Dual Band Gap Coupled Patch Antenna for Wireless Communications

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ABSTRACT

A dual frequency resonance antenna is proposed by means of a rectangular microstrip patch antenna with parasitic elements. Analysis is made using concepts of circuit theory and the measured and theoretical results are compared with simulation results obtained with IE3D simulation software. Error between experimental and theoretical and simulated values is within 1.5% and frequency ratio of the simulated, theoretical and experimental values is found to be 2.0.

Keywords: Rectangular microstrip patch (RMP), gap coupled, parasitic elements, dual band.

1. INTRODUCTION

During the last decade researches in microstrip patch antennas (MSAs) for dual band operations have garnered interest in the field of wireless communications. The dual band MSAs have two resonating bands that can be efficiently used for transmission and reception of signals. This interesting feature of dual band MSAs encourages the researchers to design study and analyze such type of antennas. First dual band MSAs was proposed by Wang and Lo [1], almost after 100 years when for the first time German scientist Heinreich Hertz propounded the concept of first antenna. A large number of research papers have been published on MSAs for dual band operation using different nomenclatures, criteria for design and analysis, shapes and for different applications [2-20].

In last decade, the many developments in a microstrip patch have gone through in terms of design and applications such as dual-band antenna-in-package with T-shaped slots [21], annular-ring microstrip antenna for GNSS applications [22], compact dual-band GPS antenna design [23], wideband dual-beam U-slot microstrip antenna [24], dual-band WLAN/UWB printed wide slot antenna for MIMO/diversity applications [25], low profile antenna for body centric communications [26], compact notch loaded half disk patch antenna for dual band operation [27], proximity fed gap coupled compact semi-circular disk patch antenna [28], F-shape microstrip line fed dual band antenna [29], small-size LTE/WWAN tablet computer antenna [30], compact 2*4 MSA array [31], toppled H-shaped microstrip patch antenna [32], proper use of meta materials have enhanced the bandwidth and gain of microstrip antenna without compromising its physical dimensions [33], triple-band single-fed compact microstrip antenna [34], multi-frequency monopole antennas that is loaded with complementary meta-material transmission line (CMTL) [35], multi-frequency complementary split ring resonators (CSRRs) [36]. All these research paper published have their own limitations such as complicated geometry, low gain, poor radiation efficiency, lack of theoretical analysis and the experimental verification of theoretical results.

In these view, simple microstrip antenna geometry is proposed using coplanar structures for dual band operation. The proposed antenna is analyzed using the concepts of circuit theory and method of moments. The simulated results of proposed antenna are compared with the theoretical and measured results.

2. THEORETICAL ANALYSIS

The geometry of proposed patch antenna is shown in Fig.1(a) and 1(b). The fed patch is kept between the two parasitic patches having equal dimensions (L×W). Photograph of the proposed antenna is fabricated and shown in Fig. 2. Radiating patch antenna is excited by the 50 âĎę coaxial connector. A simple microstrip antenna is considered as a parallel combination of resistance (R1), inductance (L_1), and capacitance (C_1) and equivalent circuit of the given patch is shown in fig.2. In fig. 3, element values R_1, L_1 and C_1 are given as [37-38],

$$C_1 = \frac{LW\varepsilon_0\varepsilon_\varepsilon}{2H}\cos^{-2}\left(\frac{\pi Y_0}{L}\right) \tag{1}$$

$$R_1 = \frac{Q}{\omega_r^2 C_1} \tag{2}$$

$$L_1 = \frac{1}{C_1\omega_r^2} \tag{3}$$

Where,
L - Length of rectangular patch
W - Width of rectangular patch
H - Thickness of the substrate material
Y_0 - y coordinates of feed point

$$f_r = \frac{c}{2L\sqrt{\varepsilon_e}}$$

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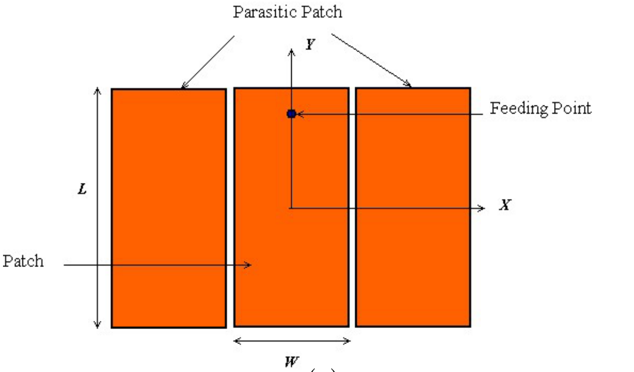
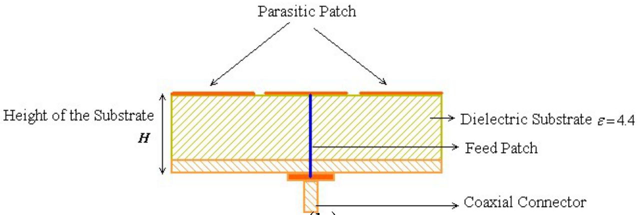


(a)



(b)

Fig.1: *Rectangular microstrip patch antenna with parasitic elements (a) Top View (b) Side View.*

$$Q = \frac{C\sqrt{\varepsilon_e}}{4f_r H}$$

where c velocity of light in m/s, f_r is resonating frequency in Hz, ε_e and is effective permittivity of the medium for $\frac{W}{H} \geq 1$ which is given as

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\left(1 + \frac{10H}{2}\right)^{-\frac{1}{2}} \quad (4)$$

where ε_r is relative permittivity of the substrate material and W is the width of patch and H is the height of patch.

The parasitic element are excited through gap coupling by fed patch, the value of capacitance (C_2), inductance (L_2) and resistance (R_2) for the identical parasitic elements can be given as shown Fig. 3(b),

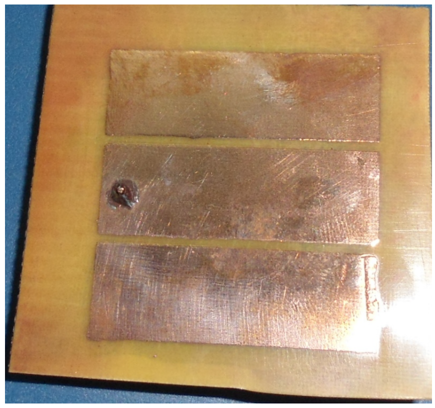
$$C_2 = \frac{LW\varepsilon_0\varepsilon_e}{2H},$$

$$R_2 = \frac{Q}{\omega_r^2 C_2} \text{ and}$$

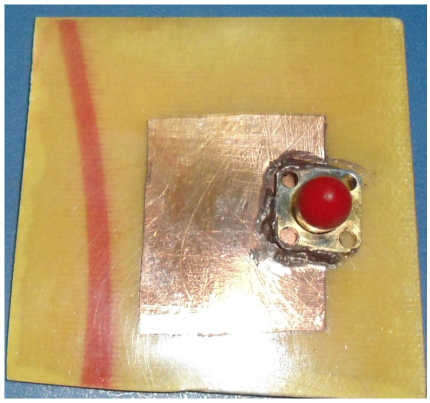
$$L_2 = \frac{1}{C_2\omega_r^2}$$

The analysis of the two gap coupled parasitic element is based on gap structure in microstrip line and corresponding equivalent circuit as shown in Fig 4. The expression of gap capacitance C_g and plate capacitance C_{p1} of the microstrip line can be calculated in the following manner [39-40],

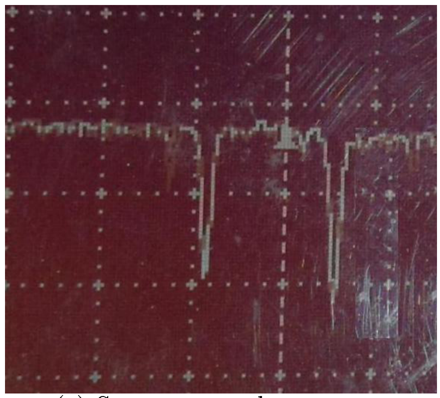
$$C_g = 0.5H \cdot Q \cdot \exp\left(-1.86\frac{g}{H}\right) \times \left[1 + 4.09\left\{1 - \exp\left(0.75\sqrt{\frac{H}{W}}\right)\right\}\right] \quad (5)$$



(a) Top view

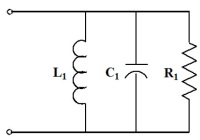


(b) Back view

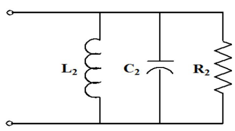


(c) Spectrum analyzer output

Fig.2: *Fabricated antenna with spectrum analyzer output.*



(a)



(b)

Fig.3: *Equivalent circuit (a) feed patch (b) parasitic patch.*

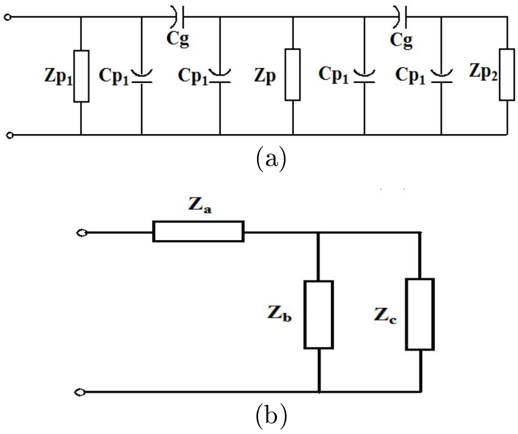


Fig.4: *Equivalent circuits diagram (a) proposed antenna and (b) modified.*

$$C_{p1} = C_L \left(\frac{Q_2 + Q_3}{Q_1 + 1} \right) \tag{6}$$

Where, Q_1, Q_2, Q_3 and Q_4 are given as,

$$Q_1 = 0.04598 \left\{ 0.03 + (W/H) \right\}^{Q_4} (0.272 + \varepsilon_r \cdot 0.07)$$

$$Q_2 = 0.107 \left[\frac{W}{H} + 9 \right] (g/H)^{3.23} + 2.09 \, (g/H)^{1.05} + \left[\frac{1.5 + 0.3(W/H)}{1 + 0.6(W/H)} \right]$$

$$Q_3 = \exp\left(-0.5978\right)^{-0.55}$$

$$Q_4 = 1.23$$

C_L is the terminal capacitance of the open circuited conductor is given as,

$$C_L = C_{ll} \frac{\sqrt{\varepsilon_{eff}}}{Z_0 C} \tag{7}$$

where C_{ll} is the conductor extension length, ε_{eff} is effective dielectric constant.

$$C_{ll} = 0.412 \frac{(\varepsilon_e + 0.3)(W/H + 0.264)}{(\varepsilon_e + 0.258)(W/H + 0.8)}$$

Z_0 is characteristic impedance of the patch, c is the velocity of light.

Therefore, input impedance of the proposed antenna of fig 3(b), is given by

$$Z = Z_a + \frac{Z_b \cdot Z_c}{Z_b + Z_c} \tag{8}$$

Where

$$Z_b = \frac{Z_p}{1 + j\omega \cdot 2 C_{P1}}$$

$$Z_a = \frac{j\omega Z_{P1} (C_g + C_{P1})}{Z_{P1} + j\omega (C_g + C_{P1})}$$

where Z_p is the impedance of fed patch and Z_{p1} is the impedance of parasitic patch and is given as,

$$Z_{P1} = \frac{1}{\frac{1}{R_2} + \frac{1}{j\omega L_2} + j\omega C_2}$$

$$Z_P = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1} + j\omega C_1}$$

Using equation (8), it is possible to calculate the total input impedance of the proposed antenna and other antenna parameters such as reflection coefficient, VSWR and return loss as given

$$|\Gamma| = \frac{Z_0 - Z}{Z_0 + Z} and\ S = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{9}$$

and the return loss is given as RL $=$20 log$|\Gamma|$.

3. DESIGN PRINCIPLES

In this work the microstrip patch antenna in its basic form consists of a metallic radiating patch and two parasitic patches. The length (L) and width (W) of the patch antenna were calculated using equations (1) and (10) which is given after [37-38].

$$W = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{10}$$

Frequency range for S band lies between 2 - 4 GHz and for C band it lies between 4-8 GHz. The width and length of the patch was chosen so that the resonating frequencies may lie in the vicinity of C band and S bands respectively. Resonating frequencies were so chosen so as to accommodate the fringing capacitance as well. Normally when a parasitic patch is placed along one side of main feed patch the bandwidth of antenna increases, but with the increase in frequency within the bandwidth, the beam maxima tends to shift away from broadside which is undesirable for many applications.

In quest to obtain a symmetrical pattern along broadside, identical parasitic patches are gap-coupled to both radiating edges so that there is same phase delay for both the parasitic patches and the overall pattern of three patches will be superposition of the individual pattern and tends to remain symmetrical with the broadside direction [37]. Design specifications of the proposed antenna are tabulated in Table 1.

4. RESULTS AND DISCUSSION

Return loss and VSWR measurements provide same information about the bandwidth and in the present work information of bandwidth has been provided by return loss measurements. A comparison between theoretical, measured and simulated result of return loss measurements is presented in fig. 5. Simulated results have been obtained using IE3D simulation software [41] from Zealand. It is observed from fig. 4 that theoretical, simulated and measured results are in close agreement. It is found that, the theoretical, simulated and measured values of lower resonance frequencies are 2.375 GHz , 2.4375 GHz and is

Table 1: *DESIGN SPECIFICATIONS OF RMPA*

Length of the patch and parasitic patches	42 mm.
Width of the patch and parasitic patches	14 mm.
Distance between feed and parasitic patches (g)	1.5 mm.
Feed point(X_0,Y_0) of the fed patch	(0,18) mm.
Dielectric constant of (ε) FR-4 substrate	4.4
Thickness of substrate (H)	1.6 mm.
Effective dielectric constant	3.86 (calculated)

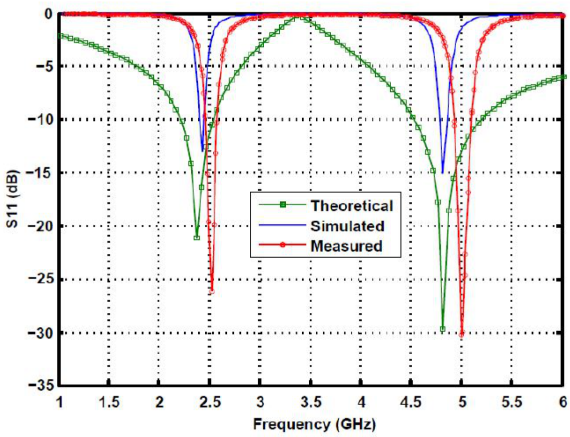


Fig.5: *Measured, theoretical and simulated return loss* $|S_{11}|$.

2.5 GHz respectively. In case of upper resonance frequencies theoretical and simulated values are found to be 4.875 GHz and measured value is 5.0 GHz. From the above results it can be safely concluded that in case of the lower resonance frequencies, there is a difference of only 1.4% between theoretical and simulated value, 1.5% between theoretical, simulated and measured value. In case of upper resonance frequencies, less than 1% error is found between the theoretical, simulated and measured value. Frequency ratio between upper and lower resonance frequencies for theoretical, simulated and measured values is nearly 2.0. The difference in theoretical, simulated and experimental values is attributed to the process of fabrication, mechanical tolerances and method of analyses employed in this case. However, at -10 dB difference can be observed between theoretical, measured and simulated values of bandwidths. This difference in bandwidth can be attributed due to several approximations and assumptions in calculation of fringe capacitance, extension length, loss tangent and effective dielectric constant for the chosen dimensions of the patch. The bandwidth in theoretical model is larger than that of measured and simulated results. Approximations made in equivalent circuit model analysis further accounts for difference in bandwidth which depends on quality factor which in turn in determined by the element values of the proposed equivalent circuit. IE3D simulator uses moment method solutions and it has been reported [42] that resonant frequencies predicted by moment method solutions are closer to measured values whereas the bandwidth predicted by moment method solutions are not so accurately predicted. Single feed patch antenna, antenna with parasitic patches on each sides were simulated using IE3D but multiband operation in such simulations was absent. The proposed antenna with parasitic patches on both sides with gap yielded two resonating frequencies below -10dB and is suitable for C and S band frequencies.

Fig. 6 (a) shows the simulated result of return loss with frequency of different substrate materials (glass epoxy, bakelite, RT duroid and foam). It is observed as the dielectric constant decreases from 2.2 to 1.0, upper resonance frequency is shifting towards lower side and as the dielectric constant increases from 2.2 to 3.02, upper resonance frequency is shifting towards higher side.

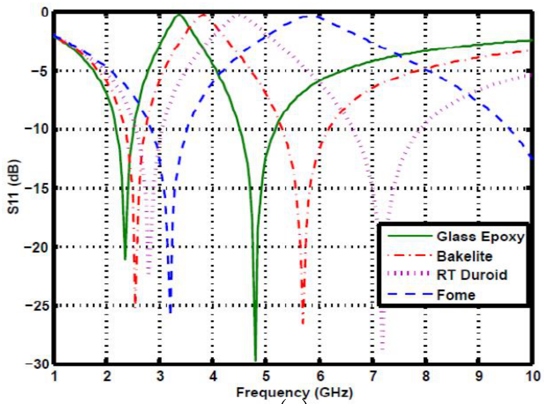
Fig.6 (b) shows the simulated result of return loss with frequency for FR-4 substrates of varying height (height varies from 0.2 to 1.6 mm). It is observed that on increasing the height form 0.2 to 1.6 mm, a shift in the lower and upper resonance frequency is observed. As the thickness of the substrate increases the impedance loci tends to become more inductive [42]. Inductive shift is primarily caused by thick substrate and it is one of the primary reasons for shift in resonating frequencies. It is observed the RT Duroid dielectric material give good result at 1.6 mm height.

Figs.7 (a) and (b) depicts the simulated and measured radiation pattern at 2.5 GHz and 5 GHz respectively for the proposed antenna. The radiation patterns are found to be linearly polarized at the two operating frequencies. It has been reported [43] that in structures such as shown in fig. 1(a) sides designated as 'L' rarely contribute to the gain of antenna. The antenna structure was simulated and the analysis of radiation patterns reveals that at both the resonating frequencies gains of the antenna is sufficiently good and the patterns obtained are fairly broad.

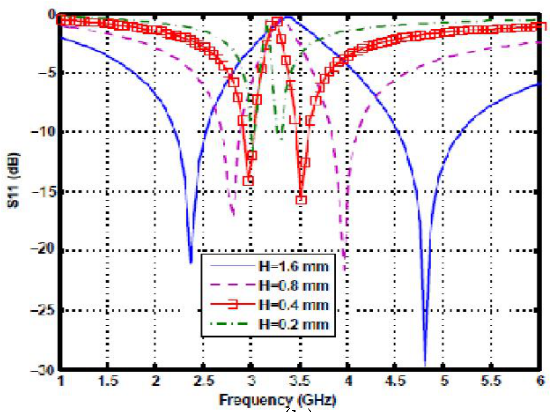
Figure 8 show the gain of the proposed antenna. It is observed that simulated and measured are in closed agreement. The gain of the antenna at higher and lower frequencies is 8.05 dBi and 4.46 dBi.

5. CONCLUSION

The proposed design of dual band microstrip antenna is useful for operation in S-band and C-band frequencies. The results are analyzed using the concept of circuit theory and method of moments. It has

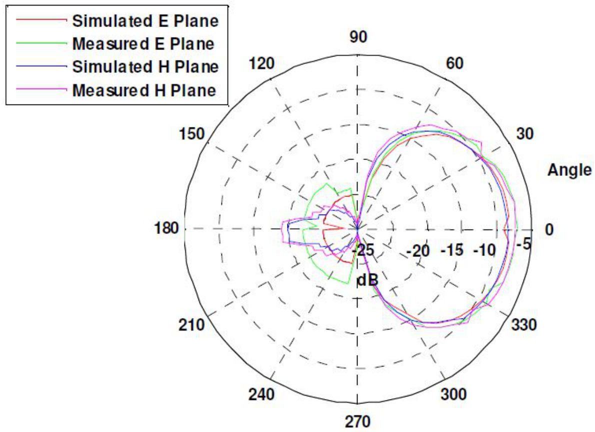


(a)

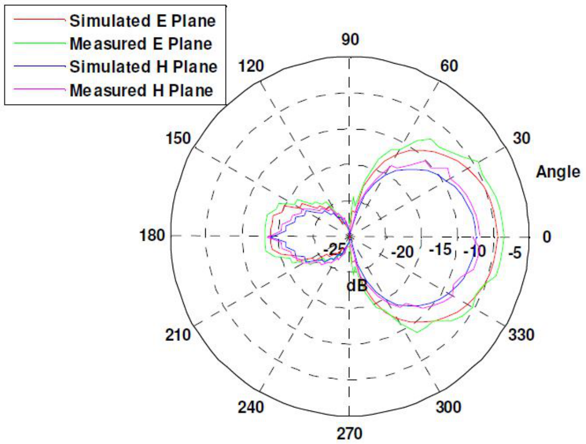


(b)

Fig.6: *Simulated* $|S_{11}|$ *vs. frequency for (a) materials of different dielectric constants and (b) for different substrate (FR-4) heights (in mm).*



(a)



(b)

Fig.7: *E and H Plane radiation pattern at (a) 2.4GHz and (b) 4.8 GHz. The vertical axis scale is in dB.*

been found that the theoretical, simulated results and measured results are in close agreement. The error is within 1.5 % between theoretical, simulated and experimentally observed values of upper and lower resonance frequencies The radiation pattern reveals fairly broad pattern which makes the antenna useful in the mentioned bands. The designed antenna can be mounted on vehicles or any wireless equipment operating between the specified frequencies.

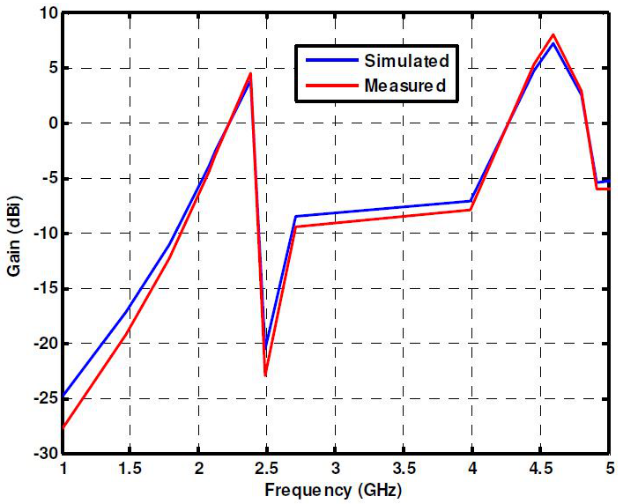


Fig.8: *Simulated and Measured gain in dBi.*

References

[1] B. Wang and Y. Lo, "Microstrip Antennas for dual frequency operation," *IEEE Trans. Antennas Propag.*, Vol. 32, pp.934-938, 1984.

[2] W. Richards, S. Davidson, and S. Long, "Dualband reactively loaded microstrip antenna," *IEEE Trans. Antennas Propag.*, Vol. 33, pp.556-561, 1985.

[3] S. E. Davidson, S. A. Long, and W. F. Richards, "Dualband microstrip antennas with monolithic reactive loading," *Electron. Lett.*, Vol. 21, pp.936-937, 1985.

[4] N.S. Nurie and R.J. Langley, "Concentric ring

microstrip antenna," *Microwave Optical Technology Lett.,* Vol. 1, pp.389-392, 1988.

[5] R.P. Owens and A.C. Smith, "Low profile dualband, dual polarized array antenna module," *Electron. Lett.,* Vol. 26, pp.1433-1434, 1990.

[6] C.S. Lee and V. Nalbandian, "Impedance matching of a dual frequency microstrip antenna with an air gap," *IEEE Trans. Antennas Propag.,* Vol. 41, pp.680-682, 1993.

[7] H.F. Hammad, Y.M.M. Antar, and A.P. Freundorfer, "Dualband aperture coupled antenna using spur line," *Electron. Lett.,* Vol. 33, pp.2088-2090, 1997.

[8] G. J. Lazzi, S. S. J. Patnaik, and O. P. Gandhi, "Experimental study on compact, high gain, low SAR single and dual-band patch for cellular telephones," *IEEE Antenna Propagat. Soc. Int. Symp.,* Vol. 1, pp.130-133, 1998.

[9] K. M. Luk, C. H. Lai, and K. F. Lee, "Wideband L-probe feed patch antenna with dual-band operation for GSM/PCS base stations," *Electron. Lett.,* Vol. 35, pp.1123-1124, 1999.

[10] R. Lelarat and R. J. Langley, "Dual band patch for mobile satellite system," *IEE Proc. Microw Antennas Propag.,* Vol. 147, pp. 421-430, 2000.

[11] M. S. Tong, M. Yang, Y. Chen and R. Mitra, "Finite difference time domain analysis of a stacked dual frequency microstrip planar inverted F-antenna for mobile telephone handsets," *IEEE Trans. Antennas Propag.,* Vol. 49, pp.367-376, 2001.

[12] F. J. Villegas, T. Cwik, Y. R. Samii, and M. Manteghi, "Parallel genetic algorithm optimization of a dualband patch antenna for wireless communications," *IEEE Trans. Antennas Propag.,* Vol. 1, pp.334-337, 2002.

[13] C. J. Wang, J. J. Lee, and R. B. Huang, "Experimental studies of miniaturized CPW fed slot antenna with the dual frequency operation," *IEEE Antenna Wireless Propag. Lett.,* Vol. 2, pp. 151-154, 2003.

[14] H. Y. Kim, Y. A. Lee, C. H. Won, and H. M. Lee, "Design of compact dualband microstrip patch antenna for GPS/K-PCS operation," *IEEE Antenna Propag. Soc. Int. Symp.,* Vol. 4, pp.3529-3532, 2004.

[15] S. Pioch and J. M. Laheurte, "Low profile dualband antenna based on a stacked configuration of EBG and plain patches," *Microw Opt. Technol. Lett.,* Vol. 4, pp.207-209, 2005.

[16] J. N. Lee, J. H. Kim, J. K. Park, and L. Y. Tseng, "Design of dualband antenna with U-shaped open stub for WLAN/UWB applications," *Microw Opt. Technol. Lett.,* Vol. 51, pp.284-289, 2009.

[17] K. G. Thomas and M. Sreenivasan, "Compact CPW fed dualband antenna," *Electron. Lett.,* Vol. 46, pp.13-14 2010.

[18] M. Veysi, M. Kamyab, and A. Jafargholi, "Single feed dual band dual linearly polarized proximity coupled patch antenna," *IEEE Antennas Propagation Mag.,* Vol. 53, pp.90-96, 2011.

[19] J. Eichler, P. Hazdra, M. Capek, T. Korinek, and P. Hamouz, "Design of a dual-band orthogonally polarized L-probe-fed fractal patch antenna using modal methods," *IEEE Antennas Wireless Propag. Lett.,* Vol. 10, pp.1389-1392, 2011.

[20] B. A. Zeb, G. Yuehe, K. P. Esselle, Z. Sun and M. E. Tobar, "A simple dualband electromagnetic band gap resonator antenna based on inverted reflection phase gradient," *IEEE Antennas Propag.,* Vol. 60, pp.4522-4529, 2012.

[21] H. Wu, J. Zhang, L. Yan, L. Han, R. Yang and W. Zhang, "Differential dual-band antenna-in-package with T-shaped slots," *IEEE Antennas Wireless Propag. Lett.,* Vol. 11, pp.1446-1449, 2012.

[22] Y. Q. Zhang, X. Li, L. Yang and S. X. Gong, "Dual band circularly polarized annular ring microstrip antenna for GNSS applications," *IEEE Antennas Wireless Propag. Lett.,* Vol. 12, pp.615-618, 2013.

[23] M. Chen and C. C. Chen, "A compact dual band GPS antenna design," *IEEE Antennas Wireless Propag. Lett.,* Vol. 12, pp.245-248, 2013.

[24] A. Khidre, K. F. Lee, A. Z. Elsherbeni and F. Yang, "Wideband dual beam U slot microstrip antenna," *IEEE Antennas Propag.,* Vol.61, pp.1415-1418, 2013.

[25] S. Mohammad, A. Nezhad, H. R. Hassani and A. Foudazi, "A dual-band WLAN/UWB printed wide slot antenna for MIMO/diversity applications," *Microw Opt. Technol. Lett.,* Vol. 55, pp.461-465, 2013.

[26] Z. G. Liu and Y. X. Guo, "Dual band low profile antenna for body centric communications," *IEEE Trans. Antennas Propag.,* Vol. 61, pp.2282-2285, 2013.

[27] A. Singh, J. A. Ansari, K. Kamakshi, A. Mishra and M. Aneesh, "Compact notch loaded half disk patch antenna for dualband operation," *Ann. Telecommun.,* DOI 10.1007/s12243-013-0383-6.

[28] A Singh, J. A. Ansari, K. Kamakshi, M. Aneesh and S. S. Sayeed, "L-strip proximity fed gap coupled compact semi-circular disk patch antenna," *Alexandria Eng. J.,* Vol. 53, pp.61-67, 2014.

[29] A. Singh, M. Aneesh, K. Kamakshi, A. Mishra and J. A. Ansari, "Analysis of F-shape microstrip line fed dualband antenna for WLAN applications," *Wireless Networks,* Vol. 20, 133-140, 2014.

[30] K. L. Wong and L. Y. Chen, "Small-size LTE/WWAN tablet computer antenna," *Microw Opt. Technol. Lett.,* Vol. 56, pp.1296-1302, 2014.

[31] M. Aneesh, J. A. Ansari, A. Singh and Kamakshi, "Effect of shorting wall on Compact

2*4 MSA array using artificial neural network," *TELKOMNIKA Indonesian J. Elect. Eng.,* Vol. 13(3), pp.512-520, 2015.

[32] M. Aneesh, G. M. Siddiqui, J. A. Ansari and A. Singh Kamakshi, "Inset feed toppled H-shapped microstrip patch antenna for PCS/WiMax application," *TELKOMNIKA Indonesian J. Elect. Eng. Comput. Sci.,* Vol. 1(2), 365- 370, 2016.

[33] Y. Cheng, R. Gong, and J. Liu, "Metamaterial extends, microstrip antenna," *Microwaves RF,* Vol. 52, pp.69-73, 2013.

[34] H. X. Xu, G. M. Wang and M. Q. Qi, "A miniaturized triple-band metamaterial antenna with radiation pattern selectivity and polarization diversity," *Progress Electromagnetics Research,* Vol. 137, pp.275-292, 2013.

[35] Xu HXiu, G. M. Wang, Y. Y. Lu, M. Q. Qi, X. Gao and S. Ge, "Multifrequency monopole antennas by loading metamaterial transmission lines with dualshunt branch circuit," *Progress Electromagnetics Research,* Vol. 137, pp.703-725, 2013.

[36] Xu HXiu, G. M. Wang, M. Q. Qi, C. X. Zhang, J. G. Liang, J. Q. Gong and Y. C. Zhou, "Analysis and design of two-dimensional resonant-type composite right/left-handed transmission lines with compact gain-enhanced resonant antennas," *IEEE Trans. Antennas Propag.,* Vol. 61, 735-746, 2013.

[37] G. Kumar and K. P. Ray, "Broadband microstrip antenna," *USA, Artech House,* 2003.

[38] I. J. Bahal and P. Bartia, "Microstrip patch antenna," *Artech House,*1980.

[39] M. Meada, "Analysis of gap in microstrip transmission line," *IEEE Trans. Antennas Propag.,* Vol. 32, pp. 1375-1379, 1972.

[40] M. K. Meshram and B. R. Vishvakarma, "Gap coupled microstrip array antenna for wide band operation," *Int. J. Electron.,* Vol. 88, pp.1161-1175, 2001.

[41] Zeland, "IE3D simulation software Version 14.05," *Zeland Inc.,* USA; 2008.

[42] D. H. Schaubert, D. M. Pozar and A. Adrian, "Effect of microstrip antenna substrate thickness and permittivity: Comparison of theories with experiment," *IEEE Trans. Antennas Propag.,* Vol. 37, pp. 677-682, 1989.

[43] Boualleg N. Merabtine, "Analysis of radiation patterns of rectangular microstrip antennas with uniform substrate," *Semiconductor Physics Quantum Electron. Optoelectronics,* 8, 88-91, 2005.