UWB Gain Enhancement of Horn Antennas Using Miniaturized Frequency Selective Surface

Mehmet A. Belen [1], Filiz Güneş [2], Peyman Mahouti [2], and Aysu Belen [2]

[1] Department of Electric and Electronic Engineering
University of Artvin Çoruh, Artvin, TURKEY
mehmetalibelen@artvin.edu.tr

[2] Department of Electronics and Communication Engineering
University of Yıldız Technical, Istanbul, TURKEY
gunes@yildiz.edu.tr, pmahouti@yildiz.edu.tr, aysuyldrm07@gmail.com

Abstract **─** In this work, enhancement of the radiation performances of horn antennas are worked out within their operation bandwidth by placing the miniaturized Frequency Selective Surface (FSS)s perpendicularly into the inner part of their flares. Here each FSS consists of only a single miniaturized double-sided inverted T-shaped square unit cell designed on the low-cost FR4 with relative permittivity 4.4, loss tangent 0.0035 and thickness 1.58 mm in 3D CST environment so that it is able to focus the propagating electromagnetic waves to increase the directivity properties like a dielectric lens, while keeping the mismatching characteristics with less size and low manufacturing cost compared to its counter parts. Herein an exponentially tapered TEM horn with the operation bandwidth of 5-13 GHz is taken as an example horn antenna for measurements. From the measured results of the prototyped module, it can be observed that the proposed module keep mismatching characteristics of the horn antenna, meanwhile the gain and beam widths are enhanced to amplify the signal in the operation band without any increase in the total volume of the module or making the design bulky. Thus, it is expected that this methodology can be implemented to horn antennas effectively reducing volume and cost of communication systems.

Index Terms **─** Enhancement, FSS, gain, horn antenna, TEM horn, UWB.

I. INTRODUCTION

Frequency Selective Surfaces (FSSs are typically designed on planar periodic arrays of metal patches or slots with filtering characteristics of electromagnetic waves aimed at certain frequencies that could be tuned with change at the geometrical parameters of the unit element and dielectric shape [1-5]. In fact, because of this band stop feature, FSSs become very important and widely used for antennas and radars' cross-section reduction in modern military platforms such as ships, aircrafts, and missiles. Communication systems in these platforms are always enclosed with FSSs. As electronic devices can be destroyed by strong electromagnetic interference (EMI), the anti-interference capability of communication systems in these platforms is urgently required. Thus, these make it required to design antenna and FSS as an integrated module called the filtering antenna with the typical works [3-5]. In the recent work [5], a Modified Double Square Loop (MDSL) unit element is designed to build a dual-band FSSs to be placed perpendicularly the aperture of a horn antenna as a band-stop prefilter for mobile communication (GSM) frequency bands operating at 900 and 1800 MHz simultaneously. Also FSS design can be used for absorbers by coatings their surfaces to selectively allow certain frequencies to pass through [6-7]. Aim of this work is to design miniaturized FSSs for enhancement of gain and beamwidths of the horn antennas by inserting perpendicularly into the bottom of their apertures while keeping their mismatching characteristics in their operation bandwidths. For this purpose, double-sided inverted T-shaped square is designed in 3D CST environment as a unit cell subject to the 5-13 GHz bandwidth of the exponentially tapered horn antenna available in our laboratory. Three unit cells are found to be sufficient to be placed to the bottom of its aperture for the enhancement of gain and beamwidth. In the next section, design and fabrication of the FSS loaded horn antenna will be given. Measurements will be followed in the third section, and finally the paper ends conclusion section.

II. DESIGN CONSIDERATIONS AND SIMULATIONS

A. TEM horn antenna

An exponentially tapered TEM horn with the operation bandwidth of 5–13 GHz is considered as a

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prototype antenna for the gain and beamwidth enhancement (Fig. 1). The geometrical dimensions of the horn antenna are given in Table 1.

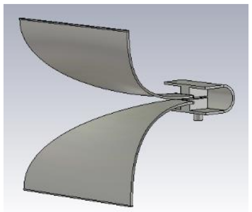


Fig. 1. 3-D view of an exponentially tapered TEM.

Table 1: Geometrical parameters of TEM horn antenna in mm

TEM Horn	Aperture Width	Aperture Height	Length
	74	73.5	60

B. FSS unit element: Double-sided inverted T-shaped square

Herein it is aimed to design FSSs for the horn antennas functioning as a dielectric lens in the requested frequency band so that they can be fixed in the inner parts of their flares, simply using foams or the equivalent materials with the unit relative dielectric constant. For this mean, a double sided inverted T-shape square is selected as a suitable geometry design to be prototyped on low cost dielectric substrate FR4 (relative permittivity 4.4, loss tangent 0.0035, thickness 1.58 mm) given in Fig. 2 and its design schematic in Fig. 3.

Design and optimization process of the FSS model is carried out in CST environment with respect to the design goals of enhanced horn antenna design so that the unit element of FSS design would act as a band pass filter with the requested operation band of 5-13 GHz and increase the directive of the horn antenna. The simulated scattering parameters of the optimized unit FSS design are given in Fig. 4 alongside of its parametric values in Table 2. As it can be seen from Table 2, the size of designed FSS model is suitable to be used as FSS array and can easily be fitted to the inner part of the horn antenna. In Fig. 5 the antenna module itself is presented, alongside of the antennas simulated return loss and gain characteristics in Figs. 6-7, where Z and the gap are taken as parameters, defined as the distances of the FSS unit from the aperture and between its elements. The optimal values for gap and Z are taken as 8 mm and 5 mm. Furthermore, the surface current and H-field distributions of the antenna are given, respectively in Figs. 8-9. As can be observed from these figures, FSS unit causes the current and H-field to be intensified in the inner part of the flare as can be expected which result in enhancement of the gain within the operation band. In the next section of the work the experimental results of prototyped FSS design will be given.

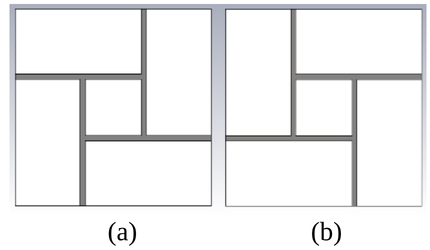


Fig. 2. Double-sided inverted T-shaped square: (a) top view, and (b) identical mirrored bottom view.

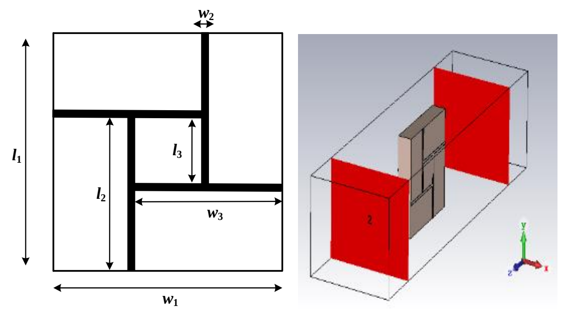


Fig. 3. Design schematic of double-sided inverted T-shaped square microstrip patch.

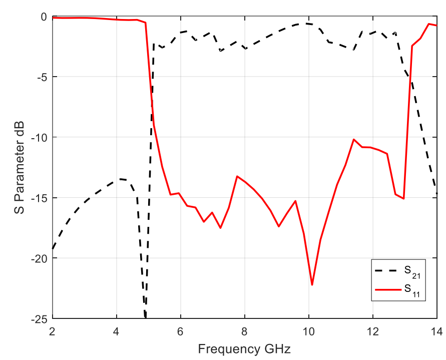


Fig. 4. Scattering characteristics of the FSS unit cell.

Table 2: Geometrical parameters of optimally designed double-sided inverted T-shaped square unit cell in mm

W_1	W_2	W_3
8	0.2	5.2
L_1	L_2	L_3
8	5.2	2.6

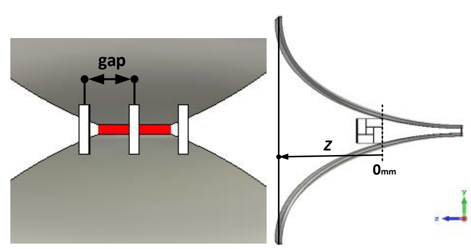


Fig. 5. Complete module.

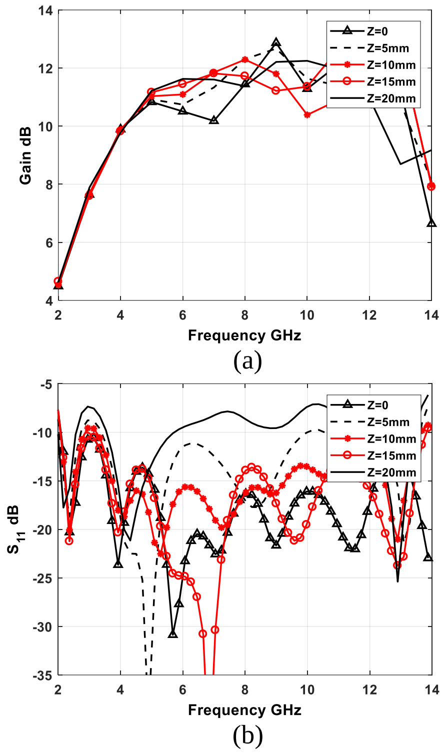


Fig. 6. Simulated: (a) maximum gain, and (b) S_{11} with respect to the FSS's distance from the antenna; gap=5mm.

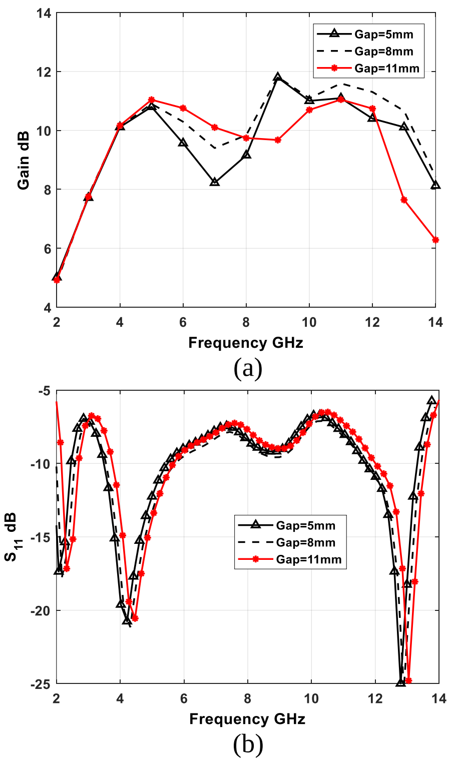


Fig. 7. Simulated: (a) maximum gain, and (b) S_{11} with respect to the FSS's; gap Z=0.

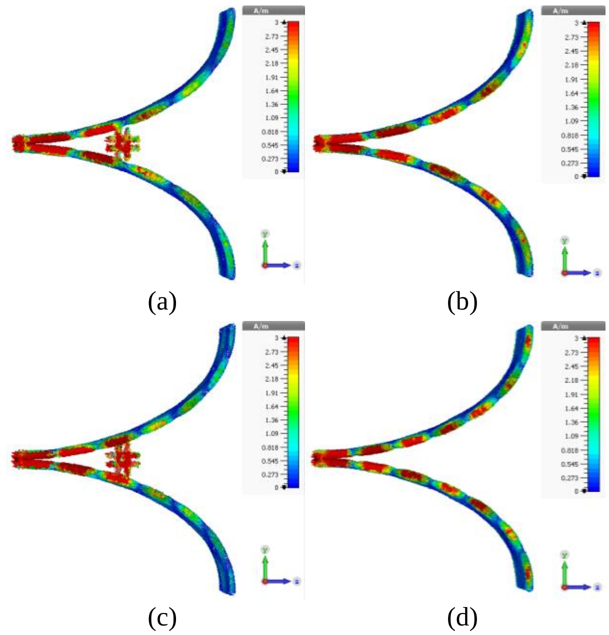


Fig. 8. Surface current distribution for 9 GHz: (a) with FSS and (b) without FSS; 12 GHz: (c) with FSS and (d) without FSS.

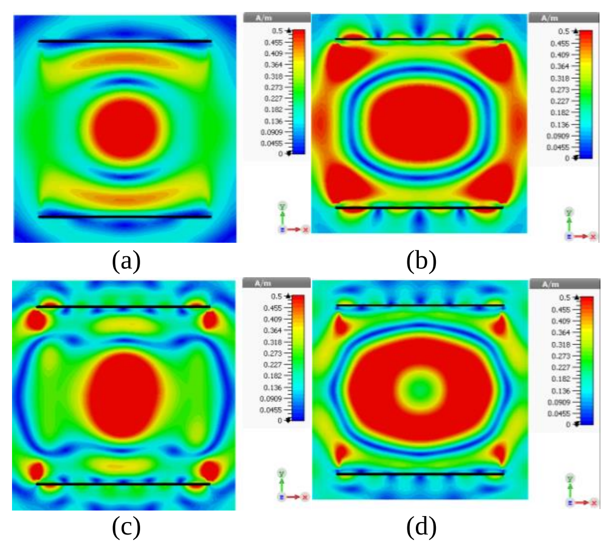
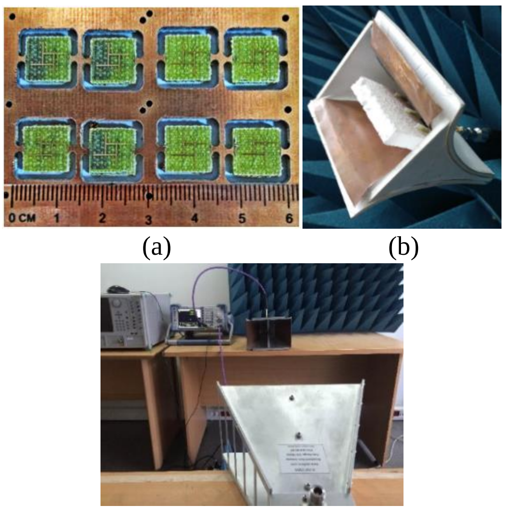


Fig. 9. H-Field distribution for 8 GHz: (a) with FSS and (b) without FSS; for 12 GHz: (c) with FSS and (d) without FSS.

III. MEASUREMENT

In this section the measurement results of the prototype module are presented. The return loss, transmission characteristic, maximum far field gain and radiation pattern of the proposed module are measured using two identical antennas in [8] as a reference antenna, the measurement setup is presented in Fig. 10 and the measurement results are given in the Figs. 11-13.

In Fig. 11, the measured return losses of the module are given. As seen from the Fig. 11, placing FSS unit into the inner part of antenna aperture does not cause any disruptive effect on the return loss performance of the antenna in the operation band. Figures 12 and 13 present the measured transmission and radiation pattern characteristics of antennas and modules at maximum gain direction $\phi=90^0$, $\theta=90^0$, respectively. As it can be seen from these characteristics, the proposed FSS unit increases the gain in the desired bandwidth 6–13 GHz, while keeping the return loss characteristics.



(a) (b) (c)

Fig. 10. Fabricated (a) unit double-sided inverted T-shaped square FSSs, (b) completed module, and (c) measurement setup.

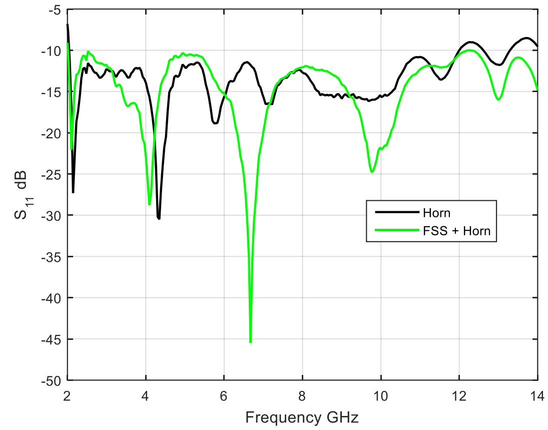


Fig. 11. Measured return loss characteristics.

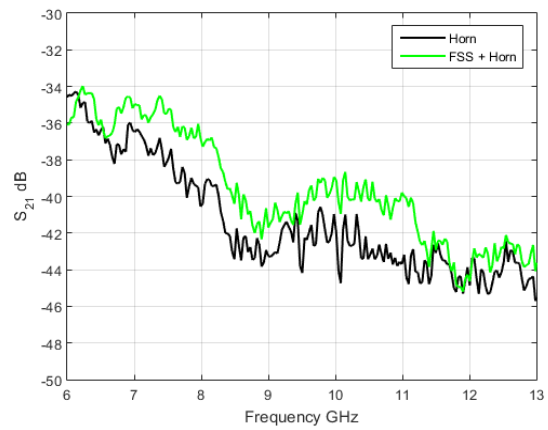
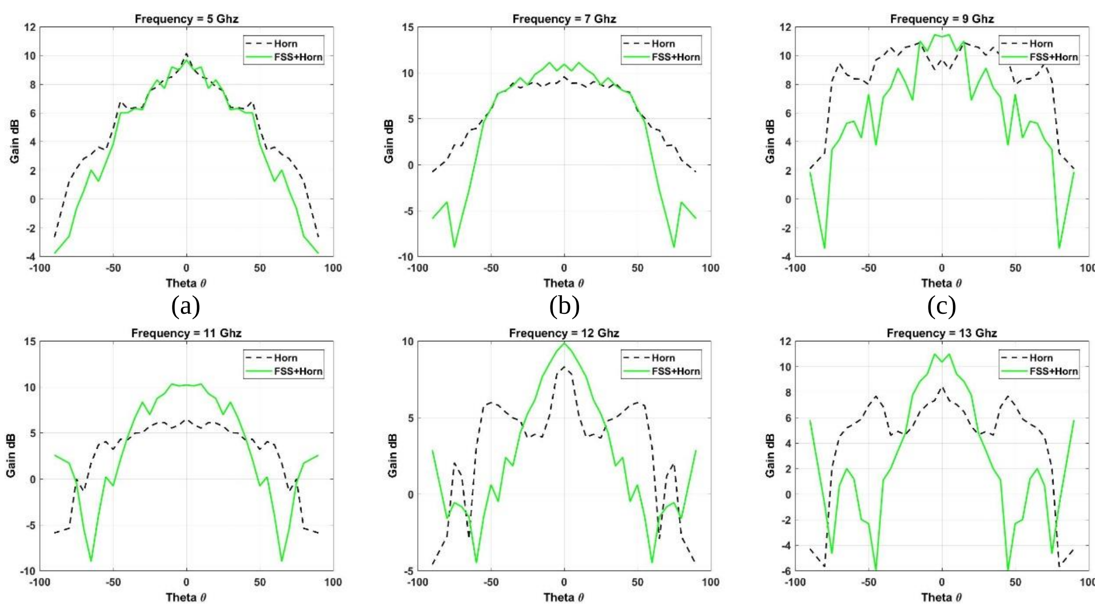


Fig. 12. Measured transmission characteristics.



(a) (b) (c) (d) (e) (f)

Fig. 13. Measured radiation patterns of the horn and FSS loaded horn antenna.

In Fig. 13, the measured radiation patterns of the antennas are presented. Furthermore the gains and 3 dB beam widths are also given in Table 3, respectively. From the characteristics in Figs. 13 (a)-(f), Tables 2 and 3, one can see the directivities of the horn are significantly increased after the implementations of FSS structures.

Table 3: Measured gain (dB) at $\phi=90^0$, $\theta=90^0$ and 3dB beamwidth (degree) measurement results

Frequency (GHz)	**Gains at $\phi=\theta=90^0$**		**3dB Beamwidth**	
	No FSS	**FSS**	**No FSS**	**FSS**
5	10.1	9.7	60	60
6	12.4	10.9	90	100
7	9.5	10.9	94	80
8	7.5	10.7	110	80
9	9.7	11.3	100	20
10	6.4	8.2	90	60
11	6.5	10.2	120	50
12	8.3	9.8	20	30
13	7.4	10.3	40	40

Table 4: Comparison of gain enhancements of typical horn modules in the similar bandwidth

	Frequency (GHz)	**Dielectric Size (mm)**	**Gain Enhancement (dB) Over Operation Band (GHz)**				
			5	**7**	**9**	**11**	**13**
Here	5-13	8x8	0	1.4	1.3	4	3
[9]	5-15	16x16	2	0	0.5	0.2	1
[10]	1-15	60x100	4	3	5	0	0

Table 5: Comparison of mismatching S11 (dB)s of typical horn modules in the similar bandwidth

***f* (GHz)**	**Here**		**[9]**	**[10]**	
	No FSS	**With FSS**		**No Lens**	**With Lens**
5	-13	-11	-12	-10	-15
7	-17	-20	-8	-14	-17
9	-16	-16	-20	-26	-15
11	-13	-13	-17	-9	-9
13	-12	-16	-25	-17	-7

Furthermore comparisons of the gain enhancements and mismatching S_{11} (dB)s among the typical macro - designed horn modules loaded dielectric lens [9] or dielectric [10] are given in Tabless 4 and 5, respectively. From these tables, one can infer that our proposed horn module using the miniaturized FSSs can work much more effectively than the counterparts within the planned operation bandwidth with low-cost and very small size loading.

VI. CONCLUSION

In this work, design of miniaturized FSS are carried out for gain enhancement of Horn Antennas to be placed to the inner part of horns flares. As it can be seen from the measurement results, the proposed module functions similar performance with the traditionally dielectric lens loaded horn antennas with less size and low manufacturing cost. The prototyped module keeps mismatching characteristics of the horn antennas, meanwhile the gain and beam-widths are enhanced to amplify the signal in the desired band without any increase in the total volume of the module or made the design bulky. Thus, it is expected that this methodology can be implemented to effectively reduce volume and cost of communication systems. This novel design methodology can easily be implemented in the communication systems where manufacturing cost, volume and weight of the module are at most importance needed for structural constraints.

REFERENCES

[1] B. A. Munk, *Frequency Selective Surfaces: Theory and Design*. John Wiley & Sons, NY USA ISBN: 0-471-37047-9, 2000.

[2] F. C. Seman and N. K. Khalid, "Double square loop FSS with slots for closer band spacing at oblique incidence," *In Proc. IEEE Asia-Pac. Conf. Appl. Electromagn*., pp. 195,198, Dec. 8-10, 2014.

[3] P. Mahouti, F. Güneş, M. A. Belen, A. Çalışkan, S. Demirel, and Z. Sharipov, "Horn antennas with enhanced functionalities through the use of frequency selective surfaces," *Int. J. RF Microwave Comp. Aid Eng*., 26: 287-293, 2016. doi:10.1002/mmce.209

[4] P. Mahouti, F. Güneş, M. A. Belen, Z. Sharipov, and S. Demirel, "TEM horn antennas with enhanced functionalities through the use of frequency selective surfaces," *The 3rd EMC Turkiye Conference*, Isik University, Maslak/Istanbul, Sep. 2-4, 2015.

[5] F. Güneş, Z. Sharipov, M. A. Belen, and P. Mahouti, "GSM filtering of horn antennas using modified double square frequency selective surface," *Int, J, RF Microwave Comp. Aid Eng*., 27, 2017. doi: 10.1002/mmce.2114

[6] J. A. Miller, J. C. Batchelor, and A. P. Edward, "FSS printed using conducting ink," *In Proc. IEEE Antennas Propag. Soc. Int. Symp*., pp. 1-4, 2010.

[7] R. D. Seager, A. Chauraya, J. Bowman, M. Broughton, R. Philpott, and N. Nimkulrat, "Fabric based frequency selective surfaces using weaving and screen printing," *Electron. Lett.*, vol. 49, no. 24, pp. 1507-1509, 2013.

[8] A-info, LB8180, 0.8-18 GHz Broadband Horn Antenna. Available at: http://www.ainfoinc.com/en/p_ant_h_brd.asp, Accessed on August 15, 2017.

[9] R. J. Bauerle, R. Schrimpf, E. Gyorko, and J. Henderson, "The use of a dielectric lens to improve the efficiency of a dual-polarized quad-ridge horn from 5 to 15 GHz," *IEEE Transactions on Antennas*

and Propagation, vol. 57, no. 6, June 2009.

[10] A. S. Türk, A. K. Keskin, and M. D. Şentürk, "Dielectric loaded TEM horn-fed ridged horn antenna design for ultrawideband ground-penetrating impulse radar," *Turkish J. Elec. Eng. & Comp. Sci*., 23: 1479-1488, 2015.