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Uros Jankovic, N. Mohottige, Djuradj Budimir, Oleksandr Glubokov

Institutions: University of Westminster, Royal Institute of Technology

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Hybrid Manufactured Waveguide Resonators and Filters for mm-Wave Applications

Uros Jankovic, Nandun Mohottige and Djuradj Budimir
Wireless Communications Research Group
University of Westminster
115 New Cavendish Street, London, UK
d.budimir@wmin.ac.uk

Oleksandr Glubokov
MST, School of Electrical Engineering
KTH Royal Institute of Technology
Stockholm, Sweden

***Abstract*— Additive and hybrid manufactured waveguide resonators and bandpass filters for mm-wave applications are presented. A K_a band 3D printed waveguide resonator with inductive windows and 28 GHz 5G band hybrid manufactured waveguide resonator and bandpass filter are designed. Hybrid manufacturing combines 3D polymer printing and conventional metal processing technologies. In order to illustrate the accuracy of the design, a 3D printed waveguide transmission line and resonator with the resonant frequency of 33 GHz are fabricated and tested.**

Keywords—3D printing; hybrid manufacturing; waveguide resonators; waveguide filters; PLA.

I. INTRODUCTION

Ongoing fast growth of additive manufacturing is now finding wide applications in mm-wave 5G [1-3] wireless and satellite systems. 3D printing can be applied to many materials, categorized as metallic and non-metallic. Metallic additive manufacturing of microwave mm-wave filter components, such as by selective laser melting (SLM) method with alloy powder, has been tested in practice so far [4], and non-metallic one using stereolithography (SLA) method with ceramic-filled resin is available as well for high-end products [5]. Although these alternatives have more advanced structure complexity, shorter turn-around time, produce less energy and material waste and can have reduced weight, the performance is still not exactly at the level of subtractive manufactured components of the same shape and price advantage is questionable.

3D printing with plastics has started being applied as inexpensive and lightweight alternative to conventional manufacturing of filter and other passive microwave components, mostly again with SLA method [6,7]. Its downsides are thermal and mechanical sensitivity. Universal problem with additive manufacturing is high surface roughness, although some technologies like SLA can produce finer details and smoother surfaces. Also, non-metallic 3D printing requires metal plating.

Here, we use the most popular consumer 3D printing technology, fused deposition modeling (FDM), also known as fused filament fabrication (FFF), to print the waveguide housing and dielectric filling supporting the filter structure, which geometries would otherwise be very hard to realize. Ecologically friendly polylactic acid (PLA) bioplastic is used as FDM filament that is heated up to the melting point, extruded through the printer nozzle, and deposited layer by layer onto a flat surface of the printer glass build plate. However, other thermoplastics such as acrylonitrile butadiene styrene (ABS) or nylon could be used as well.

Furthermore, in the case of hybrid manufacturing using conventional waveguide housing, there is no need for metal plating and surface roughness has miniscule effect onto filter performance as standard waveguide housing is used and metal elements inside the waveguide are fabricated from a metal sheet using a milling unit. Thus, there is no problem in using FDM instead of SLA as technology with currently more affordable printers and materials as well as easier for maintenance.

II. RESONATORS AND FILTERSS

A. 3D printed Waveguide Resonators

Fig. 1 shows the layout of a 3D printed waveguide resonator structure at K_a band inside WR-28 PLA dielectric waveguide housing with inner dimensions of 7.112 mm x 3.556 mm cut along the center E-plane. This half-wave resonator is 5.91 mm long.

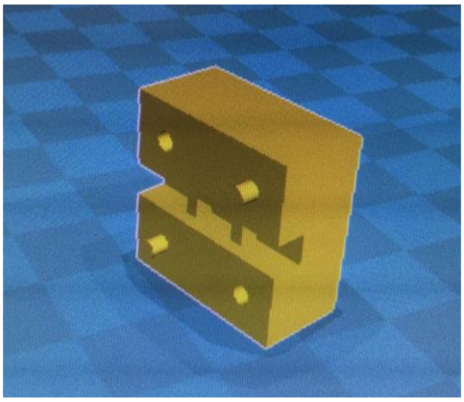

Fig. 1. Layout of a waveguide resonator in free to download Cura 3D Printing Slicing Software.

The waveguide housing was covered three times with metallic paint, having curing time of 2h for each coating layer. The metallic paint used is Ferro electronic materials 6290 0341 (L204N) silver conductive lacquer [8]. The fabricated inductive coupled waveguide resonator is shown in Fig. 2 and its simulated frequency responses in Fig. 3. The measured S_{21}-parameters of the 3D printed waveguide transmission line and waveguide resonator are given in Fig. 4.

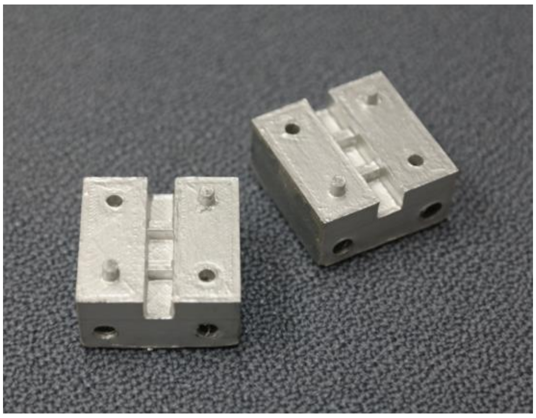

Fig. 2. Photograph of the 3D printed waveguide resonator.

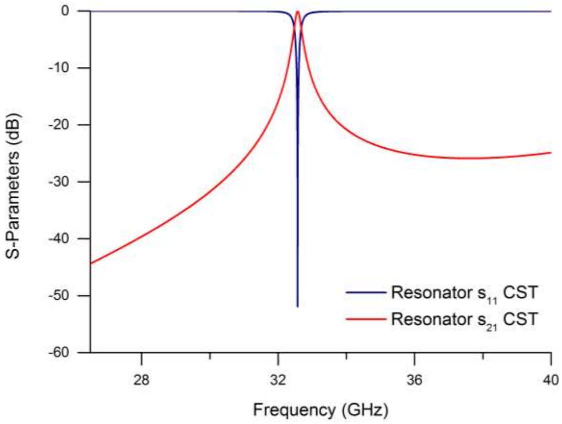

Fig. 3. Simulated S-parameters of the 3D printed waveguide resonator

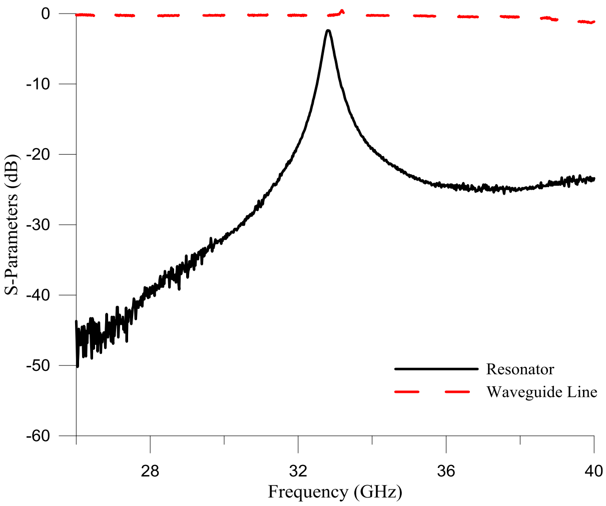

Fig. 3. Measured S_{21}-parameters of the 3D printed waveguide transmission line and waveguide resonator.

B. *Hybrid Manufactured Waveguide Resonators and Filters*

Firstly, a λg/2 resonator has been designed at 28.5 GHz (Fig. 4.). Rings with elliptical irises, which unlike standard discontinuities with circular irises have no contact with the waveguide side walls, are made out of 0.1 mm thick copper. Dielectric insert is printed on Ultimaker 2+ Extended 3D printer [9] with 0.25 mm nozzle, having the vertical resolution (thickness of a single layer which is in waveguide H-plane) of 60±5 µm. Accuracy in an H-plane is 12.5 µm. The thickness of all the boundary layers are chosen to be minimum, whereas, the fill density is 30%. Using effective medium approximation, the PLA dielectric is characterized by relative permittivity of $\varepsilon_r = 1.5$ and loss tangent $\tan\delta = 0.003$, neglecting material anisotropy.

The elliptic cylinder air cavity inside the resonator with semi major axis of 2.75 mm and semi minor axis of 2.55 mm is used to reduce dielectric losses where there is field maximum in the resonator center. Since the filter insert is physically small, the volume filled with PLA is primarily determined by the mechanical requirements to have a firm structure. Apart from the passband, the response has two upper stopband attenuation poles at around 37 GHz, coresponding to two rings, and the first spurious passband is at 40 GHz. The simulated S-parameters of the hybrid manufactured resonator inside WR-28 metallic waveguide housing is shown in Fig. 4.

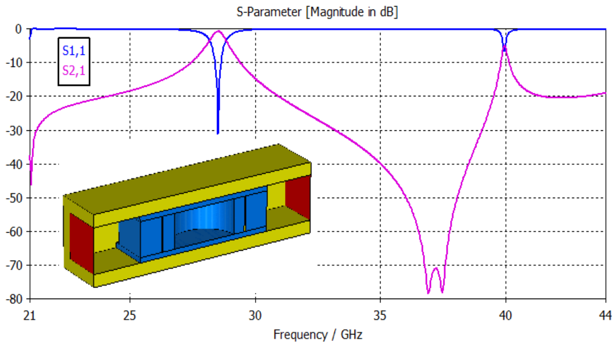

Fig. 4. Longitudinal cross section of the proposed resonator and its S-parameters.

The resonator length is 7.50 mm. Ring elliptic iris semi major axis is 1.3 mm and semi minor axis is 0.8 mm. The gap between the ring edges and the waveguide side walls both in E-planes and H-planes are 0.4 mm. Resonator PLA insert is pictured in Fig. 6, showing its printing quality and relative size.

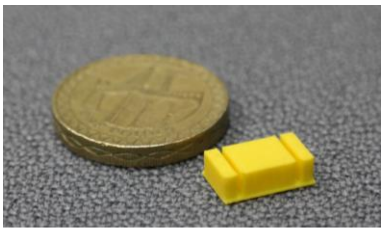

Fig. 5. Printer insert dielectric made using fused deposition modeling method.

A 28 GHz PLA WR-28 ring with inserts waveguide housing for hybrid manufactured waveguide filter is shown in Fig. 6. The electroless plating used is again Ferro electronic materials silver conductor. The designed resonator and filter have been simulated using CST Microwave Studio of CST Studio Suite [10]. The simulated S-parameters of the bandpass filter are shown in Fig. 7.

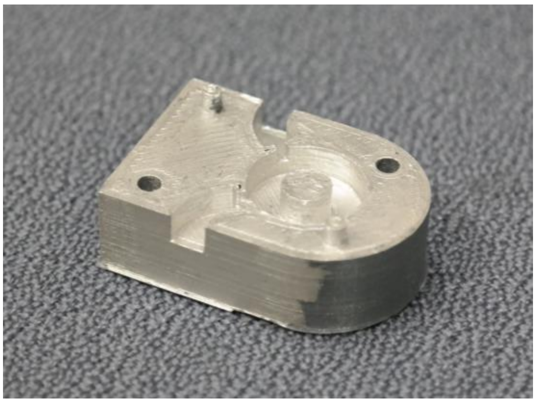

Fig. 6. Printed and metalized half-housing of the 28 GHz hybrid manufactured waveguide filter.

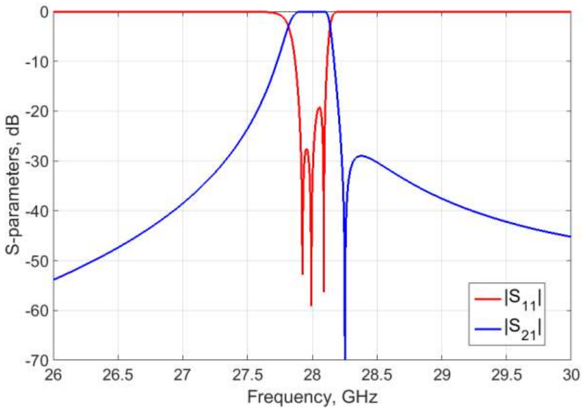

Fig. 7. Simulated S-parameters of the 28 GHz hybrid manufactured waveguide bandpass filter.

III. CONCLUSION

mm-Wave 3D printed and hybrid manufactured waveguide resonators and bandpass filters have been presented. The flexibility of 3D printing, namely fused deposition modelling, and hybrid manufacturing made open possibility for geometrical versatility of low-cost waveguide resonator and filter components. A 3D printed WR-28 waveguide resonator has been fabricated and tested. Another waveguide resonator has been made, having PLA inside the housing. A 3rd order quasi elliptic waveguide bandpass filter has been designed as well, with one transmission zero in the upper stopband.

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