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Compact Hexagonal Monopole Antenna

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Abstract

Objective: The different configurations of hexagonal monopole antennas are designed, simulated, tested and their performance is compared. **Method**: Different Hexagonal monopole antennas are designed and simulated using HFSS, these antennas are designed using Defective Ground Structure (DGS) and slots are made in ground plane and on patch. Effect of slot position on performance of antenna is examined. The antenna units are studied through simulation two antennas were fabricated and its return loss and VSWR are measured. **Findings**: The antenna parameters like return losses, VSWR, Gain and Directivity are evaluated and return losses and VSWR for the fabricated antennas are measured. It is observed that over a wide frequency band the return losses are <10 dB and VSWR is less than 2. **Applications**: These antennas can be used over UWB for Wireless and Indoor applications.

Keywords: Defective Ground Structure (DGS), Gain, Hexagonal Patch, Return Losses, Slot, UWB

1. Introduction

The frequency band of 3.1GHz-10.6 GHz was assigned by Federal communication commission for commercial Applications[1]. In these applications generally monopole antenna is used for its large bandwidth but the drawback with conventional monopole is that it is not compact and requires large ground plane perpendicular to the radiating element. Research carried out on reducing the size of antenna lead to development of UWB printed antennas using partial ground plane. Many researchers[2] are working on UWB monopole antennas with slots in patch and slots even in ground plane. These antennas are gaining attraction because of high speed data rate, low power consumption, low complexity, low cost, compact in size, less in weight and large bandwidth[3–24].

When slot is cut on the patch it effects the current distribution. By varying the slot position current distribution on the ground plane varies. The longest electrical path for the currents generated on the surface of the monopole is dependent on the lower limit of operating frequency. The shape of the slot and its dimensions play a important role in achieving UWB characteristics. Normally the current is concentrated in the bottom as well as at the left and right hand edges of the monopole. So to improve UWB characteristics slots are made on the lower edges of the patch beside the feed line. The ground plane of the antenna is also a part of radiating configuration and the current dis-

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tribution on radiating element. The gap between ground plane and patch play a crucial role in achieving wide band characteristics. For UWB characteristics with the monopole antenna defective ground structure is used. To get good matching and impedance band width bevel slots are made on the ground plane.

The performance is investigated for several compact UWB hexagonal antenna arrangements with micro strip feed to operate in the frequency band of 3GHz-12GHz. Investigations are carried out to estimate the effect of varying ground plane length and varying dimensions of slot on patch performance. For all case defective ground structure is employed. To compare the performance of these arrangements return loss, VSWR, gain and directivity are evaluated. The antennas are designed and tested using HFSS software.

Apart from evaluating performance by simulation, a hexagonal antenna with L Slot in patch and slots in ground plane (antenna1) and another with rectangular slot in patch and slots in ground plane (antenna 2) are fabricated and their return losses and VSWR values are measured.

The arrangement of the paper is as follows. The design details are given in section II. The results obtained through simulation are presented in section III. The results obtained through simulation and measurement are obtained is presented in section IV. Section V deals with discussion of results and conclusions.

2. Hexagonal Monopole Antenna Design

In order to design hexagonal monopole a rectangular patch is designed first considering a resonant frequency. Then it is made wideband antenna by cutting slots.

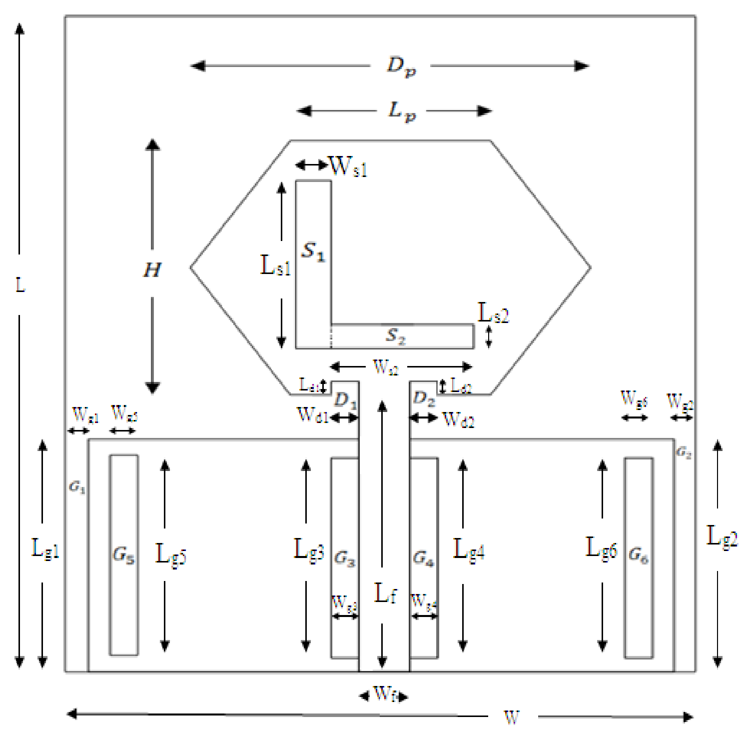

Figure 1. Structure of Antenna 1.

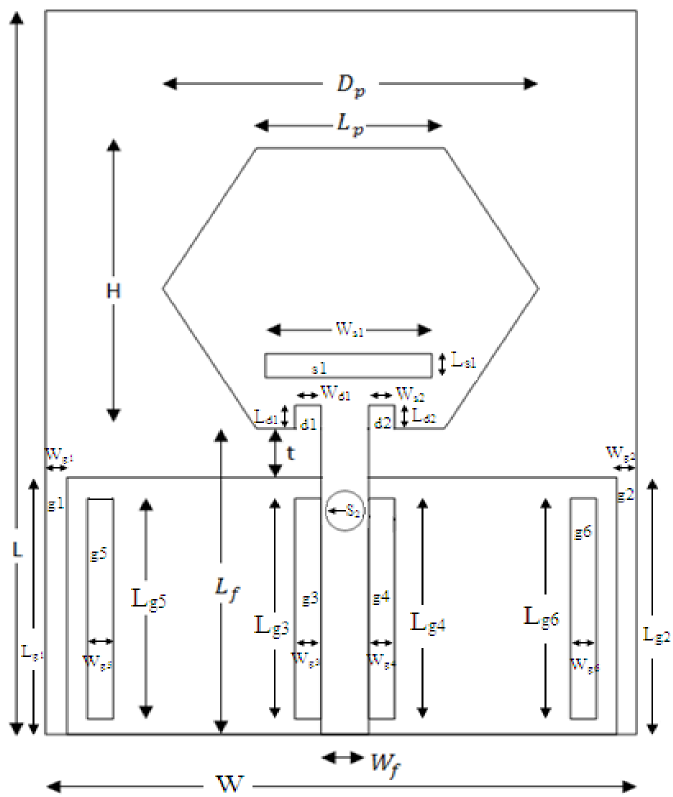

Figure 2. Structure of Antenna 2.

Finally it is converted to hexagonal shape by using equivalent expressions given later in the section. In this paper Antenna 1 is hexagonal antenna with 'L' Slot, bevel slots in the patch and slots in Ground plane is designed For this to start with the resonant frequency is taken as2.98GHz. Antenna 2 is hexagonal antenna patch with rectangular slot, bevel slots in patch and circular slot on feed line and rectangular slots in ground plane are cut and for the design to start with the resonant frequency of 7.5GHz is considered.. Substrate used is FR4 of thickness (h) 1.6mm and dielectric constant (ϵ_r) of 4.4. The antennas are designed using equations available in literature[8]. Where the different terms have usual meaning. The structures of the antennas are given in Figure 1 and 2.

In both the designs defective ground structures are used. Generally to reduce the size of the antenna without affecting the gain, bandwidth and other antenna parameters various methods like using high permittivity dielectric material, applying magneto inductive wave guide loading, slots on patch are used. To improve radiation efficiency and to reduce the spurious radiation EGB, PBG structures are used. But the simplest method is using defective ground structures.

Width of the rectangular patch

$$W = \frac{C}{2f_r\sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

Effective dielectric constant

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{12h}{W}\right]^{-0.5} \quad (2)$$

Difference between effective and actual lengths ΔL can be estimated from

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

Length of the patch

$$L = L_{eff} - 2\Delta L \tag{4}$$

Effective length is greater than actual length L due to fringing and it is calculated using the expression

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} \tag{5}$$

Length of the ground plane

$$Lg = \frac{C}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{6}$$

Width of the Ground plane

$$W_g = \sqrt{3}L \tag{7}$$

Now equating the area of the rectangular patch (L * W) to the surface area of a cylindrical wire of radius r and height h

2πrh=LW and using relation $h = L\sqrt{\epsilon_{efr}}$ (8)

The radius r will be

$$r = \frac{W}{2\pi\sqrt{\epsilon_{efr}}} \tag{9}$$

The side of hexagon is related to radius

r [24] $L_p = \frac{4\pi r}{3}$ (10)

$$H = \sqrt{3}L_p\,;\; D_p = 2L_p \tag{11}$$

Where the dimensions H,Dp are as indicated in the Figure 1 and 2

Using the above expressions the dimensions are evaluated for both the antennas and the results are given in Table 1.

The fabricated antennas are shown in Figure 3 and 4.

The dimensions obtained from design formulae are given in Table 1.

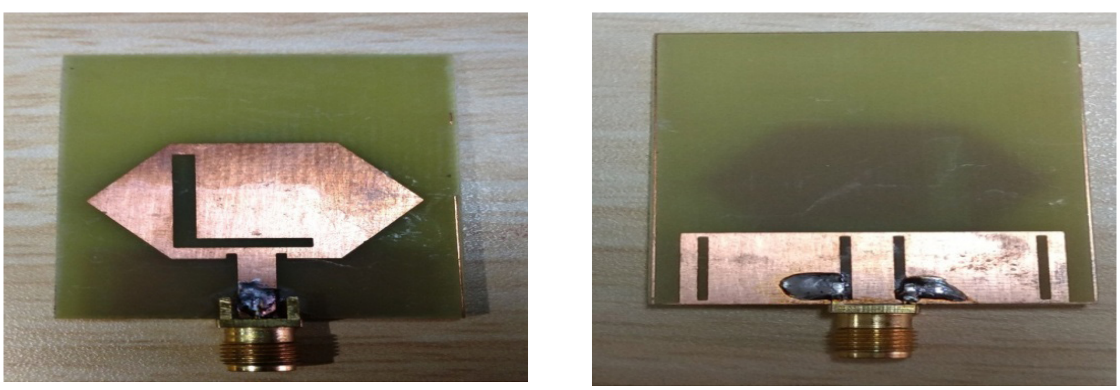

Figure 3. (a) Antenna 1 front view (b) Bottom view.

Table 1. Dimensions of Antenna 1 & Antenna 2

Parameter	Antenna 1 dimensions in mm	Antenna 2 dimensions in mm
Side Length of the patch(L_p)	13	5.437
Diameter of the monopole element (D_p)	26	10.874
Height of cylindrical monopole Antenna(H)	22.5	9.417
Length of the Ground Plane(L_g)	31	14
Width of the ground plane(W_g)	13	6
Length of the feed line(L_f)	14	9.5
Width of the feed line(W_f)	2.8	2.304
Thickness of the substrate(h)	1.6	1.6
Length of the slot s1 (L_{s1})	18.5	4.437
Width of the slot s1(W_{s1})	2	0.5
Length of the slot s2(L_{s2})	9	-
Width of the slot s2(W_{s2})	2	-
Length of the slot d1 (L_{d1})	1	0.5

Table 1 Continued

Width of the slot d1(W_{d1})	1	0.5
Length of the slot d2(L_{d2})	1	0.5
Width of the slot d2(W_{d2})	1	0.5
Length of the slots g1 and g2($L_{g1\&g2}$)	13	6
Width of the slots g1 and g2($W_{g1\&g2}$)	2	0.5
Length of the slots g3 and g4($L_{g3\&g4}$)	12	5
Width of the slots g3 and g4($W_{g3\&g4}$)	1	0.5
Length of the slots g5 and g6($L_{g5\&g6}$)	12	5
Width of the slots g5 and g6($W_{g5\&g6}$)	1	0.5
Spacing between ground plane and patch(s)	0.5	0.5
Resonant Frequency	2.98GHz	7.5GHz
Dielectric constant of the substrate	4.4	4.4
Radius of the circular slot S_2	-	1

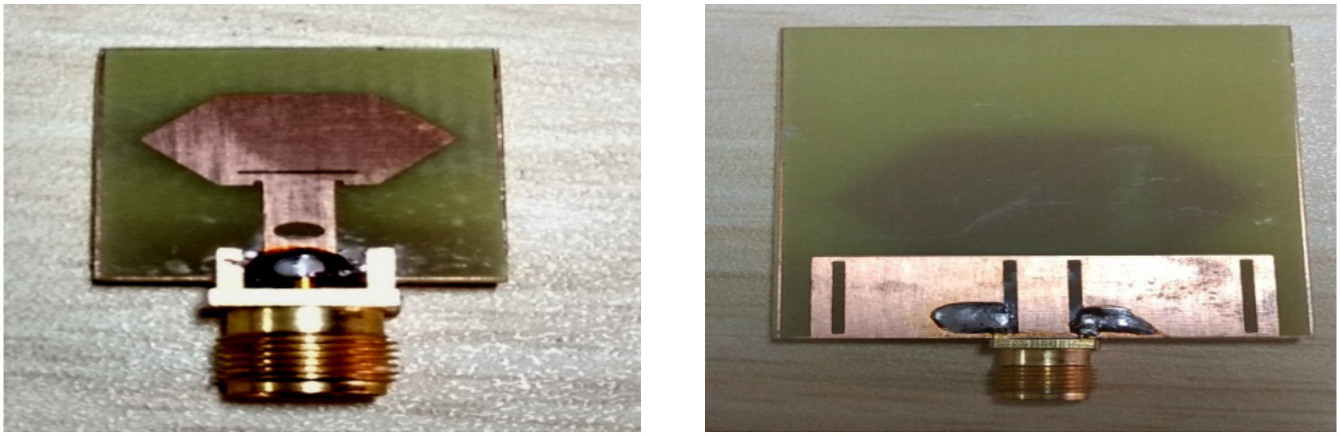

Figure 4. (a) Antenna 2 front view (b) Bottom view.

3. Results

The above designed antennas are tested using HFSS software. The simulation results are shown in Table 2–5. For Antenna 1 "L" shaped slot is placed in the patch and this antenna is designed by taking the resonant frequency 2.98GHz. From simulated results it is observed that return losses are higher than 10 dB for the entire frequency band (2.98 GHz-12 GHz) and VSWR is also less than 2 for the entire frequency band of 2.98-12 GHz. Variation of gain with frequency is given in Table 2.

Antenna1is fabricated using FR4 substrate for the fabricated antenna return losses and VSWR are measured using VNA and the results are given in Figure 5 and 6.

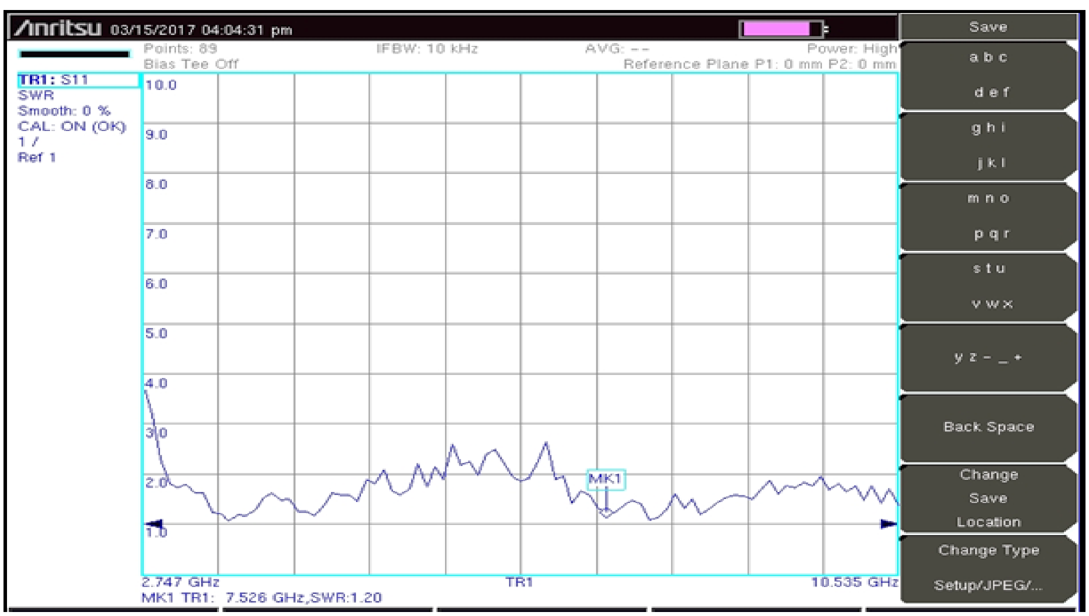

Figure 5. Measured VSWR for Antenna 1.

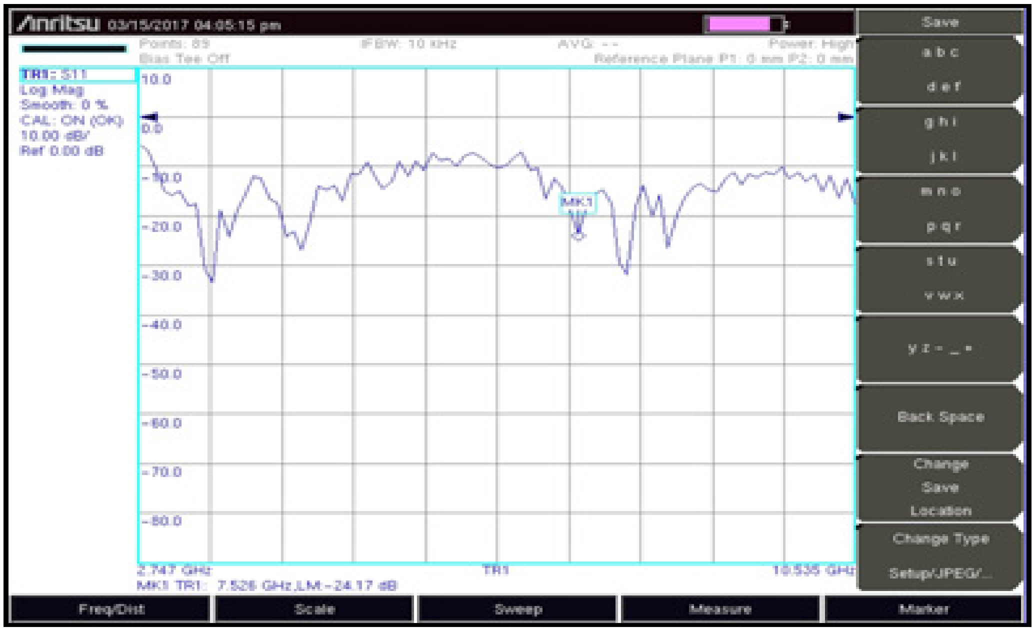

Figure 6. Measured Return losses for Antenna 1.

Table 2. Gain Vs Frequency for Antenna 1

Frequency in GHz	2.98	3.5	4	5	6	7	8	9	10	11	12	13
Gain in dB	2.15	3.993	5.17	6.61	7.44	7.48	7.66	7.35	6.616	5.16	1.56	-1.836

To get compact dimensions hexagonal patch designed with initial resonant frequency of 7.5GHz, a circular slot of radius 1mm is placed on the feed line and the effect of its position from feed point is examined on the performance of the antenna. The results are given in Table 3–5.

From the results it is observed that the performance is better when the circular slot is 4.75mm from the feed point.

Fixing the position of circular slot of 1mmradius at a distance of 4.75mm from feed point a rectangular slot of dimensions 4.437x0.5mm is cut at different locations and the performance results are presented in Table 4.

From Table 4 it is observed that when the rectangular slot is at 10.5mm distance from the feed line better results are observed.

The gain of Antenna 2 is measured at different frequencies through simulation and it is reported in Table 5.

For the fabricated antenna 2 VSWR, return losses are measured using VNA (VECTOR NETWORK ANALYZER) and results are shown in Figure 7 and 8.

Table 3. Variation of Antenna parameter with circular slot position

Position of the circular slot from feed point in mm	Frequencies GHz where return loss < 10dB	Frequencies GHz where VSWR<2	Efficiency at 7.5 GHz
4.75	3 to 15	2.9 to 15	0.9487
5	3 to 15	2.9 to 15	0.9291
5.5	2.9 to 15	2.9 to 15	0.9302
6	2.9 to 10.4, 12.9 to 15	2.9 to 10.8, 12.6 to 15	0.8874
6.5	3 to 11.3, 12.6 to 15	2.9 to 15	0.9006
7	2.9 to 6.4, 8.4 to 9.9, 13 to 15	2.9 to 6.9, 8.2 to 10.5, 12.9 to 15	0.9262
7.5	2.9 to 6.5, 8.6 to 9.5, 13.6 to 15	2.9 to 10, 13.2 to 15	0.9220
8	2.9 to 6.4, 13.3 to 15	2.9 to 6.9, 8.4 to 10, 13.2 to 15	0.9091
8.5	3.1 to 6.1, 8.6 to 9.9, 13.4 to 15	3 to 6.6, 8.3 to 9.7, 13.1 to 15	0.9970
9	3 to 6.1, 8.7 to 9.6, 13.3 to 15	2.9 to 6.6, 8.2 to 10.3, 12.9 to 15	0.9429

Table 4. Variation of Antenna parameters with rectangular slot position

Slot position at a distance feed point in mm	Frequency range (GHz) over which return losses higher than 10dB	Frequency range GHz Over which VSWR is <2	Efficiency at 7.5GHz	Directivity at 7.5GHz
10.5	**2.8 to 15**	**2.7 to 15**	**0.9341**	**2.1548**
11	2.8 to 7.2, 7.9 to15	2.7 to 15	0.9178	1.8602
11.5	2.8 to 6.9, 7.3 to 15	2.8 to 15	0.9254	1.7323
12	2.8 to 6.9, 7.3 to 15	2.8 to 6.6, 7.4 to 15	0.9154	1.8256
12.5	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9339	1.9269
13	2.7 to 15	2.8 to 6.6, 7.4 to 15	0.9140	1.7512
13.5	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.8986	1.4939
14	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9206	1.8311
14.5	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.8724	2.0990
15	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9386	1.7794
15.5	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9075	2.0213
16	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9153	1.8848
16.5	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9313	1.6803
17	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9132	1.8952

Table 4 Continued

17.5	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9079	1.7050
18	2.8 to 15	2.8 to 6.6, 7.4 to 15	0.9403	1.7268

Table 5. Gain Vs Frequency for Antenna 2

Frequency in GHz	2.98	4	5	6	7	8	9	10	11	12	13
Gain in dB	1.27	4.37	5.994	7.06	7.70	7.85	7.512	6.698	5.99	4.67	0.8216

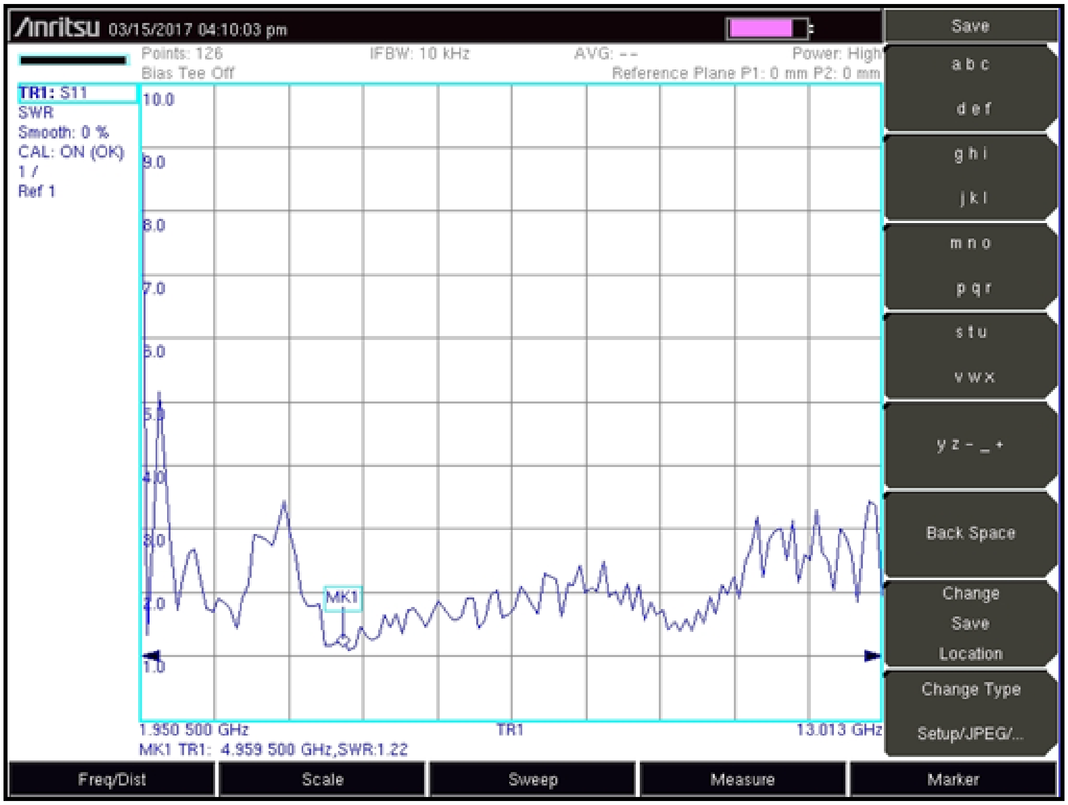

Figure 7. Measured VSWR for Antenna 2.

Figure 8. Measured Return losses for Antenna 2.

4. Discussions

In [5–9] reported different hexagonal monopole antennas with large ground plane and substrate dimensions and the antenna units are tested using different feeding techniques. It is observed that for the hexagonal patch with side length of 13mm maximum gain of 4.5dB is achieved at 7.5GHz. In some reports it is also observed that a maximum gain of 13.5 db is achieved with impedance bandwidth of 4-14GHz. But in our study the maximum gain of 7.85dB and impedance bandwidth from 2.8-15GHz are achieved with miniature dimensions.

5. Conclusion

Two hexagonal monopole Antennas are designed simulated and fabricated and their performance is compared for different antenna parameters. . It is observed that with compact antenna the desired antenna parameters are achieved. And it is also observed that with compact antenna better results are obtained.

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