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# Radio Frequency Laboratory (LRF)

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Titre : Conception d'une antenne CPW à faible SAR avec un plan de masse AMC à base de magnéto-diélectrique

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Résumé : Une structure AMC très compacte basée sur un substrat magnéto-diélectrique est proposée dans cet article. Une boucle en spirale de faible hauteur est insérée sous une structure AMC conventionnelle pour agir en tant que substrat à permittivité/permeabilité élevée, ce qui permet d'obtenir un plan AMC compact. Une réduction de 75 % a été obtenue grâce à cette technique par rapport à l'AMC conventionnel. Le plan de masse AMC modifié est inséré entre le corps humain et une simple antenne CPW. Le calcul du taux d'absorption spécifique à partir de l'analyseur d'onde complète montre qu'une réduction de 45 % est obtenue par rapport à l'antenne sans plan de masse AMC. Pour valider la structure AMC magnéto-diélectrique, deux analyseurs d'onde complète ont été utilisés. La comparaison entre les deux simulateurs montre un bon accord entre eux.

Mots-clés : antenne CPW à faible SAR, conducteur magnétique artificiel, AMC magnéto-diélectrique, structure AMC très compacte, substrat magnéto-diélectrique, boucle en spirale de faible hauteur, substrat à permittivité-permeabilité, plan AMC compact, plan de masse AMC, corps humain, taux d'absorption spécifique, analyseur d'onde complète, guides d'ondes coplanaires.

# On the Design of Low SAR CPW Antenna with Magneto Dielectric AMC Based Ground Plane

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**Abstract**— A very compact AMC structure based on a magneto-dielectric substrate is proposed in this paper. A low-profile spiral loop is inserted under a conventional AMC structure to act as a high permittivity/permeability substrate, which leads to a compact AMC plane. A 75-percent reduction was achieved by this technique compared to the conventional AMC. The modified AMC ground plane is inserted between a human's body and a simple CPW antenna. The specific absorption rate calculation from full wave analyzer shows that a 45-percent reduction is attained compared to the antenna without AMC ground plane. To validate the magneto-dielectric AMC structure, two full wave analyzers were used. The comparison between the two simulators shows a good agreement between them.

**Index Terms**— AMC, Magneto-Dielectric, SAR.

## I. INTRODUCTION

The use of cellular has been growing rapidly in the global communities [1-4]. The absorption of electromagnetic (EM) energy emitted from the cellular phone has been discussed in recent years. Exposure guidelines for protecting the human body from EM exposure have been issued in many countries. The specific absorption rate (SAR) is a defined parameter for evaluating power deposition in human tissue. For the cellular phone compliance, the SAR value must not exceed the exposure guidelines [5].

The interaction of the mobile handset with the human head has been explored by a lot of published papers.

In [6], a ferrite sheet was adopted as a protection attachment between the antenna and the human head. In [7], a study on the belongings of attaching conductive materials to the cellular phone for SAR reduction has been offered. Another approach is the use of a directional or reflectional antenna [8]. Such an antenna structure sacrifices the availability of signals received from all directions to the phone model.

Metamaterials composed of an array of split ring resonators (SRRS) were applied to the reduction of SAR [9]. With a proper design and arrangement, stop bands at desired mobile frequencies can be achieved. In [10] a perfect electric conductor (PEC) reflector was sited between a human head and the driver of a folded loop antenna. The result has showed that the radiation efficiency can be improved and the peak SAR value could be condensed.

The idea of inserting a PEC between human head and the mobile antenna is a simple technique which can omit the EM wave of antenna toward the human head.

Artificial Magnetic Conductor (AMC) can be an alternative for PEC for our purpose as they can act as a PMC at the certain frequency bands. The AMC surface has a high impedance characteristic at some frequency and can change the radiation pattern of the antenna while maintain the antenna performances such as radiation efficiency and gain when even the antenna is too close to it.

The main aim of this paper is to present a compact AMC structure and then combine it with CPW antenna in order to reduce the SAR. Apart from numerous miniaturization techniques on the patch [11-15], in this paper, we focus on the substrate. It is been shown in [16] that magneto-dielectric (MD) substrate is a good candidate for this purpose. With the use of MD good dielectric properties (high permittivity) can be achieved while the capacitive nature of patch on the high dielectric substrate can be mitigated due to magnetic properties (high permeability) of MD.

A novel low profile MD is used in this paper as a meta-substrate of a conventional AMC in order to compact the size. Simulation results show that 70% reduction is achieved with this technique.

## II. MAGNETO-DIELECTRIC AND AMC DESIGN

In this section, firstly an MD substrate design is discussed, and constitutive parameters will be extracted from the frequency response of a unit cell. Then an AMC unit cell, a combination of an MD substrate and a conventional AMC cell will be detailed.

### A. Magneto-dielectric substrate

The configuration of proposed unit cell MD is shown in Fig. 1. As is can be seen from the Fig. 1 MD is consists of metallic strips and "vias" which make a loop normal to the  $x$ -direction. The lower substrate which host the MD and the upper substrate which is reserved for AMC patch are both Rogers 4003 with the dielectric permittivity ( $\epsilon_r = 3.55$ ) and loss tangent ( $\tan \delta = 0.0027$ ). The substrate thickness is 0.8128 mm and 0.254 mm for the lower and upper substrate, respectively.

It was shown in [17] that under specific boundary conditions the constitutive parameters can be calculated from the frequency response of the unit cell. After constitutive parameters are extracted from the unit cell, one can extend and contribute the results for the whole structure.

The S parameters for the unit cell of Fig. 1 are computed using Ansoft HFSS. Both the S-parameters and the retrieved material parameters are presented in Fig. 2. Figures 2 (a) and (b) show the magnitude of the computed S-parameters and the effective constitutive parameters ( $\epsilon_{\text{reff}}$ ,  $\mu_{\text{reff}}$ ), respectively.

As it can be seen from Fig. 2 (b) at the frequency of 3.5 GHz, a little lower than the resonant frequency, both permittivity and permeability are more than 5. These new constitutive parameters are used as an artificial substrate for our conventional AMC structure.

### B. Artificial Magnetic Conductor Design

The conventional ground plane made of a good electric conducting material is impenetrable and provides a fairly good shielding and it is normally approximated by a perfect electric conductor (PEC). However, it introduces an image with a negative current to that of a source, which is placed horizontally above the ground plane. On the other hand, in order for the planar antennas to be low profile, they have to be placed horizontally and very close to the ground plane beneath them. Therefore, current cancelation of the source antenna with its image, will result in a poor input impedance matching, which in turn prevents the antenna to radiate efficiently. On the other hand, AMCs and HISs, not only maintain appropriate shielding for the electronics beneath the antennas and redirect the wave radiation to the upper half-space, but they also can provide good input impedance matching. As it is known, the image current introduced by a perfect magnetic conductor (PMC) is in parallel and in phase with its source, which is located horizontally above it. This fact is usually used to describe the improvement in the antenna input impedance characteristics when AMCs or HISs are employed as the antenna ground plane.

The unit cell geometry of the proposed magneto-dielectric substrate AMC (MDAMC) is shown in Fig. 3. FEM and Bloch-Floquet are used to identify the electromagnetic properties of the proposed MDAMC. To model the unit cell as an infinite structure, periodic boundary conditions are applied for all four side walls. A wave port was placed at the half-wavelength above the surface and normal plane wave was launched [14]. Then the reflection phase is calculated at the patch surface as a reference plane. Note that, in order to design an AMC with the zero reflection phase at the desired frequency with the equivalent substrate ( $\epsilon_{\text{reff}}=7.48$  &  $\mu_{\text{reff}}=5.5$ ) based on the formula in [17], two MDS are used in the AMC unit cell.

Figure 4 depicts the reflection phase of normally incident plane wave versus frequency for the proposed MDAMC unit cell of Fig. 3. Simulation results of two full wave analyzer, CST, and HFSS, clarified that the proposed unit cell has a zero

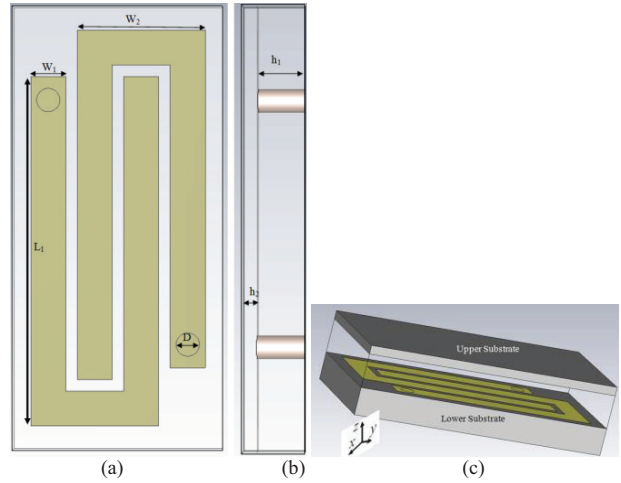


Fig. 1. Configuration of the proposed unit cell MDS (a) front view (b) side view (c) perspective view  
The parameters are set as follow;  $W_1=0.4$  mm,  $w_2=1.45$  mm,  $L_1=3.65$  mm,  $D=0.25$  mm,  $h_1=0.8128$  mm,  $h_2=0.254$  mm.

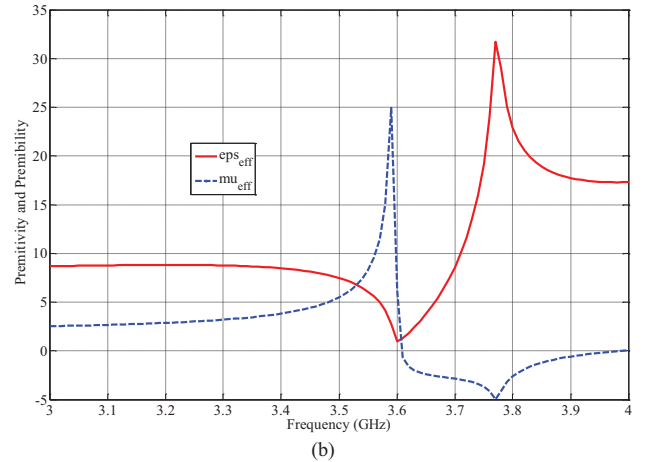
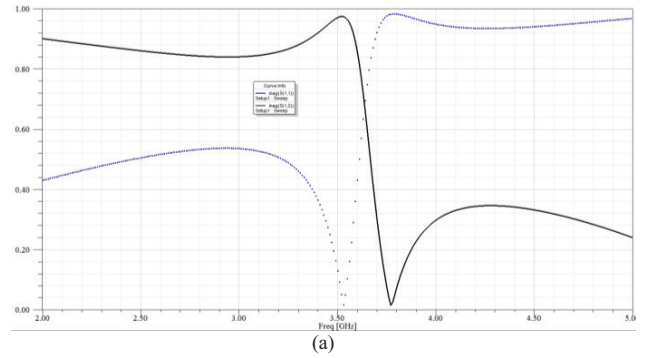


Fig. 2. (a) Magnitude scattering parameters of proposed unit cell (b) constitutive parameters curve versus frequency derived by scattering parameters

reflection phase at the 3.5 GHz, which can be used for our purpose. The overall size of the unit cell is  $5.07$  mm  $\times$   $5.15$  mm. A simulation with the same dimension are carried out with the RO4003 dielectric substrate ( $\epsilon_r=3.55$ ) and a zero

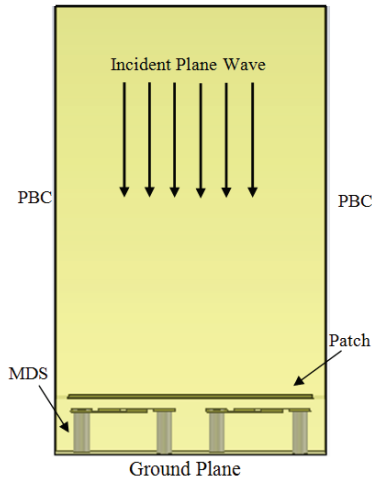


Fig. 3. Configuration of the MDAMC. The square patch has a size of  $4.75 \times 4.65 \text{ mm}^2$  with 0.25 mm gap.

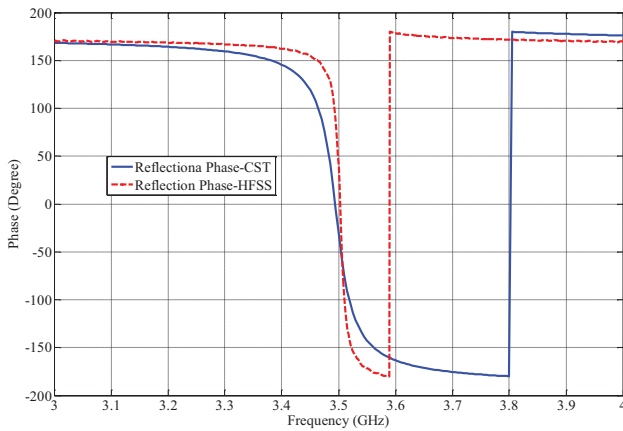
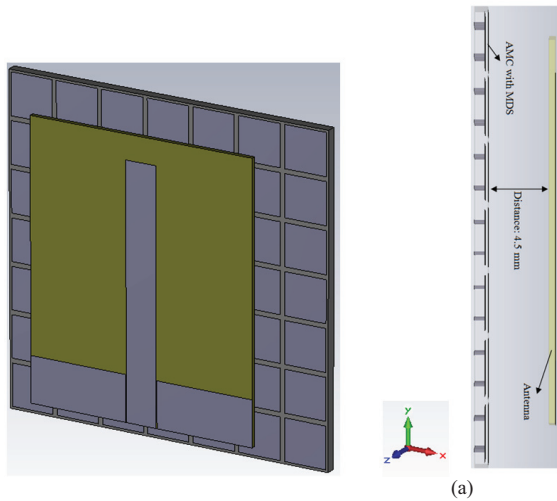


Fig. 4. Reflection phase characteristic versus frequency of the proposed MDAMC unit cell.



(b)

Fig. 5. Configuration of the proposed antenna above MDAMC (a) perspective view (b) side view

reflection phase were achieved at the frequency of 11.35 GHz.

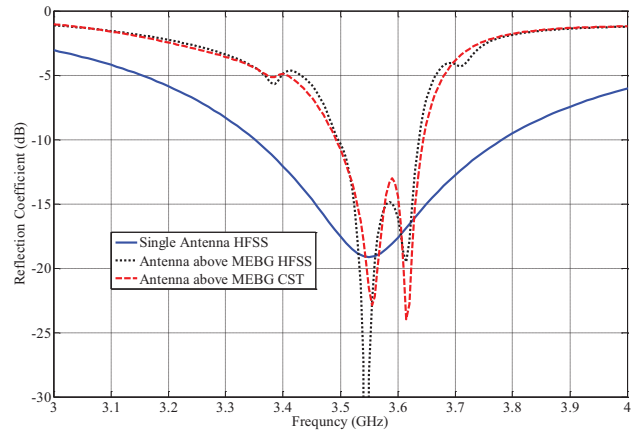


Fig. 6. Comparison between simulation results of the reflected coefficient of the CPW antenna in free space and above MDAMC with CST and HFSS

Therefore, 70% reduction in the unit cell size is achieved with utilizing the proposed MDS

### III. CPW ANTENNA PERFORMANCE ABOVE MDAMC

In this section, a simple antenna is used above the MDAMC structure and the antenna impedance and radiation field performances are carried out.

#### A. Impedance Performance

A simple CPW antenna working at the frequency of 3.5 GHz is used above an MDAMC structure. The substrate of the CPW antenna is RO5880 with dielectric constant  $\epsilon_r = 2.2$  and loss tangent  $\tan \delta = 0.0009$ . The distance between the antenna and MDAMC is chosen 4.5 mm.

Comparison between the simulation results of the single antenna, antenna above MDAMC with CST, and antenna above MDAMC with HFSS are depicted in Fig. 6. As it can be seen from Fig. 6 there is a good agreement between CST and HFSS for the antenna above the MDAMC. The bandwidth is decreased when MDAMC is used as a plane beneath the antenna. This decrease is mostly due to the bandwidth limitation of the MDAMC and the reflection phase characteristic. However, the bandwidth of the final structure is more than 100 MHz which is practical for WiMAX application.

#### B. Radiation Performance

The antenna is further characterized for its radiation properties and gain. A 3-D radiation field for the proposed CPW antenna above MDAMC at the frequency of 3.5 GHz is represented in Fig. 7. As it is known, the radiation field of single CPW antenna is omni-directional and it changes to a directional for our proposed structure.

As expected, the gain of the proposed structure is significantly (about 3 dB) higher than that of the CPW in free space and also front-to-back ratio is improved by 27 dB.

#### IV. SAR ANALYSIS

Since it is not straightforward to directly monitor or accurately predict the spatial and temporal distributions of temperature in a human body or any subject due to exposure of the electromagnetic field, power deposition as quantified by specific absorption rate (SAR) is used as a surrogate. SAR for electromagnetic energy can be calculated from the electric field within the tissue as:

$$SAR = \frac{\sigma |E|^2}{\rho} \quad (1)$$

Where  $\sigma$  is the conductivity of the tissue in  $S/m$ ,  $E$  is the electric field in  $V/m$ , and  $\rho$  is the mass density of the tissue in  $kg/m^3$ . The SAR value should not exceed the exposure limit assigned by FCC which is  $1.6 W/kg$  over  $1g$  of the tissue. To calculate the SAR, a VOXEL model is used in this work. The original model is derived from high-resolution CT data segmented into 125 tissue types. This model has a resolution of  $3.6 \times 3.6 \times 3.6 mm^3$ .

Two prototypes are considered to compare the SAR results between CPW antenna and CPW antenna above MDAMC. At the first prototype, the proposed structure has launched parallel to ear with the distance of  $4.5 mm$ , and the second prototype has the same situation without MDAMC.

Figures 8 (a) and (b) show the SAR distribution in the head model with and without MDAMC respectively. As seen from Fig. 8 the maximum of the averaged SAR over  $10 g$  is  $0.699 W/kg^3$  while this value is  $0.379$  for antenna above MDAMC. A  $45\%$  reduction can be seen from the figure 8 when the CPW antenna is used above the proposed MDAMC.

#### V. CONCLUSION

A low profile low SAR CPW antenna has been proposed in this paper. An AMC structure has been used to reduce the SAR. To reduce the size of a conventional AMC, a magneto-dielectric substrate has been utilized as an artificial substrate for the AMC.  $70\%$  reduction in terms of size were achieved by using this prototype. A simple CPW antenna has been carried out to validate the functionality of the proposed MDAMC. The comparison simulation of two full wave analyzers has shown that the CPW antenna can work at the WiMAX frequency. Then, the whole prototype has been inserted in front of a human body model as a unit antenna. The calculated SAR values for the MDAMC based antenna are very low with the reduction of  $45\%$  compares to the same antenna without the integration of MDAMC.

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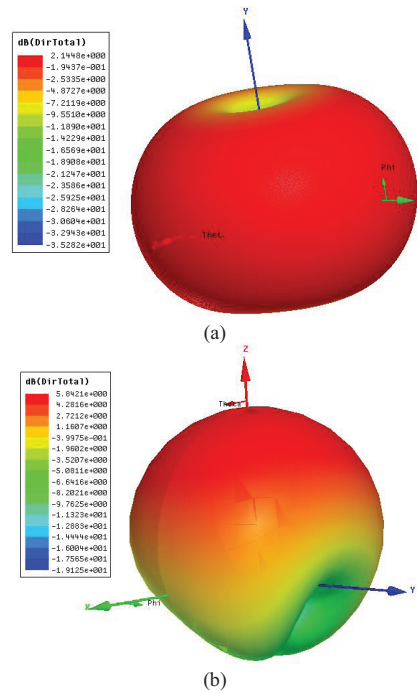


Fig. 7. radiation filed of the (a) CPW antenna in free space (b) CPW antenna above MDAMC at the frequency of  $3.5 GHz$

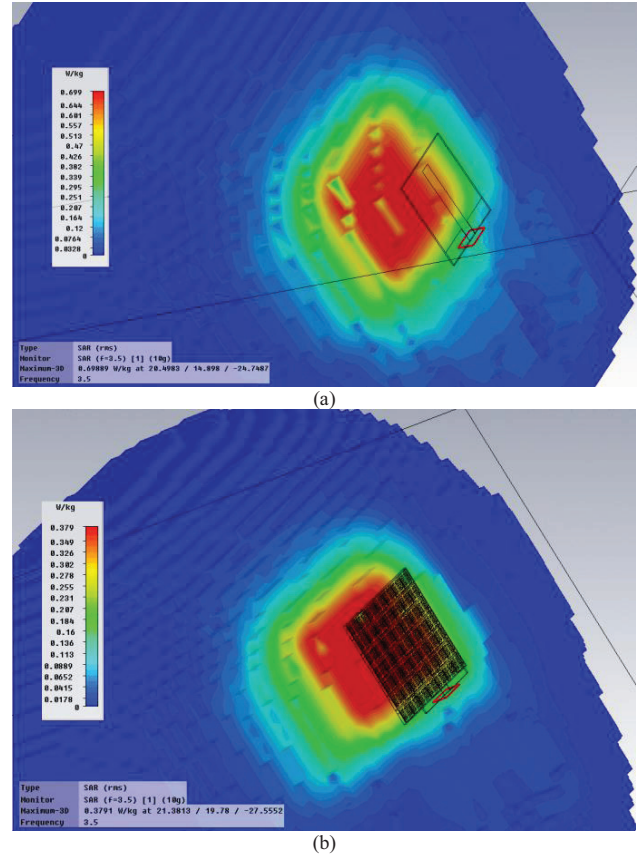


Fig. 8. Reflection phase characteristic versus frequency of the proposed MDAMC unit cell.



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