Snowmass2021 - Letter of Interest

Multiplexing Readout for next generation Dark Matter experiments with Transition Edge Sensors

Topical Group(s): (check all that apply by copying/pasting ☐/☑)

☑ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
☐ (CF3) Dark Matter: Cosmic Probes
☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
☐ (CF7) Cosmic Probes of Fundamental Physics
☐ (Other) *[Please specify frontier/topical group]*

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Abstract: (maximum 200 words)

In recent years, excitement is growing for new technologies (e.g. superfluid helium, quantum material) to look for dark matter at the sub-GeV scale that could benefit from multiplexed readout of Transition Edge Sensors (TES). For example, to form the 1 kg target needed to achieve the desired sensitivity for a light DM search would require thousands of targets cooled to 10 milli Kelvin and each equipped with a TES sensor. Multiplexing readout will be an enabling technology for these novel experiments by reducing the thermal load on the coldest cryogenic stages and reducing the overall cost of the TES readout. Multiple multiplexing readout technologies (time-domain, MHz frequency-domain, code-domain and microwave SQUID) for TES have been widely used successfully by Cosmic Microwave Background (CMB) experiments, infrared astronomy experiments and x-ray experiments. Different requirements for dark matter experiments will pose new challenges to the technology.

Main Text:

Several TES-based experiments are aiming to detect low-mass dark matter [1,2,3]. Current TESs optimized for dark matter detection have NEP of O(1) aW/rt(Hz) and future generations are expected to improve upon this by an order of magnitude [4]. To attain the exposure required to reach the full potential of this technique, several thousand TESs operated at a temperature of ~10 mK will be required. A multiplexed TES readout technology will be an enabling technology to reach these low temperatures as the cooling power of sub-Kelvin coolers drops rapidly at such low temperature and reduces the cost of readout electronics to readout thousands of sensors.

Multiplexing readout of TES sensors has already been used widely by many astrophysics experiments such as CMB, infrared astronomy and x-ray astronomy. Multiple multiplexing technologies have been developed: time-domain, MHz frequency-domain, code-domain and microwave SQUID multiplexing. The CMB community has developed these technologies to readout O(10,000) sensors with multiplexing factor of ~64 for deployed experiments using time-domain and MHz frequency-domain technologies [5,6,7]. Simons Observatory, on-going CMB experiment, will deploy with a multiplexing factor of ~1,000 with microwave SQUID multiplexing system [8,9]. SAFARI, one of the instruments on the proposed space infrared observatory SPICA, will deploy MHz frequency domain multiplexing readout with multiplexing factor of ~160 [10]. A 32-channel code-domain multiplexing readout and a 128 channel microwave SQUID multiplexing readout has been demonstrated for x-ray TES microcalorimeters [11, 12]. There is on-going effort to develop microwave SQUID multiplexing readout with multiplexing factor of few thousand for the Lynx x-ray microcalorimeter (LXM), an imaging spectrometer for the Lynx satellite mission, an x-ray telescope being considered by NASA to be a new flagship mission [13].

These demonstrations provide firm ground to start the development for multiplexed readout technology for dark matter sensors.There are some key differences that need to be addressed. Dark matter sensors are more like x-ray microcalorimeters than CMB sensors in that they are calorimeters rather than bolometers. Signals for dark matter experiments show up as a pulse rather than a continuum signal from the CMB. Because of this, readouts require an order of magnitude higher bandwidth than typical CMB experiments. There are reactive elements that limit readout bandwidth assigned to each channel. There are trade offs to be made between readout bandwidth against noise level, cross-talk and multiplexing factor. Multiplexed readout also shows promising noise performance. Current TESs optimized for dark matter detection have NEP of O(1) aW/rt(Hz) and future generations are expected to improve upon this by an order of magnitude. The SAFARI detector system is designed to have a dark NEP of 0.2 aW/rt(Hz) with a multiplexed readout system with detectors cooled to 50 milli-Kelvin.

As design parameters get modified to accommodate the dark matter sensor's impedance, readout bandwidth and available cooling power at 10 milli-Kelvin various trade-offs will be necessary. These include but not limited to,

- Optimization of SQUID amplifiers, such as development of multi-stage SQUID amplification chain as done for SAFARI
- SQUID amplifier parameters to trade off performance between dissipation power, element's size (thus yield), input/output impedance
- Optimization of reactive element
- Development of reactive bias circuit for some readout scheme to eliminate power dissipation from resistive elements
- RF cable development to reduce potential thermal load from conventional coaxial cable

The multiplexing readout community has been making these adaptations as new experiments come up with different requirements. Investment into developing multiplexed readout for future dark matter searches with TES sensors will benefit the community as the scale of experiment increases in the future.

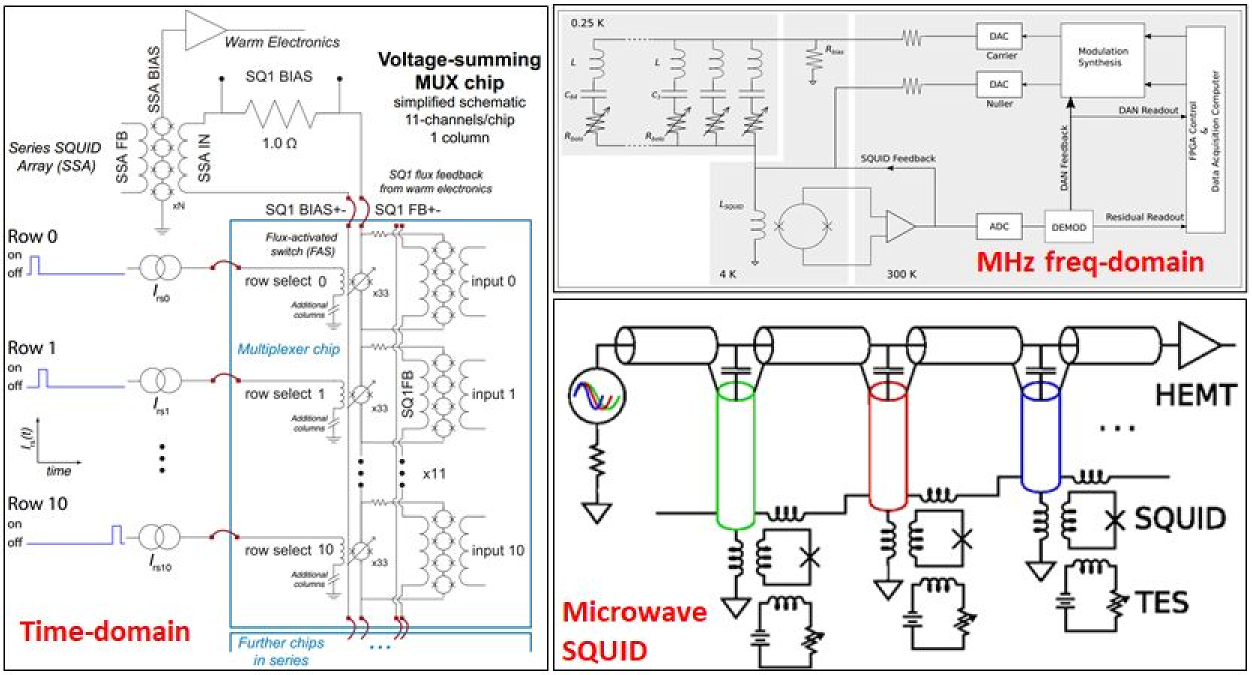

Figure 1. Circuit diagram of multiplexing readout technologies used by CMB experiments

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