A low-background test facility for spectral response measurements at 70 mK of ultra-sensitive TES detectors.

Gert de Lange, Michael D. Audley, Geert Keizer,Willem-Jan Vreeling
SRON Netherlands Institute for Space Research, Landleven 12, 9747AD Groningen, The Netherlands

***Abstract*—We have built a set-up to measure the spectral response of sensitive Transition Edge Sensors (NEP ~ 0.5x10^{-18} W/√Hz) in the frequency range from 1 to 10 THz. The TES sensors are designed to operate in the SAFARI instrument on board of the proposed SPICA mission. Key within this mission is a cooled telescope (~ 6K) with very low thermal emission. With very low-noise detectors, the instrument noise level is only limited by the intrinsic far-infrared background emission from the universe. To characterize the detectors we therefore have to use a test set-up with extremely low thermal background (< 4K) and very low (~ fW or smaller) thermal calibration powers. The TES sensors are operated at 70 mK and the sensor is placed in a horn-coupled integrating cavity. To measure the spectral response of the detectors we have developed a cryogenic measurement system with a light pipe that couples radiation from a room temperature Fourier Transform Spectrometer to the device. The cold attenuation of the light pipe system is of order 60 dB and the coupled power to the device is a few femto-Watts. This system works well and we have analyzed the spectral response of a detector in the short wavelength band of SAFARI (34-60 μm) and a broadband reference detector that operates from 30-300 μm .**

I. INTRODUCTION

THE SAFARI instrument on the proposed SPICA mission is an imaging Fourier Transform Spectrometer with arrays of Transition Edge Sensors (TES), covering the 34-210 μm wavelength range [1]. SPICA will have a cooled 6-kelvin telescope, and the noise performance of the instrument is limited by the far-infrared sky background radiation. This translates to required sensitivities of the detector arrays of a few times 10^{-19} W/√Hz. The dynamic range of TES detectors with this sensitivity is of order 10^{4}, resulting in saturation powers in the femto-watt range. For comparison: the background limit for ground based telescopes at THz frequencies is of order 10^{-15} to 10^{-14} W/√Hz, 40 to 50 dB higher than what can be achieved with a cold telescope in space! For characterization of the instrument one needs a detailed picture of the spectral and temporal response of the detector. The spectral response of the pixels is determined by the optics and band-defining filters in front of the pixel and the details of the horn-coupled cavity in combination with the TES pixel (Fig.1). The extremely low levels of acceptable radiation powers give rise to challenges in the detector calibration. In order not to saturate the detectors one can only use cryogenic black-body radiators internal to the cryostat, operating in a temperature range from 4 K to 30 K.

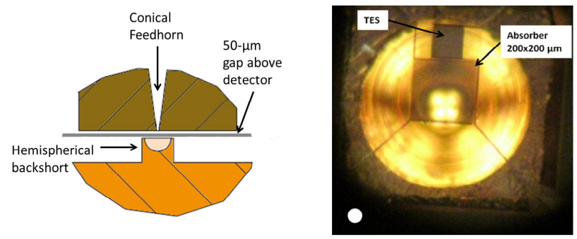

Figure 1. Left: Cross-section of feedhorn and hemispherical backshort showing position of detector. The diameter of the hemispherical backshort is 500 μm. Right: Photograph of detector sitting above hemispherical backshort. The absorber is a thin Ta film with a sheet resistance close to 377 ohm. The white circle in the lower left-hand corner indicates the size of the feedhorn's exit aperture.

Radiation from a 300-K black-body should be attenuated by a factor of at least 10^{6} to reach the allowable power levels. Contrary to ground based detectors, the optical access to the detectors via windows and heat filters in the cryostat is therefore almost impossible. For this purpose we have developed a test cryostat with an internal cryogenic calibration source and with the possibility of coupling room temperature sources via a 4-mm diameter stainless steel light pipe to the detector [2]. This test cryostat is used to measure the noise performance and the spectral response of the detector arrays.

II. EXPERIMENTAL SET-UP

We obtained the measurements described here with a room temperature Fourier Transform Spectrometer (FTS), connected to the entrance port of the light pipe. The FTS has a 900-K globar as broadband source (mechanically chopped at 1 to 40 Hz). The FTS is operated in a step-scan mode and a lock-in technique is used to measure the interferogram. The light pipe runs from the top of the cryostat via a periscope-like construction to a multi-port spherical reflecting summing cavity at 4 K (see Fig. 2). The exit port of this integrating cavity radiates via another piece of light pipe and a 400 μm diameter pinhole towards the TES detector to be measured. Only a small fraction of the power entering the scattering cavity will actually be radiated towards the TES detector, and we can further adjust the power level with 4-K pinholes placed within the light-pipe by a 4-K shutter mechanism and/or 4-K absorbers placed in the light path.

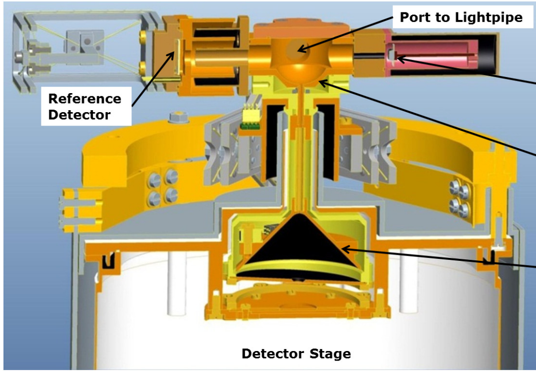

Figure 2 overview of the calibration source and the summing cavity. The black cone is a variable temperature calibration load. At the apex of the cone is a 400 µm pinhole (not visible at this scale) that is connected to the summing cavity via light pipe.

For a correct interpretation of the spectral response measured with the TES detector it is necessary first to determine the spectral content of the incoming light from the FTS that has passed through the light-pipe and the cryogenic attenuation elements. For this purpose we have placed a so-called reference detector at another exit port of the scattering cavity (see Fig. 2). This reference detector consists of another TES detector mounted in a large (w.r.t. wavelength) non-resonant cavity that is coated with absorbing material. We assume that this detector acts as a frequency independent free-standing thin metal film absorber (with a sheet resistance of 377 Ohm) that absorbs half of the incident radiation over a broad frequency range.

III. Results

As an example of some early results we show the response of a TES detector that is optimized for the short wavelength (SW) band of SAFARI (34-60 µm). Fig. 3 shows the NEP with the 4-K shutter of the light pipe open and closed. With the shutter closed we see the intrinsic NEP of the device, with a lower value of 2×10^{-18} W Hz$^{-1/2}$. The 1/f noise at low frequencies is due to the SQUID read-out. With the shutter open we observe an increase in the NEP due to the photon noise of the attenuated 300-K radiation. The spike at 40 Hz is the actual signal of the chopped globar of the FTS, which is about 15 dB above the photon noise level. The measured power at the TES detector is 3.85 fW. Fig. 4 shows (part of) the interferograms measured with both the reference detector and the TES detector with a 6-µm beamsplitter in the FTS.

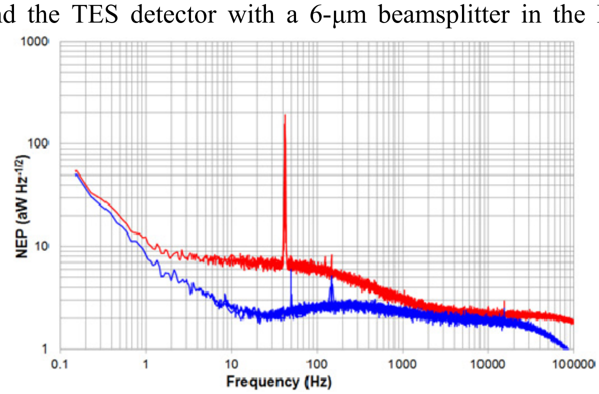

Figure 3 NEP values of the TES detector with the light pipe closed (blue) and open (red). The increase in NEP with the light pipe open is caused by photon noise of 300-K radiation. The spike at 40 Hz is the signal from the chopped globar.

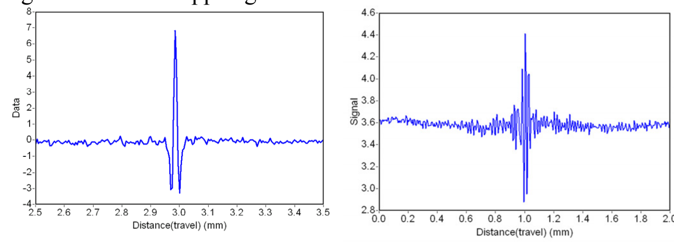

Figure 4 Left: (part of the) interferogram of the reference detector. Right: interferogram of the SW TES detector

The spectra of the interferograms shown in Fig.4 are shown in Fig.5. The plot shows the frequency response of the reference detector and the SW detector together with the transmission of the band-defining filter stack [3]. The transmission of this filter stack has been measured in separate FTS measurements. For the reference detector we observe a broadband response from 1 THz to 9 THz. The observed band-pass can be explained by the 6-µm beam-splitter efficiency of the FTS (low frequency cut-on) and the filter characteristics of a low pass filter (high-frequency cut-off) in the light pipe. The response of the SW detector is mainly determined by the SW filter stack in front of the horn and qualitatively agrees with separate transmission measurements of the filter stack. We observe no clear out-of-band stray-light. More recent measurements and detailed analysis of the spectra will be presented at the conference.

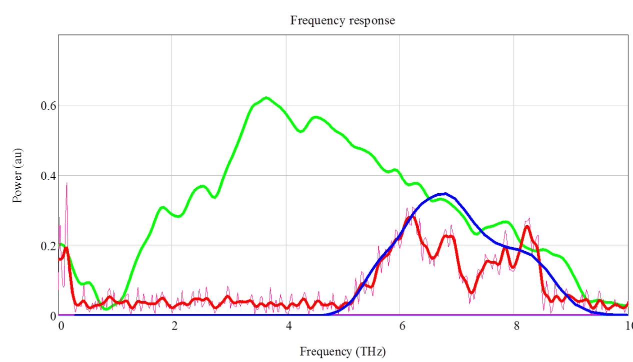

Figure 5 Measured spectrum of the reference detector (green) and the SW-pixel (red). The blue curve is the transmission of the SW filter stack (measured separately)

References

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[2]. M.D. Audley et al., J. Low Temp. Phys., in press (2014).
[3]. P.A.R. Ade et al., Proc. SPIE 6275, 62750U (2006).