

# 3D- Printed Millimeter Wave Structures

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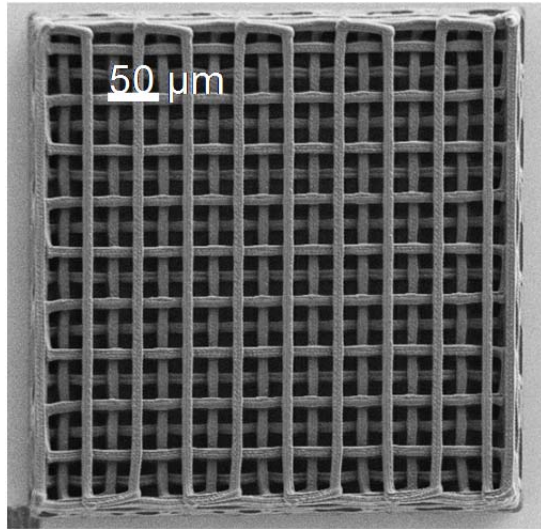
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**Abstract:** 3D printing of styrene-butadiene-styrene (SBS) and styrene ethylene/butylene-styrene (SEBS) is used to demonstrate the feasibility of 3D-printed millimeter wave (mmW) components. The dielectric properties of the two materials are characterized at mmW frequencies and show properties comparable to rexolite. A bandpass filter, which can be inserted into WR-28 waveguide, is designed and measured, showing good agreement with simulation. Additionally, a dielectric lens is printed which improves the antenna gain of an open-ended WR-28 waveguide from 7 to 8.5 dBi.

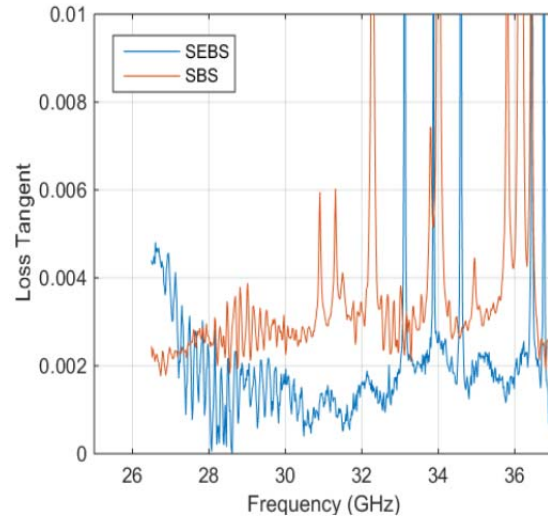
**Keywords:** 3D printing, millimeter wave components, filter, dielectric lens

## Introduction

The trend to integrate microwave systems on one chip, such as with a monolithic microwave integrated circuit (MMIC), has continued into the millimeter wave



**Figure 1:** A printed log pile demonstrates the resolution of the printer with a 10 micron nozzle.



**Figure 2:** Measured loss tangent of SEBS and SBS samples.

(mmW) band (30-300 GHz); however, integrating with off-chip parts of the system remains difficult. At lower frequencies, techniques exist to integrate the chip with external components, such as co-firing ceramics and metals in the packaging. This is not possible at mmW frequencies where the ceramics have excessive loss. We investigate the use of 3D-printed polymers for use as mmW dielectric components, which is a first step towards integrating dielectrics with MMIC components for high density mmW systems. We present a material and process which prints with low loss and resolutions compatible with mmW frequencies. This paper outlines the capabilities of our process, the electromagnetic properties of the materials we use, and the measured results of some sample

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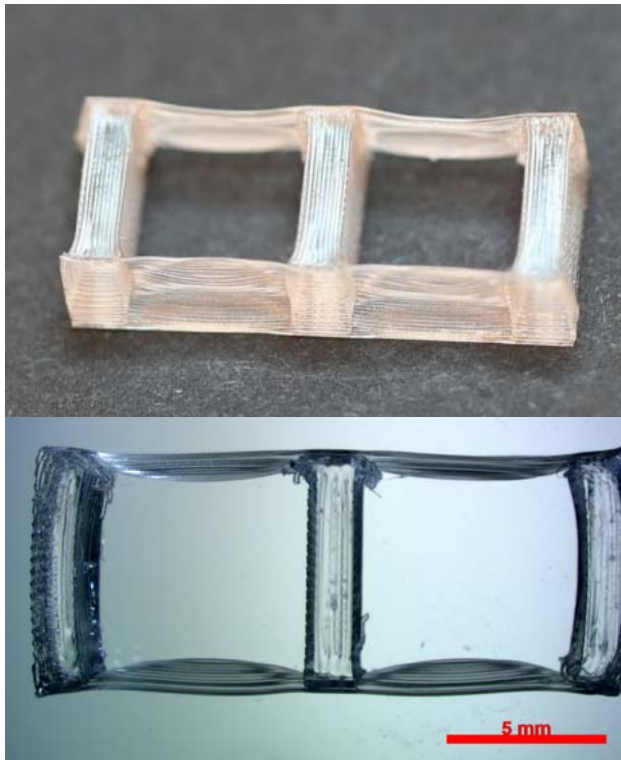
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components: a printed waveguide filter and a dielectric lens.

### Process Description

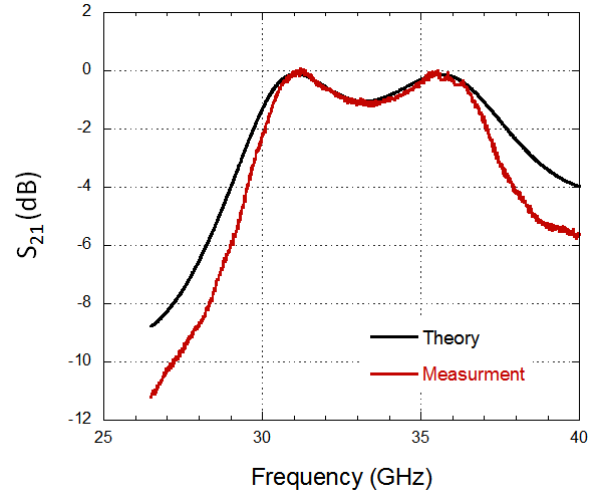
Our structures are printed with one of two machines, which are custom built by Aerotech. The first machine, used for larger resolutions, uses a 200 micron nozzle and has a print resolution of 5 microns. This is the preferred printer for larger prints because it prints faster than the high resolution system. The high-resolution system uses a 10 micron nozzle and has a 8 micrometer resolution. Figure 1 shows a log pile printed with the high-resolution system.

Two mmW test structures were printed to characterize the dielectric constant and loss using two triblock copolymers, styrene-butadiene-styrene (SBS) and styrene ethylene/butylene-styrene (SEBS). Blocks of SBS and SEBS blocks were measured in WR-28 to characterize their electromagnetic properties. The blocks were measured with a Keysight E8364C vector network analyzer and the loss and dielectric constant were extracted with Keysight proprietary software developed for this purpose. The measured dielectric constant was 2.20 for SBS and 2.52 for SEBS. The measured loss is shown in Figure 2 with results comparable to rexolite, a common low-loss dielectric



**Figure 3:** A three-section band-pass filter printed with SEBS.

with a dielectric constant of 2.49 and loss tangent of  $7.82e-4$ .



**Figure 4:** Comparison of simulated and measured results of a printed band-pass filter with three dielectric sections spaced by air.

### Filter Structures

A band-pass filter was built for use in a section of WR-28 waveguide. The filter was printed with a 200 micron nozzle and takes 45 minutes to print. Figure 3 shows a microscope image of a three-section filter printed with SBS. The measured and simulated results are shown in Figure 4, which agree with Ansoft HFSS simulations. The quality factor of the filter is about  $Q=5$ , but more selectivity could be added by adding more airgap and dielectric sections. This demonstrates that low-cost waveguide filters can be quickly designed and prototyped with our process and standard microwave filter theory [1].

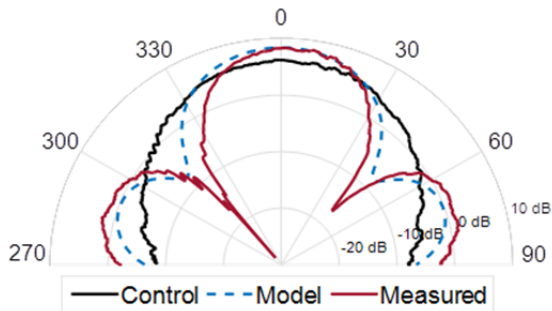
### Dielectric Lens

A second structure that shows the utility of this technique is a dielectric lens which can be inserted into an open-ended piece of waveguide to improve the gain when used as an antenna. A picture of the printed lens is shown in Figure 5. It consists of a convex lens supported by a hollow rectangular tube. The purpose of the tube is to support the lens and position it at the correct distance corresponding to its focal length [2]. It is hollow to minimize the traveling waves interaction with dielectric material until it reaches the lens. This particular design demonstrates the advantages of our additive manufacturing approach because the machining of the lens inside the tube would be difficult with conventional subtractive manufacturing techniques.

The lens is used to improve waveguide gain when used as an antenna. HFSS simulations of an open-ended



**Figure 5:** An SBS lens can be inserted into a piece of WR-28 waveguide to improve the antenna gain relative to open ended waveguide.



**Figure 6:** A comparison of the simulated E-plane gain of WR-28 waveguide, with and without the printed dielectric lens. Measurement agrees with simulation.

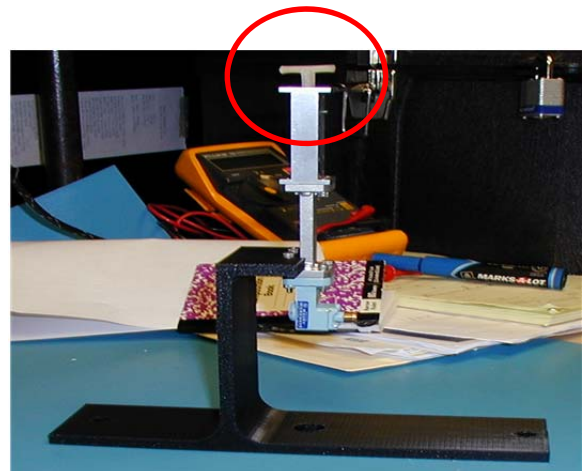
WR-28 waveguide at 30 GHz have a boresight gain of 7 dBi, as shown in Figure 6. Simulations also show that this lens design should improve the gain to 8.5 dBi, and this is in fact the case when the dielectric lens is measured in an antenna chamber. The lens, waveguide, and antenna holder for the chamber measurement are shown in Figure 7 to demonstrate the intended configuration of the dielectric lens inserted into the waveguide.

## Conclusions

We have demonstrated that a 3D printer with polymer-based materials can be printed as low-loss dielectrics in arbitrary shapes, some difficult to machine, as useful mmW components. Our process is not limited to these components, rather, we used these as a stepping stone to more complicated structures we intend to print in the future.

## References

- [1] Pozar, David M. *Microwave Engineering*. Hoboken, NJ: J. Wiley, 2005.
- [2] Saleh, Bahaa E. A., and Malvin Carl Teich. *Fundamentals of Photonics*. Hoboken, NJ: Wiley-Interscience, 2007.



**Figure 7:** The waveguide, lens, and antenna chamber holder are shown to demonstrate the intended configuration of the lens inserted into waveguide.