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Troubleshooting RFID Tags Problems with Metallic Objects Using Metamaterials

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1. Introduction

Radiofrequency Identification (RFID) is a technology that is being rapidly developed and that uses radiofrequency (RF) signals for the automatic identification of objects or persons. Although the first article regarding modulated electromagnetic backscattering (basic principle of passive RFID) was published in 1948 (Stockman, 1948) it has been a long way to progress for reaching today levels (Rao, 1999; Finkenzeller, 2004; Pozar, 2004). Nowadays RFID finds many applications in logistics, supply chain management, access control, electronic toll systems, targets identification, vehicle security, animals tracking and patients' identification in hospitals.

An RFID system is composed of a reader, a reader antenna (usually circularly polarized patch antenna), RFID 'tags' or transponders and a middleware or subsystem of data processing. A passive RFID tag consists of an antenna and an application specific integrated circuit (ASIC) chip. IC chips have complex input impedances, and their impedances vary with frequency. A key point for tag antenna design is that it must be conjugately matched with the desired IC chip for the maximum power transfer (Gevi, 2004; Rao et al, 2005).

The different types of RFID systems are distinguished by two major characteristics: the power source of the tag and the frequency of operation. With regards to the power source of the tag, they can either be active (powered by battery), passive (powered by the reader field) or semi-passive (battery assisted backscatter). According to the frequency of operation the RFID systems are generally distinguished into four frequency ranges; i.e., low frequency (LF) (125-134.2 kHz), high frequency (HF) (13.56 MHz), ultra high frequency (UHF) (433, 860-960 MHz) and microwave frequency (2.45, 5.8 GHz). In addition, the standards of the UHF RFID are different for each country: 866-869 MHz in Europe, 902-928 MHz in America and 950-956 MHz in Asia. The communication frequencies used depends to a large extent on the application. Regulations are imposed by most countries (grouped into 3 Regions: US, Europe and Asia) to control emissions and prevent interference with other Industrial, Scientific and Medical equipment (ISM).

The higher the frequency band the faster the speed of tag reading and also the larger the information storage capacity. This is the reason why UHF RFID has gained popularity in many applications and it can be expected that the same will happen in the near future with microwave RFID.

In a typical application tags are attached to objects (or persons). Each tag has a certain amount of internal memory (EEPROM) in the chip in which it stores information about the

object (or person), such as its EPC (electronic product code) or unique identification (ID) serial number and some other data depending on the application, i.e. manufacture date and product composition, (or personal information for access control or health care matters).
A passive back-scattered RFID system operates as follows: a modulated signal with periods of unmodulated carrier is transmitted by a reader and is received by the tag antenna. Then the RF voltage developed on antenna terminals during unmodulated period is converted to dc. The chip is powered up with this dc voltage and sends back the information by varying its front end complex RF input impedance. The modulation of the back-scattered signal is carried out by toggling the impedance between two different states, i.e., conjugate match and some other impedance (Rao et al, 2005)
The tag antenna, together with the chip sensitivity, plays a key role in the RFID system performance, such as the reading range (VanBladel, 2002) and compatibility with the tagged object. In sum, the requirements for RFID tag antennas are the following (Foster & Burberry, 1999):

- Good impedance matching for receiving maximum signals from the reader to power up the chip;
- Insensitive to the attached object to keep performance consistent;
- Required radiation patterns (omnidirectional, directional or hemispherical);
- Small enough and low profile to be attached to or embedded into the specified object (Rao et al, 2005);
- Robust in mechanical structure (since they could be bent in some applications);
- Low cost in both materials and fabrication.

Antennas do not operate independently of nearby objects. On the contrary, these objects can ruin the radiation properties of the antenna to different extent. In RFID systems, the material of the objects the tags are attached to should have minimum effect on tag antenna behaviour, so that the reading performances of tags, such as readable range and reading stability, do not change. However, the performance of a tag antenna varies when it is mounted on different objects (Dobkin & Weigand, 2005; Clarke et al, 2006). On the one hand if the object surface is made of a dielectric material, then the readable range is decreased due to frequency shift of the resonance frequency. On the other hand, metallic objects which are usually tagged in RFID applications seriously degrade the terminal impedance matching, bandwidth, radiation efficiency and readable range of the tag antenna. This is such a critical problem that global deployment of passive UHF RFID systems is being hindered by the performance degradation of tag antennas placed nearby metallic objects. As it has already said, in the vicinity of conductors, the antenna radiation parameters are modified; for example radiation efficiency is decreased. In addition, a metallic surface typically decreases the input impedance of the antenna (which makes that lower or not enough power can be supplied to the IC chip, so the reading range is reduced or even the tag is not read at all) and varies its resonance frequency. The electromagnetic wave is greatly reflected by the conductor surface yielding a significant reduction of the RFID tag operating distance or its total malfunctioning (Dobkin& Weigand, 2005; Clarke et al, 2006; Rao et al, 2005). These negative effects are increased at higher frequencies and so, RFID operation in the SHF band with tags attached to metallic objects presents an even more critical problem to be solved.
To overcome these problems and to obtain RFID tags usable with metallic objects, researchers have proposed different approaches:

- To design novel antennas rather than dipole based antennas (with the inconvenient of large thickness or with shorting planes). As for example patch antennas (Ukkonen et al,

2006) that already have a metallic ground plane but they show some shortcomings as narrow bandwidth and not negligible thickness. Another possibility that has been already explored are tag antennas using a planar inverted-F structure (Hirkonen et al, 2004; Kwon & Lee, 2005) that can operate well on metallic objects, since they already have large ground planes, but they have several important drawbacks such as high cost and difficulty in manufacturing, because they require multiple shorting pins and a large ground plane, as well as thick dielectric substrates.

- To use dipoles separated $\lambda/4$ from the metallic object (for example using foam, which leads to thick antenna designs and more complex manufacturing process)
- The adoption of ferroelectric material to insulate the tag from metal (which is rather expensive).
- To use Perfect Magnetic Conductors (PMCs) since they have a +1 reflection coefficient with magnitude of 1 (in the ideal lossless case) and a phase of 0º. So, they show in-phase reflection, which seems to be a proper solution to the destructive interference problem when the antenna is placed very close to the metallic plate. Thus, the PMC can be used as a barrier between the antenna and the metallic plate in order to electromagnetically insulate the antenna from the disturbing metallic plate effects. For this reason, this approach is going to be analyzed in this chapter. In addition, other advantages such as enhanced efficiency can be obtained as a reward for the use of PMCs. PMCs do not exist in nature and so they have to be synthesised. For this reason they are known as Artificial Magnetic Conductors (AMCs) and behave as PMCs over a certain frequency band.

2. Design of AMC structures for different RFID frequency bands

An Artificial Magnetic Conductor (AMC) is dual to a Perfect Electric Conductor (PEC) from an electromagnetic point of view. For design and analysis purposes, AMC condition is indicated by a reflection coefficient with magnitude of 1 (in the ideal lossless case) and a phase of 0º. The reflection phase on the AMC plane varies continuously from -180º to 180º related to the frequency and is zero at the resonance frequency. The useful bandwidth of AMC performance is defined in the range from +90º to -90º, since in this range, the phase values would not cause destructive interference between direct and reflected waves (Sievenpiper, 1999; Sievenpiper et al, 1999). The surface impedance of an AMC is very high in its bandwidth of AMC performance, so they are also known as High Impedance Surfaces (HIS).

A commonly used technique for AMCs implementation consists in using two-dimensional periodic metallic lattices patterned on a conductor-backed dielectric surface, known as PEC-baked metallo-dielectric Frequency Selective Surfaces (FSSs) and also called Electromagnetic band-gap (EBG) surfaces, as they have one or multiple frequency band-gaps in which no substrate mode can exist. However, in the absence of via holes, the AMC and EBG frequency bands do not always coincide (Goussetis et al 2006). Their unique properties have been applied to design antennas with a better gain and efficiency, lower sidelobes and backlobe level (Mosallaei & Sarabandi, 2004; Feresidis et al, 2005; Mantash et al, 2010a, 2010b). Several narrow band antennas, such as Microstrip patches and dipoles have been mounted on these periodic structures in previous works (McVay et al, 2004; Liang & Yang, 2007; Zhu & Langley, 2009). With the aim of obtaining AMC designs that can be easily integrated in low profile antennas and microwave and millimeterwave circuits, recent research efforts focus on the development of planar unilayer EBGs (in contrast to the use of multilayered FSS (Monorchio et al, 2002)) that do not need vias (Yang et al, 1999; Zhang et al, 2002; McVay et al, 2004; Kern et al, 2005). The main drawback of using unilayer FSSs over a metallic ground plane is the very narrow AMC operation bandwidth, due to EBGs' inherent resonant nature. In addition, designing compact AMCs for frequencies below 1GHz as those required in UHF RFID applications is by itself quite challenging and specially when intended to be used for RFID tags due to their size and thickness restrictions.

Each AMC unit-cell can be seen as implementing a distributed parallel LC network having one or more resonant frequencies. The resonance frequency is where the high impedance and AMC conditions occur and for a parallel LC circuit is equal to $1/\left(2\pi\sqrt{LC}\right)$, while in-phase reflection bandwidth is proportional to $\sqrt{L/C}$ .The resonance frequency and the bandwidth of an AMC depend on the unit-cell geometry together with substrate's relative dielectric permittivity and thickness. So, it is necessary to increase L and reduce C in order to obtain a wider AMC operation bandwidth. Lower frequency applications require higher L and/or C values. L can be increased using a thicker dielectric substrate and also including in the geometry narrow and long strips (lines). C can be reduced by reducing substrate's relative dielectric permittivity ε_r and increasing the gap between the metallization edge and the unit-cell edge (and so the gap between adjacent unit-cells). In order to obtain both compact size and broad AMC operation bandwidth a trade-off solution regarding ε_r and substrate thickness has to be adopted.

With the aim of searching the frequency band in which the periodic structure behaves as an AMC, its reflection coefficient for a uniform incident plane wave is simulated, using Finite Element Method (FEM) together with the Bloch-Floquet theory, modelling a single cell of the structure with periodic boundary conditions (PBC) on its sides, resembling the modelling of an infinite structure (Sievenpiper et al, 1999; Yang & Rahmat-Samii, 2003). The periodic surface is chosen as the phase reference plane. Normal plane waves are launched to illuminate the periodic surface using a waveport positioned a half-wavelength above it. The phase of the reflection coefficient of the AMC plane is compared to that of a PEC plane taken as reference, in the same way as in (Sievenpiper et al, 1999).

The aim of this section is to show an AMC structure design proper to be used for European UHF RFID frequency band tags and for 2.4GHz and 5.8GHz SHF RFID frequency band tags, using the same geometry for the AMC unit-cells and just changing the dielectric substrate and/or the unit-cell size. AMC structures for other UHF RFID bands can be easily obtained just by scaling the unit-cell metallization from the European UHF unit-cell design, and/or slightly scaling the whole unit-cell.

Unit cell size W (mm)	Thickness h (mm)	ε_r	BW (%)	Reso. freq (GHz)
16.93 ($\lambda/20$)	2.54 ($\lambda/136$)	25.0	4.63	0.864
16.93 ($\lambda/7$)	1.27 ($\lambda/98$)	10.2	5.24	2.480
11.52($\lambda/5$)	0.81 ($\lambda/64$)	3.38	7.20	5.820

Table 1. AMC Unit-cell design parameters and resulting resonance frequencies and bandwidths of AMC performance.

Table 1 shows the unit-cell dimensions and the dielectric substrate parameters to achieve the indicated resonance frequencies and bandwidths of AMC performance. The three AMC designs use commercial dielectric substrates: Transtech MCT-25 with relative dielectric permittivity ε_r=25 and loss tangent less than 0.001, Rogers RO3010 with ε_r=10.2 and loss tangent 0.0035 and RO4003C with ε_r=3.38 and loss tangent less than 0.0027.

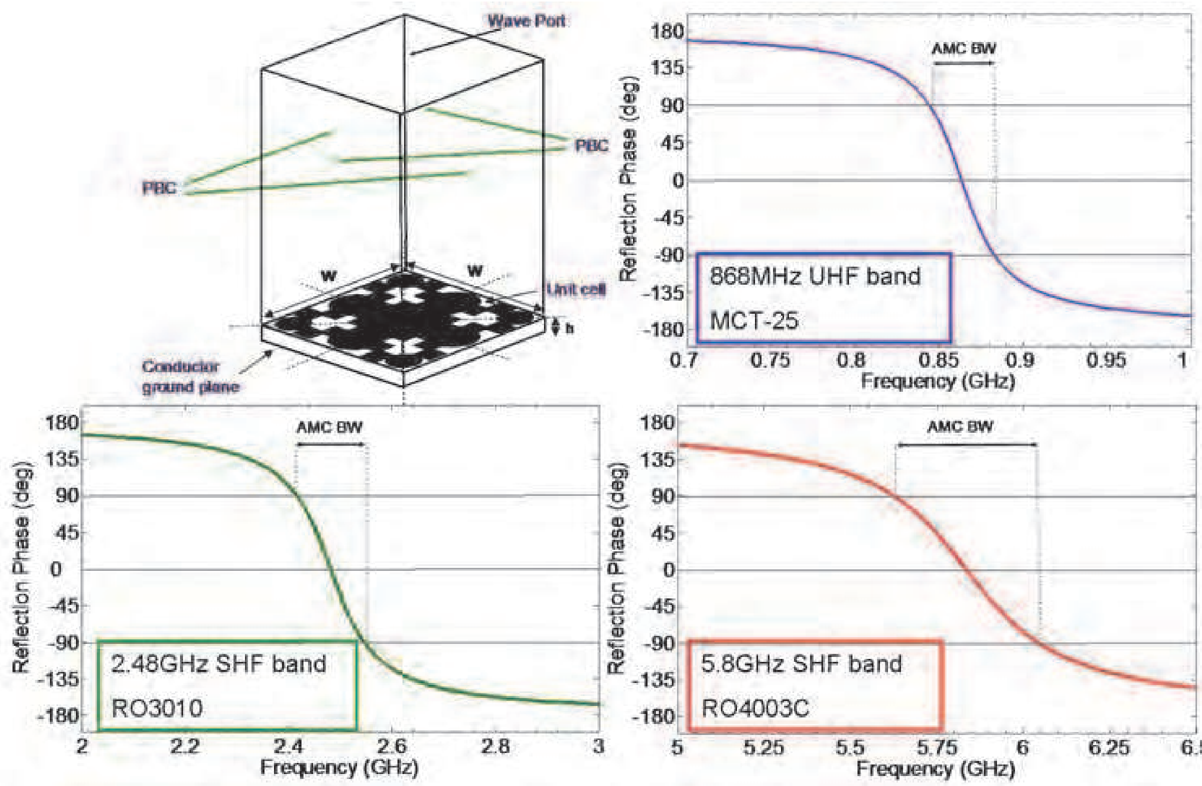

Fig. 1. Simulation model and Reflection phase of the simulated AMC prototypes

The simulated reflection phase of normally incident plane wave (field strength 1 V/m) on the AMC surface versus frequency for the designed unit cell geometry with the three different dielectric substrates is shown in Fig. 1. The bandwidth of AMC performance increases with the thickness of the dielectric substrate but decreases as the relative dielectric permittivity gets higher values. The three presented designs (see Fig.1 and Table 1) show broad bandwidth using neither via-holes nor multilayered structures, which simplifies manufacturing process and reduces the costs.

It is remarkable that the broad AMC operation bandwidth of this specific unit cell geometry makes possible its combination with an antenna without significantly reducing the antenna bandwidth, which is the common drawback pointed out when dealing with AMC structures due to their inherent narrow bandwidth.

Another major concern on AMCs operation is related to their angular stability (Simovski et al, 2005). This can be analyzed from two different points of view: the first analysis is performed with regards to AMC operation under normal incidence condition when the polarization of the incident field is varied. The second analysis is focused on the AMC performance under oblique incidence. Both of them are very important because when combining the AMC with the antenna, the angular stability of the AMC will influence the antenna radiation performance and this will have direct impact on the angular reading range of the final RFID tag depending on the position of the reader with respect to the tagged object. Following this, an AMC design with as higher angular stability as possible is desirable.

As pointed out in section 1, the negative effects of metallic objects in RFID tags are increased at higher frequencies and so the following discussions are going to be focused on an AMC to be used on 5.8GHz SHF RFID frequency band tags.

The reflection phase of the designed AMC surface has been simulated for different incident field (E_{inc}) polarization angles (φ). The unit cell design symmetry makes possible the AMC to operate identically for any polarization of the incident field (assuming normal incidence), as shown in Fig. 2. This also means that reflection phase of both TE and TM polarizations of the incident wave will be identical for normal incidence.

Regarding AMC operation under oblique incidence, it can be extracted from Fig. 3 that resonance conditions are met within an angular margin of θ_{inc}= ±58º (due to the unit cell design symmetry) for TE polarization. In this range the deviation of the resonance frequency is less than 1%. For higher incident angles the resonance frequency shifts to another band. It is also remarkable that the AMC operation bandwidth decreases from 7.20% to 3.39% as the incident angle θ_{inc} is increased from 0º to +58º. However, the 5.8GHz frequency of interest is within the AMC operation bandwidth for all the incident angles in the θ_{inc}= ±58º angular margin. This means that there is almost a 120º angular margin in which the structure performs as an AMC at 5.8GHz. For TM polarization, the angular margin reduces to θ_{inc}= ±40º, the deviation of the resonance frequency is 6.83% and the AMC operation bandwidth is preserved. So there is a 80º angular margin in which the structure performs as an AMC at 5.8GHz for both Te and TM polarizations of the incident wave, which can be considered as a very stable AMC structure.

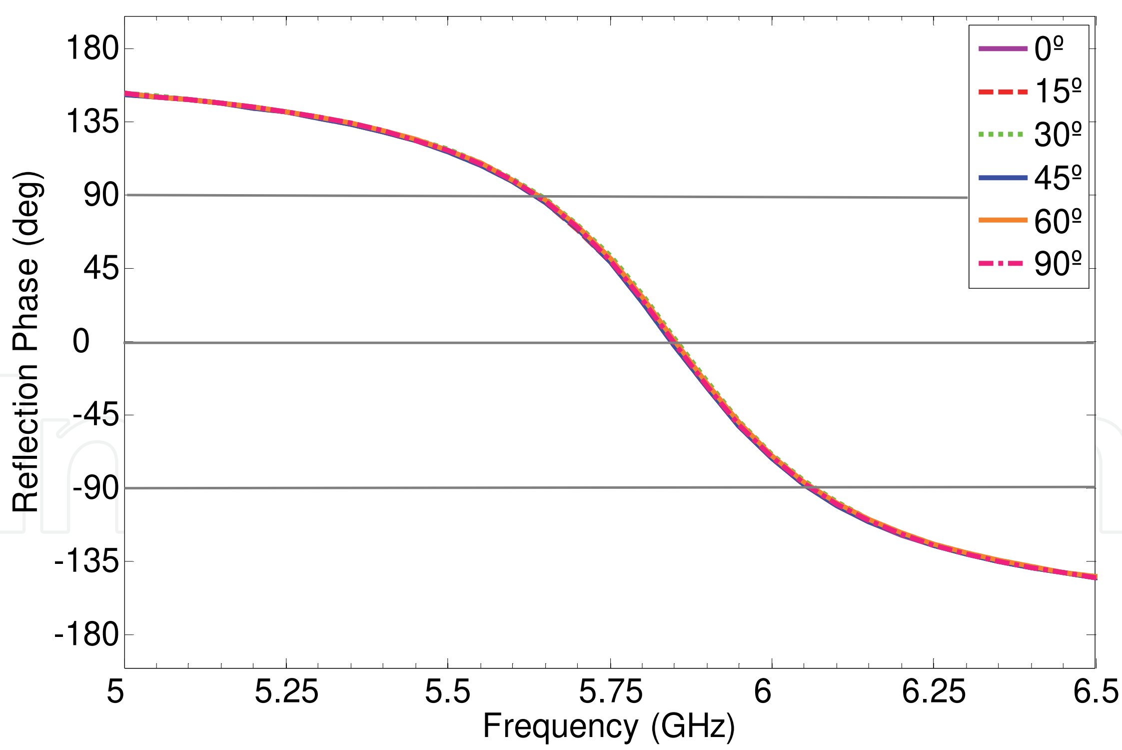

Fig. 2. Simulated Reflection phase of the AMC surface for different incident field (E_{inc}) polarization angles φ=0º, 15º, 30º, 45º, 60º and 90º.

It is important to point out that angular stability under oblique incidence depends not only on the unit cell design geometry but also on the thickness of the dielectric substrate and on the unit cell size (periodicity) compared to the dielectric substrate thickness (Hosseini et al, 2006; Simovski et al, 2005).

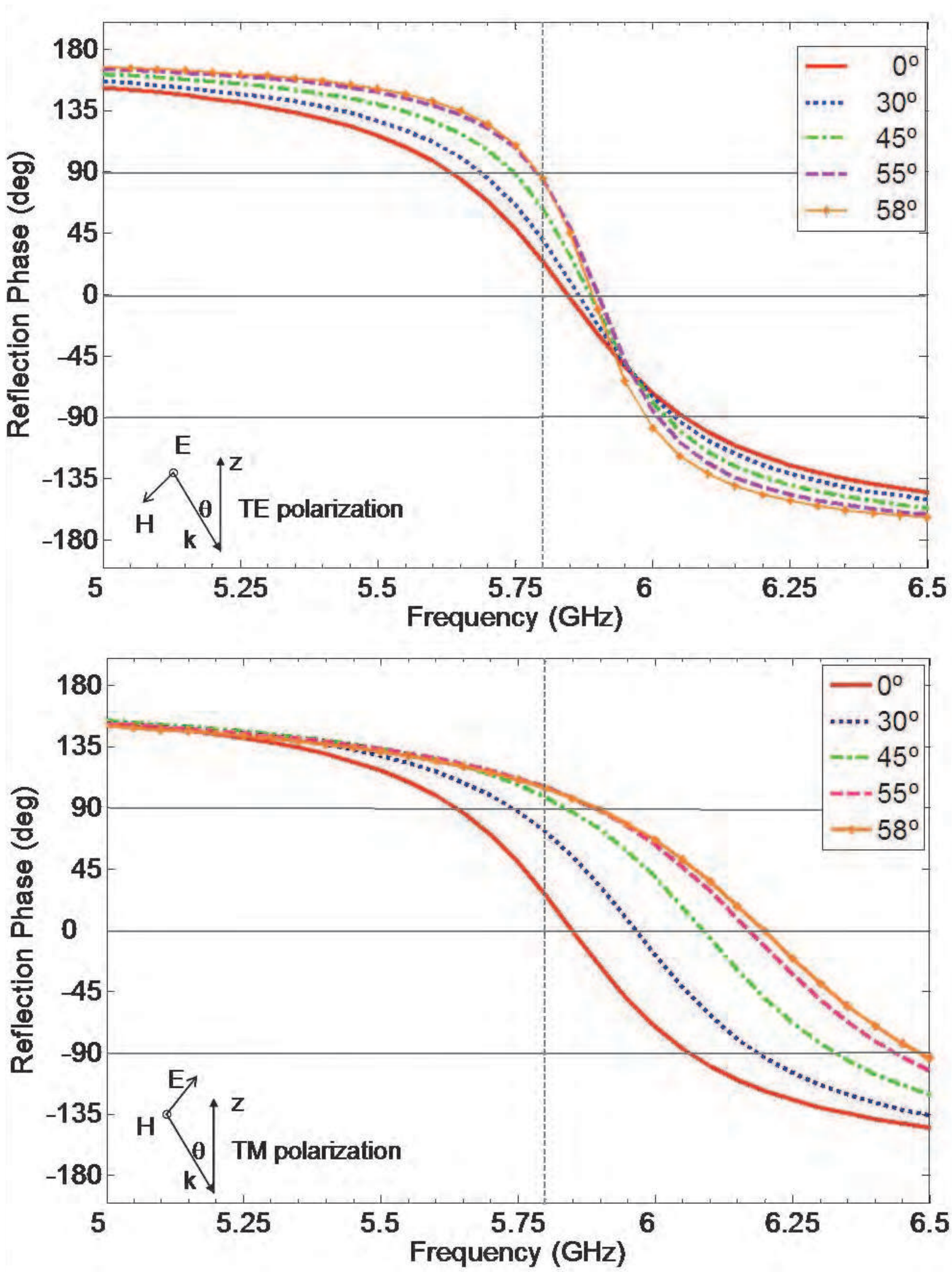

Fig. 3. Simulated Reflection phase of the AMC surface for TE (up) and TM (down) polarizations for different incident angles θ_{inc}=0°, °, 30°, 45°, 55° and 58°.

3. Antenna on AMC to be used in 5.8GHz SHF RFID tags over metallic objects

Firstly, a miniature printed CPW-fed slot antenna (Lin et al, 2005) for operating in the 5.8GHz frequency band has been designed (see Fig.4) using RO4003C, with ε_r=3.38, loss tangent less than 0.0027 and 0.813mm thickness, as dielectric substrate. A slot antenna has been chosen because it will provide wider bandwidth making easier the combination with the narrower bandwidth of AMC performance. There is no metallic layer under the antenna dielectric substrate. This antenna has a simple structure with only one layer of dielectric substrate and metallization.

The antenna dimensions together with simulated return losses for the antenna are shown in Fig. 4. The simulated operating bandwidth of the antenna (range of frequencies with S11≤-10dB) is 1.48GHz (22.0%).

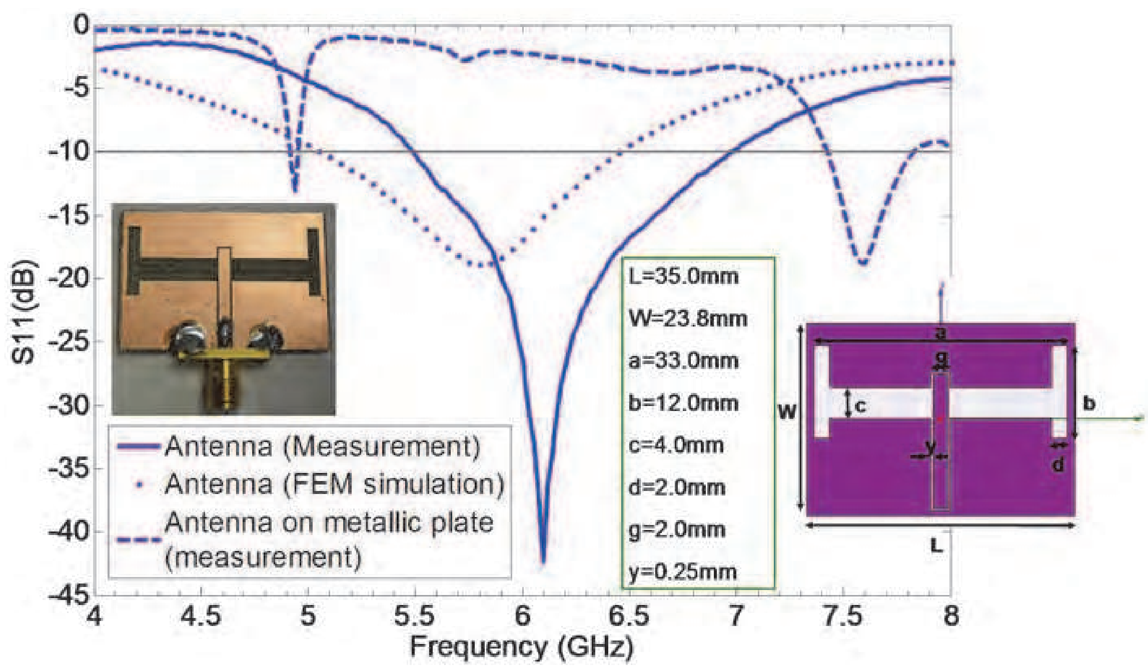

Fig. 4. Return loss of the antenna; Geometry and dimensions; Manufactured prototype.

The simulated antenna gain at 5.8GHz is 5.0 dB with very small variation along the antenna bandwidth (see Fig 5). The simulated E and H-plane radiation pattern in polar form for the antenna at 5.8GHz are shown in Fig.5. Both the CP and the XP components are represented. The E-plane radiation pattern is broadside and bidirectional. The H-plane radiation pattern is almost omnidirectional.

Regarding the AMC arrangement with respect to the antenna, several ideas have been considered. The first one is that the AMC used as antenna ground plane would electromagnetically insulate the antenna from the metallic object, without disturbing the antenna performance. The second is to minimize the size of the final prototype and to facilitate manufacturing process.

Two AMC arrangements having respectively 5x5 and 5x4 AMC unit cells have been combined with the CPW-fed slot antenna and the resulting prototypes (see Fig. 6) have been tested in terms of return loss. In both cases the antenna is fixed to the AMC structure by a 0.1mm double sided non-conducting adhesive tape.

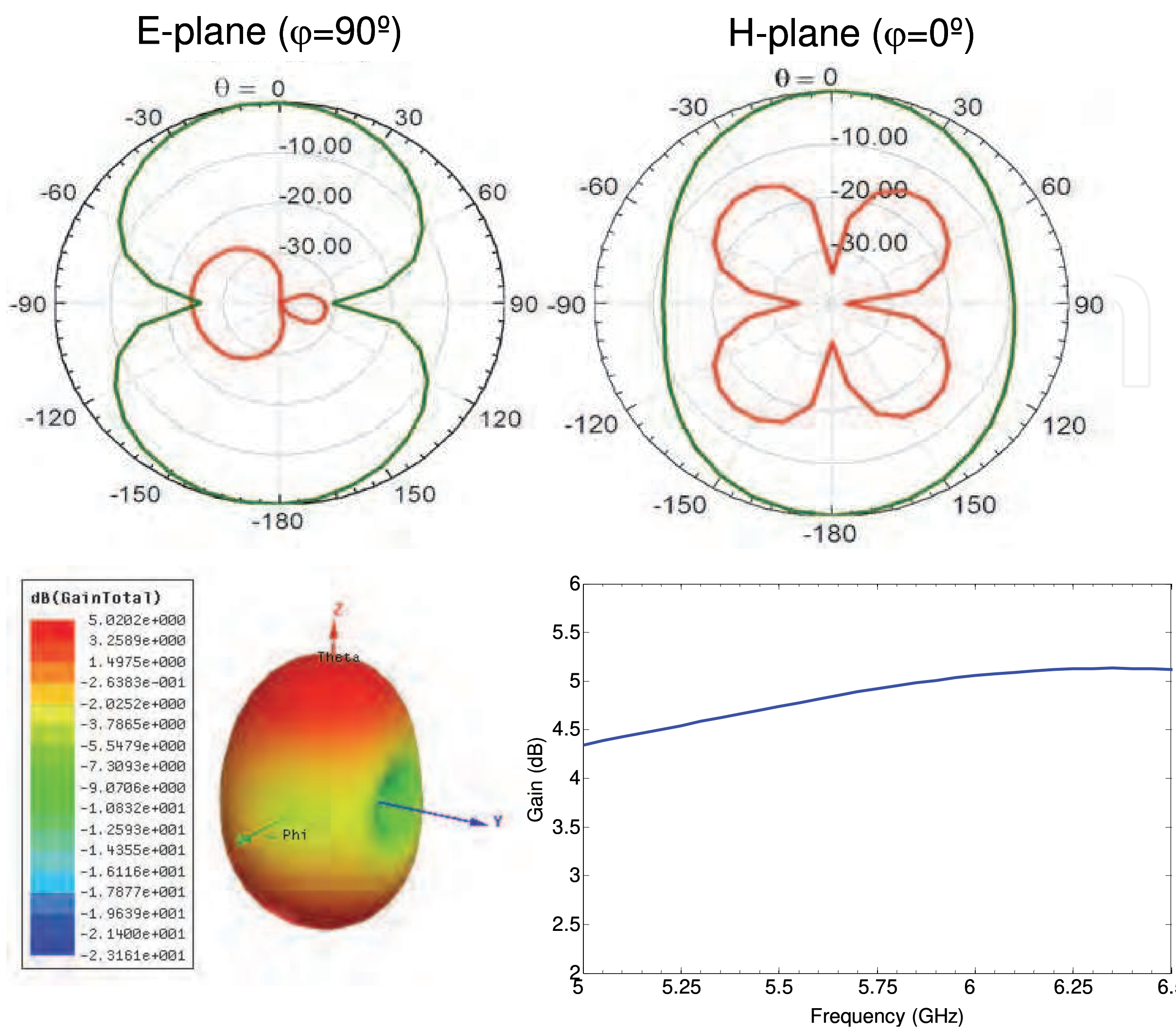

Fig. 5. CPW-fed slot antenna simulated radiation pattern (normalized, in dB) CP (green) and XP (red) components for E plane (up, left) and H plane (up, right). Three-dimensional simulated radiation pattern (down, left). Simulated antenna gain (down, right)

Prototypes of the antenna and the antenna on AMC have been manufactured using laser micromachining. The return losses of each manufactured prototype have been measured. As it can be observed in Fig.4, the measured operating bandwidth of the slot antenna is 1.5GHz (24.0%), which is wider than the 1.48GHz (22.0%) obtained by simulation. The difference in bandwidth and the frequency shift could be due to manufacturing tolerances.

From the measurements results shown in Fig. 6 it can be concluded that although the antenna on 5x5 AMC shows better return loss results than the antenna on 5x4 AMC at some frequencies, both prototypes have the same operating bandwidth and the return loss of the antenna on 5x5 AMC is also proper. So the increase of the prototype size due to the use of 5x5 unit cells is not profitable from the performance point of view. Taking this into account, the 5x4 AMC has been selected to be combined with the CPW-fed slot antenna.

The selected AMC arrangement in terms of a trade-off between performance and size is the one shown in Fig.7. The dimensions of the final structure, antenna on AMC (Fig. 7)), are Lp=57.60mm and Wp=46.08mm. The thickness is 1.626mm in the part corresponding to the antenna on the AMC and 0.813mm in the part corresponding only to AMC unit-cells.

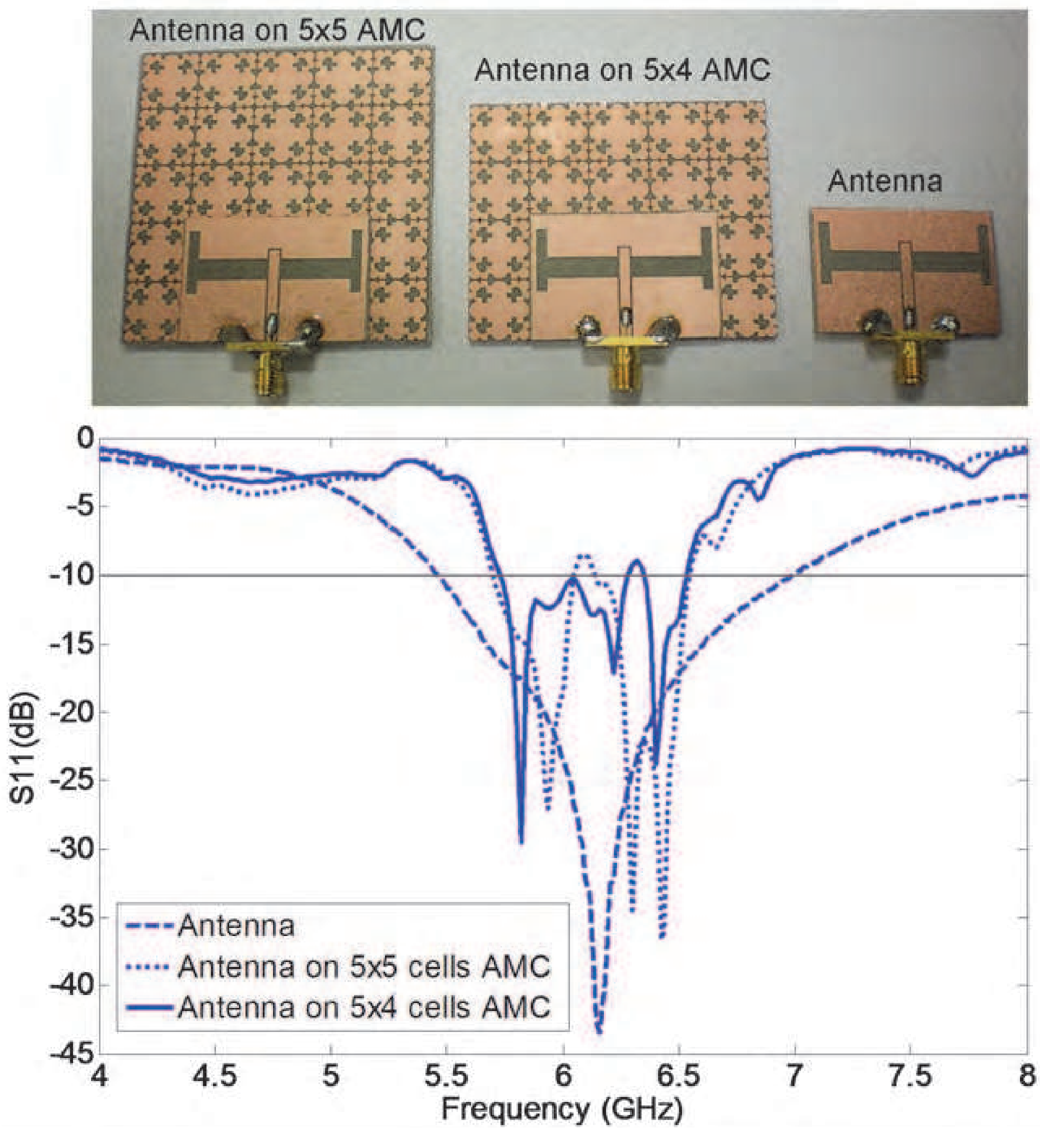

Fig. 6. Manufactured prototypes of the antenna on 5x5 cells AMC, the antenna on 5x4 cells and the antenna (up). Return loss of the Antenna, the antenna on 5x5 cells AMC and the antenna on 5x4 cells (down).

As it could be expected, when placed on a metallic plate the antenna resonance frequency has been shifted out of the SHF RFID band leading to its total malfunctioning (see Fig.4.). However, from Fig.7, it can be extracted that the antenna on AMC combination keeps the antenna operating properly in the whole antenna bandwidth, even when placed on a metallic plate, as the AMC electromagnetically insulates the antenna from the metallic plate. The measured input return loss for the antenna on AMC prototype shows two resonances: the first one is due to the joint operation of the antenna and the AMC, since the AMC operation bandwidth starts at 5.625GHz (See Fig.1). Whereas the second resonance is due to an antenna resonance out of the AMC operation bandwidth, since there is an additional RO4003C metal-backed layer below the original antenna.
According to the measurements, metallic plates do not affect the resonance frequency of the antenna on AMC. In addition, the metallic plates do not degrade the bandwidth of the antenna on AMC.

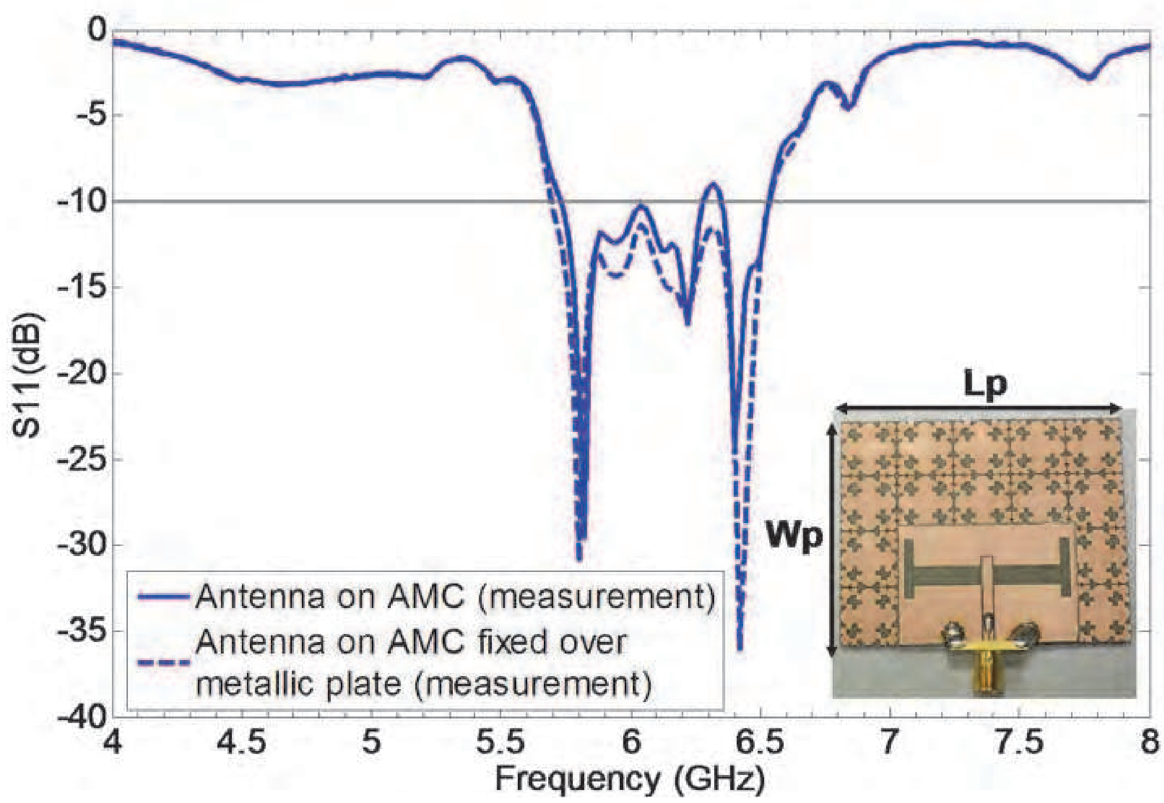

Fig. 7. Measured input return loss for the antenna and the antenna on AMC on a metallic plate; manufactured prototype.

The radiation pattern of the manufactured prototypes has been measured in anechoic chamber (see Fig. 8). The prototypes are placed in the XY plane. The measured antenna radiation pattern is in very good agreement with the simulated one, as can be concluded by comparing Fig 5 and Fig 10.
As can be observed in Fig 9, when the antenna is placed on the AMC, the maximum of the radiation pattern is displaced (the direction of maximum radiation changes). However when the antenna on AMC prototype is fixed over a metallic plate, this maximum is preserved with respect to the antenna on AMC prototype. As could be expected, the back radiation of the antenna on AMC is reduced with respect to the antenna prototype due to the in phase reflection properties of the AMC. So despite the small AMC structure, the antenna on AMC has a relatively low back radiation. Radiation pattern properties of the Antenna on AMC for RFID application are still preserved even when placed on a metallic plate.

Prototype	Gain (dB)	Pattern directivity (dB)	Efficiency (%)
Antenna	4.2	6.3	59.8
Antenna on AMC	2.2	7.0	32.0
Antenna on AMC over metallic plate	3.8	10.0	22.7

Table 2. Measured gain, directivity and radiation efficiency of the manufactured prototypes.

Fig. 8. Measurement set-up in anechoic chamber. Antenna measurement (left) and antenna on AMC over metallic plate measurement (right).

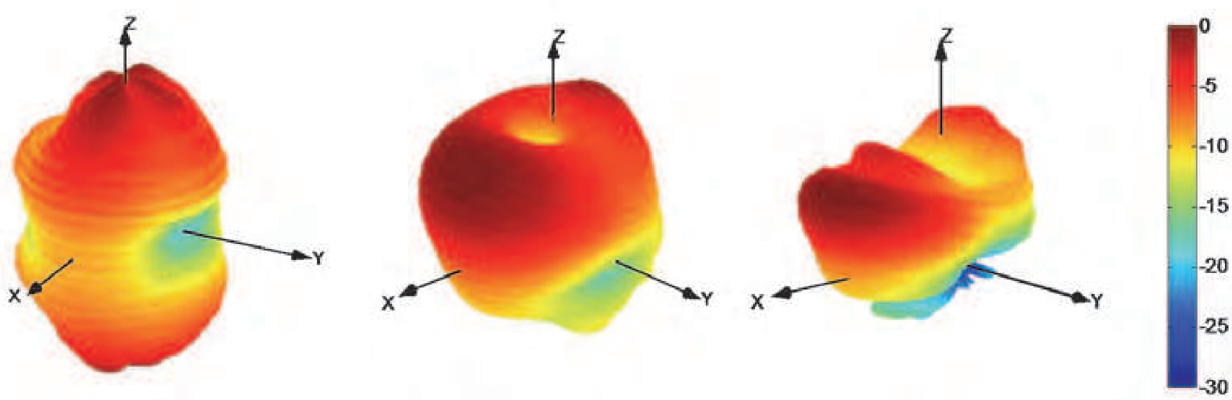

Fig. 9. Three-dimensional representation of the normalized measured radiation pattern for the three manufactured prototypes: antenna (left), antenna on AMC (center) and antenna on AMC over metallic plate (right)

In addition, the gain of the antenna on AMC fixed over a metallic plate almost preserves with respect to the gain of the antenna alone as it is shown in table 2, which represents a significant achievement.

In general, when placing an antenna on an AMC radiation properties such as gain and radiation efficiency are enhanced with respect to the antenna alone. This is due to the fact of using the AMC as a ground plane for the antenna substituting a conventional metallic ground plane i.e. antenna topologies that already have a metallic ground plane under the antenna metallization, such as microstrip patch antennas. As pointed out in section 1, these antennas can perform well with metallic objects but have narrow bandwidth and not negligible thickness. Other approaches combining antennas without metallic layer under the dielectric substrate (such as CPW-fed antennas) with AMCs for gain enhancement purposes, separate the antenna from the AMC by using an additional layer of foam. This also increases the antenna thickness which is not convenient in RFID applications. However, the slot

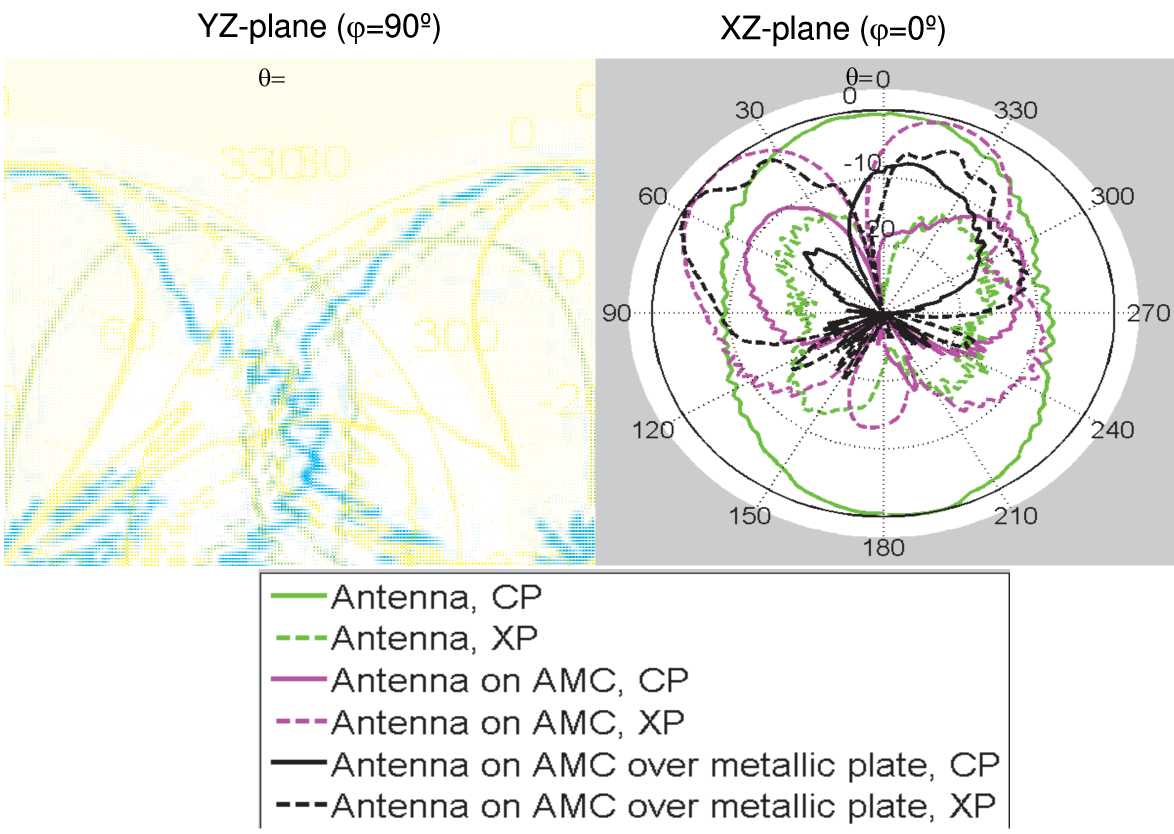

Fig. 10. Measured radiation pattern (normalized, in dB) of antenna, antenna on AMC and antenna on AMC over metallic plate. Planes φ = 90º (YZ-plane) and φ = 0º (XZ-plane).

antenna presented here has no metallic layer under the dielectric substrate and so when placing the AMC directly under the antenna to electromagnetically insulate the antenna from the metallic object, the antenna performance is slightly disturbed to some extent in terms of gain and radiation efficiency (see table II), whereas the obtained prototype exhibit proper operation over metallic objects and the gain is almost preserved compared to the antenna operating alone. All these properties are suitable for RFID application.
Another possibility tested to try to obtain enhanced efficiency (or at least preserved it) is to remove the AMC's unit cells below the antenna but this significantly reduces the antenna bandwidth as can be seen in Fig. 11 and the resonance at 5.8GHz disappears. For this reason the use of this arrangement has been declined. The only resonance that appears is at 6.45GHz and it is due to antenna having and additional dielectric substrate layer and a metallic ground plane bellow this dielectric substrate layer.
Also the antenna could be centred on the AMC arrangement which might preserve and/or enhance the radiation properties of the antenna, but this would require changing the antenna feeding increasing the complexity of the prototype and also its cost. The aim of this chapter it is to show that it is possible to obtain a compact, low profile and low cost antenna on AMC combination proper to be used over metallic objects.

4. Conclusion

A novel CPW-fed-slot antenna on AMC combination prototype suitable to be used in 5.8 GHz RFID tags on metallic objects has been presented. It has been shown that metallic plates

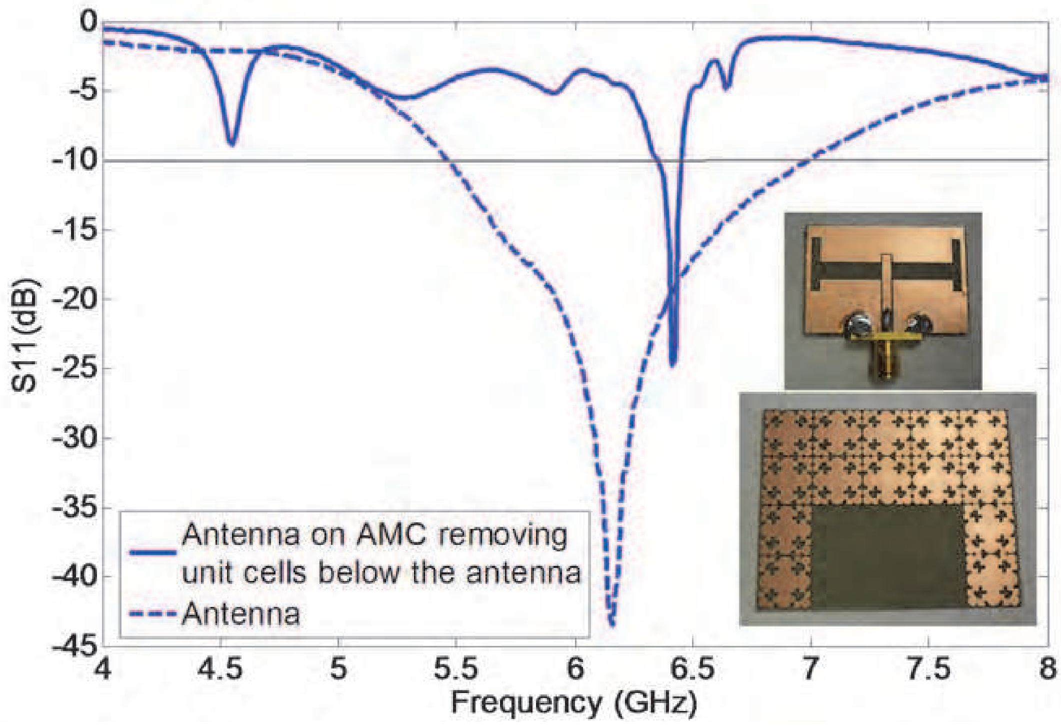

Fig. 11. Measured input return loss for the antenna and the antenna on AMC when the unit cells under the antenna are removed.

do not affect the resonance frequency of the antenna on AMC. In addition, the metallic plates do not degrade the bandwidth of the antenna on AMC.

As a reward for the AMC addition, the manufactured prototype, using a thin and low dielectric permittivity commercial substrate, exhibits proper operation both alone and when placed on a metallic plate.

The presented CPW-fed-slot antenna on AMC combination meets most of the RFID tag antennas requirements pointed out in section 1. Further research is being carried out to obtain a prototype in a bendable dielectric substrate.

By using the other presented AMC designs for UHF and 2.4GHz SHF with antennas operating at those frequency bands, problems related to RFID tags operation with metallic objects can be overcome.

5. Acknowledgment

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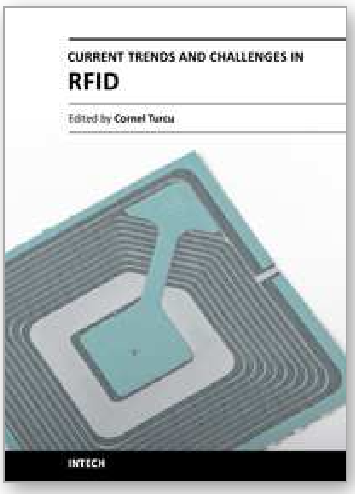

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With the increased adoption of RFID (Radio Frequency Identification) across multiple industries, new research opportunities have arisen among many academic and engineering communities who are currently interested in maximizing the practice potential of this technology and in minimizing all its potential risks. Aiming at providing an outstanding survey of recent advances in RFID technology, this book brings together interesting research results and innovative ideas from scholars and researchers worldwide. Current Trends and Challenges in RFID offers important insights into: RF/RFID Background, RFID Tag/Antennas, RFID Readers, RFID Protocols and Algorithms, RFID Applications and Solutions. Comprehensive enough, the present book is invaluable to engineers, scholars, graduate students, industrial and technology insiders, as well as engineering and technology aficionados.

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