# KID Based Submillimeter Instrument for Eurasian Submillimeter Telescopes

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**Abstract.** New challenges in submillimeter wave astronomy require instruments with a combination of high sensitivity and angular resolution, wide field of view and multi wave (multicolor)spectral range. New large single mm/submm telescopes are in high demand, as well as their inclusion in the global Event Horizon Telescope (EHT) VLBI network. At the same time, there are no large mm/submm telescopes in Asia at all while appropriate sites exist and their appearance in Asia or Eurasia is long overdue. Kinetic inductance detectors (KID) are superconducting detectors capable of counting single photons and measuring their energy in the UV, optical, and near-IR, and are ideal for large-format array implementation, which will be necessary for future telescope development. Concept of multicolor subTHzKID-array MUSICAM demo camera is given. It allows us to perform some necessary steps toward the creation of the Eurasian SubMillimeter Telescopes (ESMT).

**Keywords:** telescopes; techniques: radar astronomy; instrumentation: detectors

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## 1 Introduction

One commonly used detector technology for submillimeter wavelengths proposed in 1994 is the transition edge sensor (TES), which is a cryogenic sensor based on the strongly temperature dependent resistance near the superconducting phase transition. To read the signal from a TES, a superconducting quantum interference device (SQUID) is coupled with the detector. TES have been used for the detection of submillimeter/millimeter radiation in many types of instruments; however, their complex fabrication process and readout method make them difficult to scale to larger arrays. Relatively new type of sensor is a kinetic inductance detector (KID; also MKID, where M stands for microwave) first developed at the Caltech and the Jet Propulsion Laboratory (JPL) in the early 2000s. Its action is based on change in the surface impedance of a superconductor due to increase of kinetic inductance caused by the incident photons. KIDs can be easily fabricated on a two- to three-layer wafer and frequency-domain multiplexed; all of the readout functions are performed by room-temperature electronics, with the exception of one cryogenic amplifier. KIDs are ideal for large-array implementation, which will be necessary for future telescope development. For many applications, MKIDs are the first choice, with much simpler fabrication, operation and lower cost than TES.

MKIDs are pair breaking detectors, and can find application in wider range of frequency for different purposes. For example, the ARray Camera for Optical

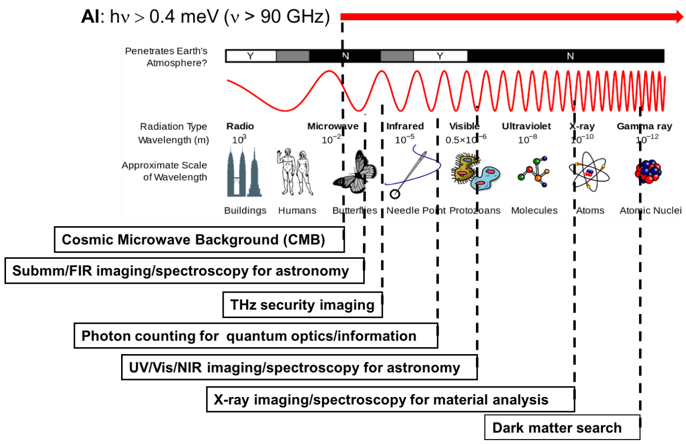


**Fig. 1.** MKID Application.

to Near infrared Spectrophotometry (ARCONs) is a photon counting optical/near-IR astronomical instrument and was successfully commissioned at Palomar 200 inch telescope. ARCONS is based on a 32 by 32 array of MKID, which are photon counting detectors that have an intrinsic energy resolution R range between 20 to 150, enabling them to perform low resolution spectroimaging without filters or dispersive optics. ARCONs was designed to be sensitive in the 0.4 to 1.1 $\mu$m wavelength rage and can timetag photons to 1 $\mu$s without read noise or dark current. ARCONS is the first astronomical instrument based on optical/near-IR MKIDs.

The example of a multicolor MKID cameras is MUSIC (Sayers et al. 2014). The discussion in this paper is based on the MUSIC instrument build for CSO. The main goal of the proposed concept of MUSICAM demo camera and its instrumental testing is to perform some necessary steps toward the creation of the Eurasian SubMillimeter Telescopes (ESMT) (Duan et al. 2020; Marchiori et al. 2020).

## 2 Concept of the MUSICAM Demo

Just like the MUSIC Multi wavelength Sub/millimeter Inductance CAMera, the proposed demo device (the MUSICAM-demo camera)will combine sensors for 4 wavelength ranges corresponding to water vapor transparency windows of 2.0 mm, 1.33 mm, 1.04 mm, and 0.86 mm, with 5×5×4 = 100 pixels. Broadband superconducting phased-array slot-dipole antennas will be used to form beams, and lumped element on-chip bandpass filters will define spectral bands (Duan et al. 2010).

### 2.1 Design of Camera Wafer

As shown in Fig. 2, signal is first received by the phased-array antenna and then split into different frequency bands determined by the BPF network. The output of each filter is fed into one LC resonator, which is coupled to the feedline.

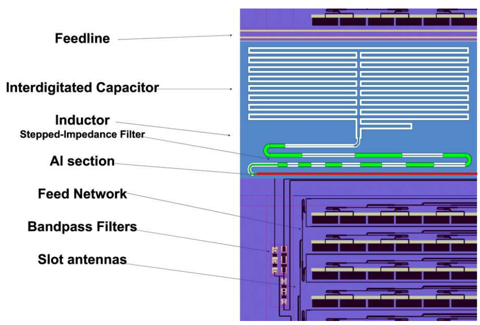


**Fig. 2.** Mask design: layout of the major components on the wafer.

As shown in Fig. 3, when the aluminum superconductor receives photons, the photons breakCooper pairs and create quasiparticles, which change the surface

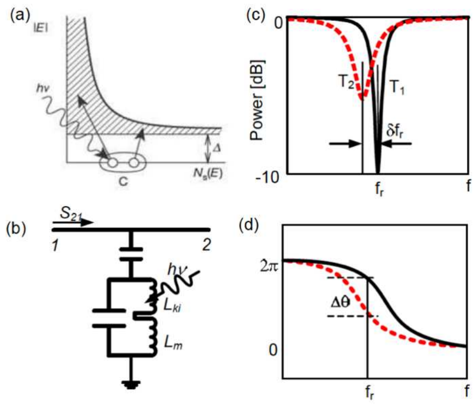


**Fig. 3.** Schematic illustration of MKID operation (a) A photon breaks Cooper pairs and creates quasiparticles in a superconducting strip. (b) The increase in the quasiparticle density changes the surface impedance. (c) The transmission through the resonant circuit exhibits a narrow dip at the resonance frequency $f_r$, which shifts when the surface impedance changes. (d) The microwave probe signal experiences a phase shift when $f_r$changes.

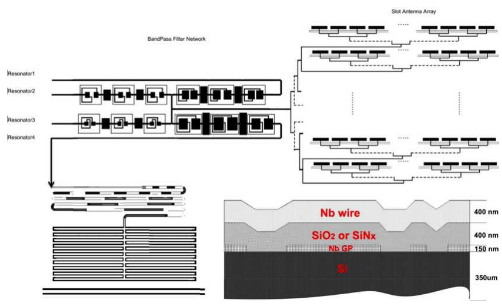


**Fig. 4.** Scaled version of the antenna, BPF network, and KID layout. (Upper right) A phased-array antenna with a binary summing tree is used to capture the signal. (Upper left) Four bandpass filters split the signal from the summing tree into four different frequency bands. (Lower left). The kinetic inductance detector layout. (Lower right) Substrate layers of the detector wafer.

impedance of the aluminum superconductor. Because the aluminum section is part of the meander inductor of the LC resonator, the photons cause the inductance of the LC resonator to change, thereby affecting its resonance properties including the phase and power (i.e., a measure of how the resonator couples to the microstrip line). By monitoring the resonance properties, we can detect signals at submillimeter wavelengths. We call such an LC resonator a microwave KID.Overall, the KID-based instrument that we developed is an ideal choice for use in submillimeter instruments because of the following features:1. The detectors are frequency-domain multiplexed with hundreds of detectors coupled through one feedline. 2. The process for fabricating a large detector array is relatively simple, consisting of two to four layers of a lithographic process on a silicon wafer.3. The readout system for this large detector array has been developed and demonstrated to satisfy large-array requirements.These advantages not only make the KID-based instrument scalable to larger arrays but also allow for cost control on a per-pixel basis.

## 2.2 Readout for Kinetic Inductance Detectors

The readout system will perform frequency domain multiplexed real-time measurements of complex microwave transmission coefficient in order to monitor the instantaneous resonant frequency of superconducting microresonators and changes in their energy dissipation. Each readout unit similar to those used in the MUSIC device will be able to cover up to 550 MHz bandwidth and read 256 complex frequency channels simultaneously. The digital electronics include the customized DAC, ADC, IF system and the FPGA based signal processing hardware developed by CASPER group. In general, the procedure for the KID

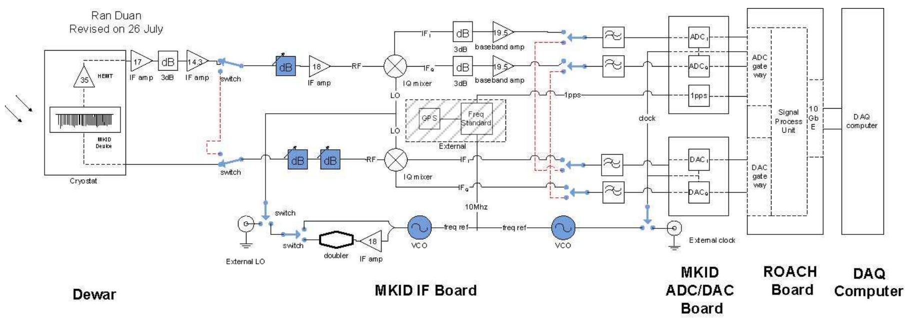


**Fig. 5.** Readout system block diagram.

readout is as follows:

1. A drive tone or carrier tone (which generally ranges from approximately 100 MHz to a few gigahertz) is sent through the transmission line on the device with which the detector is coupled. The drive tone is then modulated by the detector as it responds to the power of the astronomical signal.

2. If the modulated carrier tone is at a frequency that is too high to be directly digitized, it is down-converted using a mixer.

3. The received tone is digitized and processed. This step includes digitizing the analog signal and processing the digital signal using a field-programmable gate array (FPGA), a graphics processing unit (GPU), a central processing unit (CPU), or some combination thereof. The signal from the detector generally requires real-time processing to capture the signal source, reduce the data rate, and extract useful information.

4. Auxiliary information such as a timestamp or information regarding the telescope is stored on the data acquisition (DAQ) computer.

5. Frequently, the raw data must be subjected to additional computer-based processing steps prior to use. These steps may include serialization of the data stream, noise reduction, trans-formation of the data format or units, calibration, or mapmaking.

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