Terahertz Antenna Technologies for Space Science Applications

Goutam Chattopadhyay\(^1\), Maria Alonso-delPino\(^1\), Cecile Jung-Kubiak\(^1\), Theodore Reck\(^1\), Choonsup Lee\(^1\), Nacer Chahat\(^1\), Sofia Rahiminejad\(^1\), and David González-Ovejero\(^2\)

\(^1\) 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 review paper we explore different antenna technologies at terahertz frequencies for space science and other applications. We show that the antenna technologies generally used at lower frequencies are difficult to implement at terahertz frequencies. Additionally, one has to take a few extra steps and special care for designing antennas for space-based applications. In this paper, we review different design and implementation options for millimeter-wave and terahertz antennas for space applications. We detail how antenna design has to be a part of the overall system design for the success of the instruments for space missions. We also look into low-mass and low-profile conformal antenna technologies that will have a profound impact on future space instruments at terahertz frequencies.

Index Terms—antenna, low-profile, terahertz, CubeSat, SmallSat, silicon, micromachining.

I. INTRODUCTION

Antennas designed for low-frequencies (gigahertz range) are not always suitable at terahertz frequencies. The primary reason for that is the extreme tolerances required and antenna fabrication challenges at terahertz frequencies. It gets even more challenging when these terahertz antennas are meant for space-based applications, as they need to work in harsh space environments. These antennas need to withstand high temperature fluctuations, survive vibrations, and overcome high radiation doses.

Integration of the antenna with the rest of the science instrument or communication systems require careful antenna design with special focus on the packaging and interface issues. Moreover, commonly used antennas such as microstrip, slots, patches, and others are generally not preferred at terahertz frequencies due to their high losses. It is common knowledge that losses of traditional transmission lines increase substantially as the frequency approaches the terahertz band. This presents with design challenges in coupling the antenna to the receiver systems as the optimization of the system performance, loss, and reflections become too demanding. To overcome this, alternative antenna and feed technologies such as planar metasurface antennas, lens based leaky-wave antennas, and silicon micromachined based antennas and coupling structures at terahertz frequencies are increasingly being looked into.

Compared to lower frequencies, designing antennas at terahertz frequencies poses a multitude of challenges. Certain popular antenna designs at lower frequencies are almost impossible to implement at higher frequencies as both the Ohmic and dielectric losses render the design with low antenna efficiency. 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 at terahertz frequencies.

Space-based antennas also demand different design considerations based on the application, platform to be used, and mission lifetime. Increasingly, international space agencies are looking into CubeSats and SmallSats as viable platforms for hosting science payloads. This has opened up new avenues for antenna research. However, implementation and integration to these platforms, especially at terahertz frequencies, poses a completely different set of challenges.

In this article, we present an overview of different antenna design options at terahertz frequencies and ongoing developments in our laboratory for space-based applications.

II. ANTENNAS AND FEEDS AT TERAHERTZ FREQUENCIES

For majority of the space-based instruments, there is a need for high-gain antennas to have narrow beams for remote sensing applications and metal paraboloid reflectors are most commonly chosen for these purposes. Although it is always difficult to design and implement large reflector antennas for space missions, it gets even harder at terahertz frequencies due to the tight surface accuracy requirements.

In recent years, we have been looking into alternative technologies to the traditional metal parabolic reflectors. The focus has been to develop deployable and flat antennas at terahertz frequencies. One such antenna we have developed is balloon-based spherical reflectors for millimeter- and submillimeter-wavelengths [1], [2]. The reflective surface of the balloon antenna is formed by applying a thin metallic coating on the inside surface of the balloon. Spherical aberration of such spherical balloon reflectors can be compensated by corrective shaped reflectors or lenses.

Feed design at terahertz frequencies is very challenging as well. Due to the high tolerance requirements, traditional metal machined corrugated feed horns at these frequencies are almost impossible, particularly at higher end of the terahertz band. Our group have developed multi-flare angle
metal machined horns as well as silicon micro-lens-based feeds at these frequencies [3], [4]. Both the horn and lens-based feeds are compatible with focal plane array instruments at terahertz frequencies.

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 [5] and reflectarray antennas [6]. However, majority of them are at Ka-band and now W-band are also being considered.

We are developing low-profile terahertz antennas for SmallSat/CubeSat platforms. Fig. 1 shows a conceptual drawing of such low-profile antenna integrated on a CubeSat. For this design we use a silicon lens antenna fed by a leaky-wave waveguide. In another implementation, we used an all-metal design based on modulated metasurfaces [7]. The antenna is fed by a circular waveguide at the center. 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 terahertz receiver front-ends. 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.

ACKNOWLEDGMENT

This work was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES