Kobayashi Laboratory

High-Frequency Low-Distortion Signal Generation Algorithm with AWG

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Research Objective

Objective

Low-distortion sine wave generation for ADC test

Our Approach

DSP algorithm using AWG

AWG : Arbitrary Waveform Generator

OUTLINE

- **Research background**
- **Phase-switching algorithm**
- **Proposed solution**
- **Theoretical analysis**
- **Conclusion**

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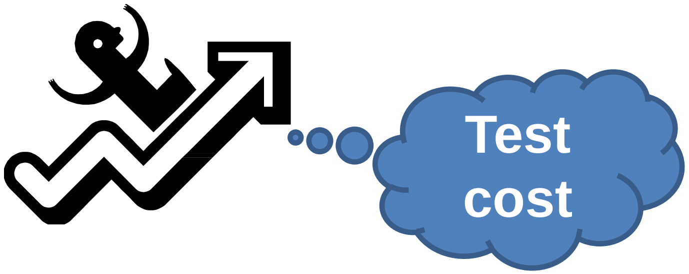
Research background

Semiconductor industry

- **Silicon cost ⇒ decreasing**
- **Test cost ⇒ increasing**

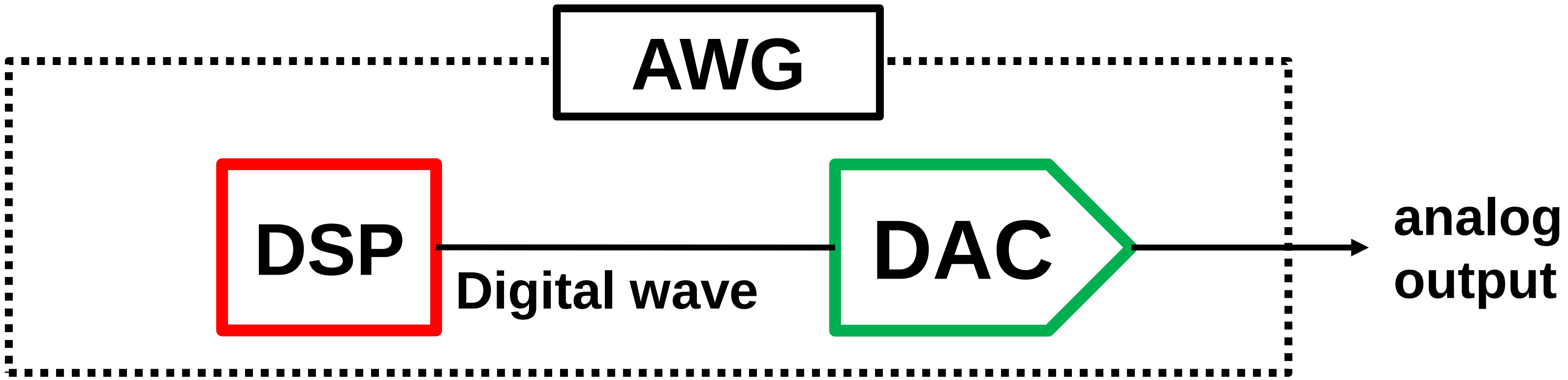


Low cost test

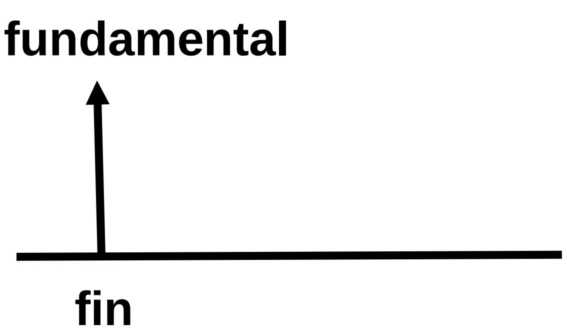
⇒ Low cost LSI production

Arbitrary Waveform Generator

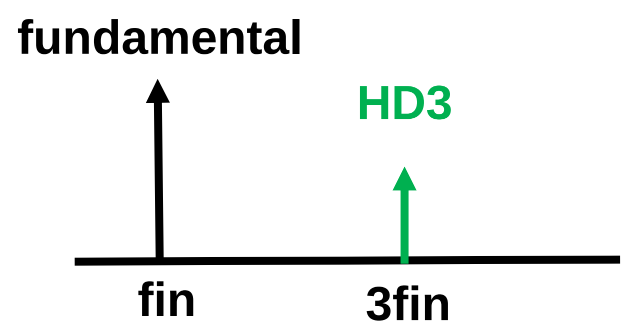
AWG : Arbitrary Waveform Generator



Ideal AWG output spectrum



Real AWG output spectrum
(DAC has 3rd nonlinearity)



DAC nonlinearity ⇨ **Harmonic distortion of AWG**

ADC Test Cost Using AWG

AWG

- AWG : Expensive
- Long testing time

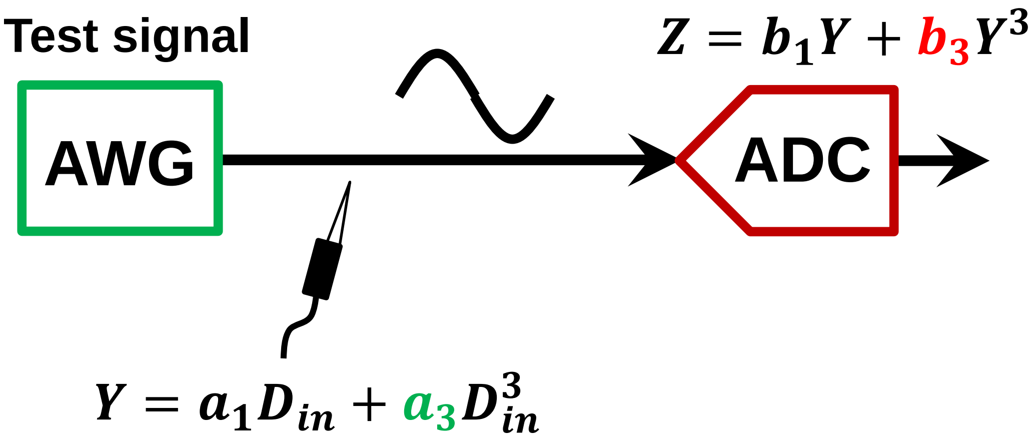
Mass production

Test cost → **high**

Low cost test → **Low cost AWG**

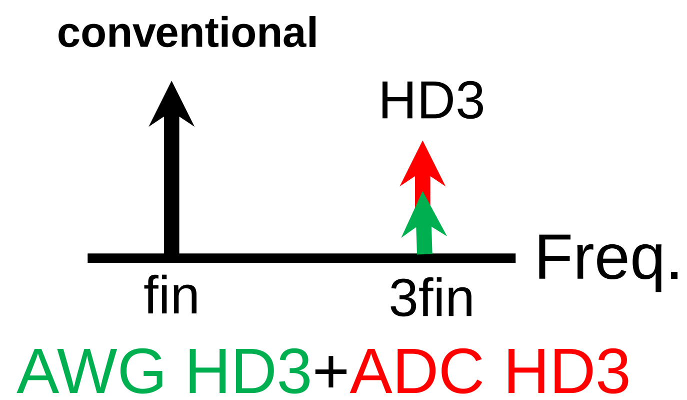
↳ Test performance

Conventional ADC Test



AWG: Arbitrary Waveform Generator

ADC output spectrum



Inexpensive AWG output includes HD3

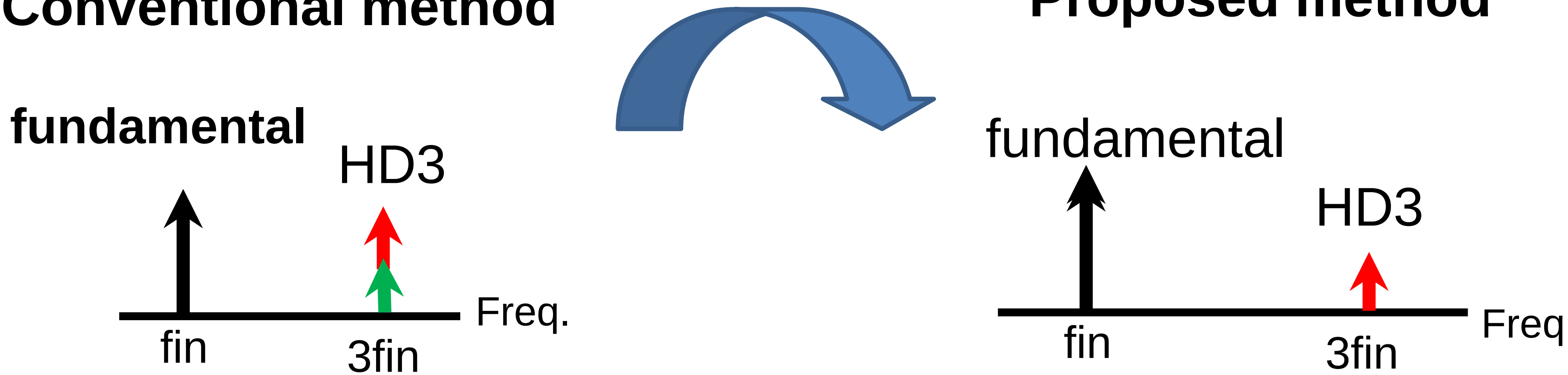
HD3 : 3rd order Harmonic Distortion

Conventional ADC nonlinearity test

→ **Over estimate of HD3**

Low-Cost, Accurate Test of ADC with AWG

Conventional method | **Proposed method**



AWG HD3+ADC HD3

Only ADC HD3

Accurate ADC linearity test with inexpensive AWG

- Only DSP program change
- No hardware change
- No requirement for AWG nonlinearity identification

OUTLINE

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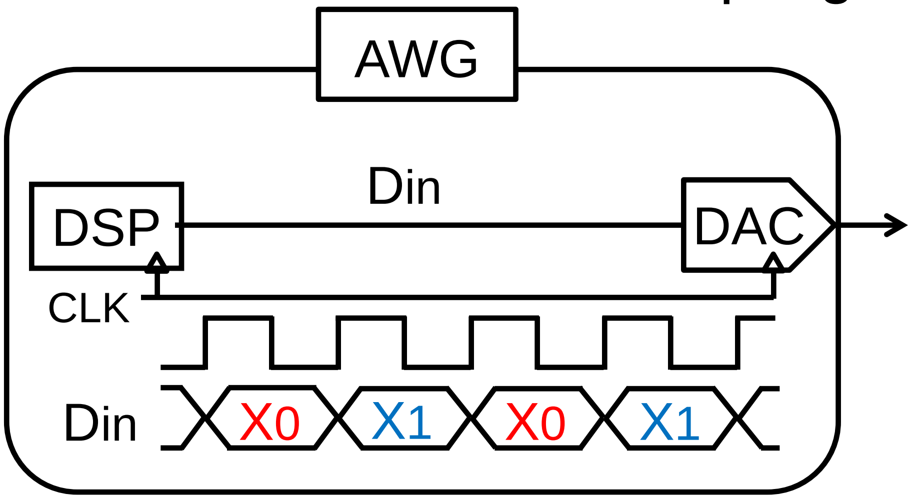
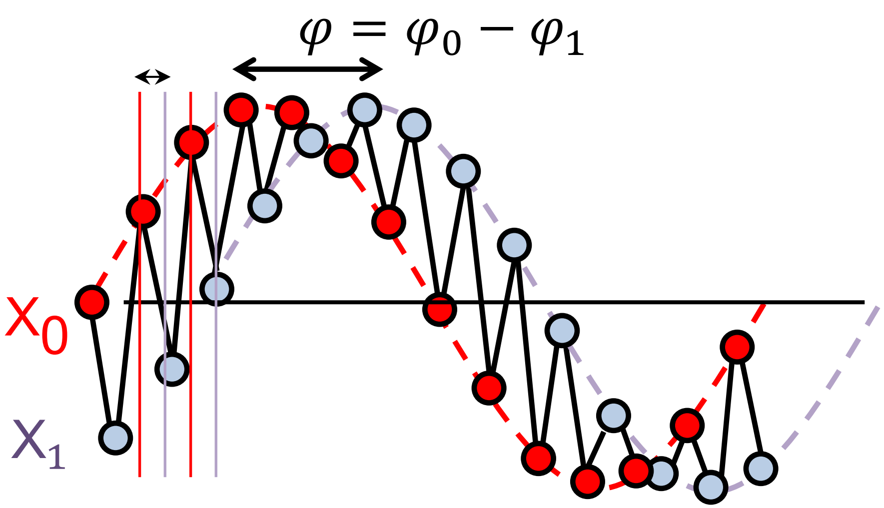
Phase switching signal algorithm

Our previous proposal

Interleave sampling X_0, X_1 every one clock



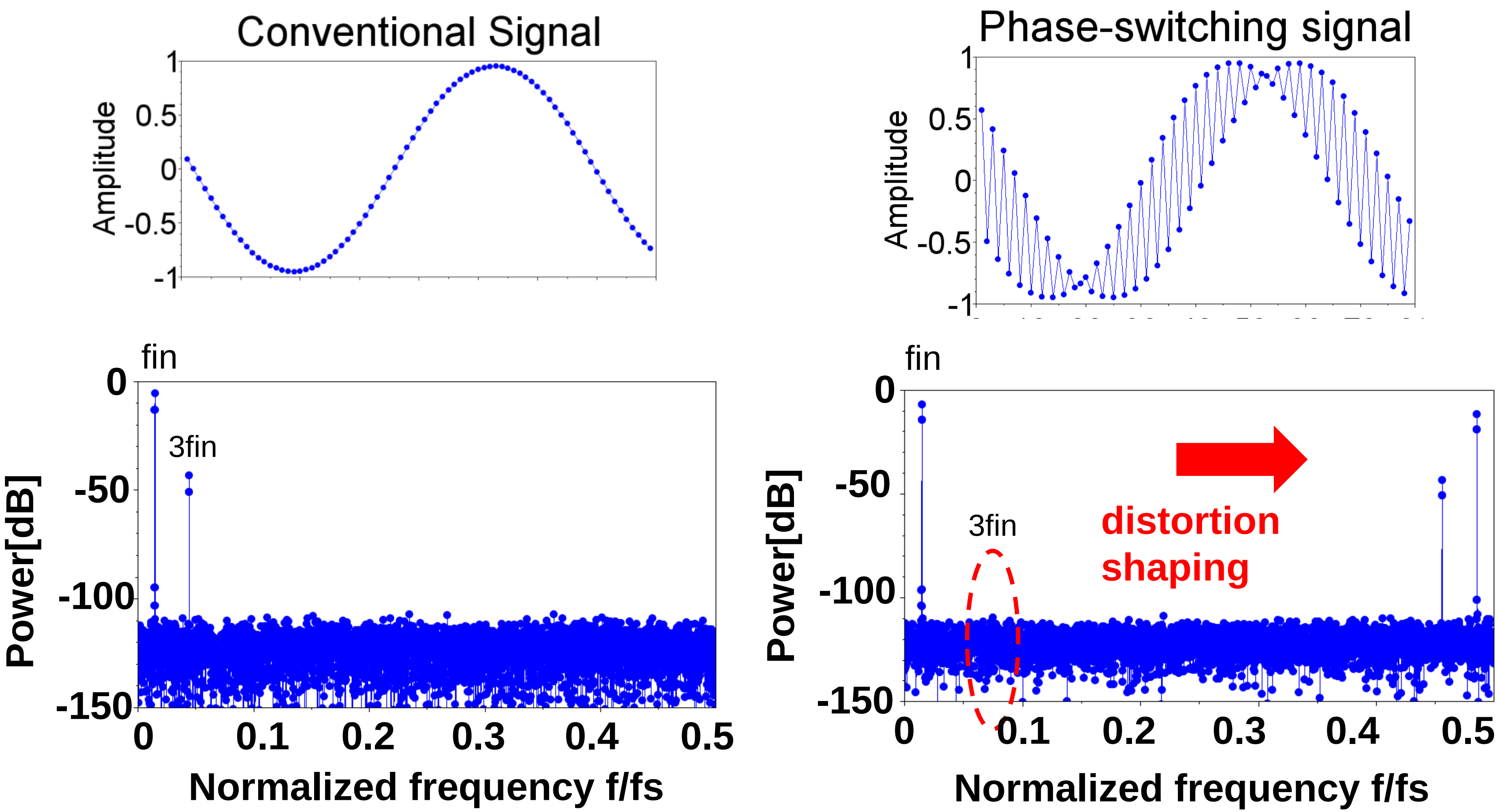


- $X_0 = A\cos(2\pi f_{in} n T_s + \varphi_0)$ … n: even
- $X_1 = A\cos(2\pi f_{in} n T_s + \varphi_1)$ … n: odd

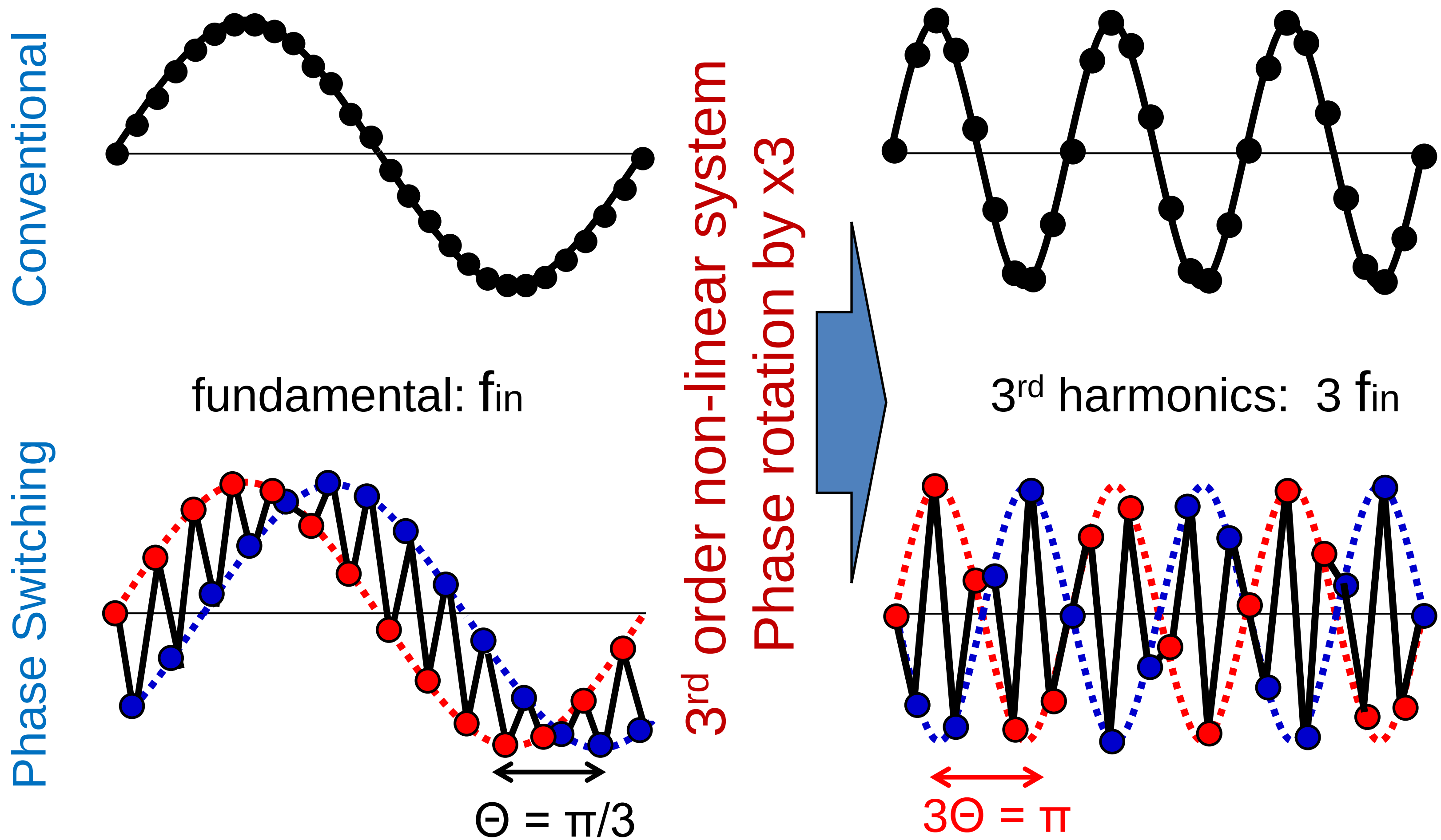
$\varphi = \varphi_0 - \varphi_1 = \pi/N$ ⇒ HD_N is cancelled.

Simulation Result of Phase Switching Signal

D_{in} $\qquad$ $Y = a_1 D_{in} + a_3 D_{in}^3$



Principle of 3rd Harmonics Cancellation

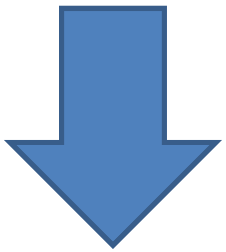


Two waves with phase difference π are cancelled

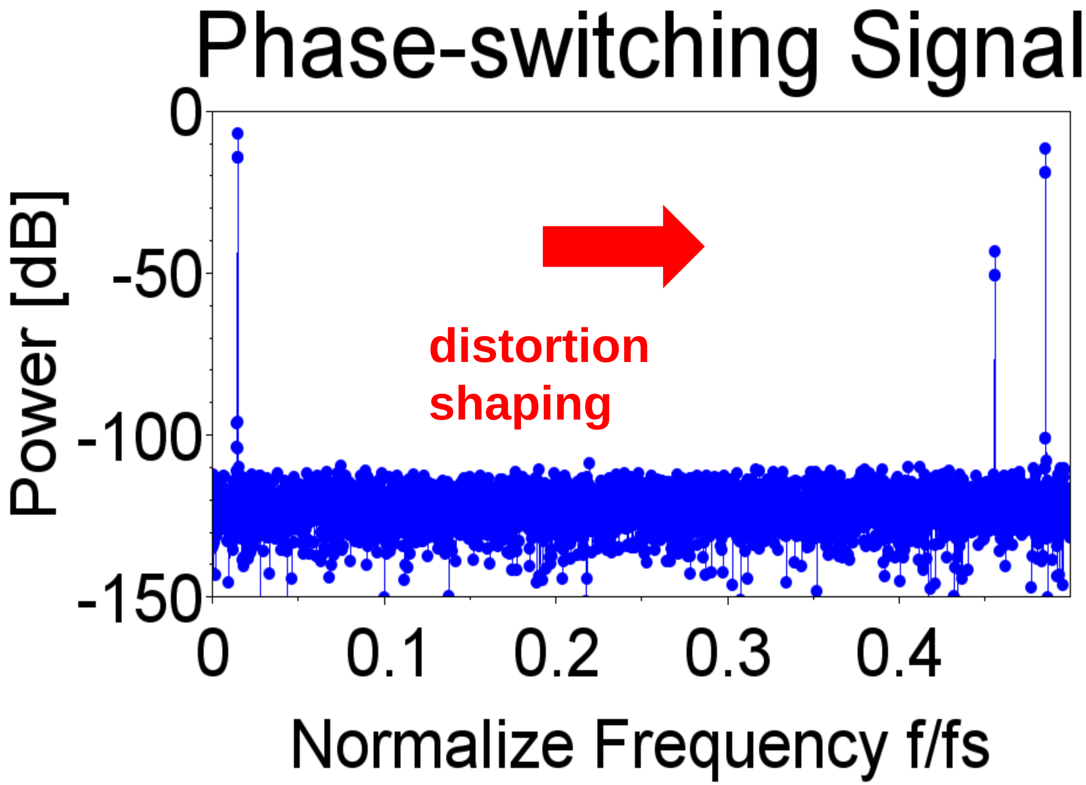
OUTLINE

Problem of Phase Switching Algorithm

"Distortion shaping" cancels HD3,
but spurious around fs/2 appears.



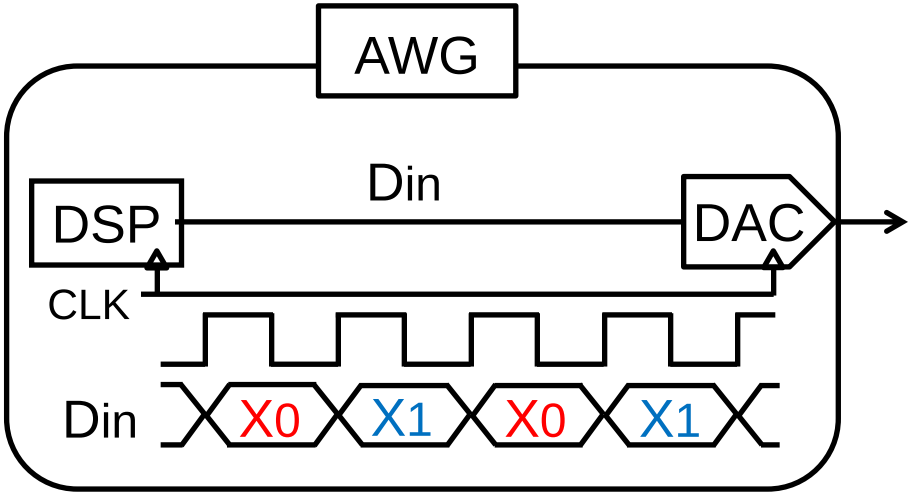
Phase switching signal is applicable only for low frequency signal generation.

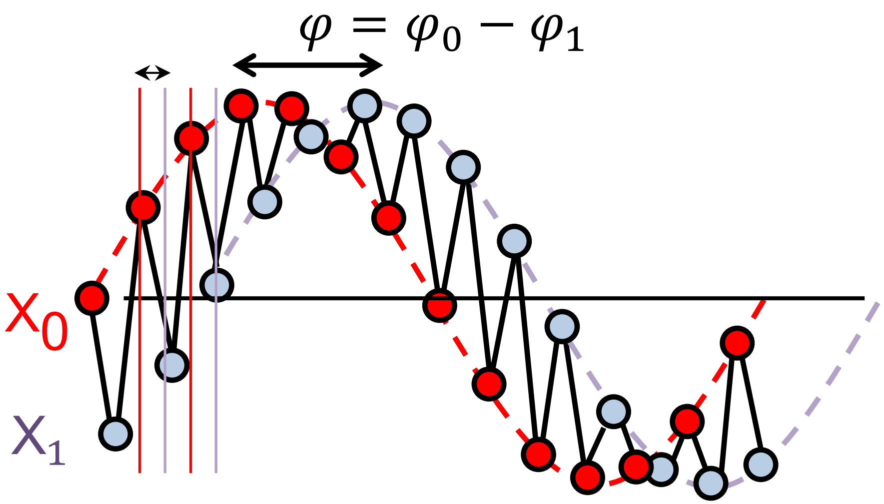


We propose phase switching method for <u>high frequency</u>

High frequency low distortion signal generation

Interleave sampling X_0 , X_1 every one clock



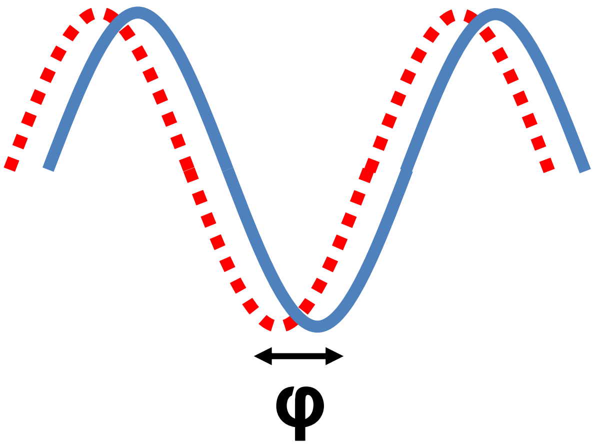


- $X_0 = A\cos(2\pi f_{in} n T_s + \varphi_0)$ … n: even
- $X_1 = A\cos(2\pi f_{in} n T_s + \varphi_1)$ … n: odd

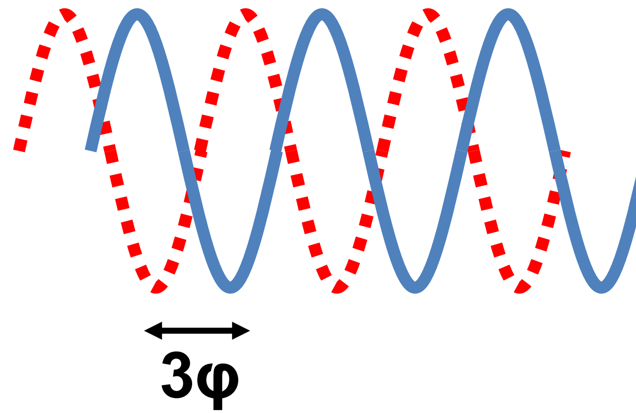
$$\varphi = \varphi_0 - \varphi_1 = \mathbf{2}\pi / N$$

N-th order image is cancelled

Unified Principle of Low-Distortion Signal Generation



3rd order nonlinearity



Two sinusoidal signals (frequency : f_{in})

Two 3rd order harmonics (frequency : $3f_{in}$)

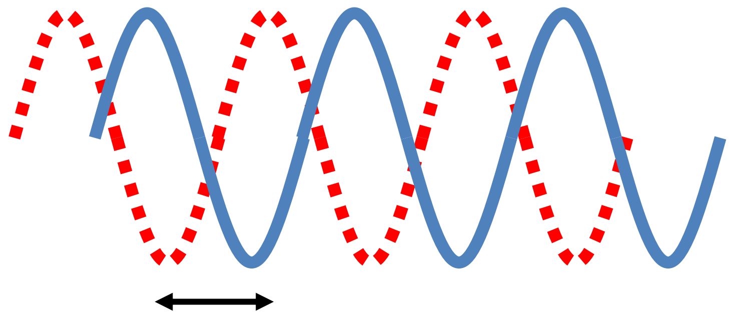
Interleave sampling every one clock (Sampling frequency : fs)

Image signal : fs/2-fin

3rd order image signal : fs/2-3fin

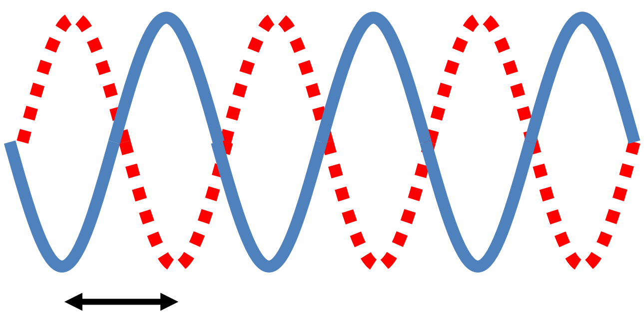
HD3 Component Cancellation

Two 3rd order harmonics



3φ

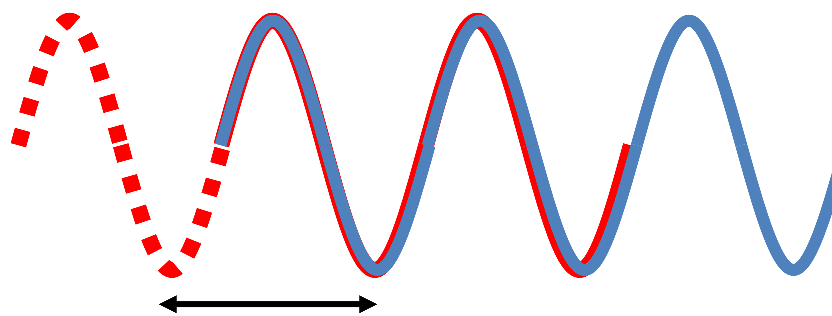
Reverse phase



$3\varphi = \pi, 3\pi, \cdots$

- **Cancelled HD3**

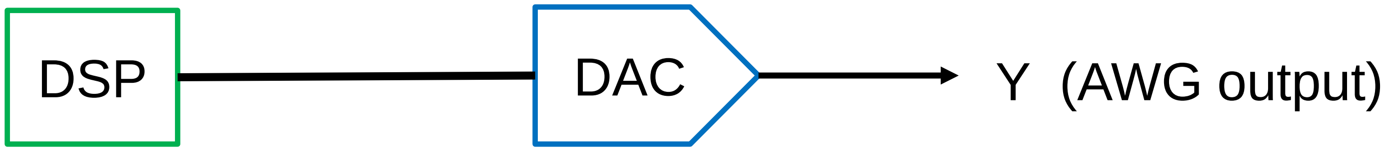
Same phase



$3\varphi = 2\pi, 4\pi, \cdots$

- **Cancelled fs/2-3fin**

AWG Output with Conventional Method

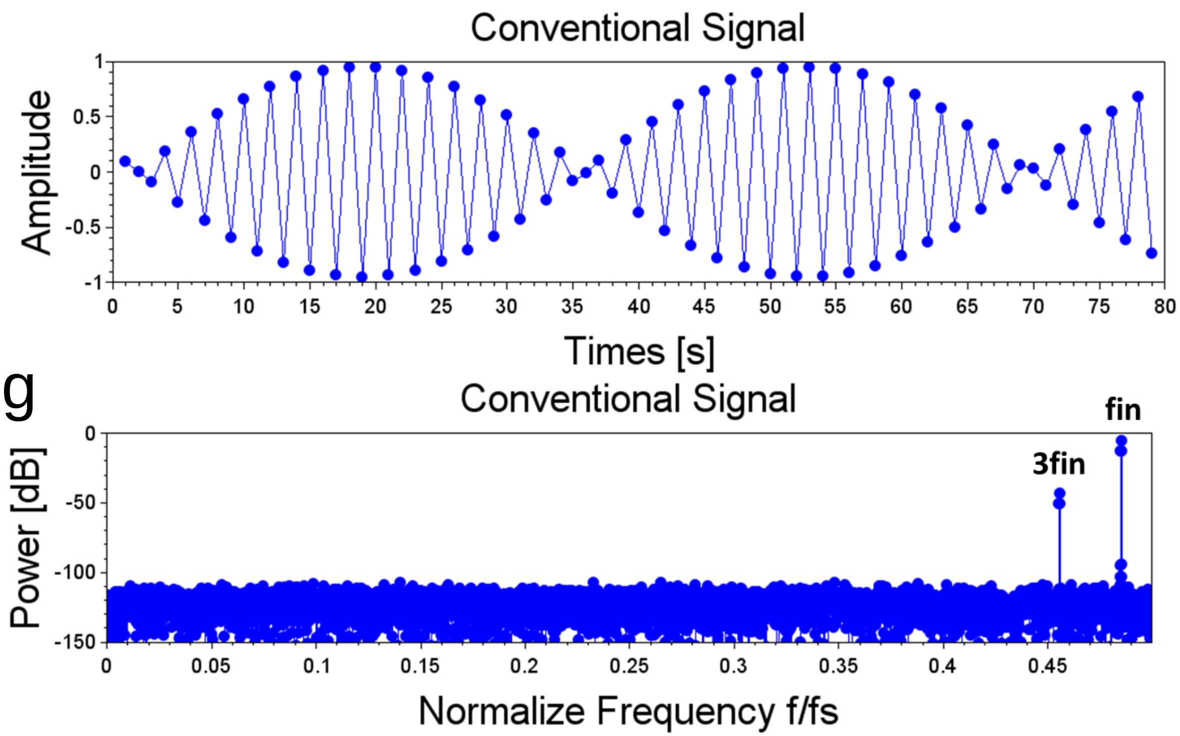


D_{in} $\quad$ $Y = a_1 D_{in} + a_3 D_{in}^3$

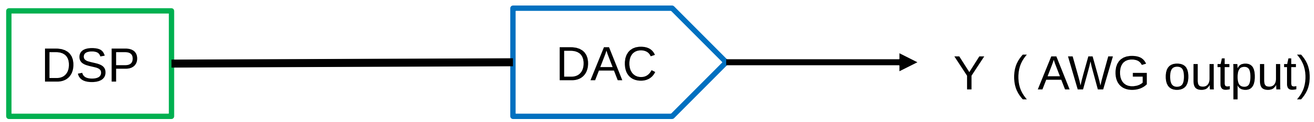
$$D_{in} = \sin(2\pi f_{in\_conv} n T_s)$$

HD3 component (3fin)

is folded back as aliasing



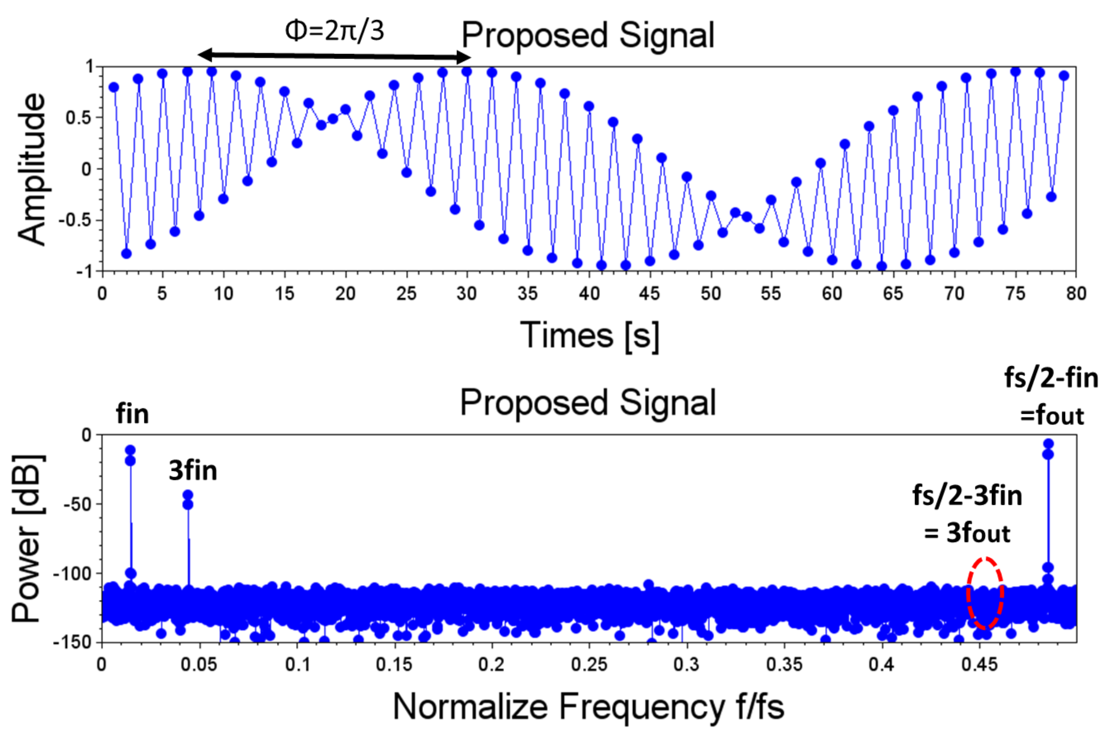
Simulation Result of Proposed Method



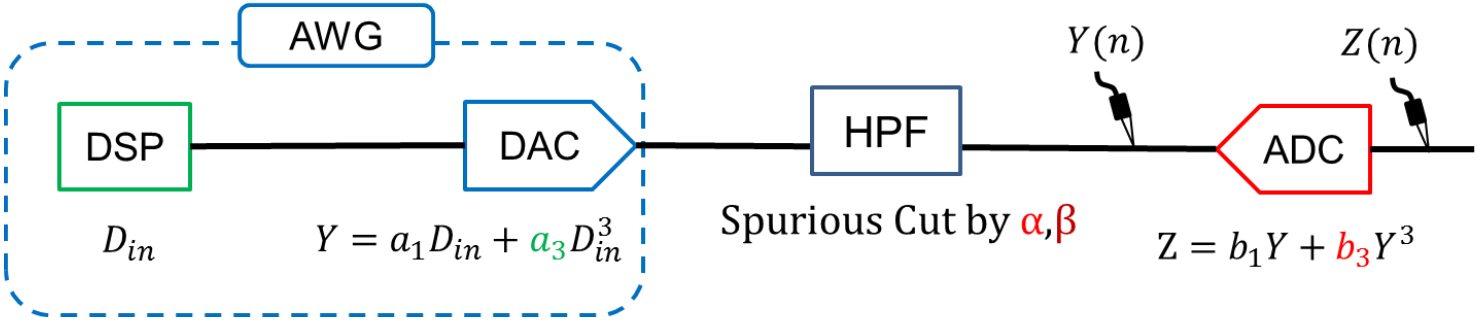
D_{in} $\quad\quad$ $Y = a_1 D_{in} + a_3 D_{in}^3$

- $X_0 = A\cos(2\pi f_{in} n T_s + \pi/3) \ldots \text{n: even}$
- $X_1 = A\cos(2\pi f_{in} n T_s - \pi/3) \ldots \text{n: odd}$

$3f_{out}$ component is cancelled



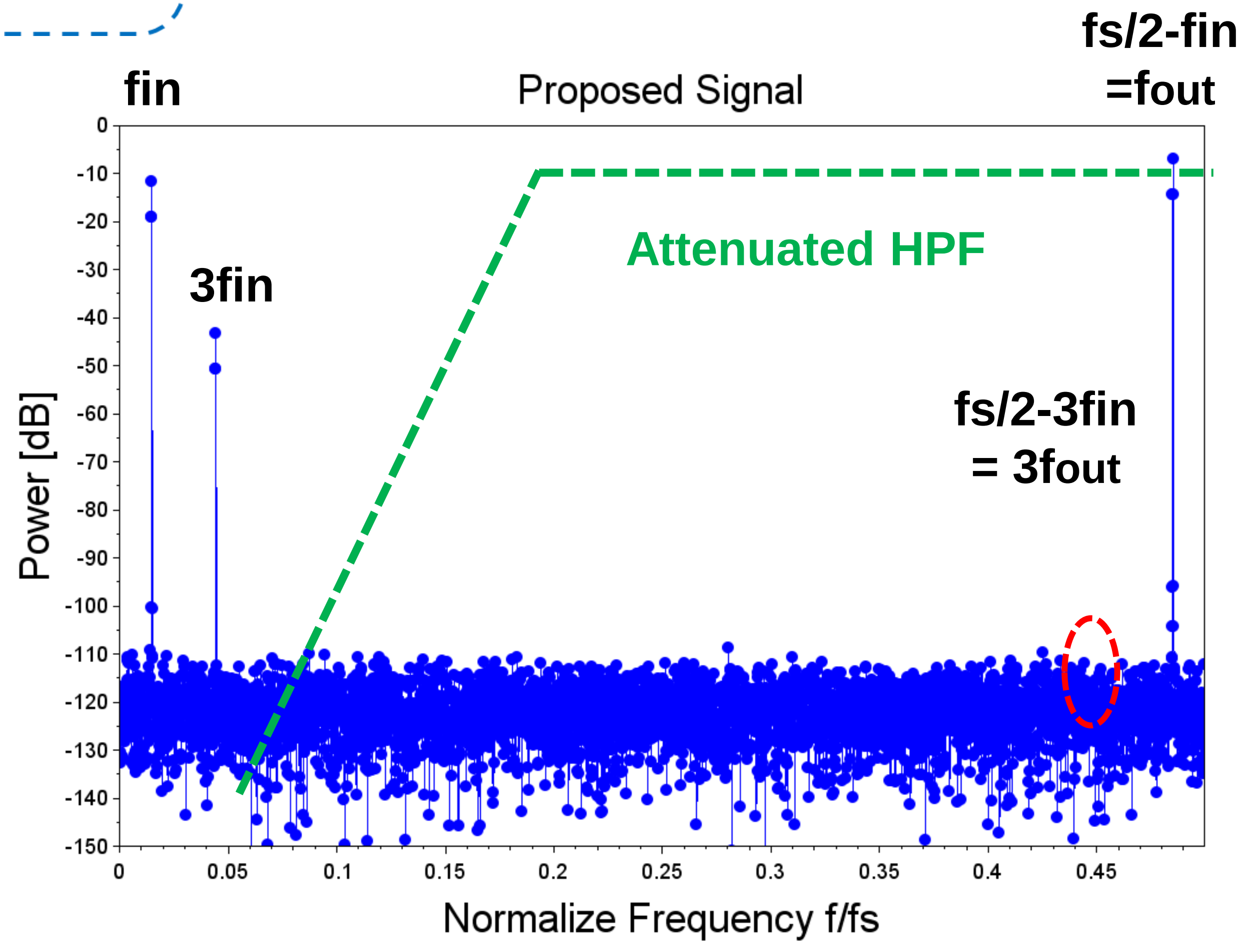
Low-Distortion High-Frequency Signal



f_{in} , $3f_{in}$ components reduction by HPF

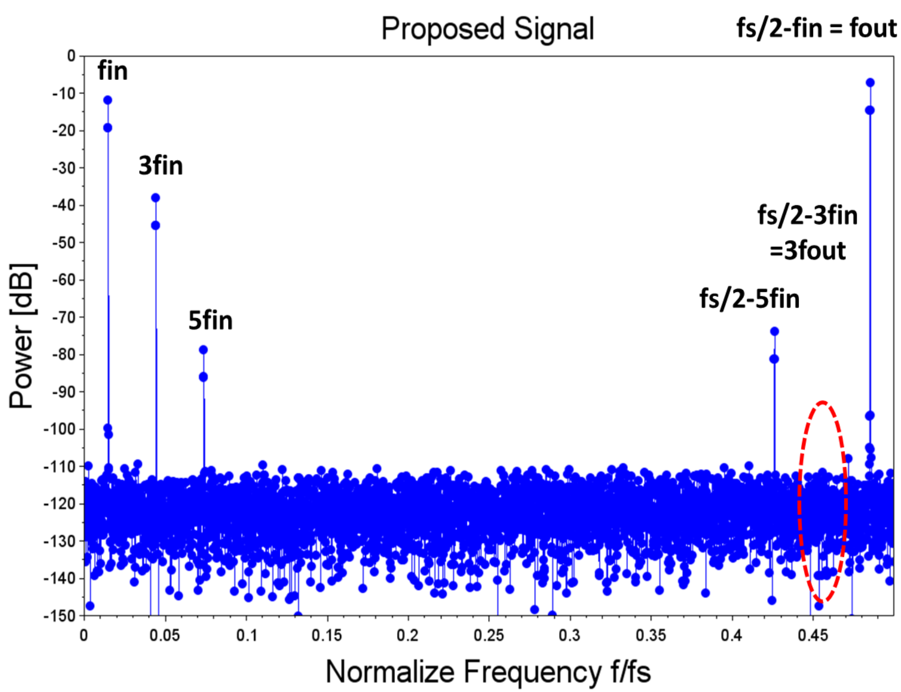
Low distortion sinusoidal signal

$$\left(f_{out} = \frac{f_s}{2} - f_{in}\right)$$

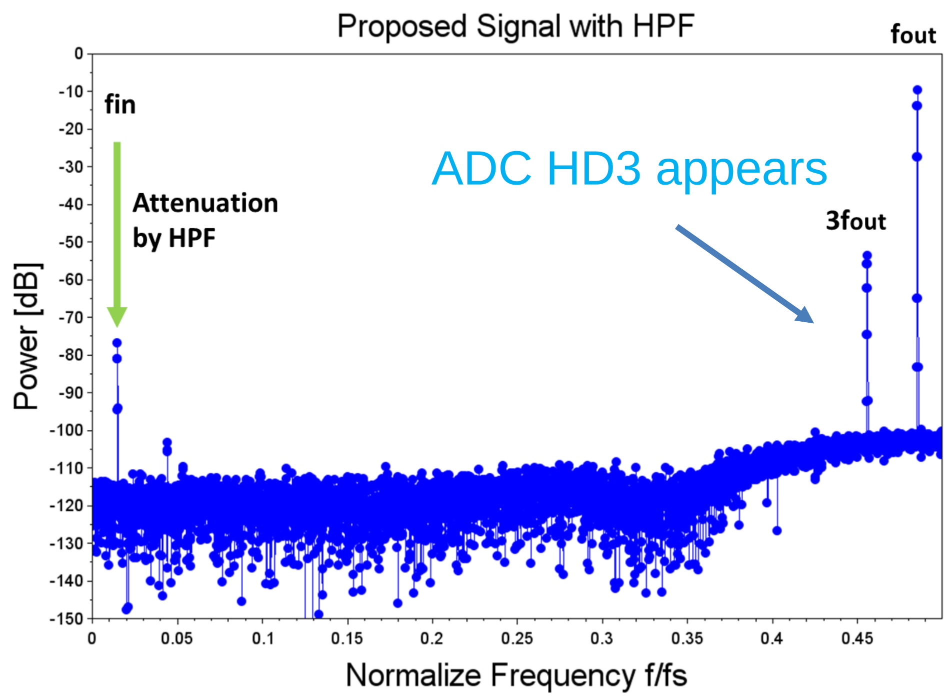


ADC Output with HPF

No attenuation of fin component



Attenuation of fin component with HPF

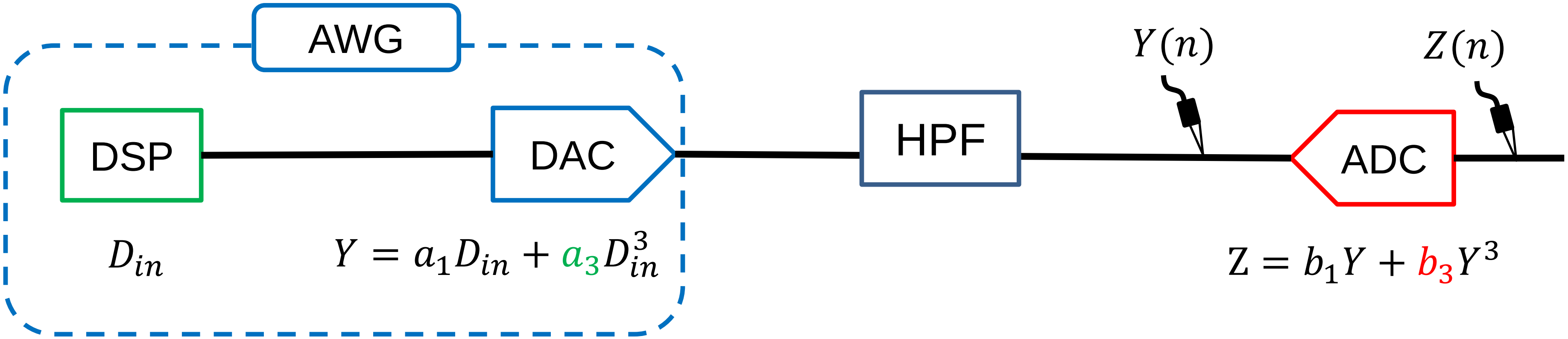


If fin component is NOT reduced ➡ ADC HD3 component is cancelled (ADC 3rd distortion cannot be measured)

If fin component is reduced by HPF ➡ Accurate ADC HD3 measurement

OUTLINE

Model for Theoretical Analysis



- AWG Input with Phase Switching

$$\mathrm{D_{in}(nT_s)} = \begin{cases} \mathrm{A} \cdot \sin\left(2\pi \mathrm{f_{in} n T_s} - \dfrac{\pi}{3}\right) & \text{n: odd} \\ \mathrm{A} \cdot \sin\left(2\pi \mathrm{f_{in} n T_s} + \dfrac{\pi}{3}\right) & \text{n: even} \end{cases}$$

- AWG Nonlinearity Model

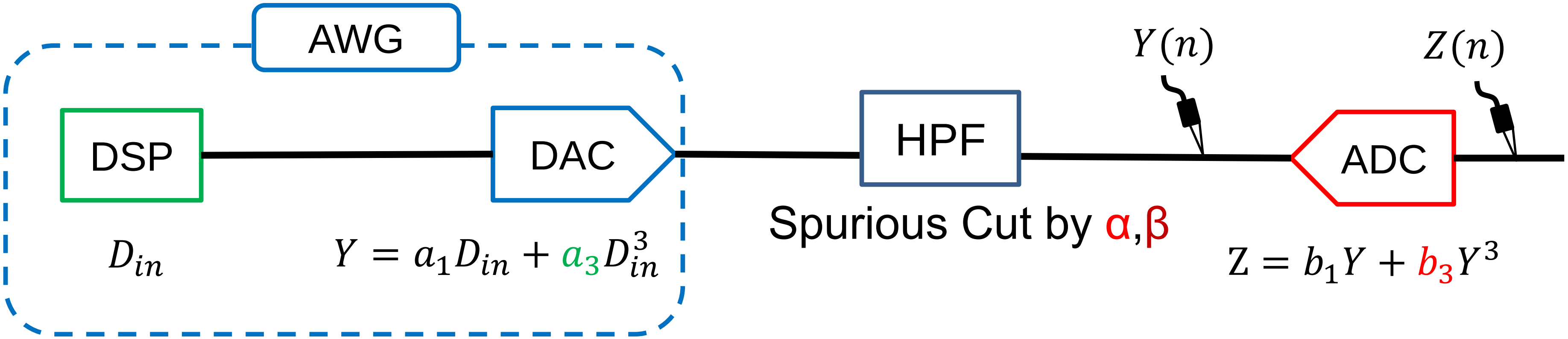
$$Y(nTs) = a_1 D_{in}(n) + a_3 \{D_{in}(n)\}^3$$

- ADC Nonlinearity Model

$$Z(n) = b_1 Y(nT_s) + b_3 \{Y(nT_s)\}^3$$

For Simplicity
$\mathbf{f_{s(AWG)} = f_{s(ADC)}}$

AWG Output Theoretical Analysis



$$Y = a_1 D_{in} + a_3 D_{in} \; = -\alpha \frac{1}{2}\left(a_1 A + \frac{3}{4} a_3 A^3\right)\sin(2\pi f_{in} n T_s)$$

$$-\beta \frac{1}{4} a_3 A^3 \sin(2\pi(3 f_{in}) n T_s)$$

$$+\frac{\sqrt{3}}{2}\left(a_1 A + \frac{3}{4} a_3 A^3\right)\cos\left(2\pi\left(\frac{f_s}{2} - f_{in}\right) n T_s\right)$$

filter

$0 \leq \alpha, \beta \leq 1$

Proposed method uses this component

f_{in}: input frecuency

f_s : sampling frecuency

ADC Output Without HPF

ADC output

$$Z(nT_s) = b_1 Y + b_3 Y^3$$

$$= \{b_1\ R + \frac{3}{4} b_3 R(R^2 + 2\alpha\beta PQ + 2\beta^2 Q)\} \cos(2\pi\left(\frac{f_s}{2} - f_{in}\right) n\mathrm{T_s})$$

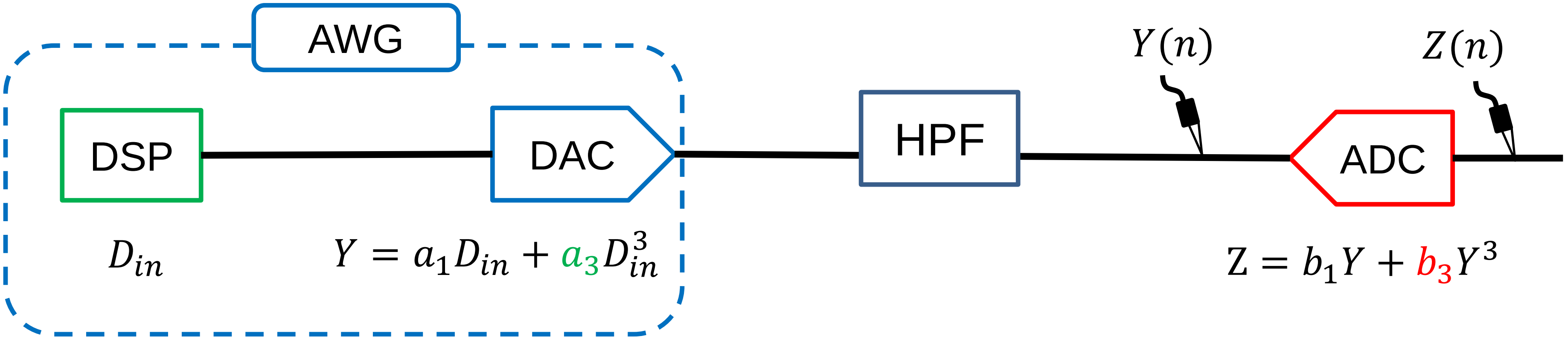
$$+ \left\{\frac{1}{4} b_3 \mathrm{R}(R^2 - 3\alpha^2 P^2)\right\} \cos\left\{2\pi\left(\frac{f_s}{2} - 3f_{in}\right) n\mathrm{T_s}\right\}$$

$$+ \cdots$$

$$\left\{\frac{1}{4} b_3 \mathrm{R}(R^2 - 3\alpha^2 P^2)\right\} = -\frac{3\sqrt{3}}{32} b_3 A^2 \left(a_1 A + \frac{3}{4} a_3 A^3\right)(\alpha^2 - 1)$$

Coefficient of $\cos\left(2\pi\left(\frac{\mathrm{f_s}}{2} - 3\mathrm{f_{in}}\right)\mathrm{nT_s}\right)$

Coefficient of HD3

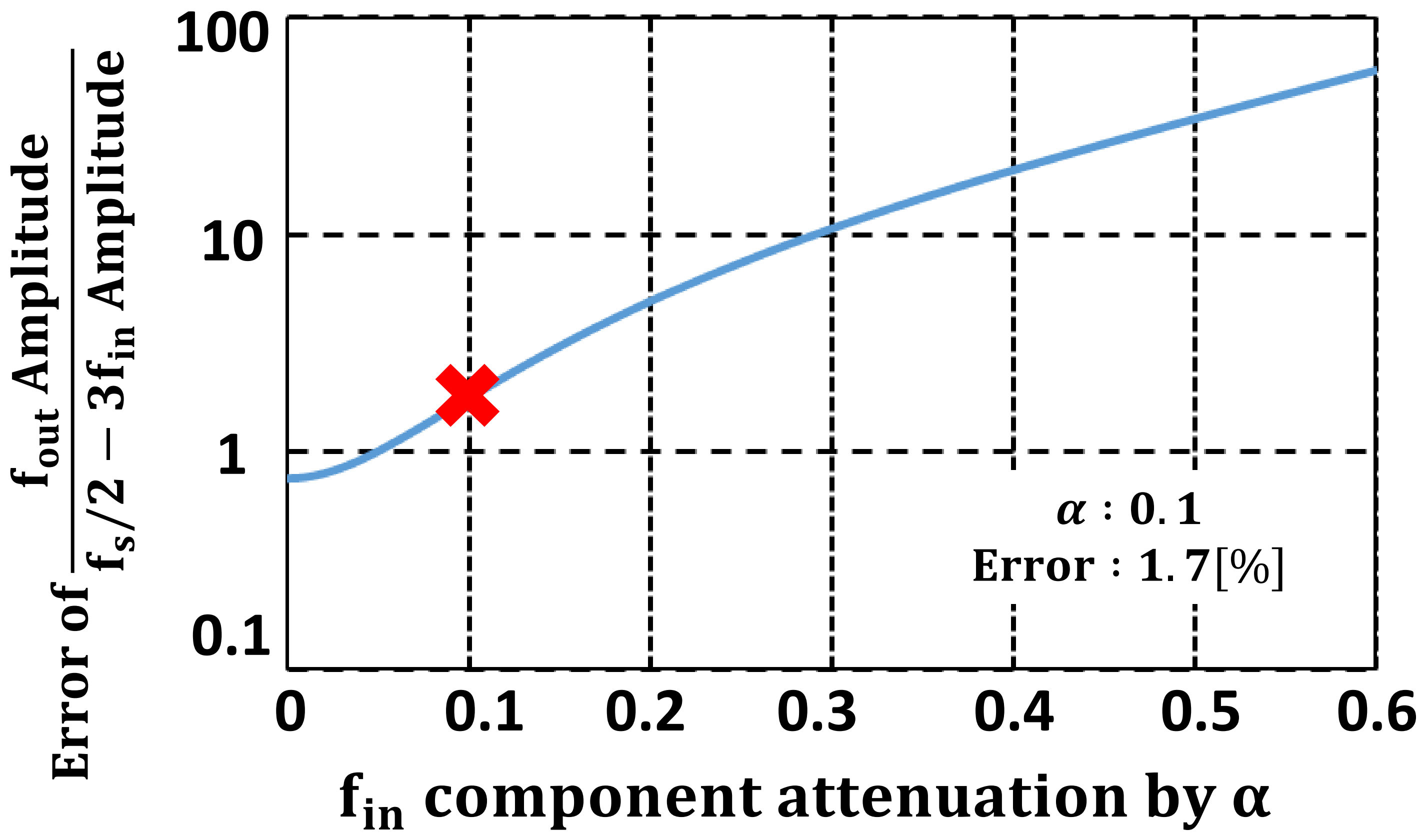


Coefficient of ADC HD3

$$= -\frac{3\sqrt{3}}{32} b_3 A^2 \left(a_1 A + \frac{3}{4} a_3 A^3 \right) (\alpha^2 - 1)$$

- When filter $\alpha = 1$, ⇨ ADC HD3 Cancelled
- When filter $\alpha \neq 1$, ⇨ Accurate measurement of ADC HD3

Attenuation Effect of HPF



Attenuation by a factor of 1/10 with HPF is easy

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Conclusion

- We have proposed high-frequency low-distortion signal generation algorithm with AWG.
- Needs only a simple analog HPF.
- No need for AWG nonlinearity identification
- Simulation shows that measurement error of ADC HD3 is as low as 1.7%.

Thank you for your kind attention!

度量衡　統一　by 始皇帝

Accurate measurement has been very important from thousands years ago.


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