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Dielectric and Dimensional Optimized Hemispherical Dielectric Resonator Antenna for Ultra-Wide Band Communications

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Abstract: - Various research teams have investigated a number of novel hybrid-type monopole-DRA variations, always concentrating on increasing the impedance bandwidth and continuously preserving monopole-like radiations. Out of various structures, hemispherical dielectric resonator antenna (HDRA) has been investigated for better bandwidth and gain. The present paper addresses the effect of different factors such as dimensions, and dielectric constant on influencing the bandwidth and gain of HDRA. By systematically varying the radius and the dielectric constant of the material of the hemisphere and, using iterative simulations and analysis, a newly designed HDRA with desired bandwidth and gain is developed. The developed HDRA structure shows a bandwidth that spans from 5.9 to 23 GHz, with a percentage of bandwidth of 118.34% and a gain of around 6 dB at 21.7 GHz. All results of the simulations were validated by HFSS software. The proposed HDRA can be used for ultra-wideband and long-distance satellite communication.

Keywords: Dielectric Resonator Antenna, Wideband, HDRA, Microwave Antenna

INTRODUCTION

An antenna is a reciprocal passive device and acts as an important component in communication systems. It serves as the interface between electromagnetic waves propagating through space and electrical signals in a circuit. Various antenna types, including wire, aperture, lens, reflector, microstrip patch, and Dielectric Resonator Antenna (DRA), are made for particular uses, frequencies, and performance requirements [1]. A Dielectric Resonator is a non-metallic, high-permittivity material that confines and resonates electromagnetic fields [2]. Unlike traditional metallic antennas, dielectric resonators use the dielectric constant of the material to support resonant modes that radiate efficiently.

Dielectric resonator antennas are commonly shaped as cylindrical, hemispherical, spherical, or rectangular. Over the past ten years, electric monopole and dielectric ring resonator (DRR) hybrid topologies have gained recognition as a feasible solution for creating small monopole antennas with wideband or ultra wideband operation [3]. Various research teams have investigated a number of novel hybrid-type monopole-DRA variations, always concentrating on increasing the impedance bandwidth while preserving monopole-like radiations[4]. Hemispherical Dielectric Resonator Antennas (HDRAs) are a specific type of dielectric resonator antenna (DRA) characterized by their hemispherical shape. An antenna consisting of a resonant dielectric hemisphere on top of a ground plane is investigated in [1]. The hemispherical design provides stable performance with nearly omni-directional radiation patterns, making it suitable for ultrawideband (UWB) and millimeter-wave applications, such as 5G, satellite, and military communications. Its simplicity in shape also allows for easier integration into compact devices. The current trend and state-of-the-art dielectric resonator antenna is discussed in a recent book authored by Petosa[5]. The reports of Guha et al [4,8,9] on hybrid monopole DRA with hemispherical dielectric ring resonator having ultra-wideband is the root of the development of a newly designed hemispherical DRA. A systematic optimization of radius and dielectric constant of HDRA has not been investigated. Table 1 shows the development of HDRA with bandwidth characteristics. The present paper optimized the radius and dielectric constant of HDRA for improved gain and bandwidths. Various simulations were conducted and best results are optimized.

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Table 1 state of the art of Hemispherical DRAs

Year	Structure investigated	ε_r	BW (-10dB)
2013	Cup - Shaped Inverted Hemispherical DRA [11]	9.2	83%
2013	Half Hemispherical Dielectric Resonator Antenna with Array of Slots [12]	9.2	29%
2014	Hemispherical DRA Based on Apollonian Gasket of Circles [13]	9.2	47%
2015	Half Hemispherical DRA with Array of Slots loaded with a Circular Metallic Patch [14]	9.2	18%
2019	Compact and Circularly Polarized Hemispherical DRA [15]	4.3	57%
2020	New Sectored Hemispherical DRA Operating at TM_{101} and TE_{111} Mode for Circular Polarization [16]	9.8	47.4%
2020	Circularly Polarized Single Feed Hemispherical DRA [17]	9.8	27.379%
2020	Wideband High-Gain Millimetre-Wave Three-Layer Hemispherical DRA [18]	20,10 and 3.5	35.8%
2022	Wideband mm - Wave Hemispherical DRA [19]	9.9	33.33%

ANTENNA DESIGN

A modified version of hemispherical DRA is developed based on the previous literature reports. The investigation was started with design parameters as used in [4]. Initially, the dielectric constant of the material of the hemisphere was chosen to be 10, the radius of the hemisphere was 5 mm, the length of the monopole 11mm, and the radius of the monopole 0.65mm. The cross-sectional view of the present HDRA with the monopole and the ground plane is shown in Fig 1.

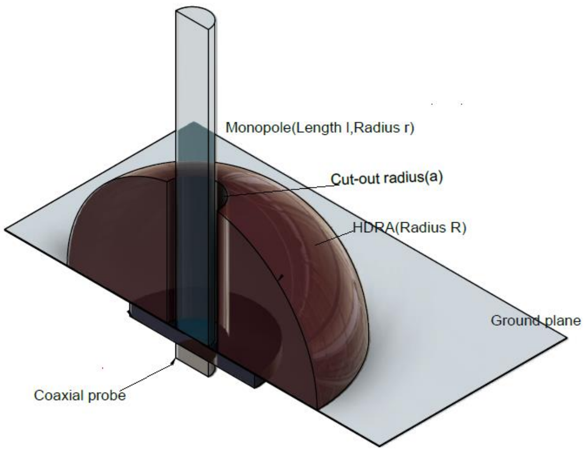


Fig 1: Cross-sectional view of HDRA

An extensive study of different characteristics of hemispherical DRA was done by varying the radius of the hemisphere and dielectric constant of the material of the developed HDRA. HFSS software has been used to generate simulation data which have been interpreted in steps. The table 2 shows the possible variations in the parameters such as radius and dielectric constant. High frequency structure simulator software was used to optimize the design of antenna for best band width and gain.

No	Parameters	Range of variation
1.	Radius of the Hemisphere (R)	3-8 mm
2.	Dielectric constant of the material	6-12
3.	Length of the monopole(l)	11mm (fixed)
4.	Radius of the monopole (r)	0.65mm (fixed)
5	Cut-out radius (a)	1.5mm

Table 2. Parametric variations in the present HDRA design

SIMULATION RESULTS AND DISCUSSIONS

The study was done in the frequency range 5 to 30 GHz by varying the radius of the hemisphere, dielectric constant of the material of the developed HDRA. Simulations were done for the above range of values and best results were optimized using the S_{11} characteristics. The percentage bandwidth was then calculated using the formula

$$\% BW = [(f_U - f_L) / ((f_U + f_L)/2)] * 100 \quad (1)$$

Table 3. Optimization of proposed HDRA for dimension keeping dielectric constant Ɛr of 10

HDRA Code	Radius Of HDRA (mm)	F_L (GHz)	F_U (GHz)	% Bandwidth
HDRA 03	3	5.8	8	31.9
HDRA 04	4	5.8	8.9	42.2
HDRA 05	5	5.8	22	116.5
HDRA 06	6	6	13.1	74.3
HDRA 065	6.5	6	12.4	69.6
HDRA 07	7	6	9	40
HDRA 075	7.5	6	8	28.6
HDRA 08	8	6	7.4	20.9

Table 3 shows the simulation results for changing the radius of the hemisphere, keeping the dielectric constant fixed at 10 in a frequency range of 2GHz to 30GHz.The return loss characteristics (S_{11}) for all the above combinations are plotted together and is shown in Fig 2. It is found that the HDRA05 with a radius of 5 mm and dielectric constant of 10 shows the best result of bandwidth of 116% with nearly 4:1 ratio. The S_{11} characteristics of the optimized HDRA is shown in Fig. 3. It is reported that the monopole alone gives a two resonance in the frequency range of 2 GHz to 30 GHz[4]. In the cylindrical DRA design, Guha et al [4] reported that the dielectric medium near the monopole alters the field configuration and induces a third resonance. The middle resonance in Fig 3 confirms the above reports. However, it can be concluded from the graph that the increase in the dielectric vicinity near the monopole decreases the bandwidth. Thus, the radius of the HDRA is optimized to 6 mm for the dielectric constant of 10.

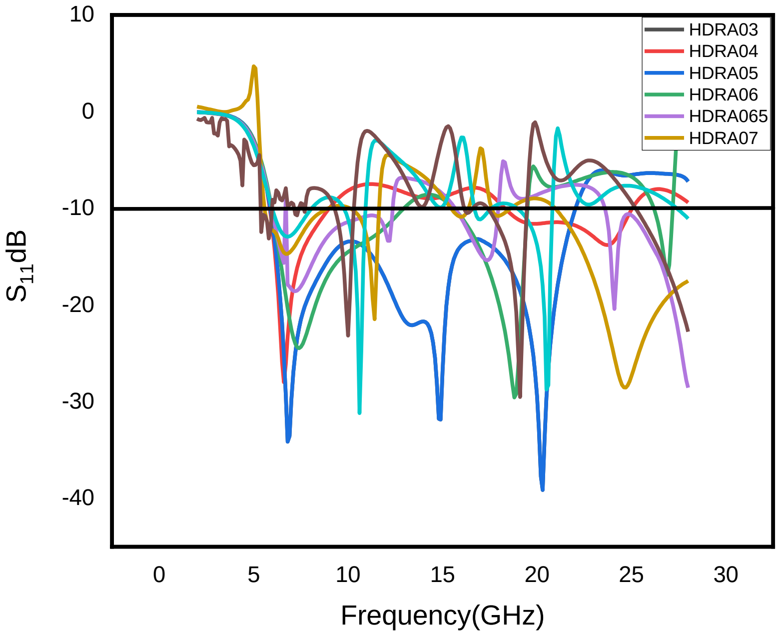


Fig 2: The optimization of HDRA design with return loss characteristics.

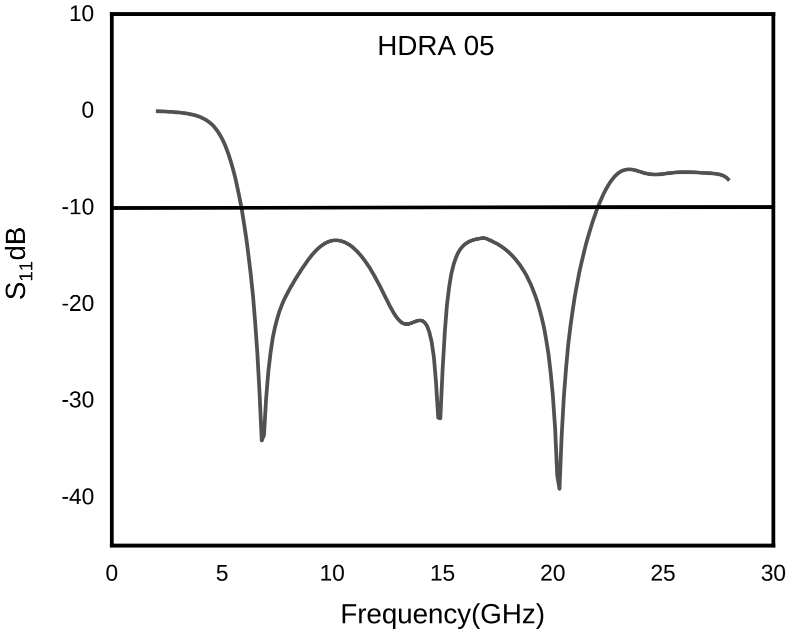


Fig 3. The Return loss characteristics of optimized HDRA

Table 4. Optimization of proposed HDRA for different dielectric constant (Ɛr) keeping the radius 5mm.

HDRA Name	Dielectric constant	F_L (GHz)	F_U (GHz)	% Bandwidth
HDRA 09	6	5.8	17.6	100.85
HDRA 10	8	5.9	23	118.34
HDRA 11	10	5.8	22	116.55
HDRA 12	12	5.9	21.2	112.91

Further simulations were conducted by keeping the radius as 5mm and changing the dielectric constants for the frequencies 2 to 30 GHz . The table 4 shows simulation results for changing the dielectric constant of the material keeping radius of the hemisphere constant. The return loss characteristics of the above combinations are also plotted together and is shown in Fig 4. It is found that the for the dielectric constant of 8, the HDRA design shows a band width of 118%. It also worth to note that the HDRA design with dielectric constant 10 also shows a band width of 116.6%. It is found that relatively large band with are observed for both the dielectric constant of 8 and 10. Hence the small tolerance the dielectric constant does not affect the return loss characteristics of HDRA considerably, which gives us the flexibility in the fabrication HDRA. From the above results it is clear that the optimised design is HDRA10.

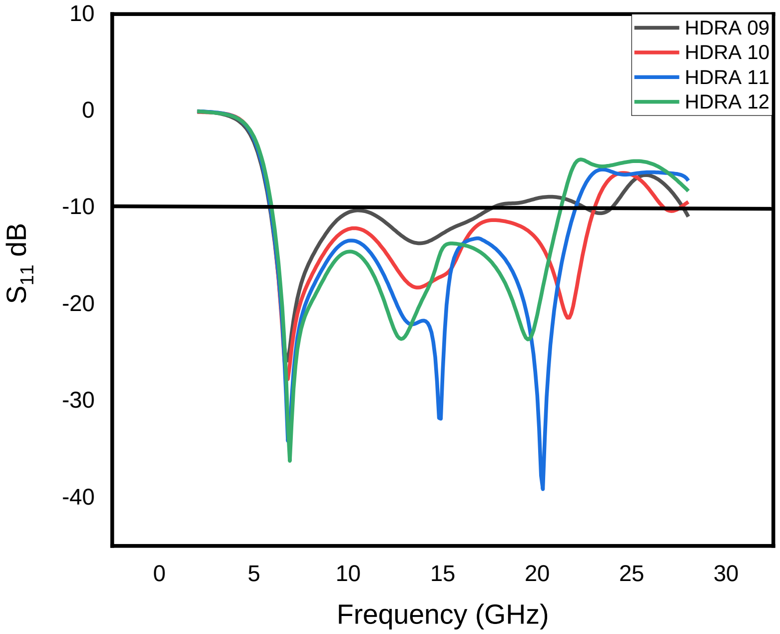


Fig 4. The return loss characteristics of HDRA for different dielectric constant.

The HDRA with dielectric constant of 8, radius of hemisphere as 5mm, length of monopole as 11mm and radius of monopole as 0.65mm shows a percentage bandwidth of 118.34 in the frequency range 5.9 to 23 GHz.The gain plot of the HDRA10 for different resonant frequencies is shown in fig 5. The highest gain is observed is 6dB for the frequency 21.6 GHz and around 3 dB gain for other resonant frequencies.

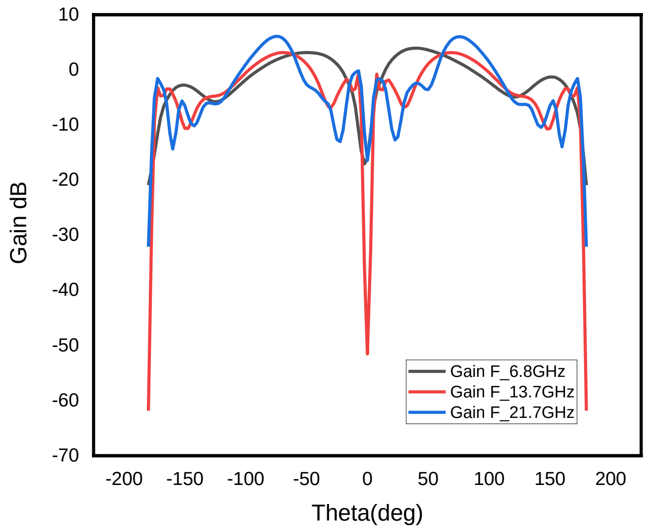


Fig 5: Gain plot of HDRA10 for different resonant frequencies

The Smith chart of the optimized HDRA 10 is shown in figure 6. It is clear that the VSWR is less than 1 in the frequency range 5.9 GHz to 23 GHz. The co-pole and cross pole radiation patterns for different resonant frequencies are also shown in figure 7.

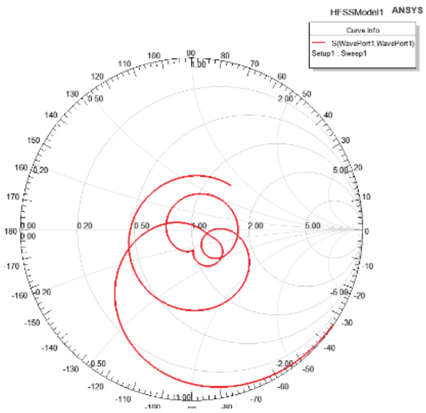
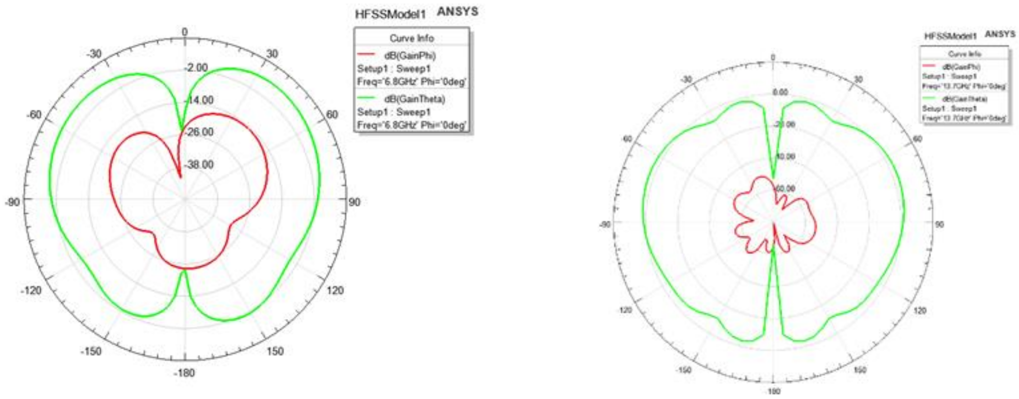


Fig 6: Smith chart of HDRA10



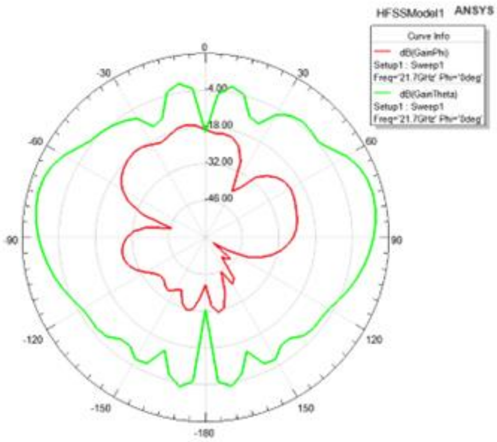


Fig 7: co-pole and cross-pole radiation patterns at different resonant frequencies

The results suggest that the Hemispherical DRA has a relatively stable performance across the tested frequencies, with good impedance matching and manageable levels of cross-polarization. The directional patterns in the radiation plots show consistency across the frequencies, indicating that the antenna can be effective in applications needing broad frequency coverage without significant alterations in its directional characteristics.

CONCLUSIONS

The design and simulation of Hemispherical Dielectric Resonator Antenna (HDRA) presented here have demonstrated the significant potential and versatility of DRAs in modern communication systems. A parametric optimization HDRA in terms of radius of HDRA and dielectric constant were done. The best result is observed with dielectric constant of the material 8, radius of the hemisphere 5mm, length of the monopole 11mm and radius of the monopole 0.65mm. The HDRA 10 shows an excellent band width of 118% in frequency range of 5.9 GHz to 23 GHz with a gain of 6 dBi at 21.5GHz. The proposed HDRA can be a promising candidate in telecommunication industry for ultra wide band and EMI sensing applications.

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