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Algorithms for Generating Low-Distortion Single-Tone and Two-Tone Sinewaves Using an Arbitrary Waveform Generator

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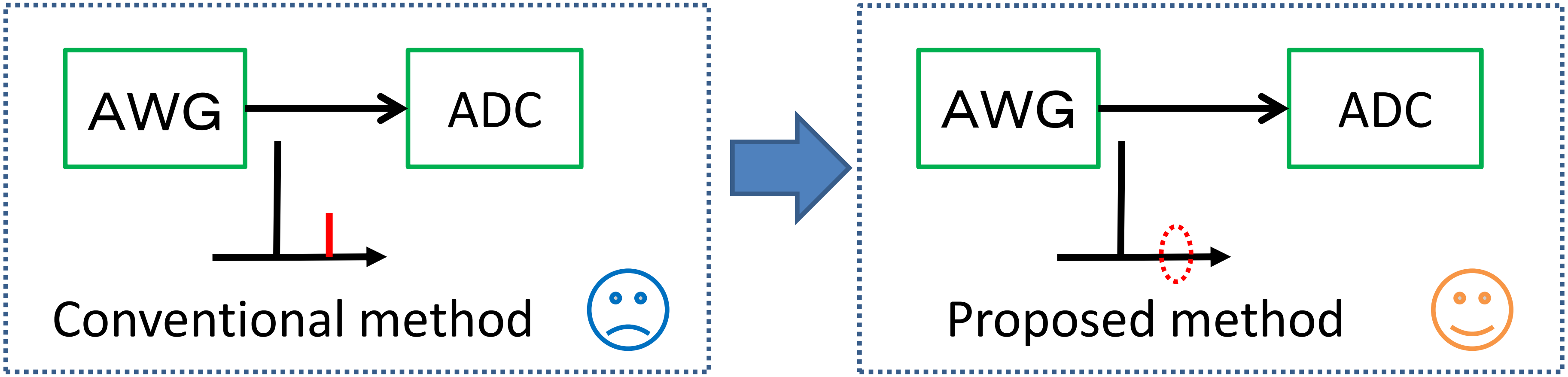
Research Goal

Generating low-distortion sinewaves
for ADC linearity testing
using low-cost AWG



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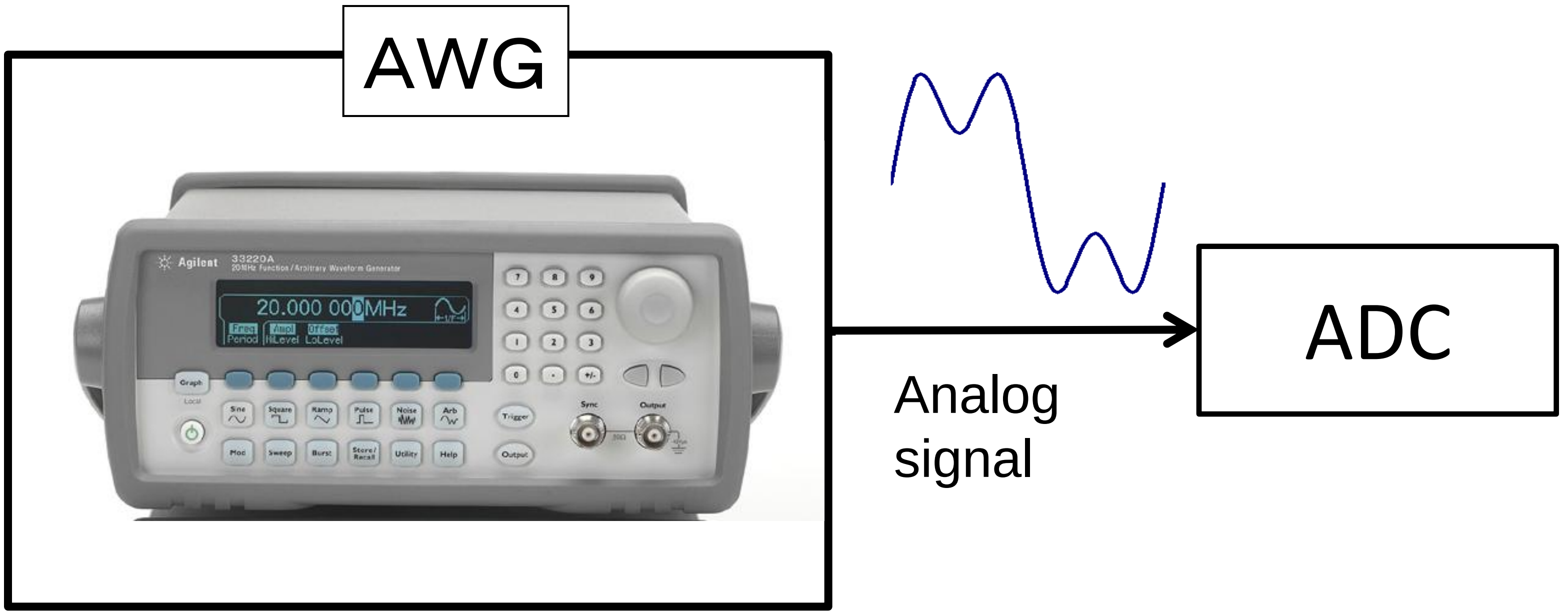
Signal Generation with AWG

AWG（Arbitrary Waveform Generator）= DSP + DAC



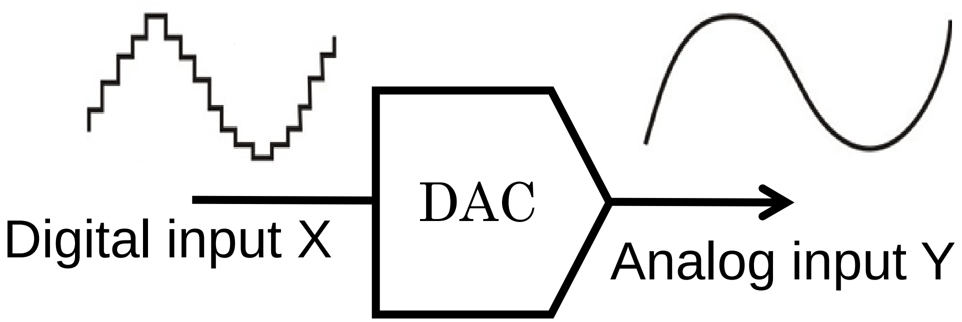
DSP generates digital signal. ➡ DAC converts it to analog signal.

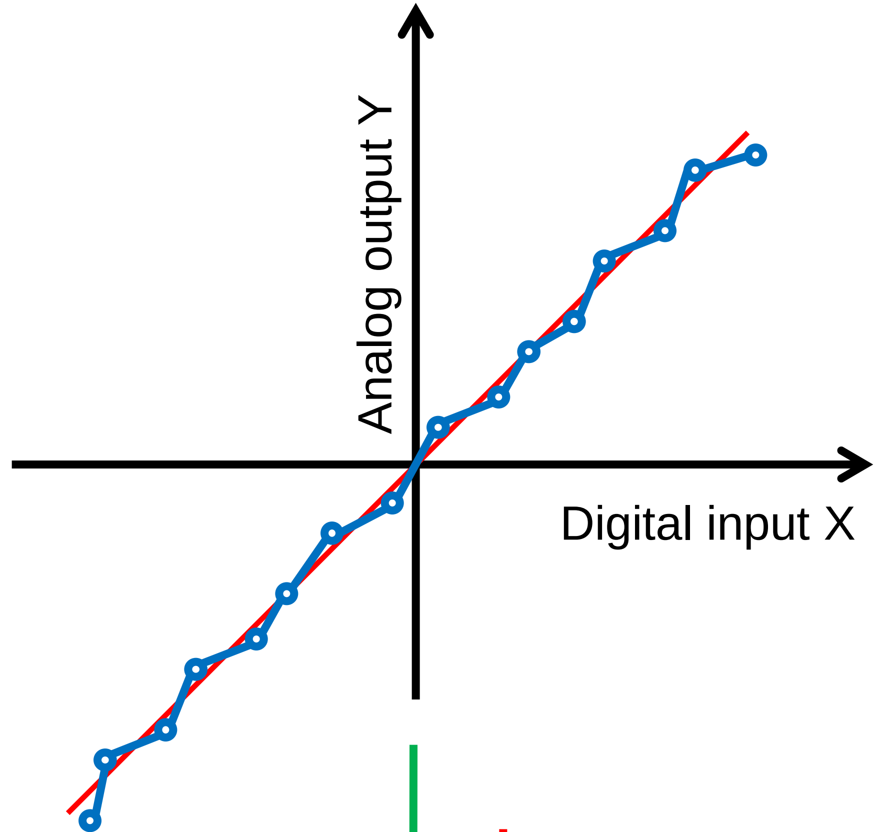
Single-tone and two-tone analog signals for ADC testing

⬇

DAC has nonlinearity

Spurious Components due to DAC Nonlinearity

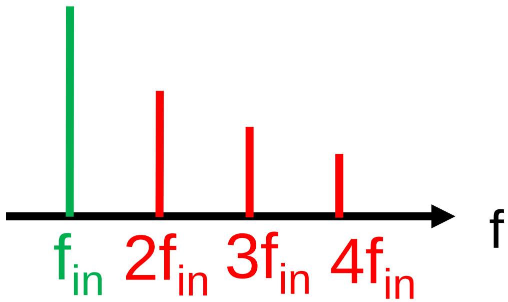




Ideal DAC output $Y=a_1X$

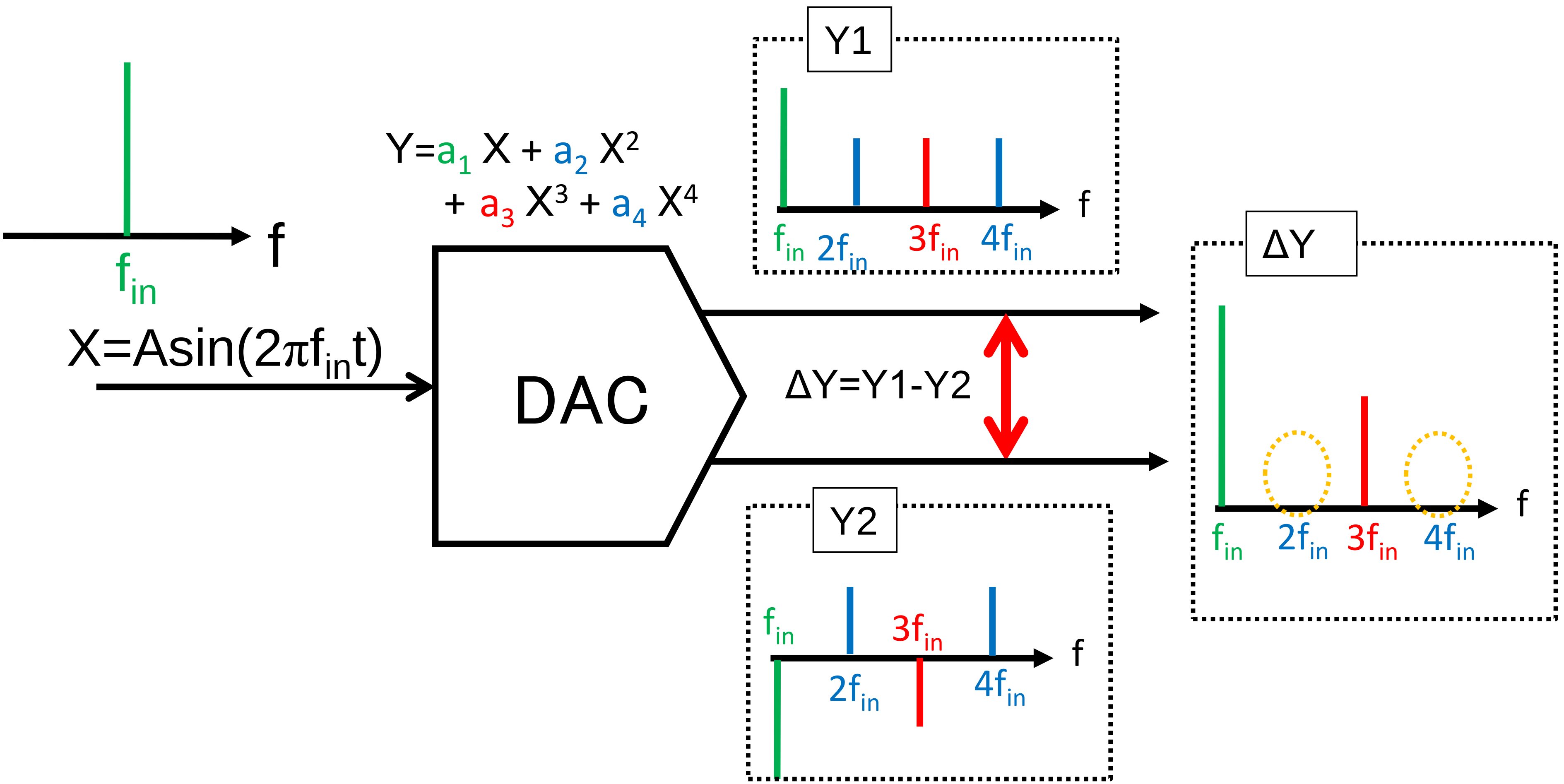
Actual DAC output $Y=a_1X + a_2X^2 + a_3X^3 + a_4X^4 \cdots$

HD2 HD3 HD4



DAC Nonlinearity → Spurious components

Use Differential Signals to Cancel Even Harmonics



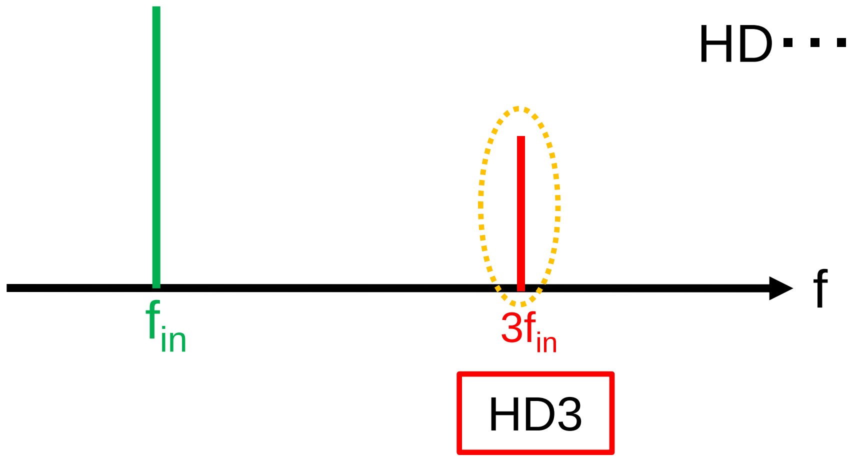
Use differential signals to cancel even harmonics.

Next focus on removing third-order harmonics

Third-order Nonlinearity Distortion Components

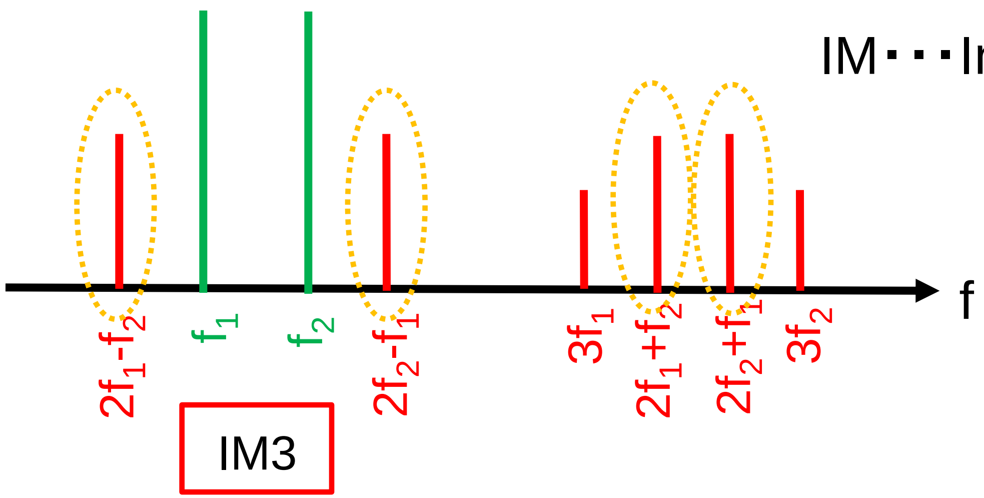
Single-tone input

HD・・・Harmonic Distortion



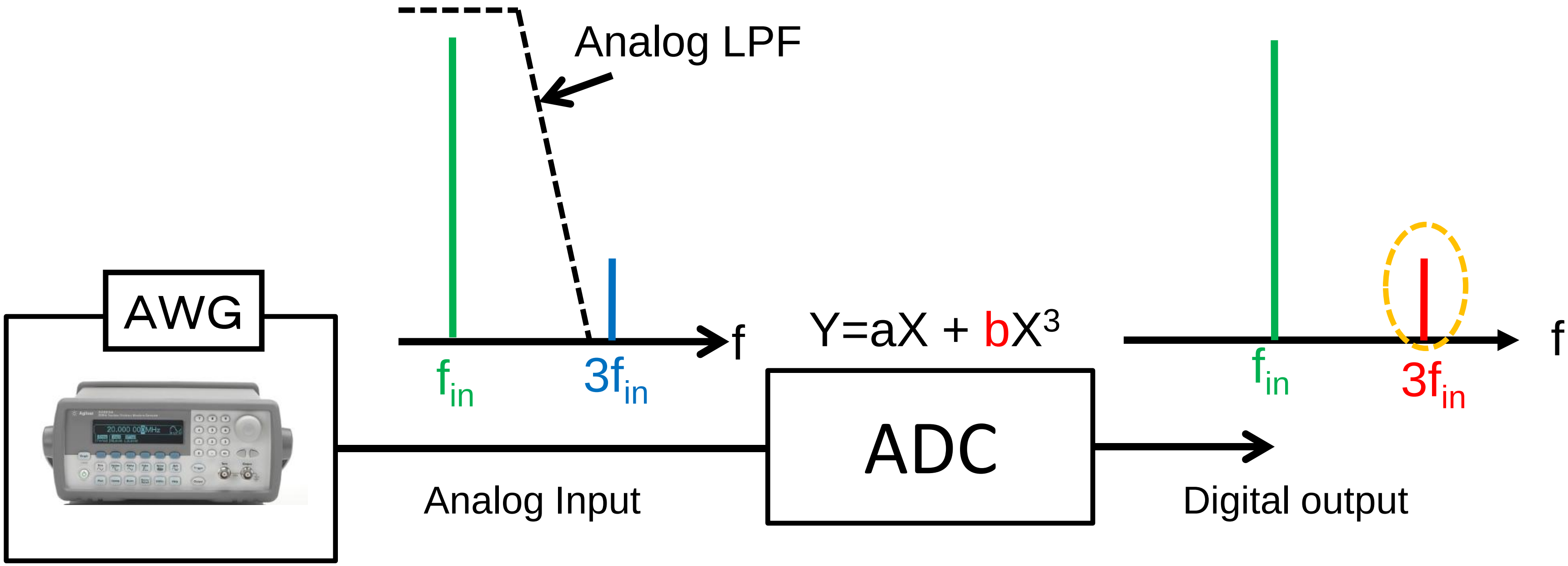
Two-tone input

IM・・・Intermodulation



IM3 components are difficult to remove with analog filter

ADC Linearity Test (Single-tone Input)



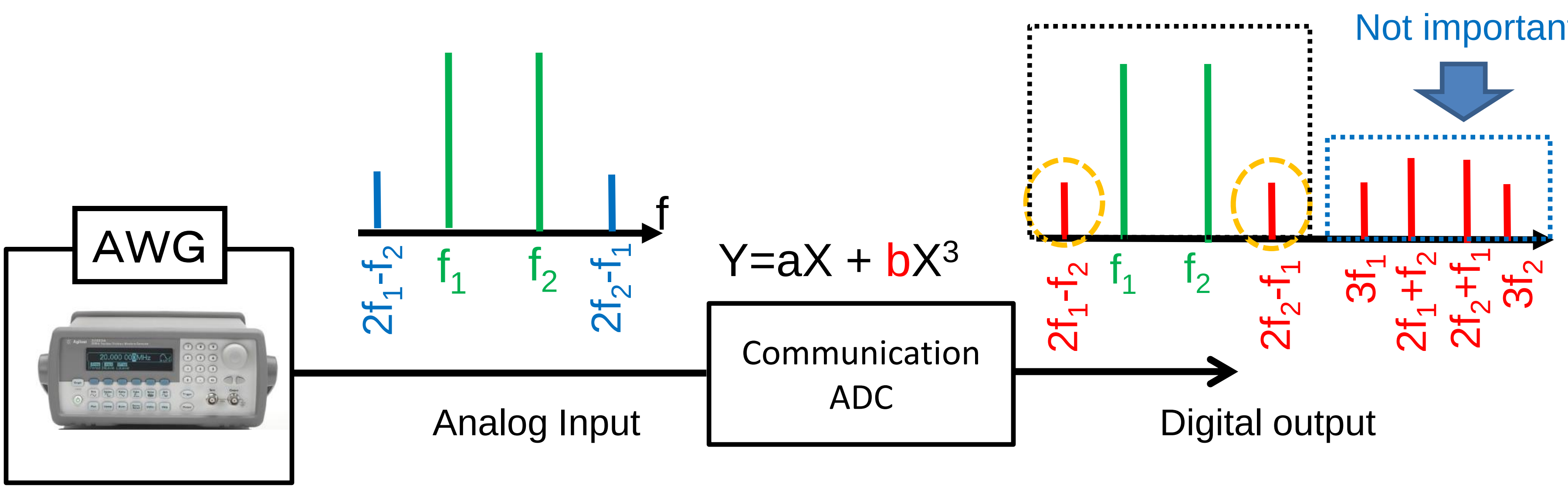
Proposed method relaxes requirements for analog LPF

Use simple analog LPF to remove HD3 (& higher harmonics)

ADC distortion can be measured & tested accurately.

Communication Application ADC Test (Two-tone Input)

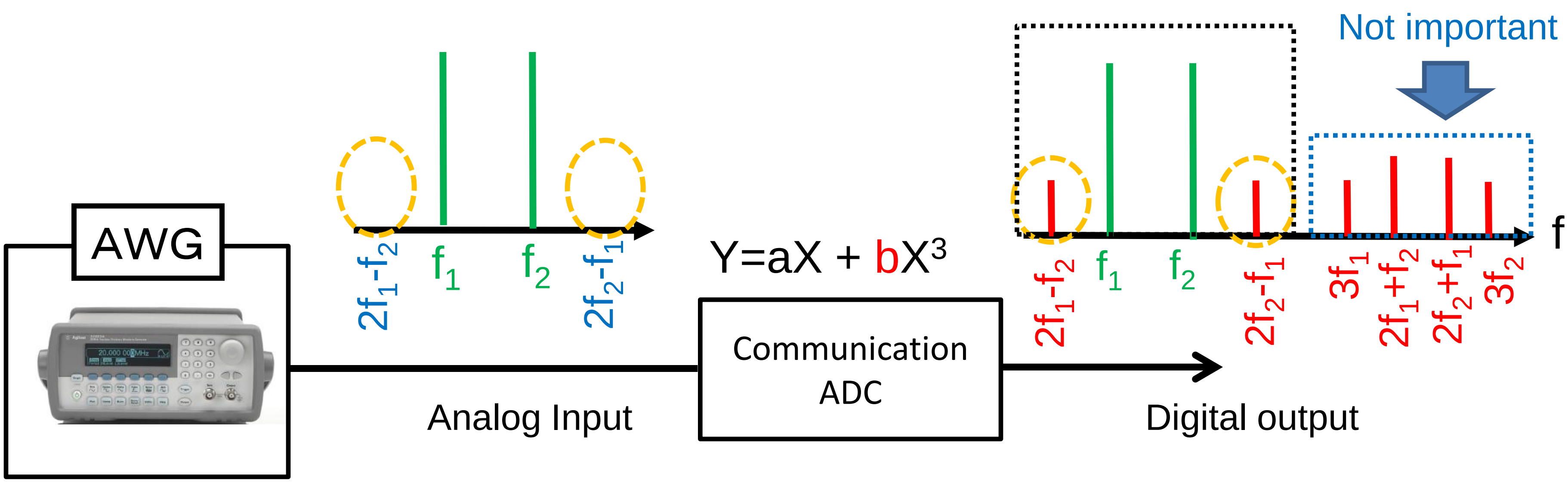
Communication ⇒ Narrow band, high frequency



IM3 ($2f_1$-f_2,$2f_2$-f_2) components in input signal are

- within signal band
- difficult to remove by analog BPF.

Communication ⇒Narrow band, high frequency



Use proposed method to cancel IM3 in analog input.

ADC distortion (IM3) can be measured & tested accurately.

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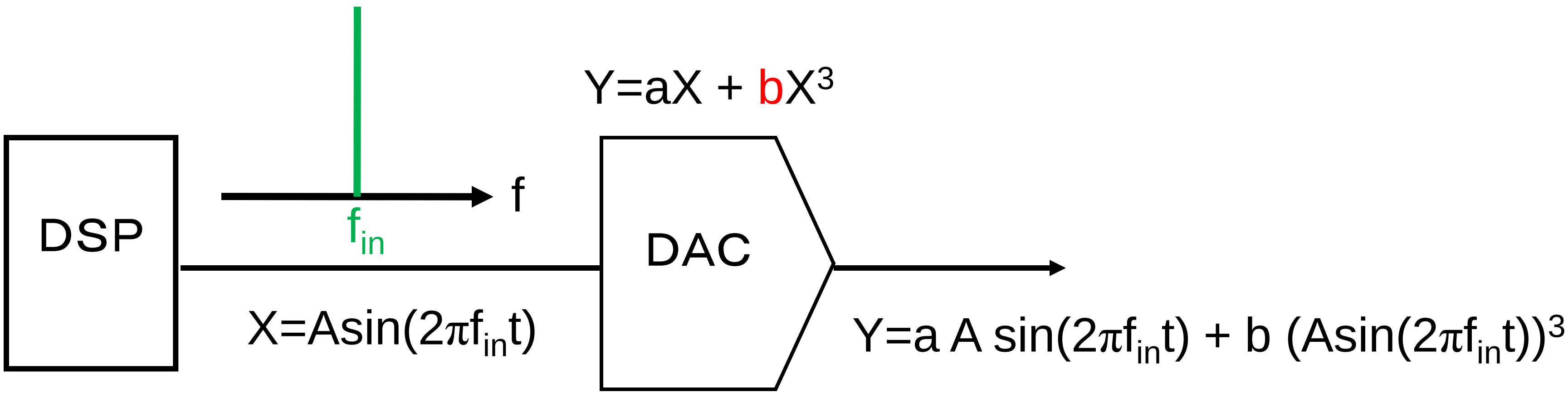
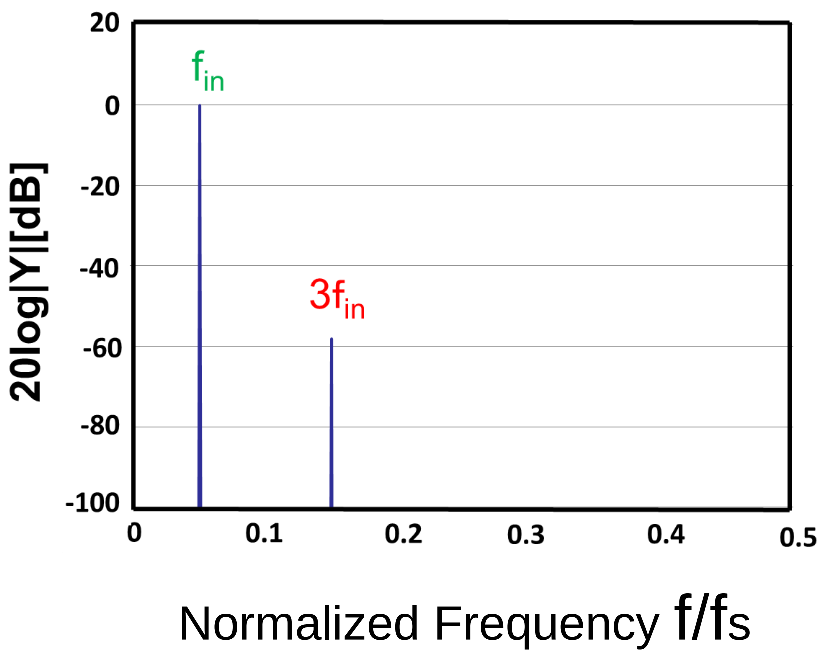
- Research Goal
- ADC Linearity Test
- <u>Conventional Test Method</u>
- Proposed Test Method
- Experimental Results
- Conclusions

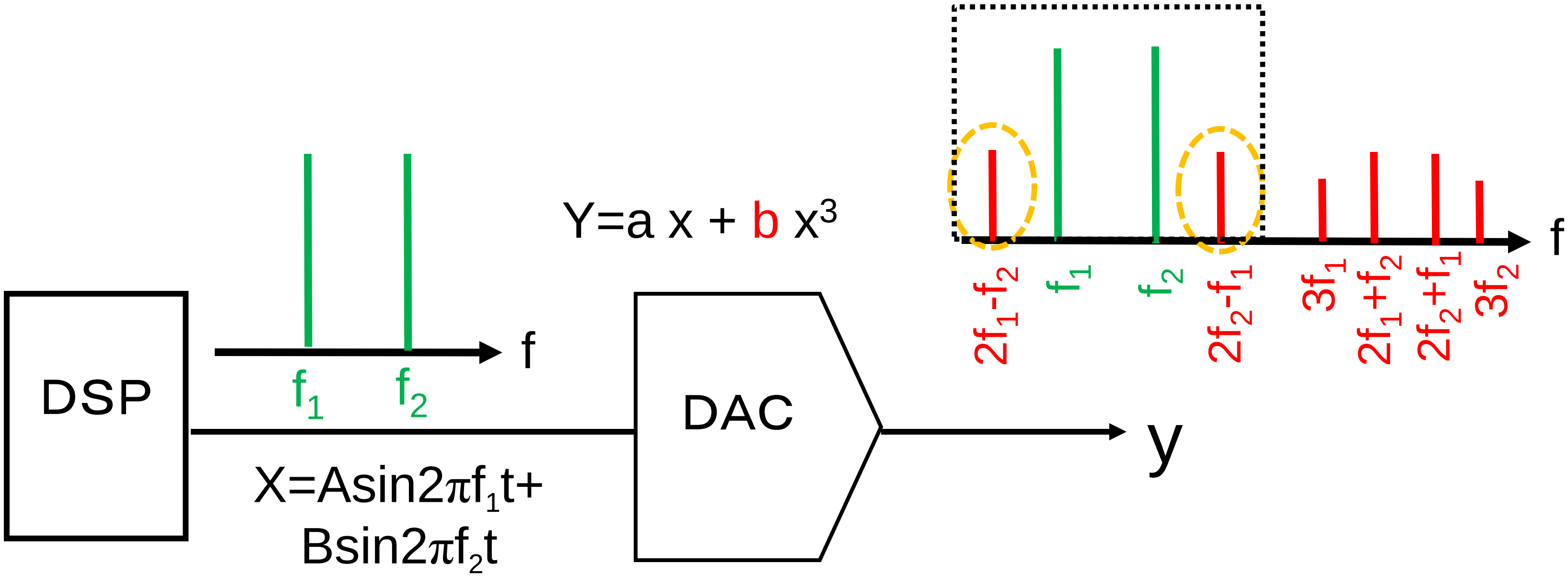
Conventional Single-tone Generation



- HD3 appears



Conventional Two-tone Generation



■IM3 appears

Contents

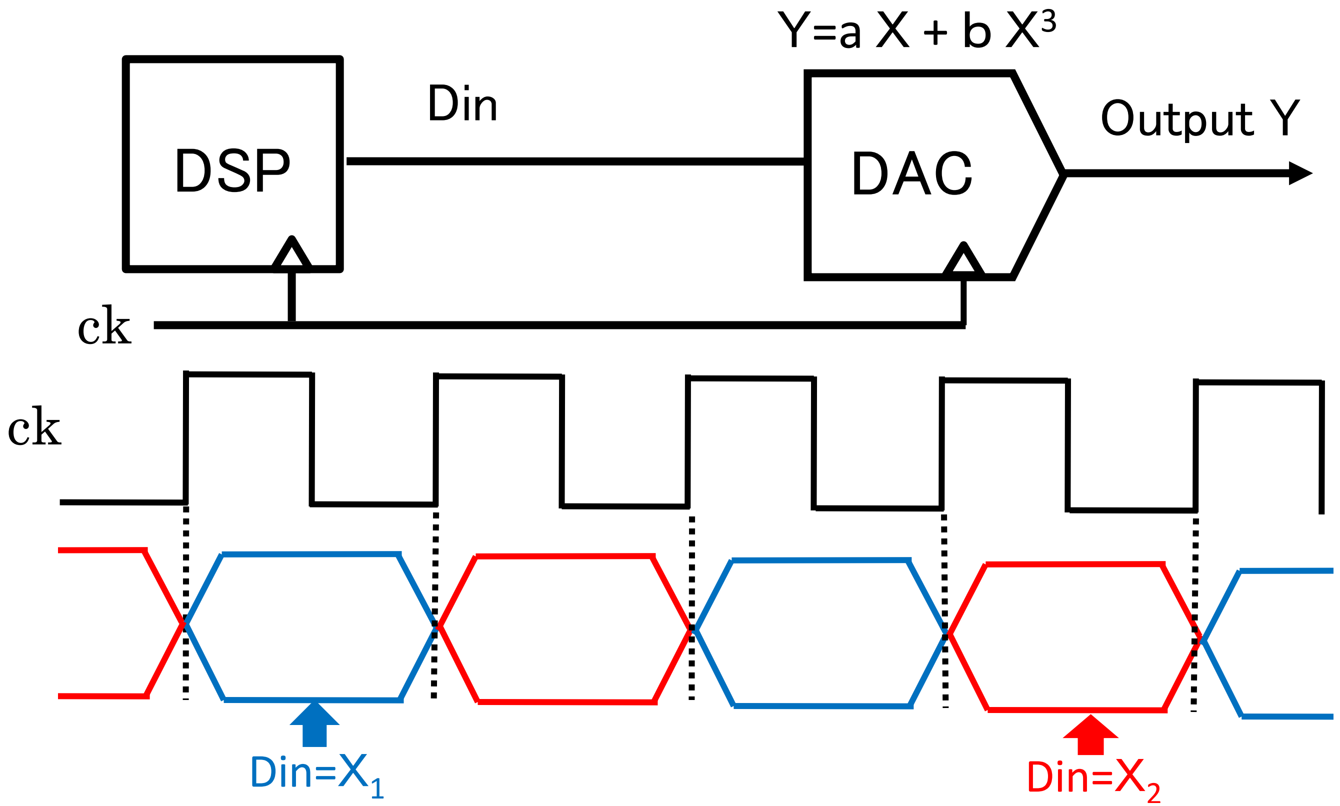
- Proposed Test Method

  - Single-tone Generation

  - Two-tone Generation

  - Algorithm Generalization

Proposed Method



Interleave X_1、X_2 by one clock and generate Din

Feed Din to DAC

Cancel distortion components of output Y

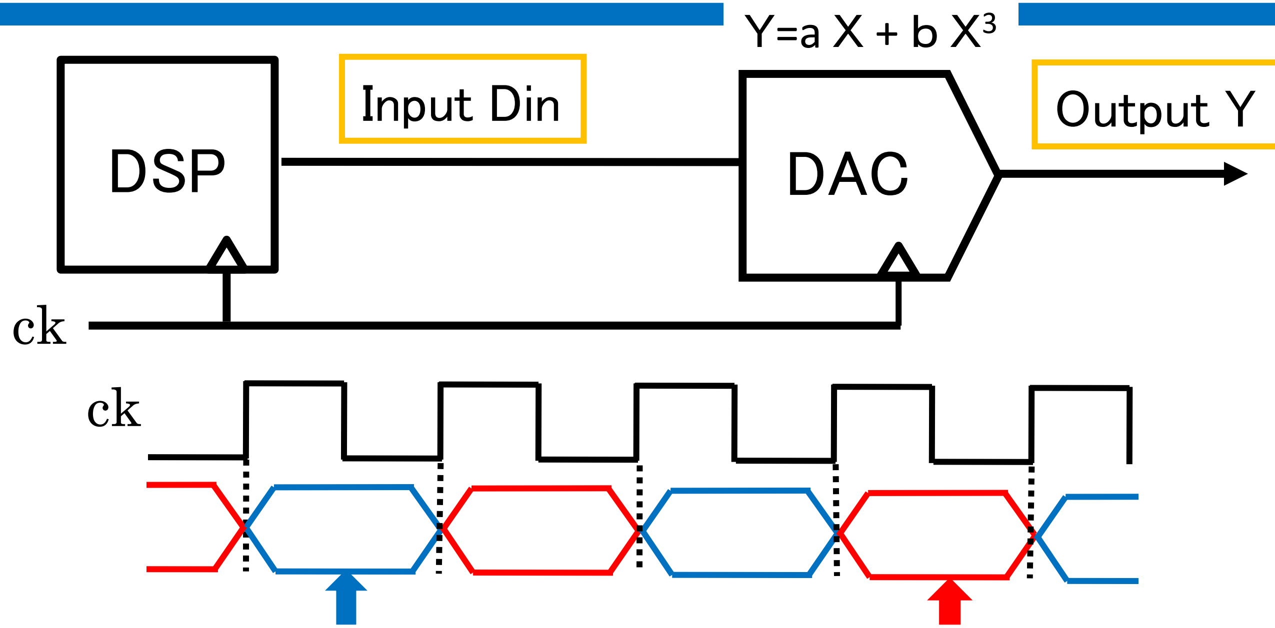
- ✓ Requires only DSP program change
- ✓ Spurious components are far from signal band

Contents

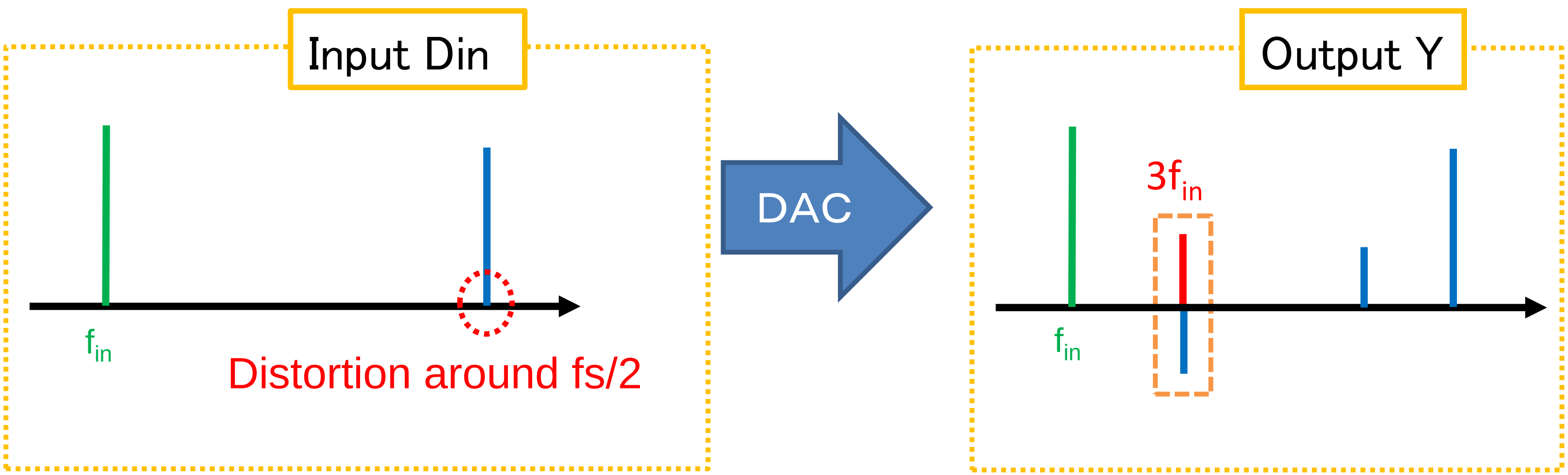
- Proposed Test Method

  - Single-tone Generation
  - Two-tone Generation
  - Algorithm Generalization

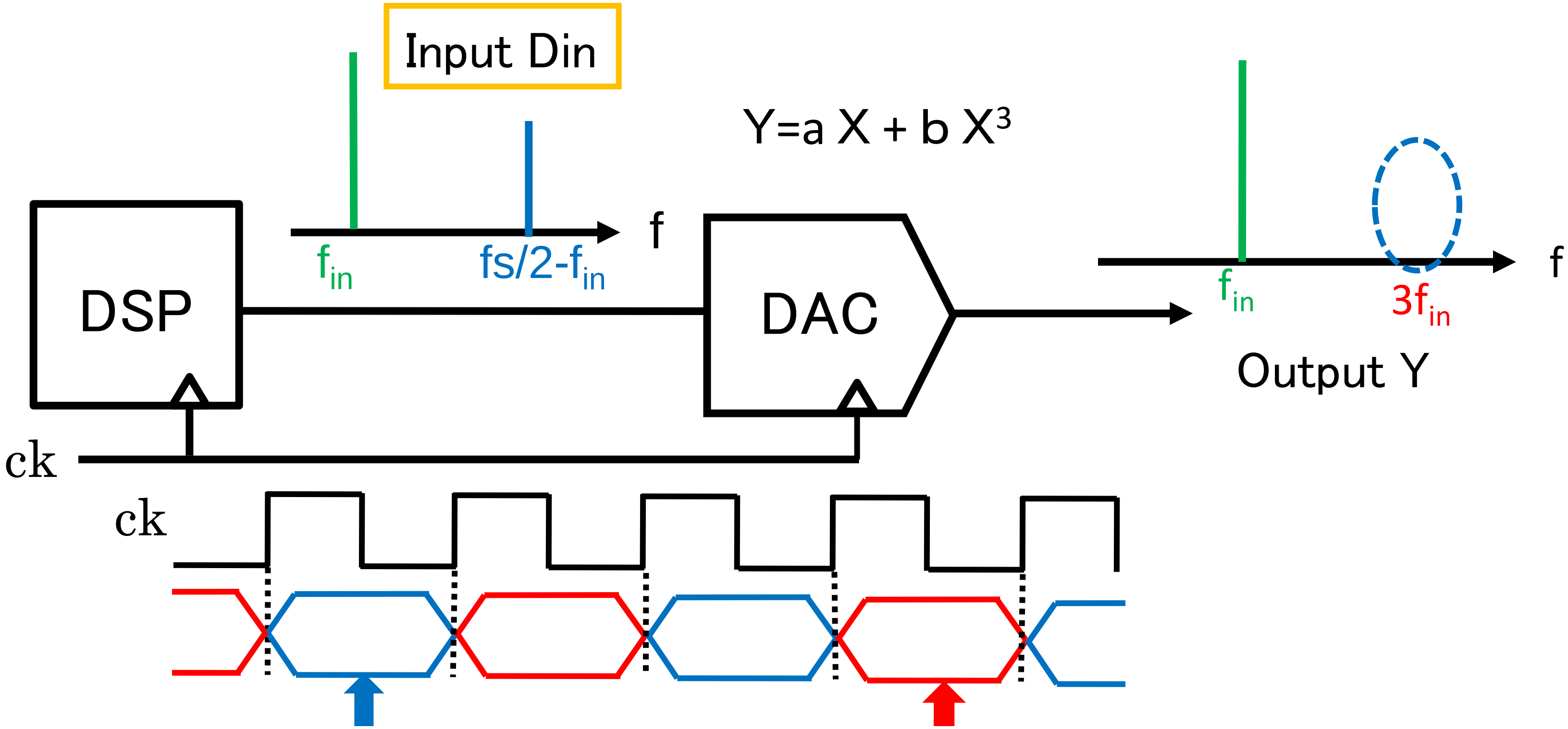
Principle of Proposed Method



Din=Asin($2\pi f_{in}t + \pi/6$)   Din=Asin($2\pi f_{in}t - \pi/6$)



Proposed Method (Single-tone)

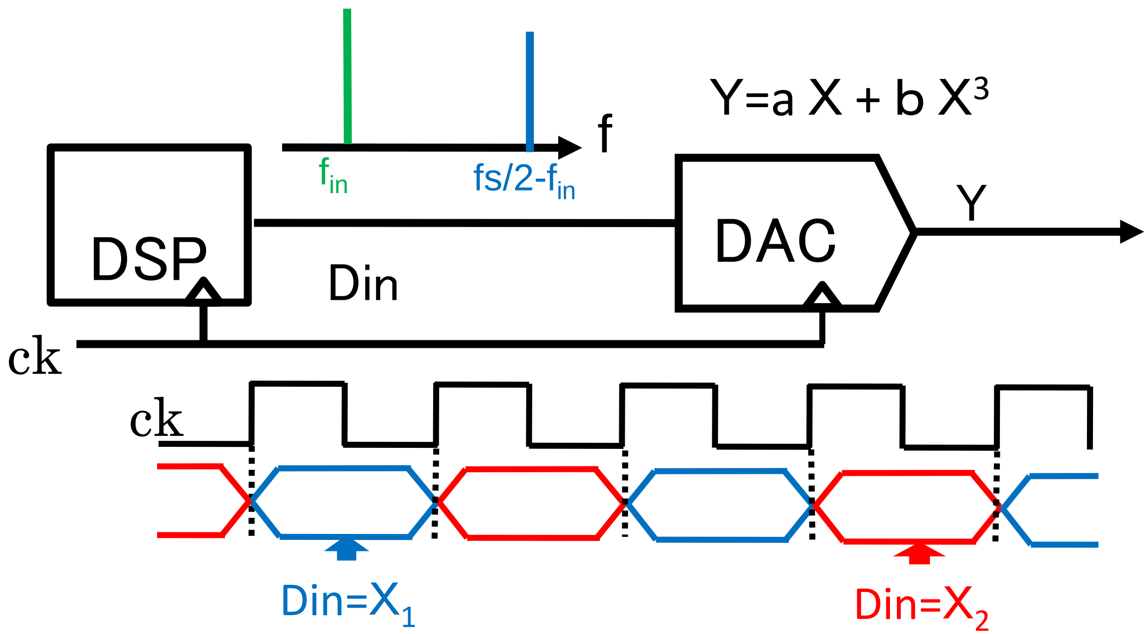


$Din = A\sin(2\pi f_{in} t + \pi/6)$ $Din = A\sin(2\pi f_{in} t - \pi/6)$

$Din = 0.87A\sin 2\pi f_{in} t + 0.5A\cos 2\pi(1/2fs - f_{in})t$

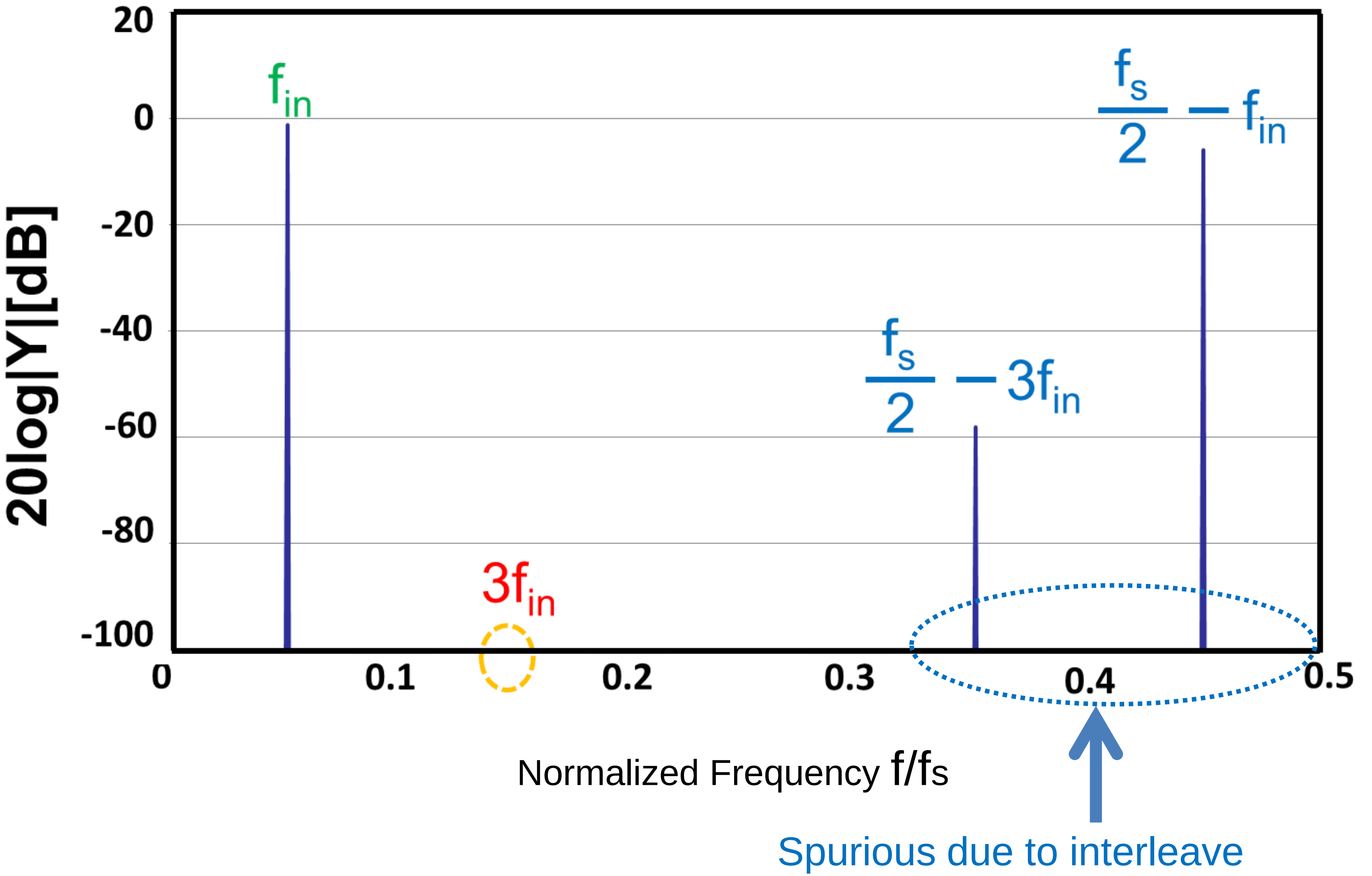
Fundamental f_{in} power reduction by 1.25dB

Simulation Condition (Single tone)



Input signal X1	$\sin(2\pi f_{in}t+\pi/6)$
Input signal X2	$\sin(2\pi f_{in}t-\pi/6)$
1^{st} coeff. a(DAC)	1.0
3^{rd} coeff. b(DAC)	-0.005
Input freq. fin	51
Sampling freq. fs	1024

Output Power Spectrum（Single-tone Input）



Contents

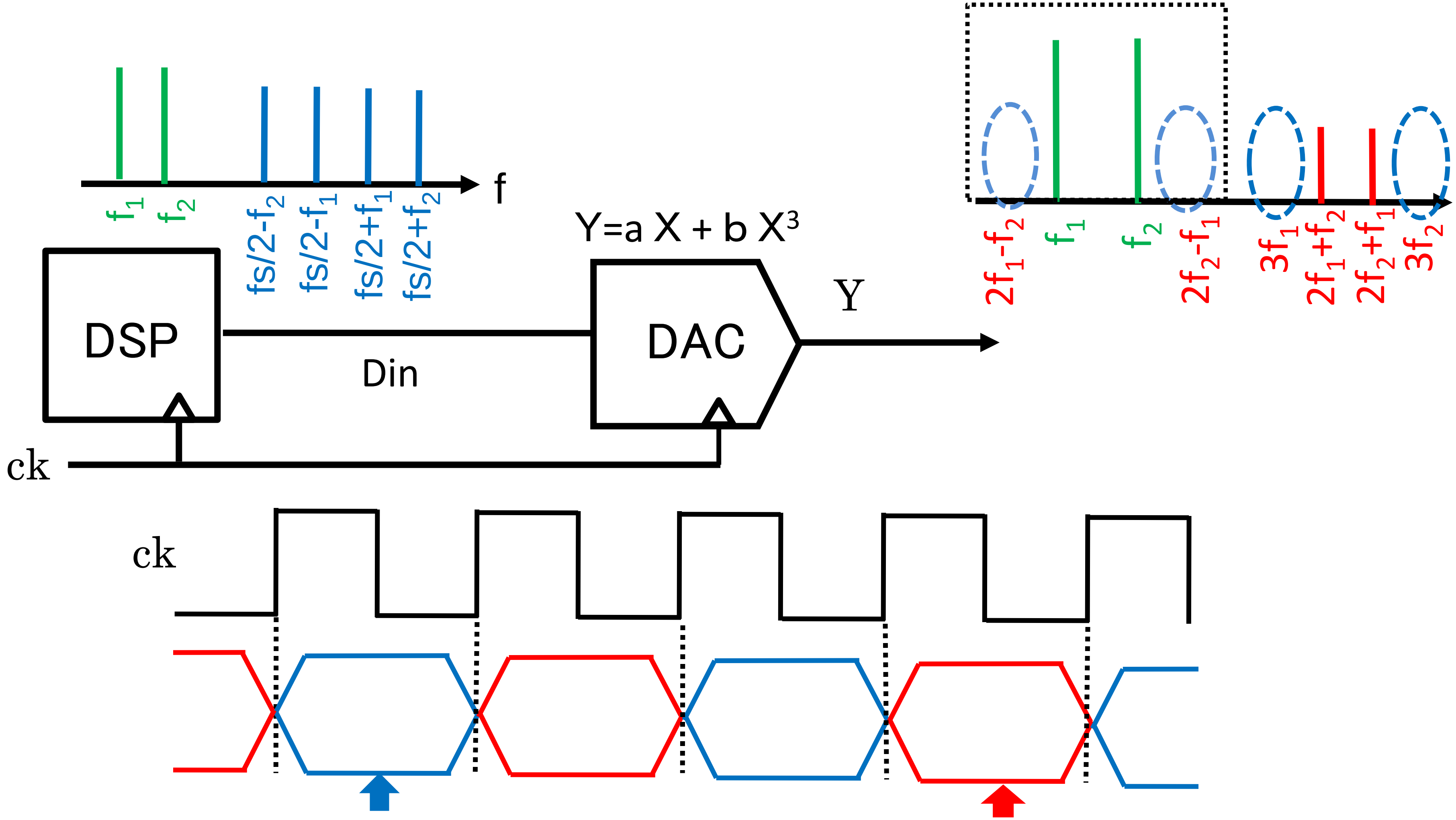
- Proposed Test Method

  - Single-tone Generation

  - Two-tone Generation

  - Algorithm Generalization

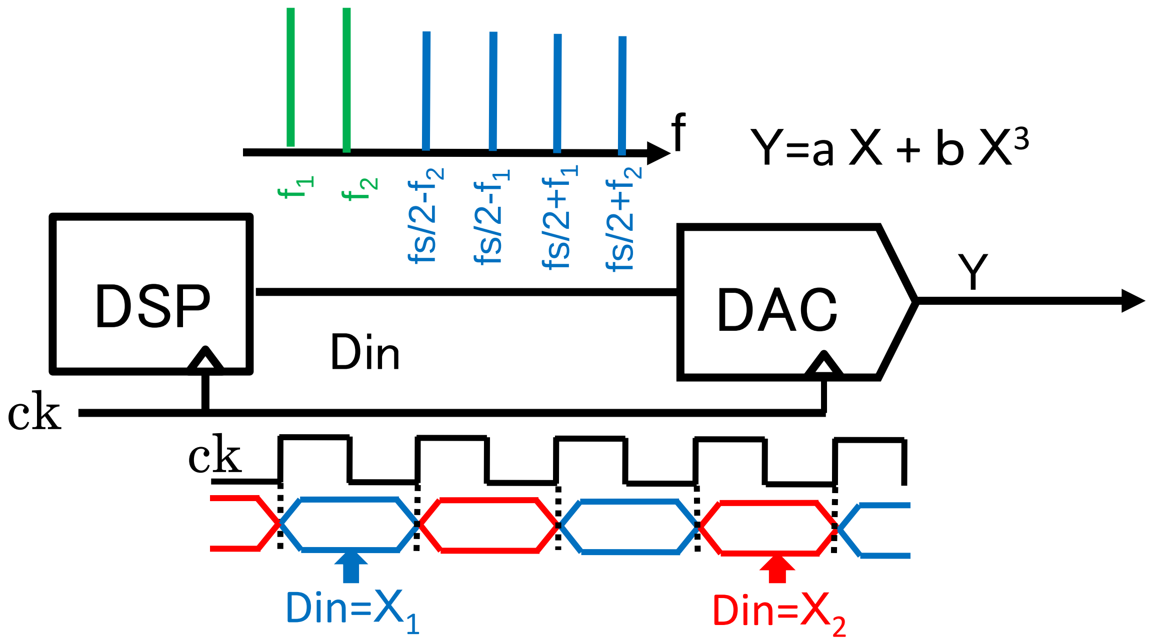
Proposed Method (Two-tone signal)



$Din = A\sin(2\pi f_1 t + \pi/6)$
$\quad + B\sin(2\pi f_2 t - \pi/6)$

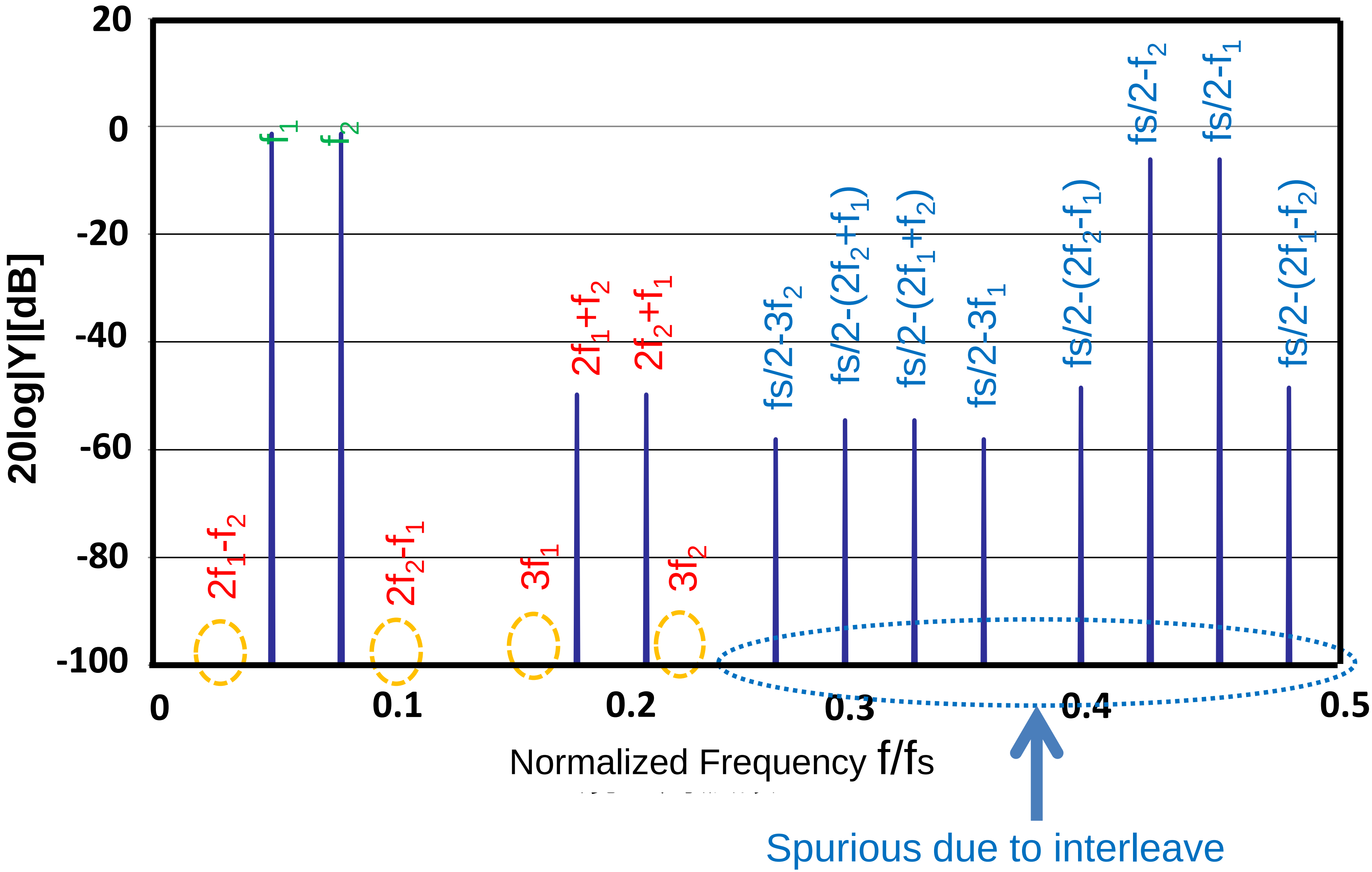
$Din = A\sin(2\pi f_1 t - \pi/6)$
$\quad + B\sin(2\pi f_2 t + \pi/6)$

Simulation Condition (Two tone)



Input signal X1	$\sin(2\pi f_1 t+\pi/6)+\sin(2\pi f_2 t-\pi/6)$
Input signal X2	$\sin(2\pi f_1 t-\pi/6)+ \sin(2\pi f_2 t+\pi/6)$
1st coeff. a(DAC)	1
3rd coeff. b(DAC)	-0.005
Input freq. f1	51
Input freq. f2	81
Sampling freq. fs	1024

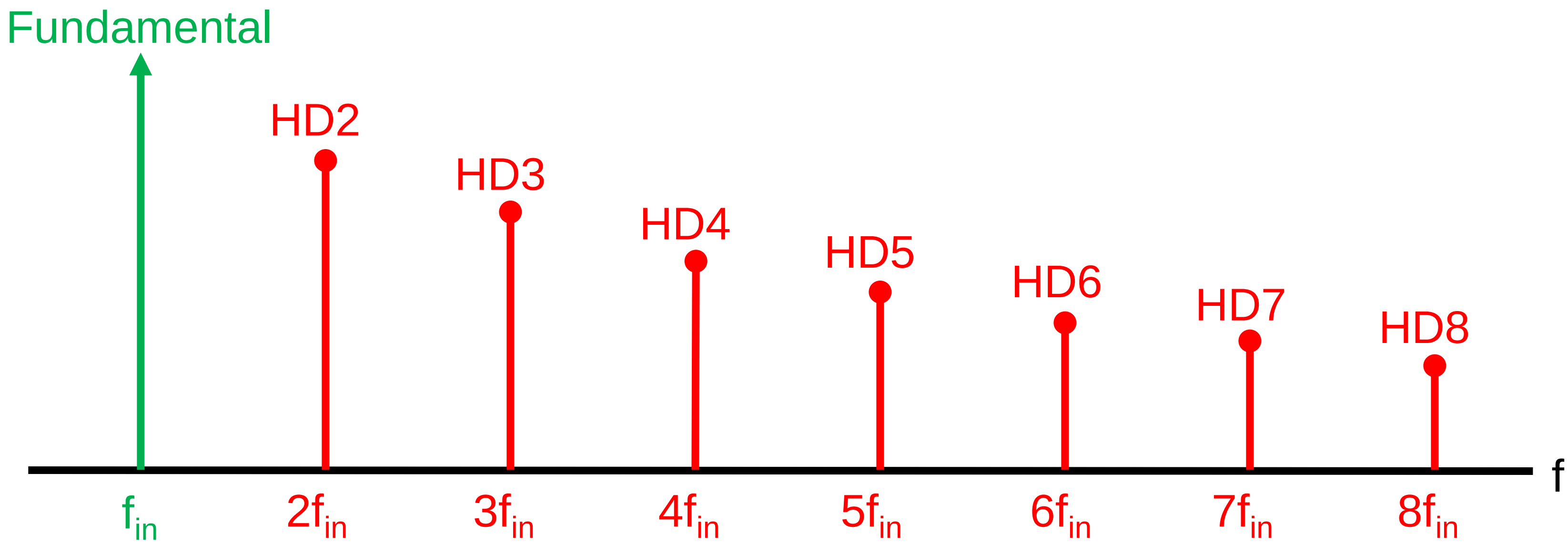
Output Power Spectrum（Two-tone Input）



Contents

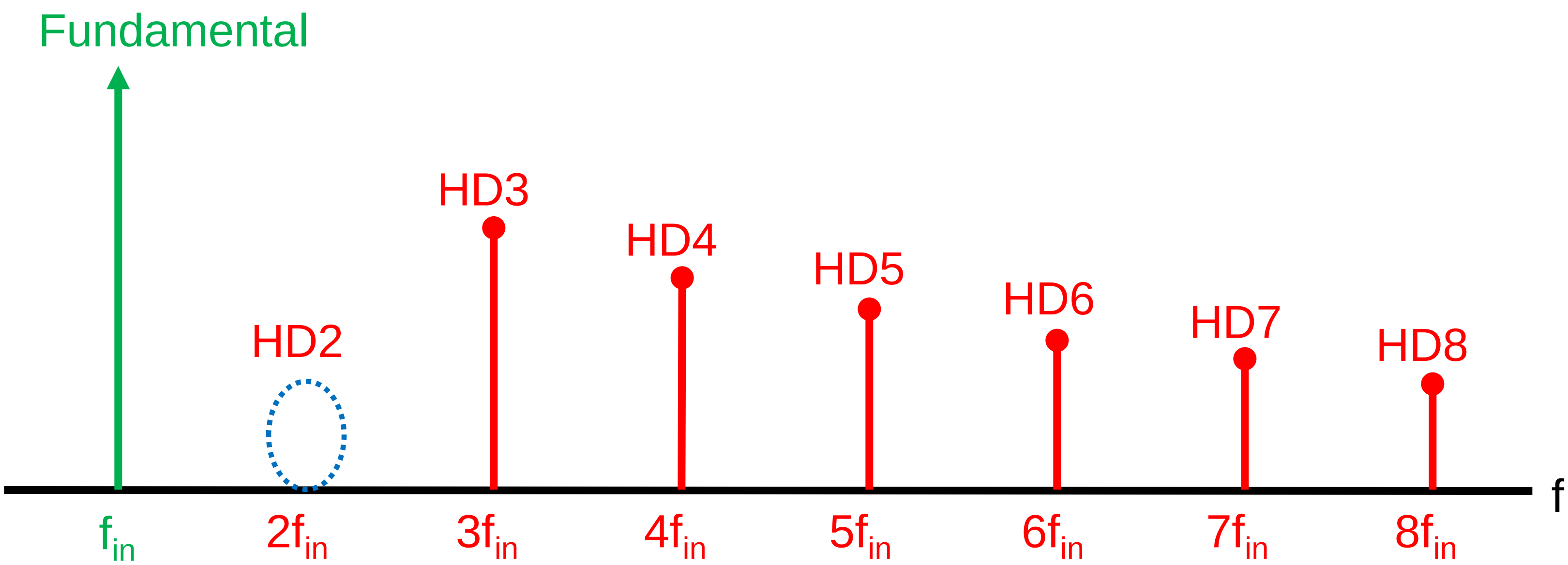
- Proposed Test Method
  - Single-tone Generation
  - Two-tone Generation
  - Algorithm Generalization

Algorithm Generalization



① HD2 cancellation
② HD2 & HD3 cancellation
③ HD3, HD5 & HD7 cancellation

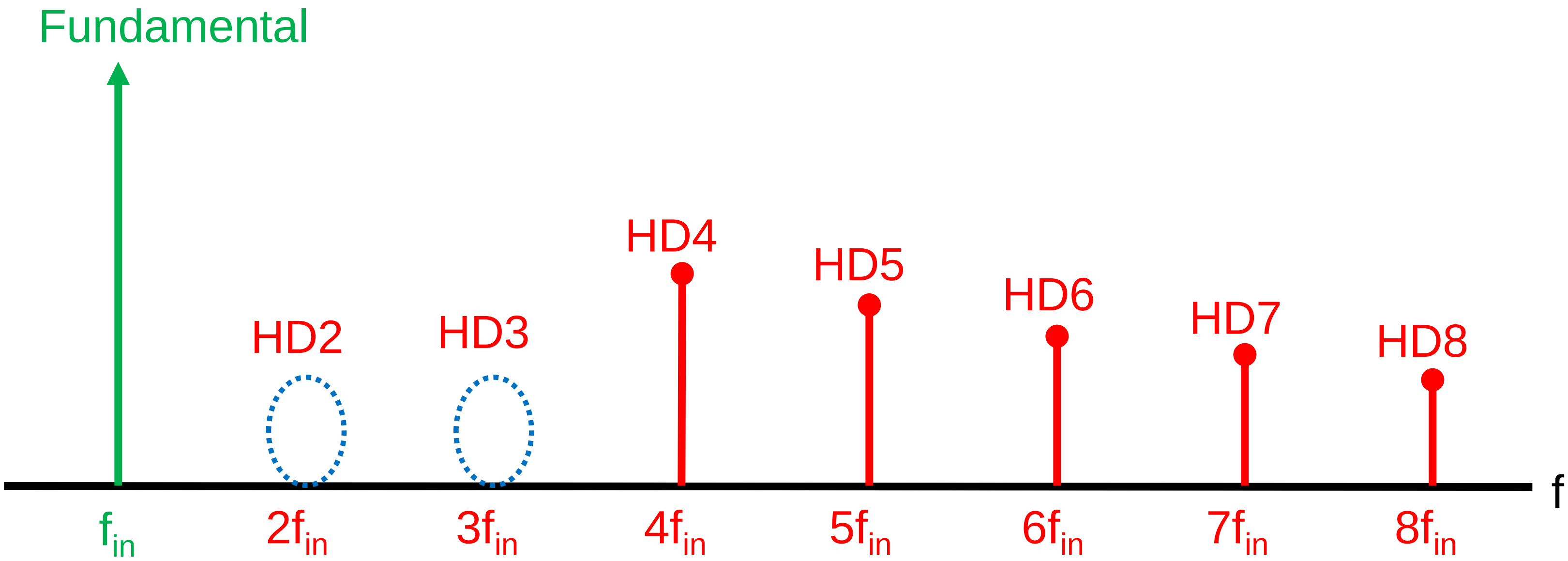
HD2 Cancellation



2-way interleave cancels HD2

$X1 = A\sin(2\pi f_{in} t + \pi/4)$ $X2 = A\sin(2\pi f_{in} t - \pi/4)$

HD2, HD3 Cancellation

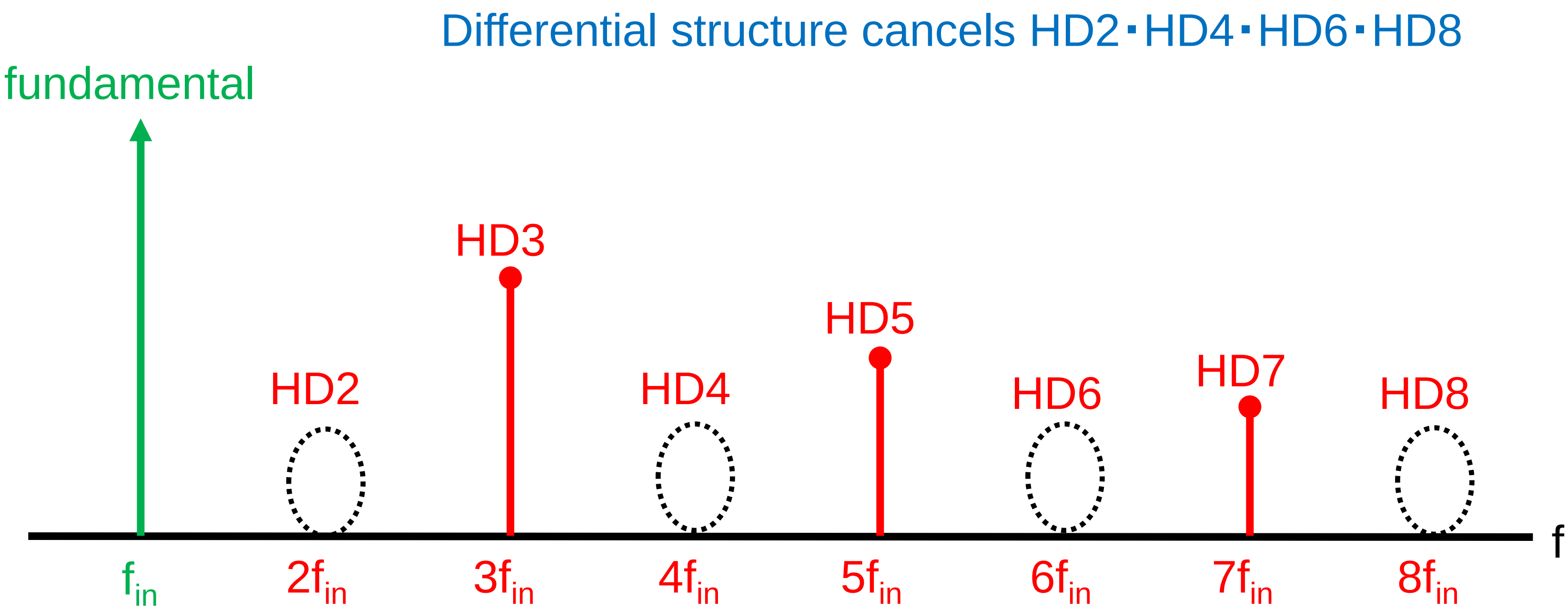


4-way interleave cancels HD2 & HD3

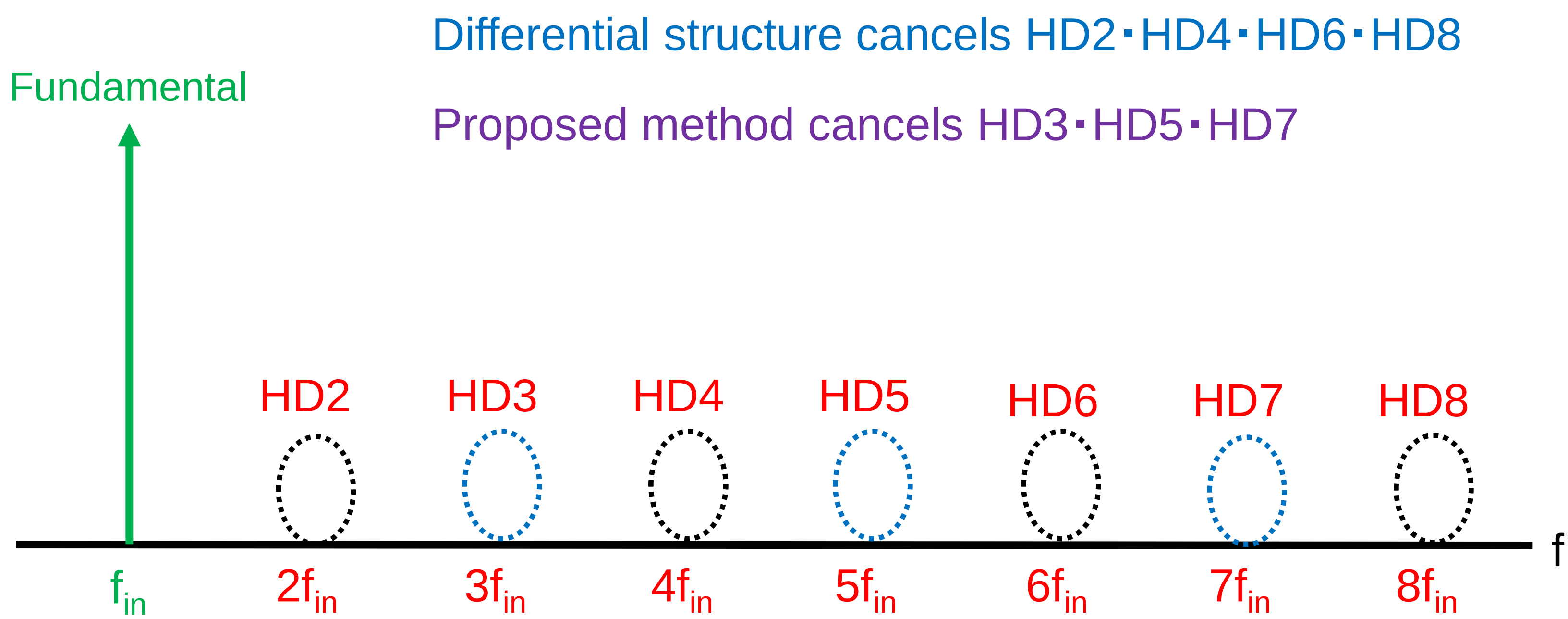
$X_1 = A\sin(2\pi f_{in} t - \pi/4 - \pi/6)$ $X_2 = A\sin(2\pi f_{in} t - \pi/4 + \pi/6)$

$X_3 = A\sin(2\pi f_{in} t + \pi/4 - \pi/6)$ $X_4 = A\sin(2\pi f_{in} t + \pi/4 + \pi/6)$

Even Harmonic Cancellation



HD3, HD5, HD7 cancellation



8-interleave cancels HD3, HD5 & HD7

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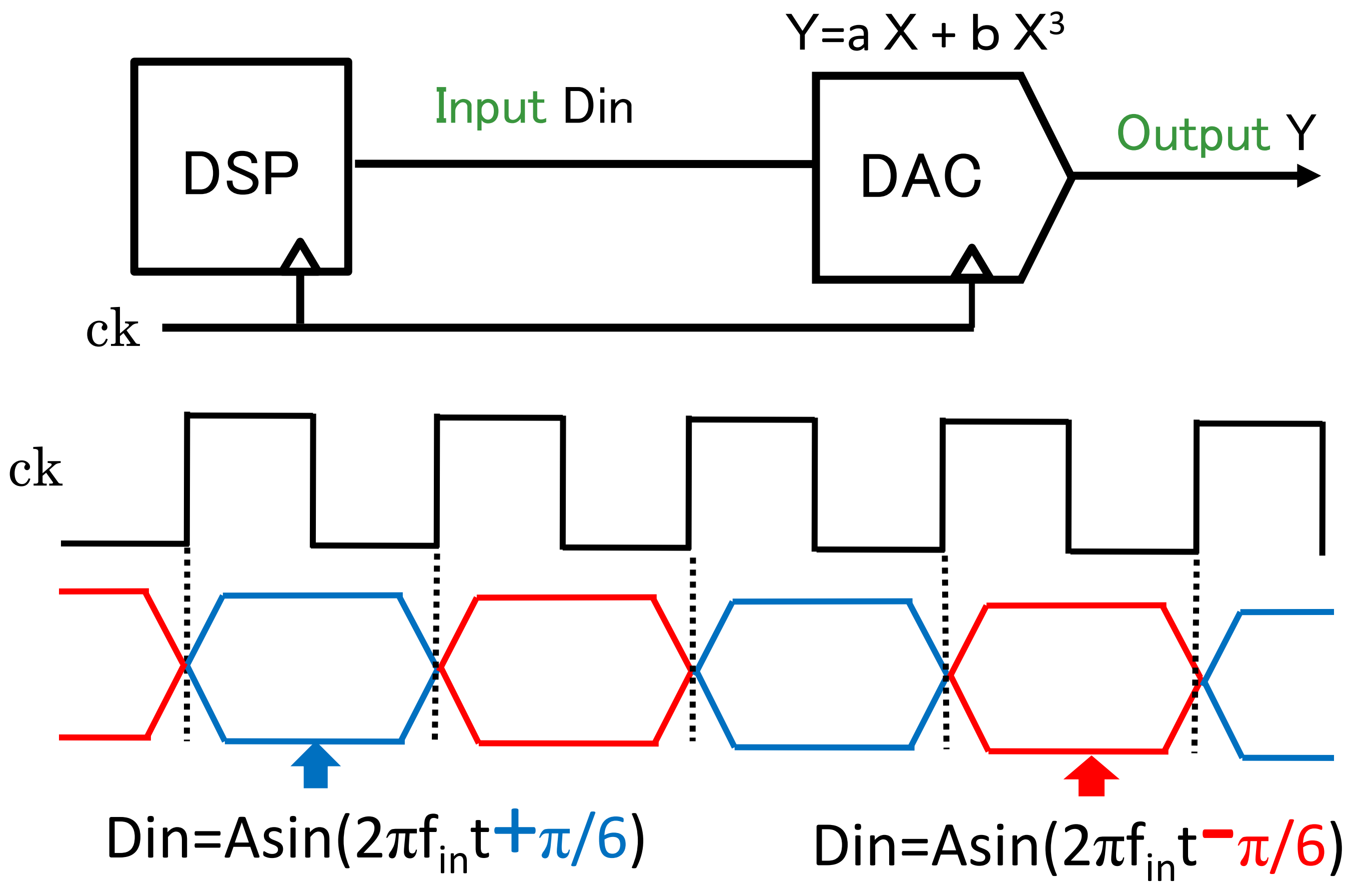
Experimental Verification

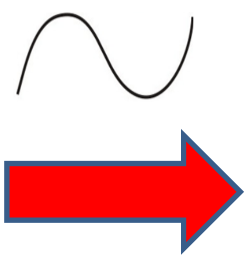


- Only DSP algorithm change in conventional AWG
- Single-tone generation with HD3 cancellation

Experiment Instrumentation

AWG
(Agilent 33120A)

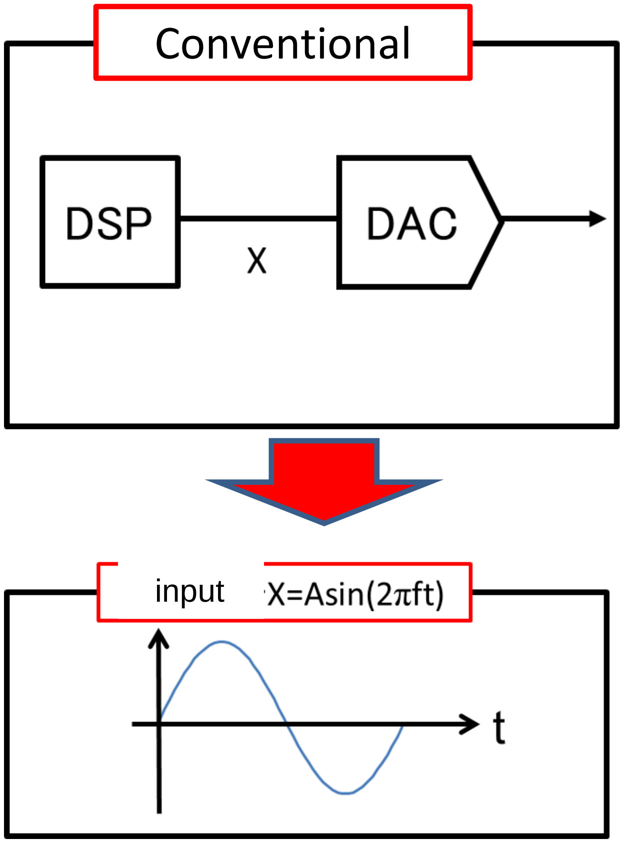
Max. Sampling frequency (Hz)	40M
Resolution (bit)	12
Linearity	△

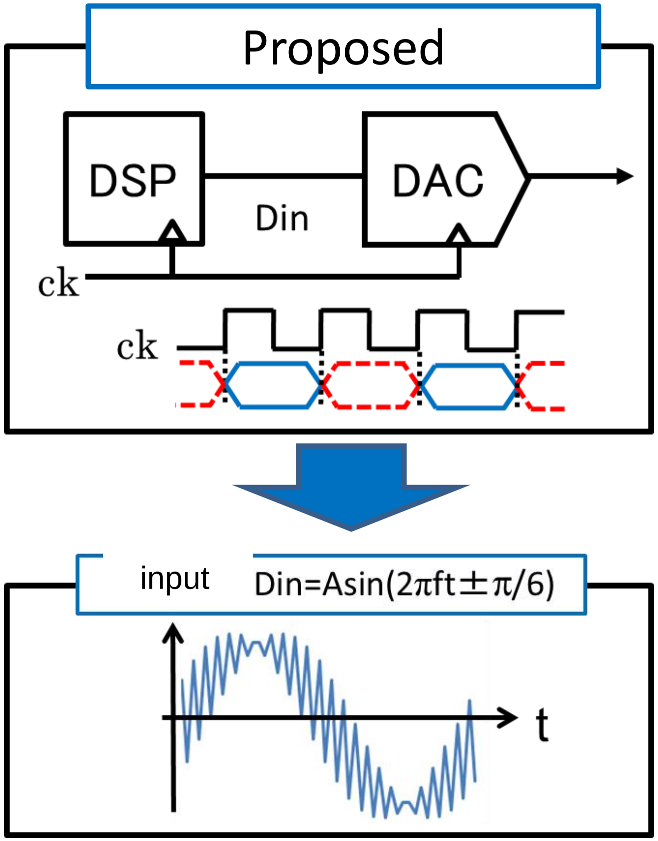


Spectrum Analyzer
(HP ESA-L1500A)

Frequency range (Hz)	9k～1.5G
Max amplitude (Vpp)	19.8

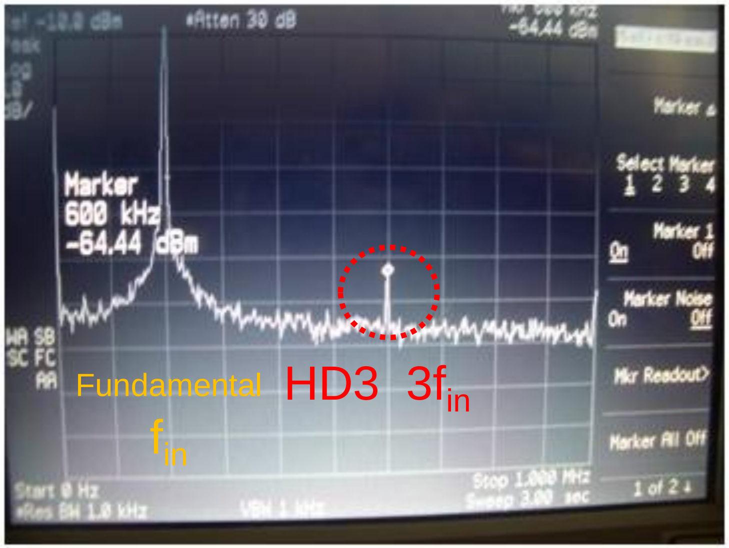
Experiment Condition





Experiment Results (fs= 10MHz, Input amplitude 1.3Vpp)

Conventional



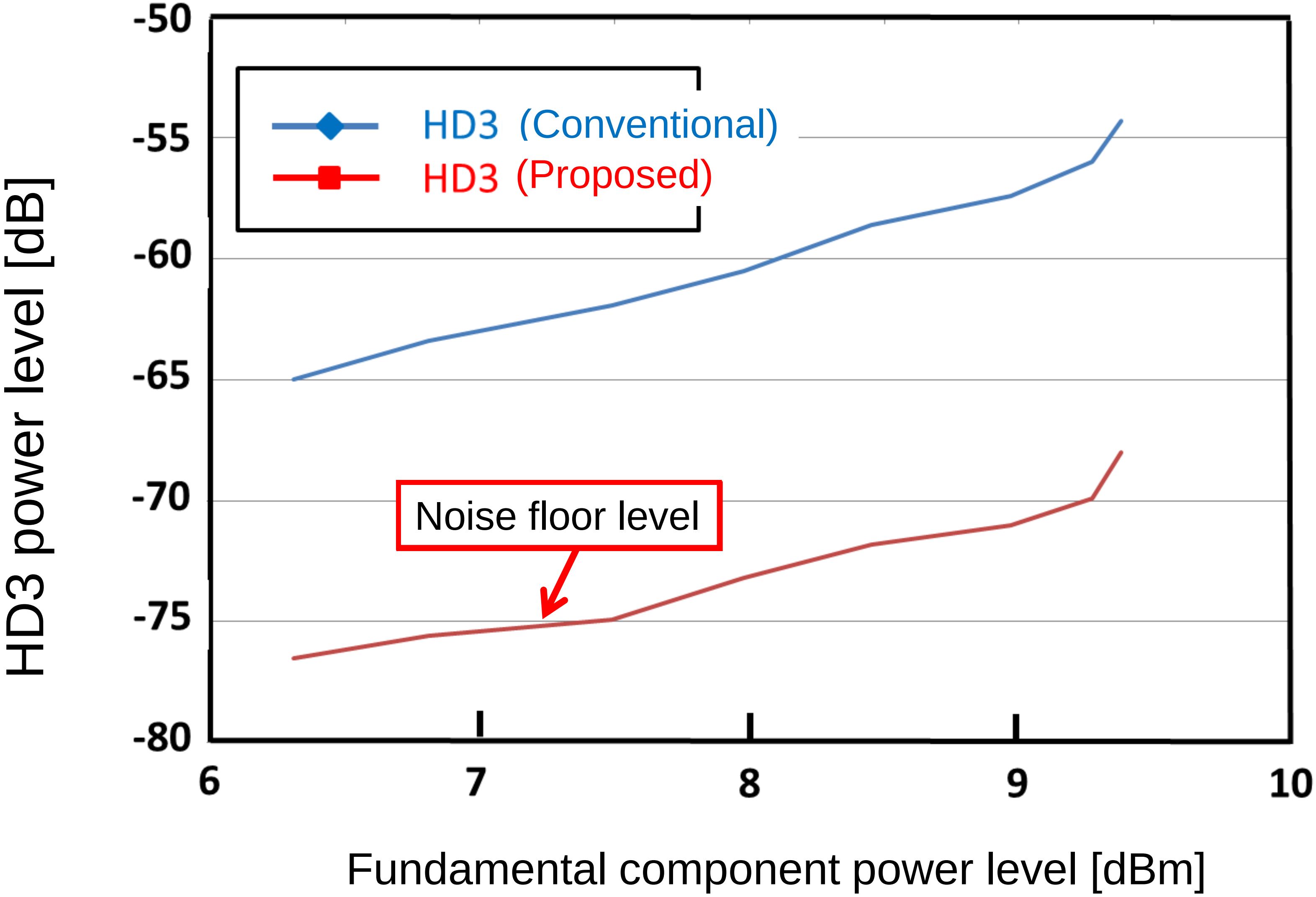
Proposed

Fundamental (1MHz) : 6.31dBm → 1.09dB → 5.12dBm

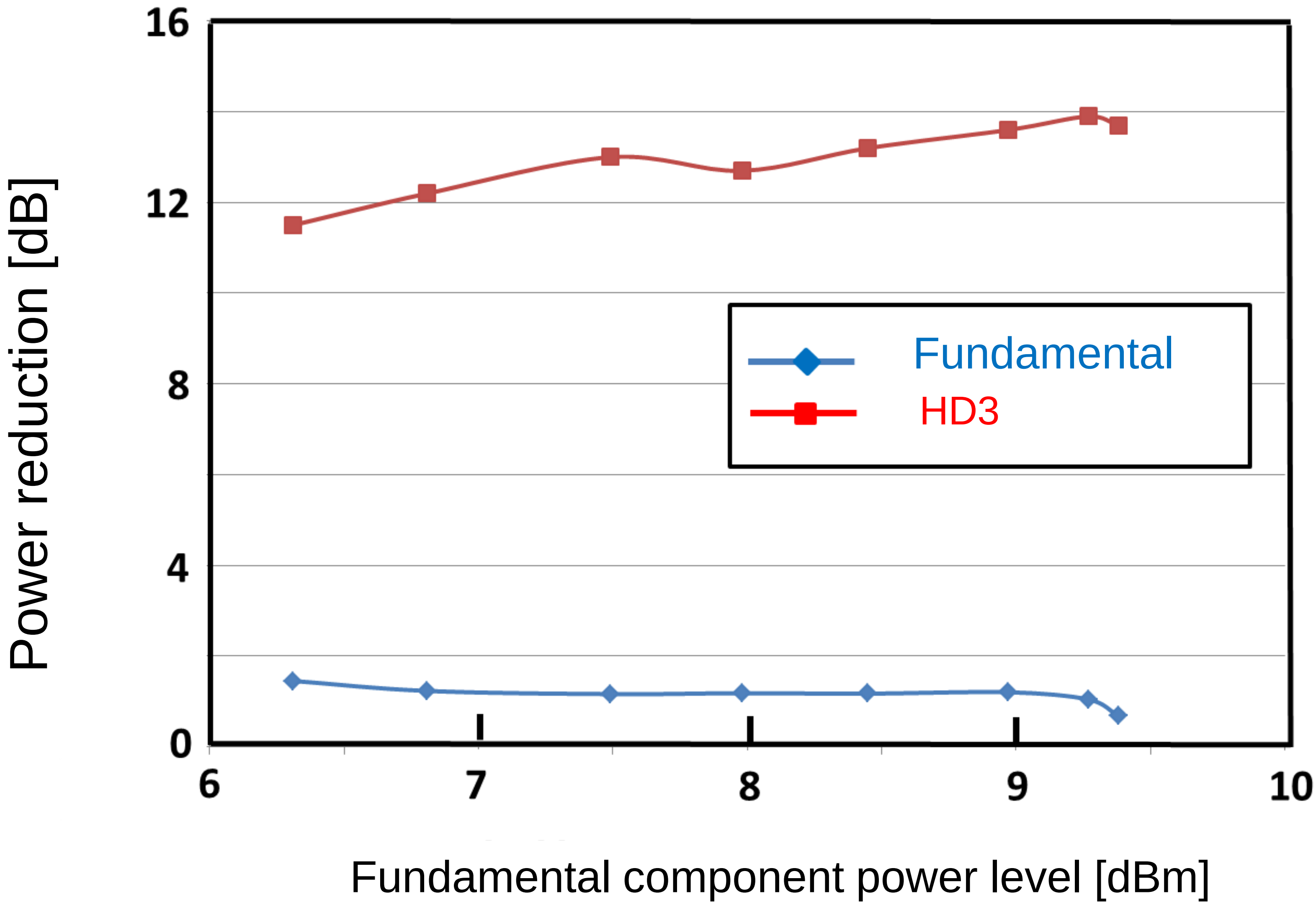
reduction

HD3 (3MHz) : -65dBm → 11.5dB → -76.5dBm (Noise floor level)

Experimental Results: HD3 (fs=10MHz)



Experimental Results: HD3 reduction (fs=10MHz)



Conclusions

- Low-distortion signal generation with AWG
- Single-tone: HD3 cancellation
- Two-tone: IM3 cancellation
- Algorithm generalization
- Only program change
- No hardware change.
- No need for AWG nonlinearity identification
- Theoretical analysis, simulation and experiment all verify the effectiveness of the proposed method

⇓

Low-cost, high-quality testing of ADC is possible

New Concept Proposal

- Proposed signal generation method

- Distortion components close to signal band are reduced
- Distortion components far from signal band may appear.

Distortion-shaping

Similar to but different from noise-shaping