Far-Infrared Room-Temperature Focal Plane Modules for Radiation Budget Instrument

Giacomo Mariani, Matthew Kenyon, John Pearson, Warren Holmes
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91125 USA

***Abstract*— This work presents focal plane modules for Radiation Budget Instrument, a passive remote-sensing instrument that follows the legacy of Clouds and Earth's Radiant Energy system to measure short and longwave Earth's radiation budget. The focal plane arrays are micromachined at JPL and integrated into sub-assembly modules to be mounted on the optical telescope of the instrument.**

I. INTRODUCTION

THERMOPILE detectors are widely used in applications that require accurate radiometry at uncooled operation. Such class of imagers does not require electrical bias, and generates a voltage output that is proportional to the input radiation signal. They have negligible 1/f noise and they are well suited for broadband and spectral radiometers for Earth and space science applications [1]. The mission goal is to produce long-term climate data records and maps of radiation budget at the top-of-atmosphere, within the atmosphere and at the surface with consistent cloud and aerosol properties at climate accuracy. The effort at JPL is to provide focal plane module assemblies composed of the thermopile detector array, a one-stage amplification board hybridized to a flex cable with a connector at the end to mate to the rest of the instrument. The calibration scheme of the instrument is designed to have the Radiation Budget Instrument (RBI) focal plane module (FPM) periodically stare at a visible calibration target, solar calibration target, and infrared calibration target to allow on-board temperature calibrations. The instrument will house three separate radiometric channels: a short-wave channel (0.2-5µm), long-wave channel (5-100µm), and a total solar channel (0.2-100µm).

II. RESULTS

The RBI detector consists of a two-pixel thermopile array designed in single-string redundant configuration, where only one pixel is used during standard operation (second pixel as backup). The rhomboid shape for the pixels is dictated by the point-spread function of the imaging/telescope system.

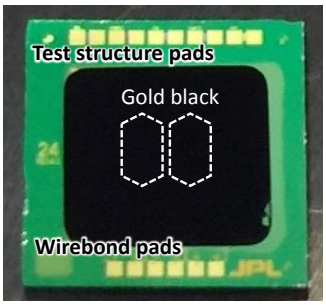

Figure 1: RBI thermopile-based focal plane array.

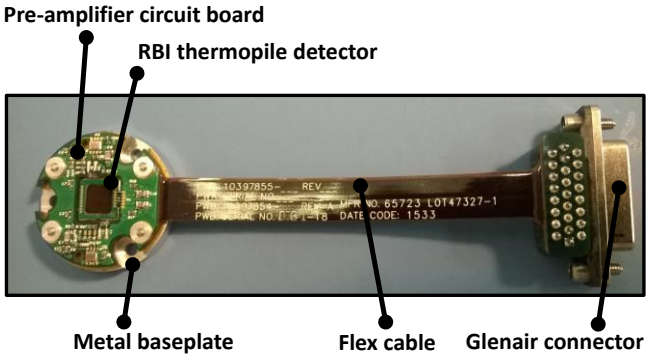

Figure 2: Fully-integrated focal plane module assembly.

Micro-machined RBI thermopile detectors are based on bismuth-antimony-tellurium (Bi-Sb-Te) alloys. These alloys convert the incident power from the scene into a voltage signal via the thermoelectric Seebeck effect, and are the heart of the sensor since they ultimately drive the signal-to-noise (SNR) of the imager [2]. In *Figure 1*, the square black region on top of the detector is a highly efficient broadband coating layer called 'gold-black' that has near unity efficiency over wavelengths between 1-100µm. After fabrication, the detectors are screened to verify that responsivity and response time values, along with additional key parameters, are compliant. The detector is epoxied down and wire-bonded to a single-stage amplification board to adequately increase the dynamic range of the signal.

Requirement	Level
FPM Responsivity [V/W]	22,000
Response Time [ms]	< 9
FPM Max Power	< 25 mW
Operating Temperature [K]	308

Table A: Key requirements.

Figure 2 shows the rigid-flex FPM assembly hybridized to the Glenair connector. *Table A* summarizes a few cardinal requirements that need to be met at the FPM level. Thermopile-based detector technology allows for far-IR imaging at room-temp.

III. RADIATION TESTING

The electrical signal output by the thermopile detector is amplified via a zero drift, single-supply, rail-to-rail, input/output operational amplifier (AD8629) fabricated on Analog Devices' 600 nm CMOS process. Critical to the mission is to study any noise performance change with respect to baseline. Noise characterization is performed before and after radiation exposure at total ionizing dose (TID) of 10krad, 5rad/s (relevant instrument environment while in orbit). Such investigation is justified as Noise-Equivalent Power strictly depends on the system noise level.

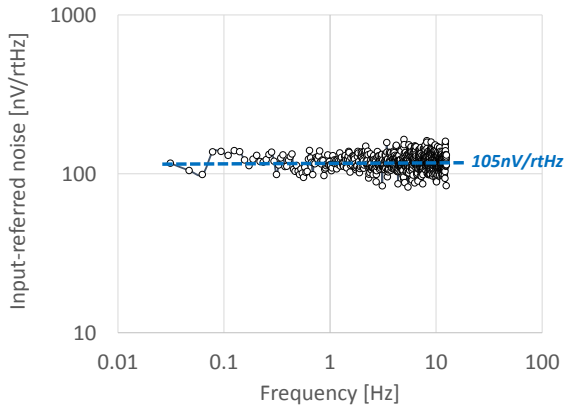

Figure 3: Input-referred noise of AD8629 before radiation exposure.

Figure 3 shows an input-referred noise measurement for AD8629 with a 500KΩ input resistor load. The baseline measurement before radiation exposure confirms that there is no 1/f contribution from the op-amp and that noise performance approaches Johnson-noise limited levels (theoretical 91nV/rtHz for a 500KΩ and noise-less amplifier).

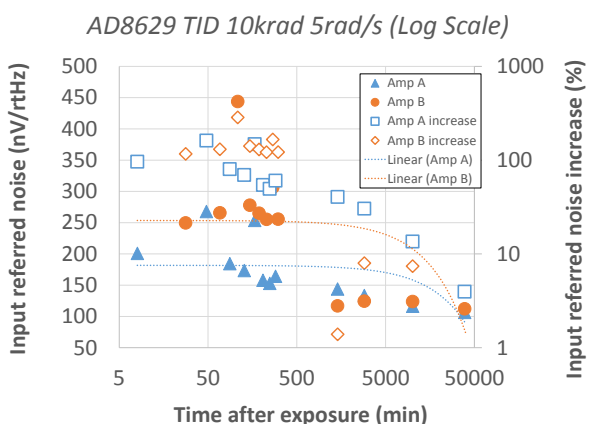

Figure 4: Input-referred noise of AD8629 before radiation exposure.

Figure 4 displays input-referred noise measurements for op-amp A and op-amp B of AD8629 with a 500KΩ input resistor load. The parts are exposed at 0min to TID 10krad at a 5rad/s rate. The measurements highlight a time-dependent asymptote of the noise performance back to baseline. This effect is due to the ionizing dose deposited at time 0min into the active components of the CMOS device in the form of trapped charges combined with interface state generation. Such effect reduces and charges anneal out over time reaching levels described in *Figure 3*. The study confirms that the AD8629 is a suitable part for the RBI focal-plane module in the JPSS-2 environment.

IV. Summary

Surface- and bulk-micromachining of RBI thermopile detector arrays and incorporation into a fully-integrated focal plane module assembly is presented as remote-sensing thermal imager in the payload of the Radiation Budget Instrument [3]. AD8629 CMOS operational amplifier has been characterized and noise performance has been investigated before and after radiation exposure. Trapped charges anneal out over time and the device recovers full functionality compared to baseline performance.

V. Acknowledgement

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.
© 2016 California Institute of Technology. Government sponsorship acknowledged.

References

[1] D. Paige et al. "Diviner Lunar Radiometer Observations of Cold Traps in the Moon's South Polar Region" Science, 2010, Vol. 330, p479-482.
[2] M. C. Foote, M. Kenyon et al. "Thermopile detector arrays for space science applications", International Workshop on Thermal Detectors for Space Based Planetary, Solar, and Earth Science Applications TDW 2003.
[3] Joint Polar Satellite System. Source: www.jpss.noaa.gov/satellites.html