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# A Compact Wideband Patch Antenna for Ultra High Frequency RFID Tag

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Original scientific paper

A compact and simple patch antenna for ultra high frequency band is current demand for RFID tag. By embedding a pair of symmetrical key-shaped slot near the non-radiating edge of the rectangular patch, a new adjacent resonant mode close to the fundamental mode is excited to form a wide half-power impedance bandwidth (Return loss  $\geq 3$  dB) of 122 MHz to cover the entire frequency range of ultra high frequency RFID operation (860-960 MHz). The structure of the antenna is completely planar without any cross or multi-layered construction thus it provides ease of fabrication and reduced cost. Performance of the antenna is evaluated by using a commercial electromagnetic simulator, Ansoft HFSS v13. Simulation results demonstrate that the antenna is able to perform considerably well when mounted on different size of metallic plate as well as in free space.

**Key words:** Patch Antenna, Planar Antenna, RFID, UHF Band

**Kompaktna širokopojasna patch antena za ultra visoki frekvencijski RFID tag.** Kompaktna i jednostavna patch antena za ultra visoki frekvencijski pojas potrebna je za RFID tag. Ugrađivanjem para simetričnih priključaka u blizini kuta pravokutne antene, koji nije izložen radijaciji, pobuđen je novi rezonantni mod u blizini fundamentalnog moda kako bi se formirao širok pojas od pola snage od 122 MHz koji pokriva cijeli visokofrekvencijski pojas RFID tehnologije (860-960 MHz). Struktura antene je potpuno planarna bez križanja i slojeva te je kao takva jednostavna za proizvodnju i smanjenog troška. Svojstva antene procijenjena su korištenjem komercijalnog elektromagnetskog simulatora, Ansoft HFSS v13. Simulacijski rezultati pokazuju dobre značajke antene kada je montirana na metalne ploče različitih dimenzija ili kada je samostalna.

**Ključne riječi:** patch antena, planarna antena, RFID, UHF pojas

## 1 INTRODUCTION

In recent years, radio frequency identification (RFID) technology has been utilized for numerous applications in various sectors such as supply chain management, logistics, vehicles tracking, toll collection, smart home, real time location service (RLTS), healthcare and so on [1-3]. With new ingenious applications employing the technology are introduced every day and this trend will steadily continue for a foreseeable future. RFID has distinct advantages over the conventional barcode technology such as, non line of sight to operate, capable of multiple read or write simultaneously and the ability to track the hidden tag. In general, RFID is a technology to automatically identify or track an object that is attached with a tag (or transponder) using radio frequency (RF) signal. Typically, tag is made of an antenna and integrated microchip. The information, normally the object's identification number stored inside the microchip is read by a reader (or interrogator) when the object is within the interrogation range. The

reader sends the information received from the tag occasionally to a host computer or network for post-processing [4].

RFID system can be classified into several categories based on its operating frequency band, tag power source and the protocol used to govern its communication. There are four main operating frequency bands in RFID which are low frequency (125-134k Hz), high frequency (13.56 MHz), ultra high frequency (860-960 MHz) and microwave (2.4 GHz) [5-6]. Selection of operating frequency is mainly influenced by the requirement of the application. Low frequency (LF) and high frequency (HF) bands in RFID offer secured communication due to close contact operation while ultra high frequency (UHF) band system is able to provide longer communication range with high data rate. The communication between tag and reader for LF and HF systems is realized by quasi-static magnetic flux coupling between tag and reader coils while UHF and microwave systems use electromagnetic wave to interact [7].

With pressing need to reduce the cost of installation, tag needs to be designed as cheap as possible. As such, most of the RFID applications adopt passive tag that operates without on board power source. The power needed for tag chip's operation is extracted from the incoming electromagnetic wave sent by the reader [8]. Tag integrated circuit modulates the reflected signal to the reader by changing its front end complex RF input impedance between two states (match and mismatch) according to the stored information. Reader demodulates the signal based on two distinct amount of signal power received. On the other hand, for system requiring long read range or integrated sensor devices, active or semi-active tags are chosen rather than the passive one.

Due to long read range, high communication speed and large storage capacity UHF system is gaining strong interest from numerous sectors compared to LF and HF band systems. Furthermore, by implementing passive tag, significant reduction on the tag cost can be made. It is known that the allocations of operating frequency for RFID in UHF band vary throughout the world. Table 1 shows the regulated operating frequency of some of the major countries [9]. From the table, it can be further summarized that the whole operating bandwidth used in UHF RFID band lies within 860 MHz to 960 MHz. A wide band tag is desirable to operate over the whole spectrum of the RFID UHF band.

As like other wireless systems, antenna plays a pivotal role in determining the overall RFID system performance. Some considerations for designing tag antenna are size, cost, read range and compatibility with the tagged objects [7]. Due to low cost, easily produced and simple construction, modified printed dipoles which exhibit omnidirectional radiation pattern are the most common antenna for UHF RFID tag. However, a typical half-wavelength resonant structure of dipole antenna was deemed big for most of RFID application. In order to reduce the size to conform to the requirement, a meandered dipole antenna has been proposed by [10]. The increase in electrical current path permits the reduction of the physical length of the antenna. A folded dipole antenna which exhibits even smaller size was presented by [11].

Although many variant of printed dipole antenna has been proposed, most of them do not perform well when mounted on metallic objects. It has been observed that dipole antennas suffer performance degradation when used for this type of application thus limits its potential for metallic application. The effects of these undesired phenomena were thoroughly studied in [8, 12]. This major limitation is due to cancellation of the incoming electromagnetic wave by the reflected signal at the boundary between the tag and the attached objects thus shifting the resonant frequency, degrading the impedance matching, lowering the radiation

Table 1. Regulatory allocation for RFID operation in the UHF band

Region/Country	Operating frequency, $f$ (MHz)
North America	902-928
Europe	865-868
China	917-922
Japan	916-921 & 952-956
Australia	918-926
Hong Kong	865-868 & 920-925
Taiwan	922-928

efficiency and distorting the radiation pattern.

To mitigate the problem, one of the most common solutions is by using a spacer to separate the tag from the metal surface which provides constructive interference between the incoming and reflected wave. However, the introduction of the spacer would contribute bulky structure. The idea of using grounded antenna such as planar inverted-F antenna (PIFA) and microstrip (patch) antenna have been presented in various works to eliminate the use of spacer. When attaching these antennas on the surface of metal, the metal surface would act as an extension of the antenna ground plane. Numerous patch shapes has been utilized in microstrip antenna design to achieve specific requirement for RFID application. A compact slotted PIFA has been proposed for mounting metallic objects [13]. However, the antennas have inherit thick structure with narrow bandwidth. Moreover, the fabrication of the antenna is also difficult due to its complex design. An attempt to increase the bandwidth of the microstrip antenna was presented by [14]. Although enhancement on the bandwidth has been achieved, it is not broad enough to cover the entire RFID UHF band.

Wideband microstrip antenna for worldwide operation was presented by [15]. While the wideband characteristic has been realized, the antenna is made of two layer structure which contributes to thick dimension at 4.0 mm. A broadband microstrip antenna with inverted E-shaped patch was proposed by [16] with thinner form factor. However, the tag antenna exhibits cross-layered construction due to adoption of shorting strip to electrically connect the patch to the ground plan. Hence, in order to eliminate the complex antenna structure for ease of fabrication and cost reduction, a complete planar low profile antenna was presented by [8]. The proposed antenna can be fabricated by directly printing the metal patch on the antenna substrate without any need of cross or multi-layer construction. This would lead to easy manufacturing of the antenna in bulk. However, the antenna does not possess broadband characteristic for universal operation.

A compact wideband microstrip antenna suitable for mounting on a metallic object is studied. With wideband

characteristics, the antenna is able to operate within the whole frequency spectrum of RFID UHF band. Furthermore, the antenna inherits planar profile without any cross or multi-layered structure which would ease its fabrication.

## 2 MATERIALS AND METHODS

The antenna design methodology for UHF band RFID tag is explained in [7]. One of the most challenging aspects in designing tag antenna is to realize the conjugate match between the complex input impedance of the antenna and the microchip to ensure sufficient power is delivered to tag IC. The reflection coefficient at the input terminal of the tag antenna is shown in Equation 1 [17]:

$$\Gamma = \frac{Z_{chip} - Z_A}{Z_{chip} + Z_A} \quad (1)$$

where, the antenna input impedance,  $Z_A = R_A + jX_A$  and the microchip input impedance,  $Z_{chip} = R_{chip} + jX_{chip}$ . The power reflection coefficient,  $\tau$ , can be determined by Equation 2 [13]:

$$\tau = |\Gamma|^2 = \frac{4R_{chip}R_A}{|Z_{chip} + Z_A|^2} \leq 1 \quad (2)$$

In addition to the above parameter, return loss,  $R_L$  is also used to describe reflection and mismatch between the antenna and the tag chip [18]. Return loss can be defined as the negative of the reflection coefficient expressed in decibels as shown in Equation 3:

$$RL = -20 \log_{10} |\Gamma|_{dB} \quad (3)$$

To further investigate the effects of complex impedance matching to the performance of the RFID system, the Friis free space equally [13] is used to determine the maximum read range,  $d_{max}$  along the  $(\theta, \varphi)$  of a given system as shown in Equation 4:

$$d_{max}(\theta, \varphi) = \frac{c}{4\pi f} \sqrt{\frac{EIRP_R}{P_{th}} (1 - \tau) G_{tag}(\theta, \varphi)} \quad (4)$$

where,  $EIRP_R$ ,  $G_{tag}(\theta, \varphi)$ ,  $P_{th}$  and  $\tau$  are the effective power transmitted by the reader, tag antenna gain, IC's minimum threshold power and polarization mismatch between reader and tag antenna respectively. By assuming the polarization of the tag antenna is matched to the reader antenna, it is found from the Equation 4 that the read range of the system can be improved by improving  $\tau$  and the antenna gain,  $G_{tag}$  while other parameters are mostly restricted by local legislation. In most cases, the maximum read range indicates the overall system performance along

with the bandwidth and radiation pattern of the antenna. In this research, major focus is given to optimize the power transfer between tag antenna and its IC for the whole range in UHF band for realizing wideband operation.

The structure and dimensions of the proposed antenna is illustrated in Fig. 1. In order to reduce the cost, inexpensive FR-4 glass-epoxy is chosen as a substrate. The dielectric constant,  $\epsilon_r$  of the substrate is 4.4 with tangential loss,  $\tan\delta$  of 0.02. The large dielectric loss lowers the Q-value of the antenna thus increase the bandwidth at the expense of reduced antenna efficiency. A trade-off among antenna volume, bandwidth and gain are inevitable for designing the tag antenna. The thickness,  $h$  of the substrate is 1.6 mm while the thickness of the copper patch and the ground plane are both 0.0358 mm. A thin substrate is necessary to maintain the antenna's low-profile structure.

For the radiating patch, the rectangular shape was chosen due to its simple form factor and ease of analysis. The resonance frequency,  $f_o$  of patch antenna is controlled by its dimension, dielectric constant and wave mode [19]. These relations are shown in Equation 5:

$$f_o = \frac{c}{2\sqrt{\epsilon_e}} \left( \frac{m}{W} \right)^2 + \left( \frac{n^2}{L} \right)^{1/2} \quad (5)$$

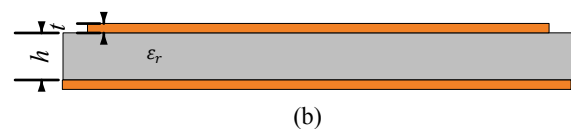
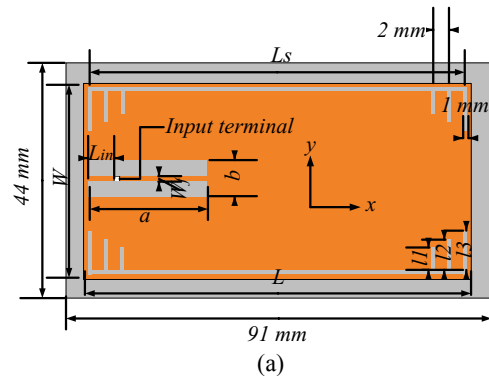


Fig. 1. Structure and dimensions of proposed antenna. (a) Top view and (b) side view

The fundamental mode,  $TM_{01}$  is first excited at resonant frequency of 882 MHz. In order to realize a wideband operation, a pair of symmetrical key-shaped slots is embedded near the non-radiating edges of the radiating patch [20]. Due to the presence of the slot, a second resonant mode,  $TM_{0\delta}$  ( $1 < \delta < 2$ ) can be properly excited close

Table 2. Microchip impedance values for three major countries

Country	Operating frequency, $f$ (MHz)	Microchip impedance, $Z_{chip}$ ( $\Omega$ )
Europe	865-868	9.4-64.26
North America	902-928	9.9-60.4
Japan	952-954	9.5-55.67

to the fundamental mode. The ratio of the frequency of the  $TM_{01}$  mode and  $TM_{0\delta}$  is made low enough to realize a wideband operation thus able to cover the entire UHF band. The adoption of the embedded slot on the main radiating body rather than traditional parasitic elements to excite the adjacent resonant modes reduces the overall size and cost of the antenna.

The proposed antenna has been designed with reference to microchip produced by Texas Instruments, RI-UHF-STRAP-08. Since the impedance of the microchip varies with the frequency and input power, a single impedance value used for the calculation of the impedance mismatch between the antenna and the IC would yield inaccurate result. As such, an extrapolation to the microchip impedance based on three major operating frequencies of the microchip at the lowest input power of -13 dBm was performed to produce a continuous variation of the microchip impedance against frequency [10]. The operating frequencies based on the microchip data sheets are given in Table 2.

To match with the tag chip, a rectangular slot is cut inside the main patch. The feeding line can be inset inside the slot where it is connected to the microchip. Since the feeding line and the radiating patch reside on the same plane, there is no cross-layered structure required which would significantly simplify the fabrication of the proposed antenna. To evaluate and compare the performance of the antenna, a simulation is done using commercial electromagnetic simulator, Ansoft HFSS v13. The performance parameters of half-power impedance bandwidth (return loss,  $RL \geq 3$  dB) and E-field and H-field radiation pattern of the antenna were obtained from the simulation. The commonly adopted 3 dB return loss impedance bandwidth is used to measure the performance of the proposed antenna [14, 16, 21-22]. The simulation of the antenna when mounted on various size of metal plate is then performed to observe the effects of metallic surface on its performance parameters.

### 3 RESULTS

The simulated results of the input impedance of the antenna are shown in Fig. 2. There are two resonant frequencies which are at 882 MHz and 953 MHz. The surface

current density is illustrated in Fig. 3 at both of the resonance modes. Moreover, the radiation patterns at E-plane and H-plane at the resonant frequencies are shown in Fig. 4 and Fig. 5. The investigation of performance of the antenna when mounted on metallic plane was carried out by simulating the antenna structure on top of  $200 \times 200$  mm<sup>2</sup> and  $400 \times 400$  mm<sup>2</sup> metal plate. The resulting half power bandwidths (Return loss  $\geq 3$  dB) for all three scenarios are depicted in Fig. 6. A minimum bandwidth of 122 MHz is observed.

### 4 DISCUSSION

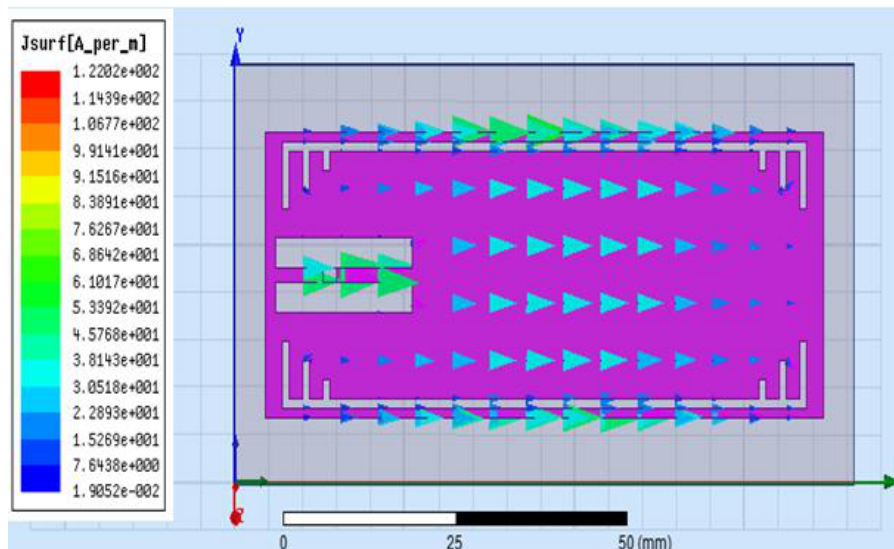
To match the input impedance of the antenna to that of the tag chip, a feed line was embedded inside the rectangular slot cut near the left edge of the radiating body. To obtain good impedance matching for both resonant modes, the resistance of the antenna can be adjusted to desired value by varying the parameter  $a$ ,  $b$  and  $W$  accordingly. Meanwhile, the inductance value is mainly affected by  $L_{in}$  and  $W_f$ . Extensive simulations were carried out to refine the parameter values to present the antenna with the appropriate inductive impedance to cancel the capacitive input impedance of the tag chip. The overall optimized design specification of the proposed antenna is summarized in Table 3.

For bandwidth enhancement, the proposed key-shaped slot embedded near the non-radiating edge is utilized. By properly adjusting the length of  $l_1$ ,  $l_2$  and  $l_3$  the excited patch surface current density of the  $TM_{01}$  and  $TM_{0\delta}$  modes can be properly perturbed, so that the two modes are excited close to each other for wideband operation. The resulting impedance bandwidth is able to cover the entire UHF RFID band to realize a universal tag antenna.

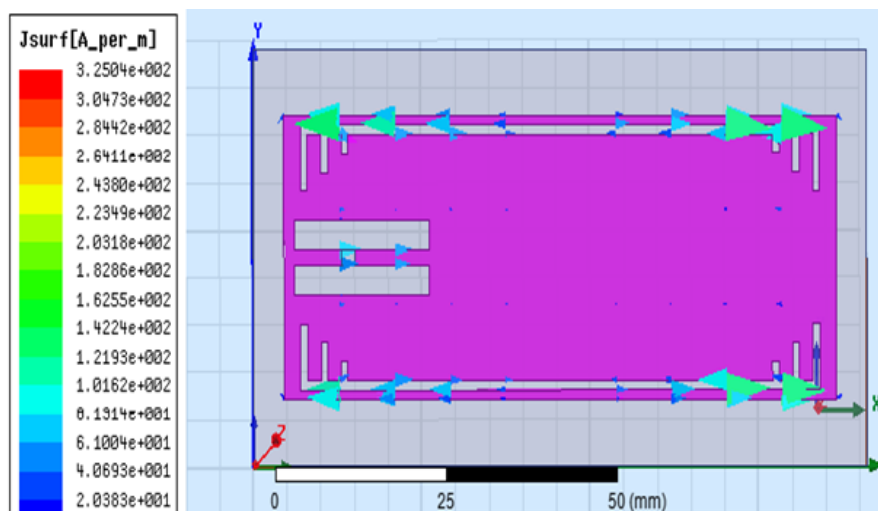


Fig. 2. Simulated results (a) resistance and (b) reactance of the antenna input impedance against the microchip conjugate input impedance

As shown in Fig. 6, the simulated return loss of the antenna at free space and when mounted on metallic plate yield wide impedance bandwidth of over 100 MHz to cover the entire UHF RFID operating band (860-960 MHz). It is expected that the antenna can work anywhere across the globe without the need to individually tune the antenna



(a)



(b)

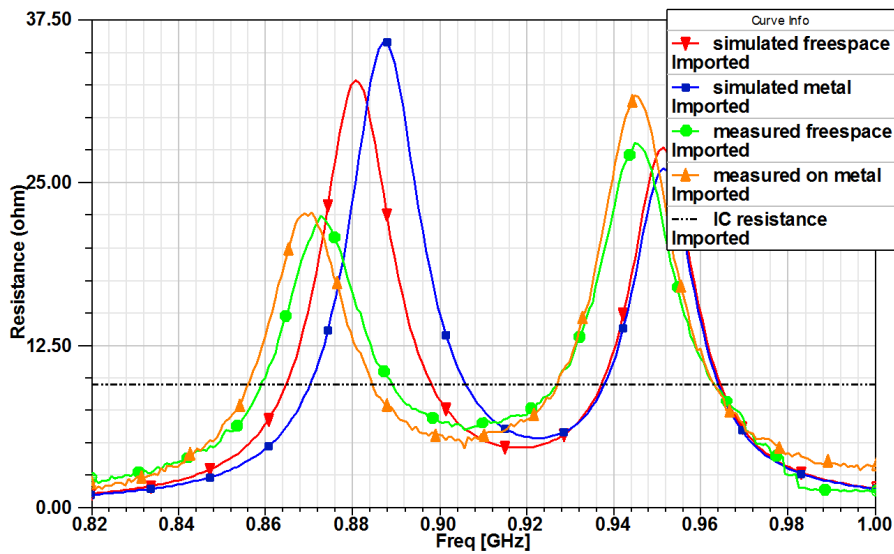
Fig. 3. Surface current distribution of the antenna at (a) 882 MHz and (b) 953 MHz

to suit specific country or region. The effect of metallic plane on the performance of the proposed antenna is very minimal due to its ground structure. The metallic objects where the tag antenna is attached act as an extension of the antenna ground structure giving little effects on its performance parameters like input impedance and radiation characteristic.

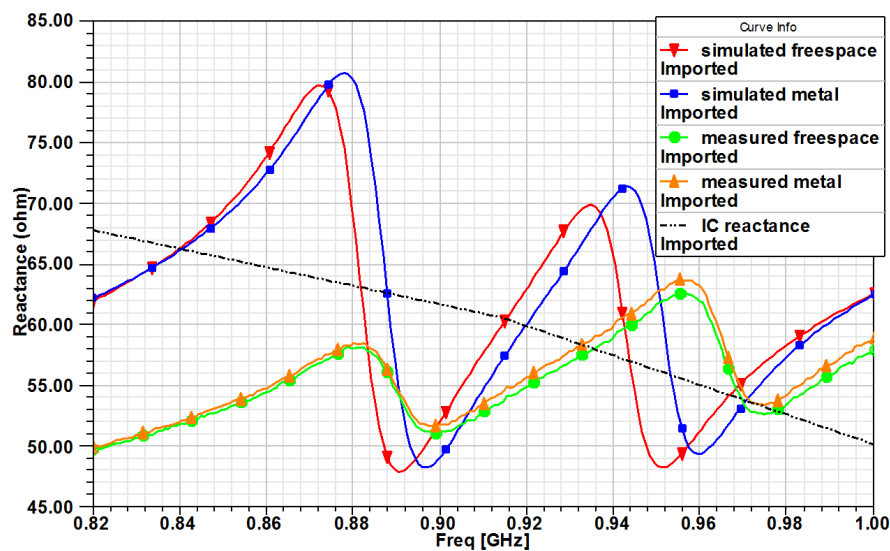
### 5 CONCLUSION

A planar microstrip patch antenna for wideband operation has been designed and simulated. The antenna is

designed for mounting on metallic objects which is normally not achievable using label-typed printed dipole antenna. Due to different operating frequencies of the UHF band RFID system amongst countries, a wideband antenna which is able to cater the entire UHF band (860 MHz-960 MHz) is desirable for universal application. A pair of symmetrical key-shaped slot embedded near the non-radiating edge of the rectangular patch is utilized to excite new adjacent mode close to the fundamental resonant mode thus forming a wide band half-power impedance bandwidth of 122 MHz ( $RL \geq 3$  dB). From the simula-



(a)



(b)

Fig. 4. Normalized E-field radiation pattern at (a) 882 MHz and (b) 953 MHz

tion results, the antenna is able to perform considerably well when mounted on various sizes of metal plate without any significant changes of its performance parameter.

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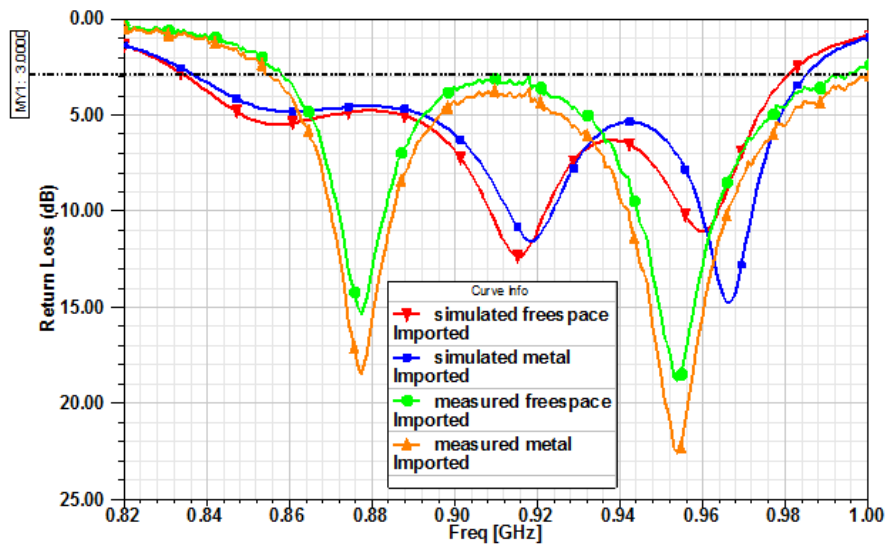


Fig. 5. Normalized H-field radiation pattern at (a) 882 MHz and (b) 953 MHz

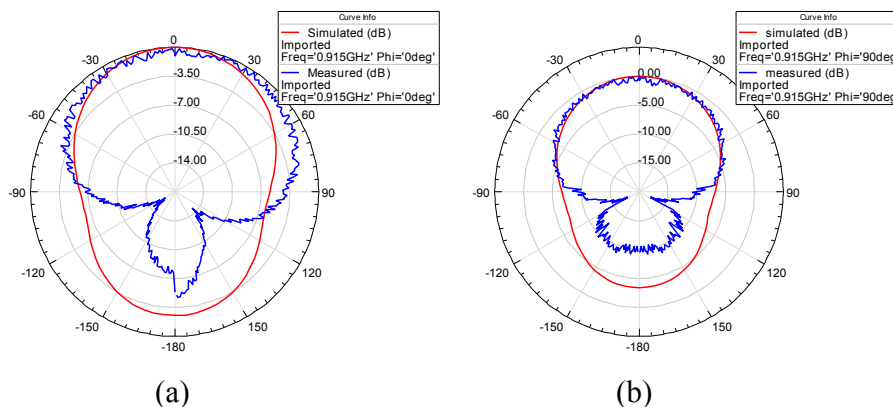


Fig. 6. Simulated return loss of the proposed antenna on free space and mounted on metallic surface

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Table 3. Optimized design parameter of the proposed antenna

Parameter	Value (mm)
$W$	30.0000
$L$	82.0000
$L_s$	77.0000
$t$	0.0358
$h$	1.6.000
$I_2$	2.0000
$I_2$	4.0000
$I_3$	6.0000
$L_{in}$	7.0000
$W_f$	1.5.000
$a$	20.0000
$b$	8.0000
Ground plane	$91 \times 44$

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