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A novel grating triangular patch antenna with transparent ground plane for C-band applications

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Abstract

In this paper, design and characterization of a novel grating equilateral triangular patch antenna for its use in C-band application is presented. At first, a simple equilateral triangular patch is designed and fabricated on glass substrate with transparent ground plane, which is followed by grating of the radiating patch in three different ways. Microstrip line feeding technique is used for excitation of the radiating patch. Return loss measurements are carried out for all the antenna samples so as to obtain the best grating line configuration. Co-polar and cross-polar radiation patterns of the simple triangular patch and the grating triangular patch antennas are measured. With the introduction of the grating lines the matching performance of the antenna increases. A shift in the resonant frequency towards the lower side of the frequency spectrum is observed with the change in the number of grating lines of the antenna, whereas changes in the radiation pattern remains insignificant.

1. Introduction

The basic front-end device of wireless communication system has been modified over the past few decades to meet the requirement of the recent technologies. Recent efforts are reported on designing antennas that can be mounted on the void transparent spaces without blocking or partially disturbing its optical transparency [1-3]. For designing such optically transparent antennas, use of various transparent conducting oxides (TCO), such as Indium Tin Oxide (ITO), Fluoride doped Tin Oxide (FTO) [4, 5], silver coated polyester (AgHT) [6], etc. are reported which inherently have some disadvantages like low gain, feeding complexities, high fabrication cost etc. [7]. These disadvantages can be overcome by designing meshed patch antenna which is an alternate way of achieving optical transparency. The optical transparency of meshed patch antenna is mainly achieved due to the passing of optical signals through the mesh openings of the radiating patch whereas it has properties similar to conventional patch antennas [8]. However, the reported studies on meshed patch antennas are mostly carried out on rectangular and circular patch geometry [9-11]. Further, the optical transparency can be increased by making gratings rather than meshes on the conducting patch which will occupy less area than the mesh structure.

In this paper, an attempt has been made to investigate the characteristics of a triangular patch antenna by introducing grating lines on it. The present work is mainly focused on the change in antenna performance with the change in the grating line numbers having same grating line widths. Three prototypes of grating triangular patch antenna have been designed and fabricated with different grating line numbers and their results are compared with the standard simple triangular patch antenna having the same outer geometrical area. Additionally, the area of transparency of the grating triangular patch antenna is compared with that of a meshed triangular patch antenna having mesh line widths same as that of the grating lines.

2. Antenna design and fabrication

Initially, an equilateral triangular patch is designed for its operation in the C-band (ISM) where the dimensions of the antenna are calculated from the resonance frequency equation of triangular patch antenna design for TM_{10} mode of operation given as [12]:

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}} \qquad (1)$$

where, $\boldsymbol{a}$ is the side length dimension of the equilateral triangle and ε_r is the effective dielectric constant of the substrate used. The antenna is fabricated on glass substrate of thickness 1 mm having a dielectric constant $\varepsilon_r = 6$. Conducting copper tape is used to fabricate the antenna on the glass substrate where a mask of required dimension is used to ensure the consistency of the dimensions for different samples which are fabricated. Microstrip feedline technique is opted for exciting the patch which is also made up of conducting copper tape. Transparent silver coated polyester film (AgHT-8) is used as the ground plane whose standard conductivity is 1.25×10^5 S/m. A small portion of the conducting copper tape is fixed on the ground plane to incorporate the connector which is used for feeding the patch.
This is followed by simulation and fabrication of triangular patch antenna by introducing grating lines. The grating lines are positioned at the base of the patch and directed towards the vertex. Each grating antenna prototypes are designed with different grating line numbers placed at equidistance from each other as shown in figure 1(a, b, c & d). Table 1 shows the designed parameters of the antenna. The widths of the boundary lines of the grating triangular patches are maintained same as that of the feed line,

whereas the width of the grating lines is maintained at a value of 0.5 mm, which is opted from the reported work on meshed patch antennas that shows the best mesh line width configuration [2]. The fabricated antenna prototypes are shown in figure 2(a, b, c & d).

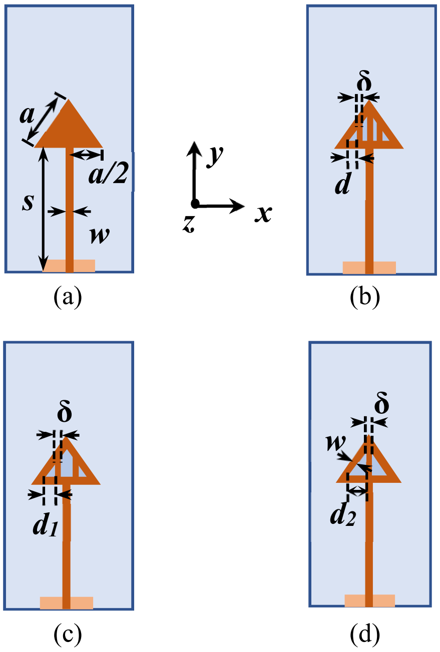


Figure 1. Schematic diagram: (a) simple triangular patch (b) prototype 1 (c) prototype 2 (d) prototype 3

Table 1. Design parameters

Parameters	Values
Designed frequency (*f*)	5.6 GHz
a	14.5 mm
s	34.0 mm
w	1.0 mm
δ	0.5 mm
d	2.4 mm
d_1	3.4 mm
d_2	5.3 mm

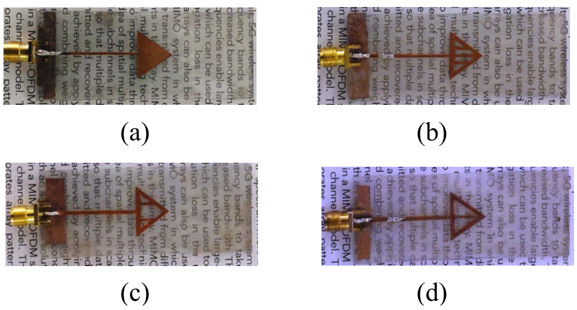
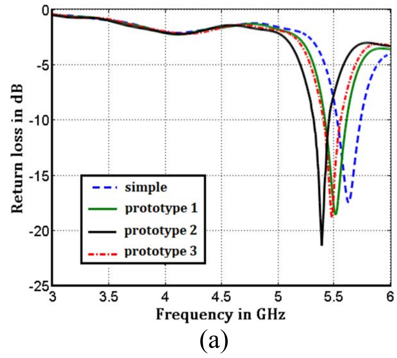


Figure 2. Fabricated antennas: (a) simple triangular patch (b) prototype 1 (c) prototype 2 and (d) prototype 3

3. Experiment results

Return loss measurements are carried out using the Rohde & Schwarz ZNB 20 Vector Network Analyzer whereas the simulations are carried out on CST-MW Studio. The simulated and the measured return loss plots are shown in figure 3(a) and figure 3(b) respectively. The peak return loss values of all the antennas at their corresponding resonant frequencies are given in Table 2.



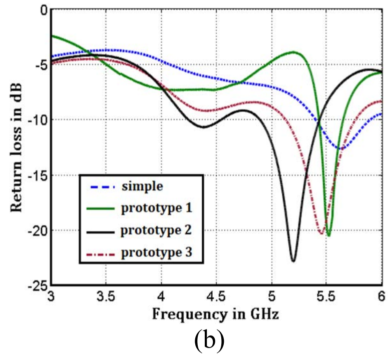


Figure 3(a). Simulated return loss plots of different antenna prototypes with and without gratings
Figure 3(b). Measured return loss plots of different antenna prototypes with and without gratings

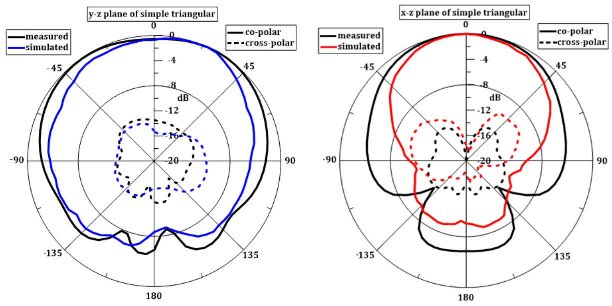
Table 2. Peak return loss values at their corresponding resonant frequencies

Antenna configuration	Results	Frequency GHz)	S_{11} (dB)
Simple	Measured	5.62	-12.66
	Simulated	5.63	-17.48
Prototype 1	Measured	5.52	-20.55
	Simulated	5.51	-18.55
Prototype 2	**Measured**	**5.19**	**-22.83**
	Simulated	**5.38**	**-21.37**
Prototype 3	Measured	5.44	-20.37
	Simulated	5.47	-18.83

From the simulated and measured return loss plots, it is observed that the introduction of grating lines on the patch increases the matching performances of the antenna. Antenna prototype 2 shows the best matching performance with a return loss value of -22.83 dB whereas the simple triangular patch holds a return loss value of -12.66 dB. Moreover, it is observed that with the introduction of the grating lines the resonant frequency shifts to the lower side of the RF spectrum than that of the simple triangular patch. The simple triangular patch resonates at 5.62 GHz where the resonant frequency shifts down to 5.19 GHz for the antenna prototype 2 which comprises of two grating lines.

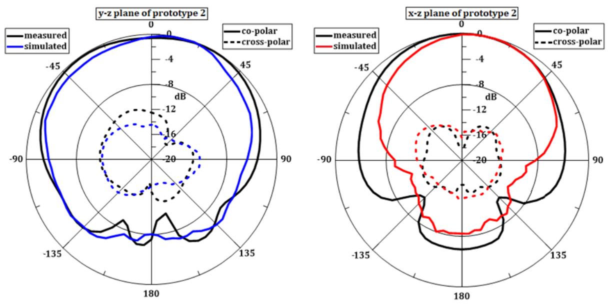
With further decrease in the grating lines number (prototype 3) the resonant frequency shifts to a value of 5.44 GHz which is also lower than that of the simple triangular patch. This shifting in the resonant frequencies of the grating triangular patch antennas may be due to the change in the electrical path length of the patch geometry as the fields propagates through the grating lines.

Co-polar and cross-polar radiation pattern measurements are carried out for all the antenna prototypes by using DAMS antenna measurement system calibrated with the vector network analyser. The measurements are carried out for the two principal planes (x-z and y-z) at their respective resonant frequencies of each antenna prototypes. The simulated and measured radiation patterns of the simple triangular patch (at 5.62 GHz) and that of antenna prototype 2 (at 5.19 GHz) are shown in figure 4(a & b) and figure 5(a & b) respectively.



(a) (b)

Figure 4(a). y-z plane of simple triangular patch
Figure 4(b). x-z plane of simple triangular patch



(a) (b)

Figure 5(a). y-z plane of antenna prototype 2
Figure 5(b). *x*-z plane of antenna prototype 2

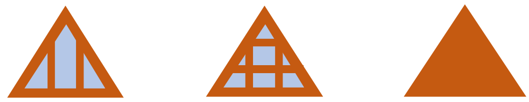
The measured and simulated radiation pattern of the antennas shows a good broadside radiation pattern with a minor deviation of the main lobe from 0˚. From the measured radiation pattern, it can be seen that the two antennas maintain a cross-polarization level of ≤ -12dB in the direction of maximum co-polarization.

4. Comparison of area of transparency

The topology of a grating, meshed and simple opaque antenna is shown in figure 6 (a, b & c). There area of transparency of the given topologies can be calculated by the equation as [13]:

$$Area_{(transparency)} = \left(Area_{(patch)} - Area_{(conductor)}\right) \Big/ Area_{(patch)} \qquad (2)$$

Table 3 shows the area of transparency of different antenna topology as calculated by using equation (2). From the calculated data it can be seen that the area of transparency of the grating triangular patch is more than the other two and thus provides a better optical transparency.



(a) (b) (c)

Figure 6. Topology of (a) grating patch (b) meshed patch (c) simple opaque triangular patch

Table 3. Area of transparency for different topology

Antenna topology	Area of transparency
Grating	50.60 %
Mesh	45.55 %
Simple opaque	0 %

5. Discussion and conclusion

In this work, a study on grating equilateral triangular patch antenna, designed and fabricated on glass substrate backed with transparent ground plane is presented. Triangular patch is opted for the design as it gives a better Q-value due to a high confinement of the field lines in it. From the measured and the simulated results, it is seen that the antenna prototype 2 shows a better matching performance with a return loss of -22.83 dB, resonating at 5.19 GHz. A shift in the resonant frequency to the lower side of the RF spectrum is observed with the change in grating line numbers, whereas the radiation pattern almost remains same as that of the simple triangular patch. Moreover, feeding complexities, high fabrication cost and other demerits that can be seen in the antennas designed with TCOs are absent in the proposed antenna design. Apart from this, the grating topology provides a better optical transparency (50.60 %) than the meshed patch antenna (45.55 %) having the same outer dimensions and line widths. The grating topology also provides a higher degree of freedom to the designers in terms of tunability due to shifting behaviour of the resonant frequency.

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