

Review of Beam-steerable Printed Antennas

2.1 BEAM STEERABLE MICROSTRIP ANTEENNA

Over the years researchers studied reconfigurable antennas for frequency, polarization and pattern diversity. Frequency diversity is achieved by changing the operating frequency of antenna while maintaining identical polarization and radiation characteristics of the antenna. Polarization diversity antennas adjust its polarization to avoid fading losses due to multipath effects. Pattern diversity of antennas are highly useful to improve system capacity, transmission rate and detection range by providing additional flexibility and directivity of radiation pattern. Beam steerable microstrip antennas are useful for various small antenna applications like mobile communication, IOT application, vehicular communication, sensor antennas etc. For such applications compact planar tunable antennas are more suitable in comparison to large phased array or reflect array antenna. Several designs topologies have been proposed to achieve beam steering in small tunable antennas using phase shifter, varactor diode and PIN diode-based feeding network. The following section presents a brief overview of different techniques to achieve these antenna topologies.

2.1.1 BEAM SCANNING FOR DUAL-POLARIZED ANTENNA WITH ACTIVE REFLECTION MTASURFACE

In this work, an active reflection metasurface is used to replace the metallic reflector of the dual-polarized antenna in Figure 2.1, which realizes the beam scanning with two polarizations. The reflection phase of the proposed metasurface can be tuned continuously by changing the bias of the varactor diodes fabricated on the reflection cell. This resulted in continuous steering of the antenna beam. By increasing the height of the reflection units, a stable phase difference in the frequency range of 3.3–3.6 GHz has been obtained.

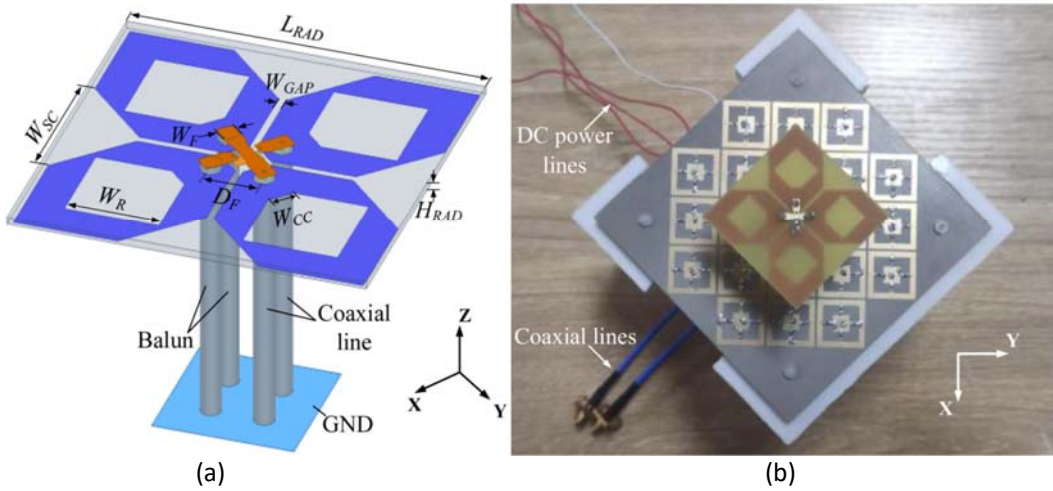


Figure 2.1: (a) Crossed-dipole structure (b) Manufactured antenna prototype

The measured S -parameters of the proposed antenna is shown in Figure 2.2 in modes 1, 2 & 3. The proposed antenna is designed for mobile communication band (3.3–3.6 GHz) in sub-6G.

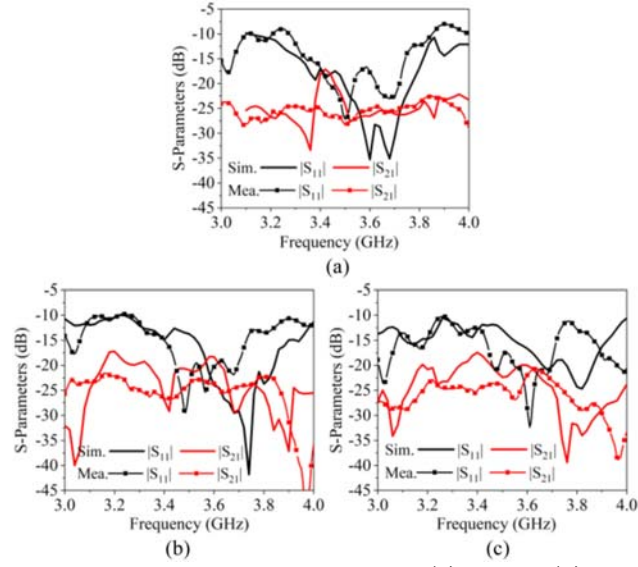


Figure 2.2: S -parameters of the proposed antenna. (a) Mode 1. (b) Mode 2. (c) Mode 3

The measured results shows that the beam-steering range is $\pm 20^\circ$ of antenna, short for voltage standing wave ratio (VSWR) is less than 1.7 and the port isolation is greater than 20 dB in the frequency range of 3.3–3.6 GHz.

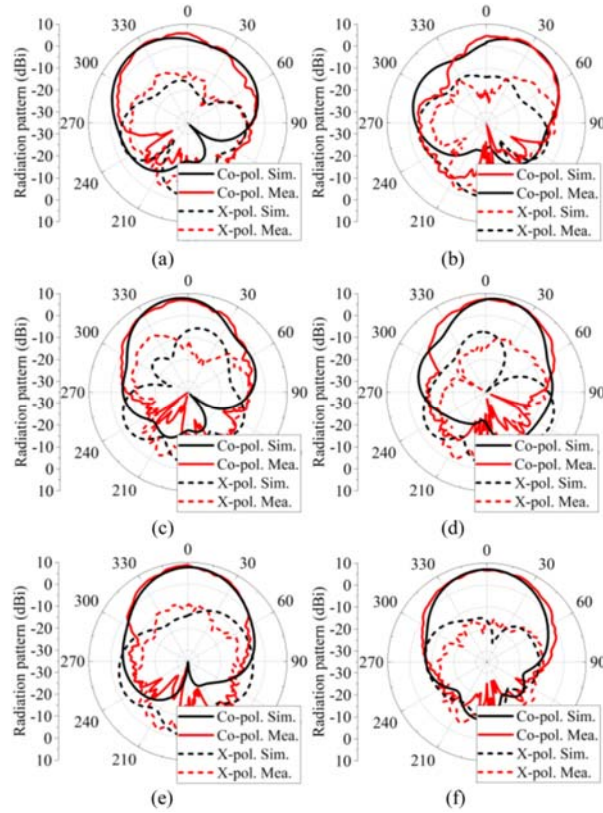


Figure 2.3: Radiation pattern of antenna at 3.4 GHz. (a) Mode 1. (b) Mode 5. (c) Mode 2. (d) Mode 4. (e) Mode 3. (f) Mode 6.

This type of antenna has a limitation of space constraints due to 3 D structure and high number of active components (Varactors) along with less beam steering.

2.1.2 PLATFORM-BASED, ELECTRICALLY-SMALL HF ANTENNA WITH SWITCHABLE DIRECTIONAL RADIATION PATTERNS

In this work, a platform-based antenna array in Fig 2.4 has been proposed that can achieve switchable, directional radiation patterns by exciting and combining the characteristic Modes(CMs) of a mid-size ground vehicle at the HF band. The amphibious assault vehicle (AVV) as a representative platform has been used to excite its CMs that have intrinsic omnidirectional and figure-eight-shaped radiation patterns using electrically small coupling elements mounted on the platform.

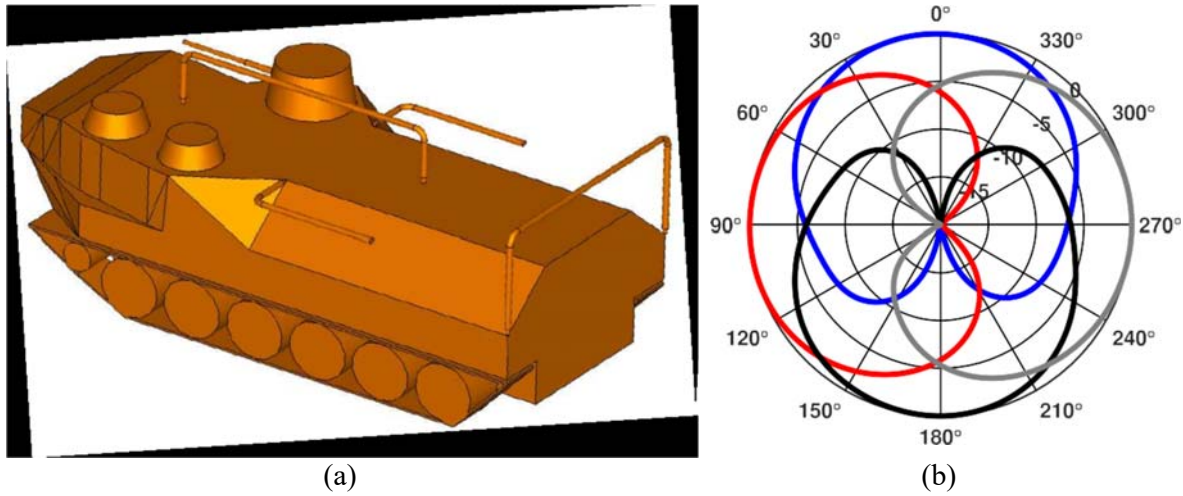


Figure 2.4: (a) Final topology of the platform and the coupling elements mounted on it. (b) Normalized cardioid-shaped radiation patterns, at 12.5 MHz

This antenna system is capable of generating such directional radiation patterns with front-to-back ratios better than 15 dB over the frequency range of 6–24 MHz. In order to validate the proposed concept, a scaled-model prototype using a simplified model of the AAV was fabricated and characterized with scale factor of 1:35 and shown in Fig 2.5 along with measured S-parameters.

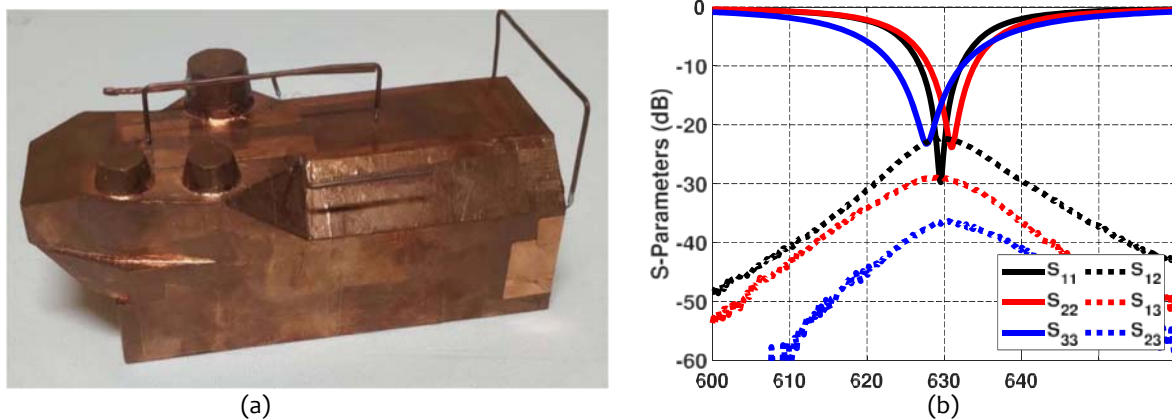


Figure 2.5: (a) Photographs of the assembled scaled-model prototype (b) Measured S-parameters of the fabricated scaled-model prototype in the vicinity of 630 MHz (corresponding to 18 MHz for the full-scale prototype).

This type of small HF antennas are suitable for short range mobile HF communication and may not cover full HF range due to its dipole length limitations. For long range HF sky wave communication the HF wire dipole antennas are more suitable.

2.1.3 STEERABLE DIPOLE ANTENNA THROUGH HUYGENS METASURFACE COATING

In this work, a dipole antenna working at 3 GHz operating frequency and surrounded by a realistic Huygens metasurfaces (HMS) structure is proposed in Fig 2.6. Reconfigurability is added by loading the unit cells with varactor diodes enabling the modulation of the phase-insertion introduced by the HMS on the xy -plane (the antenna H -plane). In particular, the HMS is designed to introduce four main radiation beams that can be steered by controlling the DC voltage of the varactors.

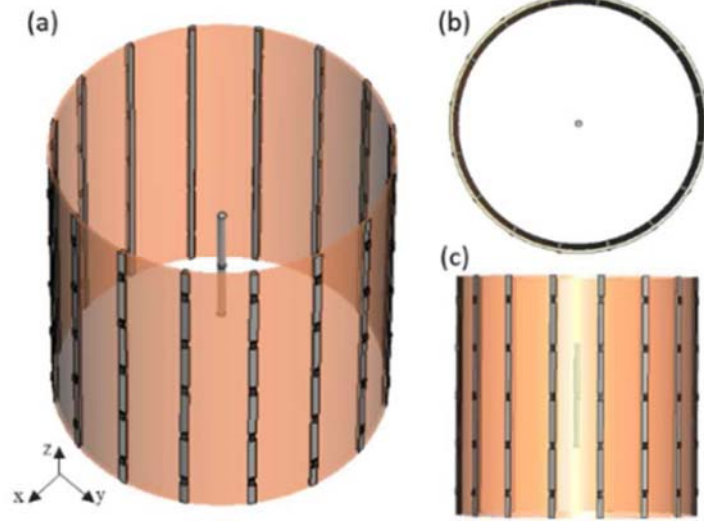


Figure 2.6: Sketch of the dipole antenna surrounded by the functionalized cylindrical HMS. (a) Perspective (b) top (xy -plane) and (c) front (xz -plane) views.

The surface impedance value of the capacitive strip is controlled by a varactor diode loading the gap. By tuning the biasing voltage of the varactors / junction capacitance C_j in the range 0.05 – 0.12 pF different radiating patterns are enabled with a phase coverage of almost 40° . In Fig. 2.7 the full-wave numerical results returned by the device in terms of gain behavior on the xy -plane are placed.

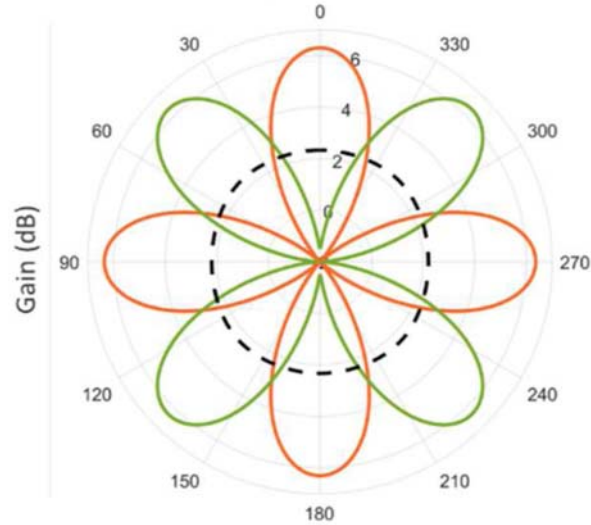


Figure 2.7: Gain polar plots of the antenna on the xy -plane for different scenarios

The limitation of this type of antenna is its non-continuous beam steering (beam switching at 40 degrees) and space constraints due to cylindrical HMS structure.

2.1.4 BEAM STEERING ANTENNA ARRAY

An end-fire beam steering antenna array has been proposed using varactor diodes as shown in Figure 2.1. In this work, an end-fire beam steering has been formed using dipole antenna array along with reflection type phase shifters integrated with varactor diodes. The capacitance value of varactor diode of reflection type phase shifter changes with the applied biasing voltage to achieve the phase shift resulting in beam steering of antenna.

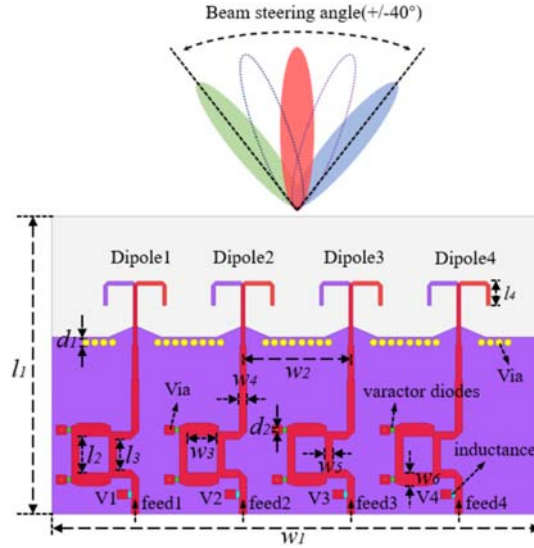


Figure 2.8: Beam steering antenna array along with radiation beam

Antenna S-parameter and gain with beam steering angles is shown in Figure 2.2 and Figure 2.3 respectively. The antenna has achieved ± 40 degree of beam steering with band width of 5.725 to 5.85 GHz. At 40 degree of scanning angle, antenna gain reduction of 1.8 dB observed at 5.8 GHz operating frequency.

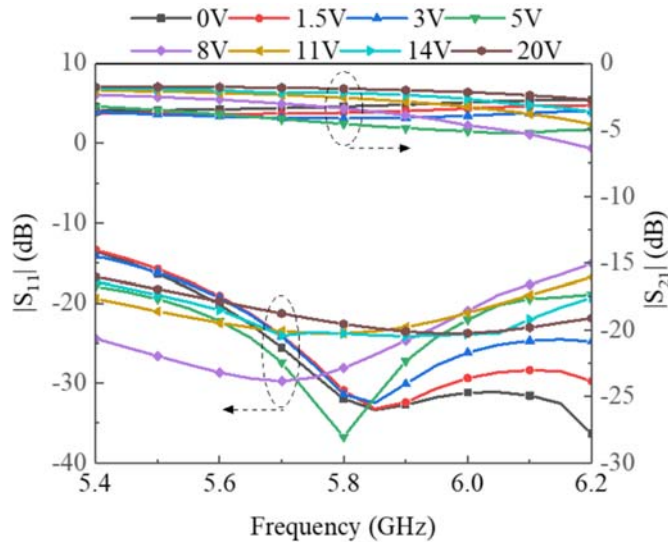


Figure 2.9: Simulated S- parameter of antenna for various biasing voltages

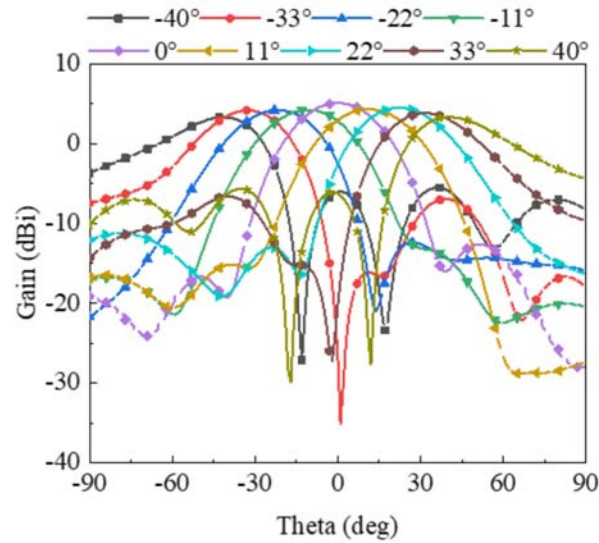


Figure 2.10: Simulated antenna gain along with beam scanning at 5.8 GHz

Antenna is integrated with 4 dipoles along with 8 varactor diodes integrated on it. 1X4 dipole antenna array in this type of configuration has limitation of high parasitic loss, high insertion loss and space complexity due to introduction of 4 reflection type phase shifters integrated with 8 varactor diodes.

2.1.5 ARC-SHAPED DIPOLE ARRAY

A dual-mode arc-shaped dipole array has been proposed for indoor base station application. In this work, dual types of beam steerable arc shaped antenna array has been presented. The first design of antenna as shown in Figure 2.3, consists of 4 arc shaped planar dipoles along with central circular reflector. The second design of antenna consists of 8 arc shaped planar dipoles deposited at two layers along with two central reflectors as shown in Figure 2.5.

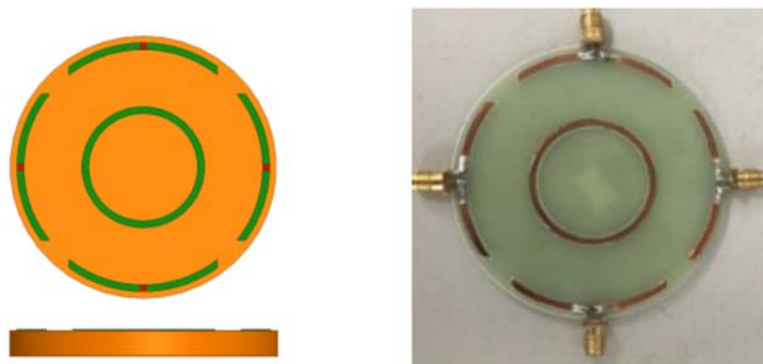


Figure 2.11: Four-element arc shaped dipole antenna array

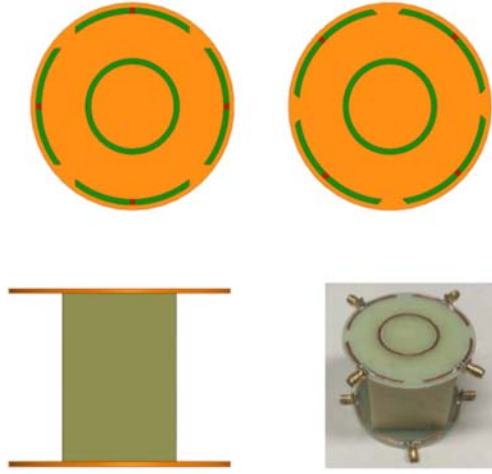


Figure 2.12: Eight-element arc shaped dipole antenna array

The s- parameter of antenna in Figure 2.6 shows its operating frequency range as 2.32-2.73 GHz. The measured radiation pattern of antenna in Figure 2.7 shows antenna beam steering at 0, 90, 180, 270 degrees.

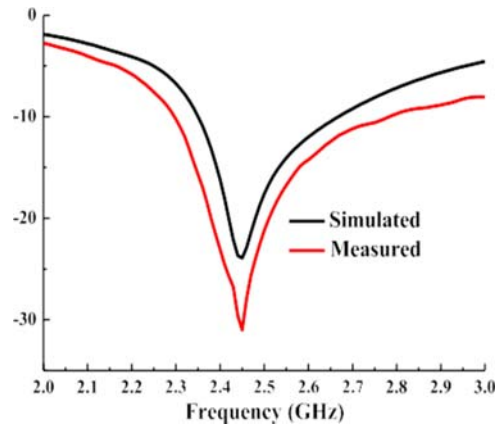


Figure 2.13: Simulated and measured S- parameter of antenna

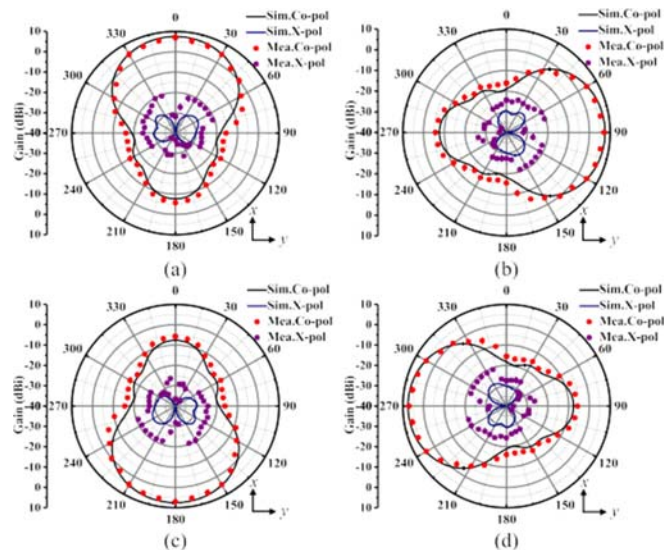


Figure 2.14: Simulated and measured radiation pattern of antenna with beam scanning at 2.45 GHz

This antenna configuration introduces 4 & 8 arc shaped dipoles with low omnidirectional gain of 1.5 dBi and 2.9 dBi respectively due to use of multiple dipoles simultaneously. Also there is 90-degree gap has been observed during beam switching of antenna. Three dimensional antenna size of 8 element antenna is considerably large for compact design antenna applications specially in ISM band application.

2.1.6 BEAM STEERABLE DIPOLE ANTENNA FOR WiMAX APPLICATION

A beam steerable dipole antenna has been introduced for WiMAX application by modulating the values of two varactor diodes inserted in two parasitic elements as shown in Figure 2.8. The antenna consists of antenna dipole along with two parasitic dipole elements integrated with varactor diodes. To realize a beam steering feature, the bias voltage of varactor diode has been adjusted.

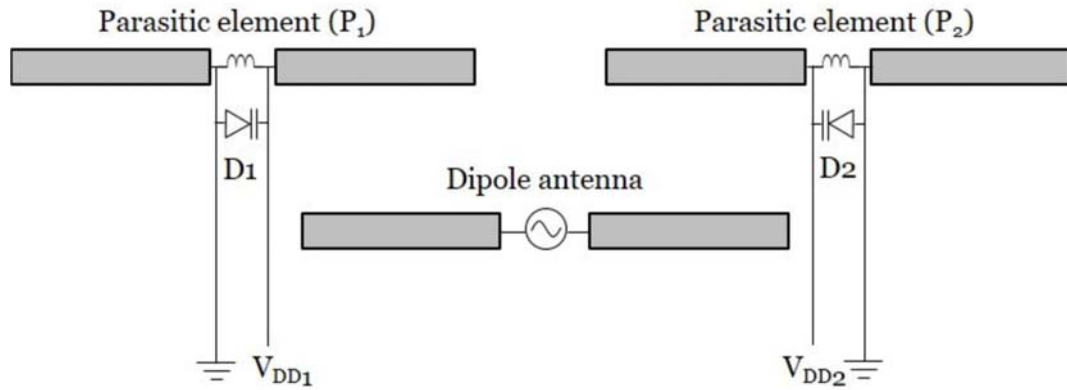


Figure 2.15: Proposed antenna design technique for beam steering with two parasitic elements with varactor diodes inserted

The antenna operates at 3.5 GHz with dimension of $1.07\lambda \times 0.52\lambda \times 0.006\lambda$. This type of antenna usage three dipole elements including two parasitic elements which increases design and space complexity. Also, parasitic elements are generally obstructive in nature and may lead to distorted radiation pattern shape as shown in Figure 2.9 as measured results.

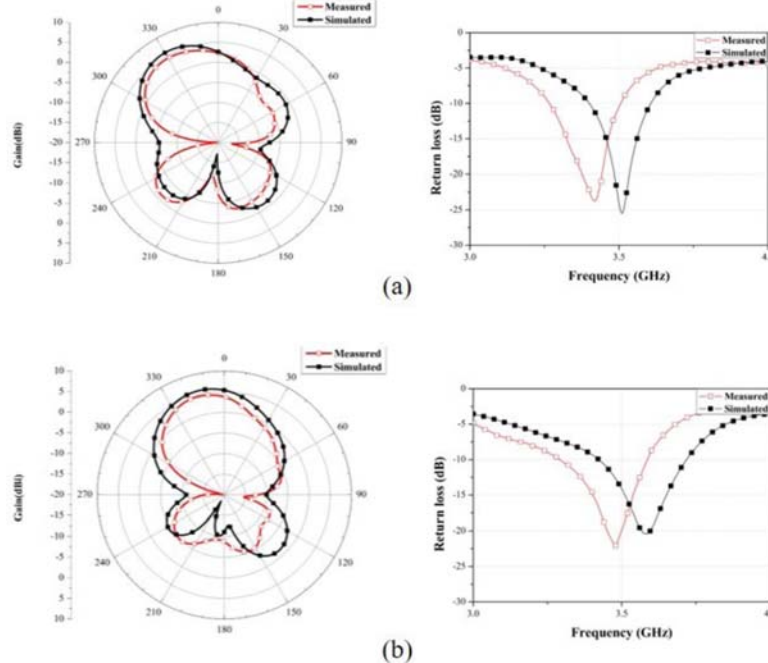


Figure 2.16: The Experiment Results of the proposed beam steerable Antenna: (a) Mode 1 (b) Mode 2

The antenna operates in non ISM band (3.5 GHz) and diode switching mechanism has not been provided along with antenna configuration for its high portability.

2.1.7 RECONFIGURABLE MICROSTRIP ANTENNA FOR BEAM STEERING IN E AND H PLANE

A reconfigurable microstrip antenna capable of beam steering in E and H plane using PIN diodes has been introduced in as shown in Figure 2.10.

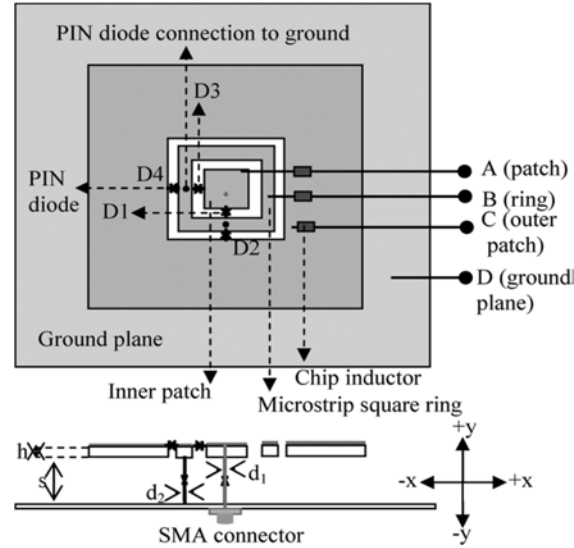


Figure 2.17: The geometry of the pattern reconfigurable antenna with integrated p-i-n diode switches

In this work, radiation pattern in conical form has been realized by a patch-slot-ring combination and same can be switchable in various directions by shaping in a single lobe pattern. Constant current loop formed in microstrip square-ring design structure produces the conical radiation pattern. A small patch in the center of antenna has been fed by a coaxial probe, excites the microstrip ring. The beam steering of antenna achieved by modifying its current distribution in microstrip ring using various combination of shorts and shorting posts. Electronic beam switching has been achieved by replacing shorts and shorting posts with PIN diode switches.

However, as shown in Figure 2.11 in S-parameter of antenna, this antenna operates at four different non ISM operating frequency 2.11, 2.08, 2.05, 2.03 GHz at four operating modes having beam shifting.

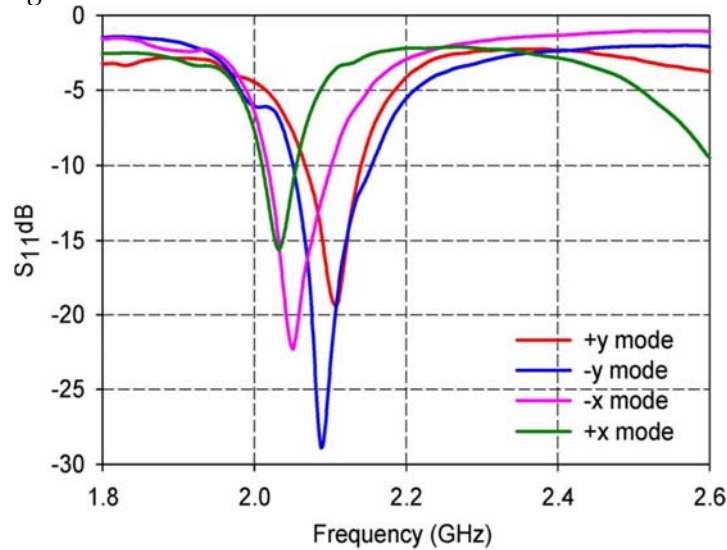


Figure 2.18: measured S- parameter of antenna

Also, the measured peak gain for the -y, +y, -x, +x modes is as 4.58, 2.71, 1.11, and 3.2 dBi respectively having high gain loss during beam switching as shown in measured radiation pattern in Figure 2.12.

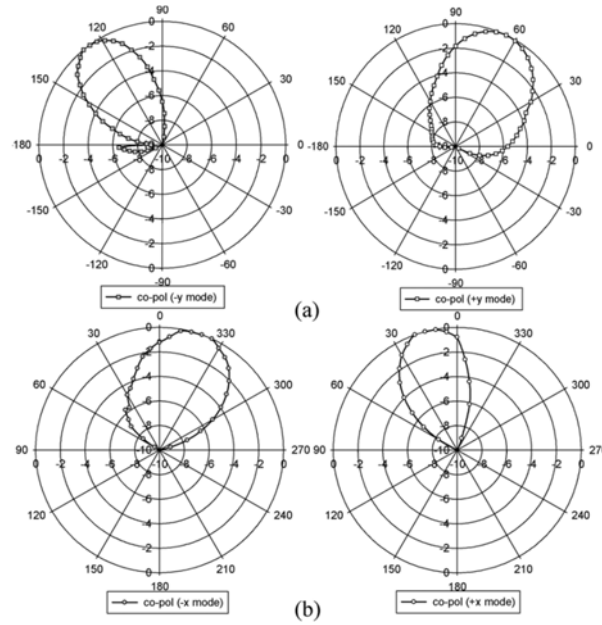


Figure 2.19: Measured radiation pattern of antenna for 4 modes (a) Azimuth plane (b) Elevation plane

2.1.8. A FREQUENCY AND PATTERN RECONFIGURABLE TWO ELEMENT ARRAY ANTENNA

A frequency & pattern reconfigurable two element array antenna has been proposed recently for beam steering using varactor diodes as shown in Figure 2.13. The antenna design is based on a stub-loaded configuration in which frequency tuning has been carried out with open stub loaded varactor diodes. Capacitance value of each varactor determines the resonance frequency of each element. In this configuration a relative phase between both antenna elements has been introduced by adjusting its capacitance value $+\Delta C_0$ and $-\Delta C_0$ resulting in beam-steering of antenna.

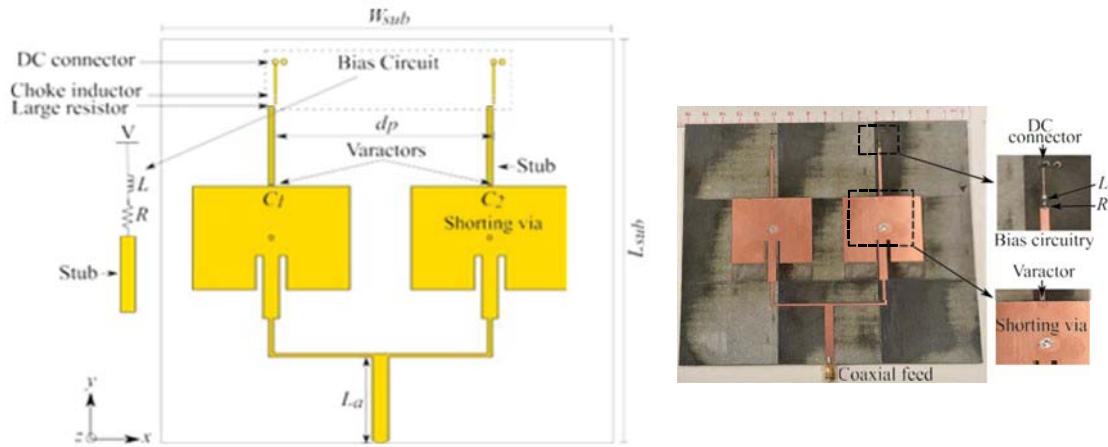


Figure.2.20: Reconfigurable two-element antenna based on stub-loaded varactors configuration excited by a T-junction power divider.

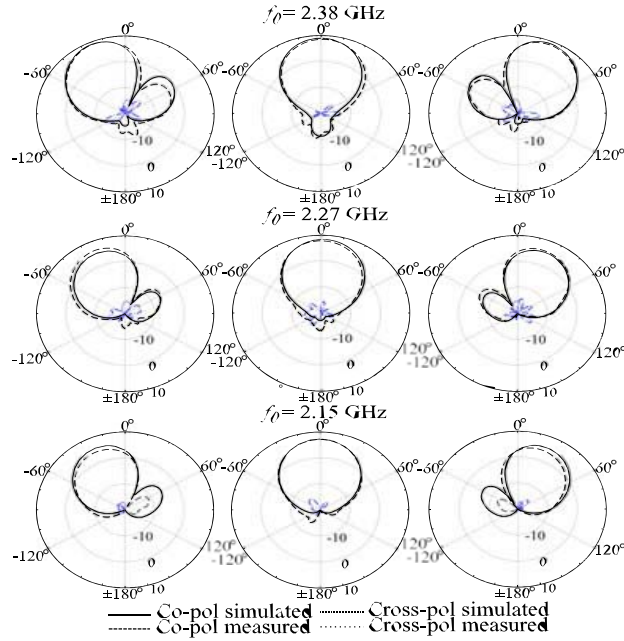


Figure 2.21: Measured radiation pattern of antenna

As shown in radiation pattern of antenna in Figure 2.14, the antenna achieves continuous beam steering from -23 degree to + 23 degree. The antenna covers frequency band from 2.15 GHz to 2.38 GHz as shown in Figure 2.15 in measured s-parameter.

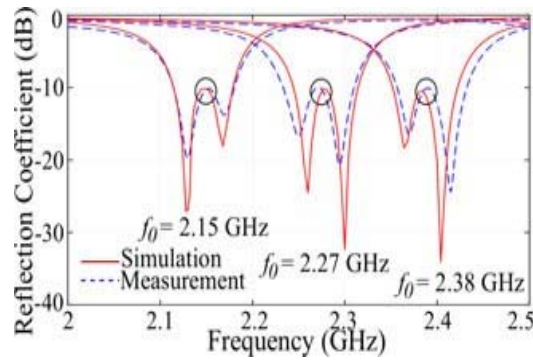


Figure 2.22: Simulated and measured S-parameter of antenna

Due to antenna design as array of two patch elements, the antenna possesses comparatively large size array architecture (151.5 mm × 160.9 mm). The antenna also has limitation of low scan angle, and high scan loss more than 3 dB.

2.1.9. PATTERN RECONFIGURABLE PATCH ANTENNA WITH SHORTING PINS

A pattern reconfigurable antenna has been introduced using two sets of shorting pins and five varactors in a square patch as shown in Figure 2.16. Beam steering in this type of configuration has been achieved using fixed stages for steering beam for specific biasing combination of multiple varactors.

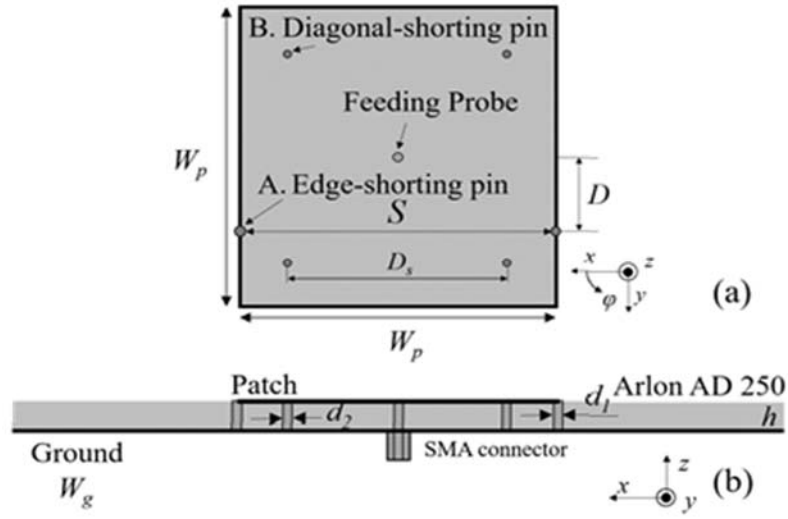


Figure.2.23: Schematic of proposed varactor loaded pattern reconfigurable patch antenna with shorting pins. (a) Top view. (b) Side view.

In this antenna, continuous beam steering realized by a square patch introduced with 4 varactors along with 2 sets of shorting pins. For various E-fields the edge shorting pins have been placed with the parallel edge of the patch. For directivity, another shorting pins symmetrically fixed along the diagonal of patch. Varactors are placed with edge-shorting pins to provide continuous beam steering.

As shown in antenna S-parameter in Figure 2.17., antenna simulated operating frequency is 7.31 GHz and measured operating frequency is 7.26 GHz with 0.05 shift between them. Antenna also operates with limited operating band width.

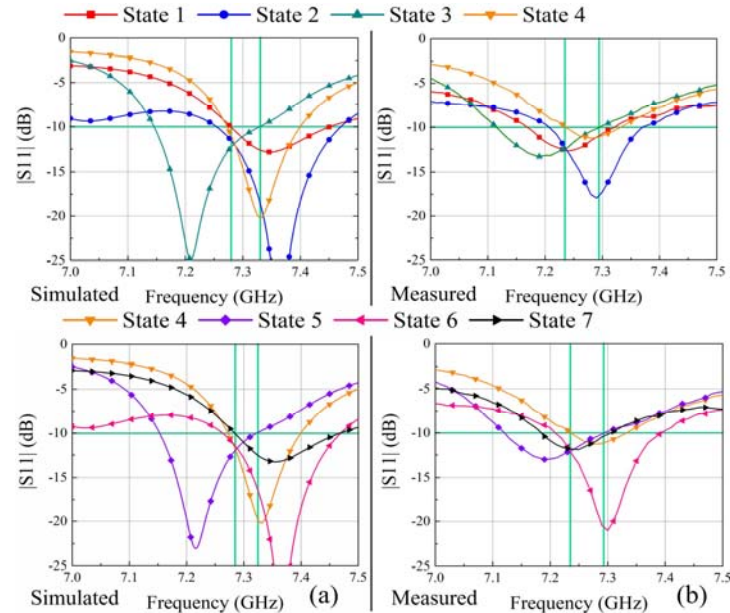


Figure 2.24: Simulated and measured S- parameter of antenna for various states

As shown in the measured radiation pattern of Figure 2.18, antenna achieves beam scanning from -55 degree to -15 degree and 19 degree to 54 degree in various states. Also 3.22 dB gain reduction observed from maximum gain of 7.55dBi.

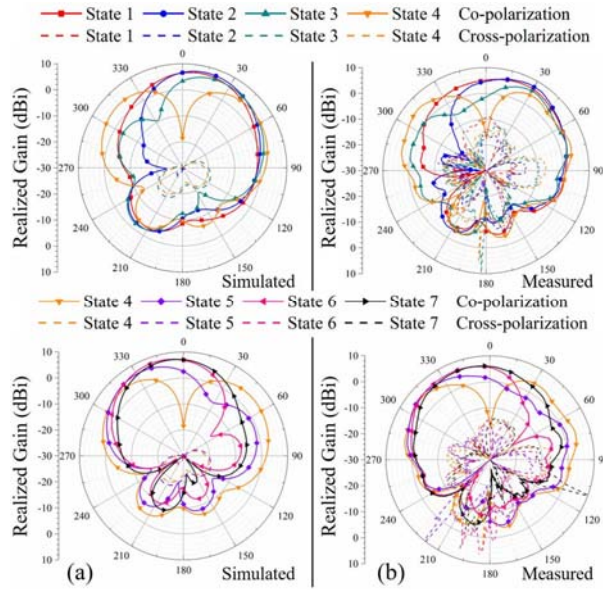


Figure 2.25: Simulated and measured radiation pattern of antenna

This antenna possesses limitation of excessive ripples and deteriorated measured radiation pattern due to DC wiring effects of multiple varactors and its parasitic elements along with high scan loss of 3.22 dB.

Several designs topologies of various microstrip antennas using varactor diode, PIN diode, shorting pins and reflect dipole antennas resulted in achieving beam steering in small tunable antennas. However, need for a more compact size, highly portable digitally controlled beam steerable printed antenna with low design cost, less complexity, less parasitic losses and high compatibility for wide applications still persists.