Novel frequency-domain multiplexing MKID readout for the LiteBIRD satellite

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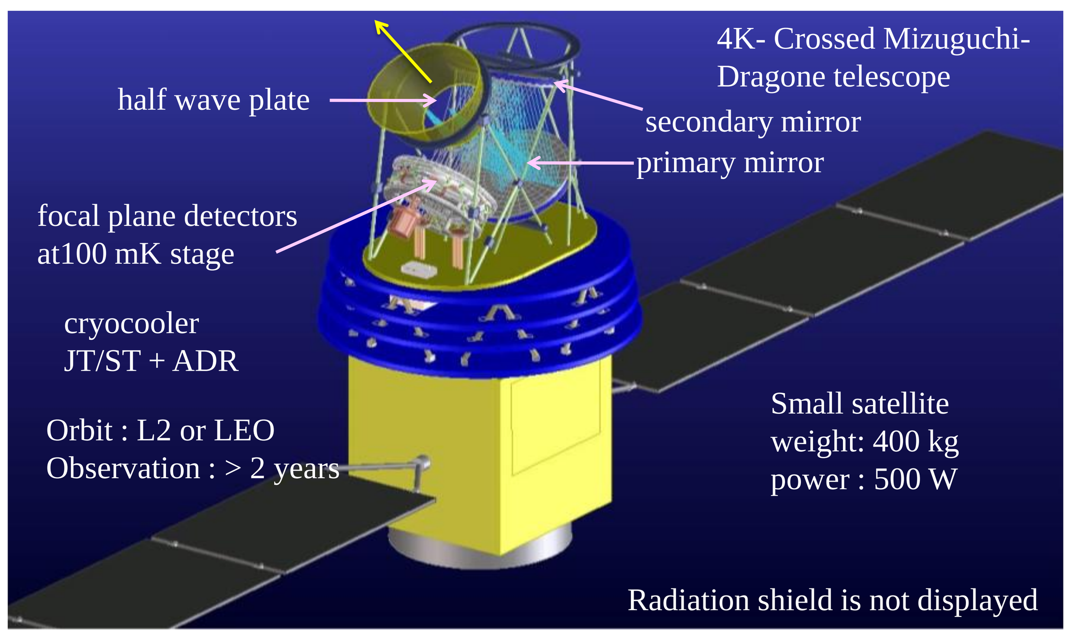
LiteBIRD

(Light satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection)



Freq [GHz]	Beam [degs]	Ndet [#]
60	1.7	312
80	1.3	156
100	1.0	590
150	0.7	434
220	0.47	434
total		1926

LiteBIRD is being designed to aim a detection of the B-mode polarization pattern imprinted on the Cosmic Microwave Background (CMB).

Requirements for focal plane detectors are

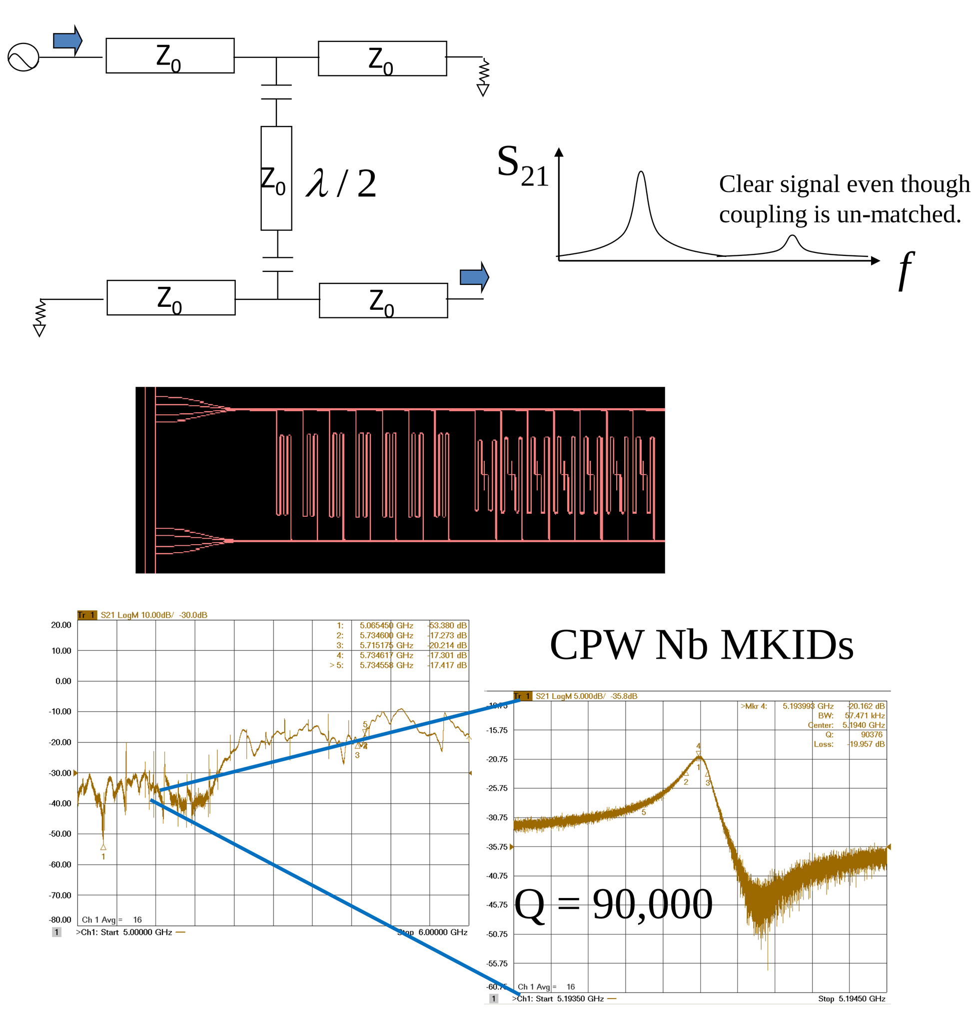
1. a high multiplexing factor → Micro Kinetic Inductance Detectors (MKIDs)
2. wide dynamic range for observing CMB and large signals caused by calibration sources.
   → readout system capable of tracking the resonant frequency of individual resonator.

Transmission-xtype Micro Kinetic Inductance Detectors (MKIDs)

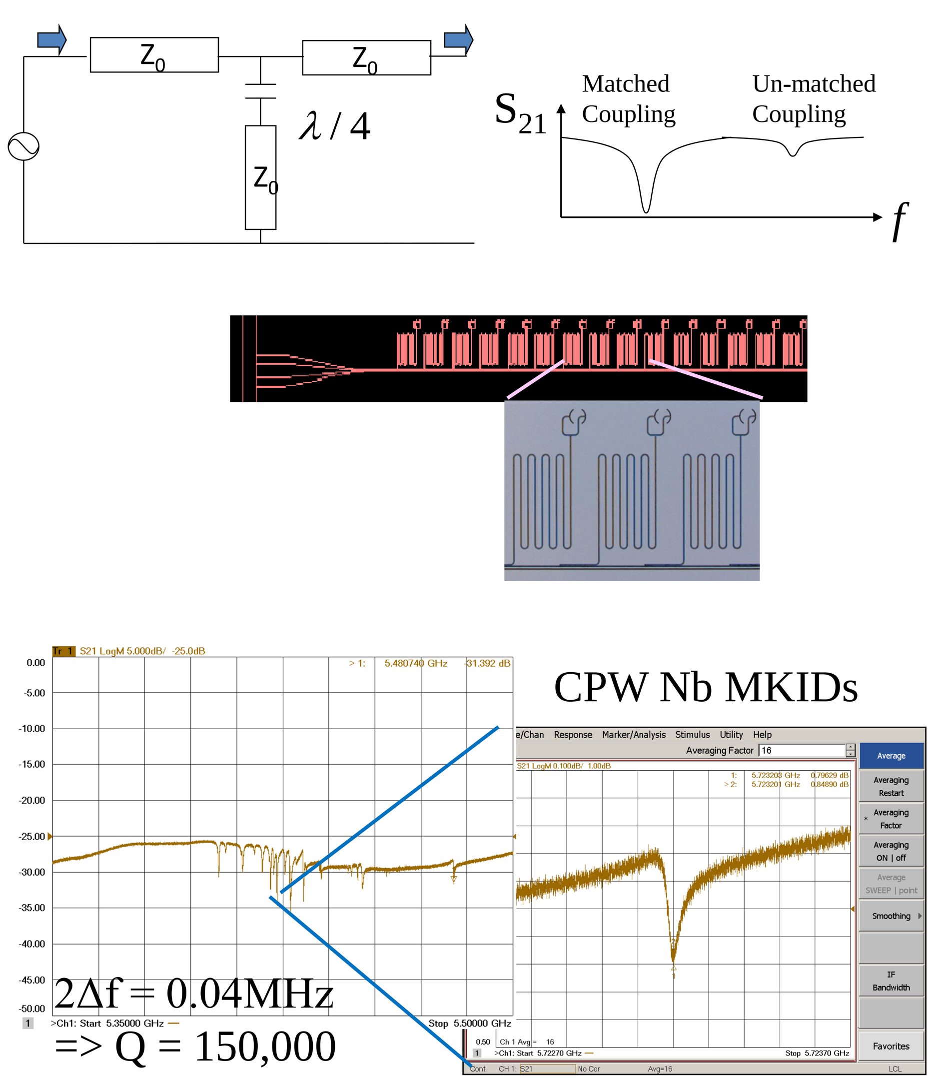
- half wave resonators -

We use the probing microwave that transmits a half wavelength resonator. The advantage of the half wavelength resonator over the quarter wavelength resonator is that the former can discard reflection and background of the probing microwaves, and offers clear microwaves passing through the resonators. The half wavelength resonator that is twice as long as the quarter wavelength resonator deteriorates sensitivity to the incident photons and the quasiparticle density. This can be compensated by making the width of the resonator small, reducing the volume and thus maintaining the quasipartile density.

Transmission type
half wave resonator



Absorption type
quarter wave resonator



The ABCD matrix of the half wavelength resonator can be written as:

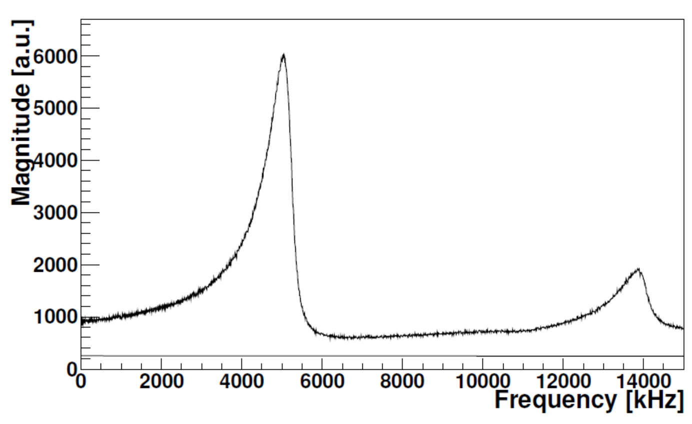
$$\begin{pmatrix} \bar{A} & \bar{B} \\ \bar{C} & \bar{D} \end{pmatrix} = \begin{pmatrix} 1 & -j\bar{X}_c \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\Phi & j\sin\Phi \\ j\sin\Phi & \cos\Phi \end{pmatrix} \begin{pmatrix} 1 & -j\bar{X}_c \\ 0 & 1 \end{pmatrix},$$

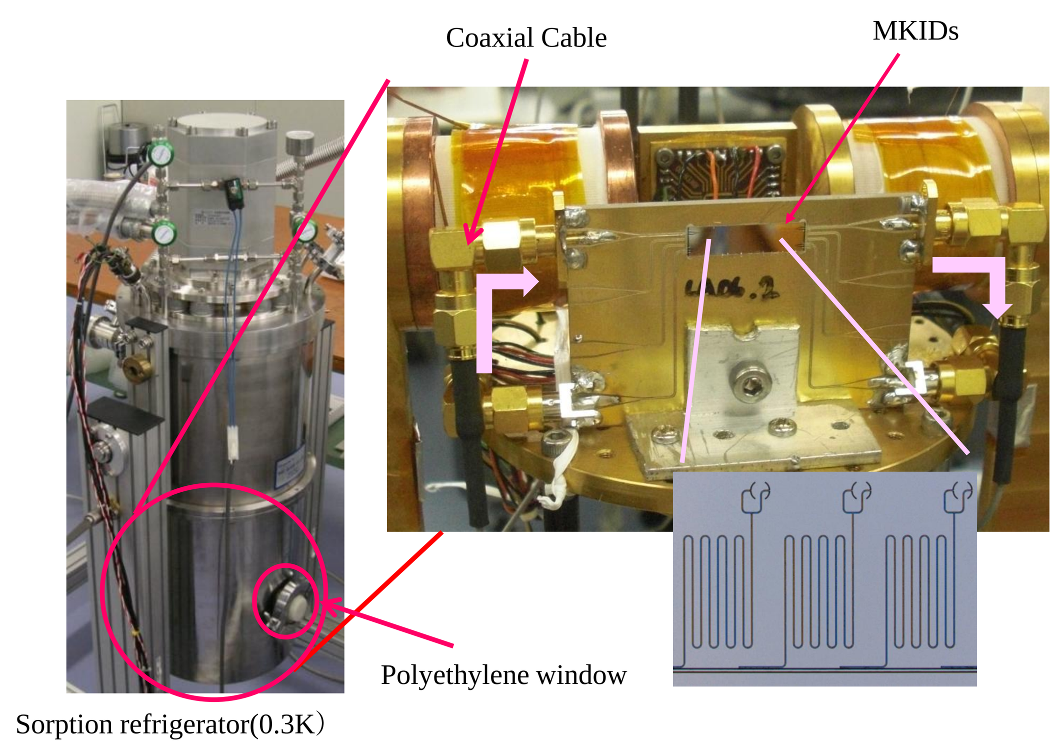
where $\bar{A}$, $\bar{B}$, $\bar{C}$ and $\bar{D}$ are the matrix elements normalized to a characteristic impedance, $\bar{X}_c$ is a normalized impedance of the coupling capacitor, and Φ is a product of the propagation constant and the length of the resonator. The scattering matrix element S_{21} is:

$$S_{21} = \frac{2}{\bar{A}+\bar{B}+\bar{C}+\bar{D}} = \frac{2}{2(\cos\Phi + \bar{X}_c\sin\Phi) + j\{(2-\bar{X}_c^2)\sin\Phi - 2\bar{X}_c\cos\Phi\}}.$$

The resonance occurs at $2\cos\Phi_r = -\bar{X}_c\sin\Phi$, $\Phi_r = \pi - \arctan(2/\bar{X}_c)$.

Aluminum half wavelength resonators used to demonstrate the resonance frequency tracking. The transmission was measured at 0.32 K.





Readout electronics

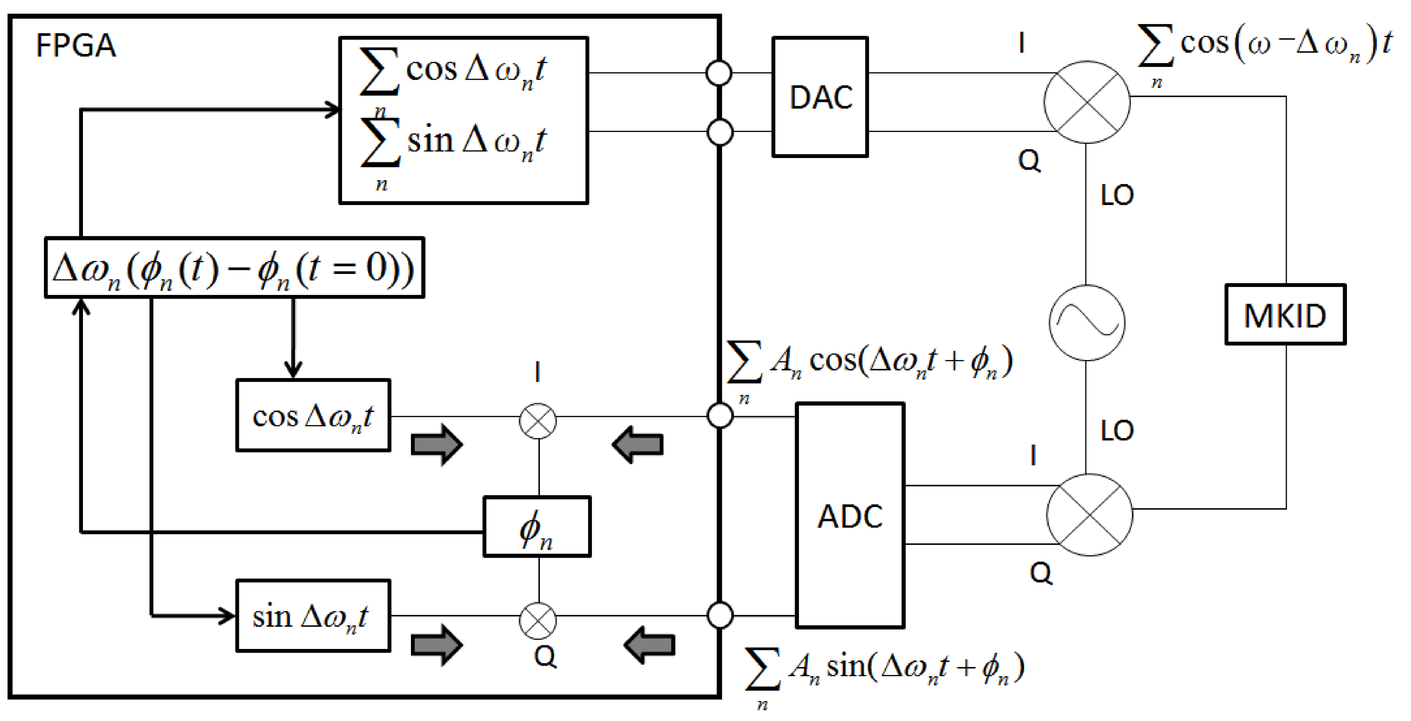
Our readout scheme uses IQ mixing technique.

1. In-phase and quadrature of probe microwaves are generated by an FPGA and up-converted.
2. The microwaves transmitting through the resonators are down-converted and divided into I and Q microwaves.
3. The I and Q microwaves are mixed with $\cos\Delta\omega_n t$ and $\sin\Delta\omega_n t$, respectively, and averaged over certain length of time. This process can be written as

$$I: \frac{1}{T}\int_T dt \sum_m A_m \cos\Delta\omega_m t \cos\Delta\omega_n t = \begin{cases} \frac{A_n}{2}\cos\phi_n & m = n \\ 0 & m \neq n \end{cases}$$

$$Q: \frac{1}{T}\int_T dt \sum_m A_m \sin\Delta\omega_m t \sin\Delta\omega_n t = \begin{cases} \frac{A_n}{2}\sin\phi_n & m = n \\ 0 & m \neq n \end{cases}$$

The multiplication can be done in parallel and yields the phase and the amplitudes of all the resonators simultaneously and continuously.



Virtex-4 FPGA, two ADCs (14 bits, 105 MHz) and two DACs (14 bits, 105 MHz) are used.

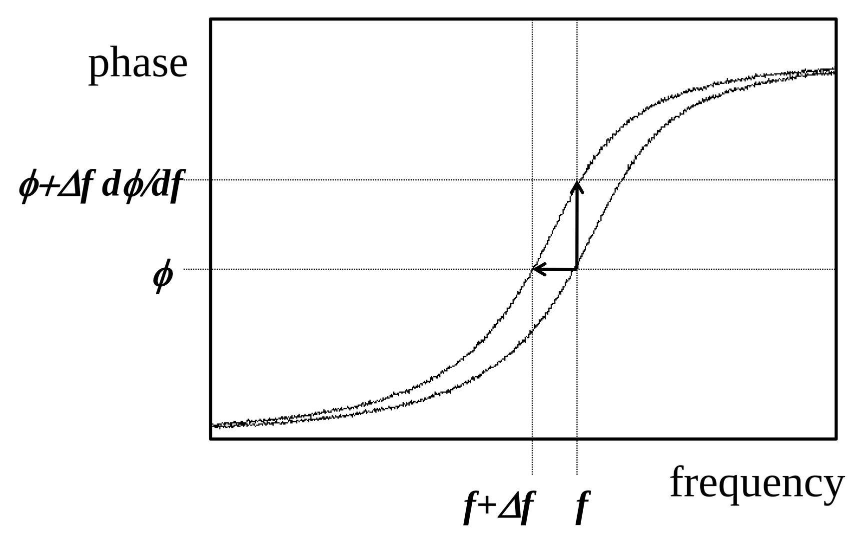
Peak tracking

The system follows the movement of the resonant frequency by keeping the initial value of the phase.

1. The millimeter-wave shifts the resonant frequency from f to $f+\Delta f$, and the phase from ϕ to $\phi + \Delta f d\phi/df$.
2. Calculate and shift the frequency from f to $f+\Delta f$.
3. Fix cable delay effect that is function of f.
4. The phase at $f+\Delta f$ becomes the initial value ϕ.

Every 78 μs

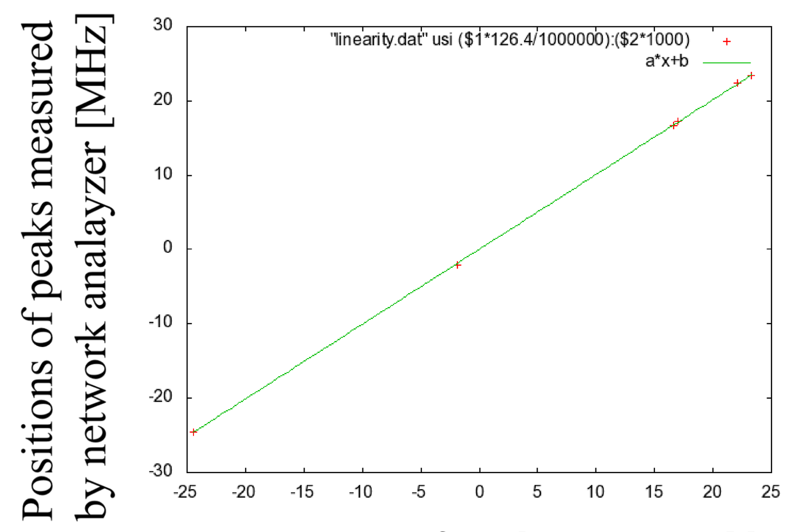
much faster than CMB signals (< 300 Hz)



Bandwidth

DACs are able to produce sinuous waves with approximately a quarter of the clock rate (= 25 MHz).
→Bandwidth should be about 50 MHz

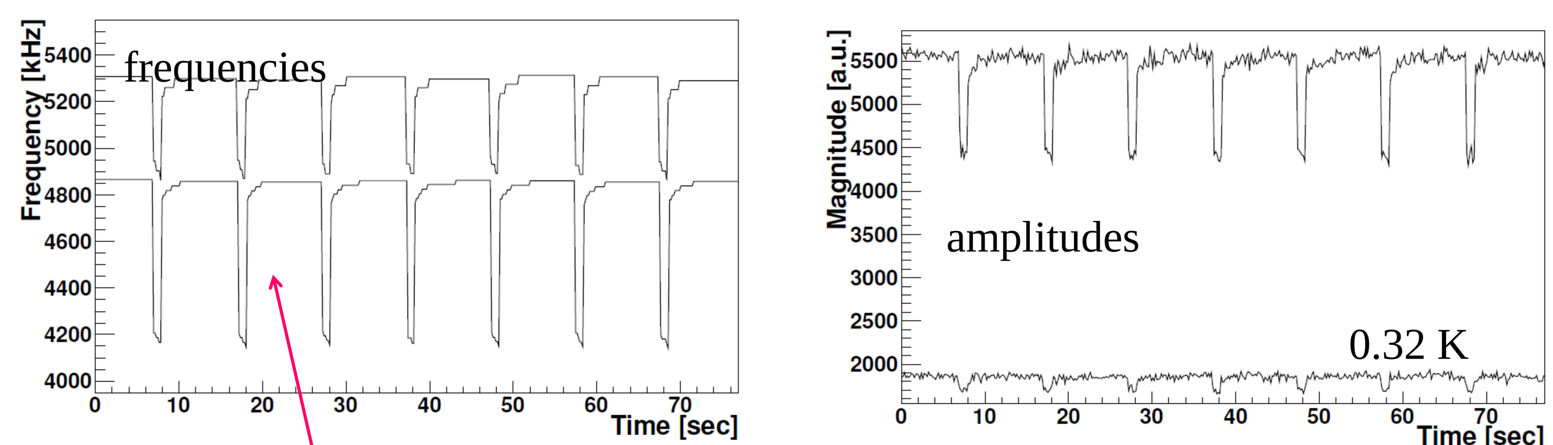
Sweep frequency and find several resonant peaks using our system and a network analyzer.
→ The peaks agree within bandwidth of 50 MHz.



Positions of peaks measured by our system [MHz]

Irradiation of pulsed Millimeter-wave

Aluminum MKIDs are irradiated with 96-GHz pulsed millimeter-waves (ON : 1 sec, OFF : 9 sec). The shifts in frequencies and amplitudes from two resonators were observed.



tail due to a temperature rise during irradiation

Summary

We have successfully demonstrated the MKID readout system with multiplexing and peak-tracking capability for large-dynamic-range measurements.

Future plan…

1. Increase the number of resonators (should be straightforward).
2. Evaluate uncertainties of the tracked frequencies due to the phase noise and $\Delta\phi/df$.
3. Adjust time duration for phase monitoring (now 78 μs).