Design of a Novel Aperture Coupled feeding Technique for a Printed Microstrip Dipole

Krishnendu Chattopadhyay, Santanu Das and Sekhar Ranjan Bhadra Chaudhuri

Abstract: A detailed study of a novel aperture coupled feed design for a printed microstrip dipole has been presented in this paper. The concept exhibits improvement from the point of view of variation in coupling level with change of width of dipole for a fixed size of aperture. The antenna is also flexible in respect of selection of substrate material in feed and radiating structure. A variation in bandwidth from 12 to 20MHz with a peak gain variation of 4 to 5 dBi for fixed length and standard width is observed for the proposed antenna. The details of simulation results are presented and discussed.

Index Terms: Aperture coupling, Coupling loop, Magnetic field, Printed Dipole, Over coupling, Under coupling, Method of moment.

1. INTRODUCTION

Dipole antennas are the oldest of all types of antennas. An antenna with a narrow rectangular strip (typically width less than $0.05\lambda_0$) is called microstrip dipole. In addition to this, another popular configuration is the centre fed dipole, whose printed version will be the printed dipole. The gap size of the centre fed printed dipole does not affect the characteristics, as long as it is smaller than a wavelength. The feed design is an important part of the dipole antenna design. In case of centre fed printed dipole, the electric field within the gap of the strip conductor is along the length of the dipole. This distribution is different from the patch, where dominant electric field component is normal to the substrate. So the printed dipole can not be fed directly with a microstrip line. One possible feed structure is the coplanar strips (CPS) geometry, which is physically and electrically compatible [1]. To feed a printed centre fed dipole by any other transmission line i.e coplanar waveguide (CPW), or coaxial probe, suitable transitions to CPS are needed. When the strips of the dipole are printed on the opposite surfaces of a dielectric sheet, it is called parallel strip line and it was analyzed by Wheeler [2]. The CPS and parallel line structures are balanced w.r.t ground plane, which can be a serious disadvantage in some applications [3]. The electromagnetic coupling (EMC) technique was first proposed by Oltman [4]. It is a feed mechanism of microstrip dipole which is compatible with MMIC environment. In EMC dipole, excitation is achieved through electromagnetic coupling to the feed line with no direct contact. As the feed line and dipole are located on same side of the ground plane, the feed line radiation contributes significantly to ripples in the radiation pattern. To eliminate the problem of parasitic radiation, aperture coupling technique has come where the feed line and radiating elements are separated by a ground plane. The coupling from feed line to antenna is accomplished through a slot in the common Ground plane[5,6], but this method has inherent problem of over coupling and under coupling of radiating elements as the coupling is highly dependent upon the relative size of aperture and width of dipole, that may result in loss of matching in some cases.

In this paper, a novel method for feeding a centre fed printed dipole has been presented, which is a modification of heuristic aperture coupling feeding technique and almost eliminates the problem of over coupling and under coupling with the change in dipole width, for a fixed aperture size. Besides this the feeding method also introduces a flexibility in choosing the permittivity of substrate material for feed structure and radiating structure, which is a critical choice for achieving suitable performance in case of normal aperture coupling. In case of aperture coupling the radiating element is excited through magnetic field [7, 8]. In this case, dipole is excited by currents generated by the induced e.m.f. into the two shorting pins connected to the extended portion of dipole, which has an adequate interaction with magnetic fields coming out through the aperture on the ground plane.

2. GEOMETRY AND CONFIGURATION

The Physical configuration of the structure is shown in Figure1. The centre fed dipole consists of thin strip conductor printed on a low permittivity substrate to maintain high radiation efficiency. In the structure the dipoles are constructed on a substrate with ε_{r2}=2.5 or 2.55 with varying thickness of h_2=0.794mm or 1.524mm, 1.6mm, and 2.5mm. The overall length of the dipole is L=26mm, with a gap, S=2mm for h_2=0.794mm, and with S=3mm for h_2=1.524mm, 1.6mm, 2.5mm at the centre. The width of the dipole (W) has been varied from 1mm to 3.6mm. The dipole is isolated from the feed line, which is printed on a substrate of ε_{r1}=10.2 and thickness of h_1=0.635mm or ε_{r1}=10 and thickness of h_1=0.508mm on other side of the common ground plane. The coupling from the feed line to radiating structure is accomplished by an aperture on common ground plane, whose configuration is shown in Figure2. The dipole is excited by currents generated by induced emf into the two shorting pins connected between the extended portion of dipole having width L_b=0.45mm and ground plane as shown in Figure1, which has an adequate interaction with magnetic fields coming out through the aperture on the ground plane. The open circuit tuning stub L_s in the feed line can be used to remove the reactive part of input impedance of dipole to improve matching.

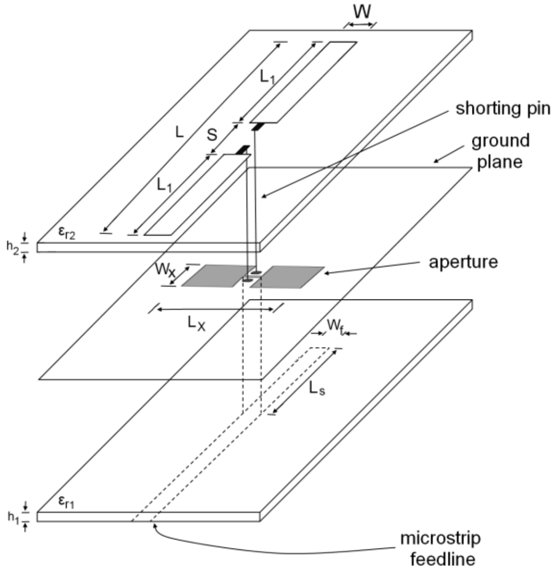

Fig.1. Modified Aperture coupled Microstrip Dipole configuration.

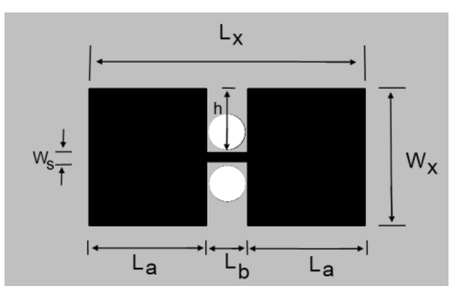

Fig.2. Expanded view of modified aperture with shorting pin location. (L_x=3mm, W_x=1.5mm, L_a=1.275mm, L_b=0.45mm, h=0.7mm,w_s=0.1mm) Structure is symmetric in nature.

3. SIMULATION RESULTS AND DISCUSSION

The simulation has been carried by MOM Based IE3D simulation software.

3.1. Study 1- Study has been done for three different widths (W) of dipole element i.e 2.279mm, 3.6mm and 1mm on different feed and radiating substrate, for fixed aperture dimensions, shown in Figure 2.

The antenna1 has been studied on feed substrate with ε_{r1}=10.2 and thickness h_1= 0.635mm and the radiating substrate is with ε_{r2}=2.5 and thickness of h_2 =0.794mm. The result is shown in Table 1.

Table1:Performance study of Antenna1 with width variation.

Width (mm)	Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)
2.279	3.521	29.08	11.27	1.61
3.6	3.227	31.02	10.57	0.91
1.0	3.898	16.88	9.26	1.66

Antenna1 substrate & element parameters: ε_{r1}=10.2, ε_{r2}=2.5, h_1=0.635mm, h_2=0.794mm, L=26mm, S=2mm.

We observe that for all the above cases, the antenna is retaining a good matching with acceptable bandwidth but resonance frequency is somewhat perturbed by the width variation. The Independence of amount of coupling with the variation of width, which was supposed to be over coupled for 1mm width and under coupled for 3.6mm width, can be clearly observed from the size of coupling loops in impedance plot as shown in Figure3b,Figure3e,Figure3h for three different widths of dipole. We observe that it is having nearly same size of coupling loop for all the three different widths. The cross polarization level is negligible both for E-plane and H-plane radiation. For H-plane it is below 40dB and for E-plane it is below 85dB w.r.t co-polar radiation level. The back lobe radiation is 26dB below the forward radiation level. Further increase in separation of printed dipole elements result in decrease of gain and bandwidth but maintain good matching.

The antenna2,antenna3,and antenna4 have been studied on feed substrate with ε_{r1}=10 and thickness 0.508mm and with the radiating substrate of ε_{r2}=2.55 and for three different thicknesses i.e 1.524mm,1.6mm and 2.5mm respectively. Table2, Table3, Table4 exhibits the result.

Table2:Performance study of Antenna2 with width variation.

Width (mm)	Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)
2.279	3.417	18.99	12.58	3.89
3.6	3.145	26.22	12.89	3.48
1.0	3.790	12.85	10.07	3.97

Antenna2 substrate & element parameters: ε_{r1}=10, ε_{r2}=2.55, h_1=0.508mm, h_2=1.524mm, L=26mm, S=3mm

Table3:Performance study of Antenna3 with width variation.

Width (mm)	Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)
2.279	3.438	25.74	15.10	4.17
3.6	3.168	22.35	18.12	3.73
1.0	3.807	15.85	13.29	4.29

Antenna3 substrate & element parameters: ε_{r1}=10, ε_{r2}=2.55, h_1=0.508mm, h_2=1.6mm, L=26mm, S=3mm

Table4:Performance study of Antenna4 with width variation.

Width (mm)	Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)
2.279	3.357	26.10	20.44	5.07
3.6	3.120	20.95	19.13	4.82
1.0	3.685	17.045	21.15	5.14

Antenna4 substrate & element parameters: ε_{r1}=10, ε_{r2}=2.55, h_1=0.508mm, h_2=2.5mm, L=26mm, S=3mm.

For all the above three cases the antenna2, antenna3 and antenna4 have been studied for the three different widths 2.279mm, 3.6mm and 1mm.we observe that the antennas maintain good matching level with gradually improving operating bandwidth from 10MHz to 21MHz with peak gain of 3.48dBi to 5.14dBi because of increasing radiating substrate thickness. The impedance loop is also not exhibiting over coupling or under coupling with the variation of antenna width for a constant aperture size as shown in Figure 4b, Figure 4e, Figure 4h for antenna2 observations only. Similar results are obtained for antenna3 and antenna4 regarding the size of the coupling loops i.e elimination of over and under coupling with the variation of width of the antennas. Study of radiation pattern reveals that, all the antennas exhibit broadside radiation pattern in dominant mode operation. The cross polar level for H-plane is about 36 to 60dB below and for E-plane it is 87 to 100dB below the co-polar level. The back lobe is below 30dB w.r.t forward power for all the above cases.

3.2. Study 2- The conceived design is also studied for the variation of feed structure dielectric constant, along with the variation of radiating substrate thickness in Antenna5, 6, 7. The results are shown in Table5,Table6 and Table7, referred to Figure.5 and Figure.6 for antenna5 and 6 only, showing return loss response, impedance plot and radiation pattern. Antenna7 also exhibits satisfactory performance. The structure has been compared with an existing concept of rectangular aperture coupled dipole antenna [5].

Table5: Performance study of Antenna5 for fixed width (W).

Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)	Aperture Type
No matching Found				Rectangle (3×0.6) mm
3.424	21.75	15.4	3.66	Shown in Figure2

Antenna5 Substrate & element parameters: ε_{r1}=4.4, ε_{r2}=2.55, h_1=0.508mm, h_2=1.524mm, L=26mm, W=2.279mm, Element separation S=3mm.

Table6: Performance study of Antenna6 for fixed width (W).

Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)	Aperture Type
No matching Found				Rectangle (3×0.6)mm
3.443	32.82	16.91	3.93	Shown in Figure2

Antenna6 Substrate & element parameters: ε_{r1}=4.4, ε_{r2}=2.55, h_1=0.508mm, h_2=1.6mm, L=26mm, W=2.279mm, Element separation S=3mm.

Table7: Performance study of Antenna7 for fixed width (W).

Resonance Frequency (GHz)	Return Loss at resonance (dB)	Bandwidth (MHz)	Peak Gain (dBi)	Aperture Type
No matching Found				Rectangle (3×0.6)mm
3.376	17.2	17.62	4.78	Shown in Figure2

Antenna7 Substrate & element parameters: ε_{r1}=4.4, ε_{r2}=2.55, h_1=0.508mm, h_2=2.5mm, L=26mm, W=2.279mm, Element separation S=3mm.

The results depicted above exhibit the flexibility of antenna operation with a different value of feed substrate dielectric constant i.e (ε_{r1}=4.4) and variation of radiating substrate thickness. The antenna exhibits good impedance matching, satisfactory bandwidth and coupling level is also similar to antenna1, antenna2, antenna3 and antenna4. The radiation patterns of antennas are broadside for dominant mode operation. The cross polar level is below 50dB for H-plane and below 90dB for E-plane for all the above cases of this study. The back lobe level is 26dB below the forward power level. So the above results exhibit satisfactory operation of antenna, even with lower value of ε_r at feed structure.

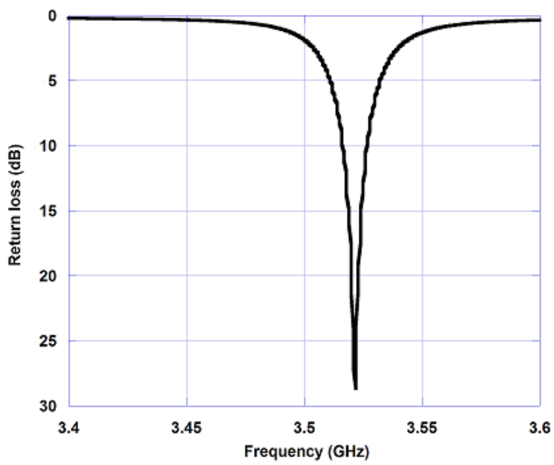

Fig.3a.Returnloss response of Antenna1, for width W=2.279mm.

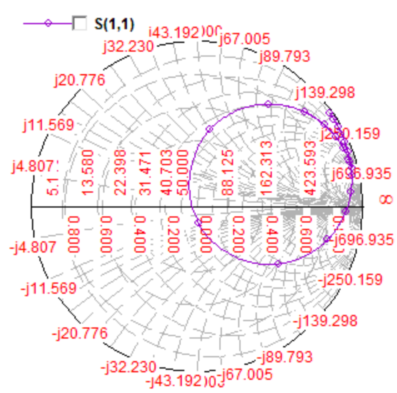

Fig. 3b. Impedance plot of Antenna1 for width W=2.279mm

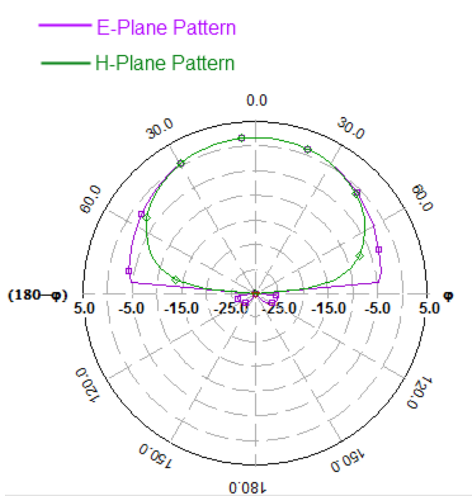

Fig. 3c. Radiation pattern of Antenna1 for width W=2.279mm.

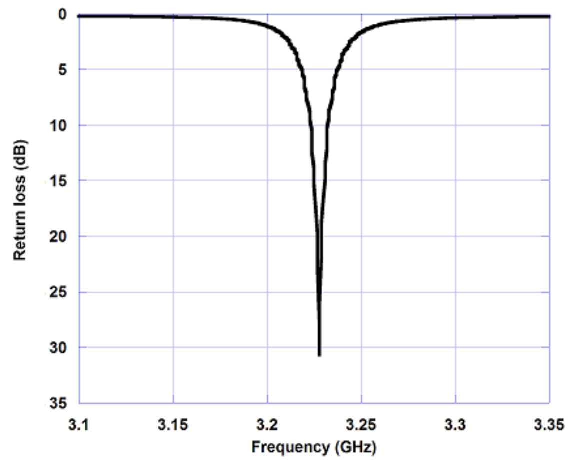

Fig. 3d. Return loss response of Antenna1 for width W=3.6mm.

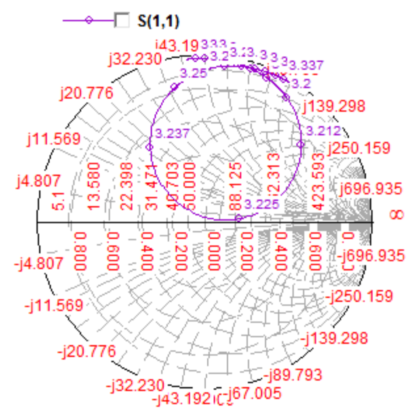

Fig. 3e. Impedance plot of Antenna1 for width W=3.6mm.

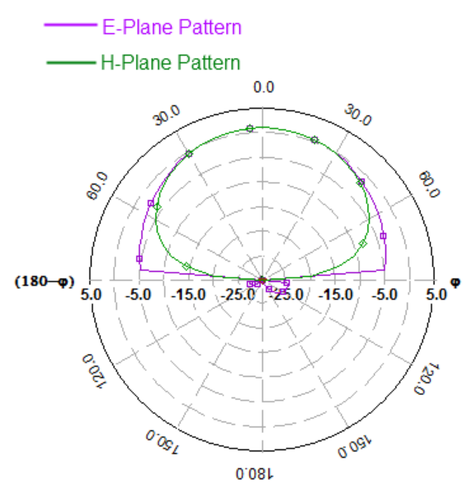

Fig. 3f. Radiation pattern of Antenna1 for width W=3.6mm.

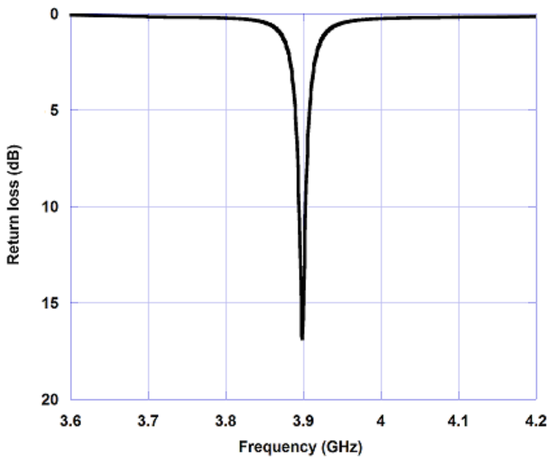

Fig. 3g. Return loss response of Antenna1 for width W=1.0mm.

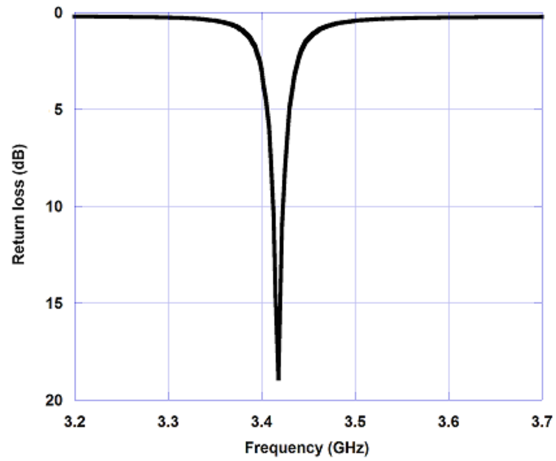

Fig. 4a. Return loss response of Antenna2 for width W=2.279mm.

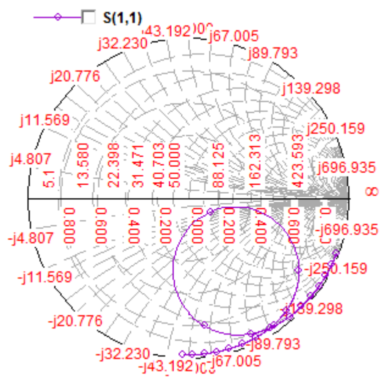

Fig. 3h. Impedance plot of Antenna 1 for width W=1.0mm.

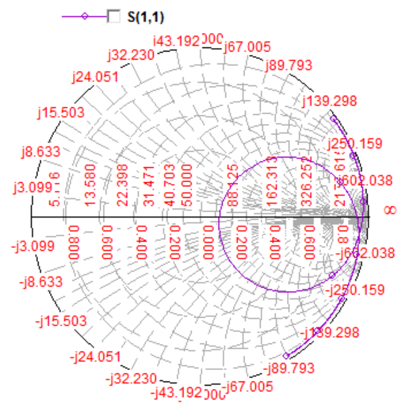

Fig. 4b. Impedance plot of Antenna2 for width W=2.279mm.

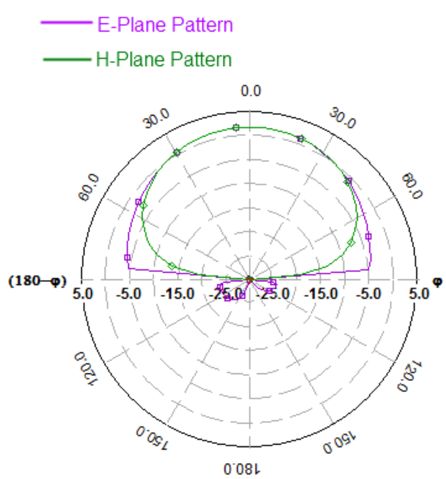

Fig. 3i. Radiation pattern of Antenna1 for width W=1.0mm.

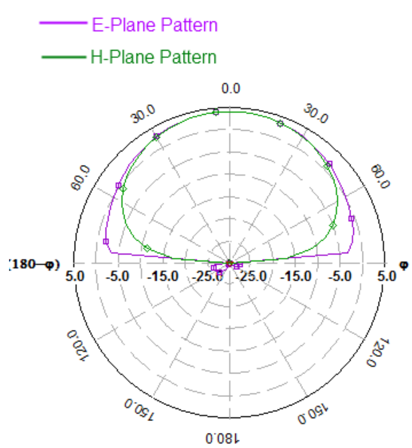

Fig. 4c. Radiation pattern of Antenna2 for width W=2.279mm.

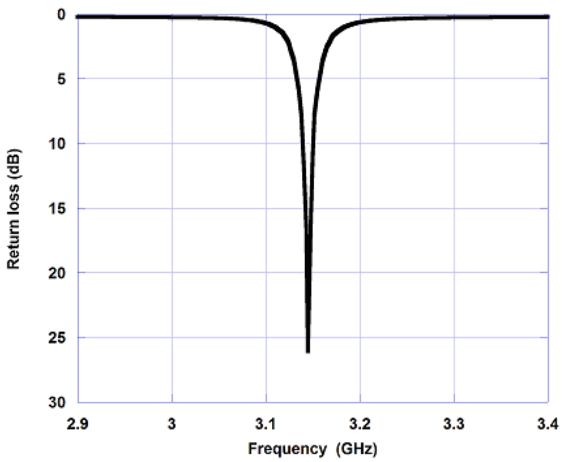

Fig. 4d. Return loss response of Antenna2 for width W=3.6mm.

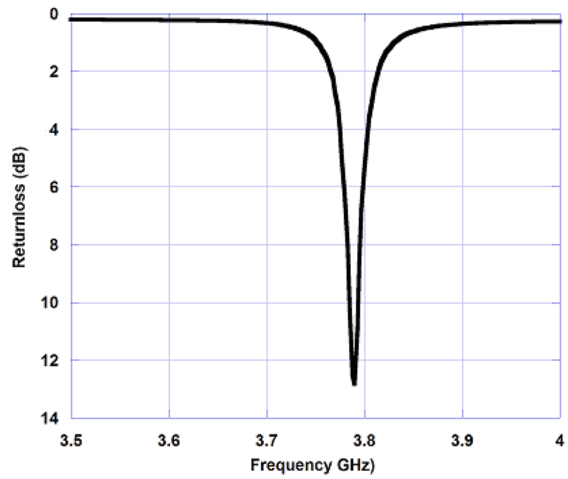

Fig. 4g. Return loss response of Antenna2 for width W=1.0mm.

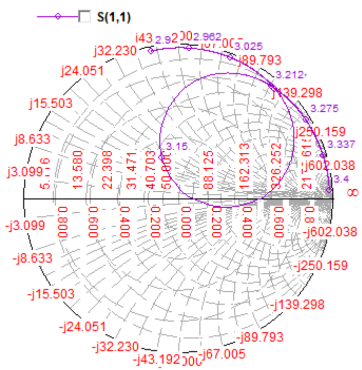

Fig. 4e. Impedance plot of Antenna2 for width W=3.6mm.

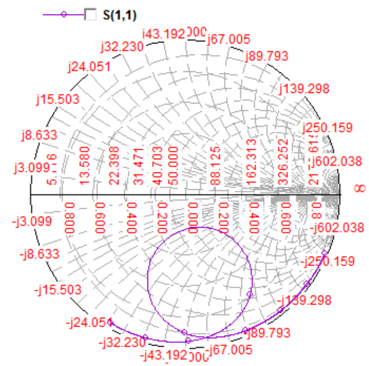

Fig. 4h. Impedance plot of Antenna2 for width W=1.0mm.

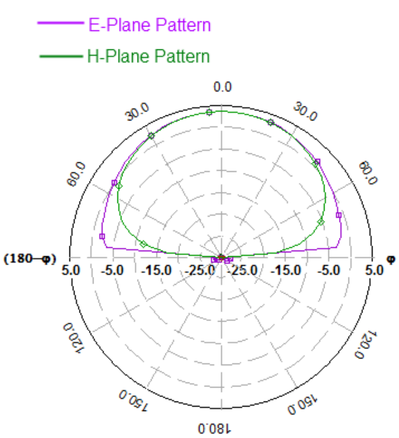

Fig. 4f. Radiation pattern of Antenna2 for width W=3.6mm.

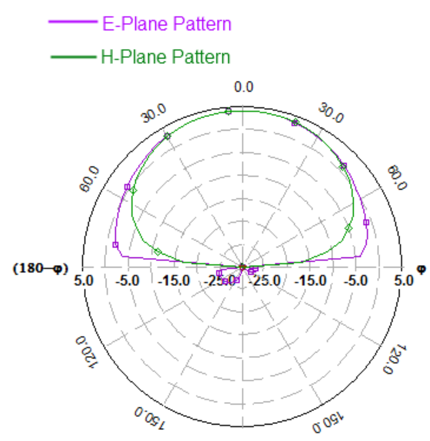

Fig. 4i. Radiation pattern of Antenna2 for width W=1.0mm.

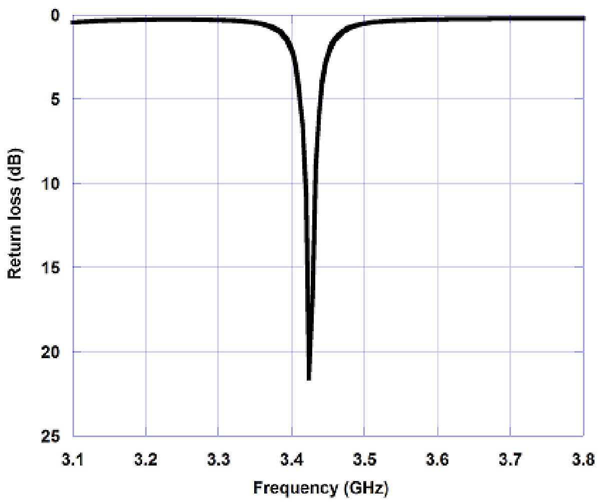

Fig. 5a. Return Loss response of Antenna5 for width W=2.279mm.

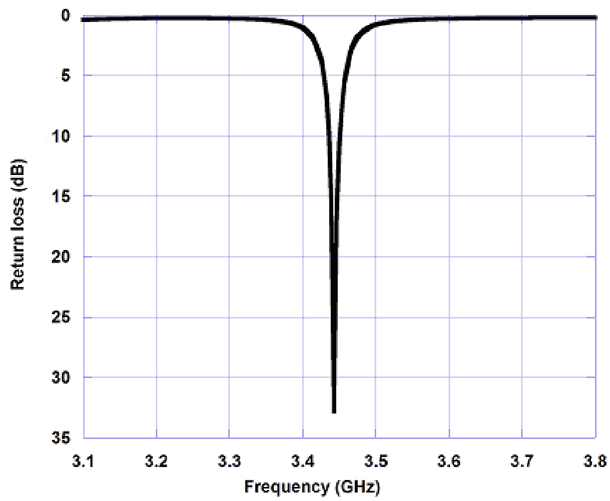

Fig. 6a. Return Loss response of Antenna6 for width W=2.279mm.

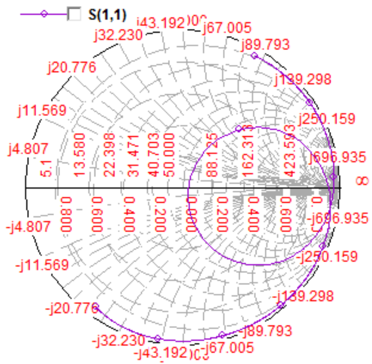

Fig. 5b. Impedance plot of Antenna 5 for width W=2.279mm.

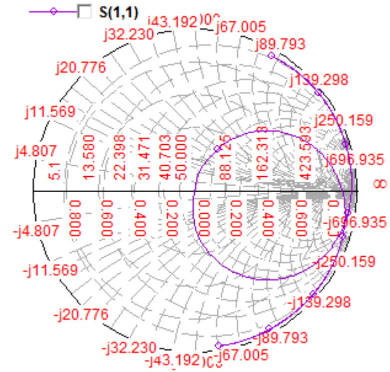

Fig. 6b. Impedance plot of Antenna6 for width W=2.279mm.

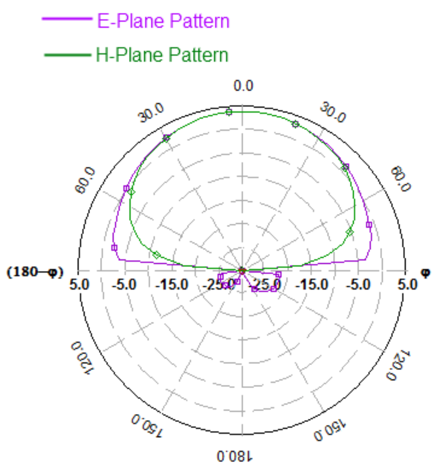

Fig. 5c. Radiation pattern of Antenna5 for width W=2.279mm.

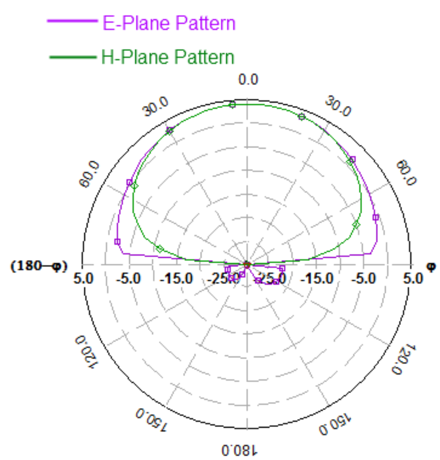

Fig. 6c. Radiation pattern of Antenna6 for width W=2.279mm.

4. CONCLUSION

A novel method of feeding the dipole antenna through aperture coupling method has been presented and discussed. With the reduction or increase of width of the radiating element for a fixed aperture size, the performance of the proposed antenna is found satisfactory and independent of over coupling and under coupling. The design also exhibits flexibility in selecting a feed structure dielectric constant to a relatively lower value exhibiting all the related parameters i.e return loss at resonance, gain, bandwidth, cross pole and back lobe radiation to an acceptable level. Hence criticality in the design of aperture coupled feeding technique for a microstrip dipole is addressed with the proposed technique.

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