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Hybrid Zeroth-Order Resonance Patch Antenna with Improved Half Power Beamwidth

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***Abstract**: Antenna miniaturization is a critical issue in today's wireless and communication systems. Omnidirectional antennas are useful for applications in wireless communication however these antennas radiate towards the broadside and antennas should protrude from ground for large radiation area. Several techniques to reduce antenna size have been proposed in the recent years. One approach is Metamaterial (MTM) based zeroth-order resonator (ZOR), ZOR antennas with the same physical size present better performance if compared to other techniques. The conventional rectangular patch antenna cannot radiate omni-directionally, despite of structural stability. Resonant frequencies of the conventional rectangular patch antenna depend on width and length of patch, and height of substrate because of finite wavelength. ZOR antennas are designed by using the ZOR mode- one of many attractive properties of the metamaterial antennas. The antenna utilizes the zeroth-order resonance (ZOR) mode of the mushroom structure and the TM_{010} mode of the conventional rectangular patch. If the directional radiation pattern of a TM_{010} mode and the omni-directional radiation pattern of a ZOR mode are combined at the same frequency, it is expected that the total radiation pattern would have the broader beamwidth.*

***Keywords:** Beam width, Fringing, Metamaterials, Microstrip antenna, Rectangular Patch Antenna, Zeroth order resonance (ZOR) antenna.*

I. Introduction

A patch antenna (also known as a rectangular microstrip antenna) is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane. The radiation mechanism arises from discontinuities at each truncated edge of the microstrip transmission line.[2] The radiation at the edges causes the antenna to act slightly larger electrically than its physical dimensions, so in order for the antenna to be resonant, a length of microstrip transmission line slightly shorter than one-half a wavelength at the frequency is used. The rectangular patch antenna is approximately a one-half wavelength long section of rectangular microstrip transmission line. When air is the antenna substrate, the length of the rectangular microstrip antenna is approximately one-half of a free-space wavelength. As the antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases.

The microstrip patch antennas have been one of the most popular antennas in modern wireless communication systems as they have several desirable attributes, such as a low-profile planar configuration, a light weight, a simple design principle, a low fabrication cost, and so on [1], [2]. The conventional rectangular patch antenna has a directional radiation pattern at the TM_{010} mode. It has a relatively narrow scanning range and hence it is difficult for the antenna to maintain a stable performance in the changing environments or the moving systems. This disadvantage created a need for an antenna with an enhanced beamwidth. For obtaining a broad beamwidth, many antennas using the various techniques have been reported. For example, by using the phase array patch structures [3], the multilayered structures [4]–[6], or the parasitic radiators [7], [8], it is possible to design the patch antennas with a broad beamwidth. However, they have several limitations such as a larger size, a difficult design, and a multi-layered structure.

II. Rectangular Patch Antenna

A patch antenna is usually constructed on a dielectric substrate, using the same materials and lithography processes used to make printed circuit boards. The most commonly employed microstrip antenna is a Rectangular patch. Dimensions of the patch are finite along the length and width and hence the fields at the edges undergo fringing. Radiation in patch antenna is due to the fringing field between the periphery of the patch and the ground plane which is a function of dimension of patch and substrate height. It increases with the height of the substrate. But as the height increases, surface waves which are unwanted radiations also increase, so an optimum value for substrate height should be chosen. Fringing makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant is introduces to account for fringing and the wave propagation in the line.

2.1 Rectangular Patch Antenna With Etched Hole

A rectangular patch antenna with an etched rectangular hole is shown in fig 1. The rectangular hole is etched in the center of a patch [15]. In addition, a circular patch and a gap (g_p)as a feeding structure are employed. A coaxial probe (50 ohms) is directly connected with the circular patch. Therefore, the excited power is coupled to the rectangular patch through the circular patch. A TM_{010} mode can be generated in this structure like a conventional rectangular patch antenna. The dimensions of the antenna are as follows: Width of the substrate W_s=45mm, Length of the substrate L_s =40mm, width of the etched hole W_e =11mm, Length of the etched hole=6mm, g_p=0.2mm, height of the substrate h_s=3.175mm, Width of the patch W_p=15mm, Length of the patch L_p=10mm, permittivity=2.2 and δ_d = 0.0009.

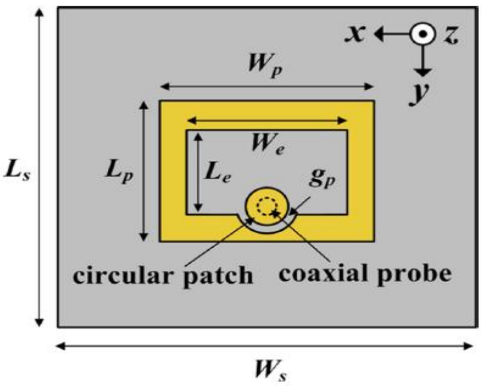

Fig. 1. Geometry of the rectangular patch antenna with an etched rectangular hole.

III. Mushroom Antenna

Mushroom antennas are made up of metamaterials which are synthetic material with unusual refractive properties, used for wireless systems. Their Optical and electromagnetic properties can be engineered by changing the geometry of its unit cells. Each artificial unit responds to the radiation from the source. The collective result is the material's response to the electromagnetic wave that is broader than normal. It can step up radiated power of an antenna, stores energy reradiates, behaves as if it was much more larger. It is an infinite wavelength antenna where infinite wavelength occurs because the propagation constant is zero. Hence its frequency does not depend on its physical length, but on the reactance provided by its unit cell.

A circular patch is directly connected with the coaxial probe, and a gap is inserted between the mushroom patch and circular patch. Therefore, an excited power is coupled from the circular patch to the mushroom patch. In general, the mushroom antenna has an infinite wavelength mode at specific non-zero frequency called a ZOR mode. The resonance frequency of a ZOR mode is determined by the area of a patch, the radius of a via, and the height of a mushroom antenna. The dimensions of the antenna are as follows: Width of the substrate W_s=45mm, Length of the substrate L_s =40mm, width of the etched hole W_e=11mm, Length of the etched hole=6mm, g_p=0.2mm, height of the substrate h_s=3.175mm, Width of the patch W_p=15mm, Length of the patch L_p=10mm,ε=2.2 and δ_d = 0.0009.

IV. Hybrid ZOR Antenna

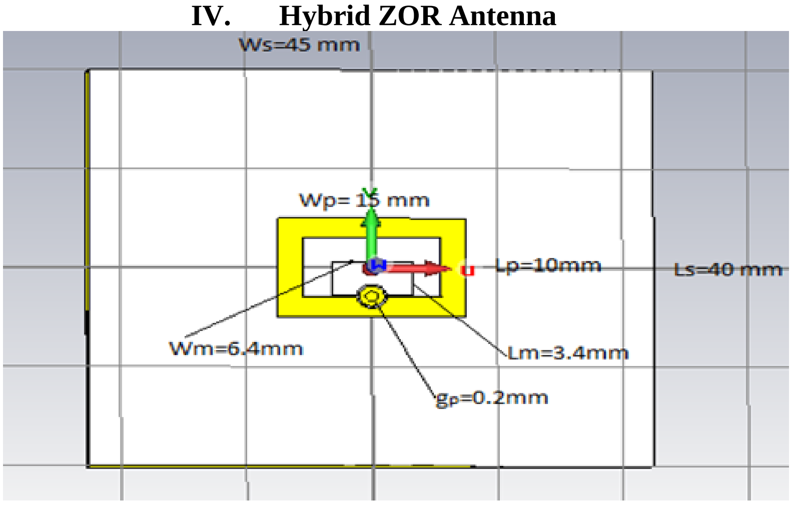

Fig 2: Hybrid ZOR antenna

To combine two modes at the same frequency, the structure where the mushroom ZOR antenna is inserted in the etched pattern of a rectangular patch antenna, is designed. The antenna utilizes the zeroth-order resonance (ZOR) mode [9], [10] of the mushroom structure and the TM_{010} mode of the conventional rectangular patch .Therefore, the proposed antenna is composed of two radiators. This antenna will be called as a hybrid ZOR antenna since it operates with the TM_{010} mode and the ZOR mode at the same frequency with a single feed. First, the rectangular etched hole allows the patch antenna to have a lower resonance frequency of the TM_{010} mode without changing the radiation pattern, the E-plane HPBW, and the size of an antenna. Second, the mushroom ZOR antenna has the omni-directional pattern. If it is assumed that the resonance frequency of the ZOR mode is the same as that of the TM_{010} mode and two modes are generated simultaneously, the directional radiation pattern and the omni-directional pattern can be combined. It is expected that the total radiation pattern would have the broader beamwidth. First, the etched rectangular hole is patterned on the center of the rectangular patch and, then, the mushroom ZOR antenna is inserted inside the hole. At the ZOR mode, an equivalent horizontal magnetic loop current is generated inside the mushroom structure, resulting in a low-profile omni-directional radiation pattern [11]–[14].

This proposed antenna has structurally several advantages. First, the antenna needs only single-layered substrate and maintains a planar configuration. Second, although the antenna has two radiators, a small size can be achieved because the mushroom ZOR antenna is added inside the etched hole. Finally, it has a simple structure. In order to excite the TM_{010} mode of an outer patch and the ZOR mode of an inner mushroom patch simultaneously, a circular feeding patch is inserted between two patches. The circular patch is directly connected to the coaxial probe. Thus, two radiators receive the incident power from the single feed. In addition, two gaps of g_p and g_m are added between the circular patch and two radiators in order to independently control the injected power to each antenna.

V. Figures And Tables

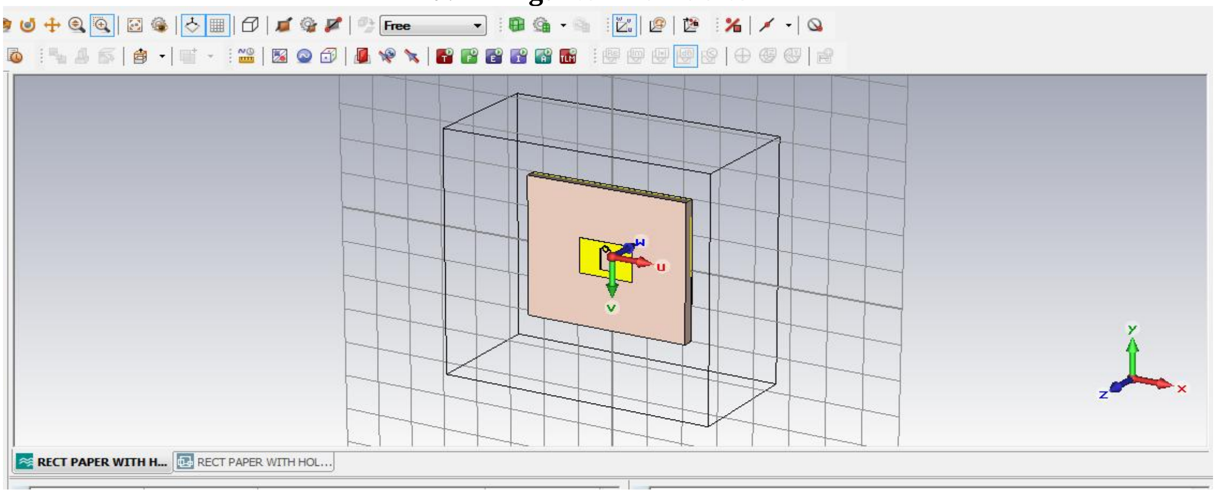

Fig 3: Rectangular patch antenna with etched hole width= 3mm

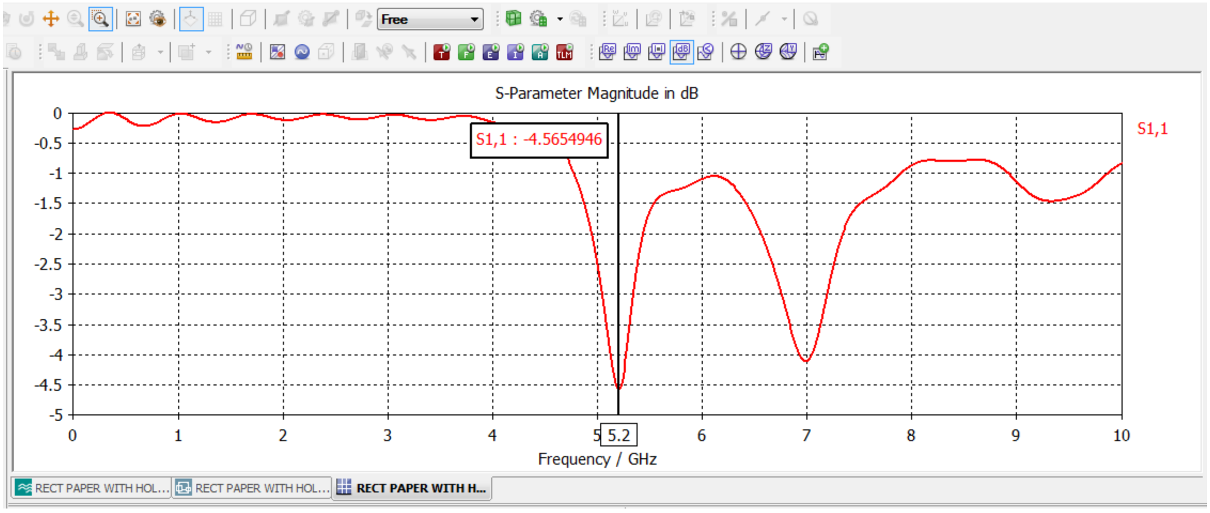

Fig 4: Resonant frequency of Rectangular patch antenna with etched hole width= 3mm

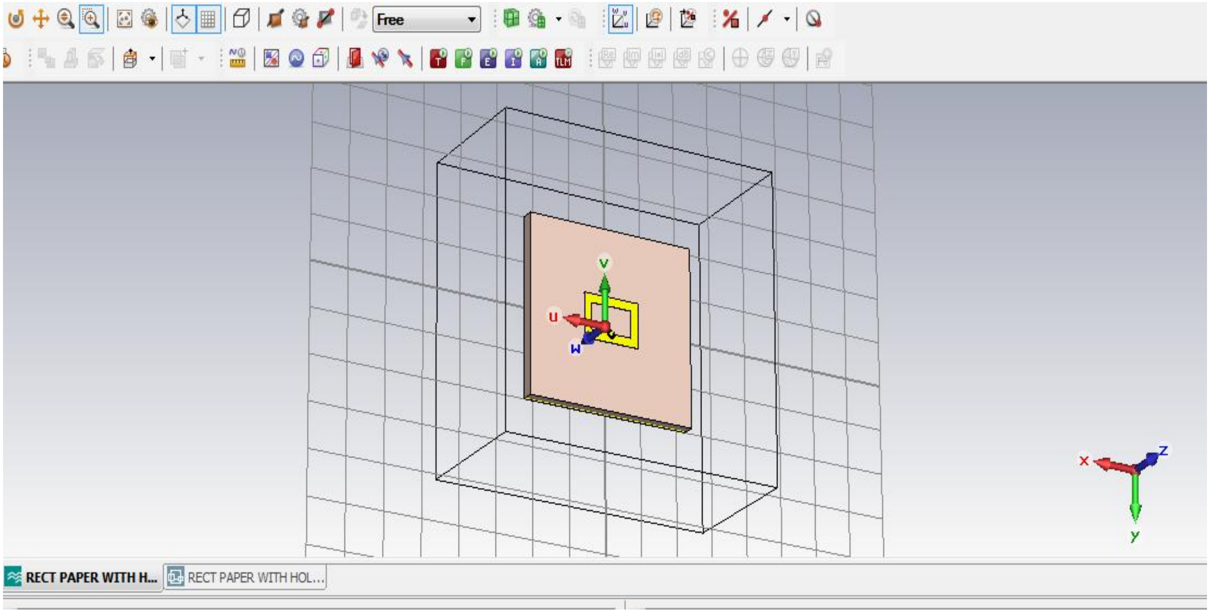

Fig 5: Rectangular patch antenna with etched hole width=11mm

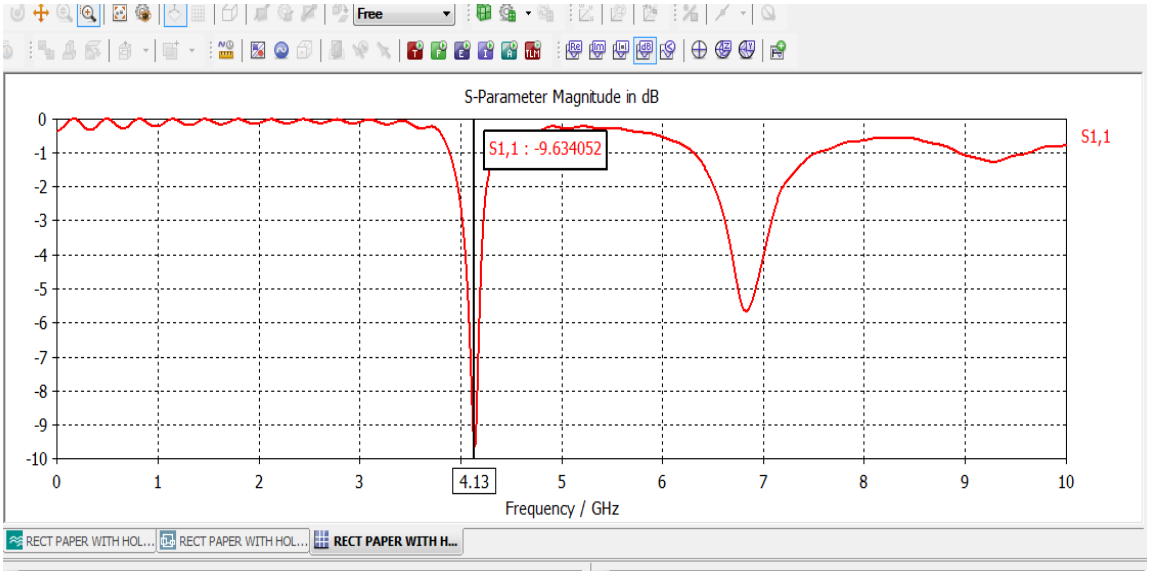

Fig 6: Resonant frequency of Rectangular patch antenna with etched hole width= 3mm

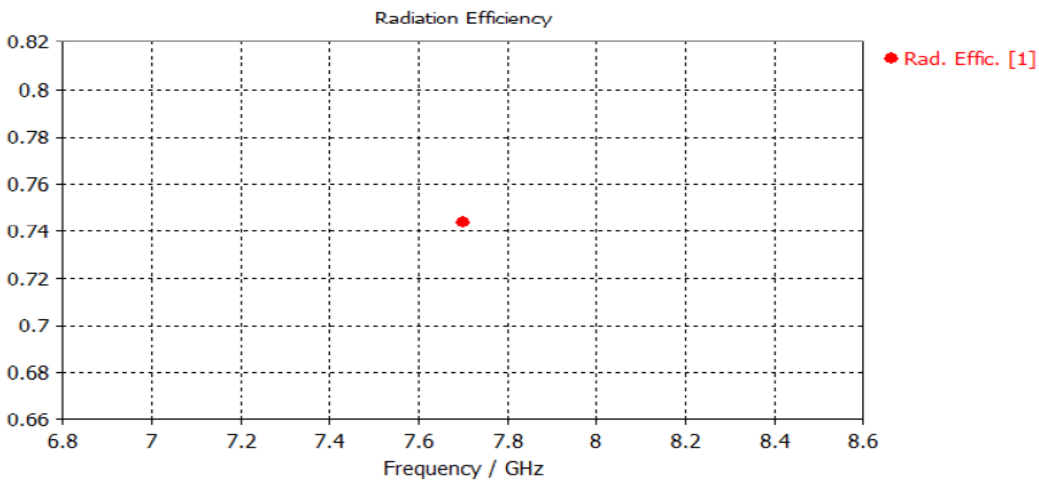

Fig 7: Radiation efficiency of Rectangular patch antenna

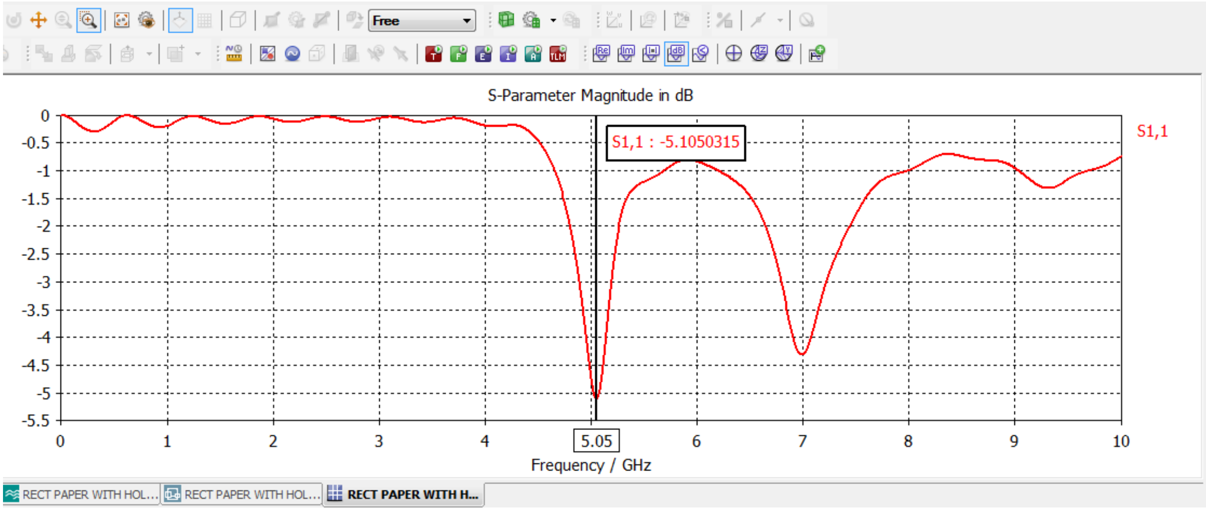

Fig 8: Resonant frequency of Rectangular patch antenna with etched hole width= 5mm

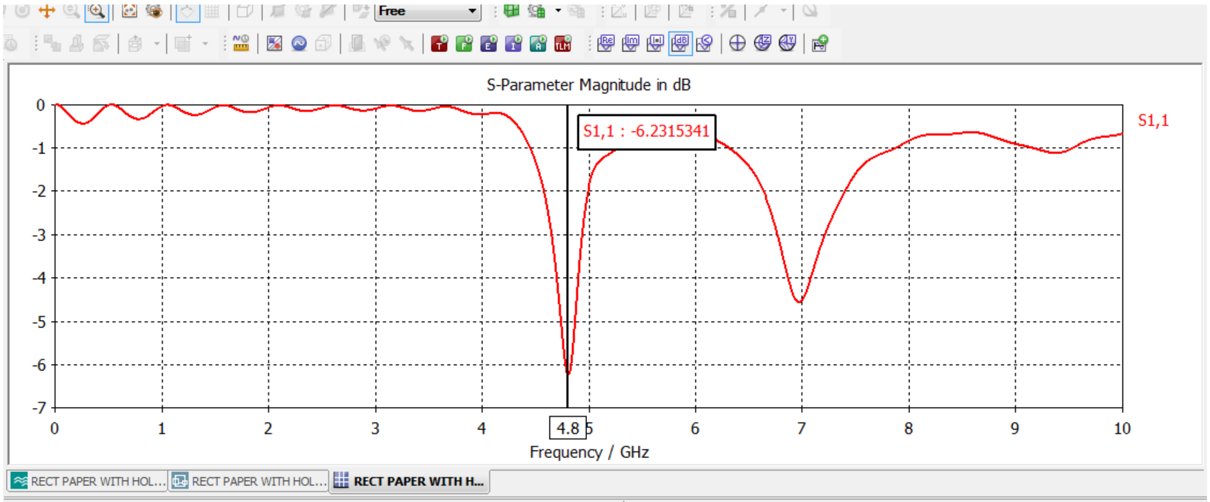

Fig 9: Resonant frequency of Rectangular patch antenna with etched hole width= 7mm

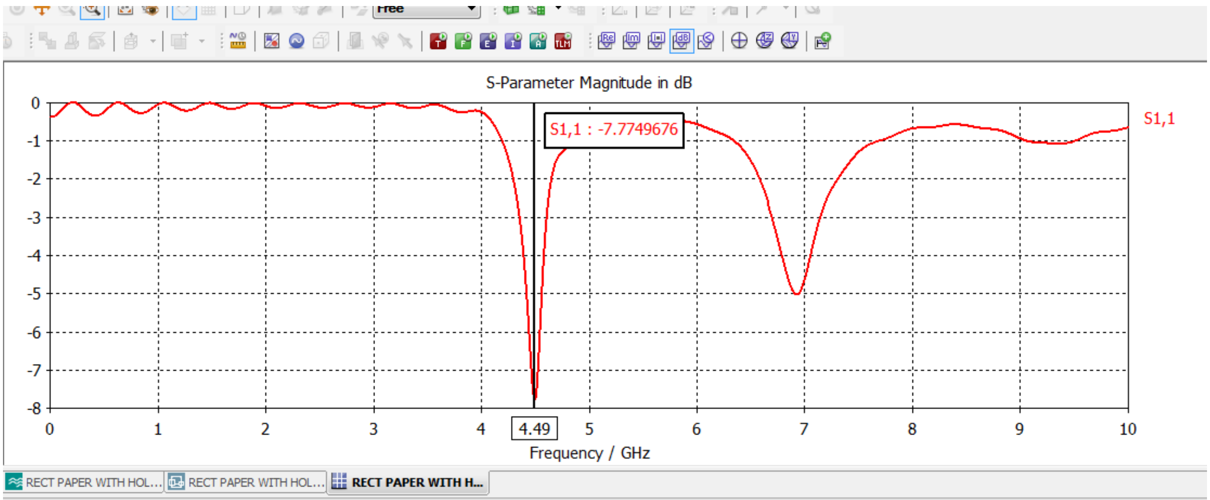

Fig 10: Resonant frequency of Rectangular patch antenna with etched hole width= 9mm

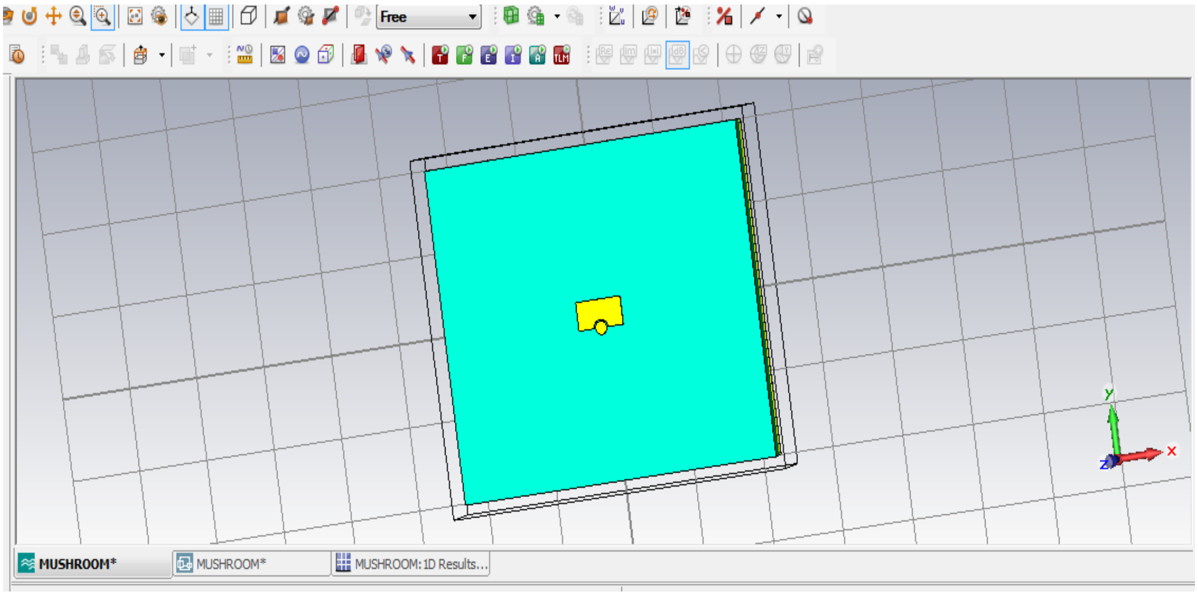

Fig 11: Mushroom antenna

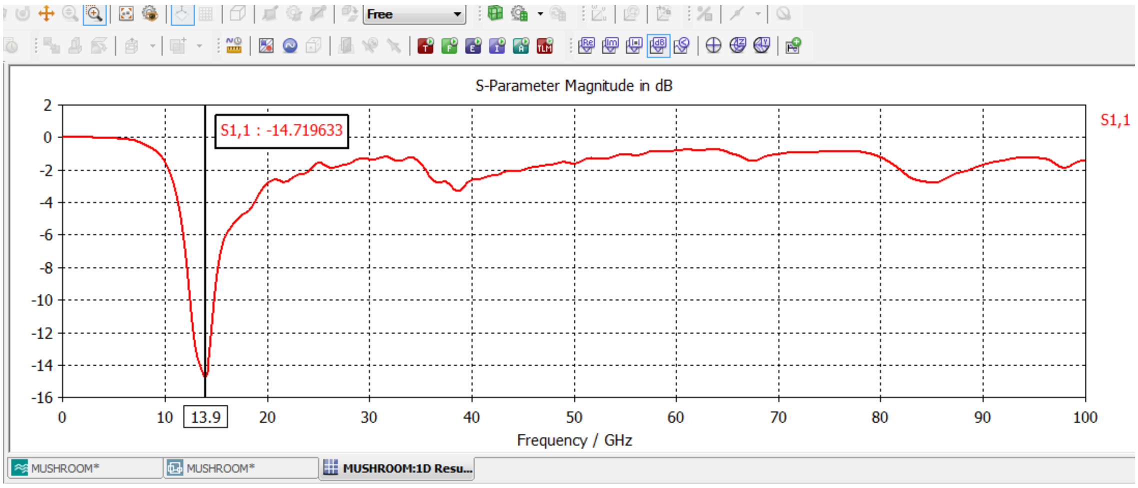

Fig 12: Resonant frequency of Mushroom antenna

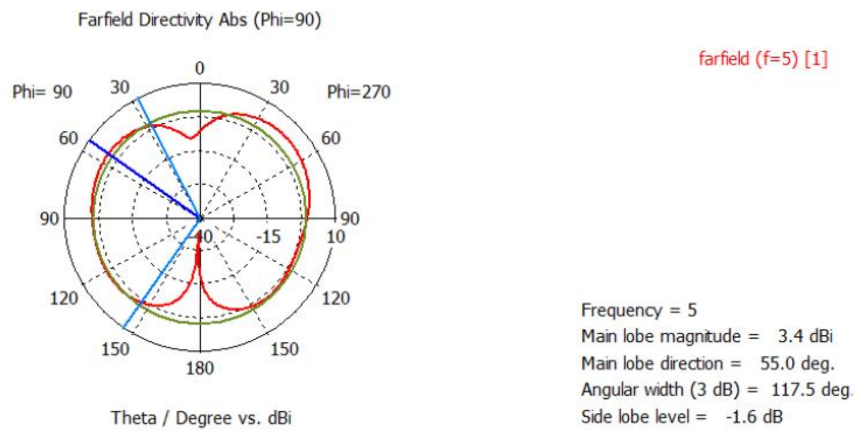

Fig 13: HPBW of Mushroom Antenna

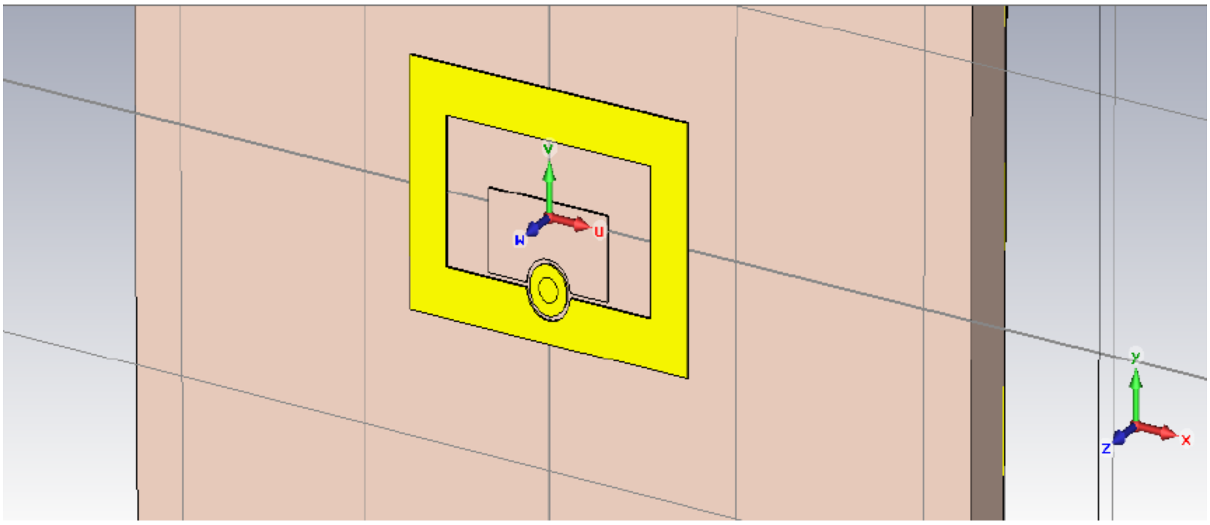

Fig 14: Hybrid ZOR antenna

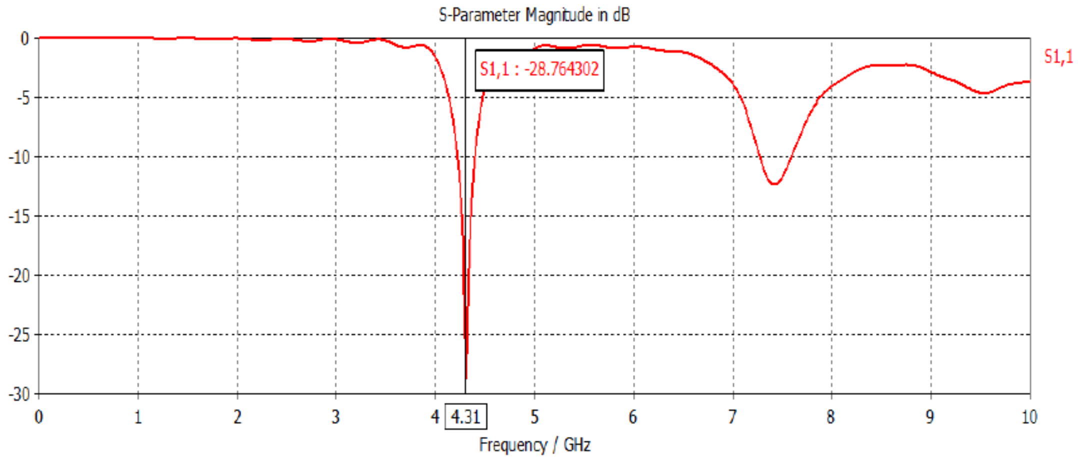

Fig 15: Resonant frequency of hybrid ZOR antenna

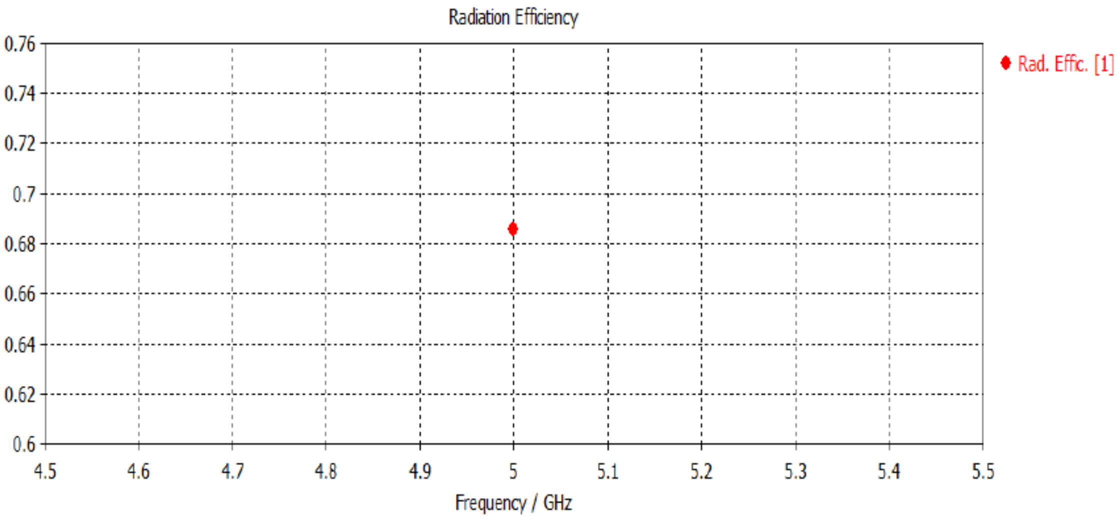

Fig 16: Radiation efficiency of hybrid antenna

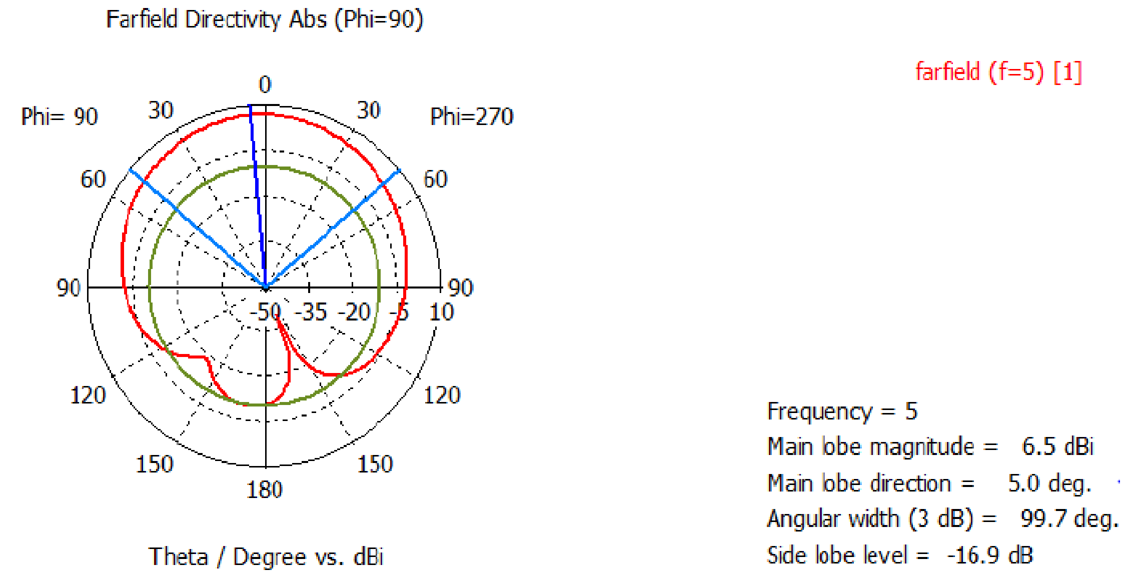

Fig 17: HPBW of hybrid ZOR antenna

Table 1: Effect of Resonant frequency on etched hole width for rectangular patch antenna with etched hole

Sl no	Etched hole width (mm)	Resonant frequency (GHz)
1	3	5.2
2	5	5.05
3	7	4.8
4	9	4.49
5	11	4.13

Table 2: Comparison of the parameters of the proposed antenna with Rectangular Patch

Parameters	Rectangular Patch	Mushroom antenna	Hybrid ZOR antenna
Resonant frequency	4.22 GHz	13.9 GHz	4.31 GHz
Half power beam width	24.8°	117.5°	99.7°
Radiation efficiency	75%	20.14%	69%
Radiated power	0.23 W	0.0053 W	0.056 W

VI. Summary Of Results

Rectangular patch antenna has very low HPBW and hence is not ideal in moving environments because of its very low scanning range. By employing the rectangular etched hole, the resonance frequency of the patch antenna is down-shifted without changing the HPBW and the size of the antenna. The E-plane HPBW is broadened compared with that of the conventional patch antenna. The proposed antenna has not only the broader E-plane HPBW but also the smaller size than the conventional rectangular patch antenna. Even though mushroom antenna has the maximum HPBW, it has very low radiation efficiency and cannot be used. So when both antennas are combined, the E Plane beamwidth as well as radiation efficiency is increased.

VII. Conclusion

A hybrid ZOR patch antenna having the broad E-plane beamwidth is designed and simulated. In order to obtain the broad beamwidth of an antenna, a TM_{010} mode and a ZOR mode are combined at the same frequency. By using the omni-directional radiation pattern of a ZOR mode, the E-plane beamwidth of a TM_{010} mode can easily be broadened. To generate a TM010 mode and a ZOR mode simultaneously, the mushroom structure is inserted inside an etched hole of the rectangular patch. The hybrid antenna has the advantages of a simple structure, a single-layered substrate, and a planar configuration even though two radiators are employed. Its resonant frequency is independent of its physical length, so ZOR antennas are very compact. It has a uniform vertical electric field towards the ground plane, so that ZOR antenna has the magnetic loop current along open ended side wall. Thus the proposed low profile antenna omni-directionally radiates and covers a larger area.

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