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# Exploiting AMC Structures in the Design of Wearable, Platform-Tolerant RFID Tags

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**Abstract**—In this work we describe a platform tolerant, versatile RFID tag, easily tunable across the global RFID frequency band. The proposed RFID tag incorporates a compact Artificial Magnetic Conductor (AMC) structure, serving as a shielding element for an ungrounded tag antenna. It can be conveniently mounted on materials with low permittivity, metal objects, or attached to the human body for wearable applications, achieving a read range above 11 meters. The tag design prioritizes simplicity in manufacturing, enabling cost-effective production. Detailed design and simulations were conducted using CST Microwave Studio, a general-purpose software for analyzing 3D electromagnetic structures.

## I. INTRODUCTION

The main challenges in designing wearable antennas arise from the significant interaction between the antenna and the human body which, being a lossy and non-uniform medium, can detrimentally impact antenna performance, leading to changes in input impedance, resonant frequency, and radiation efficiency. These effects are closely tied to antenna size, configuration, and operating frequency. Real scenarios introduce further complexities, since the distance between the antenna and the human body fluctuates due to natural movements, and the antenna's characteristics vary based on the wearer's individual and specific locations on the body. Addressing these challenges requires strategic design decisions to mitigate the impact of the human body on the antenna performance and enhance its robustness.

In the UHF frequency band, antennas with dimensions ranging from  $\lambda/5$  to  $\lambda/2$  (where  $\lambda$  represents the free-space wavelength) are commonly utilized. These sizes enable the development of a relatively effective wearable antenna that remains inconspicuous and comfortable for users. Wearable antennas without a ground plane, referred to as "ungrounded" antennas, can be seamlessly integrated into existing clothing due to recent advancements in textile antenna design and intricate circuit fabrication techniques. However, the absence of a metallic ground plane makes these antennas highly susceptible to the proximity effect of the human body. Consequently, enhancing their resilience to antenna-body coupling effects poses a significant challenge for antenna designers.

The typical efficiency of "ungrounded" printed wearable antennas is well below 10% when operating attached to the body or within a few millimeters from the wearer, which is a common scenario [1]. Given the inefficiency of ungrounded wearable antennas, a commonly adopted configuration involves a grounded structure. The ground plane, ideally

minimized in size, is printed on the back of the dielectric layer. This approach proves effective in mitigating coupling effects between the antenna and the human body. However, a large ground plane contradicts crucial requirements for wearable antennas, as the physical structure of grounded antennas significantly restricts mechanical flexibility, comfort, and wearability. To address this, a criterion has been proposed in [2, 3] to guide designers in selecting the optimal shape and size for the antenna ground plane. By modifying the ground plane to confine electric energy density away from the antenna border, degradation in antenna performance due to human body coupling can be reduced. This facilitates the design of a grounded wearable antenna with minimal impact on wearer comfort.

Alternatively, a more effective configuration with respect to grounded structures for improving wearable antenna performance involves the use of Artificial Magnetic Conductors (AMCs). These structures allow designers to maintain antenna radiation characteristics and performance by isolating the antenna from the surrounding environment [4]. This paper describes the design of a relatively small AMC structure used as a shielding element for an ungrounded RFID tag antenna at UHF frequencies selected from the open literature, namely the nested-slot suspended-patch (NSSP) antenna, a slot aperture antenna operating at 868 MHz, whose performance has been assessed and experimentally tested in [5]. The developed UHF RFID tag is versatile, serving as a wearable antenna, an on-metal tag and a platform-tolerant tag, thanks to the incorporated AMC structure. It exhibits high isolation in various environments, achieving a reading range exceeding 5.5 m on low permittivity dielectric materials, 8 m when attached to the human body, and 11 m on a 200x200 mm<sup>2</sup> metal plate. The RFID structure has been designed using CST Microwave Studio 2023, a general-purpose software for analyzing 3D electromagnetic structures.

## II. RFID TAG DESIGN

An Artificial Magnetic Conductor (AMC) is a designed surface with unique electromagnetic characteristics, created by using metamaterials like Electromagnetic Bandgap (EBG), Electric-LC (ELC), Double-Negative/Double-Positive materials (DNG/DPS), Split Ring Resonators (SRR), Photonic Band Gap (PBG) materials, metamaterial absorbers, and metamaterial beams. AMCs differ from Perfect Electric Conductors (PECs) by generating reflected waves that align with the original current, enhancing antenna radiation efficiency and gain. This allows for low-profile antenna design without the need for an excessive distance of

$\lambda/4$  between the AMC ground plane and the antenna, crucial for UHF wearable antennas. AMC structures operate as a Perfect Magnetic Conductor (PMC) within a limited frequency band, acting as narrowband structures. The physical size of the AMC unit cell is critical, typically close to half a wavelength, posing challenges in size reduction, especially in the lower UHF frequency band. A straightforward method to achieve substantial size reduction (approximately inversely proportional to  $\sqrt{\epsilon_r}$ , where  $\epsilon_r$  is the dielectric permittivity of the substrate) involves employing high permittivity dielectric materials as substrates for the AMC structure. Despite potential drawbacks such as higher losses and cost, this approach is effective in minimizing size. In this work, we choose a 1.57-mm-thick ARLON dielectric slab ( $\epsilon_r = 6$ ,  $\tan\delta = 0.0004$ ) to implement both AMC and tag, achieving a 60% size reduction compared to a substrate with  $\epsilon_r = 1$ , resulting in a compact and comfortable structure.

The AMC unit cell, designed for resonance at the RFID UHF European frequency of 868 MHz, is depicted in Fig. 1(a). The key parameter of the cell is the intercell distance  $D_B$ , which can be adjusted to tune the resonant frequency of the periodic structure. Lowering  $D_B$  decreases the resonant frequency, but it should not be too small to prevent strong coupling between adjacent cells. The chosen design value for  $D_B$  is 0.4 mm, and the AMC unit cell exhibits a periodicity of  $D = 47.35$  mm ( $0.136 \lambda_0$  at 868 MHz).

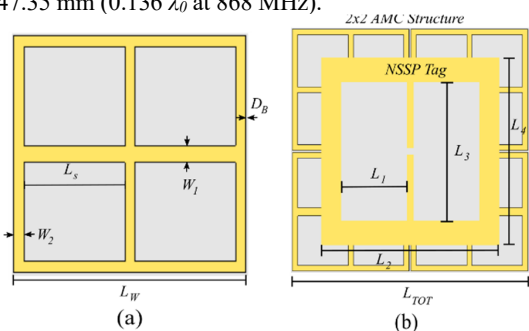


Figure 1. (a) Geometry of the proposed AMC unit cell.  $L_s = 20.25$  mm,  $L_w = 47.35$  mm,  $W_1 = 1.85$  mm,  $W_2 = 2.1$  mm,  $D_B = 0.4$  mm,  $W_s = 1.3$  mm; (b) Layout of the NSSP ungrounded tag antenna on the  $2 \times 2$  AMC structure.  $L_1 = 25.65$  mm,  $L_2 = 69.44$  mm,  $L_3 = 51.3$  mm,  $L_4 = 69.44$  mm,  $L_{TOT} = 94.7$  mm.

To highlight the benefits of utilizing the AMC structure for tag isolation from the human body, we employ the Nested-Slot Suspended Patch (NSSP) antenna proposed in [5] as the tag. Operating at 868 MHz, this single-layer slot antenna features an H-shaped slot on a suspended patch, as depicted in Fig. 1(b). The tag is etched on the same Arlon dielectric slab used for the AMC structure, and an Impinj Monza 4 microchip with an input impedance  $Z_{chip}$  of  $13-j151 \Omega$  at 868 MHz has been used. The finite AMC screen beneath the tag antenna consists of a  $2 \times 2$  unit cell array (Fig. 1b), representing the smallest size for a finite AMC structure. As a result, the combined radiator has a compact size of  $94.7 \times 94.7$  mm<sup>2</sup> ( $0.272 \lambda_0 \times 0.272 \lambda_0$  at 868 MHz).

The proposed tag on AMC was tested in free space and attached to various materials (the human body, a PET sheet, a glass sheet, and a copper metal plate). The RFID tag theoretical read range [3] is reported in Fig.2 for a transmitter

power equal to 30 dBm, assuming a reader antenna with gain  $G_r = 5.15$  dB and the read sensitivity of the IC Monza 4 equal to  $-17.4$  dBm. The presented results demonstrate that the structure is platform-tolerant and can be utilized interchangeably for tagging arbitrary objects or in wearable applications. The achieved reading range is very satisfying for each tested material the tag is attached to, ranging from 5.5 m to 11 m for glass and metal, respectively. The read ranges for the tag attached to PET, glass, or in free space are very similar, while it increases of about 2 m when the tag is attached to the human body, doubling when it is attached on a metal plate.

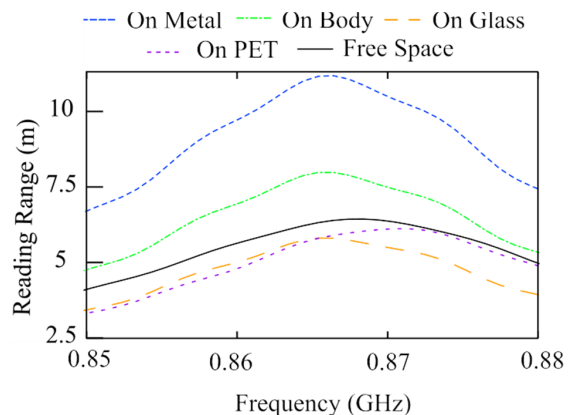


Figure 2. Input impedance of the proposed TIS sensor for different values of the PTS compound conductivity and different lengths of the PTS trace.

The designed platform tolerant RFID tag features easily tuning within the whole worldwide RFID band (from 868 to 960 MHz) and has a compact AMC structure serving as a shielding element for an ungrounded RFID tag antenna. The AMC structure enhances isolation, simplifies microchip matching, and reduces unwanted radiation towards the wearer. In addition, the tag boasts low manufacturing complexity and cost-effectiveness.

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