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Weatherproof Radiating Array based on Polyolefin Plastic Ecological Design

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ABSTRACT – An antenna design procedure has been developed based on Printed Circuit Boards (PCB) encapsulated in resins also derived from recycled materials. The conformal coating process provides structural antenna devices with the same radiating properties of the one realized with traditional approaches that makes use of metallic enclosures containing the PCB closed-up by an antenna cover. The advantages of the proposed technique are an enhanced resistance to atmospheric agents, reduced costs and weights and at the same time a lower environmental impact. Moreover the materials adopted here for the moulding process are also obtained from the recycling of industrial waste. Another peculiarity of the method is the increasing quality of the products which is oriented to the environment at a lower cost than the traditional approach. Defeating the wrong assumption "sustainability = higher costs", a legacy of business model which is now obsolete compared to the new challenges opening up to a market increasingly competitive, demanding and sensitive to "green" policies.

INTRODUCTION

In this paper we present an antenna array design procedure based on the conformal coating of a printed circuit board (PCB) including the beam-forming feeding network and the radiating elements. The encapsulated antenna addresses structural requirements including aerodynamic shape, rigidity, and resistance to weather, shock, impact, vibration and biodegradation. Electrical characteristics, such as minimal reflection and attenuation of the microwave signal are as well included. The dipole array can be used either as a stand alone or as a modular building block, to realize large planar array antennas of different size tailored on the system requirements. The technique becomes effective for large scale production of array elements. It reduces the manufacturing costs and moreover increases the overall performances of the system, in comparison to a traditional design where the feeding network requires metallic enclosures sealed to an antenna cover. The previous assembling procedure requires extensive manual work, while in the new approach the conformal coating provides structural and sealant characteristic by the process itself. Several approaches have been developed in the past on this type of antenna manufacturing, as it is reported in [1]-[2]. The activities carried on in Selex ES on this topic have been divided into two main parts. As a first step, we have designed the RF beamforming network with the etched dipoles thus constituting an unique PCB, then we have selected the material to be used for the conformal coating process. This latter part has been identified by the characterization of the materials in terms of electromagnetic and mechanical properties. The plastic materials suitable for the process have been divided into two types of structural resin foams:

1. the first based on thermosetting two-part polyurethane (PU) resin based material suitable for the injection moulding process (Elastolit® by Basf [3] and the Baydur® by Bayern [4])
2. the second is based on thermoplastic material based on polyolefin material (Ecomat® [5]).

Figure 1 - A picture of the antenna ALE9 operating on a site exposed to severe outdoor requirements

DESIGN APPROACH

The encapsulated antenna design approach has been applied to Radiating Columns (RC) used for antennas operating in L-Band (1025-1095MHz) installed on the Secondary Surveillance Radar (SSR) system for the Air Traffic Control (ATC). As a case study, our proposed tecnique has been applied to the ALE9 antenna for ATC, which is one of the best sold products of Selex ES, by more than twenty years. The ALE9 antenna architecture is based on an open planar array structure where the RCs are disposed in array configuration with metallic rods disposed between them. The primary design changes with respect to the in-house design are related to the RC, by essentially reducing the fabrication cost and improving the outdoor performances as it can be easily deducted from Figure 1.

MATERIAL CHARACTHERIZATION

The injection moulding technique needs the material to be calibrated, in order to obtain the dependence of the permittivity and the dissipation factor with respect to the density. This calibration step is obtained by reducing the material in moulds with the form of a section of rectangular waveguide (WR650) operating in the frequency band of interest as depicted in Figure 2. Several kind of resins have been reduced to rectangular septum with the aid of moulds (inset in Figure 2) and inserted inside two transitions into the waveguide. As in [6], through measurements of scattering parameters it is possible to retrieve typical electromagnetic constitutive parameters, such as the dielectric constant (DK) and the dissipation factor (DF) of the material under test, as a function of the frequency (Figures 3a, 3b) and the density of the same (Figures 3c, 3d). In Figure 3c a calibration curve has been found by interpolating the values obtained by single samples with different values of density. The results were comparable with those reported in [7]. The preliminary work allowed us to find the right balance between mechanical stiffness of the structural foam and its electromagnetic performance. The technique of injection moulding has been successfully tested on different sizes of linear arrays.

PROOF OF CONCEPT

A single dipole has been designed and manufactured to validate the proof of concept of the proposed technique (Figures 4a-f). The initial dipole impedance was calculated by using full-wave electromagnetic (EM) solver and the balun was optimized to this impedance using a CAD microwave software [8]. Thereby the RF breadboard design was completed (Figure 4e) and later a dielectric covering (encapsulation) was added over the element, for physical and environmental protection. Two types of materials have been tested; the polyurethane based foams in (Figures 4a, 4c) and polyolefin (Figures 4b, 4d). A particular attention has been paid to the RF PCB, in order to allow an adequate adhesion of the foam to the circuit and an appropriate detachment of the foam from the mould, once the foam had solidified.

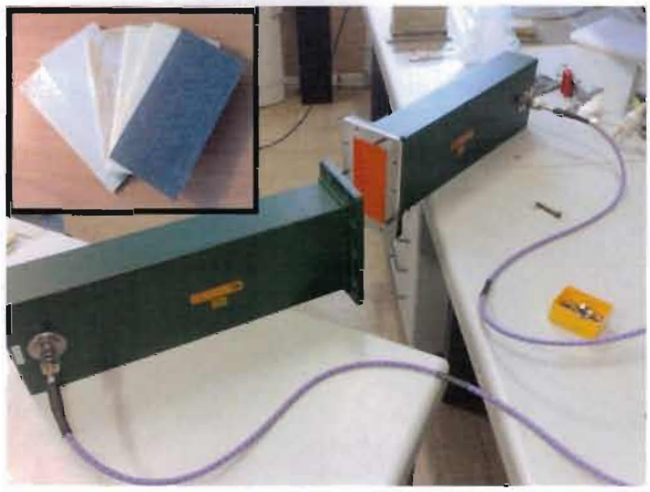

Figure 2 - A picture of the two ports waveguide method used for the measurements of the DK and DF in L-Band. Inset: different type of mould foams

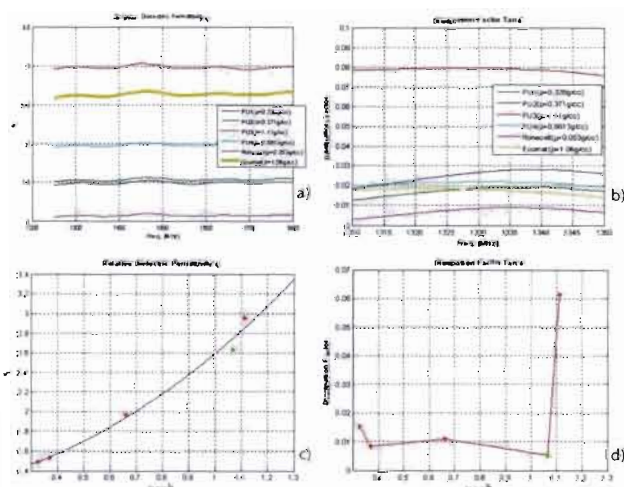

Figure 3 - Electromagnetic performances of different types of plastic foams in terms of relative dielectric constant and dissipation factor DK as a function of frequency (a)-(b) density (c)-(d)

The prototype experimentall activities have provided successful results, in terms of electromagnetic measurements (Figure 4f) and mechanical stress, thus enabling the use of the proposed technology for product manufacturing. Afterwards the technology has been applied to a product: the calibrating probes of the Identification-Friend-or-Foe (IFF) system, recently developed for an important foreing Air-Force. Such an IFF systems is a Not-Rotating IFF consisting of six fixed array panels installed on an hexagonal shape, wich perform electronic scanning of the beam, along the whole azimuthal sector, by using phased shifters. The calibrating probes for the NR-IFF have been realized by using the injection moulding process and are currently installed on the operative sites in a Country, wichi is exposed to stringent environmental requirements (Figure 4g). The next steps have been related to the validation of the technique for larger dimensions moulds and with curvatures resulting from the aerodynamic structure of the antenna realized to reduce the wind loading.

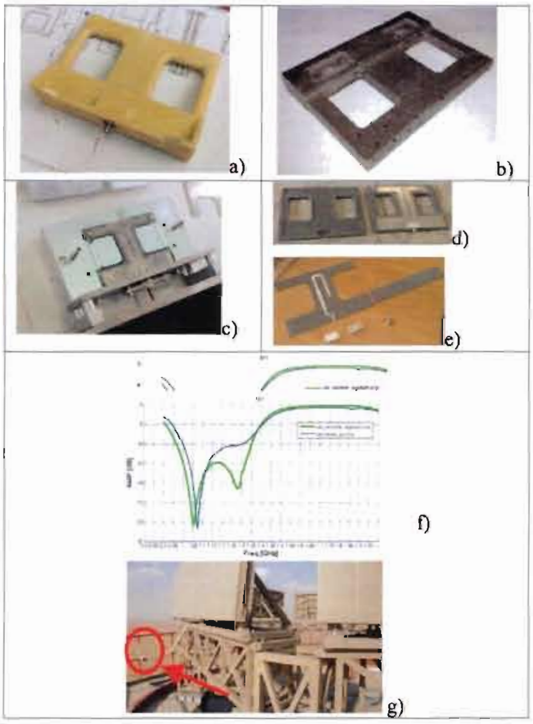

Figure 4 - Single element dipole antenna realized by using the encapsulation process a) based on Elastolit® foam b) Ecomat® foam c) PCB inside the mould d)-e) RF PCB f)input VSWR g)used as calibration probe on the NR-IFF system deployed on UAE

A linear array with a beam-forming network that feeds six radiating dipoles with a maximum size of about 900 mm has been manufactured and tested. A larger prototype antenna has emphasized some manufacturing problems related to homogeneity of the resins during reactive injection moulding.

The material chosen for the moulding has been the Eleastolit® with a density value of 0.657 gr/cm^3. Through the use of release agents onto the internal surface of the mould, it is possible to insert appropriate pigments mixed into the resin, thus achieving the painting process which is usually a harmful activity to be carried out under an extractor fan. The painting here is realized inside the casing, with a considerable reduction of the risks harmful to health. Some pictures of the antenna under the EM and mechanical tests are reported in Figures 5a-c.

ECOMAT

The next steps of our work has regarded a fruitful co-operation with the department of mechanical engineering of Selex ES (plant of Rome) that has identified a resin, Ecomat®, based on polyolefin component mixed with materials obtained from recycled waste, that provides interesting mechanical characteristics in terms of: stiffness, weatherproof resistance, paintability, customizable shapes, light-weight, low-cost and eco-compatibility. This latter patented innovative material has been recently developed by the company Ecoplan s.r.l. [5], and it is obtained through a process of extrusion of thermoplastic resins with depleted pomace (derived from the squeezing of olive) or other inert vegetable fillers. Ecomat® is a material environment-friendly and 100% recyclable. The above mentioned characteristics make attractive the use of Ecomat® instead of aluminium for manufacturing modular shelters used normally for the radar cabinets. The use of alternative ecological materials, in comparison to metallic ones such as aluminium, steel, brass, is due to the perishable raw materials and to the requirements of harmful treatments, to achieve high performance outdoor characteristics. The design of an antenna system can follow the same mechanical aspects expressed above and under this topic the use of Ecomat® has demonstrated a viable path to realize radiating devices, not only mechanical objects.

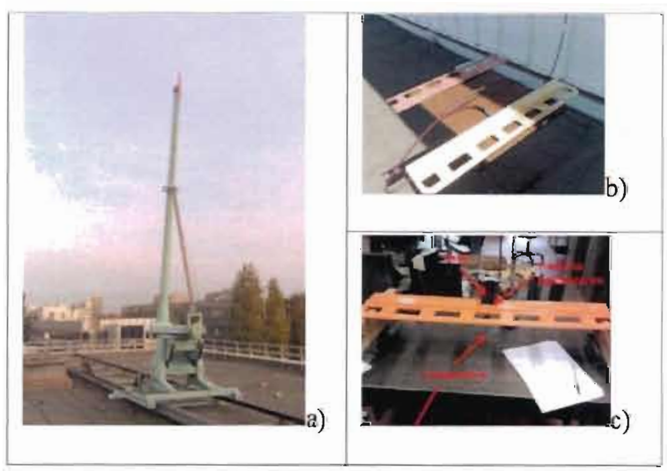

Figure 5 - 900mm long antenna array composed of six radiating elements located on a far-field antenna test range (a) and under EM (b) and mechanical test (c)

Moreover, the use of Ecomat® for antennas has required a complete characterization in terms of EM performances, since no other examples for this kind of activities are present in open literature. An extensive campaign of measurements has been carried out on samples of Ecomat®, to verifiy the homogeneity of the resin over different batch supply. As reported in Figures 3c, 3d (green dot) the Ecomat® has shown a low DF for higher value of density if compared to other PU-based foams. This characteristic is obtained for an higher value of density in the order of 1.067 gr/cm^3.

FURTHER STUDIES

The competitive advantage of the presented design methodology relies on the availability of an high-performance antenna architecture that is water/air-proof, capable of operating in all weather conditions (weather-proof), enabling a new technology that could be used to achieve antenna systems of variable size and configurations for various types of radar and communications antennas operating in the L-band. The use of techniques known as conformal coating, allows a considerable reduction in terms of assembly-cost when compared to traditional design approaches which require the use of aluminium-made support surfaces that need to be reworked with numerical control machines and treated with harmful chemical baths.

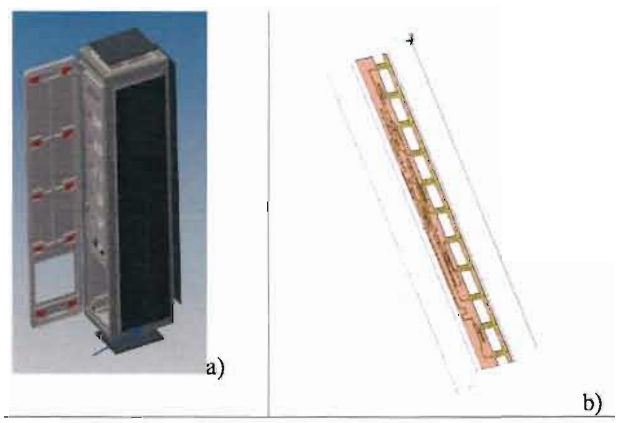

Figure 6 - Examples of use of Ecomat® for (a) radar cabinet (b) RC of the antenna ALE9

The present innovation deals with a completely new design approach that totally eliminates the structural metal parts by adopting a structural resins coating, that is suitably mixed and injected into moulds, shaped to reduce the weight and the wind resistance, providing as well the necessary stiffness to the device to make it structurally stable. The ecological material is used for both mechanical and antenna devices. Figure 6a shows a radar cabinet made of Ecomat® and Figure 6b the PCB of the RC of the antenna ALE9, before the conformal coating. The layout of the RF circuits includes the radiating elements fed by a suitable beam-forming network, providing the inverse cosecant-square coverage pattern typical of ATC systems.

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CONTACT

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