3D-Printed Frequency Selective Surfaces for Microwave Absorbers

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***Abstract* - A flat periodic FSS (frequency selective surface) is presented, which is fully fabricated by a 3D-printer and commercial 3D printing filaments which normally are used for printing metal like structures. The FSS absorber structure was developed and optimized for 10 GHz, fabricated with the 3D printer, measured afterwards and compared with the simulations. Further simulations were made with the new materials at higher frequencies and the results confirm that 3D printing technology works well and could be used to the best advantage for absorbers and other applications in the frequency range below 100 GHz.**

***Index Terms* — 3D-Printing, printed absorber, FSS.**

1. Introduction

3D printing has become very popular within the last years. In the same way, first investigations with 3D-printed devices were made in the field of electromagnetics and latest publications show that this new printing technology can also be used to the best advantage for RF and microwave engineering, e.g. for creating dielectric microwave and antenna parts [1-3]. It is also reported about the typical material properties of those thermoplastic filaments. In the following a new application for such 3D printed devices is presented, namely a printed frequency selective surface (FSS) for electromagnetic wave absorption. In this paper the 3D printing technology is used to create a flat and thin metamaterial like FSS absorber in the X-Band.

2. Investigation of the Printing Filaments

Normally, 3D printer filaments are made of plastic, like PLA (polylactic acid) or ABS and are available in all kind of colors. From *ColorFabb,* (Netherlands, [4]), special printing materials are offered, named *CopperFill* and *BrassFill*, which were developed for printing metallic like parts and which contain real metallic powder in the filaments. This fact gave us the idea that the metallic powder inside may also increase the electrical conductivity. Compared to conventional printer filaments (more or less dielectrics with moderate losses), this new material feature might enable the printing of novel RF and microwave structures for a variety of new applications (shieldings, antennas, etc.) where conductivity is needed [2]. Before starting the design and simulation process of the FSS structure, the exact electrical material parameters of the different filaments had to be determined. 2 mm thin material probes were printed and filled into a WR-90 waveguide (22.86 mm x 10.16 mm), then the scattering parameters of the probes were measured at 10 GHz and afterwards evaluated [5]. Despite the fact that there were no magnetic particles (e.g. carbonyl iron powder) in the material, artificial and effective permeability with $\mu_r > 1$ appeared (see table I). With some measurements even an effective $\mu_r < 1$ showed up. Such a behavior has been observed with other composites as well [6, 7] and is explained by the percolation phenomena in the microwave regime. Isolated conductive particles in an insulating host medium have a tendency to form clusters and eventually connected chains which cause eddy currents and therefore provide effective magnetic behavior with artificial effective relative permeability. It must be said that the material parameter measurements are critical. They were performed several times with different probes, leading to different results. The best fitting values for the simulation were measured with probes at the same thickness as the realized absorbers.

TABLE I
Measured Material Parameters (10 GHz)

Material	Density g/cm^{-3}	ε_r	tanδ_ε	μ_r	tanδ_μ
BrassFill	2.4	8.15	0.015	1.25	0.2
CopperFill	3.0	8.3	0.08	1.35	0.025

3. Simulation and Printing Process

FSS absorber design is manifold and a variety of solutions can be found in literature. As there are no comparable publications and experiences with the above described materials we started in a first attempt with a simple and well


Fig. 1. Variety of printed FSS absorbers

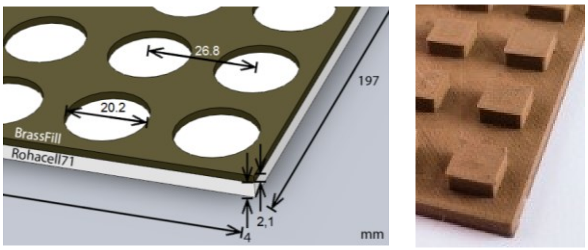

Fig. 2. left: dimensions of the 10 GHz FSS absorber
right: printed cuboid structure for 30 GHz absorber

known isolated quadratic patch design above PEC for 10 GHz, which has been used successfully with highly conductive (PEC) or ink printed structures [e.g. 8 - 10]. All simulations were performed with CST, using a unit cell and Floquet boundaries. Simulations with *BrassFill* material gave us a size of 20.3 mm for those squares, which were printed directly on a high performance *Rohacell71* foam spacer with a height of 3 mm and low relative permittivity close to one ($\varepsilon_r = 1.09$, $\tan\delta_\varepsilon = 0.0038$ @10 GHz) (refer to Fig. 1). The printing process of the structure was done with the 3D printer *Ultimaker 2* [11], equipped with a 0.4 mm printer nozzle. The specified printing accuracy is given with approximately 0.1 mm, related to the height of the printed device. This mainly results from the manual adjustment of the base plate of the printer referred to the printing nozzle. Printing accuracy could be confirmed by measurements. However, the cooling process of the thermoplastic material caused mechanical forces on the *Rohacell* [12] sheet and finally resulted in unexpected dishing of the whole absorber. Therefore the basic FSS layer structure was changed from isolated patches to periodic aperture holes in one common part. Optimum absorption with approximately 25 dB at 10 GHz could be achieved with a diameter of 20.2 mm, a spacing distance of 26.8 mm and a height of 2.1 mm (Fig. 2).

4. Results

The FSS structure with total dimensions of (169 x 197 x 2.13) mm was printed as one piece on the base plate of the printer and afterwards placed onto a 4 mm *Rohacell* foam sheet. The printing time was about 5 hours! Afterwards, reflectivity measurements were made to evaluate the new device. The frequency of maximum absorption is very close to the simulated center frequency of 10 GHz (Fig. 3). The deviation results from the printed real thickness (2.15 mm) of the structure, also from measurement uncertainties with the material parameter measurements. Further optimizations and adjustments are possible. To show the general good prospects of 3D printing devices further simulations were made at 30 GHz (assuming the same material parameters of Tab. 1, without confirmed measurement results!). Small 8.2 mm cuboids (with a height of 3.5 mm and a periodic spacing distance of 16.3 mm on a ground layer of the same material and with a height of 3.3 mm, as illustrated in Fig. 2, provide excellent broadband absorption behavior between 15 and 40 GHz. Measurements of the materials in this frequency range and further experiments with those structures will follow soon.

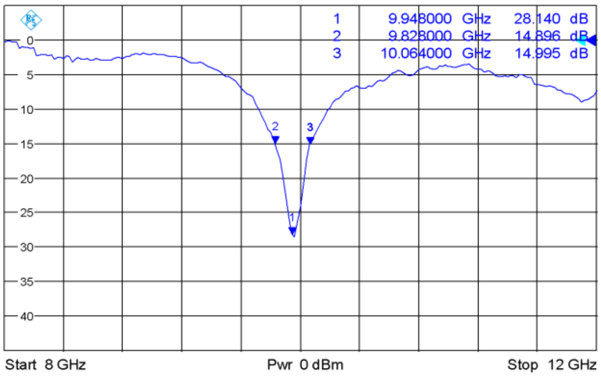

Fig. 3. Measured absorption (dB) of the 3D printed FSS

5. Conclusion

In this paper we have shown new possibilities with 3D printing structures. Special filaments with increased conductivity and even artificial magnetic properties were found which can be used advantageously for the design of FSS absorbers for 10 GHz and higher. Furthermore, true 3D structures can be fabricated in a fast way and open new possibilities for a variety of new applications in microwave and RF engineering.

Acknowledgment

Part of this work has been funded by the German Federal Ministry of Education and Research BMBF in the *FH-ProfUnt* program (FKZ 03FH039PX3).

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