Miniature Antennas for Lunar and Planetary Surface Communications

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Introduction

Surface communications assets in future NASA exploration scenarios such as robotic rovers, human extravehicular activities (EVA), and probes will necessitate small size, lightweight, low power, and robust antenna elements [1]. With the availability of space in these devices being a major concern, miniature antennas provide a potential solution toward addressing these issues. The current problem with miniature antennas, however, is their inherently low efficiencies, which will be unacceptable for low power applications. At the NASA Glenn Research Center (GRC), prototypes of several potentially useful miniature antenna designs for lunar and planetary surface communications have been investigated [2]. Specifically, two novel candidate designs which hold promise, the folded Hilbert Curve Fractal Antenna (fHCFA) and the Compact Microstrip Monopole Antenna (CMMA), are described in this paper. Both demonstrate comparable performance to a quarter-wavelength monopole, but at smaller than 1/3 the size, making them more suitable for integration in communications systems with stringent size and volume requirements (i.e., wireless sensors, space suits and others).

The folded Hilbert Curve Fractal Antenna (fHCFA)

The folded Hilbert Curve Fractal Antenna (fHCFA) was designed and simulated using Zeland’s IE3D electromagnetic simulator [3]. Depicted in Figure 1a, it consists of a third order Hilbert curve folded upon itself into four layers. The overall dimensions of the fHCFA are 5mm x 5mm x 4.5mm (Length x Width x Height), resulting in a $\lambda/30$ design, where $\lambda$ is the free space wavelength at its lowest operating frequency (2.3 GHz).

The fractal antenna shape was etched on a single plane of 0.127 mm thick Duroid® 5880 (relative dielectric constant, $\varepsilon_r = 2.2$) and consisted of microstrip lines of 0.5 mm width. Notches were cut into the Duroid® substrate to facilitate folding of the antenna into the 3D structure shown in Figure 1a. The antenna was mounted onto an aluminum ground plane and held in place with several layers of adhesive. Separation between layers was provided by 1mm thick HTP-6 foam spacers ($\varepsilon_r = 1.07$) and a probe feed was used to excite the antenna. The fabricated antenna is shown in the photograph of Figure 1b.

Return loss measurements were performed on an Agilent 8510C Vector Network Analyzer and are shown compared to simulation in Figure 2. The two frequencies of interest, 2.3 GHz and 16.8 GHz, have 10-dB bandwidths of 10 MHz (0.5%) and 500 MHz (3%), respectively. Radiation patterns for both the S-band and Ku-band resonant frequencies were measured in NASA GRC’s Cylindrical Near-Field Range Facility [4]. A comparison of measured and simulated data is shown at 2.3 GHz (S-band) and 16.8 GHz (Ku-band) in Figure 3a and 3b, respectively. Directivities of 1.6 (at S-band) and 7.3 dBi (at Ku-band) were measured and agree well with the simulated directivities of 1.5 and 7 dBi. Discrepancies between the measured and simulated return loss and radiation patterns are most likely attributable to the un-modeled dielectric loading of the adhesive tap used in fabrication and slight misalignments amongst layers.
The novelty of this design is that drastically different radiation patterns are demonstrated at different resonant frequencies (i.e., end-fire at S-band and broadside at Ku-band). The antenna accomplishes all this without the need for electrical or mechanical switching, making it less prone to failure, while maintaining simplicity of fabrication. With these properties, the fHCFA could be a potential enabling technology for lunar surface network communications or planetary exploratory missions, which will employ local area networks (S-band), as well as satellites (Ku/Ka-band), for communication links. In this manner, the fHCFA is capable of performing the tasks of two separate antennas at a size approximately than 1/8th a standard monopole.

![Figure 1 – (a) Layout of fHCFA with dimensions and (b) fabricated fHCFA](image)

**Figure 1** – (a) Layout of fHCFA with dimensions and (b) fabricated fHCFA

![Return Loss for folded Hilbert Curve Fractal Antenna](image)

**Figure 2** – Simulated and measured return loss of the fHCFA over a 2–20 GHz spectrum.

![E-Plane Radiation Pattern at 2.3 GHz](image)

**Figure 3** – (a) End-fire radiation pattern of the fHCFA at 2.3 GHz (S-band) and (b) broadside radiation pattern for the fHCFA at 16.8 GHz (Ku-band).
The Compact Microstrip Monopole Antenna (CMMA)

The Compact Microstrip Monopole Antenna (CMMA) was also designed and simulated using IE3D and is shown in Figure 4a. It consists of a tri-lobed patch surrounded by a vertical enclosure wall and a grounding wall located near the feed point. A probe feed is used to excite the patch. The overall footprint of the CMMA is approximately 12 mm x 12 mm, with a height of 11 mm, resulting in a $\lambda/12$ design.

The prototype shown in Figure 4b was etched on 1.57 mm Duroid® 5880 ($\varepsilon_r = 2.2$). The grounding wall and vertical enclosure wall were constructed from copper tape. The adhesive from the copper tape was removed and attached to the patch using Ablebond®, a conductive epoxy. A coaxial probe was inserted through the Duroid® 5880 substrate to feed an RF signal from below the antenna to the CMMA. This probe was attached 0.75 mm from the grounding wall, contacting the patch through the via shown in Figure 3b.

Return loss measurements were performed on an Agilent 8510C Vector Network Analyzer and are shown compared to simulation in Figure 5. The CMMA resonates at 2.05 GHz with a 10-dB bandwidth of 130 MHz (6.3%). Radiation patterns were measured in the Cylindrical Near Field Antenna Range at GRC. The measured radiation patterns for the E-plane and H-plane are shown in Figure 6a and 6b, respectively. From this figure, one can observe that the CMMA radiates like a monopole antenna. The directivity of the CMMA prototype was calculated to be approximately 6.0 dBi, which is comparable to the simulated directivity of 5.0 dBi. Discrepancies between the measured and simulated return loss and patterns derive from the un-modeled conductive epoxy (conductivity, dielectric loading) and imperfections in the fabricated vertical enclosure wall.

The CMMA’s unique combination of a vertical enclosure wall and a microstrip patch allows this miniature antenna to retain its high directivity and large bandwidth properties, as compared to typical miniature antennas which trade these properties to achieve their small sizes. Measured results have shown that the CMMA is capable of operating at approximately $\lambda/12$ with no trade off in its directivity. It has the potential for many applications where small omnidirectional antennas are typically used.

![Figure 4 – (a) The 3-dimensional view of the CMMA and (b) the CMMA prototype fabricated at NASA GRC.](image)
Return Loss vs. Frequency

![Graph of Return Loss vs. Frequency](image)

Figure 5 – Measured and simulated return loss of the CMMA.

![Plots comparing directivity of radiation patterns](image)

Figure 6 – Plots comparing the directivity of the measured and simulated radiation patterns of the CMMA at 2.05 GHz. (a) E-plane pattern. (b) H-plane pattern.

**Conclusion**

Two novel miniature antenna designs, the folded Hilbert Curve Fractal Antenna (fHCFA) and the Compact Microstrip Monopole Antenna (CMMA) were presented as viable candidates for lunar and planetary communications assets in which space and weight play a primary concern. Both antennas demonstrate comparable performance to the quarter-wavelength monopole, but at less than one-third the size. Uniquely, the fHCFA is also capable of higher frequency modes of operation with a distinctively different pattern, optimal for surface-to-orbiter communications.

**References:**


[3] [www.zeland.com](http://www.zeland.com)