Wearable miniaturized magneto-dielectric antennas for Body Area Network and wireless power transmission applications

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***Abstract* — Nowadays, the most modern and popular wireless applications are dedicated to highly distributed low-power systems, required to be as much as possible miniaturized. Traditionally, such techniques have been based on substrates with high dielectric constant which, however, degrade the radiation performances. A very promising alternative is offered by MD substrates: while ensuring similar overall dimensions reduction, can offer better opportunities for antenna radiation and matching properties. With this scholarship we wanted to investigate and develop some antenna miniaturization techniques to be used in these systems exploiting the properties of magneto-dielectric (MD) materials. A theory based on the distribution of superficial currents has been theoretically and numerically demonstrated.**

***Index Terms* — Magneto-dielectrics, antenna miniaturization, antenna electric and magnetic equivalent currents.**

I. Introduction

Antennas used in many kinds of new applications need to be as small as possible, in a way that they can be worn [1], and/or implanted under the tissues, as it could be for a biomedical devices. Size reduction is a very important issue since, for best antenna performances, dimensions should be of the order of the operating wavelength. Indeed, in the UHF band, where the major current applications are designed, the antenna size could reach tens of centimetres. A huge number of research projects have been dedicated to improve the design techniques and materials in the effort to pursue antenna miniaturization while keeping the best possible radiation performance.

The most well know and adopted solution is to design patch-like antennas over a dense dielectric substrate. This substrate provides a reduced effective wavelength λ but at the expenses of an increased patch-ground plane coupling, thus decreasing the field fringing effect and hence the radiation properties.

A fairly new alternative to high permittivity dielectrics is provided by the recent realization of materials characterized by relative magnetic permeability μ_r greater than unit [2]-[5]. These Magneto-Dielectrics (MD) materials could theoretically overcome the above mentioned limitations since, for a certain wavelength reduction or, equivalently, given a certain set of relative permittivity and permeability ε_r and μ_r, they could simultaneously be able to guarantee the required guided-wavelength reduction while keeping the medium impedance close to the free-space one. A very interesting and new theoretical approach has been introduced in [6, 10]. It is based on the antenna equivalent current sources, and allows to define design rules of thumb for antennas on MD substrates.

During the project, carried out under my MTT-S scholarship, I have developed an alternative theoretical design approach, validated numerically by analysing selected antenna topologies on only-magnetic (OM) substrates or only-dielectric (OD) ones. By means of the Love's principle of equivalence [7], we have computed the associated equivalent electric and magnetic current sources and we have demonstrated that, if the electric sources are prevailing, a high-permittivity substrate should be adopted; if the magnetic sources are prevailing, a high-permeability substrate should be adopted. EM simulations of these reference antenna topologies have confirmed the theoretical prediction. A paper addressing these preliminary results has been submitted to the EuMC 2014 and has been accepted for publication [9].

II. Theoretical Insights

By the Lowe's principle of equivalence, we have first computed the equivalent current sources of selected resonant antennas, embedded in different media. The integration volumes have been defined as described in the following [9]. Resonant antennas have been addressed since they guarantee the best radiation efficiency, which is needed when only ultra-low power sources are available.

We first assume that a reasonable relationship between the **E**-field magnitude in the Empty Space (ES) **E** and in a OM $\mathbf{E}_\mu$ is:

$$\left|\mathbf{E}(r\sqrt{\mu_r},\theta,\phi)\right| = \frac{1}{\sqrt{\mu_r}}\left|\mathbf{E}_\mu(r,\theta,\phi)\right| \qquad (1)$$

This relationship has been validated by numerical simulation of the patch antenna in these conditions, as shown in Fig. 1. By adopting the resonance condition, the relationship in the two media for the **H**-field magnitude can be derived [9]:

$$\left|\mathbf{H}(r\sqrt{\mu_r},\theta,\phi)\right| = \left|\mathbf{H}_\mu(r,\theta,\phi)\right| \qquad (2)$$

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Thus, if the antenna radiation properties are mainly represented by equivalent electric currents ($\boldsymbol{J_S}$), the relationship between the radiated power density for the antenna realized in the ES medium (P_{Js}) and the radiated power density for the antenna realized on the OM medium ($P_{Js}^{(\mu)}$) may be related as:

$$P_{J_S}^{\ (\mu)} \approx \mu_r^{-1} P_{J_S} \qquad (3)$$

According to the results described in [6, 10] it is clear that miniaturization by an OM material is inconvenient in this case.

Conversely, if an antenna on an OM substrate can be mainly described by magnetic equivalent currents $\boldsymbol{M_S}$, a suitable antenna miniaturization can be obtained while preserving its radiation performances. In such condition the radiated power density could be expressed as:

$$P_{M_S}^{\ (\mu)} \approx P_{M_S} \qquad (4)$$

Dual relationships hold for an antenna on an OD material.
Unfortunately current available materials usually have magneto-dielectric properties associated with dielectric and magnetic losses that could degrade the overall antenna performances. In collaboration with a material research center (CNR-ISTEC) the University of Bologna is designing new compositions to increase the relative permeability while minimizing the associated losses.

III. Numerical Validation

In this section I briefly described the numerical validation I carried out to support the theoretical approach adopted in section I.

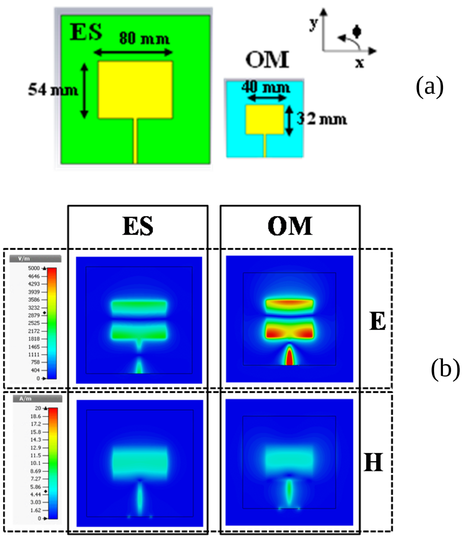

Figure 1: (a) patches topologies; (b) E- and H- near-field numerical simulation results of the two patches: the E-field for the antenna on the OM substrate is much higher than that on the empty space

A patch topology has been selected since it can be equivalently described by an array of two slot apertures excited by magnetic equivalent currents. In Fig. 1 the EM-computed E- and H-maps of two rectangular patches, designed to be resonating at 2.4 GHz, are shown. Two configurations are compared: in the first one the patch substrate is equal to free space (ES) whereas in the second one it is filled by an OM material (with (ε_r =1, μ_r=4)). The field values are taken on a cut plane in the middle of the substrate brick. These numerical results validate the relationships (1) and (2). The E-field of the patch exploiting the OM-substrate is approximately twice the one on the ES material, while the H-fields are approximately the same, considering for both fields a size compression by a factor of two. When the antenna equivalent current sources are of the electric type, as is the case of the loop antenna, the increased material permeability significantly degrades the radiated performance and should not be chosen for antenna miniaturization.

IV. Conclusions

I am grateful to the IEEE MTT-S for the opportunity I have experienced with this scholarship. I would also like to thank Prof. Alessandra Costanzo, who supervised and helped me though the whole research project. The possibility to participate to the IMS 2014 in Tampa has shown to me an amazing new world and the possibility to network with people working passionately on the edges of the microwave technologies. This project deeply engaged me and was successfully carried out. The main scientific results will be published in the proceedings of the European Microwave Week 2014 as my first accepted scientific paper. I will personally present these results in Rome.

Regarding my future, I am planning to complete my Master Degree in few months, then I will look for a new scientific experience in a microwave lab abroad and I will apply for a Ph.D. program. I am sure this scholarship will have a fundamental role in my future career that will be for sure in the microwave field.

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