Realization of Dielectric Sheets for Gain Improvement of Ultra-Wideband Horn Antennas Using 3D Printer Technology

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Abstract **─** In this work, 3D printing technology had been used to prototyped 10 dielectric sheets with relative dielectric constant of 2.5 for gain improvement of a TEM horn antenna. By loading the 3D printed dielectric sheets to the aperture of the horn antenna it is achieved to improve the radiation performance of the antenna over an ultra-wide operation band of 2-13 GHz. Here the Periodic dielectric sheets are designed to function similarly to a dielectric lens for focusing the incoming electromagnetic waves to increase directivity properties, while keeping their mismatching characteristics with less size and low manufacturing cost compared to its counterpart lens designs. The dielectric sheets had been prototyped via the use of 3D printing technology for experimental measurements. The measured performance of the proposed 3D printed dielectric loaded TEM horn antenna is compared with its counterpart ultra-wide band gain improvement methods for horn antennas in literature. From the measured results of the prototyped module, not only the proposed 3D printed dielectric sheets are smaller and have lower cost compared to their counterpart designs but also achieves to improve the gain characteristics of the antenna design over an ultra-wide band operation band without a distortion on antenna's S_{11} characteristics.

Index Terms **─** 3-D printer, dielectric sheets, gain improvement, horn antenna.

I. INTRODUCTION

The gain performance of a horn antenna design is usually based on design size. For achieving a horn antenna design with high gain performance usually can be achieved with a heavy, bulky, and either impractically long or high cost designs, especially in case of application at low band [1-2]. One of the methods to reduce the size of a horn antenna is increasing the flare angle, however this would cause large quadratic phase error at the aperture, resulting in increase of radiation patterns beam width. In literature there are different studies on preventing the quadratic phase error by placing frequency selective surfaces, metamaterials or by dielectric lens structure to the aperture of the design [3-5].

Dielectric lenses are used in the microwave area as glass lenses are used in the optical field [6]. Dielectric lenses modifies the antennas radiation pattern thanks to their ability to focus the electromagnetic waves. For gain enhancements, dielectric lens structures converts the incoming quasi-spherical wave into near plane wave. In literature there are many types of microwave lens designs for antenna gain improvement where various types of shapes, material either 2-D or nonplanar 3-D structures had been used [7-13].

Due to their phase error, single mode horn antennas has the disadvantage of poor aperture efficiency. By adding a dielectric lens structure to the aperture of a horn antenna it is possible improve aperture efficiency of the design [14-16]. Also dielectric lenses can also be used to change the aperture phase for the reduction of side lobes [17]–[19].

Herein, design and realization of 3-D printed periodic Dielectric Sheets (DS) for ultra-wideband gain enhancement of horn antennas is studied. The main goal of work is to design and realize a low cost DS design that can be prototyped using 3-D printer technology in order to improve radiation performance of a horn antenna design over the operation band of 2-13 GHz without any distortion in S_{11} characteristics. For this purpose 10 layers of 3-D printed dielectric plates are placed in the aperture of a horn antenna.

In the next section the design, simulation and prototyping of the DS are presented. After that, the measurement results of the 3-D printed Dielectric Sheet Loaded Horn Antenna (DSLHA) are investigated, finally paper ends with conclusion section.

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II. DESIGN AND FABRICATION OF DIELECTRIC SHEETS LOADED HORN ANTENNA

In this section, firstly an exponentially TEM horn antennas operates within the bandwidth of 2-13 GHz (Fig. 1) is taken for both simulation and measurement test of the 3-D printed dielectric lens's. The design parameters of the antenna are given in Table 1.

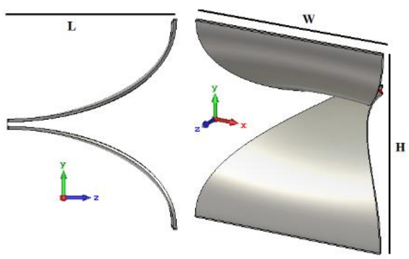


Fig. 1. Exponentially tapered TEM.

Table 1: Parameters of TEM horn antenna in (mm)

Aperture		**Length**
Width	**Height**	
74	73.5	60

The next element of the module is the DS element. As it mentioned before dielectric loaded horn antenna designs are based on integration of a dielectric material based lens structures and horn antennas for focusing the incoming electromagnetic waves. The proposed 3-D printable DS is shown in Fig. 2. The design consists of 10 parallel placed DS in front of the antenna. The dielectric constant of DS structures are ε_r = 2.5 with thickness value of *hs*. Also the DS units has an air gap distance of *d*. the optimal geometric parameters values for the proposed DS module are given in Table 2.

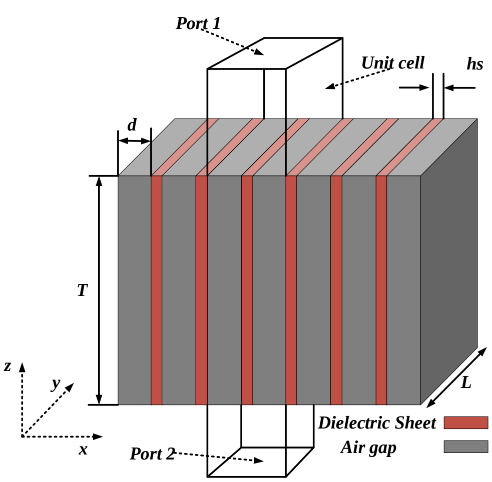


Fig. 2. Proposed DS model for DSLHA module design.

Table 2: Design parameters of dielectric sheet

T	25 (mm)	**h_s**	1.8 (mm)
L	73.5 (mm)	**Air gap (d)**	6.2 (mm)
Substrate	PLA 73%, ε_r = 2.5		

In Fig. 3 simulation setup of the DSLHA is presented. The simulated S_{11} ad gain of two antennas are shown in Fig. 4. As It can be seen from the simulation results both antennas have similar simulated bandwidths for S_{11}<−6 dB, thus using the 3-D printed DS for gain improvement has no distortive effect on S_{11} characteristics. As it can be seen from Fig. 4 (b), the proposed DSLHA module has a simulated gain values of almost 14 dB while the TEM horn antenna achieves almost 10 dB gain at 8 GHz frequency. In Fig. 5, the simulation results of far field gain of both antenna design are presented.

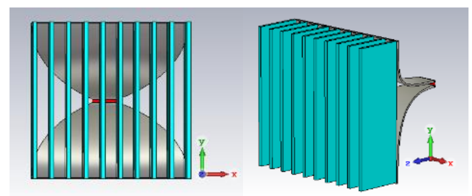


Fig. 3. Proposed module.

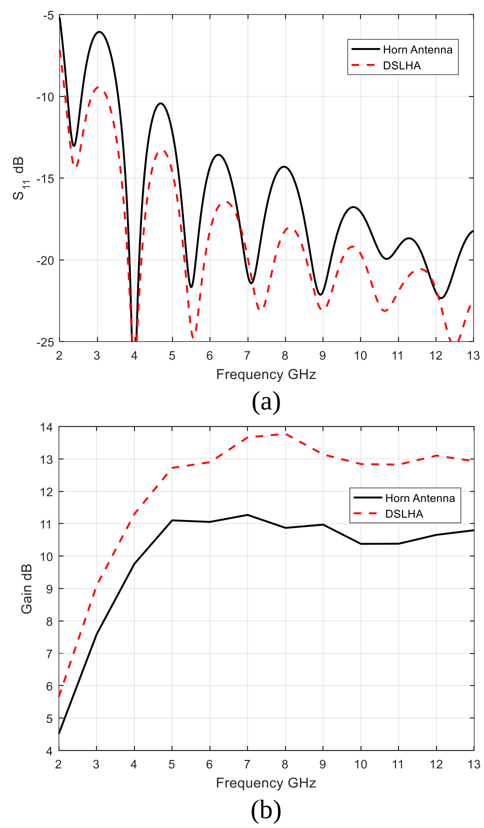
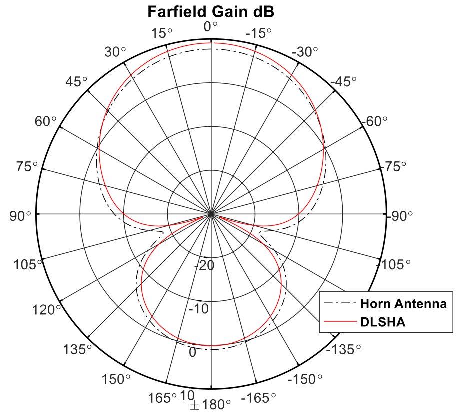
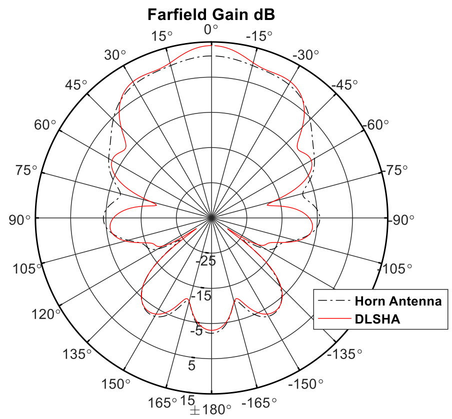


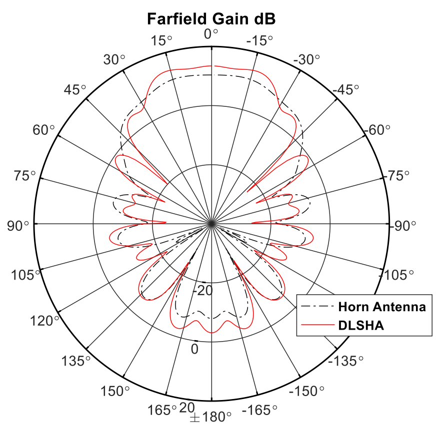
Fig. 4. Simulated (a) S_{11} and (b) gain



(a)



(b)



(c)

Fig. 5. Simulated far field gain at: (a) 3, (b) 8, and (c) 12 GHz.

III. MEASUREMENT

The measurement setup and results of the DSLHA are given in this section. Figure 6 gives the prototyped TEM horn, 3-D printed Dielectric sheets, DSLHA and the measurement setup set-up in the laboratory environment.

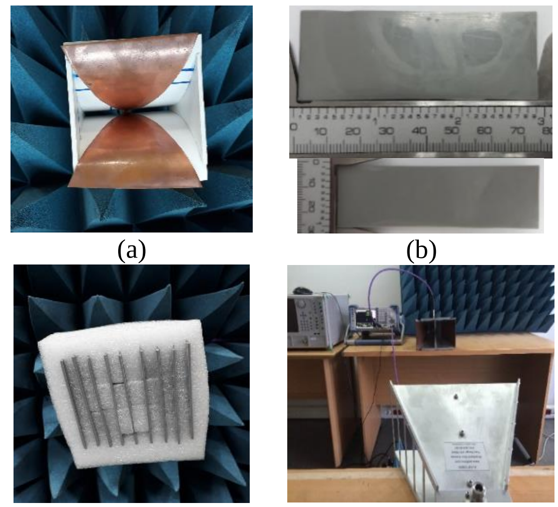

(a) (b) (c) (d)

Fig. 6. (a) Prototyped TEM horn antenna, (b) 3D printed dielectric sheets, (c) prototyped DSLHA, and (d) measurement setup.

The S_{11} characteristics, and radiation patterns of the prototyped 3-D printed DSLHA are measured using 2 identical antenna in [20]. In Fig. 7 the measured S_{11} of the DSLHA and TEM horn antenna are given. From the Fig. 7 it can be concluded that implementation of DS elements to the horn antenna does not have any disruptive effect on the S_{11} characteristics over the operation band.

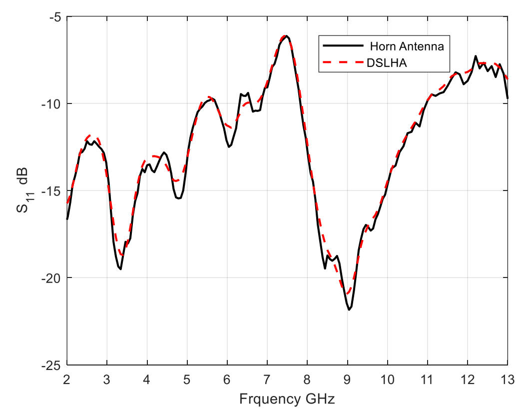


Fig. 7. Measured S_{11} characteristics.

The measured radiation patterns of the DSLHA and horn antenna are presented in Fig. 8, Tables 3-4. From the measurement results it can be concluded that the 3-D printed dielectric sheet designs can increase the directivity of the horn antennas over the operation band of 2-13 GHz. Especially the 3-D printed DS elements achieves to improve directivity of the TEM horn antenna @ 11-12 GHz by focusing the divided radiation towards the maximum direction.

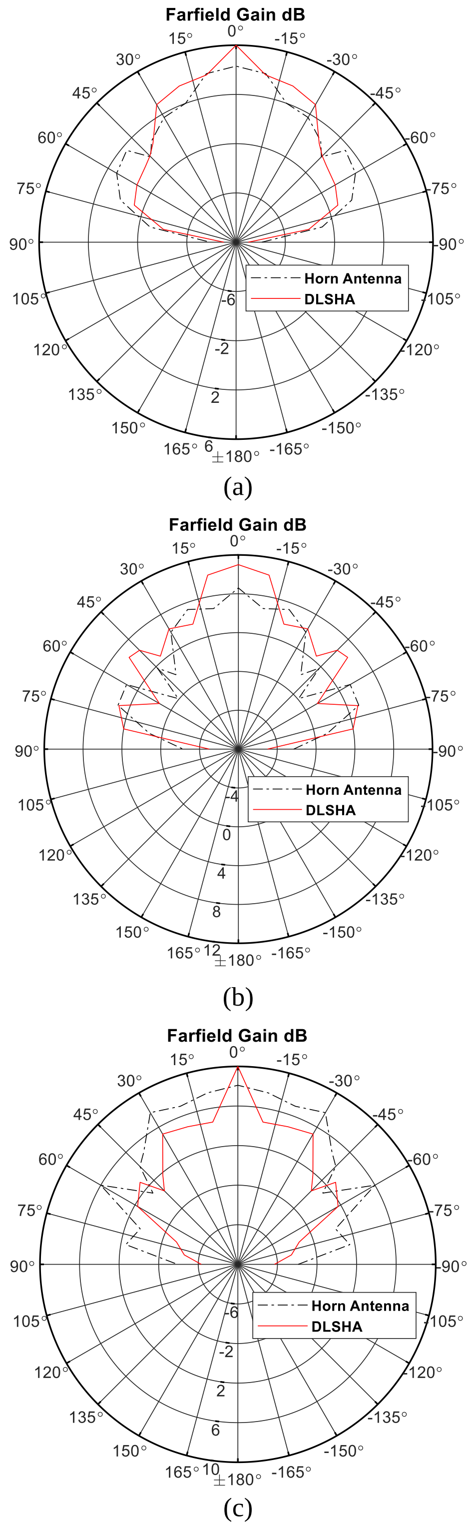


Fig. 8. Measured radiation patterns at: (a) 2, (b) 7, and (c) 12 GHz.

Table 3: Measured gain dB at ϕ=90º, θ=90º

f (GHz)	Model		Frequency (GHz)	Model	
	Horn	**DSLHA**		**Horn**	**DSLHA**
2	4	6	**8**	8.2	10.8
3	4	7	**9**	8	11
4	9	11	**10**	10	11.8
5	10	12	**11**	8	9.8
6	10	11	**12**	8	10
7	8.5	11	**13**	8.8	11

Table 4: Measured 3dB beam width in degree

Frequency (GHz)	Model		Frequency (GHz)	Model	
	Horn	**DSLHA**		**Horn**	**DSLHA**
2	60	60	**8**	100	35
3	100	60	**9**	60	80
4	60	60	**10**	60	35
5	60	30	**11**	100	50
6	50	30	**12**	80	30
7	70	30	**13**	70	60

Table 5: Comparison of gain enhancements of typical horn modules in the similar bandwidth

	Dielectric Size (mm)	Gain Enhancement (dB) Over Operation Band (GHz)					
		2	**5**	**7**	**9**	**11**	**13**
Here	25x73.5x1.6	2	2	2.5	3	1.8	2.2
[21]	---	---	2	0	0.5	0.2	1
[22]	100x100x30	---	4	3	5	0	0
[23]	100x100x30	---	4	5	5	4	4

Furthermore comparisons of the gain enhancements among the typical macro designed dielectric lens loaded horn modules [21-23] are given in Table 4, respectively. From the table, one can concluded that the proposed DSLHA module achieves better performance with the relatively small volume within the requested operation band compared to its counterpart designs.

IV. CONCLUSION

Herein, a relatively small volume dielectric sheet design had been prototyped using 3-D printer technology to form a DSLHA module operates within the operation band of 2-13 which achieves an almost 2 dB gain improvement over the operation band of the implemented horn antenna. As it can be seen from both simulation and measurement results of gain and S_{11} characteristic, the proposed 3-D printed dielectric sheets does not have distortive effect on the S_{11} characteristics of design, while the dielectric sheets start to focus the radiation pattern of the horn antenna at higher operation frequency of 11-12 GHz to increase the maximum gain. Thus, it is expected that 3-D printer technology can be applied for fast, accurate and low cost prototyping of more complex dielectric lens designs.

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