Analog Circuit Session 1

Oct. 23, 2020
14:15-14:30

Study on Crest Factor Controlled Multi-tone Signal for Analog RF Circuit Testing

Yukiko Shibasaki, Koji Asami, Akemi Hatta
Riho Aoki, Anna Kuwana, Haruo Kobayashi

Gunma University

Research Objective

Probe signal

input

$cos(\omega_1 t)$

$cos(\omega_2 t)$

$\vdots$

$cos(\omega_n t)$

Analog Circuit

output

$A_1 cos(\omega_1 t + \theta_1)$

$A_2 cos(\omega_2 t + \theta_2)$

$\vdots$

$A_N cos(\omega_n t + \theta_n)$

Single tone

- **Good SNR**
- **Long testing time**

Multi-tone

- **Short testing time → Low cost**
- **Low SNR → Low test accuracy**

Target: Short-time & high-accuracy testing of analog IC frequency response using multi-tone signal

Outline

- Background
- Initial Phase setting
  - Modified Newman Phase
  - Fibonacci Phase
- Spectrogram comparison
- Summary

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Wideband Wireless Communication IC Test

Bandwidth in wireless communication → Expanding

5G : 400MHz　WiGig : 2GHz

Orthogonal Frequency Division Multiplexing (OFDM)

- **High efficiency of frequency utilization**
- **High quality communication**

- **Weak to non-linear distortion**

To test transmission quality of designed devices

- **Effective to use a waveform with actual PAPR**

Conventional Testing Method

Adjacent channel power ratio measurement

▪ Use standard compliant waveform

High precision

Test development takes time→High test cost

Crest Factor (CF) control

▪ Use **multi-tone** instead of OFDM

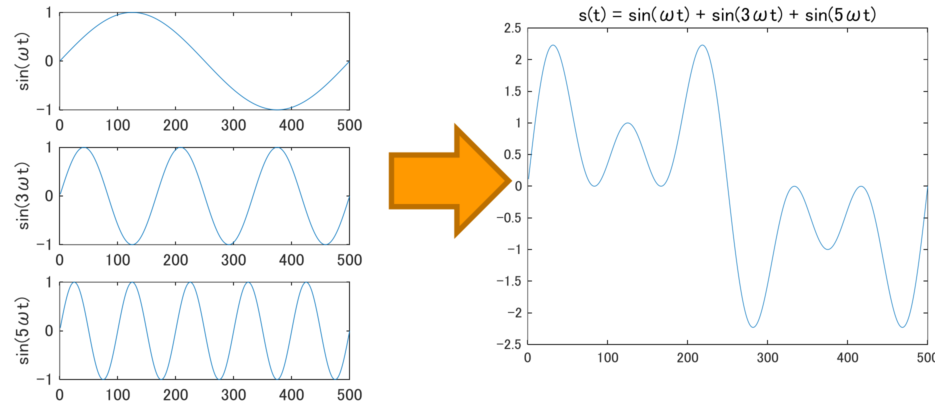
Test cost **reduction**

- Wideband frequency characteristics measurement at once
- Easy signal generation

Multi-tone Signal

Sum of multiple tone signals with different frequencies

$$s(t) = \sum_{k=1}^{N} A_k sin(\omega_k t + \theta_k)$$



Probe signal

input

$$\sum_{k=1}^{N} A_k sin(\omega_k t + \theta_k)$$

→ **Linear system (Filter, etc.)** →

output

$$\sum_{k=1}^{N} B_k sin(\omega_k t + \varphi_k)$$

- **Wideband: Test at once →Short testing time**
- **Lower SNR → Low-accuracy test**

Crest Factor

$$\text{Crest Factor[dB]} = 20\log_{10}\left[\frac{\text{Peak Amplitude}}{\text{RMS}}\right]$$

$$※\ \text{PAPR[dB]} = 10\log_{10}\left[\frac{\text{Peak Power}}{\text{Average Power}}\right]$$

- Phase control can minimize crest factor
  → Improving SNR
- Any crest factor can be set by phase control
  → Today's talk

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Newman Phase in Multi-tone Signal

$$s(t) = \sum_{k=1}^{N} A_k sin(\omega_k t + \theta_k)$$

Newman phase

$$\theta_k = \frac{\pi}{N}(k-1)^2$$

Known as CF minimization algorithm for multi-tone signal

Reference :

D. J. Newman, “An L1 Extremal Problem for Polynomials”, American Mathematics Society (Dec.1965).

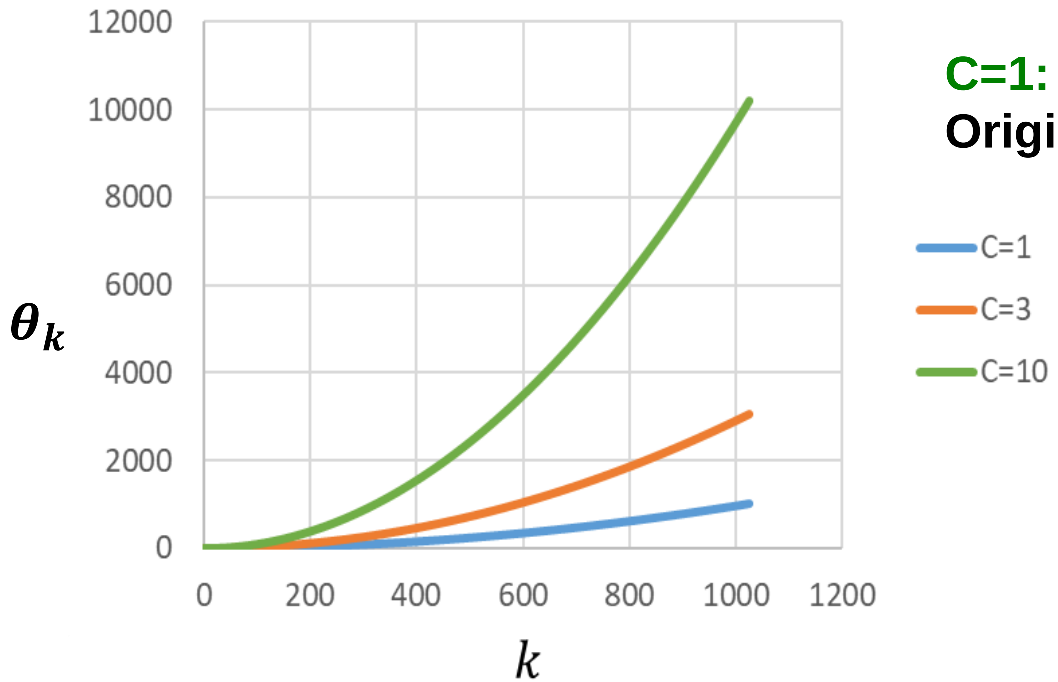
Modified Newman Phase

Our proposal

Modified Newman phase

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

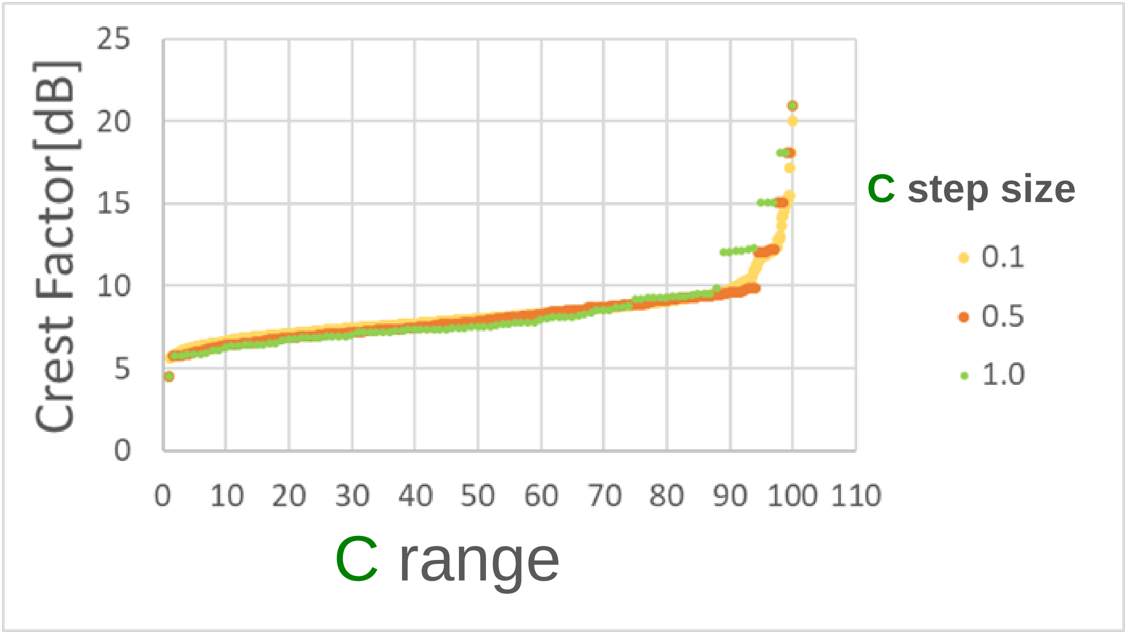
C: control coefficient



C=1:
Original Newman phase

Modified Newman Phase CF Controlled Range

C range: 1.0 ~ 100.0



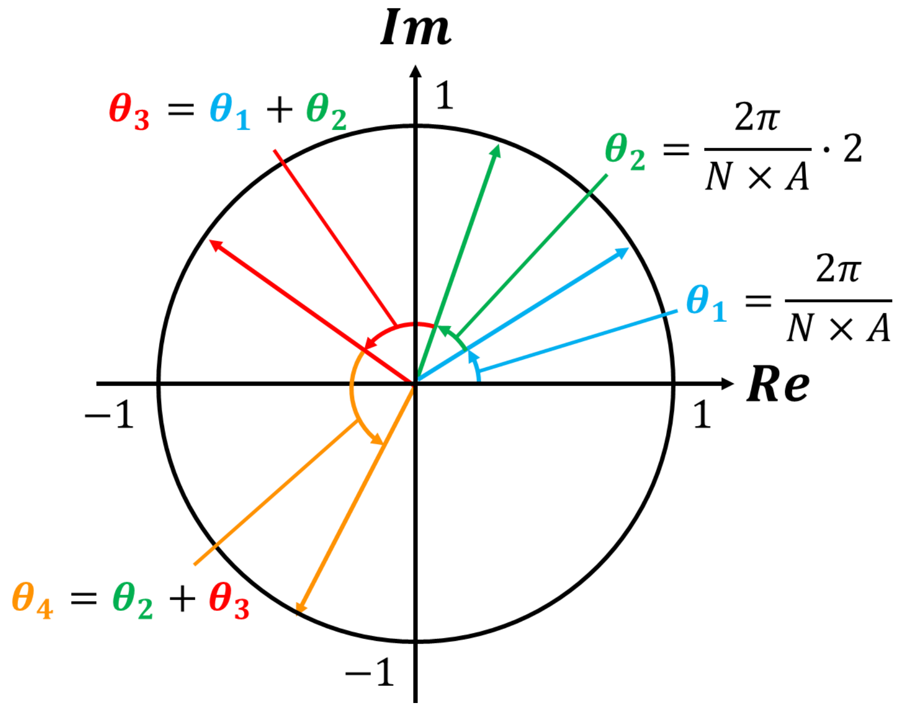
CF controlled range: 4.5 dB ~ 21 dB

CF between 6 ~ 10 dB: high resolution control with C

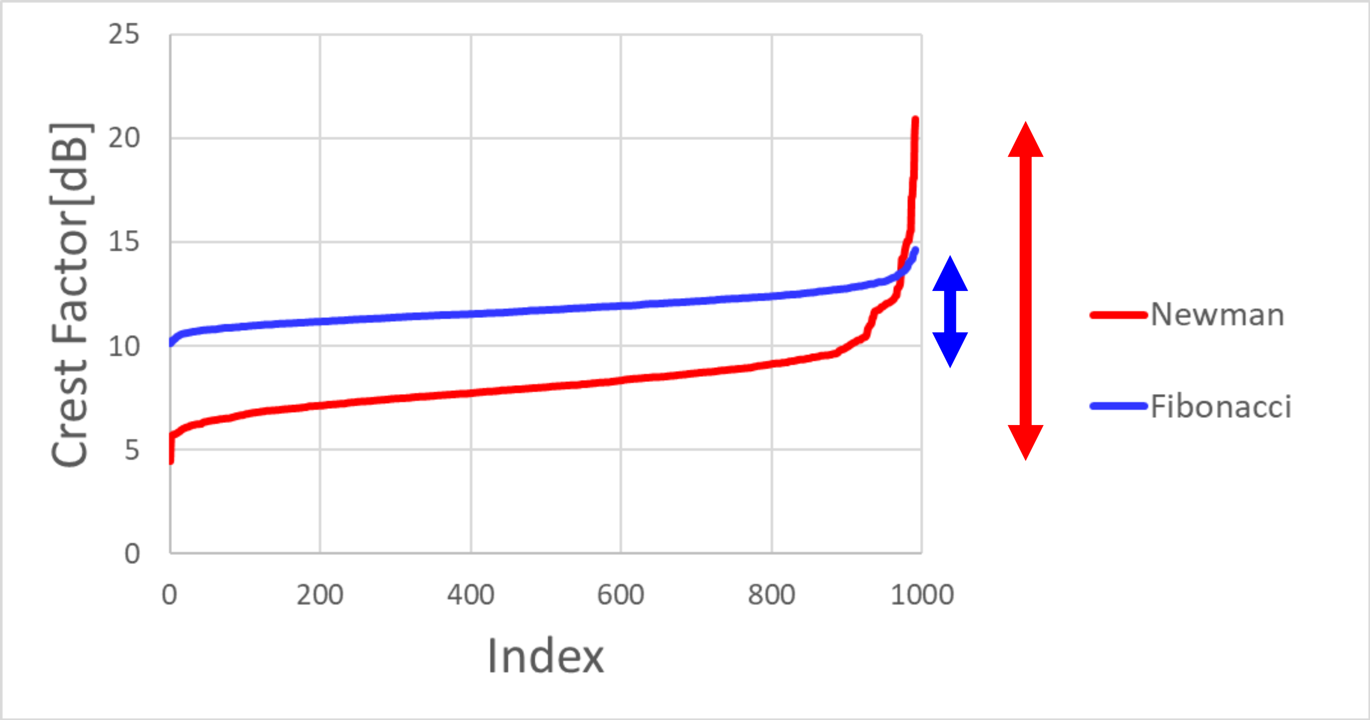
Fibonacci Multi-tone Signal

Initial phase of 1st freq. : $\theta_1 = \dfrac{2\pi}{N \times A}$

Fibonacci phase : $\theta_k = \theta_{k-2} + \theta_{k-1}$



Crest Factor Controlled Range



Newman : 4.5 ~ 21 dB → 16.5 dB

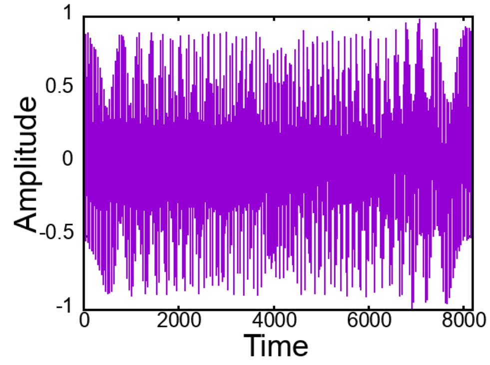
Fibonacci : 10 ~ 15 dB → 5.0 dB

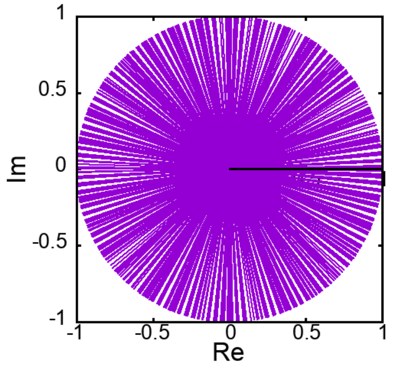
CF controlled range: narrow

Modified Newman Phase Waveform and Initial Phase

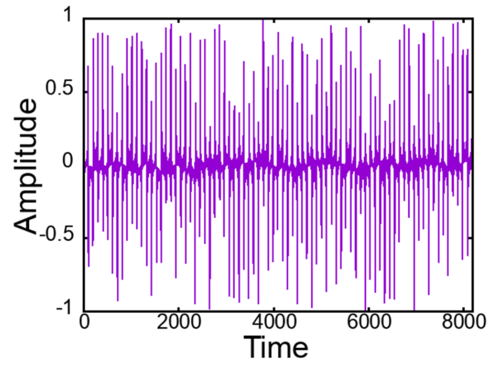
Multi-tone waveform | **Each Initial phase**

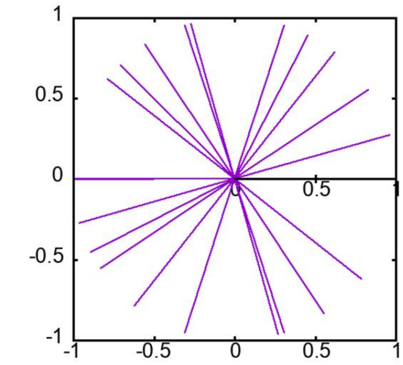
CF = 10.01 dB





CF = 14.3 dB





Quality Deterioration

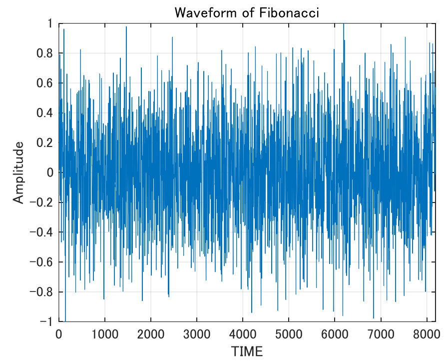
Decrease # of phases

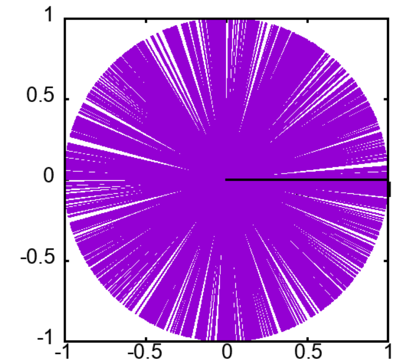
Fibonacci Phase Waveform and Initial Phase

Multi-tone waveform

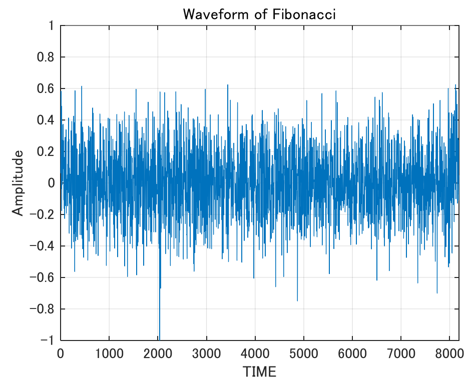
Each Initial phase

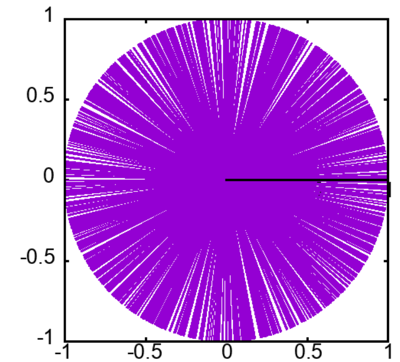
CF = 10.1 dB





CF = 14.0 dB



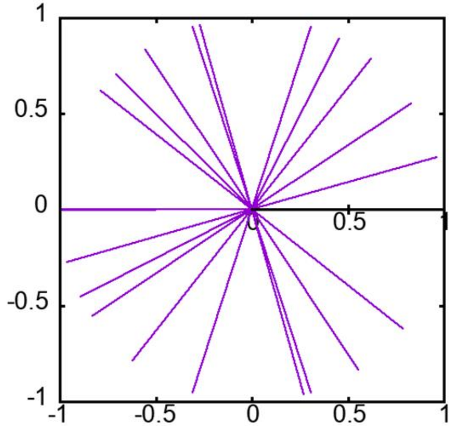


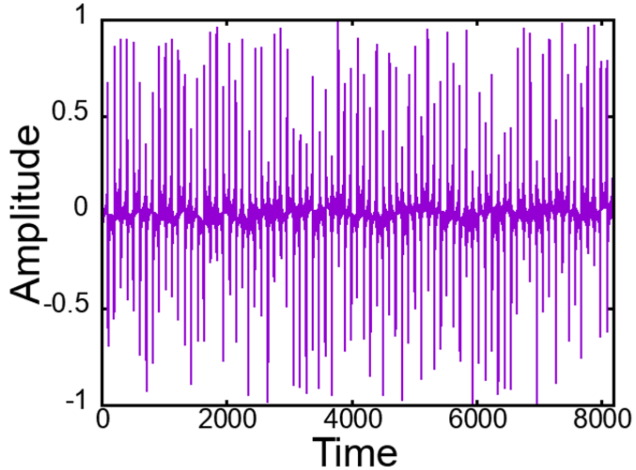
Quality
No Deterioration

No Decrease
# of phases

Modified Newman Phase and Fibonacci Phase

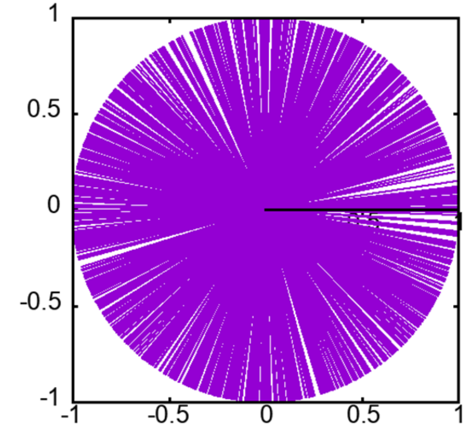
Modified Newman Phase CF=14.3 dB

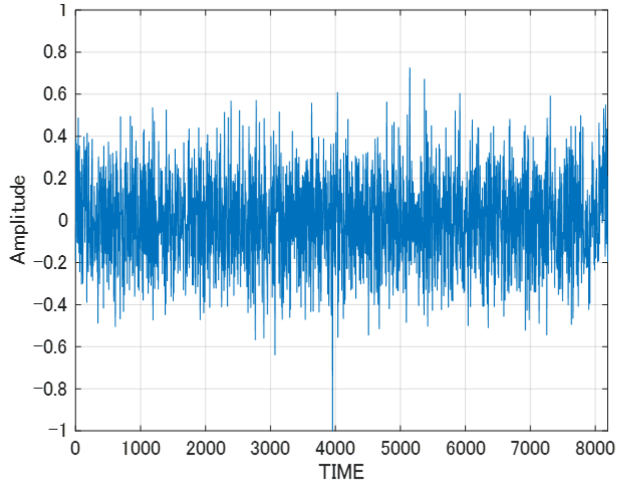




Number of different phases increase

Fibonacci Phase CF=14.4 dB





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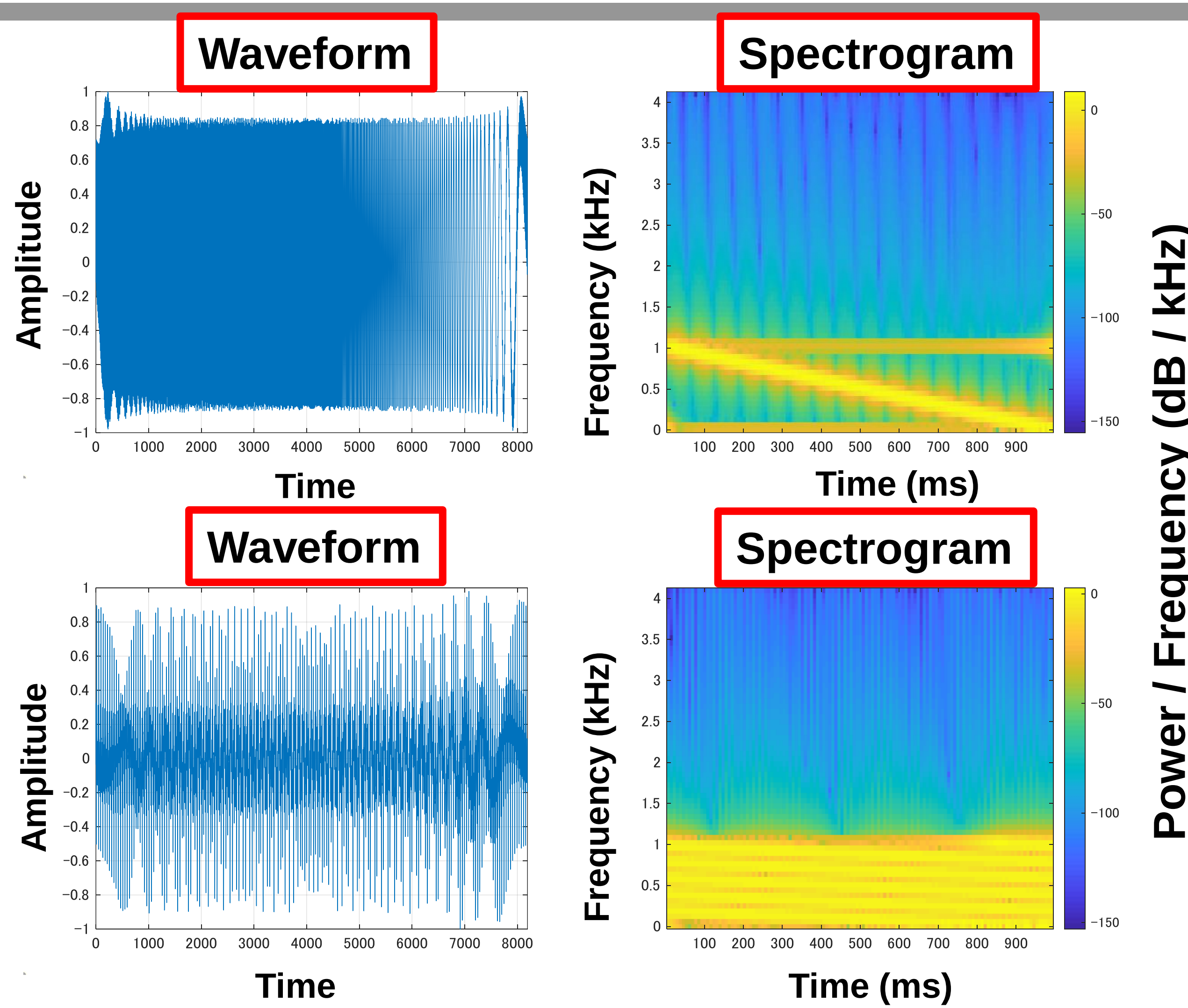
Newman Phase Spectrogram

CF
4.46 dB

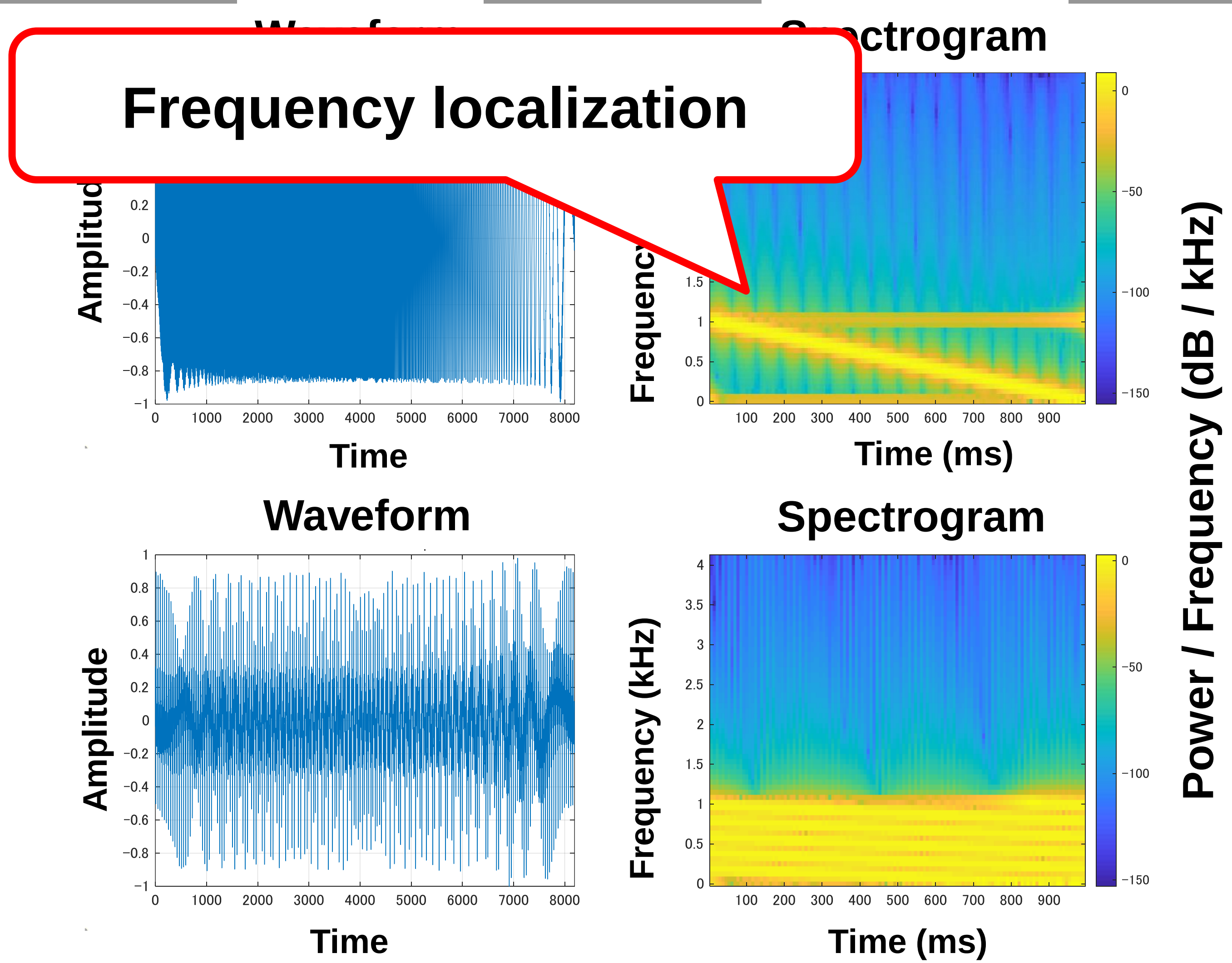
CF
10.0 dB



Newman Phase Spectrogram

CF
4.46 dB

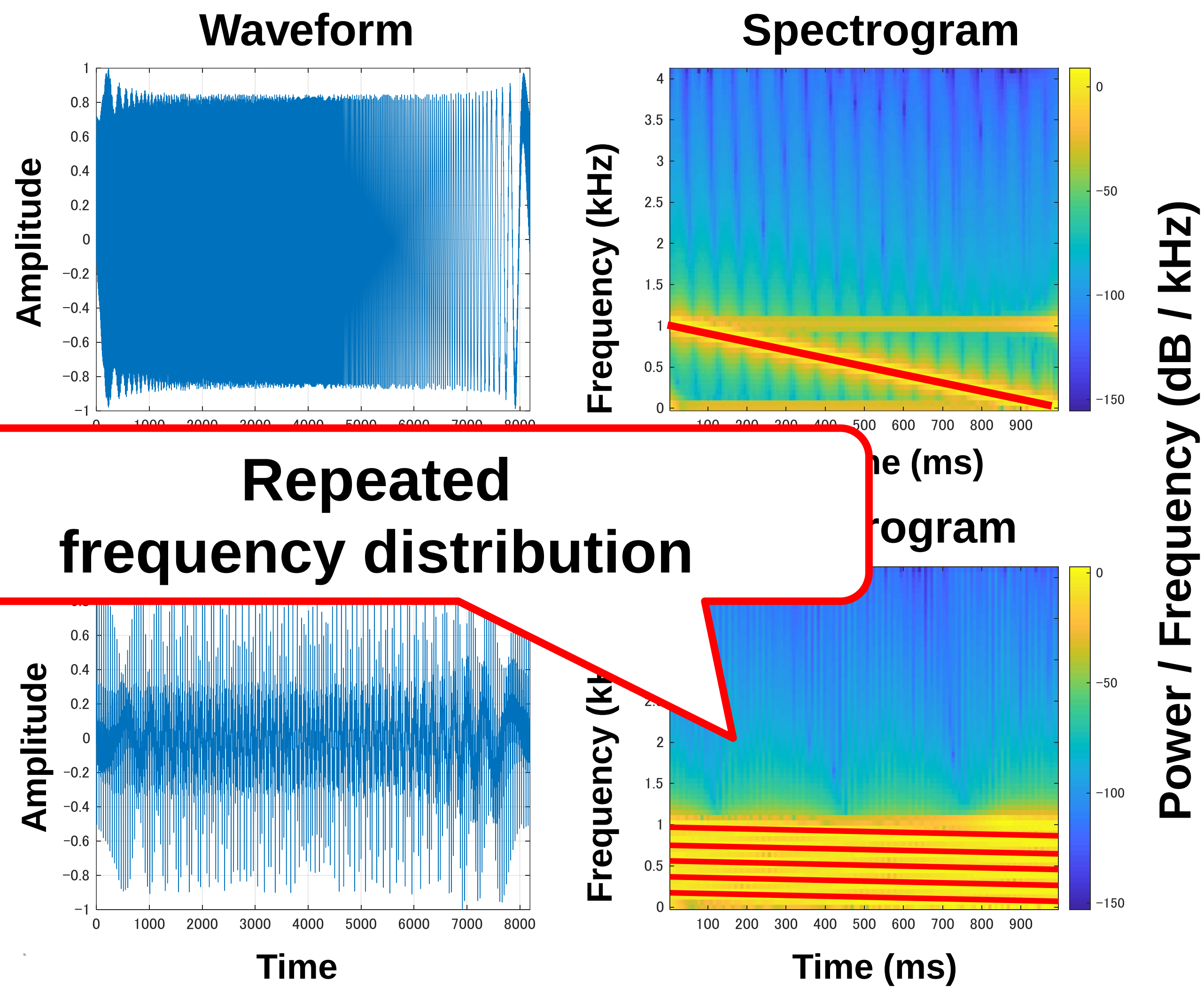
CF
10.0 dB



Newman Phase Spectrogram

CF
4.46 dB

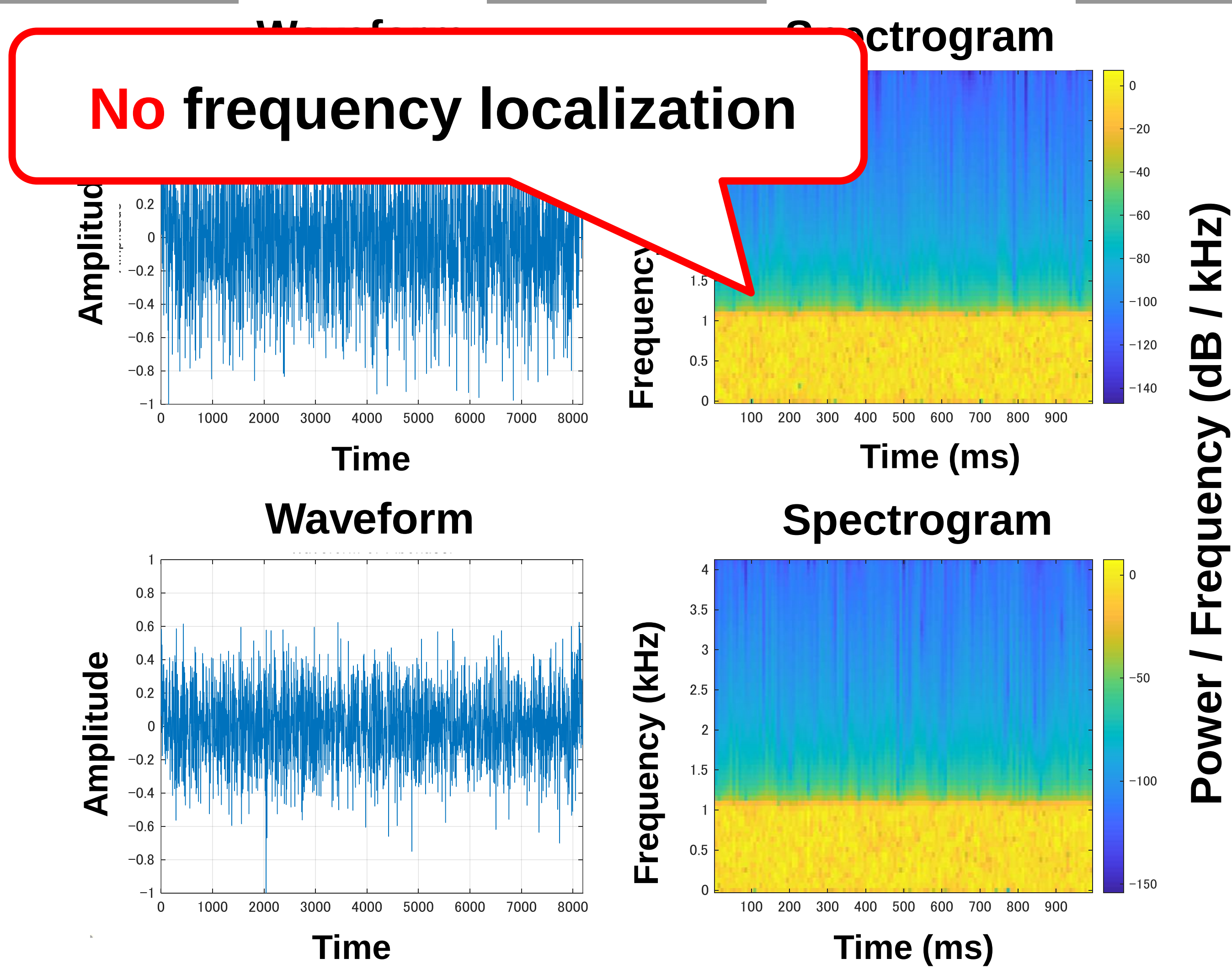
CF
10.0 dB



Fibonacci Phase Spectrogram

CF
10.1 dB

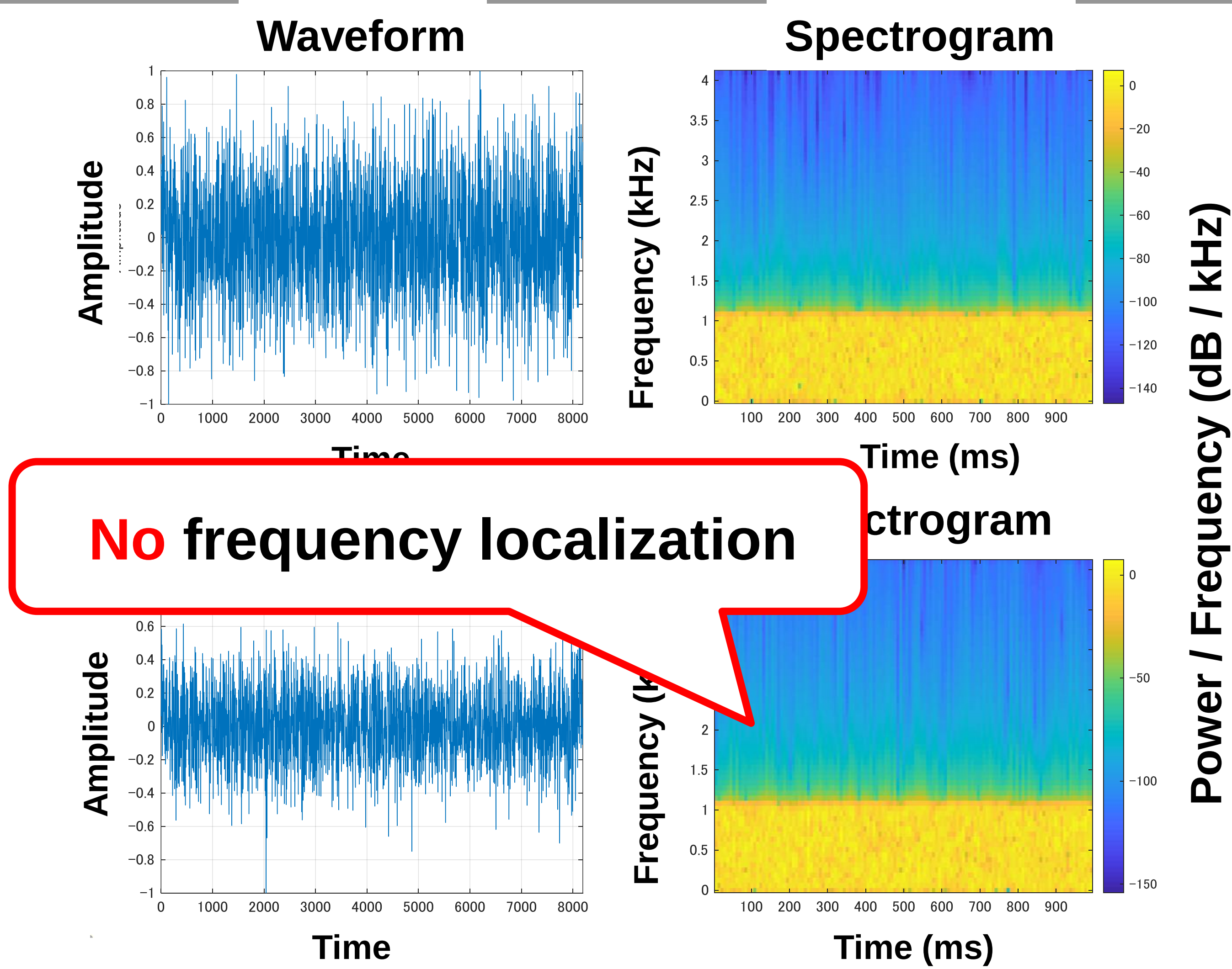
CF
14.0 dB



Fibonacci Phase Spectrogram

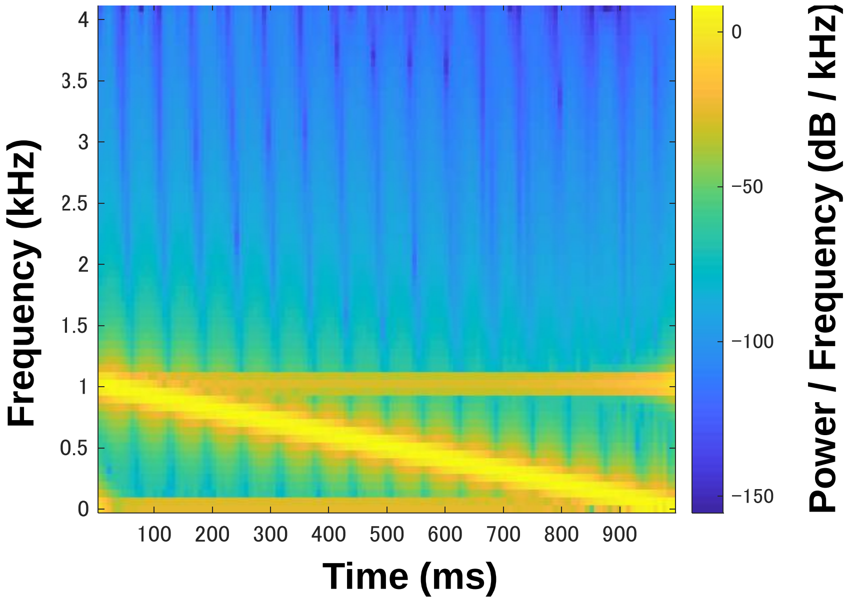
CF
10.1 dB

CF
14.0 dB

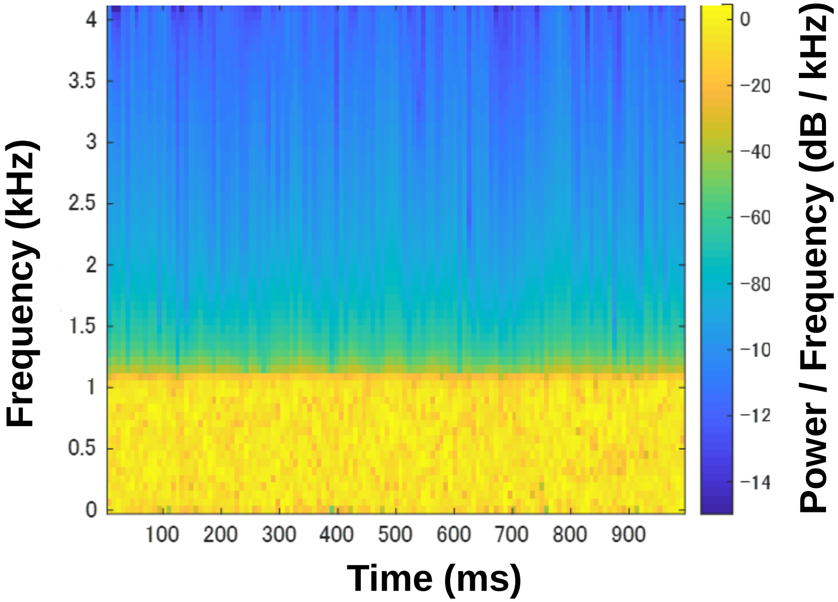


Waveform Quality and Spectrogram

Spectrogram of modified Newman



Spectrogram of Fibonacci



With frequency localization

↓

Waveform quality
Deteriorated

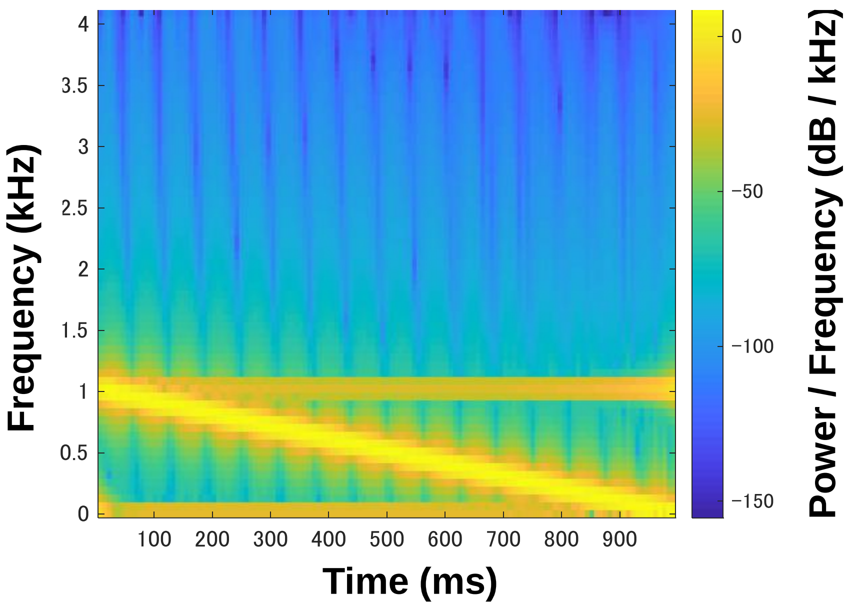
No frequency localization

↓

Waveform quality
improved

Waveform Quality and Spectrogram

Spectrogram of modified Newman

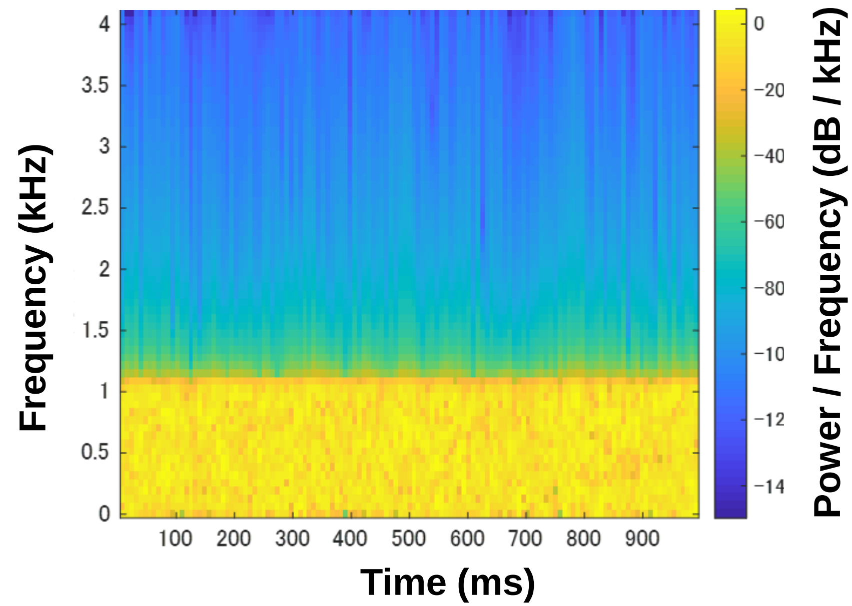


With frequency localization

Waveform quality

Deteriorated

Spectrogram of Fibonacci



No frequency localization

Waveform quality

improved

Frequency localization effects waveform quality

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Summary

- We have constructed two algorithms
  to control crest factor of multi-tone signal.

  Controllable range: 4.5 to 21 dB

- We have shown that
  for analyzing its waveform quality,
  phase distribution evaluation
  using unit circle and spectrogram is effective.