Frequency sweeping scheme
Readout system

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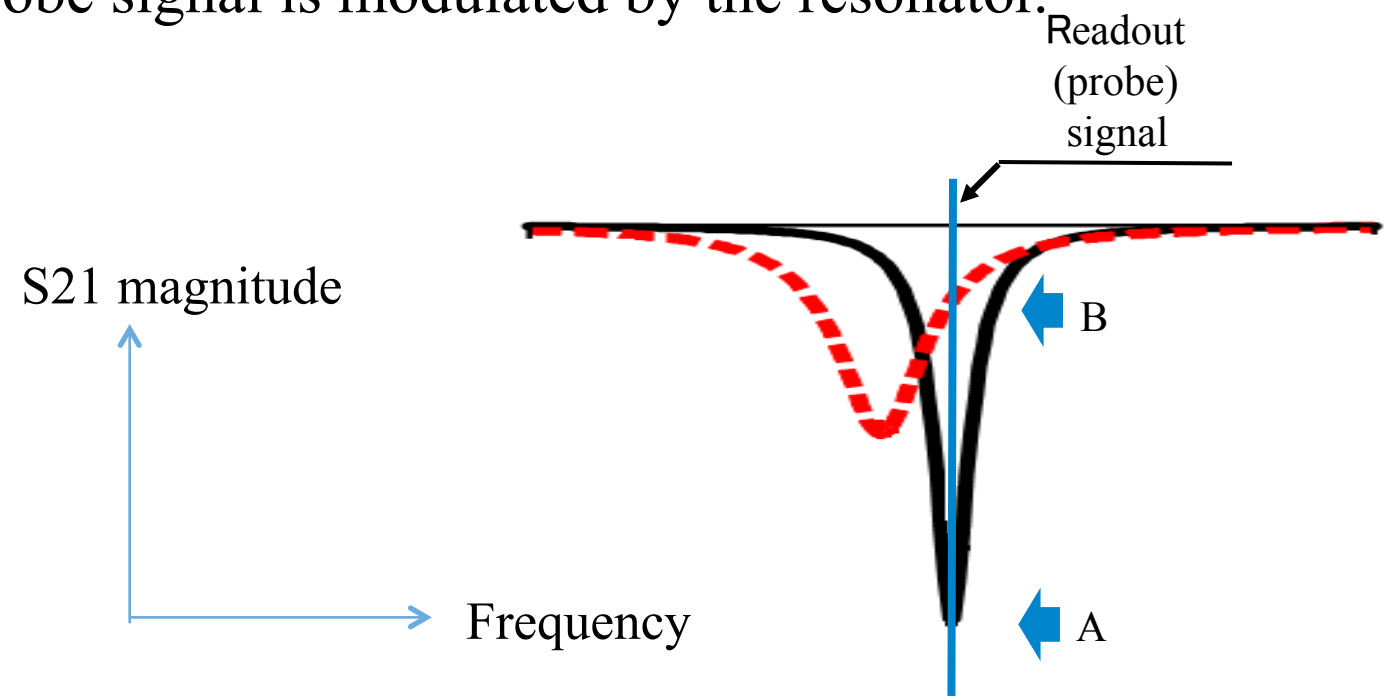
How to detect optical loading ?

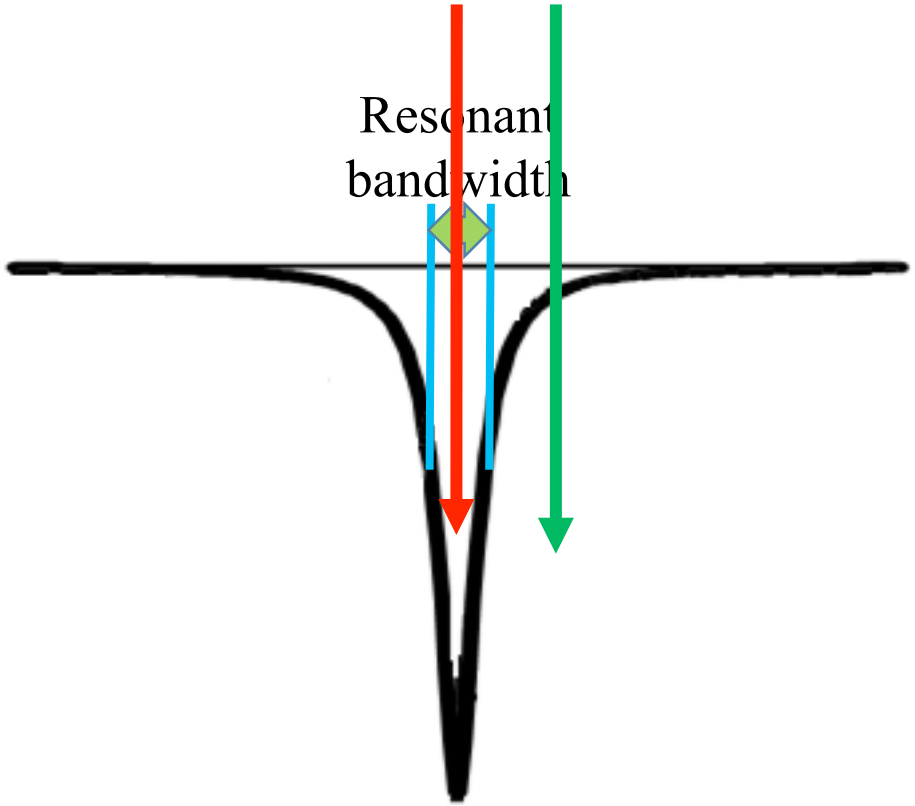
The MKID detects the optical loading as the change in the resonance frequency.
The probe signal is modulated by the resonator.



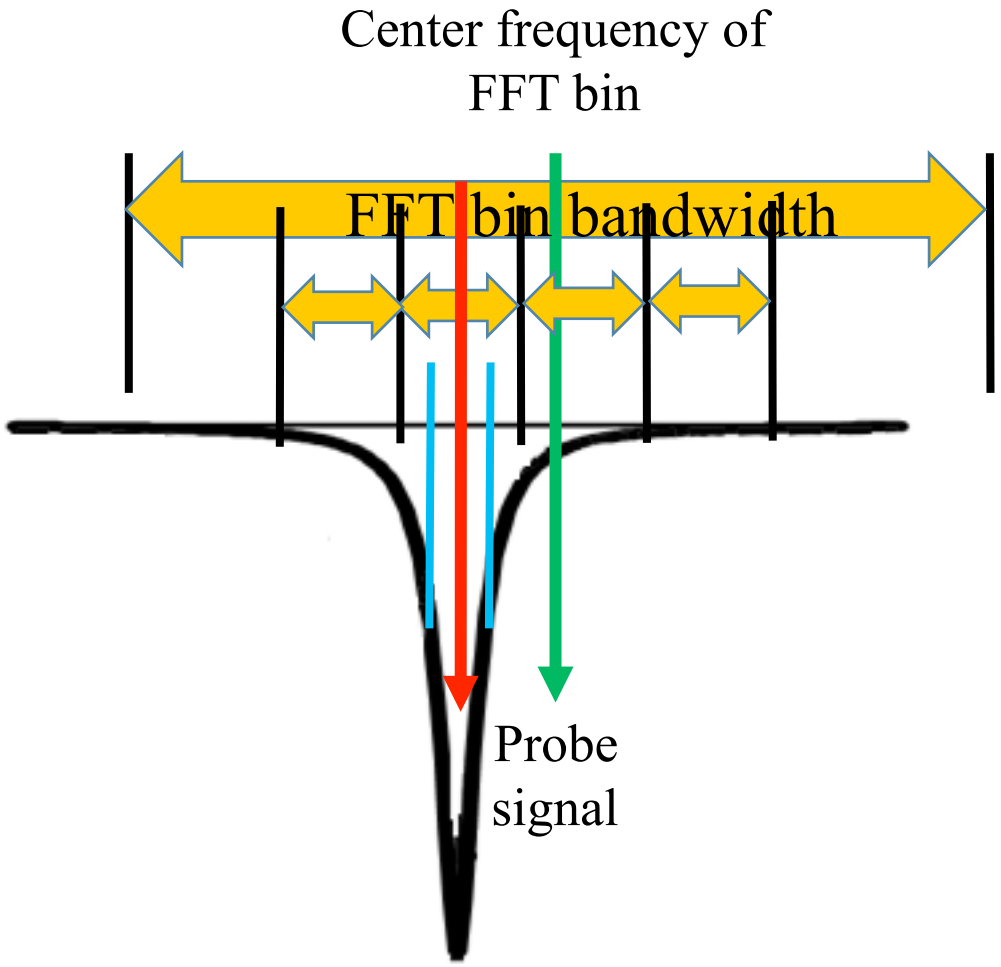
Initially, a microwave probing signal is tuned to the resonant frequency of the lowest optical loading state, and any optical loadings are estimated from the changed phase and amplitude at the probing signal frequency.

Requirements on the readout (probe) signal?

Measured SNR is not sufficient if the probe signal is not within the resonance bandwidth. The probe signal frequency should be adjusted into the resonant bandwidth precisely or the detected signals have low SNR.



One possible solution to improve the frequency resolution is to increase the number of FFT points.

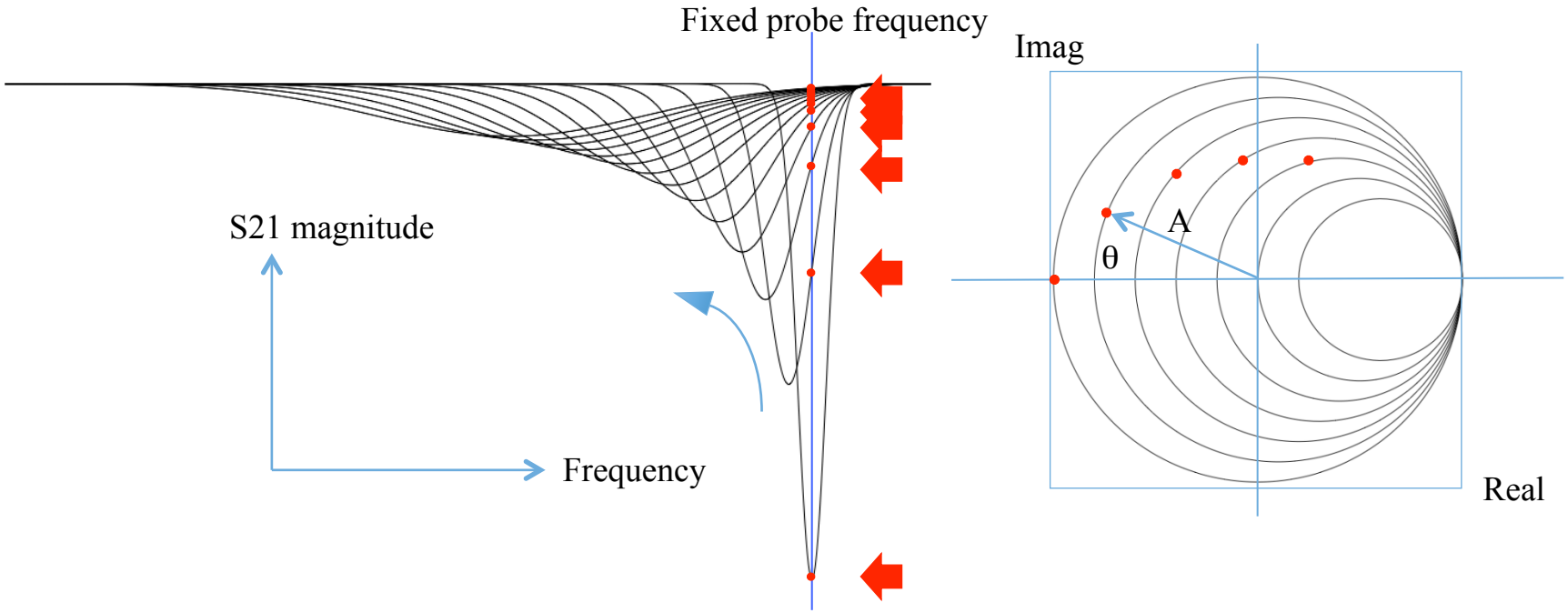


Increasing the number of FFT points makes the readout system larger.

An optical loading causes the resonance frequency to shift to lower frequency and the resonance dip to decrease in depth.

The shifted resonant frequency is estimated by the fixed probing signal.

The changed resonant frequency is measured indirectly.



It requires high-quantization A/D.

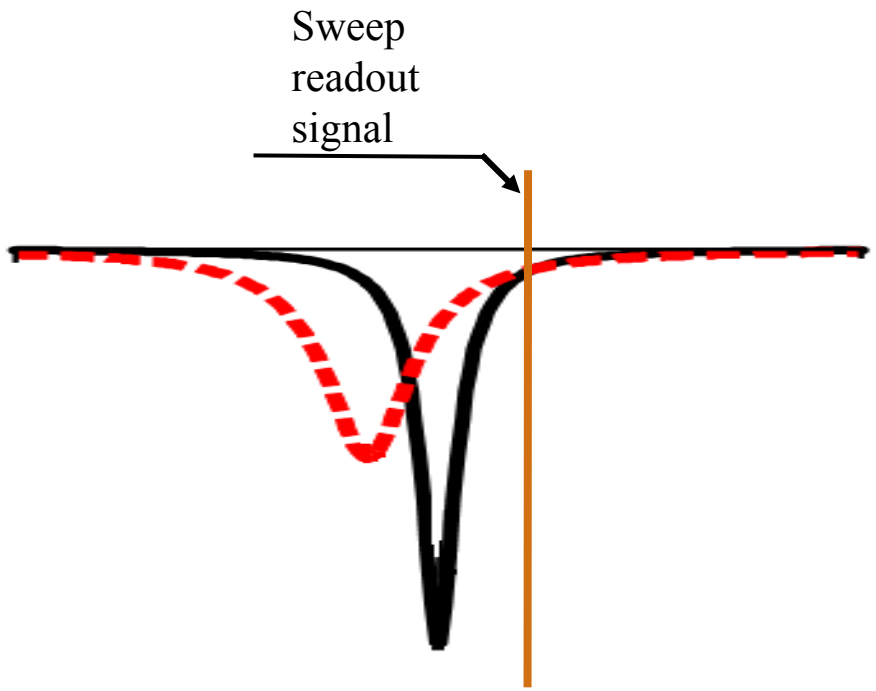
(1) To maintain sufficient SNR even with the optical loading states, this method requires a high-quantization A/D converter.

(2) The frequency bandwidth of the probe comb signals increase with the array scale, frequency domain multiplexing array requires a high-rate-sampling A/D converter.

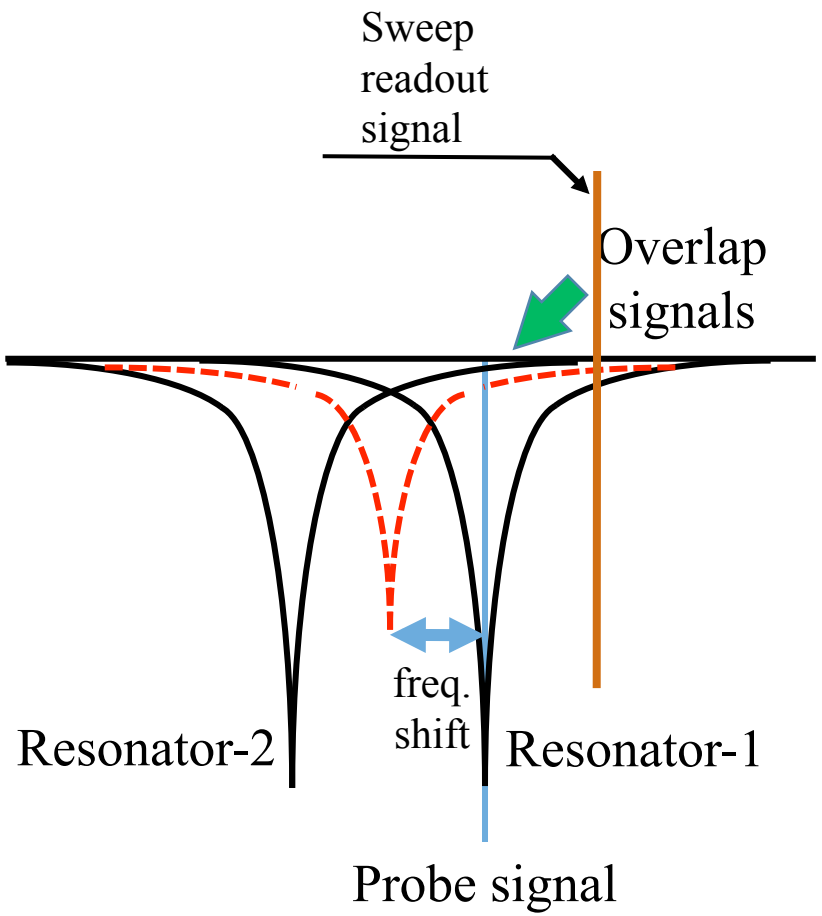
The high-quantization and the high-rate-sampling are incompatible functions.

Local frequency sweeping scheme

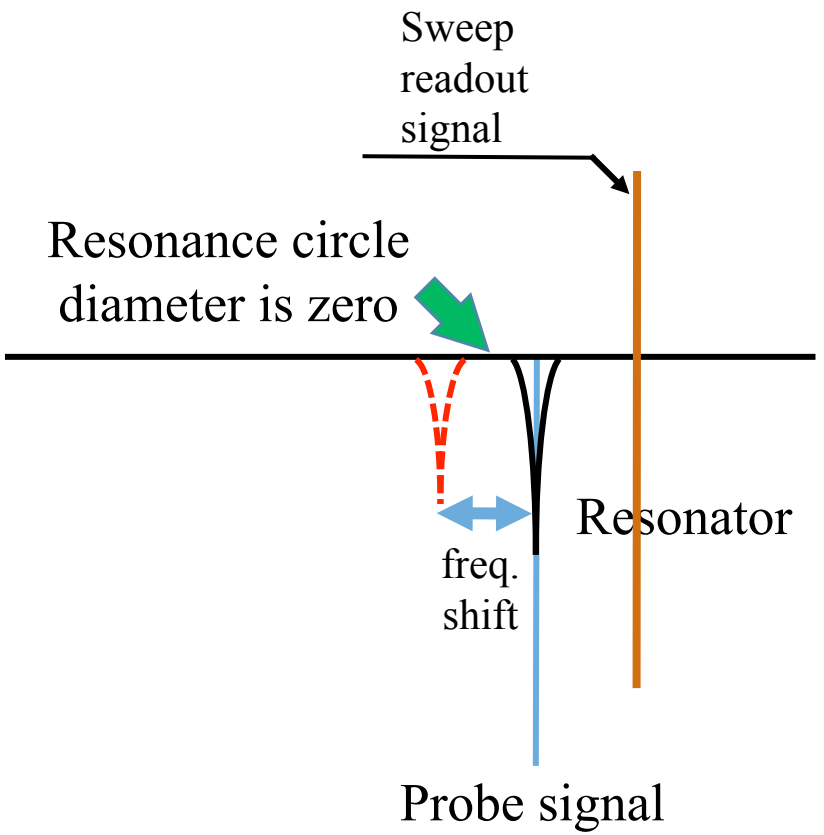
In this scheme, the resonance frequency is
directly measured by a swept frequency probe signal,
making it possible to measure the phase/amplitude
after optical loading with a high-SNR.



The precise initial frequency tuning is unnecessary.

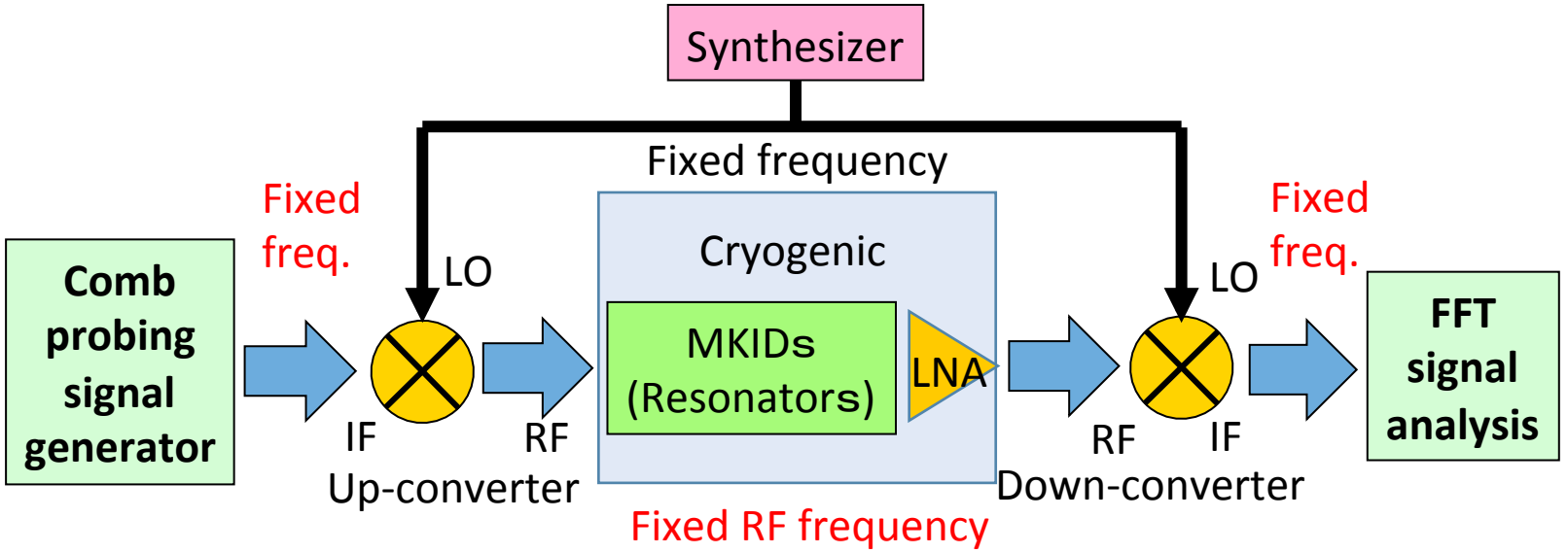


A strongly coupled resonator



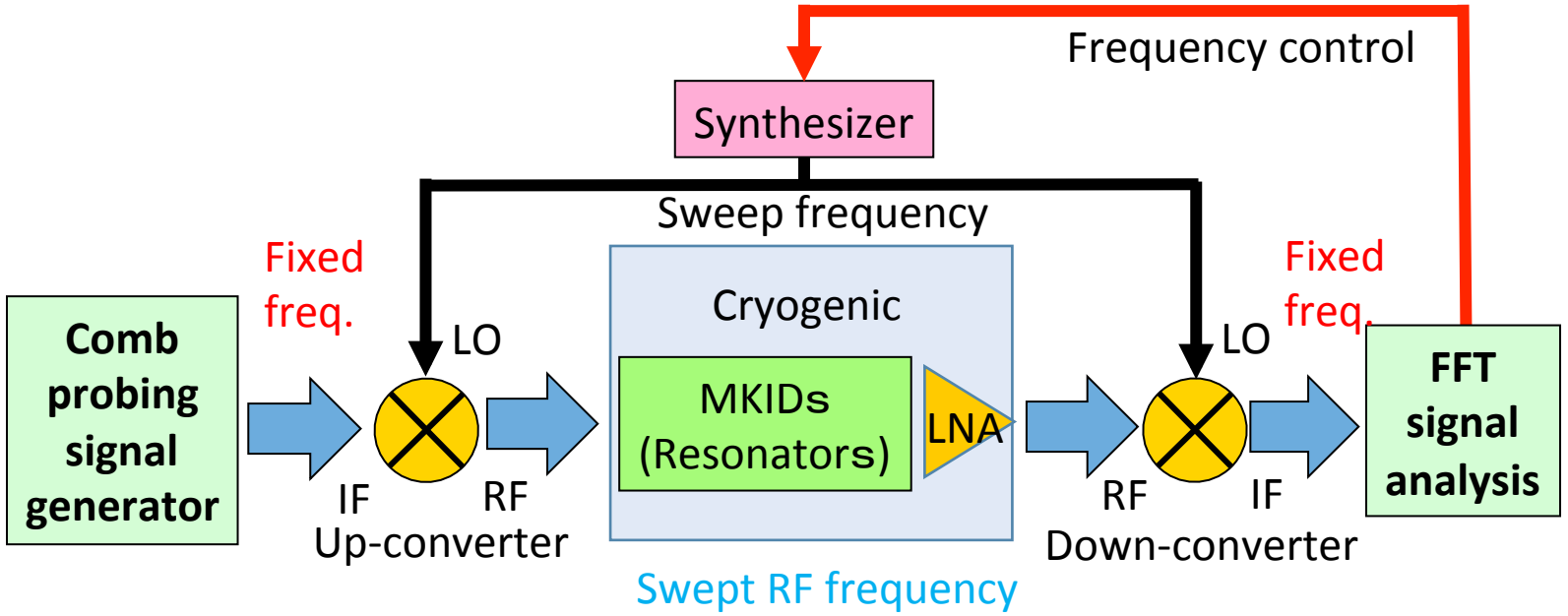
A weakly coupled resonator

Current scheme



A synthesizer provides the LO signal,
forming a homodyne frequency conversion scheme.

Local frequency sweeping scheme



Forming a homodyne frequency conversion scheme.

From a view of the readout system, the digitally generated comb signal and the received comb signal are exactly same frequency in any case.
Due to the LO signals of down-converter and up-converter being common, the phase instability of the frequency sweep of the LO signal is canceled out.

Two applications:

(1) Increase frequency resolution

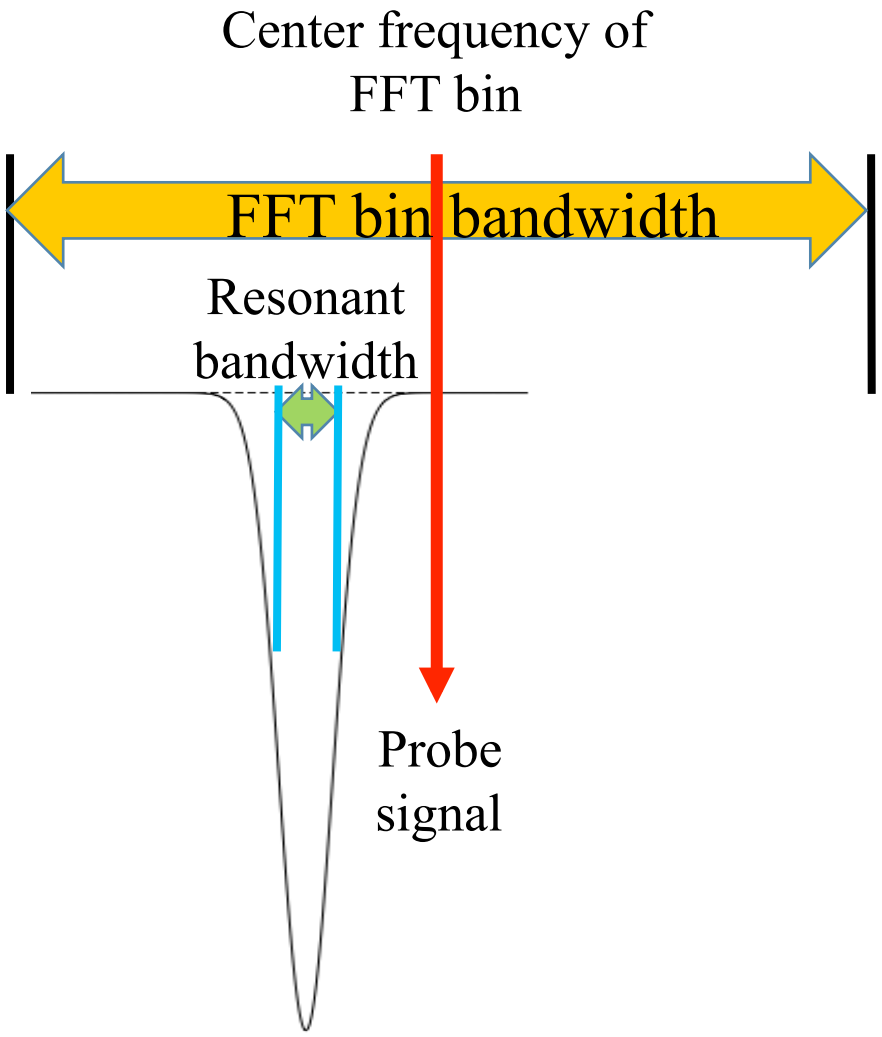
Sweep frequency range < FFT bin bandwidth

(2) Increase frequency dynamic range

Sweep frequency range > FFT bin bandwidth

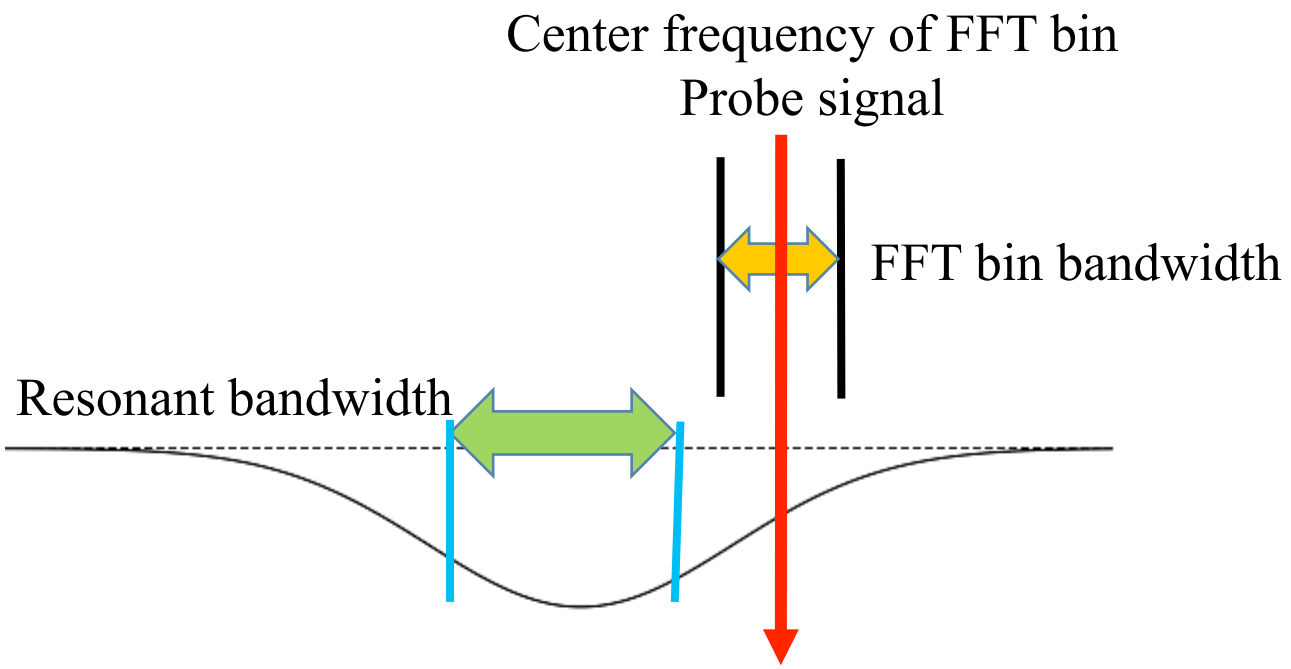
Increase frequency resolution

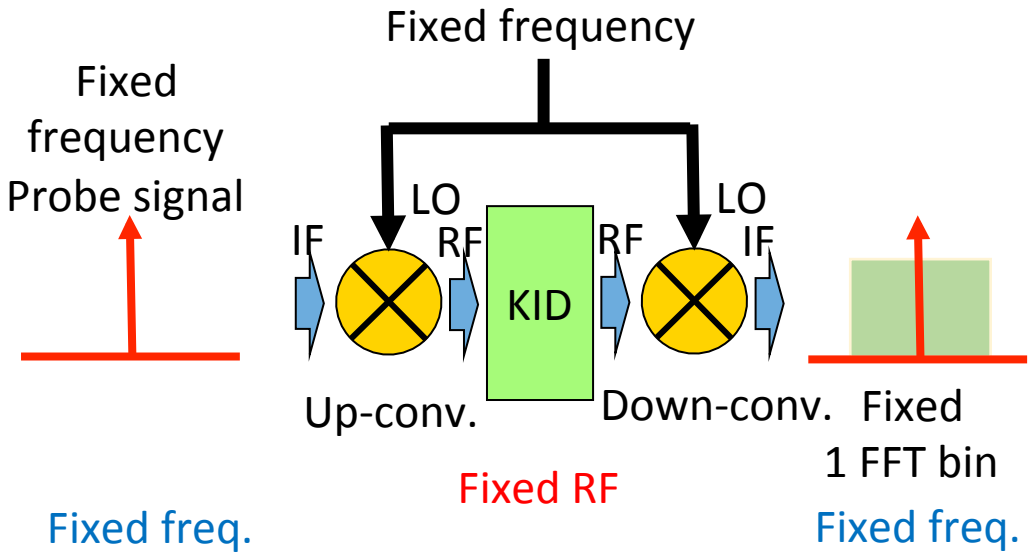
Sweep range < FFT bin bandwidth

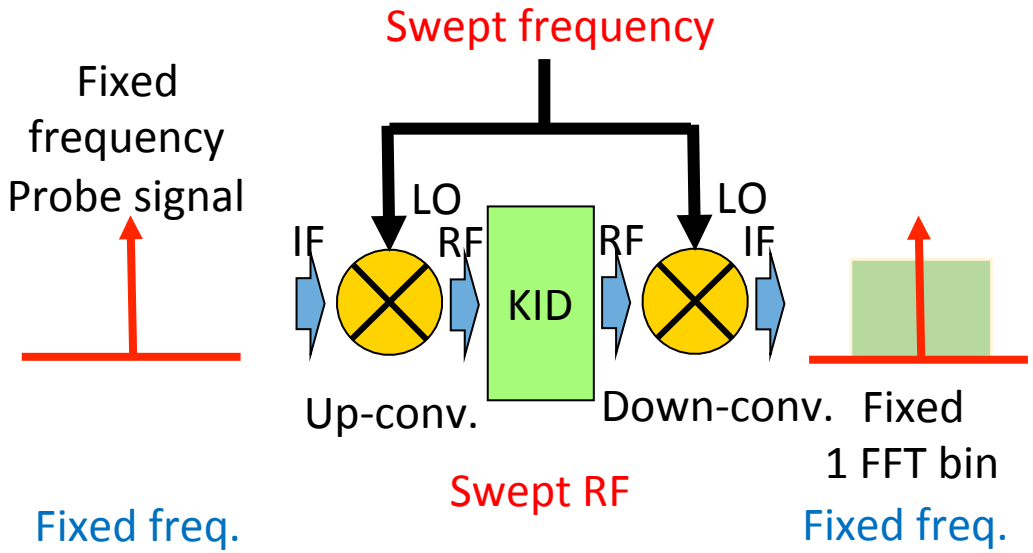


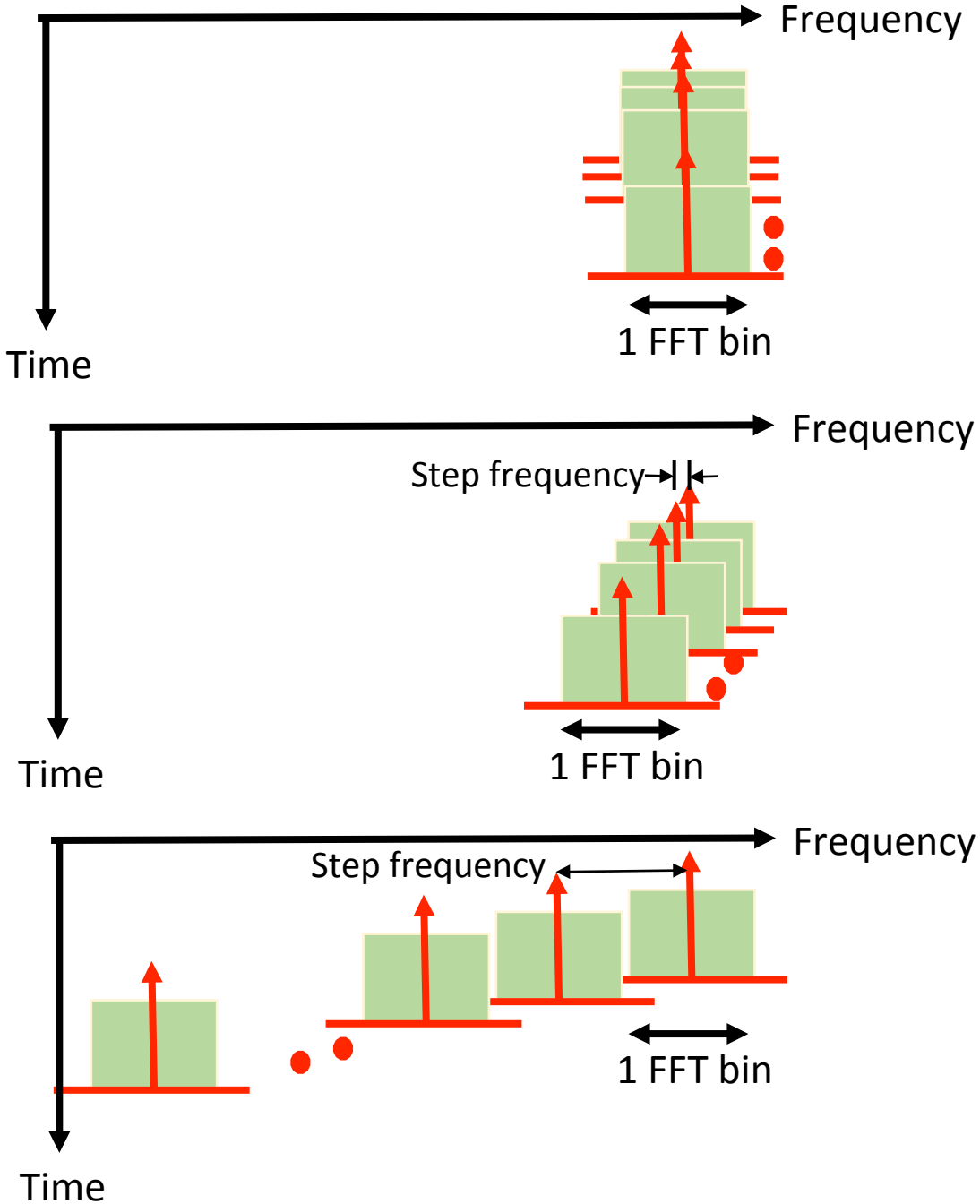
Increase the dynamic range

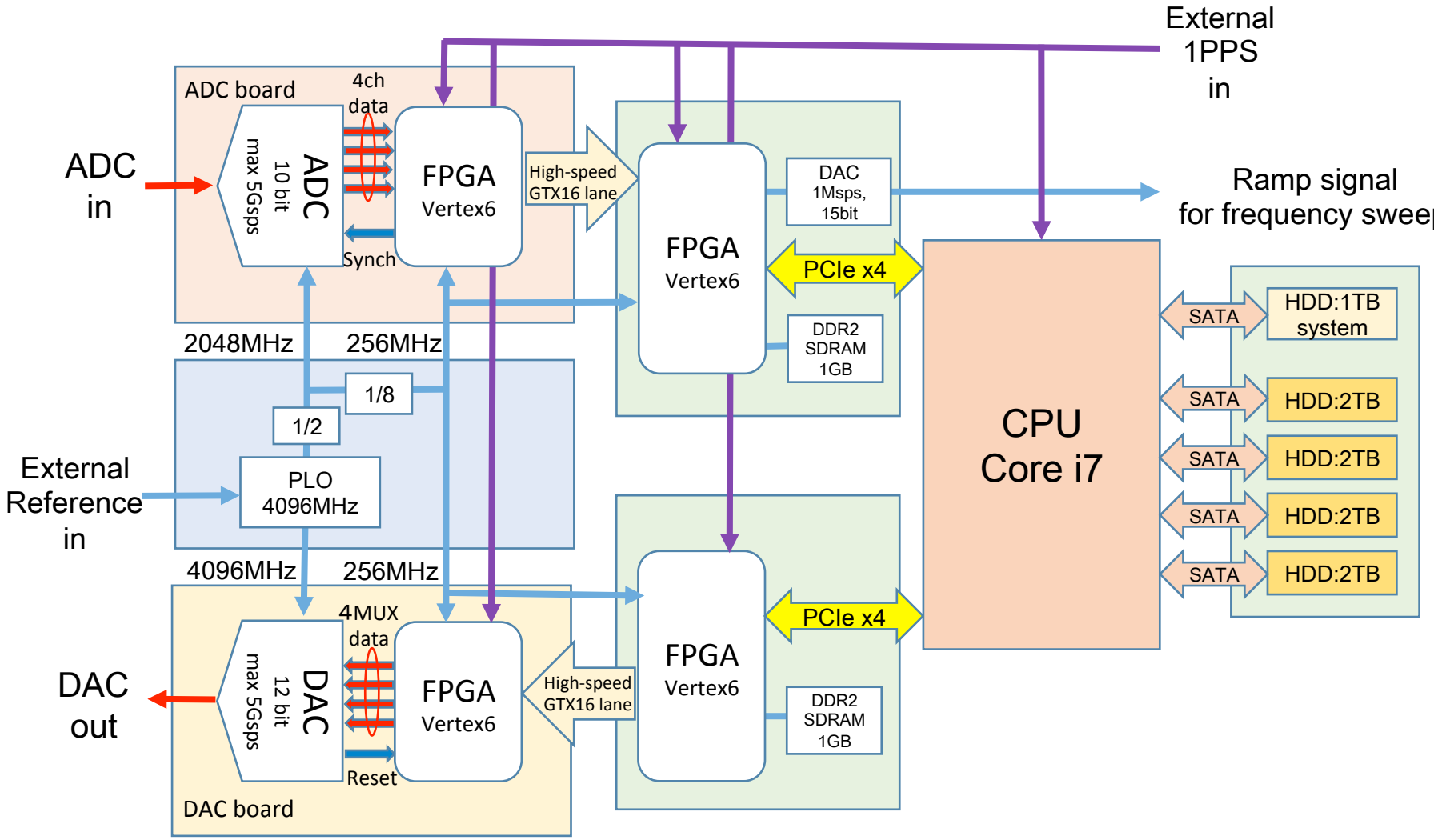
Sweep range > FFT bin bandwidth




Fixed frequency
Fixed frequency Probe signal
LO
IF
RF
KID
RF
LO
IF
Up-conv.
Down-conv.
Fixed 1 FFT bin
Fixed RF
Fixed freq.
Fixed freq.


Swept frequency
Fixed frequency Probe signal
LO
IF
RF
KID
RF
LO
IF
Up-conv.
Down-conv.
Fixed 1 FFT bin
Swept RF
Fixed freq.
Fixed freq.

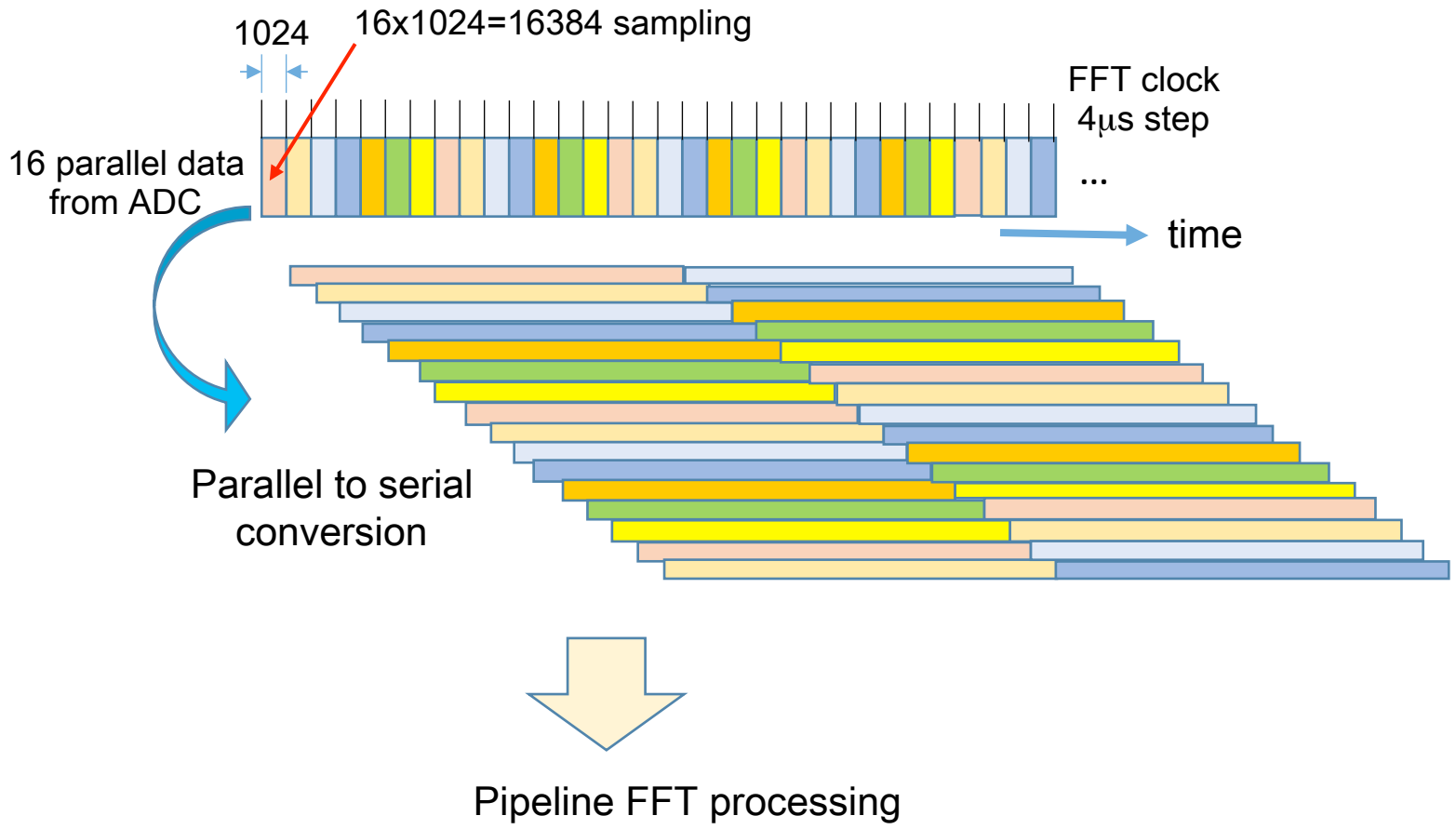

Frequency
Time
1 FFT bin
Frequency
Step frequency
Time
1 FFT bin
Frequency
Step frequency
Time
1 FFT bin

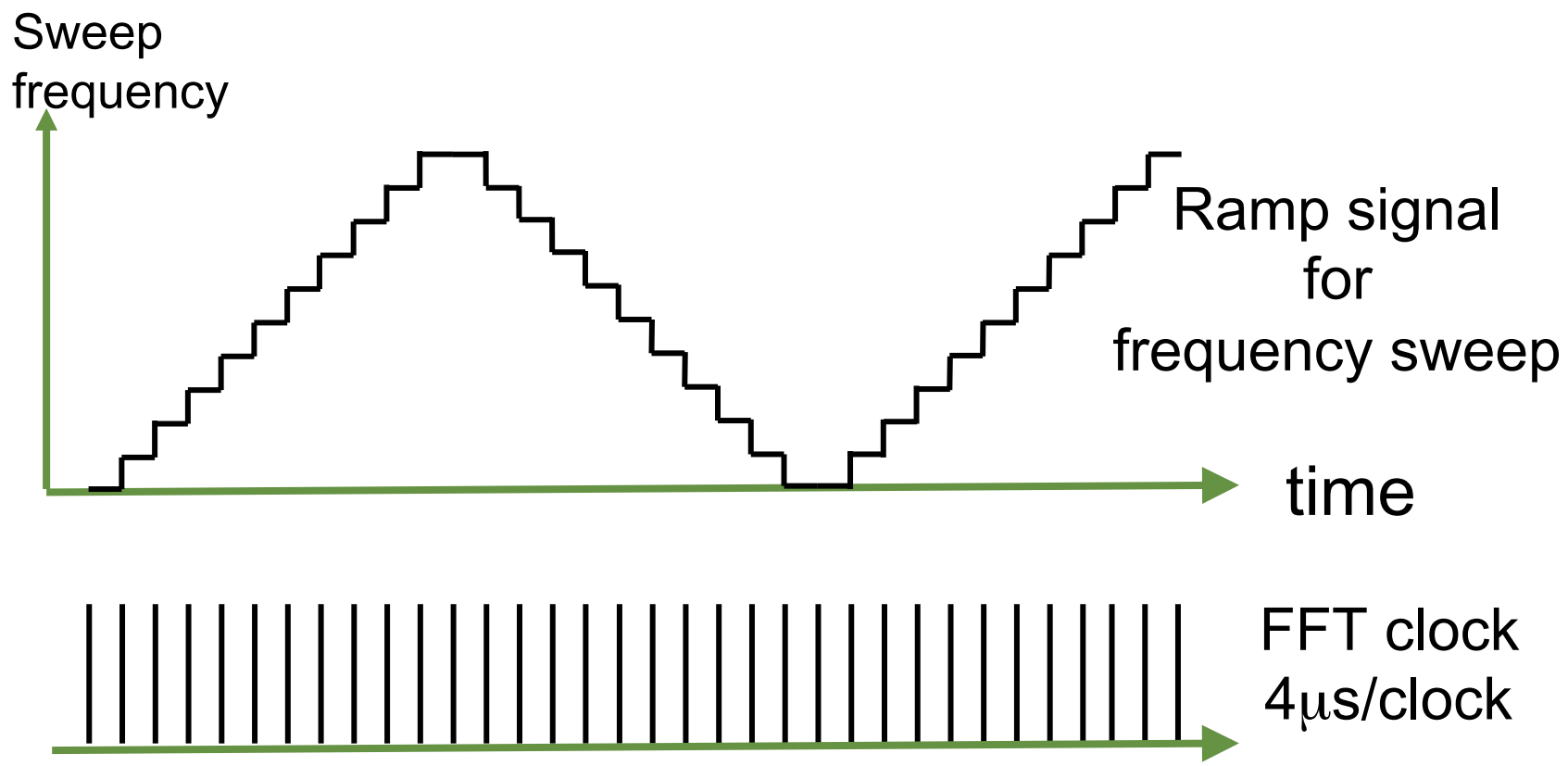

External
1PPS
in
ADC board
4ch
data
ADC
in
ADC
10 bit
max 5Gsps
FPGA
Vertex6
High-speed
GTX16 lane
FPGA
Vertex6
DAC
1Msps,
15bit
PCIe x4
DDR2
SDRAM
1GB
Ramp signal
for frequency sweep
Synch
2048MHz
256MHz
1/8
1/2
External
Reference
in
PLO
4096MHz
CPU
Core i7
SATA
HDD:1TB
system
SATA
HDD:2TB
SATA
HDD:2TB
SATA
HDD:2TB
SATA
HDD:2TB
4096MHz
256MHz
4MUX
data
DAC
out
DAC
12 bit
max 5Gsps
FPGA
Vertex6
High-speed
GTX16 lane
FPGA
Vertex6
PCIe x4
DDR2
SDRAM
1GB
Reset
DAC board

An issue of consideration

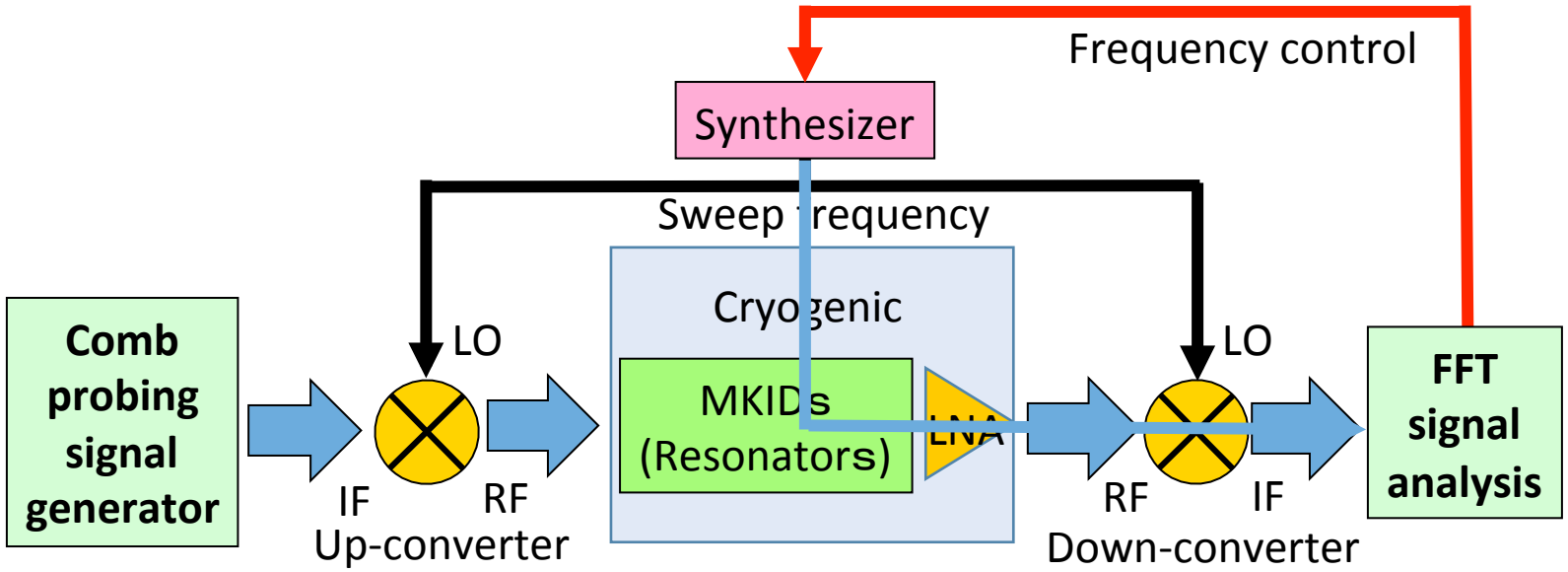
There is a possibility that the frequency sweep causes
a measurement error during FFT processing.
It is desirable that the probe frequency is unchanged
during the FFT processing (data acquisition) period.

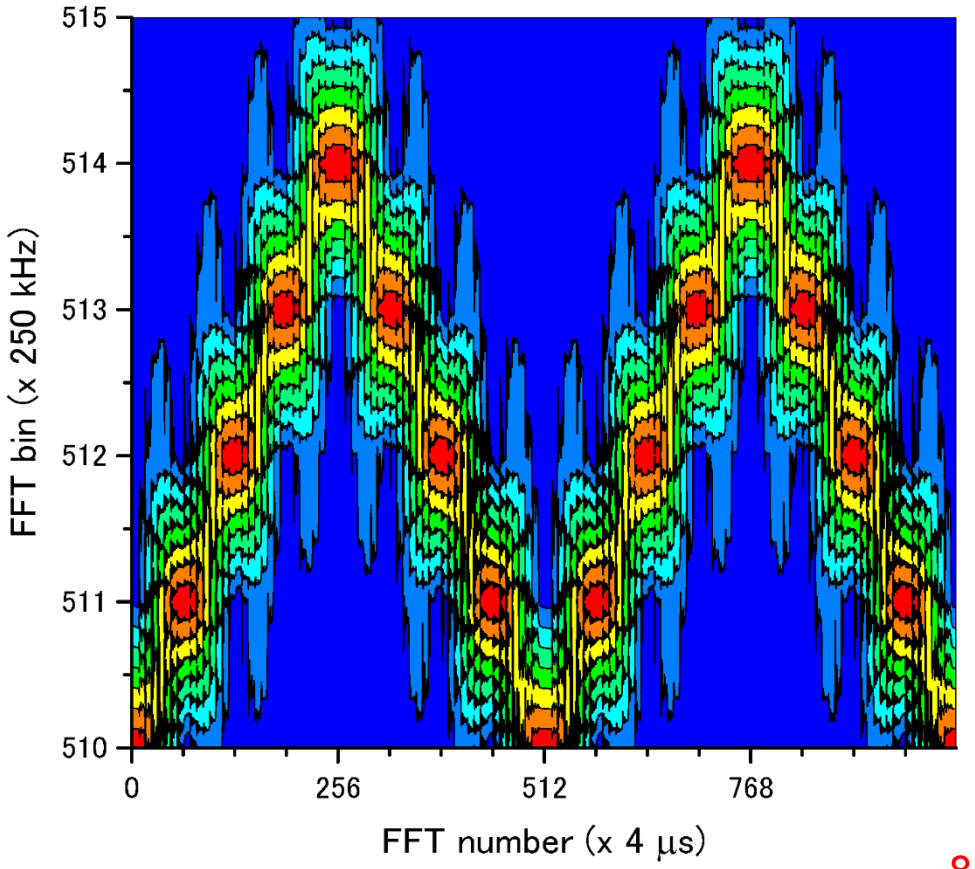
This means that
the frequency sweep should be step wise
and
the timing of the frequency step should be synchronized
with the FFT processing (data acquisition) timing.

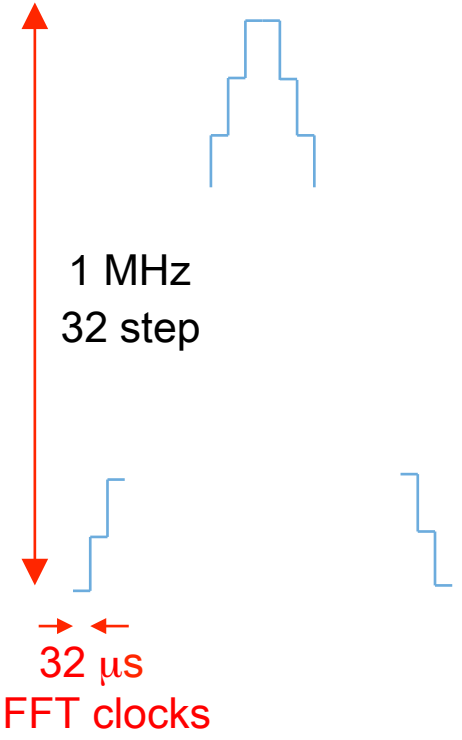

1024
16x1024=16384 sampling
FFT clock
4μs step
...
16 parallel data
from ADC
time
Parallel to serial
conversion
Pipeline FFT processing

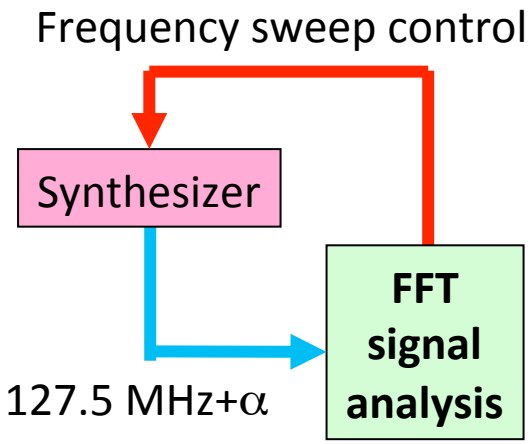

Sweep
frequency
Ramp signal
for
frequency sweep
time
FFT clock
4μs/clock

Signal timing check

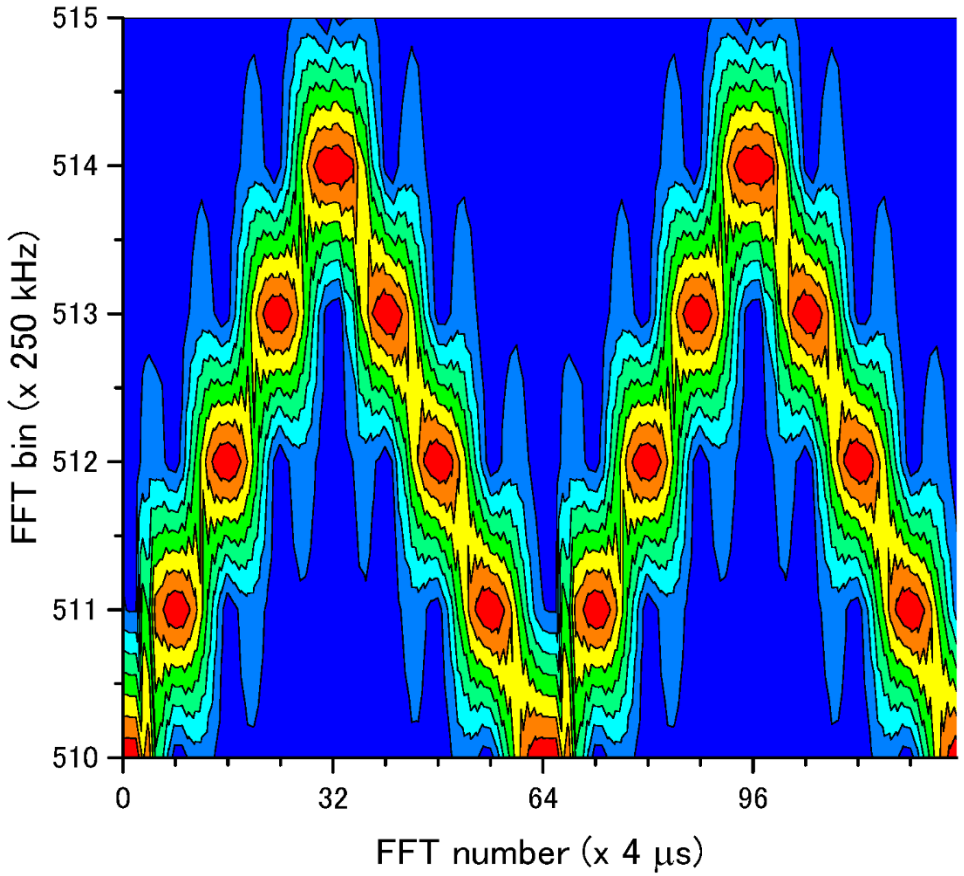


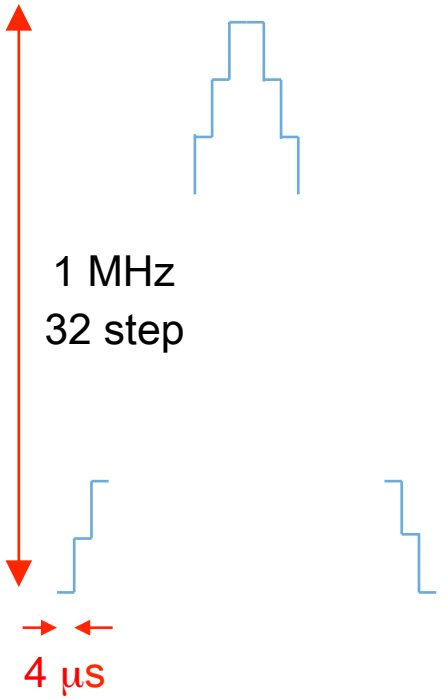


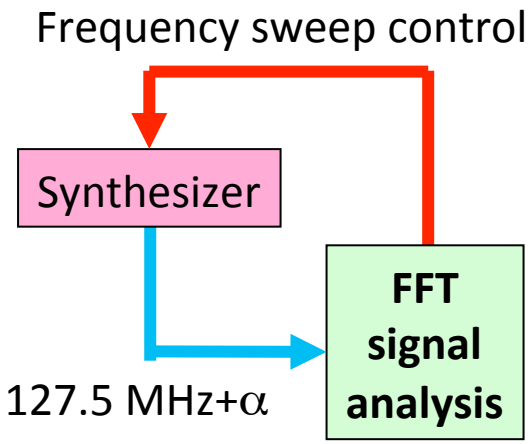




127.5 MHz = 250 kHz x 510

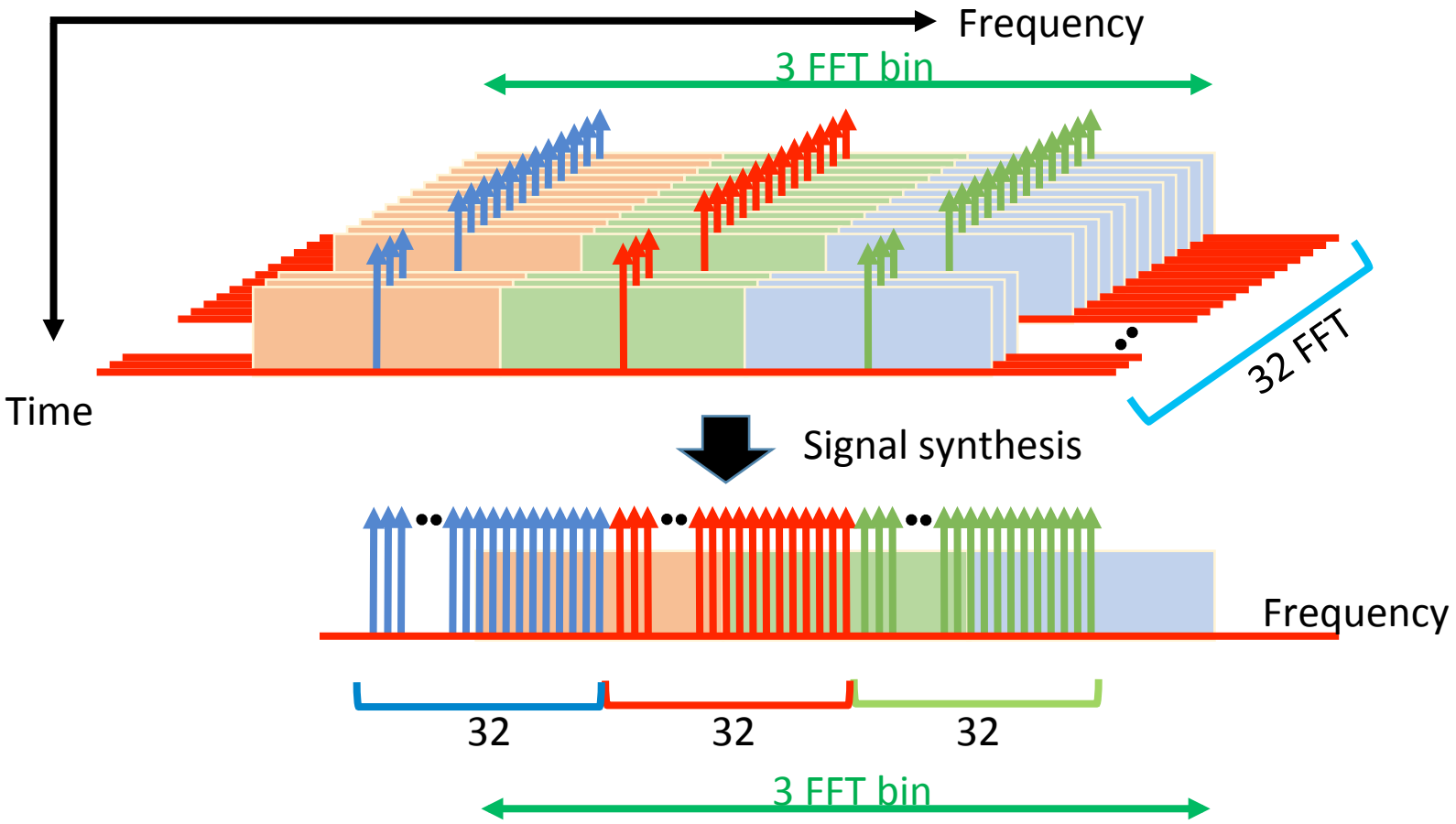




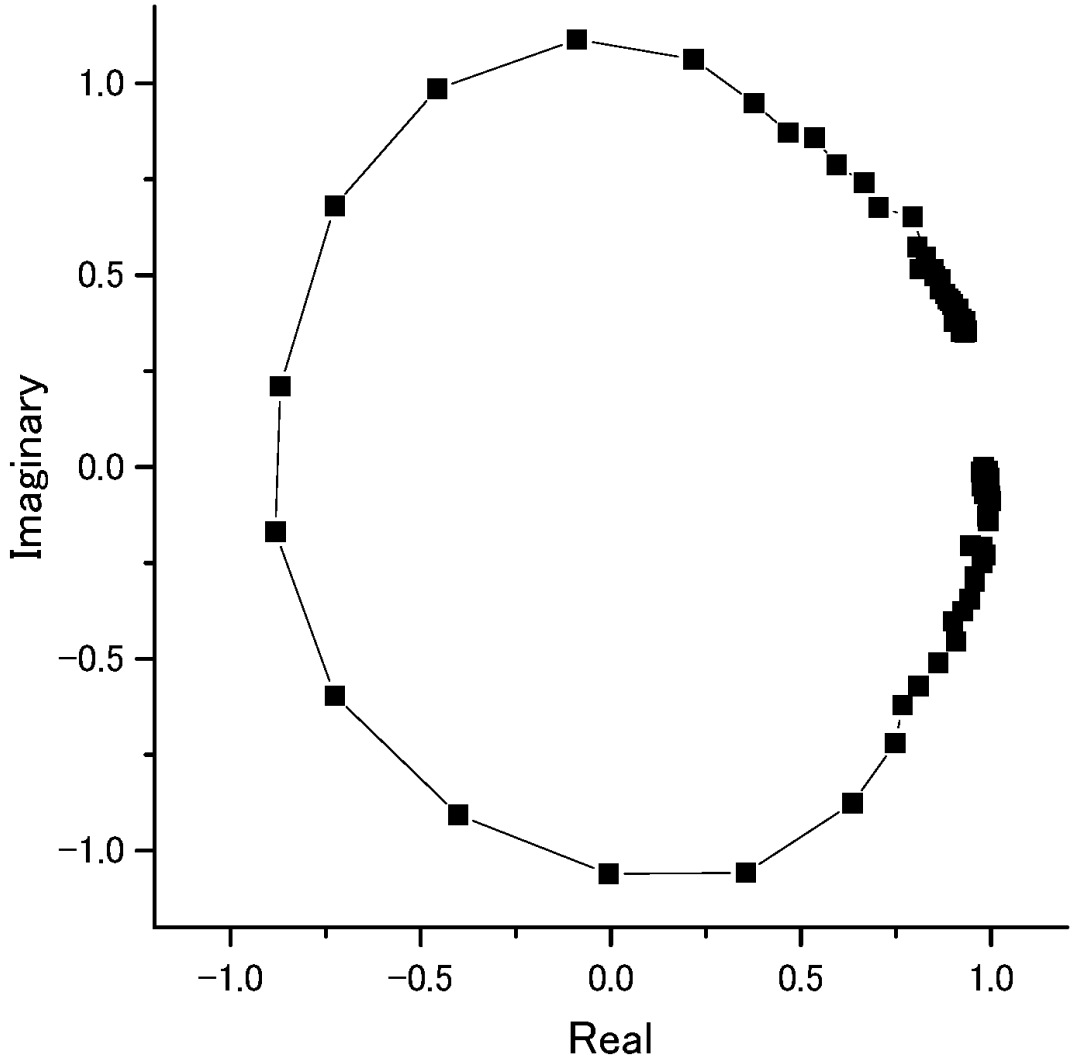


127.5 MHz = 250 kHz x 510

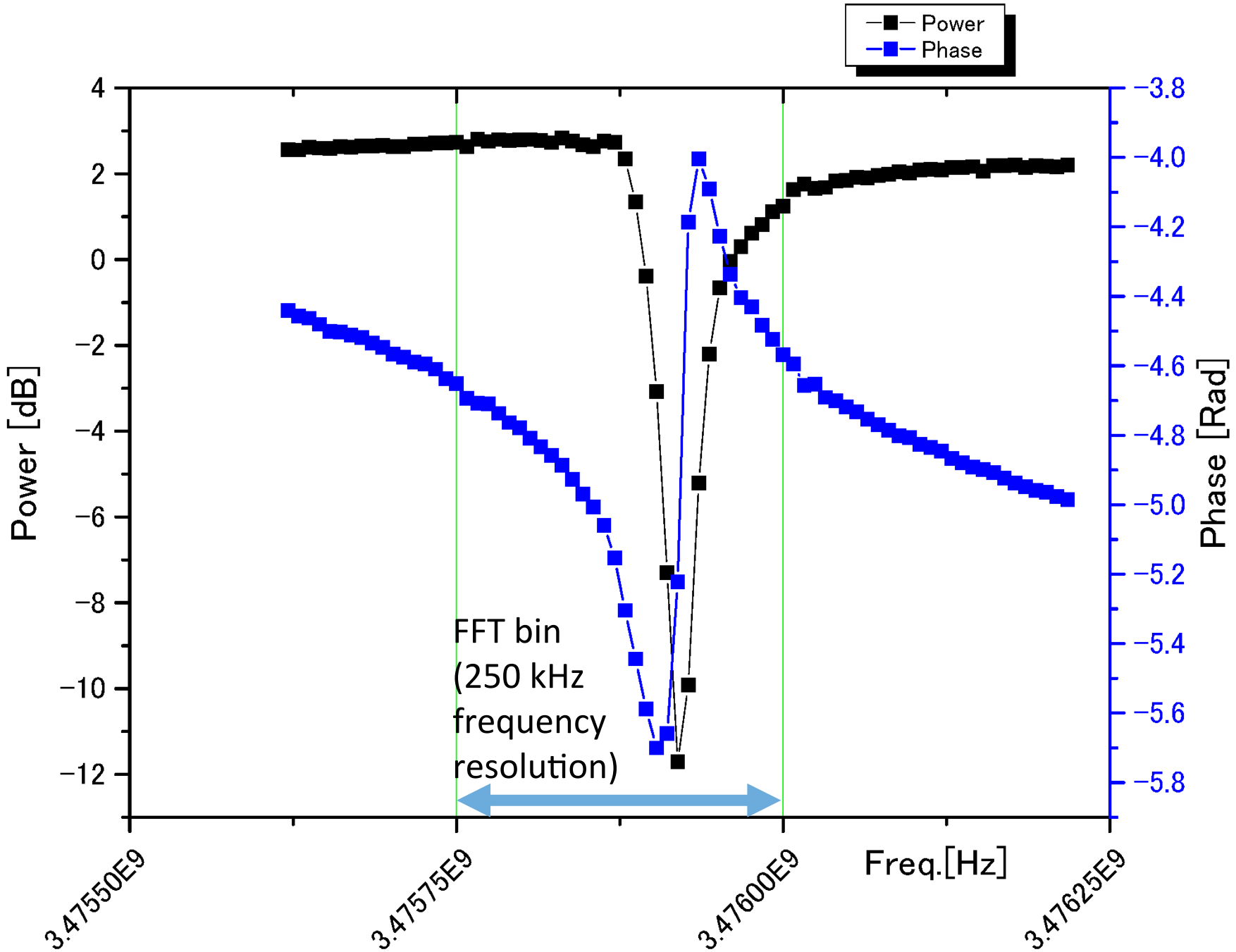
Increase frequency resolution (32 times)



Frequency sweeping with 3 probe signals.
In the normal usage, a probe signal corresponds to a resonator on one-to-one basis.



The trajectory in the complex plane of S21 parameter through a MKID with frequency sweep.


Power
Phase
Power [dB]
Phase [Rad]
Freq.[Hz]
FFT bin
(250 kHz
frequency
resolution)
4
2
0
−2
−4
−6
−8
−10
−12
−3.8
−4.0
−4.2
−4.4
−4.6
−4.8
−5.0
−5.2
−5.4
−5.6
−5.8
3.47550E9
3.47575E9
3.47600E9
3.47625E9

Features of the system

The LO frequency sweep scheme is
intended to increase the frequency dynamic range:
the frequency interval of the sweep frequency is greater than that of the FFT bin
for the ground-based telescope,

and to increase frequency resolution without increasing the number of FFT points:
the frequency interval of the sweep frequency is narrower than that of the FFT bin
for the space telescope.

Neither the precise initial tuning (tune the probing signal to the resonant frequency of the lowest optical loading state) is necessary any more.