Antennas for Space Instruments from GHz to THz

Goutam Chattopadhyay¹, Maria Alonso-delPino¹, Cecile Jung-Kubiak¹, Theodore Reck¹, Choonsup Lee¹, Nacer Chahat¹, David González-Ovejero², and Imran Mehdi¹

¹ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA, goutam@jpl.nasa.gov
² Institut d’Électronique et de Télécommunications de Rennes - UMR CNRS 6164, Rennes Cedex, France

Abstract—In this paper we present an overview of different antenna technologies for space-based instruments. We show that some of the designs that work well at gigahertz frequencies are difficult to implement at terahertz frequencies due to tight tolerance and rms surface finish requirements. We also show that antenna designs are dictated not only by the frequency of operations but also by the space platform of choice. In this paper, we also present ideas for low-profile terahertz antennas for implementation on SmallSat and CubeSat platforms.

Index Terms—antenna, low-profile, terahertz, micro-lens, silicon, micromachining.

I. INTRODUCTION

Antennas for space applications need special care. They need to withstand high temperature variations, survive vibrations, and overcome high radiation doses.

Antenna design has always been a multi-disciplinary field. It starts with electromagnetic design of the antenna, optimizing different performance criteria such as directivity, gain, far-field and near-field radiation patterns, and input reflections. Then comes fabrication, mechanical design, thermal design, and implementation. Antennas for space applications add a few more additional requirements such as accelerated life-cycle testing, mechanical stability analysis and tests, and radiation tests.

Compared to lower frequencies, designing antennas at terahertz frequencies poses a multitude of challenges. Certain designs popular at lower frequencies, such as patch antennas and arrays, are generally not suitable at terahertz frequencies because of high Ohmic and dielectric losses. Other antennas and feeds which are suitable both at lower as well as higher frequencies, such as reflectors and horns, presents fabrication and assembly challenges due to micron-scale tolerance requirements as we move to the terahertz frequencies.

Space-borne antennas also demand different design considerations based on the application, platform to be used, and mission lifetime. For example, astrophysics instruments generally require large reflector antennas fed with horn or other feed elements to have relatively narrow beam to peer into far-off distances of the universe. Since most often the astrophysics missions target Lagrange 2 (L2) position for stable orbit location (approximately 1.5 million km from Earth), it is possible to fly large rockets which can carry somewhat larger antennas. On the other hand, planetary missions are limited by the size of the payloads as they are required to fly much larger distances. Hence, the antenna sizes for planetary instruments are smaller. However, they still need high gain antennas for communications as they need to send the data back from large distances. For Earth science applications, the antenna size can be either large or small, depending on specific applications.

In this article, we report on different ongoing antenna developments in our laboratory for space-borne applications, from gigahertz to terahertz frequencies.

II. ANTENNA AND FEED DESIGNS

For large aperture antennas, metal paraboloid reflectors are most common. Although it is always difficult to design and implement large reflector antennas for space missions, it is particularly challenging to do that at terahertz frequencies due to the tight surface accuracy requirements. As a general rule of thumb, the surface accuracy and rms surface roughness should be of the order of $\lambda/10$ to $\lambda/50$, depending on the specific requirements, frequency of operations, and cost of fabrication.

Fig. 1. Photo of a 100 cm inflatable balloon reflector with metalization over the half of its surface. Details of the geometry of the spherical reflector with point feed is shown in [1].

In recent years, we have been looking into alternative technologies to these large metal reflectors. There has been an effort to develop deployable large reflector antennas. One such antenna we have been working on is balloon-based spherical reflectors for millimeter- and submillimeter-wave frequencies [1], [2]. For these antennas, the reflective surface is formed by applying a thin metallic coating on the inside surface of the balloon. The RF radiation passes through the transparent balloon material and reflects off the metallic
operations in space environments. Silicon micro-lens of such a 20x24 lens array antenna we developed for coefficient of thermal expansion mismatch during them with antennas which does not cause severe CTE 
[5]. One of the critical aspect of these receivers is to integrate antennas integrated to silicon micromachined receivers solve minimizing the effect of spherical aberration.

For reflector antennas, the feed is also an important and challenging element, particularly at terahertz frequencies. Due to tolerance requirements, it gets increasingly difficult to fabricate traditional metal machined corrugated feed horns at these frequencies. We have been developing multi-flare angle metal machined horns as well as silicon micro-lens based feeds at terahertz frequencies [3], [4]. Both these feeds are compatible with focal plane array systems at terahertz frequencies. Moreover, we are also exploring the possibility of using these micro-lenses, in conjunction with miniaturized piezo electric motors, for electronic beam scanning. It is has been a challenge to accomplish electronic beam scanning of antennas at terahertz frequencies due to the unavailability of reliable phase shifters with high phase resolution.

To have low-loss and highly compact space-based instruments at terahertz frequencies, we have developed silicon micromachined packaging techniques that allows development of high-performance multi-pixel receiver arrays [5]. One of the critical aspect of these receivers is to integrate them with antennas which does not cause severe CTE (coefficient of thermal expansion) mismatch during operations in space environments. Silicon micro-lens antennas integrated to silicon micromachined receivers solve that problem as both have similar CTE. Fig. 2 shows a photo of such a 20x24 lens array antenna we developed for 1.9 THz multi-pixel receiver arrays.

Fig. 2. A 20 x 24 silicon lens array at 1.9 THz fabricated in the same fabrication process as the silicon micromachined receivers to reduce CTE mismatch and highly compact instruments.

III. ANTENNAS FOR SMALLSAT/CUBESAT PLATFORMS

Due to high cost of large missions, space agencies such as NASA and others are increasingly looking into SmallSat and CubeSat platforms for scientific missions as well as for providing communication capabilities for other missions. These shoebox-size satellites require highly compact and low-power instruments integrated with innovative antennas. SmallSat/CubeSat missions that provide communication support require large high-gain antennas. Often scientific missions on CubeSat platforms also require large antennas with focused beams to provide better spatial resolutions. However, for CubeSat missions, deployable antennas are the only option for larger apertures.

Recently, there has been substantial progress in developing deployable antennas that can be either stowed inside a CubeSat or folded on the sidewalls of CubeSats. Primary example of them are parabolic metal mesh reflectors [6] and reflectarray antennas [7] for communication and radar applications. However, operating frequency of these antennas has been limited to Ka-band, and there are some ongoing efforts to design similar antennas at W-band.

We are developing low-profile terahertz antennas for SmallSat/CubeSat platforms. These antennas can also be folded onto the sidewalls of the CubeSats and deployed in space. Fig. 3 shows a conceptual drawing of such low-profile antenna integrated on the sidewalls of a CubeSat. In one such implementation, we are using an all-metal design based on modulated metasurfaces [8]. The antenna is fed by a circular waveguide at the center and is excited by TM_{01} surface waves. The advantage of this antenna compared to reflectarrays is that it does not need any feed-deployment leading to more compact design. We fabricated a 300 GHz antenna using silicon micromachining techniques. This antenna can easily be integrated with micromachined receiver front-ends. Fig. 3 also shows detail drawings of the antenna where different colors represent different heights of metal pins used to modulate the surface waves generated in the metasurface structure. We are also developing other low-profile terahertz antennas suitable for CubeSat platforms by using silicon metasurface structures in transmission mode.

In the future, we want to develop low-profile high-gain antennas with electronic beam scanning capability at terahertz frequencies. Electronic beam steering is common at gigahertz frequencies. However, to accomplish that capability at terahertz frequencies will need quite a few developments that we plan to focus on in near future.

Fig. 3. Schematic drawing showing the concept of low-profile terahertz antenna integrated on the side walls of a CubeSat. Details on the right show the antenna structure with metal pins where different colors represent different heights of the pins.
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REFERENCES


