EPSC Abstracts
Vol. 13, EPSC-DPS2019-1075-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Solid State Electro-Optic Devices for Planetary Exploration with Small Satellites

Nancy Chanover (1), David Voelz (2), and Steven Stochaj (2)
(1) Astronomy Department, New Mexico State University, Las Cruces, New Mexico, USA, (2) Klipsch School of Electrical and Computer Engineering, New Mexico State University, Las Cruces, New Mexico, USA (nchanove@nmsu.edu)

Abstract

Low Size, Weight, and Power (SWaP) requirements of new mission architectures have led to innovations in miniaturized approaches to traditional narrow-band imaging systems. The acousto-optic tunable filters (AOTFs) are electro-optic, solid state devices that have been used for multispectral or hyperspectral imaging both on ground-based telescopes and on interplanetary spacecraft. These devices offer high spectral resolution in a compact system with no moving parts. In this work we discuss a notional science case and the necessary modifications for using AOTFs as an enabling technology on a small satellite mission to an ice giant planet. Hyperspectral imaging of an ice giant atmosphere would enable studies of the atmospheric structure, dynamics, and temporal variations thereof.

1. Motivation

Solar system exploration has recently undergone several paradigm shifts in terms of mission architectures. More capable rovers, the surface reconnaissance of extremely low gravity objects, and small satellites are now leading to new modalities for exploring solar system targets. A common element for nearly all of these approaches is instrumentation with low Size, Weight, and Power (SWaP) requirements.

One low SWaP technology that has become more widely used in planetary exploration is the acousto-optic tunable filter (AOTF), an electro-optic, solid state device. These have been used for multispectral or hyperspectral imaging for several decades [7, 4, 5, 1, 2], and in more recent years they have been flown on interplanetary spacecraft (see [6] and references therein).

2. Technology Description

AOTFs utilize a birefringent crystal – one whose optical properties are altered in the presence of an acoustic wave – as the spectral selection element. Tellurium dioxide (TeO_2) is a commonly used material for AOTF devices as it has the widest operating wavelength range of $\sim$0.4 μm to nearly 5 μm [7]. AOTFs are "tunable" in the sense that when high frequency (10-200 MHz) acoustic waves are driven into the crystal, this sets up a traveling acoustic wave through the crystal that effectively modulates its index of refraction. When broad-band light is incident on the crystal while it is acoustically active, roughly half of that light passes through the crystal undiffracted, while the other half is diffracted into two orthogonally polarized narrow-band beams that exit the crystal at a small, fixed angle. The wavelength of the narrow-band beams is a function of the frequency of the input acoustic wave; tuning the RF frequency of the input thus modulates the wavelength of the outgoing narrow-band beam.

AOTF systems are generally very compact (a few cm in size) and have low power requirements (in some cases utilizing $\sim$ 1 Watt or less of RF power). This, along with the fact that they have no moving parts, make them particularly attractive for planetary flight projects. When used as the filter element in hyperspectral imaging applications, there is a tradeoff in terms of crystal design between spectral grasp and spectral resolution. Typical CCD-based instruments have made use of AOTFs with coverage between 0.45–0.95 μm and a resolution R ($\lambda/\Delta\lambda$) $\sim$ 250-400 [2]. These devices can be used to rapidly acquire spectral scans across the full range of sensitivity, thereby assembling a hyperspectral image cube, or images can be acquired at judiciously chosen wavelengths appropriate for a specific science application.

3. Notional Operational Scenario

We previously considered AOTFs for imaging applications on a balloon-borne platform [3]. Here we discuss a notional science case and the necessary modifications for using AOTFs as an enabling technology on small satellite (SmallSat) missions. In this operational scenario we envision one or more SmallSat spacecraft as a ride-along capability added to an ice giant flyby mission. The SmallSat(s) would be released on approach to the ice giant system and would orbit the planet to collect remote sensing data on the planet, satellites, and rings.

3.1. Imaging

Hyperspectral imaging of the ice giant atmospheres would enable studies of the atmospheric structure, dynamics, and temporal variations thereof. Methane plays an important role in the atmospheres of the ice giants as it influences the depths to which one can sound through different cloud layers. Hyperspectral imaging is an effective tool for studying the vertical structure of the atmospheres of the ice giants since it enables the acquisition of numerous images taken at wavelengths corresponding to varying degrees of methane absorption. Cloud activity also could be monitored at wavelengths corresponding to the highest cloud contrast. From an orbiting SmallSat platform a longer temporal baseline could be acquired for tracking the motions and evolution of these cloud features. AOTFs offer a unique capability for the acquisition of hyperspectral image cubes in an ice giant system that provide fundamental insights into atmospheric structure and dynamics.

3.2. Platform Considerations

AOTFs are radiation hard, which makes them an attractive option for space-borne platforms. However, employing an AOTF on a SmallSat would require addressing several challenges that are unique to AOTFs. Most significantly, the TeO_2 crystals cannot withstand the ultracold temperatures of deep space; previous thermal qualification efforts indicated that a critical temperature at which the crystals cracked was around 150 K [6]. Thus thermal isolation of the crystal would need to be a design requirement. We discuss several design strategies for enabling the use of AOTFs on a SmallSat platform in an ice giant system.

4. Summary and Conclusions

AOTFs can serve as a low SWaP, spectrally agile, radiation hard alternative to traditional narrowband filter approaches for imaging from a tightly constrained orbiting SmallSat platform. We discuss the adaptability of different existing AOTF imaging system for this kind of application, and identify key science questions that can be addressed with this technology.

Acknowledgements

This work was supported by NASA's Solar System Observations program and NASA's PSTAR program.

References

[1] Chanover, N. J., Glenar, D. A., and Hillman, J. J., Multispectral near-IR Imaging of Venus Nightside Cloud Features, J. Geophys. Res. 103 (E13), 31335, 1998.

[2] Chanover, N. J., Anderson, C. M., McKay, C. P., Rannou, P., Glenar, D. A., Hillman, J. J. and Blass, W. E., Probing Titan's Lower Atmosphere with Acousto-Optic Tuning, Icarus 163 (1), pp. 150-163, 2003.

[3] Chanover, N. J., Voelz, D. G., Glenar, D. A., and Young, E. F., AOTF-Based Spectral Imaging for Balloon-Borne Platforms, J. Astron. Instrumentation, 3, 1440005, 2014.

[4] Glenar, D. A., Hillman, J. J., Saif, B. and Bergstralh, J., Acousto-Optic Imaging Spectropolarimetry for Remote Sensing, Applied Optics, 33 (31), pp. 7412-7424, 1994.

[5] Glenar, D. A., Hillman, J. J., LeLouarn, M., Fugate, R. Q. and Drummond, J. D., Multispectral Imagery of Jupiter and Saturn Using Adaptive Optics and Acousto-Optic Tuning, Publ. Astron. Soc. Pacific, 109, pp. 326-337, 1997.

[6] Korablev, O. I. and Dobrolenskiy, Y. S., Acousto-optic Tunable Filter Spectrometers in Space Missions, Applied Optics, 57, 10, pp. C103-C119, 2018.

[7] Smith, W. M. H., Schempp, W. V., Conner, C. P., and Katzkat, P.: Spectral Imagery with an Acousto-Optic Tunable Filter, Publ. Astron. Soc. Pacific, 99, pp. 1337-1343, 1987.