Varactor diode loaded pentagonal microstrip patch antenna

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This paper presents the design, simulated and tested results of a compact varactor diode integrated conventional pentagonal patch antenna with different sides and also compares the results with a similar patch antenna. Proposed pentagonal microstrip patch antenna (PMSA) 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 PMSA 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 2.69 to 2.74 GHz for the value of VSWR between 1.05-1.11. The proposed antenna also gives circular polarisation radiation with slots. It is observed that the proposed antenna shows frequency agility behaviour in the frequency range 2.69-2.74 GHz with bias voltage varying from 0-5V.

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Keywords: Circular polarization, Bandwidth and frequency agility, MSA (microstrip antenna), ADS (Advanced design software) and AIA (Active integrated antenna)

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1. Introduction

Microstrip patch antenna consists of a metallic radiating patch backed up by a dielectric substrate and a ground plane below that. Nowadays, MSAs are widely used in many applications due to their advantages such as low profile, lightweight, planer configuration and ease of fabrication. As the main limitation of MSAs is their inherently narrow BW [1]. An AIA can be regarded as an active microwave circuit in which the output or input port is free space instead of a conventional 50Ω interface. Active antennas reduce size, weight and cost over conventional designs which are very useful in microwave systems [2-4]. Active antennas overcome several of the shortcomings of traditional antennas [5]. They are almost frequency independent, in the sense that their bandwidth is dependent on the active circuitry rather than the radiating element. Also a careful design of the connected amplifier can ensure a very broadband performance of the antenna. 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 constraint on space. The simulation results are encouraging for practical application. 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.

This paper presents the design and simulation of a compact, low-cost varactor diode integrated active pentagonal patch antenna with different sides and compares the results with a similarly configured passive antenna. The simulation and measured results in this paper can be used as design reference for the practical design of the active antenna. A simple pentagonal microstrip patch antenna (PMSA) was designed and simulated using HFSS.V.13 and ADS and its various parameters such as return loss, VSWR and input impedance were obtained. Then shape of this PMSA was modified by cutting various slots in it at appropriate positions. A new technique for designing the frequency agile microstrip antenna is presented and also increase in operational BW of PMSA was observed. The proposed antenna inhibiting of a single microstrip patch like low gain, thin substrate thickness, light weight and much small bandwidth, make it more versatile. This type of antenna is aggressive miniaturized to meet requirements of the wireless communication system. This printed patch antenna is low profile antenna, contented to planar and non-planar surfaces, simple and inexpensive to manufacture from present day printed technology. In designing a compact patch antenna, the materials having higher value of dielectric constant must be used which are less dexterous and results in narrow bandwidth. Hence conciliation must be reached between antenna dimensions and antenna performance [1-4]. The design and recreation of circularly polarized patch antenna, which can be implemented by properly making a small sized sector from a side of the equilateral-pentagon, patch [5]. The pentagonal-shaped microstrip patch antenna can be designed with only one probe feed to get circular polarization and it can be used for many wireless applications at different frequencies [6-16]. This paper explains firstly Antenna analysis and design and finally, it simulates the designed antenna which gives 6.8336 dB Gain at 2.42GHz with good circular polarization. Microstrip antennas are commonly used at frequencies from 1 to 100 GHz and at frequencies below ultrahigh frequency, UHF microstrip patch become exceptionally large. Pentagonal microstrip patch gives better performance than the rectangular patch antenna. Geometry of a pentagonal patch is shown in Fig. 1. It supports both linear and circular polarization. The pentagonal patch antenna gives circular polarization with only one feed where as rectangular patch antenna requires multiple feeds to get circular polarization [9]. The pentagonal patch antenna can also use multiple feeds and this type of antenna with multiple feeds can also give multiband operations [10].

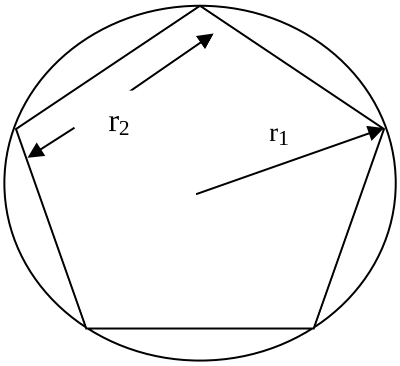

Fig. 1. Geometry of a pentagonal patch

1.1. Pentagonal patch antenna

1.1.1. Antenna design

The pentagonal antenna size calculations were made considering the invariance of the electrostatic energy below the pentagonal and circular patches, keeping their areas remain constant [3]. The relationship between the circles (r_1) to the side arm of the regular pentagon (r_2) is given in equation 1 (Fig. 2).

$$r_2^2 = \frac{\pi r_1^2}{2.37} \tag{1}$$

Side arm of the pentagon (r_2) = 1.175 r_1

In the derivation of the expression (1), the pentagonal patch is assumed to be a resonant cavity with perfectly conducting side walls. Because a circular disc is the limiting case of the polygon with large number of sides, in this case number of sides are 5. The resonant frequency of the dominant as well as for the higher order modes can be calculated from the formula:

$$\mathrm{f_{np}} = \frac{\mathrm{X'_{np}c}}{2\pi \mathrm{r_1}\sqrt{\varepsilon_\mathrm{r}}} \tag{2}$$

Where $J_n(x)$ represents the zeros of the derivative of the Bessel function of the order n, as is true for TE mode circular waveguides, however for the lowest order modes;

$$\mathrm{X'_{np}} = 1.84118 \tag{3}$$

The length of each side of the pentagonal antenna is calculated by using equation (1) & (2). For coaxial feeds, the location of the feed point is usually selected to provide a good impedance match.

1.1.2. Design specifications

The proposed pentagonal patch antenna has been designed using following specifications as given Table 1:

Table 1. Specifications

Substrate material	RT-Duroid
Feeding technique	Coaxial feed
Operating frequency range	2.0-3.0 GHz
Dielectric substrate (ε_r)	2.2
Velocity of light	$3*10^8$ m/s
Loss tangent	0.0014
Operating frequency (f)	2.42 GHz
Conductivity (copper)	$5.8 * 10^7$ S/m
Height of substrate (h)	62 Mil

1.2. Pentagonal antenna of unequal sides

Fig. 2 shows the geometry of the unequal sides pentagonal patch antenna. The reason behind selecting the pentagonal 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 pentagonal patch antenna and circularly polarized radiation has been achieved by adjusting the position across the antenna. Hence the proposed antenna geometry is chosen to be a pentagonal patch antenna and fed with a 50 Ω coaxial cable for better impedance matching.

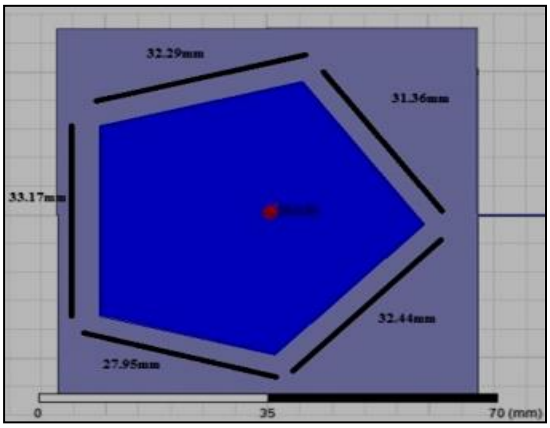

Fig. 2. Proposed structure of pentagonal patch antenna with unequal sides

At first the feed position is varied and its effect on the input impedance, S_{11} and V.S.W.R. are measured. The coaxial cable impedance in general is 50 Ω. 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.

The following results are obtained from the ANSOFT HFSS,V.13 simulation tool; these results are incorporating the antenna parameters as the designed pentagon shaped microstrip patch antenna gives the reflection coefficient as shown in the Fig. 3- i.e., S_{11} (dB) is -19.062 dB which is minimum at resonant frequency of 2.42 GHz. The radiation pattern is depicted from the Fig. 5. The designed antenna has axial ratio of 11.694 dB shown in Fig. 7 and VSWR is 1.943dB, Fig. 4. Also it gives 6.59 dB Gain at phi= 90^0 at 2.42 GHz shown in Fig. 8.

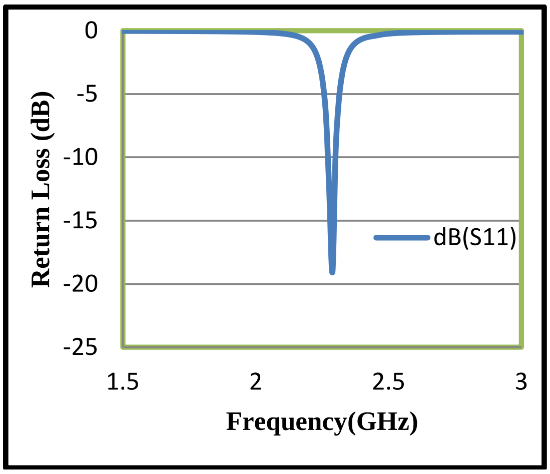

Fig. 3. Return loss of proposed unequal antenna

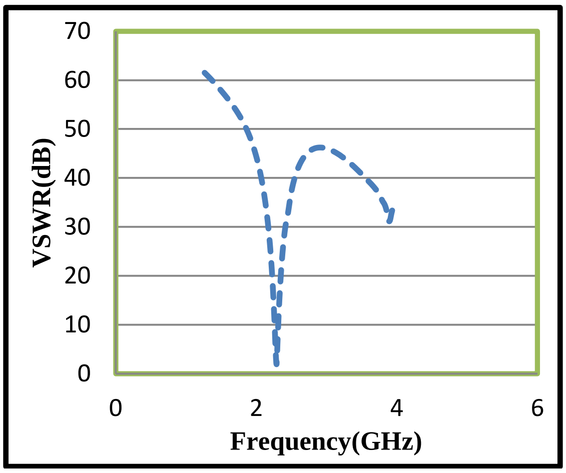

Fig. 4. VSWR of proposed unequal antenna

The radiation pattern near the resonant band frequencies are shown in Fig. 5. The radiation pattern of the antenna shows that it is Omni-directional as well as circularly polarized with small levels of cross polarization. Fig. 6 shows the simulated input impedance of the pentagonal patch antenna with unequal sides.

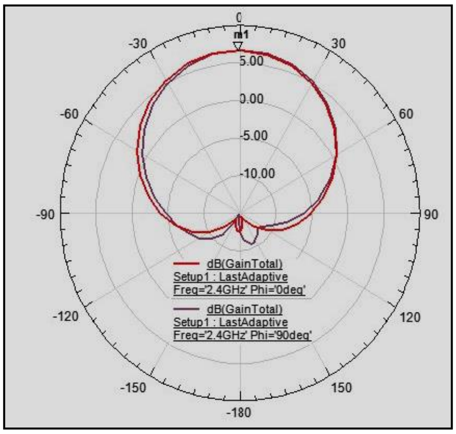

Fig. 5. Radiation pattern of unequal pentagonal antenna

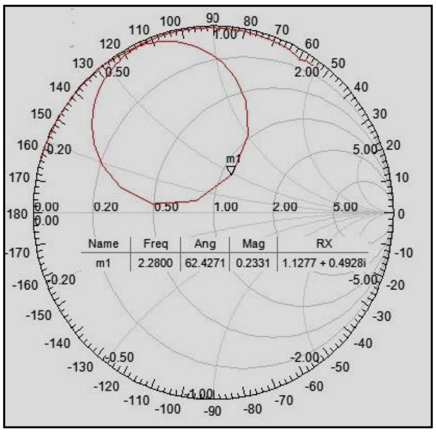

Fig. 6. Input impedance of proposed patch unequal at 2.45 GHz

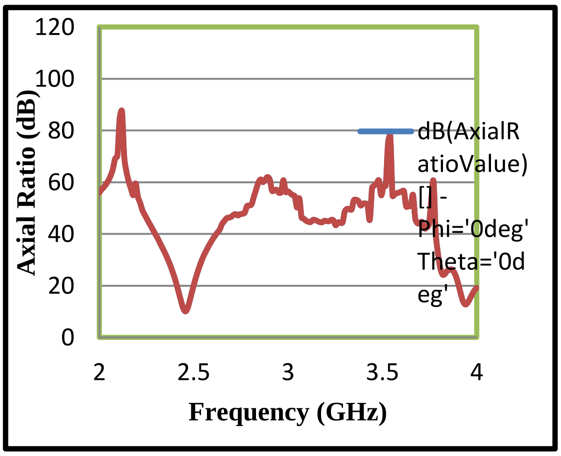

Fig. 7. Axial ratio of proposed unequal antenna

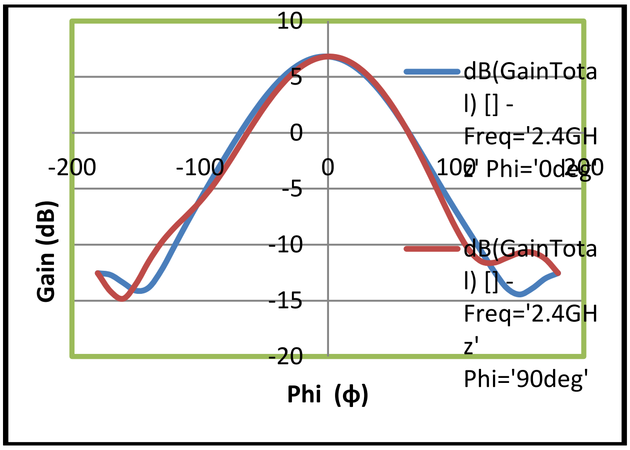

Fig. 8. Total Gain of proposed unequal antenna

2. Design of PMSA with different sides having slots

The geometry of a proposed pentagonal patch antenna having slot with unequal side with its dimensions has been shown in Fig. 9. The patch antenna is constructed on same dielectric substrate. The designed pentagonal microstrip patch antenna is a wideband small antenna with a thickness (*h*) of 62 mil and loss tangent of 0.0014. The substrate i.e.; considered for microstrip antenna is RT-Duroid with dielectric constant ε_r = *2.2*. The circularly polarized antenna which can be easily implemented by properly slice a section (*L*) from a side of the equilateral-pentagon patch in which the fundamental resonant mode of the equilateral - pentagon microstrip antenna and it is split into two near-degenerate orthogonal modes with equal amplitudes and a 90^0 phase difference [11-12]. The designed antenna which is operating at 2.42 GHz with circular polarization has many advantages compared to the other microstrip patch antennas.

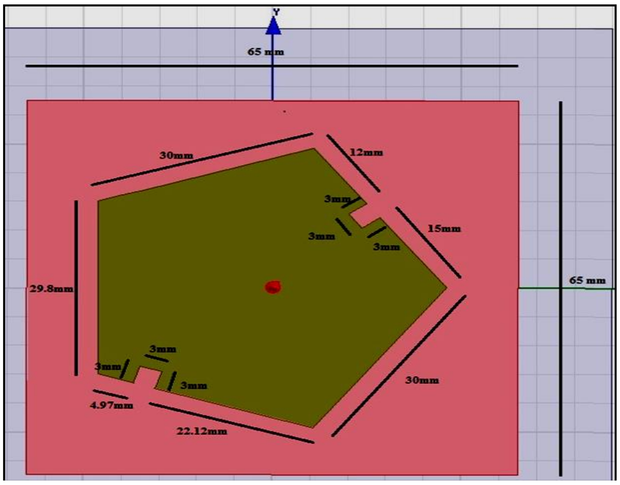

Fig. 9. Proposed pentagonal patch antenna with slots

2.1. Reflection coefficient (S11)

At first the feed position is varied and its effect on the input impedance, S_{11} and VSWR are measured. The coaxial cable impedance in general is 50 Ω. 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. From Fig. 10, it can be seen that the proposed antenna after adding the slot bandwidth at 2.45 GHz. has been increased and is around 60 MHz, from Figs. 10&11, it is clear that the simulated and measured results of return loss are closely same.

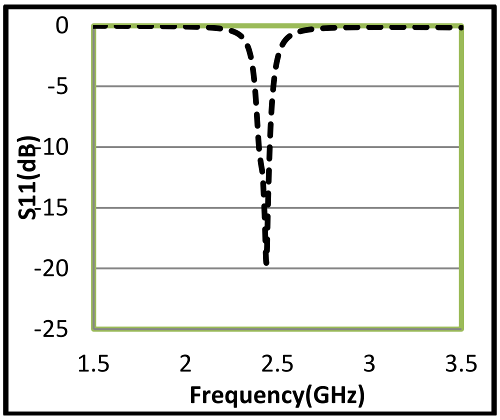

Fig. 10. Reflection coefficient of pentagonal pentagonal patch antenna with slots

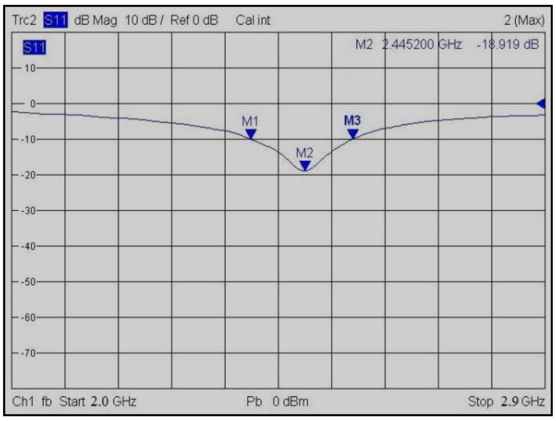

Fig. 11. Measured Reflection coefficient of patch antenna with slots

2.1.1. Radiation pattern

The radiation pattern near the resonant band frequencies are shown in Fig. 12. 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 θ =30° at 2.42 GHz. The radiation pattern of the antenna shows that it is Omni-directional as well as circularly polarized with small levels of cross polarization.

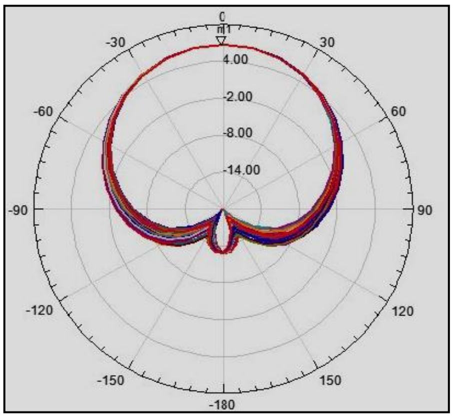

Fig. 12. Radiation pattern of pentagonal patch antenna with slots

The Total Gain is 6.6737 at phi = -10^0 at 2.41 GHz frequency shown in Fig. 13.

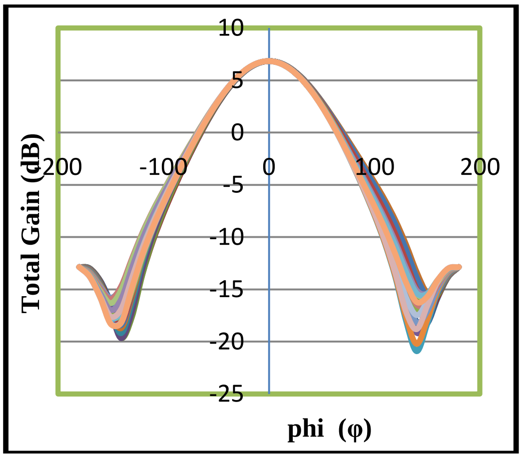

Fig. 13. Total Gain of pentagonal patch antenna of patch antenna with slots

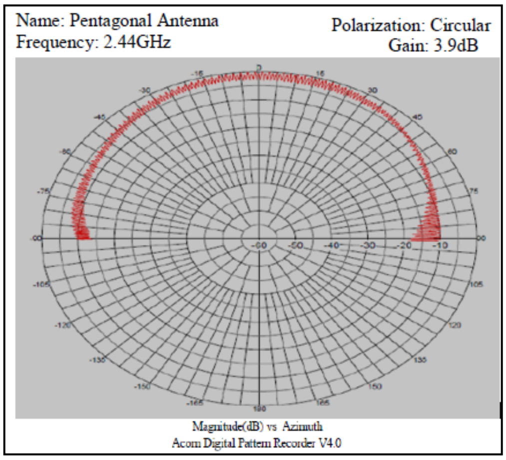

Fig. 14. Measured Radiation pattern of patch antenna with slots

2.1.2. Impedance curve

The input impedance is defined as “the impedance presented by an antenna at its terminals. The value of impedance is passing through 1 on both the smith chart; it shows the perfect matching of probe impedance and patch impedance.

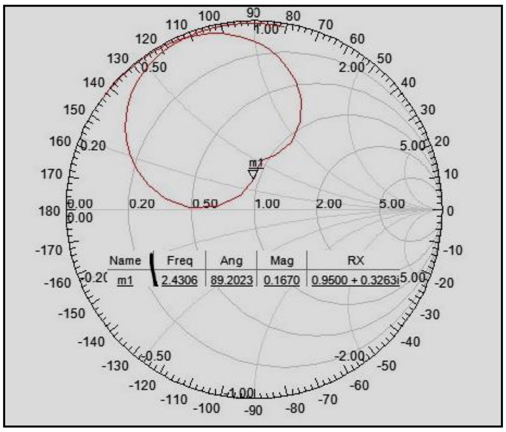

Fig. 15. Simulation Result of pentagonal patch Input Impedance using Smith Chart

2.1.3. VSWR

The simulated value of VSWR is 1.84891 at 2.42 GHz, and corresponding values of VSWR with frequency is plotted is Fig. 16.

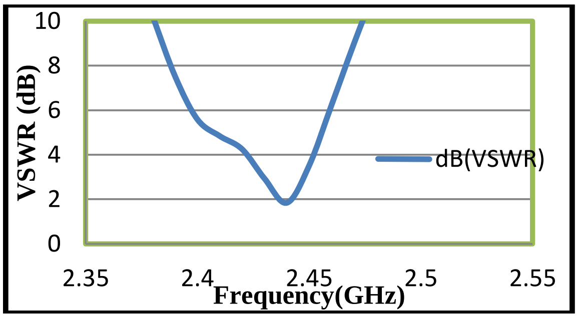

Fig. 16. VSWR of pentagonal patch antenna

2.1.4. Axial ratio

Axial ratio with respect to frequency is shown in Fig. 17, and found that axial ratio at the resonant frequency (2.42 GHz) is around 2.8367 dB which shows that slotted patch is circularly polarized as compared to antenna without slots.

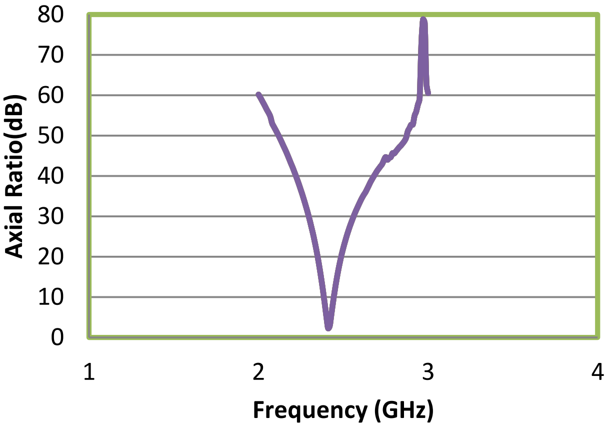

Fig. 17. Axial ratio of pentagonal patch antenna with slots

Table 2. Various parameters of proposed structures

Antenna Characteristics	PMSA unequal sides	PMSA with slots
Designed frequency(GHz)	2.28	2.43
Return loss(dB)	-19.06	-19.53
VSWR	1.943	1.84
Axial Ratio	11.694	2.83
BW(MHz)	30	60
Gain(dB)	6.59	6.87

From Table 2 it has been seen that proposed antenna with slots shows circular polarization as compared to antenna without slots.

3. Active pentagonal antenna of different sides with slots

Active integrated antennas (AIAs) are widely used in the area of wireless communications, both for civilian and military purposes. The success of such devices is mainly due to their low cost, low profile, good compatibility with integrated circuits, great conformability on curved surfaces and reduced space occupancy. 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. Here varactor diode has been integrated on pentagonal patch antenna with slots. This arrangement is then simulated using ADS.

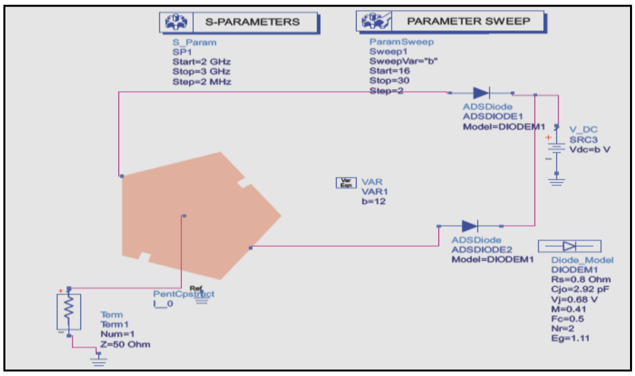

Fig. 18. Arrangement of pentagonal patch with Varactor Diode

Fig. 18 shows the arrangement of pentagonal patch integrated with varactor diode to form active patch antenna, while Fig. 19 shows the prototype of fabricated pentagonal antenna loaded with varactor diode.

3.1. Fabricated patch antenna

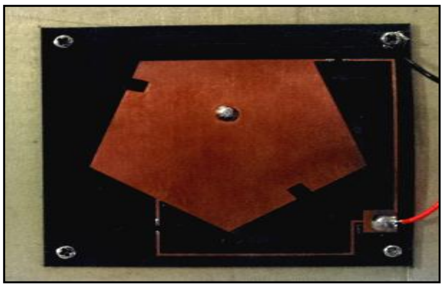

Fig. 19. Fabricated Pentagonal Antenna loaded with Varactor diode

It has been observed that with varying bias voltage antenna return loss decreases and antenna gives 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. Fig. 22 shows return loss for varactor loaded active patch antenna with bias voltage varying from 0 to 5 volts. Measured results of varactor loaded pentagonal patch antenna are tabulated in Table 3.

Table 3. Measured Results of varactor loaded pentagonal patch antenna

Bias voltage (V)	Resonating frequency (GHz)	Return loss (dB)	Gain (dB)	VSWR	Input Impedance (Ω)	Bandwidth (MHz)
0	2.690	-24.44	3.8	1.05	52.19	30
1	2.698	-23.91	3.7	1.04	49.59	40
2	2.706	-23.34	3.9	1.01	49.99	40
3	2.720	-22.11	3.6	1.02	51.59	30
4	2.732	-22.47	3.8	1.10	53.45	30
5	2.742	-20.73	3.7	1.11	54.44	35

From Table 3 it can be concluded that bias voltage of 2v give better results in terms of gain, BW, impedance and VSWR.

3.2. Input impedance

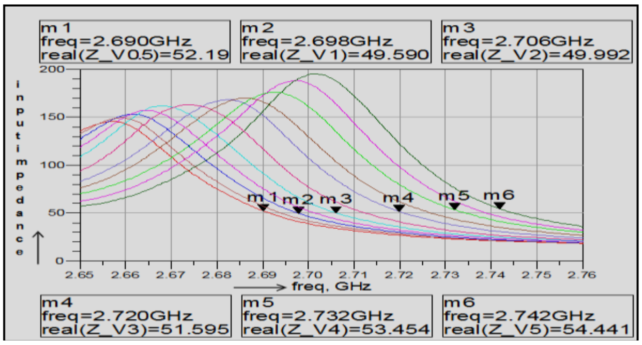

Fig. 20. Frequency Agile Pentagonal Antenna Input Impedance Results

3.3. VSWR

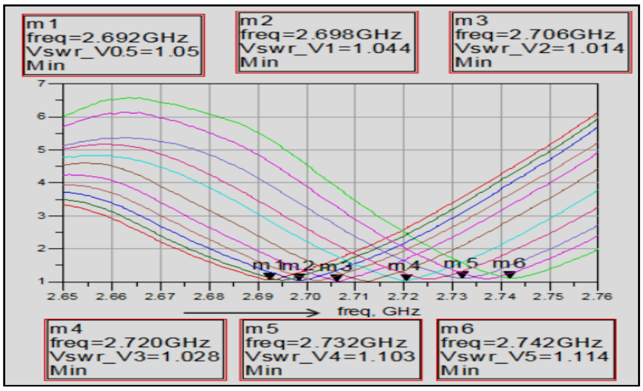

Fig. 21. VSWR for Frequency Agile Pentagonal Antenna

3.4. Return loss

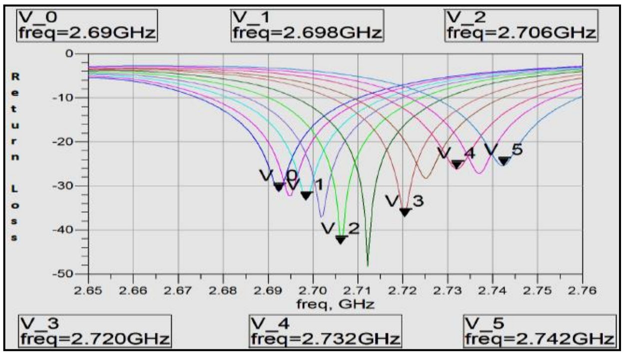

Fig. 22. Measured return loss for varactor loaded PMSA

3.5. Variation of radiation pattern with bias voltage

Fig. 23 shows variation of radiation pattern with bias voltage of 0.5V, 2V, 4V and 5V.

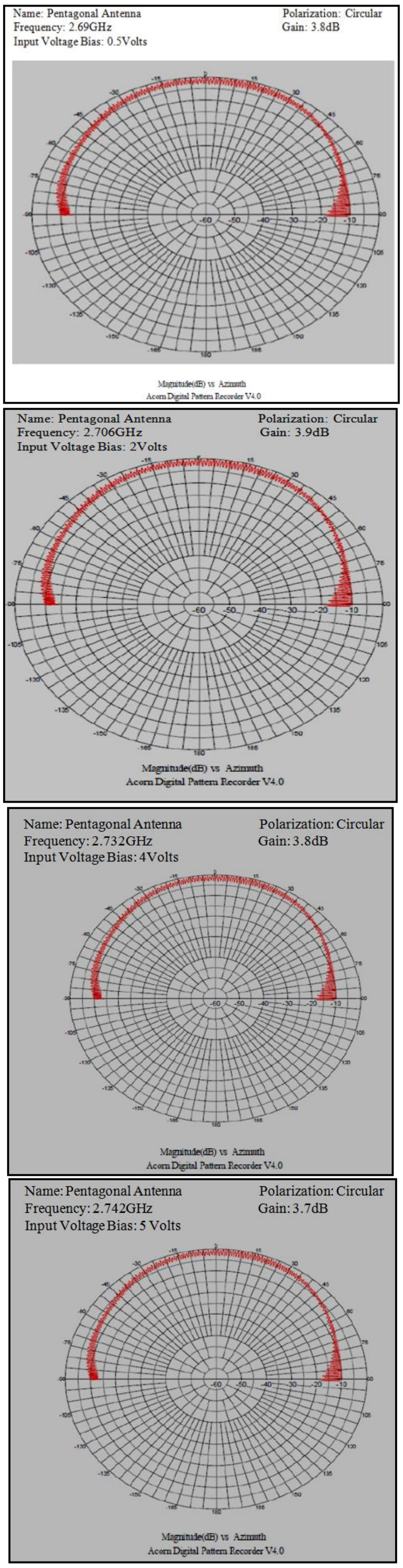

Fig. 23. Measured radiation pattern variation with bias voltage for varactor loaded PMSA

4. Conclusion

In this paper, design, simulation and experimentation of conventional and varactor integrated pentagonal patch antenna has been presented. The antenna has been designed at 2.4 GHz (ISM Band) and excited using coaxial feeding techniques and its performance characteristics such as return loss, axial ratio, VSWR, input impedance, radiation pattern has been calculated. The antenna with slots gives circular polarization (AR < 3 dB) as compared to the antenna without slots in terms of 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 is -24.44dB, impedance is 50 Ω, VSWR is 1.01, BW is 40 MHz and gain is 3.9dB has 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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References

[1] V. R. Gupta, N. Gupta, Microwave Review 29 (2006).
[2] M. T. Torres et al., Memorias del 7º Congreso Internacional de Cómputo en Optimización y Software, CICOS 09. UAEM, Cuernavaca, Morelos, México 200 (2009).
[3] G. Kumar, K. P. Ray, Artech House Publishers, London, 2003.
[4] I. Bahl, P. Bhartia, S. Stuchly, IEEE Transactions on Antennas and Propagation **30**(2), 314 (1982).
[5] Wen-Shyang Chen, Horng-Dean Chen, Antenna and propagation society international symposium, IEEE, **3**, 424 (2001).
[6] T. Noro, Y. Kazama, Antennas and Propagation Society International Symp. IEEE **3A**, 467 (2005).
[7] Rasouli, M. Kencana, et.al. Conference on Robotics Automation and Mechatronics (RAM), IEEE 68 (2010).
[8] R. Kant Singh, D. C. Dhubkarya, International Conference on Emerging Trends in Electronic and Photonic Devices & Systems 364 (2009).
[9] He Haidan, Proceedings in Microwave and Millimeter Wave Technology 381 (2002).
[10] Sang Heun Lee, Young Joong Yoon, Conference on Bioinformatics and Biomedical Engineering (iCBBE), 4th International, 1 (2010).
[11] Natarajan, D. Chatterjee, Antennas and propagation Society International Symposium, IEEE, 720 (2003).
[12] Ravindra Kumar Yadav, Jugul Kishor, Ram Lal Yadava, IJECET **4**(1), 43 (2013).
[13] Moglia, A. Menciassi, M. O. Schurr, P. Dario, Biomedical Micro devices **9**, 235 (2007).
[14] T. Noro, Y. Kazama, Antennas and Propagation Society International Symposium, IEEE, **3A**, 467 (2005).
[15] R. K. Yadav et al., International Journal of Engineering Science and Technology (IJEST), **3**(8), (2011).
[16] L. Economou et al, IEE Proc. Microwave Antennas Propagation **145**, 416 (1998).

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