LOW NOISE ELECTRONIC READOUT FOR AN ICE GIANTS NET FLUX RADIOMETER FOCAL PLANE ASSEMBLY. D. Tran[1,2], G. T. Quilligan[1], N. Gorius[1,2], G. Nehmetallah[2], and S. Aslam[1], [1]NASA, GSFC, 8800 Greenbelt Rd., Greenbelt, MD 20771, USA, shahid.aslam-1@nasa.gov, [2]The Catholic University of America, 620 Michigan Avenue NE, Washington DC 20064, USA, 63tran@cua.edu.

Introduction: The next decadal planetary flagship mission may well be to one of the ice giant planets. Extended studies of one or both ice giants, including *in situ* with an entry probe, are necessary to further constrain models of solar system formation and chemical, thermal, and dynamical evolution, the atmospheric formation, evolution, and processes, and to provide additional ground truth for improved understanding of extrasolar planetary systems [1]. An Ice Giants Net Flux Radiometer (IG-NFR) will be a valuable contribution to a suite of scientific instruments for addressing the scientific objectives. In this abstract, a low noise electronic readout for the IG-NFR detector Focal Plane Assembly (FPA) is presented.

IG-NFR Science Objectives: Ice giant meteorology regimes depend on internal heat flux levels. Downwelling solar insolation and upwelling thermal energy from the planetary interior can have altitude and location dependent variations. Such radiative-energy differences cause atmospheric heating and cooling and result in buoyancy differences that are the primary driving force for Uranus and Neptune's atmospheric motions [2]. The three-dimensional, planetary-scale circulation pattern, as well as smaller-scale storms and convection, are the primary mechanisms for energy and mass transport in the ice giant atmospheres and are important for understanding planetary structure and evolution [3][4][5]. These processes couple different vertical regions of the atmosphere and must be understood to infer properties of the deeper atmosphere and cloud decks. It is not known in detail how the energy inputs to the atmosphere interact to create the planetary-scale patterns seen on these ice giants [6]. Knowledge of net vertical energy fluxes would supply critical information to improve our understanding of atmospheric dynamics.

An IG-NFR [7][8][9] on a probe descending deep into the atmosphere will contribute to this understanding by measuring the up- and down-welling radiation flux, as a function of altitude. The net flux, the difference between upward and downward radiative power per unit area crossing a horizontal surface per unit area is directly related to the radiative heating or cooling of the local atmosphere.

IG-NFR Focal Plane Assembly Overview: The IG-NFR vacuum micro-vessel with a synthetic diamond window, **Fig. 1,** houses the fold mirror, filters, Winston cone non-imaging optics, and detector FPA, so as to mitigate rapid excursions of temperature during the probe descent. A close hexagonal-packing array of Winston cones with filter band inputs gives seven spectral channels; each Winston cone is designed to give a 5° clear field-of-view. The FPA uses uncooled single pixel thermopile detectors for good sensitivity of the radiation flux. A stepper motor rotates the vacuum micro-vessel, to each of the five sequential viewing angles (±80°, ±45°, and 0°).

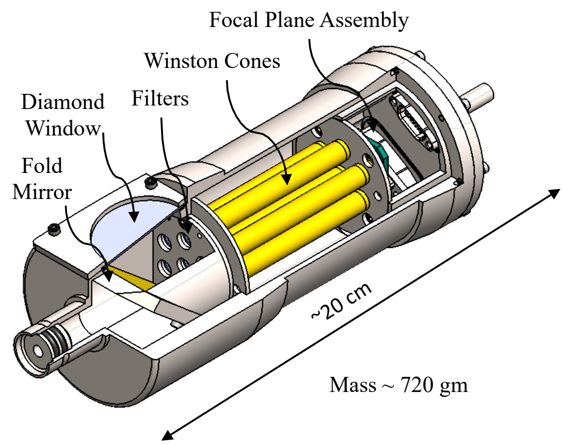

Figure 1. IG-NFR seven detector channel FPA is housed in a vacuum micro-vessel to mitigate rapid excursions of temperature during a probe descent.

Parallel Readout Architecture: The readout electronics is an important sub-system of the instrument. Its design must satisfy the science requirements while also remaining small in size, weight and power. Moreover, due to the rapid descent of the probe into the atmosphere, all channels must be readout simultaneously, in real-time and deterministic fashion. To achieve this goal, a radiation hard multi-channel digitizer (MCD) application-specific-integrated-circuit (ASIC) developed at NASA GSFC [10] was utilized to digitize analog signals from the thermopile array. All of the active components of the analog front-end are also located on the MCD-ASIC to further reduce the size of the backend electronics. However, for flexibility, the MCD-ASIC was initially designed to output only 1-bit stream from multiple channels to the host processor. In order to convert it to useful data words, an FPGA has been used to obtain such data words and operate the electronic readout circuit. The whole signal processing chain from MCD-ASIC to FPGA setup is fully capable of digitizing 20 analog channels simultaneously. The simplified signal processing chain is shown in **Fig. 2** and the electronic readout hardware is shown in **Fig. 3**.

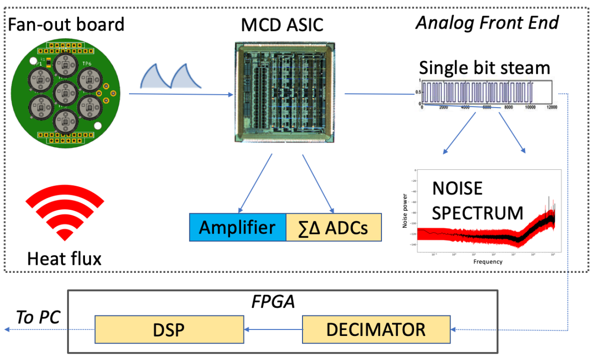

Figure 2. Seven thermopiles on a fan-out board convert heat energy to electrical signals. The MCD-ASIC outputs 1-bit stream with shaped noise spectrum. The FPGA capture the bit stream, process and transfer data to a PC.

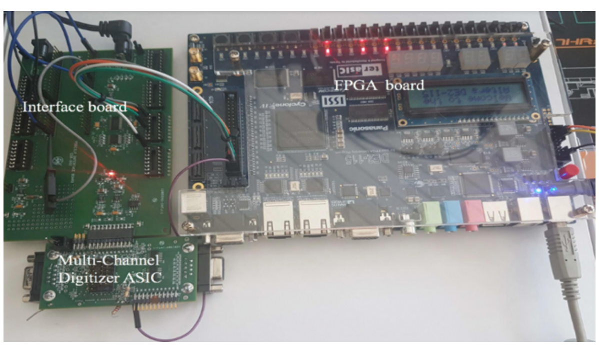

Figure 3. To fully leverage the parallel mode of the MCD-ASIC and increase the transfer data rate from readout electronics to PC, a custom in-house firmware for FPGA has been developed.

Readout Noise: The MCD-ASIC employed two patented mechanisms: auto-zero differential amplifier and gated CDS integrator (GCI) [11] [12] along with sigma-delta ADC to achieve very low noise in low frequency region. This strategy can be detailed as following. Firstly, the GCI modulates the input signal to higher frequency region. Thus, it helps to avoid amplifying the *1/f* noise and offset voltage presented in the signal path. Before demodulating it back original baseband, a high frequency filter can be used to further reduce *1/f* noise, or any offset voltage presented. However, the GCI is still vulnerable to offset voltage of the non-idea amplifier itself since it can lead to saturation. This problem is eliminated if an auto-zero differential amplifier is used in the first place. Finally, the sigma-delta ADC digitizes the analog signal and pushes most of the quantization noise to higher frequency region which will be effectively filtered out by the decimator.

An input-shorted noise of 12.27 nV/√Hz at room temperature with 240 samples per second output rate was measured. This makes the thermal noise from the thermopile detector (~18 nV/√Hz) the dominant noise source in the system. **Fig. 4** shows a typical spectrum of an individual channel. Notice the noise level near to the DC region is lower than band-pass region.

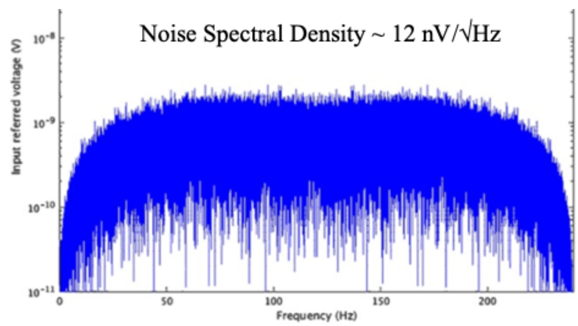

Figure 4: MCD-ASIC input referred integrated noise with channel gain of 250 V/V and ADC sample rate of 240 Hz.

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