Highly-Compact Terahertz Planetary/Cometary Instruments

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There has been only a handful of terahertz planetary science instruments that were baselined for space missions in recent years. The primary reason is that the terahertz heterodyne spectrometer instruments are relatively more power hungry and require more mass and volume compared to instruments at other frequencies.

Over the last several years, groups around the globe have made tremendous strides in reducing mass, volume, and power requirements for terahertz heterodyne instruments by focusing on innovative component developments and packaging solutions. Usage of commercial silicon foundries to develop low-power CMOS based components as well as low-profile antenna technology developments helped in this regard. As a result, it is possible to field highly-compact and low-power high spectral resolution heterodyne instruments for various planetary applications for space missions.

These developments have led to the consideration of using other platforms such as balloon-borne, SmallSats, and CubeSats. Traditionally, SmallSats and CubeSats and their related instrumentation development was primarily done by university undergraduate student teams. However, in recent years, the international space agencies have been actively looking into CubeSats and SmallSats as useable platforms to supplement main missions as well as use them for standalone scientific missions. NASA has flown such missions even to Mars for providing communication infrastructure during entry-descent-landing [1].

Development of compact and low-power terahertz scientific instruments for planetary applications, particularly on SmallSat and CubeSat platforms, poses a host of challenges: the lack of available space, severe restrictions on DC power availability, and antenna size limitations are some of them. For example, one has to be innovative in the design of the antennas as traditional high gain reflector antennas (for scientific payload as well as for data communication) are not practical for these platforms. Deployable antennas are preferred; however, even though some efforts are being made in this area, such antennas at terahertz frequencies are either not available yet, or the performance is not satisfactory. In recent years, metasurface and lens based low-profile antennas have been getting a lot of attention to address some of these challenges.

At JPL, we have developed a fully functional submillimeter-wave standalone scientific instrument for planetary science applications. The modular instrument architecture we adopted allows the instrument to be used for standard planetary science missions to the outer-planets, asteroids, or comets, and on CubeSat/SmallSat platforms.

Specifically, we have developed a low-mass (~2 kg) and low-power (~5W) 500-600 GHz high-resolution spectrometer instrument capable of remotely measuring water isotopes and deuterium/hydrogen (D/H) ratios on comets. The broadband instrument can also do trace-gas spectroscopy at this band. The instrument's 18 cm diameter aperture (which can be easily changed to larger diameter aperture, if required) consists of a novel low-profile leaky-wave lens-based antenna with a waveguide feed. We also have developed a low-profile reflector-based antenna that can be implemented instead of the lens antenna if so desired. A microelectromechanical system (MEMS) based calibration switch is integrated along with a variable temperature waveguide-based calibration load, all of which are integrated with the receiver front-end. A low-power (~300 mW) CMOS-SoC-based synthesizer at W-band with Schottky diode-based frequency multipliers generates the LO signal to pump a Schottky-diode based subharmonic mixer with state-of-the-art mixer noise temperature (~1000K). We have also developed a low-power (~1.5 W) CMOS-based backend spectrometer with 3 GHz available bandwidth and 4096 channels. This allows the overall instrument mass and power to be in the range ideal for implementation on planetary/cometary missions to outer planets. We have flown this instrument on a balloon-borne platform for technology demonstrations and TRL advancement.

In this presentation, we will provide the design and implementation of the 500-600 GHz spectrometer instrument with details of innovative packaging solutions, antenna technology, and low-power backend solutions suitable for future planetary science missions.

References

[1] S. Asmar et al., "Mars Cube One (MarCO) Shifting the Paradigm in Relay Deep Space Operations," in the Proceedings of the 14th International Conference on Space Operations (SpaceOps 2016), Daejeon, Korea, May 2016.