Resonance Spectra of MKIDs Obtained with Frequency Sweeping Scheme

Makoto Nagai[1]★, Yosuke Murayama[1,2], Tom Nitta[2], Hitoshi Kiuchi[1], Yutaro Sekimoto[3],
Hiroshi Matsuo[1], Wenlei Shan[1], Masato Naruse[4], and Takashi Noguchi[5]

1) NAOJ, 2) University of Tsukuba, 3) JAXA, 4) Saitama University, 5) The University of Electro-Communications

★) makoto.nagai@nao.ac.jp

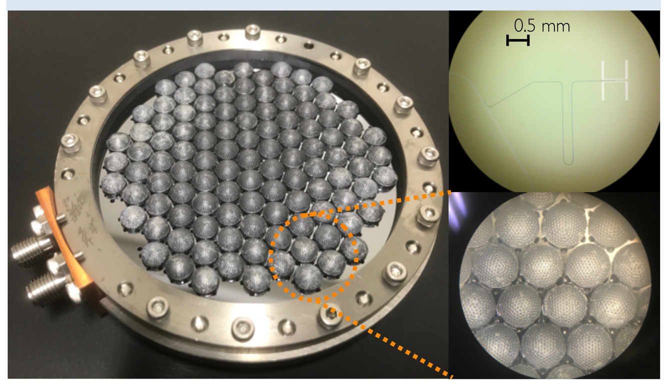
ABSTRACT: We are developing a detector array for astronomical observation in 100-GHz band using Microwave Kinetic Inductance Detector (MKID) and a readout system for the array with frequency sweeping scheme, which uses a frequency sweeping probe signal instead of a fixed-frequency probe signal. This scheme enables us to obtain resonance spectra of MKIDs in an array simultaneously and to derive the resonance frequencies related to the power of incoming radiation. It has the advantage that the dynamic range is higher than the standard scheme, and that the derived resonance frequencies are not affected by changes of gain and delay in the transmission line. The resonance profile measured, however, can be distorted by frequency sweeping, and it is necessary to evaluate the effect of frequency sweeping on resonance spectrum. We made measurements using the scheme with several frequency-sweep velocities and checked dependence of the resonance frequency and the Q-factor on it. A slow frequency sweep causes only small difference of resonance spectrum from an ideal profile, and is suitable for astronomical application.

INTRODUCTION

MKID Camera

Detector array for radio continuum using MKID

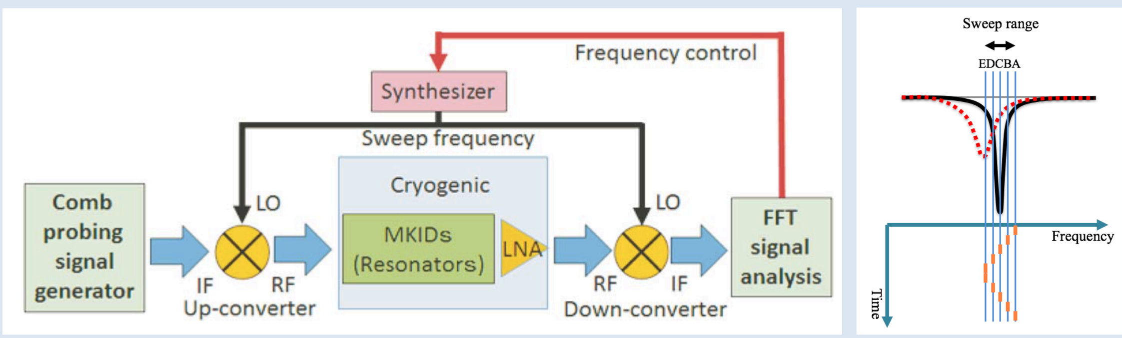
- Multi-pixel readout is a key technology.



Frequency Sweeping Scheme

FFTS + Frequency Sweeping (FS)

- Probe tones are sweeped synchronously.
- Resonance frequency can be determined directly.
- High dynamic range, high frequency resolution.
- Robust against gain and delay variation.



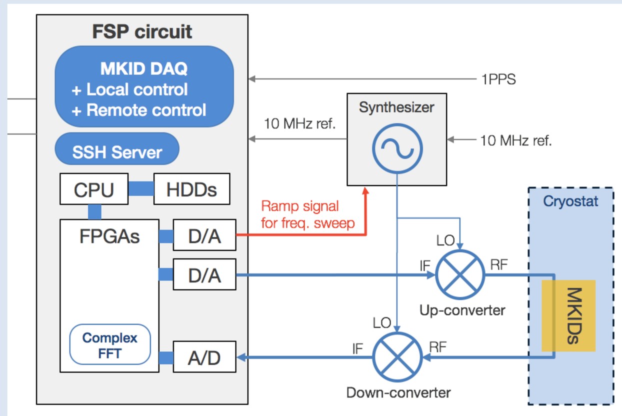
MEASUREMENT

We measured a MKID array fabricated at Advanced Technology Center (ATC), NAOJ, using different frequency sweep velocities in dark condition.

- 109 pixel array of slot antenna + Al MKID for 90—110 GHz band
- Readout system: proto-type FS probe circuit
- 4 resonances in 3.3—3.8 GHz band chosen, measured simultaneously
- Frequency step changed w/ FFT window fixed (4 μs)
- Scan velocity: 0.25 — 2.345 GHz/s (e.g. we use VNA with ~2.5 MHz/s)

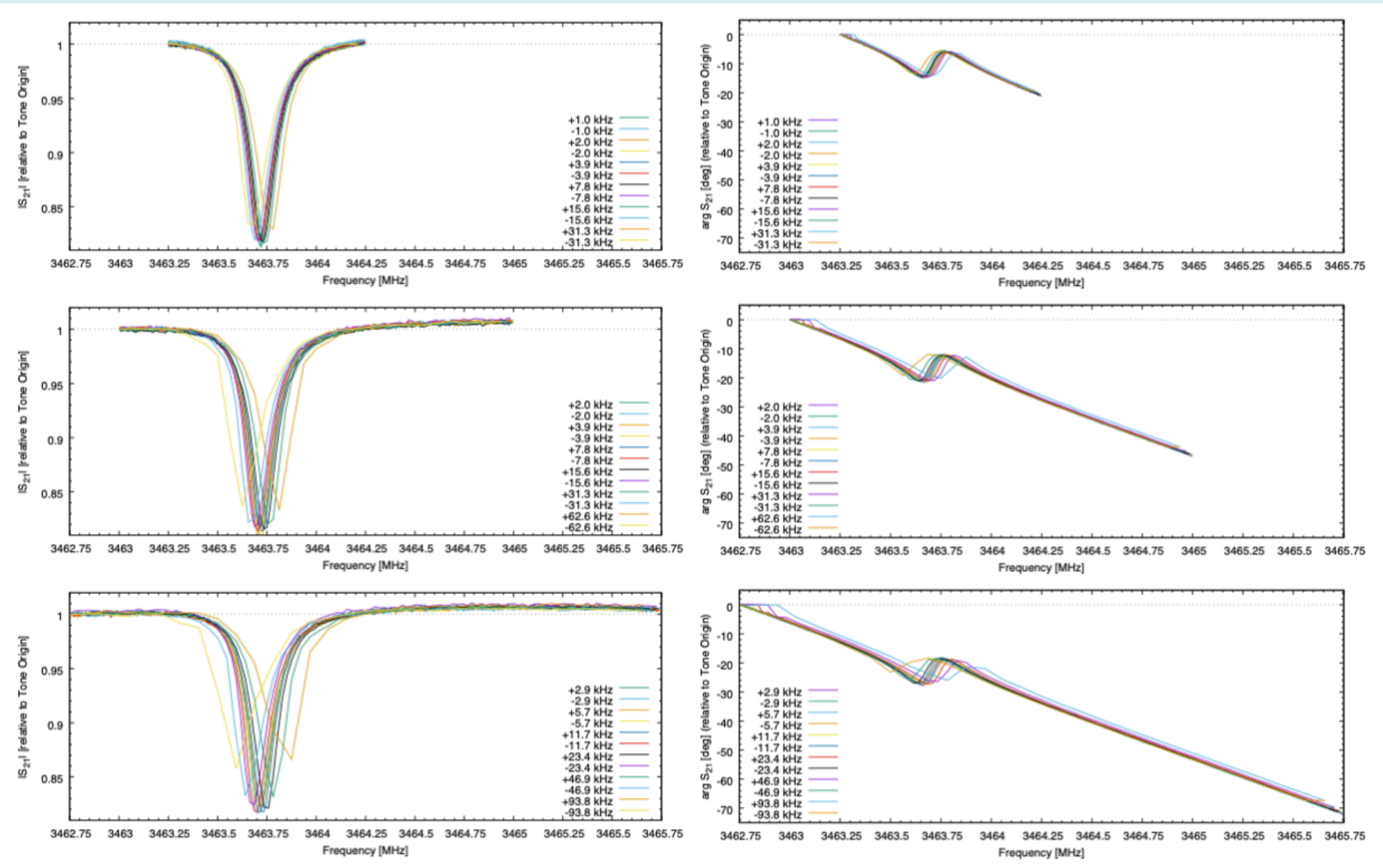
Table 1 Bin Width of Frequency Sweep Step

	Step [kHz]		
Steps	1 MHz	2 MHz	3 MHz
2^5	31.3	62.6	93.8
2^6	15.6	31.1	46.9
2^7	7.8	15.6	23.4
2^8	3.9	7.8	11.7
2^9	2.0	3.9	5.7
2^{10}	1.0	2.0	2.9



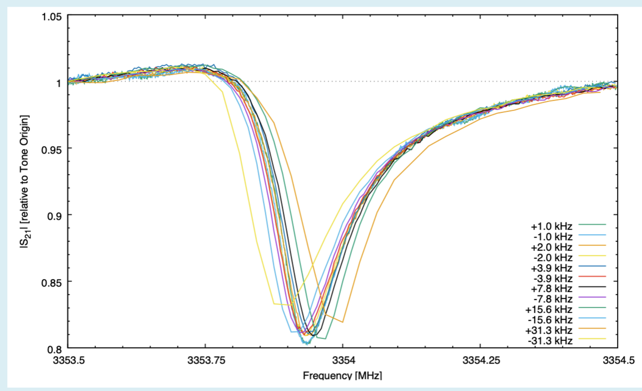
RESULT

Resonance Spectra



All spectra of a resonator (#2), amplitude and phase.

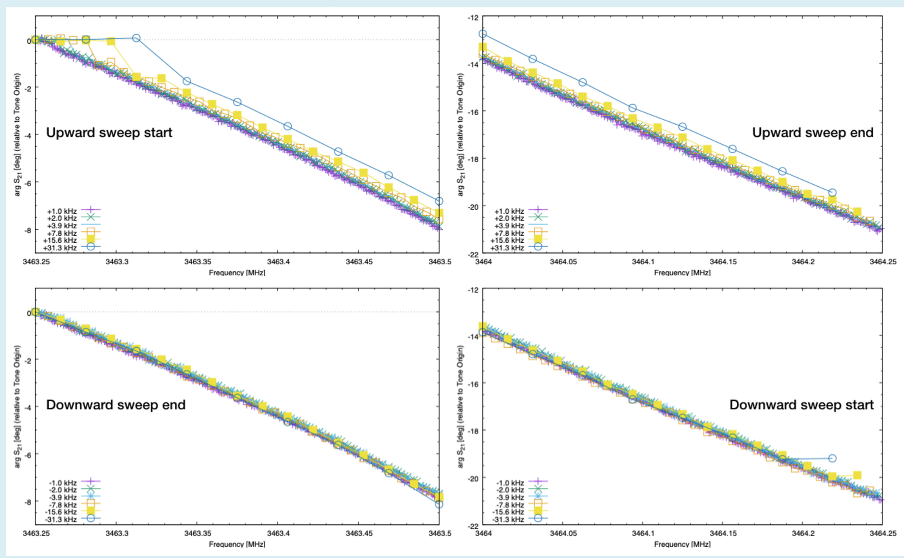
- Among the spectra, 3 resonators have symmetric resonance shape while 1 resonator has an asymmetric profile.
- Resonance shape moves toward direction same as sweeping.
- Higher the sweep velocity, larger the distorsion of shape.
- Largest sweep steps are comparable to the resonance width.



A resonator w/ asymmetric profile (#1)

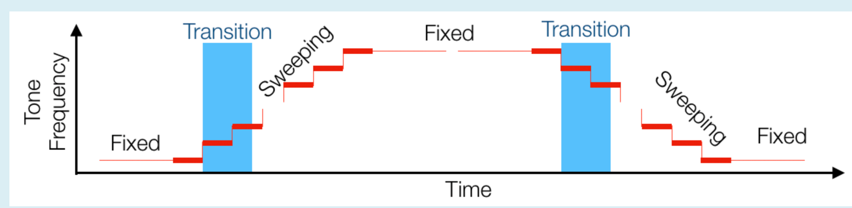
Ends of Sweep Range

There appears a feature of phase at starting part of sweeping, which is at off resonance.



Phase of spectra of a resonator (#2)

This probably comes from the transition from a state of fixed tone to that of sweeping tone.



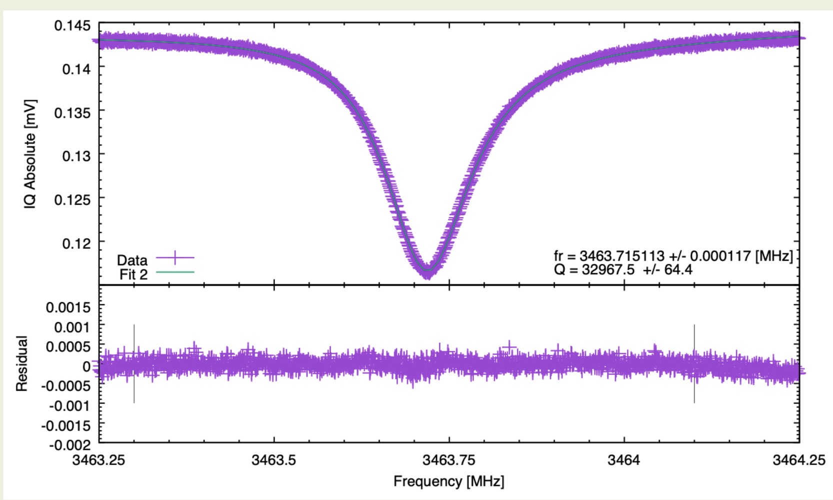
DISCUSSION

Resonance Parameters

Fitting to IQ amplitude, $|S_{21}|$, w/ skewed Lorenzian

$$x(f; f_r, Q) = Q\frac{f - f_r}{f_r}$$

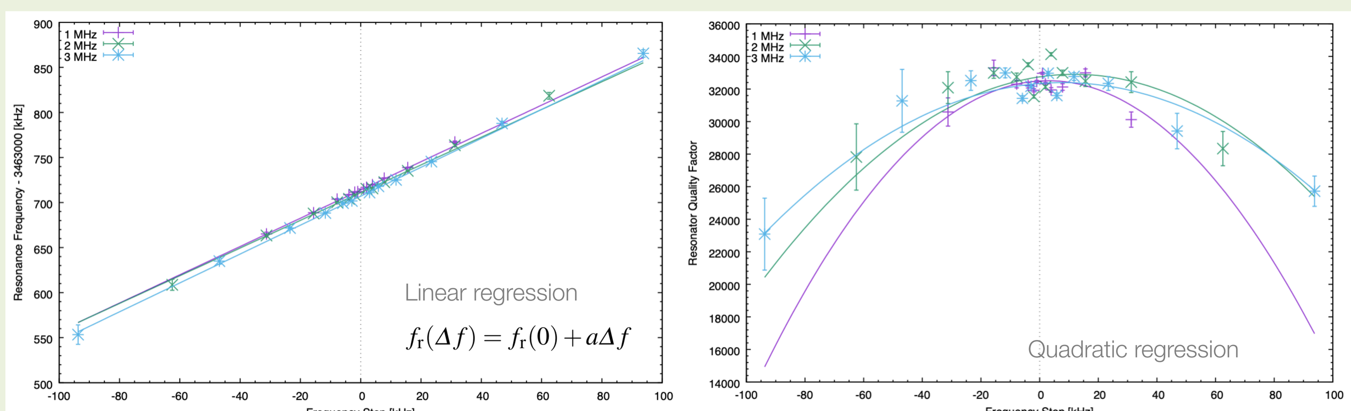
$$S(f; f_r, Q, a_1, a_2, c_0, c_1, c_2) = c_0 + c_1(f - f_o) + c_2(f - f_o)^2 - \frac{a_1}{1 + 2x^2} + \frac{a_2 x}{1 + 2x^2}$$



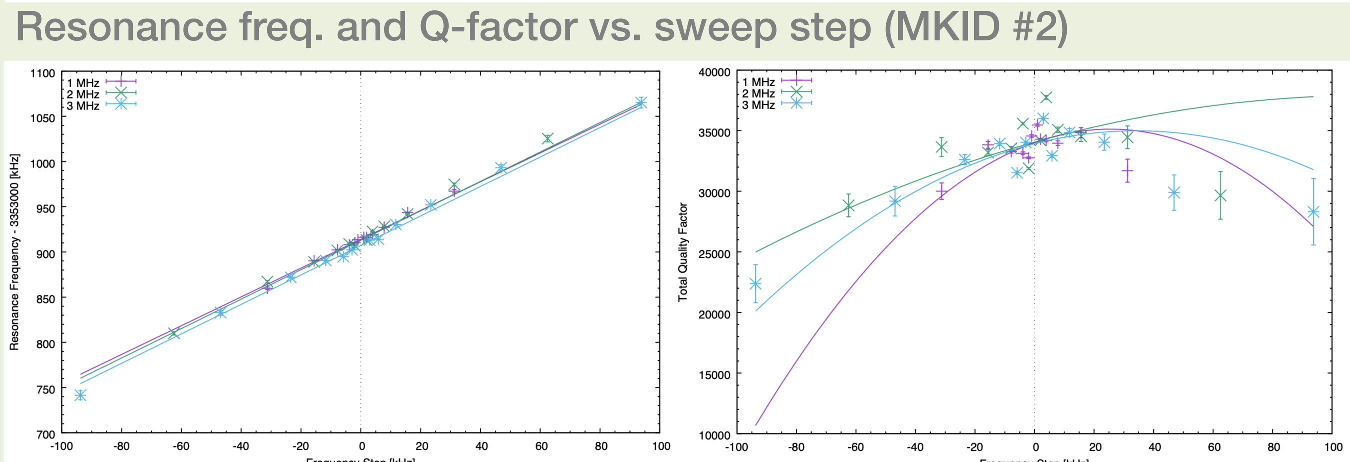
Example of fit: MKID #2, sweep width of 1 MHz, +1.0 kHz step.

Table 2 Resonance Paramters and Coefficient of Frequency Shift by Sweeping

MKID	f_r [MHz]	Q	a Sweep Width 1 MHz	2 MHz	3 MHz
# 1	3353.914	3.4×10^4	1.59 ± 0.07	1.63 ± 0.15	1.63 ± 0.09
# 2	3463.714	3.2×10^4	1.57 ± 0.05	1.54 ± 0.06	1.60 ± 0.04
# 3	3708.497	3.8×10^4	1.66 ± 0.04	1.64 ± 0.02	1.71 ± 0.04
# 4	3733.440	4.0×10^4	1.71 ± 0.07	1.68 ± 0.04	1.72 ± 0.04



Resonance freq. and Q-factor vs. sweep step (MKID #2)



Same plots for an asymmetric resonance (MKID #1)

- Apparent resonance frequency is linear of sweep velocity for all data, and values of coefficient, a, are almost the same.
  - It corresponds to a delay of ~6 μs, but actual delay is ~40 ns.
- Q-factor shows a tendency to decrease with higher sweep velocity, though they have dispersion.

CONCLUSION

- Resonance shape is changed by sweeping, while the resonance frequency shift is propotional to sweep velocity.
- Mechanism of distortion by sweeping is not understood yet; it is not a simple frequency slip.
- Resonance frequency shifts by sweeping can be corrected, and thus the sweeping scheme can be used for MKID camera operation.

Future Prospects:

- Measurement under optical condition
- Physical model of a resonator and frequency sweeping

References:

1. H. Kiuchi+, IEEE TST **5**, 456 (2015)
2. K. Karatsu+, JLTP **176**, 459 (2014)
3. M. Nagai+, JLTP **193**, 585 (2018)