1A: Analog and Mixed-Signal Test (Room 1206)
1:25 pm – 1:50 pm
Sep. 4, 2019

Crest Factor Controlled Multi-Tone Signals for Analog/Mixed-Signal IC Testing

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ADVANTEST

Outline

- Research Background
- Crest Factor Minimized Multi-tone Signal
  - Multi-tone Generation Algorithms
  - Frequency Shift
- Crest Factor Controlled Multi-tone Signal
- Summary

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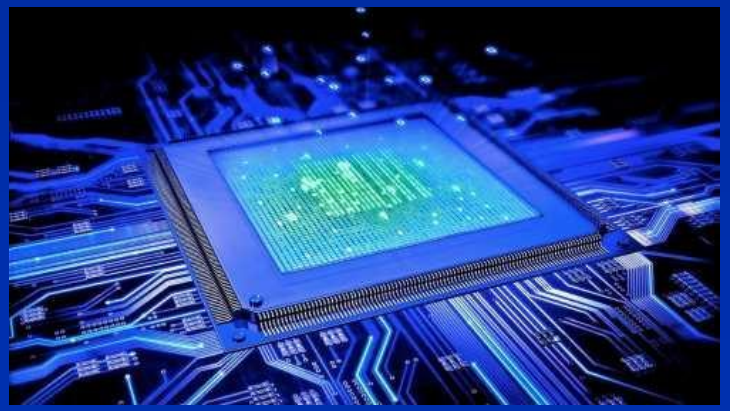
Research Background

Analog/Mixed–Signal IC becomes rapidly complicated

Require :

- To reduce cost by shorten testing time in analog circuit part
- To improve quality



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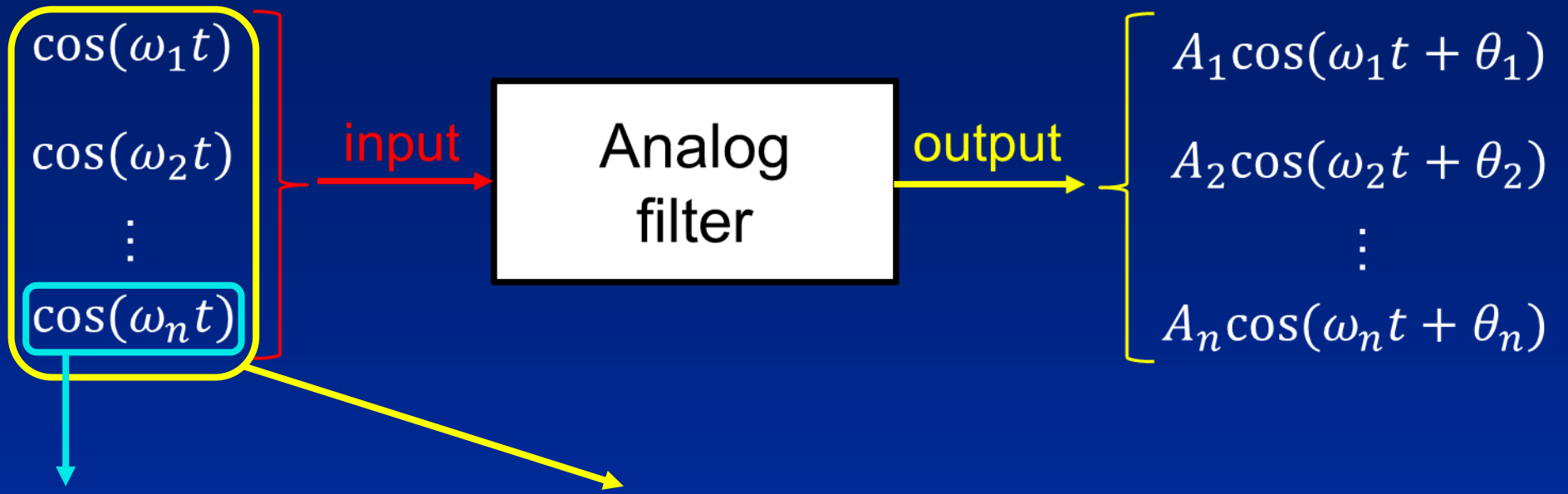
Purpose of this work



Single-tone

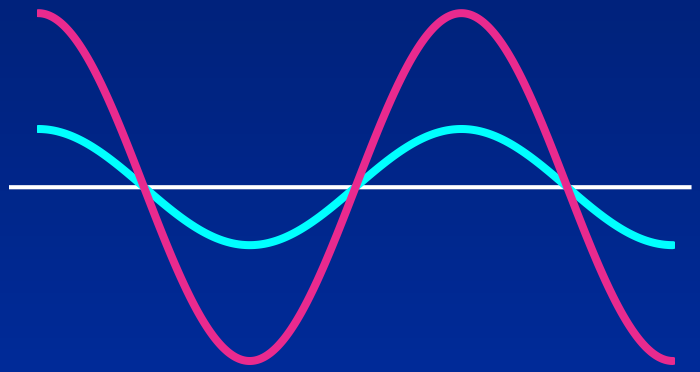
- Good SNR
- Long testing time

Multi-tone

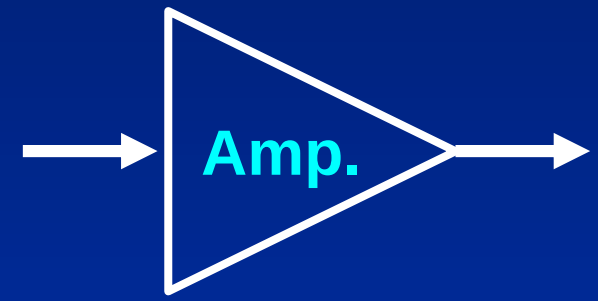
- Short testing time
- Lower SNR → Low-accuracy testing

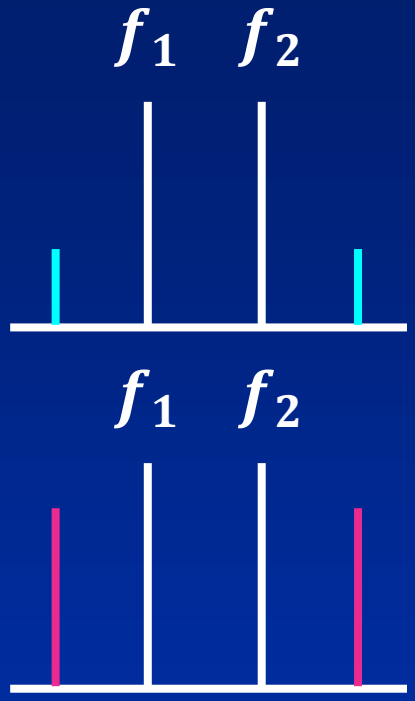
Purpose : Short-time & high-accuracy testing for analog IC using multi-tone signal

In a system with nonlinear distortion



Too large amplitude

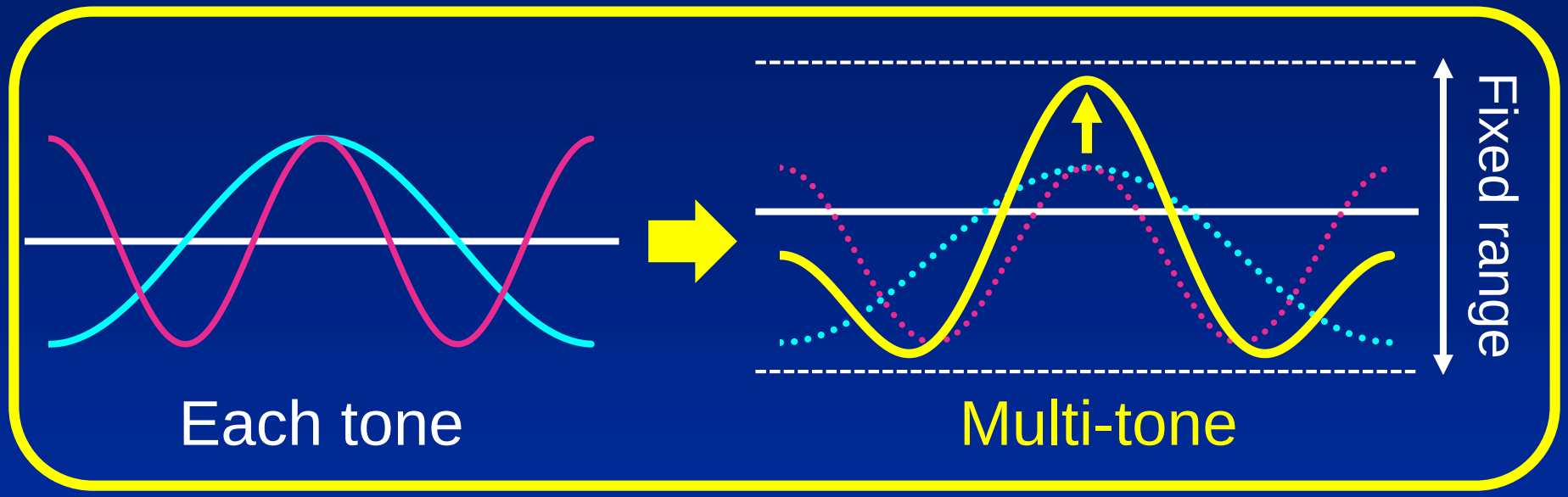




Cause large IMD

① Multi-tone must be created within fixed voltage range

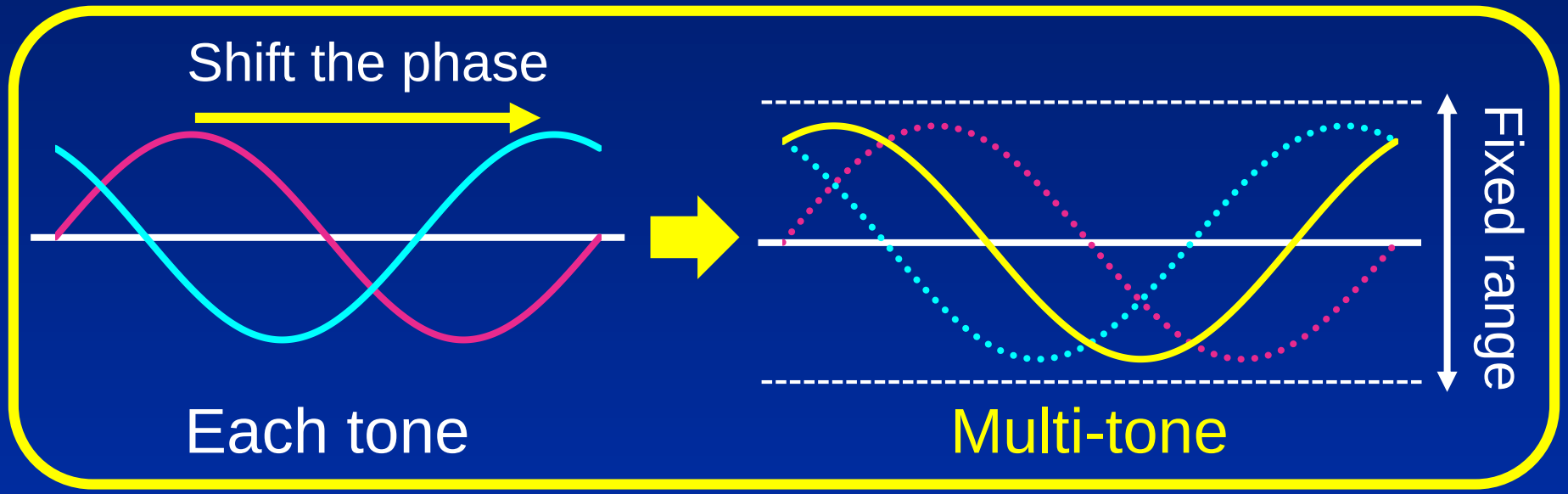
When generating multi-tone in phase



Increase amplitude (peak value) of multi-tone signal

Amplitude of each tone become smaller

When generating multi-tone by adjusting phase



Increase of amplitude is prevented = each tone larger

② Multi-tone must be created by adjusting phase

Effective measure for lower SNR

Multi-tone must be created within a fixed range
by adjusting phase

Maximize RMS

II

Maximize dynamic range (DR)

II

Minimize crest factor (CF)

※ $\mathrm{CF} = 20Log(PEAK/RMS)$

Effective measure : Using algorithm to minimize CF

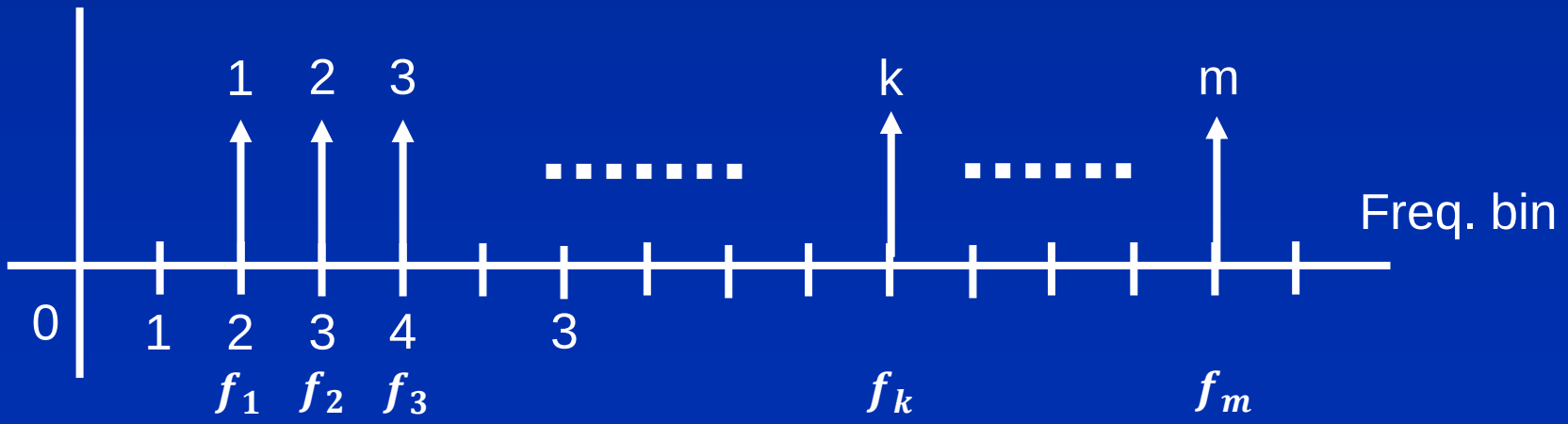
Multi-tone Generation Algorithms

Basic formula :

$$s(t) = G\sum_{k=1}^{m} cos(\frac{2\pi f_k t}{N} + \phi_k)$$

N : Resolution
m : Number of tones

Kitayoshi phase : $\phi_k = \pi k(k+1)/N$
Newman phase : $\phi_k = \pi(k-1)^2/N$
Schroeder phase : $\phi_k = -\pi k(k-1)\ /N$

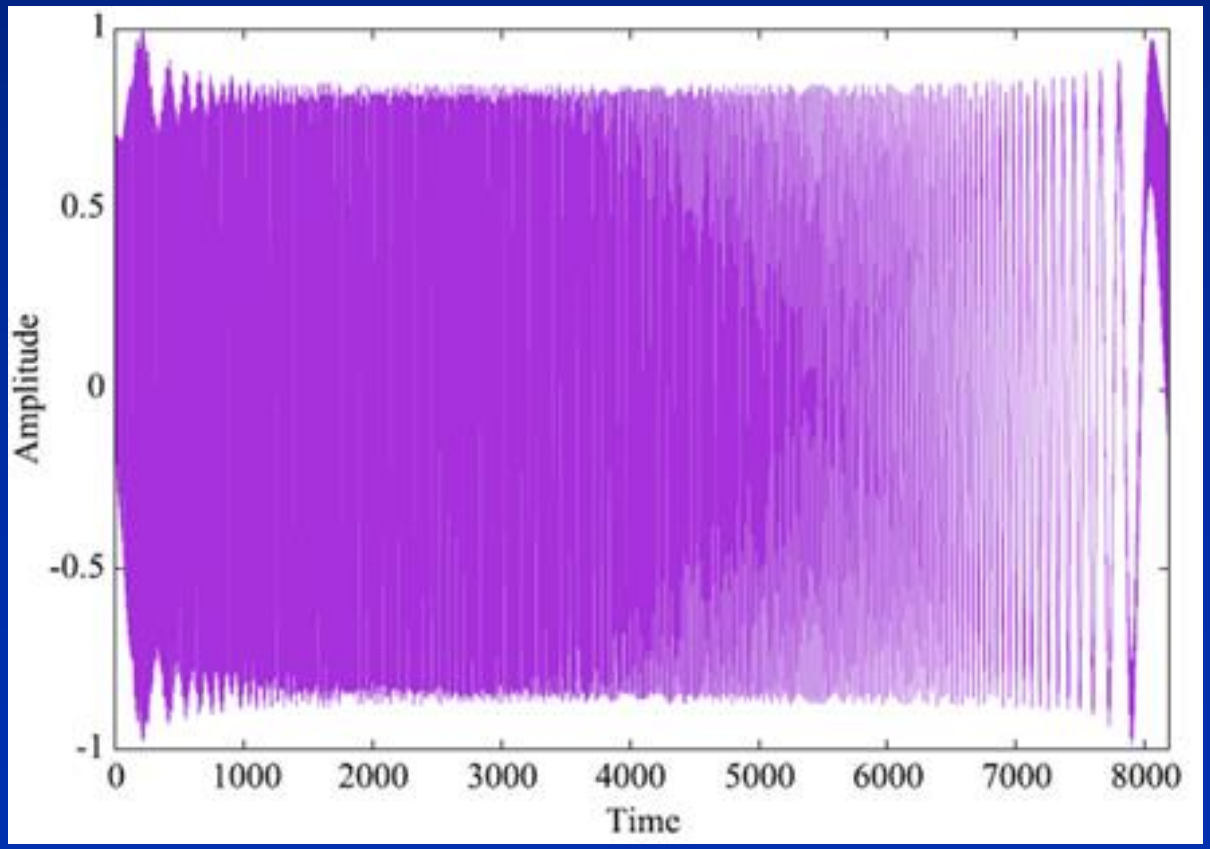


Simulation Result (Newman Algorithm)

$$s(t) = G\sum_{k=1}^{m} cos(\frac{2\pi f_k t}{N} + \frac{\pi}{N}(k-1)^2)$$

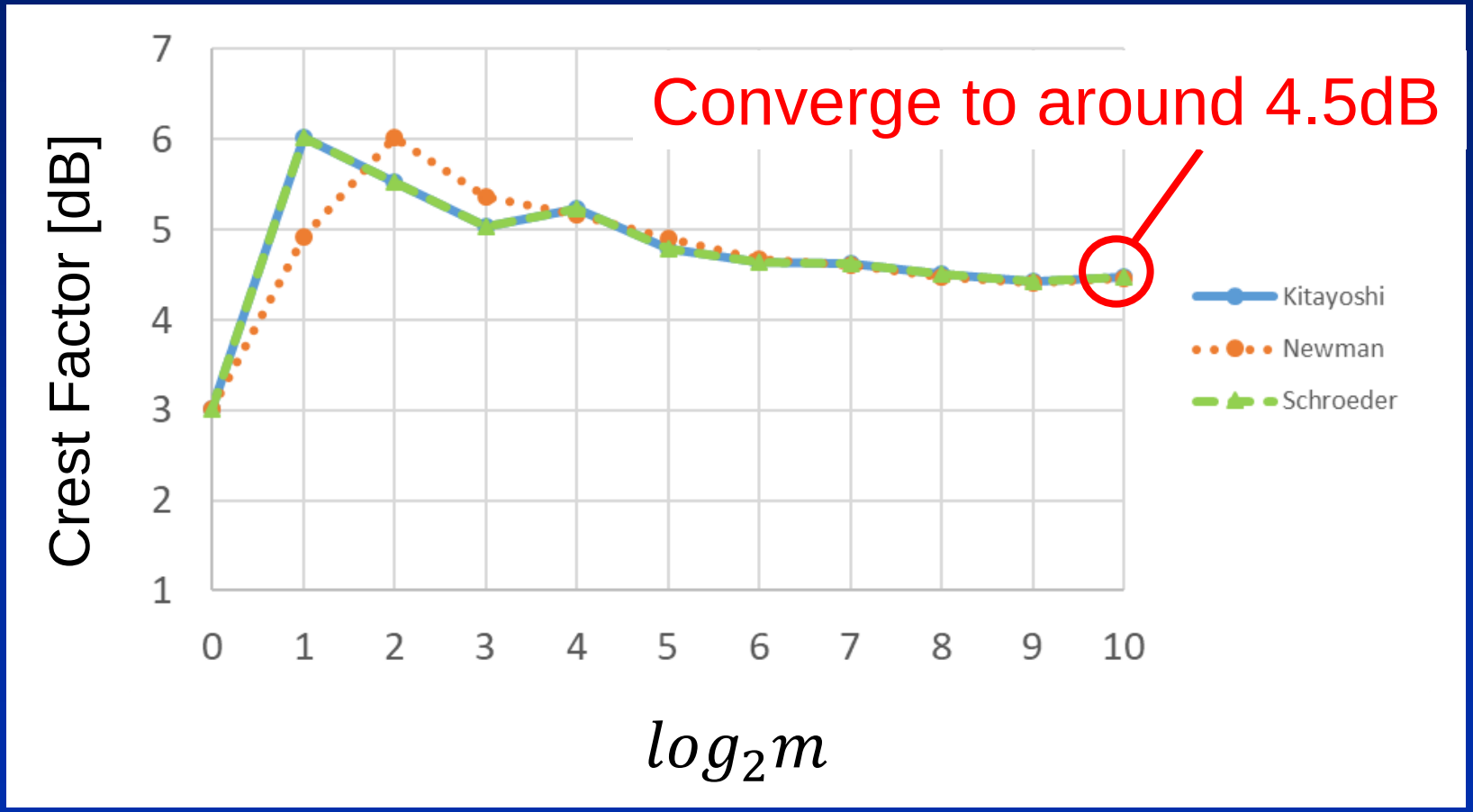
$G = 1/A_{max}$
adjust the amplitude to 1

N = 8192 m = 1024 G = 2.6×10^{-2}



Relationship between m & CF

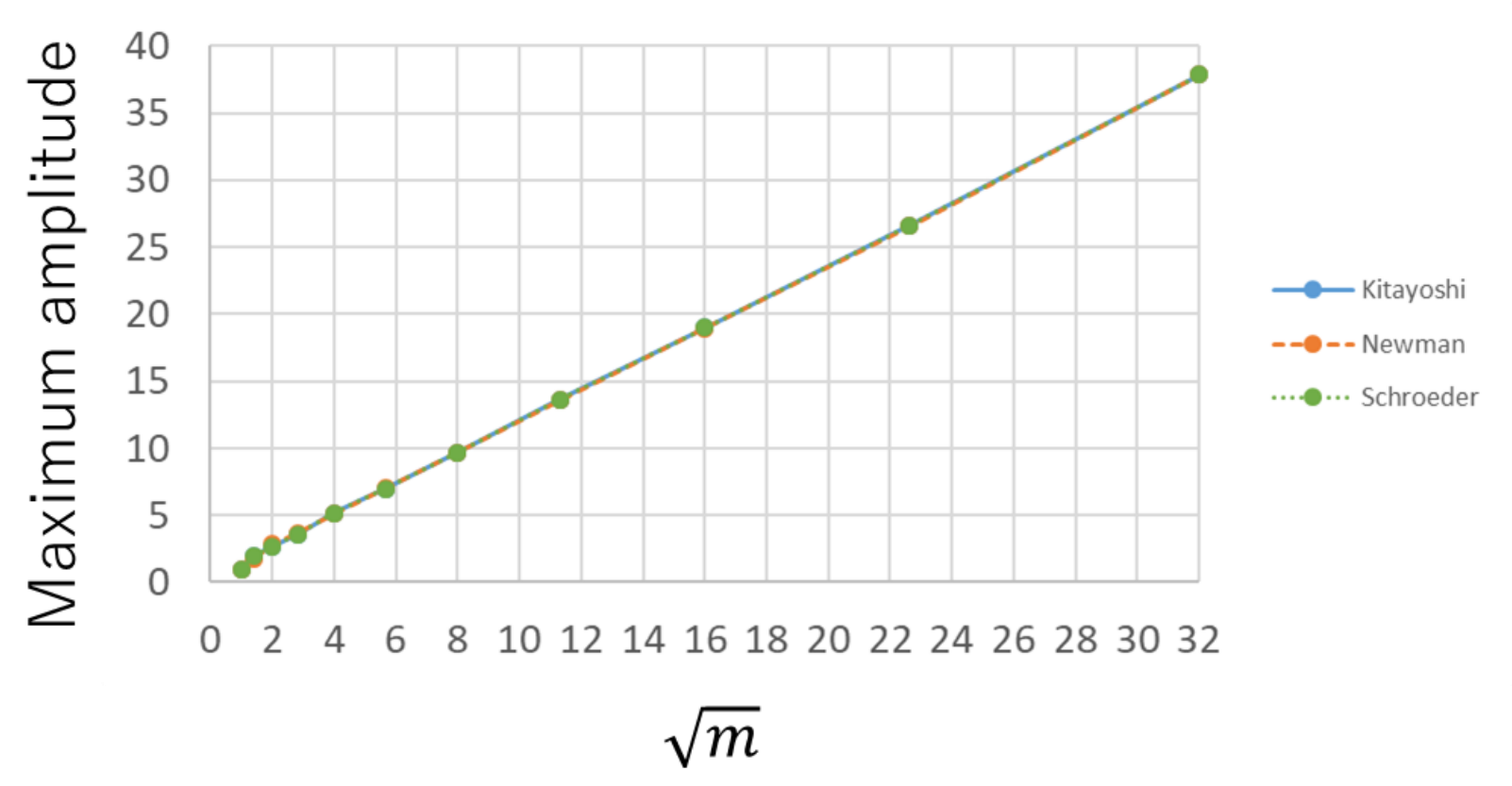
※ m = Number of tones



3 algorithms : almost consistent

Relationship between m & A_{max}

※ m = Number of tones

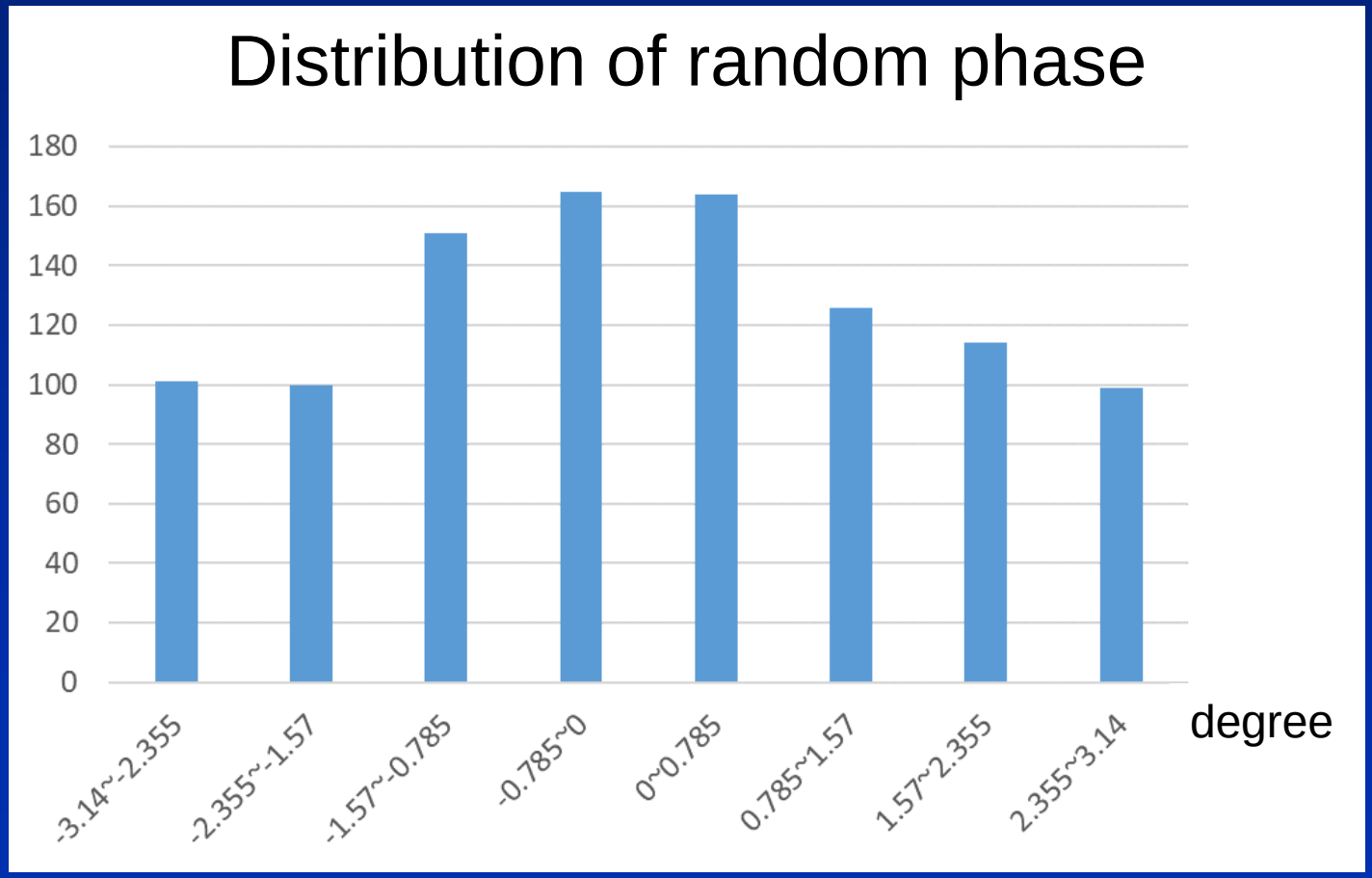


Maximum amplitude (A_{max}) proportional to $\sqrt{m}$

Random phase (random initial phase)

$$s(t) = \sum_{k=1}^{m} \cos\left(\frac{2\pi \boldsymbol{f_k} t}{N} + \phi_k\right)$$

ϕ_k : random numbers with a Gaussian distribution generated by using C language

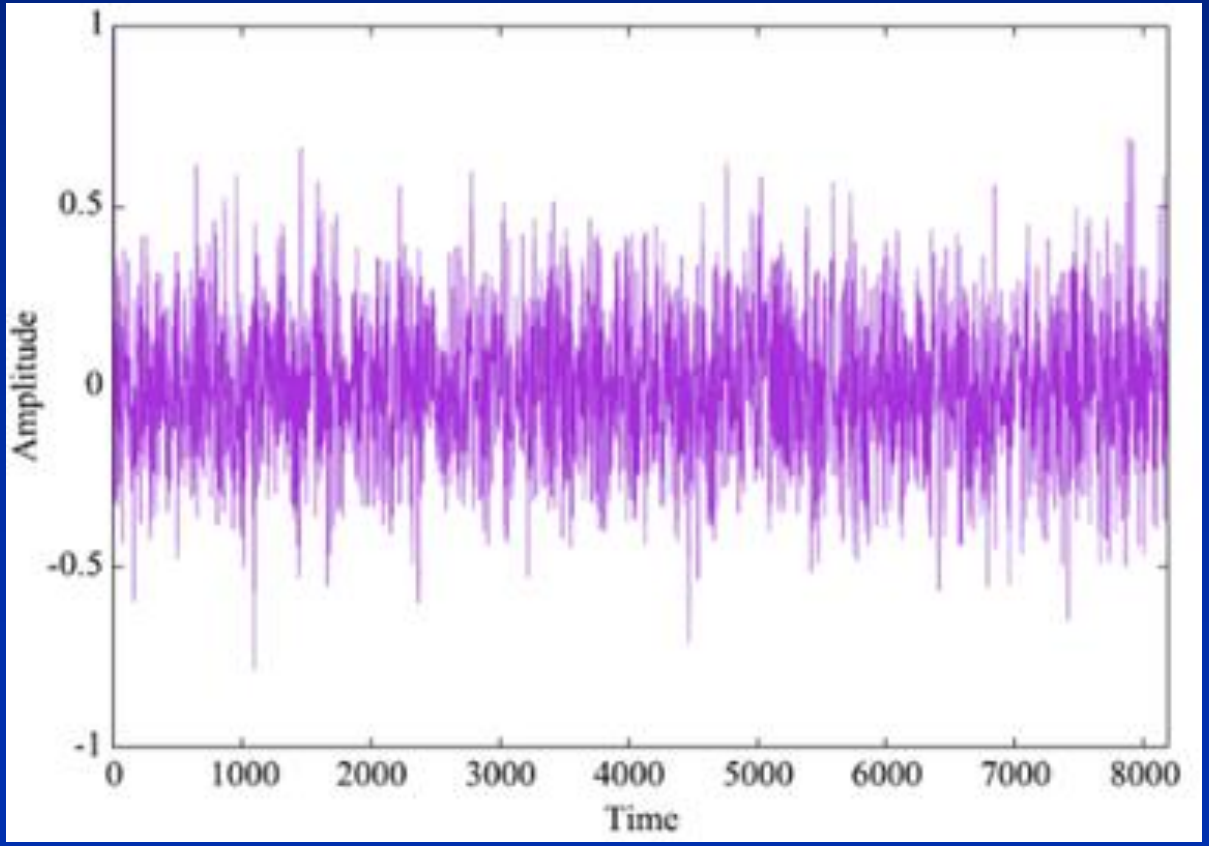


Waveform (random initial phase)

$$s(t) = \boldsymbol{G} \sum_{k=1}^{m} \cos\left(\frac{2\pi \boldsymbol{f_k} t}{N} + \phi_k\right)$$

$G = 1/A_{max}$
adjust the amplitude to 1

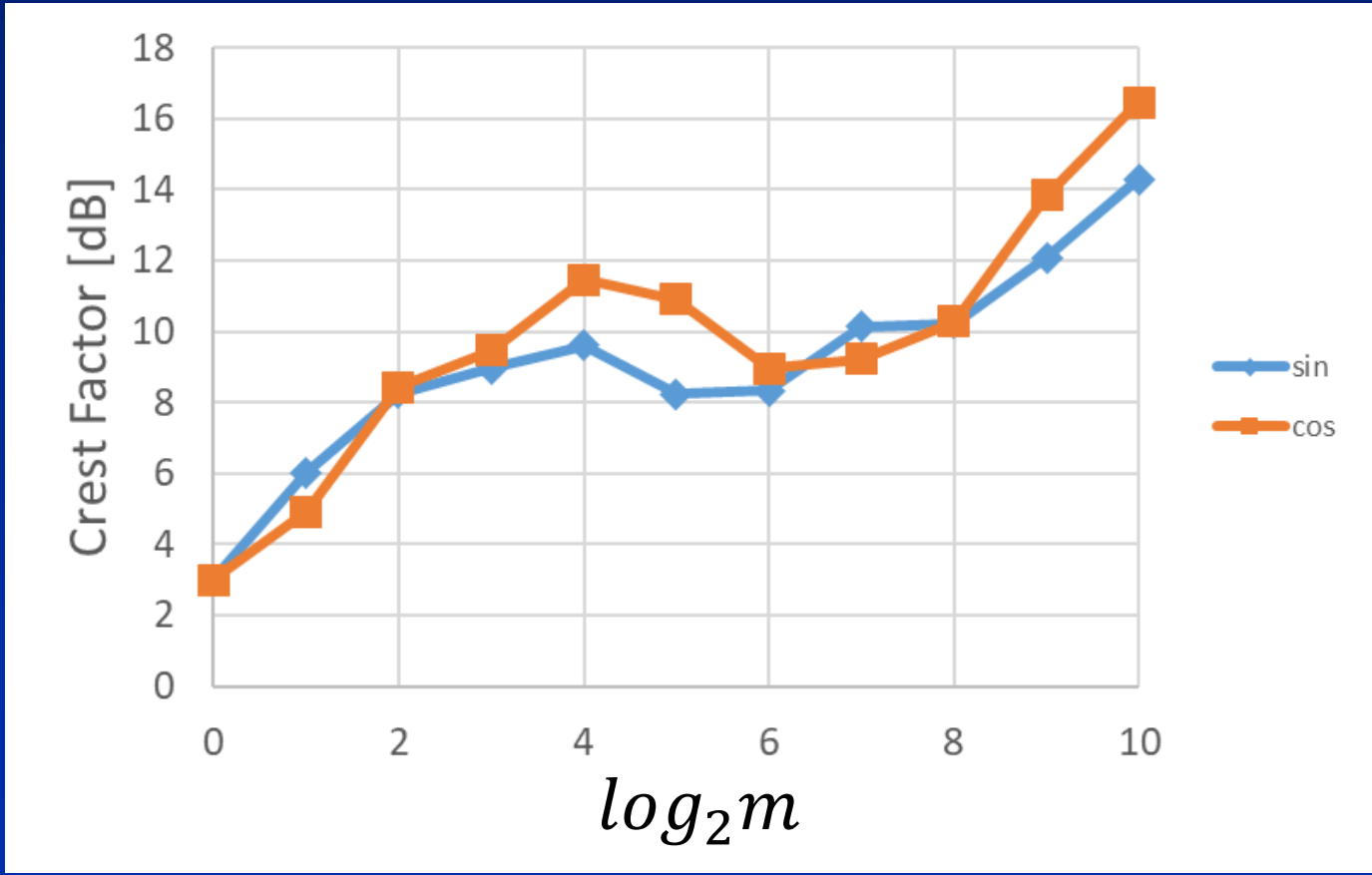
N = 8192 m = 1024 G = 6.6×10^{-3}



Relationship between m & CF

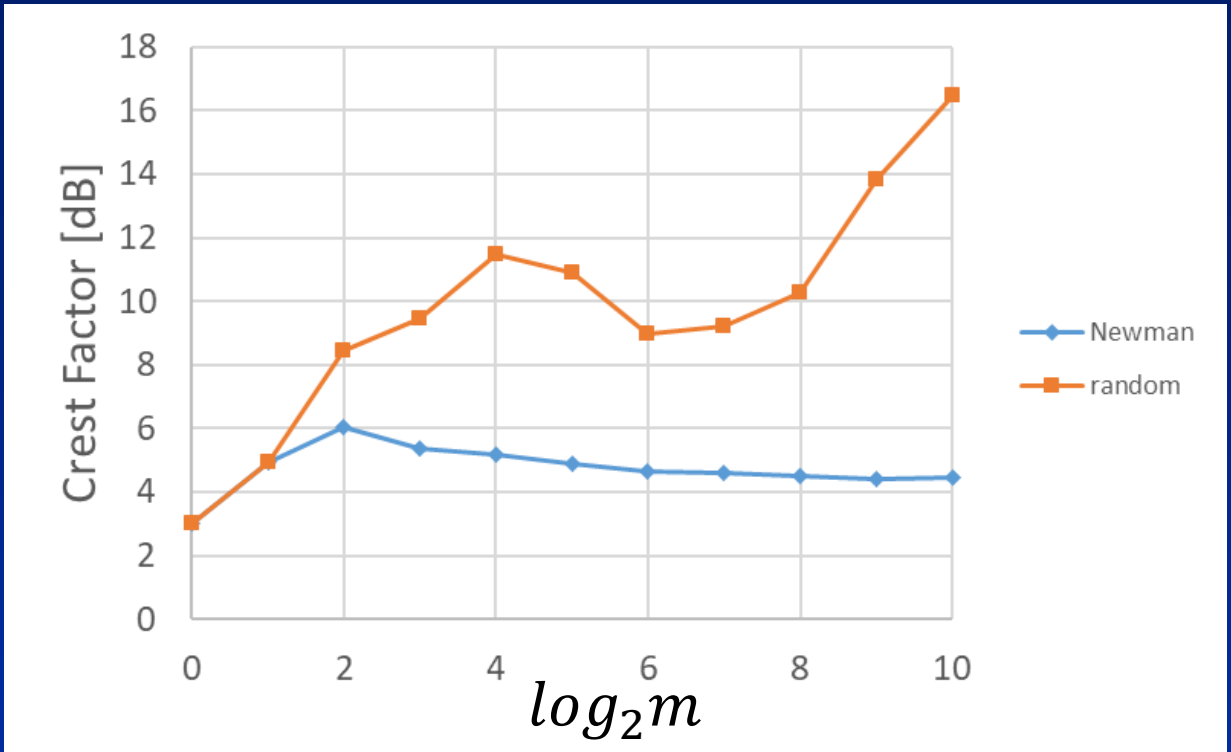
(Random initial phase)

※ m = Number of tones



CF tends to increase as m increase

Comparison of CF ※ m = Number of tones

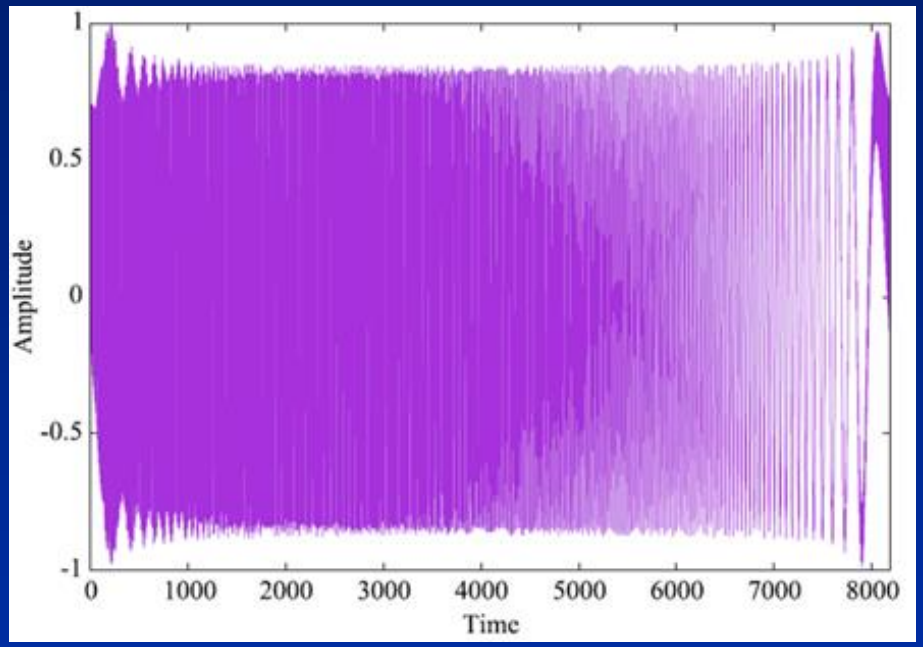


Random : CF tends to increase as m increase
Newman : CF converges to around 4.5

Newman algorithm can reduce crest factor

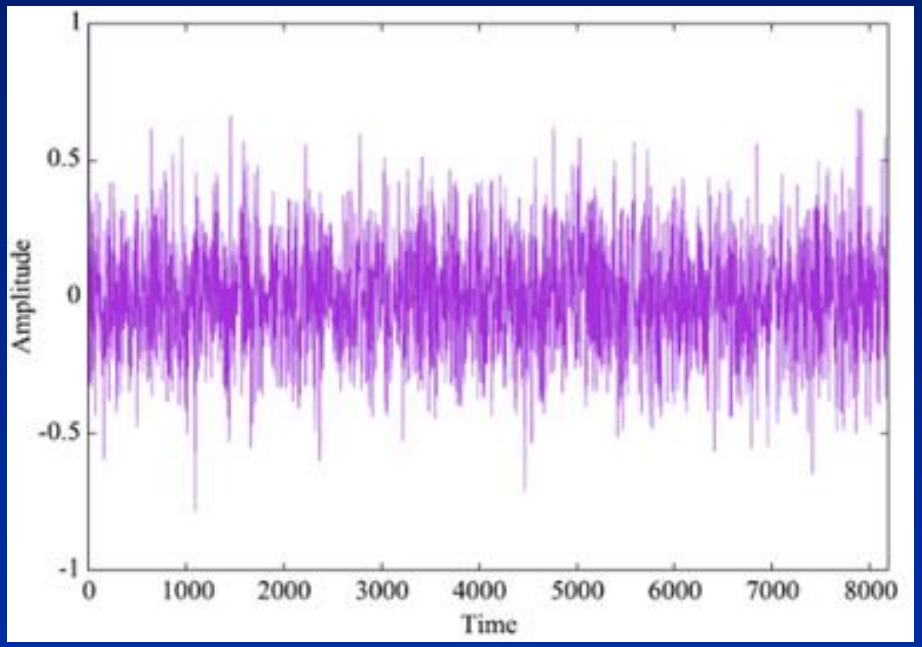
Comparison of waveform

Newman phase



CF = 4.5 [dB] RMS = 0.60

Random phase



CF = 16.5 [dB] RMS = 0.15

RMS value: **Newman phase** > Random phase

Newman algorithm can generate high-accuracy signal

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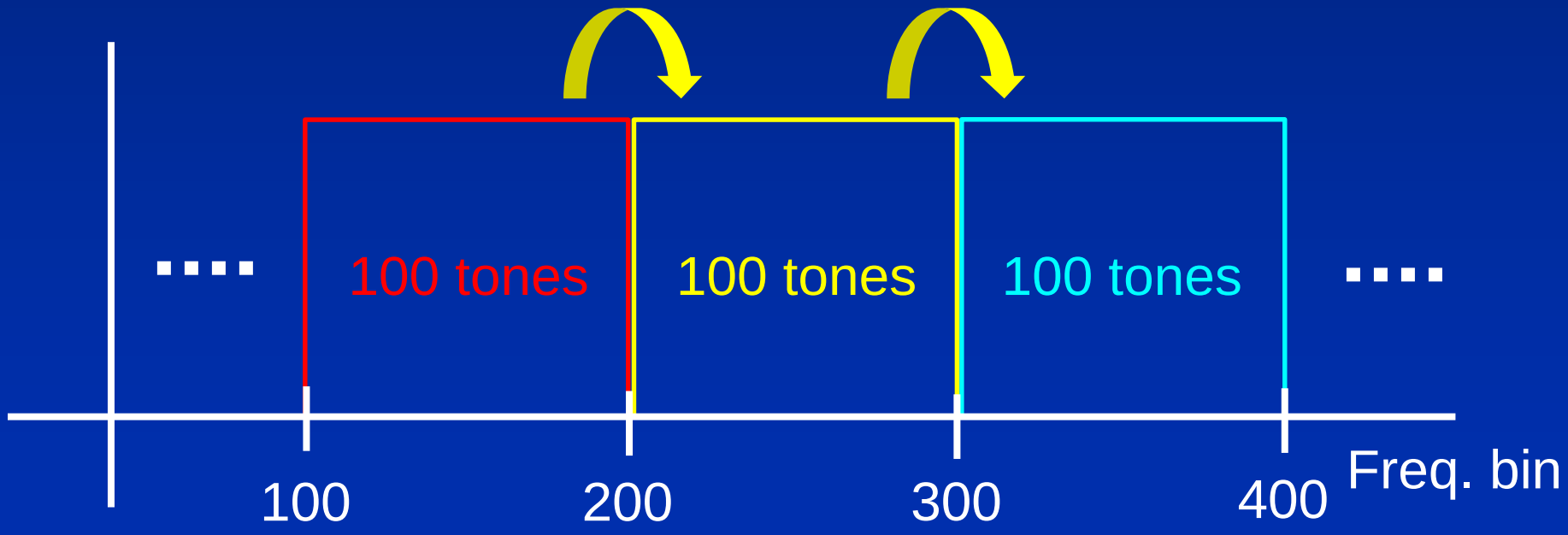
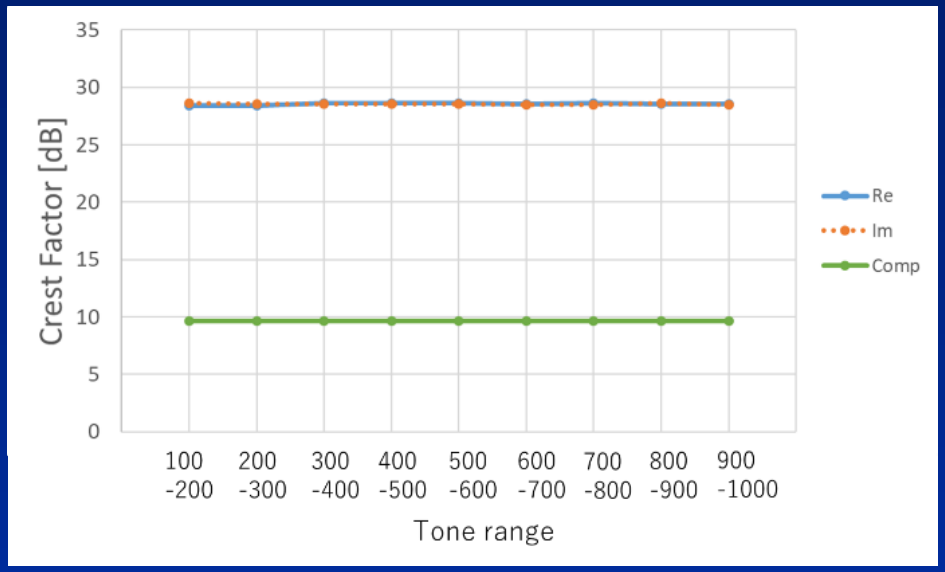
Frequency shift

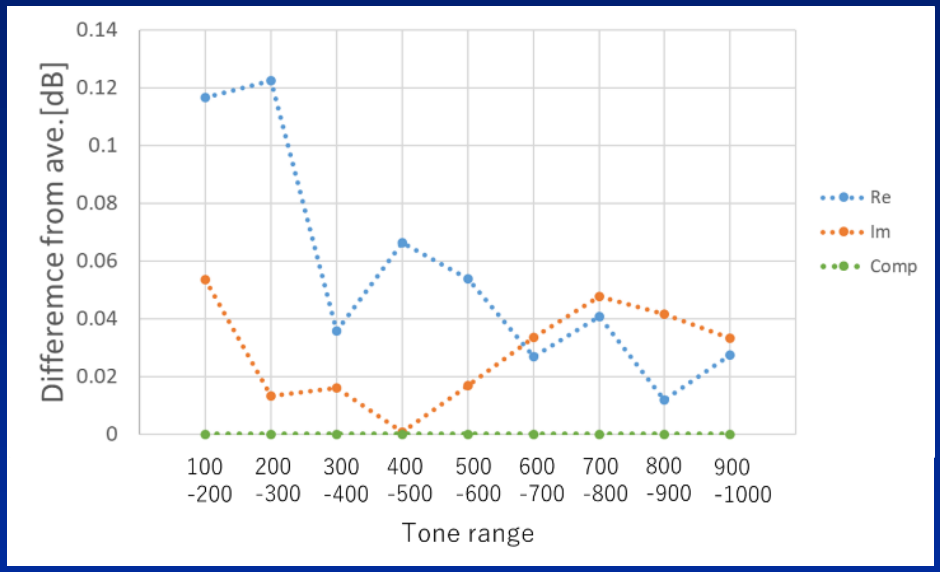
$$s(t) = G\sum_{k=1}^{m} cos(\frac{2\pi f_k t}{N} + \frac{\pi}{N}(k-1)^2)$$

100 tones (m) are shifted in simulation



Simulation result





Real part of signal
Imaginary part of signal
} CF slightly changes

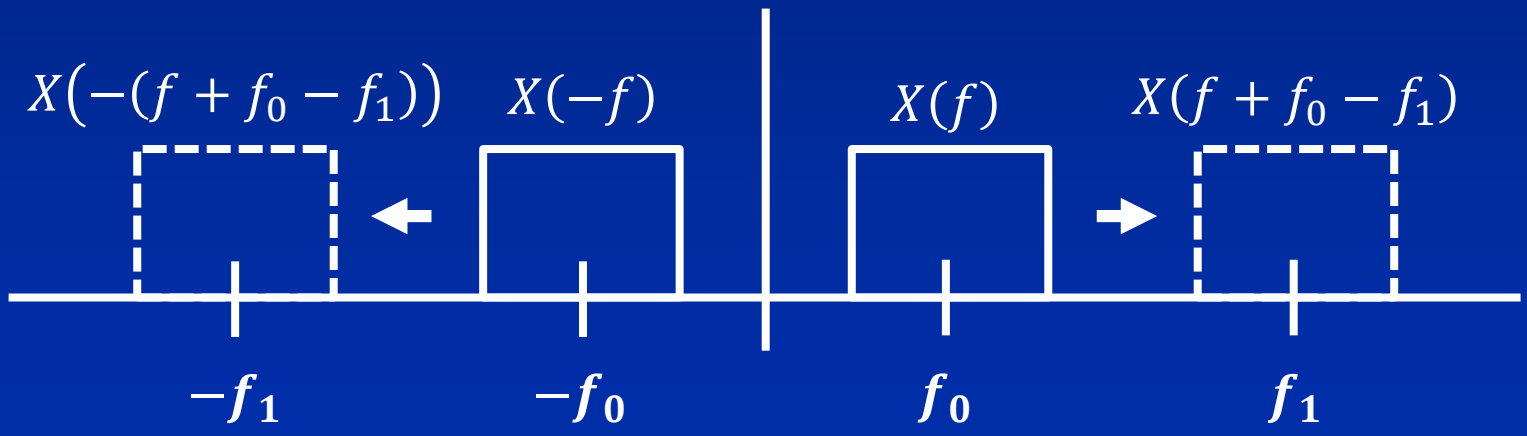
Complex signal ⟶ CF keeps constant

Analytic formula

$$X(f) * \delta(f + f_0 - f_1) = \int_{-\infty}^{\infty} X(\sigma)\,\delta(f + f_0 - f_1 - \sigma)$$

$$= X(f + f_0 - f_1) \rightarrow e^{j2\pi(f_1 - f_0)t} x(t)$$

Negative range $\rightarrow e^{-j2\pi(f_1 - f_0)t} x(t)$



Algorithms can generate high-accuracy testing signal in any frequency range

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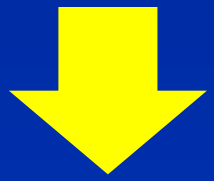
Problem of conventional method

Bandwidth used in wireless communication is expanding

ex) 5G : 800MHz WiGig : 2GHz

Conventional test method : 2-tone IMD

- To be measured in several range
- To generate a waveform conforming to the standard

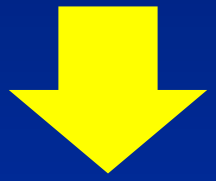


Long testing time = increase test cost

Purpose of CF control

Crest Factor of the modulation waveform depends on the communication standard

ex) 5G : around 11dB



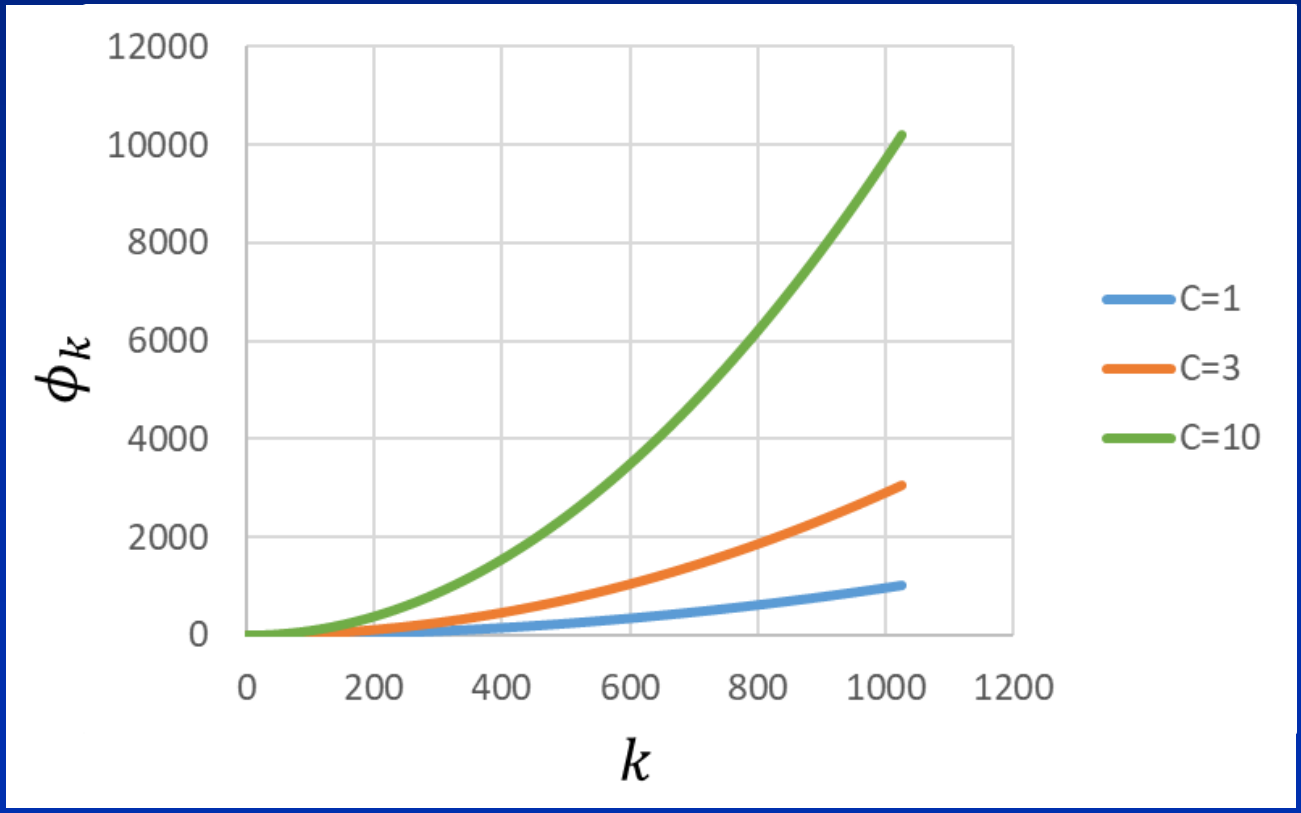
Using CF controlled multi-tone signal

- reduce testing time (test cost)
- make possible to test closer to practical use than conventional method

CF control method

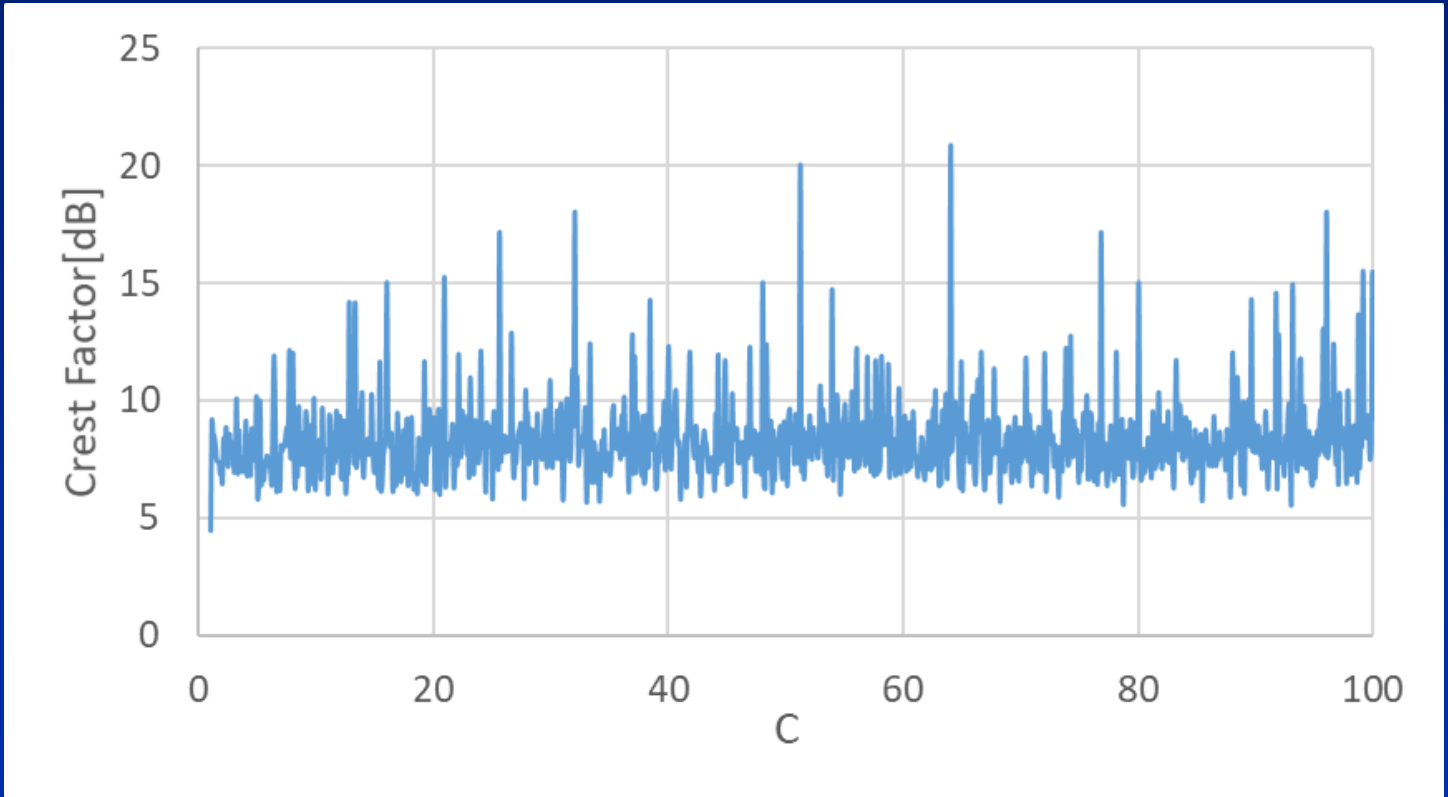
Modify the Newman algorithm

$$\phi_k = C \times \frac{\pi}{N}(k-1)^2$$



Relationship between C & CF

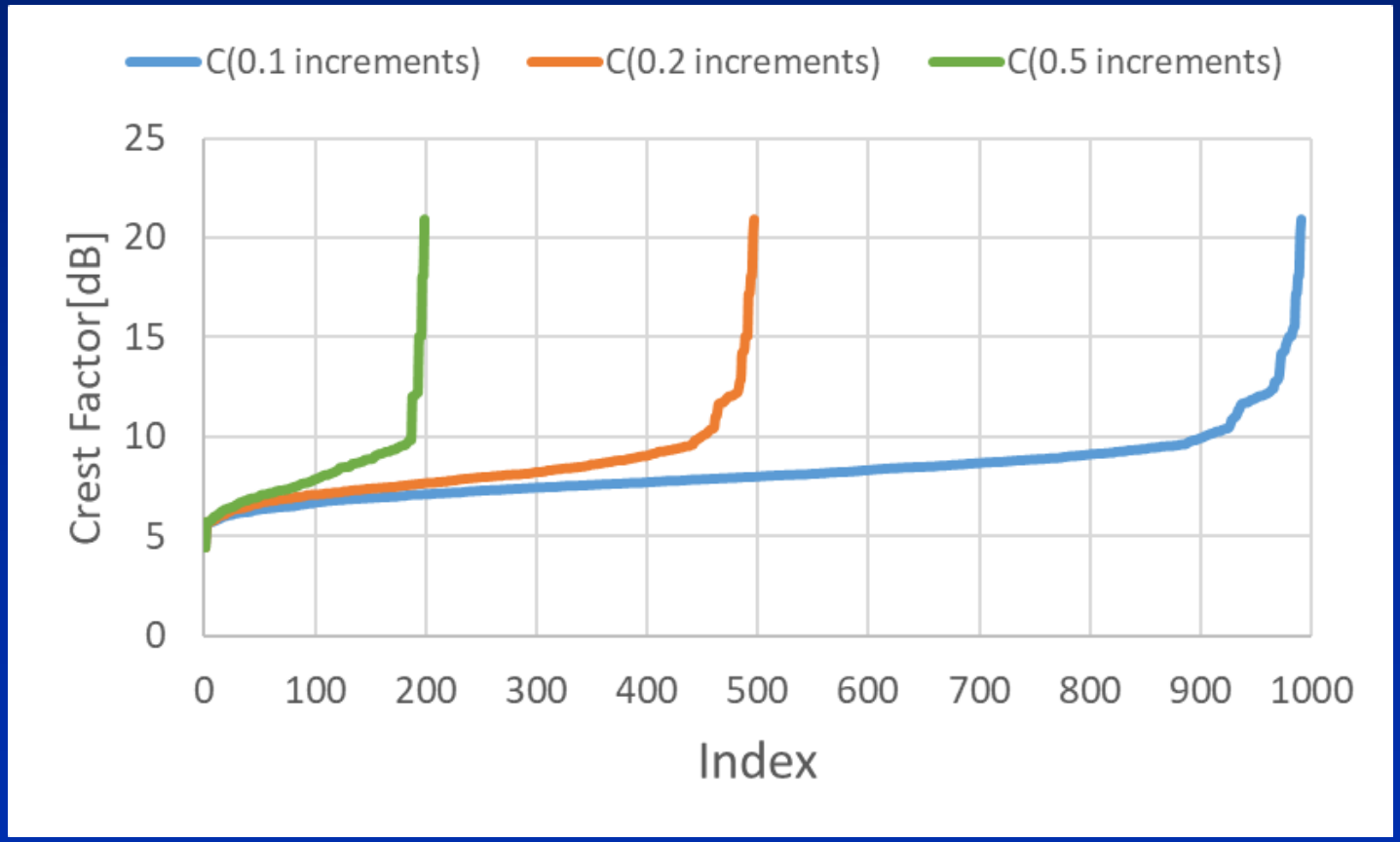
C : varied 1 ~ 100 in increments of 0.1



CF changes by using modified Newman phase

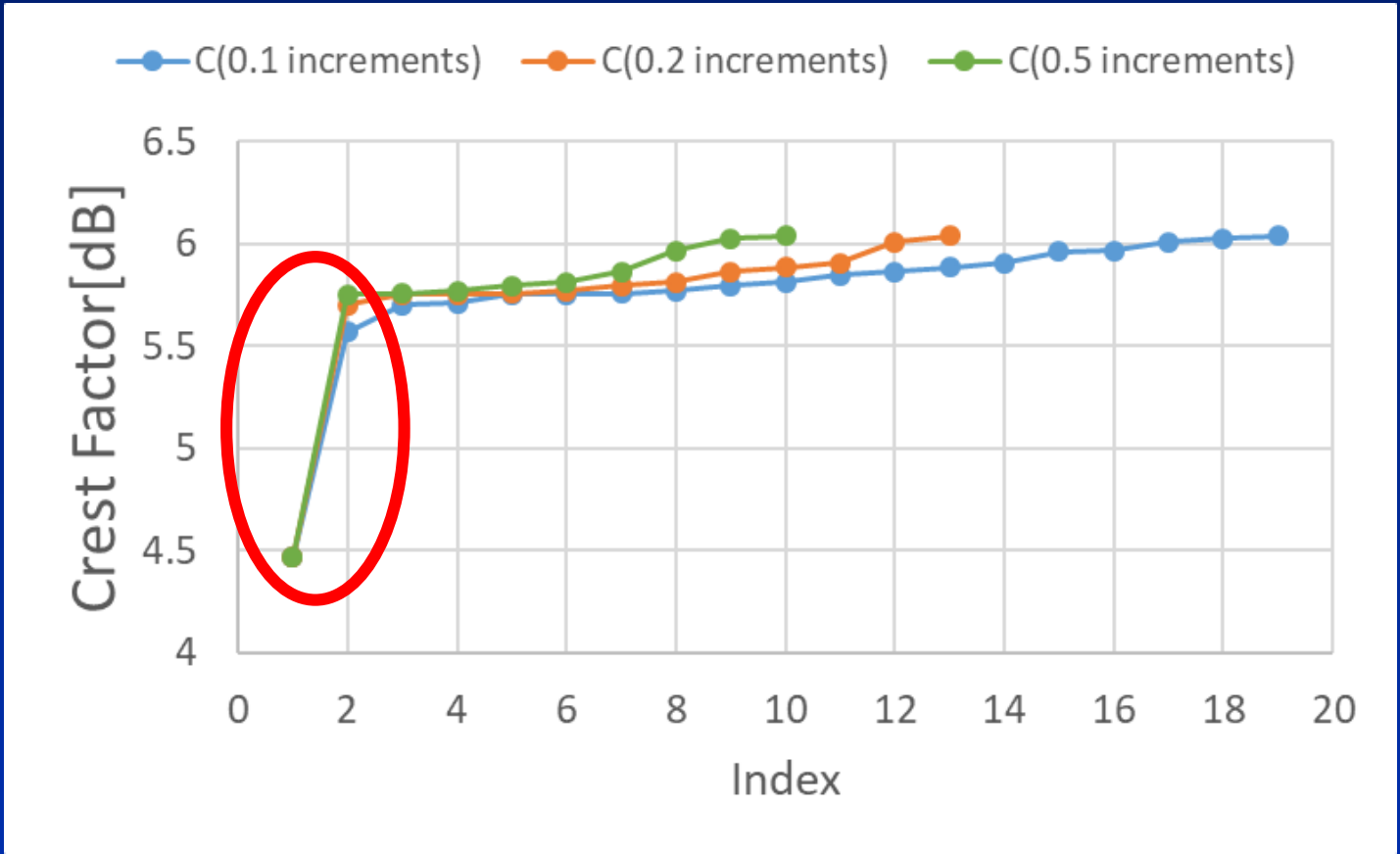
Sorted simulation result

C : varied 1 ~ 100
in 0.1, 0.2 ,0.5 increment



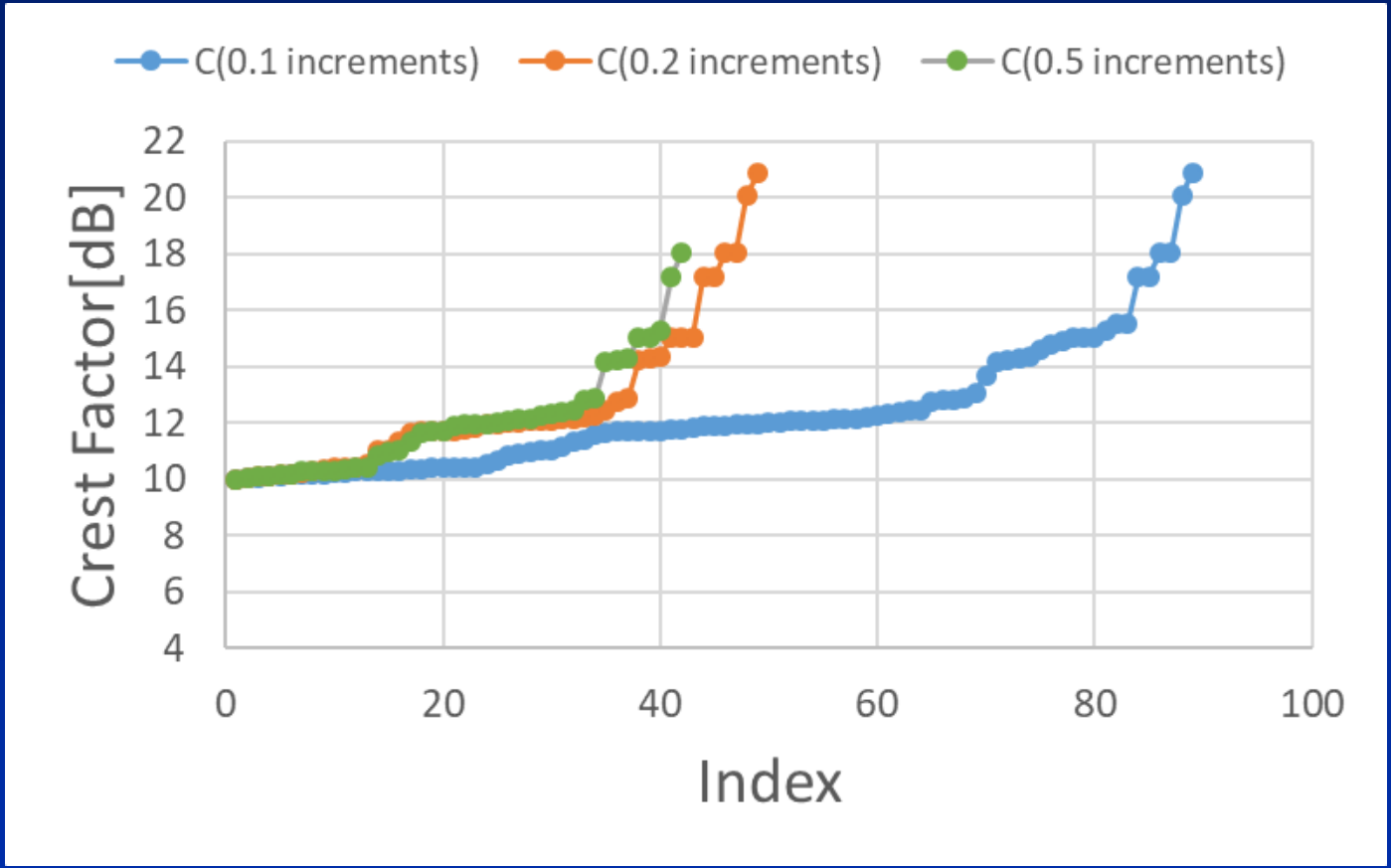
Get CF value of about 5 ~ 20dB

Enlarged view of under 6dB



Not get CF value of 4.5 ~ 5.5dB in each increment

Enlarged view of over 10dB

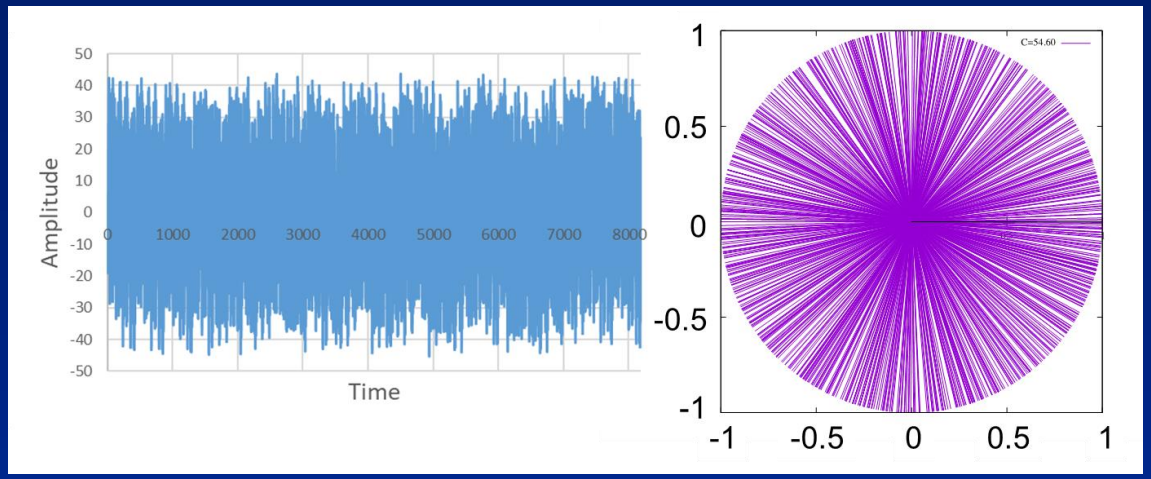


0.1 increment : resolution is fine up to 16dB

Increment becomes smaller = CF resolution better

Waveform & phase characteristics

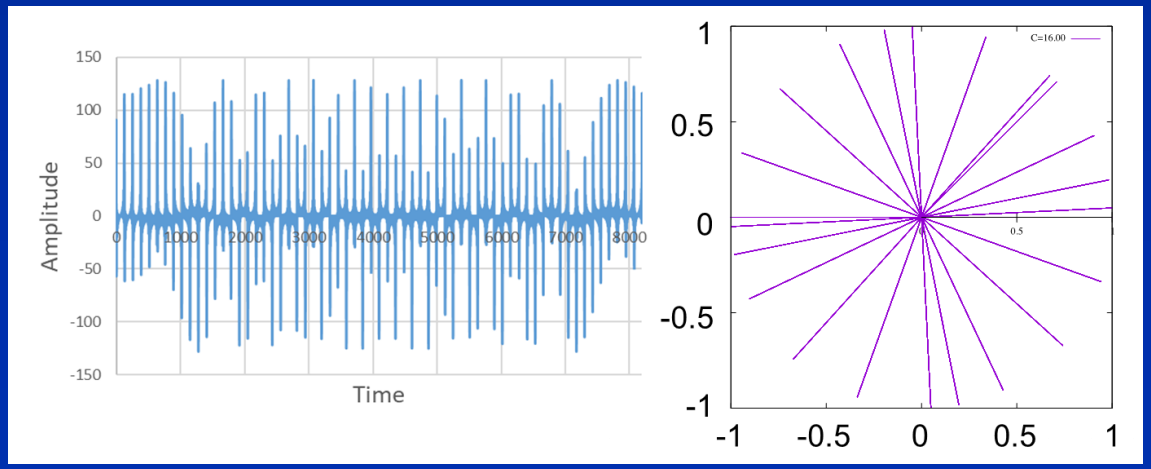
C = 54.6
CF = 10.0[dB]



as CF increases

- Quality of waveform deteriorate
- Number of phases get fewer

C = 16
CF = 15.1[dB]



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Summary

- **CF minimized multi-tone signal**

  Algorithms can generate high-accuracy testing signal

- **CF controlled multi-tone signal**

  Modified Newman algorithm can generate signal with the desired CF

- **Next project**
  - Clarify the relationship between phase & CF
  - Confirm by simulation & experiment

Q&A

Q：CF minimized multi-tone signal　において
　　Newmanアルゴリズムを使用するのはなぜか？

A：様々な研究成果をみると、一般的には、
　　3つのアルゴリズムのうち、
　　Newmanアルゴリズムが最もCFを最小化できる
　　といわれているため。