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# INNOVATIVE APPROACH TO THE DESIGN AND MANUFACTURING OF WAVEGUIDE FILTERS USING ADDITIVE MANUFACTURING

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## ABSTRACT

This paper presents an innovative approach to the design and realization of waveguide filters using additive manufacturing. A comparative study is made between 2 filters respecting the same specifications. One filter is designed to be manufactured in multiple pieces and the second one is conceived for a monolithic building taking into consideration the rules of additive manufacturing (AM). A silver coating process allows to weld the multiple pieces structure together and to minimize the insertion loss of both filters.

## INTRODUCTION

In the telecommunication satellite field, filtering of signals is mandatory. Waveguide filters are generally a preferred technology due to their better power handling capability and low insertion loss compare to other technologies. Historically, because of manufacturing techniques used in metallurgy, subtractive manufacturing was first used to build waveguide filters. From a block of material, parts of the latter were removed until the aimed shape was achieved. This type of manufacturing process has a few limits, first it restricts the geometry of cavity resonators mostly to rectangular or cylindrical shape and it requires an assembly step in the manufacturing process with parts being screwed together thanks to flanges or by welding the parts together thus adding costs and delay to the fabrication process.

The additive manufacturing (AM) technology, on the opposite, is showing a lot of new opportunities in the manufacturing of waveguide filters. As it is detailed in [1], techniques like material extrusion, material jetting or stereolithography allow for the fabrication of monolithic parts available in different kinds of polymers. The realization of RF components is done by the metallization of the inner surfaces to realize waveguides filters for instance. These technologies enable the manufacturing of waveguide filters, much lighter than the ones made by subtractive manufacturing. [2] points out some limits of these techniques. Polymers have a high coefficient of thermal expansion which makes it more difficult to build a filter with the desired dimensions. Furthermore, they have a low thermal conductivity which can be an issue when looking for high power handling capability.

In the present work, the fourth technique presented in [1], which is the Selective Laser Melting (SLM) technology is selected because of the use of a metallic powder to build filters which will bring good thermal and mechanical properties. It is a powder bed fusion process that allows for instance fabrication in a single piece [3], [4] and offers more freedom in the geometry of cavities [5]. The addition of dimples [4] or the depressed shape of the super ellipsoid cavity in [5] allows to move higher order modes at higher frequencies. Using subtractive manufacturing, a screw or a post at the same location would have been needed to realize the same function. It also minimizes the risk that would bring overhanging surfaces. However, one of the main drawbacks using this technology is the roughness of the surface. This issue can be minimized by considering the angle of the build as was done in [6].

A lot of techniques are currently available to improve the surface's roughness such as shot peening or chemical polishing. SLM can be used with different materials such as aluminum or titanium alloys [1]. The use of aluminum alloys like AlSi10Mg with a good electrical conductivity in the order of  $1.6 \times 10^7 S/m$  [3] can be sufficient if the surface roughness does not impact the insertion loss significantly. Other metals having an electrical conductivity much lower than the one of AlSi10Mg, they need to be plated with silver or copper for instance. The study presented here falls within this perspective.

After manufacturing a filter using SLM, in the post processing steps a silver coating called LiCS (Liquid Chemical Suspension) is used which has multiple benefits : the minimization of the insertion loss thanks to the electrical conductivity of silver, the welding of different conductive metallic parts, an improvement in the surface roughness and a heat treatment, all in the same process step.

In order to test the use of the LiCS coating in the manufacturing process, two microwave filters were designed. The aim is to conclude on the fact that this silver coating can bring a solution to the current limits of AM which are that downward faces or roofs are difficult to realize and the poor surface roughness compared to subtractive manufacturing. One filter is made in multiple parts using SLM and then assembled thanks to the silver coating while the second one is made in a single piece and then silver coated.

In the following sections, the baseline filter and the specifications of the filters are presented then the two structures to be manufactured are illustrated and finally a comparative analysis is made on the pros and cons of each structure.

## BASELINE FILTER

The structure selected as the baseline filter to which the other filters will be compared to is a quasi-elliptic fourth order filter using cylindrical cavities. Each filter follows the coupling topology in Fig. 1. The vertical modes  $TE_{113}$  are coupled to the input and output waveguides thanks to rectangular inductive irises (S-1 and 4-L couplings). The couplings between the vertical and horizontal modes are realized by using screws at  $45^\circ$  between them (coupling 1-2 realized by post  $C_{12}$  and coupling 3-4 realized by  $C_{34}$  in Fig. 2). The couplings 1-4 and 2-3 are physically done by using rectangular irises in a cross shape between the 2 cavities of Fig. 2. More details about how to compute the dimensions of the filter are given in [7].

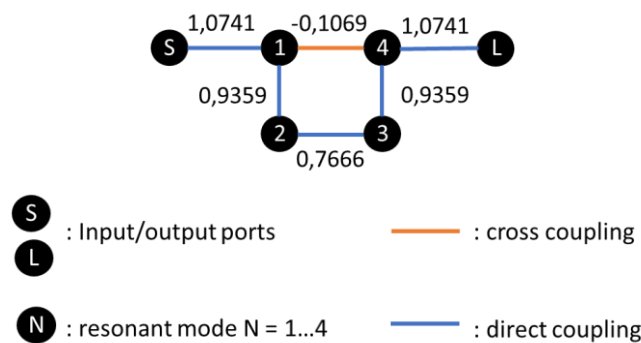


Fig. 1. Folded coupling topology

Each number in Fig. 1 (1.0741, 0.9359,...) represent the coupling values selected to respect specifications such as return loss lower than -22 dB and the positioning of 2 symmetrical transmission zeros that give an out of band rejection better than -40 dB.

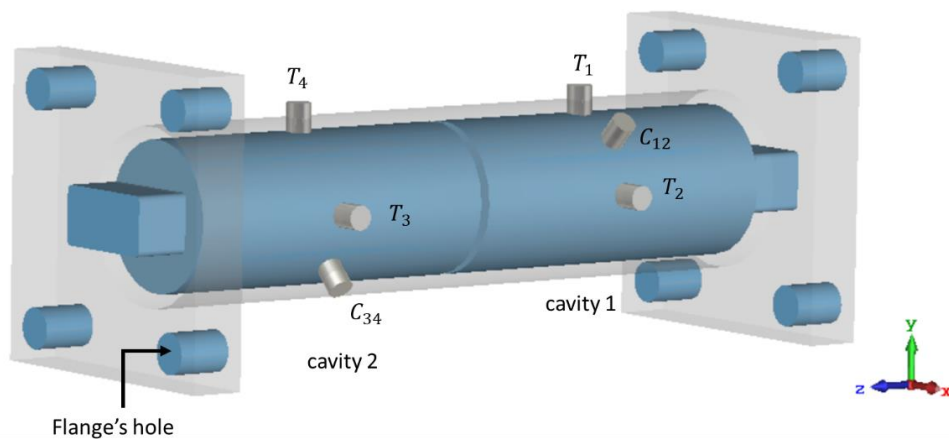


Fig. 2. Design of baseline filter

The baseline filter has a length of 5.91 cm and the radius of the cavities is 5.5 mm. Other goal of this study is to look for new shapes of resonant cavities that can shrink the total volume of the filter while respecting the same specifications.

## CAVITIES GEOMETRY

The shapes of the cavities were modified to be manufactured in two different ways. In Fig. 3, the conical cavity in the middle was chosen to be part of a filter made in multiple pieces. The rounded cone on the right, was chosen for a

monolithic manufacturing. These two cavities having a smaller volume than the cylindrical one, their quality factor is also smaller but simulation results show that it does not affect the frequency response of the filters.

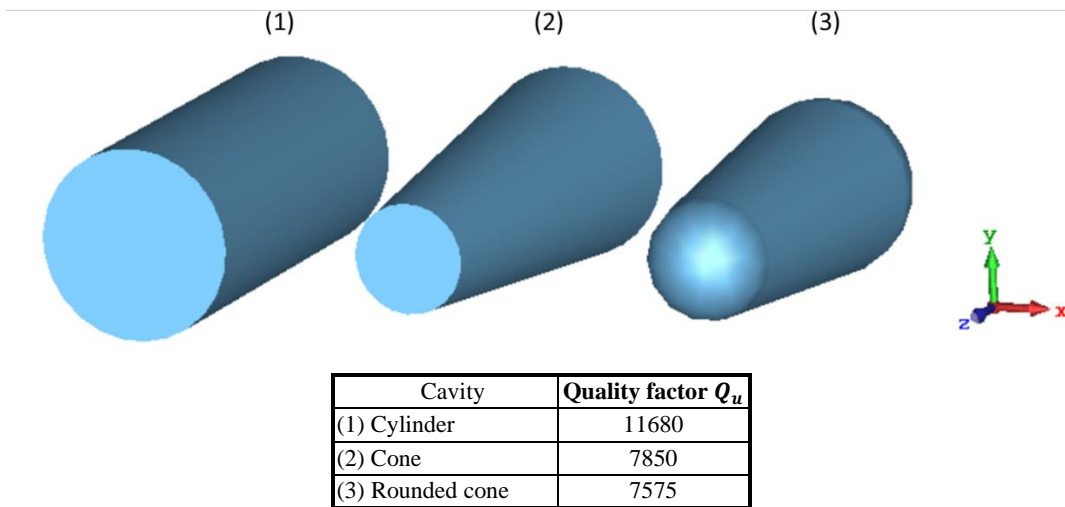


Fig. 3. Studied cavities shape

The selected metal powder for the SLM manufacturing of the 2 conical structures is the TA6V. Due to lead time issues both filters are not yet manufactured. The entire process involves the SLM manufacturing, a chemical polishing to improve the surface roughness and finally the silver plating.

### MULTIPLE PIECES STRUCTURE

The idea of this design is to place the iris realizing the  $M_{23}$  coupling in Fig. 1 at the smallest diameter of the cone because the coupling is more important than the  $M_{14}$  one. Thanks to the AM process, it is possible to build the pieces 1 and 3 in the Fig. 4 simultaneously. The realization is done along the z-axis with both flanges at the WR034 standard downward. The piece 2 which is the cross iris is made separately by Computer Numerical Control milling giving more precision on the manufacturing tolerances. In Fig. 4b, the  $M_{14}$  coupling is realized by the horizontal iris and the  $M_{23}$  coupling by the vertical one.

The use of the LiCS coating allows to wield the 3 pieces together to make the whole filter. This design offers a benefit in the building time because the 2 cavities can be built simultaneously and there is no welding time to consider as it is being done during the silver coating process. It is also more reliable on the manufacturing tolerances as there is no conflict with the limits of AM.

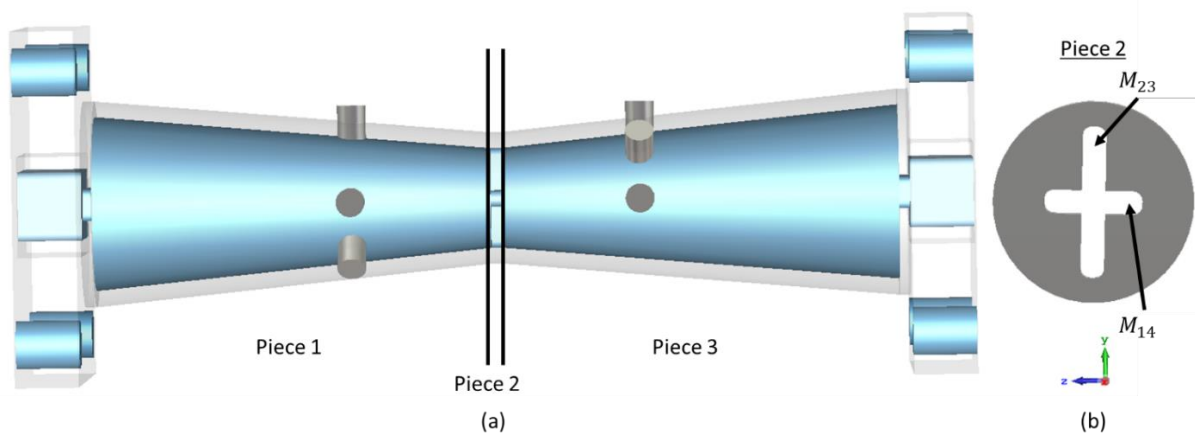


Fig. 4. Design of the multiple pieces structure – (a) y0z side view – (b) cross iris view

### MONOLITHIC STRUCTURE

This design is using the rounded cone 3 in the Fig. 3. Because of the necessity to remove the unmelted powder the iris had to be at least 1.5 mm wide while the irises of the previous structures were 1 mm wide. This increase in width added with the longer thickness of the cross iris leads to an increase in the smallest diameter of the cone in Fig. 5. Nonetheless, by reducing the biggest diameter of the cone from 5.5 mm to 5.06 mm, it is still possible to shrink the volume of the cavity.

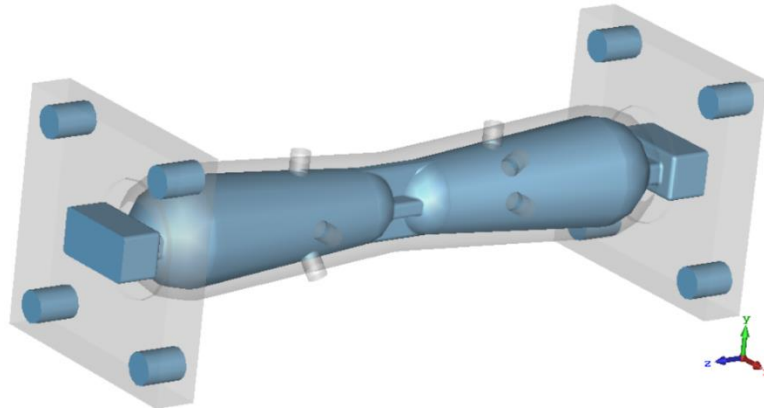


Fig. 5. Design of the monolithic structure

## COMPARATIVE ANALYSIS

According to the simulation results in Fig. 6, each structure can respect the specifications of a return loss smaller than -22 dB and have an out of band rejection better than -40 dB. The small spurious mode on the right hand side generated by the coupling screws being a little too much screwed are moved higher in frequency for the two conical cavities but the disturbance happens to be more important for the structure made in multiple pieces. There is a slight loss in selectivity compared with the filter using cylindrical cavities. The unloaded Q of the baseline filter is 3044, the one of the filter made in multiple pieces is 2114 and the filter made in a single piece has an unloaded Q of 1701. These Q values illustrate the loss in selectivity and are only simulated ones that do not take into account the surface roughness achievable by the manufacturing process chosen. A volume reduction is achieved in the order of 1.49 for the first design in multiple pieces and 1.6 for the second one made in a single piece. Once the filters fabricated, an evaluation of the achieved unloaded Q will be carried out and compared to the simulated ones.

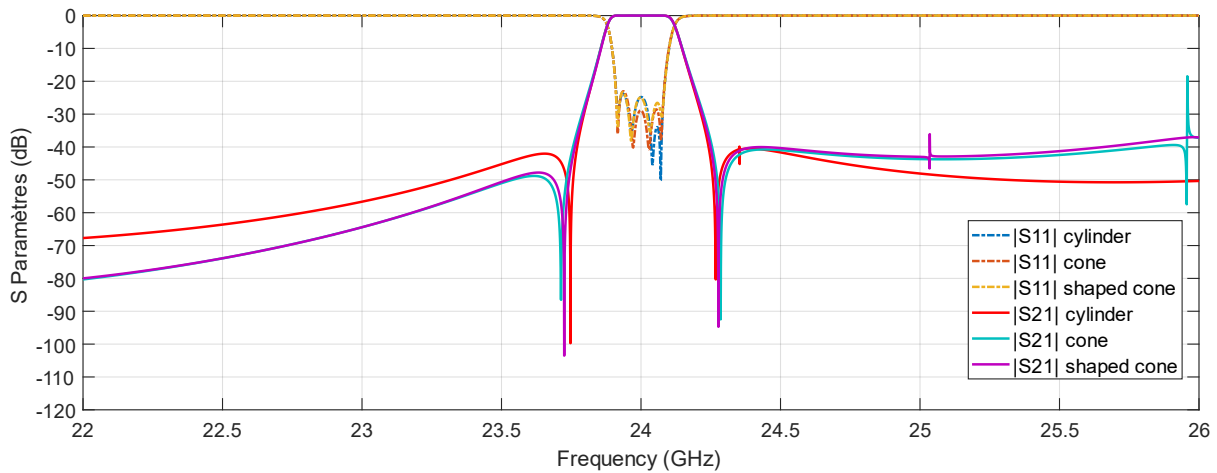


Fig. 6. Simulation results – S parameters comparison between the different structures

## CONCLUSION

Two 4<sup>th</sup> order filters were presented in this paper. The simulations have demonstrated the possibility to shrink the volume of the vacuum inside the filter. The upcoming measurement results will decide on the usefulness of the LiCS coating.

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