National Aeronautics and Space Administration

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

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Objectives: The overall goal is to create a CubeSat capable of detecting water at 557GHz and 1114GHz. These are important water emission lines that will allow for Earth observation and planetary missions in the future. Our project seeks to integrate the following components:

- A metamaterial (flat and lightweight) lens which operates at both frequencies.
- 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.
- A 3GHz ASIC spectrometer with 1MHz resolution. This was previously developed by JPL, and has been flown as part of a HASP balloon payload. Following this integration, we plan to package the instrument into a flight-ready cubesat payload.Currently, our primary objective is designing, manufacturing, and testing a 500 GHz flat metamaterial lens which will serve as a prototype to demonstrate that our design process is effective at creating flat lenses at 500 GHz and above. In order to do this, secondary goals include testing and developing our design and simulation code to ensure it is consistent with a 20 GHz prototype lens we manufactured and tested previously.

Background: 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 perform these observations [3].
Previous missions, such as the SWAS and Herschel space telescopes, have observed the 557 GHz water line. 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 $60M, and Herschel $1.1B , 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].

Approach and Results: Since last year, we have been focused on designing a prototype 480 GHz metamaterial lens. This frequency was chosen to allow us to measure it using existing 500 GHz VNA extenders at ASU. The design is 115 um thick and 120 mm in diameter. It is made up of 10 layers of patterned copper sandwiched between 11 layers of 10 um thick polyimide. The design has been tested via the simulation code that we completed last year. We have found that the Strehl ratio of the lens is 0.79, which is very close to optimal. The inefficiency that is present in the lens is mostly dielectric loss: roughly 17.5% of power is lost to dielectric loss. Reflective loss and optical loss are very low: roughly 2.0% each. We have observed that the optical loss gets significantly worse outside a fractional bandwidth of 5%. Dielectric and reflective loss remain about the same. We suspect this is primarily because the lens has a very low f-number (roughly f/1). We have simulated alternative designs at f/3 and observed significantly better bandwidth. We expect to be able to manufacture the design within the next month or two.

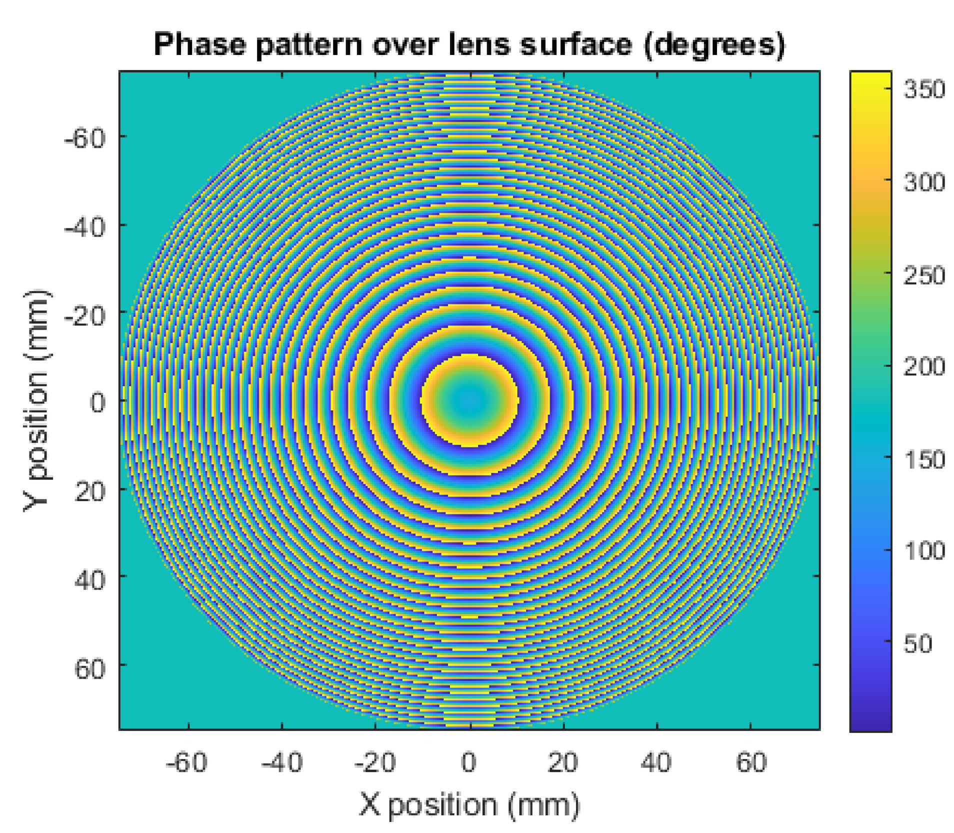

Fig 1. This is the phase design of the 480 Ghz metamaterial lens. (Note: the lens size has been truncate from 150mm when this figure was created to 120mm to account for manufacturing keep-out zones)

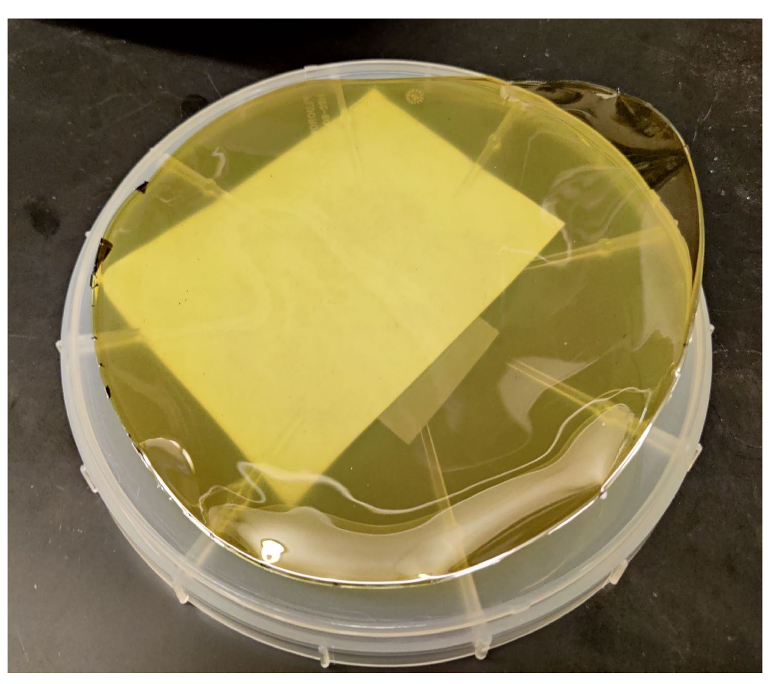

Fig. 2. Pictured below, the yellow circle is a sample of the substrate which will be used to create our metamaterial lens. The substrate is 200um thick polyimide. The material is not perfectly flat, but it is flexible, so a mount will be used to hold it flat. We will soon begin characterizing the substrate at the 500 GHz frequencies we intend to use it.

Significance/Benefits to JPL and NASA: CubeSat technology offers a unique opportunity to cost-effectively explore parts of space that were previously only observable by very expensive space telescopes. In this project, we are developing and increasing the TRL of technology that will be useful for a variety of future cubesat-based observing missions. In particular, this should facilitate future missions that seek to observe water both outside and inside the Earth's atmosphere, as well as missions that would benefit from the space- and weightsaving spectrometer and metamaterial lens that we are testing here. In particular, the metamaterial lens development works towards solving a critical need for implementing far infrared and submillimeter missions using smallsats: large aperture, low SWAP-C antennas. The first steps taken here with relatively small aperture planar focusing optics can be extended to larger apertures using segmented optics combined with the larger format fabrication processes (300mm and 370mm x 470mm) to realize meter scale planar optics.

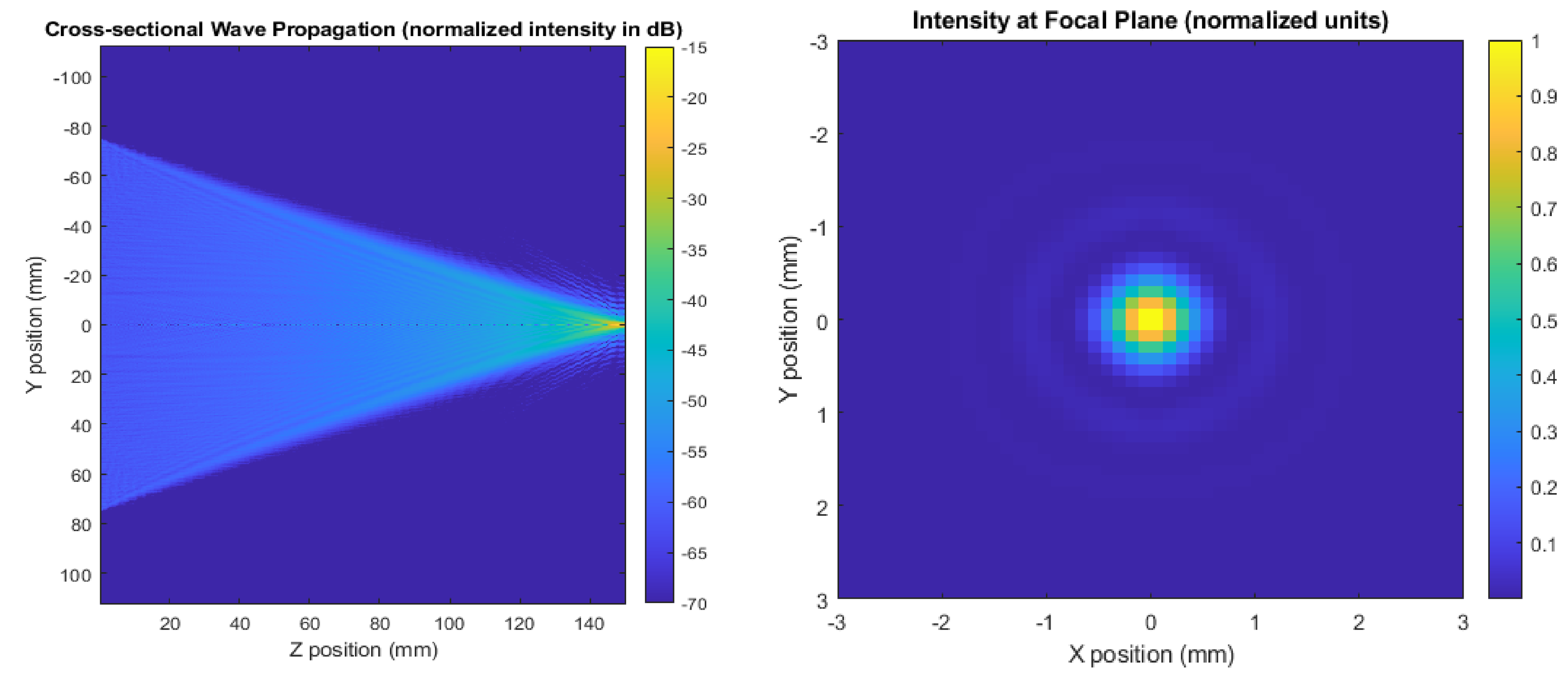

Fig 2. Left: A side-on view of the beam propagation simulation, from the lens (left of plot) to the focal point (right of plot). As can be seen, the focal distance is 150mm. Right: The point-spread function of the lens (equivalently, the intensity of a plane wave propagated through the lens at the focal plane) is plotted here. As expected, it resembles an Aery pattern.

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