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Miniaturization and Bandwidth Enhancement of a Slot Loaded Microstrip Patch Antenna Using Defected Ground Structure

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Abstract

A compact microstrip patch antenna with improved bandwidth is proposed in this paper for applications in wireless communication. The combination of slot loaded patch and defected ground plane provides much improved bandwidth in comparison to a conventional rectangular microstrip patch antenna. Two symmetrical open ended J – shaped slots are introduced on the ground plane of the antenna to improve the operating bandwidth of the proposed antenna and also to reduce the size of the proposed antenna. A −10 dB impedance bandwidth of 3040 MHz ranging from 5.10–8.14 GHz is achieved, which is 46% around the centre frequency 6.59 GHz. The size of the proposed antenna has been reduced by 92% compared to conventional rectangular microstrip patch antenna. The proposed antenna is suitable for IEEE802.11.a (5.15–5.35 GHz, 5.725–5.825 GHz), WiMAX (3.3–3.7GHz, 5.25–5.85 GHz), HiperLAN2 (5.47–5.725 GHz) and HiSWaNa (5.15–5.25 GHz) wireless application bands.

Keywords

Bandwidth Enhancement, Defected Ground Plane, Microstrip Patch Antenna, Size Reduction, Wireless Communication

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1. Introduction

The modern wireless communication system requires compact and efficient antenna as a part of it. Conventionally, it is not possible by a single antenna to support several frequency bands allocated to different communication systems. Again usage of many antennas is usually restricted by volume and cost constraints of the applications. So a single antenna with broad impedance bandwidth may be the alternative choice. Recently, microstrip patch antenna has attracted the attention of research community due to its low cost, small size and light weight. However, major limitation of microstrip patch antenna is narrow bandwidth typically of about 2-5%. So bandwidth enhancement of microstrip patch antenna has become a major branch of activity among the microwave and antenna designers. Researchers have offered different methods like aperture coupling [1], use of a shorting pin [2], stacked patch [3], modification in the feed [4], staggering effect [5], slot loaded radiating patch [6-7],combinations of slotted patch and ground plane [8] to enhance the bandwidth of microstrip patch antenna. The effect of parasitic elements on microstrip patch was also investigated to achieve broadband operation from microstrip antenna [9]. Monopole microstrip antenna [10], dielectric resonator antenna [11] and fractal shaped antenna [12] were also realized for broadband operation. Lai et al. [1] proposed a aperture couple microstrip patch antenna with maximum bandwidth of 16% ranging from 2.25–2.65 GHz. Cao et al. [2] investigated the effect of shorting pin on microstrip antenna and he reported 9.5% bandwidth. The notched loaded stacked microstrip antenna reported bandwidth of only 23.6% [3]. Bandwidth of microstrip antenna was

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increased up to only 11% by using L probe feeding but the achieved bandwidth is not sufficient to cover frequency band requirements of most of the modern wireless communication systems [4]. Mandal et al. [5] reported slightly improved bandwidth of about 27% using staggering effect but the large dimension of the antenna is still major disadvantages which limit its practical applications. The frequency reconfigurable U slot microstrip antenna has achieved bandwidth of 750 MHz ranging from 2.60–3.35 GHz but it does not cover the bandwidth requirement of 5 GHz high speed wireless LAN [6]. Again, Kushwaha et al. [7] increased the impedance bandwidth up to 25% but the dimension of the antenna is very large (40×60×1.6 mm^3). A low profile E shaped microstrip antenna with bandwidth of about 9% of the centre frequency is reported [8]. The effect of gap between the main patch and U shaped parasitic elements were investigated for band width enhancement of microstrip patch antenna whichprovides 28.36% bandwidth at centre frequency 5.5 GHz [9]. Liu et al. [10] proposed a monopole microstrip antenna with shorting vias and coupled rings which have achieved a bandwidth of 27.4%. Recently, Mukherjee and Raj [11] has proposed the hemispherical dielectric resonator antenna with maximum bandwidth 16.44% but this antenna requires high dielectric constant substrates which is not readily available. Khanna and Srivastava [12] designed a square patch antenna with modified edges and square fractal slots with a bandwidth of 30%.

This paper also relates to bandwidth enhancement of microstrip patch antenna by using the combinations of slot loaded patch and defected ground structure. But apart from bandwidth enhancement the proposed antenna also provides significant size reduction of about 92% and multiresonant characteristics to support multiple communication systems. The novelty of our work is multiresonant characteristics, size reduction and wide operating impedance bandwidth in compact size without using thick foam substrate, shorting pin, stacked patch, or modifications in the feed. The proposed antenna is designed with thin, inexpensive, low-dielectric-constant FR4 substrate. The proposed antenna offers much better −10 dB impedance bandwidth of 3040 MHz (5.10–8.14 GHz) compared to previously reported antenna structures in much compact dimension (26 × 22 × 1.5875 mm^3). Theproposed antenna covers the bandwidth requirements of IEEE802.11.a (5.15–5.35GHz, 5.725–5.825GHz), WiMAX (3.3–3.7GHz, 5.25–5.85GHz), HiperLAN2 (5.47–5.725 GHz) and HiSWaNa (5.15–5.25 GHz) wireless application bands.

The advantages of the proposed antenna in comparison to the reported antennas [1–12] are

(i) The size of the antenna is much small (26×22 mm^2).

(ii) The structure of the antenna is less complex.

(iii) The proposed antenna provides multiple resonant frequencies.

(iv) The proposed antenna provides sufficiently large bandwidth (5.10–8.14 GHz) which is 46% of the centre frequency.

(v) The same antenna provides narrowband and wideband resonant characteristics.

(vi) The proposed antenna offers 92% size reduction.

(vii) The proposed antenna has attained a peak directivity of about 7.5 dBi.

(viii) Peak radiation efficiency is 73%.

2. Antenna Geometry

The structures of the proposed patch and defected ground plane of the proposed antenna are shown in Figure 1 and 2, respectively. The proposed antenna is designed with FR4 substrate with dielectric constant ε_r = 4.4 and thickness h = 1.5875mm. For proposed antenna structure broad operating bandwidth is achieved when the defected ground plane is realized by etching off a simple open ended inverted J shape (defect) from the ground plane and the patch is also designed with simple Y shaped slots. The parameters of the proposed antenna are finalized by parametric study using IE3D software [13] to meet the design goal. The optimal dimensions of the proposed patch are L_1=8, L_2 = 7, L_3 = L_4 = L_7 = 1, L_5 = L_8 = L_9 = 6, L_6 = 0.5, L_{10} = 2, W_1= 12, W_b = 16, H_1 = H_2 = 7.75 mm. The dimensions of the proposed defected ground plane are B_1 = 26, B_2 = 22, C_1 = D_1 = 11.5, C_2 = D_2 = 3.5, C_3 = D_3 = 4.5, C_4 = D4 = 4, Y_1 = Y_2= 1, E_1 = E_2 = E_3 = 12, X_1 = X_3 = 10.5, X_2 = 1, Z_1 = Z_2 = 5.5, I_1 = I_2 = 0.5 mm.

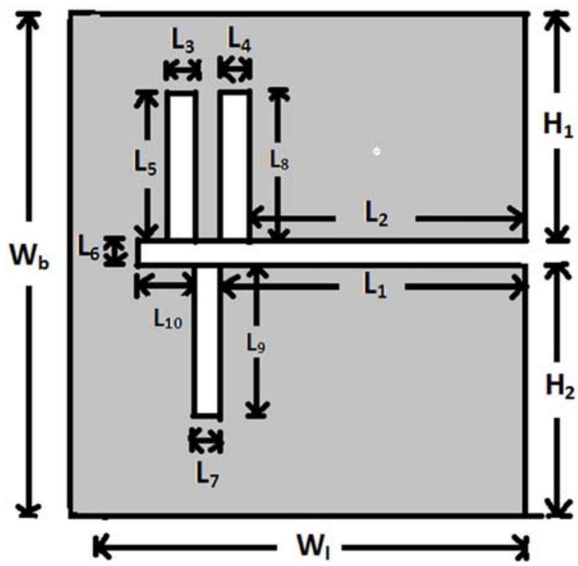

Figure 1. Structure of the proposed patch.

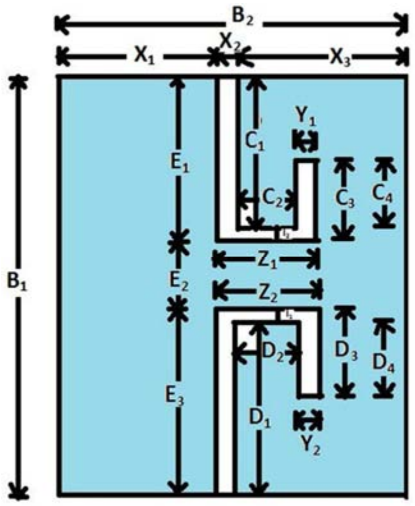

Figure 2. Structure of the proposed defected ground plane.

3. Parametric Study

The impact of varying the design parameters of the antenna on reflection coefficient versus frequency is studied. The effect of variations of the probe feeding location of the patch on the bandwidth of the proposed antenna is also studied analyzed [See Figure 3]. The optimum result in terms of both improvement of bandwidth and reflection coefficient is achieved when the probe is fed at X=2.5 mm,Y=3 mm, considering centre (X = 0 mm, Y = 0 mm) as the origin. Alteration of location of the feeding points result in narrower −10 dB bandwidth and less sharp resonances. The impact of varying the design parameters (E_1,E_3) and (C_3,D_3) simultaneously on the reflection coefficient of the antenna is demonstrated in Figure 4. It is clear from the Figure that by increasing or decreasing the above parameters, the −10 dB bandwidth (5.10–8.14 GHz) did not effectively changes but the reflection coefficient is below – 10 dB level at first resonant frequency 1.6 GHzdue to the proposed dimension, for which maximum size reduction of about 92% is achieved.

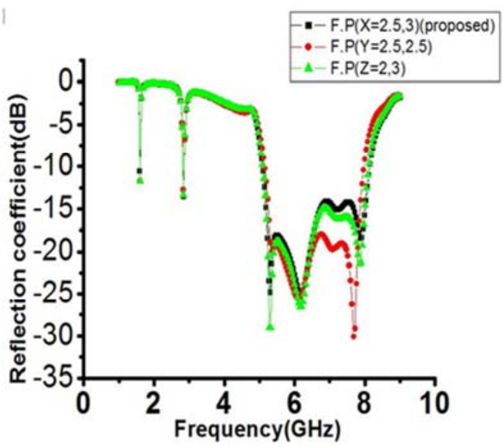

Figure 3. Reflection coefficient versus frequency due to variations of probe feeding location.

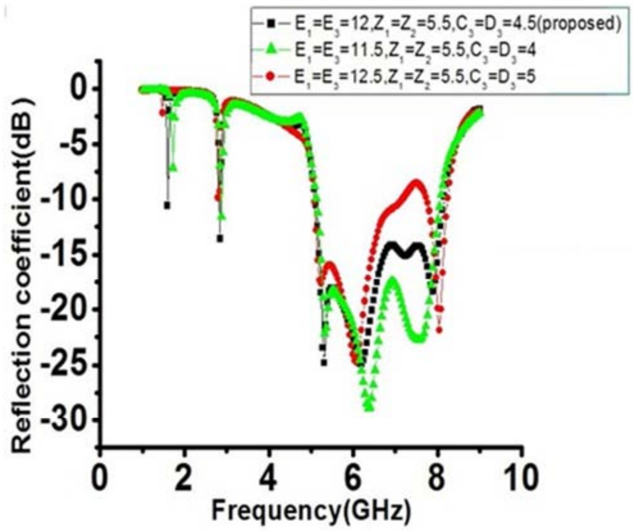

Figure 4. Reflection coefficient versus frequency as a function of ground plane slot parameters.

4. Surface Current Distribution

The surface current distributions of the proposed at 1.6 and 2.8 GHz are shown in Figures 5–6. Due to the defected ground plane, the surface current increases to maximum and mainly it is concentrated around the symmetrical “J” shaped defect. Depending on the shape and dimensions of the defect, resulting in a controlled excitation and propagation of the electromagnetic waves, it is clear that surface current density is stronger around the slots which creates extra resonance path and varies the resonant frequency of the antenna. Due to the resonant behavior of defected ground structure (DGS), it may be compared with the LC parallel resonator that means the equivalent circuit of DGS consists of an inductance and capacitance in parallel. For the proposed antenna structure, due to the defected ground plane, the equivalent inductive part increases and produces equivalently a high effective dielectric constant, thereby decreasing the resonant frequency for which compactness is achieved. Due to the modifications in the ground plane, a parasitic field or fringing is created and this creation of fringing field increases the coupling between the conducting patch and ground plane. This increased coupling enhances the bandwidth of the antenna. The bandwidth enhancement process may also be realized by obtaining more than one resonant frequency that radiates under −10dB level and due to staggering effect their resonance envelopes provide broad impedance bandwidth.

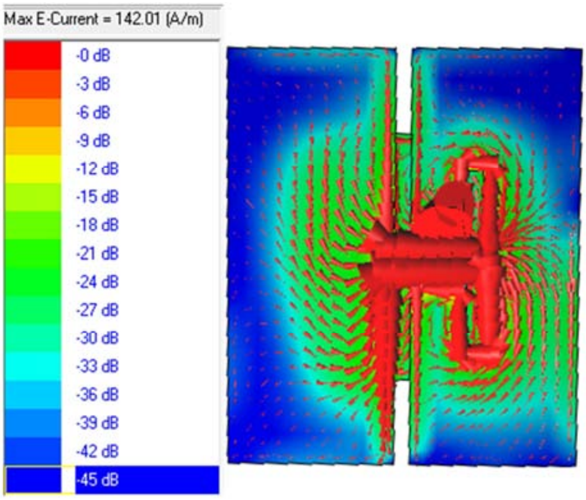

Figure 5. Surface current at ground plane for 1.6 GHz.

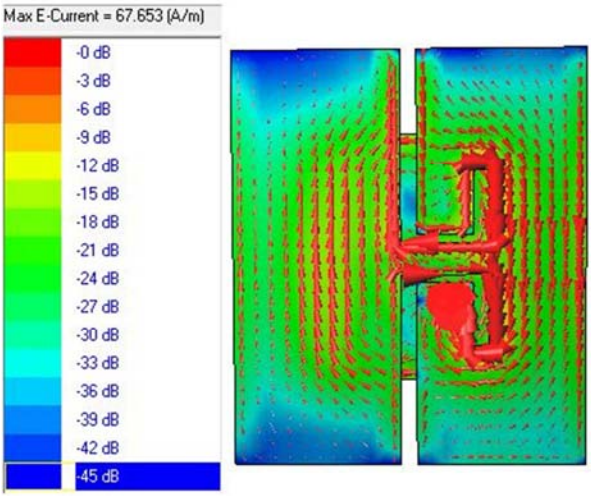

Figure 6. Surface current distribution at ground plane for 2.8 GHz.

5. Results and Discussion

The proposed antenna structures are simulated using Method of Moment based IE3D software. Figure 7 shows the simulated reflection coefficient versus frequency of proposed antenna which is designed with a combination of slot loaded patch and defected ground structure. The simulated result shows that the proposed antenna resonates at a frequency of 1.6GHz and 2.8GHz with reflection coefficients −11.18 and −13.64 dB, respectively. The simulated result shows that with the defection in the ground plane, there exists a single frequency band of wide impedance bandwidth. A −10dB impedance bandwidth of 3.04 GHz is obtained from 5.10 to 8.14GHz which is around 46% bandwidth around the centre frequency of 6.59 GHz. The size of the antenna has been reduced by 92% in comparison to the conventional rectangular microstrip antenna operating at 1.6 GHz with patch area (57.05×44.42 mm^2). The Simulated E and H plane radiation patterns of the proposed antennas at different resonant frequencies are shown in Figures 8–10. It is seen from the radiation patterns that acceptable cross polarization levels are achieved at respective frequencies. The radiation patterns are almost similar and stable throughout different frequency bands. The proposed antenna exhibits bidirectional radiation patterns which may be utilized in bidirectional radars. The bidirectional radiation characteristics are achieved due to partial removal of the conducting material from the ground plane. The gain versus frequency plot of the proposed antenna is shown in Figure 11. The simulated peak gain of the proposed antenna is about 2.7dBi at 5.2GHz. The plot of simulated directivity versus frequency of the proposed antenna is shown in Figure 12. The proposed antenna attains peak directivity of about 7.5dBi at 8.1 GHz. The simulated radiation efficiency of the proposed antenna is shown in Figure 13. Peak radiation efficiency of about 73% is obtained at 1.6 GHz.

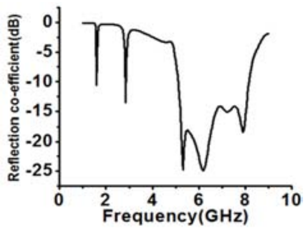

Figure 7. Reflection coefficient of the proposed antenna.

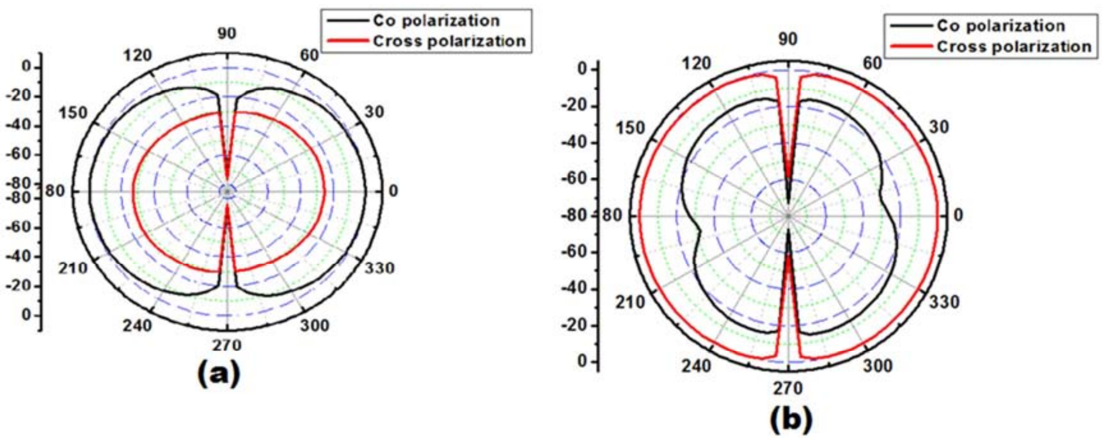

Figure 8. Radiation pattern of the proposed antenna at 1.6 GHz (a) E plane (b) H plane.

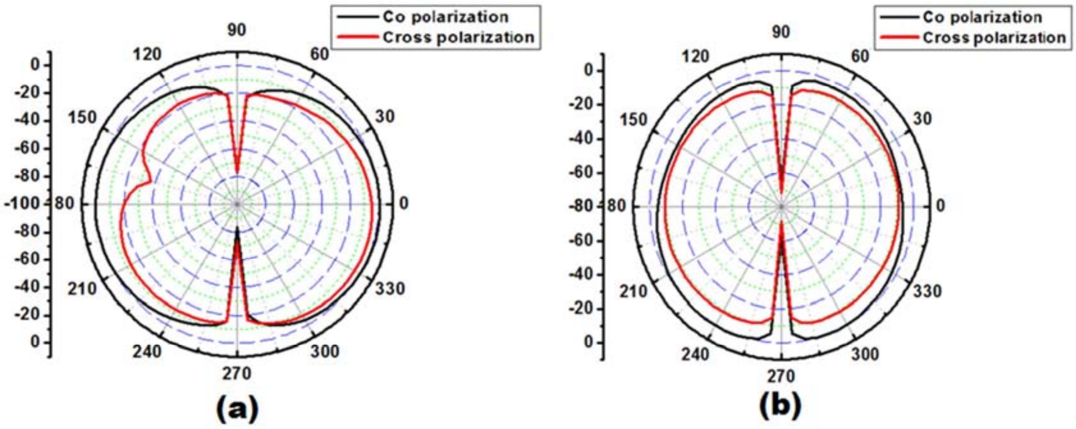

Figure 9. Radiation pattern of the proposed antenna at 2.8 GHz (a) E plane (b) H plane.

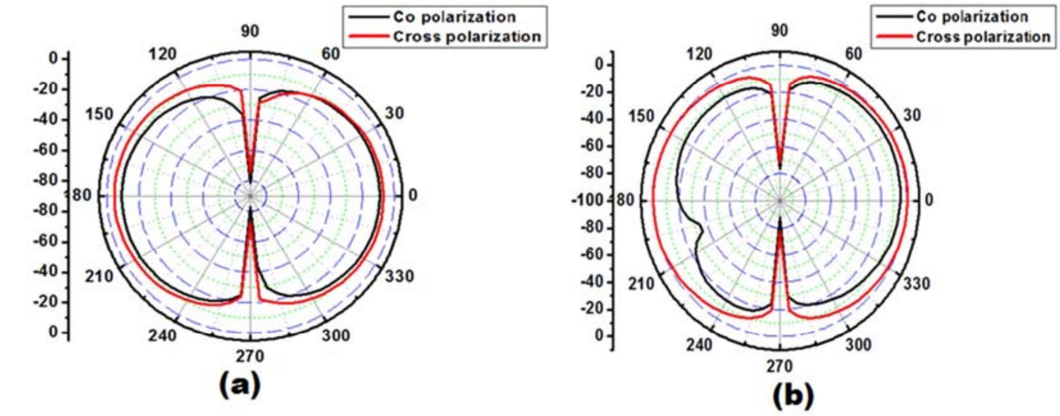

Figure 10. Radiation pattern of the proposed antenna at 6.4 GHz (a) E plane (b) H plane.

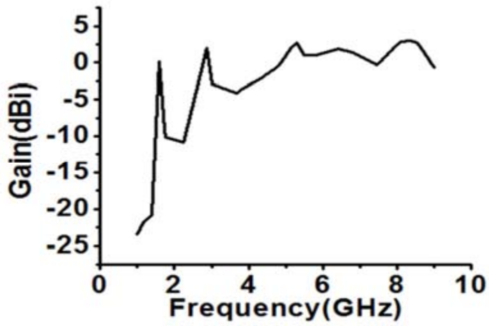

Figure 11. Gain versus frequency plot of the proposed antenna.

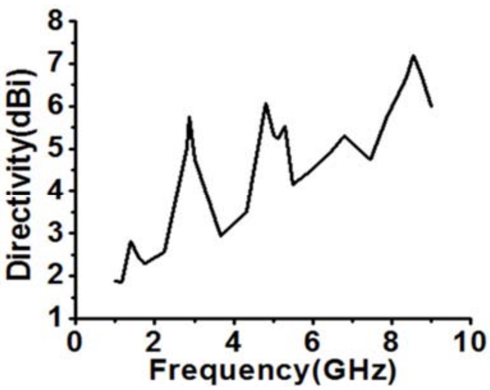

Figure 12. Directivity versus frequency plot of the proposed antenna.

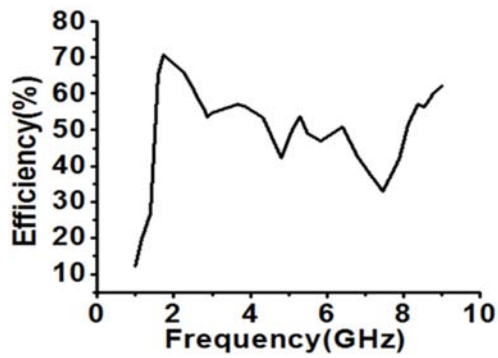

Figure 13. Efficiency versus frequency plot of the proposed antenna.

6. Conclusion

Theoretical investigations of single feed, compact multi-frequency and wideband microstrip patch antenna have been carried out in this paper. The simulated reflection coefficient and other parameters of proposed antenna have been studied and analyzed using method of moment based IE3D software. The wideband operation along with size reduction and multi resonance characteristics are achieved due to combinations of slot loaded patch and defected ground plane structure. The bidirectional radiation patterns are obtained due to defection in the ground plane. The single antenna provides size reduction (92%) and wide operating impedance bandwidth (46%) with moderate gain of about 2.7 dBi. The wide band is achieved from 5.10GHz–8.14GHz, which covers the bandwidth requirements for IEEE802.11.a (5.15–5.35 GHz, 5.725–5.825 GHz), WiMAX (3.3–3.7 GHz, 5.25–5.85 GHz), HiperLAN2 (5.47–5.725 GHz) and HiSWaNa (5.15–5.25 GHz) wireless application bands. The proposed antenna is suitable for several wireless communication systems due to its low cost, light weight, compact size and broad operating bandwidth.

References

[1] C.-H. Lai, T.-Y. Han and T.-R. Chen, “Broadband aperture-coupledmicrostrip antennas with low cross polarization and back radiation”, ProgressIn Electromagnetic Research Letters, Vol. 5, pp. 87–197, 2008.

[2] W. Cao, B. Zhang, H. Li, T. Yi, AijunLiu, “A Broadband Microstrip Dipole Antenna Loaded with Shorted Pin”, International Conference on Microwave and Millimeter Wave Technology (ICMMT), pp 1035–1037, 2010.

[3] K. Ushakiran, Ravi. M. Yadahalli, R. M. Vani, P. V. Hunagund, “Compact broadband stacked dual wide slit loaded rectangular microstrip antenna”, Indian journal of Radio and Space physics, Vol. 37, pp. 366–369, 2008.

[4] M. T. Ali, N. Nordin, N. Ya’acob, M. N. M. Tan “Design of wideband Microstrip patch antenna using L probe fed at 2.6GHz” ICCCE, 2012, 961–965.

[5] K. Mandal, S. Sarkar. P. P. Sarkar, “Bandwidth enhancement of Microstrip antenna by staggering effect, Microwave and Optical technologyletters, Vol. 53, pp.2446–2447, 2011.

[6] S.-L. S. Yang, A. A. Kishk, K-F Lee, “Frequency reconfigurable U slot microstrip patch antenna”, IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 127–129, 2008.

[7] R. S. Kushwaha, D. K. Srivastava, J. P. Saini, S. dhupkariya, “Bandwidth enhancement for microstrip patch antenna with microstrip line feed”, ICCCT, pp. 183–185, 2012.

[8] Y. Chen, S. Yang, and Z. Nie, “BandwidthEnhancement Method for Low Profile E-Shaped Microstrip PatchAntennas”, IEEE Transactions on Antennas and Propagation, vol. 58, no. 7, pp 2442–2447, 2010.

[9] J. A. Ansari, and R. B. Ram, “Analysis of a compact and broadband microstrip patch antenna”, Microw. Opt. Technol. Lett., Vol. 50, pp. 2059–2063, 2008.

[10] J. Liu, S. Zheng, Y. Li, and Y. Long, “Broadband Monopolar Microstrip Patch Antenna With Shorting vias and Coupled Ring”, IEEE Antennas and Wireless Propagation Letters, Vol. 13, pp. 39–42, 2014.

[11] B. Mukherjee, and A. Raj “Investigation of a hemispherical dielectric resonator antenna for enhanced bandwidth of operation,” International Journal of Applied Electromagnetics andMechanics, Vol. 43, pp. 457–466, 2013.

[12] Khanna, A, D. K. Srivastava, “Modified edged microstrip square patch antenna with square fractal slots for bluetooth applications”, Int. J. Eng. Research Technol. Vol. 3, pp.320-323, 2014.

[13] Zeland Software Inc. IE3D: MoM-Based EM Simulator.

Biography

Sudipta Das, is working as an Assistant Profeesor in Department of Electronics and Communication Engineering. He is presently pursuing Ph.D from University of Kalyani, INDIA. His area of research interests are Microstrip Antenna and Filter design. He has contributed almost 35 international research articles in various journals. The Biography of Mr. Sudipta Das is selected in Marquis Who’s who in the World 2016 (33rd Edition).