A New Meandered-Stripline Fed Dual Band Patch Antenna

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Abstract **─** A new circular shaped patch antenna loaded with vertical slots and fed by meandered-stripline on a high dielectric material substrate is proposed in this paper, and experimentally verified the performance of the printed prototype. With the deployment of meandered-stripline structure to excite in the assistant of partial ground plane, the experimental results show that the proposed antenna has achieved wider bandwidth with satisfactory gain. The measured impedance bandwidth (voltage wave stand ratio, VSWR <= 2) of the proposed antenna at lower band is 400 MHz (600 MHz - 1 GHz) and at upper band is 700 MHz (2.25 GHz - 2.95 GHz). The peak gains of -1.18 dBi and 4.87 dBi have measured with topmost radiation efficiencies of 82.0% and 92.6% and have observed at lower band and upper band respectively. The performance criteria and almost consistent radiation pattern make the proposed antenna as a suitable candidate for UHF RFID, WiMAX and WLAN applications. The designing of antenna model and the parametric study have been performed with commercially available EM simulation software on 64-bit windows PC. The proposed antenna model has been validated by comparing the obtained experimental results with the output from the numerical simulation and apparently shows good agreement between them.

Index Terms **─** Bandwidth enhancement, finite element method, meandered-stripline feed, microstrip antenna, patch antenna, planar antenna, RFID, WiMAX, WLAN.

I. INTRODUCTION

The last couple of years, the innovative research ideas with the help of cutting-edge technology have contributed an intense boost to the wireless communications. Our todays social life always demanded cost effective, portable, compact, radiation efficient and reliable wireless communication devices. Thus, the request for designing printed, planar, small-sized, wideband, multiband and highly efficient antennas are escalated. The wideband and multiband functionality in antennas is a fundamental requirement nowadays to equip with the communication systems so that it can utilize the space effectively to increase portability and satisfy the standard operating frequency bands [1-3]. The microstrip antennas are being increasingly used in communication systems since they inherently got some promising preferences other than conventional antennas while considering size, cost, manufacturing process, durability and conformability [4]. On the other hand, intrinsically the microstrip patch antennas also suffer from narrow bandwidth which in turn deteriorates the performance while covering up some specific bands. The review process unfolds numerous patch antennas of various sizes and shapes of radiating patch with a number of dissimilar techniques that proposed in widening the impedance bandwidth. Out of the bandwidth broadening techniques, some can be mentioned here as for example, introducing separate slit lines [5-6], implementing unusual feeding techniques [7-8], integrating metallic strip

Submitted On: June 25, 2013
Accepted On: September 27, 2014

surrounding the radiating patch or some of its parts as parasitic element [9], using thick substrate or higher dielectric substrate [10], embedding array of similar geometric pattern based patch structure named differently as electromagnetic band gap (EBG) [11] and metasurface [12], employing metamaterial [13]. However, not all the above mentioned designs can significantly increase the bandwidth and gain of the antenna. Moreover, the extensive review of the recent articles has revealed the presence of trade-off between the antenna characteristics and the complex structure, time inefficient, cost ineffective antenna designs.

In the recent couple of years, the idea of meandered-stripline-fed patch antenna has gained potential interest among the antenna researchers. This technique is less cumbersome and cost effective in widening the bandwidth of patch antenna [14]. The microstrip-line-fed patch antennas ensure several stunning properties, as for example less radiation loss, low cross-polarization, easy fabrication and integration, no need to use via hole in the existing microstrip technology. Taking the advantage from strip-line-fed, a meandered-stripline-fed circular type patch antenna loaded with slits of similar width has been designed to cover two important frequency bands, namely ultra-high frequency (UHF) band for Radio Frequency Identification (RFID) and lower wireless/ Worldwide Interoperability for Microwave Access (WiMAX) band. A considerable amount of interest has been paid to the RFID system in UHF band due to its organizational and commercial use of its tracking and identification capabilities. In general, the UHF RFID system functions at the bands of Europe (865-867 MHz) and/or North America (902-928 MHz) [15-16]. On the other hand, WiMAX is based upon IEEE 802.16-2004, which is later modified to IEEE Std. 802.16e-2005 and it has different spectrum allocation in different parts of the world based on the standard band 2.3 GHz, 2.5 GHz and 3.5 GHz [17-18].

A new planar microstrip antenna has been proposed in this paper with detail configuration and the process of obtaining optimal design structure where the circular radiating element is loaded with a couple of vertical slots (along the y axis) and fed by meandered stripline structure. To demonstrate and analyze the performance characteristics of the proposed antenna, a physical model has been fabricated with a patch diameter of 38 mm (0.114λ), substrate thickness of 2 mm (0.006λ) and fed by meandering-stripline structure. Through numerous parametric studies, it has been revealed that the appropriate placement of slots on the circular patch along with the advantages of partial ground [19] and meandered-stripline structure can facilitate to attain the extended impedance bandwidth and good radiation properties, which make it suitable for dual-band wireless communication systems like UHF RFID and WiMAX applications.

II. DESIGNING ANTENNA STRUCTURE

The full wave 3-dimensional high frequency electromagnetic structural simulation (HFSS) tool [20] is used for the design and simulation of the proposed meandered-stripline-fed vertical slot loaded circular patch antenna. Like other typical microstrip patch antennas, the proposed antenna contains an SMA connector in its side, a meandered structure microstrip line to feed the radiating patch, a circular type radiating patch introduced with slotline of the same width on top and a rectangular ground plane at the bottom. The meandered-line-fed microstrip patch antenna structure and its associated detail dimensions are given by Fig. 1. The radiating patch is circular type where three types of different vertical rectangular slots of similar width (1.5 mm) are introduced. The radius of the circular patch (R) is chosen as 19 mm (0.057λ) and the length of its narrow rectangular slot lines are 32 mm (L3, L4), 24 mm (L2, L5) and 18 mm (L1, L6) for middle slots, side slots and outer side slots respectively. Therefore, half of the circular radiating patch is symmetrical to the other half along x-axis, thus effectively help to enhance the radiation by cancelling the cross-polarization effect. In between the radiating patch and partial ground plane, a 2 mm thick ceramic filled bio-plastic substrate of relative permittivity (ε_r) 15 is being inserted. Since impedance agreement is considered as very much sensitive to the geometry of the feed arrangement, a parametric study has been performed to find out best choice of meandered structure to feed the patch antenna. The radiating patch is excited by an optimized meandered stripline structure which is also coupled to the SMA connector by impedance matching. The optimal dimensions of the proposed antenna are offered in Table 1.

Table 1: Optimal dimension of the design antenna

Param.	Dim., mm	Param.	Dim., mm
W	41	L	51
W1	7	L1, L6	16
W2	33	L2, L5	24
SW	1.5	L3, L4	32
R	19	*Lg*	5
-	-	*Lf*	5

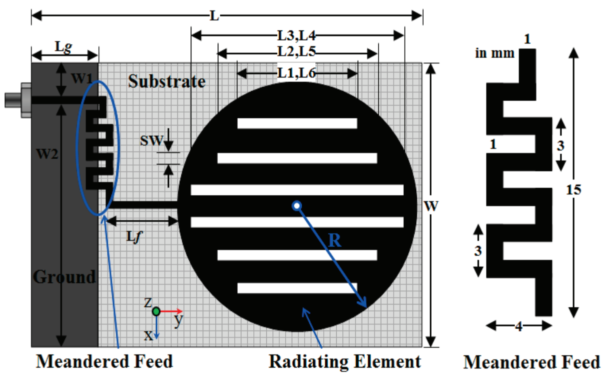

Fig. 1. Geometric configuration of the meandered stripline-fed patch antenna.

III. PARAMETRIC STUDY

The parametric studies are performed on several antenna variables to achieve optimized geometric structure and hence better impedance matching for the microstrip planar antenna. For the parametric studies, the numerical simulations have been done by finite element method (FEM) based commercial 3D simulator HFSS – has well established reputation in terms of accuracy. The parametric studies consider only the cutting slot inside the circular shaped radiating patch and the feeding structure to it. It is already known to the antenna researchers that some of the parameters (e.g., dimension of antenna, feed location) and performances (e.g., gain, radiation efficiency) have an effect on the patch antenna, these are excluded from parametric studies. For better understanding the impact of the parameter on the antenna performance, only one parameter has been picked for investigation while other parameters were left as it is. The Optimetrics engine from HFSS has been utilized successfully by setting up variables to carry out different parametric studies.

On a priority basis, the parametric study is being focused on the numbers of slots inside the circular radiating patch and its placement variation while considering the constant width of 1.5 mm. The graphical presentation in Fig. 2 validates the study and outcome. At the center of the radiating patch, the slots are etched out symmetrically by placing at the same distance from the central line. In this arrangement, the lower frequency is said to be getting closer to the achieved resonant frequency at VSWR less than 2. The symmetrical placement of the two side slots is responsible for the higher frequency band. The outer side slots inside the circular patch significantly affect the excitation, and the resonant frequencies are achieved at 0.9 GHz and 2.5 GHz with VSWR 1.24 and 1.3 respectively.

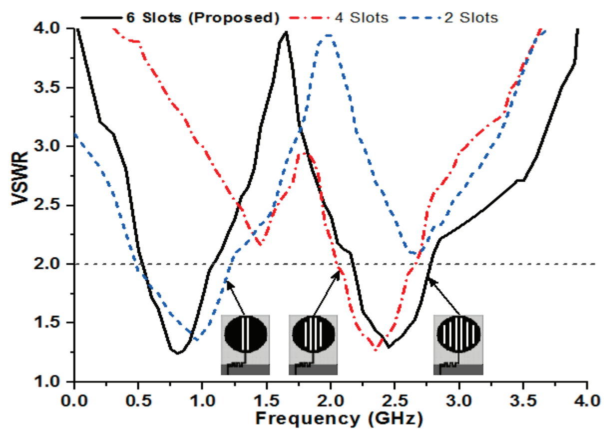

Fig. 2. Simulated VSWR for different numbers of slot inside radiating patch.

The parametric study has extended to analyze the effect of slot width and thus finding the optimal width to attain satisfactory VSWR with broader bandwidth. Figure 3 exhibits the graph for VSWR vs frequency for different width of the slots on circular patch structure. It is clearly understood from the figure that, the slot width of 1.5 mm is optimal for achieving comparatively wider impedance bandwidth and lower VSWR other than the slots of 1 mm and 2 mm width. Further investigations have been performed on the feeding structure to the patch which is responsible to contribute in the bandwidth widening process through good impedance matching. Figure 4 illustrates the antenna performance in terms of VSWR for different feeding arrangement. In the case of the L - strip and straight stripline feed, the return loss at center frequency and bandwidth are close by those of the meander strip feeding.

However, under the situation of 50 Ω impedance matching, the meander stripline feed structure offers the best agreement and exhibits broader bandwidth compared to other feeding method. Additionally, with the assist of partial ground plane the meander stripline structure promotes longer resonant mode by adapting the electric length which play vital role in bandwidth enhancement. The adjustable electrical length for different excitation in the case of meandered stripline feed also liable to produce comprehensible current phase distribution along the proposed antenna which may lead to reduce cross-polarization effect.

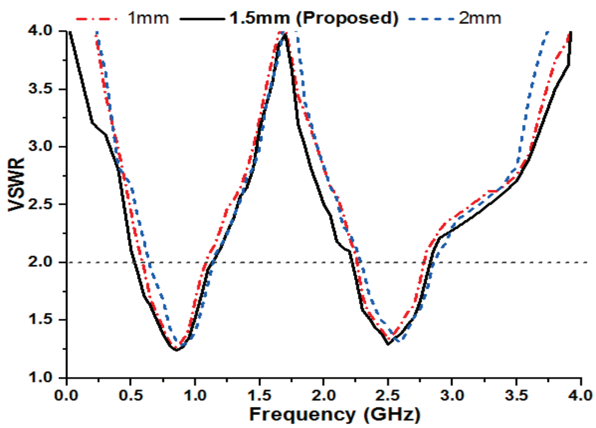

Fig. 3. Simulated VSWR against frequency for different width of the slot.

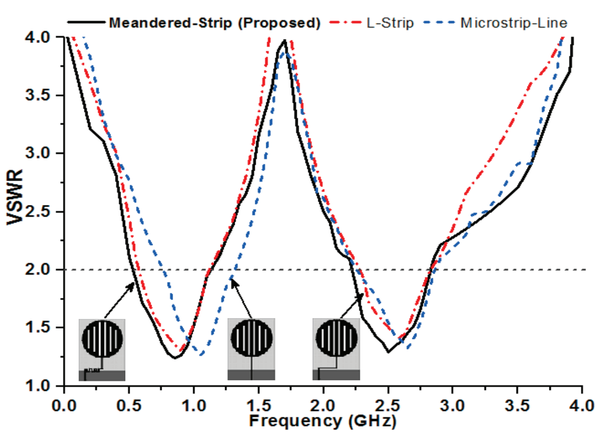

Fig. 4. Simulated VSWR for different feeding structure.

IV. RESULTS AND DISCUSSIONS

The 3D electromagnetic structure solving functionality of FEM based HFSS simulator has been utilized for performing numerical analysis and finding the optimized structure of the meandered-stripline fed circular type microstrip patch antenna. The accomplishment of the parametric study gives an optimized geometric structure of the proposed antenna, which is realized through in house PCB LPKF prototyping machine to get a physical test model and present in Fig. 5. Afterwards, the antenna parameters have been measured with the help of Agilent's Vector Network Analyzer (Agilent E8362C) in a standard sized anechoic measurement chamber. The simulation and measured antenna parameters have been further evaluated and graphically presented by available software package and computer aided tools.

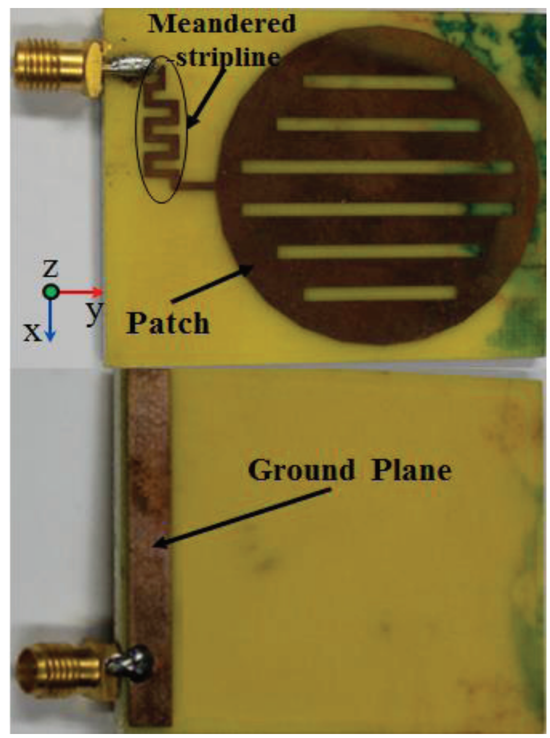

Fig. 5. Photograph for the prototype of the proposed antenna

Figure 6 shows the measured and simulated VSWRs against the frequency of the proposed two band antenna. The graphical output undoubtedly presents an excellent agreement between the simulated and measured VSWR. However, a diminutive deviation can be seen in between the simulated and measured results, which may occur on behalf of the fabrication tolerance affected by thickness uncertainty and/or existed inconsistency in the substrate material. The measured impedance bandwidth (VSWR <= 2) range from 600 MHz to 1 GHz (44.4%) and 2.25 GHz to 2.95 GHz (28%) respectively. It is apparent that the attained bandwidth of the proposed antenna can successfully cover the UHF RFID and 2.3/2.5 GHz WiMAX/WLAN bands.

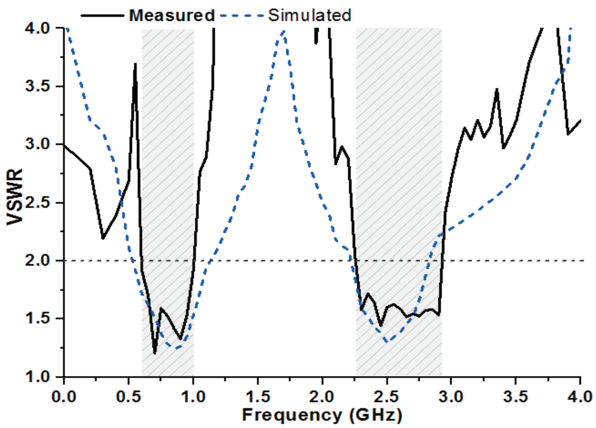

Fig. 6. The simulated and measured VSWR of the proposed meandered-strip-fed patch antenna.

The full-wave electromagnetic simulation software HFSS also make available the distribution of surface currents along the radiating patch and feed line. The proposed antenna further studied in terms of surface current distribution at two of its resonant frequencies, more specifically at 0.9 GHz and 2.5 GHz which are furnished through Fig. 7. At lower frequency of 0.9 GHz, an increased amount of surface current is seen to flow through the lower part of the radiating patch and also nonuniformity of current distribution can be seen along the meandered-stripling-fed structure. The surface current path in this case is less disturbed, which lead to generation of almost homogeneous electric and magnetic fields and thus provides less cross-polarization. Whereas at high frequency of 2.5 GHz, the distribution of surface current along the radiating patch and meandered-stipline-fed structure is almost uniform except the middle stripline of the patch which seems to carry slightly more surface currents. Stronger current distributions are also noticeable at the start and end terminal of the meandered-stripline-fed structure. Furthermore, in comparison to the lower frequency the variation of the current phase along the storylines of the radiating patch are clearly visible. The resulted effect can be validated through radiation pattern where a slight increase of cross-polarization and little discrepancy in E- and H-field can be realized.

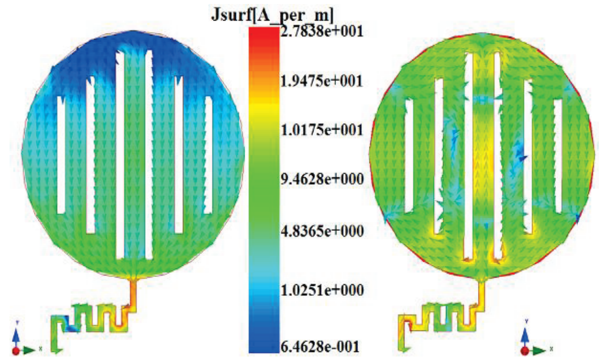

Fig. 7. Distribution of surface current at 0.9 GHz and 2.5 GHz.

The analysis of the proposed antenna performance has further carried out in terms of radiation characteristics. Figure 8 exhibits the far-field radiation patterns in E-plane and H-plane for the frequencies at 0.9 GHz and 2.5 GHz respectively. In the typical case of patch antenna, the radiation pattern in the E-plane is marginally widespread than that of the H-plane which is readily observable from the figure. For lower frequency, the co-polarization patterns for E- and H-plane are almost symmetric and directional. However, in the event of higher frequency the co- and cross-polarization patterns over the off-boresight angles for E-plane are much disturbed due to the fact of abnormal current phase along the length of the antenna. However, the effect of cross-polarization for both E- and H-plane at high frequency is increased to some extent, since the variation of the current phase suppresses the excitation responsible to increase cross-polarization effect. Typically, excitation from higher order modes distorts the electric currents, more specifically near to feed-patch joint which lead to degraded radiation. Use of a meander-stripline-feed essentially diminishes this issue as seen the current distribution patterns in Fig. 7. Through critical analysis, it can be concluded that the designed meandered-stripline-fed vertical slot-loaded circular patch antenna performs well in by providing a nearly conformal radiation pattern radially for operating bands by maintaining low cross-polarization.

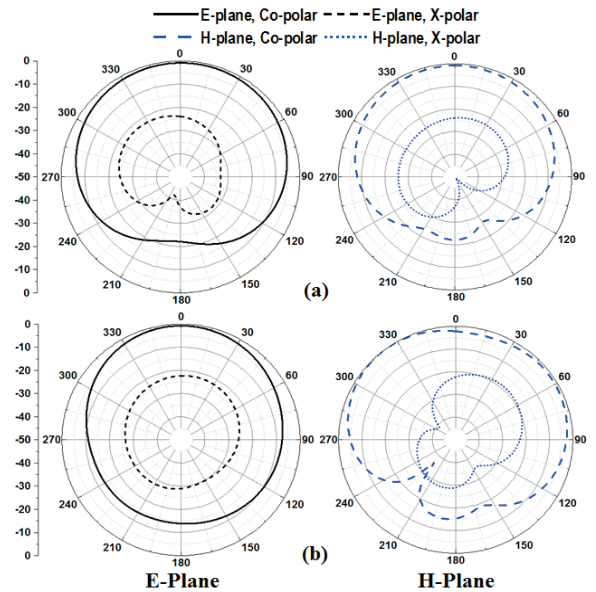

Fig. 8. Radiation patterns for the proposed antenna at: (a) 0.9 GHz, and (b) 2.5 GHz.

It is often typically considered that the antenna performance is being compromised in between the realized gain and operating bandwidth. For comparatively wider bandwidth of the antenna, it is necessary to ensure the measured antenna gain can meet the requirement for specific application. Free-space ranges are used to measure the gain of the designed dual-band antenna by utilizing two identical horn antennas whose gain and radiation patterns are known. Figure 9 shows the measured and simulated gains against the corresponding operating frequency bands. For the lower operating band at 0.6 GHz - 1 GHz the average and maximum gains are -3.34 dBi and -1.18 dBi respectively. Whereas, for the upper band at 2.25 - 2.95 GHz, the average and maximum gain are 3.15 dBi, 4.87 dBi and 2.85 dBi respectively, and this is why directivity of the designed antenna increased at high frequency. Figure 10 exhibits the radiation efficiency of the proposed antenna. It has been observed that the maximum radiation efficiency 76.65% is achieved at a lower UHF RFID band with average efficiency over the band is 63.03%. On the contrary, for WiMAX/WLAN band the achieved average and maximum radiation efficiencies are 82.02% and 92.6% respectively.

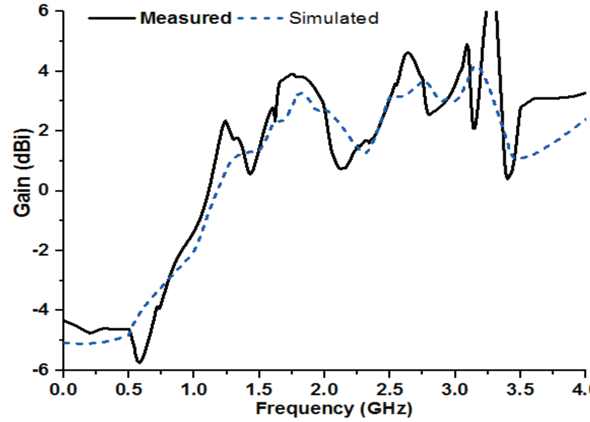

Fig. 9. Simulated and measured gain of the proposed antenna.

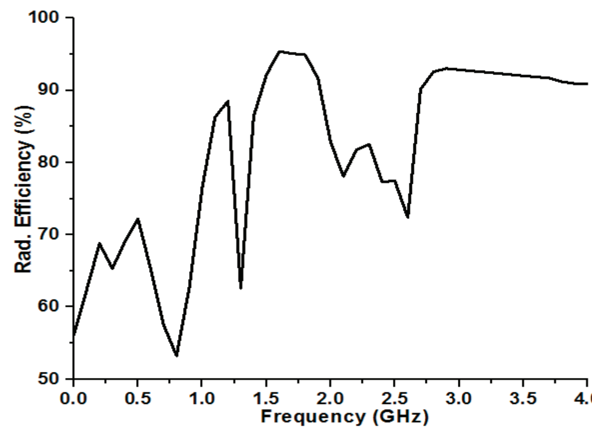

Fig. 10. Radiation efficiency of the proposed antenna.

Table 2 presents a concise comparative study between the performances of proposed and some existing antennas. The tabulated data clearly shows that, the proposed antenna is comparatively smaller in dimension with enhanced bandwidth and higher gain. On the contrary, some of the specified antennas have reported a higher gain with compromised fractional bandwidth and dimension. Additionally, these antennas would require more space to accommodate inside small, portable device which is not a preferable situation.

Table 2: Comparison between the proposed and some existing antenna

Ref.	Overall Dimension (mm^2)	Fract. Bandwidth (%)	Gain (dBi)
Proposed	40x50	44.4, 28	-1.18, 4.87
[6]	50x100	6.26, 8.16	-2.4, -0.64
[8]	40x40	28, 21	1.77, 1.72
[13]	25.4x29.2	1.36, 2.96	-3.5, 1.6
[21]	108x108	26.2, 22.2	3.5, 4.2

V. CONCLUSIONS

In this article, we have proposed a new slotline loaded circular shaped microstrip planar antenna with meandered-stripline feed structure. The design parameters of the antenna have been critically analysed through EM simulator to achieve the optimum geometric structure for the prototype antenna. The final optimized dimensions of the antenna is of 0.114λx0.114λx0.006λ, which is fabricated using in-house machineries. The experimental results from the fabricated antenna prototype represent that enhance bandwidth have been achieved for using the partial ground assisted meandered-stripline fed structure. The achieved fractional bandwidth of 44.4% (0.6-1 GHz, resonant frequency 0.9 GHz) for the lower band and 28% (2.25-2.95 GHz, resonant frequency 2.5 GHz) for the upper band with respect to their corresponding lower frequency cut at VSWR=2. The proposed antenna design with its optimal dimensions offer good agreement between the simulated and measured data. The antenna performance and communication quality in terms of bandwidth, radiation and gain, the proposed dual-band planar antenna comply with the requirements from UHF RFID and WiMAX/WLAN applications.

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