

## **CIRCULAR MICROSTRIP SLOT ANTENNA FOR DUAL-FREQUENCY RFID APPLICATION**

**J. J. Tiang<sup>1, 3</sup>, M. T. Islam<sup>2, \*</sup>, N. Misran<sup>1, 2</sup>, and J. S. Mandeep<sup>1, 2</sup>**

<sup>1</sup>Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia

<sup>2</sup>Institute of Space Science (ANGKASA), Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia

<sup>3</sup>Faculty of Engineering, Multimedia University, Persiaran Multimedia, 63100 Cyberjaya, Selangor, Malaysia

**Abstract**—A compact wideband dual-frequency microstrip antenna is proposed in this paper. By employing an offset microstrip-fed line and a strip close to the radiating edges in the circular slot patch, an antenna operating at dual frequency with the impedance bandwidth of 26.2% and 22.2% respectively is presented. By attaching a strip to the radiating edges opposite to the microstrip-fed line, this alters the current distribution and radiation on the antenna at the second resonant frequency. The second frequency is also tunable by varying the lengths of the microstrip-fed line. It is demonstrated that the proposed antenna covers the widebands of UHF and microwave for RFID application. A good agreement is obtained between the simulated and experimental results.

### **1. INTRODUCTION**

Microstrip patch antenna has been extensively used in communications system owing to its attractive characteristics such as low profile, low cost, light weight and easy to fabricate [1, 2]. However, one of the main issues of microstrip patch antenna is the narrow bandwidth. A number of techniques to overcome the limitation have been suggested to provide the characteristics of wideband antenna including increase of substrate

---

*Received 2 September 2011, Accepted 4 October 2011, Scheduled 9 October 2011*

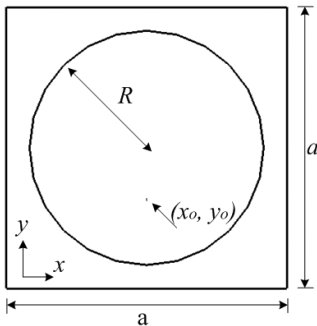
\* Corresponding author: Mohammad Tariqul Islam (tariqul@ukm.my).

thickness, slotted patch antenna or stacked shorted patches [3–15]. Many investigation associated to microstrip slot antennas have been reported [16–23].

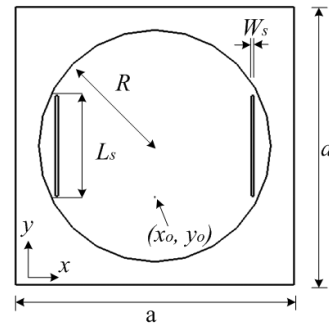
Radio frequency identification (RFID) is an automatic identification technology that uses radio waves to transfer data between a reader and a tag attached to an object for objective of identification and tracking [24]. The radiated wave energizes the IC chip to allow proper communication of data transfer between the RFID reader and the tag. Reader antenna is required to be low in profile yet provides wideband characteristics of complex worldwide regulatory environment. The most common frequencies of RFID technology used are low (125 kHz), high (13.56 MHz), ultra high (858–930 MHz), and microwave (2.4 GHz) [25]. The UHF and microwave bands are widely used due to their advantages of long read range and high data rate, it is favorable to design a single antenna which operates on both frequency bands.

A variety of dual-band slot loaded antennas have been reported in [26–28]. The dual-frequency characteristics have been demonstrated owing to a pair of slot is placed close to the radiating edges. However, the proposed antenna utilizes probe feeding that results in narrow bandwidth. In [29], a microstrip-fed line used in the circular slot antenna has been reported. However, the bandwidth of the antenna has yet been enhanced for dual-band operation.

In the present paper, an offset microstrip-fed line is used and a strip is inserted at the radiating edges in the circular slot patch. The additional strip is found to improve the current distribution and radiation mechanism. This in turn to enhance the wideband characteristics of the microstrip patch antenna. Moreover, a frequency



**Figure 1.** Basic circular disc patch antenna.



**Figure 2.** Slot-loaded circular disc patch.

control method has been carried out to tune the second resonant frequency to cover the complex worldwide UHF and microwave band frequency for RFID application.

## 2. ANTENNA CONFIGURATIONS

The basic structure of circular disc patch antenna is initially evaluated and is shown in Figure 1. The circular patch has a circular radius of  $R$ ; and is printed on a substrate of thickness  $h$  and relative permittivity  $\epsilon_r$ . The antenna ground plane is in square shape with dimension of  $a \times a$ . Impedance matching is obtained by using a single probe feed at a position  $(x_o, y_o)$  away from the patch center. The resonant frequency of an  $T_{nm}$  is shown in [30] as

$$f_{nm} = \frac{X_{nm}c}{2\pi R_e\sqrt{\epsilon_r}} \quad (1)$$

in which  $X_{nm} = m_{th}$  zero of the derivative of Bessel function of order “ $n$ ”,  $c$  = velocity of light,  $R_e$  = effective radius of the circular disk  $\epsilon_r$  = dielectric constant of the substrate.

The first five values of  $X_{nm}$  are shown in Table 1.

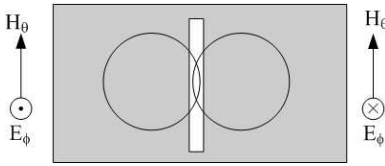
**Table 1.** Order mode of  $X_{nm}$  values.

$n, m$	1, 1	2, 1	0, 2	3, 1	1, 2
$X_{nm}$	1.841	3.054	3.832	4.201	5.331

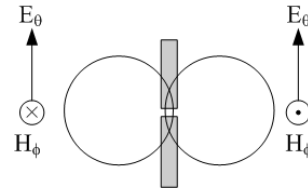
The parameter  $X_{nm}$  determines the frequency ratio of various modes of resonant frequency.

Figure 2 shows a slot loaded disc circular patch antenna. It is formed by a pair of parallel slots with dimension of  $L_s \times W_s$  which is placed close to radiating edge of the circular patch. The slot loaded circular patch design is enhanced from the basic circular patch to allow the two broadside-radiation modes ( $TM_{11}$  and  $TM_{12}$ ) of the basic circular patch to be excited close to each other to meet the required frequency ratio. The  $X_{nm}$  of fundamental mode  $TM_{11}$  is 1.84; and  $TM_{12}$  is given by 5.33. It is calculated that the frequency ratio of the two significant modes is close to 2.9. The frequency ratio of the two operating frequencies can be tuned by adjusting the slot locations and lengths.

Slot antenna is classified as an aperture type antenna. Based on the Babinet's principle, it is associated to the radiation and impedance characteristic of an aperture or slot antenna to that of the field of its dual antenna.



**Figure 3.** The slot antenna.



**Figure 4.** The dipole antenna.

As an example in Figures 3 and 4, it shows that the radiation pattern is the same as that of the complementary dipole consisting of a perfectly conducting flat strip of the same geometry, with the electric ( $E$ ) and magnetic ( $H$ ) fields are interchange.

Babinet's principle defines that the far fields radiated by the antenna with the slot and those radiated by the complementary structure are related by:

$$E_{\theta s} = H_{\theta c} \quad (2)$$

$$E_{\phi s} = H_{\phi c} \quad (3)$$

$$H_{\theta s} = -\frac{E_{\theta c}}{\eta_0^2} \quad (4)$$

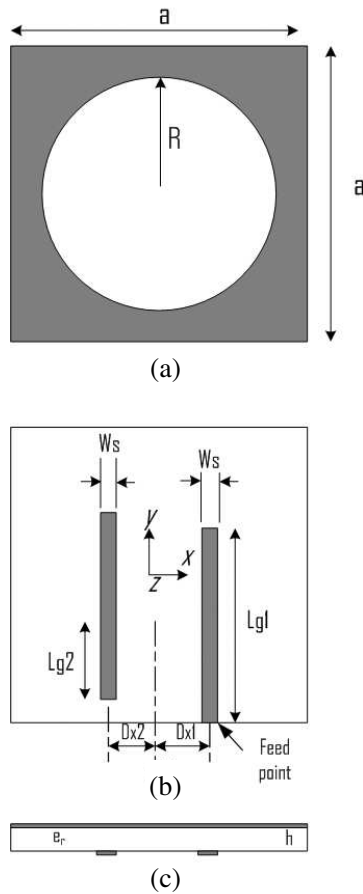
$$H_{\phi s} = -\frac{E_{\phi c}}{\eta_0^2} \quad (5)$$

in which  $s$  = slot,  $c$  = complementary and  $\eta$  = intrinsic impedance of free space.

Based on the principles of slot antenna and the slot loaded circular patch, a new dual band antenna is proposed. Figure 5 shows the proposed slot antenna with the patch square dimension of  $a \times a$  is cut out with a circular slot of the radius,  $R$ . A photograph of the fabricated prototype is shown in Figure 6. Because the probe-fed circular disc antenna offers narrow bandwidth, an offset microstrip-fed line is used and a strip is inserted at the radiating edges in the circular slot patch to enhance the wideband characteristics of the slot antenna. The proposed slot antenna greatly demonstrates to cover the widebands of UHF and microwave for RFID application.

### 3. RESULTS AND DISCUSSION

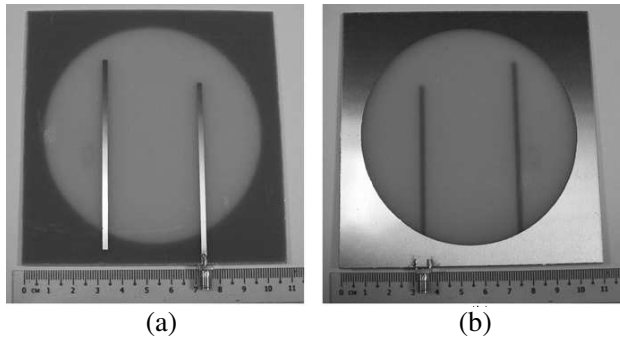
The proposed antenna is simulated using CST Microwave Studio. Figures 7 and 8 show current distributions of two slot antennas: with a strip and without a strip respectively. The patch surface current



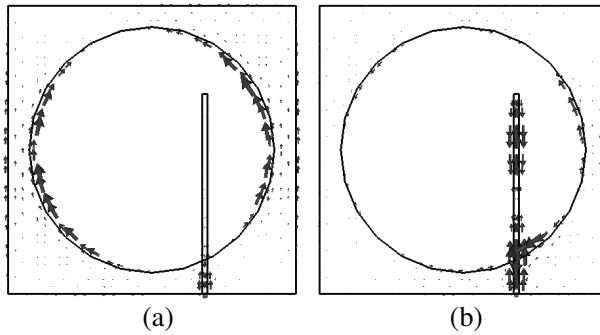
**Figure 5.** Geometry of the proposed antenna. (a) Front view, (b) back view and (c) side view.

distributions for the two operating frequencies: lower ( $f_1 = 870$  MHz) and upper frequency ( $f_2 = 2.45$  GHz) are illustrated.

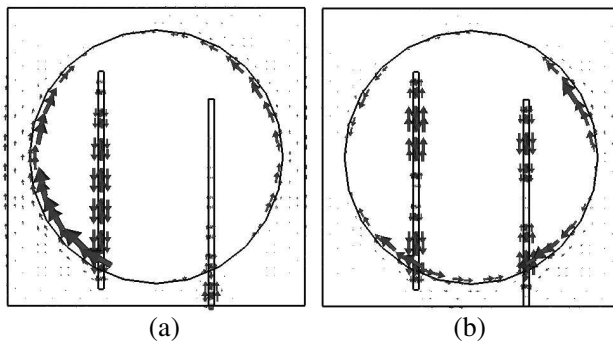
It can be observed that for frequency mode of  $f_1$ , the antenna with strip allows minor perturbations of current distribution in the patch (shown in Figure 8(a)) as similar to current distribution of the antenna without the strip (shown in Figure 7(a)). This results in radiation mechanism associated with lower frequency  $f_1$  mode same as that the patch without strip as shown in Figure 9. For current distribution at upper frequency of  $f_2$ , the Figure 7(b) shows the antenna without strip constrains the current flow around the circular patch slot as compared to  $f_1$  (shown in Figure 7(a)). By adding appropriate strip to the



**Figure 6.** Photograph of the fabricated proposed antenna. (a) Front view, (b) back view.



**Figure 7.** Current distribution of the antenna without strip for (a)  $TM_{11}$  at 870 MHz and (b)  $TM_{12}$  at 2.45 GHz.



**Figure 8.** Current distribution of the proposed antenna with strip for (a)  $TM_{11}$  at 870 MHz and (b)  $TM_{12}$  at 2.45 GHz.

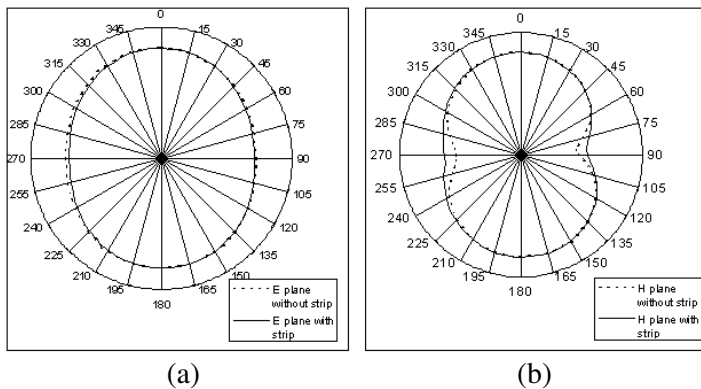


Figure 9. *E*-field and *H*-field radiation of the antenna at 870 MHz.

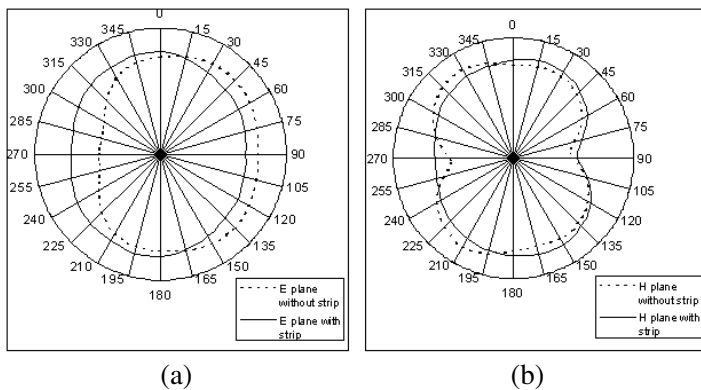


Figure 10. *E*-field and *H*-field radiation of the antenna at 2.45 GHz.

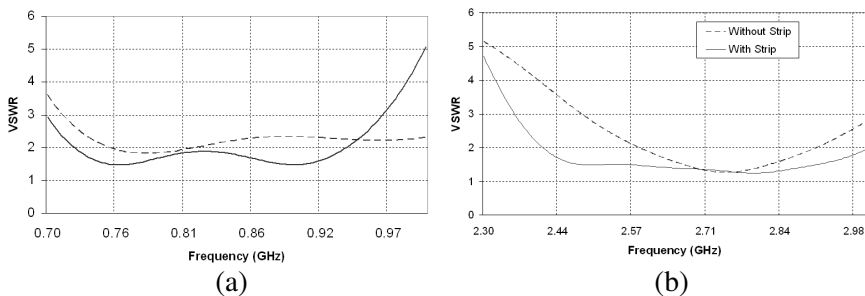


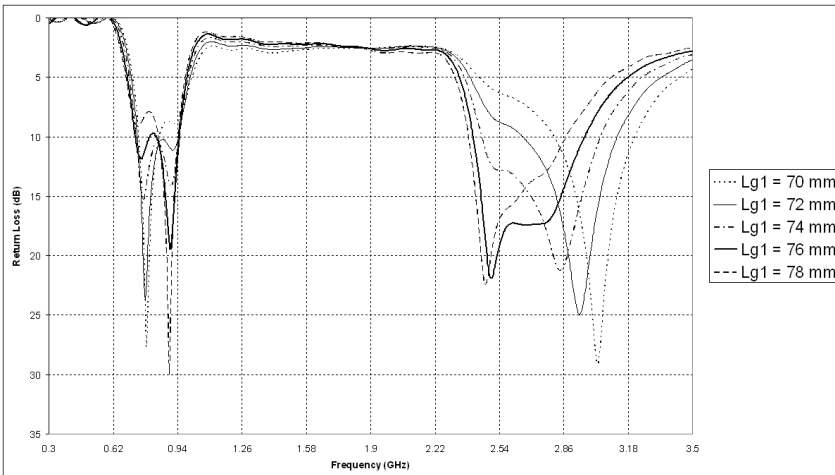
Figure 11. VSWR versus first resonant frequency for the antenna with and without strip.

circular patch, this creates large extension of current flows circulating uniformly at the patch slot as shown in Figure 8(b). Subsequently, the radiation pattern of  $f_2$  (shown in Figure 10) becomes uniform similar to that of  $f_1$  mode (shown in Figure 9).

The simulated VSWR results with first and second resonant frequencies for the antenna with strip and without strip is illustrated in Figure 11. The bandwidth is determined from the results of VSWR  $< 2$ . The results of resonance, bandwidth and gain from Figure 11 are tabulated in Table 2.

**Table 2.** Comparison of the performances of the antenna with strip and without strip.

		Antenna without strip	Antenna with strip
First resonance	Frequency (GHz)	0.782	0.83
	Bandwidth (MHz)	45	208
	Gain (dBi)	3.631	3.688
Second resonance	Frequency (GHz)	2.7462	2.7057
	Bandwidth (MHz)	249	578
	Gain (dBi)	5.667	5.04



**Figure 12.** Variation of return loss versus frequency for different values of microstrip-fed line.



It is observed that the antenna with strip demonstrates significant improvement of bandwidth for the first resonant frequency and second resonant frequency. This can be explained by the more uniform current distribution in attaching a strip to the radiating edges opposite to the microstrip-fed line. A gain of 3.688 dBi is found for the first resonance. On the other hand, for the second resonance, the gain is 5.04 dBi which is slightly lower than the antenna without strip.

By adjusting the length of the microstrip-fed line ( $Lg_1$ ), the upper frequency of  $f_2$  can be tuned. Figure 12 shows the return loss of the proposed antenna with different length of microstrip-fed line.

It is found that the first resonant frequency can be easily controlled by selecting the radius of circular slot patch. It is desired to propose a method in controlling the secondary frequency with minimum effect on the primary resonant frequency. The parameter that can be used to control the secondary resonant frequency is microstrip-fed line length

**Table 3.** Simulated results for the antenna with the strip and without strip.

$Lg_1$ (mm)	$f_1$ (GHz)	Bandwidth (MHz)	$f_2$ (GHz)	Bandwidth (MHz)
70	0.7896	99.2	2.476	406.4
72	0.78	201.6	2.508	470.4
74	0.7736	217.6	2.86	595.2
76	0.9046	217.6	2.9464	556.8
78	0.9016	96	3.036	489.6

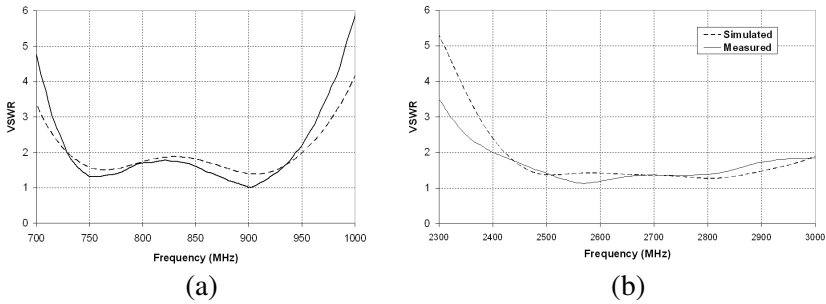
**Table 4.** Design specification of proposed circular microstrip slot antenna.

Substrate material	FR4
Relative permittivity of the substrate, $\epsilon_r$	4.55
Thickness of the dielectric ( $h$ )	1.6 mm
Radius of the circular disk patch ( $R$ )	46 mm
Width of the slot, $W_s$	2 mm
Length of the microstrip-fed line, $Lg_1$	75 mm
Length of the strip, $Lg_2$	75 mm
Distance of microstrip-fed line, $Dx_1$	20 mm
Distance of strip, $Dx_2$	20 mm
Square ground plane ( $a \times a$ )	108 mm $\times$ 108 mm

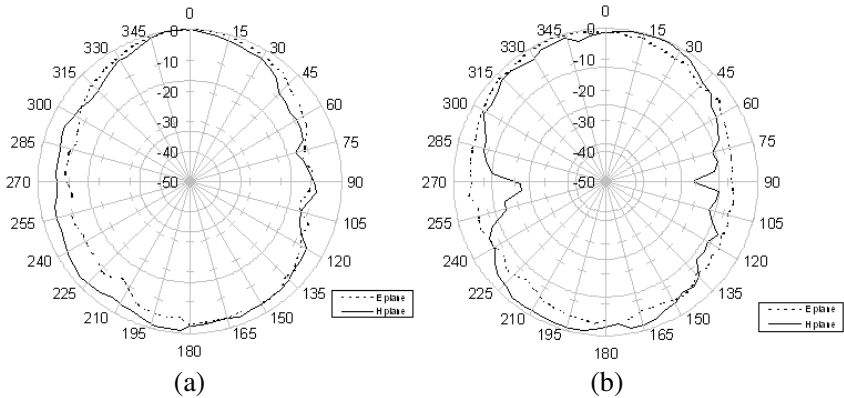
of  $Lg_1$ . Table 3 shows the simulated results of primary frequency, secondary frequency and their bandwidths by adjusting the length of microstrip-fed line. It is found that the increasing  $Lg_1$  results in an increase of second resonant frequency.

The optimum parameters of the proposed prototype antenna in Table 4 are illustrated.

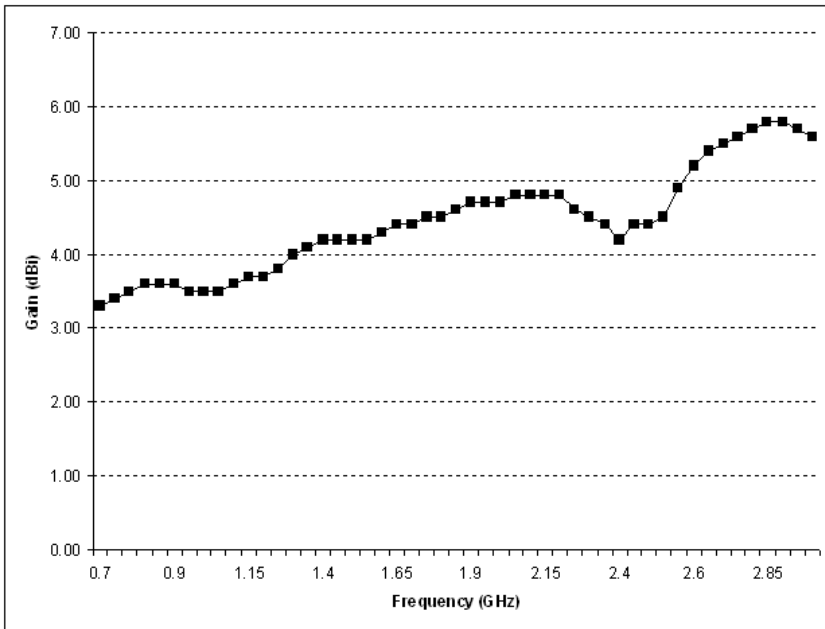
Figure 13 shows the VSWR results of the proposed antenna. It is observed that the proposed slot antenna has demonstrated the dual-band behaviour with wideband characteristics. The measured bandwidth for lower frequency and upper frequency are 220 MHz (from 730 MHz to 950 MHz) and 600 MHz (from 2.4 GHz to 3 GHz) respectively. The measured radiation patterns of the proposed antenna



**Figure 13.** Simulated and measured VSWR results of the proposed antenna.



**Figure 14.** Measured radiation pattern of (a) 870 MHz and (b) 2.45 GHz.



**Figure 15.** Measured antenna peak gain.

in the  $E$ -plane and  $H$ -plane at the operating frequency of 870 MHz and 2.45 GHz are shown in Figure 14. The measured antenna peak gain is illustrated in Figure 15. The antenna gain remains better than 3.5 dBi from 730 MHz to 950 MHz for the UHF RFID band. The antenna gain rises steadily from 4.2 dBi at 2.4 GHz to 5.6 dBi at 3 GHz over the whole microwave RFID band.

#### 4. CONCLUSION

In this paper, a new dual band microstrip slot antenna has been evaluated. An offset microstrip-fed line is employed and an additional strip is inserted close to the radiating edges in the circular slot. The aid of strip demonstrates significant wideband characteristics due to efficient current distribution and radiation mechanism. The second resonant frequency can be tuned by adjusting the microstrip-fed line length. Finally, the proposed antenna has been demonstrated to perform the wideband characteristics to cover universal dual band UHF and microwave for RFID application.

## REFERENCES

1. Lo, Y., D. Solomon, and W. Richards, "Theory and experiment on microstrip antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 27, No. 2, 137–145, 1979.
2. Lotfi Neyestanak, A. A., "Ultra wideband rose leaf microstrip patch antenna," *Progress In Electromagnetics Research*, Vol. 86, 155–168, 2008.
3. Chen, Y., S. Yang, S. He, and Z.-P. Nie, "Fast analysis of microstrip antennas over a frequency band using an accurate MoM matrix interpolation technique," *Progress In Electromagnetics Research*, Vol. 109, 301–324, 2010.
4. Islam, M. T., M. Moniruzzaman, N. Misran, and M. N. Shakib, "Curve fitting based particle swarm optimization for UWB patch antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 17–18, 2421–2432, 2009.
5. Liu, R.-H., Z.-H. Yan, J.-B. Jiang, and Y. Bai, "Small printed ultra-wideband antenna with an inverted F-slotted ground," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 11–12, 1497–1504, 2009.
6. Islam, M. T., M. N. Shakib, and N. Misran, "Design analysis of high gain wideband L-probe FED microstrip patch antenna," *Progress In Electromagnetics Research*, Vol. 95, 397–407, 2009.
7. Elsharkawy, Z. F., A. A. Sharshar, S. M. Elhalafawy, and S. M. Elaraby, "Ultra-wideband A-shaped printed antenna with parasitic elements," *Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 14–15, 1909–1919, 2010.
8. Chakravarty, T. and A. De, "Design of tunable modes and dual-band circular patch antenna using shorting posts," *IEE Proceedings — Microwaves, Antennas and Propagation*, Vol. 146, No. 3, 224, 1999.
9. Islam, M. T., M. N. Shakib, and N. Misran, "Broadband E-H shaped microstrip patch antenna for wireless systems," *Progress In Electromagnetics Research*, Vol. 98, 163–173, 2009.
10. Vedaprabhu, B. and K. J. Vinoy, "An integrated wideband multifunctional antenna using a microstrip patch with two U-slots," *Progress In Electromagnetics Research B*, Vol. 22, 221–235, 2010.
11. Islam, M. T., M. N. Shakib, and N. Misran, "Multi-slotted microstrip patch antenna for wireless communication," *Progress In Electromagnetics Research Letters*, Vol. 10, 11–18, 2009.

12. Aydin, E., "Computation of a tunable slot-loaded equilateral triangular microstrip antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 14–15, 2001–2009, 2009.
13. Chen, X., G. Fu, S. X. Gong, J. Chen, and X. Li, "A novel double-layer microstrip antenna array for UHF RFID," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 11–12, 1479–1487, 2009.
14. Tsai, C.-L., S.-M. Deng, C.-H. Tseng, and S.-S. Bor, "Antennas with two shorted rectangular-ring slots coupled by microstrip line for the opposite sense CP in the wide-band operations," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 10, 1367–1375, 2009.
15. Qubati, G. M. and N. I. Dib, "Microstrip patch antenna optimization using modified central force optimization," *Progress In Electromagnetics Research B*, Vol. 21, 281–298, 2010.
16. Barbarino, S. and F. Consoli, "UWB circular slot antenna provided with an inverted-L notch filter for the 5 GHz WLAN band," *Progress In Electromagnetics Research*, Vol. 104, 1–13, 2010.
17. Li, C.-M. and L.-H. Ye, "Improved dual band-notched UWB slot antenna with controllable notched bandwidths," *Progress In Electromagnetics Research*, Vol. 115, 477–493, 2011.
18. De Villiers, J. P. and J. P. Jacobs, "Gaussian process modeling of CPW-FED slot antennas," *Progress In Electromagnetics Research*, Vol. 98, 233–249, 2009.
19. Gao, G.-P., M. Li, S.-F. Niu, X.-J. Li, B.-N. Li, and J.-S. Zhang, "Study of a novel wideband circular slot antenna having frequency band-notched function," *Progress In Electromagnetics Research*, Vol. 96, 141–154, 2009.
20. Lee, Y.-C. and J.-S. Sun, "Compact printed slot antennas for wireless dual- and multi-band operations," *Progress In Electromagnetics Research*, Vol. 88, 289–305, 2008.
21. Wang, C.-J. and S.-W. Chang, "Studies on dual-band multi-slot antennas," *Progress In Electromagnetics Research*, Vol. 83, 293–306, 2008.
22. Wang, M.-F., J.-X. Xiao, and S.-W. Wang, "Study of a dual-band notched wideband circular slot antenna," *Journal of Electromagnetics Waves and Applications*, Vol. 24, Nos. 17–18, 2445–2452, 2010.
23. Zhao, K., S. Zhang, and S. L. He, "Enhance the bandwidth of a rotated rhombus slot antenna with multiple parasitic elements,"

- Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 14–15, 2087–2094, 2010.
24. Landt, J., “The history of RFID,” *IEEE Potentials*, Vol. 24, No. 4, 8–11, 2005.
  25. Finkenzeller, K., *RFID Handbook*, 2nd edition, 195–219, John Wiley & Sons, 2003.
  26. Maci, S., G. Biffi Gentili, P. Piazzesi, and C. Salvador, “Dual-band slot-loaded patch antenna,” *IEE Proceedings — Microwaves, Antennas and Propagation*, Vol. 142, No. 3, 225–232, 1995.
  27. Ansari, J. A., A. Mishra, N. P. Yadav, and P. Singh, “Dualband slot loaded circular disk patch antenna for WLAN application,” *International Journal of Microwave and Optical Technology*, Vol. 5, No. 3, 124–129, 2010.
  28. Lu, J.-H. and K.-L. Wong, “Slot-loaded, meandered rectangular microstrip antenna with compact dual frequency operation,” *Electronics Letters*, Vol. 34, No. 11, 1048–1050, 1998.
  29. Ooi, P. C. and K. T. Selvan, “A dual-band circular slot antenna with an offset microstrip-FED line for PCS, UMTS, IMT-2000, ism, bluetooth, RFID and WLAN applications,” *Progress In Electromagnetics Research Letters*, Vol. 16, 1–10, 2010.
  30. Garg, R., P. Bartia, I. Bhal, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, Norwood, MA, 2001.