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Input Signal and Sampling Frequencies Requirements for Efficient ADC Testing with Histogram Method

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Outline

- Objective
- ADC Test with Histogram Method
- Input Sine Wave and Sampling Frequencies Relationship in ADC Histogram Test Method
  - Sine Wave Histogram and Waveform Missing
  - Golden Ratio Sampling
  - Metallic Ratio Sampling
  - Prime Number Ratio Sampling
- Conclusion

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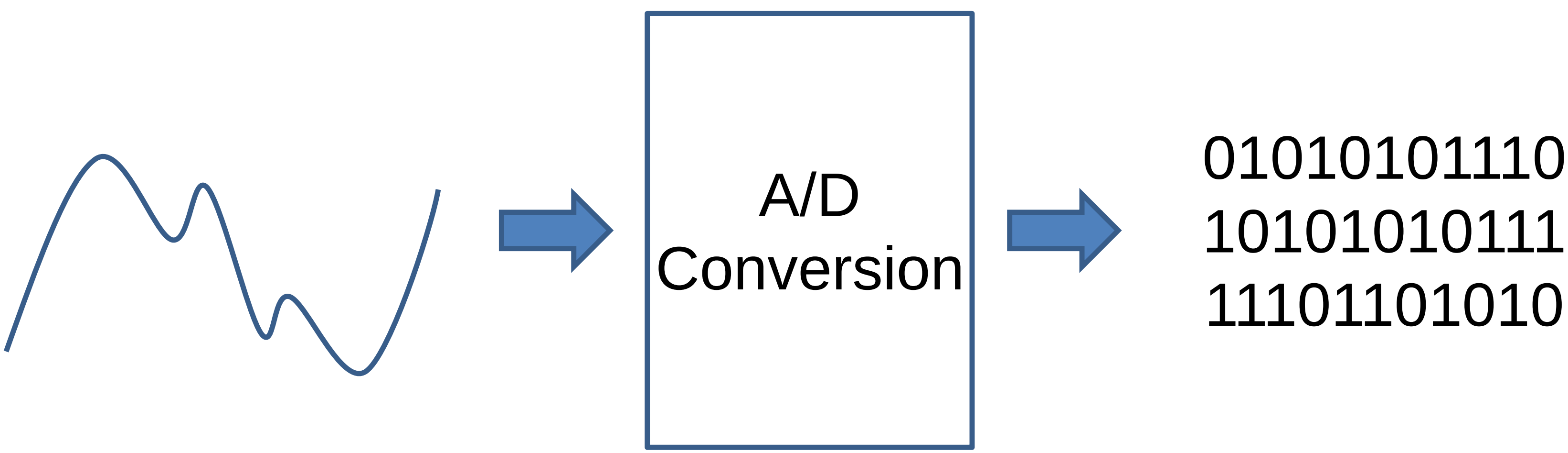
Background

IoT era is coming !

ADC is a key component

- Analog signal
- Digital signal

Sampling



High quality & Low cost ADC test is required

Research Objective & Approach

SAR ADC linearity test takes a long time

- low-speed sampling
- high-resolution

Test cost is proportional to test time

This Work

ADC linearity test with histogram method:
Investigation of "high efficiency relationship" between input and sampling frequencies

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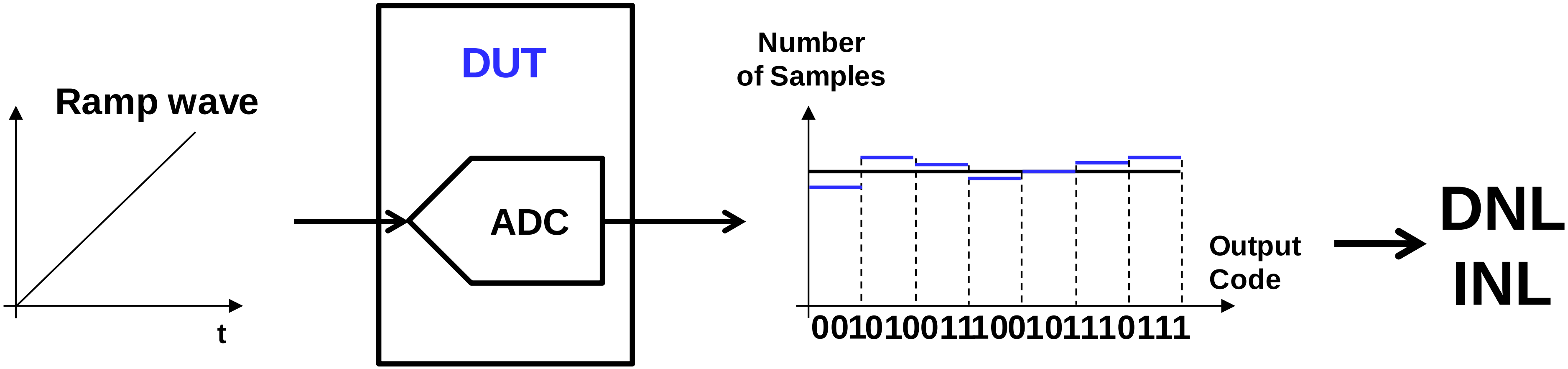
Conventional Linearity Testing 1

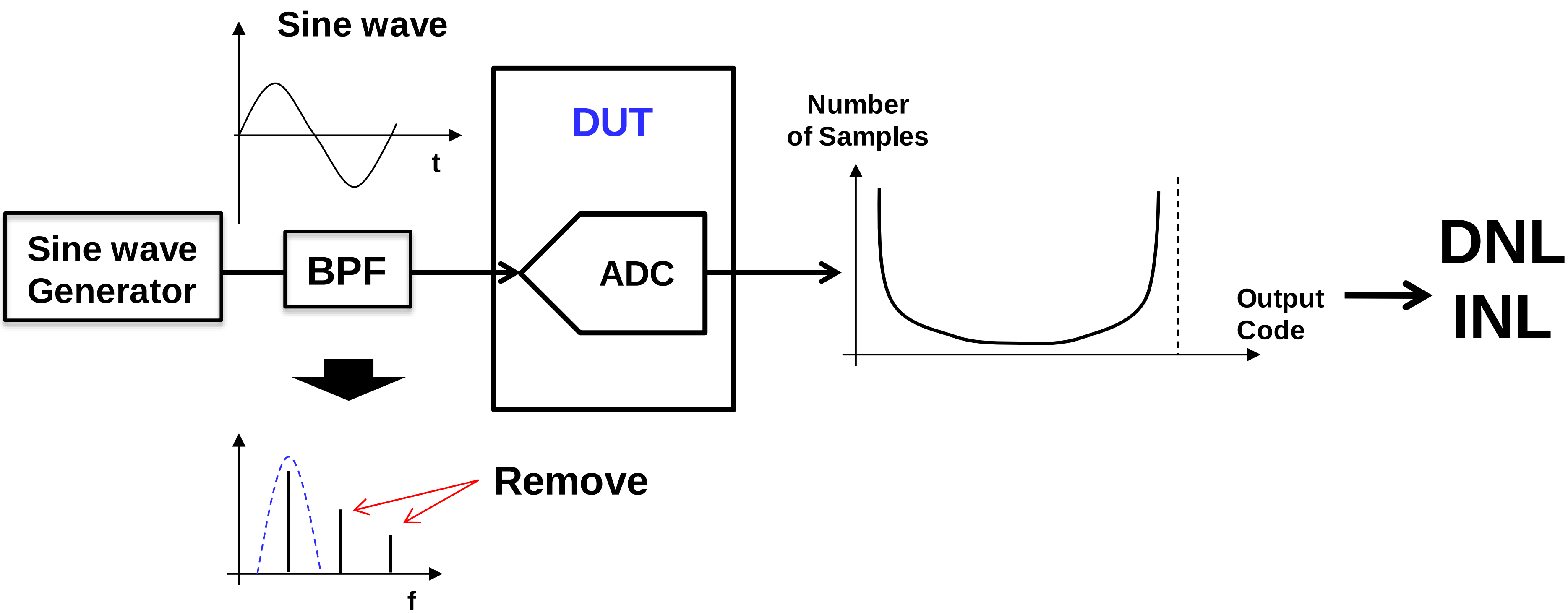
■Histogram method (Ramp wave input)



- ADC output histograms for all bins are equal
  if ADC is perfectly linear
- Highly linear ramp signal generation is difficult
  (limitation up to 14-bit ADC)

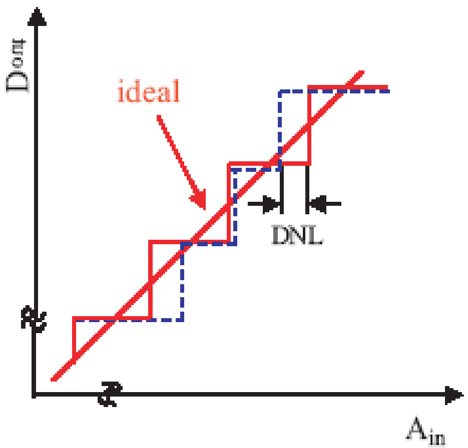
Conventional Linearity Testing 2

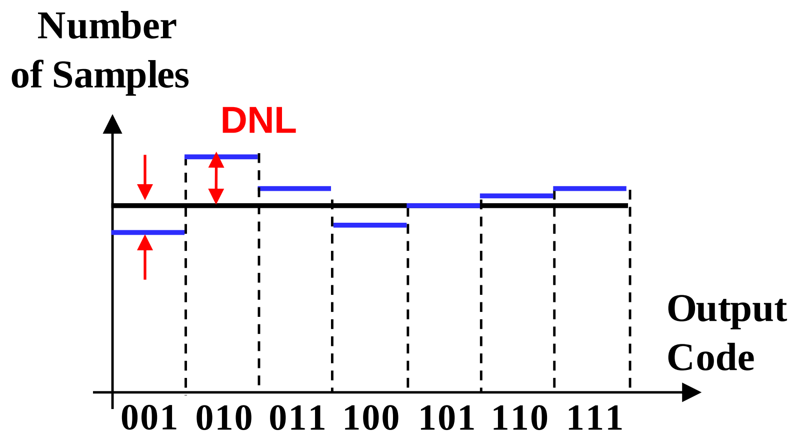
■Histogram method(Single sine wave input)

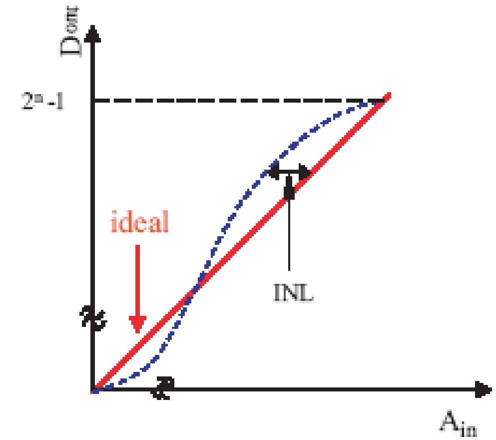


- Low distortion sine using an analog filter
- Number of samples is small around the middle of output range ➡ Many samples required (long test time)

DNL & INL







- Important ADC testing items

DNL : Difference between
actual step width and ideal value

INL : Deviation from ideal conversion line

$$INL(k) = \sum_{i=1}^{k} DNL(i)$$

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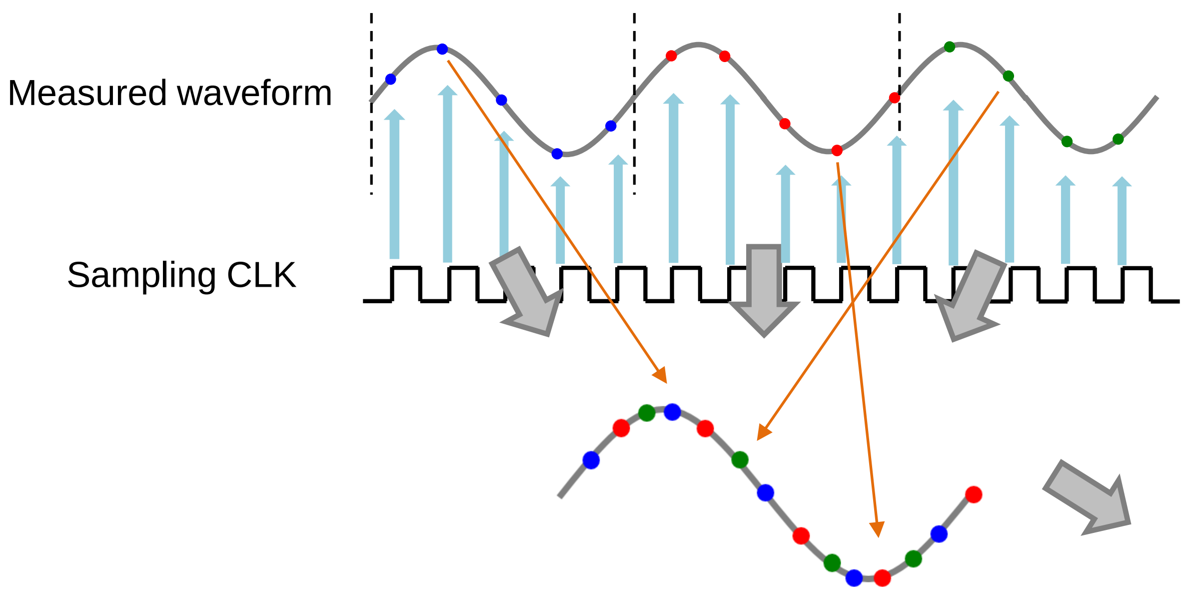
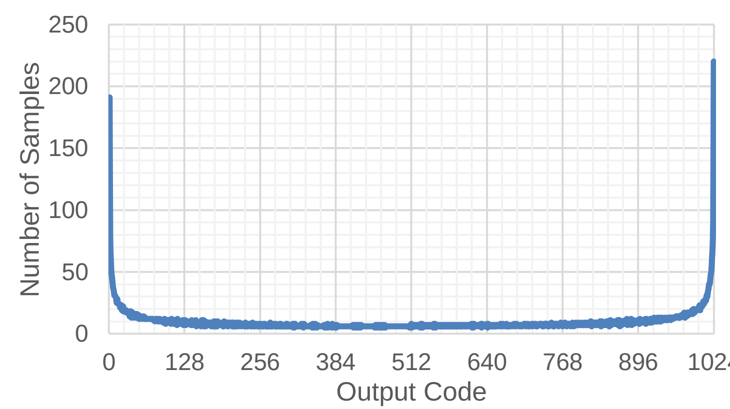
Sine Wave Histogram



- Sampled histogram is compared with PDF.
- Histogram is obtained.
- DNL , INL are calculated.

PDF:
Probability Distribution Function

$$p_{(v)} = \frac{1}{\pi\sqrt{A^2 - v^2}}$$



Repetitive waveform sampled asynchronously

⇩

Reconstruct a 1-period waveform

Waveform Missing

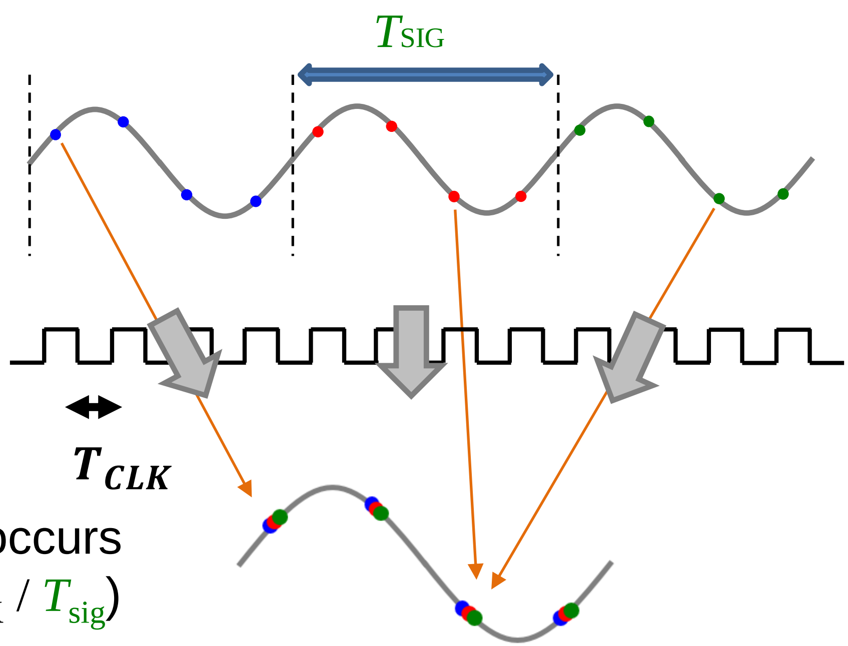
Repetitive waveform sampled asynchronously

⇩

Reconstruct a 1-period waveform

Measured waveform

Sampling CLK



Waveform missing occurs at special ratio (T_{CLK} / T_{sig})

A large amount of data is required to reconstruct the waveform ➡ Test time: long

Waveform Missing

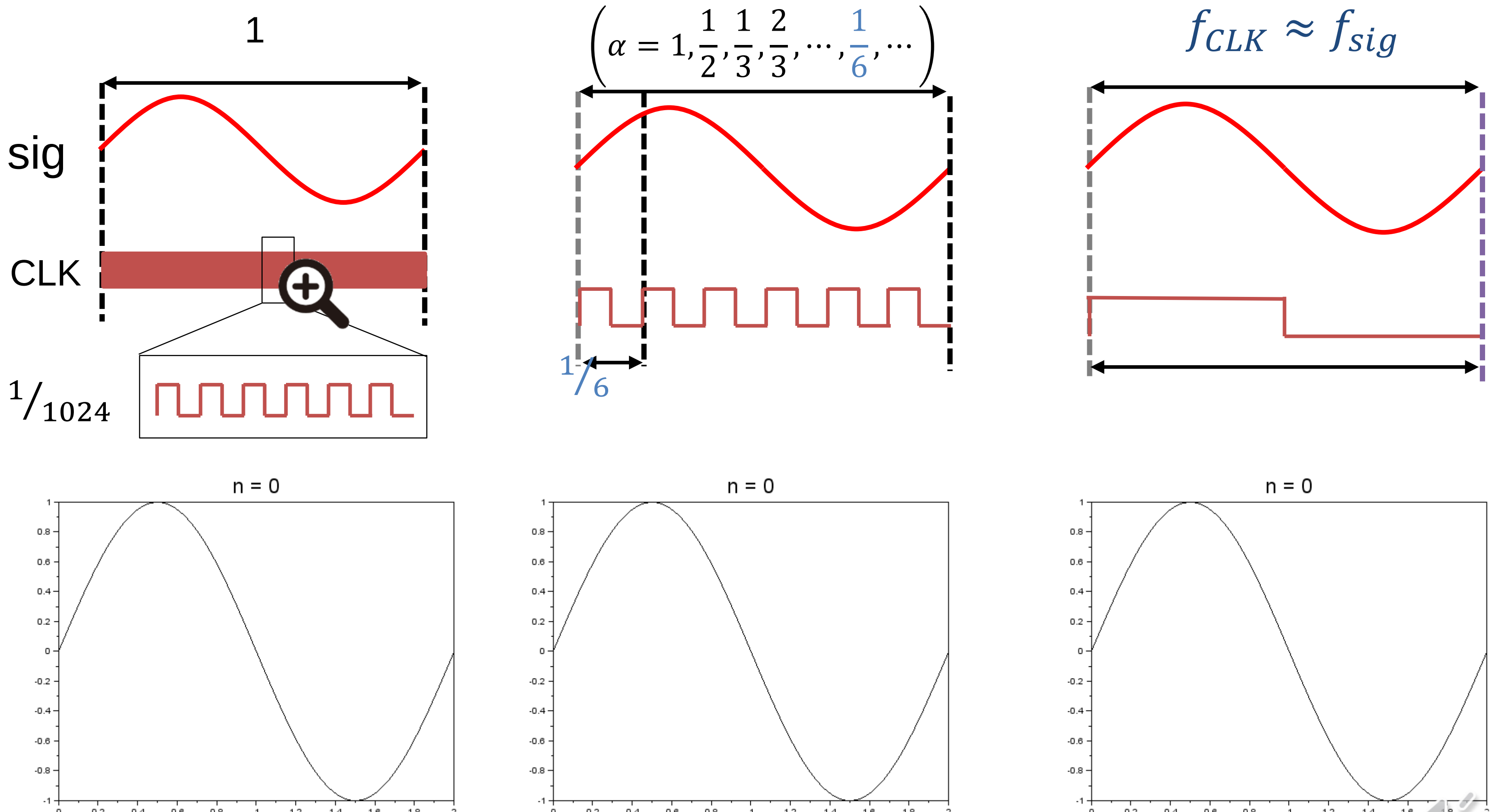
$f_{CLK} \gg f_{sig}$

$f_{CLK} \approx \frac{1}{\alpha} f_{sig}$

Special ratio

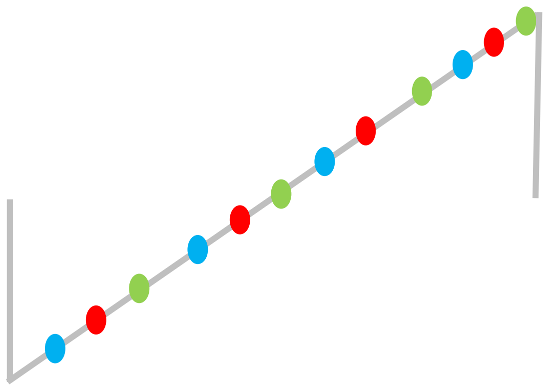
T_{CLK} and T_{sig} , f_{CLK} and f_{sig}

$f_{CLK} \approx f_{sig}$

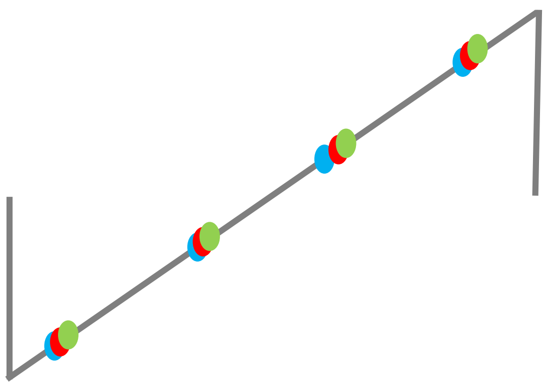


Yuto Sasaki, Yujie Zhao, Anna Kuwana and Haruo Kobayashi, "Highly Efficient Waveform Acquisition Condition in Equivalent-Time Sampling System", 27th IEEE Asian Test Symposium, Hefei, Anhui, China (Oct. 2018)

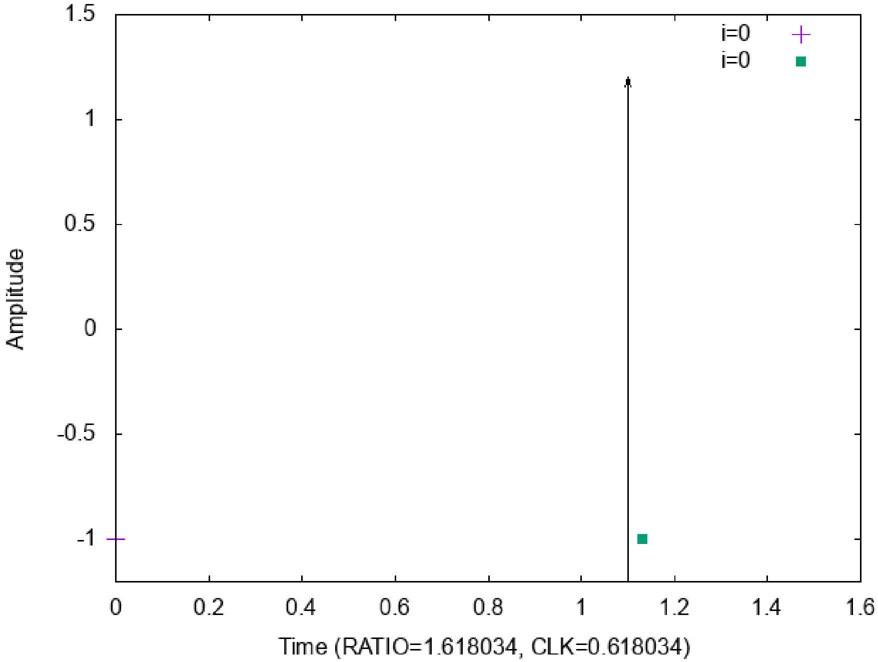
Waveform Missing for Saw Signal

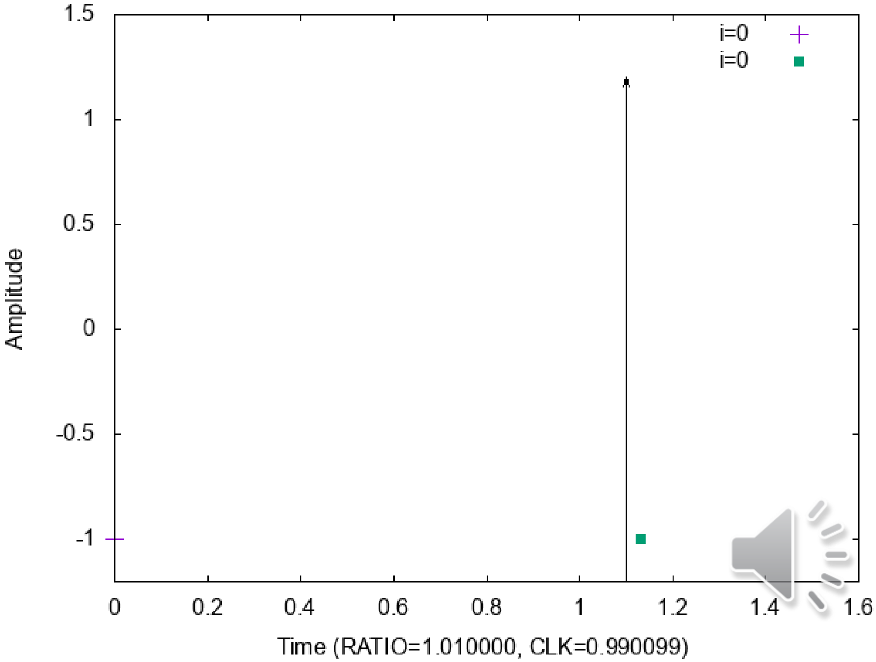


Normal situation



Waveform Missing





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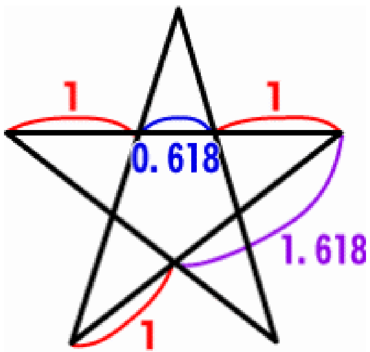
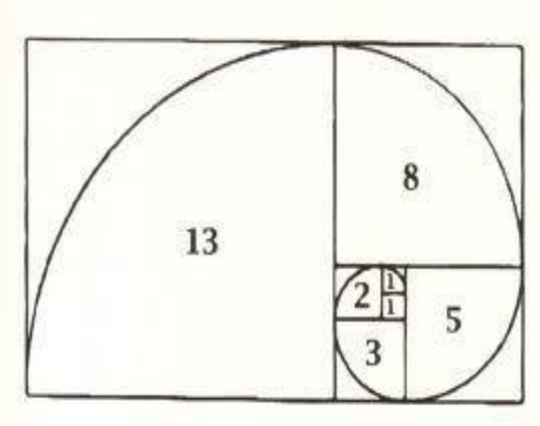
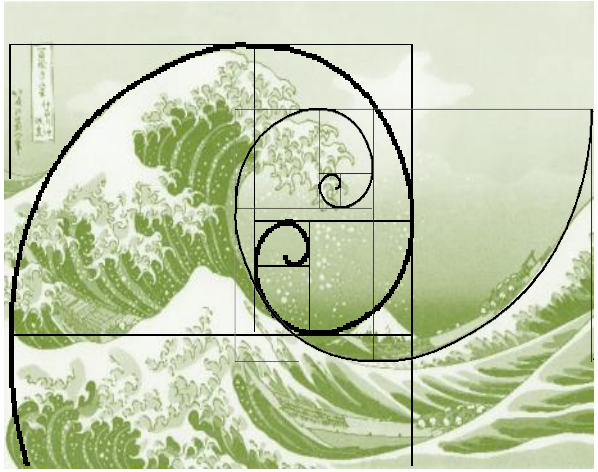
Golden Ratio

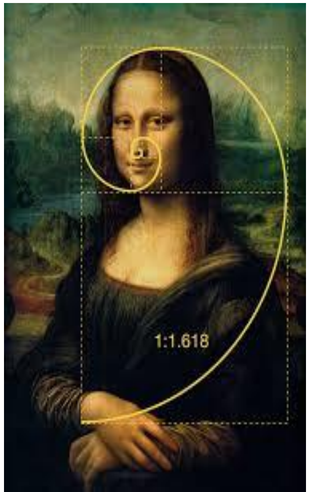
Golden Ratio: $$\lim_{n\to\infty}\frac{F_n}{F_{n-1}} = 1.618033988749895 = \varphi$$

The most beautiful ratio







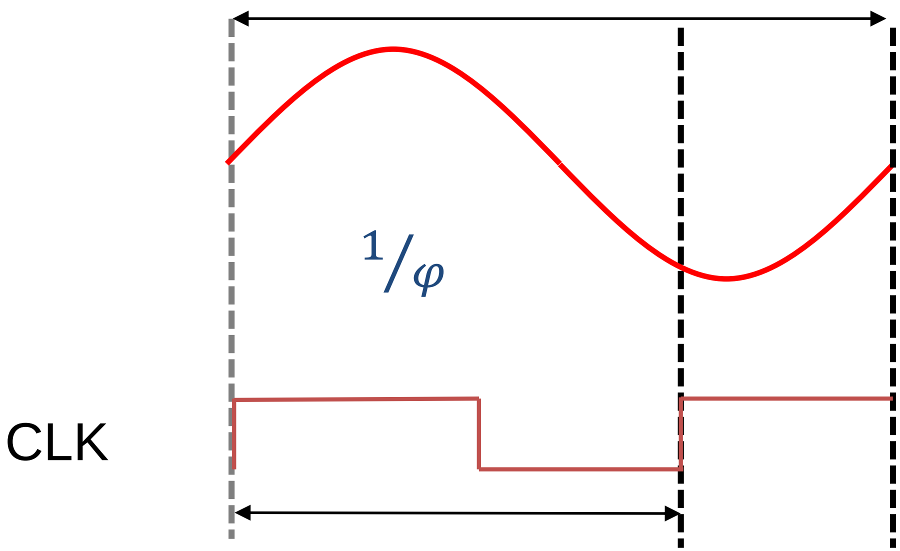


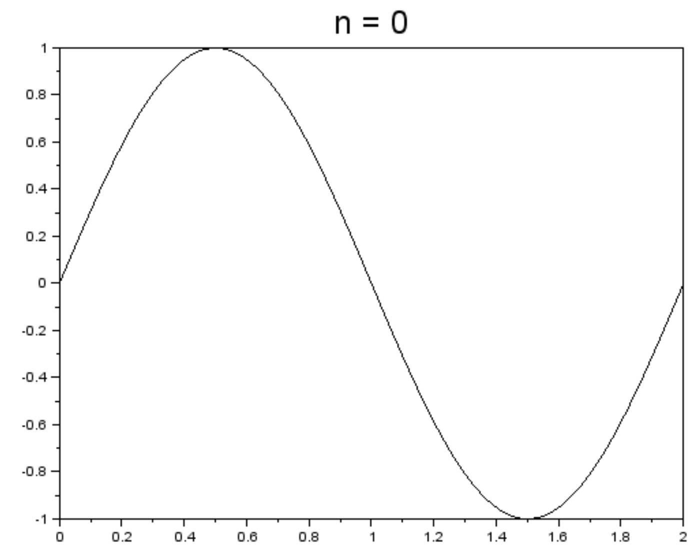
Golden Ratio Sampling

Golden Ratio φ

$$f_{CLK} = \varphi \times f_{sig}$$

φ = 1.6180339887…





Proposal of sampling conditions for the highest waveform acquisition efficiency

Yuto Sasaki, Yujie Zhao, Anna Kuwana and Haruo Kobayashi, "Highly Efficient Waveform Acquisition Condition in Equivalent-Time Sampling System", 27th IEEE Asian Test Symposium, Hefei, Anhui, China (Oct. 2018)

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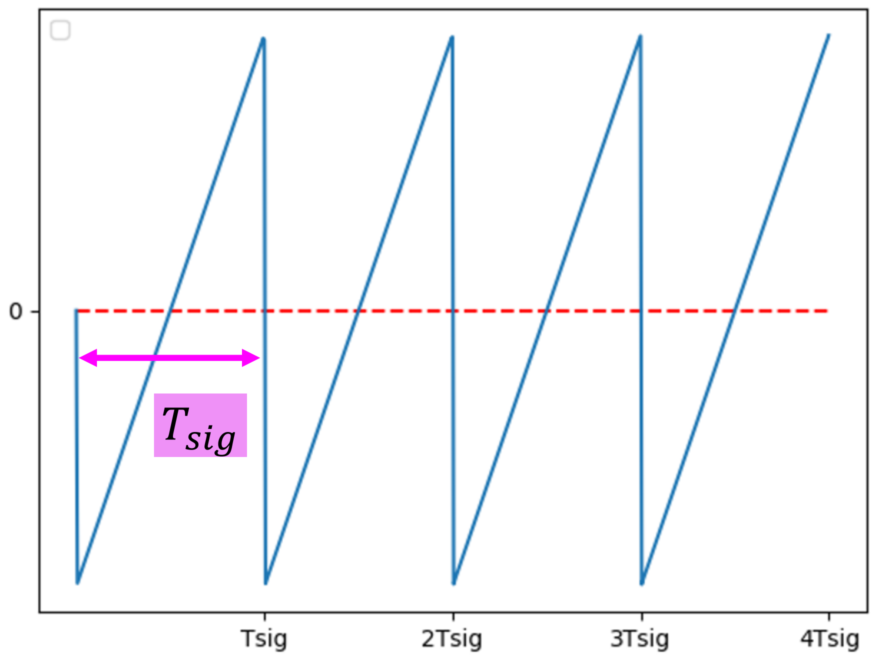
Metallic Ratio

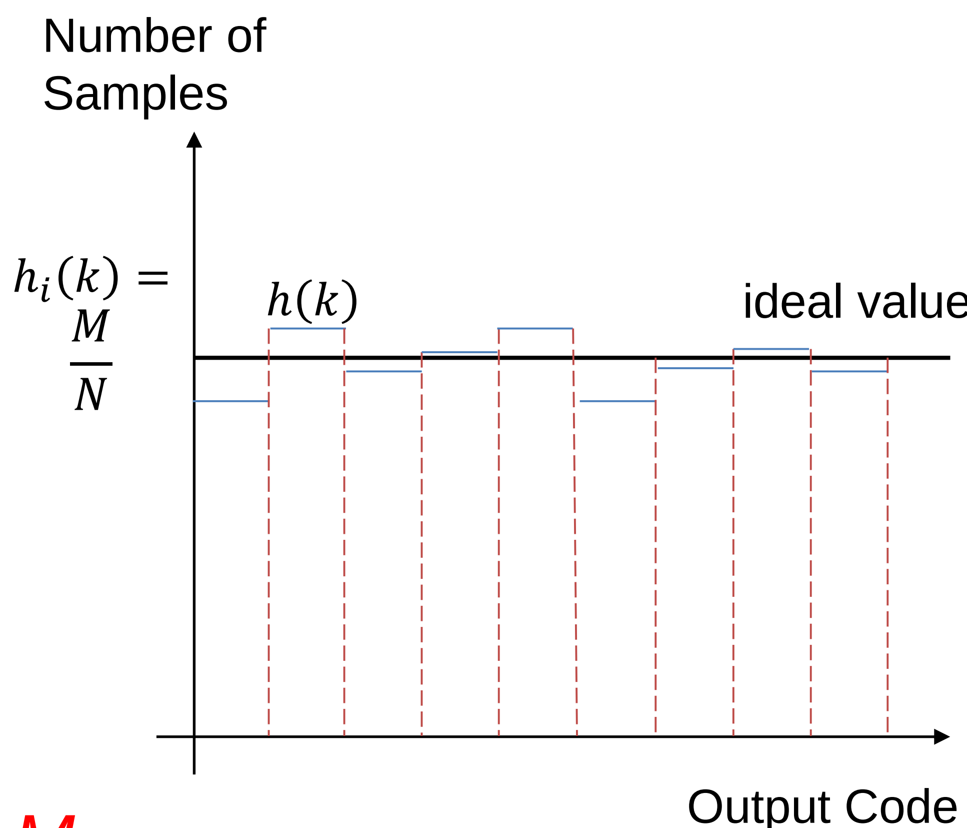
Golden Ratio: $\lim_{n\to\infty} \frac{F_n}{F_{n-1}} = 1.61803398874989.. = \varphi$

n		Decimal	
0	1		
1	$\frac{1+\sqrt{5}}{2}$	1.6180339887…	Golden Ratio
2	$1+\sqrt{2}$	2.4142135623…	Silver Ratio
3	$\frac{3+\sqrt{13}}{2}$	3.3027756377…	Bronze Ratio
4	$2+\sqrt{5}$	4.2360679774…	
…	…		
n	$\frac{n+\sqrt{n^2+4}}{2}$		

Generalization of Golden Ratio

Histogram of Saw Signal





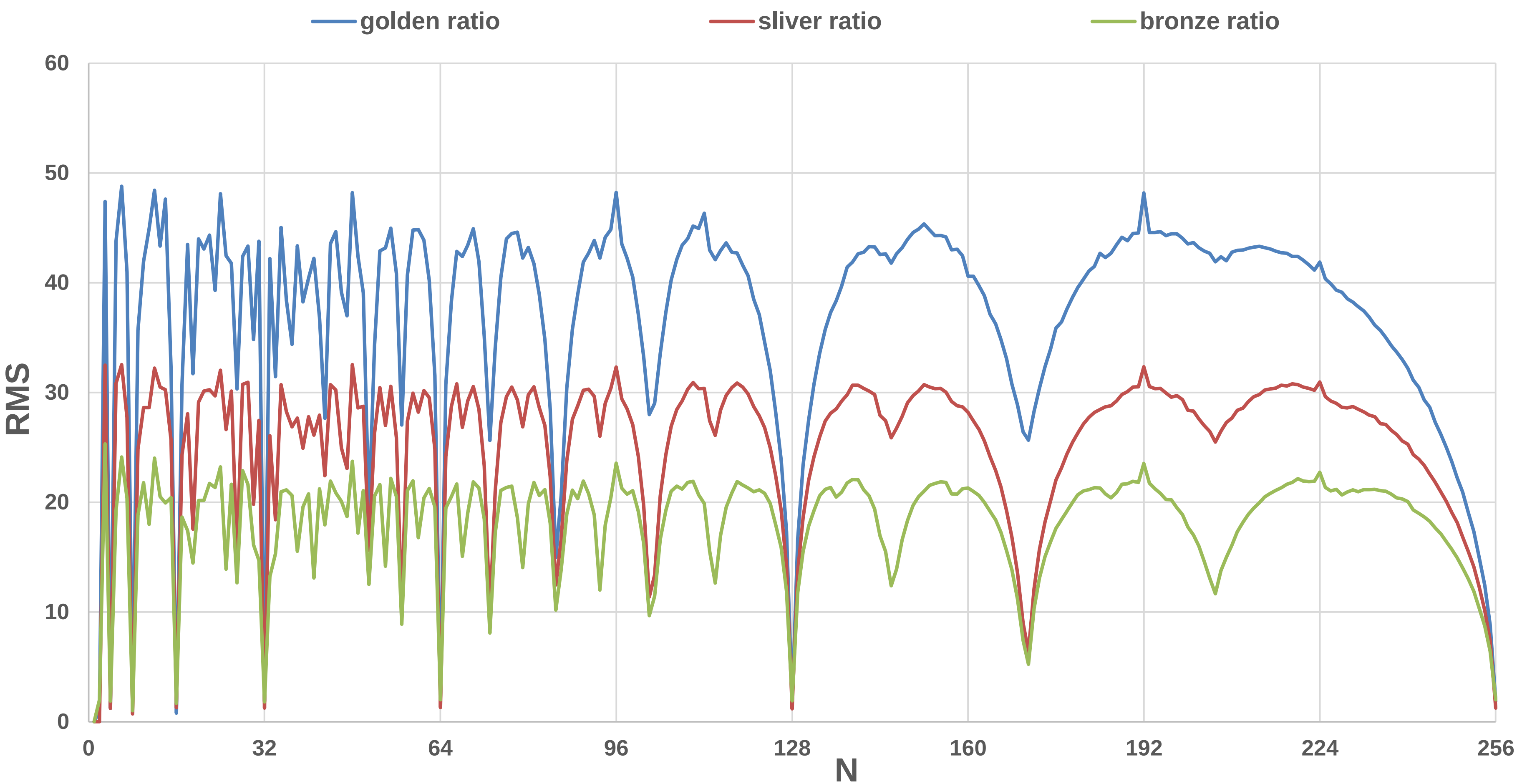
Total number of samples: *M*

ADC resolution :*N*.

ideal value $h_i(k) = \frac{M}{N}, k = 1,2,3,\ldots,N$ error $e(k) = \frac{N \cdot h(k)}{M} - 1$

RMS Error Calculation

Total number of samples: M=65536



Root mean square error
between actual and ideal histograms

$$RMS = \sqrt{\frac{\sum (\mathrm{e}(k))^2}{N}}$$

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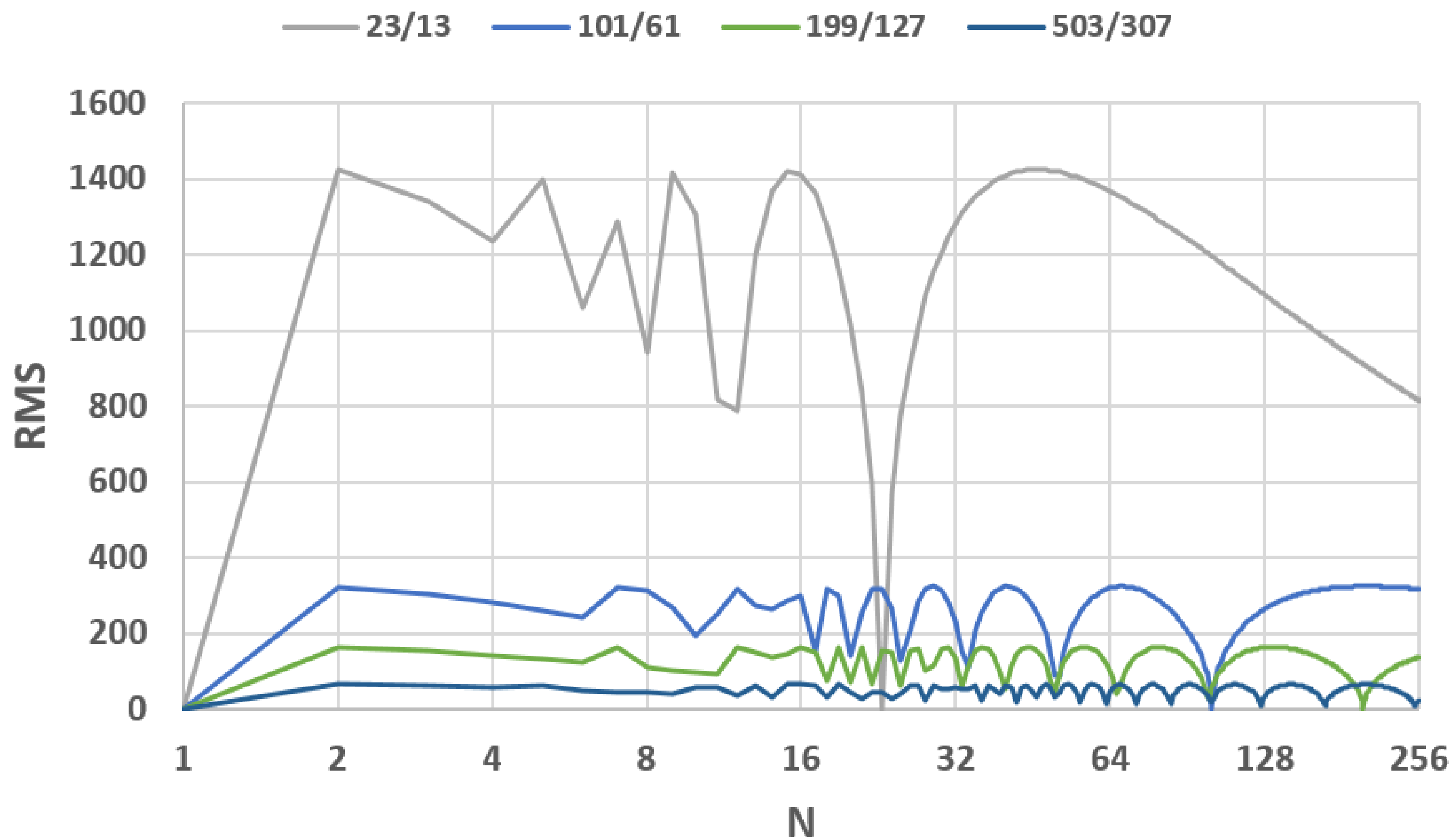
RMS of Prime Number Sampling

$f_{CLK} = f_{sig} \times RATIO$

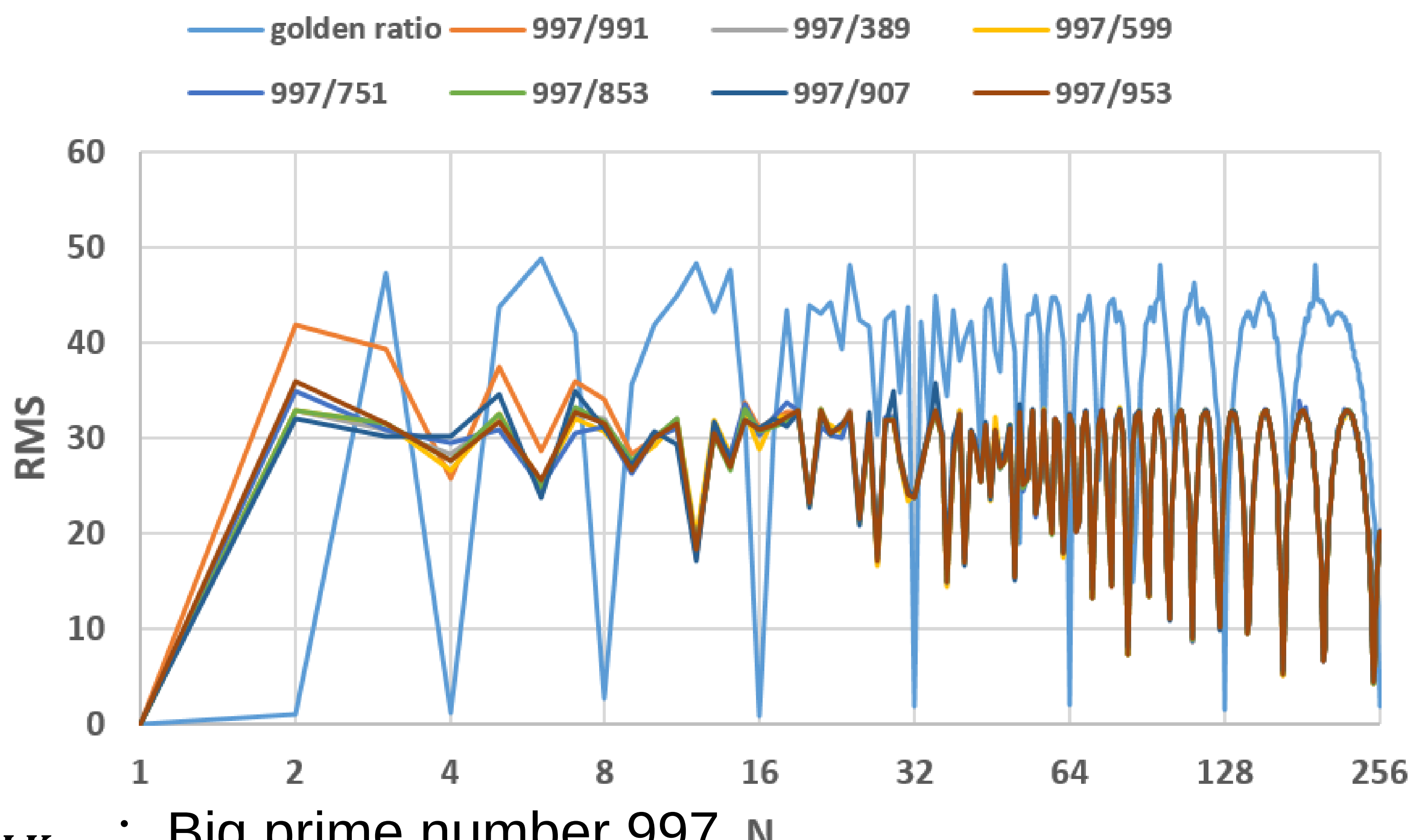
Total number of samples: M=65536



RATIO with two large prime numbers ⇒ Small RMS
In contrast, Golden Ratio has a smaller RMS

RMS of Prime Number Sampling: Big Number Case

Total number of samples: M=65536



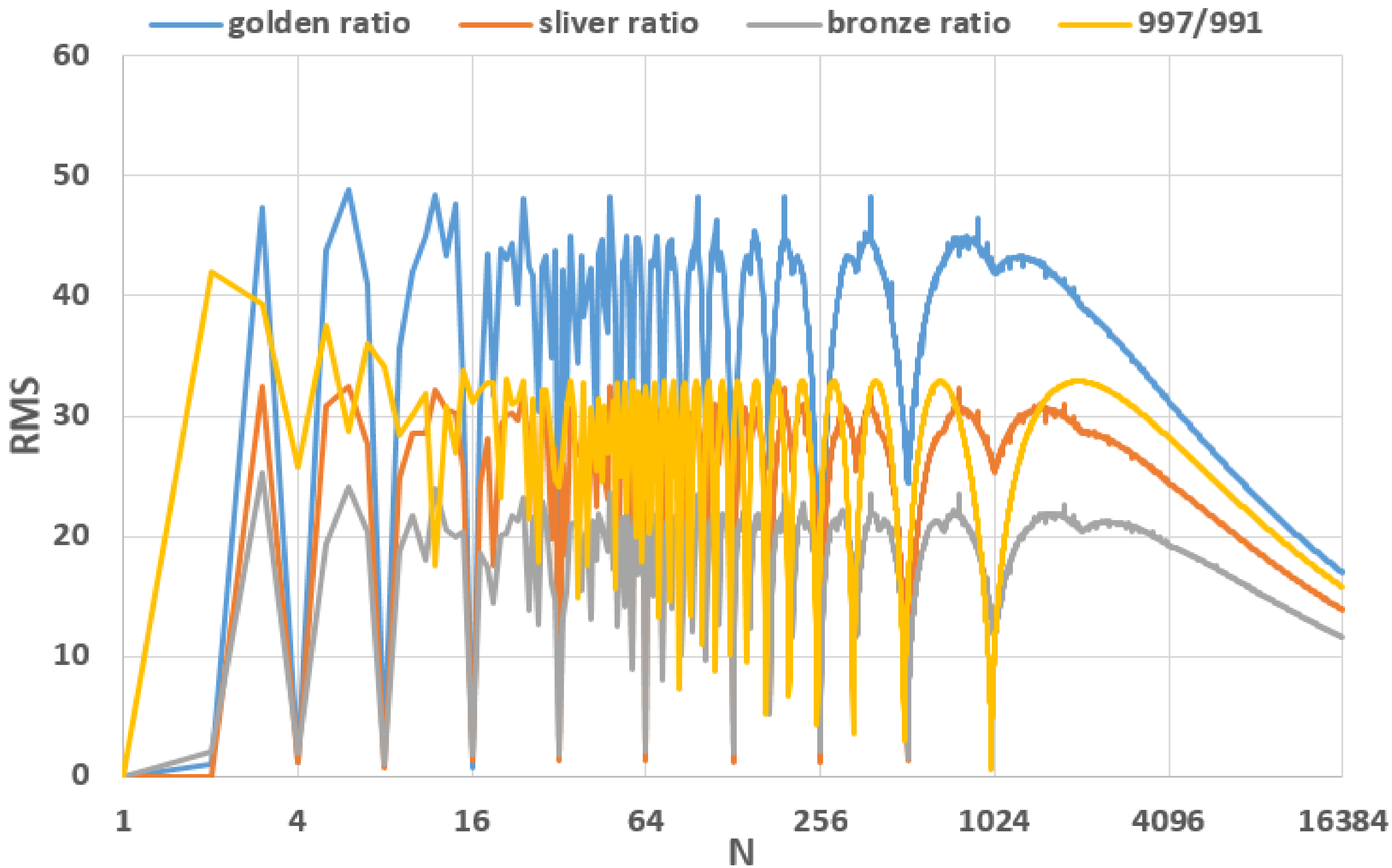
f_{CLK} : Big prime number 997

f_{SIG} : Some prime numbers 389,599,751,853,907,953,991

→ almost the same

RMS Comparison

Total number of samples: M=65536



Increasing N to 16384,
Bronze ratio result is better (RMS range is smaller)

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Golden Ratio sampling
Efficiency: high
Sampling frequency: low

Metallic ratio sampling
Efficiency: high
Sampling frequency: high

Prime number ratio sampling
Efficiency:Not good
Sampling frequency: low

Next work

- Like the golden ratio
  Find conditions for efficient sampling
  at a specific location
  (ADC resolution N=256,512,1024,2048,4096)

Thanks for your attention.