Wine Glass Shaped Microstrip Antenna with Woodpile Structure for Wireless Applications

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ABSTRACT:
The hexagonal shaped slotted Wine glass shaped Co Planar Waveguide (CPW) fed antenna for wireless applications is proposed in this paper. The Woodpile based Electronic Bandgap (EBG) structure is used as linked ground surface for bandwidth and gain enhancement. The performance characteristics of different sized strip widths of woodpile structures with wine glass shaped antenna have carried out; the antenna resonates in the band of 2GHz, 5 GHz, and 7 GHz. The band width enhancement of 43 % and gain of 9 dB at 1.9910 GHz for 1mm strip width of woodpile has observed. In addition, the group delay variation and E –plane co and cross polarization radiation patterns for various strip widths of woodpile structure have obtained. The group delay is maintained less than 5 nanosecond and there is a significant difference between co and cross polarization for E- plane radiation patterns for 1mm strip width of woodpile structure. The antenna is fabricated with hexagonal slot and 1mm strip width woodpile structure and tested for return loss and radiation pattern.

KEYWORDS: CPW Fed Antenna, Electronic Band Gap Structure, Wood Pile Structure.

1. INTRODUCTION

Mobile radio and wireless communications are the areas of research now-a-days. Micro strip antennas meet all the requirements for these communications. These antennas are low profile, conformal to planar and non-planar surfaces, compatible with MMIC designs. Also, when a particular patch shape and mode are selected, resonant frequency, polarization radiation pattern and impedance can be obtained according to application and necessity [1].

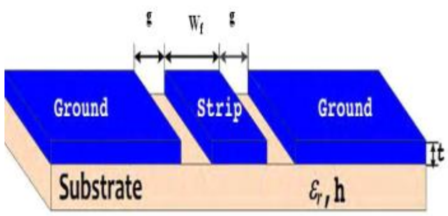
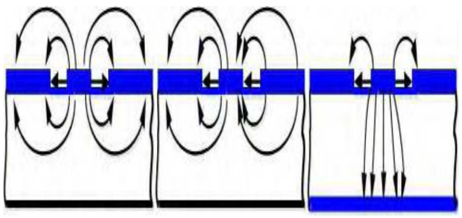


Fig. 1. Coplanar Waveguide Structure (CPW).

The performance characteristics of antenna also depend on the type of signal inputting or feeding techniques. There are four major techniques for feeding micro strip antenna like coaxial feeding, micro strip line feeding, aperture feeding and inset feeding. Among all these, CPW (Coplanar Waveguide) feeding is easy to fabricate, simple to match with Micro-strip antenna by controlling the inset position and simple to model electrically. CPW feeding consists of a center metallic strip which carries signal from feed location to microstrip antenna and two side plane conductors which act as ground surface. Fig.1 shows the construction of CPW feeding with side ground planes.

The microstrip patch, CPW line and ground surfaces are printed on one side of substrate. The directivity of this antenna can be increased by printing partial or complete ground plane on another side (back side) of the substrate. The electric field lines in coplanar fed waveguide are shown in Fig. 2. The field lines for grounded and ungrounded waveguide forming different modes are explained. The CPW comprises of three conductors with different potentials. Transmission line theory for a three-wire system is used to explain even and odd mode solutions as illustrated in Fig. 2. The coplanar mode which is also called as desired even mode [Fig. 2 (a)] consists of ground planes at both sides of the center strip, whereas the slot line mode [Fig. 2 (b)], also called as parasitic odd mode, consists of opposite electrode potentials. When the bottom side of the substrate is metalized, a zero-cutoff frequency with additional parasitic parallel plate mode exists [Fig. 2(c)].

When an asymmetric discontinuity is impinged by a coplanar waveguide such as bend, parasitic slot line mode can be exited. To generate equal potential and to avoid unwanted modes, ground places are connected to air bridges or bond wires.



(a) (b) (c)

Fig. 2. Electrical field distribution in Coplanar Waveguide: (a) Desired even mode (b) Parasitic odd mode (c) Parasitic parallel plate mode with ground surface on two sides.

At low frequencies, TEM distribution which seems as electromagnetic fields distribution of even mode is shown in Fig. 3. At higher frequencies, the fundamental TE mode (H mode) exists with elliptical polarization of the magnetic field in the slots [2].

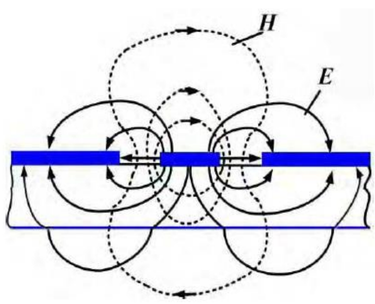


Fig. 3. Electromagnetic field distribution at low frequency.

The length of feed line and spacing between ground plane and micro strip patch decide the characteristic impedance (Z_0) of feed line which is matched to micro strip antenna impedance. Equations 1–5 give the relations between impedance of micro strip feed line and dimensions of feed line.

$$Z_0 = \frac{60\pi}{\sqrt{\varepsilon_{eff}}} \frac{1}{\frac{K(k)}{K(k')} + \frac{K(kl)}{K(kl')}} \quad (1)$$

Where,

$$k = \frac{W_f}{(Wf+2g)} \quad (2)$$

$$k' = \sqrt{1-k^2} \quad (3)$$

$$kl = \frac{\tanh\left(\frac{\pi W_f}{4h}\right)}{\tanh\left(\pi \frac{W_f}{Wf+2g}\right)} \quad (4)$$

$$\varepsilon_{eff} = \frac{1+\varepsilon_r \frac{K(k')K(kl)}{K(k)K(kl')}}{1+\frac{K(k')K(kl)}{K(k)K(kl')}} \quad (5)$$

Where W_f is width of micro strip feed line, h is the height of substrate, g is the gap between the ground plane and micro strip feed line, ε_r is relative permittivity of substrate.

The main advantage of CPW fed antenna is its wide band characteristic. Whereas the disadvantage is, it has more spurious radiations from strip line to ground surface. These spurious radiations cause surface waves which are propagated along the surface of the ground surface. These waves do not participate in radiation and so efficiency of antenna reduces.

The Electronic Band Gap (EBG) structure when applied with antenna as modified ground surface improves the performance of antenna such as suppression of surface waves, increasing gain antenna, improving radiation pattern of antenna.

In this paper, a novel wine glass shaped CPW fed, EBG structure (modified) based ground surface, is presented. The wine glass shape of antenna is derived from triangular shape which was also simulated for comparison. It is observed that the wideband characterization of antenna has eliminated if triangular shape of micro strip antenna is simulated and compared to wine glass shaped antenna.

2. LITERATURE REVIEW

In recent past, there are few methods reported on the development of CPW fed antenna with different shapes of EBG structures for the bandwidth and gain enhancement. Some of the recent studies which are reported have been disclosed in this section.

Modification in ground surface of microstrip antenna is implemented in terms of Defected Ground Structure, Electronic band gap structures. The disturbance to surface waves is the prime objective of these structures. EBG structure restricts the propagation of the surface waves in a particular band of frequencies. The frequency band is determined using the geometry of EBG cell. Each EBG cell acts as a parallel combination of Capacitor and Inductor which resonates at a frequency [3].

The shape of CPW fed antenna and the inclusion of slot on it play a vital role in bandwidth enhancement. The geometrics of microstrip antenna which are inspired by naturally occurring shapes like flowers, leaves also prove advantageous for making them wide band and compact due to their smooth curvature and exceptional subsections. Various shapes of microstrip antennas have been studied for compact wideband antenna. Few of them are butterfly shape [4], inverted cone slot [5], tapered slot with tuning patch [6], inverted L-strip slot [7], inverted U shape slot [8].

Liling Sun [4] introduced a novel butterfly-shaped patch antenna for wireless communication. Two symmetrical quasi-circular arms and two symmetrical round holes are incorporated into the patch of a microstrip antenna to expand its bandwidth. The diameter and positions of circular slots are optimized to achieve a wide bandwidth.

A.K. Gautam [7] proposed a novel coplanar waveguide (CPW)-fed compact ultrawideband (UWB) microstrip antenna to minimize the monopole antenna by loading of inverted L-strip over the conventional monopole patch antenna to lower the height of the antenna. The ground was vertically extended toward two sides of the single radiator.

L.N. Zhang [8] designed an ultra-wideband printed monopole antenna with a band notch characteristic and stable omnidirectional radiation. The antenna design adopts a beveled square patch as a monopole, a double feed technique and a microstrip feeder embedded with an inverted U-shaped slot.

Puneet Khanna [13] proposed a coplanar waveguide-(CPW-) fed compact wideband defected structure shaped microstrip antenna. Defected structure is produced by cutting the U shape antenna in the form of two-sided T shape. The proposed antenna consists of two-sided T shape strip as compared to usual monopole patch antenna for minimizing the height of the antenna. The large space around the radiator is fully utilized as the ground is on the same plane as of radiator.

Situ Rani Patre [14] designed a semi-elliptical partial ground plane in which feed is given through tapered microstrip line with broadband flower-shaped patch antenna. To design the desired proposed antenna, the conventional circular patch is reshaped to get broadband flower-shaped patch, which consists of distinct smaller segments and larger perimeter without changing the (largest) patch radius.

Hu Liu [15] proposed a microstrip coplanar waveguide (CPW) fed rectangular slot antenna with a compact structure of circularly polarized broadband antenna. The wideband feeding network power divider (PD) consists of a Wilkinson PD and a 90° phase difference comparator. The in-phase quadrature and equal magnitudes are provided by the four CPW feed lines having even modes. Excitation of circular polarizations can be done over a very broad frequency band. To improve the antenna gains a reflector is added to the antenna structure. To enhance the impedance matching, the inverted configuration is placed with the reflector in the slot side.

Debakanta Behera in [16] proposed a compact coplanar waveguide (CPW) fed frequency reconfigurable bow-tie microstrip antenna and experimentally verified that the proposed system can be tuned at different bands between 1.94 and 3.27 GHz in single-band and dual-band modes. Two slots are carefully introduced on the ground plane of the antenna where two active varactor diodes are placed to vary its fundamental mode of radiation by variation of capacitance.

3. ANTENNA GEOMETRY AND DIMENSIONS

The shape of wine glass has smooth curvature along the length, so it becomes travelling wave type structure when implemented as antenna. Its width is varying from bottom of the glass towards its open end which is responsible for its wide bandwidth which is explained using following equations through 5 to 10.

For any arbitrary shaped patch antenna, the fractional bandwidth is given by,

$$\frac{\Delta f}{f_0} = \frac{1}{Q_t} \tag{6}$$

Where Δf is difference between two frequencies and $f_0$is center frequency and Q_t is total quality factor which mainly depends on Q_{rad} which quality factor is due to radiation (space wave losses).

$$Q_{rad} = \frac{2\omega\varepsilon_r}{hG_t/l}K \tag{7}$$

Where K depends on the dimensions of antenna length (L) and width (W), G_t/l is the total conductance per unit length of radiating aperture.

For rectangular patch operating in dominant mode TM^x_{010},

$$K = \frac{L}{4} \tag{8}$$

$$G_t/l = \frac{G_{rad}}{W} \tag{9}$$

Using equations (7), (8) and (9),

$$Q_{rad} = \frac{2\omega WL\varepsilon_r}{4hG_{rad}} \tag{10}$$

From equations (6) and (10), it is observed that fractional bandwidth is inversely proportional to dimensions of antenna (length and width). In wine glass shaped antenna, the width (W) is decreasing smoothly form open end to feed line which is responsible for the enhanced fractional bandwidth.

The two-dimensional (2-D) woodpile structures is proposed as the EBG based ground surface. The dimensions of woodpile strips are varied for parametric study of their effects on antenna parameters. Also, the slot is engraved in the antenna structure to increase the bandwidth of antenna.

The geometrical configuration and dimensions of proposed antenna are shown in Fig. 4. The antenna is printed on cheap and readily available FR4 (Glass Epoxy) substrate with thickness h=1.6mm, relative permittivity ε_r= 4.4 and loss tangent tan δ =0.02. The patch antenna has width W=41.56 mm, top to bottom length L= 26.93mm, ground surface width W_g=40.5mm, length L_g=31 mm. The micro strip line length L_s =33.56 mm and spacing between ground surface and micro strip antenna s= 2.56 mm. The gap between central strip and ground surface is g=0.7mm. The antenna, ground plane and CPW feed line are printed on substrate of size 85mmx85mmx1.6mm.

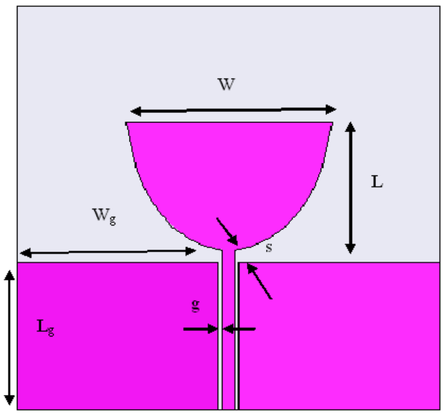


Fig. 4. Geometrical configuration and dimensions of wine glass shaped Microstrip antenna.

Table 1. Parameters of Wine Glass shaped Micro strip antenna.

Parameter	**Dimension in mm**
W	41.56
L	26.53
W_g	40.5
L_g	31
g	0.7
s	2.56

This antenna is included with a hexagonal shaped slot of dimension 5mm. Fig. 5 shows S11 plot for antennas with and without slot. The simulated result shows that the structure without slot excites at resonating frequencies at 1.69 GHz, 4.16 GHz, 6.55 GHz,8.21 GHz. Whereas, the antenna with slot resonates at 1.54 GHz,3.81GHz ,6.45 GHz,8.01 GHz,9.45 GHz. Table 1 shows the impedance bandwidths for the first two resonating frequencies for these antennas.

It is observed that the impedance band width is increased due to inclusion of slot. Also, the slot causes the resonating frequencies to reduce in comparison to without slot antenna. The rigorous experimentations were performed to select the shape of slot in the antenna like circle, triangle, square, rectangular etc. Among all, hexagonal shape shows highest bandwidth due to its number of corners. Figure shows the comparative return loss characteristics for microstrip antenna with and without slot. It is observed that the impedance bandwidths are more at resonating frequencies for MSA with slot than without slot. Table 2 tabulates the bandwidths at respective resonating frequencies.

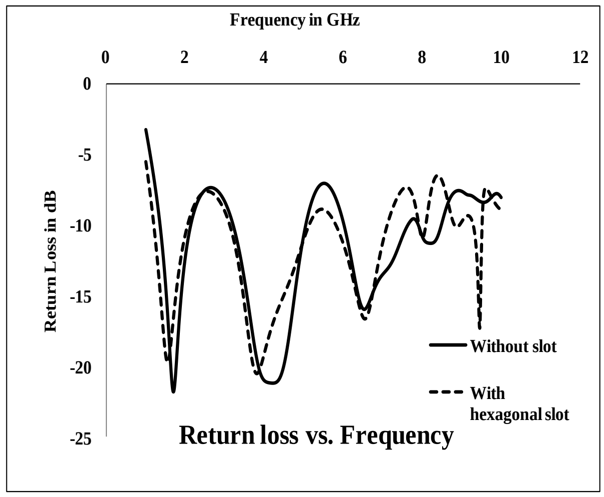
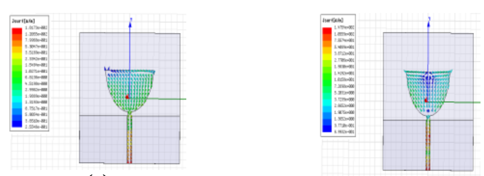


Fig. 5. Return loss vs frequency for without slot and with slot.

Table 2. Impedance bandwidths for antennas with and without slot.

Antenna without slot		**Antenna with slot**	
Impedance BW at 1.69 GHz	Impedance BW at 4.16 GHz	Impedance BW at 1.54 GHz	Impedance BW at 3.81 GHz
0.87 GHz	1.86 GHz	1.07 GHz	2.02 GHz

Figs. 6,7 and 8 show the surface current distributions at resonating frequencies. The higher modes for observed for antenna with slot.



(a) (b)

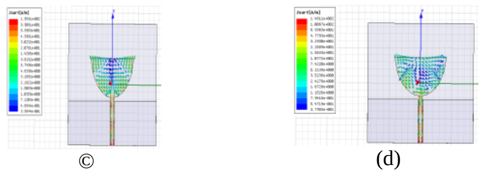


Fig. 6. The surface current distribution on the wine glass shaped antenna without slot at (a) 1.6937 GHz (b) 4.1982 GHz (c) 6.5315 GHz (d) 8.2432 GHz.

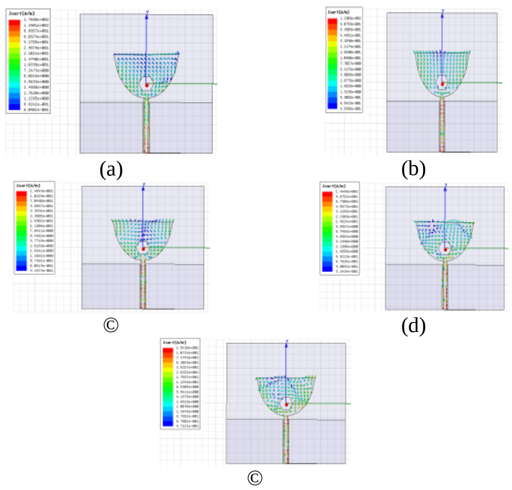


Fig. 7. The surface current distribution on the wine glass shaped antenna with slot at (a) 1.5495 GHz (b) 3.808 GHz (c) 6.5405 GHz (d) 8.0180 GHz © 9.4595.

The ground surface modification is also proposed in this paper for antenna parameter improvement. The side ground planes are replaced with Electronic Band (EBG) structure. The 3-dimensional woodpile structures one such EBG structure which is implemented for antenna gain improvement. The 3-D woodpile structure consists of dielectric bars piled on one another [9]. This structure is slightly modified into 2-dimensional model and metallic strips are pile horizontally and vertically. Fig. 8 shows the modified 3-D woodpile structure.

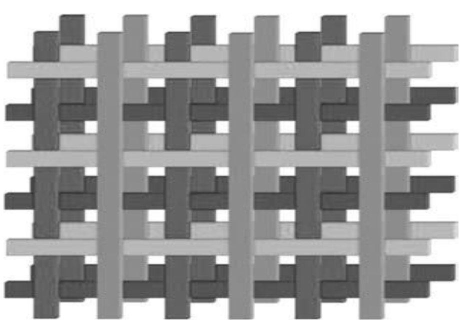


Fig. 8. Three-dimensional EBG structures: (a) a woodpile dielectric structure

In this paper, 2-D woodpile structure is considered which is piling of rectangular strips of width1mm, 2mm and 3 mm (3mmx3mm) across the two ground planes. The gap width between the strips is kept as 1mm,2mm and 3mm respectively for parametric study of effect on antenna parameters.

The geometry of wine glass shaped antenna with 2-D woodpile structure-based ground plane is shown in Fig. 9.

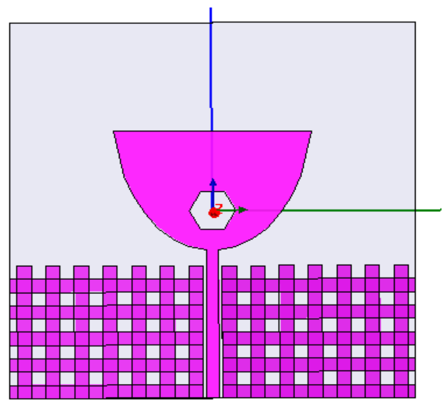


Fig. 9. Wine glass Microstrip antenna with 2-D wood-pile structure as ground plane.

4. PARAMETRIC STUDY OF WOOD PILE BASED GROUND SURFACE

In this section, the influence of size of woodpile strips on antenna performance is presented and discussed. The return loss characteristics for 1mm,2mm and 3mm woodpile structures are shown in Fig. 10.

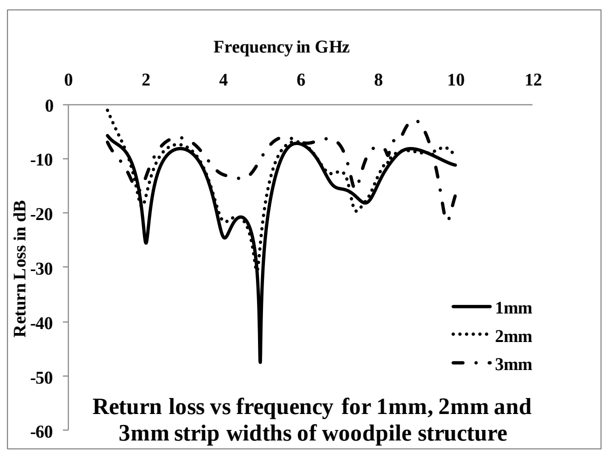


Fig. 10. Return loss vs. Frequency for various woodpile structures.

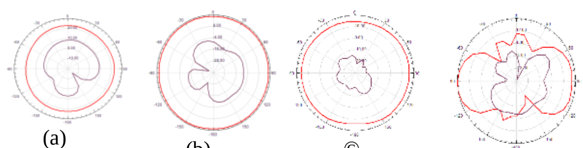
From figure, it is observed that the resonant frequencies are shifted to higher values as the strip width is decreased. The bandwidths corresponding different resonating frequencies are tabulated in Table 3. It is observed that the bandwidths corresponding to respective resonating frequencies decrease. Table 3 tabulates the bandwidths at corresponding frequencies.

Table 3. Impedance bandwidths for various strip widths of woodpile structure.

Antenna Type	Resonant Frequency in GHz	Bandwidth at Resonant Frequency in GHz	% Band width
Antenna with 1mm woodpile structure	1.9910	0.8649	43.44
	4.9459	2.1622	43.71
	7.6847	2.0360	26.49
Antenna with 2mm woodpile structure	1.8739	0.7477	39.90
	4.8649	2.0	41.11
	7.3964	1.8649	25.21
Antenna with 3mm woodpile structure	1.8018	0.8739	48.50
	4.4955	1.3694	30.46
	7.4234	0.5135	6.91

From Table 3, it is found that the significant % bandwidth is maintained for 1mm strip width wood pile structure as compared to other widths of strips.

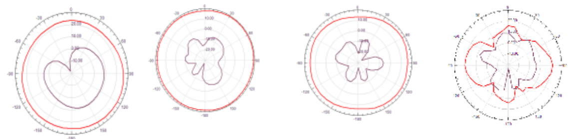
The E plane co polarization and cross polarization radiation patterns are shown in Figs. 11, 12 and 13 for various strip widths of woodpile structure. There is significant difference in the cross-polarization level in the E-plane for all the three strip widths of woodpile structure. The first three resonant frequencies show the level differences between co and cross polarization levels, but the forth resonant frequency fails to offer the level difference. Also, it has found out that the proposed antenna has nearly good omnidirectional radiation patterns at first three resonant frequencies.



(a) 1.9910 GHz (b) 4.0180 GHz © 4.9459GHz (d) 7.6847 GHz

_____ E-Co-polarization
_____ E- Cross Polarization

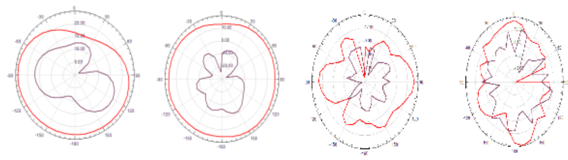
Fig. 11. Radiation pattern at Various Resonant Frequencies for Wine glass shaped Woodpile based ground surface for 1mm strip width.



(a) 1.8919 GHz (b) 4.0180 GHz © 4.8649 GHz (d) 7.4234 GHz

_____ E-Co-polarization
_____ E- Cross Polarization

Fig. 12. Radiation pattern at Various Resonant Frequencies for Wine glass shaped Woodpile based ground surface for 2mm strip width.

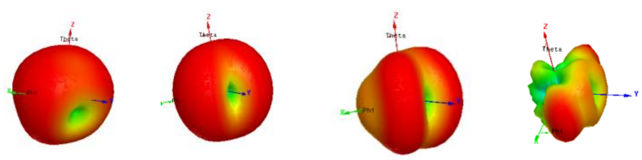


(a) 1.8018 GHz (b) 4.4414 GHz (c) 7.4234GHz (d) 9.7928 GHz

_____ E-Co-polarization
_____ E- Cross Polarization

Fig. 13. Radiation pattern at Various Resonant Frequencies for Wine glass shaped Woodpile based ground surface for 3mm strip width.

Gain is the important parameter in the design of wideband antenna. Figs. 14, 15 and 16 illustrate the gain patterns for three strip widths of woodpile structure. It was found that the gain of the antenna varies from 3.4 dB to 9 dB for various frequencies.



Peak gain G=9.006 dB at 2GHz; Peak gain G=4.3078 at 4.009GHz; Peak gain G=3.9604 dB at 4.9550 GHz; Peak gain G =6.8476 dB at 7.7117 GHz

Fig. 14. 3-Dimensional Gain of Wine glass shaped antenna with woodpile EBG structure with 1mm strip width at various resonating frequencies.

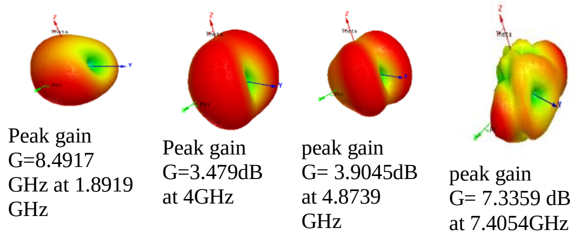


Fig. 15. 3-Dimensional Gain of Wine glass shaped antenna with woodpile EBG structure with 2mm strip width at various resonating frequencies.

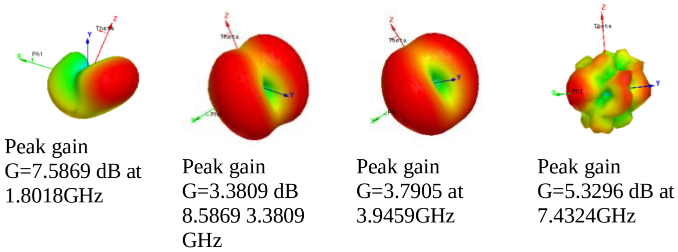


Fig. 16. 3-Dimensional Gain of Wine glass shaped antenna with woodpile EBG structure with 3mm strip width at various resonating frequencies.

Group delay is also an important parameter in the design of wideband antenna at microwave frequency range as it shows the degree of distortion in the transmitted pulse. The group delay of less than 5 ns is expected for good pulse transmission. Fig. 17 shows the comparative variation of group delays for strips widths of 1mm,2mm and 3mm of woodpile structure. It was observed that 1mm strip width woodpile structure shows good results as compared to 2mm and 3mm strip widths. The group delay is maintained below 5 ns for all the cases of strip widths.

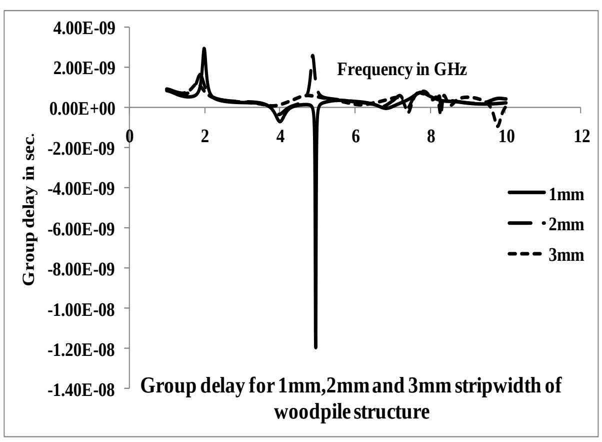


Fig. 17. Group delay for various strip widths of woodpile structure 1mm,2mm and 3mm.

5. FABRICATION AND TESTING OF ANTENNA

The simulation and parametric study of CPW fed Wine glass shaped microstrip patch antenna with hexagonal slot with various sized woodpile strip width EBG structure has carried out in previous sections. From those findings, it is observed that woodpile structure with 1mm strip width shows better return loss, gain and group delay as compared to 2mm and 3mm strip widths. Hence, the antenna with hexagonal slot and 1mm woodpile EBG structure and dimensions as discussed in section II was fabricated using printed circuit board technology. Fig. 18 shows the photograph of fabricated antenna.

Fig. 18. Fabricated CPW fed microstrip antenna with hexagonal slot and 1mm strip width woodpile EBG structure.

The fabricated antenna is tested by Rogers R&S ZNB Vector Network Analyzer for return loss measurement and Antenna measurement system for gain measurement. Fig. 19 shows the comparative graph of return loss for simulated and fabricated antenna.

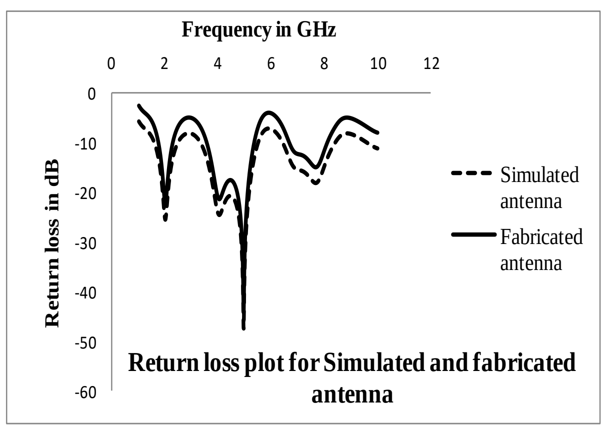


Fig. 19. Comparative plot of Return loss for simulated and fabricated antenna.

From Fig. 19, it is observed that simulated and fabricated results are agreeing with each other. The fabricated antenna shows similar dips for return loss.Fig. 20 shows the comparative plot for E-plane co-polarization for simulated and fabricated antennas at 1.99 GHz.

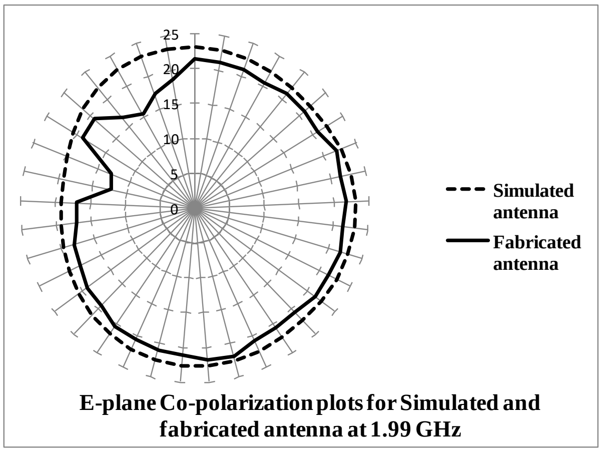


Fig. 20. E-plane co-polarization for simulated and fabricated antennas at 1.99 GHz.

From Fig. 20, it is observed both simulated and fabricated antennas are radiating in front direction. The pattern is little bit distorted from back side for fabricated antenna as compared to simulated antenna.

6. CONCLUSION

The novel hexagonal slotted wine glass shaped CPW fed Microstrip antenna with Woodpile based EBG structure is proposed. The unique shape of antenna has found to be useful for increasing the fractional bandwidth. The parametric study of antenna parameters depending on different sized strips of woodpile structure was carried out. The bandwidth is 43 % and gain of 9 dB was achieved using 1mm strip width of wood pile structure. The group delay was maintained below 5 ns for all combinations of strip widths which prove advantageous for distortion less pulse transmission. The antenna is fabricated with 1mm strip width of 1mm woodpile EBG structure and tested for return loss and E-plane co-polarization. The antennae resonate majorly around 2GHz, 4 GHz and 7 GHz and therefore these antennas are useful for wireless communications especially for ISM band, Wi-max wireless communication systems.

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