Pulse Tube Interference in Cryogenic Sensors

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Abstract

Transition edge sensors (TES) are extremely sensitive superconducting sensors, operating at 100 mK, which can be used to detect X-rays and Cosmic Microwave Background. The goal of our project is to design the electronics to read out an array of 10000 of these sensors by using microwave signals. However, we noticed the pulse tube used to maintain cryogenic temperatures caused interference in our readout. To determine the cause of the signal distortions, we used a detector with a 370 MHz sampling rate to collect and analyze sensor data. Although this data provided little information towards the nature of the noise, it was determined through a maintenance procedure that the 0.3 mm stainless steel wires were being vibrated due to acoustic waves, which distorted the signal. Replacing this wire appeared to cease the interference from the sensor data.

- Cosmic Microwave Background
- X-ray Detection
 - “Color” Imaging: Energy Resolution of 1.3 eV at 1.5 keV for temperatures at 100 mK
 - Time stamping: Order of 10^{-6} s
- Array of ~10,000 sensors
 - Using microwaves allows many sensors on 1 wire

Resonant Frequency of RLC Circuits

Transmitted Power vs. Frequency

Superconductors and TES

Cryogenic System

- TES is couple to a Superconducting Quantum Interference Device (SQUID)
- SQUID is coupled to the resonant circuit
- Current change from TES $\rightarrow$ Detected and amplified by SQUID $\rightarrow$ Inductance change in RLC circuit $\rightarrow$ Shift in f_0
- Sweep broadband noise through resonant circuit to measure frequency response

Image by Kent Irwin

Keeping the Sensor Cold

Pulse Tube Interference

Plot by Sarah Kernasovskiy

- Noticed interference on the Spectrum Analyzer in sync with pulse noise
- Resonance Peaks appeared to widen, narrow, and shift
 - Possible change in Q of resonant circuit
 - Possible aliasing due to changes in resonance
- Brought in a detector with a 370 MHz sampling rate to measure frequency response over time

Driving a Signal

Noise Band

Sensor Response

Analyzing the Signal

Waterfall FFTs

Waterfall FFTs

Checking Our Measurement Techniques

- Generated flux through the SQUID to manually shift the resonance
- Showed measurement techniques can resolve small shifts in frequency, down to 1 line width

Waterfall Plot: Fluxramp at 35 Hz

FFT: Pulse Tube “Noise” On

FFT: Pulse Tube “Noise” Off

Analyzing the Resonances

	Resonance [MHz]	Std. Dev	Resonance [MHz]	Std. Dev	Resonance [MHz]	Std. Dev
Off	154.012	0.0021	160.7	0.55	142.1	1.43
On	154.011	0.0015	160.7	0.53	142.1	1.36

	Resonance [MHz]	Std. Dev	Resonance [MHz]	Std. Dev
Off	136.69	1.58	148.053	0.0068
On	136.69	1.59	148.053	0.0066

Changes in Shape of Resonance?

- Averaged power over waterfall FFTs for tube on and off
 - Compared depth and width of resonances

Possible Phase Offsets?

Pulse Tube Off

Pulse Tube On

Turning the Sensor Off and On Again

- Sensor was warmed up to replace parts
 - 0.3 mm stainless steel wire in cryogenic chamber replaced with thicker, more stable wire
- Noise vanished
- Likely physical vibration affecting signal in wire

Plot by Sarah Kernasovskiy

In Summary: Don't Go Chasing Waterfall FFTs

- Pulse tube refrigerator caused interference in resonant circuit
- 0.3 mm wire was replaced, noise vanished
- Questions still remain:
 - Why did noise appear on spectrum analyzer, not on data taken by our devices?
 - Spectrum analyzer may drive a different power level
 - Could the new wires just be masking the underlying problem?
 - Exact cause is still unknown

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Questions?