ITC-Asia 2018

Aug. 17, 2018
Session 3B_1
Analog Test

Low-Distortion One-Tone and Two-Tone Signal Generation Using AWG Over Full Nyquist Region

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Research Objectives

Objective

For ADC testing

- Low-distortion signal generation
- Low cost AWG
- Full Nyquist Region

Our Approach

- Phase-Switching-Method

⇓

- Only AWG program change
- No need for AWG nonlinearity identification

Outline

- Research Background
- Phase-Switching Method
- Low & High-Frequency Signal Generation
- Mid-Frequency Signal Generation
- Experimental Results
- Conclusions

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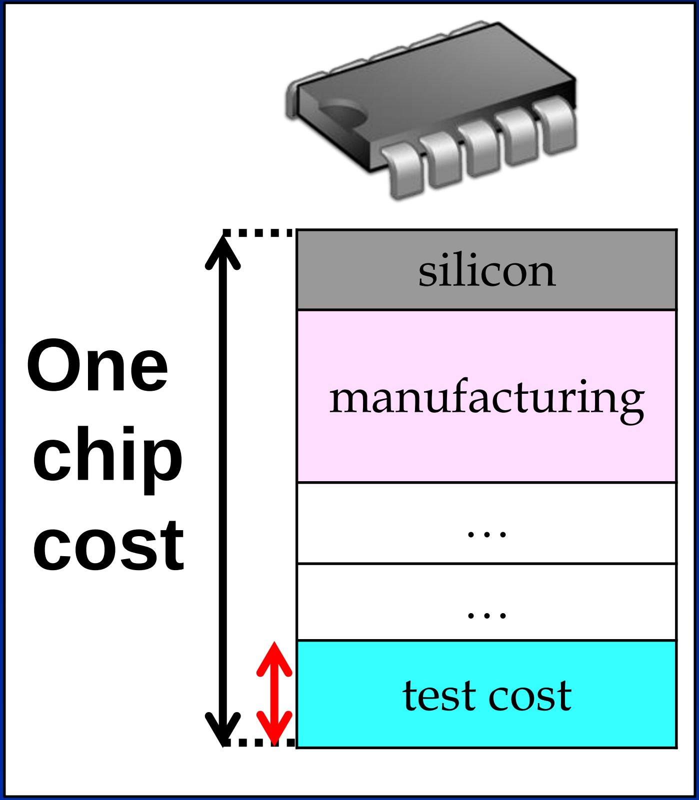
Research Background

Silicon cost per transistor → **decreasing**

Test cost → **increasing**

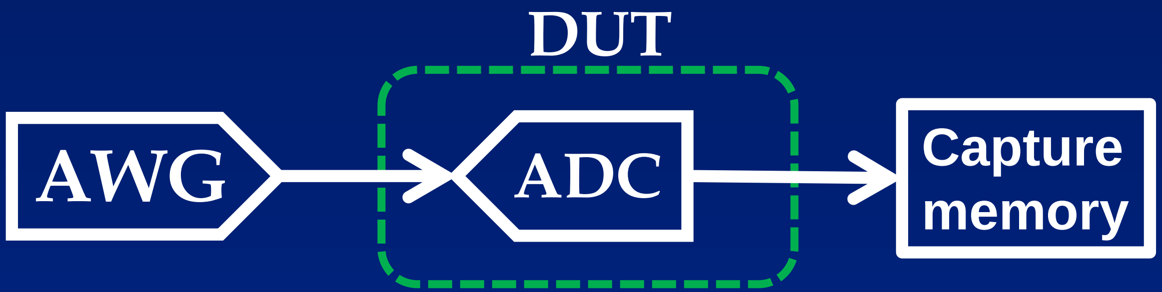


Low cost test

→ **Low cost LSI production**

ADC Test Cost Using AWG

ADC test system :



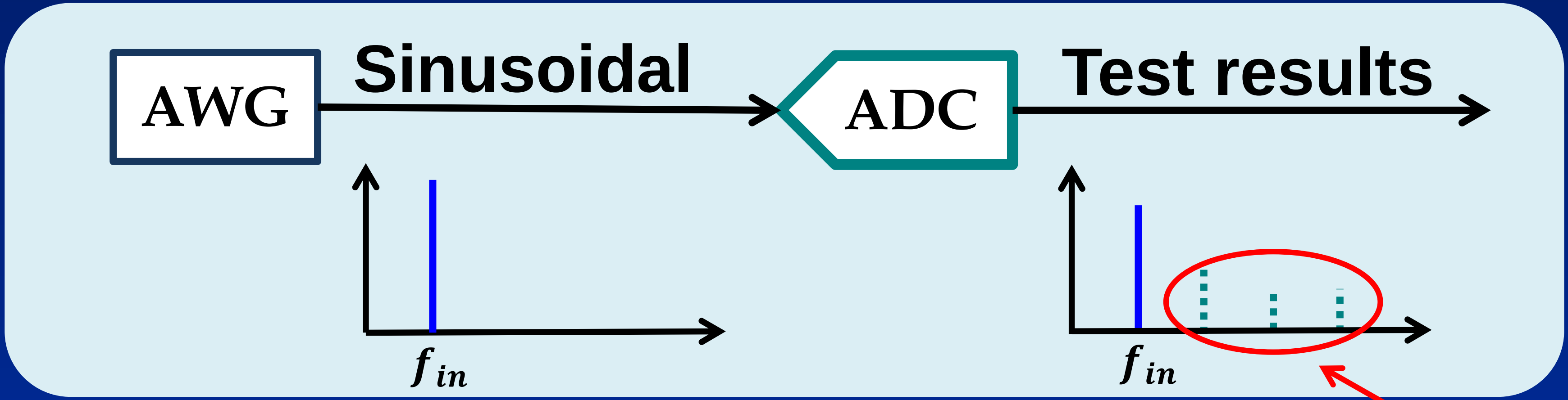
AWG : High Precision
Arbitrary Waveform Generator

Expensive

	Cost	Quality
Expensive AWG	**bad**	**good**
Low-price AWG	**good**	**bad**
Low-price AWG + Proposed method	**good**	**good**

Ideal and Real Signal

The ideal



AWG

Sinusoidal

ADC

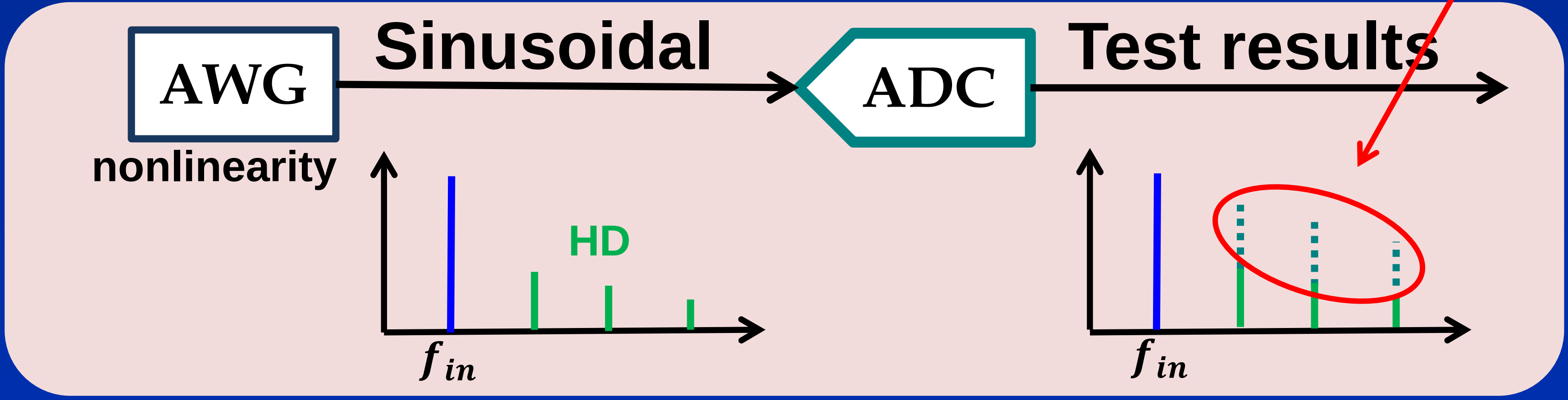
Test results

f_{in}

f_{in}

Evaluated value

The real



AWG

nonlinearity

Sinusoidal

ADC

Test results

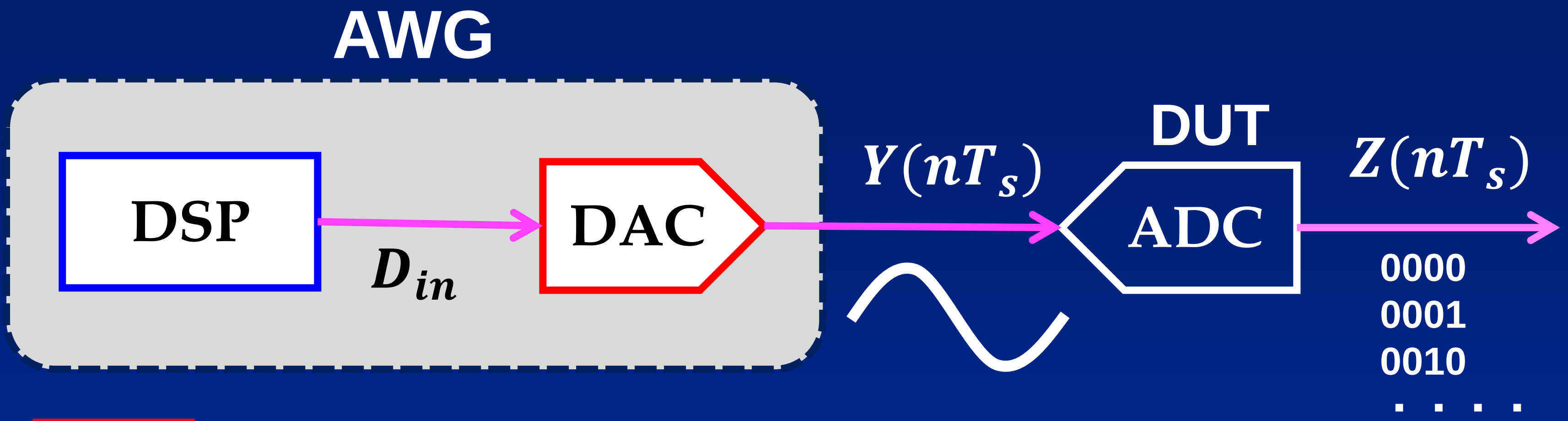
HD

f_{in}

f_{in}

HD: Harmonic Distortion

Arbitrary Waveform Generator



- DAC output

$$Y(nT_s) = a_0 + a_1 D_{in} + a_2 {D_{in}}^2 + a_3 {D_{in}}^3 + \cdots$$

DAC nonlinearity → harmonic distortion

Low-distortion signal generation
Only DSP program change

DSP : Digital Signal Processor

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Phase Switching Algorithm

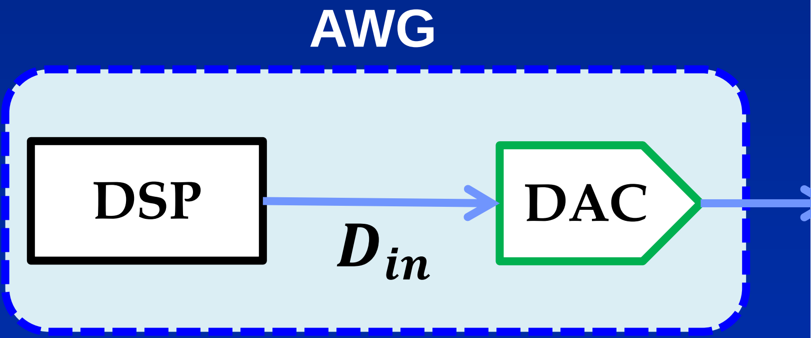
Phase Switching Algorithm

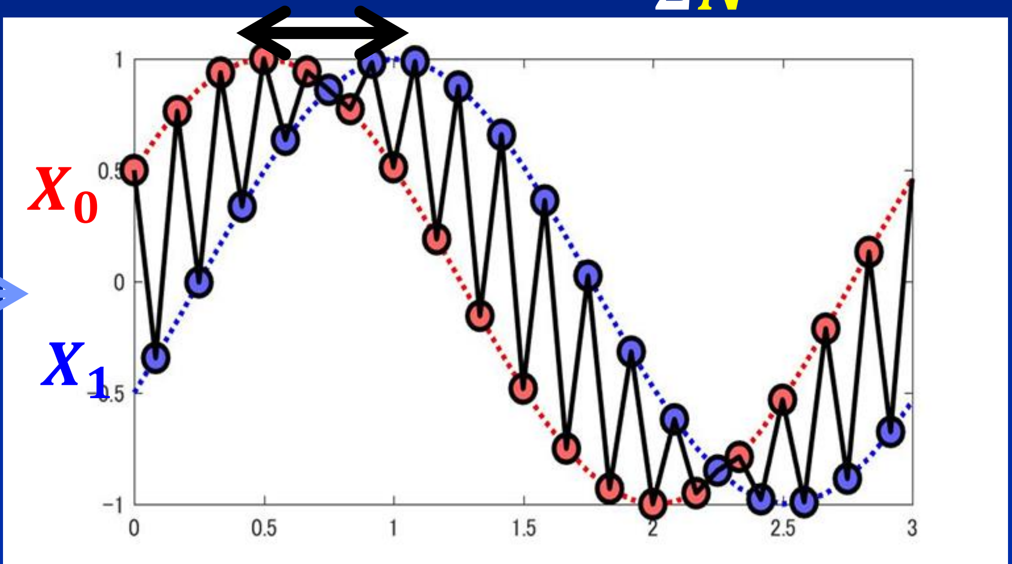
step 1． φ_0, φ_1 phase shift

step 2． Choose alternately

Nth harmonic cancelled

$$\varphi_0 = \varphi_1 = \frac{\pi}{2N}$$





$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} n T_s + \varphi_0) & n\text{: even} \\ X_1 = A\sin(2\pi f_{in} n T_s - \varphi_1) & n\text{: odd} \end{cases}$$

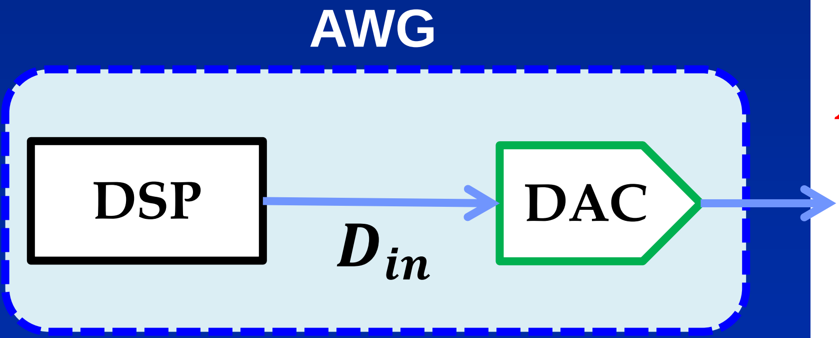
Phase Switching Algorithm

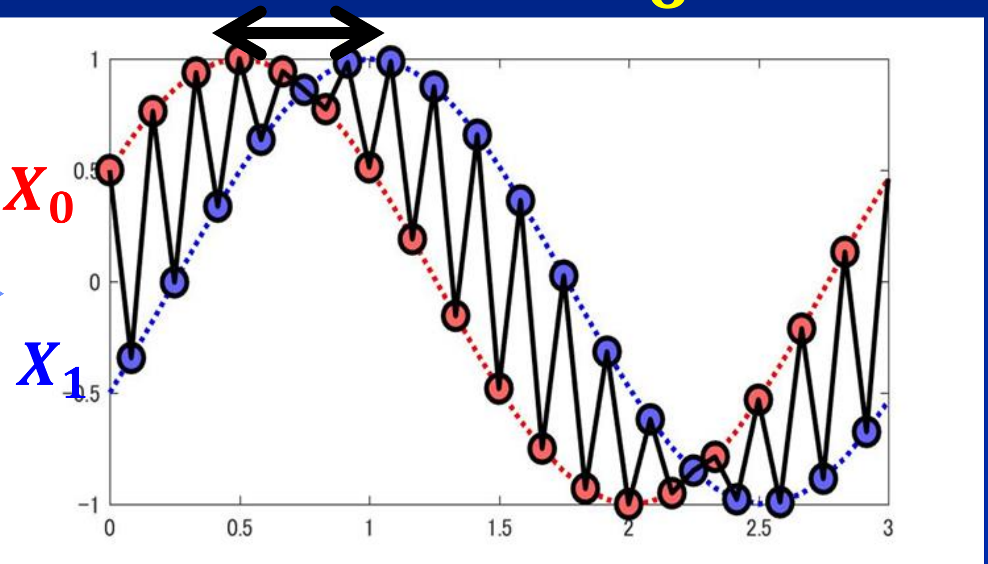
Phase Switching Algorithm

step 1 . φ_0, φ_1 phase shift
step 2 . Choose alternately

3rd harmonic suppression

$$\varphi_0 = \varphi_1 = \frac{\pi}{6}$$





$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s + \pi/6) & n\text{: even} \\ X_1 = A\sin(2\pi f_{in} nT_s - \pi/6) & n\text{: odd} \end{cases}$$

Phase Switching Signal Equation

$$Y(nT_s) = \left(\frac{1}{2} + \cos\left(2\pi\frac{f_s}{2}nT_s\right)\right)\left(a_1X_0 + a_3{X_0}^3\right) + \left(\frac{1}{2} - \cos\left(2\pi\frac{f_s}{2}nT_s\right)\right)\left(a_1X_1 + a_3{X_1}^3\right)$$

$$= \frac{4a_1A + 3a_3A^3}{4}\left(e^{j\varphi_0} + e^{-j\varphi_0}\right)\sin(2\pi f_{in}nT_s)$$

$$- \frac{a_3A^3}{8}\left(e^{j3\varphi_0} + e^{-j3\varphi_0}\right)\sin(2\pi 3 f_{in}nT_s)$$

$$- \frac{4a_1A + 3a_3A^3}{4}\left(e^{j\varphi_0} - e^{-j\varphi_0}\right)\sin\left(2\pi\left(\frac{f_s}{2} - f_{in}\right)nT_s\right)$$

$$+ \frac{a_3A^3}{8}\left(e^{j3\varphi_0} - e^{-j3\varphi_0}\right)\sin\left(2\pi\left(\frac{f_s}{2} - 3f_{in}\right)nT_s\right)$$

Fundamental wave

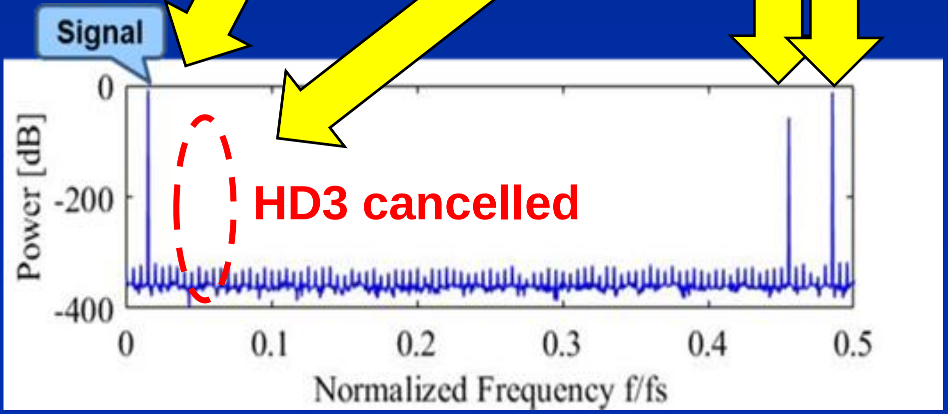
HD3

HD3 image

Fundamental image

$$In\ \ case\ \varphi_0 = \frac{\pi}{6}$$

$$\left(e^{j3\varphi_0} + e^{-j3\varphi_0}\right) = 0$$



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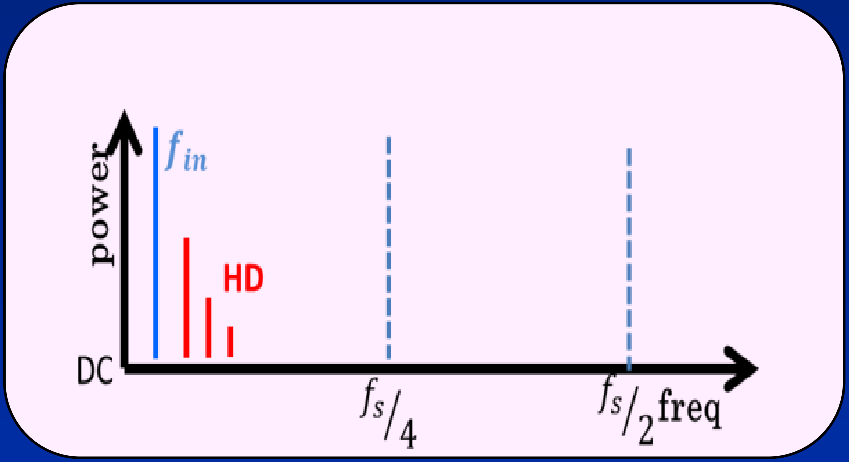
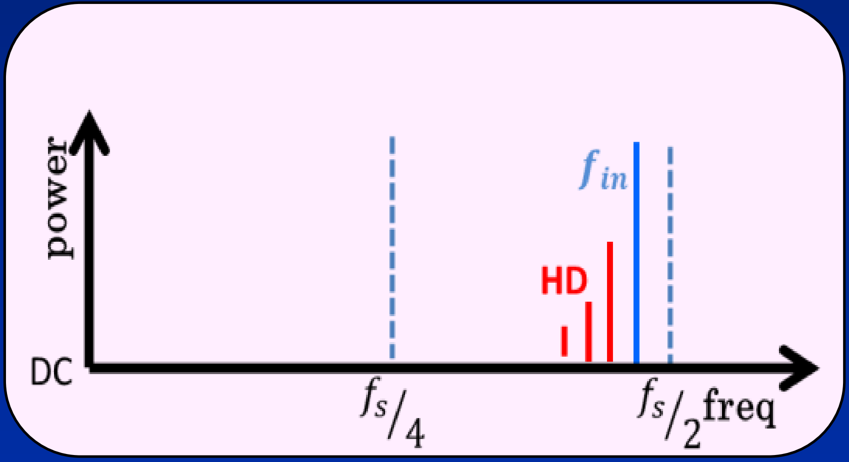
Low & High-Frequency Signals

Low-Frequency Signal

High-Frequency Signal

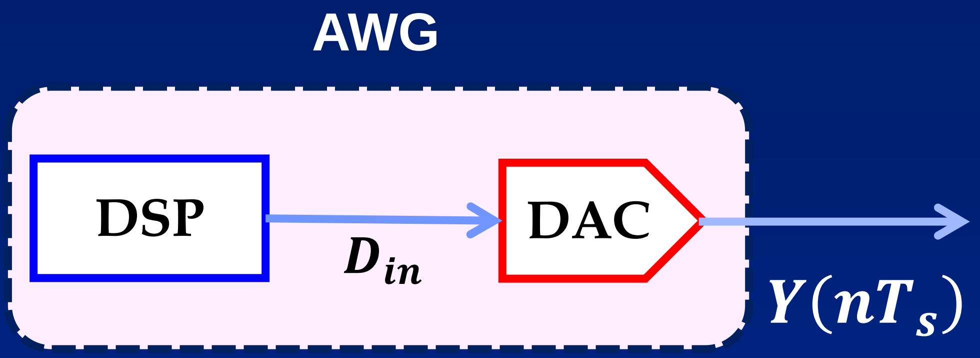




Near DC

Near Nyquist frequency

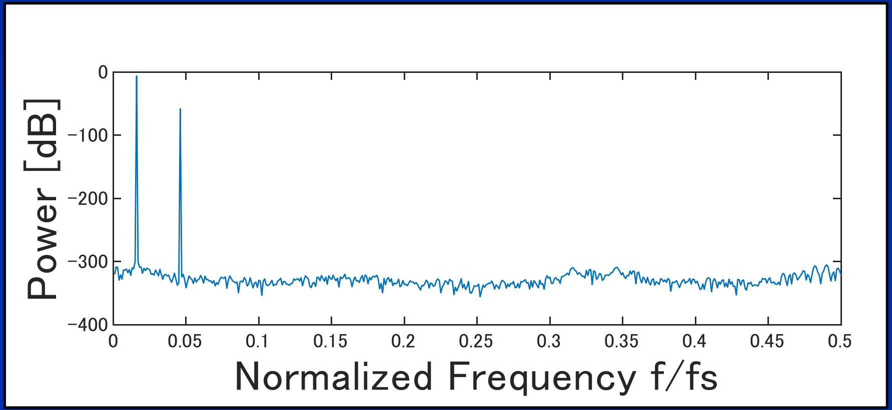
Low Freq. Single-Tone Signal Generation

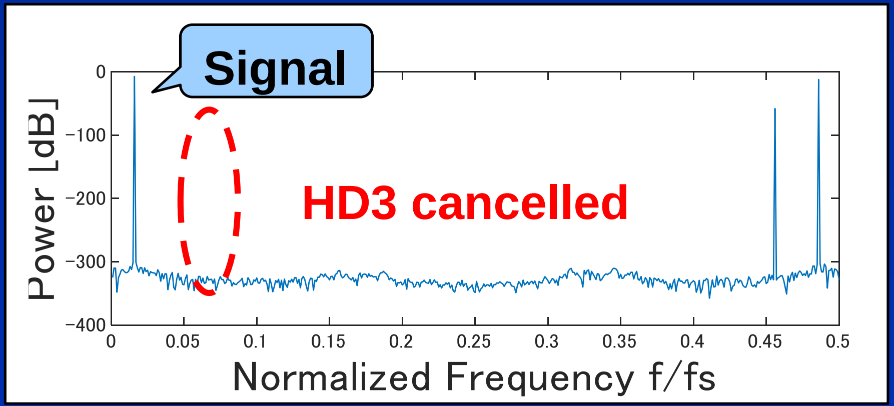


$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s + \varphi_0) & n\text{: even} \\ X_1 = A\sin(2\pi f_{in} nT_s - \varphi_1) & n\text{: odd} \end{cases}$$

$$\varphi_0 = \varphi_1 = \frac{\pi}{2N}$$

Nth order is cancelled

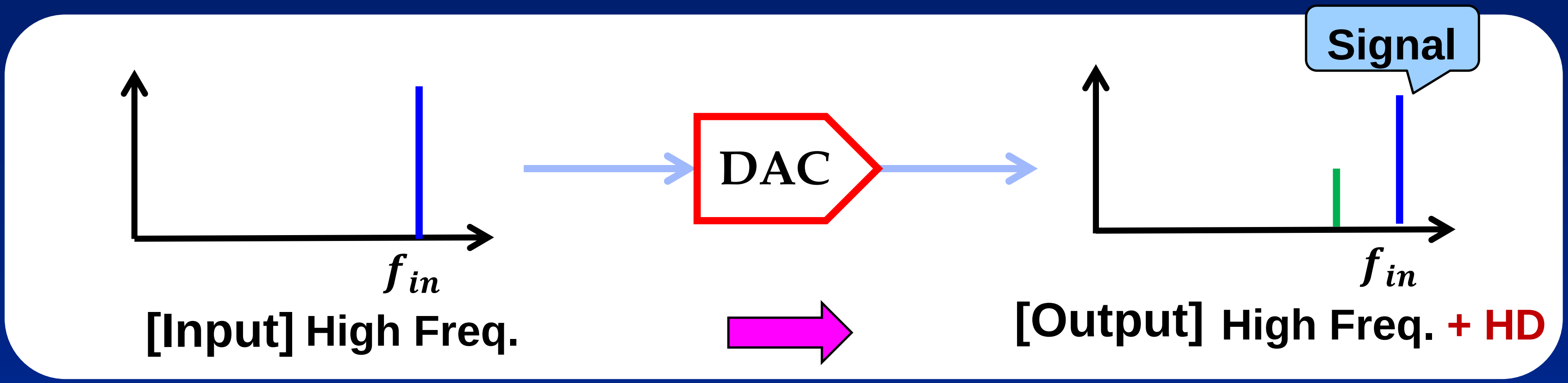




$$f_1/f_s = 3/200$$

High Freq. Signal Generation

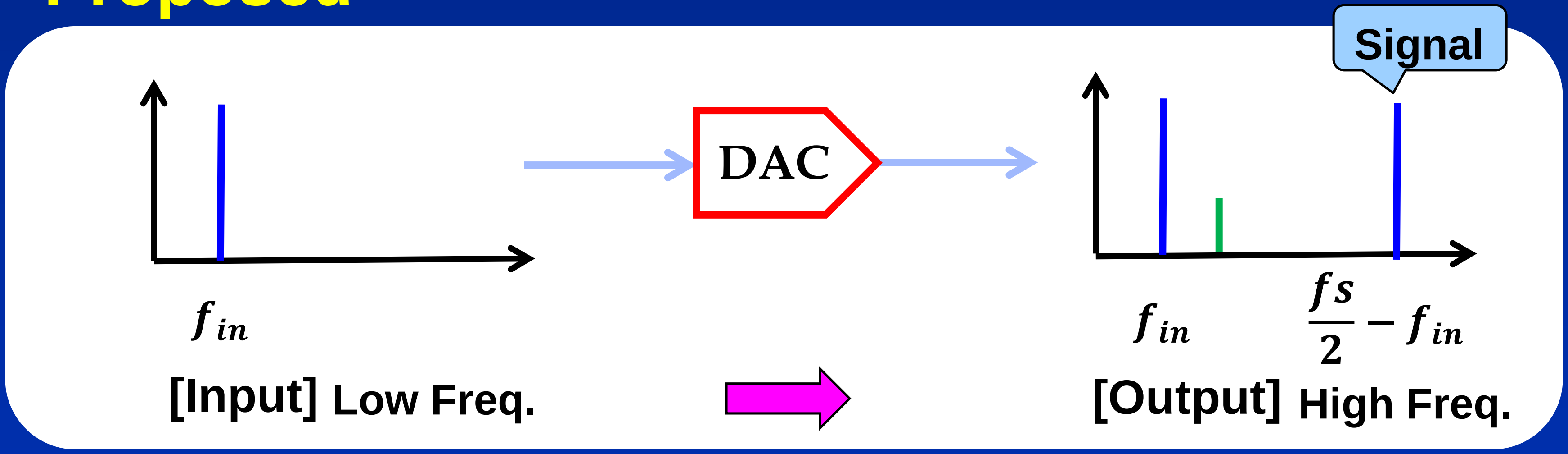
Conventional



[Input] High Freq.

[Output] High Freq. + HD

Proposed



[Input] Low Freq.

[Output] High Freq.

$fs/2-f_{in}$ deal with high-freq. signal

Phase Switching Signal Equation

$$Y(nT_s) = \left(\frac{1}{2} + \cos\left(2\pi\frac{f_s}{2}nT_s\right)\right)\left(a_1X_0 + a_3{X_0}^3\right) + \left(\frac{1}{2} - \cos\left(2\pi\frac{f_s}{2}nT_s\right)\right)\left(a_1X_1 + a_3{X_1}^3\right)$$

$$= \frac{4a_1A + 3a_3A^3}{4}\left(e^{j\varphi_0} + e^{-j\varphi_0}\right)\sin(2\pi f_{in}nT_s)$$

Fundamental wave

$$-\frac{a_3A^3}{8}\left(e^{j3\varphi_0} + e^{-j3\varphi_0}\right)\sin(2\pi 3f_{in}nT_s)$$

HD3

$$-\frac{4a_1A + 3a_3A^3}{4}\left(e^{j\varphi_0} - e^{-j\varphi_0}\right)\sin\left(2\pi\left(\frac{f_s}{2} - f_{in}\right)nT_s\right)$$

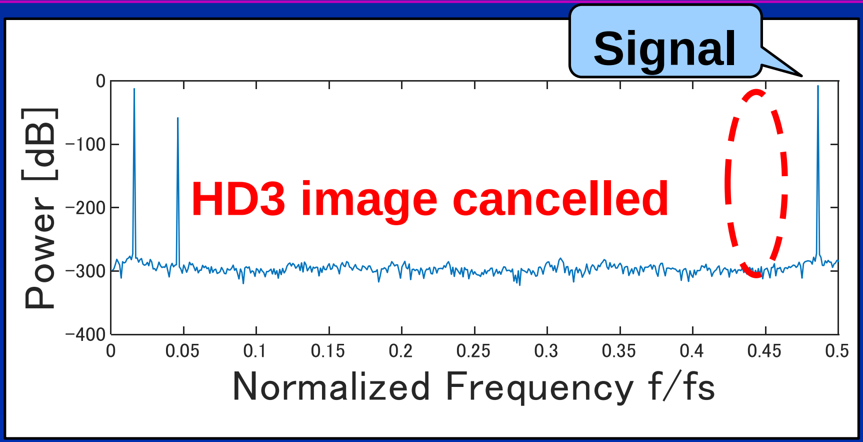
HD3 image

$$+\frac{a_3A^3}{8}\left(e^{j3\varphi_0} - e^{-j3\varphi_0}\right)\sin\left(2\pi\left(\frac{f_s}{2} - 3f_{in}\right)nT_s\right)$$

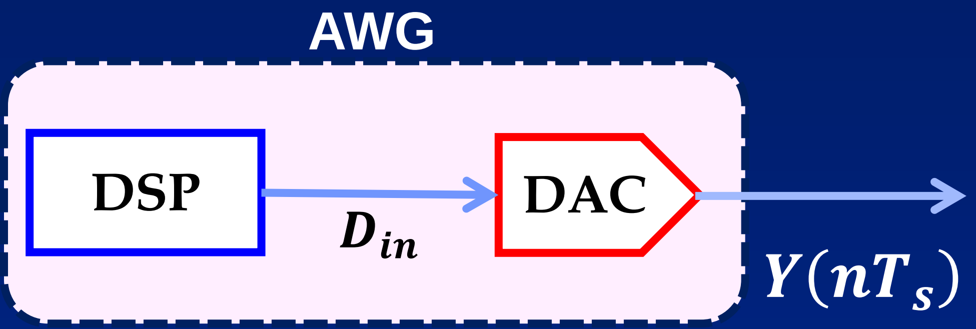
Fundamental image

$$In\ \ case\ \varphi_0 = \frac{\pi}{3}$$

$$\left(e^{j\varphi_0} - e^{-j\varphi_0}\right) = 0$$



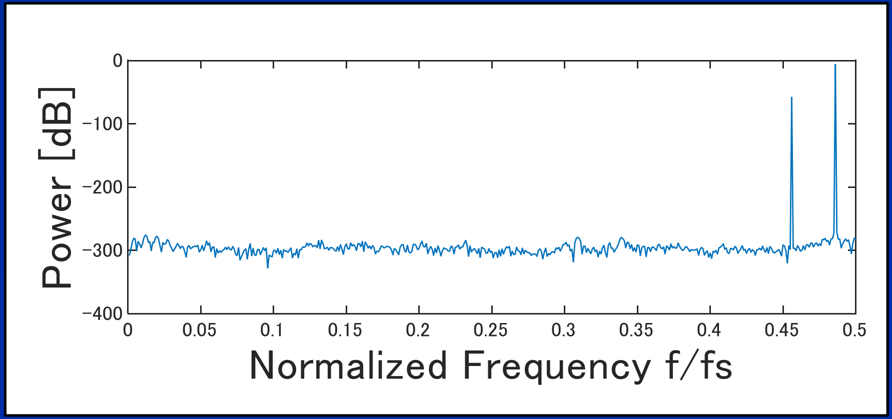
High Freq. Single-Tone Signal Generation

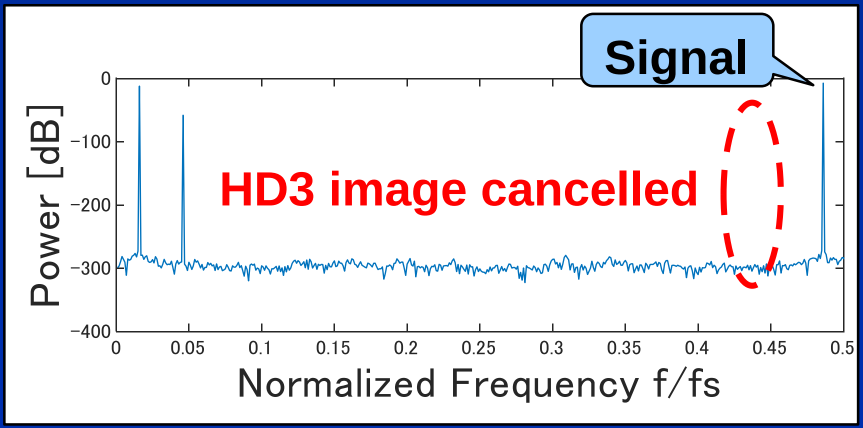


$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s + \varphi_0) & n\text{: even} \\ X_1 = A\sin(2\pi f_{in} nT_s - \varphi_1) & n\text{: odd} \end{cases}$$

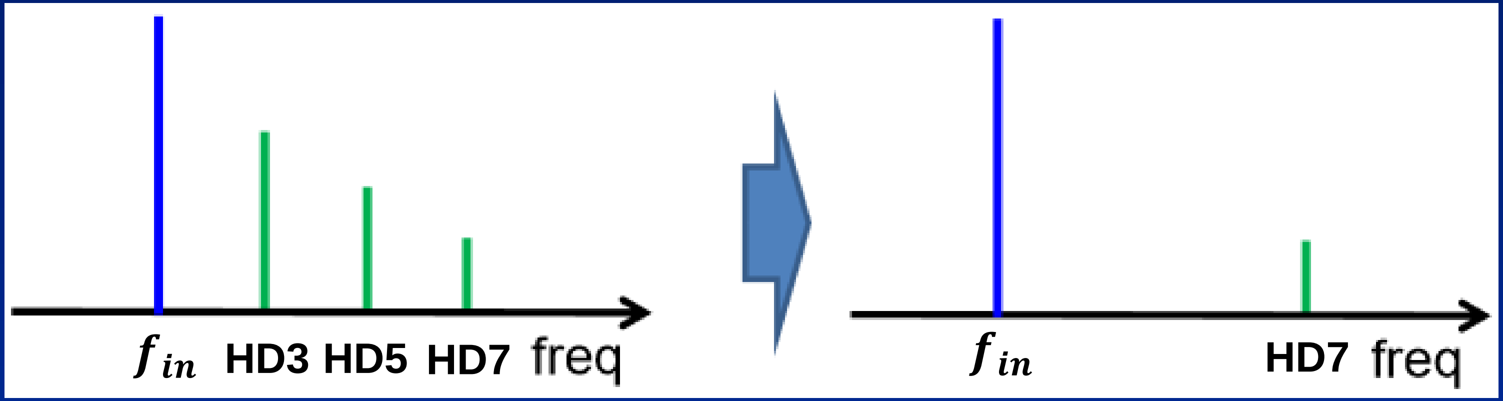
$$\varphi_0 = \varphi_1 = \frac{\pi}{N}$$

Nth order image is cancelled





Multiple Harmonics Suppression



Example : 3rd & 5th cancel at once

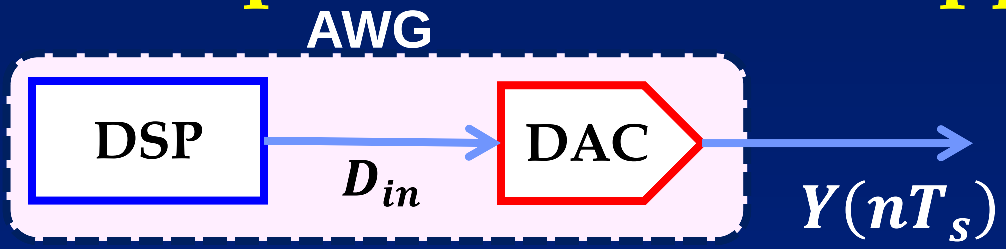
Single

1 shift parameter ($\varphi_0(=\varphi_1)$)
2-phase switching (X_0, X_1)

Multiple

2 shift parameters (φ_a, φ_b)
4-phase switching(X_0, X_1, X_2, X_3)

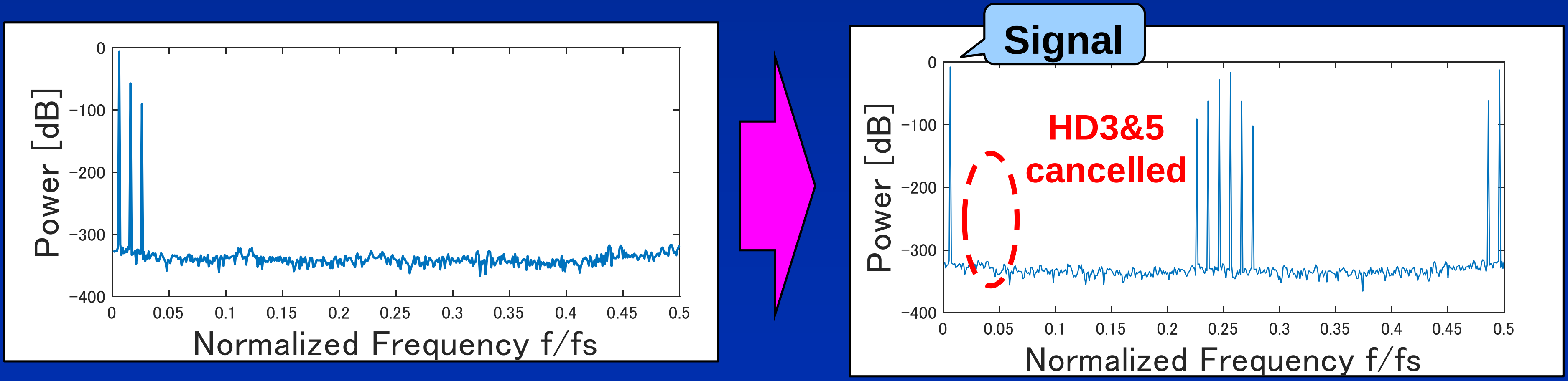
Low Freq. Multiple Harmonics Suppression



$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s - \varphi_a - \varphi_b) & n = 4k \\ X_1 = A\sin(2\pi f_{in} nT_s - \varphi_a + \varphi_b) & n = 4k+1 \\ X_2 = A\sin(2\pi f_{in} nT_s + \varphi_a - \varphi_b) & n = 4k+2 \\ X_3 = A\sin(2\pi f_{in} nT_s + \varphi_a + \varphi_b) & n = 4k+3 \end{cases}$$

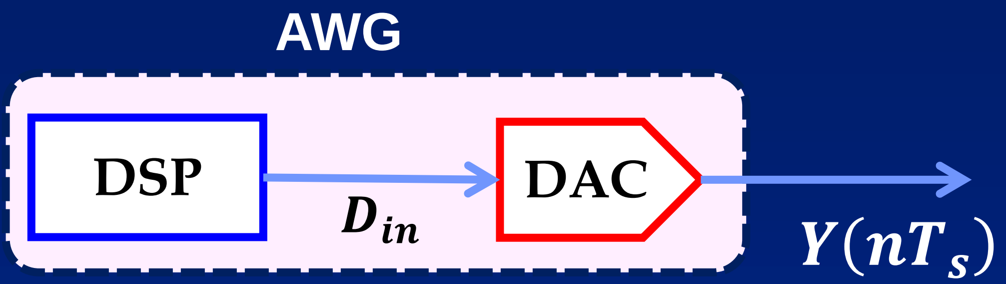
$$\varphi_a = \frac{\pi}{2M} \qquad \varphi_b = \frac{\pi}{2N}$$

M **&** ***N*****th orders are cancelled**



$$f_1/f_s = 1/200$$

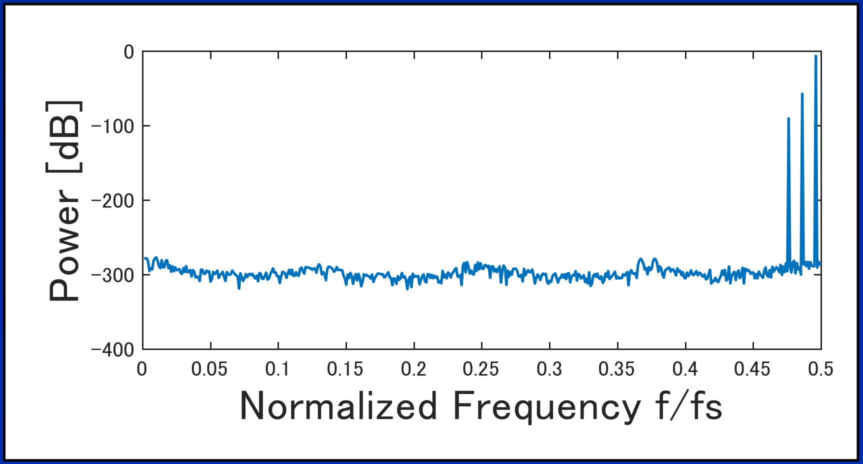
High Freq. Multiple Harmonics Suppression

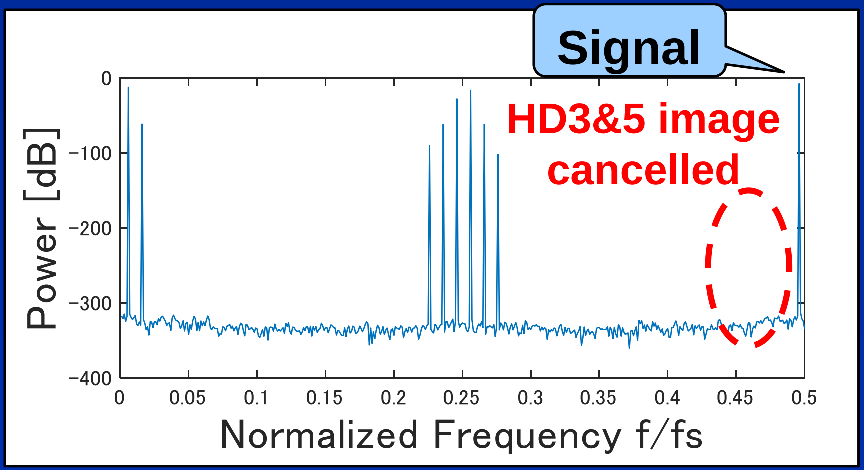


$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s - \varphi_a - \varphi_b) & n = 4k \\ X_1 = A\sin(2\pi f_{in} nT_s - \varphi_a + \varphi_b) & n = 4k+1 \\ X_2 = A\sin(2\pi f_{in} nT_s + \varphi_a - \varphi_b) & n = 4k+2 \\ X_3 = A\sin(2\pi f_{in} nT_s + \varphi_a + \varphi_b) & n = 4k+3 \end{cases}$$

$$\varphi_a = \frac{\pi}{M} \qquad \varphi_b = \frac{\pi}{N}$$

***M* & *N*th order images are cancelled**





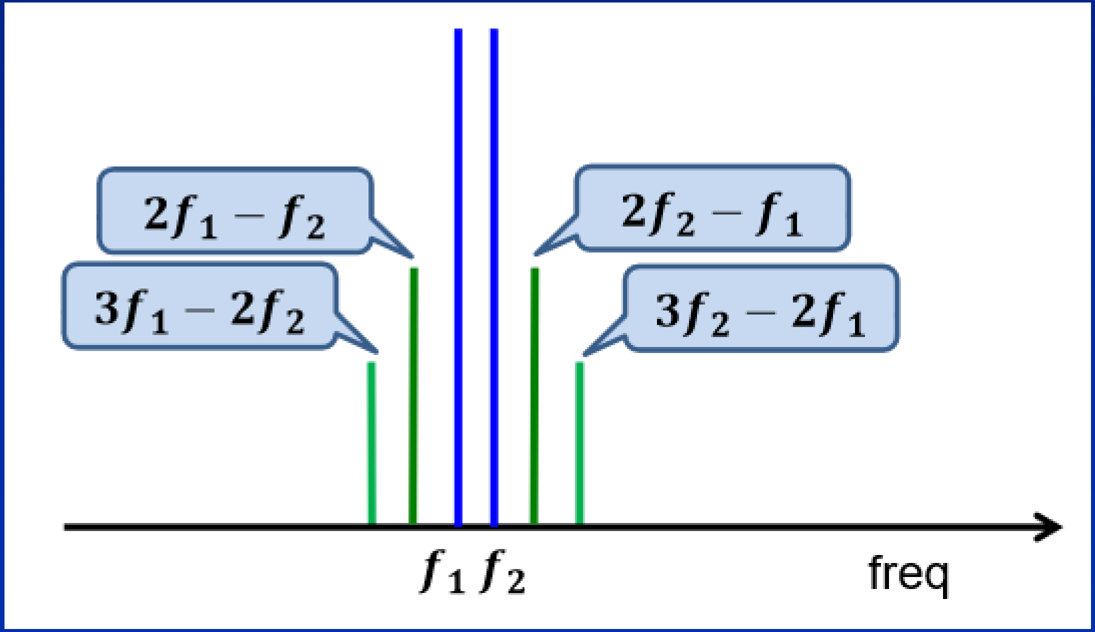
Signal

HD3&5 image cancelled

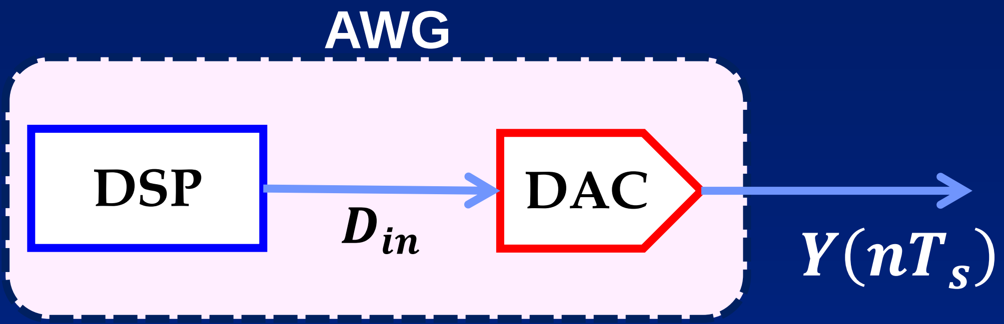
Two-Tone Signal Generation

$$D_{in} = A\sin(2\pi f_1 n T_s) + B\sin(2\pi f_2 n T_s)$$

- **Inter Modulation Distortion (IMD)**



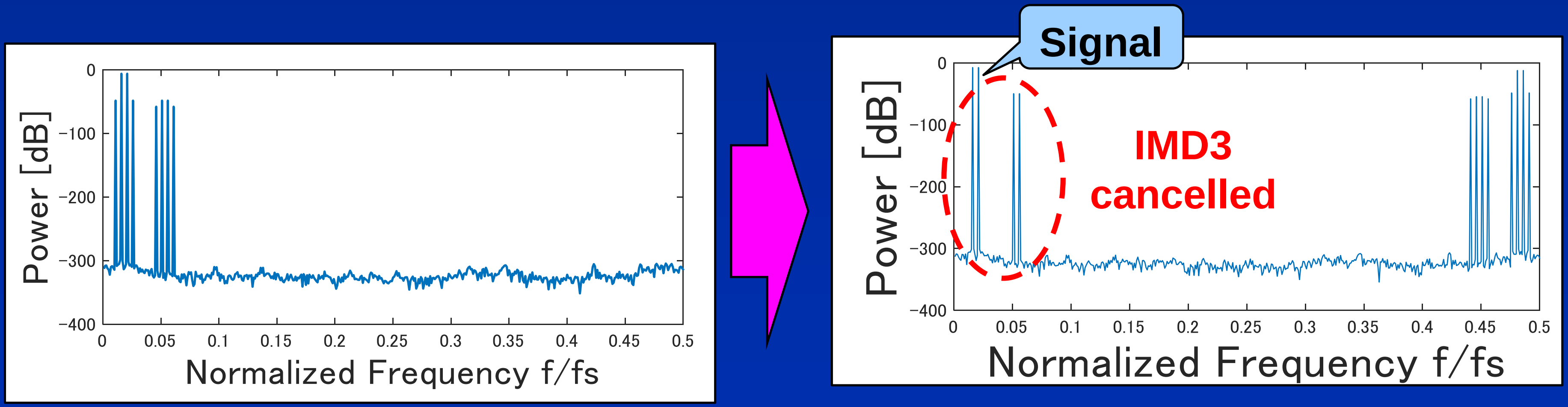
Low Freq. Two-Tone Signal Generation



$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_1 nT_s + \varphi_0) + B\sin(2\pi f_2 nT_s - \varphi_0) & n\text{: even} \\ X_1 = A\sin(2\pi f_1 nT_s - \varphi_0) + B\sin(2\pi f_2 nT_s + \varphi_0) & n\text{: odd} \end{cases}$$

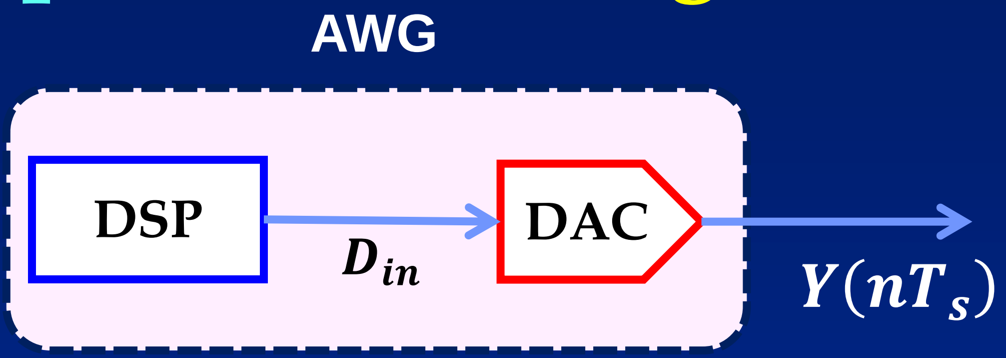
$$\varphi_0 = \frac{\pi}{2N}$$

***N*th order IMD is cancelled**



$$f_1/f_2/f_s = 3/4/200$$

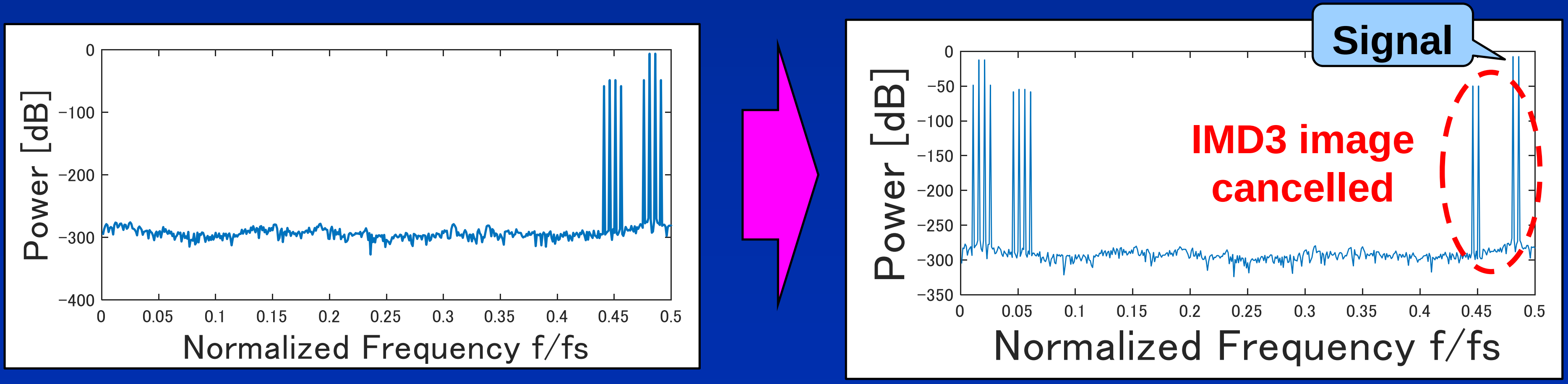
High Freq. Two-Tone Signal Generation



$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_1 nT_s + \varphi_0) + B\sin(2\pi f_2 nT_s - \varphi_0) & n\text{: even} \\ X_1 = A\sin(2\pi f_1 nT_s - \varphi_0) + B\sin(2\pi f_2 nT_s + \varphi_0) & n\text{: odd} \end{cases}$$

$$\varphi_0 = \frac{\pi}{N}$$

***N*th order IMD image is cancelled**



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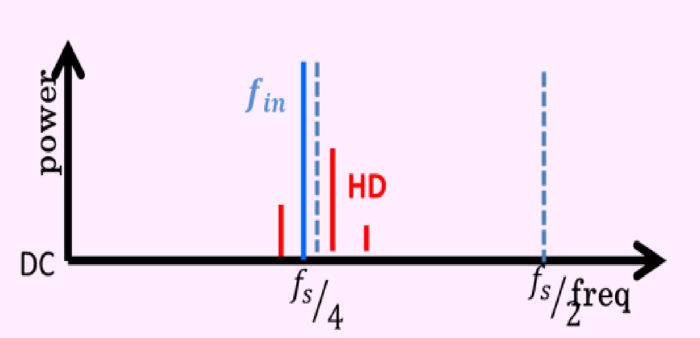
Mid Freq. Harmonics Suppression

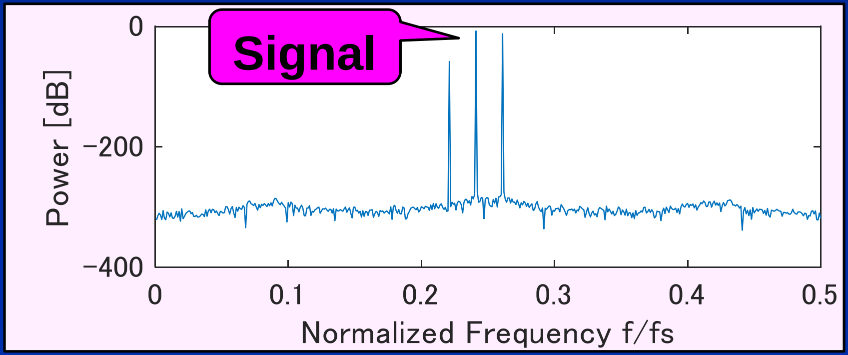
Mid Freq.



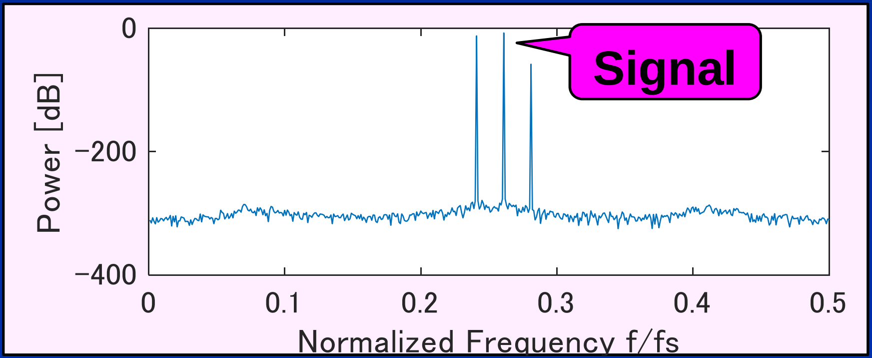
Frontier

phase switching

Low Freq. Generation



High Freq. Generation



HD or HD image near signal
is not suppresseed

New Phase Switching Algorithm

Low Freq. High Freq.

Choose alternately

$X_0 \rightarrow X_1 \rightarrow X_0 \rightarrow X_1$

smart idea

Mid Freq.

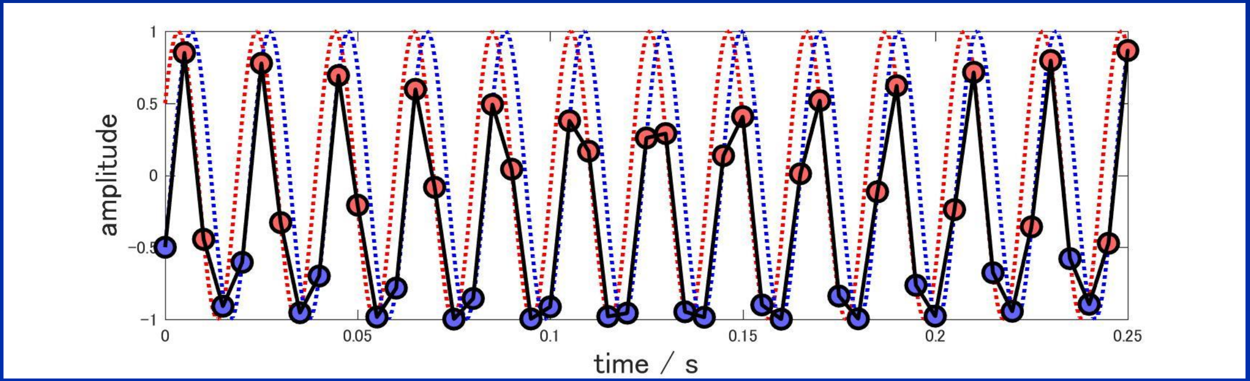
2-point interleaving

$X_0 \rightarrow X_0 \rightarrow X_1 \rightarrow X_1$

$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} n T_s + \varphi_0) & n = 4k-3, 4k-2 \\ X_1 = A\sin(2\pi f_{in} n T_s - \varphi_0) & n = 4k-1, 4k \end{cases}$$

$$\boldsymbol{\varphi_0 = \frac{\pi}{2N}}$$

***N*th order is cancelled**

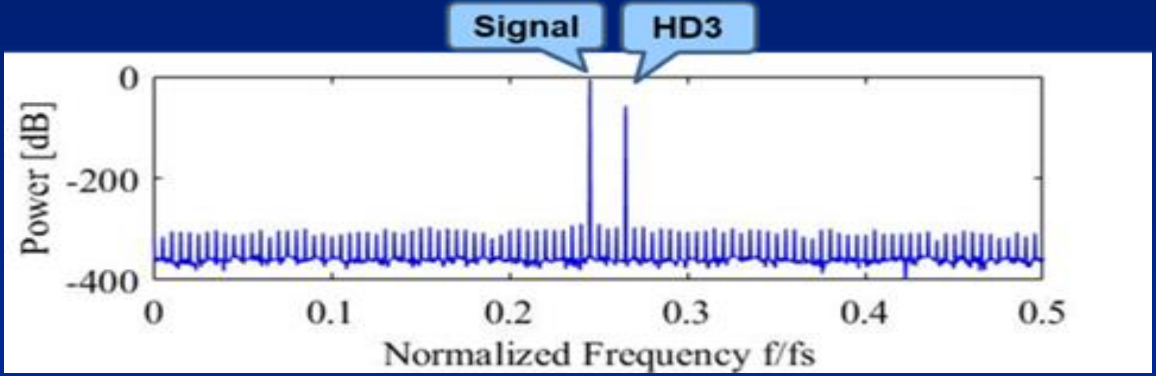


Spurious components are split into low and high frequency regions

Mid Freq. HD3 Suppression

Conventional

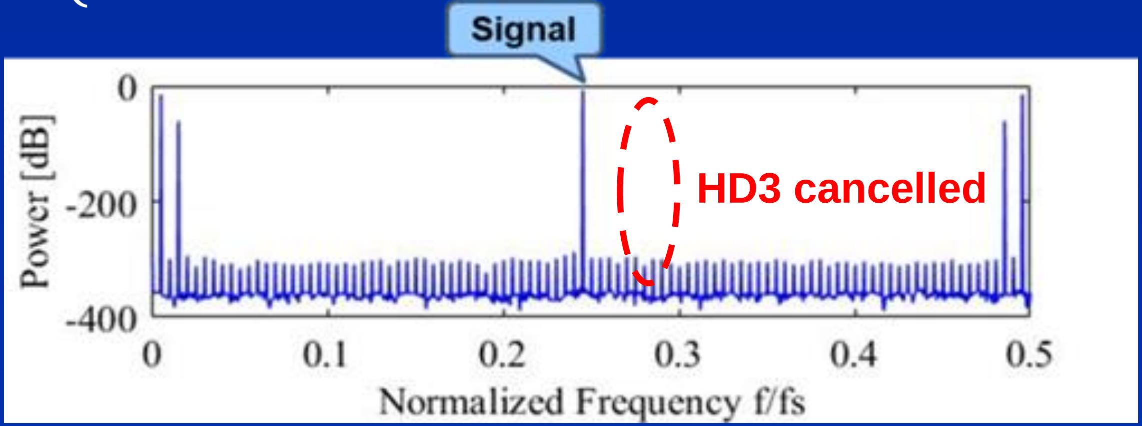
$$D_{in} = A\sin(2\pi f_{in} nT_s)$$



$$Y(nT_s) = a_1 D_{in} + a_3 {D_{in}}^3$$
$f_{in}/f_s = 49/200$,
$A = 1$,
$a_1 = 1$,
$a_3 = -0.01$
$\varphi_0 = \frac{\pi}{6}$

Proposed

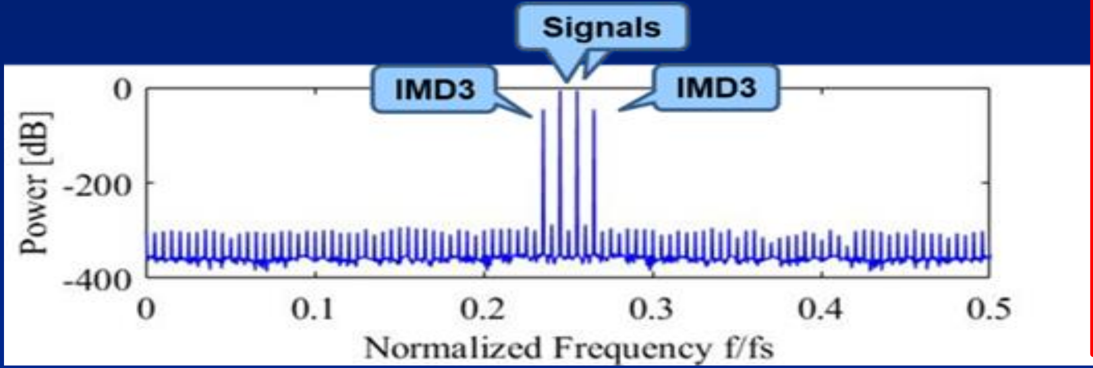
$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s + \varphi_0) & n = 4k-3, 4k-2 \\ X_1 = A\sin(2\pi f_{in} nT_s - \varphi_0) & n = 4k-1, 4k \end{cases}$$



Mid Freq. Two-Tone IMD3 Suppression

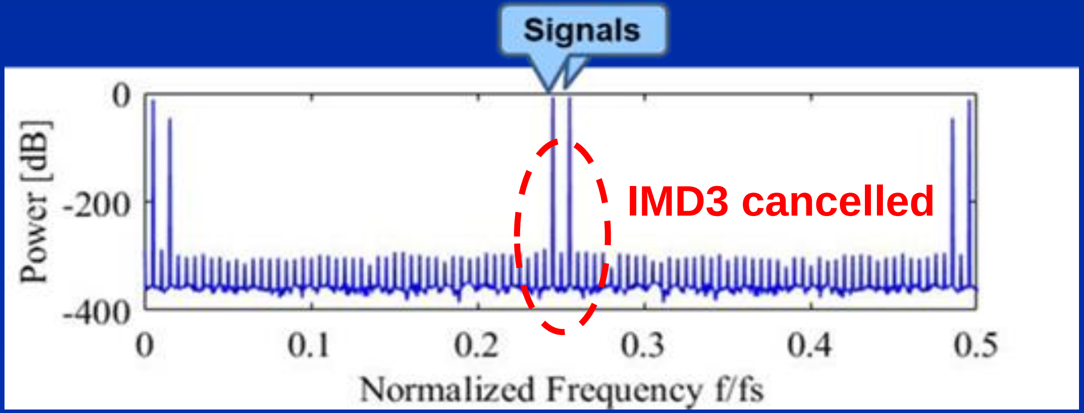
Conventional $D_{in} = A\sin(2\pi f_1 nT_s) + B\sin(2\pi f_2 nT_s)$

$$Y(nT_s) = a_1 D_{in} + a_3 {D_{in}}^3$$
$$f_1/f_s = 49/200,$$
$$f_2/f_s = 51/200$$
$$A = 1,$$
$$B = 1,$$
$$a_1 = 1,$$
$$a_3 = -0.01$$
$$\varphi_0 = \frac{\pi}{6}$$



Proposed

$$D_{in} = \begin{cases} X_0 = A\sin(2\pi f_{in} nT_s + \varphi_0) + B\sin(2\pi f_{in} nT_s - \varphi_0) & n = 4k-3, 4k-2 \\ X_1 = A\sin(2\pi f_{in} nT_s - \varphi_0) + B\sin(2\pi f_{in} nT_s + \varphi_0) & n = 4k-1, 4k \end{cases}$$



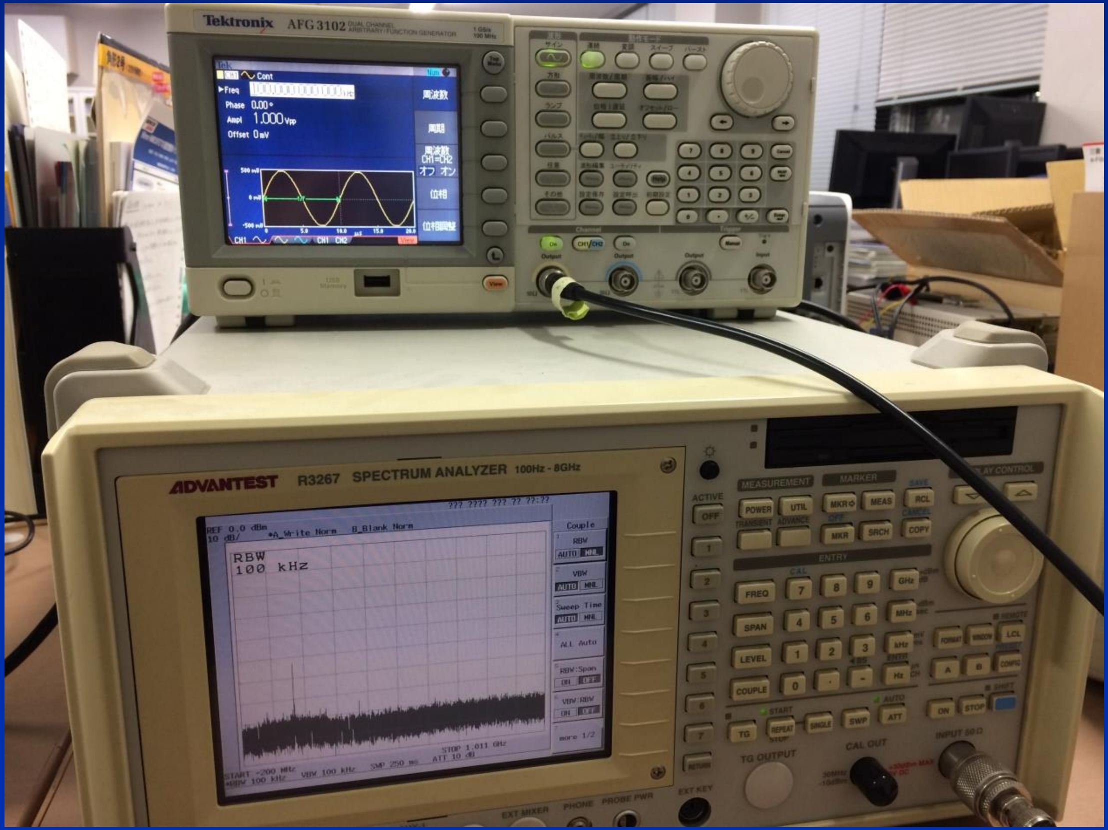
Outline

- Research Background
- Phase-Switching Method
- Low & High-Frequency Signal Generation
- Mid-Frequency Signal Generation
- Experimental Results
- Conclusions

Experiment using AWG

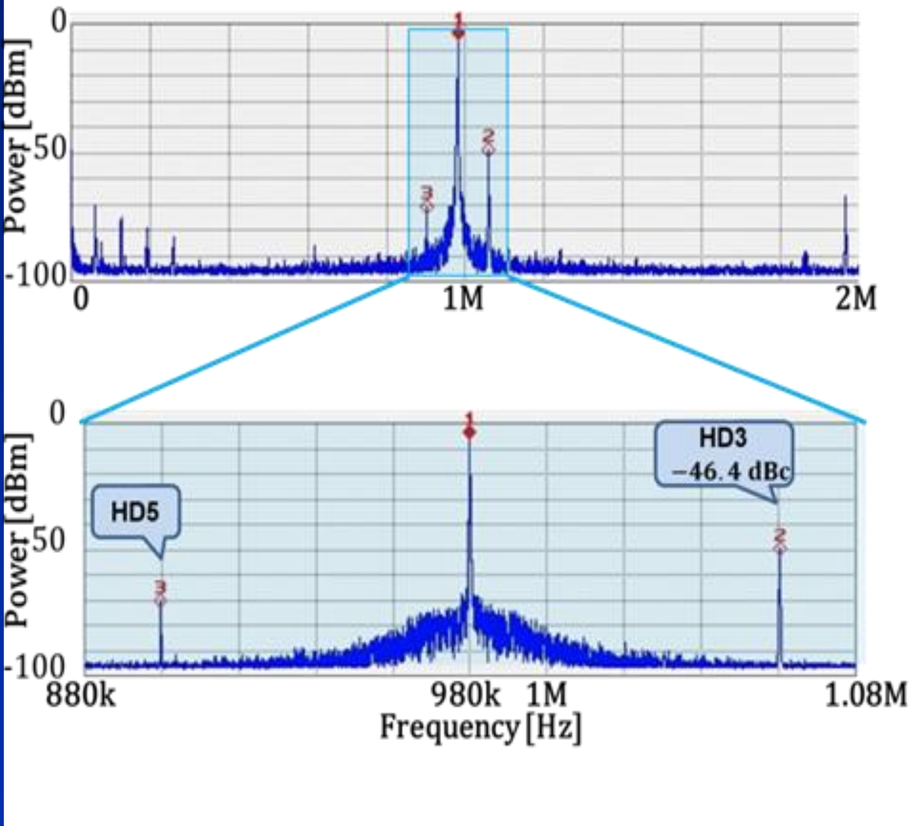
AWG
(Tektronix　TDS1001C-EDU, MAX 40MHz,500Msample/s）

Spectrum analyzer
（Advantest　R3267, Measurable band 100Hz – 8GHz）

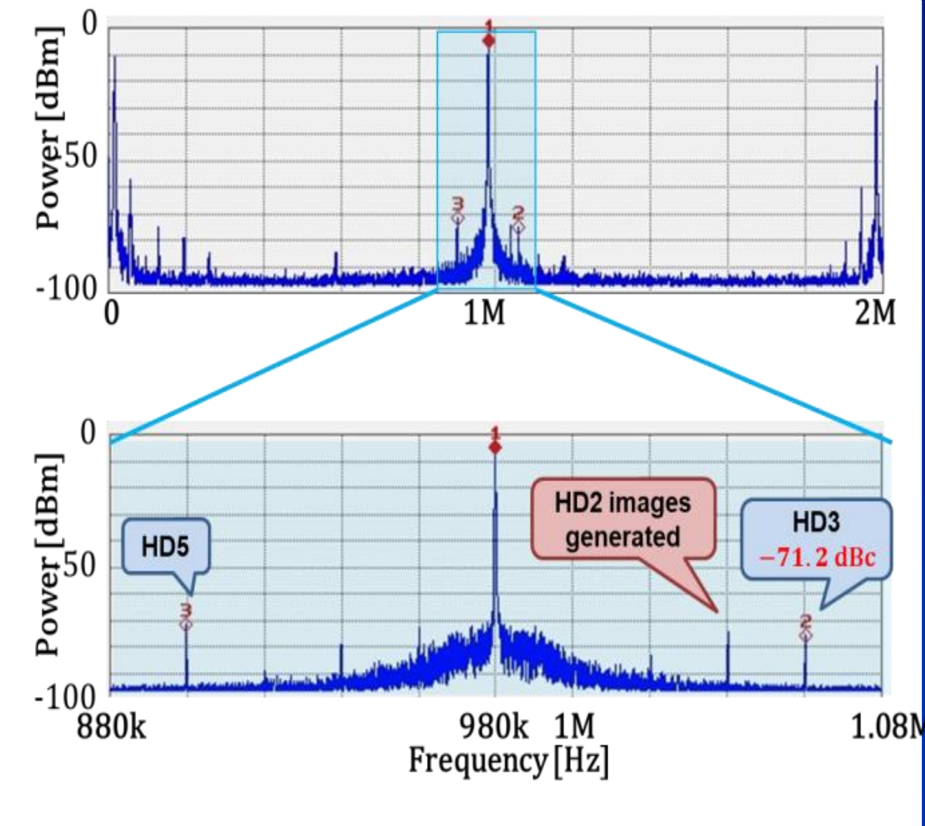


Mid Freq. HD3 Suppression

Conventional Method



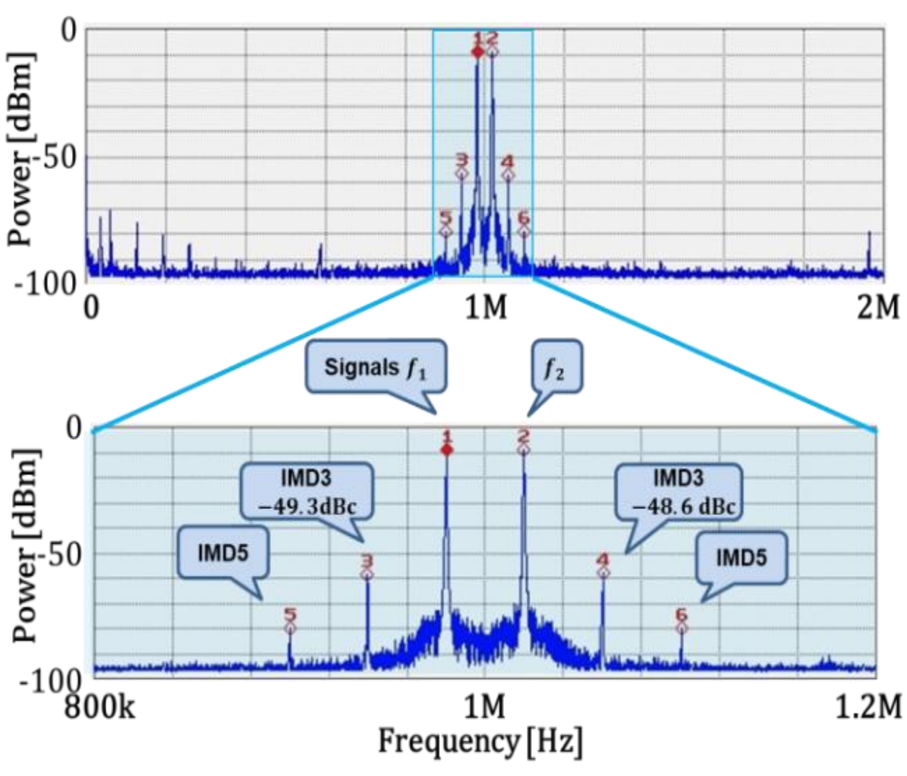
Proposed Method



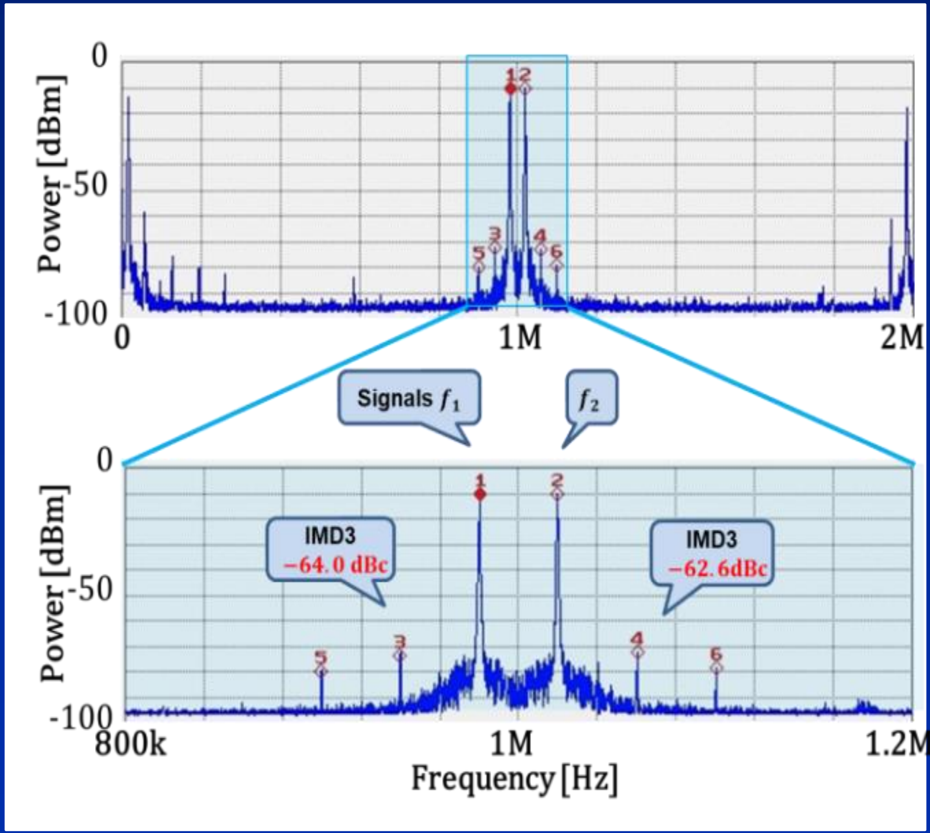
$$f_s = 4\text{MHz}, \qquad f_{in} = 980\text{kHz}$$

Mid Freq. Two-Tone IMD3 Suppression

Conventional Method



Proposed Method



$$f_s = 4\text{MHz}, \qquad f_1 = 980\text{kHz}, \qquad f_2 = 1020\text{kHz}$$

Outline

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Conclusions

- We have proposed Mid-Freq. single/two-tone signal generation algorithms
- Simulation/experimental verification shows their effectives
- In conjunction with previous research, we have completed Full Nyquist Range low-distortion signal generation method