Single Feed Dualband Miniaturized E-shaped/U-slot Patch Antenna

N. P. Yadav[1] **and M. R. Tripathy**[2]

[1]School of Electronic Engineering and Optoelectronic Technology
Nanjing University of Science and Technology, 210094, China
[2]Department of Electronics and Communication Engineering
Amity School of Engineering and Technology
Amity University Uttar Pradesh, Noida 201313, India

Abstract— This letter presents the design of dual band microstrip patch antenna. This antenna is with single layer E-shaped patch loaded by two U slots. The -10 dB return loss impedance bandwidths of 2.26% and 1.91% are realized at center frequencies of 10.94 GHz and 13.06 GHz with gains of 9.12 dBi and 8.54 dBi respectively. The radiation patterns are also presented. Compared with the published results of the similar scenario, in this design the size is reduced. The design guidelines are provided.

1. INTRODUCTION

During the recent years there has been rapid development in dual band microstrip antenna due to its wide applications in many communication systems. Dual band characteristics can be achieved with the same structure by exciting two different modes with suitable feed point [1], using stacked structures [2], loading reactive stub [3], slots [4], coplanar multi conductor structures [5] etc.. The broadband characteristic of a rectangular, circular and stacked U-shaped slot microstrip patch antenna has been reported [6–9], in which two different but close resonant frequencies in a single patch are combined to give a wideband operation. On the other hand, if the excited resonant frequencies are far apart, a dual-frequency operation can be achieved with the U-slot antenna [10–13]. A slot antenna has special advantage because of its simple structure, such as wider bandwidth, less conductor loss [15–17]. A probe feed microstrip antenna with an internal U-shaped slot having large impedance bandwidth with broadside radiation pattern are reported [18]. In this paper, the design of E-shaped/U-slots loaded rectangular patch antenna at single layer with co-axial feeding technique has been proposed. This antenna has improved the radiation efficiency and gain with reduced size which are the advantages over the earlier reported paper [14]. The working frequency bands are SAR (10.81 GHz–11.06 GHz), VSAT (12.92 GHz–13.17 GHz). From the simulation studies, it is found that the proposed antenna can achieve dual-band performance, high gains, reduction in the size and better band isolation. Details of the proposed antenna and its performance are given in next parts.

2. ANTENNA DESIGN AND THEORETICAL CONSIDERATION

2.1. E-shaped/U-slots Loaded Rectangular Patch Antenna

The proposed configuration of the antenna is shown in Fig. 1. In this letter a new type of two U-shaped slots loaded E-shaped, single layer rectangular patch antenna have been proposed for dualband applications. The dimensions of two U-slots and notches are chosen in such a way so that proposed antenna can exhibit dual frequency behavior with good matching condition.

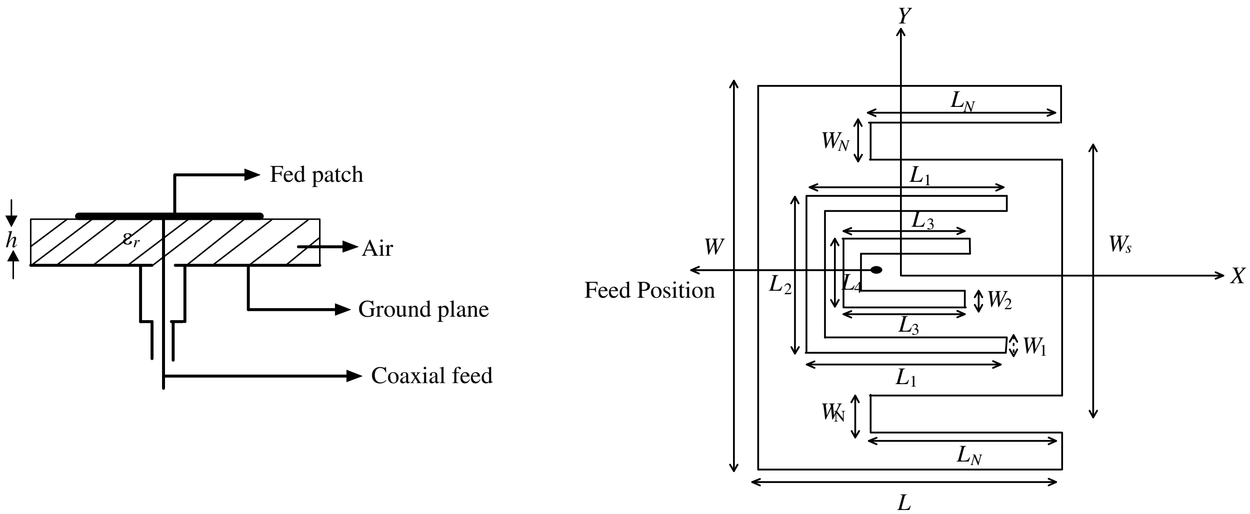
The E-shaped is simpler in construction. The two parallel notches have the same length L_N and same width W_N. The separation [17, 18] of the two notches is W_S. There are thus only three parameters ($L_N W_N$, W_S) for the notches used here. Similarly the two symmetrically U-shape slots are simpler cut in same patch. The vertical slots length of first and second U-shape are L_1 and L_3, similarly horizontal slots length are L_2 and L_4 and width of both U-slots are W_1 and W_2. In this way the six parameters are included in two U-shapes, i.e., (L_1, L_2, L_3, L_4, W_1, and W_2).

A probe feed is located at the point (-6.425, -0.475) for good excitation of the proposed antenna over a dualband. The current distributions of the proposed antenna in two difference frequency bands are given in Fig. 2.

Microstrip patch is considered as a parallel combination of capacitance (C_1), inductance (L_1) and resistance (R_1) as shown in Fig. 3.

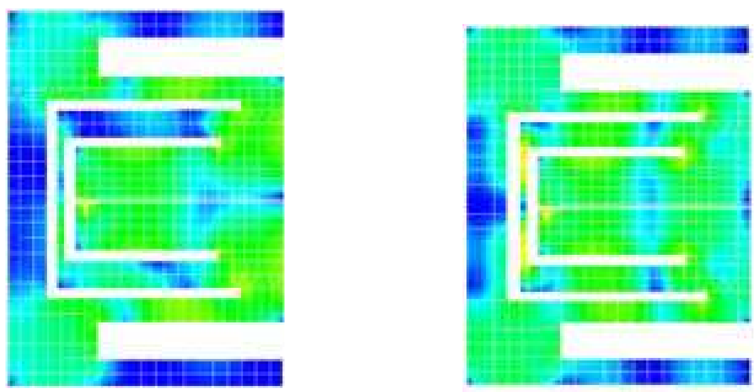
The values of R_1, L_1, and C_1 can be given as [19].

$$Q_r = \frac{c\sqrt{\varepsilon_e}}{4fh}$$



(a) (b)

Figure 1: (a) Top view and (b) side view geometry of the proposed antenna.



(a) (b)

Figure 2: Current distribution at two difference resonance frequency. (a) Current distribution at 10.94 GHz. (b) Current distribution at 13.06 GHz.

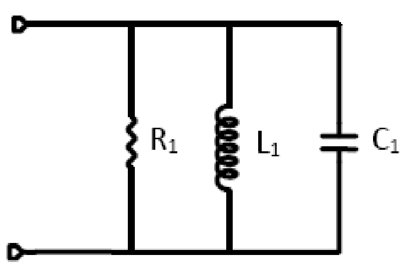


Figure 3: Equivalent circuit of fed patch antenna.

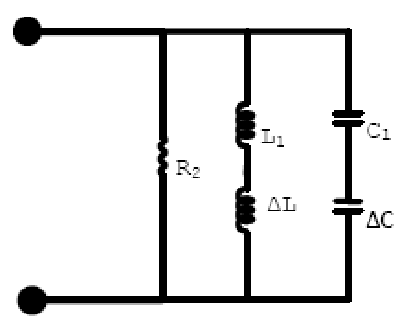


Figure 4: Modified equivalent circuit due to symmetrically notch cut in fed rectangular patch.

where

c = velocity of light.

f = design frequency.

ε_e is effective permittivity of the medium which is given by [10].

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right)^{-1/2}$$

where, ε_r = relative permittivity of the substrate material.

Therefore, the impedance of the patch can be derived using Fig. 3.

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

When two parallel notches are cut in the patch the current distribution are shown in Fig. 2 and the equivalent circuit of the initial patch is modified and can be given as shown in the Fig. 4.

The values of series inductance (ΔL) and series capacitance (ΔC) are calculated [20, 21]. After considering the coupling capacitance C_c the equivalent circuit of the proposed antenna is modified as shown in the Fig. 5. The value of coupling capacitance can be given as [22].

$$C_c = \frac{-(C_1 + C_T) + \sqrt{(C_1 + C_T)^2 - C_1 C_T \left(1 - 1/k_c^2\right)}}{2} \tag{2}$$

where $C_T = \frac{C_1 \Delta C}{C_1 + \Delta C}$ and $k_c = \frac{1}{\sqrt{Q_1 Q_2}}$ in which Q_1 and Q_2 are the quality factor of both the resonators.

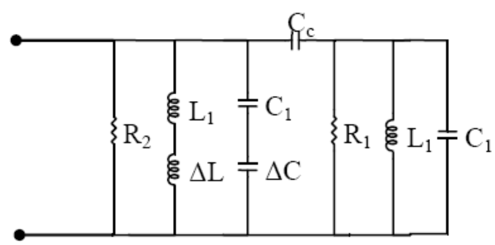


Figure 5: Equivalent circuit of symmetrically notch loaded single layer rectangular patch antenna.

The resonance resistance of the modified configuration of the rectangular patch can be calculated as [23]. Now using the equivalent circuit shown in Fig. 5 one can calculate the total input impedance of the notch loaded rectangular patch antenna as

$$Z_{NR} = \frac{Z_1 Z_2}{Z_1 + Z_2} \tag{3}$$

in which

$$Z_1 = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1} + j\omega C_1} + \frac{1}{j\omega C_c}$$

and

$$Z_2 = \frac{1}{\frac{1}{R_2} + \frac{1}{j\omega L_T} + j\omega C_T}$$

in which $L_T = L_1 + \Delta L$ Slot in microstrip patch can be analyzed by using duality relationship between the dipole and the slot. In this paper the patch is fed by a coaxial feed ($50\,\Omega$). The U-shape slot is considered as three slots, i.e., two parallel to x-axis and the third one perpendicular to the x-axis. The impedance of a single slot parallel to the x-axis is given as [20].

$$Z_s = R_r\left(kL_1\right) - j\left\{120\left(\log\left(\frac{L_1}{d}\right) - 1\right)\cot\frac{kL_1}{2} - X_A\left(kL_1\right)\right\} \tag{4}$$

where

$k = \frac{2\pi}{\lambda}$ (wave vector).

L_1 = length of the slot.

and $X_A(kL_1)$ is given as

$$X_A(kL_1) = 30 \left\{ \begin{array}{l} 2S_i(kL_1) + \cos(kL_1)\left[2S_i(kL_1) - S_i(2kL_1) - \sin(kL_1)\right] \\ \left[2C_i(kL_1) - C_i(2kL_1) - C_i\left(\frac{2kw_1^2}{L_1}\right)\right] \end{array} \right\}$$

where w_1 is the width of the slot and R_r is the radiation resistance and is given by

$$R_r = \frac{2W_T}{I_m^2} = \frac{-\eta_0}{2\pi} \int_0^{2\pi} \frac{\cos\frac{k^2\cos\theta}{2} - \cos\frac{kL_1}{2}}{\sin\theta} d\theta \tag{5}$$

here $\eta_0 = 120\pi$ (characteristic impedance of free space).
$W_T =$ total radiated power.
$I_m =$ maximum current in the slot.
Radiation resistance R_r is calculated as

$$R_r = 60 \left\{ \begin{array}{l} C + \ln(kL_1) - C_i(kL_1) + \frac{1}{2}\sin(kL_1)\left[S_i(2kL_1) - 2S_i(kL_1)\right] \\ +\frac{1}{2}\cos(kL_1)\left[C + \ln\left(\frac{kL_1}{2}\right) + C_i(2kL_1) - 2C_i(kL_1)\right] \end{array} \right\} \tag{6}$$

where C (Euler's constant) $= 0.5772$.
and $S_i(kL_1)$ and $C_i(kL_1)$ are the sine and cosine integral and given as

$$S_i(x) = \int_0^x \frac{\sin(x)}{x} dx$$

and $C_i(x) = -\int_x^\infty \frac{\sin(x)}{x} dx$.

Now the impedance of slot perpendicular to the x-axis is given as

$$Z_{sp} = -j\left[120\left(\ln\frac{L_3}{w_1} - 1\right)\cot\left(\frac{kL_3}{2}\right)\right]$$

$L_3 =$ length of the slot along y-axis.

The equivalent circuit of the proposed antenna can be given as shown in Fig. 6(a) in which Z_{U1} is the impedance due to two U-slot vertical lengths and Z_{U2} is the impedance due to base length of the U-slot, Z'_{U1} and Z'_{U2} is the same for other U-slot patch antenna. And Z_{NR} is the impedance of notch loaded rectangular patch.

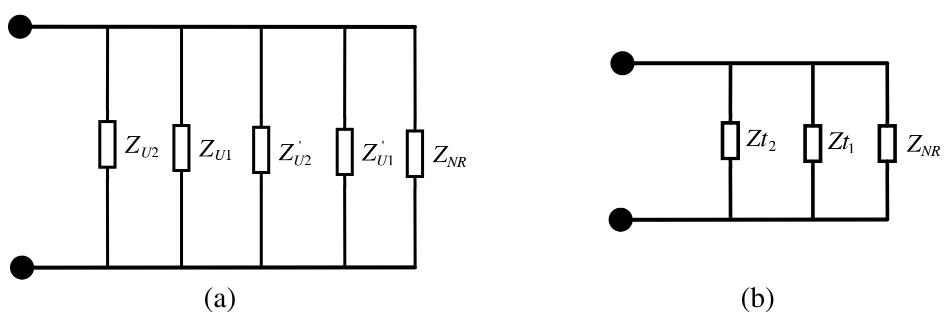


Figure 6: (a) Equivalent circuit of the proposed antenna. (b) Its modified circuit.

Now the total input impedance of double-U slot loaded parallel notch cut rectangular patch antenna can be calculated from Fig. 6(b) as

$$Z_T = \frac{Z_{t1}Z_{t2}Z_{NR}}{Z_{NR}Z_{t2} + Z_{NR}Z_{t1} + Z_{t1}Z_{t2} + Z_{NR}} \tag{7}$$

where

$$Z_{t1} = \frac{Z_{U2}Z_{U1}}{Z_{U2} + Z_{U1}}$$

$$Z_{t2} = \frac{Z'_{U2}Z'_{U1}}{Z'_{U2} + Z'_{U1}}$$

and Z_{NR} which is given by above equation Using this equation one can calculate the various antenna parameters for proposed antenna.

$$\Gamma = \frac{Z_0 - Z_T}{Z_0 + Z_T} \tag{8}$$

Table 1:

Frequency	10.0–14.0 GHz
W	40.0 mm
L	30.0 mm
L_N	20.0 mm
W_N	4.0 mm
L_1	20.0 mm
L_2	20.0 mm
L_3	16.0 mm
L_4	13.0 mm
W_1	1.0 mm
W_2	1.0 mm
Dielectric (ε_r)	22 (0.127 mm)
Thickness (h) air	1.0 mm
Feed Location (X_0, Y_0)	(−6.425, −0.475)

3. RESULTS AND DISCUSSION

Simulation results were carried out to demonstrate the performance of the proposed antenna.

From Fig. 7, it is seen the return loss versus frequency that, the return loss of the first band designed microstrip patch antenna is −21.98 dB at the frequency of 10.94 GHz with a frequency band 10.81 GHz to 11.06 GHz, similarly the second band is obtained at return loss −27.50 dB at the frequency of 13.06 GHz with a frequency band 12.92 GHz to 13.17 GHz. This shows that it is very useful for the radar communication.

The simulated E and H plane cross and Co-polarization radiation patterns of the proposed antenna at 10.94 GHz (lower resonance frequency) and 13.06 GHz (Upper resonance frequency) are shown in Figs. 8–9. It can be seen that, there is small deviation in maximum power in case of upper resonance frequency in comparison to lower resonance frequency. The simulated peak gains

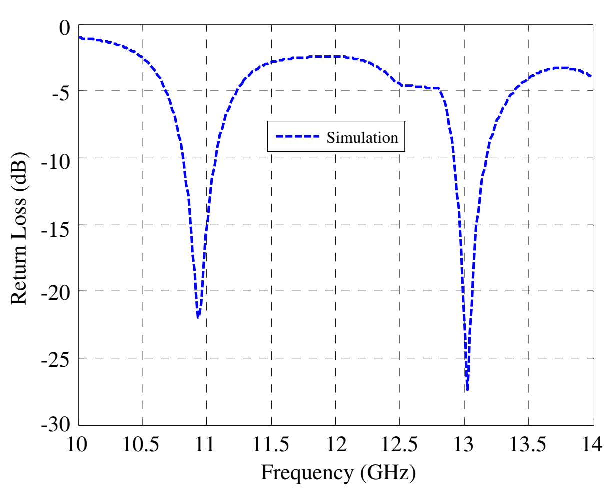


Figure 7: Comparative plot between return loss and frequency of the proposed antenna.

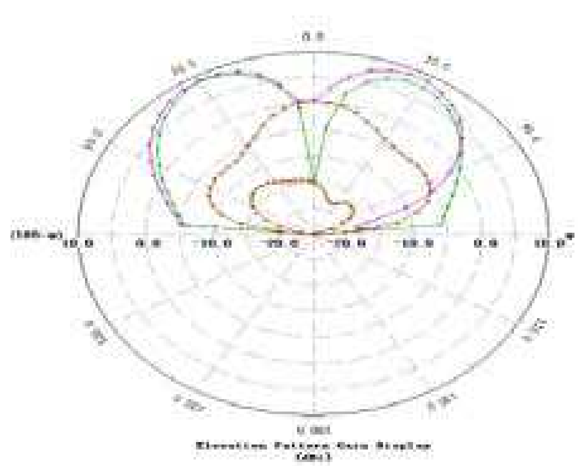


Figure 8: Simulated radiation patterns both E and H plane in cross and co-polarization of dualband antenna at 10.94 GHz resonance frequency.

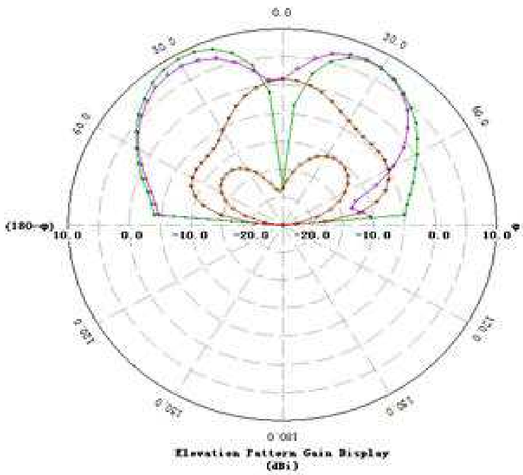


Figure 9: Simulated radiation patterns both E and H plane in cross and co-polarization of the dualband antenna at 13.06 GHz resonance frequency.

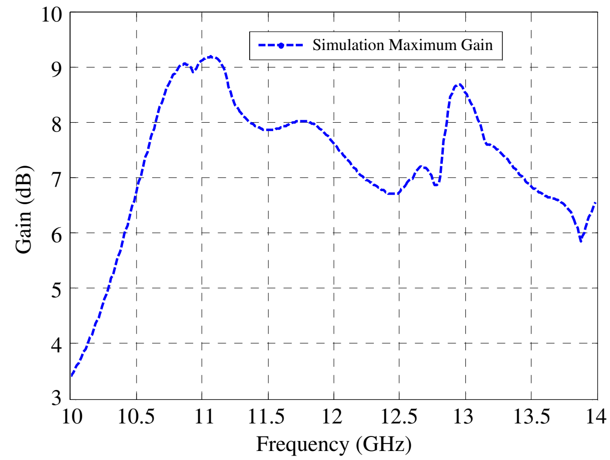


Figure 10: Gain versus frequency of the proposed antenna.

of the antenna are 9.12 dBi and 8.54 dBi shown in Fig. 10. The above study shows the influence of size and shape of notches, slots and thickness of substrate on the impedance bandwidth.

4. CONCLUSION

This proposed method for the design of dual-band patch antenna results in a structure which is simpler and easier to fabricate than the structures described before. The presented design demonstrates the use of U-slots and E-shaped patch to get the dualband operation of rectangular patch antenna. This modified rectangular patch antenna can be used for radar applications. It fulfills the demands of applications such SAR and VSAT Antenna provides impedance bandwidth of 2.26%, 1.91% at two different application bands. The peak gains are 912 dBi, and 8.54 dBi respectively.

REFERENCES

1. Richards, W. F., S. E. Davidson, and S. A. Long, "Dualband reactively loaded microstrip patch antenna," *IEEE Transaction on Antennas and Propagation*, Vol. 33, 556–561, May 1985.
2. Ansari, J. A., P. Singh, S. K. Dubey, R. U. Khan, and B. R. Vishvakarma, "H-shaped stacked patch antenna for dual band operation," *Progress In Electromagnetic Research B*, Vol. 5, 291–302, 2008.
3. Division, S. A., S. A. Long, and W. F. Richards, "Dual band microstrip antennas with monolithic reactive loading," *Electronic Lett.*, Vol. 21, 936–937, Sep. 1985.
4. Wang, E., J. Zheng, and Y. Liu, "A novel dual-band patch antenna for WLAN communication," *Progress In Electromagnetic Research C*, Vol. 6, 93–102, 2009.
5. Mishra, A., P. Singh, N. P. Yadav, J. A. Ansari, and B. R. Vishvakarama, "Compact shorted microstrip patch antenna for dual band operation," *Progress In Electromagnetic Research C*, Vol. 9, 171–182, 2009.
6. Esfahlani, S. H. S., A. Tavakoli, and P. Dehkhoda, "A compact single-layer dual-band microstrip antenna for satellite applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 931–934, 2011.
7. Mok, W. C., S. H. Wong, K. M. Luk, and K. F. Lee, "Single Layer single patch dual band and triple band patch antennas," *IEEE Transaction on Antennas and Propagation*, Vol. 61, No. 8, 4341–4344, Aug. 2013.
8. Hsu, C. K. and S. J. Chung, "Compact antenna with U-shaped open-end shaped open-end slot structure for multi-band Handset application," *IEEE Transaction on Antennas and Propagation*, Vol. 62, No. 2, 929–932, Feb. 2014.
9. Osman, H. A., E. A. Abdallah, and A. A. Abdel-Rahim, "A novel broadband compact circular disk microstrip antenna for wireless application," *PIERS Online*, Vol. 4, No. 7, 761–766, 2008.

10. Ansari, J. A. and R. B. Ram, "Broadband stacked U-slot microstrip patch antenna," *Progress In Electromagnetics Research Letters*, Vol. 4, 17–24, 2008.
11. Ansari, J. A., S. K. Dubey, P. Singh, R. U. Khan, and B. R. Vishvakarama, "Analysis of U-slot loaded patch antenna for dualband operation," *Int. J. Microwave and Opt. Techno.*, Vol. 3, 80–84, 2008.
12. Bhalla, R. and L. Shafai, "Resonance behaviour of single U-slot and double U-slot antenna," *Microwave and Opt. Techno. Lett.*, Vol. 32, 332–335, 2002.
13. Guo, Y. X., K. F. Lee, and K. M. A. Luk, "Dualband patch antenna with two U-shaped slot," *Microwave and Opt. Techno. Lett.*, Vol. 26, 73–75, Jul. 2000.
14. Meng, F. and S. K. Sharma, "A single feed dual-band (2.4 GHz/5.8 GHz) miniaturized patch antenna for wireless local area network (WLAN) communications," *IEEE URSI GASS*, 978-1-4673-5225-3, 2014.
15. Ysai, S. N., H. H. Hsin, H. K. Dia, and K. T. Cheng, "Arcuate slot antenna," Assembly US Patent, No. 6373443, 2002.
16. Axelrod, A., M. Kisliuk, and J. Maoz, "Broadband microstrip fed slot radiator," *Microwave Journal*, Vol. 32, 81–84, 1989.
17. Yang, F., X.-X. Zhang, X. Ye, and Y. Rahmat-Sammi, "Wide-band E-shaped patch antennas for wireless communication," *IEEE Transactions on Antennas and Propagation*, Vol. 49, No. 7, 1094–1100, Jul. 2001.
18. Ang, B.-K. and B.-K. Chung, "A wideband E-shaped microstrip patch antennas for 5–6 GHz wireless communications," *Progress In Electromagnetic Research*, Vol. 75, 397–407, 2007.
19. Bahal, I. J. and P. Bhartia, *Microstrip Antennas*, Artech House, Boston, MA, 1985.
20. Zhang, X. X. and F. Yang, "Study of a slit cut on a microstrip antenna and its applications," *Microwave and Opt. Techno. Lett.*, Vol. 18, 297–300, 1998.
21. Bahal, I. J., *Lumped Elements for RF and Microwave Circuits*, Artech House, Boston, 2003.
22. Terman, F. E., *Electronic and Radio Engineering*, 15–73, Kogakusha, Tokyo, 1955.
23. Balanis, C. A., *Antenna Theory Analysis and Design*, 728–746, 2nd Edition, Wiely, New York, 1997.