# Revisit to Accurate ADC Testing with Incoherent Sampling Using Proper Sinusoidal Signal and Sampling Frequencies

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# Research Objective

To achieve high accuracy

Signal-to-[ noise + distortion ] ratio  (SINAD) testing of ADC
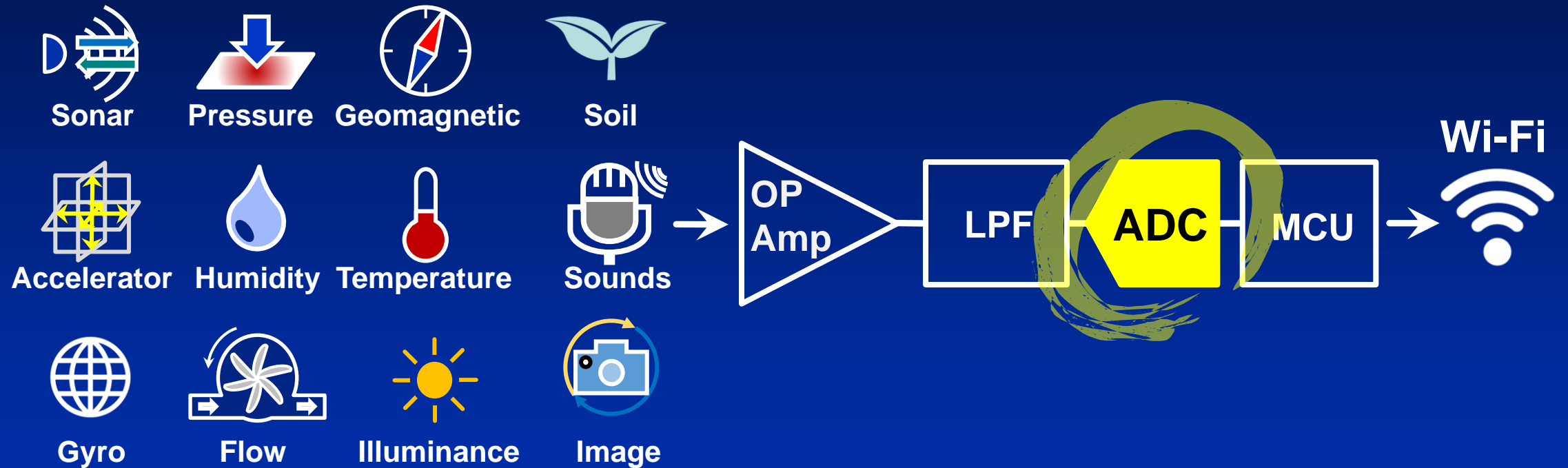
w/o any complicated conditions

### Achievements

- ✓ **Simplified Condition**
- ✓ **High Accuracy**

# Outline

- **Research Background**

- **Difficulty of SINAD Testing**

    – **Coherent Sampling**
    – **Incoherent Sampling**

- **Likelihood of Incoherent Sampling improvement**

- **Exploration of Optimized Signal Frequency**

- **Recommendation of Signal Frequency**

- **Conclusion**
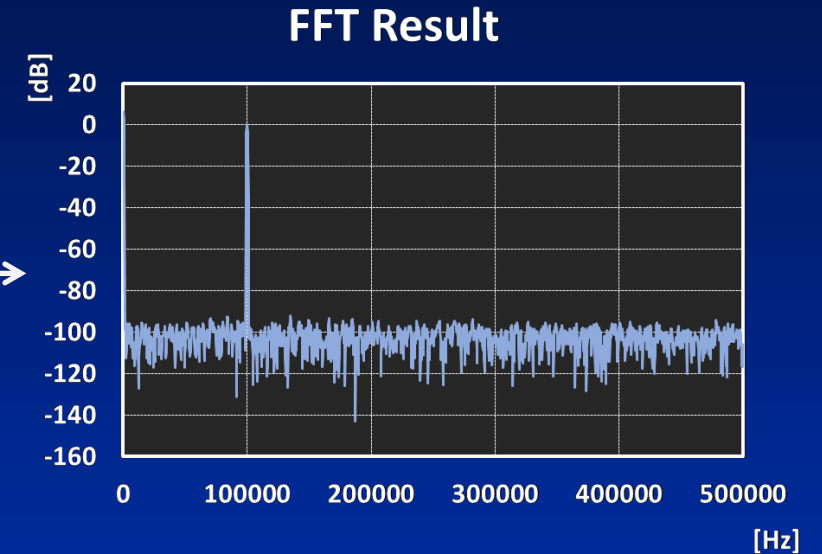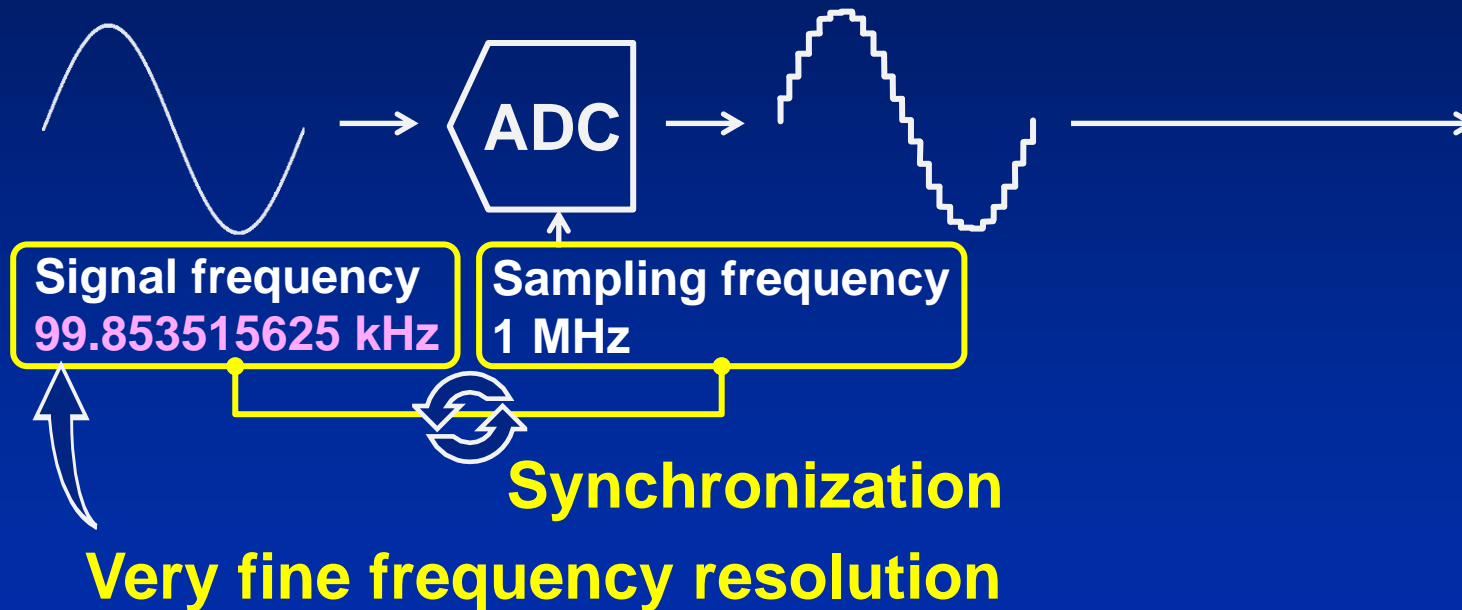
# Research Background

## IoT Sensor Network



ADC is a key component of IoT system

# Difficulty of SINAD Testing

## Coherent Sampling

SAR 12bit 1Msps ADC 4096-point FFT

**Signal frequency**
**99.853515625 kHz**

**Sampling frequency**
**1 MHz**

ADC

**Synchronization**

**Very fine frequency resolution**

**FFT Result**

[dB]

20
0
-20
-40
-60
-80
-100
-120
-140
-160

0    100000   200000   300000   400000   500000
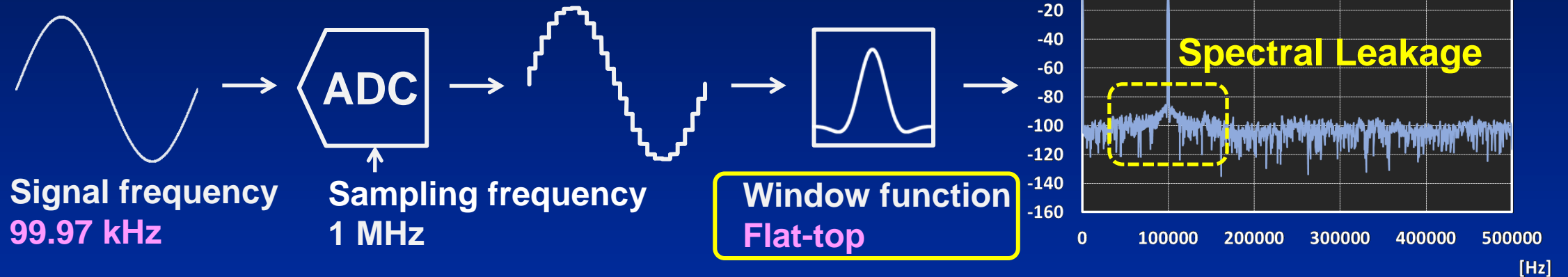
[Hz]

**SINAD : 73.6 dB**

**Good Result**

**Difficult to setup the environment w/o complicated condition**

# Difficulty of SINAD Testing

## Incoherent Sampling

SAR 12-bit 1-Msps ADC 4096-point FFT



**Signal frequency**
**99.97 kHz**

**Sampling frequency**
**1 MHz**

**Window function**
**Flat-top**

**FFT Result**

**Spectral Leakage**

**SINAD : 71.2 dB**

**Degraded** ↘

## Additional calculation

**Flat-Top Window**

$$w[n] = a_0 - a_1 \cos\left(\frac{2\pi n}{N}\right) + a_2 \cos\left(\frac{4\pi n}{N}\right) - a_3 \cos\left(\frac{6\pi n}{N}\right) + a_4 \cos\left(\frac{8\pi n}{N}\right)$$

$$n = 0,1,2,3,\dots,N-1, \ a_0 = 0.21557895, \ a_1 = 0.41663158$$
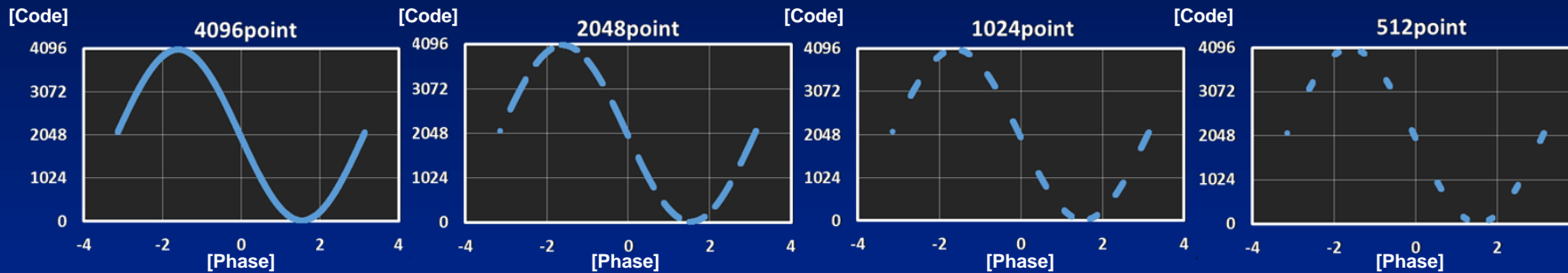$$a_2 = 0.277263158, \ a_3 = 0.083578947, \ a_4 = 0.006947368$$

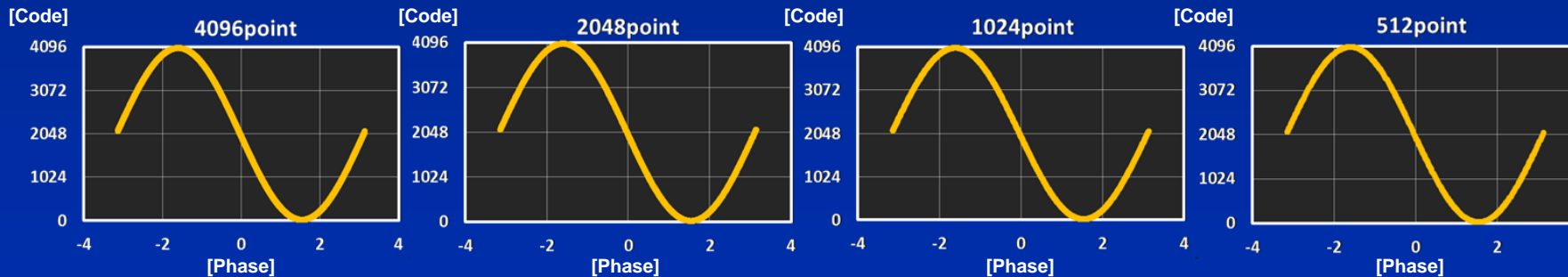## Spectral leakage of window function affects SINAD

# Likelihood of Incoherent Sampling Improvement

## Figure out histogram of signal frequency for 12bit ADC

➢ **99.97 kHz (Initial)**



➢ **100.318107302943 kHz (≈ Golden ratio)**



*Metallic ratio*

$$M_n = \frac{n + \sqrt{n^2 + 4}}{2}$$
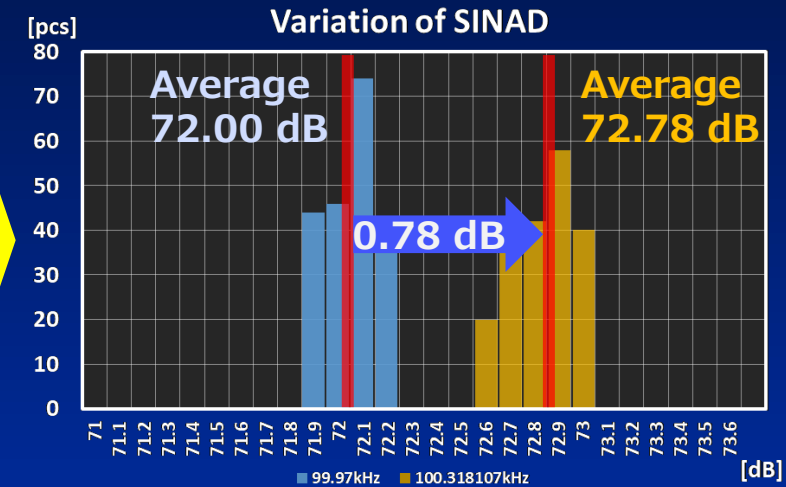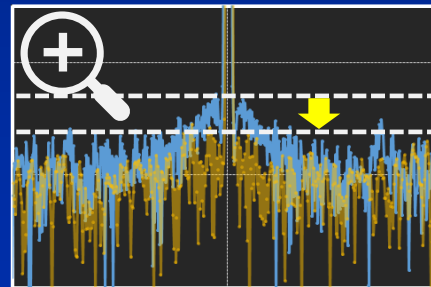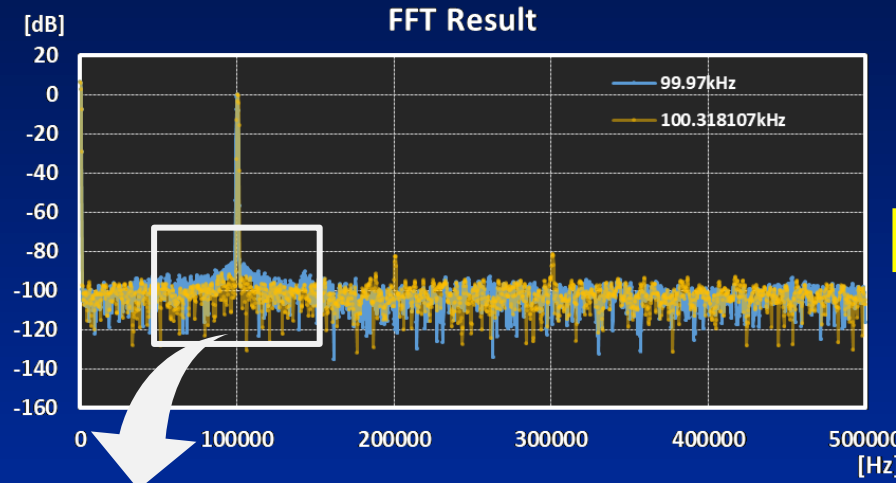
$n = 1 : Golden\ ratio$

**Golden ratio frequency is more random than initial one**

# Likelihood of Incoherent Sampling Improvement

## Simulation for Comparison btw 99.97 kHz and 100.3181… kHz

**Condition**

✓ **Signal frequency**
- 99.97 kHz
- 100.318107302943 kHz
  (≈Golden ratio)

✓ **ADC (Functional model)**
12 bit, 1.0 Msps

✓ **Window function**
Flat-top

✓ **FFT size**
4096 points

✓ **Variation data**
200 points different phase



**Spectral leakage is reduced**

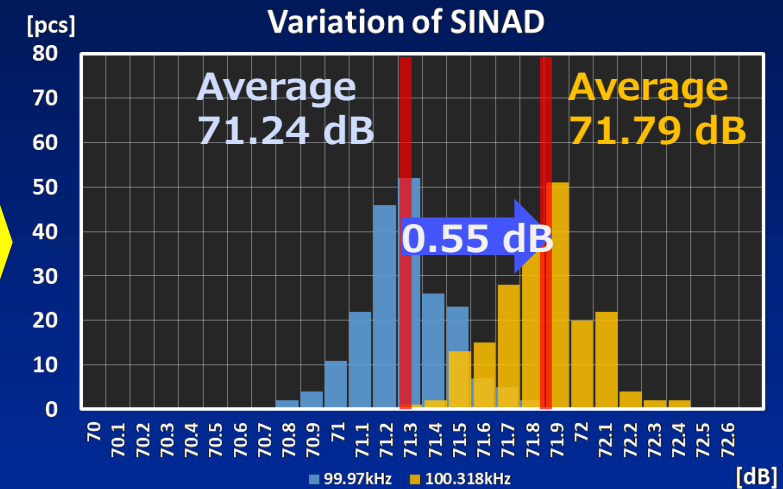**Improvement by 0.78 dB**

**SINAD is improved in simulation**

# Likelihood of Incoherent Sampling Improvement

## Validation for Comparison btw 99.97 kHz and 100.318 kHz

**Condition**

✓ **Signal frequency**
·99.97 kHz
·100.318 kHz
(≅Golden ratio)

✓ **ADC (BU79100G)**
12 bit, 1.0 Msps

✓ **Window function**
Flat-top

✓ **FFT size**
4096 points

✓ **Variation data**
200 samples

**FFT Result**

**The same tendency as simulation**

**Variation of SINAD**

Average **71.24 dB**    Average **71.79 dB**
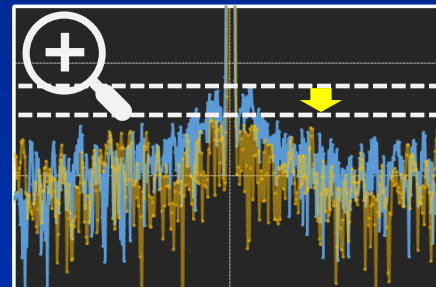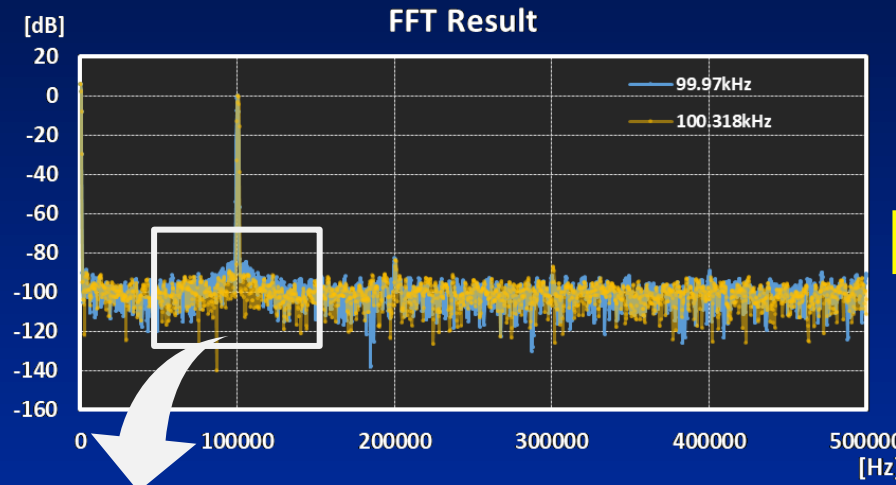
**0.55 dB**

**Improvement by 0.55 dB**

## SINAD is improved using actual samples

# Exploration of Optimized Signal Frequency

## Investigation
Frequency Response of SINAD w/ Flat-Top Window

### Condition

✓ **Signal frequency**
99.5 kHz ~ 100.5 kHz
1 Hz step, 1001 points

✓ **ADC (Functional model)**
12 bit, 1.0 Msps

✓ **Window function**
Flat-top

✓ **FFT size**
4096 points



Frequency Response of SINAD (Flat-Top Window)

Accurate data is acquired nearby coherent frequency

Max : 73.84 dB
99.609 kHz    99.854 kHz    100.098 kHz    100.342 kHz
1.47 dB
Min : 72.37 dB
99.97 kHz (Initial)    100.318kHz (Golden ratio)

**Depending on signal frequency, SINAD varies from 72.37 dB to 73.84 dB**
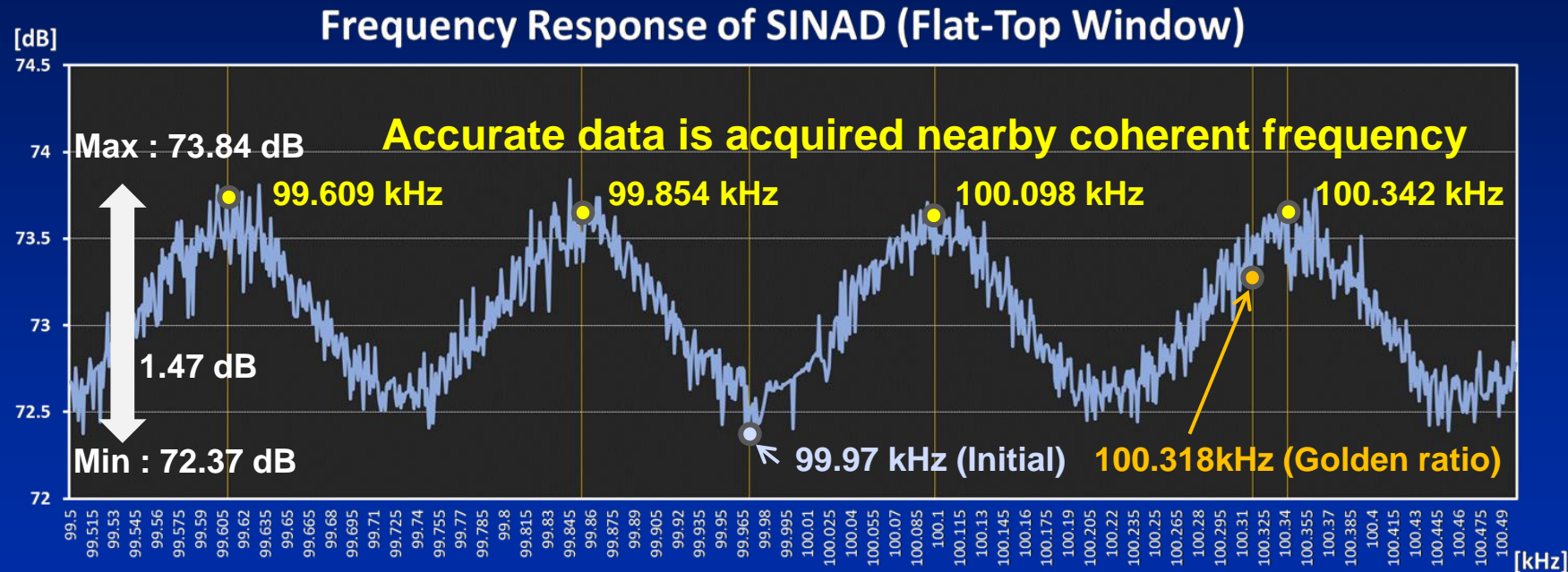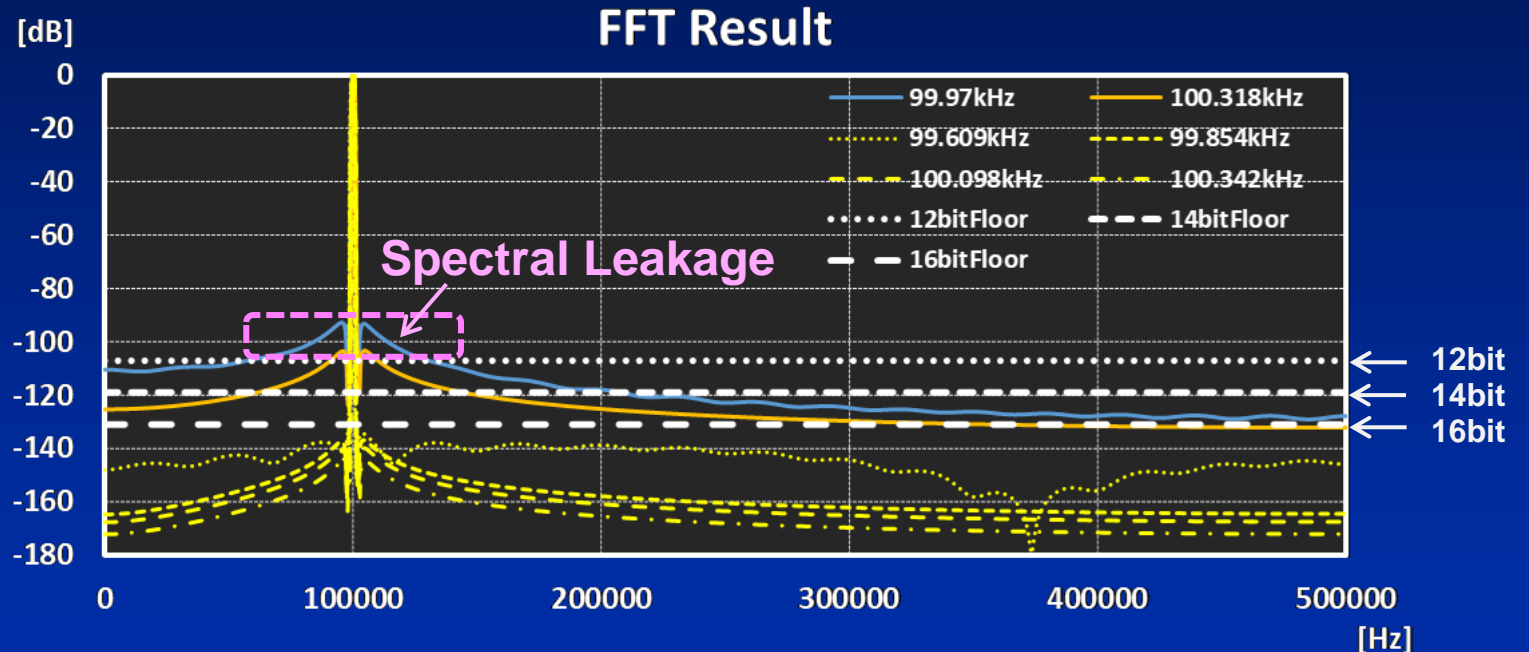
**Frequency response of window function appears**

# Exploration of Optimized Signal Frequency

## Investigation
Frequency Response of Sine Wave w/ Flat-Top Window

### Condition

- ✓ **Signal frequency**
  - 99.97 kHz (Initial)
  - 100.318 kHz (≅ Golden Ratio)
  - 99.609 kHz (≅Coherent)
  - 99.854 kHz (≅Coherent)
  - 100.098 kHz (≅Coherent)
  - 100.342 kHz (≅Coherent)

- ✓ **ADC (Functional model)**
  Numerical, 1.0 Msps

- ✓ **Window function**
  Flat-top

- ✓ **FFT size**
  4096 points



**FFT Result**

Spectral Leakage

Legend: 99.97kHz, 100.318kHz, 99.609kHz, 99.854kHz, 100.098kHz, 100.342kHz, 12bitFloor, 14bitFloor, 16bitFloor

12bit, 14bit, 16bit

**Both 99.97 kHz and 100.318 kHz are NOT suitable for over 12bit ADC**

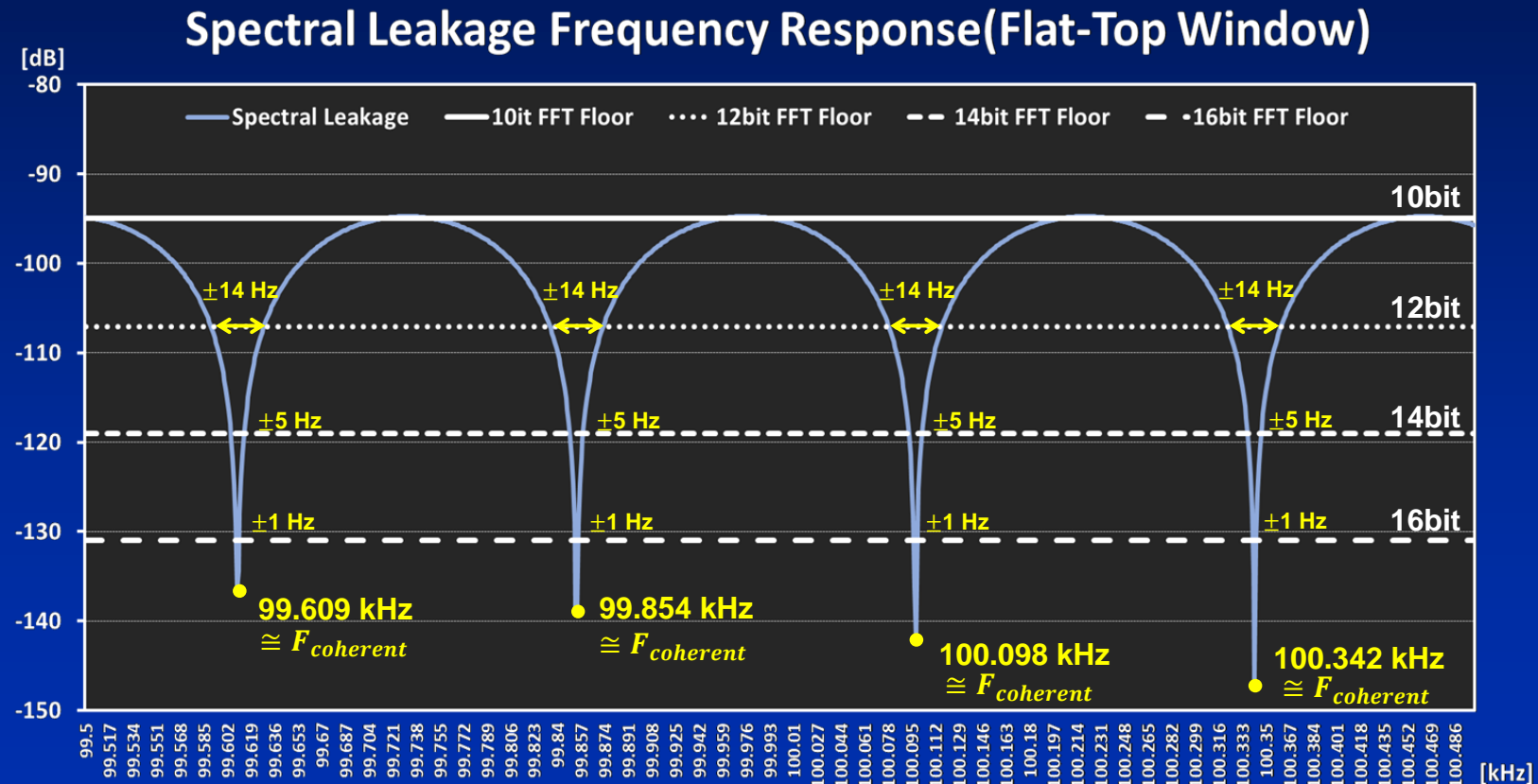## Frequency response of window function affects spectral leakage

# Exploration of Optimized Signal Frequency

## Investigation
Frequency Response of Spectral Leakage w/ Flat-Top Window

### Condition

✓ **Signal frequency**
99.5 kHz ~ 100.5 kHz
1 Hz step, 1001 points

✓ **ADC (Functional model)**
Numerical, 1.0 Msps

✓ **Window function**
Flat-top

✓ **FFT size**
4096 points

✓ **Definition of spectral leakage**
Fundamental frequency $\pm100$ bin
in case of 4096 points



**Spectral Leakage Frequency Response(Flat-Top Window)**

— Spectral Leakage — 10it FFT Floor ···· 12bit FFT Floor — 14bit FFT Floor — 16bit FFT Floor

$\pm14$ Hz · $\pm14$ Hz · $\pm14$ Hz · $\pm14$ Hz
$\pm5$ Hz · $\pm5$ Hz · $\pm5$ Hz · $\pm5$ Hz
$\pm1$ Hz · $\pm1$ Hz · $\pm1$ Hz · $\pm1$ Hz

99.609 kHz $\cong F_{coherent}$
99.854 kHz $\cong F_{coherent}$
100.098 kHz $\cong F_{coherent}$
100.342 kHz $\cong F_{coherent}$

10bit, 12bit, 14bit, 16bit

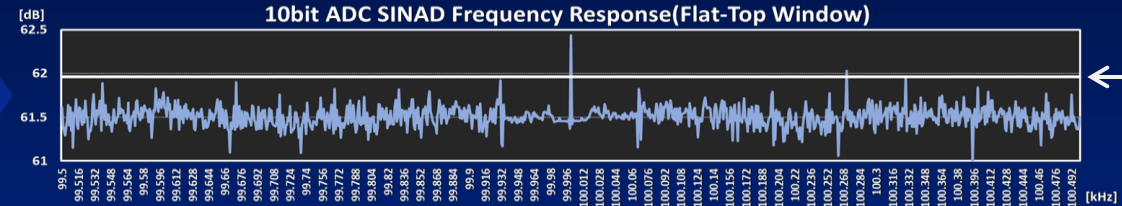**Optimized signal frequency was found**

# Exploration of Optimized Signal Frequency

## Confirmation of Optimized Signal Frequency for SINAD
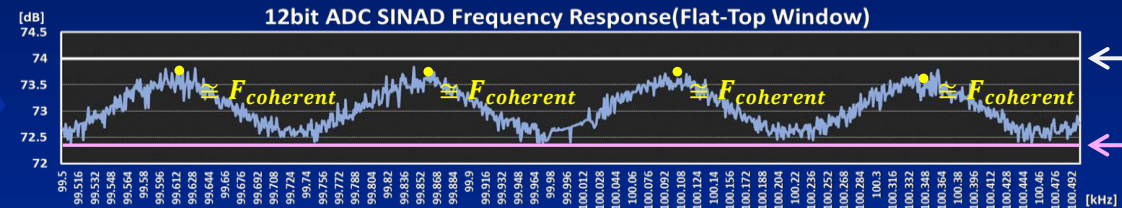
### Condition

- ✓ **Signal frequency**
  99.5 kHz ~ 100.5 kHz
  1 Hz step, 1001 points

- ✓ **ADC (Functional model)**
  ・10bit, 1.0 Msps
  ・12bit, 1.0 Msps
  ・14bit, 1.0 Msps
  ・16bit, 1.0 Msps

- ✓ **Window function**
  Flat-top

- ✓ **FFT size**
  4096 points

**10bit**
**No Effect**

**12bit**
**w/ Effect**

**14bit**
**w/ Effect**

**16bit**
**w/ Effect**



10bit ADC SINAD Frequency Response(Flat-Top Window) — 61.96 dB (Ideal)

12bit ADC SINAD Frequency Response(Flat-Top Window) — 74.00 dB (Ideal), ↘ 1.63 dB, 72.37 dB (Worst)
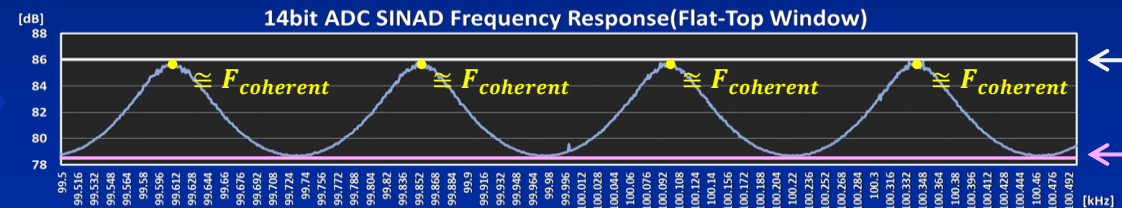
14bit ADC SINAD Frequency Response(Flat-Top Window) — 86.04 dB (Ideal), ↘ 7.41 dB, 78.63 dB (Worst)
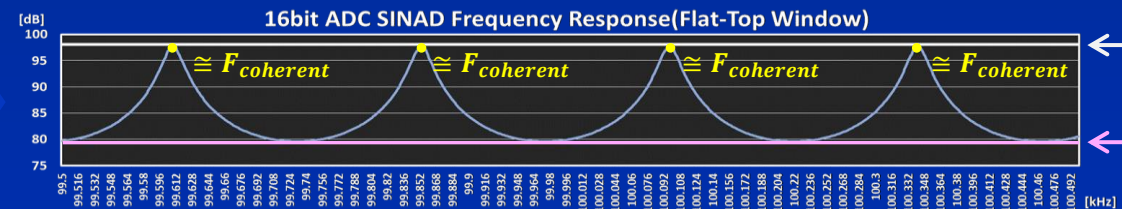
16bit ADC SINAD Frequency Response(Flat-Top Window) — 98.08 dB (Ideal), ↘ 18.49 dB, 79.59 dB (Worst)
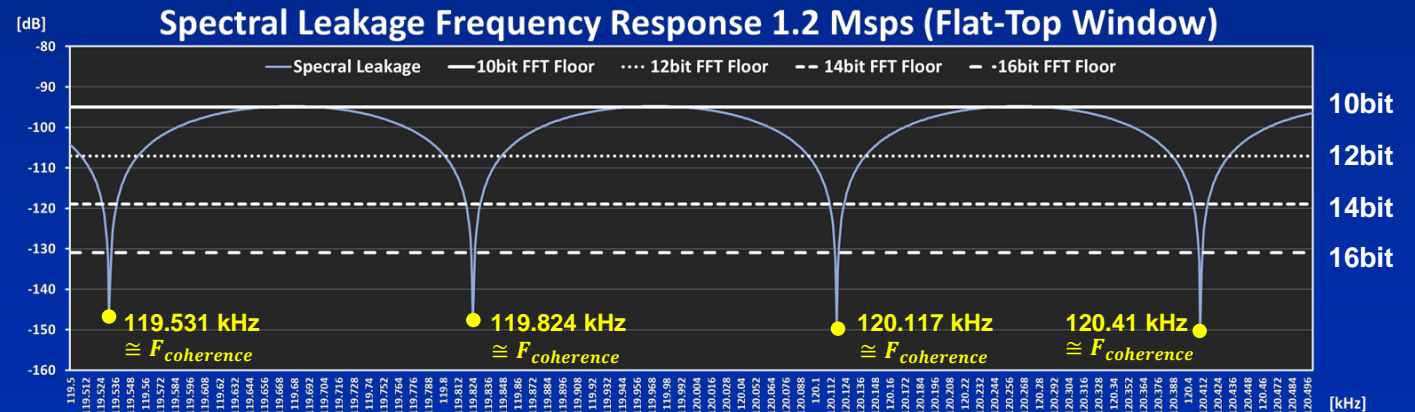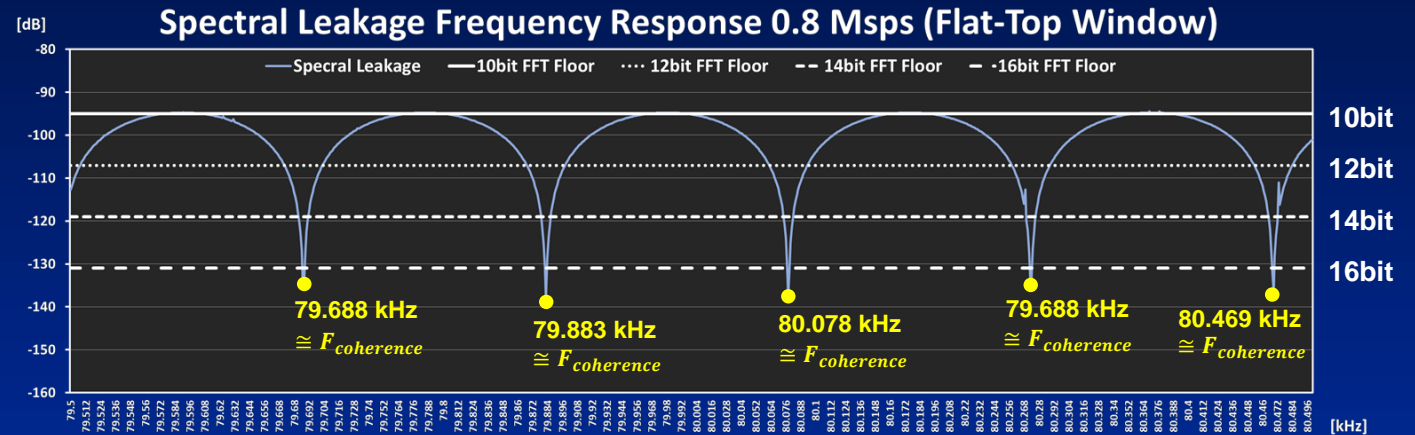
## Consideration of signal frequency for over 12bit ADC SINAD

# Exploration of Optimized Signal Frequency

## Confirmation of Sampling Frequency Variation

### Condition

✓ **Signal frequency**
  - 79.5 kHz ~ 80.5 kHz (0.8 Msps)
  - 119.5 kHz ~ 120.5 kHz (1.2 Msps)
    1 Hz step, 1001 points

✓ **ADC (Functional model)**
  - Numerical, 0.8 Msps
  - Numerical, 1.2 Msps

✓ **Window function**
  Flat-top

✓ **FFT size**
  4096 points



Spectral Leakage Frequency Response 0.8 Msps (Flat-Top Window)

79.688 kHz $\cong F_{coherence}$
79.883 kHz $\cong F_{coherence}$
80.078 kHz $\cong F_{coherence}$
79.688 kHz $\cong F_{coherence}$
80.469 kHz $\cong F_{coherence}$



Spectral Leakage Frequency Response 1.2 Msps (Flat-Top Window)

119.531 kHz $\cong F_{coherence}$
119.824 kHz $\cong F_{coherence}$
120.117 kHz $\cong F_{coherence}$
120.41 kHz $\cong F_{coherence}$

**Coherent frequencies will be able to obtain accurate SINAD**

# Recommendation for Signal Frequency

## How to Decide Coherent Frequency for Incoherent Setup

$$F_{coherence} = N_{sin} \cdot F_s / N_{samples}$$

$N_{sin}$ : **Number of sinwave periods in total samples**
$F_s$ : **Sampling frequency**
$N_{samples}$ : **Number of samples**

### Condition

✓ **Signal frequency**
99.5 kHz ~ 100.5 kHz
1 Hz step, 1001 points
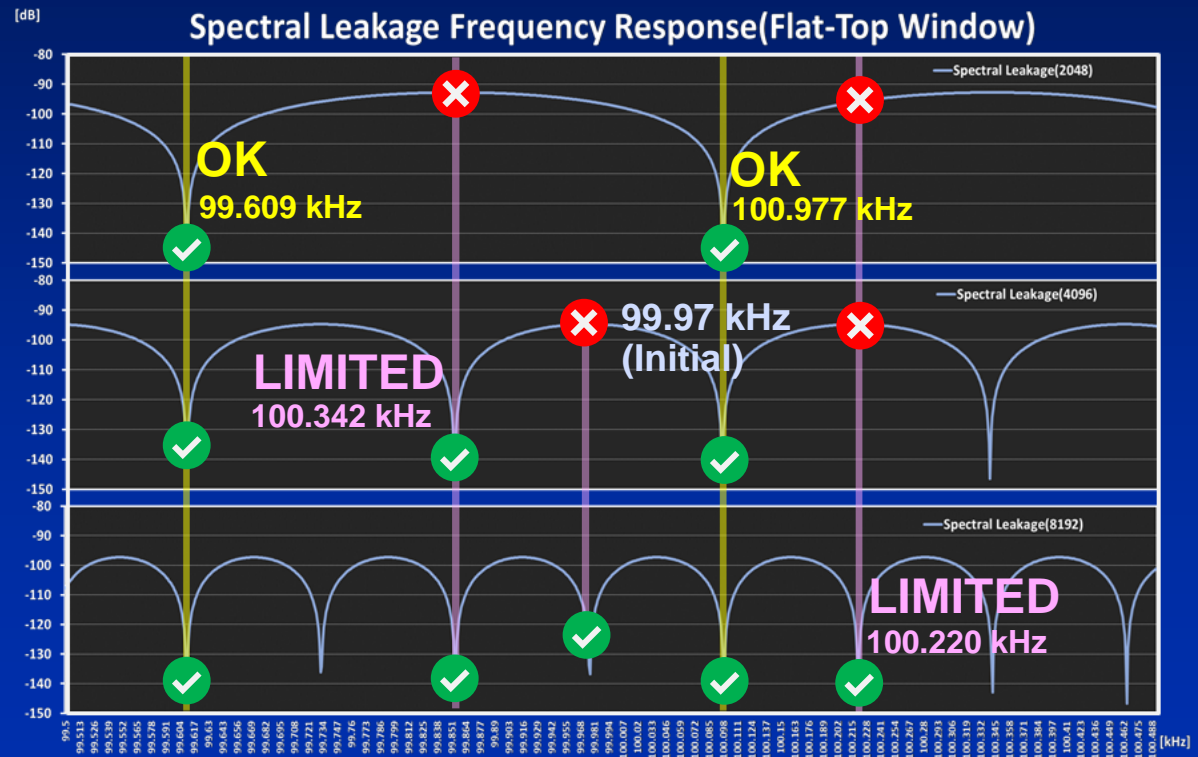
✓ **ADC (Functional model)**
Numerical, 1.0 Msps

✓ **Window function**
Flat-Top

✓ **FFT Size**
·2048 points
·4096 points
·8192 points

**2048 points** ≫

**4096 points** ≫

**8192 points** ≫



Spectral Leakage Frequency Response(Flat-Top Window)

OK 99.609 kHz
OK 100.977 kHz
LIMITED 100.342 kHz
99.97 kHz (Initial)
LIMITED 100.220 kHz

## Set signal frequency according to the FFT size

# Conclusion

**ADC SINAD Testing**

- ✓ **Simplified Condition**

  **Realized incoherent sampling setup**

  **w/o any complicated conditions**

  **such as coherent sampling setup**

- ✓ **High Accuracy**

  **Found out appropriate signal frequency**

  **for high accuracy testing w/ flat-top window**