Emerging Technologies and Concepts for 5G Applications－

A. Making Additive Manufactured Ceramic Microwave Filters Ready for 5G

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Abstract – **Additive manufacturing (AM) techniques for filter applications have proven to be vital in enabling a variety of forms and shapes best suitable for 5G application. However, in order to guarantee a good RF performance of the passive components, certain aspects have to be taken into account. When it comes to dielectric resonators manufactured in ceramic AM, the quality of the metallization is crucial. Based on a simple prototype, this paper reports on the performance when using an advanced coating technique applied to a 3D printed ceramic body.**

INTRODUCTION

In the last decades, wireless communications experienced an exponential growth in terms of number of users and number of applications (in smartphones, high definition satellite television, wireless internet and many more). Having a higher number of users and services in a wireless system, requires enhanced hardware and software, thus pushing the boundaries of current technologies. A high number of common wireless systems (broadcast radio, television, LTE, 5G, Wi-Fi, etc.), operate in the same frequency spectrum, hence the manufacture of filtering components with advanced responses is fundamental to provide a communication link with a certain quality level.

Microwave and RF passive components realized by additive manufacturing (AM) have received an increasing interest in the last years. Different materials can be used for AM, including plastics, metals, and ceramics. The latter are classically employed in filters as dielectric resonators (DR) for a wide range of industrial applications. In the case of components manufactured entirely out of plastics and ceramics, an additional metal layer has to be deposited in order to shield the structure, thus avoiding radiation of the electromagnetic fields.

Compared with other technologies, DR filters represent a very good trade off technology between performance and size. Indeed the overall volume of the component can be significantly reduced thanks to the dielectric properties of the ceramic materials and the quality factor (Q) is usually comparable to that of pure waveguide implementations [1]. As a result, DR filters are often utilized in wireless systems [2, 3].

The main components of DR filters are: a ceramic/dielectric elements (usually in the shape of a post or a puck) that act as resonators, and a metallic enclosure which provides shielding. A recurring issue with such family of filters is how to combine the ceramic parts and the metallic enclosure. For TE configurations, low-permittivity materials are usually glued to the ceramic material and metal walls, properly placing the dielectric resonator within the cavity [4]. However, the manual assembly of these elements frequently leads to a misalignment of the parts, resulting in a significant degradation of the filter response. At the same time, the use of high-loss adhesive materials to connect the different blocks reduces inevitably the RF performance of the filter [5]. In other cases, such as TM dielectric resonator filters, the ceramic block is designed to fit in a metal cavity [6]. By doing so, adhesive composites can be eliminated, relying only in the mechanical pressure applied to ensure electrical contact and to keep the puck in place. This approach frequently leads to cracks in the ceramic material when assembling the filter because of manufacturing tolerances of the parts and uncertainties when fastening the cavity. Even in these cases, ensuring a proper contact between the ceramic and metallic parts is not a trivial task. The importance of developing a simple assembly for DR filters is reflected in the large amount of publications produced in the last decade on such topic [7–9]. Nevertheless, recent advances in AM techniques have motivated researchers to apply such technology to develop DR with complex shapes in order to ease their assembly within custom-made metallic enclosures [10–13].

STATE OF THE ART OF AM

AM is a layer-by-layer process for producing 3D objects directly from computer-generated models. Consequently, the manufacturing cost depends on the volume of the object instead of its complexity, allowing designers to incorporate increasingly complex shapes in their designs. Furthermore, this technology can be applied to ceramic materials (as well as metals and plastics), leading to important advances in the realization of microwave filters during the last few years.

The successful application of AM processes to the development of microwave filters built out of ceramic materials was originally demonstrated in [10]. In this work, later expanded in [11], stereolithography was employed to build a 2D electromagnetic bandgap (EBG) structure out of a high-permittivity material (zirconia). Then, the ceramic block was introduced within a rectangular cavity to realize a narrowband filter. With a manufacturing accuracy of 50 μm, the manufactured structure showed a significant frequency shift (1.5%) compared with numerical simulations for a filter working at a reasonably high frequency (33 GHz). However, this frequency deviation could be simply compensated by introducing tuning screws.

A recently developed fabrication technique is the so called Lithography-based Ceramic Manufacturing (LCM) which is based on a layer-by layer stereolithography [14]. A new family of monoblock DR filters completely manufactured out of ceramics is presented in [14]. In contrast with other proposed topologies, these filters implement classical TM dielectric resonator structures that do not require any assembly (beyond connecting the input/output flanges to feed the component). A block containing the dielectric resonator cylinder along with the walls of the

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cavity is manufactured in one step using AM. This monolithic approach avoids the typical misalignment issues common in DR filters. Furthermore, it is suitable for mass production, requiring minimal human interaction during its manufacture. For completion solely the already mentioned metallization of the external surfaces has to be performed.

COATING OF THE DR FILTER

A simple proof-of-concept prototype was shown in [14] (Fig. 1.a), however, its electrical performance had room for improvement, mainly due to the fact that the metal coating was applied manually. In other words, the samples were hand-painted using a conductive varnish. Therefore, the need to apply a suitable metallization technique capable of accurately depositing a thin layer of metal with improved conductivity properties arose.

In the present run, the coating is the result of a multistage procedure that can be subdivided into several process steps. After the surface preparation and activation, a rinsing stage is applied. The actual application of the metal takes place by spraying, utilizing a double nozzle painting gun. With this specially attributed gun, two water-based solutions, the oxidant and the reducer, are applied at the same time. A chemical reaction takes place as soon as the two solutions come together, resulting in an accumulation of the metal layer on the samples. In the present case, a layer thickness of 3 µm was applied resulting in an adequate electric conductivity.

(a) (b)

Figure 1. 2-pole TM filter (a) manually painted and (b) professionally coated

MEASUREMENT

The professionally coated prototype, shown in Fig. 1.b, features the same design and dimensions as the original version (Fig. 1.a). For the measurement we used the ZVA 24 from Rohde & Schwarz which was calibrated for a frequency range between 1 GHz and 20 GHz. The RF signal was coupled into (out of) the filter using two standard SMA connectors whose inner conductors were precisely cut to match the designed length in order to achieve the desired input (output) coupling.

The results of the new prototype measurements are shown in Fig. 2 where, compared to the simulation, a shift of the center frequency of 100 MHz can be observed. The measured IL is 0.7 dB at the center frequency vs. 0.2 dB expected in the simulations, carried out with metal conductivity 6.3×10^{7} S/m and a $\tan\delta=10^{-4}$ for the ceramic (alumina). It is worth noticing that the measured RL leads to a loss of 0.45 dB in the transmission coefficient. This means that the net loss due to the materials alone is 0.25 dB (in very good agreement with the simulation). In the same filter metallized with metal paint [14] the measured IL=1.5 dB (or 0.9 dB if reflection losses are taken out). In the implementation presented here (with professional coating) the measured Q factor is 1500 vs. 600 obtained with metal paint [14]. In order to compensate for the mismatched response and the centre frequency shift, tuning mechanisms should be foreseen in future implementations.

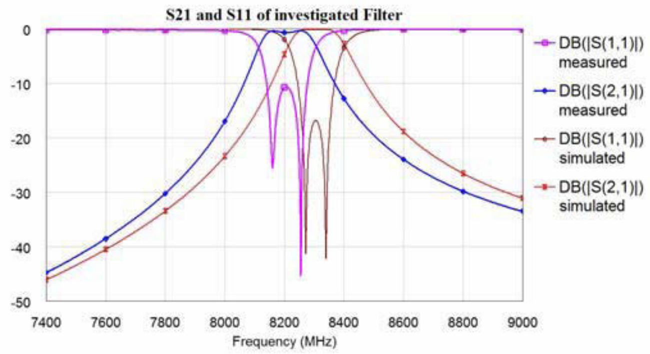

Figure 2. Comparison of measured and simulated S-parameters

CONCLUSION

A challenge in the present task is the interdisciplinary approach where three fields of expertise are involved: RF-filter design, additive manufacturing, and metallization technology. Professional exchange and deep technical understanding of the process steps of the involved technology partners are necessary to find a trade-off between the form that is optimal in terms of RF-properties and what is technically feasible and economically justifiable.

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