Professional paper

Informacije MIDEM
Journal of Microelectronics,
Electronic Components and Materials
Vol. 43, No. 1(2013), 74 – 80

Investigation of a Compact Dual-band Handheld RFID Reader Antenna

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Abstract: The design of a dual band operational compact antenna is investigated in this paper for RFID handheld reader application. The dual frequency operation of the antenna is achieved by using a U-shaped slot on the patch and a L-shaped slot in the ground plane. The shorted wall connecting the patch and the ground plane plays a vital role to make it compact. The overall dimension of the patch is 20×36 mm2 which is very compact with respect to the operating frequencies. Moreover, the air gap between the patch and the ground plane provides the circuitry to be embedded within the antenna. The antenna achieves a -10 dB impedance bandwidth of 12 and 10.4% respectively covering all sub-bands of universal UHF and ISM 2.4GHz bands. The antenna is seen to operate with linear polarization with stable omni-directional radiation characteristics in both E- and H-planes.

Key words: Dual band, RFID, shorted wall, compact antenna, handheld.

Raziskava kompaktne dvopasovne ročne DFID bralne antene

Povzetek: V članku je predstavljen načrt dvopasovne kompaktne antene za uporabo v ročnih RFID bralnikih. Delovanje antene pri dveh frekvencah je omogočeno s pomočjo U reže na krpici in L reže na ravnini mase. Kratka stena, ki povezuje krpico z ravnino mase igra pomembno vlogo pri kompaktnosti naprave. Celotne dimenzije krpice so 20×36 mm2, kar je zelo majhno glede na frekvenco delovanja. Dodatno zračna reža med krpico in ravnino mase vzpostavlja vgrajeno zanko z anteno. Antena dosega -10 dB impedančno pasovno širino 12 in 10.4 % pri pokrivanju vseh pod pasov pri UHF in ISM 2.4 GHz. Predvideno je, da antena deluje z linearno polarizacijo in stabilno vsesmerno radiacijsko karakteristiko v E in H ravnini.

Ključne besede: Dva pasa, RFID, skrajšana stena, kompaktna antena, ročna naprava.

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1. Introduction

Radio frequency identification (RFID) systems have been widely used recently in supply chain management by retailers and manufacturers to identify and track goods efficiently [1]. RFID system provides a wireless detection of the goods which usually consists of reader/writer and tag. Typically, the reader transmits RF power to the tag, which then sends a unique coded signal back to the reader, while the writer can change the information contained within the tag. Therefore, in the reader side the antenna needs to be carefully designed to ensure good performance of the RFID system. The system can be operated in different frequency bands in accordance to the standard regulation. Several frequency bands have been assigned to the RFID applications, such as 125 kHz, 13.56 MHz, around 900 MHz, 2.45 and 5.8 GHz [2].

There is not a single, universal RFID frequency that is capable of working in all applications. Different RFID technologies will be complementing each other, each used in applications that most suit its characteristics. For example, UHF is best used in logistics, baggage tagging and case pallet tracking, where longer read range is needed, whereas HF is best used in item-level tagging and in areas where liquid and metals are involved but HF may fail in the read range category and speed. The challenge for this technology is to increase the read range and its flexibility to environmental factors for different applications [3, 4].

Recently, UHF and ISM bands are becoming more attractive because of their suitability and cost effectiveness for various applications. UHF RFID tags dominate the market due to their salient features of long distance and high speed reading, more data storage capability and being more immune to environmental factors such as liquids and human presence [5, 6]. However, there is not a specific UHF range accepted worldwide for the RFID applications. Spectral allocation for UHF RFID applications by governments varies from one country to another [7].

902 – 928-MHz band in North and South of America
(840 - 955 MHz) in Asia-Pacific region:
- 840.5 – 844.5 and 920.5 – 924.5 MHz in China
- 865 – 868 MHz, 920 – 925 MHz in Hong Kong
- 919 – 923 MHz in Malaysia
- 866–869 and 920–925 MHz in Singapore
- 952–955 MHz in Japan
- 865 – 867 MHz in India
- 920 – 928 MHz in Taiwan
- 908.5 – 910 MHz, 910 – 914 MHz in Korea
- 920 – 926 MHz in Australia and so on

866 – 869 MHz in Europe

On the other hand, the advantage of using ISM bands like 2.4GHz (2.40-2.483GHz) is a higher range with high data transfer rate, but the drawback is that a clear line of sight from the antenna to the tag should be assured [8]. However, as the operating frequency of RFID systems rises to the microwave region, the reader antenna design becomes more acute and critical. In this circumstance, microstrip antennas are very attractive choice because of their well-known advantages of low profile, light weight, conformal to carrier and easy production [9-14].

Nevertheless, a dual band antenna is capable of replacing two single band antennas. For that reason, more designs of multi-band antennas for RFID readers were presented to fulfill the requirement of the RFID industry. However, in order to fulfill the requirements of the handheld RFID application, the antennas of the devices must be compact and compatible to the circuitry. These antennas are either too big to be incorporated in the handheld RFID reader [15-20] or needs an extra space on the PCB board of the device that might not be covered by the circuitry [21].

In this paper, a compact dual-band handheld RFID reader antenna has been proposed in which the radiating patch is at the top portion of the handheld device and can be very suitable to be adjusted with the circuitry of the reader. A combination of shorted wall patch technique [22] with a U-shaped slot on the patch and an L-shaped slot in the ground is used to achieve the compactness and dual-frequency operation. The proposed antenna is able to operate in almost all the frequencies of universal UHF and ISM 2.4GHz frequency bands.

2. Design of the antenna

The configurations of the proposed antenna are illustrated in Figures 1, 2 and 3. The antenna primarily consists of four components: the printed ground plane, the air substrate, the printed patch with a Superstrate and the shorted wall. The ground plane is assumed to be the common ground for the circuitry and other internal components of the handheld RFID device. The area of the Ground plane is selected to be 40×100 mm^2, which is capable to be embedded in any handheld RFID device. The ground plane is fabricated on a glass-reinforced epoxy resin material namely FR4 with dielectric constant of 4.6 and loss tangent of 0.02. The thickness of FR4 material is 1.6mm which is chosen due to its availability. An L-shaped slot is etched from the ground. This slot provides the required impedance matching to achieve both the frequency bands accurately.

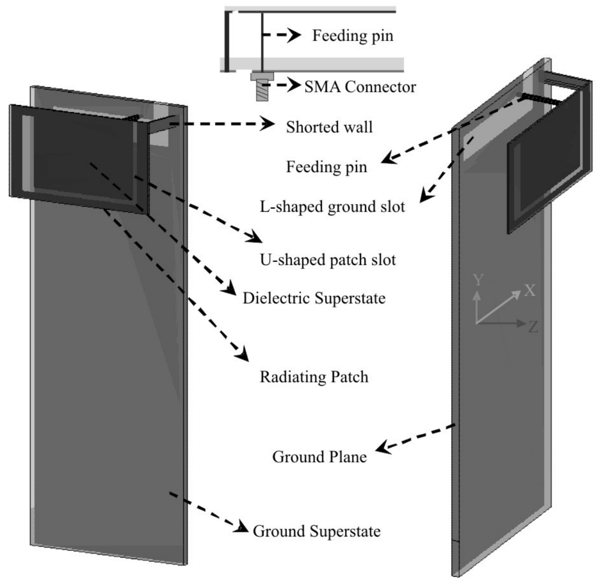

Figure 1: Perspective and side view of the proposed antenna

Air is used as the substrate of the proposed antennas because the free space between the ground plane and patch will be useful to the circuitry of the device. The thickness of air used in this antenna is of 10 mm. A Rogers RO4003 Substrate with dielectric constant of 3.38 and loss tangent of 0.0027 is used as a superstrate to design the patch of the antenna. It is worth mentioning that this 0.508 mm thick Rogers superstrate acts like a protecting cover for the antenna patch section which might prevent it from the abnormal weather condition and environmental hazards. The antenna is fed with as 50Ω SMA connector. The middle pin of the SMA connector is connected to the top patch and the surrounding ground connection is connected to the ground plane of the antenna.

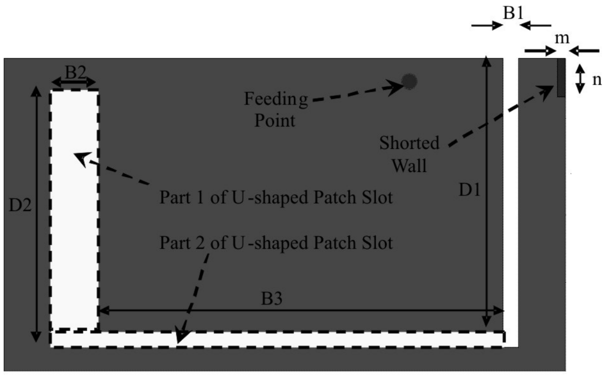

Figure 2: Top view of the patch section

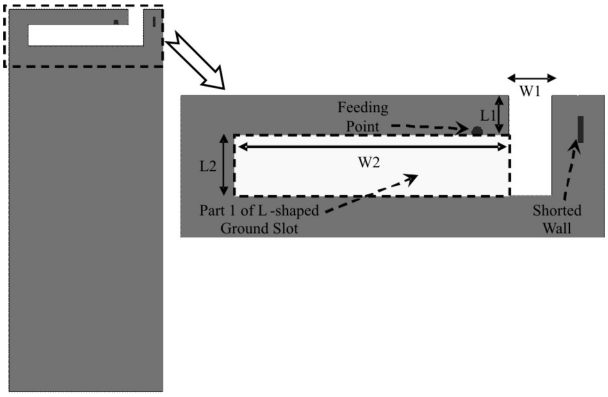

Figure 3: Top view of the ground plane and an enlarged view in the inset

A U-shaped slot is cut on the patch structure. This U-shaped slot is vitally important to achieve the UHF band operation. The overall dimension of the patch is 20×36 mm^2 which is very compact with respect to the operating frequencies. The shorting wall is assumed to be a copper strip with length of 11.6 mm and width of 2.5 mm. The thickness of the strip is 0.5 mm which is soldered at the top corner of the patch and connects it with the ground plane. The shorted wall is mainly responsible for the compactness of the antenna and to be compatible for the handheld application [22]. The optimized values of the antenna parameters are given in Table 1.

3. Parametric analysis

Parametric analysis has been performed to facilitate an elaboration of the design and optimization processes for readers. Various parameters are investigated to examine the effects of the antenna parameters on return loss as well as the impedance bandwidth of the antenna. This study covers the influences of varying lengths of the U- and L- shaped slots and dimensions the shorting wall. For better convenience of the effect on the performance of the antenna upon changing the parameters, only one parameter is changed at a time, while keeping others unchanged [17] Method-of-moment (MoM) based full wave commercially available electromagnetic software IE3D is used in for this analysis.

Table 1: Optimized values of the antenna geometry

Name of the parts	Parameters	Values (mm)
Ground Plane	L1	4
	L2	5.5
	W1	4
	W2	26
Patch	D1	17.5
	D2	16.5
	B1	1
	B2	3
Shorted Wall	m	0.5
	n	2.5
Air Thickness	t	10

The dependencies of the resonating frequencies and bandwidth on L- and U- shaped slots are described in Figure 4. It is observed that these slots have the most vital influence on the resonance. When the part 1 of the L-shaped slot is erased, the antenna achieves only one resonance and that falls down between the middle of our desired frequencies. The removal of whole L-shaped ground slot reveals that the impedance matching of the antenna is primarily dependent on it.

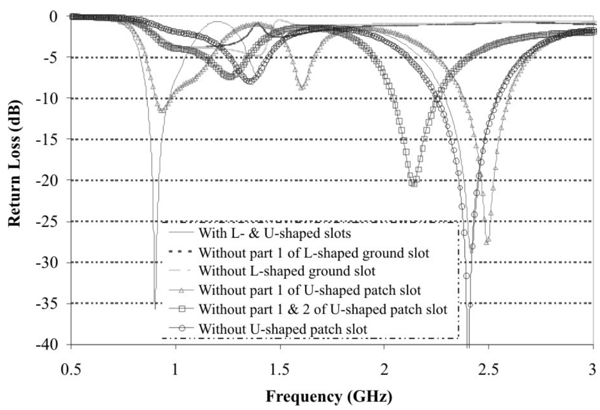

Figure 4: Return losses for the L-, U- shaped slots and various parts of these slots

The antenna can operate in the ISM 2.4 GHz band even the U-shaped slot is not etched on the patch. But the

U-shaped slot and various parts of are very influential on the UHF frequency band and the dimension of the U-shaped slot defines the lowest operating frequency.

In Figure 5 and 6, the effect of various dimensions of L-shaped ground slot is shown. Increasing the value of L1 increases the first resonating frequency point and decreases the resonating point from ISM band; while in both cases the return loss tends to decrease. However, the increments of the value of W1 slightly change the bandwidth of UHF band, but drastically change the ISM band of operation. Therefore, it is important to have a close eye on these two parameters at the time of optimization.

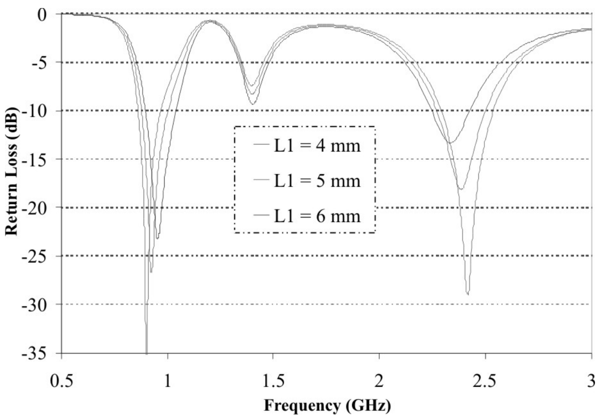

Figure 5: Return losses for different values of *L1*

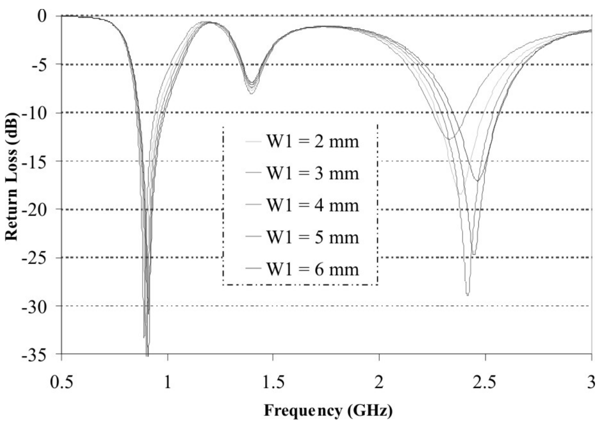

Figure 6: Return losses for different values of *W1*

From Figures 7 and 8, it is evident that the dimensions of L2 and W2 affect the resonating frequencies very much. When the valued of L2 and W2 are increased from the optimized ones, both the resonating frequencies for UHF and ISM bands decreases to some lower frequencies. This might be because of the increment of current paths with the increase of L2 and W2 values.

The lengths D1 and D2 of the U-shaped patch slot are very important mostly to tune the ISM band of 2.4GHz. From Figure 9, it is seen that, when the value of D1 is

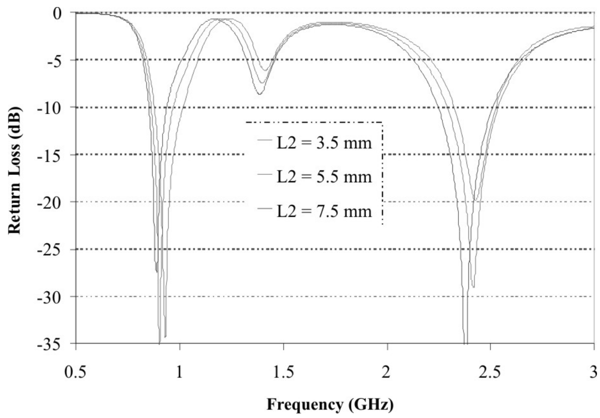

Figure 7: Return losses for different values of *L2*

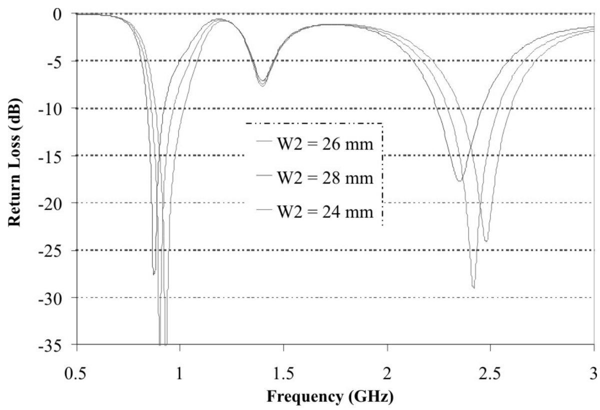

Figure 8: Return losses for different values of *W2*

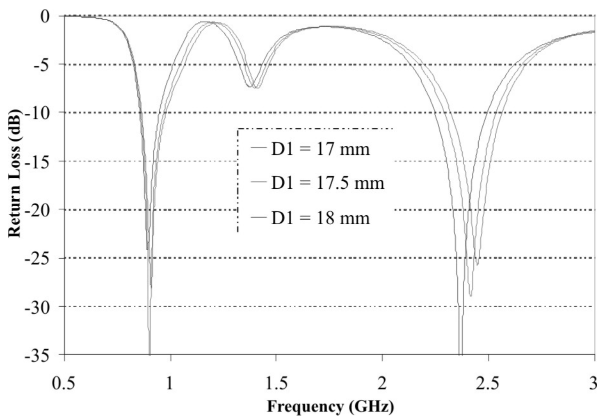

Figure 9: Return losses for different values of *D1*

increased from the optimized value, it provides higher impedance matching. As a result, the antenna attains lower frequencies for ISM band and vice versa. However, the increment of D2 produces some degenerative matching for the antenna, shown in Figure 10. So in this case, the resonating frequency point for ISM band decreases, even though the current path increases. This proofs that the antenna optimization of this antenna is a matter of observation on the impedance matching rather than merely calculating the length of resonating current path. Figure 11 exhibits the dependencies of the return loss on the value of B1. It is vivid that slot width B1 has only influence on the UHF frequency band. The bandwidth and resonating frequency tends to increase with the increment of the value of B1, while the ISM band remains almost unchanged. However, the value of B2 does not have vital effect of the return loss characteristics of the antenna and so it is not mentioned here.

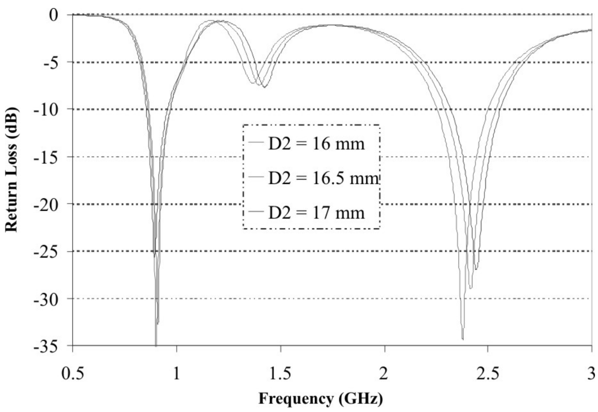

Figure 10: Return losses for different values of *D2*

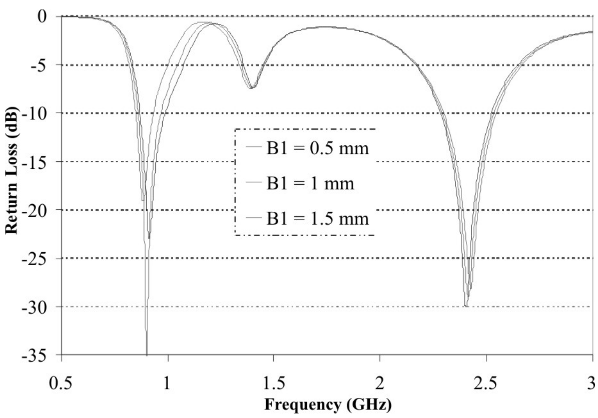

Figure 11: Return losses for different values of *B1*

Lastly, the influence of the shorted wall has been observed. Figure 12 demonstrates that the width, *n* of the shorting wall is very influential for the impedance matching of the ISM band. With the increase of the width, *n* the resonating frequency tends to increase and vice versa. However, the thickness, *m* of the shorting wall does not involve draining much current from the patch to ground. No change of return loss is observed when varied from the optimized value of 0.5 mm and so is not mentioned here.

4. Antenna performances

Figure 13 illustrates the return loss of the proposed antenna. It is observed that the antenna is capable to operate in UHF and ISM 2.4GHz RFID bands. In the lower band, the antenna operates from 860 to 970 MHz (110 MHz) which is equivalently 12% with respect to the center frequency, 915MHz of the operating band. This resonance covers almost all the frequencies of the universal RFID operation. The readings of the return loss are taken in reference to -10dB level. Moreover, the antenna achieves a bandwidth of 250MHz (from 2.29 GHz to 2.54 GHz). This ISM band has an impedance bandwidth of 10.4%, which entirely covers the required band of RFID application.

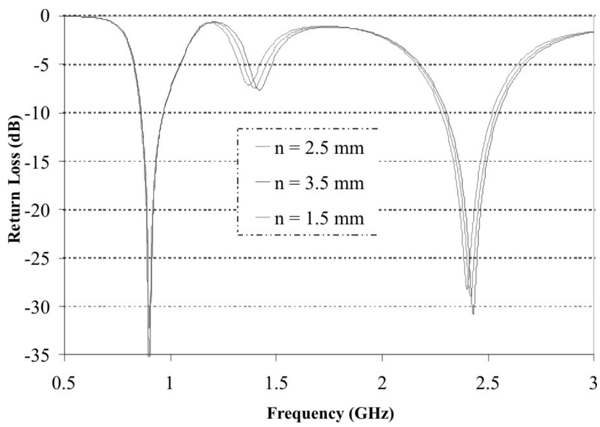

Figure 12: Return losses for different values of *n*

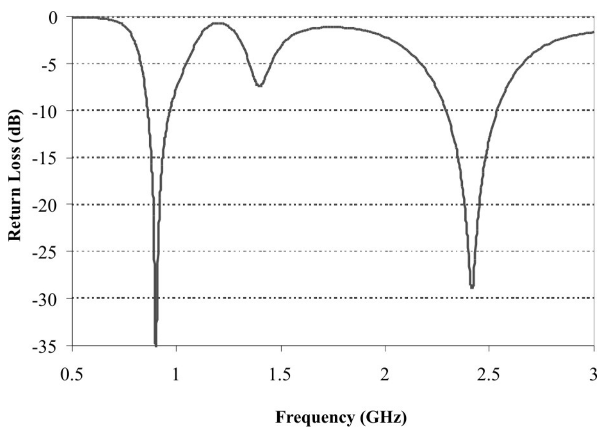

Figure 13: Return loss of the proposed antenna

The maximum gain obtained from the antenna is shown in Figure 14. The antenna is capable to provide a maximum gain of 1.9dBi in the UHF band. In case of the ISM band the antenna attains a peak gain of 2.5dBi at approximately 2.5GHz. The values of the gains are literally enough for short-range handheld operation. The radiation efficiency of the antenna roams around 80% and 75 % respectively at UHF and 2.4 GHz ISM bands. Thus the antenna can communicate efficiently with the surrounding RFID tags.

The E- (XZ) and H- (YZ) plane radiation patterns of the proposed antenna for 900MHz and 2.4GHz is depicted in Figure 15. In the higher ISM band the radiation patterns are a bit distorted, when compared with those the lower UHF band. This can be imputed to the higher harmonics generated by the antenna in the higher frequencies. However, from the polar plots it is evident that the antenna is able to direct the maximum radiation to the boreside (angle = 0 degree) in both the functional bands.

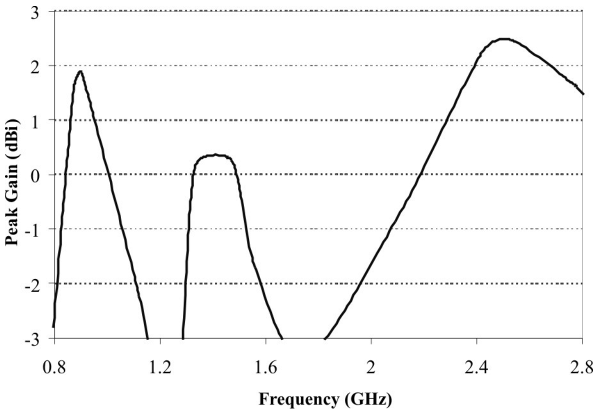

Figure 14: Maximum gain of the proposed antenna

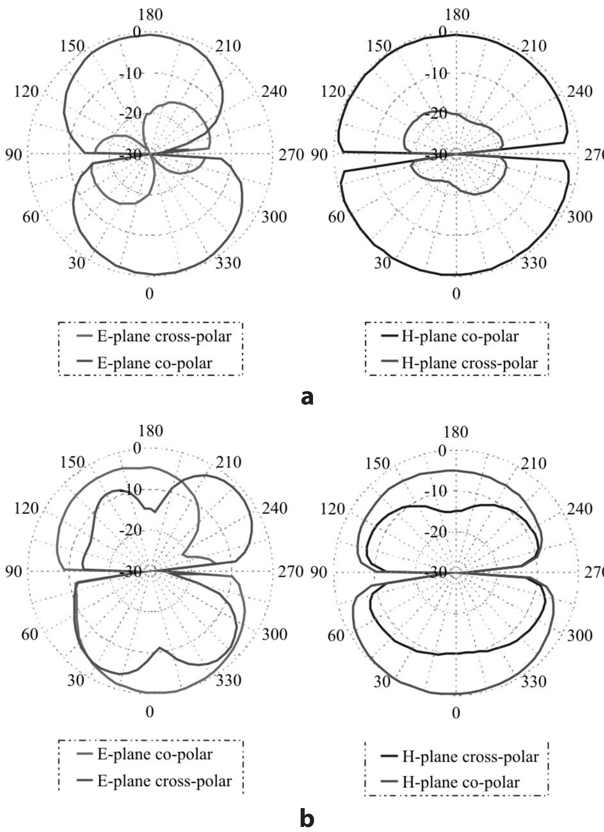

Figure 15: E- (XZ) & H- (YZ) plane radiation patterns of the proposed antenna (in dB unit) at (a) 900MHz and (b) 2.4GHz

Conclusion

A compact RFID antenna for handheld application is presented in this paper. The antenna is able to operate in both UHF and ISM 2.4 GHZ bands. The dual frequency operation of the antenna is achieved by using a U-shaped slot on the patch and a L-shaped slot in the ground plane. The shorted wall connecting the patch and the ground plane plays a vital role to make it compact. The overall dimension of the patch is 20×36 mm^2 which is very compact with respect to the operating frequencies. Moreover, the air gap between the patch and the ground plane provides the circuitry to be embedded within the antenna. The suggested antenna shows good performances in terms of return loss with a -10-dB impedance bandwidth of 110 MHz (860–970MHz) in UHF band and 250 MHz (2.29–2.54 GHz) in ISM band. The functional bands are quite capable of operating in almost all the frequencies used for universal UHF and ISM bands. Moreover the antenna provides good radiation characteristics, which makes the antenna a suitable candidate for the handheld short-range applications.

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Arrived: 17. 12. 2011
Accepted: 6. 03. 2013