3D screen printing for high frequency devices implemented in Groove Gap Waveguide technology

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ESA Technical Officer: Isabel Olaya Leon, ESTEC, Noordwijk

Executive Summary Report

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1 ABSTRACT

This technical report details the outcomes of a project aimed at developing high-frequency components using Groove Gap Waveguide (GGW) technology, leveraging 3D screen printing for the manufacturing process. This technology does not require contact between the different parts and enables fully metallic distribution networks in a much simpler way than conventional rectangular waveguide. In recent years, this technology has demonstrated to be a good candidate for antennas and even filters with very low insertion loss. 3D Screen-printed waveguide devices reveal the advantage to be suitable for mass-production, which also offers the possibility of cost-reduction. Conventionally manufactured (i.e. milled) components are manufactured successively one after the other. Additionally, depending on the center frequency, the milling machine is required to have very small tolerances for higher frequency regimes. Mass-production of such components is therefore cost- and time-intensive. Furthermore, a lot of material is removed during milling, which is critical from an environmental point of view.
The project's primary objective was to assess the feasibility and optimize the process of using 3D screen printing to fabricate metallic 2.5D GGW structures, such as filters and resonators, for devices operating in the millimeter-wave spectrum above 75 GHz. The project focused on producing components in the WR-6 (110-170 GHz) and WR-10 (75-110 GHz) frequency bands, widely used in telecommunications and space applications.

2 PROJECT OBJECTIVES AND SCOPE

2.1 Manufacturing Process Development

The goal was to develop a reliable manufacturing route for GGW (Groove Gap Waveguide) components, using the 3D screen printing process (see Fig. 1) to achieve high resolution, good surface finish, and precise geometrical accuracy. This was particularly important for the high-frequency applications targeted by the project, where even minor deviations in component dimensions can significantly affect performance.

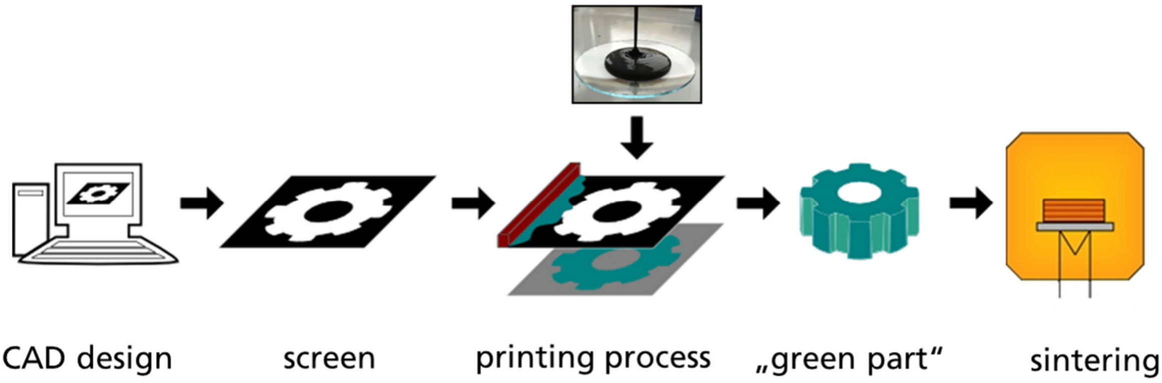

Figure 1: Process chain of the 3D screen printing process.

2.2 Design and Fabrication of GGW Components

The project included the design, fabrication, and characterization of key components such as transmission lines, resonators, and third-order filters in GGW technology. These components were manufactured using 3D screen printing and then subjected to rigorous testing to validate their electrical and geometric properties. A key technical challenge was to maintain dimensional tolerances within ±15 µm and surface roughness (R_a) below 3 µm to ensure optimal performance at high frequencies. Fig. 2 shows a cross-section of a GGW structure in the WR-10 band, including its dimensions.

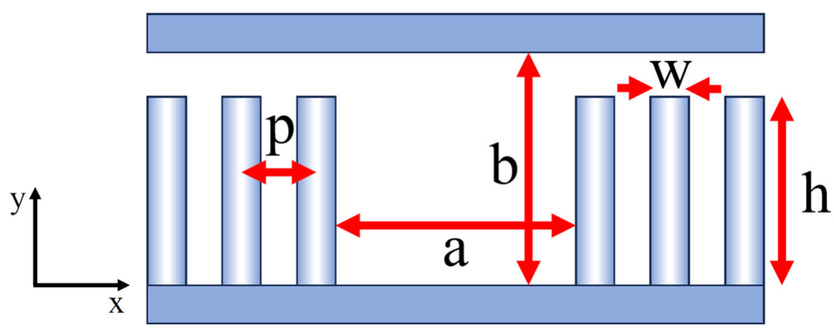

Figure 2: Cross-section of the GGW. Dimensions are as follows (all in mm): a = 1.651, b = 0.8255, h = 0.79, p = 0.45, w = 0.3.

2.3 Materials Selection and Processing

Tungsten-copper was chosen as the primary material system due to its low shrinkage during sintering, making it ideal for maintaining the tight tolerances required for high-frequency devices. The material system offers several advantages:

- Low lateral shrinkage during sintering, critical for achieving high geometrical precision.
- Good thermal and electrical conductivity, which is essential for maintaining low losses in high-frequency applications.

2.4 Iterative Process Refinement

The design and manufacturing processes were refined through multiple iterations. Early iterations focused on understanding the limitations of the 3D printing and sintering processes, while later stages incorporated improvements based on the initial results. This iterative approach led to the optimization of component geometries, printing process parameters, and material formulations, ensuring that the final components met the stringent performance requirements.

3 KEY ACHIEVEMENTS

3.1 3D Screen Printing Process for GGW Components

The project successfully established a 3D screen printing process for GGW structures. This additive manufacturing technique was shown to be suitable for creating high-precision components with fine features, such as cylindrical pins used in the GGW architecture. A key advantage of 3D screen printing over other additive processes is its ability to produce components with smooth surfaces and low roughness, which is critical for reducing losses in high-frequency devices.

The process was divided into two main steps:

- Printing: A suspension containing tungsten and copper powders was printed layer-by-layer to build the component geometry. The suspension's viscosity was carefully controlled to ensure uniform layer deposition.
- Sintering: After printing, the components were densified in a sintering furnace. Two sintering approaches were tested: infiltration with copper foil and a master alloy route, with the former showing better results in terms of dimensional stability and overall performance.

3.2 Design and Testing of GGW Components

Several GGW components were designed and manufactured for both the WR-6 and WR-10 bands, including:

- Transmission Lines: These were designed to achieve a return loss of at least 25 dB.
- Resonators: Designed for center frequencies of 90 GHz (WR-10 band) and 140 GHz (WR-6 band).
- Third-Order Filters: Designed to operate at specific frequency ranges (90-92 GHz for WR-10 and 140-143 GHz for WR-6), the filters were manufactured to investigate the accuracy of the printing process and the impact of geometrical deviations on their electrical performance.

Fig. 3 shows the basic designs for the three different components. The dimensions of the pin structure have been adapted for the WR-6 and WR-10 bands respectively.

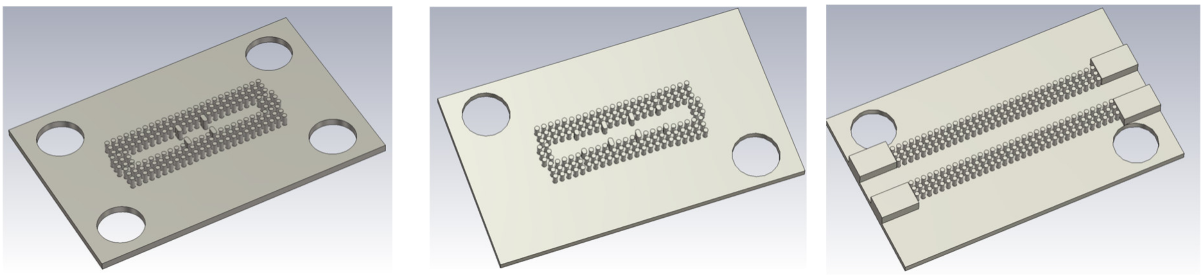

Figure 3: (a) Resonator, (b) Filter, (c) Through line.

These components were characterized electrically and geometrically, with results showing that the 3D screen printing process can produce GGW components that perform well at high frequencies. The measured components showed good agreement with simulated designs, though there were some discrepancies in the exact center frequencies and insertion losses, which were attributed to minor dimensional deviations during the printing and sintering processes.

3.3 Material and Process Optimization

The project highlighted the importance of material selection and process control in achieving the desired component properties. Tungsten-copper was found to be a suitable material system, providing low shrinkage and good thermal stability during the sintering process. The project team refined the printing and sintering processes to minimize deviations from the design specifications, achieving shrinkage rates as low as 0.8% for some components.

The two material processing approaches (copper infiltration and the master alloy route) were compared:

- Copper Infiltration: In this approach, the printed tungsten skeleton was infiltrated with molten copper during the sintering process. This method produced components with low lateral shrinkage, making it easier to maintain the tight dimensional tolerances required for high-frequency GGW components.
- Master Alloy Route: This approach involved printing a mixture of tungsten and copper powders. While this method simplified the process, it resulted in higher shrinkage rates and some distortion, making it less suitable for components with tight tolerance requirements.

3.4 Measurement and Characterization

Extensive testing was carried out to characterize the electrical and geometric properties of the manufactured components. For electrical characterization the components were tested using a network analyzer to measure their S-parameters, which provides an insight into the electrical performance and from which conclusions can be drawn about the manufacturing accuracy of the GGW components. Individual measurement sample holders were manufactured for the WR-6 and WR-10 bands for electrical characterization. This is shown as an example in Fig. 4 for the measurement holder of the filters and resonators in the WR-6 band. The basic structure is identical for the WR-10 band, although it should be noted that a separate measurement holder was developed for the respective through lines. The results indicated that while the manufactured components generally met the design specifications, some further refinements were needed to improve their performance in terms of return loss and insertion loss.

- Electrical Performance: The components exhibited good return loss and insertion loss characteristics, though some deviations were noted in the center frequencies of the filters and resonators. These deviations were attributed to minor geometric inaccuracies during the printing process. Fig. 5 shows an example of the measured S-parameters of two 3rd order filters in the WR-6 band. The good agreement between simulation and measurement is clearly recognisable. Furthermore, the comparison of the measured S-parameters shows the high repeatability of the 3D screen printing process.
- Geometric Accuracy: The printed components showed high dimensional accuracy, with pin diameters and heights closely matching the design specifications. However, there were some issues with lateral shrinkage and base plate bending during the sintering process, which impacted the final dimensions of the components.

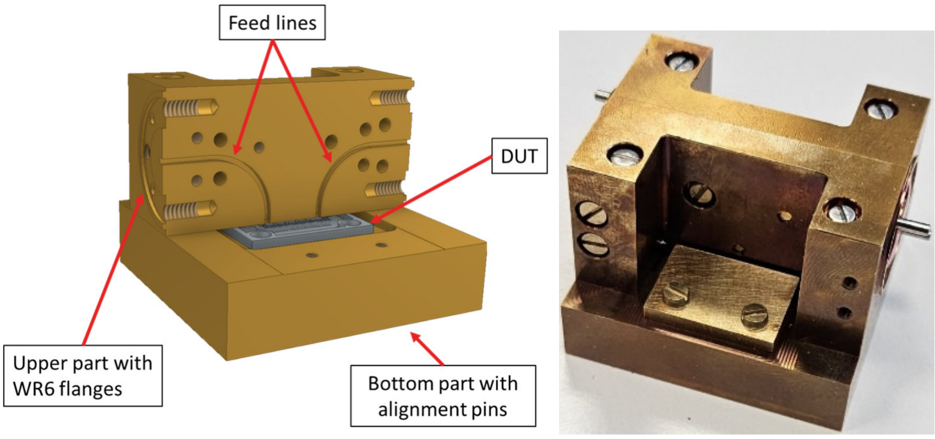

Figure 4: CAD model of the optimized WR6-band measurement holder (left) and fully assembled measurement holder (right). DUT means device under test.

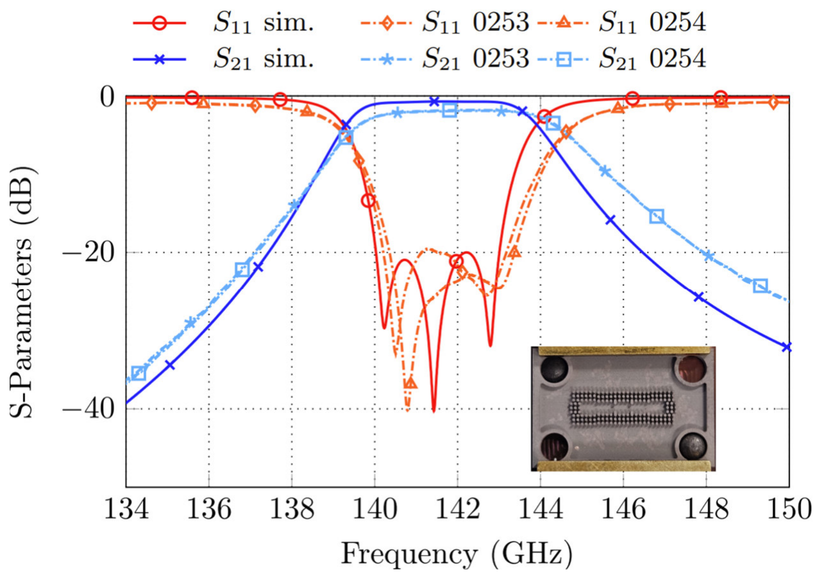

Figure 5: Measurement results of the third order WR6-band GGW filters 04818_0253 and 04818_0254 compared to simulation.

4 CHALLENGES AND LESSONS LEARNED

4.1 Sintering and Shrinkage Control

One of the key challenges encountered during the project was controlling the shrinkage of the printed components during the sintering process. While the tungsten-copper material system helped to minimize shrinkage, further refinements to the sintering process are needed to achieve more consistent results. The project team noted that adjusting the sintering temperature and infiltration process could lead to improved dimensional stability in future iterations.

4.2 Dimensional Deviations

While the 3D screen printing process demonstrated good overall accuracy, some minor dimensional deviations were observed, particularly in the height of the pins and the base plates. These deviations had a noticeable impact on the electrical performance of the components, particularly in terms of return loss and insertion loss. Additional process optimization, including better control over the paste viscosity and layer height during printing, will be necessary to achieve the required precision.

4.3 Electrical Contact and Alignment

During the electrical characterization of the manufactured components, some challenges were encountered with ensuring good electrical contact and precise alignment between the printed components and the measurement sample holders. This was addressed by refining the measurement setup and improving the alignment between the components and the measurement sample holders.

5 CONCLUSION AND FUTURE WORK

The project successfully demonstrated the potential of 3D screen printing for manufacturing high-frequency GGW components. The results indicate that 3D screen printing can be used to produce complex GGW structures with high precision, making it a viable manufacturing method for components operating above 75 GHz.

While the project achieved significant milestones, further work is recommended to refine the sintering process and improve control over material properties. Future work should focus on:

- Further optimizing the tungsten-copper material system to reduce shrinkage and improve dimensional stability.
- Refining the printing process to ensure a more precise control over the final dimensions of the printed components.
- Improving the electrical characterization setup to ensure more accurate alignment and better electrical contact between the components and the measurement apparatus.
- Pushing the technology to a higher TRL level
- Development of GGW components for commercial use in the analyzed frequency bands together with industrial partners.

Overall, the project has provided valuable insights into the capabilities and limitations of 3D screen printing for high-frequency applications and has laid the groundwork for further advancements in the field.