# Spherical Dielectric Resonator Antenna for 5G Application

**Ashok kumar** ( ashok.k@ipu.ac.in )
Guru Gobind Singh Indraprastha University https://orcid.org/0000-0003-4696-6524
**Rajveer Singh Yaduvanshi**
AIACTR: Ambedkar Institute of Advanced Communication Technologies and Research

**Research Article**

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# Spherical Dielectric Resonator Antenna for 5G Application

Ashok Kumar
USICT, GGSIPU
Delhi, India
ashok.k@ipu.ac.in

Rajveer Singh Yaduvanshi
ECE, AIACTR
Delhi, India
yaduvanshirs007@gmail.com

*Abstract— In this article Spherical DRA has been formulated , simulated and proto type developed. The detailed theoretical analysis along with simulations and measured results at 5.8 GHz have been presented in this article. The SDRA at 5.8 GHz covering 5G frewuenci band. The proposed design antenna provides the gain of 7.3 dB and return loss -25 dB. The measured results are in good match with simulated result. The proposed SDRA are good for 5G wireless networks, as well as other sub-6 band in wireless communication systems.*

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## I. INTRODUCTION

Currently high data speed is a major factor using wireless technology. 5G have been started in 2017 and commercialized in 2020[1][2]. The speed of 5G is 1GB/ second.The key characteristics of a 5G device are high performance, high speed, low latent, light weight and small size[3][4]. The 5G technology offer the channel aggression and higher channel capacity with higher data rate. Published cellular designs have been focused on 3G/4G technology[5][6]. The 5G network support two sets. These sets are long range sub -6 band and high capacity mmWave. The long range sub-6 GHz is for FR1 and the high capacity mmWave spectrum is for FR2[7][8]. The 5G provided support for multimedia applications. The 5G are below 6GHz and under 100GHz[9][10]. The proposed SDRA working at 5.8GHz. SDRA is widely commercialized for up to date 5G networks.Currently LTE used band 42 at 2.6GH and 5G used band 43 at 3.5 GHz in wireless communication systems[11][12]. Due to requirement of faster data transfer well past the 4G wireless standard .4G wireless standard is 100 times slower then the fastest 5G standard. So 5G is better than 4G wireless standard[13][14].Noticeable application in the field of sub-6 band and microwave. Since wireless power transmission technology via microwave has been undergoing devoplement[15][16]. Wireless power transmission is when electric load received the electric energy from the power source with the absence of wire. Wireless power transmission is advantageous when instant and continuous energy transfer is required[17][18]. When compared to wired connection, wireless power transmission is better.The first article on hemispherical dielectric resonator antenna was publiced in 1984[19][20]. The hemispherical dielectric resonator antenna used two resonant mode for investigation[21][22]. Authors also have done done logical study on hemispherical dielectric resonator antenna like impedance, efficiency, mode and gain have been made[23][24]. Antenna is the most important part of wireless networks. Two class of antenna are dielectric resonator antenna and microstrip patch antenna[25][26]. The main advantages of dielectric resonator antenna are low cost and small size[27][28]. Dielectric resonator antenna has higher impedance bandwidth compare to microstrip patch antenna[29][30]. Past work we have investigation into polarization of the rectangular and cylindrical DRA and design the pattern on them[31][32]. In this article implement and design the pattern of spherical DRA. We used the spherical DRA for the higher order mode and high gain. The SDRA is designed using CST software. This article is organized as follow. Section II antenna design and its dimensions, Section III formulations, Section IV result and discussion and Section V conclusion.

## II. ANTENNA DESIGN

SDRA( Spherical dielectrics resonator antenna) was placed on slotted ground plane and simulated with the help of HFSS (antenna design software). Here we have used silicon (Er=10) dielectric material for SDRA which is easily available around us. Here the aperture coupling has been used to feed the antenna. SDRA as a dielectric cause lower conduction losses. Compact size of SDRA make it more suitable for use in antenna design. Its high gain, high bandwidth and low losses increase the overall performance of the antenna. The geomatry of proposed spherical dielectric resonator antenna is given in figure 1.

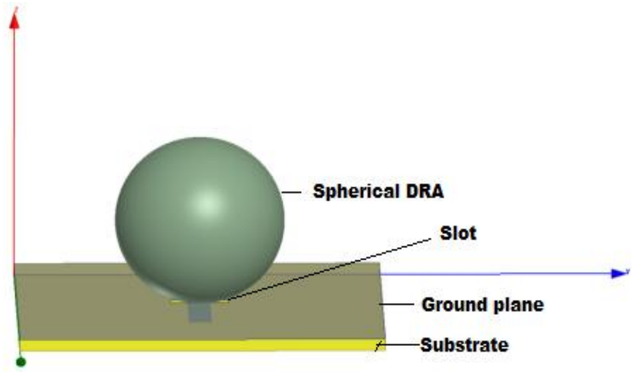


**Figure. 1.** Spherical DRA

The proposed design is fabricated on commercially available FR1 substrate with permittivity 10 and loss tangent 0.0001. The proposed SDRA dimensions are comparable with the size of latest 5G devise available. The propotype antenna is given in figure 2

**Figure. 2.** Spherical DRA

Most spherical, cylindrical, rectangular and conical shaped DRA operate at the elemental resonance. Spherical permits for small size with specific dielectric material permittivity. The resonance frequency is 5.8GHz with a sphere diameter 10 mm. The centre of the resonator has higher Efield magnitude. The SDRA to achieve a minimum return loss. The dimentions of the designed SDRA are given in table 1. The size of all geometry are in MM.

TABLE 1 DIMENSIONS OF SDRA[18]

| S No. | Element | Dimentions/ Material |
|---|---|---|
| 1 | Spherical DRA radius ‘r’ | 10mm |
| 2 | H Spherical DRA height ‘h’ | 20mm |
| 3 | Permittivity | 10 |
| 4 | Input frequency | 5.8 GHz |
| 5 | Gain | 6.5 dBi |
| 6 | Substrate | Silicon Dioxide |
| 7 | Dimension of the substrate | 50x50 mm |

## III. FORMULATIONS

The multi pole electric field and magnetic field are

$$\mathbf{E}(\omega, r) = \sum_{lm}[c(lm)h_l\,(kr)LY_{lm}(\hat{r}) + d(lm)\,(j\omega\epsilon)^{-1}curl(h_l(kr)LY_{lm}(\hat{r})]$$

and

$$\mathbf{H}(\omega, r) = \sum_{lm}[(-j\omega\epsilon)^{-1}c(lm\,curl(h_l\,(kr)LY_{lm}(\hat{r}) + d(lm)h_l(kr)LY_{lm}(\hat{r})]$$

Where

$$\mathbf{L} = -ir \times \nabla$$

This is because $h_l(kr)LY_{lm}(\hat{r})$ convinces the Helmholtz calculation and orthogonal to the radial order $\hat{r}$ . Further, it is simply verified that $div(h_l(kr)LY_{lm}(\hat{r}) = 0$ because $\hat{r}.L = 0$ and $div(LY_{lm}(\hat{r}) = 0$. All Maxwell equations in free space are convinced by the multipole fields. That’s noted $h_l(kr)LY_{lm}(\hat{r})$ is tatally transverse. Its radial component disappear while $curl(h_l(kr)LY_{lm}(\hat{r}))$ convences Helmholtz equations but have both appear radial and transverse component. Its separation obviously disappear because the separation of a curl is 0. The Maxwell equations are convencrs by the multipole fields because

$$curl(curl(h_l(kr)LY_{lm}(\hat{r}))) = \nabla div(h_l(kr)LY_{lm}(\hat{r}))) - \nabla^2(h_l(kr)LY_{lm}(\hat{r})) = k^2 h_l(kr)LY_{lm}(\hat{r})$$

That’s noted $h_l(x)$ are the Hankel functions formulations as $h_l(x) = x^{-1/2}\ J_{l+\frac{1}{2}}(x)$ where $J_v(x)$ convences Bessel’s equation

$$x^2 J_v''^2(x) + xJ_v'(x) + (x^2 - v^2 J_v(x) = 0$$

It can be validated by straghtly substituting $\psi = h_l(kr)LY_{lm}(\hat{r})$ within Helmholtz equation

$$(\nabla^2 + k^2)\psi = 0$$

Expressed the coordinate in spherical-polar and that is getting from radial equation for $h_l(kr)$. This can also obtained by the method of divergence of variables.

The oscillation frequency of the electric field and magnetic field into the spherical cavity obtain quantized by reson of need that radial component of the H- field and the tangential component, ie, $\hat{\theta}$ , $\hat{\Phi}$ the components of the E- field are needed to disappear on spherical surface, ie at r = R. Now,

$$\hat{r}.LY_{lm} = 0$$

$$r.curl(h_l(kr)LY_{lm}(\hat{r}))$$

$$-div(h_l(kr)r \times LY_{lm}(\hat{r}))$$

Since

$$curl\ r = 0$$

Also

$$\hat{r}. \times LY_{lm} = -ir \times (r \times \nabla)Y_{lm}$$

$$-ir\partial_r Y_{lm} + ir\nabla Y_{lm} = ir\nabla Y_{lm}$$

Thus

$$r.curl(h_l(kr)LY_{lm}(\hat{r}))$$

$$= -div(ih_l(kr)r^2\ \nabla\ Y_{lm}(\hat{r}))$$

The boundary conditions imply that

$$\hat{r}.H = 0, \hat{r} \times E = 0, r = R$$

Hence,

$$\sum_{lm}[c(lm)h_l\,(kr)\hat{r} \times LY_{lm}(\hat{r}) + d(lm)(j\omega\epsilon)^{-1}\hat{r} \times curl(h_l(kr)LY_{lm}(\hat{r})))]|r = R = 0$$

And the multipole magnetic field as

$$\sum_{lm}[c(lm)\hat{r} \times LY_{lm}curl(h_l(kr)LY_{lm}(\hat{r})))]|r = R = 0$$

Now

$$\hat{r} \times curl\,(f(r)g(\hat{r})) = \hat{r} \times (f'(r)(\hat{r}) \times g(\hat{r})) + \hat{r} \times (f(r)\nabla \times g(\hat{r}))$$

Used to our difficulty, this becomes

$$\hat{r} \times curl(h_l(kr)LY_{lm}(\hat{r}))$$

$$= \hat{r} \times \left(kfh'(kr)(\hat{r}) \times LY_{lm}(\hat{r})\right) + \hat{r} \times (h_l(kr)\nabla \times LY_{lm}(\hat{r})))$$

$$= -kh_l{}'(kr)LY_{lm}(\hat{r}) + \hat{r} \times (h_l(kr)\nabla \times LY_{lm}(\hat{r})))$$

$$i\nabla \times LY_{\psi}(\hat{r}) = \nabla \times (r \times \nabla_{\psi}(\hat{r})) = \nabla_{\psi}{}^2(\hat{r})\, r - (r, \nabla)\nabla_{\psi}(\hat{r}) + \left(\nabla_{\psi}(\hat{r}), \nabla\right)r - 3\nabla_{\psi}(\hat{r})$$
$$= r\nabla_{\psi}{}^2(\hat{r}) - r\partial_r\nabla_{\psi}(\hat{r}) - 2\nabla_{\psi}(\hat{r})$$
$$r\nabla_{\psi}{}^2(\hat{r}) - \nabla_{\psi}(\hat{r})$$

Thus

$$\hat{r} \times curl(h_l(kr)LY_{lm}(\hat{r})) = -(kh_l{}'(kr) + \frac{h_l(kr)}{r}LY_{lm}(\hat{r})$$

Thus, our orderline situation reduce to

$$c(lm)h_l(kr)\hat{r} \times LY_{lm}(\hat{r}) - \left(\frac{d(lm)}{j\omega\epsilon}\right)(kh_l{}'(kr) + \frac{h_l(kr)}{r}LY_{lm}(\hat{r}) = 0, r = R,$$

$$c(lm)r\nabla^2 Y_{lm}(\hat{r}) = 0, r = R$$

These field

$$c(lm) = 0, kRh_l{}'(kR) + h_l(kR) = 0$$

Thus our oscillation frequencies $\omega(ln), n = 1,2, \ldots$ are the root of the equation

And the answer for the multipole fields inside the SDRA is given by the below superpositions.

$$\omega Rh_l{}'(\omega R/c) + h_l(\omega R/c) = 0$$

The radiation pattern of far field on spherical created by surface current

The relavant multipole fields are

$$\mathbf{E}(t, r) = \text{Re}[\sum_{lm}(d(lmn)/j\omega(ln)\epsilon\exp(j\omega(ln)t)curl\{h_l\left(\frac{\omega(ln)r}{c}\right)LY_{lm}(\hat{r})\}]$$

and

$$\mathbf{H}(t, r) = \text{Re}[\sum_{lm}(d(lmn)\epsilon\exp(j\omega(ln)t)h_l\left(\frac{\omega(ln)r}{c}\right)LY_{lm}(\hat{r})]$$

Where

$$\mathbf{r} = (r, \theta, \Phi)$$

## IV. RESULTS AND DISCUSSIONS

Theoretical study of SDRA, and all significant antenna parameters like radiation pattern, antenna gain, return loss, input impedance , E field and H field etc have been analysis and ploted successfully. Measured and simulated results have been obtained.

The measured and simulated radiation pattern and gain of spherical dielectric resonator antenna in xz plane at 5.8GHz are given in figure 3. The measured and simulated gain are 10dB and 7.3dB respectively. The comparison of measured and simulated gain are given in table 2.

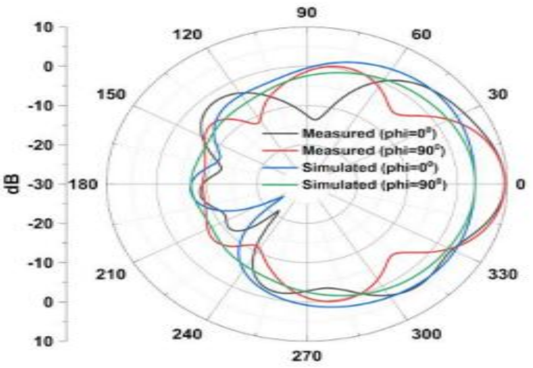


**Figure. 3.** Gain measured & simulated *of* Spherical DRA

Table-2 Gain (simulated and measured)

| S. No | Results | Frequency (in GHz) | Phi (in deg) | Gain (in dB) |
|---|---|---|---|---|
| 1. | Simulated | 5.8 | 0 | 7.3 |
| 2. | Measured | 5.8 | 0 | 10 |

The results of measured and simulated return loss are given in figure 4. The 10dB simulated impedance bandwidth is 5.5-5.4GHz.The 10dB measurd impedance bandwidth is 5.5-5.9GHz. The impedance bandwidth of measured and similated antennas are 7% and 5.4% respectively.

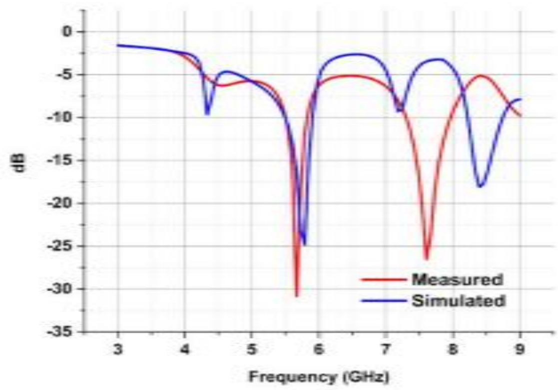


**Figure. 4.** Return loss measured and simulated of Spherical DRA

The measured and simulated return loss are -25dB and -31dB respectively. The comparison of measured and simulated gain are given in table 3.

Table-3 Return Loss (simulated and measured)

| S. No | Results | Frequency (in GHz) | $S_{11}$ (in dB) |
|---|---|---|---|
| 1. | Simulated | 5.8 | -31 |
| 2. | Measured | 5.8 | -25 |

The electric field in SDRA is given in the figure 5. The electric field parameters have been obtained. The study of electric multipole resonator at microwave frequency is most important for radiation pattern.

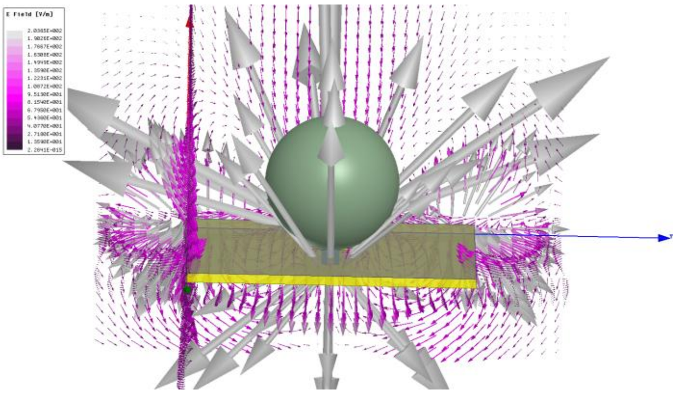

**Figure.5.** E field in spherical DRA

The magnetic field in SDRA is given in the figure 6. The magnetic field parameters have been obtained. The study of magnetic multipole resonator at microwave frequency is most important for radiation pattern .

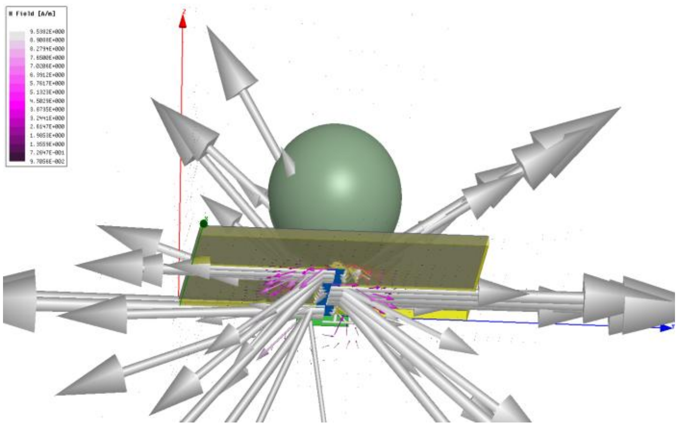

**Figure.6.** H - field in spherical DRA

This is clear that magnetic fields and electric fields have element in x-axis, y-axis and z-axis of the coordinate system.

**Table-4 Comparison of proposed SDRA with reference antennas**

| Ref. | Shape of DR | Frequency (in GHz) | Gain (in dB) | Impedance bandwidth (in %) |
|---|---|---|---|---|
| 4 | One eighth sphere | 3.4 | 6.5 | 9.4 |
| 8 | Quarter sphere | 3.37 | 5 | 35 |
| 12 | Hemi sphere | 77 | 6.89 | 4.0 |
| 16 | Sphere | 5.8 | 9.12 | 2.6 |
| 20 | Sphere | 104 | 9.0 | 9.0 |
| 24 | Sphere | 180 | 7.9 | 11 |
| Proposed | Sphere | 5.8 | 10 | 7.0 |

The comparison between proposed SDRA and the reference antenns with indexes are given in table 4. Its clear that proposed SDRA has higher gain. The proposed antenna has get better radiation quality.

## V. CONLCUSION

The proposed SDRA structure is simply and easily to be fabricated.The SDRA designed at 5.8 GHz.The SDRA has impedance bandwidth 7% and a gain 10 dB.The SDRA Return loss is -26dB. The proposed SDRA is well used for in 5G or wireless communication system.The far fields formulations have also been developed. The quality factor for microwave spherical DRA has been formulated. The main objective of the antenna design is to capture useful signals available in the surrounding in the range of microwave frequency and utilizes the same for various 5G applications in the different fields.

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# Figures

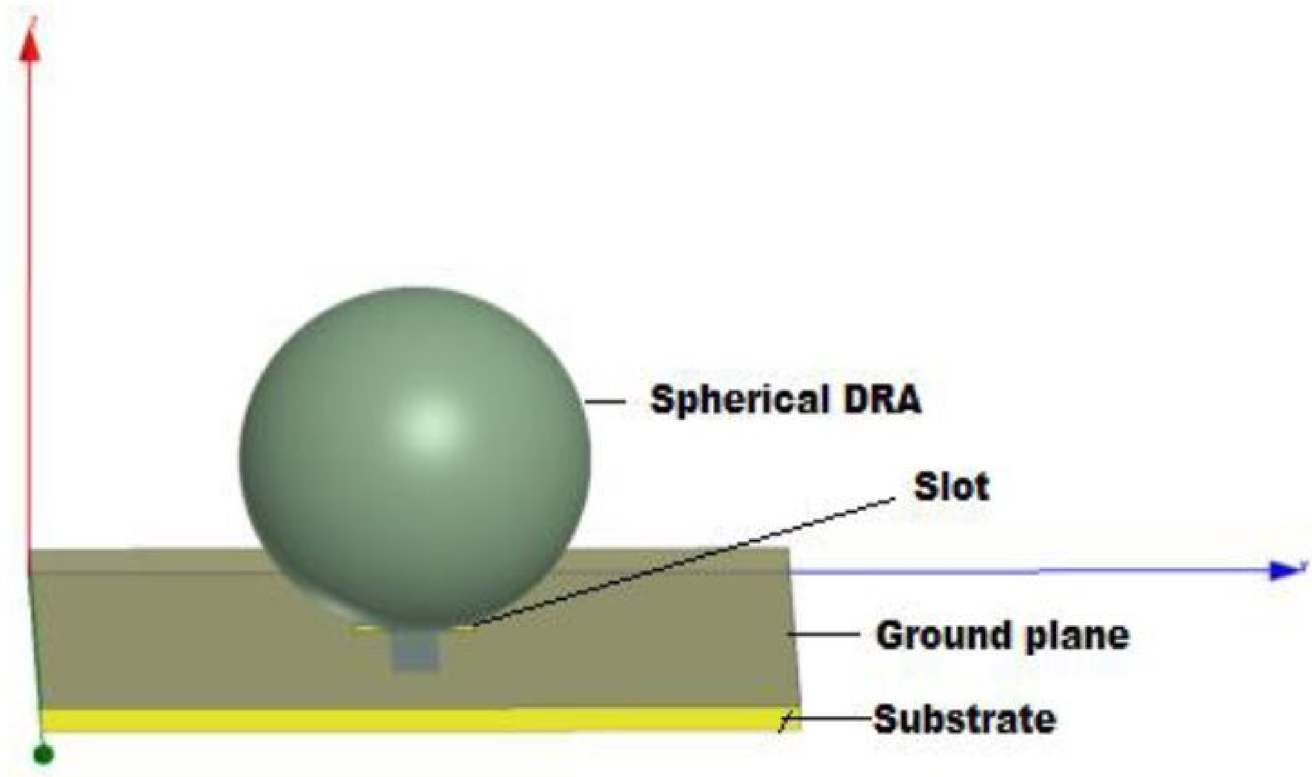


**Figure 1**

Spherical DRA

**Figure 2**

Spherical DRA

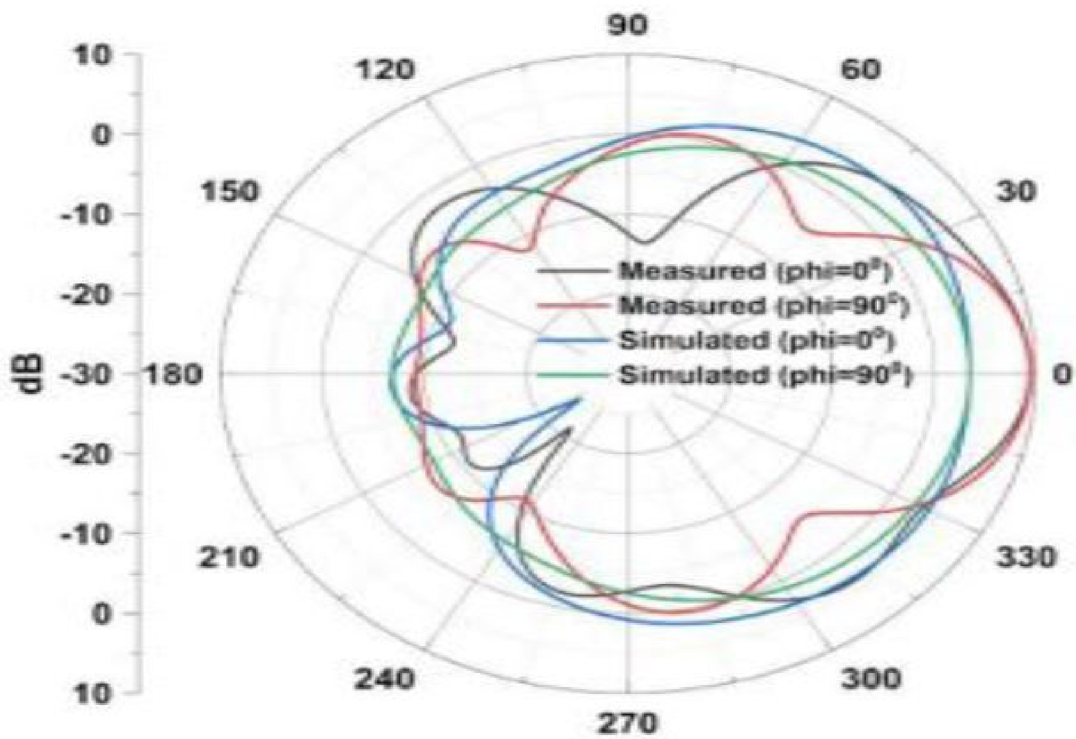


**Figure 3**

Gain measured & simulated of Spherical DRA

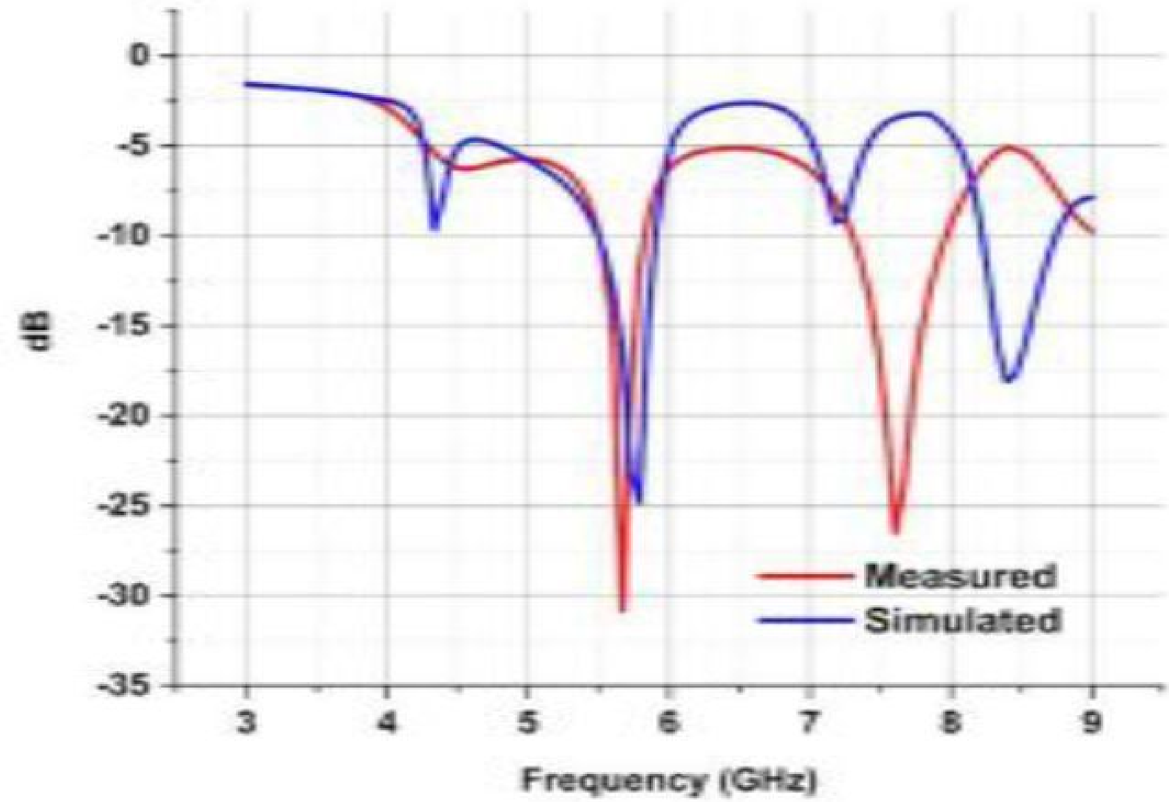


Figure 4

Return loss measured and simulated of Spherical DRA

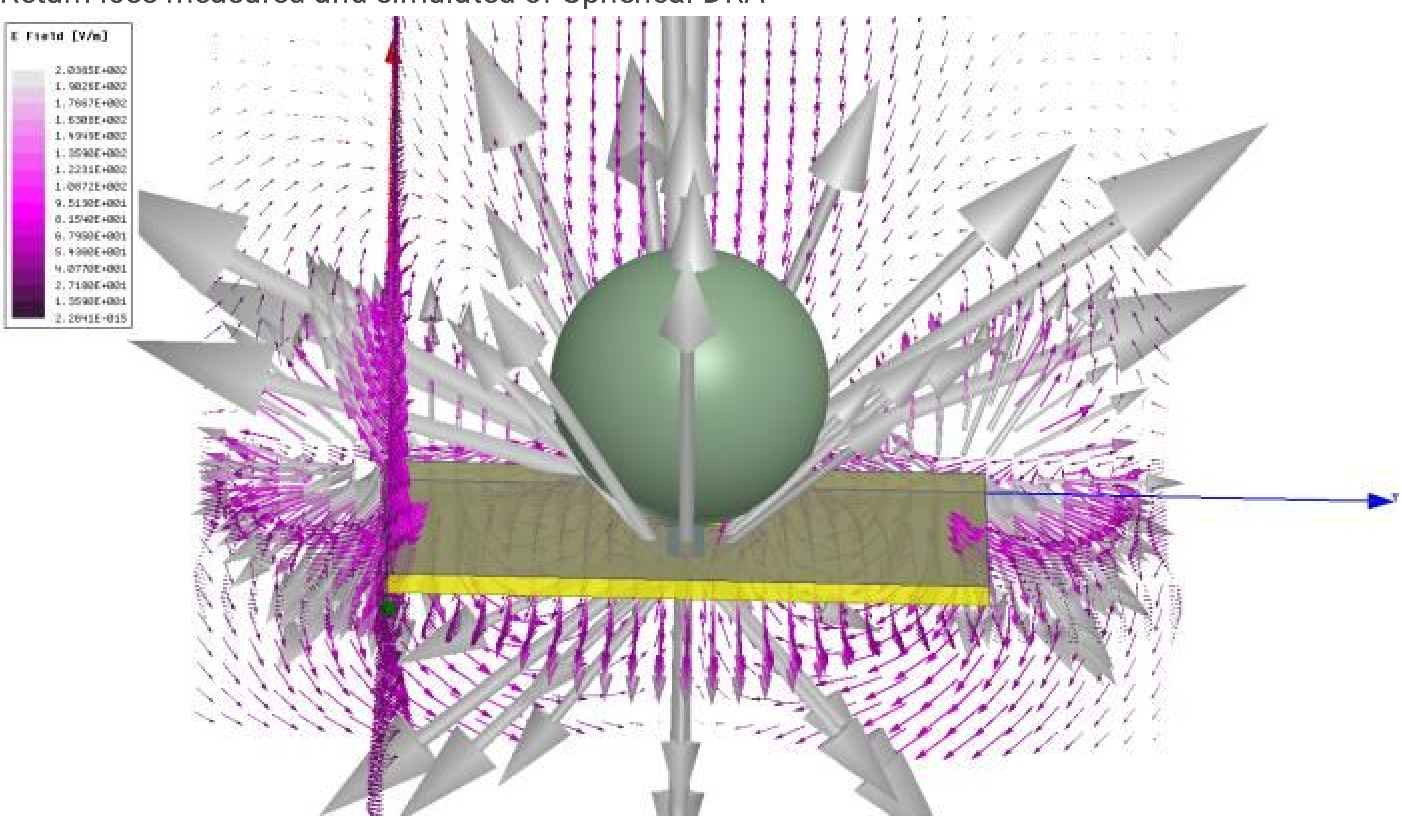

**Figure 5**

E field in spherical DRA

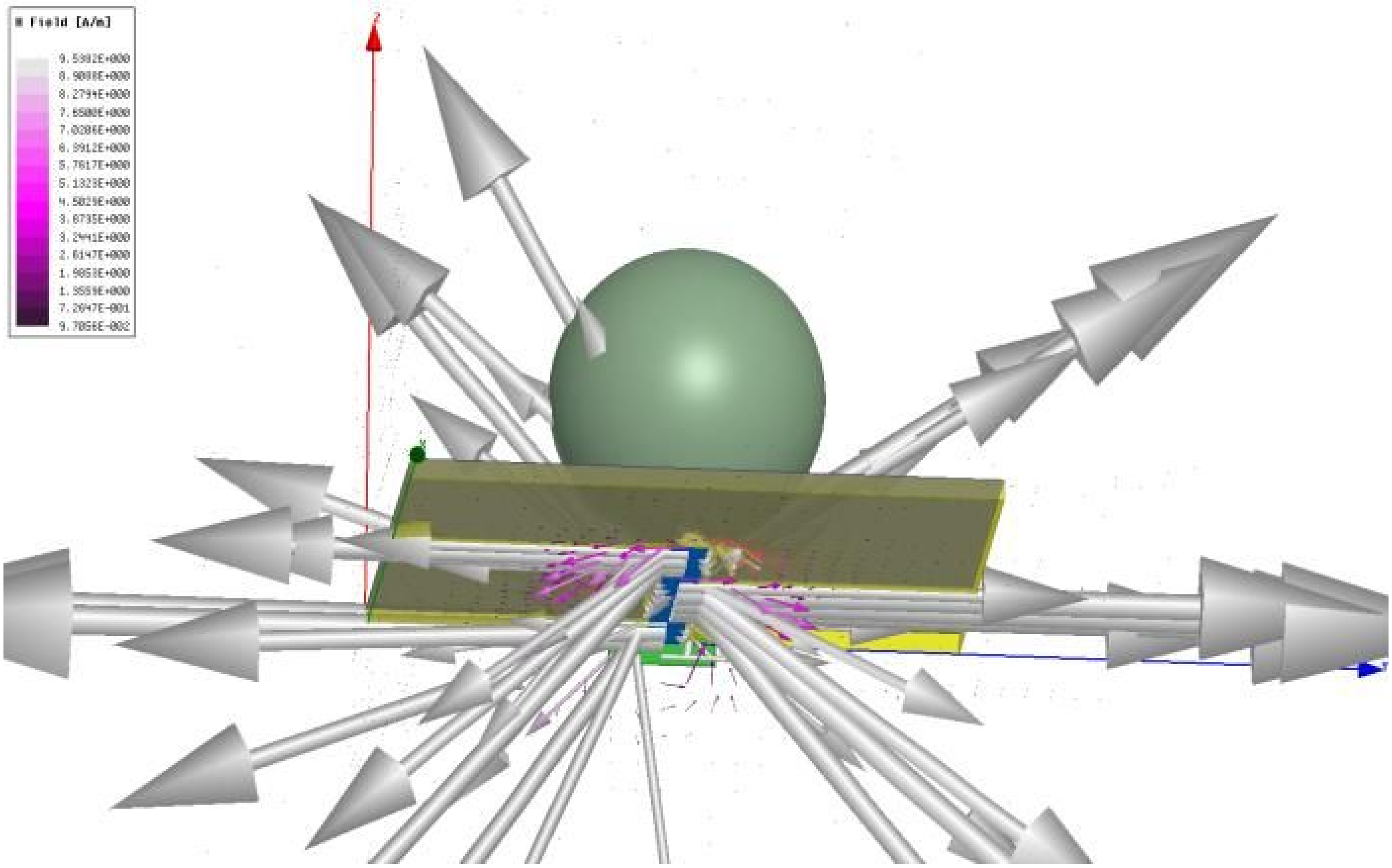


**Figure 6**

H - field in spherical DRA