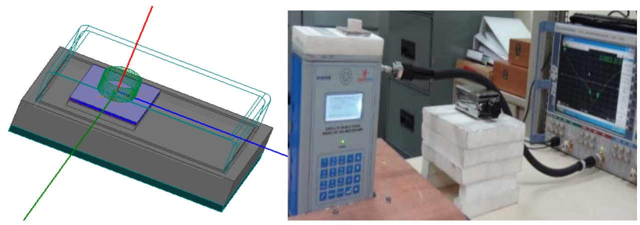


Fig 15(c). Return Loss Vs Frequency with respect to variation in measured dielectric constant

We find that at S band in order to achieve optimized best RF performance, with in a best fitted dielectric constant of 20, Dimension tolerance up to 200μ can be , also variation in measured dielectric constant of DR block is good enough in the range of (±0.2).

V. RESULTS & DISCUSSION

Once element level analysis is completed, then it is very important to do analysis with Terminal itself, at least with Top interface layout, where Antenna is to be placed as well as with radome. Ultimately Antenna working functionality is to be checked with in SMR terminal only.



(a) (b)

Fig 16(a) Antenna with radome at Terminal top cover simulated view (b) DRA with terminal (at Top)

Detailed analysis was carried out of DRAntenna in presence of terminal where antenna was put on top of terminal having a SMA (cable) interface to the circuitry of Terminal. Simulated &Measured Return loss of Antenna at terminal matches so closely, having a wide return loss bandwidth as shown in Fig17.

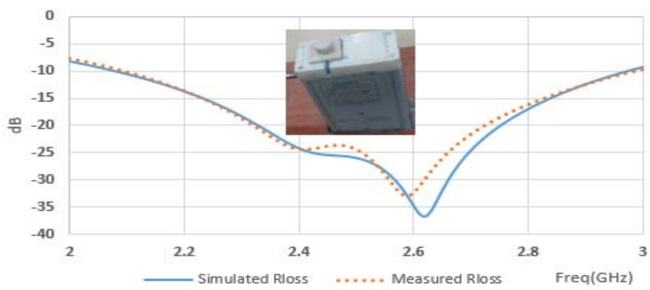


Fig.17 Simulated & Measured Return loss

Simulated radiation pattern of DRA with Terminal itself at Edges Frequencies 2.560 GHz & 2.690 GHz are shown in Fig.18(a).

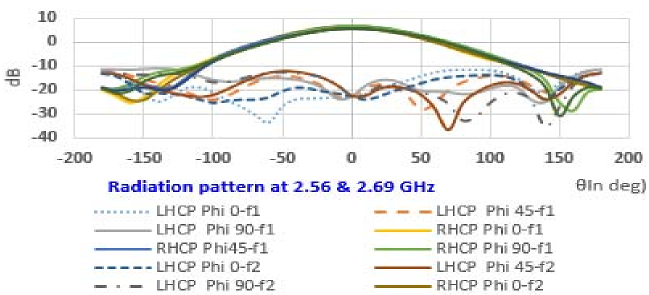


Fig.18-(a) Simulated radiation pattern at 2.56,2.69 GHz.

Simulated Antenna Peak Gain (along with Terminal) is 5.9dB, while at (θ ± 45º) is better than 2.6dB, even back lobe Level is also better than 16dB (which is a good number in such kind of miniaturized Antennas), The Difference between Co & Cross Pol Level of Antenna is better than 15dB ($\theta \pm 45^o$), which exhibits AR <3dB over the desired band.

Antenna Gain and Axial ratio was measured at Anechoic chamber in the presence of Terminal itself, measured gain of Antenna was found to be > 2.5dB (in the desired Beam width) over All 16 phi cuts (0º to 337.5°). Antenna was successfully working in The Terminal. Measured Radiation pattern& Axial ratio at 2.56GHz & 2.69 GHz.is shown below in Fig18(b),18(c) & Fig. 19(a),19(b).

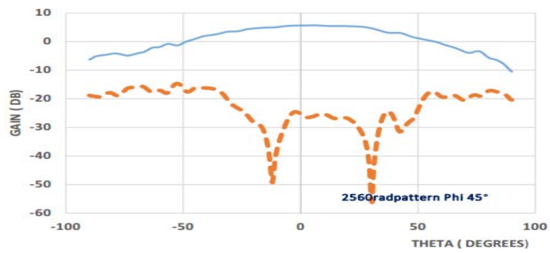


Fig. 18(b) Measured Radiation pattern at 2.56 GHz

Fig. 18(c) Measured Axial ratio at 2.56 GHz

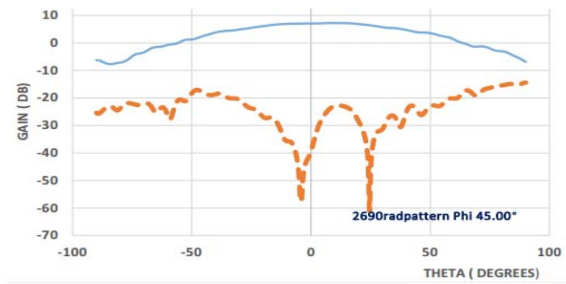


Fig. 19(a) Measured Radiation pattern at 2.69 GHz

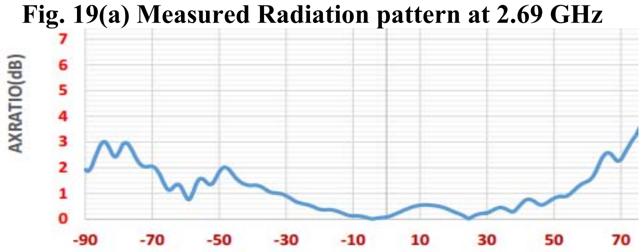


Fig. 19(b) Measured Axial ratio at 2.69 GHz

VI. CONCLUSIONS

A Right Hand Circularly Polarized DRA on a grooved ground plane feed by dual pin with Wilkinson PD that addresses the frequency shift due to fabrication issues has been described. The DRA in the proposed configuration is simulated, fabricated & measured. Measured results reasonably matches with simulated results demonstrating significant enhancement on CP performance as well as Impedance Bandwidth. Antenna exhibits impedance bandwidth of 20.5% for VSWR ≤ 1.3, 3dB AR bandwidth of nearly 9%. With this compact size & excellent RF performances, the proposed DRA is promising candidate for antenna for all type of Handheld Terminals like Reporting Terminal, broadcast receiver & SMR Terminal (MSS Handheld terminals –User segments) for various Application. (Tx, Rx, Tx/Rx) in MSS Band.

VII. ACKNOWLEDGEMENTS

The Authors sincerely thank Shri D.K. Das, Director (SAC), ISRO for encouragement to carry out their work. The Authors also would like to thank Shri Ashok K, Dr.H Sreemoolanadhan, Scientist/Engineer Advanced Material Ceramic division/VSSC to provide Indigenous Ceramic Block of sharp RF properties. The Authors sincerely would like to acknowledge Shri Alok Kumar Singhal Scientist SCAD/ASG for valuable discussion, Shri Indra Prakash & Shri H S Solanki Scientist, AMF/ASG/SAC for their support in characterization. We also wish to thank Shri Chandraprakash Scientist, SCTD/SNGG for their continuous support in Testing of Antenna with handheld terminal.

REFERENCES

1. Aldo Petosa and Apisak Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," IEEE Antennas and propagation Magazine, Vol.52, No.5, October2010
2. Stanislav Ogurtsov, Slawomir Koziel, "Design of Circularly Polarized DRAs with Improved Axial ratio bandwidth,"978-1-5090-2886-3/16,2016IEEE
3. A. Petosa, Dielectric resonator Antenna handbook, Norwood, MA: Artech House,2007.
4. S.A. Long, M.W. McAllister, and L.C. Shen, "The Resonant Cylindrical Dielectric Cavity Antenna," IEEE Trans.Antennas Propag., vol.31, no.3, may 1983, pp.406-412.
5. A. Motevasselian, A. Elgart and B.L.G. Johnson, "A circularly polarized Cylindrical Dielectric Resonator Antenna usingahelicalExciter,"IEEETrans.Antennaspropag.,vol.61,no.3,mar.2013,pp.1439-1443
6. D.M. Pozar, "Power Dividers and directional Couplers," Microw.Eng.,4th ed., Hoboken, NJ, USA: John Wiley & Sons, 2012, pp.363-367
7. http:// antenna.mppa.gr/design equations.html