Optimization of a PID controlled TES detector array for use in an FIR double-Fourier interferometer

Chris S. Benson*[1], Jeremy P. Scott, Locke D. Spencer

***Abstract*—As part of the ongoing efforts in the development of a laboratory-based double-Fourier transform interferometer in the far-infrared, we present the characterization of a custom-developed cryogenic transition edge sensor detector array system.**

Keywords—Detectors, Bolometers, Transition-edge Sensors Fourier Interferometry, Spectroscopy, Far-infrared, Instrumentation

I. Introduction

Double Fourier interferometry provides a promising path to achieve broadband observations of the far-infrared (~0.3—10 THz) with sub-arcsecond spatial resolution [1]. We have developed a double-Fourier Transform interferometer (2FTI) instrument coupled to a unique array of 25 multiplexed TES bolometers to provide laboratory-based validation of this technique [2].

Each detector in the array is maintained at a bias temperature on the TES thermometer's superconducting transition by conduction to the surrounding cryogenic environment, optical loading, the bias circuitry of the TES, and a heating element controlled by a proportional-integral-derivative (PID) loop. At the start of each measurement pulse, the heater is switched on for a selected time period before a measurement of the TES voltage is made and fed into the PID feedback calculation. This voltage is a proxy for TES temperature and regulates the heater power used to maintain the temperature setpoint. In this way, the heater power provides a measure for the optical loading on the TES detector [3]. The feedback loop corresponding to a single detector measurement can be seen in Fig. 1. This detector system was developed by QMC Instruments [3].

The optimization of the detector array requires consideration of the adjustable timing of the heater duty cycle, the delay after heater shutoff before measurements of the TES state are used in PID calculation, and the tuning of the PID feedback loop. Also, the performance of the detector array should be considered within the context of the 2FTI as the scanning speed of the interferometer's spectral arm is limited by detector time constants [4].

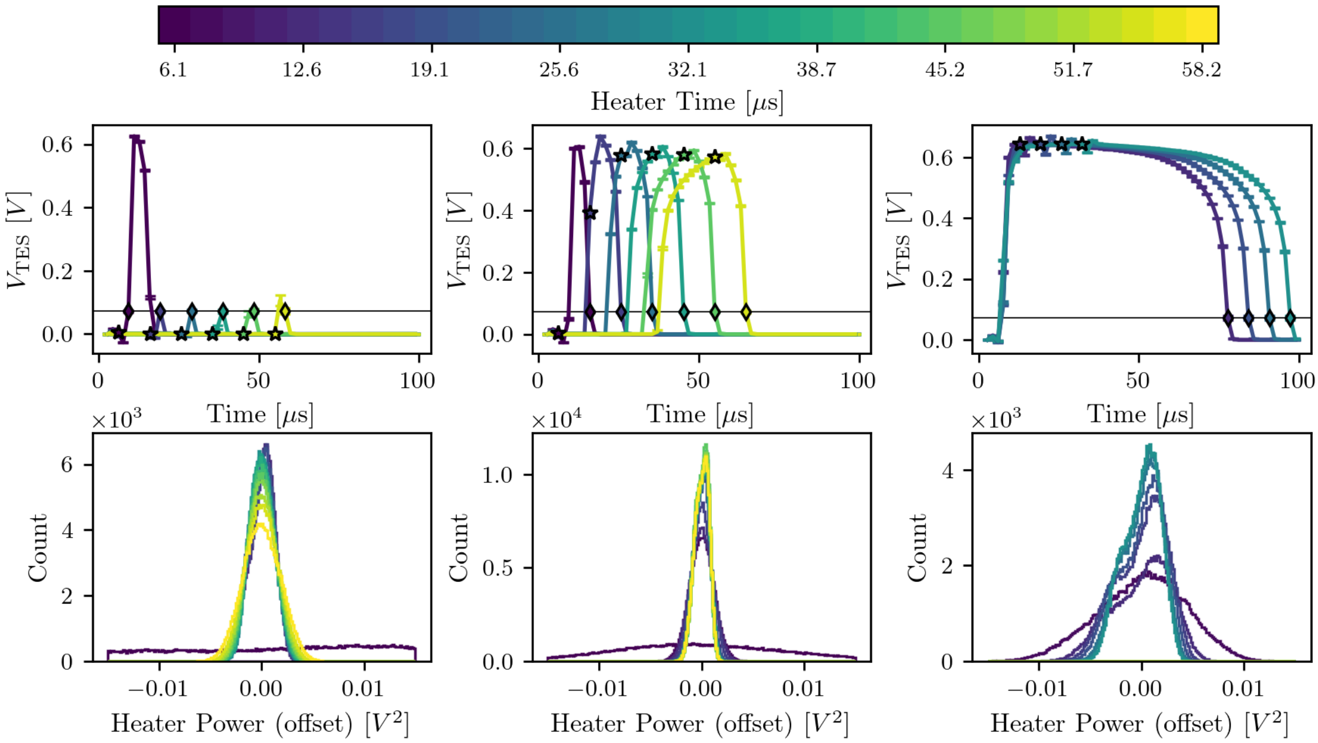

Fig. 1. The timing between when the heater is shut off and when measurements of the TES voltage are used in PID calculation is shown for time delays of 3.25 (left), 9.75 (center), and 65.00 (right)\,μs for a range of heater duty cycles. The top row of plots shows the TES signal averaged over several thousands of detector measurements. TES voltage measurements marked by a star indicate the TES state corresponding to when the heater is switched off while those marked by a diamond show the TES state that is used in the PID calculation. The PID setpoint is marked by the horizontal black line. The bottom row of panels displays the distribution of heater powers, represented by the square of the voltage across the heating element, used to maintain the setpoint for each case. The distribution of heater power values corresponds to the detector's measurements of optical loading and demonstrates the stability of the detector signal. Adjusting the timing of the detector measurement loop results in an offset in detector signal with shorter heater times and longer time delays requiring more heater power.

[1]Institute for Space Imaging Science, University of Lethbridge, Lethbridge, T1K 3M4, Canada

II. Timing Parameters

The timing of a single detector measurement is defined by the time for which the heating element is active and the time that is waited before the TES state is measured and used to calculate the heater value for the subsequent measurement (see Fig. 1). These timing effects have been studied by considering the signal stability of the central detector as its timing parameters were varied while viewing a ~6 K static optical load.

We have found that a time delay of 9.75 µs between when the heater is shut off and when the TES state is read for PID calculation causes the TES to be heated above its transition into the non-linear region before cooling down towards the setpoint and provides the most stable detector signal. This is shown by the central panels of Fig. 1. If the time delay is too short, the measurement of the TES state used in the PID loop is taken on the rising edge and can be subject to electrical pickup noise from the heater switching off resulting in a less stable detector signal (shown by the leftmost panels of Fig. 1). If there is too long of a delay between the heater and TES state measurements for PID calculation, the TES spends most of the time of a single measurement pulse in a non-linear state and a much less stable detector signal. Additionally, we have found that if the heater is on for less than 10 µs, the PID loop is unstable unless the TES voltage is read ~65 µs after the heater is switched off.

III. PID tuning

Tuning the gain values associated with each term of the PID calculation can optimize the performance of the associated detector.

The frequency response of the central detector was measured using the spectral arm of the 2FTI while viewing a quasi-monochromatic source provided by a frequency-tunable photomixer [5]. Through scanning the spectral arm at different speeds, sinusoidal optical modulation on the detectors is achieved up to ~600 Hz. The detector response to this modulation is shown in Fig. 3 at two different gain states associated with the P and I terms of the PID calculation. Increasing the gain associated with the I term while decreasing the gain of the P term results in a faster detector time constant and thereby a higher cutoff frequency.

The faster detector time constant and higher spectral scanning speeds that can be reached as a result can be useful in increasing the frequency of the spectral modulation of the 2FTI to avoid 1/f noise. In spite of this, we have measured decreased signal-to-noise in detector signal with the PID loop is I-term dominated [3]. Optimizing the PID parameters of the detector array for use in the 2FTI will require consideration of both effects.

IV. Conclusion

We have found optimal TES performance with a time delay of ~9.75 µs between heater switch-off and reading the TES state for PID calculation. Additionally, PID tuning of the detector array will require consideration of the SNRs of the detectors as well as their frequency response. The effective time constant of each detector should be selected such that the noise resulting from increasing the gain associated with the I parameter of the PID loop does not outweigh the reduction in 1/f-noise obtained from the scanning speed of the interferometer's spectral arm.

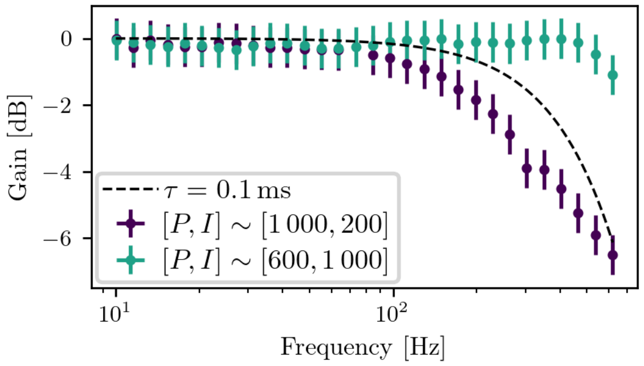

Fig. 3. The frequency response of the central detector under two PID tuning conditions is shown. The modelled frequency response behaviour of a nominal TES detector with an effective time constant of 0.1 ms is shown by the dashed black line [6].

References

[1] D. Farrah, K. E. Smith, D. Ardila, Bradford et al., “Review: far-infrared instrumentation and technology development for the next decade”, *Journal of Astronomical Telescopes, Instruments, and Systems*, vol. 5, p. 020901, Apr. 2019.

[2] L. D. Spencer, P. A. Ade, W. F. Grainger, M. J. Griffin, R. Juanola-Parramon, D. A. Naylor, E. Pascale, G. Savini, and B. M. Swinyard, “Development of a far-infrared double Fourier spatial/spectral interferometery laboratory testbed instrument”, *Fourier Transform Spectroscopy*. Optical Society of America, 2015, pp. FT4A-6.

[3] L. D. Spencer, R.V. Sudiwala, C. S. Benson, J. P. Scott, M. D. De Silva, T. Jones, J. Cox, K. Wood, and P. A. Ade, “Optimization of a cryogenic transition-edge sensor detector array for far-infrared astrophysics”, *Space Telescopes and Instrumentation 2022: Optical, Infrared, and Millimeter Wave*, vol. 12180. SPIE, 2022, pp. 1018-1035.

[4] L. D. Spencer, D. A. Naylor, B. M. Swinyard, A. A. Aramburu, T. R. Fulton, T. L. Lim, S. D. Yonayette, and I. S. Schofield, “A Fourier transform spectrometer for ground testing of the Herschel/SPIRE instrument”, *Optical, Infrared, and Millimeter Space Telescopes*, vol. 5487. SPIE, 2004, pp. 501-512.

[5] A. J. Deninger, A. Roggenbuck, S. Schindler, and S. Preu, “2.75 THz tuning with a triple-DFB laser system at 1550 nm and InGaAs photomixers” *Journal of Infrared Millimetre Terahertz Waves*, vol. 36, no. 3, pp. 269-277.

[6] K. D. Irwin and G. C. Hilton, “Transition-edge sensors”, *Cryogenic particle detection*, pp. 63-150, 2005.