3D Metal Printed Sierpinski Gasket Antenna

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Abstract **– In this research, the design, simulation, and fabrication of the first ever 3D metal printed Sierpinski gasket antenna, with multiple resonance characteristics is reported. The antenna is fabricated from Titanium alloy Ti-6Al-4V, using the Direct Metal Laser Sintering (DMLS) technique. Mechanical considerations like Rumsey's principle and the support structures required for overhanging 3D printed structures have also been studied in detail and discussed. The validity of the DMLS technique for manufacturing a complex shaped (fractal) antenna is assessed, by comparing CST (Computer Simulation Technology) simulation results with the measured data.**

1 INTRODUCTION

Additive Manufacturing (AM) or 3D printing technology allows 3D parts to be fabricated directly from Computer Aided Design (CAD) data, sliced into stacks or in a layer-by-layer fashion, without the need to plan the transformation from 2D into 3D. Complex parts, which were extremely difficult or in some cases impossible to be manufactured at all using conventional tooling methods, can now be built with a short lead time, with good reliability and the high level of precision [1]. In a very short span of time, AM has found its application in almost all leading engineering areas, such as aerospace, automotive, medical fields, consumer products and military.

Recent research in 3D printing has also focused on RF/Microwave components [2]-[4]. These 3D components can be fabricated using Stereolithography, where the physical structure is fabricated using non-conducting thermoplastics, such as Acrylonitrile Butadiene Styrene (ABS), and then usually metallized or painted in order to make the printed electromagnetic component functional. Uniform coating or selective coating, adds an extra processing step over the polymer printed component, and also has to be done very precisely, in order to achieve acceptable electromagnetic performance from the component.

This research presents the first 3D metal printed Sierpinski gasket antenna for wireless applications using DMLS technology. In earlier published research, DMLS has already been used to manufacture a waveguide fed antenna array, while EBM has been used to manufacture a 3D printed metallic horn antenna [3] [4]. Both the DMLS and EBM antennae have been produced as early demonstrations of the power of AM for microwave components, using metallic materials. In this research, the selection of the Sierpinski gasket antenna is done as another early example of 3D printing, where the geometry is more complex. The aim of this research is to push the limits of 3D metal printing in the field of complex antenna manufacturing. However, 3D metal printing imposes some unexpected restrictions on antenna design, which will be outlined later in section 4.

2 SIERPINSKI GASKET ANTENNA

The Sierpinski gasket is named after the Polish mathematician Sierpinski, who described some of the main properties of a fractal shape in 1916 [5]. In this case, the discontinuities (or fractals), increase the perimeter of the material so that the antenna has multiple electrical lengths, which leads to multiband behavior [6]. Historically, this feature has been exploited in 2D antenna designs, but in this research, a 3D extension is presented, so instead of triangles, tetrahedrons are arranged in a self-symmetric fashion.

To the best of the authors' knowledge, a 3D Sierpinski antenna has only been built twice [7] [8]. Anguera. J, et al in [7], presented a very light-weight, fractal-shaped, Sierpinski-carpet, cylindrical hole, monopole antenna, fabricated with metallized foam, where the antenna possessed multiband characteristics. In [8], the first 3D full-metal version of a Sierpinski gasket antenna was manually fabricated using brass. The antenna possessed multiband characteristics; however, differences between computational and measured results could be easily seen, which might have occurred due to geometrical inaccuracies during the manual fabrication of this complex-shaped antenna. The manual fabrication challenges mean that the differences between the measured and simulation results will increase, if the radiating monopole structure were designed for a higher wavelength.

3 ANTENNA FABRICATION

The proposed antenna was fabricated using the DMLS machine EOSINT M280, with the Titanium alloy Ti-6Al-4V as the conducting material. The antenna designed is a 2nd iteration, Sierpinski gasket antenna, with a large side length of 46.7 mm, on a finite rectangular copper ground plane, of area 160 mm x 100 mm, with 1 mm thickness, as shown in Figure 1.

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Figure 1: Sierpinski gasket antenna fabricated using DMLS technology on Ti-6Al-4V

4 MECHANICAL CONSIDERATIONS

4.1 Support Structures

In the process of 3D printing, where models are built layer-by-layer, each layer is supported by previously printed layers underneath it. In order to print structures with shallow angles (with reference to the horizontal plane building plate) and cantilever sections, extra support structures are needed to ensure the printed objects' integrity and print quality. An industry rule of thumb with DMLS technology is that support structures are needed, if the structure has an overhanging angle (θ) less than a material-specific value. For example, with the Ti-6Al-4V allow used here, θ=45º. The overhanging angle varies from material to material, as well as from technique to technique, and also depends on other factors, such as manufacturing layer thickness, the width of the printed line, and the melt temperature, to ensure a high print quality [9]. While the proposed Sierpinski gasket antenna satisfies the condition of the maximum overhanging angle (θ) for the alloy Ti-6Al-4V using DMLS, i.e. θ=60º, nonetheless a conservative approach was taken and support structures were still added, as shown in Figure 2.

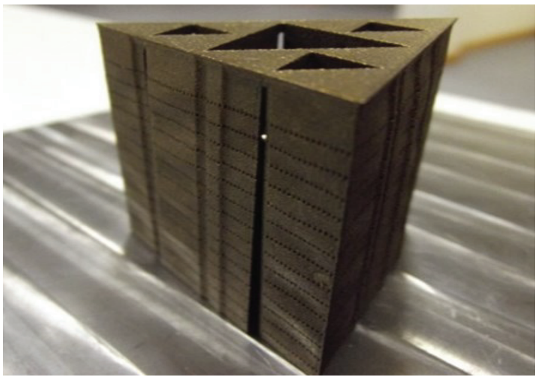


Figure 2: 3D metal printed Sierpinski gasket antenna with build support structure

The supports appear as individual pillars, constructed as a network of interconnected pieces, deliberately brittle for easy removal from the model.

4.2 Build Orientation

The recent research has shown that build orientation plays an important role in influencing the construction time as well as the mechanical properties of the printed structure. In publication [10], the author has mentioned the importance of considering the build orientation of 0º, 45º, and 90º on test samples during the designing process. It was concluded that the mechanical properties such as tensile strength, residual stress, fatigue as well as surface roughness are highly dependent on the orientation of the build.

However, due to the complex geometry of the Sierpinski antenna, it was decided to choose a build orientation of 90º w.r.t the building platform, so that the proposed antenna corresponds to the minimum fatigue and possess maximum tensile strength.

4.3 Ring Width

The "ring width" (parameter related to the width of the excitation point) of the Sierpinski gasket antenna is important from the perspective of multiband features. V H Rumsey, in the early sixties, established what is now known as Rumsey's Principle and is the current notion of broadband antennae. According to Rumsey's Principle, if the geometry of an antenna is solely the function of an angle, then the antenna parameters will be independent of the frequency [11]. However, in 1999 Hohlfeld and Cohen proposed an extension to Rumsey's Principle, known as the Hohlfeld-Cohen-Rumsey (HCR) condition, stating that self-symmetry is one of the underlining requirements. For the antenna to be frequency independent, it needs to be symmetric along the origin as well, where the origin is the antenna feeding point [12]. However, as the flare angle in the case of Sierpinski gasket antenna remain fixed at approximately 60º, the HCR condition will not be considered further in this work. But it should also be noted that even the slightest variation caused at the ring width have an impact on antenna's input impedance.

One more complication related to the ring width is that having an antenna built in an upside-down orientation, a minimum of 1.90 mm of ring width diameter is required to successfully build the antenna. Furthermore, in order to connect the antenna with a feeding circuit, the ring width should be big enough to facilitate soldering, if required. It should also be noted the ring width may be further increased when soldering or conductive epoxy is applied to the feed point.

CST simulations were carried out and are shown in Figure 3. During the simulation, it was observed that even a minor increase in the radius value (r) of ring width causes the wider antenna bandwidth and also lead the antenna resonance frequency dip to shift towards the higher frequency bands.

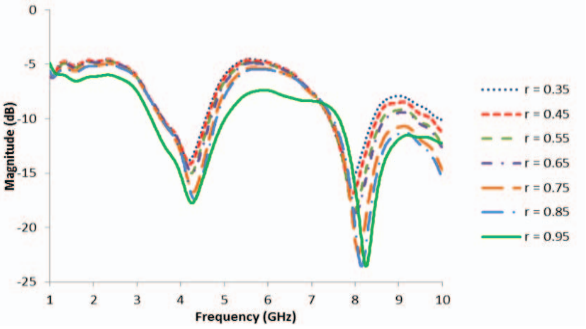


Figure 3: Variation in frequency due to ring width effect

4.4 Feed Point Challenges

After the antenna fabrication, the next task was to connect the antenna circuitry to an N-type connector. One of the major challenges faced, as the antenna was fabricated from Titanium, was to establish an RF antenna connection with a feeding circuitry. The chosen Titanium alloy is very difficult to solder, as the metals oxidize readily as its temperature elevates during soldering, making it extremely difficult to solder an antenna onto a connector. For this reason, the antenna was glued onto the connector with the help of a conductive silver epoxy adhesive having < .001Ω-cm volume resistivity.

As can be seen in Figure 4, a laboratory clamp was employed to mount the antenna onto the feed.

Figure 4: Mounting an antenna onto the feed setup

It is also noteworthy that a challenge in the gluing process was achieving a consistent, perpendicular orientation was not easy. Mounting an antenna in this way may lead to variation in the input impedance from one mounting to another, and hence, a better set up will be employed in the future. However, this variation should be quite small, as has been shown in publication [13], where the author has performed experiments on the variation of the input impedance due to changes in the tilt angle of a planar monopole antenna.

4.5 Equilateral Triangle

A three-dimensional Sierpinski gasket antenna is an arrangement of tetrahedrons in a self-symmetric fashion stacked one upon another, which gives the antenna multiband characteristics. However, in practice, a 3D Sierpinski gasket antenna cannot be realized with infinitely small joints (unlike a 2D realization) to be mechanically rigid, for example in practice, one tetrahedron should overlap the adjacent one. This was confirmed during the physical examination of the antenna, as it was observed that the triangular sides were not perfectly equilateral. This means that the antenna geometry is no longer in the shape of an equilateral triangle, but is now simply an isosceles triangle. However, it does not affect the multiband behavior of the antenna, as the structure is still self-symmetric.

5 RESULTS

The above-mentioned antenna was designed, optimized and simulated on CST software. The return loss coefficient (S_{11}) and path loss (S_{21}) of the antenna were measured on a Rhode and Schwarz ZVB 20 Vector Network Analyser (VNA). Figure 5 shows the comparison of measured and simulated reflection characteristics of the 3D metal printed Sierpinski gasket antenna. Both the results are in good agreement with each other.

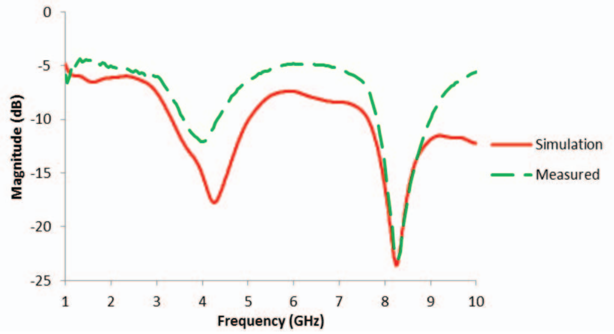
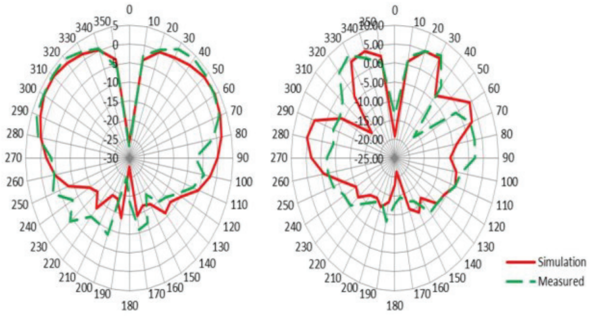


Figure 5: Simulated and measured reflection coefficient

The antenna resonates at both the fundamental frequencies, of 4.2 GHz and 8.4 GHz, maintaining its multiband feature. The measured and simulated gains at both the corresponding resonant frequencies are shown in Figure 6.



a) b)

Figure 6: Simulated and measured gain radiation pattern a) 4.2 GHz b) 8.4 GHz

The simulated gain at 4.2 GHz was found to be 5.07 dB compared to the measured gain of 4.07 dB, at 8.4 GHz, the measured gain was found to be 4.45 dB compared to the simulated gain of 6.64 dB. The difference between the measured and the simulation value could be due to the effect of surface roughness, this effect is significant at higher frequencies. However, in this research, no efforts have been made to reduce the surface roughness of the antenna using surface treatment process such as wetblasting or polishing as explained in [14], which could lead to further improvement of results.

4 CONCLUSION

From an RF design and realization perspective, 3D printing offers great advantages, as an efficient and easy method for printing complex geometries.

The complex geometry antenna described in this work is a Sierpinski gasket antenna, created using a DMLS 3D metal printer. The design restrictions and challenges are explained in detail in the body of the work. The antenna RF performance was measured and found to be in good agreement with simulation results, in terms of bandwidth and radiation characteristics.

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