An AMC Based Antenna for Telemedicine Applications

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Abstract **─** In this paper, we present an antenna design for telemedicine applications operating in the Industrial Scientific Medical (ISM) 2.4 GHz band. The design is based on a printed monopole antenna integrated with an artificial magnetic conductor (AMC) ground plane. The AMC ground plane is utilized to isolate the user's body from undesired electromagnetic radiation in addition to eliminating the antenna's impedance mismatch caused by the proximity to human tissues. Moreover, specific absorption rate (SAR) is analyzed based on a numerical human body model (HUGO) to assess the design feasibility. Results show that the radiation characteristics, impedance matching, and SAR values of the proposed design are significantly improved compared with conventional antennas.

Index Terms **─** Artificial magnetic conductors (AMCs), printed monopoles, specific absorption rate (SAR), telemedicine.

I. INTRODUCTION

Telemedicine has evolved tremendously during the past decade due to the increasing demand for remote monitoring of human vital signs. Telemedicine applications involve but are not limited to seniors monitoring, post surgery patients recovery tracking, and monitoring the body performance of astronauts and athletes during exercise [1]. The health parameters that may be transmitted wirelessly to remote stations (off body mode) in telemedicine systems range from heart rate, blood pressure, body temperature to blood glucose levels and ECG wave forms [2]. In addition to off body applications, on body mode is also necessary for communication between sensor devices located on or within the patient's body [3]. For optimal performance, wearable antennas are required to be small in size, lightweight, and robust. They also have to be comfortable and conformal to the body shape, yet they must maintain high performance in terms of reliability and efficiency. Electro textile based antennas seem to be a low profile solution for a wearable application; however, they are prone to discontinuities in substrate material, fluids absorption, bending, and compression [4]. Microstrip antennas in general offer favorable characteristics in terms of radiation characteristics (directional radiation pattern which is desired in telemedicine application i.e. radiates outside the patient's body). Furthermore, microstrip antennas offer a low profile construction, low cost, and ease of fabrication; however, they suffer from a very narrow bandwidth, that is, any minor shift in the resonant frequency would cause a channel disconnection. Thus, a low profile antenna with hemi spherical radiation pattern and a relatively wide bandwidth is needed to be employed in this application.

Previous work was primarily focused on achieving an omni-directional radiation pattern [5, 6]. However, a uni-directional radiation pattern of the patch antenna is favorably desired in wearable applications, to avoid unnecessary radiation exposure to the human body, radiation losses and impedance mismatch.

Several techniques [7-10] have been reported to solve the aforementioned issues including the use of cavities, absorbers, and shielding planes. However, these techniques lead either to an unacceptable increase in the antenna's height, or a more complicated manufacturing process. In [8], a

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reflector patch element is utilized to decrease the rear directed radiated field. The performance of this technique is highly dependent on the ground plane size, furthermore, it is based on a stack of multiple (five) layers which leads to a complex high profile system. In [9], a study on the effects of including conductive materials within cell phones for reducing SAR has been presented. The study demonstrated that the position of the shielding material is an important factor to the technique's effectiveness. In [10], a single negative (SNG) metamaterial is utilized to suppress the EM wave propagating towards the human body, though efficient, it does not offer a low profile solution.

In this paper, we propose a compact printed monopole antenna integrated with an artificial magnetic conductor (AMC) ground plane which is utilized to reflect the electromagnetic radiation in phase in order to minimize the radiation exposure towards the user's body and eliminating the antenna's impedance mismatch caused by the proximity of human tissues. It is well known that a perfect electric conductor (PEC) has a reflection phase of 180° for a normally incident plane wave, while a perfect magnetic conductor (PMC), which does not exist in nature, has a reflection phase of 0° [13]. Image theory states that a PEC ground plane causes the antenna's current and its image to cancel each other, in other words shorting the antenna. This is responsible for dropping the real part of the antenna impedance towards zero ohms, while the imaginary impedance approaches infinity. Thus, a significant amount of the electromagnetic energy is trapped between the antenna and the ground plane; hence, the antenna can no longer radiate efficiently. This is the opposite scenario if an AMC is placed instead of PEC due to its reflection of electromagnetic wave with zero phase shift.

In Section II, we present the description of our proposed design and principle of operation. In Section III, we discuss the radiation characteristics and performance of the antenna system on a numerical human model. In Section IV, the specific absorption rate (SAR) is evaluated for the design with and without the AMC structure for comparison purposes. Finally, conclusions are given in Section V.

II. ANTENNA SYSTEM DESIGN

The proposed antenna along with the AMC structure was designed and optimized using CST Microwave Studio which is based on the finite integration technique (FIT) [11]. For validation purposes, Ansoft HFSS which is based on the finite element method (FEM) [12] is used for further results verification.

A. Antenna design

The proposed antenna is designed to operate in the Industrial Scientific Medical (ISM) 2.4 GHz band. As shown in Fig. 1, the antenna design which was previously reported by the authors of this paper [13] consists of a U-shaped monopole. This type of winding decreases the structure size without a disturbance to the radiation pattern or significant degradation of the efficiency (with respect to a free space monopole/dipole. The separation distance between the monopole arms is chosen as 6 mm which achieves the minimum return loss. It should be noted that smaller separation distance leads to an increased capacitive coupling between the arms which yields an increased impedance mismatch. The U-shaped monopole is fed by a 1.5 mm wide 50 Ω microstrip line. Both the monopole and the microstrip line are printed on the same side of a 26.5 mm x 25 mm Kapton polyimide substrate which offers a very low profile (50.8 μm) yet very robust with a very high tensile strength and a dielectric constant of 3.4 and a loss tangent of 0.002. On the other side of the substrate, a 12.5 mm x 25 mm copper ground plane is positioned behind the microstrip line. The electrical length of the U-shaped monopole in addition to the ground plane size controls the resonance frequency of the antenna. It is worth mentioning that the considered antenna was fabricated using a conductive ink based on sliver nano particles which is ink-jetted over the kapton polyimide substrate by a Fujifilm Dimatix DMP 2831 material printer followed by a thermal annealing at 100° C for 9 hours. Three layers of ink were deposited on the substrate to achieve a robust and continuous radiating element/feed line. The antenna's geometry and dimensions are depicted in Fig. 1 and Table 1, respectively.

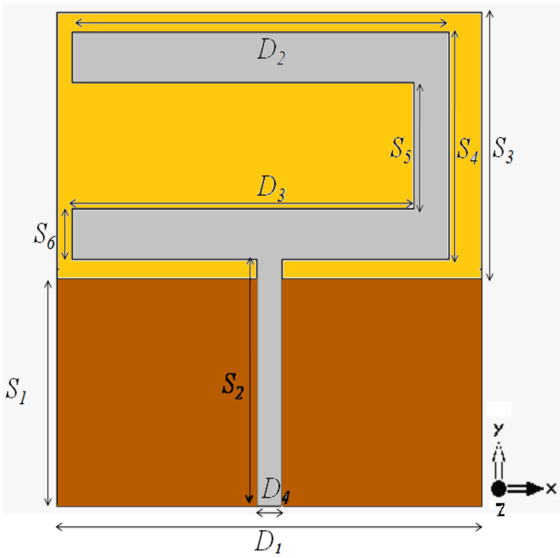


Fig. 1. Geometry and dimensions of the proposed printed monopole (the shaded area represents the ground plane on the opposite side).

Table 1: Single band antenna dimensions in millimeter

S_1	12.5	D_1	25
S_2	13.5	D_2	22
S_3	14	D_3	20
S_4	12	D_4	1.5
S_5	6		
S_6	3		

B. AMC based system

As is well known, utilizing AMC structures as ground planes significantly enhance the gain of dipole/monopole antennas [14, 15].

As stated previously, a PEC has a reflection phase of 180° for a normally incident plane wave, while a PMC, which does not exist in nature, has a reflection phase of 0°.

AMC which was first proposed by [15] can be artificially engineered to emulate a PMC, i.e.: have in-phase reflection coefficient properties in a specified frequency band. AMCs are typically realized based on periodic metallization patterns. The reflection phase of an AMC surface varies continuously from -180° to +180° versus frequency, and crosses zero at the AMC resonance frequency. The useful bandwidth of an AMC is generally defined as -90° to +90° on both sides of the resonant frequency [15].

In this research, a 3 x 3 unit cell of square patch based AMC (without vias) is designed to operate in the same frequency range as the antenna's (2.45 GHz) with a bandwidth of 200 MHz. The AMC is utilized to isolate the user's body from unnecessary radiation and to eliminate the antenna's impedance mismatch. The total size of the AMC is 58 mm x 58 mm printed on a substrate with 1.5 mm thickness and 4.5 mm dielectric constant. Figure 2 depicts the reflection phase profile of the proposed AMC structure.

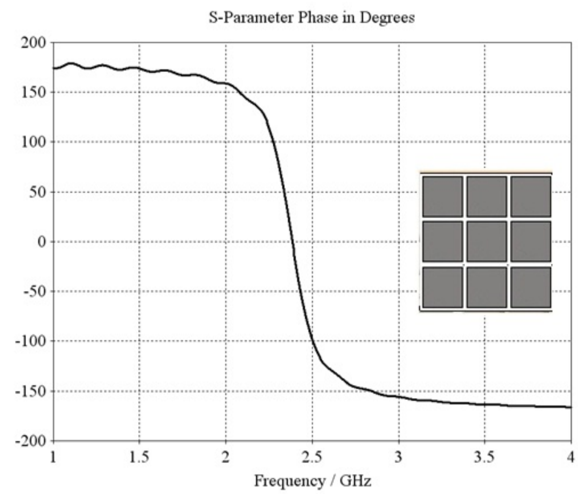


Fig. 2. Reflection phase profile of the AMC unit cell.

III. ANTENNA SYSTEM'S PERFORMANCE

The proposed antenna without AMC was first simulated in free space then over a HUGO numerical human model to study the effect of the human tissues proximity on the antenna's performance. HUGO is an anatomical 3D volume and surface data set of the human body which is based on the visible human data set produced by the National Library of Medicine. The HUGO data set is segmented and categorized into 40 different types of tissues and is available at a 1x1x1 mm voxel size [16]. The antenna is positioned on the arm of the human model as a typical realistic setup. To reduce the simulation time, a portion of the arm with a reasonable size (sectional area of about 25 times the antenna's size) is selected instead of simulating the entire numerical model; it should be noted that this approximation is fair since the specific absorption rate (SAR) distribution does not exceed this number (as will be observed later in Section IV). The number of mesh cells is reduced from 28,366,422 down to 1,423,934 mesh cells. It is worth mentioning that symmetry planes were applied to the AMC's unit cell structure to further reduce the simulation time required for reflection phase extraction since it has a geometrical symmetry. Electric wall (E_t=0) is applied in the YZ plane while a magnetic wall (H_t=0) is applied to the XZ plane in compliance with the assigned boundary conditions needed to simulate periodic AMC structures. Thus, 75% reduction in the mesh cells is achieved (from 128,000 down to 32,000) in addition to an extreme reduction in the simulation time. The overall simulation time is recorded to be 86 minutes on an Intel Xeon^{TM} 3.40 GHz CPU with a 16 Giga Byte RAM workstation. As is well known, if the number of the adopted mesh cells is not enough, enormous error may be induced which leads to accuracy deterioration of the entire simulation. Hence, to simultaneously retain the simulation efficiency and results accuracy, the number of mesh cells was mainly determined through sufficient meshing of the antenna element and AMC structure where the smallest geometric detail (i.e. AMC gap, antenna's microstrip line, etc,..) is covered by at least two mesh cells both horizontally and vertically. The numerical setup for the antenna-Hugo model is shown in Fig. 3.

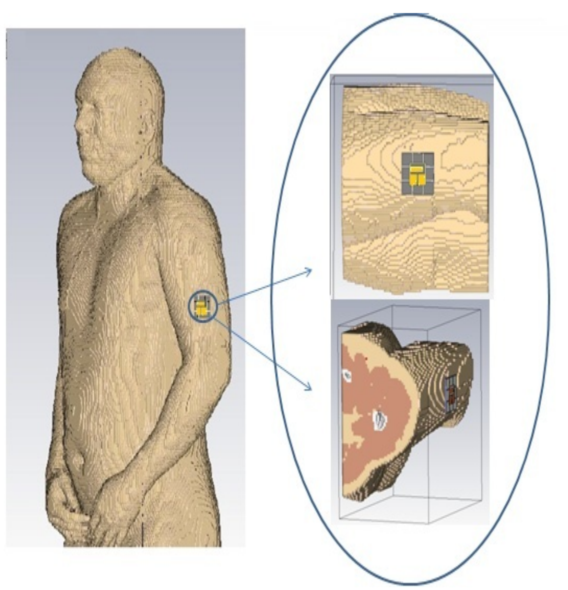


Fig. 3. Numerical human model (HUGO) used for realistic antenna performance testing.

To further validate the simulation results obtained from CST microwave studio, a simplified human arm model is synthesized based on a skin-fat-muscle scheme using the Ansoft HFSS full wave EM solver. The electrical properties of each material are imported from the HUGO model. The antenna is simulated on the human arm model with and without the AMC structure.

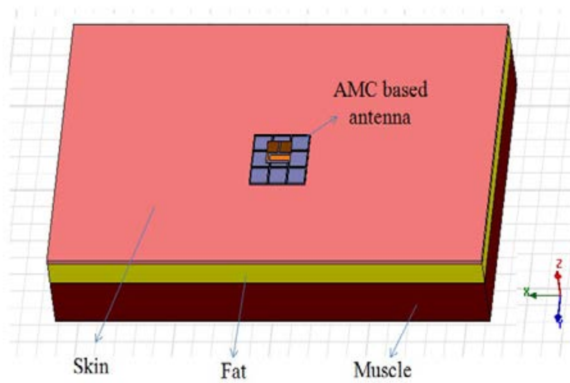


Fig. 4. Numerical human arm model in HFSS including the electrical properties of each layer.

As can be seen in Fig. 5, CST results for the return loss of the antenna with AMC on HUGO is -23 dB at 2.45 GHz, while the achieved -10 dB return loss bandwidth is 130 MHz. removing the AMC leads to a 95 MHz (4%) shift in the resonance frequency to the lower side, and an increase in the return loss (about 7 dB). HFSS results show good agreement with CST's. The antenna also experiences a shift to a lower frequency when the AMC is removed with an increase in return loss but to a less extent compared to CST results.

As stated earlier, integrating the AMC structure with the antenna (as a ground plane) overcomes the abovementioned problems associated with the human tissues proximity. Furthermore, the radiation pattern turns to a hemi-spherical when the AMC is included compared to an omni-directional radiation pattern for the conventional monopole.

It is evident from Fig. 6 that a considerable improvement in terms of gain is achieved (4.1 dB) by including the AMC structure with respect to a free-space monopole. The simulated gain for the proposed antenna system is 6.2 dB compared to 2.1 dB for the original case. It should be noted that using a PEC ground plane instead of AMC would lead to a high profile system since a separation of λ/4 is required to achieve in phase reflection. The separation distance could be reduced if the monopole is placed on top of a high permittivity dielectric slab backed by a PEC; the drawback of using this technique is that high permittivity substrates support surface waves which trap a significant amount of power radiated by the monopole and become the main radiation source, which consequently leads to a distortion in the radiation pattern.

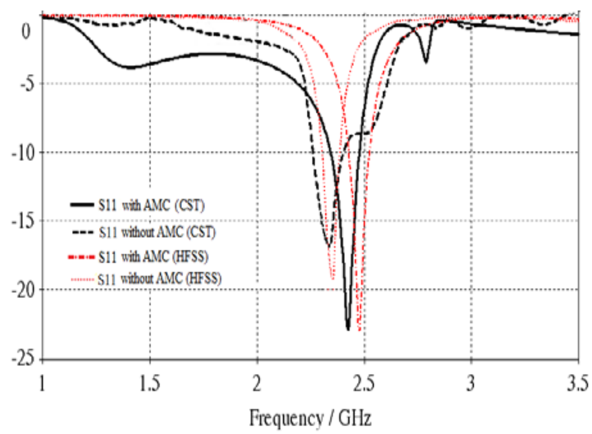
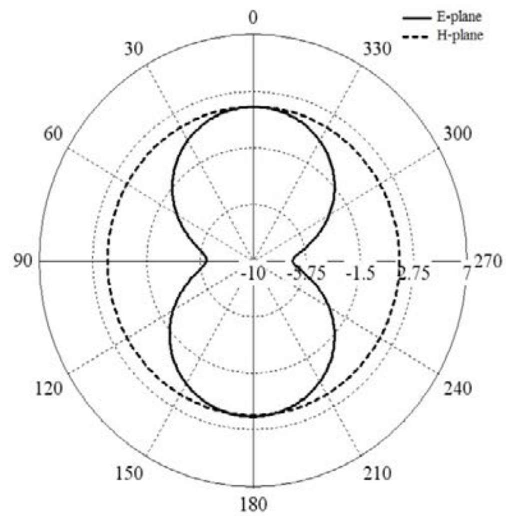


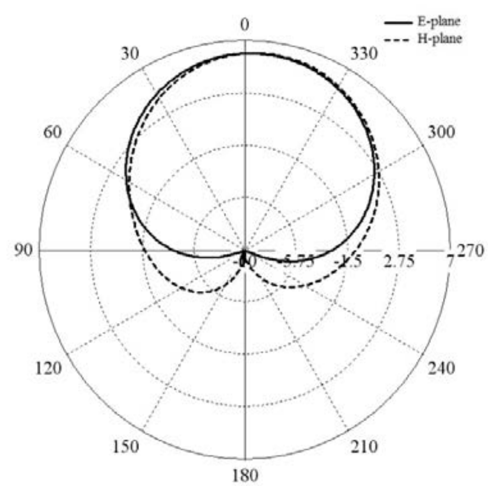
Fig. 5. S_{11} parameters for the antenna on a human numerical model (with and without AMC).

IV. SAR ANALYSIS

The specific absorption rate (SAR) is a standard measure used to evaluate electromagnetic power deposition in the human tissues. SAR values must not exceed the exposure guidelines specified by the Federal Communication Commission (FCC). The maximum allowed SAR in USA and Canada is 1.6 W/kg averaged over 1g of tissue [17]. SAR was simulated using the HUGO human model to reflect realistic situations. For comparison purposes, both the proposed design and the antenna without AMC were simulated. As is well known, the radiated power of mobile phones can range from 21dBm (125 mW) to 33 dBm (2W) depending on the adopted power class; on the other hand, a wireless router can range from a typical 15 dBm (30 mW) to 27 dBm (500 mW). Since FCC has not standardized the power limit in telemedicine systems yet, a 100 mW power input is chosen as benchmark to evaluate the performance of the antenna systems (with and without AMC) in terms of SAR values. For the considered power input, the proposed design achieved a SAR value of 0.68 W/Kg while the same antenna without AMC experiences a 1.68 W/Kg which is above the specified rate allowed by the FCC. Thus, the proposed design achieved a 60% reduction in SAR. SAR values for both cases are depicted in Fig. 7.



(a)



(b)

Fig. 6. E-plane (YZ cut) and H-plane (XZ cut) radiation patterns for (a) printed monopole antenna and (b) the same antenna based on AMC ground plane.

V. CONCLUSION

In this paper, we reported a printed monopole antenna design based on an AMC ground plane intended for telemedicine applications. The AMC ground plane is utilized to eliminate the impedance mismatching and frequency shift caused by the human tissues proximity. Furthermore, the in-phase reflection characteristic of the AMC structure significantly reduced the undesired electromagnetic radiation towards the patient's body which is essential to the performance of telemedicine antenna systems. The proposed antenna has an operating bandwidth of 5.4% at 2.45 GHz with a unidirectional radiation pattern. The calculated SAR values for the AMC based antenna were very low with a reduction of about 60% compared to the same antenna without the integration of AMC. To conclude, the proposed antenna would be a good candidate for wireless body area network (WBAN) and telemedicine applications in terms of SAR, efficiency, bandwidth, and stability.

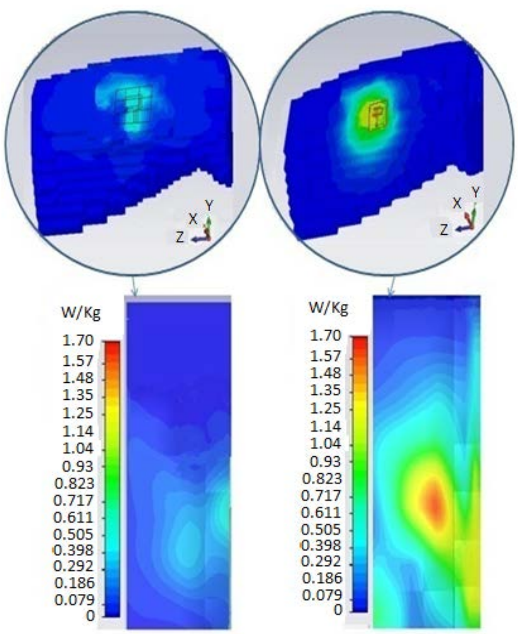


Fig. 7. SAR values for the proposed design (left) and for the same design without the AMC structure (right).

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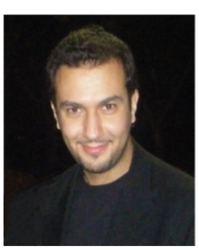

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Daniel G. Rucker received his Bachelors of Science in Systems Engineering from the University of Arkansas at Little Rock in Spring 2007. He was accepted by the National Science Foundation (NSF) for a Research Experience for Undergraduates program in the summer of 2006 at the Arecibo Observatory in Puerto Rico. There he worked on digital electronics and radar control. Following this work, he shifted his undergraduate research to microstrip antennas for biomedical devices at UALR. Currently, he is pursuing a Ph.D. in Applied Science at the University of Arkansas at Little Rock. His current research areas are microstrip antennas, low power wireless sensor systems, and systems engineering design. In the area of microstrip antennas, his work is focused on implantable and wearable microstrip antennas for biomedical applications.