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Byunggil Yu
Kwangwoon University

Frances J. Harackiewicz
Southern Illinois University Carbondale, fran@engr.siu.edu

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RFID Tag Antennas Mountable on Metallic Platforms

Byunggil Yu[1], Frances J. Harackiewicz[2] and Byungje Lee[1]
[1]Kwangwoon University
[2]Southern Illinois University Carbondale
[1]Korea
[2]USA

1. Introduction

Auto identification provides information without direct contacts and human intervention errors. Auto identification technology has become very popular in industries, such as the service industry, inventory control, distribution logistics, security systems, transportation and manufacturing process control. So far, the bar code technology leads the auto identification industry, but it has several limitations such as low storage capacity, required line-of-sight contact with the reader, and physical positioning of the scanned objects.
Recently, the radio frequency identification (RFID) has been an attractive alternative identification technology to the barcode. The numerous potential applications of the RFID system make ubiquitous identification possible at frequency bands of 125 KHz (LF), 13.56 MHz (HF), and 860-960 MHz (UHF). The RFID system generally consists of two basic components: the reader and the tag, which communicate with each other by electromagnetic waves. The reader can be a read or a read/write device that uses an antenna to send an electromagnetic wave to wake up the tags. The tag is the data carrying device located on the object being identified. In general, the performance of the tag seriously affects the performance of the whole RFID system. The tag consists of the tag antenna and the microchip. Since good connection and power transmission between the tag antenna and the microchip directly impact on the RFID system performance, the tag antenna has to be designed considering its operating environments or platforms.
As the use of RFID systems increases, manufacturers are pushing toward higher operating frequencies (UHF band) for long reading range, high reading speed, capable multiple accesses, anti-collision, and small antenna size compared to the LF or HF band RFID system. As the operating frequency of the RFID system becomes higher, the major part of the RFID system that mostly affects the ability to read the tag is the antenna.
There are several possible antenna types which can be used for RFID tags in this frequency band. The dipole types of antennas such as folded dipoles and meandered dipoles are used in many applications since they can be printed on a very thin film. However, when they are mounted on the metallic objects, the antenna performance is seriously decreased because of the reactance variation on the antenna impedance. Particularly, the UHF band RFID system is a passive system where a tag does not contain its own power source. Therefore, the reader

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antenna sends a radio signal into the air to activate the tag, then listens for a backscatter from the tag, and reads the data transmitted by the tag. Passive tag antenna must be designed to transmit maximum power to the microchip without possible losses. Therefore, near perfect impedance matching is required between the tag antenna and the microchip. Designing a passive tag antenna matched with the complex microchip impedance is the most challenging factor, since a microchip has very high Q (quality factor) due to its small resistance and large capacitive reactance. Also, the impedance of an RFID tag antenna varies when it is mounted on different objects. Especially, metallic objects strongly affect the antenna performance by lowering the tag's efficiency. Therefore, tag antennas have to be designed to enable tags to be read near and on metallic objects without severe performance degradation. In order to obtain stable antenna performance on various metallic platforms, minimizing the effect of the metallic supporting object is meaningful work. In this chapter, several types of antennas which are mountable on metallic platforms are introduced and analyzed.

2. Electromagnetic waves near metallic platforms

An RFID system communicates by electromagnetic waves. When designing the RFID tag antennas mountable on metallic platforms, it is very important to understand the behaviour of the electromagnetic fields near metallic surfaces since the antenna parameters (the input impedance, gain, radiation pattern, and radiation efficiency) can be seriously affected by metallic platforms. In this section, the behaviour of electromagnetic fields near metallic surfaces will be considered.

2.1 Boundary conditions for a general case

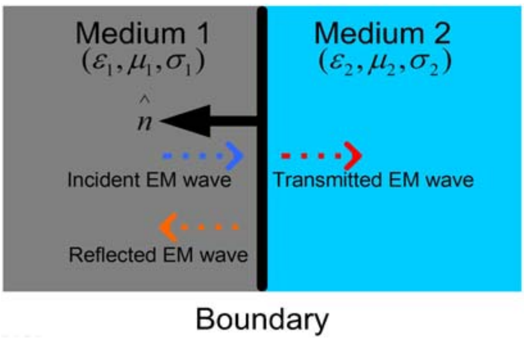


Fig. 2.1 Electromagnetic boundary between two media

Now we want to see how the electromagnetic fields behave at the boundary between a pair of dielectrics or between a dielectric and a conductor. Fig. 2.1 shows the electromagnetic boundary for a general interface between two media. The amplitude and phase of the incident and reflect waves are changed by the material (ε, μ, σ) properties. A UHF-band passive RFID system uses the modulated backscatter method, so the amplitude and phase of the reflected signal are very important. The electromagnetic boundary conditions for a general case can be expressed as follows:

$$\hat{n} \times (E_1 - E_2) = 0 \tag{2-1}$$

$$\hat{n} \cdot (D_1 - D_2) = 0 \tag{2-2}$$

$$\hat{n} \times (H_1 - H_2) = J_s \tag{2-3}$$

$$\hat{n} \cdot (B_1 - B_2) = 0 \tag{2-4}$$

where
$\hat{n}$ is the unit normal vector to the boundary directed from medium 2 to medium 1
E is the electric field intensity (V/m), D is the electric flux density (C/m^2)
H is the magnetic field intensity (A/m), B is the magnetic flux density (W/m^2)
ρ_s is the surface charge density (C/m) , J_s is the surface current density (A/m^2)
By using above boundary conditions, we can also find the electromagnetic boundary conditions for the cases of PEC (Perfect Electric Conductor).

2.2 Boundary conditions at the PEC interface

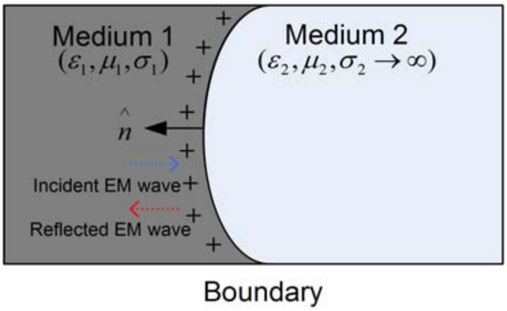


Fig. 2.2 Boundary conditions at the interface of PEC

If medium 2 is a PEC with infinite conductivity, all field components must be zero inside of the PEC. Then, we can express the boundary conditions at the interface as follows:

$$\hat{n} \times E_1 = 0 \quad \text{or} \quad E_{1t} = 0 \tag{2-5}$$

$$\hat{n} \cdot D_1 = \rho_s \quad \text{or} \quad D_{1n} = \rho_s \tag{2-6}$$

$$\hat{n} \times H_1 = J_s \quad \text{or} \quad H_{1t} = J_s \tag{2-7}$$

$$\hat{n} \cdot B_1 = 0 \quad \text{or} \quad B_{1n} = 0 \tag{2-8}$$

It is noticed that there are no tangential components of the electric field on a PEC boundary, and there are only normal components of the electric field for oscillation. On the other hand, there are no normal components of the magnetic field on a PEC boundary. There are only tangential components of the magnetic field. In addition, normal incident waves are totally reflected from the interface because the skin depth of the PEC is zero. Therefore, the amplitude of incident wave and reflected wave are the same, but their phases are 180^0

different. In other words, while the total of the incident and reflected electric fields at the PEC boundary will be zero, the total magnetic field (tangential component) will be doubled at the PEC boundary surface.

3. Effects of metallic platforms on RFID tag antenna

Since RFID systems frequently apply near the metallic environment, the effect of metallic platforms should be considered in designing the tag antenna. As mentioned in the previous section, there are only the normal component of the electric field and tangential component of the magnetic field near the surface of the metallic platform. Therefore, any RFID tag antenna whose performance mostly depends on either the tangential component of the electric field or the normal component of the magnetic field may be faced with considerable performance degradation when it is attached to or close to a metallic platform. In addition, the tag antenna parameters such as the input impedance, resonant frequency, gain, radiation pattern, and the efficiency will be changed. The maximum power transmission can be realized only if the tag antenna impedance is equal to the conjugate of the microchip impedance. The impedance of the microchip is not the normal 50 ohm or 75 ohm, and it may be a random value, or vary with frequency and driving power. A microchip has also a high Q (quality factor) at its terminals, which makes it not easy to attain the conjugate match between the tag antenna and the microchip. In other words, a small variation in the impedance causes serious antenna performance degradation. A metal or liquid based platform also causes the shifting of resonant frequency and degradation of radiation efficiency. To solve these problems, some special types of tag antennas that will not be affected too much when attached to a metallic platform should be designed. In general, UHF-band RFID systems have used dipole-type tag antennas for non-metallic platform. However, if this type of tag antenna is mounted on the metallic platforms, then the reading range is significantly decreased. So, we need another tag structure for metallic platforms. One simple solution is to use an antenna which has its own ground plane to operate. Then, the microstrip antenna may be a good choice for identifying metallic objects.

3.1 Dipole type of RFID tag antenna

In practical applications of a passive UHF-band RFID system, the tag antenna should be designed with low profile, so that its vertical current is limited. The label-type tag antenna where the dipole is printed on a thin film has been used in many non-metallic platforms. When it is mounted near or on metallic platforms, its radiation will be damaged by an inductive current excited in opposite direction. Now we will consider the performance degradation of dipole type antenna near the metallic platform. Fig. 3.1 shows a meandered dipole tag antenna above the metallic platform. Fig. 3.2 shows the simulated antenna impedance by varying the distance (H) of a dipole antenna from a $2\lambda x\ 2\lambda$ metallic platform at UHF band. This simulation is done by Ansoft HFSS Ver. 11. One can see that the impedance is varied due to a parasitic capacitance between the tag antenna and the metallic platform. Fig. 3.3 shows the radiation efficiency by varying frequency and the distance (H) of the antenna from a metallic platform. It is noticed that the radiation efficiency is decreased significantly when a tag is located close to the metallic platform. To maintain a certain level of radiation efficiency, the label-type tags where the dipole is printed on very thin film generally should be kept the proper distance from the metallic platform. However, this makes the size of a tag antenna larger and limits its applications.

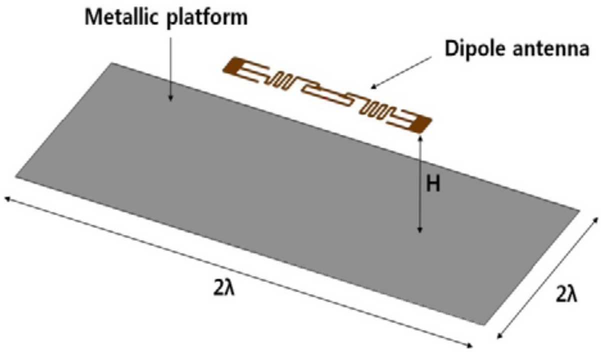


Fig. 3.1 Conventional dipole tag antenna above the metallic platform

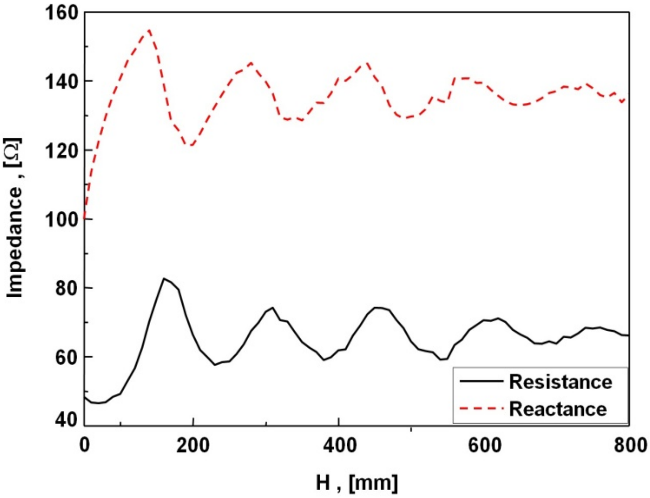


Fig. 3.2 Impedance variation as a function of the distance (H) between a dipole antenna and a metallic platform at UHF band

3.2 Microstrip patch antenna

Some studies have proposed using a microstrip patch tag antenna for metallic platforms. Even if these microstrip patch tag antenna can be applied easily to metallic platforms, there are several things to consider. Those are the size and shape of the metallic platform and attached position. In general, a microstrip patch antenna has stable performance when it has a ground plane size of more than 0.25 λ from the radiating patch. However, a microstrip patch antenna with such a ground size makes the antenna larger in dimension and more expensive.

Fig. 3.4 shows a conventional microstrip patch antenna designed by Ansoft HFSS with 50 Ω input impedance on a dielectric substrate (ε_r=1). It has a dimension (L x W x h) of 140 *mm* x 154 *mm* x 10 *mm*, respectively, and its center frequency is 900 MHz. Now mounting this patch antenna shown in Fig. 3.4 on the metallic platform as shown in Fig. 3.5, the antenna input impedance is observed by varying the size (A) of the metallic platform. Fig. 3.6 notices

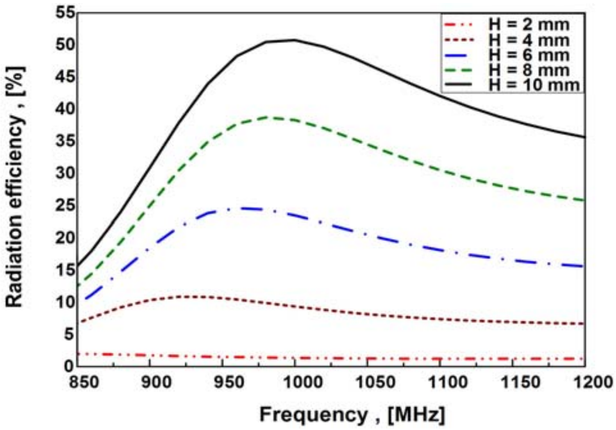


Fig. 3.3 Radiation efficiency as a function of the distance (H) between a dipole antenna and a metallic platform for different frequencies

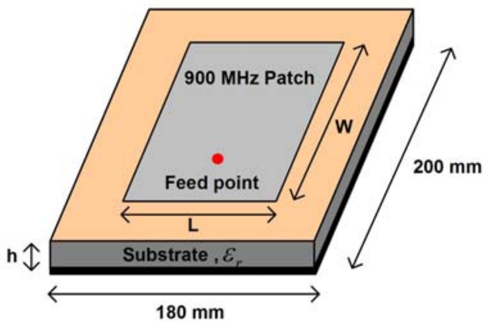


Fig. 3.4 Conventional microstrip patch antenna operating at 900 MHz

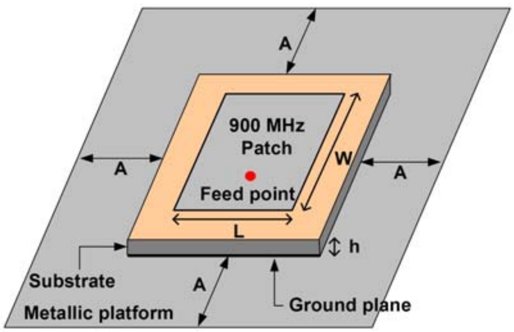


Fig. 3.5 Microstip patch antenna mounted on the metallic platform

that the input impedance and the resonant frequency change with different sizes of metallic platforms. The characteristic of the input impedance changes rapidly when the size (A) of the metallic platform becomes 0.2 λ. Designing a passive tag antenna matched with the complex microchip impedance is the most challengeable factor, since a microchip has very high Q(quality factor) because of its small resistance and large capacitive reactance. Therefore, tag antennas have to be designed to enable tags to be read near and on metallic platforms without severe performance degradation.

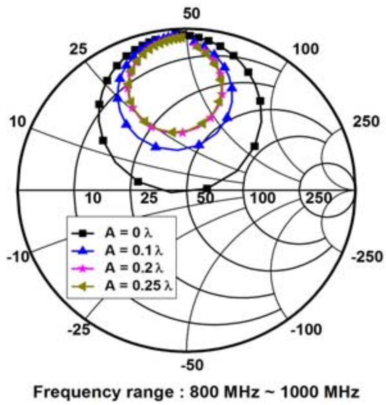


Fig. 3.6 Impedance characteristic with varying the size of the metallic platform

4. RFID tag antennas mountable on metallic platforms

In the previous section, effects of metallic platforms on RFID tag antennas are considered. Conventional tag antennas suffer degradation in performance when attached near or to metallic platforms. To solve the problem brought by the metallic objects, some special tag antennas should be designed. These antennas usually have a metallic ground. Some metallic platforms, which make the performance of the tag antenna worse, are modified to be as an extended part of the antenna to improve its performance. Therefore, in order to obtain stable antenna performance on various metallic platforms, minimizing the effect of the metallic supporting object is a very meaningful work. In this section, a number of RFID tag antennas suitable for mounting on metallic platforms will be discussed. Brief design concepts and some results will also be included for several tag antennas.

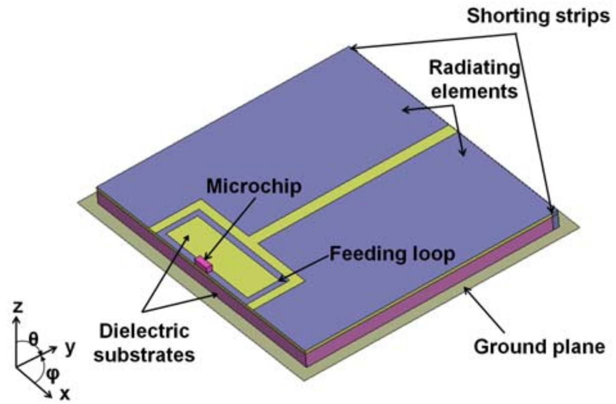
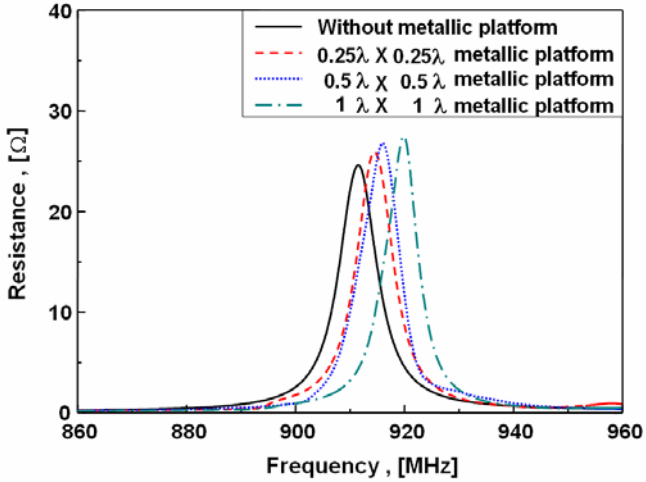


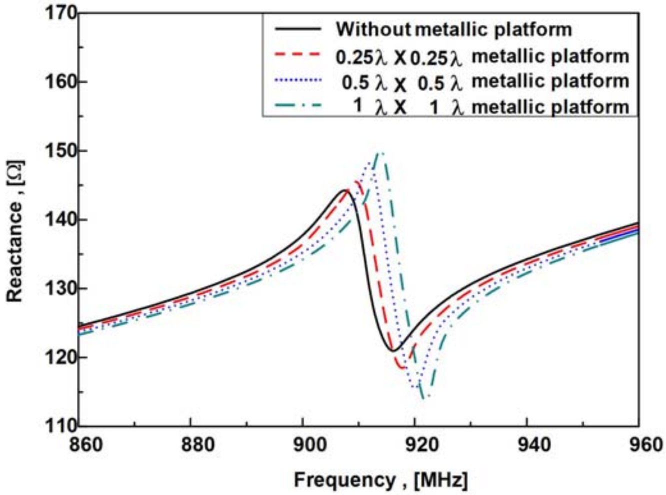
Fig. 4.1 Structure of the balanced-type microstrip patches for tag antennas

4.1 Balanced-type microstrip patches

The direction of the fringing field of a PIFA-type antenna is always from the radiating element to the ground plane, and vice versa. Although this type of an antenna has its own ground plane, its performance will be affected when attached to the metallic platform. To make up for this drawback, the balanced-type microstrip patch antenna (Yu et al., 2007) as shown in Fig. 4.1 was proposed. The proposed tag antenna consists of two symmetric shorted radiating elements and a feeding loop. Two symmetric radiating elements are etched on a substrate layer, and electrically shorted to the ground plane through the shorting strips. The feeding loop, which is connected to the microchip, is inductively coupled so that the currents on patches are out of phase with equal amplitude. The



(a)



(b)

Fig. 4.2 Simulated impedance characteristics with different sizes of metallic platforms conjugate match is achieved between antenna and microchip by adjusting the perimeter of the feeding loop and the gap between the radiating elements. Then, the proposed tag antenna gives a smaller variation of the antenna performance than that of conventional tag antennas when the tag is mounted on the various sizes of the metallic platforms.

Fig. 4.2 shows the simulated impedance characteristics of the tag antenna with different sizes of metallic platforms. One can see that the impedance variation is small without metallic platform and with various sizes of metallic platforms. Therefore, we can expect that this tag antenna gives smaller variation in the antenna performance than that of conventional tag antennas when the tag is mounted on the various sizes of the metallic platforms.

Although the currents on the radiating elements excited by the feeding loop are out of phase with equal amplitude, the direction of the surface current is very important so as to obtain the performance of a perfectly balanced antenna. Therefore, the symmetric shorting strips with respect to the y-axis are used to achieve more balanced current distributions as shown in Fig. 4.3. The main direction of the electric field is along with the x-axis since two symmetric patches are excited out of phase. This is the major difference from the radiation mechanism of the conventional PIFAs or IFAs, which cause the performance variation and reduction due to the electrical coupling between the radiator and ground plane. The proposed antenna has its main electrical coupling between two radiating elements rather than between the radiator and ground plane. This means the radiation of this antenna comes mainly from the two adjacent radiating elements. Therefore, considerable reduction of the effect of the metallic platform can be achieved. Fig. 4.4 shows the radiation efficiency for various sizes of metallic platforms. One can see that the reduction of radiation efficiency due to size variation of metallic platforms has not reached values that impede operation.

Fig. 4.5 shows the measured power bandwidth for different sizes of the metallic platforms. All the peaks have been normalized to 0 dB. The power bandwidth is defined as the half-power bandwidth of the antenna aperture, which is equivalent to +3 dB in required transmitted power P_{tx}. HPBW (Half Power Band Width) is 902 MHz ~ 928 MHz, and the variation of resonant frequency is less than 5.5 MHz. These variations are much smaller than those of the conventional tag antennas. The bandwidth within the 3 dB power variation shows that this antenna has a very good tolerance for different sizes of metallic platforms. Fig. 4.6 shows the radiation patterns. It is noticed that the direction of the antenna's main beam does not vary with the size of the metallic platform.

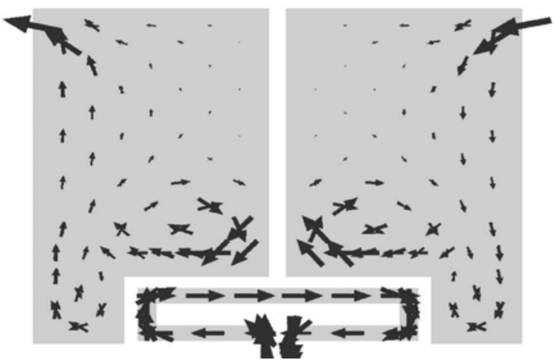


Fig. 4.3 Surface current distribution of balanced-type microstrip patches

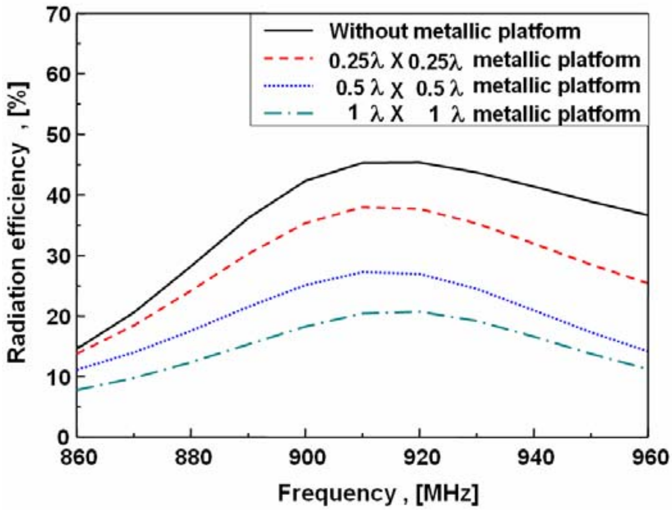


Fig. 4.4 Simulated radiation efficiency for different sizes of metallic platforms

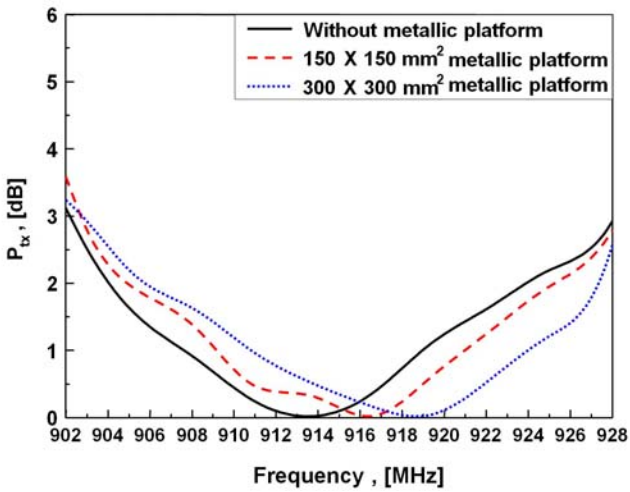


Fig. 4.5 Measured power bandwidth versus for different sizes of the metallic platforms

4.2 Compact microstrip patch

As mentioned, performance of a RFID tag antenna can becomes worse under the impact of a metallic environment. To overcome this problem, several PIFAs, IFAs, or microstrip patch antennas have been proposed. However, they still have the complexity of manufacturing because of the vertical feeding structure along with a microchip and use thick or multi-layered substrates. When it comes to designing RFID tag antenna for metallic platforms the dimension and complexity of the antenna are very important factors as they relate to the manufacturing cost. One way to reduce manufacturing costs is to keep the tag antenna design as simple as possible.

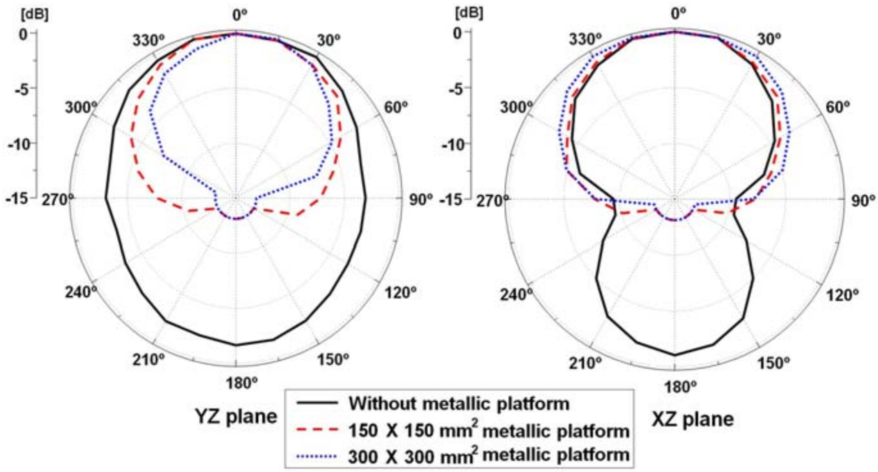


Fig. 4.6 Measured radiation patterns with different sizes of metallic platforms

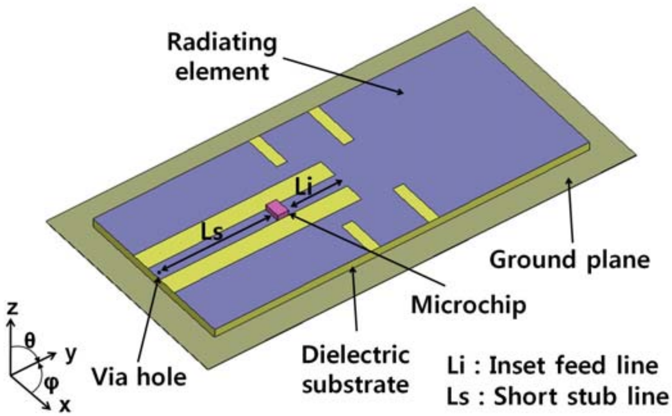
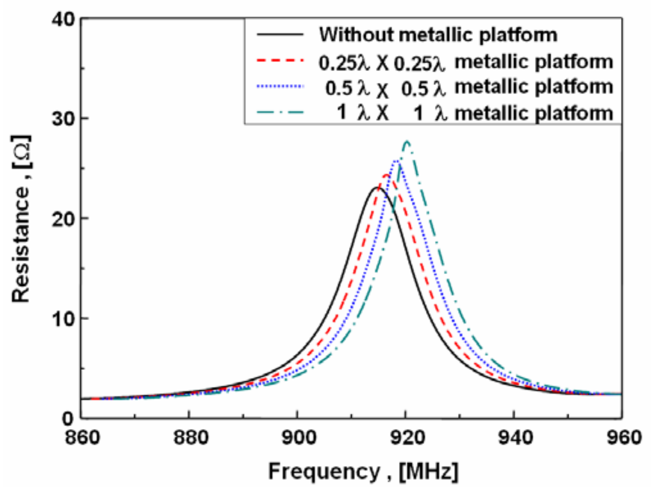
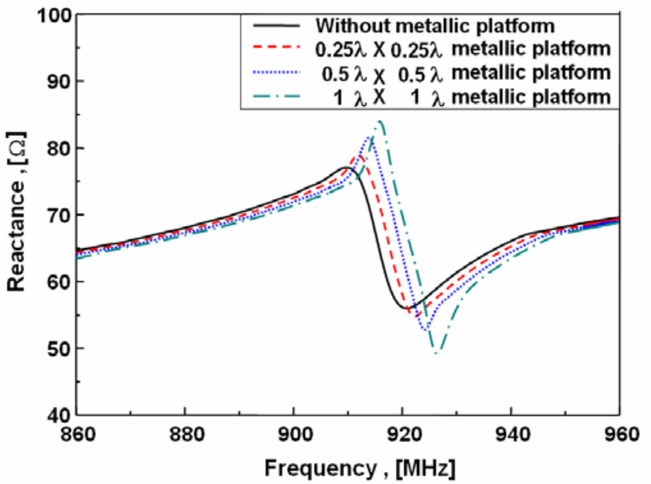


Fig. 4.7 Structure of the compact patch-type tag antenna

A new type of RFID tag antenna mountable on metallic objects in UHF band is proposed (Lee & Yu, 2008). This antenna can reduce the complexity of manufacturing and thickness of the antenna by using a microstrip patch type structure which has a single layer and the feed line on the same layer of the simple radiating patch. Moreover, this antenna makes the conjugate impedance match between the antenna and the microchip easy without additional matching networks. Fig. 4.7 shows the geometry of the compact patch-type tag antenna (Lee & Yu, 2008). The feed line is divided into the inset feed line (length of L_i) and the short stub line (length of L_s). The short stub line is electrically shorted to the ground plane by a via hole. The slits are symmetrically embedded on the radiating patch along the y-axis to reduce antenna size. The complex antenna impedance can be controlled by varying the length of the feed line (length of the inset feed line: L_i, length of short stub line: L_s). The conjugate match between the antenna and microchip can be achieved by adjusting the length of the inset feed line (L_i) and the length of the short stub line (L_s), which is much easier than previously reported techniques. Impedance matching can be achieved without major modification of the radiator and additional matching networks. It should be mentioned that changing L_i mainly affects the resistance while changing L_s mainly affect the reactance.



(a)



(b)

Fig. 4.8 Simulated impedance characteristics for different sizes of metallic platforms

Fig. 4.8 shows the simulated impedance characteristics of a compact tag antenna with different sizes of metallic platforms. It is noticed that the impedance variation is small without metallic platform and with various sizes of metallic platforms. Therefore, the impedance has very good tolerance for different sizes of metallic platforms. Fig. 4.9 shows the radiation efficiency versus frequency for various sizes of metallic platform. One can see that the radiation efficiency increases as the size of the metallic platform increases.

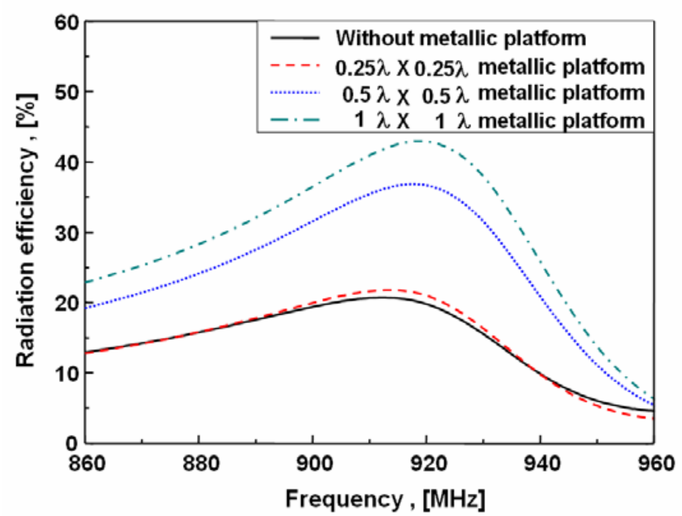


Fig. 4.9 Simulated radiation efficiency for different sizes of metallic platforms

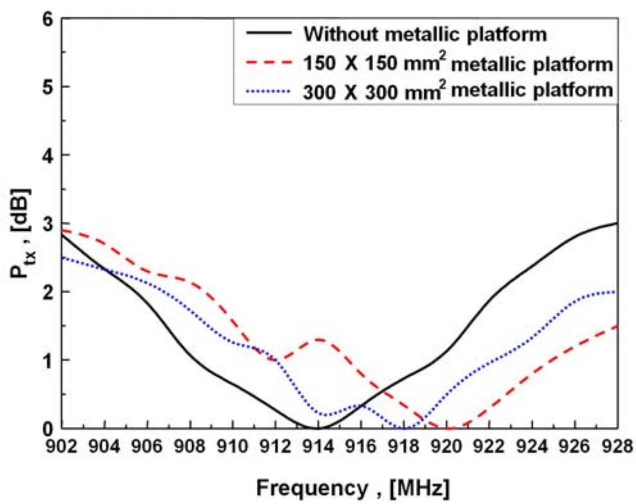


Fig. 4.10 Measured power bandwidth versus the different sizes of the metallic platforms

Fig. 4.10 shows the measured power bandwidth versus frequency when the tag is mounted on different sizes of metallic platforms. The bandwidth within 3 dB power variation for the square metallic platform of 150 ~ 300 mm length remains good. So, the bandwidth has a very good tolerance for the large sized metallic platforms. Fig. 4.11 shows the measured radiation patterns. It is shown that the direction of the antenna main beam does not vary with the size of the metallic platform, and its directivity is increased as the size of metallic platform increases. One can see that the proposed antenna gives a good performance when it is even mounted on various sizes of metallic objects.

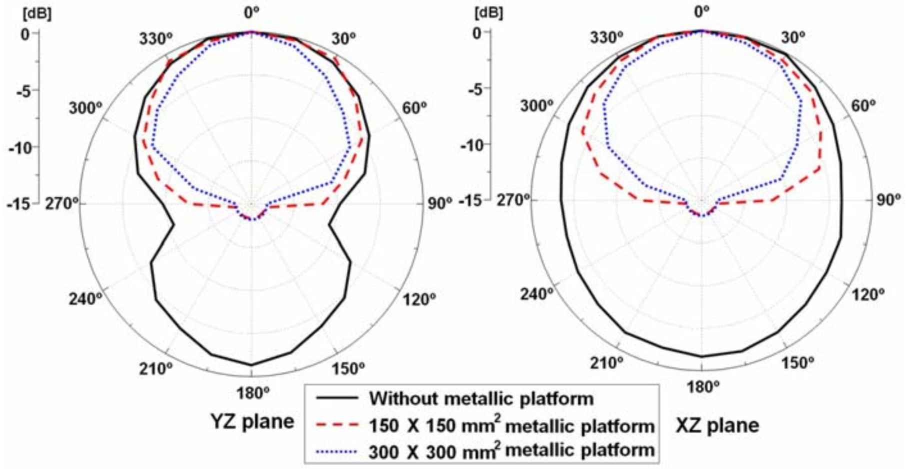


Fig. 4.11 Measured radiation patterns with different sizes of metallic platforms

4.3 Other RFID tag antennas

Two types of tag antennas which can be attached to metallic platforms have been introduced and discussed in earlier subsections. In addition to these, there are other types of tag antennas suitable for metallic platforms.

As mentioned in the previous section, incident electromagnetic waves totally reflects from metallic surfaces with a phase reversal. The metallic objects near an antenna change the antenna parameters and degrades radiation efficiency. Therefore, the metallic surface should be used as a ground plane of the antenna or as an energy-improving reflector. Both the patch with EBG ground plane and patch antenna with regular ground plane for a tag antenna attachable to metallic surfaces are analyzed (Ukkonen et al., 2005). According to their results, the patch antenna with EBG ground plane has higher radiation efficiency than the regular patch antenna. This is due to the suppression of surface waves when the EBG ground plane is used. However, the EBG structure needs a periodic structure. So it makes an antenna expensive, and its structure becomes larger.

According to the electromagnetic boundary conditions we mentioned, for magnetic field, there are only tangential components and no normal components of this field to the metallic surface. The tangential component of the magnetic field will be doubled when it is very near the metallic surface. The RFID tag antenna design (Ng et al., 2006) here exploits the fact above by having a loop antenna oriented such that the plane of the loop is perpendicular to the plane of the metallic surface where the RFID tag will be attached. With this orientation, the RFID tag antenna has improved performance when attached near a metallic platform, and this antenna has allowed better coupling to the magnetic components of the interrogation fields. Various types of loop antennas perpendicular to the plane of the

metallic surface can be considered for the tag antenna. Although the circular loop antenna is the most common among all loop antennas, a rectangular loop is chosen to keep smaller height of a tag antenna.
Other types of tag antennas using a shorting plate (Hirvonen et al., 2004), a printed inductor (Son et al., 2006), and a U-shaped slot (Kwon & Lee, 2005) have been proposed to improve the antenna performance for metallic platforms.

5. Conclusion

The RFID is an emerging technology making ubiquitous identification possible. The potential applications of the RFID are numerous. A UHF (902-928 MHz) band RFID system becomes more attractive for many industrial services because it can be used for many applications such as security and access control, asset management, transportation, supply chain management, and baggage handling with high reading speed, capable multiple accesses, anti-collision, and long reading distance. Since RFID systems are applied in many fields, the technology used to realize the antenna without severe performance degradation for various types of platforms is perhaps the most important technology in improvement of the RFID system performance.

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