Noise Performance of the Multiwavelength Sub/millimeter Inductance Camera (MUSIC) Detectors

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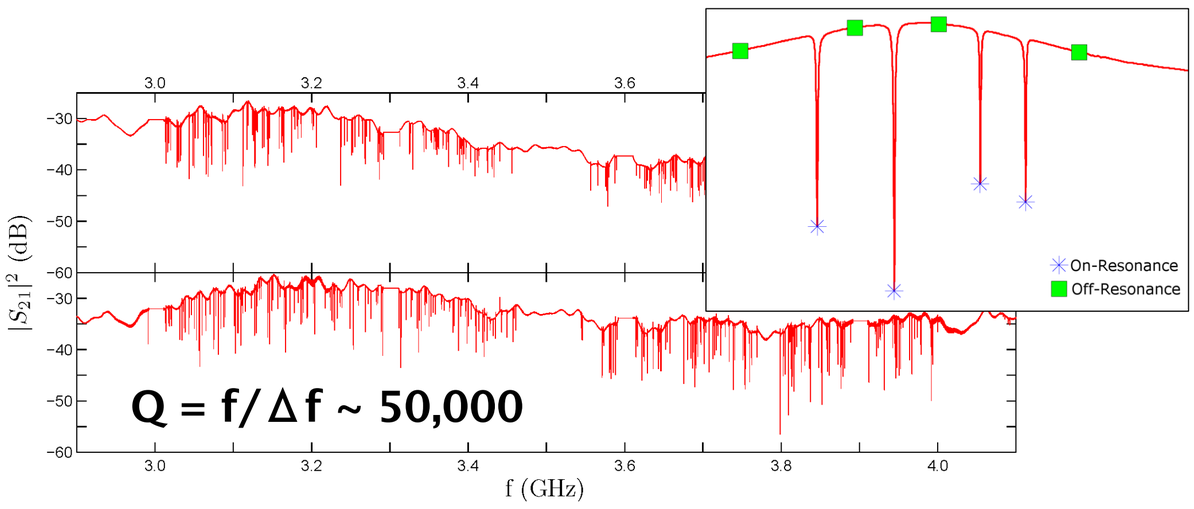
Abstract

MUSIC is a multi-band imaging camera that employs 2304 Microwave Kinetic Inductance Detectors (MKIDs) in 576 spatial pixels to cover a 14 arc-minute field of view, with each pixel sensitive to 4 bands centered at 0.85, 1.0, 1.3, and 2.0 mm. In April 2012 the MUSIC instrument was commissioned at the Caltech Submillimeter Observatory with a subset of the full focal plane. We examine the noise present in the detector timestreams during observations taken in the first two years of operation.



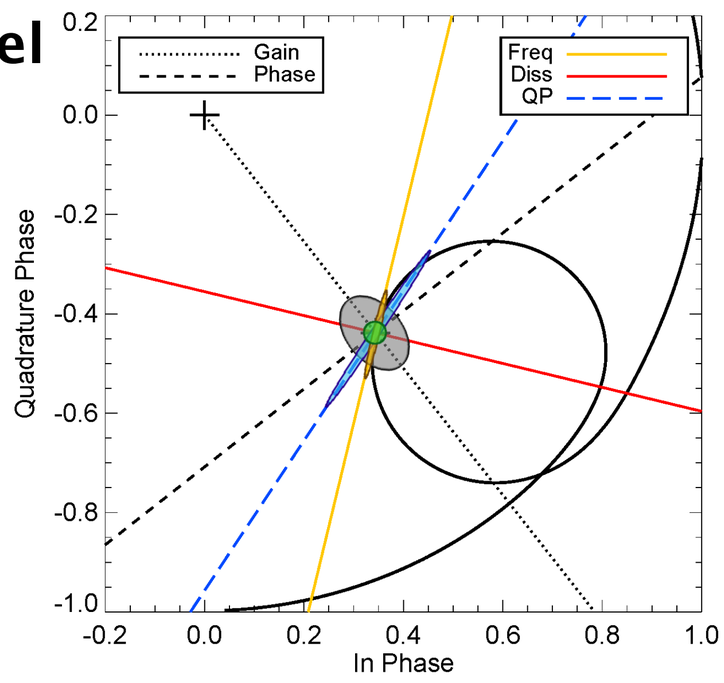
Left: Microwave transmission through 2 MUSIC arrays. **Right:** Zoom-in on four resonators.

Theoretical Model

MKIDs are superconducting micro-resonators coupled to a feedline.

Photons break Cooper-pairs in the superconductor, increasing the quasi-particle density and changing both the reactance and resistance of the resonant circuit. This results in a change in both the frequency and dissipation of the resonator, which is read out as a change in the complex transmission of a microwave probe signal centered on-resonance.

MUSIC uses a homodyne mixing technique to perform fast measurements of the complex transmission through MKIDs at 3-4 GHz.



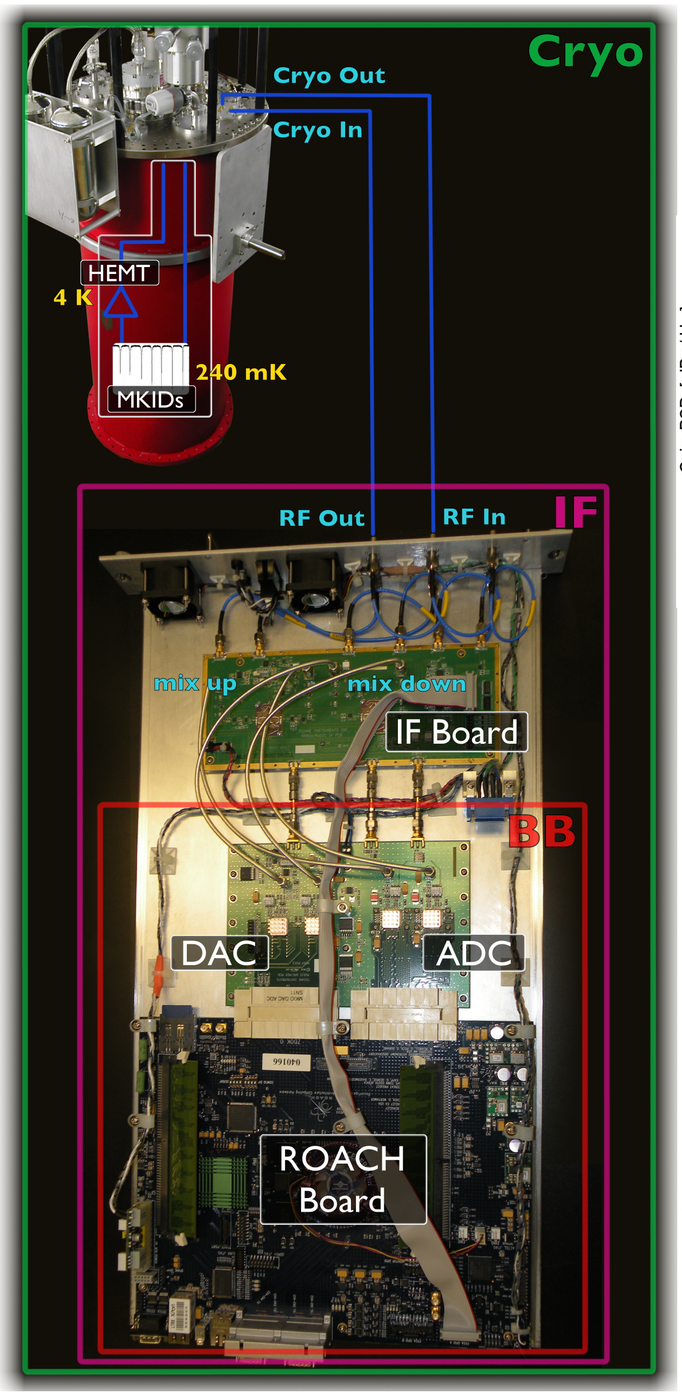
Solid black line denotes the complex transmission near resonance as a function of frequency. Ellipses are centered on the resonant frequency and provide rough approximations of the relative covariance of the various noise sources. The color of the ellipse corresponds to the color of the name in the table below.

The MUSIC detectors are susceptible to the following sources of noise:

Noise	Direction	PSD	On-Resonance	Off-Resonance	Correlated
Amplifier	Isotropic	white	✓	✓	
Multiplicative Electronics	Gain/Phase	1/f and drift	✓	✓	✓
TLS	Freq	$f^{-1/2}$	✓		
Fluctuations in Atmospheric Emission	QP	$f^{-8/3}$	✓		✓
Photon	QP	white	✓		
Generation - Recombination	QP	white	✓		

Note that astronomical signal lies in the quasi-particle (QP) direction, which is rotated 5-15 degrees from the frequency direction.

Measured Electronics Noise

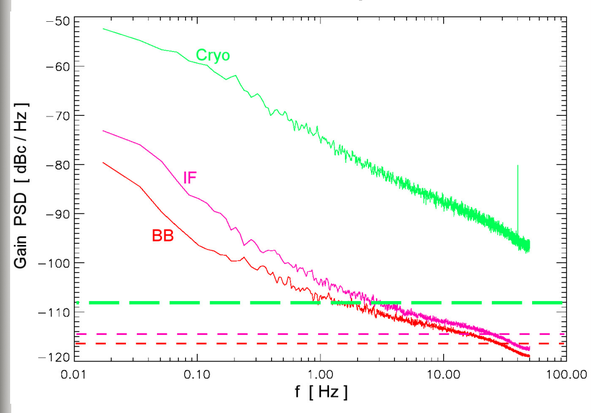


Schematic of the MUSIC readout for 144 MKIDs (half of one array). Built around the CASPER ROACH platform with Xilinx Virtex-5 FPGA.

This electronics noise is correlated among carrier tones at different frequencies and therefore removable. We treat the gain and phase fluctuations as common signal and use the off-resonance data to determine the weighted least squares estimate of this signal in the presence of the amplifier white noise.

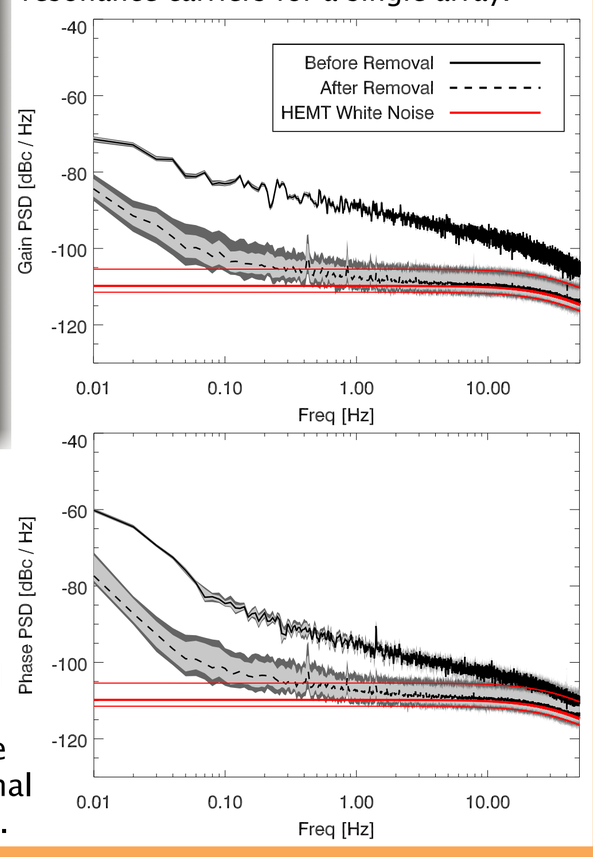
The various electronic components suffer from 1/f and drift type gain and phase noise due to (primarily):

- Fluctuations in amplifier gains
- Drift in cable delays

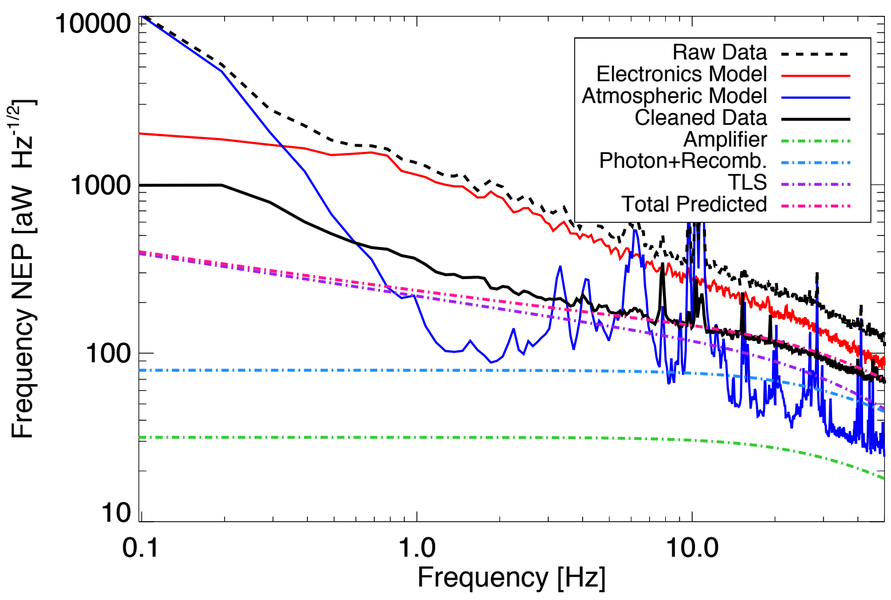


Above: Measured noise in the gain direction of the BB, IF, and Cryo sub-systems. White noise denoted by dashed line.

Below: Performance of the electronics noise removal in the gain and phase direction. Solid lines denote median value. Contours enclose 68% and 95% of the off-resonance carriers for a single array.



Measured Detector Noise



*Noise Equivalent Power or the power incident on the MKID from the antenna that yields S/N=1 in a 1 Hz output bandwidth.

NEP* in the frequency direction in units of 10^{-18} W / rt-Hz. Cleaned data is obtained by subtracting the electronics and atmospheric noise model from the raw data. It agrees well with the predicted noise (dash-dotted lines) at frequencies greater than 2-3 Hz. We are dominated by two-level system (TLS) noise, and a factor of ~3.5 above background limited performance (BLIP) at 1Hz.