VERTEX-FED HEXAGONAL ANTENNA WITH LOW CROSS-POLARIZATION LEVELS

Abhishek JOSHI, Rahul SINGHAL

Department of Electrical and Electronics Engineering, Birla Institute of Technology & Science,
Vidya Vihar, Pilani, Rajasthan 333031, India

abhishek.joshi@pilani.bits-pilani.ac.in, rahulsinghal@pilani.bits-pilani.ac.in

DOI: 10.15598/aeee.v17i2.3004

Abstract. *Probe-fed hexagonal patch antenna suffers from impedance mismatch especially when feed is located at one of the vertices of polygon. Hexagonal planar antennas also suffer from high cross polar levels. This paper proposes a method to overcome impedance mismatch and to increase co-polarization level by reducing ground plane. Vertex feeding is demonstrated in this paper to establish improvement in impedance values more clearly. The impedance at any vertex of a hexagonal patch is too high when compared to the characteristic impedance of the probe. Three vertex-fed hexagonal antennas are developed to demonstrate the effect of ground plane reduction within C-Band. The proposed technique can be optimized to match the impedance and achieve good return loss where monopole radiation characteristics are not an issue. A vertex-fed reduced ground hexagonal antenna is proposed here that operates around 5 GHz with a frequency span of 600 MHz. Thus, the proposed antenna is quite suitable for indoor wireless LAN (UNII-1) applications.*

Keywords

Ground plane reduction, hexagonal antennas, probe-fed antennas, vertex-fed antennas, WLAN.

1. Introduction

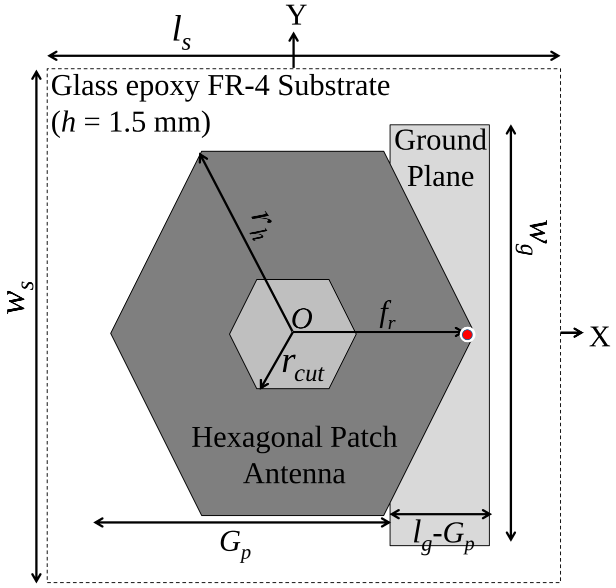
Hexagonal structure and its derivatives are proposed and investigated in detail [1], [2] and [3]. Hexagonal antennas excite higher modes and exhibit wide-band behaviour at higher frequencies when the input probe is connected directly to one of the vertices of the hexagon [4] and [5]. Multiple resonances are observed due to the mismatch in impedance in a probe-fed hexagonal antenna [6]. To obtain single resonance, it is necessary to suppress or filter out all additional modes. To suppress spurious radiation, Split Ring Resonators (SRRs) and Complementary SRRs (CSRRs) have been utilized earlier [7] and [8]. Another solution to resolve the issue of the impedance mismatch in case of a thick substrate is capacitive probe compensation [9]. Capacitive probe compensation techniques such as a Parallel Plate Capacitor (PPC) and annular ring can be used to match the impedance of the inductive probe when a dielectric substrate of thickness greater than $\lambda/10$ [10] is used to expand antenna's operating bandwidth [11]. PPC can be used to improve impedance matching at lower modes in probe-fed hexagonal antenna [12]. It is necessary to recognize a method to match the impedance in case of a thinner substrate where the thickness is less than $\lambda/10$. Ground plane reduction technique can improve impedance matching as earlier demonstrated for a clamshell mobile phone [13]. The overlap area between patch and ground plane is minimal when monopole antennas are designed for UWB applications [14] and [15]. WSN nodes radiating through antennas with a truncated ground plane are developed to optimize the size and the bandwidth constraint [16]. Ground plane reduction technique is also used to achieve ultra wideband in a coplanar antenna [17]. The effect of dimensions of the ground plane, on radiation patterns of the antenna, has been investigated by Noghanian et al. [18]. Truncation of the ground plane has an influence on gain as well as on the impedance bandwidth of an antenna as revealed by the parametric studies [19]. The effect of the size of a ground plane on antenna performance has been studied and analyzed [20]. A potential solution to overcome the issue of impedance mismatch is reduced ground technique. The impedance matching using defected ground structure has been achieved in [21]. Tong et al.

theoretically investigated ground plane size reduction and recommended an optimized ground plane size [22]. This paper utilizes the reduced ground technique to match the impedance of the patch with the probe in vertex fed hexagonal patch antenna without using the SRRs, CSRRs, PPC or annular ring.

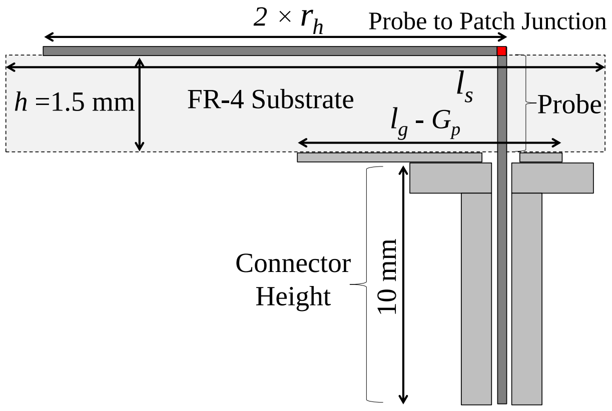
In this paper, an impedance matched vertex-fed hexagonal antenna with a truncated ground plane is proposed and analyzed experimentally. The second section of the paper describes the design of proposed antennas while demonstrating the effect of ground plane reduction in C-Band. Third section of paper discusses the effect of reduced ground on return loss and impedance through measurement results. Besides an impedance match, reduction of ground plane suppresses additional resonances if any. The fourth section of the paper discusses observations from antenna radiation pattern measurements and far-field gain measured in an anechoic environment. The final section concludes the findings and observations in the proposed work. The paper proposes a technique in a directly fed hexagonal antenna by reducing dimensions of the ground plane to achieve improvement in impedance matching, to decrease cross polarizations levels and to suppress adjacent resonances, if any.

2. Antenna Design and Simulation

The vertex-fed hexagonal patch antennas with the reduced ground are designed as shown in Fig. 1(a) while the cross-section along the x-axis is shown in Fig. 1(b). To understand the effect of reduced ground, three antenna prototypes are designed and fabricated. Dimensions of features used for all three antennas are shown in Tab. 1. In all antenna prototypes, substrate material FR-4 ($\epsilon_r = 4.3$ and $\tan\delta = 0.025$) with height ($h = 1.5$ mm) is used. In all antenna prototypes, Standard Sub-Miniature (SMA) connector with a pin diameter of 1.24 mm is used to feed the hexagonal patch. The height of the outer conductor is 10 mm with radius 2.57 mm as shown in Fig. 1(b). First antenna prototype (Antenna 1) does not consist of a hexagonal slot while antenna prototypes, i.e. Antenna 2 and Antenna 3 are designed with a hexagonal slot. The values of radii of hexagonal slot are indicated in Tab. 1. Dimensions of the hexagonal slot are optimized using method already suggested in [5] which demonstrates small improvement of antenna gain too. While performing the experiments, the size of the antennas is varied to verify the performance of reduced ground at different resonances within the C-band. The approach to improve impedance matching is to vary the ground plane dimensions while keeping the substrate height (h) constant. The area of the hexagonal patch that overlaps with the ground plane reduces which results in variation of the patch capacitance.



(a) Schematic view.



(b) Cross sectional view.

Fig. 1: Proposed vertex fed hexagonal antenna with reduced ground.

Tab. 1: Values of parameters used in three antenna designs.

Design parameters (mm)	**Antenna 1**	**Antenna 2**	**Antenna 3**
Substrate Length (l_s)	32	44.44	46
Substrate Width (w_s)	33.5	44.44	46
Effective Ground Length (l_g-G_p)	10.44	14.24	9
Ground Width (w_g)	24.44	33.33	39
Hexagonal patch Circumradius (r_h)	12	15	17.5
Ground reduction factor (G_p)	14	19	28
Feed point radius from O (f_r)	10	14	17.5
Slot radius (r_{cut})	0	2.5	3

The substrate dimension plays a significant role in co- and cross-polarization levels [23]. The value chosen for substrate dimensions for all antenna designs were optimized to limit cross-polarization levels. Simple RLC resonant equivalent circuit can be used to model the proposed antennas [6] and [24]. Lumped elements (RLC) can be obtained for different antennas i.e. Antenna 1, 2 and 3, as given by Eq. (1), Eq. (2) and Eq. (3), respectively.

$$C_{patch} = \left(\frac{\epsilon_0 \epsilon_r}{2h}\right)\left(\frac{3\sqrt{3}r_h^2}{2}\right)\left(1-\frac{G_p}{l_g}\right), \qquad (1)$$

$$L_n = \frac{1}{\left(2\pi f_n\right)^2 C_{patch}}, \qquad (2)$$

$$R_n = \frac{Q}{\left(2\pi f_n\right) C_{patch}}, \qquad (3)$$

where, f_n is centre frequency of operating band, and, h and ϵ_r are substrate characteristics, respectively.

An equivalent circuit can be modeled on similar lines as in [6] with patch capacitance (C_{patch}), inductance (L_n), resistance (R_n) for a given f_n can calculated using the Eq. (1), Eq. (2) and Eq. (3) which can be further used to calculate patch impedance (Z_{patch}) and Z_{11} as expressed in Eq. (4) and Eq. (7) respectively. The capacitance (C_{j1} and C_{j2}) and inductance (L_{j1}) exist because of probe to patch junction. The probe itself exhibits resistance (R_p) and inductance (L_0+L_p) when inside the substrate. The height of the probe outside the substrate introduces resistance (R_{ph}), inductance (L_{ph}) and capacitance (C_{ph}).

$$Z_{patch} = \frac{1}{\dfrac{1}{R_n} + j2\pi f C_{patch} + \dfrac{1}{j2\pi f L_n}}. \qquad (4)$$

Then, the reflection coefficient (dB) can be calculated using Eq. (5).

$$S_{11}(\mathrm{dB}) = 20\log_{10}\left(\frac{Z_{11}-Z_0}{Z_{11}-Z_0}\right), \qquad (5)$$

where, Z_{11} is expressed in Eq. (7) and Z_0 is 50 Ω.

The expression given in Eq. (1) is used to calculate C_{patch} for different values of G_p, where C_{patch} is equivalent capacitance calculated for a series combination of C_{fg} (full ground capacitance), ΔC_{rg} (reduced ground capacitance), and ΔC_{hs} (hexagonal slot capacitance), where, n represent number of resonant tank circuits.

$$\frac{1}{C_{patch}} = \frac{1}{C_{fg}} + \frac{1}{\Delta C_{rg}} + \frac{1}{\Delta C_{hs}}. \qquad (6)$$

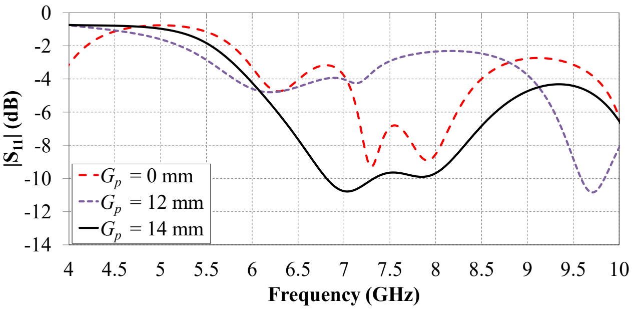


Fig. 2: Antenna 1: reflection coefficient, S_{11} (dB).

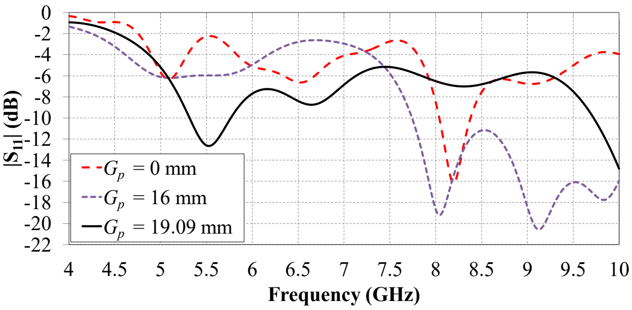


Fig. 3: Antenna 2: reflection coefficient, S_{11} (dB).

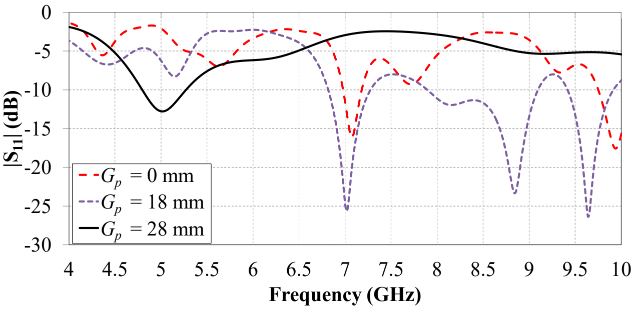


Fig. 4: Antenna 3: reflection coefficient, S_{11} (dB).

To obtain $|S_{11}| < -10$ dB, the ground plane is optimized by reducing it by a factor, G_p. Antenna 1, 2 and 3 radiates at 7 GHz, 5.5 GHz and 5 GHz respectively. To understand the effect of reduced ground on impedance, reflection coefficient for all the three antenna configurations are simulated for three different values of factor G_p i.e for full ground ($G_p = 0$ mm), half ground ($G_p = l_g/2$) and optimized ground. When a reduced ground with $G_p = 14$, 19 and 28 mm is used with Antenna 1, 2, 3, $|S_{11}| < -10$ dB at 7 GHz, 5.5 GHz and 5 GHz, is achieved as observed in Fig. 2, Fig. 3 and Fig. 4 respectively. It is observed that a planar antenna design requires optimization of dimensions of its ground plane to improve reflection coefficient at a desired frequency before its application. It is important to note that the reduction in area of ground plane is significant while matching the impedance and achieving $|S_{11}| < -10$ dB. In case of Antenna 1 and Antenna 2, the optimized value of G_p is observed when 57.3 % of ground area is reduced but results in spurious frequency as may be observed in Fig. 2 and Fig. 3. When the ground is reduced by 77 % the perfect impedance matching is observed in case of Antenna 3 as shown in Fig. 4.

The impedance at vertex is very high which is not suitable when probe is placed at vertex as may be observed in Fig. 2, Fig. 3 and Fig. 4 in all the three configurations with full ground i.e. $G_p = 0$ mm. Due to truncation of ground plane, the effective capacitance of the patch compensates the impedance mismatch due to probe feeding at resonant frequency. Values of impedance increase due to probe feeding, but optimum or reduced ground can compensate any mismatch in impedance due to probe location. The phenomenon of impedance matching is further verified with the measurement results in the next section of the paper. It is interesting to note that reduction in G_p excites modes at lower frequencies.

In order to distinguish the modes at resonating frequencies, the magnetic mode field i.e. $\vec{H}$-field at distinct phases of the excitation signal are observed. The magnetic mode field for Antenna 1 is displayed in Fig. 5(a) and Fig. 5(b) at frequencies 7.02 GHz and 7.86 GHz respectively. The magnetic mode field for Antenna 2 is reflected in Fig. 5(c) and Fig. 5(d) at frequencies 5.5 GHz and 6.64 GHz respectively. The magnetic mode field for Antenna 3 is reflected in Fig. 5(e) and Fig. 5(f) at frequency of 5 GHz at phases at 45° and 90° respectively. The magnetic mode field analysis suggests that frequencies 7.02 GHz, 5.5 GHz and 5 GHz correspond to same mode while frequencies 7.86 GHz and 6.64 GHz have same mode. Since the second mode is suppressed in Antenna 3 the two different modes are plotted at phases 45° and 90°.

3. Experimental Results

The picture of all developed antenna prototypes, as designed and discussed earlier in Sec. 2. , are shown in Fig. 6. To characterize the fabricated antennas for return loss and impedance, Keysight's (N9928A) Vector Network Analyzer (VNA) is used. The return loss of the fabricated antennas is observed and presented in Fig. 7. The Antenna 1, 2 and 3 resonate at 7 GHz, 5.5 GHz and 5 GHz respectively. When return loss of Antenna 1 and 2 are compared, it can be observed from Fig. 7 that although frequency shifts from 7 GHz to 5.5 GHz due to change in dimensions, but antenna behavior remains unchanged. Vertex-fed hexagonal patch antenna generates multi-mode response in case of Antenna 2 and Antenna 3.

Additional resonances can create interference in diversity applications thus spurious radiation needs to be suppressed. The presence of spurious radiation at 7 GHz is also observed in case of Antenna 2. Similarly, spurious frequency is also observed in return loss of Antenna 1 at 8.8 GHz in X-band as shown in Fig. 7. Further reduction of ground plane evidently suppresses spurious frequency but with the slight shift of resonating frequency from 5.5 GHz to 5 GHz, due change in the radius the hexagon from 15 mm to 17.5 mm. An undesired mode can be suppressed by reduced ground technique where monopole radiation characteristics are not an issue. It is interesting to note that there is a 200 MHz enhancement in the impedance bandwidth when Antenna 2 and 3 is compared. As the ground plane reduces, the antenna capacitance reduces, which in turn compensates the inductive probe. Based on the observations of measured return loss, it can be concluded that ground plane dimensions play significant role in matching the impedance of the probe.

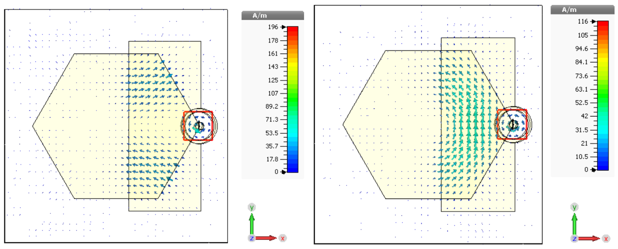
The value of the impedance Z_{11} is $33 + j0.55$ at 7 GHz, $53.92 + j18.94\ \Omega$ at 5.5 GHz and $53.37 - j5.2\ \Omega$ at 5 GHz for Antenna 1, 2 and 3 respectively as shown in Fig. 8. By observing the measured value of impedances for all three antenna configurations, it can be noticed that initial inductive impedance of the hexagonal patch is tuned by ground plane reduction factor, G_p (see Fig. 1). Although ideally reactive impedance should be zero, small value of reactance is observed. One of the reasons for difference from the ideal value is fabrication tolerance. Real value of impedance is close to expected value of 50 Ω i.e. impedance of the probe, in case of Antenna 3.

4. Antenna Pattern Measurements

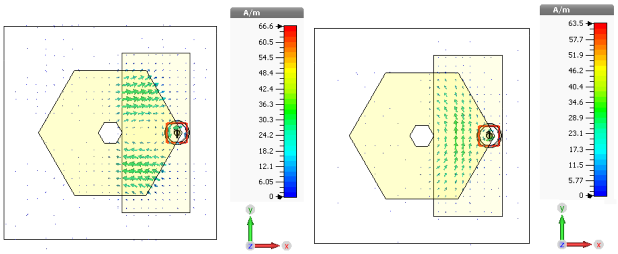
The radiation patterns of all three antenna prototypes are measured in an anechoic environment at their resonant frequencies. Pre-calibrated standard Dual Ridge Horn (DRH) transmits power to measure the absolute far-field gain of the fabricated antennas for the two fundamental planes. For the measurement of far-field gain, Agilent's (E-4412A) Power Sensor and Agilent's (E-4418B) Power Meter are used to sense and measure the received power while Keysight's (N5173B) Signal Generator is used to transmit power through the DRH antenna as shown in Fig. 9.

The transmitting antenna provides gain of 8.5 dB and 6 dB in the two different planes which are further used to calculate the antenna gain. The antenna under test is rotated from 0° to 350° in 10° increments while losses due to cable, the path loss and the absolute transmitted and received power are also measured to calculate antenna gain. The transmitting antenna is 60 cm apart from the receiving antenna which is greater than the Fraunhofer distance required. Signal generator feeds transmitting antenna a power of 18 dBm.

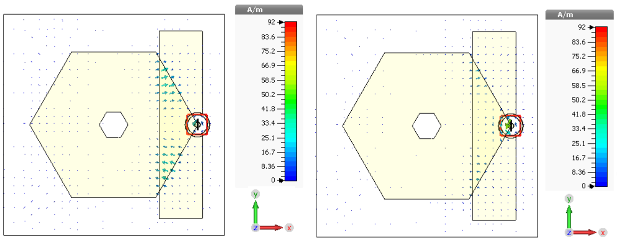
$$Z_{11} = R_{ph} + j2\pi f L_{ph} + \cfrac{1}{\cfrac{1}{R_p + \cfrac{1}{\cfrac{1}{\cfrac{1}{\cfrac{1}{Z_{patch}} + j2\pi f C_{j2}} + j2\pi f L_{j1}} + j2\pi f C_{j1}} + j2\pi f L_0 + j2\pi f L_p} + j2\pi f C_{ph}}. \quad (7)$$



(a) Antenna 1 at 7.02 GHz at 90° phase. (b) Antenna 1 at 7.86 GHz at 90° phase.

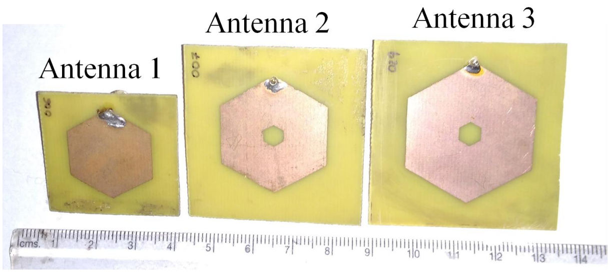


(c) Antenna 2 at 5.5 GHz at 90° phase. (d) Antenna 2 at 6.64 GHz at 90° phase .

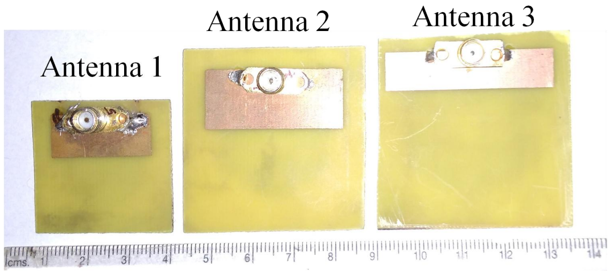


(e) Antenna 3 at 5 GHz at 45° phase. (f) Antenna 3 at 5 GHz at 90° phase.

Fig. 5: Magnetic mode field of the antennas at two different frequencies to distinguish different mode.



(a) Front.



(b) Back.

Fig. 6: Antenna 1, 2 and 3 prototypes.

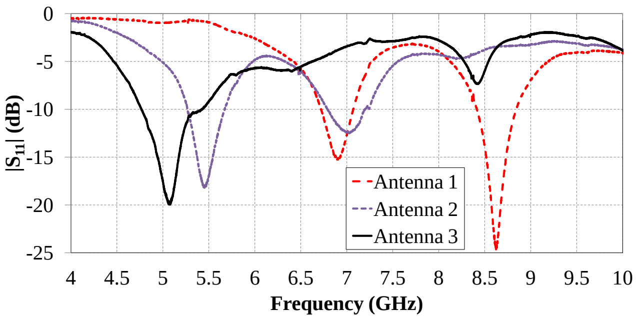
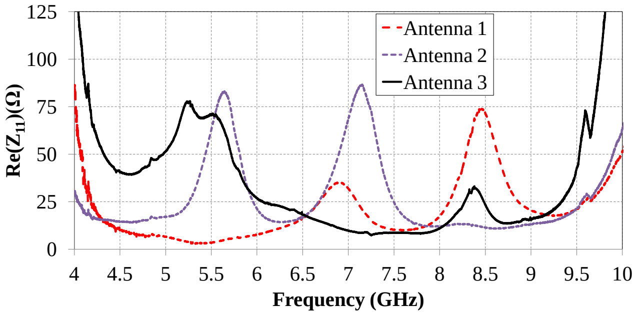


Fig. 7: Measured return loss, $|S_{11}|$ (in dB).

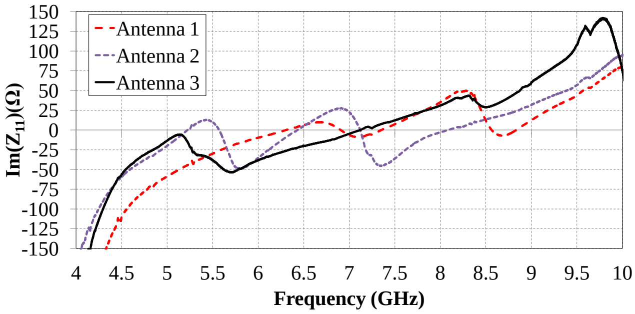
Finally, the received power is measured and data are used to calculate the far-field gain.

The co-polar (Eco/Hco) and the cross-polar (Ecx/Hcx) patterns are measured for the Antenna 1, 2 and 3 at 6.91 GHz, 5.45 GHz and 5 GHz as shown in Fig. 10(a), Fig. 10(b), Fig. 10(c) respectively.

A difference of around 20 dB is observed between co-and cross-polar levels at antenna bore-sight for the H- and E-plane in all antenna prototypes. The peak gain at the antenna bore-sight is approximately constant at 3 dB even when the resonant frequency shifts from higher to lower band i.e. 6.91 GHz in case of Antenna 1, 5.45 GHz in case of Antenna 2 and 5.01 GHz in case of Antenna 3. Although the patch radius of Antenna 3 is 1.45 times the Antenna 1 but the gain of Antenna 3 is approximately equal to gain of Antenna 1 at lower frequency due to the fact that the bandwidth of Antenna 3 is higher as compared to Antenna 1. It appears to follow Bode-Fano criterion which states that wider bandwidth can be achieved at an expense of higher reflection coefficient [25]. The nulls of the cross polarization level are centered at 0° for all the three



(a) Real part.



(b) Imaginary part.

Fig. 8: Variation of the input impedance of the proposed antennas.

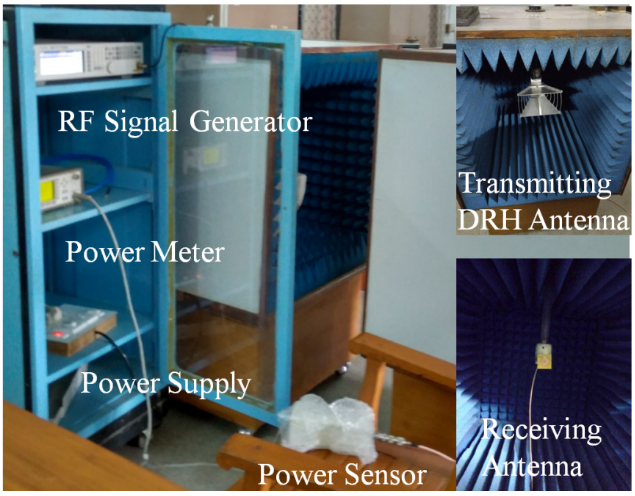
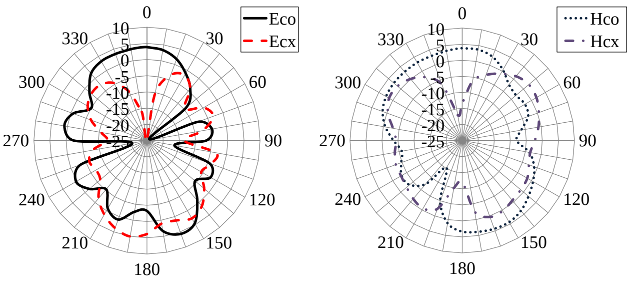
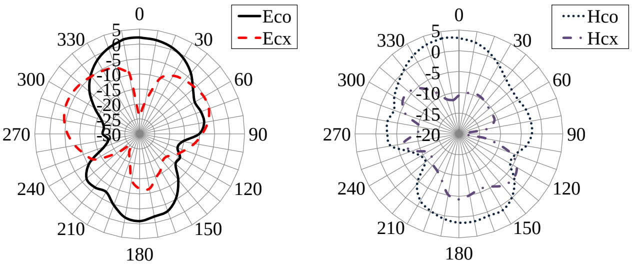


Fig. 9: Picture of Measurement Setup [Inset: transmitting and receiving antennas].

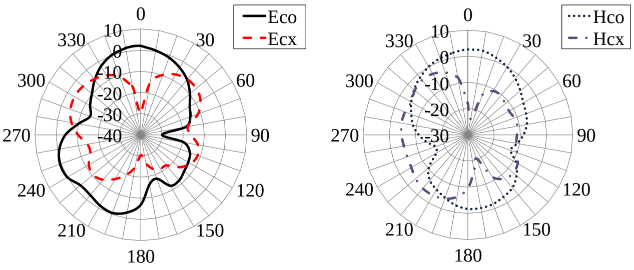
antenna prototypes. Due to the reduced ground plane, the proposed antennas have quasi-monopole radiation patterns. The gain of proposed antenna (Antenna 3), obtained using Friss transmission equation when applied to data collected from radiation pattern measurement, is found to be 3 dB. The 3-dB beamwidth are approximately 60° and 50° for H- and E-plane respectively. The proposed antenna is suitable for wireless LAN (UNII-1) applications.



(a) Antenna 1 at 6.91 GHz.



(b) Antenna 2 at 5.45 GHz.



(c) Antenna 3 at 5.1 GHz.

Fig. 10: Measured Co- and Cross-polar patterns.

5. Conclusion

This paper presents a technique to match impedance and in effect, to suppress any additional resonance in a directly fed hexagonal patch antenna. Technique of ground plane reduction is used for matching the impedance at a frequency radiated by the proposed antenna. The proposed antenna exhibits matched impedance at 5 GHz with a value of $53.37 - j5.2\ \Omega$ which is very close to 50 Ω. The Antenna 3 radiates a gain of 3 dB and operates within a bandwidth of 600 MHz at 5 GHz making it suitable for WLAN (UNII-1) applications. The co- and cross-polar levels when observed at 5.1 GHz have a more than 25 dB difference at antenna bore-sight in both H- and E-plane. Higher order mode is suppressed by more than 10 dB due to ground plane reduction in case of proposed Antenna 3.

Acknowledgment

Authors thanks Department of Science and Technology, New Delhi, India (Reference Number: SR/FST/ETI-346/2013) for funding equipment for this research work.

References

[1] KUMAR, G. and K. P. RAY. *Broadband microstrip antennas*. Boston: Artech House, 2003. ISBN 978-1580532440.

[2] RAY, K. P., M. D. PANDEY, R. RASHMI and S. P. DUTTAGUPTA. Compact configurations of hexagonal microstrip antennas. *Microwave and Optical Technology Letters*. 2013, vol. 55, iss. 3, pp. 604–608. ISSN 1098-2760. DOI: 10.1002/mop.27396.

[3] BILOTTI, F. and C. VEGNI. Design of polygonal patch antennas for portable devices. *Progress In Electromagnetics Research B*. 2010, vol. 24, iss. 1, pp. 33–47. ISSN 1937-6472. DOI: 10.2528/PIERB10020208.

[4] JOSHI, A. and R. SINGHAL. Edge perturbation effect in polygonal patch antennas. In: *Proceedings of the International Conference on Signal Processing, Computing and Control (ISPCC)*. Waknaghat: IEEE, 2015. pp. 97–101. ISBN 978-1-4799-8436-7. DOI: 10.1109/ISPCC.2015.7375005.

[5] JOSHI, A. and R. SINGHAL. Gain improvement in polygonal patch antennas. In: *Proceedings of the Annual IEEE India Conference (INDICON)*. New Delhi: IEEE, 2015, pp. 1–5. ISBN 978-1-4673-7399-9. DOI: 10.1109/INDICON.2015.7443606.

[6] JOSHI, A. and R. SINGHAL. Probe-fed regular hexagonal narrow-slot antenna with reduced ground plane for WLAN applications. In: *2016 IEEE Region 10 Conference (TENCON)*. Singapore: IEEE, 2016, pp. 1312–1316. ISSN 2159-3450. DOI: 10.1109/TENCON.2016.7848225.

[7] LEE, J-.G. and J.-H. LEE. Suppression of spurious radiations of patch antenna using split ring resonators (SRRs). In: *IEEE Antennas and Propagation Society International Symposium 2005*. Washington D.C: IEEE, 2005, pp. 242–245. ISBN 0-7803-8883-6. DOI: 10.1109/APS.2005.1551985.

[8] ALI, A., M. A. KHAN and Z. HU. Microstrip Patch Antenna with Harmonic Suppression using Complementary Split Ring Resonators. In: *2007 International workshop on Antenna Technology: Small and Smart Antennas Metamaterials and Applications*. Cambridge: IEEE, 2007, pp. 361–363. ISBN 1-4244-1088-6. DOI: 10.1109/IWAT.2007.370149.

[9] KOVITZ, J. M. and Y. RAHMAT-SAMII. Using Thick Substrates and Capacitive Probe Compensation to Enhance the Bandwidth of Traditional CP Patch Antennas. *IEEE Transactions on Antennas and Propagation*. 2014, vol. 62, iss. 10, pp. 4970–4979. ISSN 1558-2221. DOI: 10.1109/TAP.2014.2343239.

[10] LIU, J., Z. TANG and Y. YIN. Wideband omnidirectional antenna with novel feeding structure for improving radiation patterns. *Electronics Letters*. 2017, vol. 53, iss. 13, pp. 830–832. ISSN 0013-5194. DOI: 10.1049/el.2017.0941.

[11] KASABEGOUDAR, V. G. and K. J. VINOY. Coplanar Capacitively Coupled Probe Fed Microstrip Antennas for Wideband Applications. *IEEE Transactions on Antennas and Propagation*. 2010, vol. 58, iss. 10, pp. 3131–3138. ISSN 1558-2221. DOI: 10.1109/TAP.2010.2055781.

[12] JOSHI, A. and R. SINGHAL. Lower Mode Excitation in Vertex-Fed Slotted Hexagonal S-Band Antenna. *AEU - International Journal of Electronics and Communications*. 2018, vol. 87, iss. 1, pp. 180–185. ISSN 1434-8411. DOI: 10.1016/j.aeue.2018.02.008.

[13] LEE, C. T. and K. L. WONG. Internal WWAN Clamshell Mobile Phone Antenna Using a Current Trap for Reduced Ground Plane Effects. *IEEE Transactions on Antennas and Propagation*. 2009, vol. 57, iss. 10, pp. 3303–3308. ISSN 1558-2221. DOI: 10.1109/TAP.2009.2029612.

[14] ELLIS, M. S., Z. ZHAO, J. WU, Z. NIE and Q. H. LIU. Small planar monopole ultra-wideband antenna with reduced ground plane effect. *IET Microwaves, Antennas & Propagation*. 2015, vol. 9, iss. 10, pp. 1028–1034. ISSN 1751-8733. DOI: 10.1049/iet-map.2014.0538.

[15] CHEN, Z. N., T. S. P. SEE and X. QING. Small Printed Ultrawideband Antenna With Reduced Ground Plane Effect. *IEEE Transactions on Antennas and Propagation*. 2007, vol. 55, iss. 2, pp. 383–388. ISSN 1558-2221. DOI: 10.1109/TAP.2006.889823.

[16] KAKOYIANNIS, C. G., G. STAMATIOU and P. CONSTANTINOU. Small square meander-line antennas with reduced ground plane size for multimedia WSN nodes. In: *2009 3rd European Conference on Antennas and Propagation*. Berlin: IEEE, 2009, pp. 2411–2415. ISBN 978-1-4244-4753-4.

[17] MARYNOWSKI, W. and J. MAZUR. Design of UWB Coplanar Antenna with Reduced Ground Plane. *Journal of Electromagnetic Waves and Applications*. 2009, vol. 23, iss. 13, pp. 1707–1713. ISSN 1569-3937. DOI: 10.1163/156939309789566905.

[18] NOGHANIAN, S. and L. SHAFAI. Control of microstrip antenna radiation characteristics by ground plane size and shape. *IEE Proceedings - Microwaves, Antennas and Propagation*. 1998, vol. 145, iss. 3, pp. 207–212. ISSN 1350-2417. DOI: 10.1049/ip-map:19981819.

[19] ANSAL, K. A. and T. SHANMUGANANTHAM. A novel CB ACS-fed dual band antenna with truncated ground plane for 2.4/5GHz WLAN application. *AEU - International Journal of Electronics and Communications*. 2015, vol. 69, iss. 10, pp. 1506–1513. ISSN 1434-8411. DOI: 10.1016/j.aeue.2015.07.004.

[20] JHA, K. R. and G. SINGH. Analysis of the Effect of Ground Plane Size on the Performance of a Probe-fed Cavity Resonator Microstrip Antenna. *Wireless Personal Communications*. 2013, vol. 71, iss. 2, pp. 1511–1521. ISSN 0929-6212. DOI: 10.1007/s11277-012-0889-7.

[21] KUMAR, C., M. I. PASHA and D. GUHA. Defected Ground Structure Integrated Microstrip Array Antenna for Improved Radiation Properties. *IEEE Antennas and Wireless Propagation Letters*. 2017, vol. 16, iss. 1, pp. 310–312. ISSN 1548-5757. DOI: 10.1109/LAWP.2016.2574638.

[22] TONG, K. F., K. F. LEE and K. M. LUK. On the effect of ground plane size to wideband shorting-wall probe-fed patch antennas. In: *2011 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications*. Torino: IEEE, 2011, pp. 486–486. ISBN 978-1-4577-0048-4. DOI: 10.1109/APWC.2011.6046774.

[23] KISHK, A. and L. SHAFAI. The effect of various parameters of circular microstrip antennas on their radiation efficiency and the mode excitation. *IEEE Transactions on Antennas and Propagation*. 1986, vol. 34, iss. 8, pp. 969–976. ISSN 1558-2221. DOI: 10.1109/TAP.1986.1143939.

[24] GARG, R., P. BHARTIA, I. BAHL and A. ITTIPIBOON. *Microstrip antenna design handbook*. Boston: Artech House, 2001. ISBN 0-89006-513-6.

[25] POZAR, D. M. *Microwave Engineering*. 4th ed. Hoboken: John Wiley. ISBN 978-81-265-4190-4.

About Authors

Abhishek JOSHI was born in Rajasthan, India. He received Bachelor's degree in Electronics and Communication Engineering from Rajasthan Technical University, Kota, Rajasthan, India, in 2010 and Master's degree in Digital Communication from Rajasthan Technical University, Kota, Rajasthan, India, in 2013. He is currently working towards the Ph.D. degree in the Department of Electrical and Electronics Engineering, Birla Institute of Technology and Science, Pilani-Campus, Pilani, Rajasthan, India. His current research interests include different antennas design, wideband microstrip antennas for UWB applications and wireless communication, analysis of antenna with equivalent circuit models, designing the periodic structures such as AMCs, and FSSs, and antenna design with AMC surfaces.

Rahul SINGHAL received his B.E. in Electronics Engineering from Nagpur University in 1999. Post graduation, he started his teaching career itself. He taught electronics engineering courses for six years in KNMIET, Modinagar. During the tenure, he joined his M.Tech in Digital Communication from Uttar Pradesh Technical University. He received his M.Tech in 2007 and soon after, he got registered in his Ph.D. at Birla Institute of Technology and Science (BITS), Pilani-Campus, Pilani, which he completed in 2013. He is now working as an Assistant Professor in Department of Electrical and Electronics Engineering, BITS, Pilani since 2013. His doctoral work lies in the area of integrated optics involving the design and technology development of various passive photonic components like optical waveguides and power splitters. His present research interest lies in area of planar antenna design and radio over fiber/ FSO network for communication applications. He has authored and co-authored technical papers in various reputed international journals and conferences. He is a member of the IEEE, a fellow of the Optical Society of India and the Institution of Electronics and Telecommunication Engineers (India).