Wideband Cylindrical Dielectric Resonator Antenna Operating in $HEM_{11\delta}$ Mode With Improved Gain: An Effect of Superstrate and Parasitic Sheet

Sounik Kiran Kumar Dash and Taimoor Khan*
Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Assam, India

Abstract

A compact slot-coupled dielectric resonator antenna is designed, fabricated, and characterized. A narrow transparent non-metal superstrate and parasitic sheets are used to improve the far-field characteristics like: gain, co-pol and cross-pol. The antenna operates over 17.71% bandwidth (6.95-8.3) GHz with ~8 dBi peak gain and at the same time it maintains a separation of 45 dB, 20 dB between co-pol and cross-pol in H-plane and E-plane, respectively. The efficiency of the proposed antenna is above 85% in the operating band. The measured results shows fairly good matching with their simulated counterparts. The performance of the antenna shows its potential for X-band wireless applications.

1. Introduction

Recently dielectric resonator antenna (DRA) has become the point of analysis among the antenna researchers for wireless applications [1-3]. The low loss, high radiation efficiency, wideband, three-dimensional design as well as excitation flexibility, etc. are the main advantages behind its popularity. From the day of its inception in 1983 to till now, it has been updated a lot for various applications [3-4]. However, sometimes it faces application restraints because of moderate gain ~5dBi [5]. So different methods like stacking [6], EBG [7], surface mounted horn [8], superstrate [9], etc. have been proposed for gain improvement. Though all of these methods are considered as effective in terms of improving the gain, still they deal with some lacunas like, stacking of DR [6] affects the Q-factor, hence performance, realization of EBG [7] in ground plane substrate needs high precision and becomes costlier. In case of [8], the weight of metal sheet may cause application limits for some space applications. Among these techniques, superstrate approach, like [9], is probably considered as simple in terms of performance and economic fabrication. However, the reported one [9] was designed for 3.7 GHz applications and the physical size is also large. So the gaps of [6-9] need to be addressed properly.

Keeping these points in mind, authors have proposed and designed a cylindrical shaped dielectric resonator covered by a narrow dielectric superstrate. The outcome of this proposal can be considered as; i) ~50% improvement of gain and reached to ~8 dBi peak value, ii) wide impedance band of 17.71%, iii) high co-to-cross pol ratio of >45 dB, iv) compact size, and (v) economic fabrication process, zero maintenance, and compact size. The organization of this paper is as follows; the proposed antenna configuration is shown in Section II. Design and analysis followed by prototype and characterization is shown in Section III and Section IV respectively. Finally the concluding remark is given in Section V followed by references.

2. Proposed Antenna Configuration

The proposed antenna model is depicted in Figure 1. A FR4 sheet ($a = b = 40$mm) of $\varepsilon_r = 4.4$ and 1.6 mm thickness is used for ground plane substrate. One square slot ($l_1 = w_1 = 5$mm) is made on the top side of the ground plane substrate while a microstrip feed line ($l_2 = 24$mm, $w_2 = 2$mm) is made on the opposite side of the slot. A set of parasitic sheet of each ($l_3 = 20$mm, $w_3 = 17$mm) made on either side of the feed line. A dielectric resonator ($r = h = 5$mm) of $\varepsilon_r = 10$ is placed above the slot. Another FR4 sheet ($p = 40$mm, $q = 20$mm) of $\varepsilon_r = 4.4$ and 1.6 mm thickness is placed above the DR at an air gap of $g = 2$ mm. This model is first simulated using commercial FEM solver HFSS v17.2 and then prototyped using standard economic engineering process.

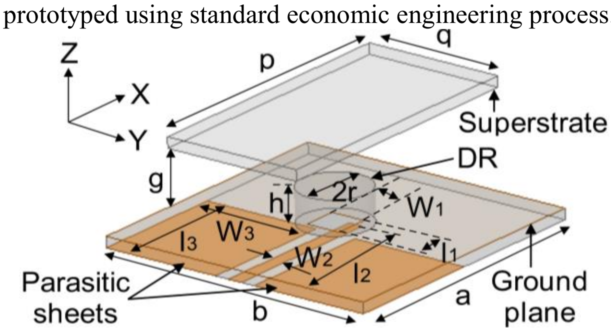


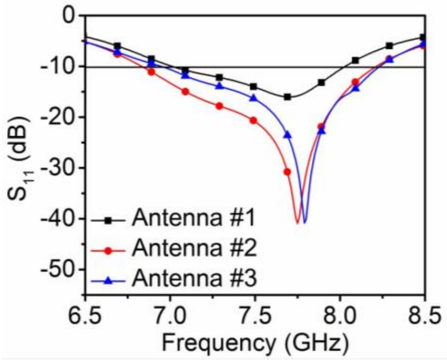
Figure 1. Schematic diagram of the proposed antenna.

3. Design and Analysis

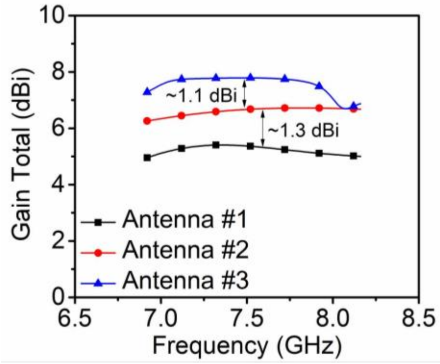
This proposed antenna is developed in three different stages, like: standalone DRA (Antenna #1), DR with superstrate (Antenna #2), and DR with superstrate and parasitic sheet (Antenna #3). This study begins with a standalone cylindrical DR ($\varepsilon_r = 10$) of $r = h = 5$mm placed over a square-slot of $l_1 = w_1 = 2$mm and fed by a microstrip feed line of specified dimension as stated in Section 2. Then the resonant frequency is calculated as 7.9 GHz using eqn. (1), which further signifies the excitation of hybrid $HEM_{11\delta}$ mode. To reach the proper 50Ω matching near 7.9 GHz, the dimension of slots are varied between 1mm-to-7mm and fixed at $l_1 = w_1 = 5$ mm.

$$f_{r(HEM_{11\delta})} = \frac{c}{2\pi r} \times \frac{6.324}{\sqrt{\varepsilon_{rd}+2}} \times \left[0.27 + 0.36\left(\frac{r}{2h}\right) + 0.02\left(\frac{r}{2h}\right)^2\right] \tag{1}$$

The parametric study of l_l and w_l for matching as well as gain are not shown here for brevity. At this condition antenna operates over 13.56% bandwidth (7.01-8.03) GHz and 5.4 dBi gain [Figure 2]. This antenna is considered as Antenna #1. Next to this, the dimensions of the ground plane are also varied just to cross verify that, the antenna resonance only depends upon DR dimension. However, these results are not included for brevity.



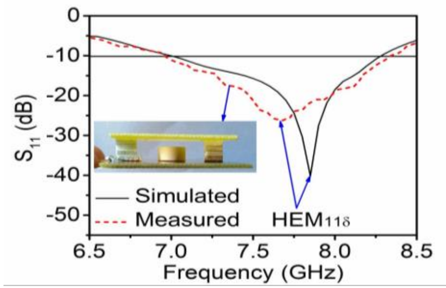
(a)



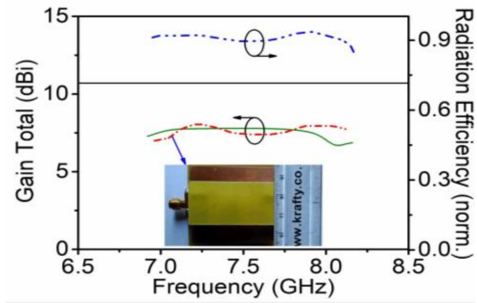
(b)

Figure 2. Comparison of different types of configurations in terms of (a) S_{11}, (b) gain total.

It is known that, a metallic/non-metallic superstrate has distinctive effect on far-field characteristics [1-2]. Hence, a dielectric ($\varepsilon_r = 4.4$) FR4 sheet (length (p) = width (q) = 40mm) and thickness of 1.6 mm is placed above the DR at a random height of $g = 5$ mm. To optimize the gain and S_{11}, certain tuning process was applied for length (p) and width (q). Both p and q were varied between 20mm-to-40mm with a step-size of 10mm. Total sixteen number of such combinations of p and q, are examined for gain total observation and found that, the gain becomes stronger while the superstrate is oriented along X-axis of XY-plane [Figure 1]. Finally, a peak gain of 6.72 dBi is obtained at p = 40mm and q = 20mm. This configuration (Antenna #2) also increases the bandwidth to18.21% [Figure 2]. In the third phase, a set of rectangular parasitic sheet is made on either side of the feed line (Antenna #3). This improves the coupling energy into the DR as well as improves the far-field characteristics, which results 7.85dBi gain and 16.86% bandwidth [Figure 2].



(a)



(b)

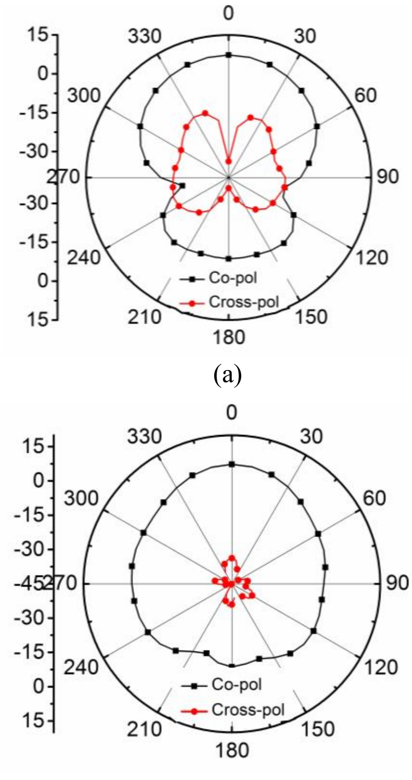
Figure 3. Comparison of simulated and measured results; (a) S_{11}, (b) gain total, and only simulated radiation efficiency in (b). [Inset of (a) and (b) shows the side and top view of the prototype respectively]

4. Prototype and Characterization

The fabricated prototype is shown in the insets of Figure 3. Eccostock HiK dielectric rod ($\varepsilon_r = 10$, tan $\delta = 0.002$) is used for shape out the required DR. The required ground plane and superstrate substrate are made from FR4 sheet of ($\varepsilon_r = 4.4$, tan $\delta = 0.04$). Copper removal technique is applied to create the feed, slot, and other requisites of the proposed superstrate. After properly placing of all the parts, the model is characterized for S_{11}, gain total and radiation patterns. The measured results shows fairly good matching with their respective simulated ones [Figure 3(a), Figure 3(b)]. The measured S_{11} was found to operate over (6.95-8.3) GHz (i.e. 17.71% BW) with ~8 dBi peak gain. The reason behind the variation between the simulated and measured results could be; variation of loss tangent between the simulated and the fabricated ones, and effect of unconsidered soldering and foam spacers. The simulated radiation patterns are shown in Figure 10. A separation of about 45 dB between the co-pol and cross-pol is obtained in in H-plane, while this is 20 dB in E-plane. It can be noted that, during the operation the antenna promises ~ 90% radiation efficiency [Figure 3(b)]. The performance comparison of all antennas are shown in Table 1.

Table 1. Comparison of All Three Antennas

Antenna		Bandwidth	Gain	Effi.
#1		(7.01-8.03)GHz, 13.56%	5.4 dBi	~90%
#2		(6.84-8.21) GHz, 18.21%	6.72 dBi	~90%
#3	Sim.	(6.95-8.23) GHz, 16.86%	7.85 dBi	~90%
	Mea.	(6.95-8.3) GHz, 17.71%	~8 dBi	NA



(a)

(b)

Figure 4. Simulated radiation pattern at 7.8 GHz; (a) E-plane, (b) H-plane.

5. Conclusion

A wideband dielectric resonator antenna is investigated for gain improvement. The effect of superstrate and parasitic sheet on gain is properly addressed. It can be noted that, the superstrate has more influence on gain when it is oriented in the direction of antenna polarization. The measured results shows 17.71% wide impedance bandwidth and ~8dBi peak gain. The fabrication and implementation of this proposed one is quite simple and economic than those existing ones. This antenna can be suitable one for X-band applications, once appropriate scope is created.

6. References

1. A. Petosa, Dielectric Resonator Antenna Handbook, Norwood, MA, USA: Artech Publication House, 2007.

2. S. K. K. Dash, T. Khan, and A. De, "Modelling of dielectric resonator antennas using numerical methods: A review," J. *of Microwave Power and Electromagnetic Energy*, **50**, 4, 2016, pp. 269-293, doi: 10.1080/08327823.2016.1260677.

3. S. K. K. Dash, T. Khan, and A. De, "Dielectric resonator antennas: An application oriented survey," *Int. J. RF Microw. Comput. Aided Eng.*, 2016, doi:10.1002/mmce.21069.

4. S. A. Long, M. McAllister and Liang Shen, "The resonant cylindrical dielectric cavity antenna," *IEEE Trans. Antennas Propag.*, **31**, 3, May 1983, pp. 406-412.

5. Y. Pan and S. Zheng, "A low-profile stacked dielectric resonator antenna with high-gain and wide bandwidth," *IEEE Antennas Wireless Propag. Lett,* **15**, 2016, pp. 68-71.

6. Y. Hwang, Y. Zhang, K. Luk, and E. Yung, "Gain-enhanced miniaturized rectangular dielectric resonator antenna", *IET Electron. Lett,* **33**, 5, February 1997, pp. 350-351.

7. T. A. Denidni, Y. Coulibaly, and H. Boutayeb, "Hybrid dielectric resonator antenna with circular mushroom-like structure for gain improvement", *IEEE Trans. Antennas Propag.*, **57**, 4, April 2009, pp. 1043-1049.

8. Nasimuddin and K. P. Esselle, "A low profile compact microwave antenna with high gain and wide bandwidth," *IEEE Trans. Antennas Propag.*, **55**, 6, June 2007, pp. 1880–1883.

9. K. Dutta, D. Guha, C. Kumar and Y. M. M. Antar, "New Approach in Designing Resonance Cavity High-Gain Antenna Using Nontransparent Conducting Sheet as the Superstrate", *IEEE Trans. Antennas Propag.*, **63**, 6, June 2015, pp. 2807-2813.