Design of UWB Antennas Integrating Geopolymer Material

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***Abstract*— Two new designs of reduced volumetric ultra-wideband antennas (UWB) are proposed in this paper. These antennas are intended to radiate in the air medium over the frequency band of 0.3 – 3GHz. This work demonstrates that the combination of innovative dielectric materials along with either resistive load or the association of the radiation provided by an electric dipole and a magnetic loop offers an efficient way for reducing antennas dimensions. Furthermore, one of the proposed antenna has been manufactured and validated by the first experimental results.**

Index Terms—Ultra Wide Band antennas; Geopolymer; Antenna size reduction

I. Introduction

Ultra-wideband applications such as medical imaging, telecommunications or radars require an appropriate antenna design with minimum dimensions. Ultra-wideband radar systems offer the benefit of achieving the wide spectrum containing low frequencies, which is crucial for applications such as the identification of buried objects. The limitation of the antenna dimensions is critical for radar applications, because of the low frequency radiation (ideally a few tens of Megahertz).

Among many antennas existing in the literature, K-antenna (Fig. 1) [1] provides reduced antenna dimensions and high efficiency. The K-antenna is a combination of an electric dipole, a TEM horn and a magnetic loop. It has been chosen as the basic structure for the proposed antenna designs.

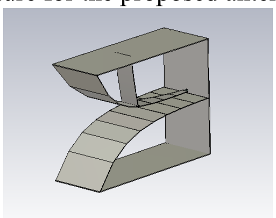


Fig. 1. Example of K antenna

This research topic is based around the design of UWB progressive wave antennas (Ultra Wide Band), whose dimensions are reduced by using three different techniques: (i) the first one employs the principle of filling the appropriate dielectric material [2] inside the antenna, such that main dimensions of the antenna are divided by the square root value of the real relative dielectric permittivity (ε'_r) of the used material. However, the gain and the field parameters of the antenna are divided by a factor of ε'_r and $\sqrt{\varepsilon'_r}$, respectively.

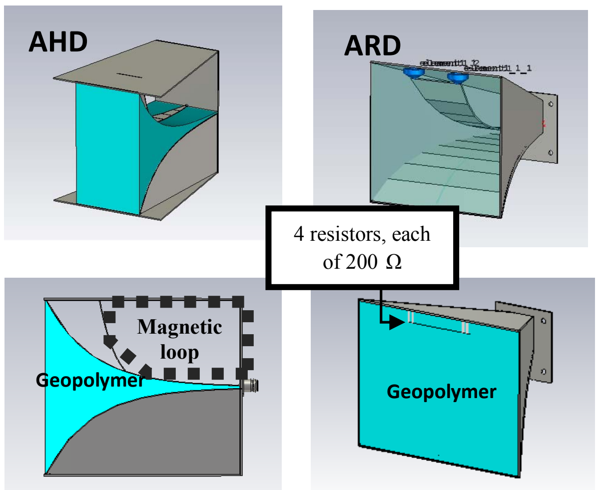
(ii) The second technique uses the effective combination of the radiation provided by the electric dipole [1] and a magnetic loop.

(iii) The last technique uses resistive elements (resistors). However, the drawback of this technique is low efficiency at low frequencies operations [3].

The elaboration of new type of materials such as Geopolymer, [4] consolidated in cold conditions have been realized. The dielectric characteristics (εr and tanδ) of these materials are determined by a measurement bench [5].

II. Realised Antenna Structures

Two antennas have been designed based on the geometry proposed by Koshelev [6]. The first **A**ntenna structure presents a combination of **H**ybrid (electrical and magnetic) radiation along with the use of a **D**ielectric material, we refer this antenna design as **AHD** whose dimensions are 22.7cm × 20.7cm × 18cm (L × H × W) (Fig. 1), respectively. This AHD antenna is intended to operate in an air medium over the frequency bandwidth of 300MHz to 3GHz. The second antenna structure associates the use of **R**esistive loads (four resistors of 200 Ω value) which are located at the aperture of the **A**ntenna and a **D**ielectric material. The antenna is referred as **ARD,** intended to operate in the same frequency band whose dimensions are 15.3cm × 14cm × 17cm (Fig. 2), respectively.



(a) (b)

Fig. 2. AHD antenna (a) ARD antenna (b)

The AHD antenna is partially filled with Geopolymer dielectric material whose dielectric permittivity ε'_r = 3.2 and the loss tangent tanδ = 0.03 at 1.5GHz (Fig. 8). This specific value of ε_r has been selected in order to minimize the reflection between the interface of dielectric/air at the antenna's aperture and to obtain smooth propagation of waves to the air medium. Furthermore, the value of the loss tangent will not disturb much the antenna operation, as it is not intended to operate at specific resonant frequency. The AHD antenna dimensions have been calculated using the square root of the average dielectric permittivity value of the air and Geopolymer dielectric material. The integration of the magnetic loop on the AHD antenna allows to enhance the low frequency behavior and to minimize the reactive energy caused by the imaginary part of its input impedance. This significantly help to increase the directivity of the antenna and to ensure good impedance adaptation over the desired frequency band of work; this has been proved by Koshelev in [6].

The ARD antenna is also intended to radiate in the air medium. However, it has been completely filled with the same Gepolymer dielectric material. The resistors located at the aperture help to absorb the waves which are not radiated especially at low frequencies.

The simulated antennas reflection parameters are shown in Fig.3 and 4, respectively. A good adaptation (S_{11}<-10 dB) is obtained over the desired frequency bandwidth of 0.3 – 3 GHz.

The radiated field of simulated AHD and ARD structures (Fig.4 and 6) are calculated from 1m to the antenna's aperture, for the applied input voltage of 1V. The magnitude of the radiated peak-to-peak field for the AHD and ARD antennas are 0.76V and 0.63V for a group delay of 0.14ns and 0.43ns, respectively. The group delay is calculated using the following equation [8]:

$$\tau_{g_{rms}} = \sqrt{\frac{1}{\Delta f}\int_{f1}^{f2}(\tau_g - \overline{\tau_g})^2\,df} \qquad (1)$$

With $\tau_g(f) = -\frac{\partial\varphi}{2\pi\partial f}$ and $\overline{\tau_g} = \frac{1}{\Delta f}\int_{f1}^{f2}\tau_g\,df = -\frac{\Delta\varphi}{2\pi\partial f}$

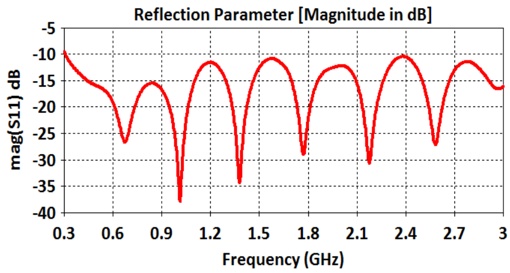


Fig. 3. Reflection parameter of AHD antenna

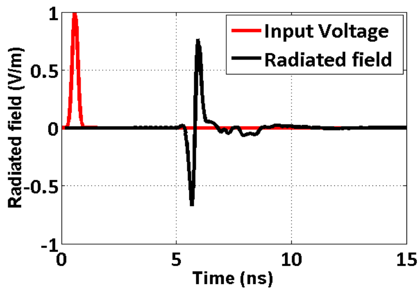


Fig. 4. Radiated field of AHD antenna

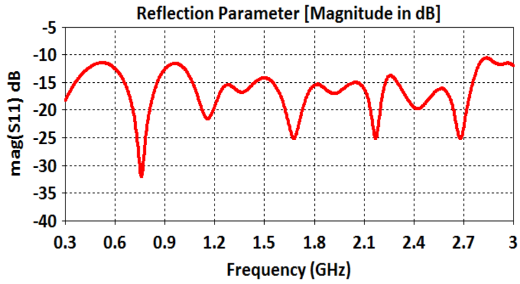


Fig. 5. Reflection parameter of ARD antenna

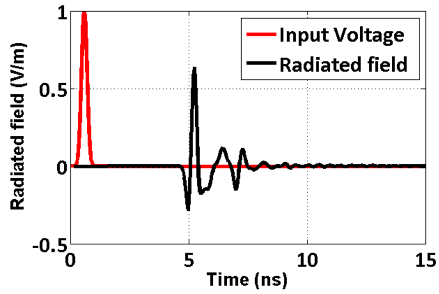


Fig. 6. Radiated field of ARD antenna

III. Elaboration of an Innovative Material

A. Geopolymer material

Today, it is becoming increasingly important to develop materials, which are safe and eco-friendly such as Geopolymer. The significance of fabricating Geopolymer material for antenna applications is to control and obtain the desired dielectric permittivity value of material, which can be directly filled into the antenna, even at ambient temperature conditions, without exothermic reaction like with resin [7].

B. Experimental Process for Obtaining Geopolymer

The experimental protocol for obtaining Geopolymer material is shown in Fig. 7. The permittivity measurements of different mixture formulations showed reproducible values of permittivity ranging from 3 to 10.

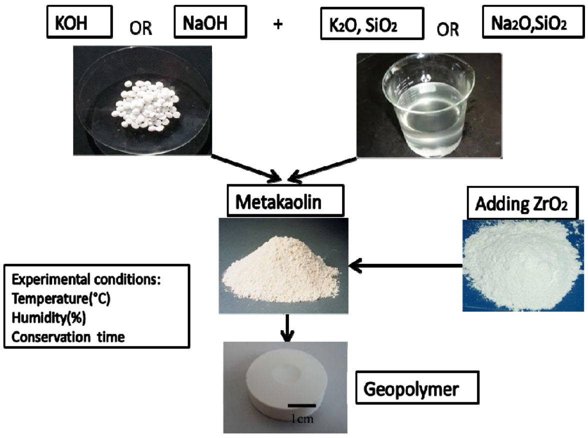


Fig. 7. Experimental process for obtaining Geopolymer material

C. Loading Geopolymer Material Characteristics

The dielectric characteristics of the Geopolymer material, which will be used to fill the antennas, designed to radiate in the air medium is shown in Fig. 8.

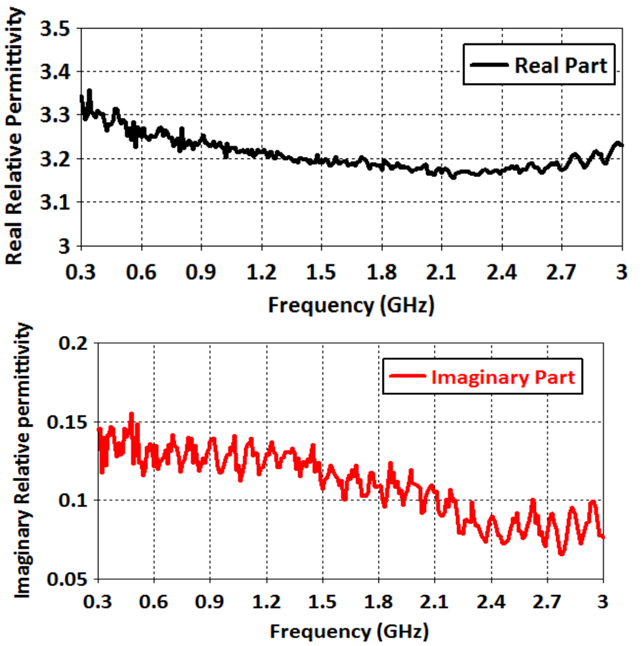


Fig. 8 . Dielectric characteristics of a Geopolymer sample

The dielectric material measurements were realized using the DAK-12 Kit (Fig.9) [5] product line from Schmidt & Partner Engineering AG (SPEAG), which offers high-precision dielectric parameter measurements (permittivity, conductivity, and loss tangent) over the frequency range from 10 MHz to 3 GHz. The probe is connected using a cable to a VNA.

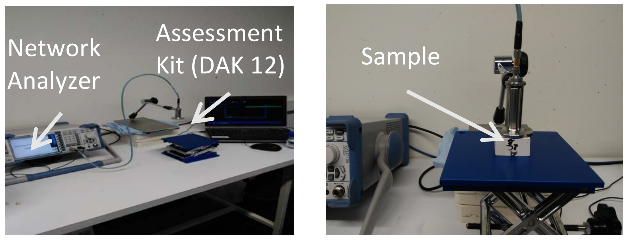


Fig. 9.The Dielectric Assessment Kit (DAK 12)

The characteristics obtained from the preliminary Geopolymer sample (Fig. 8) have been used in CST MICROWAVE in order to define the physical properties of the material used in the simulation. The results of the ARD antenna simulation led to the fabrication of a prototype.

IV. Manufacture Of The ARD Antenna

The ARD antenna have been fabricated using 3D printing technique and 316L stainless steel by the SLM (Selective Laser Melting) process on a Renishaw AM 250 machine(Fig. 10).

The preliminary unload ARD antenna reflection parameter measurement demonstrates a good agreement with the simulation result.

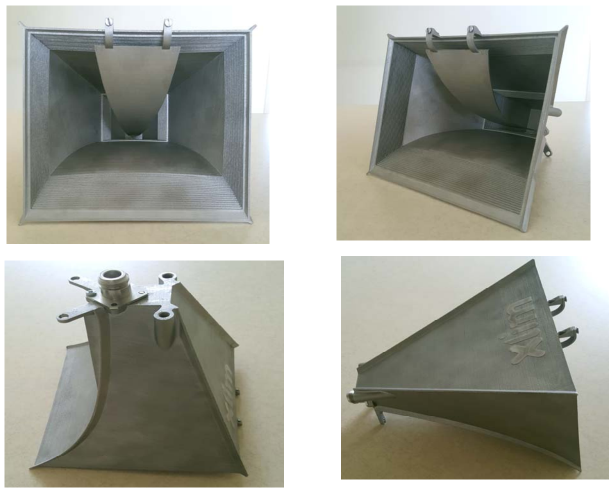


Fig. 10. ARD Antenna without Geopolymer and resistive loads

V. Conclusion

In this work, two new UWB antenna designs have been proposed. We have emphasized the advantage of using the dielectric material for an UWB antenna design to reduce its dimensions. Moreover, the contribution of Geopolymer material in obtaining the desired dielectric constant has also been described. The preliminary measurements of the fabricated ARD antenna without filling the dielectric material have been made and found to be in good agreement with the simulation. The preparation of the desired dielectric permittivity value of the material and the filling protocol are in the final phase. The respective measurement results of the complete antenna will be presented at the meeting.

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