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Novel Varactor Diode Loaded Frequency Agile Hexagonal Microstrip Patch Antenna

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Abstract: *This paper presents the design and simulated results of a compact varactor diode integrated conventional hexagonal patch antenna with different sides and also compares the results with a similar patch antenna. Proposed hexagonal microstrip patch antenna (HMSA) was designed and simulated using HFSS.V.13 and ADS and its various parameters such as return loss, VSWR and input impedance were determined, and shape of this HMSA was modified by cutting various slots in it at appropriate positions. The variable capacitance diode loading method enables the impedance matching for the frequency band from 2.67 to 2.71 GHz for the value of VSWR in between 1.02-1.16. The proposed antenna also gives CP radiation with slots. In addition to it is observed that the proposed antenna shows frequency agility behavior in the frequency ranges 2.67-2.71 GHz with bias voltage varying from 0 to 5V.*

Keywords: *Hexagonal Microstrip antenna;Bandwidth enhancement; Circular polarization(CP); Varactor diode.*

1. Introduction

Microstrip patch antenna consists of a metallic radiating patch backed up by a dielectric substrate and a ground plane below that. Now days, MSAs is widely used in many applications due to their advantages such as low profile, lightweight, planer configuration and ease of fabrication. However the main limitation of MSAs is their inherently narrow BW [1]. In order to improve the BW of MSA, the idea of integrating active devices has been implemented for last many years. Such types of antennas are known as active integrated antenna. The active integrated antenna (AIA) has been a growing area of research in recent years.

An AIA can be regarded as an active microwave circuit in which the output or input port is free space instead of a conventional 50 Ω interface. Active antennas reduce size, weight and cost over conventional designs which are very useful in microwave systems [2-4]. Active antennas overcome several limitations of traditional microstrip antennas [5]. They are almost frequency independent that is their bandwidth is depends on the active circuitry rather than the radiating element. Also a careful design of the connected amplifier may ensure broadband characteristics of the antenna. Similarly the gain of the antenna can also be controlled by using the amplifiers. Since the active antenna is electrically small compared to the passive one, the overall length is much less than the conventional antenna, and thus can be used in places where there is limitation of space.

Integrated Antennas and Active integrated antennas (AIAs) are widely used in the area of wireless communications, both for civilian and military purposes. In particular, AIAs are devices in which a passive antenna element and an active circuitry are integrated together on the same substrate. The integration of active solid state devices like oscillators, varactor diode, gun diode, amplifiers, and mixers grants greater compactness, lower costs and higher power efficiencies with respect to conventional passive layouts[6-11].

In this paper, a varactor diode has been modeled in ADS and integrated with a hexagonal microstrip patch antenna with unequal side to form an active antenna latter which is modeled in HFSS. The reason behind selecting the hexagonal microstrip antenna that, it has smaller size compared to the square and circular microstrip antennas, as well as better impedance bandwidth over rectangular and square microstrip antennas for a given frequency. Therefore, authors have designed a coaxial fed hexagonal patch antenna and circularly polarized radiation has been achieved by adjusting the position across the antenna. It is found that the obtained results are encouraging for practical applications. As it enhances BW of HMSA a comparative analysis of the various geometries of MSA obtained by cutting slots inside the radiating patch indicate considerable improvement in BW without much sacrifice on other performance parameters of MSA such as return loss, VSWR and its input impedance. Also when slots are inside the radiating patch it shows the good circular polarization

1.1. Frequency Agility

Frequency agility is the ability of a radar system to quickly shift its operating frequency to account for atmospheric effects, jamming, mutual interference with friendly sources, or to make it more difficult to locate the radar broadcaster through radio direction finding [12]. Frequency agility behavior of the proposed antenna will also be used in these applications.

2. DESIGN SPECIFICATIONS FOR PASSIVE MICROSTRIP PATCH ANTENNA

Design specifications for the proposed patch antenna are as follows**.**

Parameters	**Value**
Substrate	RT Duroid
Substrate Thickness	62 mil
Feed location	(7, 01, 0)
Substrate Size	(65×65) mm
Outer Radius	2.06 mm
Inner Radius	0.6 mm
Design frequency	2.45 GHz

3. DESIGN OF HMSA WITH UNEQUAL SIDES

The geometrical configurations of top and side views of the hexagonal patch antenna are shown in Fig 1 & Fig 2.Since a circular disc is the limiting case of the polygon with large number of sides, the resonant frequency for the dominant as well as for the higher order modes can be calculated from the formula of the circular disc by replacing radius *a* by equivalent radius $a_{eq.}$[6-7] i.e.

$$f_{np} = \frac{X'_{np}.c}{2\pi a_{eq}\sqrt{\varepsilon_r}} \quad (1)$$

Where X'_{np} are the zeros of the derivative of the Bessel function $J_n(x)$ of the order *n* and the equivalent radius $a_{eq.}$ is determined by comparing areas of a regular hexagon and a circular disk of radius $a_{eq.}$i.e.

$$\pi {a_{eq}}^2 = \frac{3\sqrt{3}\, S^2}{2}$$

$$a_{eq.} = 0.9094\, S \quad (2)$$

Thus the resonant frequency of a hexagonal element may be expressed as:

$$f_r = \frac{X'_{np}.c}{2\pi.(0.9094S).\sqrt{\varepsilon_r}} = \frac{1.1X'_{np}.c}{2\pi S\sqrt{\varepsilon_r}} \quad (3)$$

And for the lowest order mode TE_{11}

$X'_{np} = 1.84118$ (4)

Hence f_r =2.45GHz (5)

Using these design parameters and mathematical expressions, the proposed antenna has been designed and performances are examined using HFSS, and the obtained results are described in the following sections.

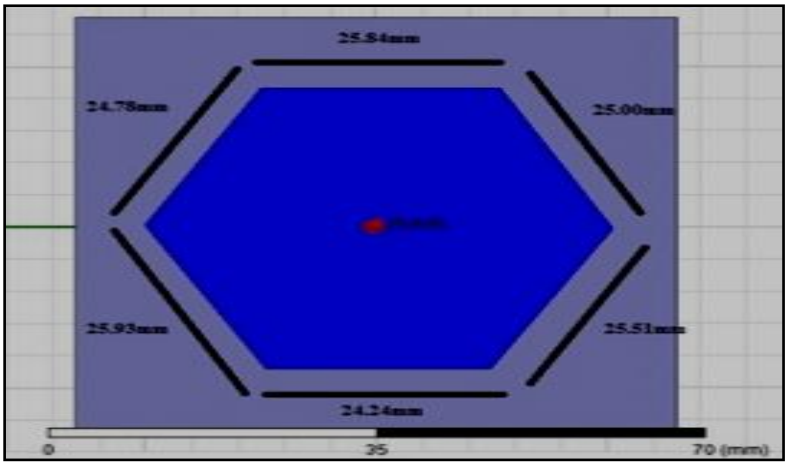


Fig1. *Top view of hexagonal patch with different sides*

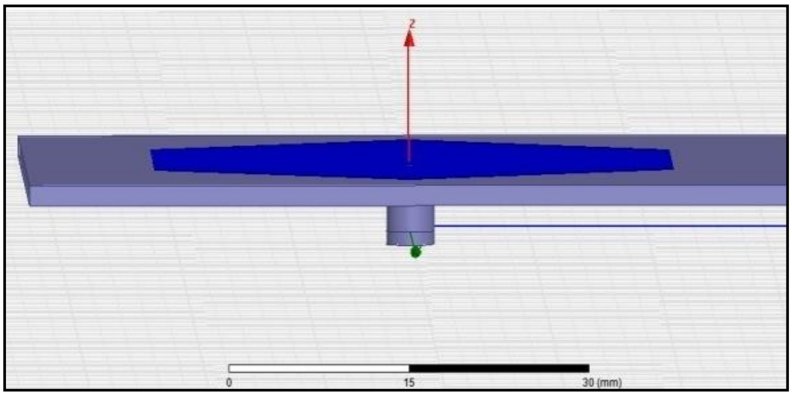


Fig2. *Side view of HMSA with coaxial feed*

Here a feed location point is to be found out on the conducting patch where patch impedance is 50 Ω. This feed point gives maximum radiation because of proper matching with 50 Ω coaxial feed. At first the feed position is varied and its effect on the input impedance, S_{11} and VSWR are measured. The variation in return loss with frequency is shown in Fig 3, which shows that the value of VSWR is minimum at resonant frequency.

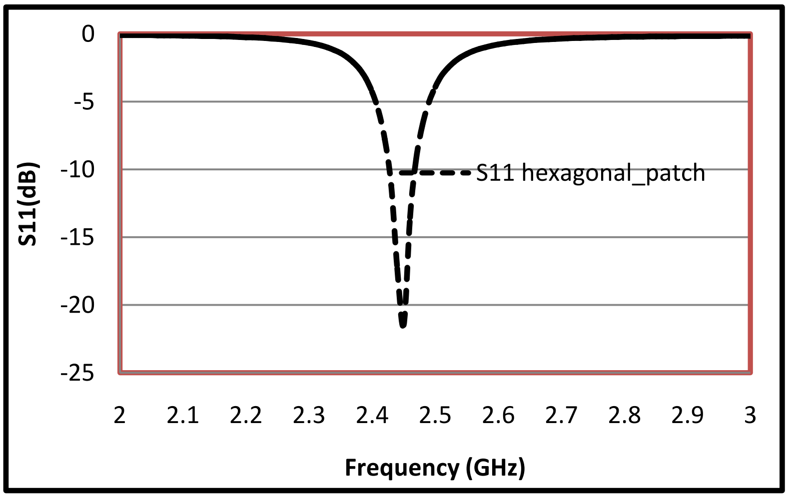


Fig3. *Variation of the return loss with frequency of proposed patch antenna*

The radiation pattern near the resonant band frequencies are shown in Fig 4 and observed that with an increase in frequency, the radiation pattern varies and the cross polar level increases significantly to the extent that the radiation becomes maximum along $\Phi = 0°$ at 2.45 GHz. The radiation pattern of the antenna also shows that it is Omni directional as well as circularly polarized with small levels of cross polarization.

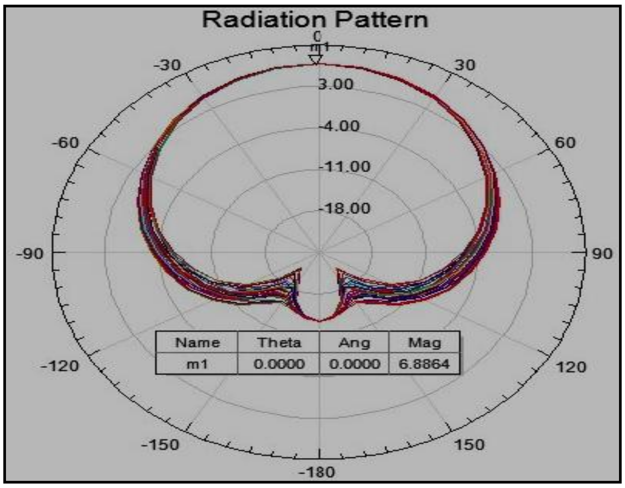


Fig4. *Radiation pattern of hexagonal patch with $\Phi = 0^0, 90^0$, Total Directivity is 7.0007.dB*

The simulated results of VSWR with frequency are plotted in Fig 5 which indicates that that the value of VSWR is 1.94891 at 2.45 GHz.

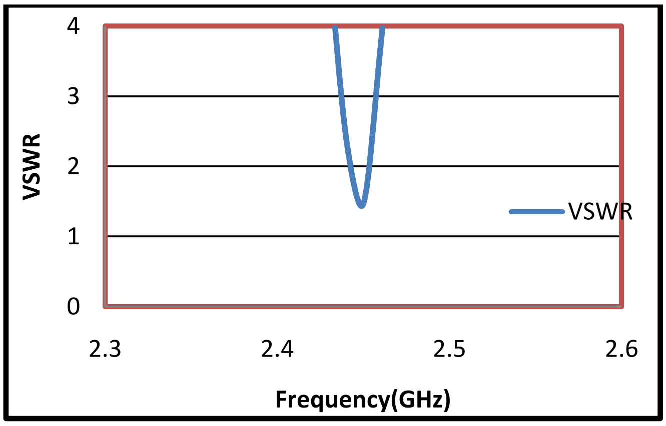


Fig5. *VSWR verses frequency of hexagonal patch antenna*

The simulated input impedance & axial ratio of the hexagonal patch antenna with unequal sides is plotted in Fig 6a & Fig 6b respectively.

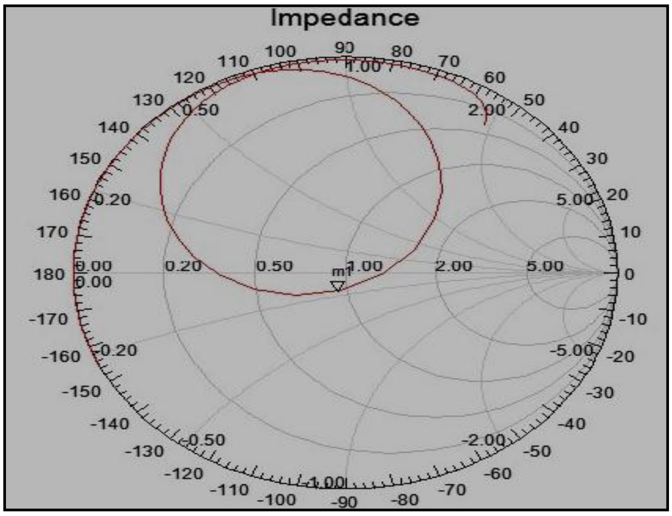


Fig6a. *Simulation result of hexagonal patch input impedance loci using smith chart*

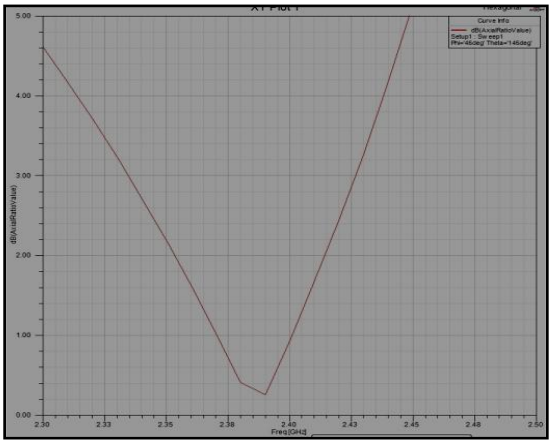


Fig6b. *Simulation result of hexagonal patch axial ratio*

4. Design of HMSA with Different Sides Having Slots

The geometrical configuration of proposed hexagonal patch antenna with slot and unequal sides has been shown in Fig 7.Where the patch antenna is constructed on same dielectric substrates. The designed hexagonal microstrip patch antenna is a wideband compact antenna with a thickness (*h*) of 62mil and loss tangent of 0.0014. The substrate considered for microstrip antenna is RT-Duroid with dielectric constant $\varepsilon_r = 2.2$.

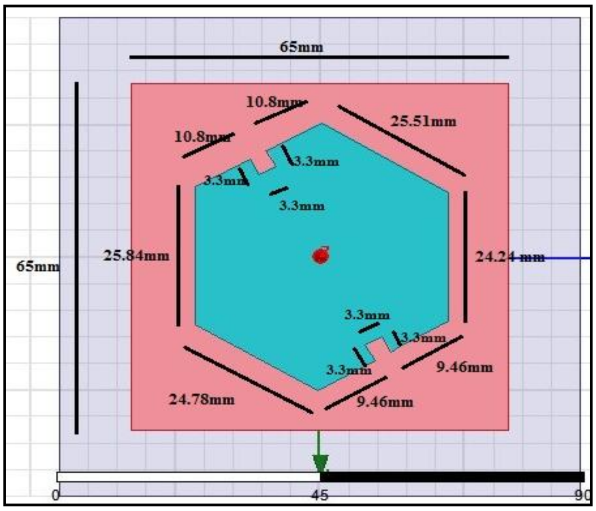
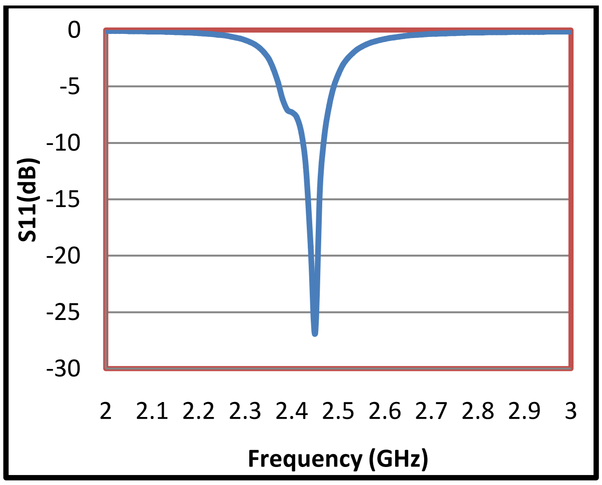
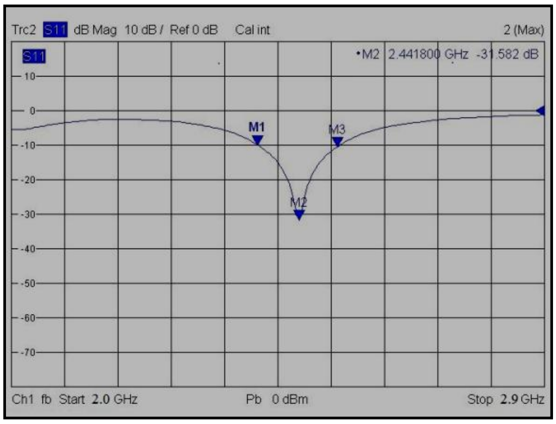


Fig7. *Proposed hexagonal patch antenna with slots*

Fig 8a, gives simulated while Fig 8b shows measured result of return loss for hexagonal patch antenna with slots and it can be seen that the proposed antenna after adding the slot increases the bandwidth at 2.45 GHz and BW is 50MHz.



8a. *Simulated*



8b *Measured*

Fig8a & 8b. *Reflection coefficient of hexagonal patch antenna with slots*

The variation of axial(AR) ratio with frequency shown in Fig 9, and shows that axial ratio at the resonant frequency (2.45GHz) is around 0.9546 dB. This shows that the proposed antenna with slots gives circularly polarized radiation shown in Table 1. It is clear that the proposed antenna with slots gives circular polarization as compared to the antenna without slots.

Table1. *Various parameters of proposed antenna*

Antenna Characteristics	HMSA unequal sides	HMSA with slots
Designed frequency(GHz)	2.45	2.44
Return loss(dB)	-21.4	-27
VSWR	1.05	.95
Axial Ratio(dB)	0.235	1.46
BW(MHz)	45	50
Gain(dB)	7.0	6.88

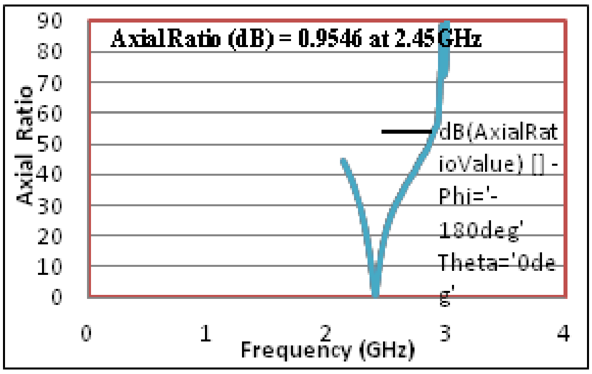


Fig9. *Axial ratio of hexagonal patch antenna with slots*

However Fig 10 shows the total gain for the hexagonal patch antenna with slots is 4.7809 dB at $\Pi=0^0$.

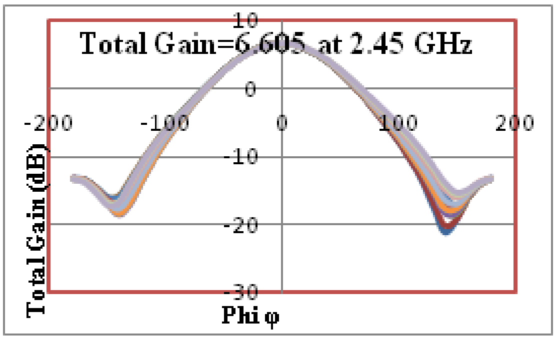


Fig10. *Total gain of hexagonal patch antenna*

5. Active Hexagonal Antenna of Different Sides with Slots

Here varactor diode has been integrated in hexagonal patch antenna with slots and then simulated using ADS.

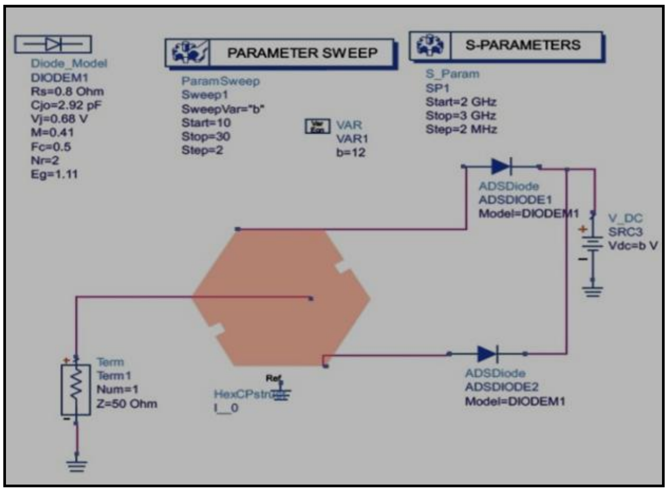


Fig11. *Arrangement of hexagonal patch with varactor diode*

Fig 11 shows the arrangement of hexagonal patch antenna integrated with varactor diode to form active patch antenna, while Fig 12 shows the prototype of fabricated hexagonal antenna loaded with varactor diode.

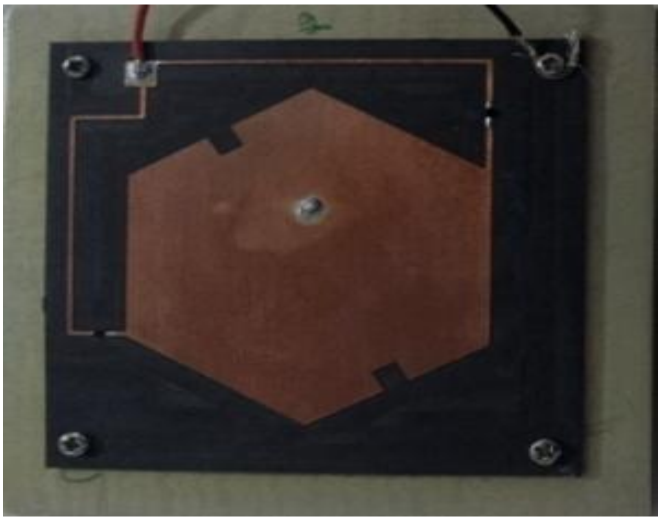


Fig12. *Fabricated hexagonal antenna loaded with varactor diode*

From the obtained results it has been observed that with varying bias voltage antenna return loss decreases and antenna shows frequency agility. Figs 13-15 show a measured return loss, impendence and VSWR for varactor loaded active patch antenna with bias voltage varying from 0 to 5 volts. However measured results of varactor loaded hexagonal patch antenna are tabulated in Table 2.

Table2. *Measured results of varactor loaded hexagonal patch antenna*

Bias voltage (Volts)	Resonating frequency (GHz)	Return loss (dB)	Impedance (Ω)	BW measured (MHz)	VSWR (dB)
0	2.67	-30.1	47.84	40	1.05
1	2.67	-36.3	49.14	40	1.02
2	2.68	-42.3	50.50	40	1.02
3	2.69	-29.0	50.45	40	1.05
4	2.70	-25.6	53.14	40	1.11
5	2.71	-23.7	52.04	30	1.16

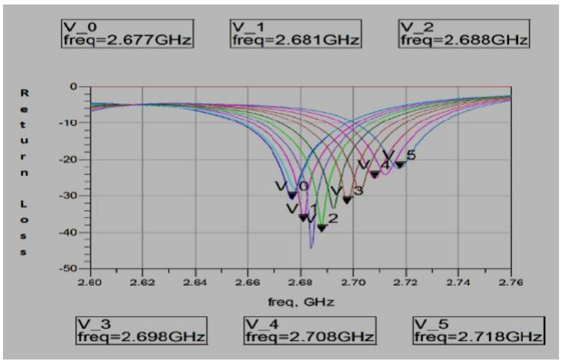


Fig13. *Measured return loss for varactor loaded hexagonal antenna with bias voltage 0-5 volts*

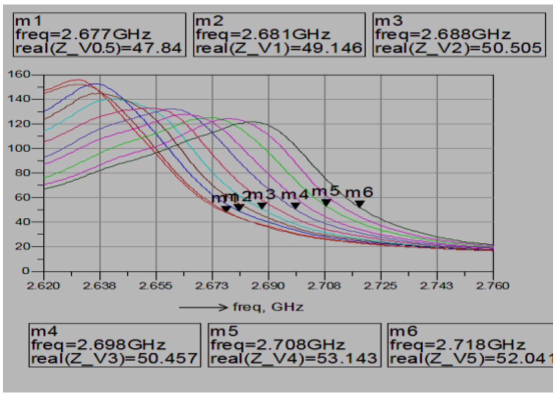


Fig14. *Measured impedance of varactor loaded hexagonal antenna with bias voltage 0-5 volts*

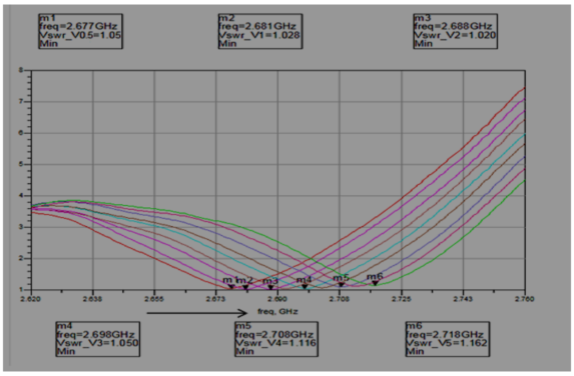


Fig15. *Measured VSWR for varactor loaded hexagonal antenna with bias voltage 0-5 volts*

6. Conclusion

In this paper, design, simulation and experimentation of conventional and varactor integrated hexagonal patch antenna has been presented. The active device and the patch antenna have been considered as a composite unit instead of taking them as independent units whereas in conventional wireless or radar systems antenna and circuit they are being considered as separate element. The antenna has been designed at 2.45GHz (ISM Band) and excited using coaxial feeding techniques and its performance characteristics such as return loss, axial ratio, VSWR, input impedance and radiation pattern has been calculated. The antenna with slots gives circular polarization (AR < 3 dB) as compared to the antenna without slots in addition to gain and bandwidth improvement. In particular for a bias voltage of 2V the performance of antenna is found to better than others, and the value of parameters like return loss -42.3, impedance 50 Ω, VSWR 1.02, BW 40 MHz and gain 3.9dB have been observed. It has also been observed that antenna loaded with active element and applying proper bias voltage gives frequency agility which is importantly required in radar applications.

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