Virtual Research Presentation Conference

TeraCube: A Cubesat Terahertz Spectrometer for Earth and Planetary Remote Sensing

Principal Investigator: Jose V. Siles (386H)
Co-Is: Adrian Tang (386H), Chris Groppi (ASU), Cassandra Whitton (ASU)
Program: SURP

Assigned Presentation RPC-267

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

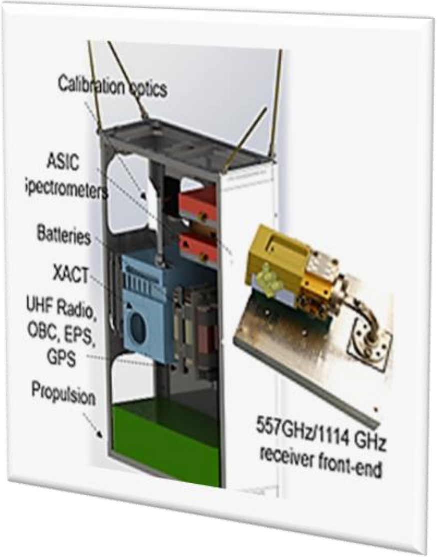
Abstract

The goal of the TeraCube project is to create a 6U (10cm x 20cm x 30cm) cubesat which is capable of spectroscopically observing water at its 557 GHz and 1113 GHz emission lines. Both lines of water are excellent diagnostics of water vapor in the interstellar medium, the Earth’s atmosphere, and in the atmospheres of other planetary bodies. Observing the pair of lines further allows us to determine the temperature of the water. These capabilities are enabled through a combination of existing but young technologies that allow for terahertz observations on a miniaturized platform. Particularly, this project seeks to integrate:

1) A metamaterial (flat and lightweight) lens which operates at both frequencies. This is still in the design phase.

2) A single-block heterodyne receiver and downconverter which operates at both frequencies. This has been previously developed by JPL and ASU for an SSTP award.

3) A 3GHz ASIC spectrometer with 1MHz resolution. This has been previously developed by JPL.



Problem Description

The observation of water is of great interest to studies of the interstellar medium, planetary science, comets, and Earth observing. Unfortunately, observing extraterrestrial water from the ground or even using balloon-borne telescopes is virtually impossible, due to the large amounts of water in the Earth's atmosphere. This means that satellite missions are the only way to practically perform these observations [3].

Previous missions, such as the SWAS and Herschel space telescopes, have observed the 557 GHz line of water. SWAS was unable to observe the 1113 GHz line, however, and so our cubesat represents an improvement in that aspect. Observing both lines allows us to determine the temperature and column density of the water. In addition, while SWAS cost 60 million dollars, and Herschel 1.1 billion Euro, TeraCube would allow for a comparable number of observing hours to be obtained at a small fraction of that cost.

With the support of additional technologies, a future possibility for technology introduced by TeraCube would be an interferometric constellation of cubesats. Such an interferometer would allow for greatly increased angular resolution that could be used, for instance, to probe the water structure in interstellar disks, which would increase our understanding of the star formation process [1-3].

Methodology

The primary goal of this current year has been creating software which would allow us to design a metamaterial lens operating at both 557 GHz and 1113 GHz, and to then design, manufacture, and test that lens.

Most current lenses deployed on cubesats are curved geometric lenses or Fresnel lenses. These tend to be somewhat heavy and bulky, and incur reflective losses unless an anti-reflection coating is used. A metamaterial lens, which is a lens which achieves a focus by using sub-wavelength material patterning, by contrast can be made very thin and light, and can have anti-reflective properties built into it.

For this project, we are building on previously-existing code which uses optimization techniques to find optimal metal patterns to create such a lens. The lens is made of metal patterned on polyimide. To test the lens, we intend to measure the far-field beam pattern it produces when illuminated by a matching receiver. We expect to find an angular resolution comparable to that of a geometric lens of the same diameter.

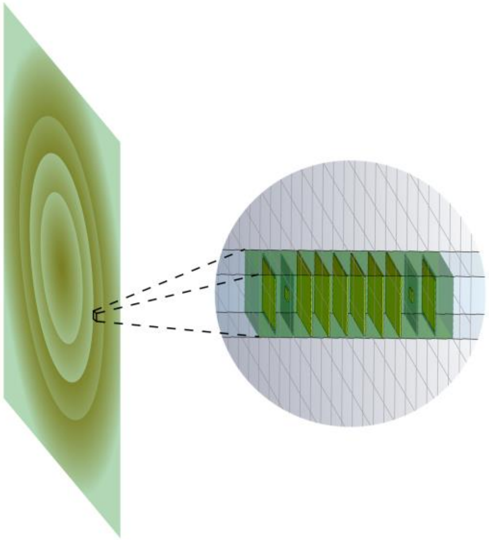


Fig. An example of a metamaterial lens, demonstrating how layers of patterned embedded metal are embedded within the lens to obtain refractive properties. Credit: Cassie Whitton

Results

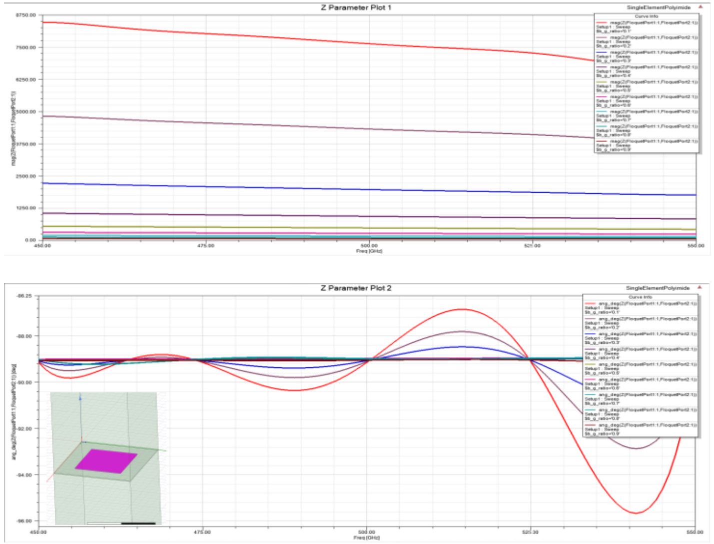
Our previously-set goal for this September was to be nearly-finished with the lens design and simulation software. This would have hopefully allowed us to have the metamaterial lens designed, manufactured, and tested by the end of December.

Unfortunately, due to disruptions caused by Covid-19, software development has been slower than expected. While most of the core lens model has been created, including the electromagnetic simulations which form the basis of the software, there are key parts of the model which have not yet been implemented, such as the interpolation algorithm which aids in the optimization of the lens elements.

We are currently aiming to have the lens manufactured by the end of December. In order to do so, we will complete the implementation of the interpolation algorithm, which will allow us to test and use the optimization algorithm to design the lens. We will then implement the simulation part of the software, which will allow us to have greater confidence that our lens design will work. We will then have the lens manufactured by ASU’s Flexible Display Center.

Testing the lens is still complicated by the restrictions placed on lab use by Covid. However, we hope to begin testing the lens by early 2021.

Fig. Simulation models of small metal elements (right) are the building blocks of the design software. By measuring these elements at multiple different sizes, we can build a library which allows us to optimize a lens for the best possible focus. Credit: Cassie Whitton



Publications and References

1. EA Bergin, GJ Melnick, JR Stauffer, MLN Ashby, G Chin, NR Erickson, PF Goldsmith, M Harwit, JE Howe, SC Kleiner, et al. Implications of submillimeter wave astronomy satellite observations for interstellar chemistry and star formation. The Astrophysical Journal Letters, 539(2):L129, 2000.
2. EA Bergin, MJ Kaufman, GJ Melnick, RL Snell, and JE Howe. A survey of 557 ghz water vapor emission in the ngc 1333 molecular cloud. The Astrophysical Journal, 582(2):830, 2003.
3. CK Walker. Terahertz astronomy. Crc Press, 2015.