Development of Microwave Kinetic Inductance Detector and its Readout System for LiteBIRD

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***Abstract*—We have developed a microwave kinetic inductance detector (MKID) and its readout system for the satellite LiteBIRD (Light satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection). Primordial gravitational waves generated by inflation have produced an odd-parity pattern B-mode in the cosmic microwave background (CMB) polarization. LiteBIRD aims at detecting this B-mode polarization precisely. It requires about 2000 detectors capable of detecting a frequency range from 50 to 250 GHz with ultra low noise. Superconductive detectors are suitable for this requirement. We have fabricated and tested an MKID and its readout system.**

We have designed an antenna-coupled MKID. Quasi-particles are created by incident radiation and are detected as a change of the surface impedance of a superconductor strip. This change of the surface impedance is translated to the change of the resonant frequency of a microwave signal transmitted through the resonator.

We also have developed a new readout system for an MKID. An MKID can detect signals with a wide dynamic range, and can be multiplexed in a single readout line. The commonly used readout system that monitors the amplitude and phase at a certain resonant frequency is not suitable for LiteBIRD that requires a large dynamic range. We have developed a new readout system capable of tracking the resonant frequency change based on the phase monitoring. We report the recent R&D status of developing a MKID and its readout system for LiteBIRD.

***Index Terms*—LiteBIRD, MKID, Readout, Tracking.**

I. Introduction

PRIMORDIAL gravitational waves (PGW) are relics of the inflation epoch observed in the cosmic microwave background (CMB) radiation.PGW gives us the characteristic polarization pattern, so-called "B-mode" polarization. The precise measurement of this specific polarization pattern corresponds to the detection of primordial gravitational waves, and also leads to the verification of various inflation models.

LiteBIRD(Light satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection) [1] is being designed to aim a detection of the B-mode polarization pattern imprinted on the CMB. The goal of LiteBIRD is precise measurement of the CMB polarization and verification of the inflation model. About 2,000 high sensitive detectors with wide frequency band (50 250 GHz) are needed for this purpose. Due to the limited cooling power, a high multiplexing factor is required for building a large detector array, and the MKID [2] is one of the candidates as suitable detector.

MKID (Microwave Kinetic Inductance Detector) is a kind of the superconductive detectors. A typical MKID is made of a feed line and many resonators which have various resonant frequencies. A resonator has a capacitive coupling to the feed line and the feed line is fed by microwaves of different frequencies. The resonator absorbs appropriate microwaves. When a MKID is irradiated, quasiparticles created by incident radiation are sensed by measuring the change in the surface impedance of a strip superconductor. This effect can be monitored as the phase transition or shifting the resonant frequency of a microwave signal transmitted through the resonator.

One of the remarkable feature of MKID is high multiplexing power. Actually, MKID can be multiplexed in a single feed line, and this characteristic point is suitable for the large focal plane detector array in the satellite. The readout system uses the IQ mixing technique [3] or Fast Fourier Transform (FFT) [4], but they are not enough to take advantage of the multiplexing power. Our newly developing readout system tracks the movement of the resonant frequency for individual resonator by monitoring the phase transition, and hence, it enable us to have a large dynamic range. The new readout system is based on the change of the phase to measure the resonant frequencies. Thus, it is free from fluctuation of the amplitude.

II. Readout System

OUR newly developing readout system make use of IQ mixing technique except the tracking of the resonant frequencies. IQ mixing enables us to readout resonators with random spacing of resonant frequencies. This feature is superior to FFT, and the readout for random spacing frequencies is essential for continuous measurement.

Our readout system handles the microwave signal transmitted through the MKID with FPGA (Field Programable Gate Array). FPGA generates the In-phase ($\sum_{\rm n} \cos \Delta\omega_{\rm n} {\rm t}$) and quadrature ($\sum_{\rm n} \sin \Delta\omega_{\rm n} {\rm t}$) of the probe microwaves, and these microwaves are up-converted into $\sum_{\rm n} \cos\left(\omega \quad \Delta\omega_{\rm n}\right) {\rm t}$ with mixers and hybrid couplers, where ω shows the local oscillator frequency and $\omega \quad \Delta\omega_{\rm n}$ is the frequency of the

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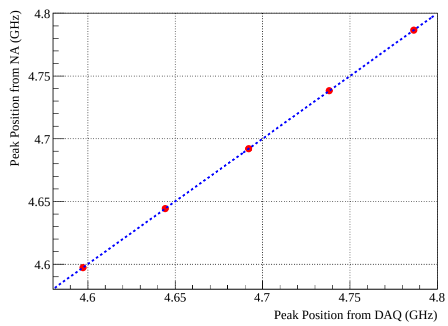

Fig. 1. Resonant Frequencies measured with Our Readout System and Network Analyzer

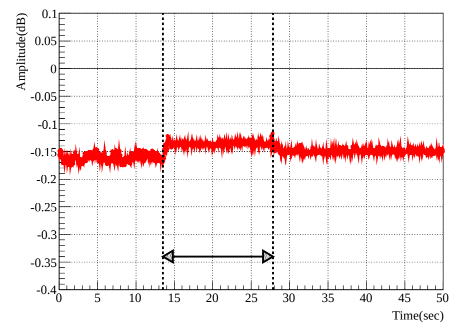

Fig. 2. Variation of the Amplitude of the Resonant Peak (Resonant Cavity). Vertical black dot line shows the time when the resonant frequency was changed.

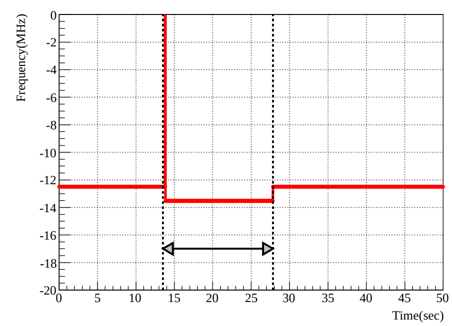

Fig. 3. Behavior of Tracking the Resonant Frequency (Resonant Cavity). Vertical black dot line shows the time when the resonant frequency was changed.

resonator. The transmitted microwaves through the resonators are down-converted and divided into I and Q elements. The I and Q microwaves are mixed with $\cos \Delta\omega_{\rm n} {\rm t}$ and $\sin \Delta\omega_{\rm n} {\rm t}$ respectively, and averaged over certain length of time. A sequence of these steps can be expressed as the following equation.

$$\frac{1}{\rm T}\int_{\rm T} dt \sum_{\rm m} {\rm A_m} \cos \Delta\omega_{\rm m}{\rm t} \cos \Delta\omega_{\rm n}{\rm t} = \begin{cases} \frac{\rm A_n}{2}\cos\phi_{\rm n} & ({\rm m}={\rm n}) \\ 0 & ({\rm m}\neq{\rm n}) \end{cases}$$

$$\frac{1}{\rm T}\int_{\rm T} dt \sum_{\rm m} {\rm B_m} \sin \Delta\omega_{\rm m}{\rm t} \sin \Delta\omega_{\rm n}{\rm t} = \begin{cases} \frac{\rm B_n}{2}\sin\phi_{\rm n} & ({\rm m}={\rm n}) \\ 0 & ({\rm m}\neq{\rm n}) \end{cases}$$

Here, $\rm A_m$, $\rm B_m$ show the amplitude, $\phi_{\rm n}$ is the phase of the resonator, and T is the duration time for averaging the products, which is sufficiently longer than $2\pi/\Delta\omega_{\rm n}$.

The key feature of our readout system is to be able to track the resonant frequency of target resonator. When the resonator is irradiated with millimeter-wave, the surface impedance of superconductor changes and then the phase at initial resonant frequency shifts from ϕ to $\phi + \Delta\phi$. With this event, our system accommodates the frequency to keep the initial value of the phase. Therefore, the resonant frequency of the resonator moves from f to f + Δf.

III. R & D Status

WE built a digital readout system with XtreamDSP Development Kit-IV consisting of a Virtex-4 User FPGA, two ADC channels (14-bit, 105 MHz) and two DAC channels (14-bit, 105 MHz). DACs can create sinuous waves with approximately a quarter of the clock rate. Therefore, bandwidth of the readout system covers about 50 MHz (25 MHz). The actual bandwidth was evaluated by sweeping frequency, finding out several resonate peaks, and comparing them with those of network analyzer. The resonate frequencies measured with our system is in well agreement with the results of network analyzer (Fig.1).

We made a slight modification to our system from previous version [5]. Specifically, we made it possible to control resonant frequencies to be monitored by address. This modification enables us to simplify VHDL code and facilitate the expansion of multiplexed readout. To verify new algorithm, we performed two experiments. One is the experiment with the resonant cavity whose resonant frequency can be changed by hand, and second is that with MKID. In the experiment with MKID, we observed the behavior of the resonant frequency by our system when a MKID was irradiated by visible wavelength. We got positive results from the experiment with resonant cavity (see Fig.2, 3). However, in the experiment with MKID, it is difficult to see the change of the resonant frequency due to the noise although the amplitude was slightly changed.

IV. Conclusion

MKIDS is one of a suitable detector for LiteBIRD, which aims to observe the characteristic pattern of cosmic microwave background polarization. The remarkable feature of this detector is high multiplexed power. We are developing the readout system for MKIDs to maximize its multiplexed power. The key feature of our readout system is tracking the resonant frequency by keeping initial value of the phase. It enables us to have a large dynamic range.

We made a slight modification to our system from previous one, and verified the new algorithm by resonant cavity or irradiating a MKID with optical wavelength. Our system could monitor the resonant frequencies, and follow the variation of the amplitude after irradiation. In addition to this, we confirmed new algorithm worked properly in the experiment with the resonant cavity. On the other hand, it is difficult to observe the change of the resonant frequency due to the noise equivalent of signal when a MKID was irradiated by visible wavelength.

On the basis of these results, we try to test the readout system again after improving the signs-to-noise ratio. Aside from this, we plan to introduce more powerful User FPGA (Virtex-6) to deal with more complicated on-board signal processing.

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