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3D Printed Triply Periodic Minimal Surfaces Lattices for Shielding Applications at Microwaves

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Abstract—3D printing is changing the antennas and propagation, as well as the microwave devices worlds. The possibility of prototyping innovative geometries is pushing the designers to identify new topologies for microwave applications. In this framework, the modeling based on implicit surfaces such as triply periodic minimal surfaces has been underestimated. In this work we will numerically investigate 3D printed TPMS lattices in the MW range. By using dielectric data of a copper-loaded PLA, we studied different unit-cell size for TPMS structure and characterized the absorption and shielding behavior in the range 1-20 GHz. We identified that 3D printed TPMS lattices with 20% and 40% porosities could be useful for shielding in the X- and K-bands.

I. INTRODUCTION

Additive manufacturing (AM) is a popular tool for rapid prototyping. AM is currently used in electromagnetic (EM) research to manufacture devices (e.g., antennas, filters, sensors) that would be complex or expensive to prototype or realize according to traditional manufacturing technologies [1]. Among AM strategies, 3D printing of microwave (MW) devices is gaining attention since moving from planar to the third dimension provide new degrees of freedom [2]. 3D printing technologies were used to manufacture all-dielectric periodic structures to be used as MW absorbers, antenna radomes, EM shields, reflectors, and polarizers [3]. This bandgap and metamaterial devices, depending on their unit-cell, possess a frequency response that depends on the geometrical parameters and ratio between cell size and operating wavelength (λ_0), but also on the guided mode resonances and Mie resonances [3]. The research efforts are often oriented to find new unit-cell with useful and effective properties.

In this work, we will investigate the MW response of 3D printed all dielectric structures based on triply periodic minimal surfaces (TPMS) unit-cell. TPMS are a class of non-self-intersecting surfaces created by local surface area minimization principle, which can provide advanced or multifunctional performance for a range of applications [4]. In [5], the manufacturability and the low-frequency electrical conductivity of selective laser sintering (SLS) produced graphite cellular lattice structures designed by the mathematically known TPMS were studied. There is a limited understanding of the possibility of TPMS for MW applications. Since the complex dielectric permittivity ($\epsilon_r^* = \epsilon' - j\epsilon''$) is a key quantity for cell miniaturization and bandwidth enhancement, and given that, so far, the 3D printing industry did not provide too many RF-specific materials, few high performing materials are available. For the fused filament

fabrication (FFF), considered in this study, polylactic acid (PLA), bronze-, brass-, copper-infused PLAs are commercially available, and their EM properties are reported to be appealing for MW applications. However, there is a lack of characterization, therefore the dielectric spectroscopy of a metal-filled PLA is also performed in the range 1-20 GHz. This work can pave the route for the design of innovative 3D printed MW devices based on TPMS.

II. METHODS

A. Unit-cell Modeling

TPMS are minimal surfaces embedded on \mathbb{R}^3 , thus having a null mean curvature and being periodic on the three spatial directions x, y, z [4]. TPMS can be easily computed in the Euclidean space by approximating their complex domain Enneper-Weierstrass representation using an implicit function and level, iso-surface of a sinusoidal function $F: \mathbb{R}^3 \rightarrow \mathbb{R}^3$ [4]. We focused our efforts to study the MW behavior of the Schwarz primitive (P) surface, that, in its implicit form, can be computed as [4]:

$$\mathcal{F}_P = \cos(X) + \cos(Y) + \cos(Z) = K \quad (1)$$

where $X = \omega_x x$, $Y = \omega_y y$ and $Z = \omega_z z$, being ω_i the spatial periods (with $i = x, y, z$) and K is a constant. The Matlab-based MS Lattice application has been used to derive a solid unit cell from two offset TPMS. In this work we considered a 20% and 40% porosity. The computational geometry representation of the investigated TPMS unit-cell solids is reported in Fig. 1.

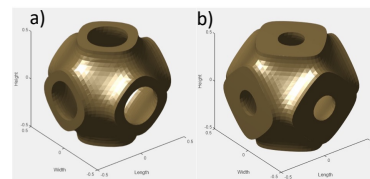


Figure 1. TPMS unit cells.

B. Dielectric Characterization of 3D-printed Filaments

The Form Futura *MetalFil*, a PLA type of 3D printer filament with 80% copper filling (density of 3.4 g/cc), is selected as material for the TPMS structures. The commercial 3D printer Raise 3D N2 Plus 3D-printer has been used to print cylindrical samples of 1 cm and 5 cm of diameter. A 0.6 mm extruder has been used, while the layer height was set to 0.2 mm, with a 50°C bed temperature and the extrusion temperature was fixed to 195°C, for a printing speed of 50

mm/s. Samples with infill percentage varying from 20% to 100%, with a 20% step, have been printed and characterized in terms of their MW properties.

The measurements were carried out by using a 3.5 open-ended coaxial probe dielectric assessment kit system (SPEAG), connected to a Rhode & Schwarz ZNB20 vector network analyzer (VNA), for deriving the complex reflection coefficient at the probe-material interface and retrieving the complex permittivity according to a capacitive model. Following an open, load and short calibration, measurements were performed in the range $f \in [1,20]$ GHz for all infill densities.

C. Unit-cell Analysis

The “.stl”. files have been imported in CST Microwave Studio (Dessault, GE) and their frequency response in the range $f \in [1,20]$ GHz has been analyzed by using unit-cell boundary conditions and Floquet port using the frequency domain solver. The case of normal incidence is preliminary considered. The scattering parameters, the reflectivity, transmittance, absorbance and shielding effectiveness (SE) were studied.

III. RESULTS

The results of the dielectric permittivity and the loss tangent of the PLA filled with anodized copper are reported in Fig. 2. As the infill increases, the ϵ_r' increases too from 4 to ~ 4.5 . The loss tangent is ~ 0.02 for a 20% infill and it increases to 0.04 for 100% infill. These $\tan \delta$ values were observed below 10 GHz. These values are similar to the value reported in for metal-loaded PLA filaments [6]. We considered the properties of 100% infill *MetalFil* to investigate the P surface unit-cell MW response.

The simulated absorbance and SE values are reported in Fig. 2, for the 20% and 40% TPMS unit-cells. For a unit-cell of 1 cm poor interaction with the fields is observed throughout the entire frequency range. The fact that small TPMS unit-cell are not absorbing nor reflecting is coherent with the limit unit-cell size of $[\lambda_0/10, 2\lambda_0/5]$ [3]. On the other hand, for sizes of 2 and 3 cm a narrowband shielding behavior is observed (Fig. 2a and 2b). The SE range is 20-50 dB. These values are comparable to literature ones [5]. It can be notice that the structure behaves like a mild absorber above 6 GHz (max. 60%). For the 40% TPMS a similar absorbance spectrum was found (Fig. 2c), whilst this TPMS unit-cell structure for 2 cm and 3 cm size have a SE that reach 20-30 dB for almost the whole C-band (5.5-8.6 GHz, Fig. 2d). A bandwidth enhancement is observed (Fig. 2b vs. Fig. 2d) and a larger coverage of Ku- and K band is noticed.

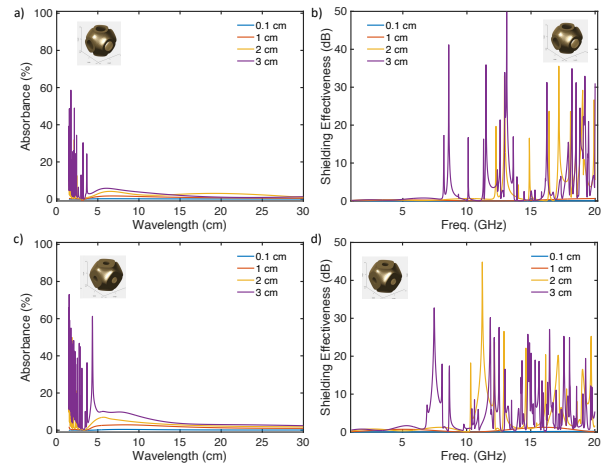


Figure 2. a) Absorbance and b) SE for 20% porosity P surface unit-cell. c) Absorbance and d) SE for 40% porosity P surface unit-cell.

IV. CONCLUSIONS

This work dealt with the numerical investigation of 3D printed TPMS-based shields in the MW range. By using dielectric data of a copper-loaded PLA, we studied different unit-cell size for TPMS structure and characterized the absorption and shielding behavior in the range 1-20 GHz. We identified that, for a mild absorption of $\sim 60\%$, 3D printed TPMS lattices with 20% and 40% porosities could be useful for shielding in the X- and K-bands. Future works will deal with the study of different TPMS. Measurements and validation will be performed to corroborate the simulation results, considering the influence of 3D printing settings on the shield performances.

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REFERENCES

- [1] D. Helena, et al., "Antenna Design Using Modern Additive Manufacturing Technology: A Review," *IEEE Access*, vol. 8, pp. 177064-177083, 2020, doi: 10.1109/ACCESS.2020.3027383.
- [2] C. Tomassoni, et al., "3D Printing of Microwave and Millimeter-Wave Filters: Additive Manufacturing Technologies Applied in the Development of High-Performance Filters with Novel Topologies," *IEEE Microwave Magazine*, vol. 21, no. 6, pp. 24-45, June 2020, doi: 10.1109/MMM.2020.2979153.
- [3] R. A. Mellita, S. S. Karthikeyan and P. Damodharan, "Additively Manufactured Conformal All-dielectric Frequency Selective Surface," *2020 50th European Microwave Conference (EuMC)*, Utrecht, Netherlands, 2021, pp. 772-775, doi: 10.23919/EuMC48046.2021.9338224.
- [4] M. B. Lodi et al., "Design and Characterization of Magnetic Scaffolds for Bone Tumor Hyperthermia," in *IEEE Access*, vol. 10, pp. 19768-19779, 2022, doi: 10.1109/ACCESS.2022.3151470.
- [5] X.-C. Ye, et al. "Electrical properties of 3D printed graphite cellular lattice structures with triply periodic minimal surface architectures." *Materials Research Express*, vol. 6, no. 12, ID: 125609, 2019, doi: 10.1088/2053-1591/ab569b
- [6] R. Kronberger and P. Soboll, "New 3D printed microwave metamaterial absorbers with conductive printing materials," *2016 46th European Microwave Conference (EuMC)*, London, UK, 2016, pp. 596-599, doi: 10.1109/EuMC.2016.7824413