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Development of a sealed 3D printed dielectric filled waveguide filter with embedded lattices

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***Abstract*—In this paper the authors present the development process of a novel 3D printed 4-pole dielectric filled waveguide filter which was implemented with embedded lattice elements. The final part is sealed to simplify the metallisation process. The authors provide useful fabrication techniques and tuning methods to improve the manufactured part and make the design less sensitive to fabrication tolerances.**

***Index Terms*—Additive manufacturing, ceramics, dielectrics, dielectric materials, microwave filters, microwave propagation**

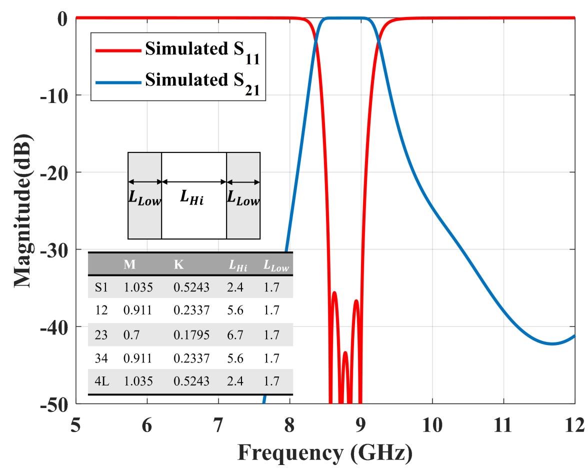
I. Introduction

Additive manufacturing (AM) provides the opportunity to exploit materials and construct geometries in novel and exciting ways. The topic has been gathering large amounts of interest, Specifically in the radio frequency (RF) community [1]. Often RF components are printed in plastic or metal and then metallised where necessary, with AM providing new degrees of freedom. Printing plastics and ceramics provides an additional element of flexibility with a range of dielectric materials. These material used can achieve wide ranges of dielectric constants at different loss levels. When porosity is included in parts using lattices for example, materials can achieve a range of dielectric constants without the need for a material change [2]-[5].

The porous lattice concept was taken further and embedded in an alumina dielectric-filled waveguide, to implement band-pass filtering in [6]. The work presented in this paper aims to highlight some of the challenges experienced in the fabrication stage and propose design solutions to overcome these. The ceramic parts in this paper were printed in collaboration with Lithoz in Lithalox HP360 using a Cerafab printer.

II. Filter overview

The proposed four pole bandpass filter [6] was designed with a center frequency of 8.8 GHz and a 600 MHz bandwidth. This filter was manufactured using Lithography-based Ceramic Manufacturing (LCM) 3D printing of alumina with an $\varepsilon_r = 9.5$ and a $\tan\delta = 8\cdot10^{-5}$. The filter consists of five impedance inverter sections which are constructed using a high impedance lattice sandwiched between solid sections of alumina representing the low impedance portions. The dielectric-filled rectangular waveguide was then fed using an integrated transition, where the simulated performance and initial design values are shown in Figure 1. The concept was to have the structure eventually metallised directly to keep the structure as compact and lightweight as possible; however, for the first attempts, a cavity was milled for the filter to isolate the print process issues, excluding the additional complexity and losses associated. Additionally, to simplify cleaning, the first prototypes have latices which are open top and bottom, which cannot be metallised until sealed. The fabricated filter inside the cavity is shown in Figure 2, with the ceramic part of the filter having overall dimensions of W:7.12× H:3.556 × L:55 mm^3.



	M	K	L_{Hi}	L_{Low}
S1	1.035	0.5243	2.4	1.7
12	0.911	0.2337	5.6	1.7
23	0.7	0.1795	6.7	1.7
34	0.911	0.2337	5.6	1.7
4L	1.035	0.5243	2.4	1.7

Fig. 1. Simulated filter idealised performance with design values [6].

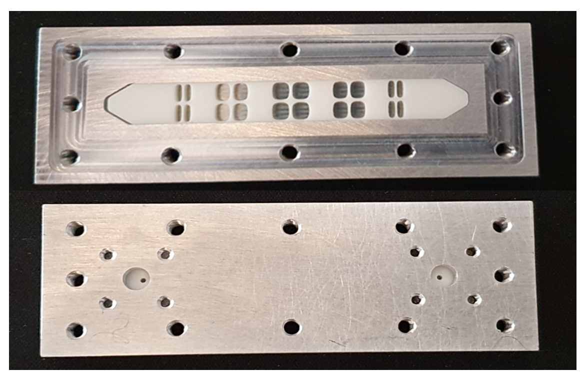


Fig. 2. Fabricated dielectric-filled rectangular waveguide filter top and bottom with SMA connectors removed.

III. Fabrication challenges discussion

The first prototyping rounds highlighted several areas that needed to be optimised before the filter would function as designed.

- **Non-uniform shrinkage:** During the fabrication process, the 3D printed parts must go through a debinding and sintering stage to produce dense ceramic parts. These steps cause the parts to shrink and need to be compensated for by scaling the print by compensation factors. Usually, the shrinkage compensation factors for HP360 are 1.233 in XY and 1.273 in Z direction [7]. This expected shrinkage applies to the dense parts but was found not to apply to the porous lattice elements. Measurements found the hollow portions of the lattice were compressed by around 8.5% and the solid portions stretched by around 5%. The overall effect adds up to the low impedance sections having incorrect electrical lengths compared to the design. Investigation found that the hollow sections have less contact area to the oven floor and experience less friction than the solid parts. To counteract this, the filters are printed with a sinter guide, Figure 3, which is slightly larger than the structure itself and can be placed underneath. The guide helps pull the part together more uniformly allowing for a more predictable shrinkage.
- **Warpage:** As the filters are long and narrow, they tend to warp upwards during the sintering process. This warpage leads to parts that are not flat and when inserted into the cavity, will crack under stress from the lid. This can be corrected for components such as this by having an additional sintering step during which the part is brought up to temperature with a weight on top of it, thus being ironed flat.
- **SMA feed:** Figure 4 shows an X-ray image of the assembled filter used for analysis. In Figure 5 close-up pictures of the SMA feed are shown, highlighting that the implementation chosen created several challenges. Firstly as the print system works using 40 x 40 μm^2 pixels, with pixels only being on or off, curves end up jagged making the fit imprecise. The area also experiences overpolymerisation, which leads to the radius being approximately 60μm larger than design, and needs to be compensated for in the print stage. The smaller than designed feed holes made ensuring the feeds reached the desired depth very difficult and led to gaps as shown in Figure 5. After the print process, the part undergoes a cleaning step to remove uncured slurry before debinding and sintering. The deep and narrow pin feed holes, which are sealed at one end, cause some residual slurry to remain in the bottom corners, which contributes to problems when trying to insert the SMA pins. A redesign of the feed structure will be discussed in the next section to combat these fabrication challenges.
- **Sealing for metallisation:** The use of open lattice structures chosen provides a challenge in the post-processing of the part. As mentioned above, any open areas will collect uncured slurry during the print, which must be removed to ensure the correct infill/dimensions. Due to this, all void areas in the print need to have openings to make cleaning possible. These openings make cleaning the part easy; however, this makes complete metallisation impossible. A novel sealing method was developed to enable both these requirements.

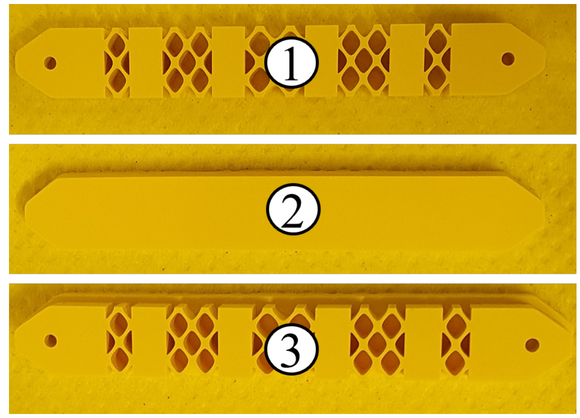


Fig. 3. Printerd filter (1) and sinter guide (2), with filter placed on top (3).

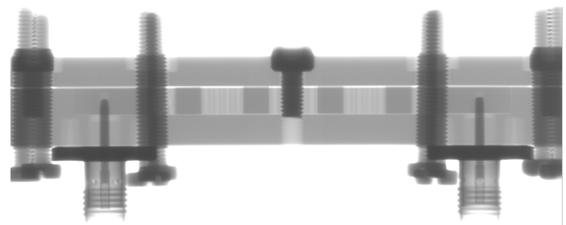


Fig. 4. Filter X-ray side on

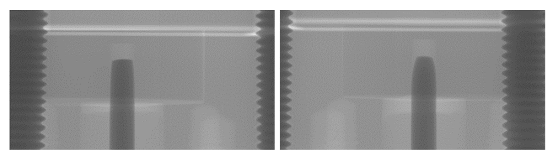


Fig. 5. Close up left and right feed pin X-ray.

IV. Novel Sealing Method and Filter Redesign

In the previous sections, two critical areas were identified, lattices require a sealing solution and feed redesign to improve the fabrication results.

Lattice sealing process: Ensuring a sealed waveguide with embedded lattices is critical for the metallisation goal of this design. To achieve this, a method of cleaning and then sealing the lattice structure before sintering needed to be developed. The part was printed in two pieces, the base filter structure with one lattice side open and a lid which will be used to close the structure as shown in Figure 6. The lid was made as thin as possible while still being stable enough to handle in the unsintered state. The lid included teeth along the length, which were designed to fit into corresponding slots on the filter body. These were made 2 pixels smaller on each side to compensate for overpolymerisation effects and still be able to fit into the slot. The dimensions and design of one of the

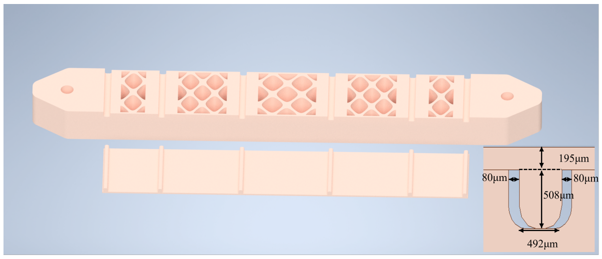


Fig. 6. Printed two section filter for sealing.

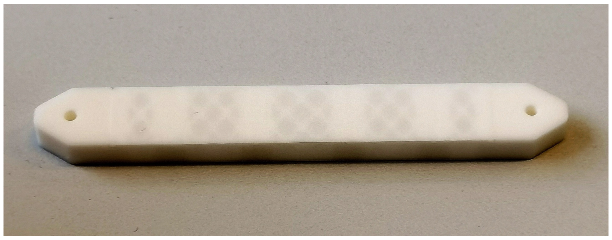


Fig. 7. Final sealed ceramic part.

teeth are shown in Figure 6. Some uncured alumina slurry was applied to each of the slots and the lid ”glued” in place for the debinding and sintering process, during which the two parts fuse together into one solid. Figure 7 shows the final dense ceramic part resulting from this process.

Feed redesign: The feeding of the waveguide in the initial design proved challenging to implement and required a redesign. The requirement for direct contact between the alumina and the SMA pin needed to be removed and an intentional airgap included. This required the first impedance inverter to be removed and the input coupling directly controlled through the depth of the pin. The hole was also made to cover the entire depth of the filter to be able to adjust the input coupling and improve the cleaning process.

Lattice length deviation compensation: Although the sinter guides helped improve the lattice shrinkage predictability, it was decided to include a means to compensate for additional deviations during the next prototyping stage. This was achieved by redesigning the lattice elements to be able to accommodate screws embedded halfway through the waveguide. The screws can be used to reduce the electrical length by inserting them further or increasing it by removing them. The screws can recover performance for deviations of over $\pm 600\,\mu$m of each of the lattices. The screws, however, come at the cost of additional conductive losses and moving the upper spurious bands closer to the filter passband, but will allow demonstration of the design concept and can be removed in future iterations. The screws will be attached using glued threaded screw guides similar to those used in [7]. The layout of the redesigned filter with tuning screws is shown in Figure 8.

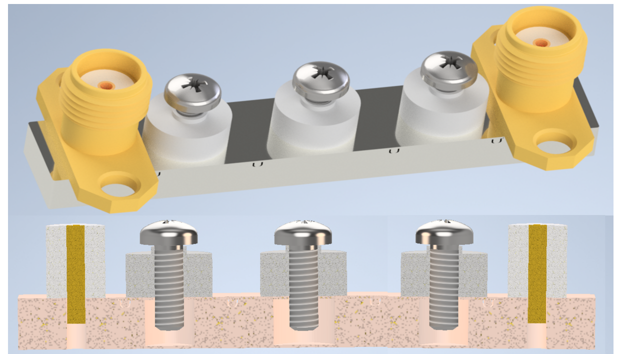


Fig. 8. Model of sealed filter with redesigned feed and tuning screws.

V. Conclusion

This paper discusses the challenges of implementing a lattice-based dielectric filled waveguide filter, with solutions provided to overcome each. A novel method of fabricating sealed dielectric components with impeded lattice structures was presented and successfully demonstrated. Finally, a redesign of the filter with tunability for improved tolerance recovery was proposed.

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