A Cryogenic Millimeter Wavelength Test Facility

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Abstract— **We have built a cryogenic test system for extensive characterization of detectors at millimeter wavelengths. This instrument allows the measurement of the detector optical responsivity, noise, spectral response, and time constant. The design of the system provides optical loading conditions typical of space, sub-orbital, or ground-based experiments. The design of this instrument is presented here, along with initial results.**

I. Introduction

Temperature controlled cryogenic blackbody loads are typically used to characterize the performance of ultra-sensitive detectors designed for optical loading conditions encountered by space-based instruments. This technique can provide accurate measurements of the responsivity and noise of the detector in the band of interest. Measurements of the spectral and temporal response of the detectors are often made using a chopped source outside the cryostat that illuminates the detectors through a window in the wall of the Dewar. Stray radiation from the laboratory environment often increases the optical loading above that expected for space-based operation.

To overcome these limitations, we have developed a novel test system that includes both a cryogenic blackbody source and an external electronic millimeter wavelength photon source operating at room temperature, which illuminates the detectors via a waveguide.

II. Design of the Test Setup

The test setup is built in a STAR Cryoelectronics DRC-100 pulsetube precooled adiabatic demagnetization refrigerator (ADR), which provides cold stages at approximately 50 K, 3 K, 1 K, and 100 mK. Photographs of the setup are shown in Fig. 1 and Fig. 3, while a schematic diagram is shown in Fig. 2.

A. The Cryogenic Blackbody Source

The cryogenic blackbody is made of a slab of Eccosorb MF-110 glued to a copper sheet for thermal equalization. A hole in the copper sheet allows radiation to pass through and be attenuated by the Eccosorb. The temperature of the Eccosorb is controlled using a weak thermal link to either the 3 K or 1 K stage and a heater resistor. The Eccosorb slab is anti-reflection coated with sheets of PTFE. Details of the blackbody source are presented in [1].

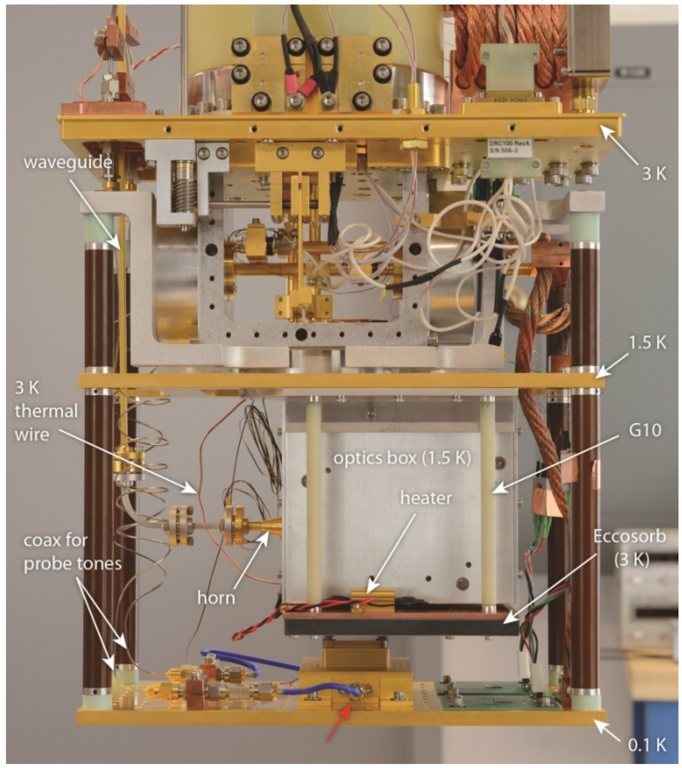

Fig. 1 Detailed photograph of the test setup. The device under test is attached to the 100 mK plate at the bottom of the image. In the configuration shown, the copper thermalizing plate is above the Eccosorb slab. When the external millimeter wavelength source is used, the copper plate is below the Eccosorb so that reflections in the optics box are terminated in the absorber.

B. The Electronic Millimeter Wavelength Source

The key improvement of our test setup is the addition of a waveguide-coupled electronic photon source covering 140-160 GHz. The source is built around a Millitech AMC-05 active times-twelve frequency multiplier. The multiplier can be driven by either an amplified thermal noise source to produce broadband noise, or by a microwave signal generator for measuring response at a single frequency. A PIN-diode switch at the input of the multiplier provides the ability to modulate the source on sub-microsecond timescales. At the output of the multiplier, a pair of variable attenuators provides a total dynamic range of over 80 dB in output power. Finally, a bandpass filter after the attenuators is used to precisely define the bandwidth of the noise and to suppress spurious harmonics.

The source is coupled into the cryostat using WR-6.5 waveguide with a vacuum feed-through, shown in Fig. 3. Lengths of stainless steel waveguide provide thermal isolation between 300 K, 50 K, and 3 K. At the end of the waveguide the radiation is launched with a conical horn into a crossed-Dragone optics box, which produces a plane wave incident onto the Eccosorb slab, and then the detectors. The Eccosorb slab acts as a cold attenuator. A thin PTFE membrane in the waveguide at 3 K absorbs stray IR radiation from the 300 K end.

As shown in Fig. 2, the source is connected to the cryostat through a 20 dB coupler, which helps minimize reflections. A Virginia Diodes zero-bias diode detector on the through port of the coupler allows us to continuously measure the output power of the source.

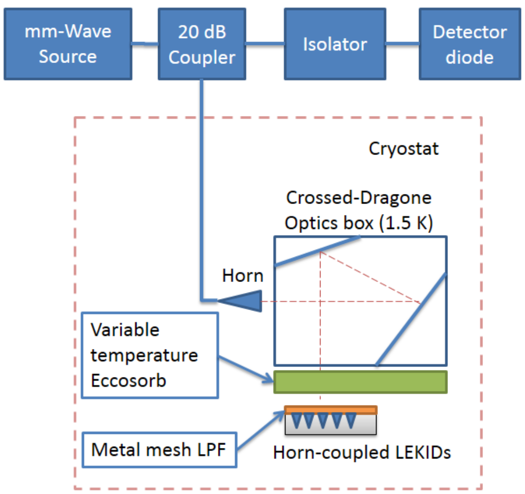

Fig. 2 Simplified schematic of the test configuration.

III. Initial Results

In the process of commissioning this test setup, we have made a number of initial measurements of an array of horn-coupled aluminum LEKID devices. The design and performance of these devices is described in detail in [1].

A. *Spectral Response Measurements*

To measure the spectral response of detectors, we connect a Hittite HMC-20 signal generator to the PIN-diode switch at the input of the multiplier. We square-wave modulate the PIN switch and synchronously demodulate the resulting detector data to track and remove any drift. An example spectral response measurement is shown in Fig. 4.

B. *Time Constant Measurements*

One of the unique features of this system is that the PIN-diode modulator allows us to inject extremely short duration pulses of millimeter wavelength power, which is useful for measuring the time constant of our detectors. The lumped-element kinetic inductance detectors (LEKIDs) that we built and tested have time constants <100 µs. In particular, the quasiparticle recombination time constant is an important parameter for studying the physics and performance of the devices. This time constant is typically measured using either pulses of light from an LED, or from the cut-off frequency in the device noise spectrum [2]. In contrast, we are able to directly observe the response of our devices to rapid pulses of millimeter wavelength radiation. An example measurement of device time constant versus bath temperature is shown in Fig. 5.

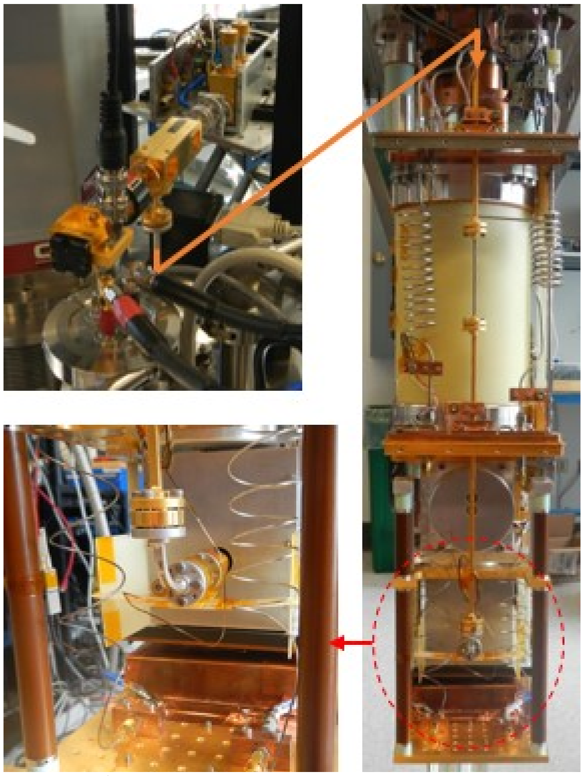

Fig. 3 Upper left: the millimeter wavelength source, coupler, isolator, and diode detector. Right: waveguide plumbing. Lower left: detailed view of the horn and entrance to the optics box.

C. *Responsivity Measurements*

This test setup provides two independent methods of measuring the detector responsivity. First, the blackbody load temperature can be stepped to directly provide a measurement of detector output per kelvin. Second, the broadband millimeter wavelength source power can be adjusted with the variable attenuators. The source output power is continuously measured with the zero bias detector, providing a precise measurement of the relative power incident on the devices under test, relaxing the impact of the stability and repeatability of the attenuators. We are currently working on cross calibrating these two methods to provide high confidence measurements of both the power and temperature responsivity of our detectors.

D. *Initial Noise Measurements*

By combining the measured responsivity with the raw noise in the recorded detector time series, we are able to directly calculate the noise equivalent power or temperature (NEP or NET) of our detectors. Once we are confident in our absolute power calibration, this information can be used to provide a measurement of the optical efficiency of the detectors. We will present initial results at the conference.

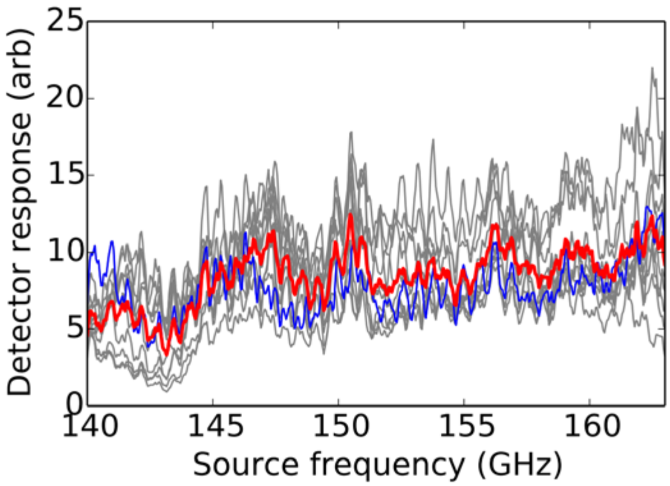

Fig. 4 Example spectral response measurement of an array of aluminum LEKIDs obtained using this setup. Each of the gray curves shows the response of a single detector. The response of a single detector is highlighted in blue for clarity. The average response across the array is shown by the thick red curve. The fringing is due to reflections in the test setup rather than the intrinsic detector response, and can be corrected for.

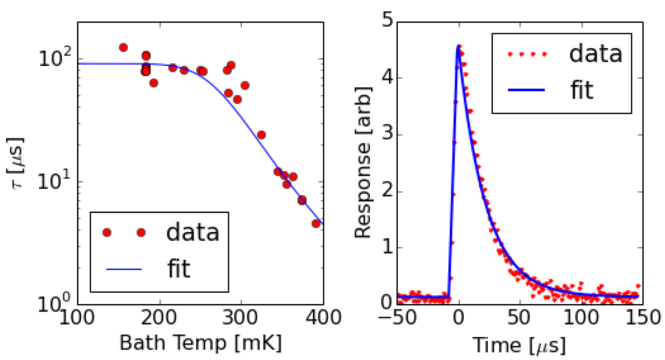

Fig. 5 Left: example time constant data from an aluminum LEKID, measured as a function of bath temperature. The time constant saturates below 300 mK because of background illumination from the Eccosorb. Right: The device response to a 2 μs wide pulse of radiation from the millimeter wavelength source.

IV. Further Applications

In addition to the features demonstrated here, we are working to commission a number of other modes of operation. A few examples are given below.

To check detector arrays for undesired response to high frequency out-of-band radiation, we plan to use the WR6.5 waveguide as an over-moded "light pipe" coupled to a Martin-Pupplet interferometer outside the cryostat. We have also begun to use the interferometer to more accurately characterize the spectral shape of the millimeter wavelength radiation produced by the source.

The rectangular waveguide and crossed-Dragone optics provide extremely high polarization purity. By inserting waveguide twists of different angles before the horn, we can measure the polarization response of the detectors under test. In the future we may also add a rotatable cryogenic half-wave plate to the optical path to provide more fine grained polarization characterization.

V. Conclusions

This test facility provides a number of novel features that are particularly useful for characterizing ultra-sensitive detectors (especially LEKIDs) under realistic optical loading conditions for space, sub-orbital, and ground-based experiments.

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