All-Metal Antennas for Applications in Extreme Space Environments

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***Abstract*—The feasibility of an all-metal antenna for transmission of science data by spacecraft, landers, and rovers operating in the extreme environment of space is investigated. The all-metal antenna is of the short backfire type with a waveguide feed and generates a circularly polarized radiation. The investigation includes the modeling, design, fabrication, and characterization of the antenna. The paper summarizes the preliminary results. Potential applications of an all-metal antenna include communication systems required to operate in the extreme hot environment of Venus and in the extreme cold and high radiation environment of Jupiter's icy moon.**

I. Introduction

NASA's planetary science mission requirements and operating environments are very diverse and different for each mission. This is especially true in the case of missions to Mercury, which requires antennas to operate at temperatures as high as 300°C and to Jupiter's Icy Moons, which require antennas to operate at cryogenic temperatures and in high ionizing radiation environments [1], [2]. To ensure reliable operation over extended periods of time and to relay back to Earth science data from the above extreme planetary environments, an all-metal spacecraft antenna and lander/rover antennas are desirable. In the past, to meet the above space flight requirements, researchers have investigated all-metal narrow-wall waveguide slotted arrays [1], patch arrays [2], [3], reflector antenna [4], monopole parasitic antenna [5], and short backfire antenna [6]. The antenna parameters are briefly summarized in Table I.

In this paper, we focus on the design, fabrication, and characterization of an all-metal, circularly polarized, square waveguide fed, short backfire antenna for the above space applications. To achieve circular polarization (CP), we plan on integrating a linear-to-circular polarizer in the waveguide feed. The antenna operates at X-band frequencies (8.40 to 8.45 GHz) designated for space to Earth downlink. In contrast to [6], our design uses rectangular waveguide for the power divider and feed network for the array, which then transitions into a square waveguide with a polarizer for exciting the main and sub-reflectors of the individual elements. A major advantage of an all-metal antenna is that it prevents electrostatic charge buildup and its associated noise by eliminating all dielectric materials in the antenna construction. Our study indicates that the backfire antenna has high gain, high efficiency, with low side lobes and excellent front-to-back ratio [7]. In addition, because of its high gain, a single backfire element can replace several patch elements in an array antenna [7]. Furthermore, the antenna has small axial length when compared with waveguide fed pyramidal horn antennas of comparable radiation patterns [8]. Moreover, backfire antenna allows for extending the features of large reflector antennas (e.g., high gain, low side lobes, and equal E- and H-plane beamwidths) to smaller diameters, which is an advantage in space-constrained applications [9]. The measured characteristic of the all-metal backfire antenna will be presented at the symposium.

TABLE I. Parameters of All-Metal Antennas for Space Applications.

Antenna Type	Frequency (GHz)	Gain (dBi) & Polarization	Operating Environment	Reference
Narrow-wall Waveguide 8 x 26 Slotted Array	8.425	28, RHCP	Mercury	[1]
8 x 8 Patch Array	8.425	25.3, RHCP	Europa Lander	[2]
5 x 5 Patch Array	0.6 & 1.250	18.6 & 18.9, Linear	Juno	[3]
0.23m dia. Reflector	26.25	32 (simulated), RHCP	Earth Observing Satellite in LEO	[4]
Centrally fed Monopole with 8 Parasitic Elements	8.428	5.0, RHCP	Martian Transponder	[5]
19-Element Short Backfire Array	1.54675	24, RHCP	Mobile Space Comm. Satellite in GEO	[6]

II. Short Backfire Antenna Single Element

A development study is currently ongoing and in this context a literature search was conducted to investigate in general the design and RF performance of short backfire antennas. Typical antenna element gains, achievable across the frequency range of 1 to 10 GHz and resulting from the above study, are presented in Fig. 1. The figure shows that the element gain is typically in the range of 14 to 15 dB. Hence, the target value for the element gain for our development is 14 dB at X-band. The schematic of the short backfire antenna element discussed in this work as well as that of its cross-sectional view are shown in Figs. 2 (a) and (b), respectively. The feed is a square waveguide and houses the polarizer to convert the input linearly polarized wave to a radiated circularly polarized wave. Additionally, the waveguide feed is inserted into the main reflector for higher gain [10]. Typical dimensions of the short backfire antenna element, which serve as input to our computer modeling and simulations task are indicated in the caption of Fig. 2 (b).

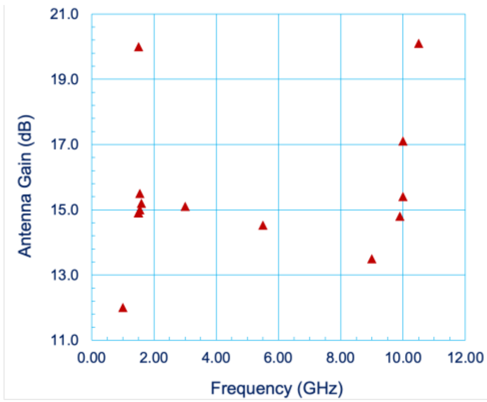

Fig. 1. Gain vs. frequency for short backfire antenna reported in the literature.

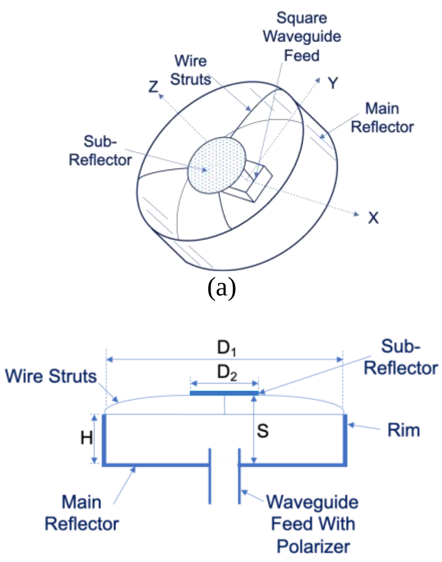

Fig. 2. Schematic. (a) Short backfire antenna. (b) Cross-sectional view showing the waveguide inserted into the main reflector. D1 = $2\lambda_0$, D2 = $0.6\lambda_0$ to $0.7\lambda_0$, H = $0.25\lambda_0$, S = $0.6\lambda_0$, where λ_0 is the free-space wavelength corresponding to the operating center frequency.

III. Short Backfire Array Antenna Feed design

We plan to extend the single element design initially to a 2 x 2 sub-array consisting of four short backfire antennas. This study would then lead to the development of a 4 x 4, 16-element array antenna for higher gain. The elements in the 4 x4 array will be arranged in a square grid (Fig. 3). The feed structure (Fig. 3) will be composed of rectangular waveguide consisting of T-junctions and mitered right angle bends like the design presented in [11].

IV. Antenna manufacturing Technique

The single element prototype antenna will be manufactured using conventional metal machining techniques. However, the construction of the larger 4 x 4 array, will utilize additive manufacturing techniques [12].

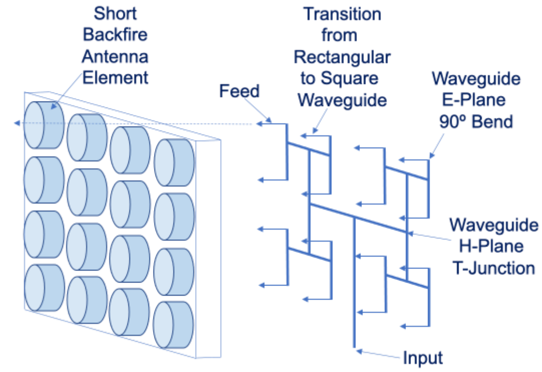

Fig. 3. Schematic of sixteen-element 4 x 4 array and waveguide feed network.

V. Conclusions and Discussions

The design and construction of an all-metal short backfire antenna single element as well as a 4 x 4 array are briefly discussed.

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