[1] Nandini M. Ammanagi
[2] Revanasiddappa S. Kinagi
[3] Ravi M. Yadahalli
[4] Rasika B. Naik
[5] Monali Chaudhari
[6] Saylee Gharge

Slotted Capacitively Coupled Elevated Microstrip Antenna

Abstract: - Tri-slotted radiating patch elevated in air with a small capacitive feed is proposed. The novelty in the proposed work is the in-depth comprehension of capacitive fed slot-cut Microstrip Antenna in terms of its resonance curve, surface current distribution, VSWR bandwidth(BW), radiation patterns; gain etc. is reported and studied in reference to the various modes introduced in the due course to yield a Triple band Microstrip Antenna.

Keywords: Microstrip Antenna (MSA), Broadband Capacitive fed RMSA (BCRMSA), Triple Band Capacitive fed Tri-slotted RMSA (TCTRMSA).

I. Introduction

Large bandwidth MSA's can be designed for all commercial applications using a suspended MSA on a low cost glass epoxy substrate. The MSA is suspended in air (ϵ_r=1) provides maximum radiation efficiency with larger gain [1]. The coaxial probe works well to feed an electrically thick substrate of thickness of nearly $0.08\lambda_0$, beyond which a capacitive feed technique is used [2-4]. With the capacitive feed method, the air suspended MSA's can be optimized for broader bandwidth, broadside radiation pattern and stable gain over the desired band [2,3]. Cutting slots of resonant length inside the patch at appropriate locations combine with the patch modes to yield Multi-band MSA [5-7]. The Hyperlynx 3D EM Software from Mentor graphics [8] has been used for the simulation of the antenna design. FR4 also known as glass epoxy substrate (ϵ_r=4.4, h=1.6mm, tanδ=0.002) has been considered for fabrication. In order to hold the substrate in air, acrylic spacers were placed at the four corners. The SMA connector of probe diameter of 1.2mm used to excite the antenna. R & S - ZVH-8 Vector Network Analyzer used for measurements.

II. Broadband Capacitive Fed Rmsa (BCRMSA)

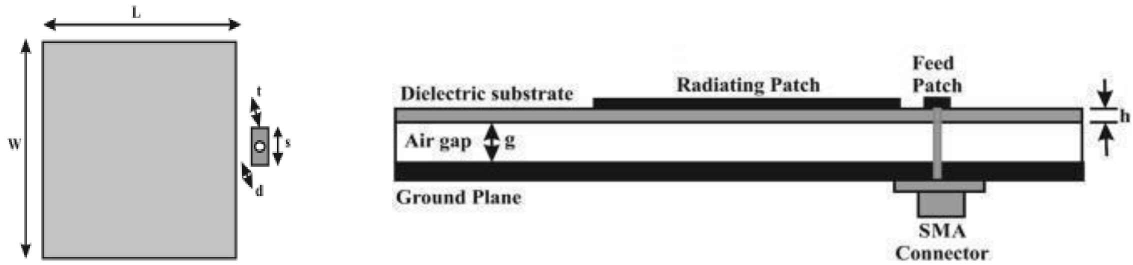
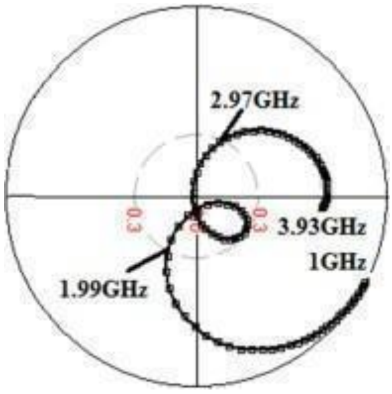


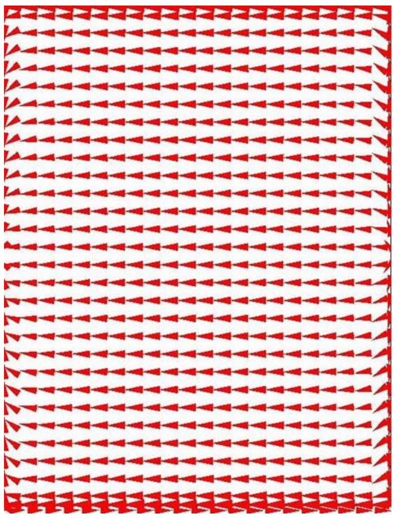
Fig. 1. (a) Top and (b) Side view of BCRMSA

[1] Department of Electronics and Telecommn Engineering, V.E.S. Institute of Technology, Mumbai, Maharashtra, India.
Email: nandini.ammanagi@ves.ac.in
[2] Department of Electronics and Commn Engineering, Sharnbasva University, Kalaburagi, Karnataka, India.
Email: revansk@gmail.com
[3] Department of Electronics and Commn Engineering, Methodist College of Engineering & Technology, Hyderabad, Telangana, India.
Email: yadahalliravim@gmail.com
[4] Department of Electronics and Telecommn Engineering, V.E.S. Institute of Technology, Mumbai, Maharashtra, India.
Email: rasika.naik@ves.ac.in
[5] Department of Electronics and Telecommn Engineering, V.E.S. Institute of Technology, Mumbai, Maharashtra, India.
Email: monali.chaudhary@ves.ac.in
[6] Department of Electronics and Telecommn Engineering, V.E.S. Institute of Technology, Mumbai, Maharashtra, India.
Email: saylee.gharge@ves.ac.in

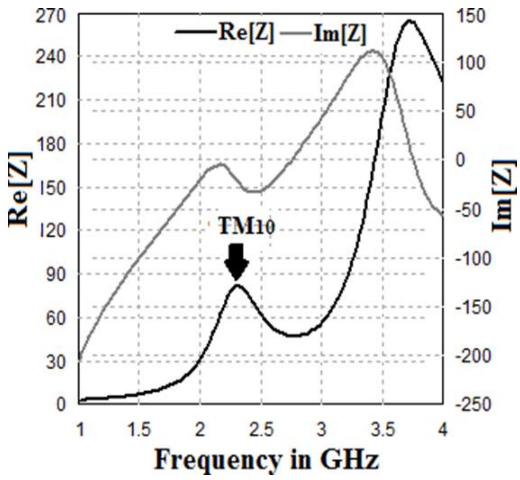
The BCRMSA is presented in Fig 1(a, b). A large rectangular shaped patch sized (L,W) = (35.5mm, 45.6mm) is etched on one side of the FR4 substrate (ϵ_r=4.4, h=1.6mm, tanδ=0.002) which is elevated in air with dielectric constant (ϵ_r=1, tanδ=0), at a distance (Δ) equal to 15mm, giving a total substrate thickness (h+Δ) of 16.6 mm. A small rectangular patch of size (t,s) = (1.4mm, 4mm) placed at a distance (d) of 1 mm is used to feed the large patch. Note, the effective dielectric constant $\epsilon_{eff} < \epsilon_r$. The RMSA dimensions are designed using the transmission model equations [1] to resonate at f_r = 2 GHz for TM_{10} fundamental mode. Coaxial probe is soldered to the small patch which electromagnetically couples to the larger patch. As the total substrate thickness increases, the coaxial probe feed length from the ground plane to the patch also increases resulting in an increase in the probe inductance which can be nullified by the small capacitive feed [3] and also providing larger bandwidth. For proper impedance matching, the parameters such as dimensions of the small patch (t & s), separation between the small patch and the large patch (d), air gap (g) separation are all optimized.



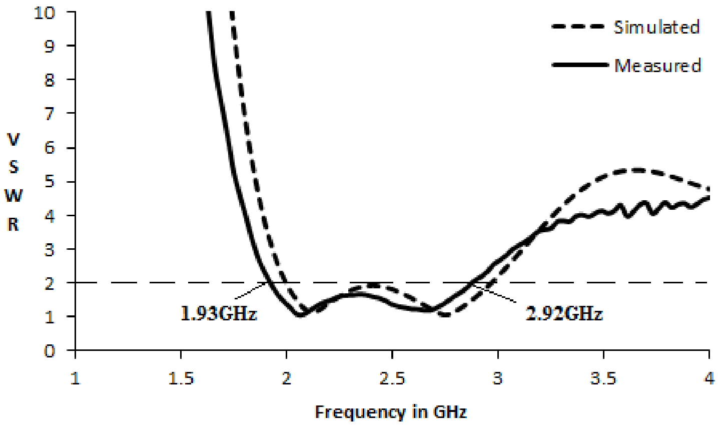
(a)



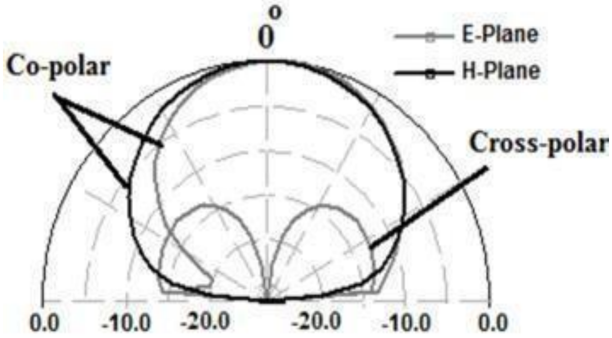
(b)



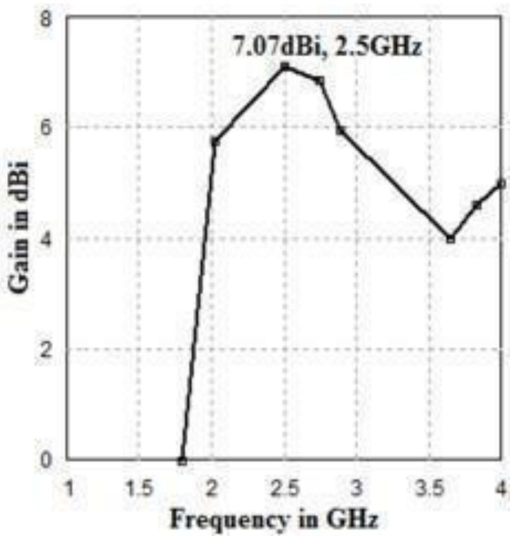
(c)



(d)



(e)

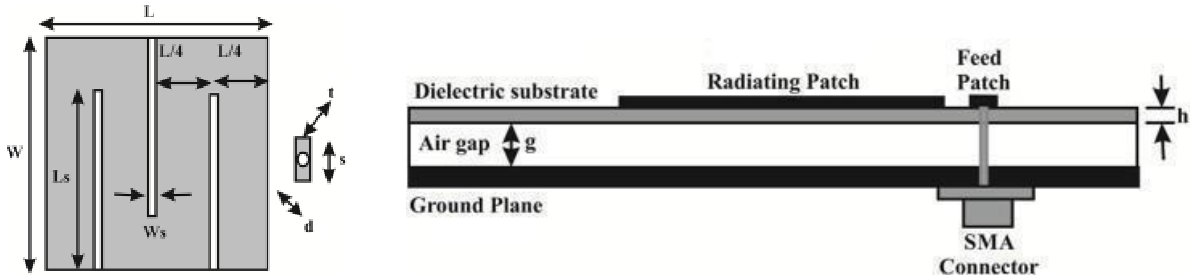


(f)

Fig.2. (a) Simulated Input Impedance (b) Surface current distribution of radiating patch at 2.5GHz (c) Resonance curve plot (d) VSWR graph (e) E-field and H-field radiation pattern at 2.5GHz (f) Gain plot

The simulated Input impedance is presented in Fig.2a. From the surface current distribution of the radiating patch presented in Fig.2b, at the first frequency TM_{10} mode exists. The surface currents show one λ/2 variation along the patch length and no variation along patch width. For the coaxial feed at the center of the small patch, the first peak present in the resonance curve plot presented in Fig. 2c is at 2.31GHz. The higher order mode does not exist as the impedance matching for it is not realized for the given feed location. The measured VSWR BW is 990MHz (40.82%) and the simulated VSWR BW is 960MHz (38.7%) show a close alignment in Fig.2d. For a ground plane sized 75x75mm^2, broadside and symmetrical radiation patterns at the resonance frequency are presented in Fig.2e for both E-field and H-field. The maximum gain of 7.07dBi at the resonance frequency and a gain of greater than 6dBi over the entire BW is presented in Fig.2f.

III. TRIPLE BAND CAPACITIVE FED TRI-SLOTTED RMSA (TCTRMSA)



(a) (b)

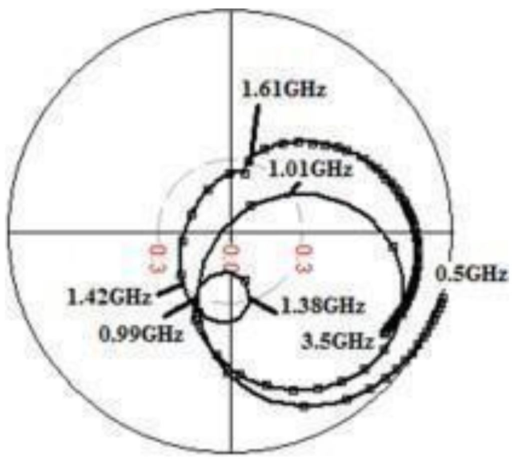
Fig. 3. (a) Top and (b) Side view of TCTRMSA

Three rectangular slots are integrated inside the large patch as presented in Fig.3 (a, b). The slots are spaced adjacent at a separating distance of L/4 from each other. The slots are cut along the non-radiating edges of the large patch and are of quarter wavelength length. Thus the slot and the patch are of the same polarization. The width of the slot is 1mm. The un-slotted capacitive fed RMSA presented in Fig1 (a, b) resonates at a center frequency of 2.5GHz. The simulated Input Impedance is presented in Fig.4a. The three peaks represent the resonance frequencies of the configuration presented in the VSWR graph in Fig.4b . The simulated triple frequencies are at (1.01, 1.37 and 1.49) GHz with their respective VSWR bandwidth 20MHz (1.98%), 10MHz (0.73%) and 180MHz (11.92%).The measured triple frequencies are at (0.984, 1.35 and 1.47) GHz with their respective VSWR bandwidths 35MHz (3.56%), 20MHz (1.48%) and 190MHz (12.9%).

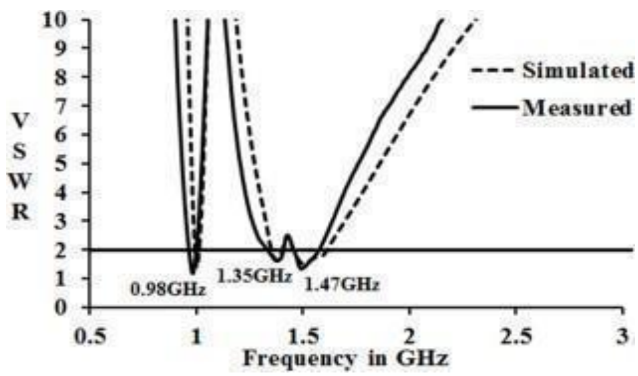
For the given feed location higher order modes are excited along with the fundamental mode as seen in the resonance curve plot presented in Fig.4c. The various resonance frequencies for the range 1-4 GHz for the fundamental and higher order modes [1] calculated using the equation (1).

$$fmn = \frac{c}{2\sqrt{\epsilon eff}}\sqrt{\left(\frac{1}{Le}\right)^2 + \left(\frac{1}{We}\right)^2} \qquad (1)$$

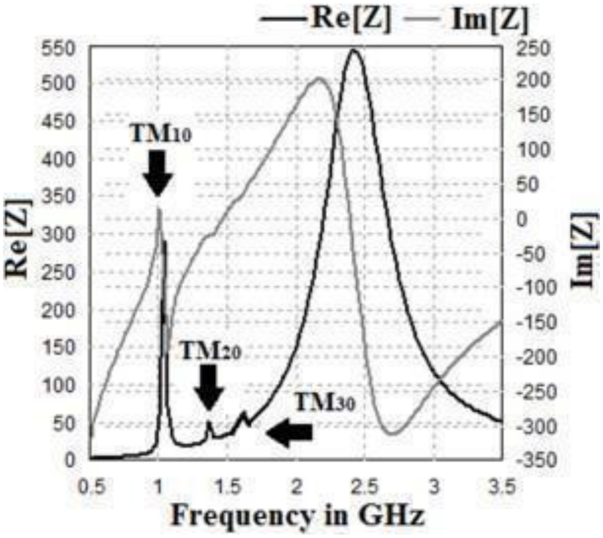
where L_e and W_e are the effective length and width of the RMSA considering the emanating fields surrounding the edges of the patch.



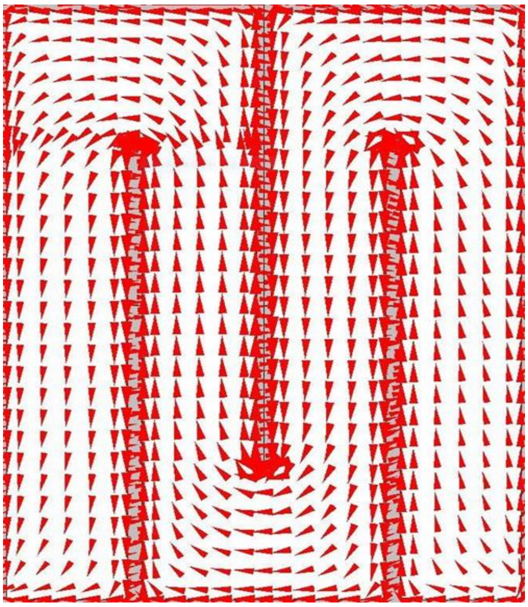
(a)



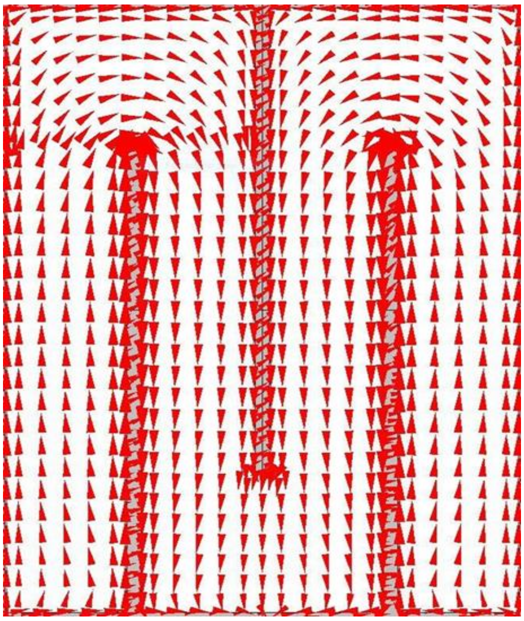
(b)


Re[Z]
Im[Z]
TM10
TM20
TM30
Frequency in GHz
550
500
450
400
350
300
250
200
150
100
50
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
0.5
1
1.5
2
2.5
3
3.5

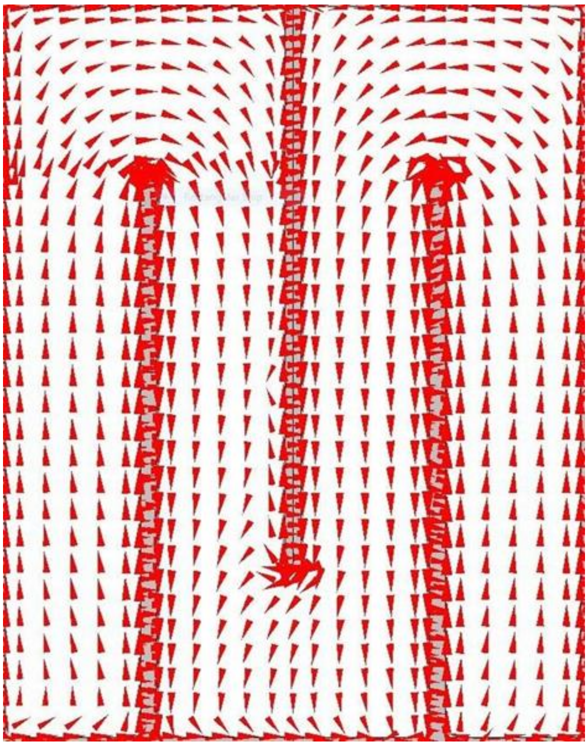
(c)



(d)



(e)



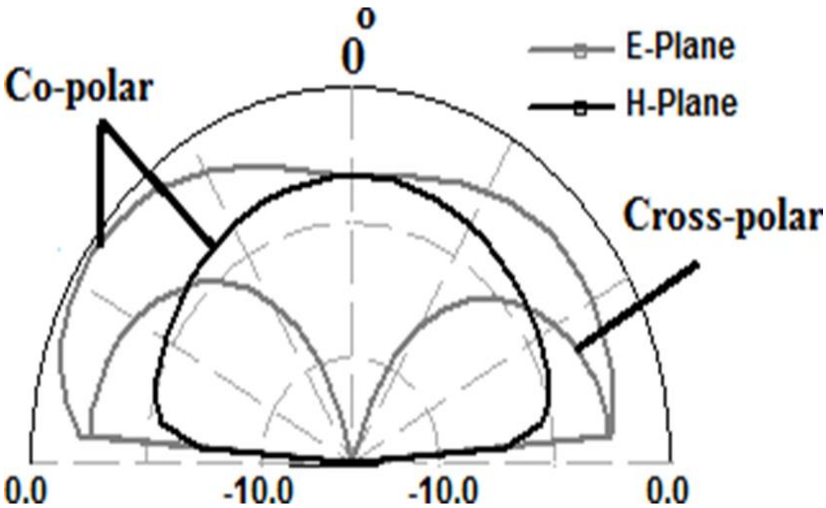
(f)

Fig.4. (a) Simulated Input Impedance (b) VSWR graph (c) Resonance curve plot, Surface Current Distributions of slotted radiating patch at (d) 1.04GHz (e) 1.37GHz (f) 1.58GHz

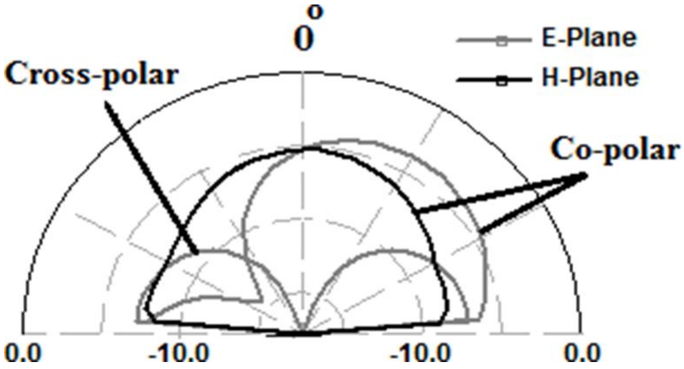
From the Fig. 4c, the first peak at 1.04GHz corresponds to fundamental TM_{10} mode. The next two peaks correspond to the higher order modes TM_{20} (1.37GHz) and TM_{30} (1.58GHz). For the given feed location, the impedance matching is not realizable for other higher order modes and hence does not exist.

The mode variation over VSWR BW is investigated using the simulated surface current distributions as presented in Fig.4 (d, e, f) with surface currents circulating around the slots. At the first resonance frequency, one $\lambda/2$ variation in surface currents along the patch length and no variation along the patch width indicate the TM_{10} mode. At the second resonance frequency, two $\lambda/2$ variations in surface currents along the patch length and no variation along the patch width indicate the TM_{20} mode and at the third resonance frequency, three $\lambda/2$ variations in surface currents along the patch length and no variation along the patch width indicate the TM_{30} mode.

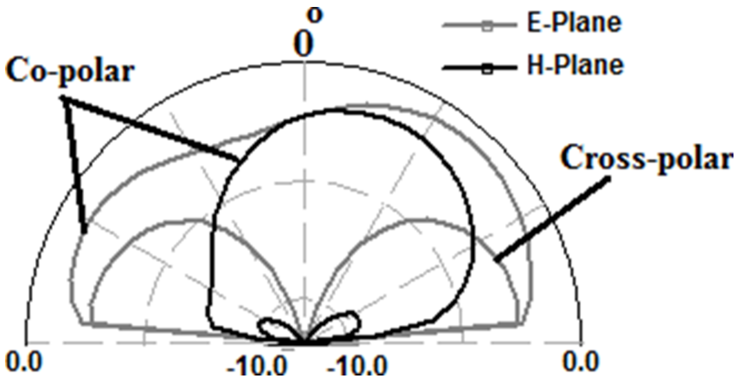
Comparing the simulated frequencies of the resonance curve plot presented in Fig. 4c there are two modes introduced TM_{20} and TM_{30} apart from TM_{10} . It is observed that TM_{10} mode has reduced from 2.644GHz to 1.04GHz, and same is the case with mode TM_{20} and TM_{30} at 1.37GHz and 1.58GHz respectively. As the slots cut are perpendicular to the surface currents for each of the modes, it is observed that as the vertical length of slots increases, the length of the surface current for that mode increases and hence reduces its frequency.



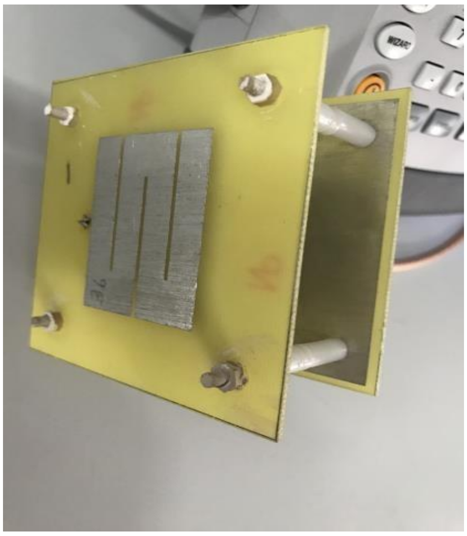
(a)



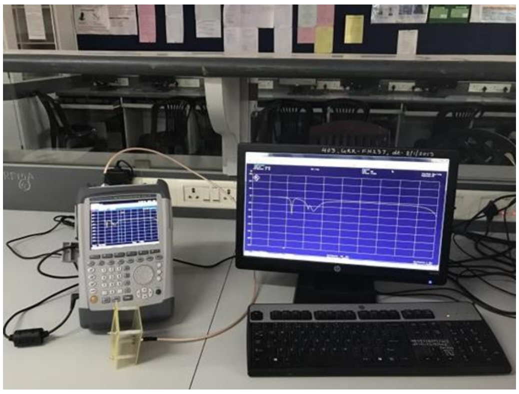
(b)



(c)



(d)



(e)

Fig.5. E-field and H-field radiation pattern at (a) 1.04GHz (b) 1.37GHz (c) 1.58GHz (d) Fabricated configuration of TCTRMSA (e)Testing on Vector network Analyser

Fig.5 (a, b, c) depicts the simulated radiation patterns at the triple frequencies with E-field and H-field planes aligned along $\Phi=0^0$ and $\Phi=90^0$ respectively. At the second and third resonance frequency, due to the vertical surface currents at the modified higher order modes, the radiation pattern shows higher cross polar levels reducing the antenna gain to around 1dBi over the entire BW. The fabricated prototype tested on Vector Network Analyser is presented in Fig.5 (d,e). A detailed analysis to study the effect of slots on the patch resonant modes is carried out. It is inferred that the feed location and resonant slot length alter the frequencies of higher order modes along with the fundamental mode to realize the triple band response of the antenna.

IV. CONCLUSION

Triple band MSA elevated in air with a small capacitive feed has been discussed. In the Triple frequency design, the tri- slotted patch adds modes TM_{20} and TM_{30} near the primary mode TM_{10} to result in tri-band characteristics. The fractional VSWR bandwidths are 3.56%, 1.48% and 12.9% with their frequency ratios $f_{r3}/f_{r2}=1.08$ and $f_{r2}/f_{r1}=1.37$. The various characteristics studied show a close compliance with the simulated and measured results.

REFERENCES

[1] G. Kumar and K.P. Ray, "Broadband Microstrip Antennas", Artech House, Norwood, Mass, USA, 2001.

[2] Veeresh G. Kasbegoudar, Dibyant S. Upadhyay and K. J. Vinoy, Research Article "Design Studies of Ultra-Wideband Microstrip Antennas with a Small Capacitive Feed", HindawiPublishing Corporation International Journal of antennas and Propagation Volume 2007, Article ID 67503, 8 pages doi:10.1155/2007/67503.

[3] Nandini M. Ammanagi and Ravi M. Yadahalli, "Slot loaded Capacitive Fed Suspended RMSA with Meandered Ground Plane", Journal of Engineering Science and Technology Vol. 14, No. 5 October 2019, pp. 2979-2990 @ School of engineering, Taylor's University.

[4] R.T. Cock and C.G. Christodoulou, "Design of a two layer capacitively coupled, microstrip patch antenna element for broadband applications", IEEE Antennas Popag. Soc. Int. Symp. Dig., vol. 2, 1987, 936-939.

[5] K.L. Wong, "Compact and Broadband microstrip antennas", Wiley, New York, 2002.

[6] A. A. Deshmukh and K.P. Ray, "Half U-Slot Loaded Multiband Rectangular Microstrip Antennas, "International Journal of Microwave and Optical Technology, 2,2, July, 2007, pp.216-221.

[7] Amit A. Deshmukh, Tejal A. Tirodkar, Apurva A. Joshi and K. P. Ray, "Broadband Gap-Coupled Slot Cut Rectangular Microstrip Antennas", Proceedings of INDICON-2013, 13th–15th December 2013, Mumbai, India. (IEEE Digital Library, DOI:10.1109/INDCON.2013.6725954)

[8] Hyperlynx 3D EM Software V15.3 (formerly called IE3D).