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METALLIZED FOAMS FOR ANTENNA DESIGN: APPLICATION TO FRACTAL-SHAPED SIERPINSKI-CARPET MONOPOLE

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Abstract—The technology of metallized foam offers a new approach to design wire-like, flat, and 3D antennas. Only the necessary metal skin depth (some microns in UHF band) is deposited over arbitrary shaped structures. Thanks to this technology, new antenna designs have been possible offering low weight, possible shaping, and innovative

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architectures. To demonstrate these possibilities, a monopole inspired in the Sierpinski fractal carpet is built. The proposed design is suitable for a pico-cell base station antenna since the antenna operates at GSM850, GSM900, GSM1800, GSM1900, UMTS, Bluetooth/WLAN, WIMAX, and WIFI featuring an omni-directional radiation pattern and an average total efficiency of 79%.

1. INTRODUCTION

Foam-like materials are, due to their intrinsic structure, very light-weight. These materials typically exhibit low dielectric constant and loss tangent. Such properties make foams very attractive to be used as substrates for the fabrication of antennas in applications requiring light-weight, low-loss, reduced bill of materials, less mechanical complexity while preserving the electromagnetic performance [1–6].

Current antenna manufacturing techniques either use metal wires or plates, or are based on printed circuit technology using substrates such as PTFE (Teflon) or fiber-glass (FR4). In addition to the fact that the antennas fabricated using these conventional technologies are not light-weight, they are also limited in terms of antenna geometry, since it is difficult to fabricate 3D antennas. Therefore, another important advantage of metallized foams over conventional manufacturing techniques is the capability of designing complex full three-dimensional structures, conforming the antenna to the environment in which it has to operate.

This paper presents the application of metallized foams to design a fractal-inspired monopole. Self-similar fractals and other related shapes have attracted many researchers thanks to its geometrical properties to design multi-band and small antennas, multi-band elements and arrays, high-directivity antennas, low side-lobe and under-sampled arrays [6–38].

The paper is divided as follows: Section 2 presents an introduction to the metallized foam fabrication process. Section 3 shows the results for reflection coefficient, total antenna efficiency, and radiation patterns. Finally, conclusions are presented.

2. THE MANUFACTURING PROCESS

Basically the principle is a deposition of metal on arbitrary shaped foam thanks to a chemical process during which the piece is immersed sequentially into several saline liquids. As a consequence:

- There is no glue to attach the metal on a dielectric support. At the same time there is no perturbation, and the material keeps its initial dielectric constant.
- The shape can be arbitrary because the process uses liquids. These liquids offer the possibility to get a very good contact whatever the shape is. For instance metallized holes can be done between several layers.

In the microwave-band the metal thickness is usually between 5 and 20 microns. Metal is deposited on surfaces because the foam is a closed cell structure. To illustrate the deposit of thin layer the Fig. 1 shows examples of via holes of different length and diameter. An example of a horn antenna made of metallized foams is shown in Fig. 2. It is interesting to outline that the weight of the horn antenna is only 54 g. Low weight is an interesting feature for several reasons. For example, low weight simplifies the installation of antennas in towers (ex: antenna arrays for base station applications are installed in high towers or at the top of buildings). Moreover, for antennas installed in cars, trains, airplanes, low weight reduces the fuel consumption. This may be an interesting feature for aerospace applications since launching a light antenna to space implies less fuel and as a consequence, less cost.

More details on the fabrication process can be found in [6].

This principle of electro deposition can be found in the literature but not on foams as shown in this particular case which requires a specific chemical treatment of the foam. Said technique has been useful for a certain kind of fractals, the random fractals such as the fractal tree [39, 40].

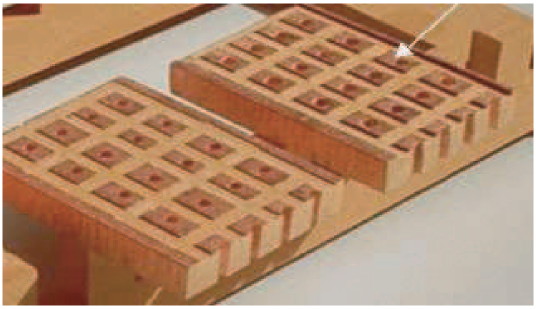

Figure 1. Examples of via-holes between metallized layers on foam.

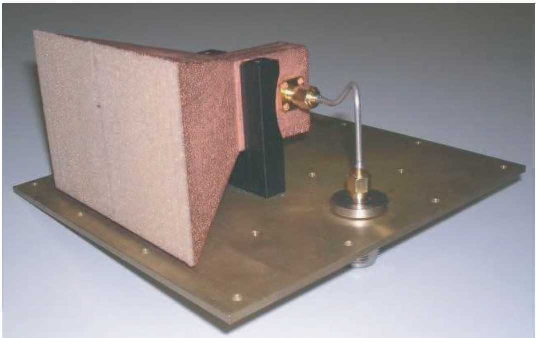

Figure 2. Example of a horn antenna fabricated using the metallized foam technique. Frequency of operation is 5.9 GHz. Weight of the horn antenna is only 54 g. (ground plane is not included). The N-type connector can be attached to the foam using screws since the foam presents a rigid structure.

3. RESULTS

This section shows the performance of a fractal-shaped monopole antenna fabricated using the foam technology. The example uses a monopole type antenna inspired in the Sierpinski carpet antenna [9, 10]. To improve the bandwidth of such a monopole, several techniques have been proposed in the literature such as stacking two elements. Instead of adding two parallel antenna elements as proposed in [9, 10] only one thick foam structure has been realized. Furthermore, to simplify the mechanical realization circular holes were drilled keeping the initial surface ratio between the various holes. The fabrication process has been done at Advanten-Lab. In this case the total monopole height h is equal to 76 mm. The 5 mm thick foam layer is metallized in one pass process. Fig. 3 shows the picture of the antenna over a limited ground plane. The electromagnetic analysis has been realized using software CST — Microstripes. The dimensions are $h = 76$ mm (corner to corner), foam thickness = 5 mm, gap feeding = 1 mm and limited ground plane (250 mm × 250 mm).

The antenna has been designed rotating the Sierpinski carpet 45° (Fig. 4). The reason for this 45° is to avoid the horizontal current to be electrically close to the ground plane since the current along the edge cancels out with its image. This image cancelation provokes mismatching. Several techniques have been proposed in the literature to avoid the mismatching effect of horizontal currents in square-shaped monopoles. For instance, in [41], a square-shaped monopole is fed using a double-feed mechanism. This forces the current to flow in a vertical way, minimizing the horizontal current and thus, reducing mismatching. This technique improves the bandwidth of a square-shaped monopole from 75.0% to 137.5%. However, it requires a power splitter. Another alternative to reduce the horizontal current is by minimizing the horizontal edge by geometry shaping, such as using circles or ellipsoids [42, 43].

The main antenna parameters have been measured to validate the fabrication procedure from 0.5 GHz up to 6 GHz, since this frequency range allocates the most relevant communication systems for mobile and wireless services such as GSM850, GSM900, GSM1800, GSM1900, UMTS, Bluetooth/WLAN, WIMAX, and WIFI.

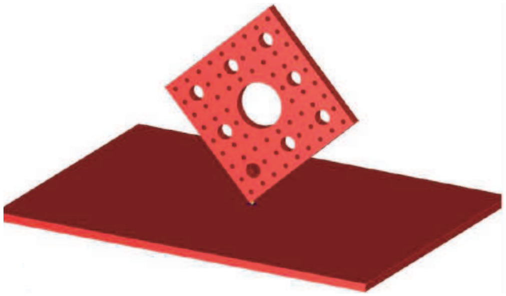

Figure 3. Geometry of the simulated antenna. The dimensions are $h = 76$ mm (corner to corner), foam thickness $= 5$ mm, gap feeding $= 1$ mm and limited ground plane (250 mm $\times$ 250 mm: not to scale).

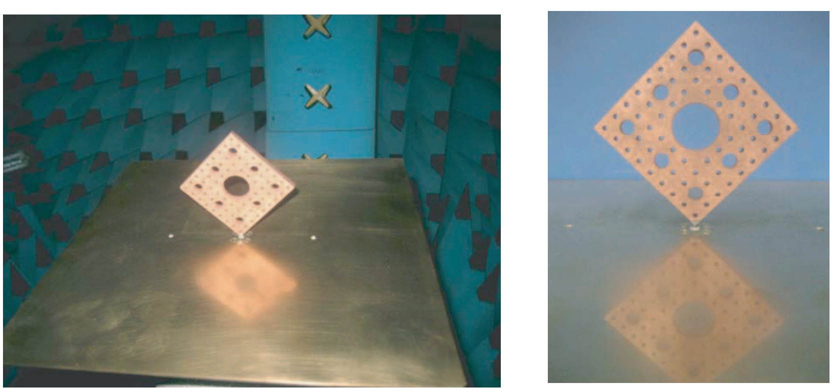

Figure 4. Antenna mounted on a square ground plane 250 mm $\times$ 250 mm. Antenna weight is only 5 g. PVC foam has been used to fabricate the antenna. Copper thickness $= 40$ microns.

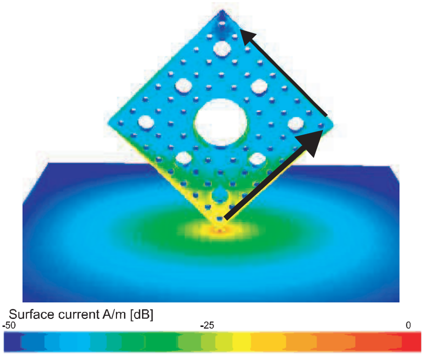

Figure 5. Surface current distribution at 700 MHz. The arrows show a qualitative representation of the current intensity which is maximum at the base and gradually decreases to the top corner.

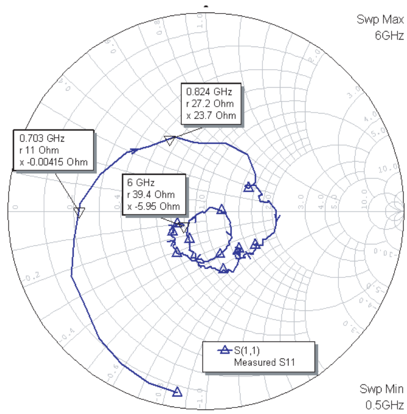

Figure 6. Measured reflection coefficient showing the first resonant frequency 703 MHz.

Regarding the antenna dimensions, they have been adjusted to have a quarter-wave behavior at 700 MHz since this frequency is lower than 824 MHz (the edge of GSM850). This secure margin has been provided to ensure a good matching from 824 MHz to higher frequencies ($\sim$ 6 GHz). Surface current simulation shows that the current at 700 MHz is mainly concentrated along the edge, having a maximum at the feeding point and gradually decreasing to the top corner (Fig. 5). This current distribution follows that of a linear monopole operating at the quarter-wavelength mode where the current follows a sinusoidal distribution having a maximum at the base and a minimum at the open end. Since the current is concentrated along the antenna edges, the total length is two times the side (107 mm). 107 mm is 0.249λ at 700 MHz. This results in an antenna height of $h = 76$ mm as shown before. It is worth noting that the first resonance frequency occurs at 703 MHz (Fig. 6).

Reflection coefficient presents a broad band behavior having a $S_{11} < -7.7$ dB from 824 MHz to at least 6 GHz (Fig. 7), that is a bandwidth of more than 151% ($S_{11} < -7.7$ dB). Total efficiency is measured using 3D pattern integration using Satimo Stargate-32 anechoic chamber placed at Fractus-Lab. Total efficiency (η_t) takes into account both matching (S_{11}) and radiation efficiency (η_r) as follows: $\eta_t = \eta_r \cdot (1 - |S_{11}|^2)$. The measured total efficiency shows an average value of 79% approximately for all bands (Fig. 8, Table 1). Finally, 3D radiation patterns and directivity at the central frequency of each operating band have been measured (Fig. 9–Fig. 11). For the low-bands (GSM850 and GSM900), the antenna radiates similarly to a dipole since the ground plane is not large enough. However, at the upper bands, the antenna radiates more as a monopole having a directivity of around 4 to 6 dBi. All radiation patterns present a null at the zenith direction ($\theta = 0°$) and an omni-directional pattern. This kind of antenna may be suitable for small base station antennas such as those used as hot-spots in urban areas. It should be outlined that the ground plane determines the radiation pattern, specially the direction of maximum radiation and back lobe. For finite ground planes, the maximum is not generally in the direction of the ground plane but at an angle above it [44]. This may be an advantage in some cases. For example, if the antenna is placed in the roof, the maximum points the floor which maximizes the power to the users. If the ground plane is smaller, the back radiation increases which may decrease the directivity or interfere with another cell.

Besides the radiation pattern data, the cross polarization level (XPD) has also been measured. Although the antenna has been rotated 45°, the polarization is vertical as far as the fundamental mode is concerned, since the horizontal currents are quite mitigated due to the image currents. For upper frequencies, the horizontal currents are not as mitigated as in low frequencies because they are electrically higher from the ground plane. As a consequence, XPD is degraded but still larger than 15 dB (Table 2).

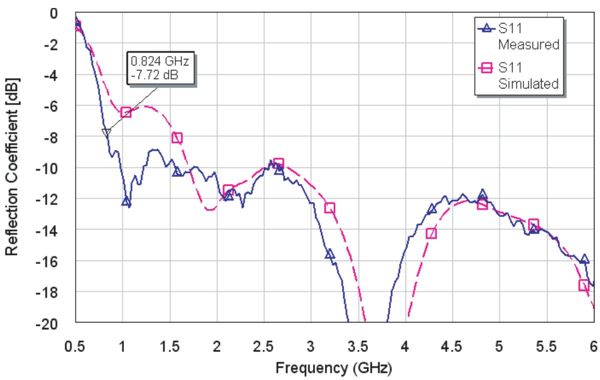

Figure 7. Antenna presents a good reflection coefficient from 824 MHz up to 6 GHz where the main mobile/wireless standards operate (from GSM850 up to WIFI).

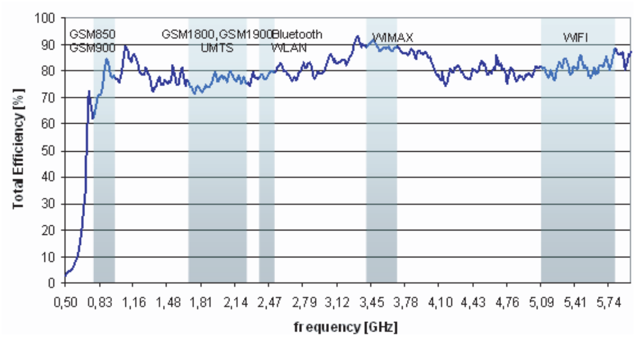

Figure 8. Measured total efficiency.

Table 1. Measured total efficiency averaged across the band. Total efficiency is measured using 3D pattern integration.

Communication System	Measured total efficiency [%] averaged across the band
GSM850 (824–890 MHz)	76.5
GSM900 (880–960 MHz)	80.9
GSM1800 (1710–1880 MHz)	73.3
GSM1900 (1850–1990 MHz)	76.0
UMTS (1920–2170 MHz)	77.4
Bluetooth/WLAN (2.4–2.484 GHz)	78.3
WIMAX (3.4–3.69 GHz)	89.1
WIFI (5.1–5.825 GHz)	81.6

Table 2. Measured XPD at $\theta = 90^\circ$ plane.

Frequency [MHz]	Minimum XPD at θ=90° plane [dB]
850	19.9
920	19.7
1800	18.0
1900	17.8
2100	18.0
2450	17.3
3550	15.4
5500	15.4

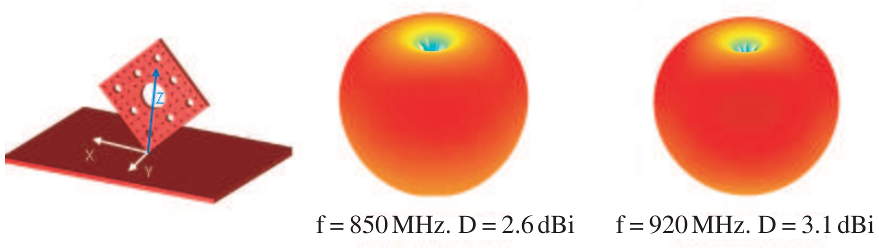

Figure 9. Measured 3D patterns and directivity at frequencies of GSM850 and GSM900.

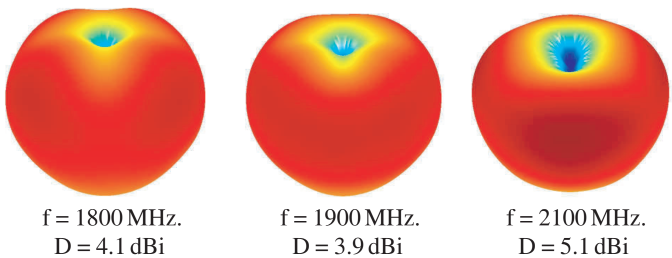

Figure 10. Measured 3D patterns and directivity at frequencies of GSM1800, GSM1900, and UMTS.

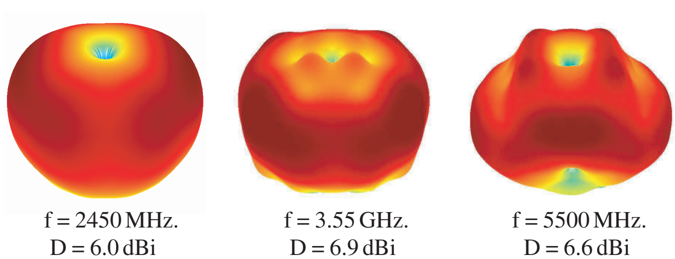

Figure 11. Measured 3D patterns and directivity at frequencies of Bluetooth/WLAN, WIMAX, and WIFI.

4. CONCLUSIONS

A square Sierpinski-inspired carpet monopole has been designed using the possibilities of the metallized foam technology. It has been shown that the parallel two printed circuits initially proposed in the literature can be replaced by one thick layer of metallized foam with cylindrical via-holes instead of square shape.

In terms of impedance bandwidth, the reflection coefficient is less than −7.7 dB from 824 MHz up to more than 6 GHz having a total average efficiency of 79%. This prototype may be useful as an antenna for pico-cell base station applications covering the following standards GSM850, GSM900, GSM1800, GSM1900, UMTS, Bluetooth, WLAN, WIMAX and WIFI.

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