

Beam-Steerable Printed Dipole Antenna Using Varactor Diodes

4.1. INTRODUCTION

Various pattern reconfigurable antenna arrays, reflect arrays, phased arrays or tunable antenna configuration are in application nowadays for beam steering. Conventional phased arrays although is traditionally used for beam steering, however it has limitations of high cost, complexity and finite beam scanning coverage. Electrically beam steerable tunable antennas have advantages due to less maintenance, small size, rapid orientation speed and less power usages. This type of antennas can be used in various applications with enhanced spectral efficiency and improved system performance. For many applications Electronically scanned reflector arrays have been introduced. Resonance frequency and reflection phase have been controlled by tuning impedance of meta-surface using varactor diodes. However micro-strip reflect arrays has generally narrowband operation compared to conventional reflectors. Beam steerable microstrip antennas are useful for various small antenna applications like mobile communication, vehicular communication, sensor antennas etc. For such applications comparatively large phased array / reflect array antennas are less suitable in comparison to compact planar tunable antennas.

Beam steering in various small tunable antennas have been proposed in previous research works. A reconfigurable microstrip antenna was introduced for beam switching application using 4 p-i-n diodes. This type of antenna cannot be incorporated for continuous scanning. A frequency & pattern reconfigurable two element array antenna has been developed recently for beam steering using varactor diodes. This antenna has limitation of low scan angle, comparatively large size array structure and more parasitic losses due to multiple varactors. A pattern reconfigurable antenna has been introduced using two sets of shorting pins and five varactors in a square patch operating similar to (1x2) array. Beam steering in this type of configuration has been achieved using fixed stages for steering beam for specific biasing combination of five varactors. Excessive ripples and deteriorated measured radiation pattern also observed due to DC wiring effects of multiple varactors and its parasitic elements along with high scan loss of 3.22 dB. A beam steerable dipole antenna has been introduced by modulating values of two varactors inserted in two parasitic elements. Parasitic elements are generally obstructive in nature and antenna uses various modes based on biasing combination of varactors which limits continuous scanning and possesses more parasitic loss.

In this chapter a varactor tuned inverted V dipole antenna has been proposed using single varactor diode for steering the beam in elevation plane. The proposed antenna has the advantages of having very low design cost, compact size, less complexity and easily integrated architecture and least parasitic losses. The proposed antenna provides efficient solution to establish adequate coverage in elevation plane. Tilting angle of antenna radiation pattern has been controlled by gradually varying the capacitance value of varactor diode by changing its biasing voltages keeping fixed value of parallel inductance. Continuous Beam steering up to ± 30 deg with respect to its end fire has been achieved electronically at 2.35 GHz while keeping scan loss below 1 dB and all antenna parameters within limits.

In past research works, it has been demonstrated the performance of inverted V dipole antenna achieve noticeable increase in SNR and occupies less horizontal space in comparison to horizontal dipole antenna. Proposed Dipole Antenna designed as inverted V dipole by tilting both dipole arms at ± 30 degree angle from horizontal axis resulting 120-degree interior angle between them. The application of proposed Beam Steerable Planar Dipole Antenna can be in the area of wireless communication, sensor application, vehicular communication and point to point communication.

4.2 ANTENNA DESIGN

The antenna consists of inverted V printed dipole arms etched opposite sides of FR-4 substrate along with feed-line, ground plane and biasing line with copper material as shown in Figure.7.1. The length and height of dipole is kept $\lambda/4$ from ground plane at 2.35 GHz. A varactor diode Skyworks SMV 2020 along with a parallel inductor (5 nH) mounted at one end of dipole arm.

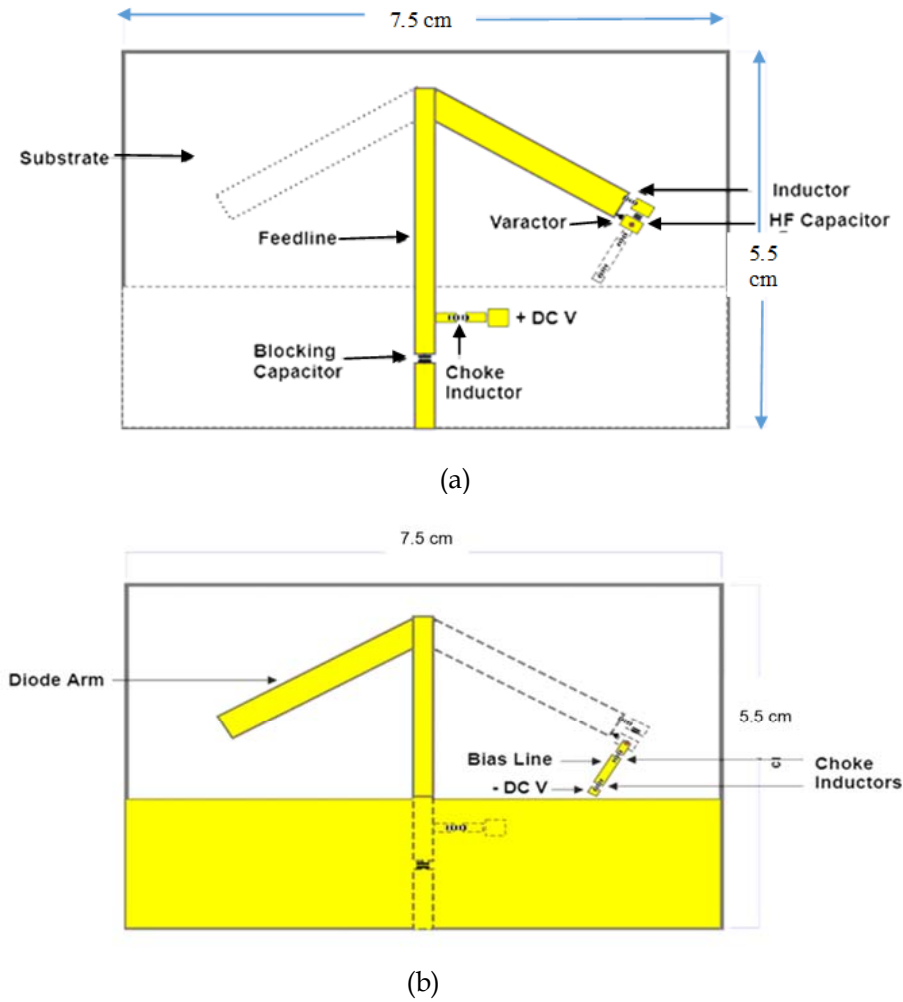


Figure.4.1:: The geometry of proposed inverted V planar dipole antenna highlighting intrinsic layers (a) Top (b) Bottom



Figure.4.2: Circuit equivalent diagram of varactor SMV 2020 along with parallel inductor

In order to apply the required DC voltage across mounted varactor diode a biasing circuit has been placed across antenna. Biasing line kept intentionally at back side of dipole leg at bottom side of substrate vertically. Positive DC supply terminal applied at point +DC V at one side of antenna connected to one end of varactor and -ve supply connected at opposite side at point -DC V connected to other end of varactor through via hole. DC supply fed at point '+ DC V' and '-DC V' of antenna through RF chokes of 50nH each to avoid undesired RF current on bias lines. An additional choke inductor placed at point '- DC V' to facilitate - ve DC supply fed directly from ground plane if required. A blocking Cap (30 PF) has been placed between SMA connector and + DC V point. This prevents DC current entering inside RF source. There may be possibility of short circuiting of inductor (5 nH) mounted parallel to varactor after application of DC biasing. Therefore, at the end of dipole arm a high frequency capacitance of 30 PF has been placed between one end of varactor diode and parallel inductor. This will facilitate blocking of DC supply towards parallel inductor and facilitate only RF signal to pass through it.

The equivalent circuit of varactor SMV 2020 consists of junction capacitance (C_v) in series with its parasitic elements (R_p , L_p) as shown in Figure 4.2. The graph between varactor capacitance value and reverse voltage shown in Figure 4.3. As reverse voltage increases from 0 to 20 volts, varactor diode capacitance value decreases from 3.2 PF to 0.35 PF.

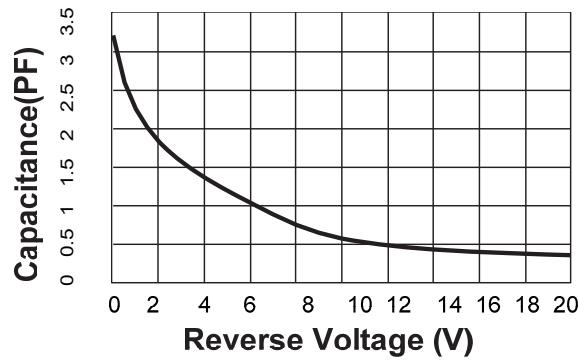


Figure.4.3: SMV 2020 capacitance vs reverse voltage

Antenna biasing circuit specification comprising of varactor capacitance, parallel inductance, RF choke, blocking capacitor and parasitic elements values is shown in Table 4.I.

Table 4.1: Antenna specifications

1	Varactor Diode (SMV 2020)	C_v	0.35 – 3. 2 PF
2	Parallel Inductor	L_s	5 nH
3	RF Choke	L_c	50 nH
4	Parasitic Elements of Varactor	R_p L_p	4.7 ohm 0.7 nH
5	Blocking Capacitor	C_b	30 PF

4.3 CONTINUOUS BEAM STEERING PRINCIPLE

The capacitance across Varactor diode SMV 2020 increases from 0.35 PF to 0.59 PF as biasing voltage varies from 20V to 9.8V. Varactor Diode (C_v) along with parallel inductor (L_s) acts as a LC resonator and produces the anti-resonance behavior resulting in rapid change in reactance at specified frequency on changing its capacitive value as shown in Figure 4.4. The equivalent reactance of parallel resonator is given by Eq 4.1:

$$Xl = Im \left[\left\{ \frac{1}{R_p + j\omega L_p + (1/j\omega C_v)} + \frac{1}{j\omega L_s} \right\}^{-1} \right] \quad (4.1)$$

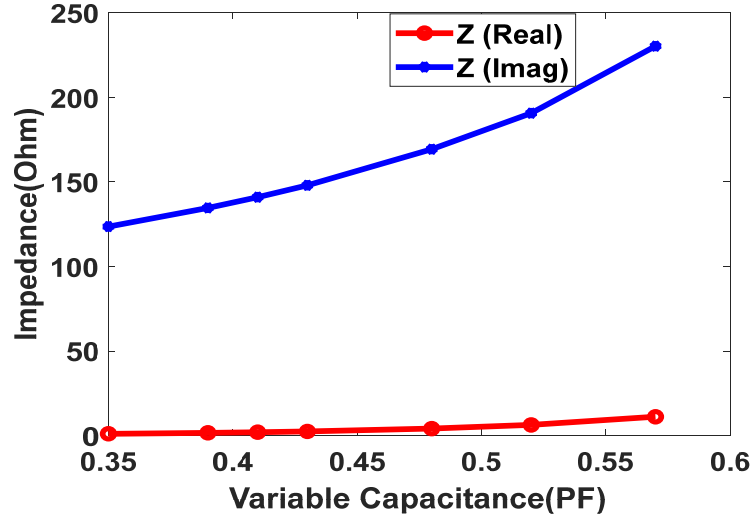


Figure.4.4: Equivalent impedance of parallel resonator (Real and Imaginary) at 2.35 GHz for various capacitances of Varactor

The equivalent impedance of parallel resonator shows, as the capacitance of varactor diode increases the reactance of parallel resonator also increases simultaneously. Near point of resonance the large change in reactance observed due to parallel LC resonance characteristics. This results in rapid variation of impedance and electrical length of dipole which in turn alter current distribution of antenna. To establish this phenomena, variation of current distribution for various capacitance values of proposed antenna has been ascertained and depicted in Figure 4.5. Considerable variance in current distribution of proposed antenna has been observed at each time when the varactor diode capacitance value changes.

The relation between current distribution and electric field for half wavelength dipole is given by Eq 4.2:

$$E(\theta) = jn\{(I \exp(-jkr)) / 2\pi r\} \times [\{\cos(kl \cos \theta / 2) - \cos(kl / 2)\} / \sin \theta] \quad (4.2)$$

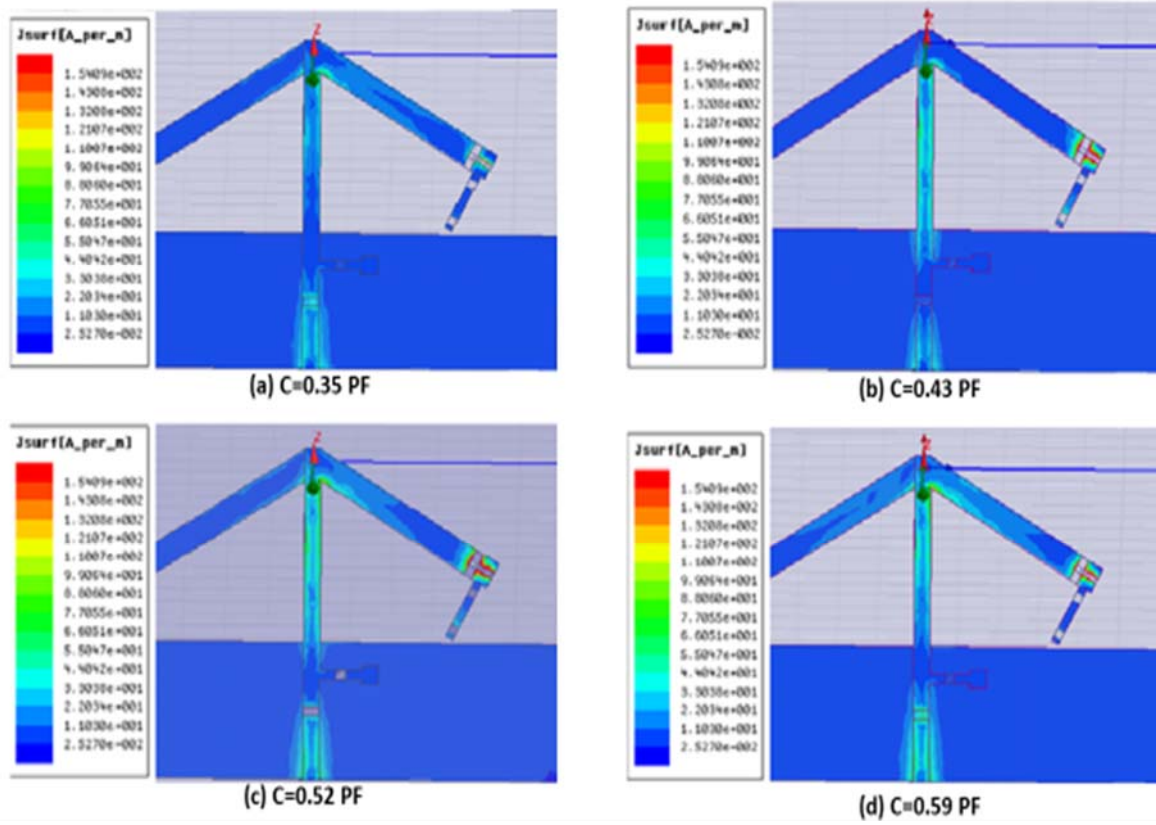


Figure.4.5: Current distribution of proposed antenna for various capacitance values

Due to variation in current distribution of antenna, electric field pattern shows a deflection resulting in achieving beam steering in elevation due to variation in capacitive load. As value of biasing voltage varies, the capacitance value of Varactor Diode changes gradually which steers the radiation pattern accordingly. Measured Antenna reflection coefficient for three capacitance values ($C=0.43$ PF, $C=0.48$ PF, $C=0.57$ PF) of varactor diode covering most of the operating band shown in Figure 4.6 demonstrates almost nil variation in resonance frequencies.

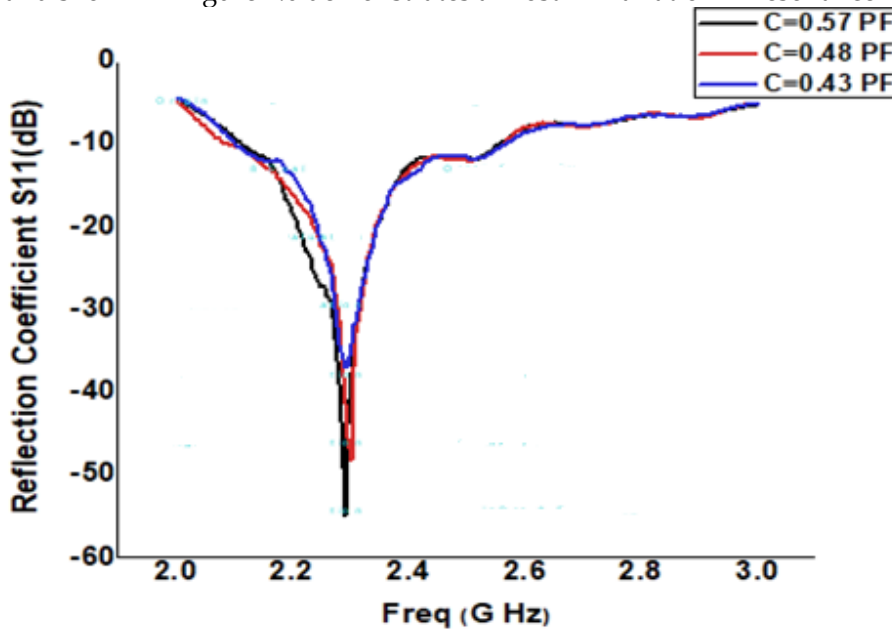


Figure.4.6: Measured Reflection Coefficient (S_{11}) of Proposed Antenna at various capacitance values

4.3.1. PRINCIPLE OF RADIATION PATTERN

Full wave simulation for various capacitance values using ANSYS HFSS demonstrates that the antenna radiation pattern start steering towards one side (Ist quadrant) maintaining sufficient Gain. Steering process continues with sufficient gain and antenna radiation efficiency till approx. +30 degrees. Further increment in C value steers antenna beam from 1st quadrant to 2nd quadrant. Further increment in C value steers antenna beam from -30 degree to 0 degree with sufficient gain and antenna radiation efficiency. Continuous 60-degree phase shift (± 30 degree both side) can be achieved w.r.t. its endfire successfully by controlling varactor capacitance value from 0.35 PF to 0.59 PF. The simulated co-pol and cross-pol results shown in Figure.4.7.

The cross-pol radiation pattern observed more than 20 dB below co-pol radiation pattern. Gain of antenna has been maintained during continuous beam steering of proposed antenna. The radiation pattern shown in Figure 4.6 has been simulated in yz plane ($\phi=90$ degree).

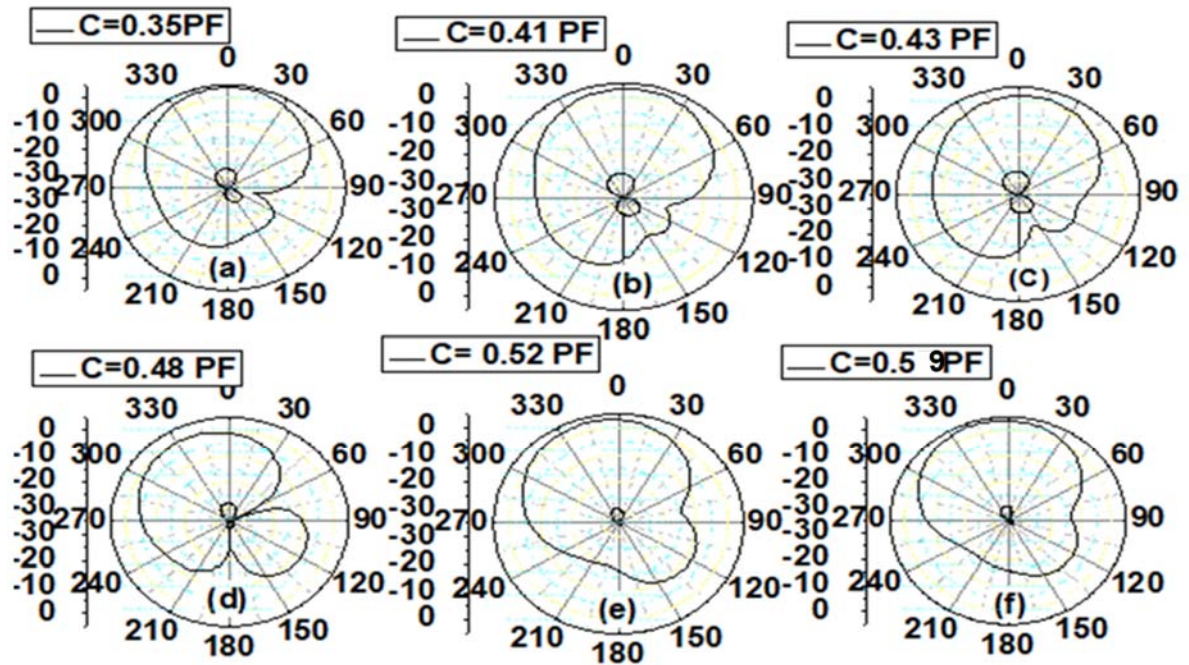
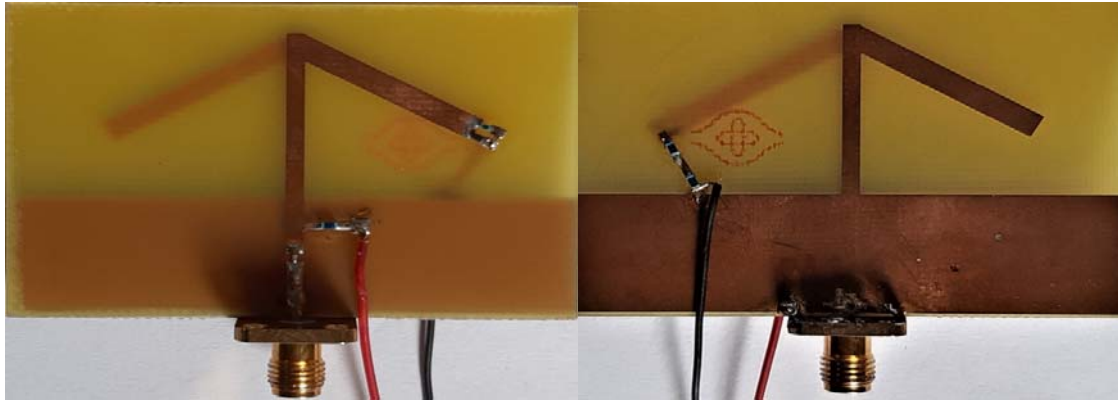


Figure.4.7: Simulated Radiation Pattern (Co-pol and Cross-pol) in yz plane for various varactor capacitance values with beam steering: (a) 0 deg (b) 20deg (c) 30deg (d) -30 deg (e) -20 deg (f) 0 deg.

4.4 EXPERIMENTAL DEMONSTRATION

Figure.4.8 shows the photograph of Fabricated antenna. RF signal to antenna fed through SMA connector connected to feed line (inner) and ground plane (outer). The biasing voltage to varactor diode applied through biasing line 50nH RF choke.



(a)

(b)

Figure.4.8: Fabricated Inverted V Planar Dipole Antenna (a) Top View (b) Bottom View

The various antenna parameters (Radiation pattern, Gain, co-pol, cross-pol) has been measured in anechoic chamber shown in Figure 4.9.

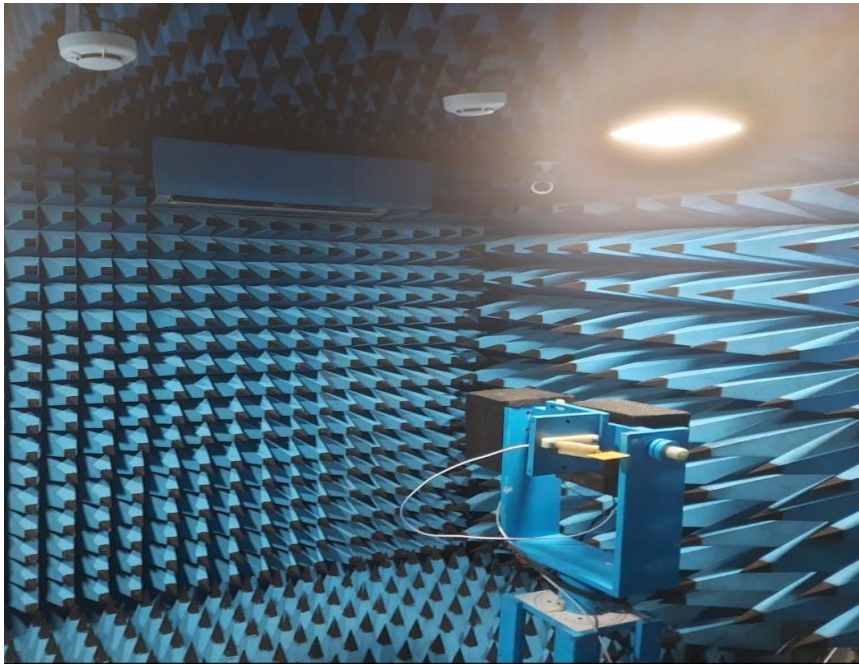


Figure.4.9: Antenna measurement set up in Anechoic chamber

Measured antenna reflection coefficient demonstrate the antenna operating frequency from 2.2 G Hz to 2.42 G Hz (220 MHz band width) which is sufficient for most of the small printed antennas. Also frequency shifting for various capacitance values is almost negligible.

The main operating frequency is kept at 2.35 GHz for various capacitive values. The measured radiation pattern showing the cross-pol result for randomly selected capacitance value ($C=0.59$ PF) well below -20 dB is shown in Figure 4.10.

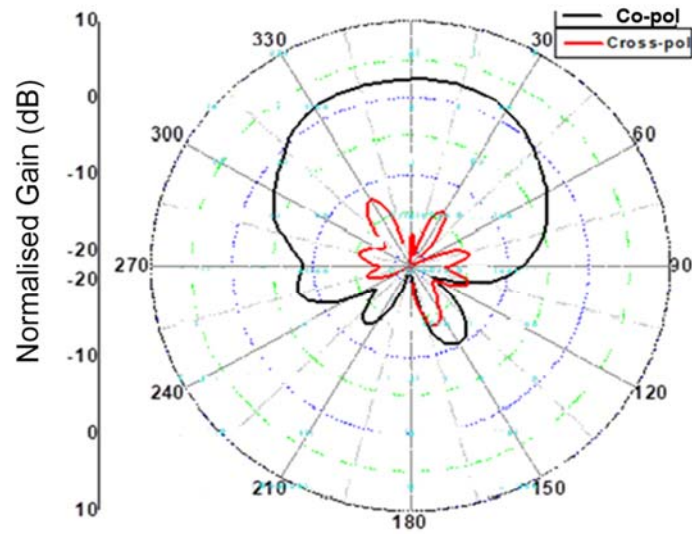


Figure 4.10: Measured Co-pol and Cross-pol radiation pattern of proposed Antenna at $C=0.59$ PF

As shown in Figure 4.11, the designed antenna during beam steering experiences scan loss less than 1 dB as antenna gain varies between 4.1 dB to 3.1 dB for +30 deg and 4 dB to 3 dB for -30 deg of beam steering at 2.35 GHz operating frequency. Antenna efficiency remains within 83 % to 68 % to maintain ± 30 deg beam steering. Measurement details of proposed antenna is placed in Table 4.2.

Table.4.2: Measurement details of proposed antenna

Band Width	220 MHz (2.2-2.42 GHz) 9.36%
Antenna Gain (Max)	4.1 dB
Operating Frequency	2.35 GHz
Cross Polarisation	Below -20 dB
Scan Loss	1 dB

The proposed antenna is capable of steering beam +30 degree and -30 degree in elevation continuously w.r.t. to its end fire by tuning varactor between 0.35 to 0.43 PF and 0.48 to 0.59 PF keeping all parameters well within limits. Beam steering beyond ± 30 degree has not been considered due to further reduction in antenna gain (scan loss) marginally below 3 dB.

Hence, the proposed work attains capability of 60-degree continuous beam scanning using least no of diodes and elements (Qty 01) while maintaining less than 1 dB scan loss along with sufficient antenna gain and operating band width.

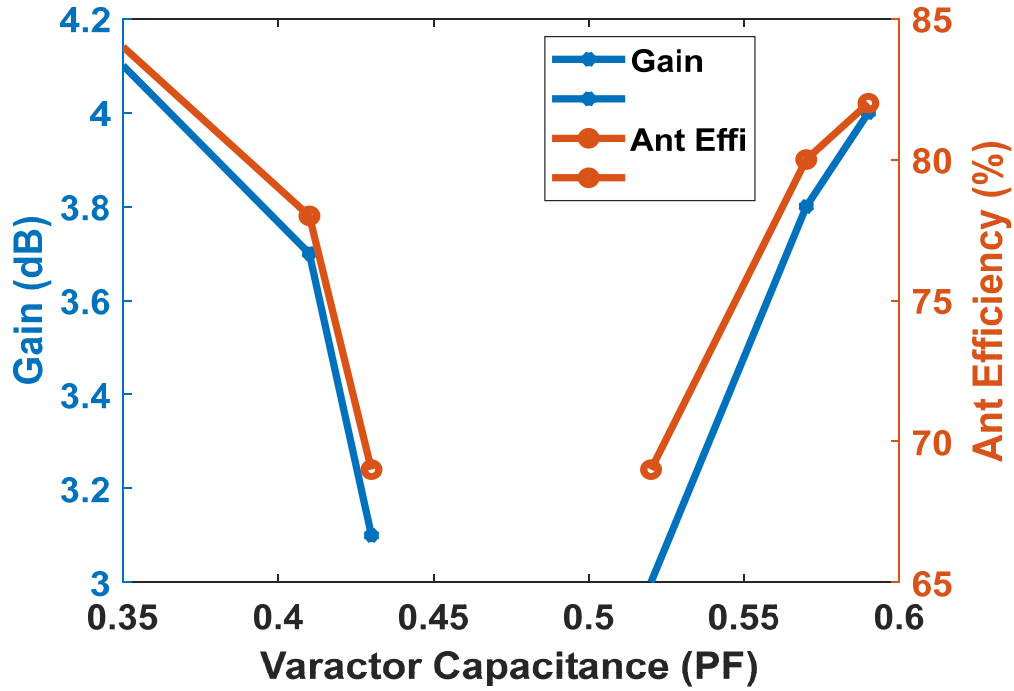


Figure.4.11. Gain and Rad Efficiency of proposed antenna for various capacitance values

4.5 MEASURED RESULTS ANALYSIS

Measured and simulated radiation pattern results of proposed antenna for randomly selected six biasing voltages of varactor diode with various capacitances is shown in Figure 4.12. The measured radiation pattern shown in Figure 4.12 shows upper half of radiation pattern with (0 degree to 180 degree) while avoiding back lobe in lower half of radiation pattern.

Measured result shows that beam steering is achieved from -30 to +30 degree while maintaining sufficient gain by adjusting the capacitance value of SMV 2020 varactor diode from 0.35 PF to 0.43 PF (Bias voltage 20 V to 14V) and 0.48 PF to 0.59 PF (Bias voltage 12 V to 9.8 V) respectively keeping constant value of parallel inductor (5 PF) at 2.3 GHz frequency.

When varactor diode capacitance applied as 0.35PF, 0.41PF, 0.43PF respectively, the proposed antenna attains beam steering of 0 deg, 20 deg, 30 deg. In case varactor capacitance applied as 0.48PF, 0.52PF, 0.59PF respectively, the proposed antenna attains beam steering of 0 deg, -20 deg, -30 deg. The above applied capacitance has been achieved by applying appropriate biasing voltages on varactor diode as per data sheet. Hence by applying appropriate biasing voltage across varactor diode from 9.8 V to 20 V, beam steering from -30 degree to + 30 degrees can be achieved.

Figure 4.12 shows, measured results of proposed planar inverted V dipole antenna found in reasonably good agreement with simulated ones.

The measured peak gain of antenna found above 4 dB. The cross-pol results found well below co-pol radiation pattern. The antenna demonstrates continuous beam steering from -30 degree to +30 degree.

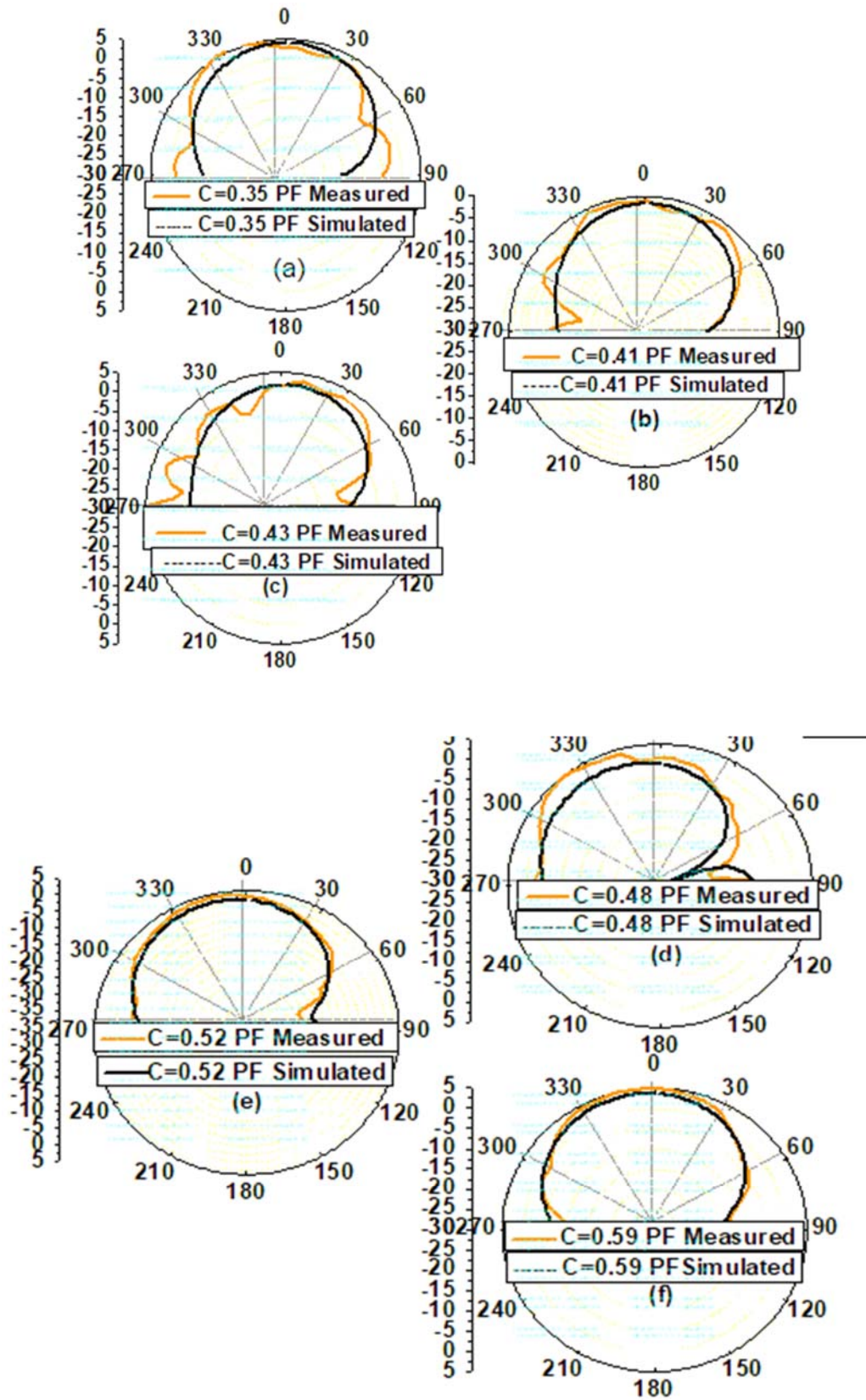


Figure4.12: Measured and Simulated Radiation Pattern (yz-plane) of proposed antenna with beam steering highlighting main lobe (+90 to -90 deg) for various capacitance values (a) 0 deg (b) 20 deg (c) 30 deg (d) -30 deg (e) -20 deg (f) 0 deg

Proposed Planar Inverted V Dipole Antenna is capable of continuous beam steering (± 30 degree) electronically using Single Printed Dipole and single varactor diode. Table 4.3 compares the characteristics of previous works with present work.

Table.4.3: Comparison of previous works

Chapter No	Ant type	Antenna Dimension (cm)	Scan Loss	Parasitic Losses	Beam Scan Angle (Deg)	No of Elements	Comparative Analysis
[2.1.7]	Microstrip Patch	Large (17.5 x 17)	>1 dB	High (4 p-i-n Diodes)	Beam Switching (65,13)	01 patch	1. More parasitic loss 2. No continuous scanning 3. Large size
[2.1.8]	Patch Array	Large (15.15x16.09)	>1 dB	Med (2 Varactors)	+ 23 to -23 Continuous	02 patch	More space requirements due to dual elements
[2.1.6]	Reflect Dipole	Med (9.2x4.5)	>1 dB	Med (2 Varactors)	63 (329 to 32) Continuous	01 Dipole with 02 parasitic elements	Parasitic element generally obstructive in nature
This work	Printed Dipole	Small (7.5x5.5)	<1 dB	Low (1 Varactor)	60 (± 30) Continuous	01 Dipole	Less space requirement and least parasitic losses due to single element and single varactor

4.6 CONCLUSION

Proposed antenna in this chapter can be used as a low cost small form factor model to verify the concept of beam steerable inverted V HF dipole antenna discussed in chapter 6 having similar design topology. Various pattern reconfigurable Antennas for pattern diversity have design complexity, high cost, more resistive/ parasitic losses and large external space requirements. Most of electrically tuned antennas requires more than one dipole and multiple tuning elements mounted on common platform for scanning between two angles / switching at different elevation angles. Proposed Planar Inverted V Dipole Antenna is capable of continuous beam steering (± 30 degree) electronically using Single Printed Dipole and single varactor diode. Resistive and parasitic losses of proposed antenna is considerably low along with low design cost and the least space requirements. Proposed antenna can easily be used in wireless communication, mobile/ vehicular communication, sensor application and as an element of phased array antenna successfully.