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

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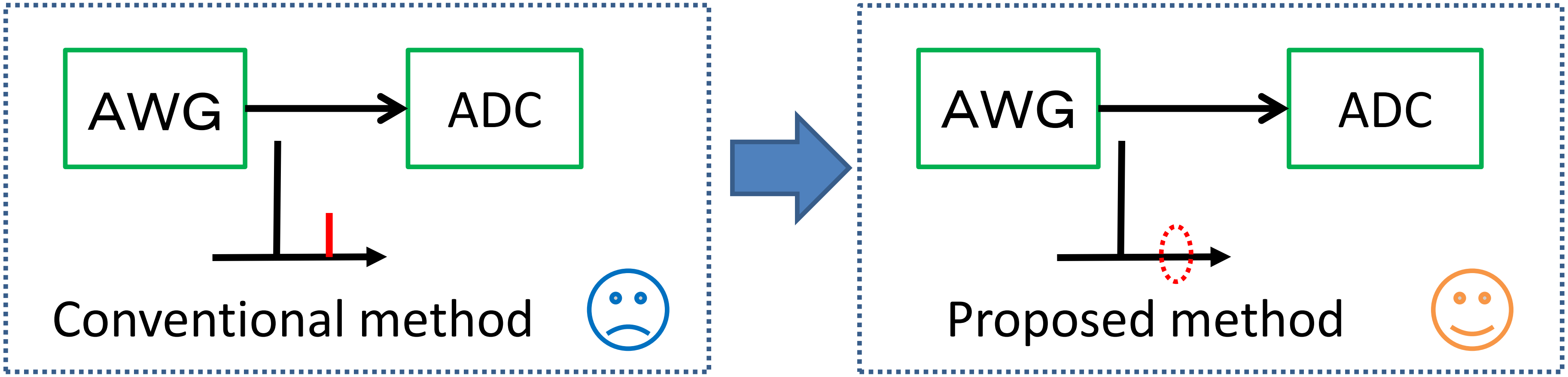
Research Goal

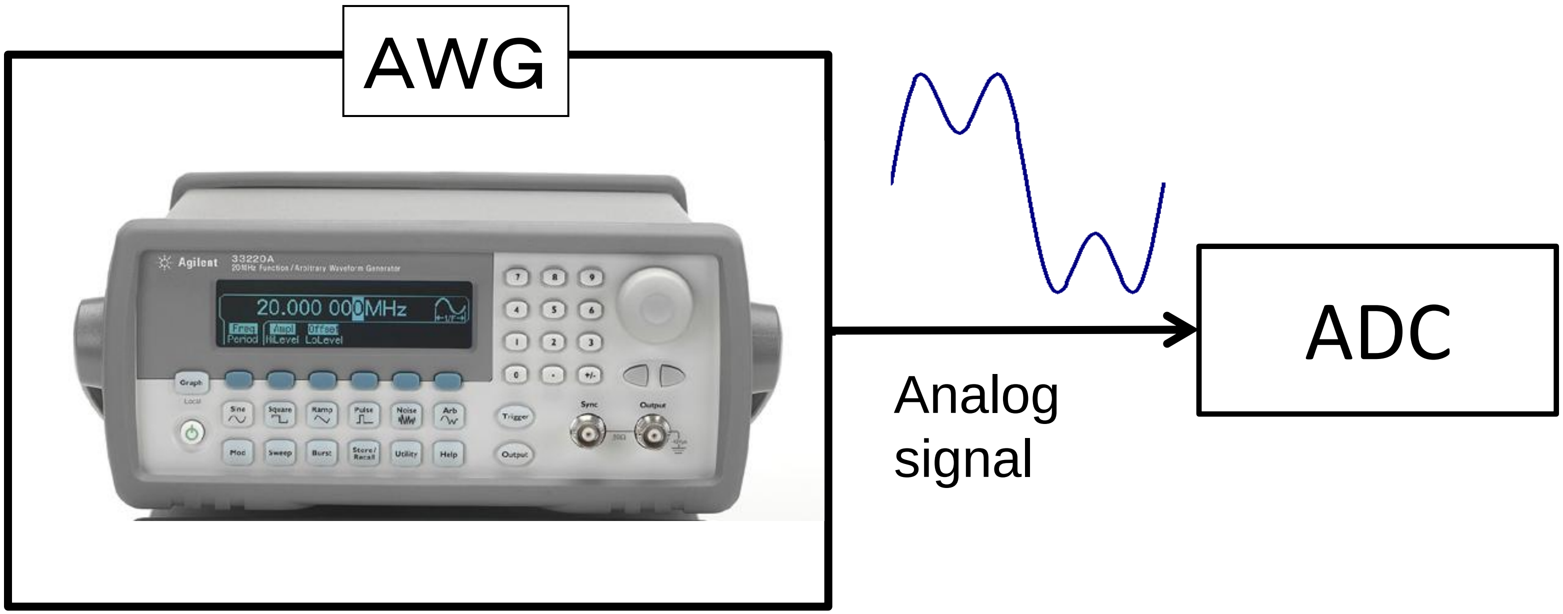
Generating low-distortion sinewaves
for ADC linearity testing
using low-cost AWG



Contents

Signal Generation with AWG

AWG（Arbitrary Waveform Generator）



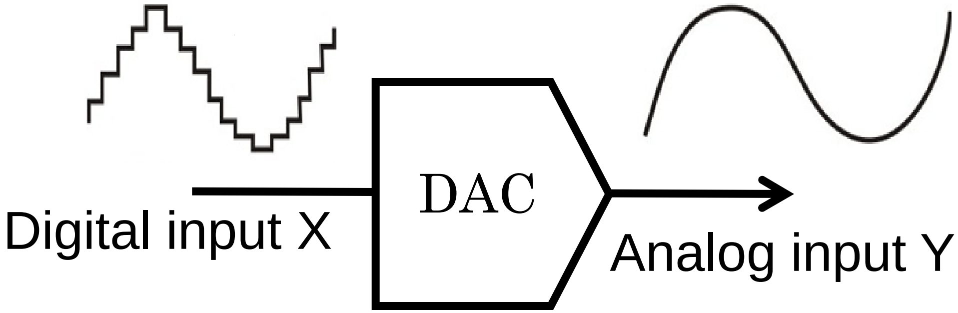
DSP generates digital signal. ➡ DAC converts it to analog signal.

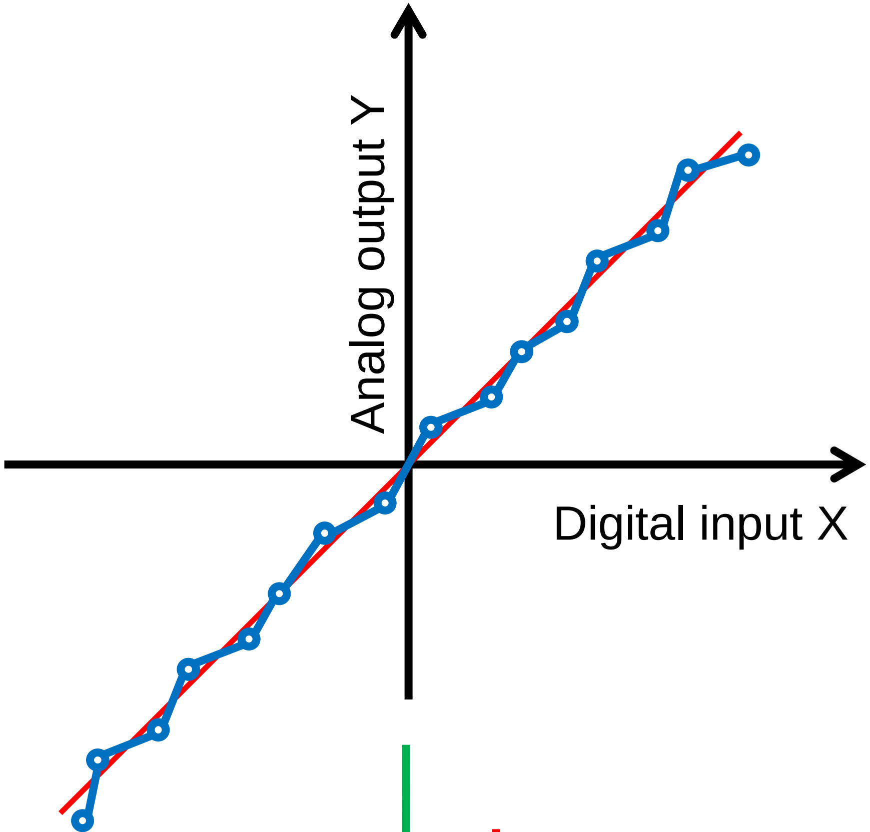
Single-tone and two-tone analog signals for ADC testing

⬇

DAC has nonlinearity

Spurious Components due to DAC Nonlinearity

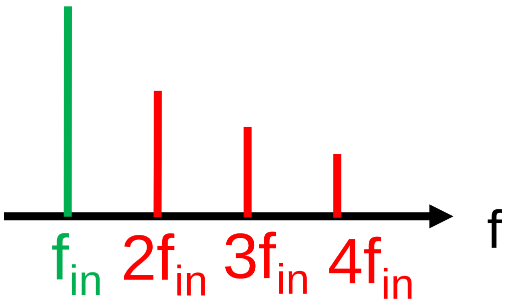




Ideal DAC output $Y=a_1X$

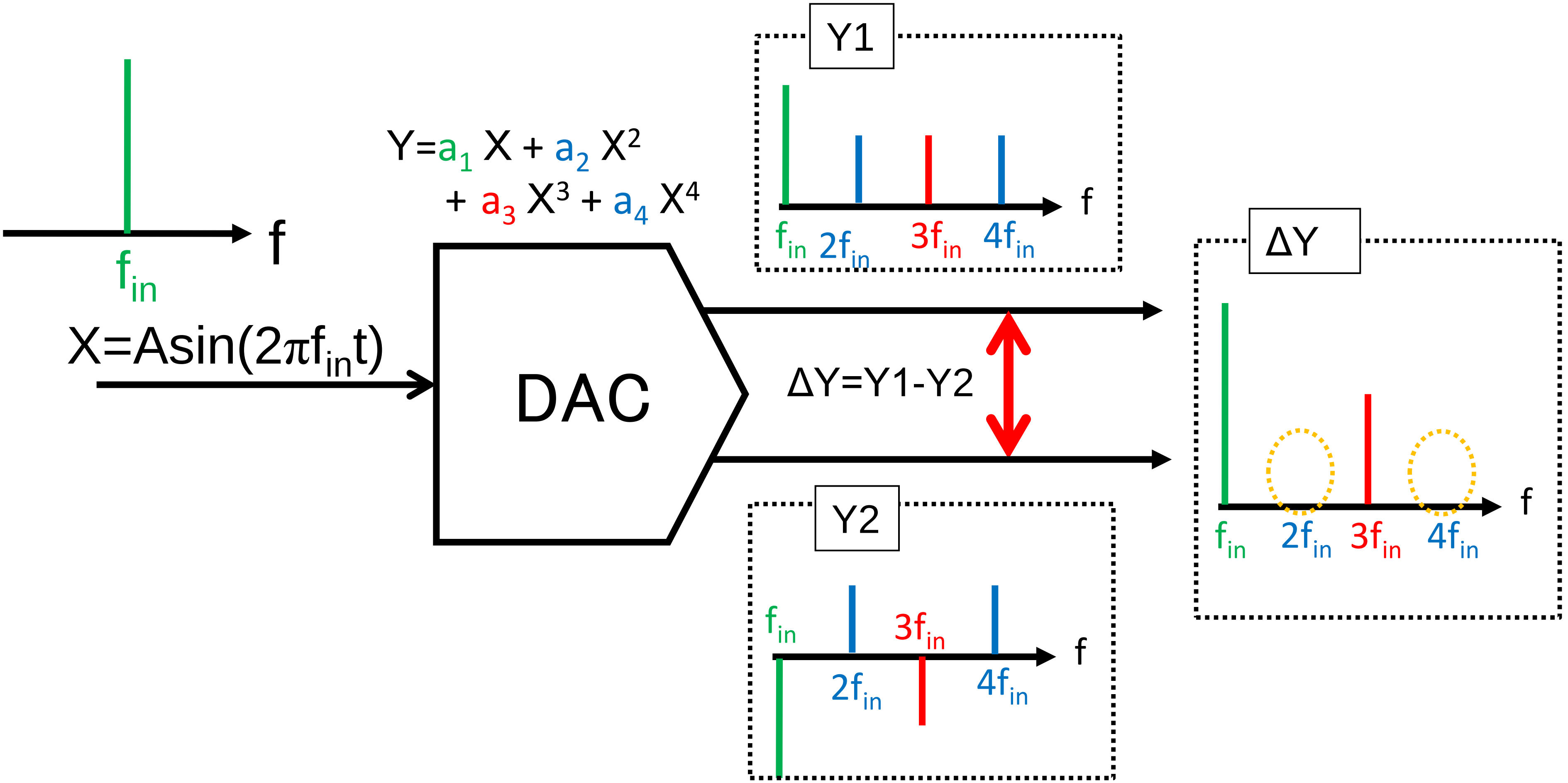
Actual DAC output $Y=a_1X + a_2X^2 + a_3X^3 + a_4X^4 \cdots$

HD2 HD3 HD4



DAC Nonlinearity → Spurious components

Use Differential Signals to Cancel Even Harmonics



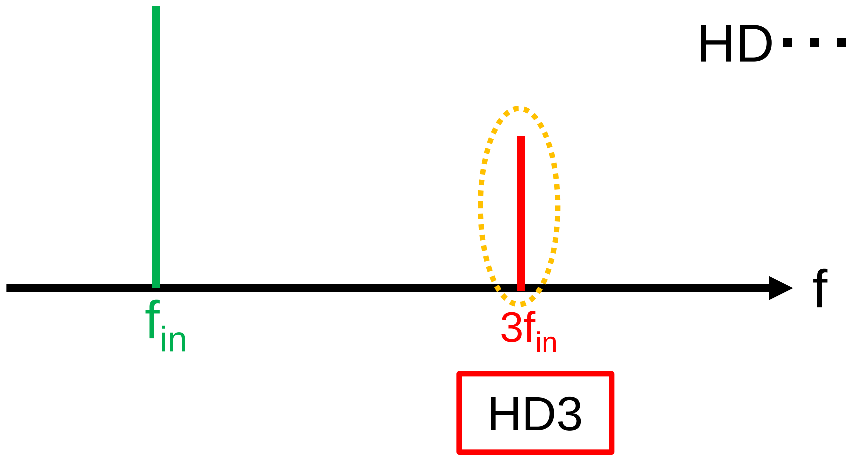
Use differential signals to cancel even harmonics.

Next focus on removing third-order harmonics

Third-order Nonlinearity Distortion Components

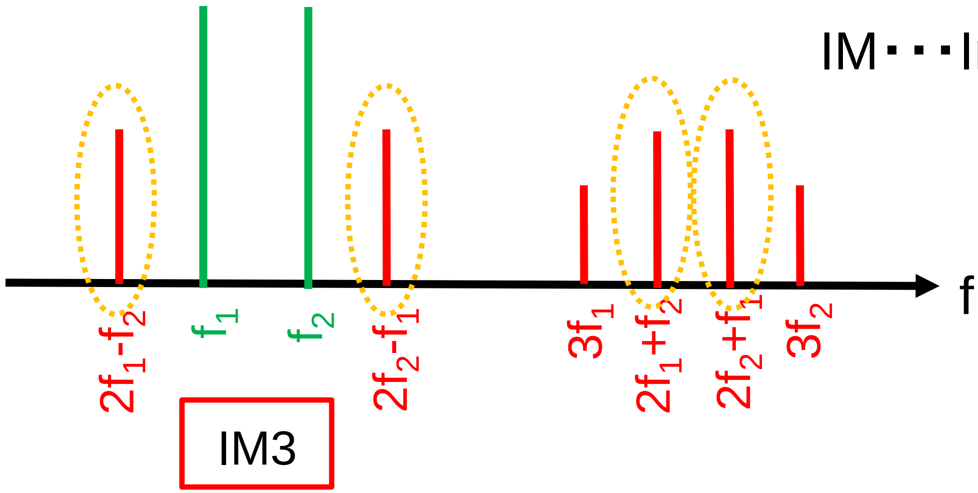
Single-tone input

HD・・・Harmonic Distortion



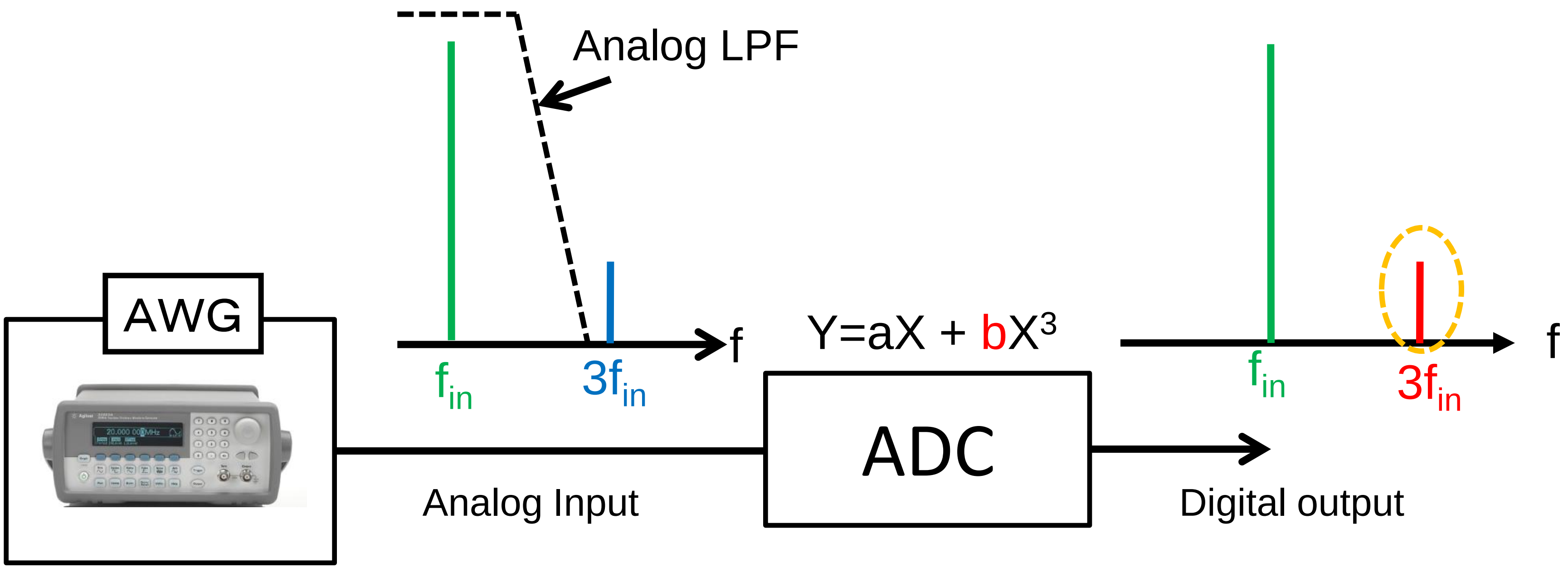
Two-tone input

IM・・・Intermodulation



IM3 components are difficult to remove with analog filter

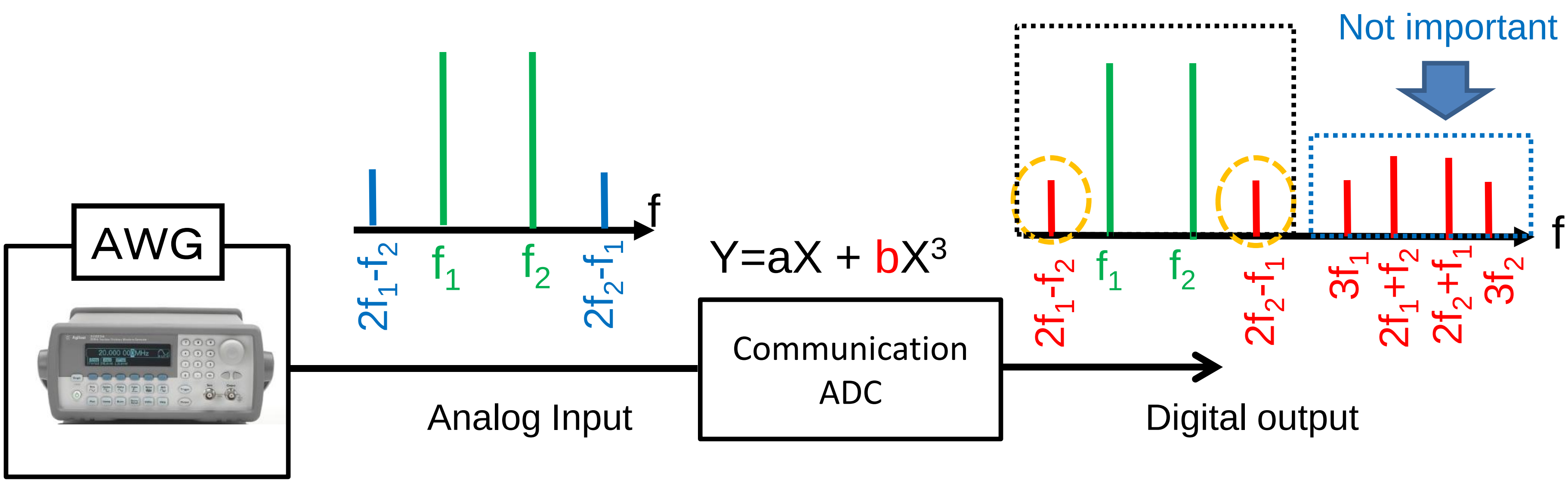
ADC Linearity Test (Single-tone Input)



Can use analog LPF to remove HD3 (& higher harmonics)

ADC distortion can be measured & tested accurately.

Communication ⇒ Narrow band, high frequency

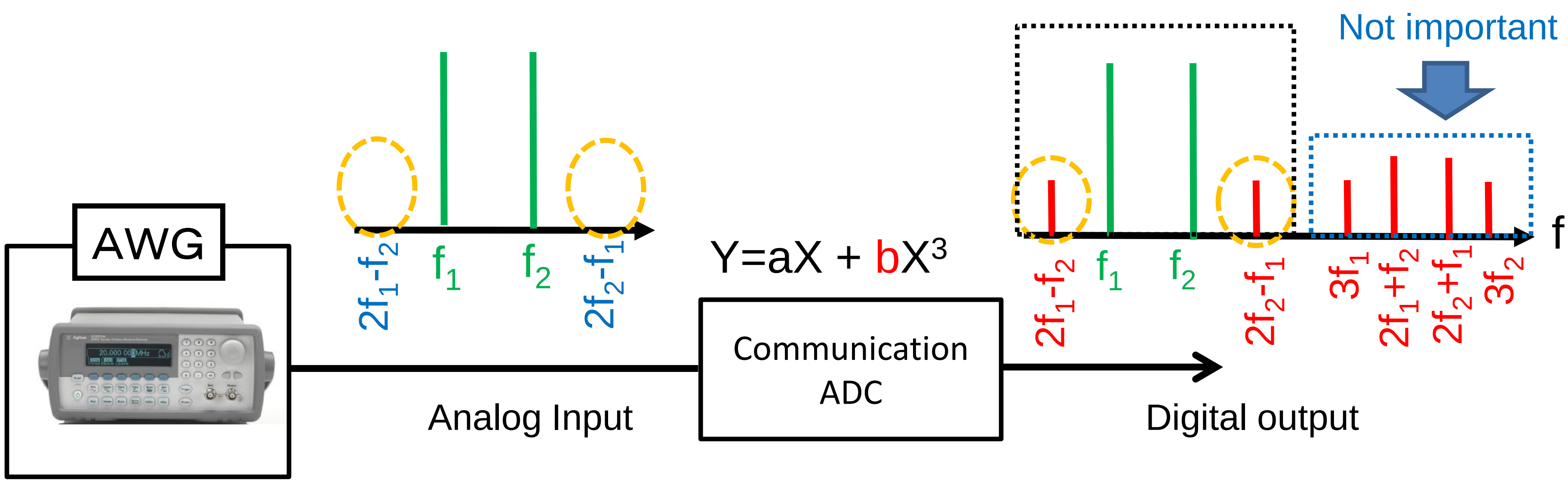


IM3 ($2f_1-f_2$, $2f_2-f_2$) components in input signal are

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

Communication Application ADC Test (Two-tone Input)

Communication ⇒ Narrow band, high frequency

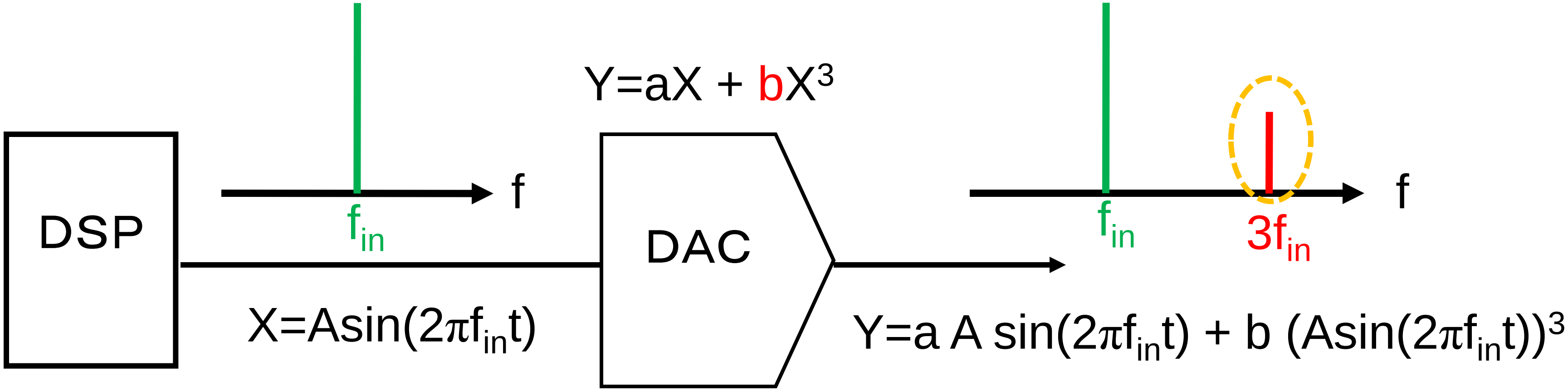


Use proposed method to cancel IM3 in analog input.

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

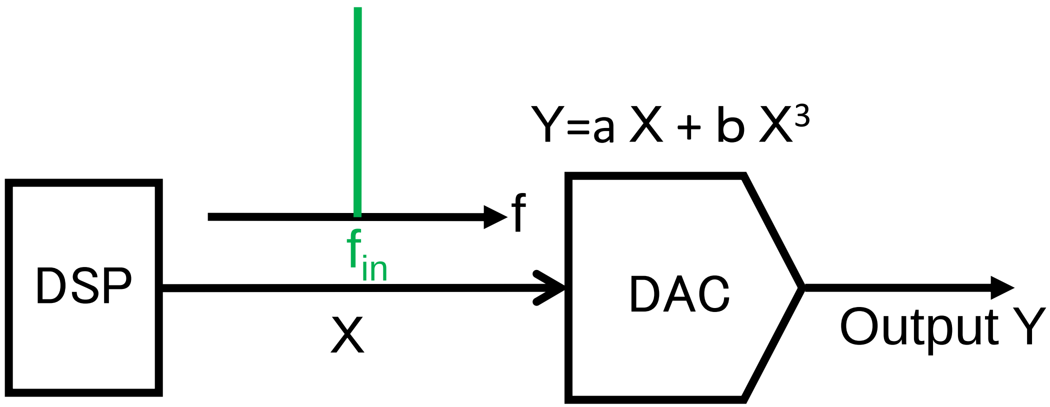
Contents

Conventional Single-tone Generation



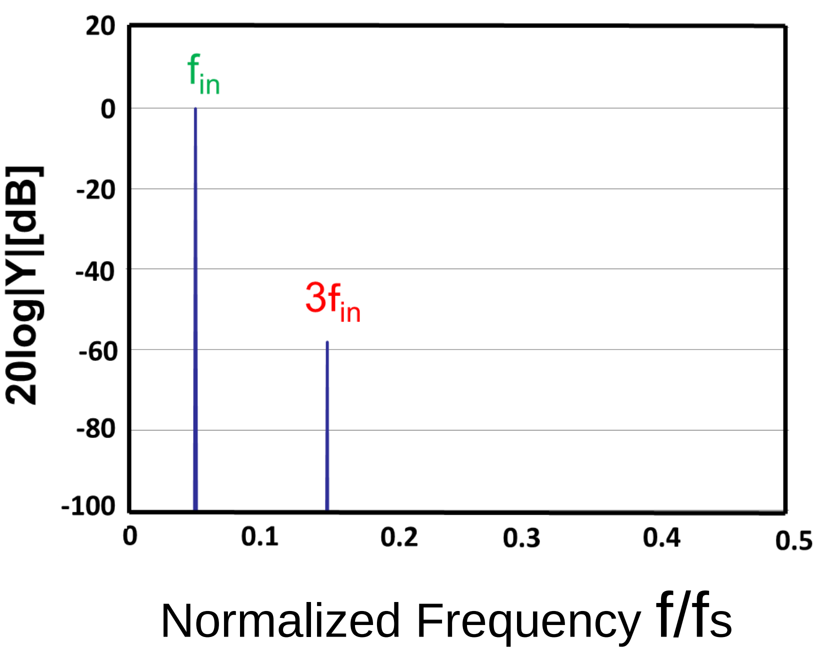
■HD3 appears

Simulation Condition (Single-tone)

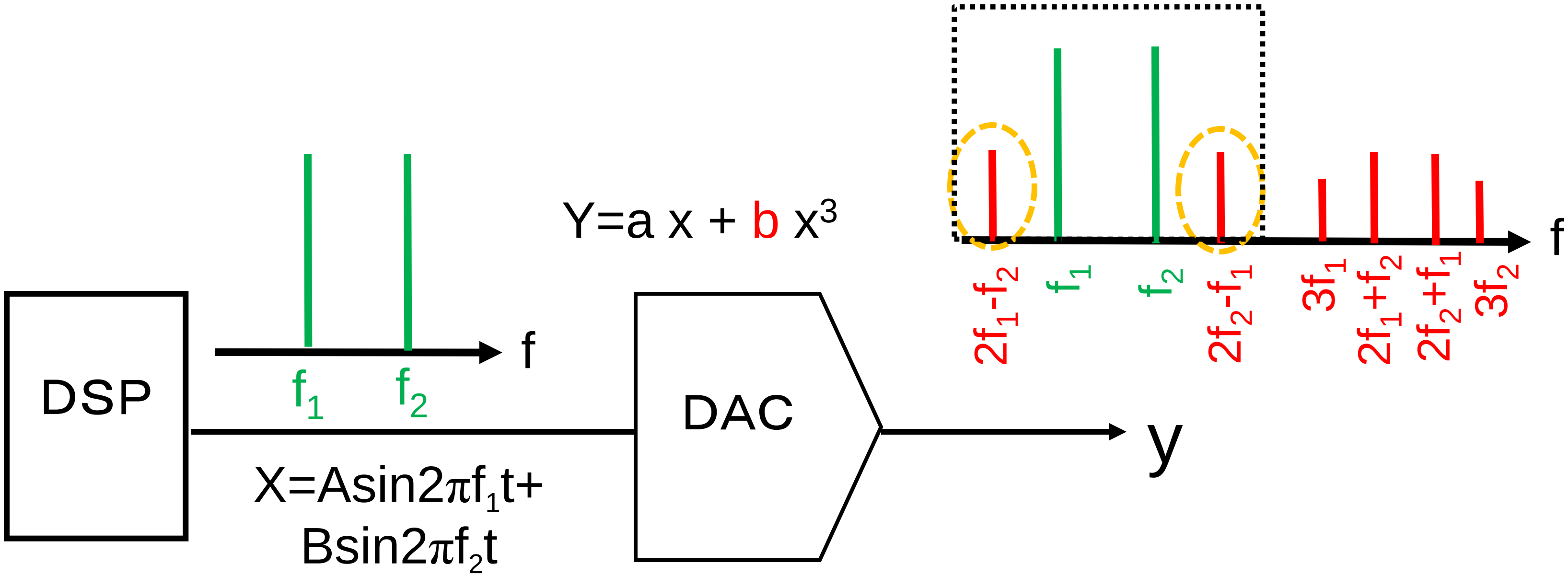


Input signal X	$\sin(2\pi f_{in} t)$
1st coeff. a (DAC)	1.0
3rd coeff. b (DAC)	-0.005
Input freq. fin	51
Sampling freq. fs	1024

Output power spectrum is obtained by FFT

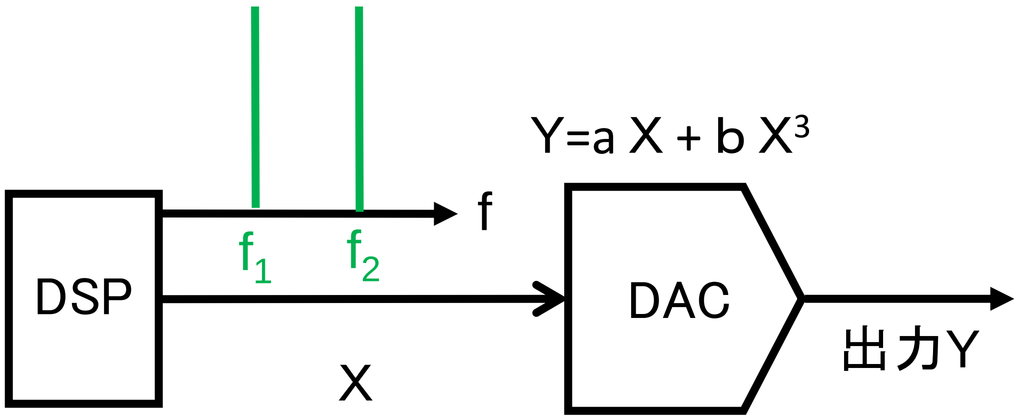


Conventional Two-tone Generation



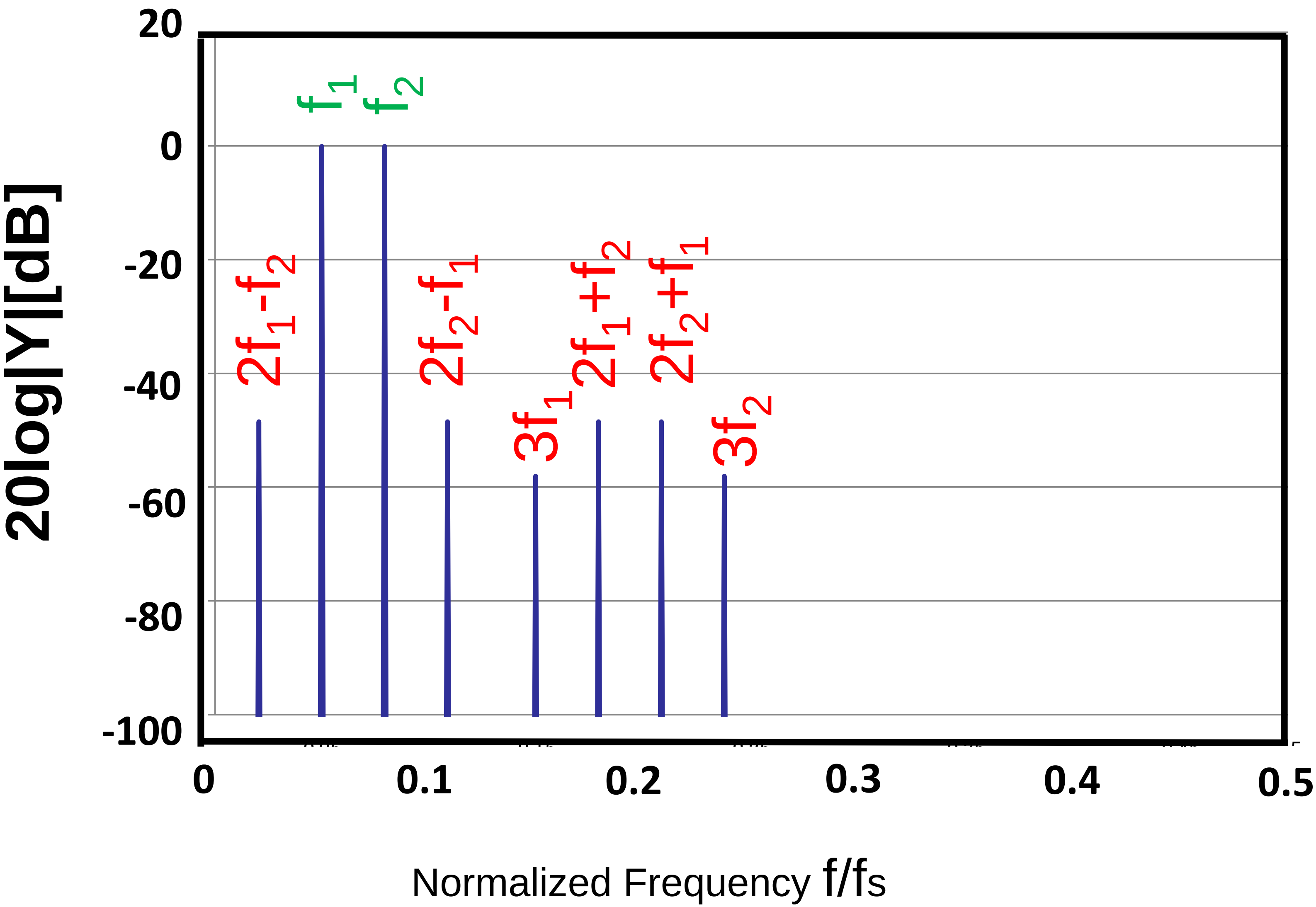
■IM3 appears

Simulation Condition (Two-tone)



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

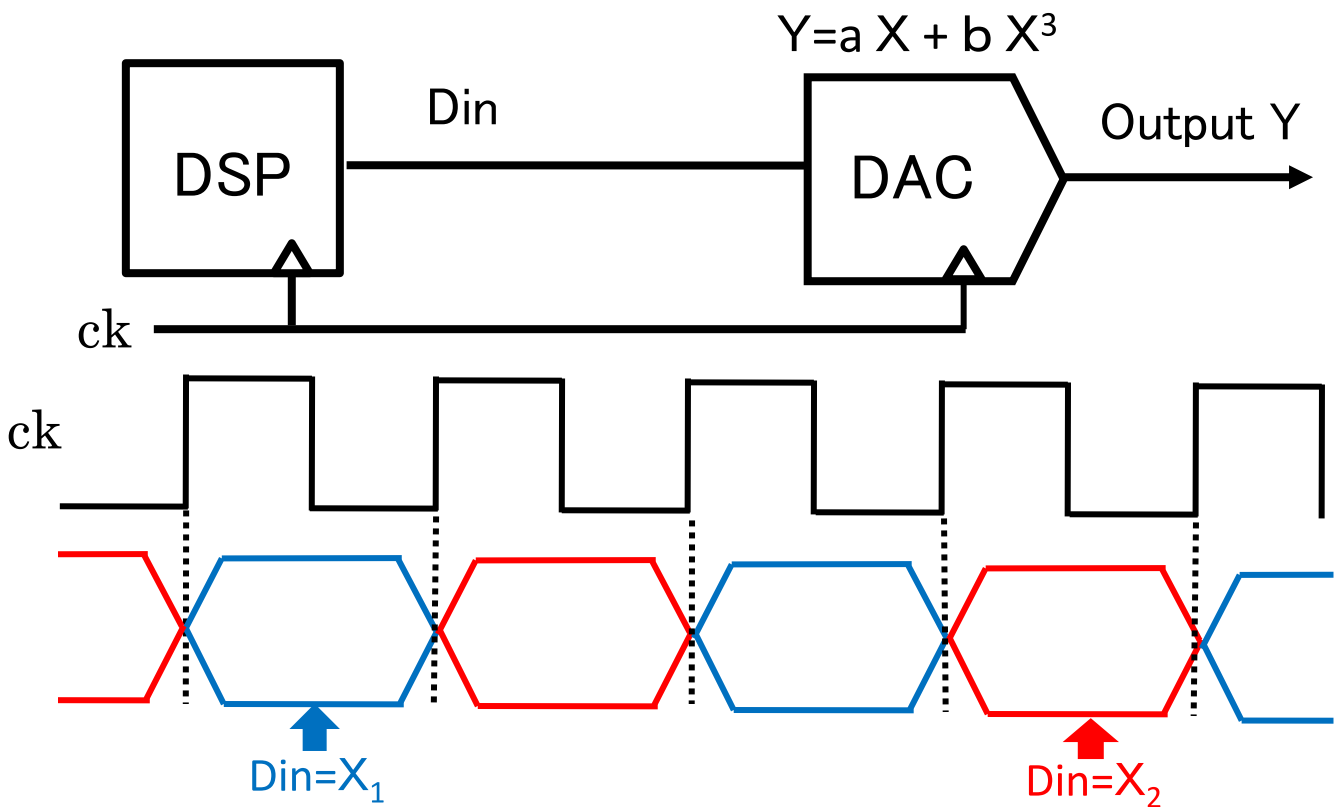
Output Power Spectrum（Two-tone Input）



Contents

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

Proposed Method



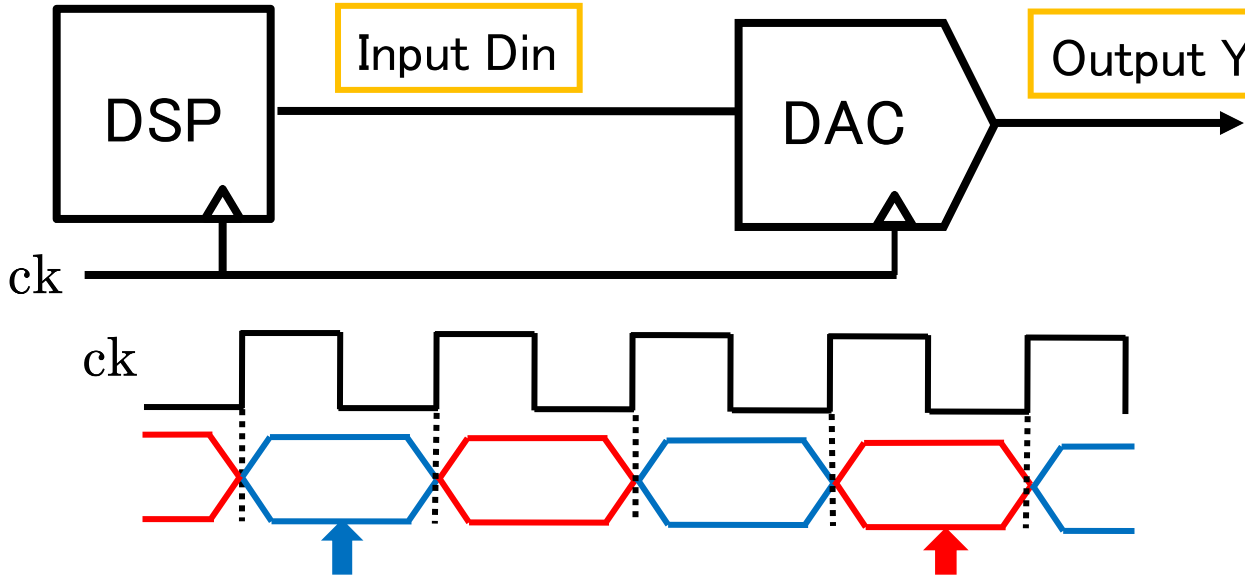
Interleave X_1、X_2 by one clock and generate Din

Feed Din to DAC

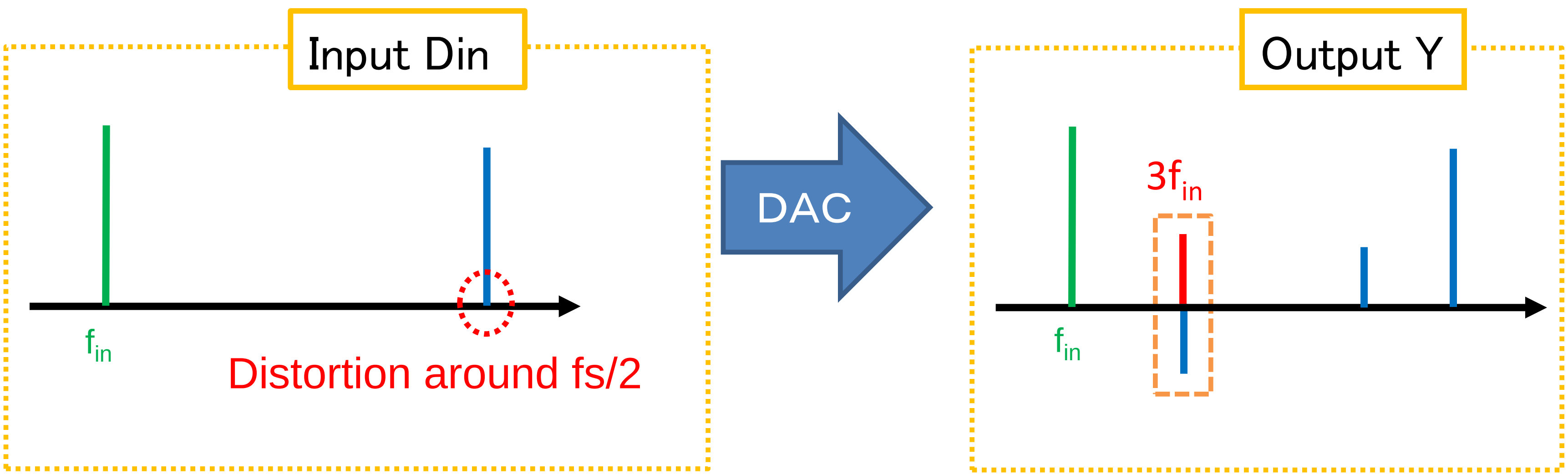
Cancel distortion components of output Y

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

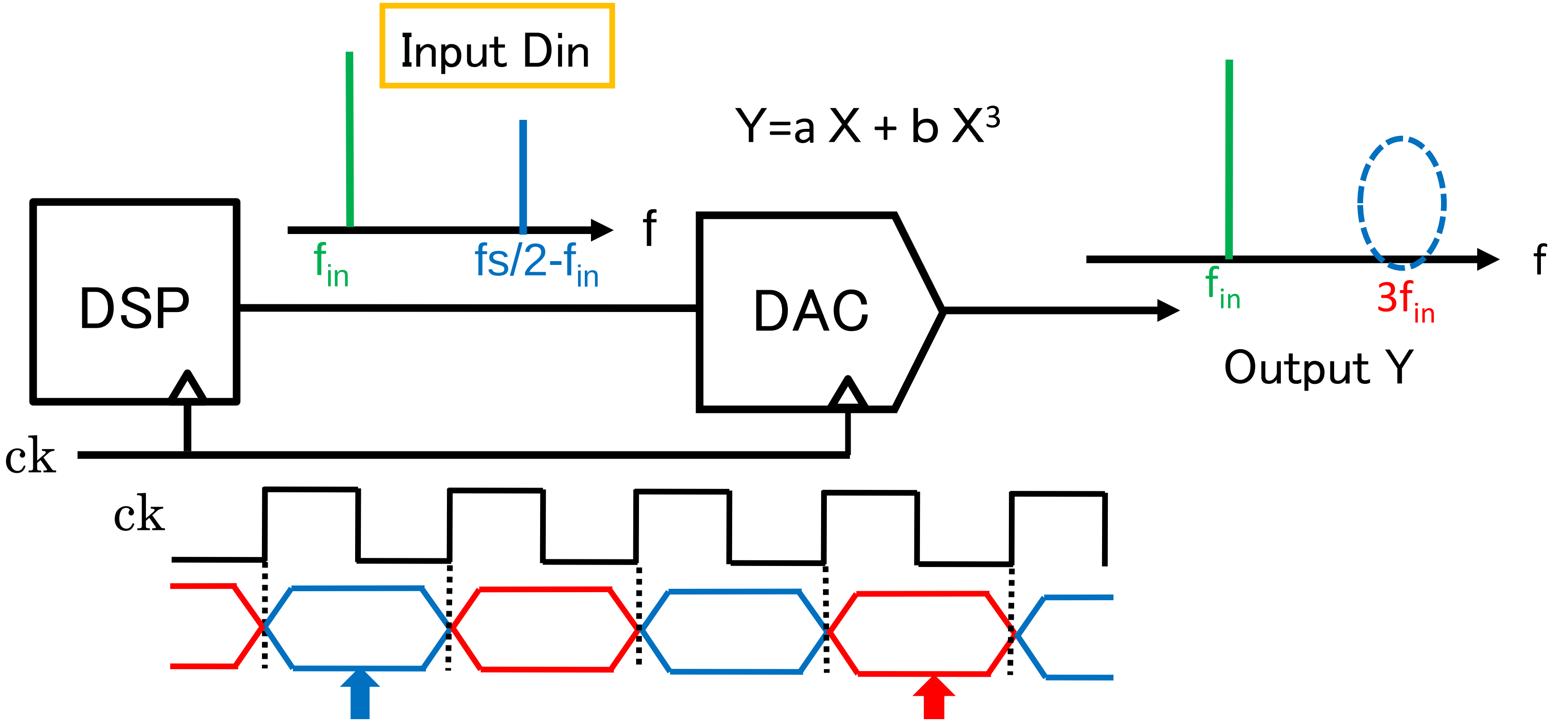
Principle of Proposed Method



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



Proposed Method (Single-tone)

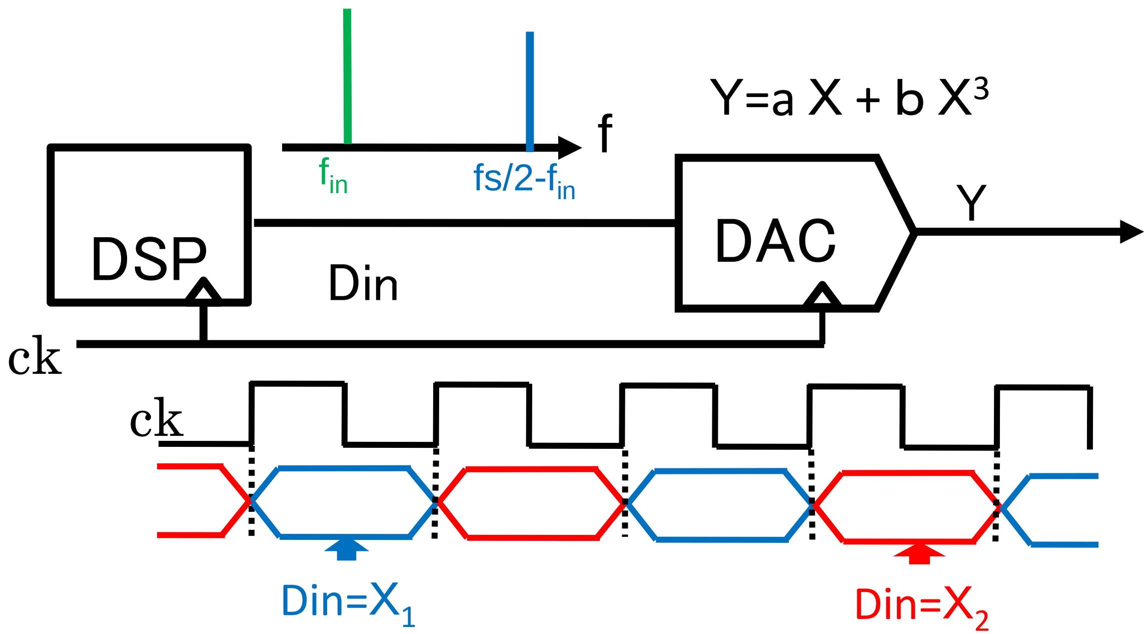


$Din = A\sin(2\pi f_{in} t + \pi/6)$ $Din = A\sin(2\pi f_{in} t - \pi/6)$

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

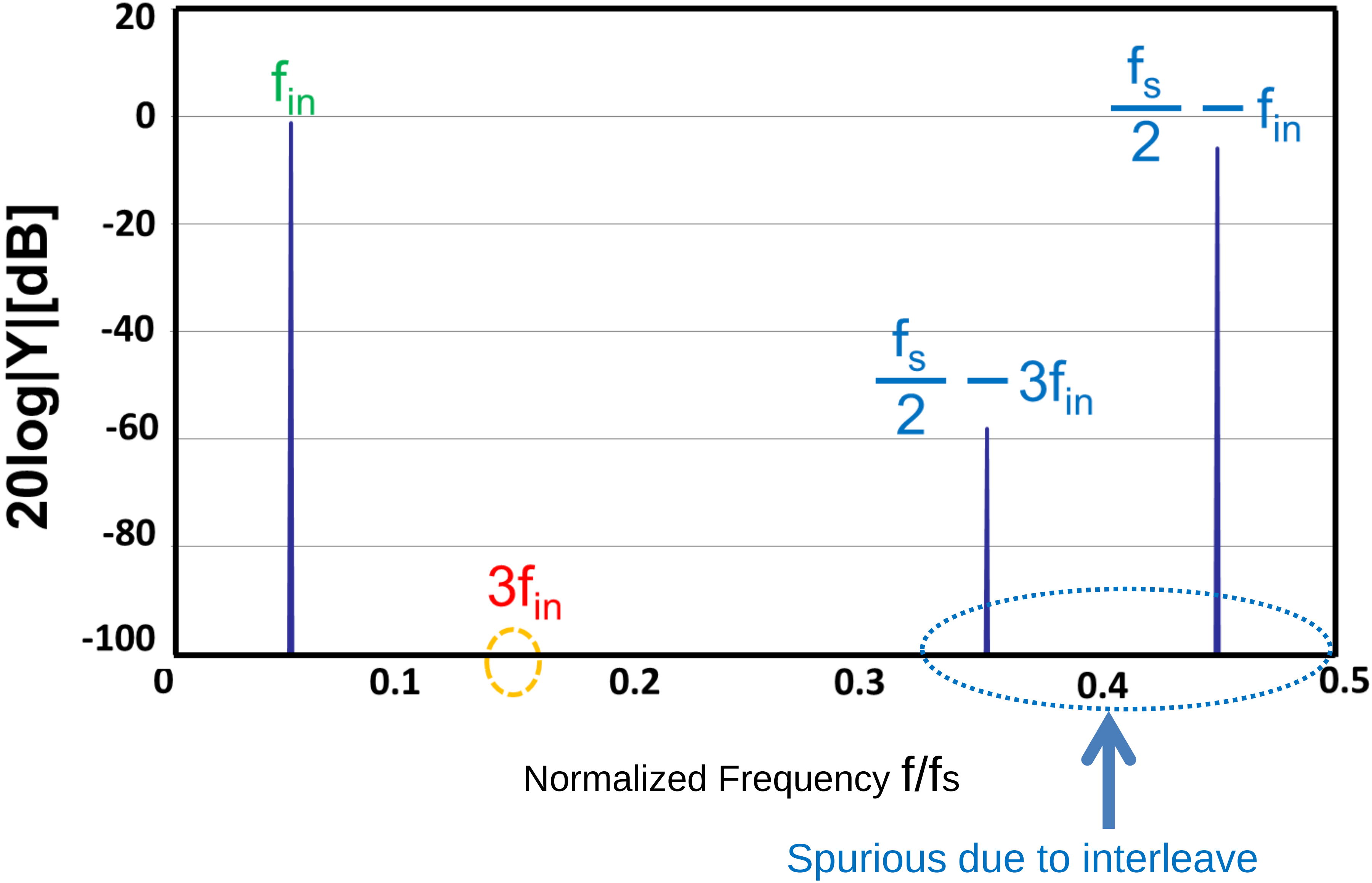
Fundamental f_{in} power reduction by 1.25dB

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
3^{rd} coeff. b(DAC)	-0.005
Input freq. fin	51
Sampling freq. fs	1024

Output Power Spectrum（Single-tone Input）



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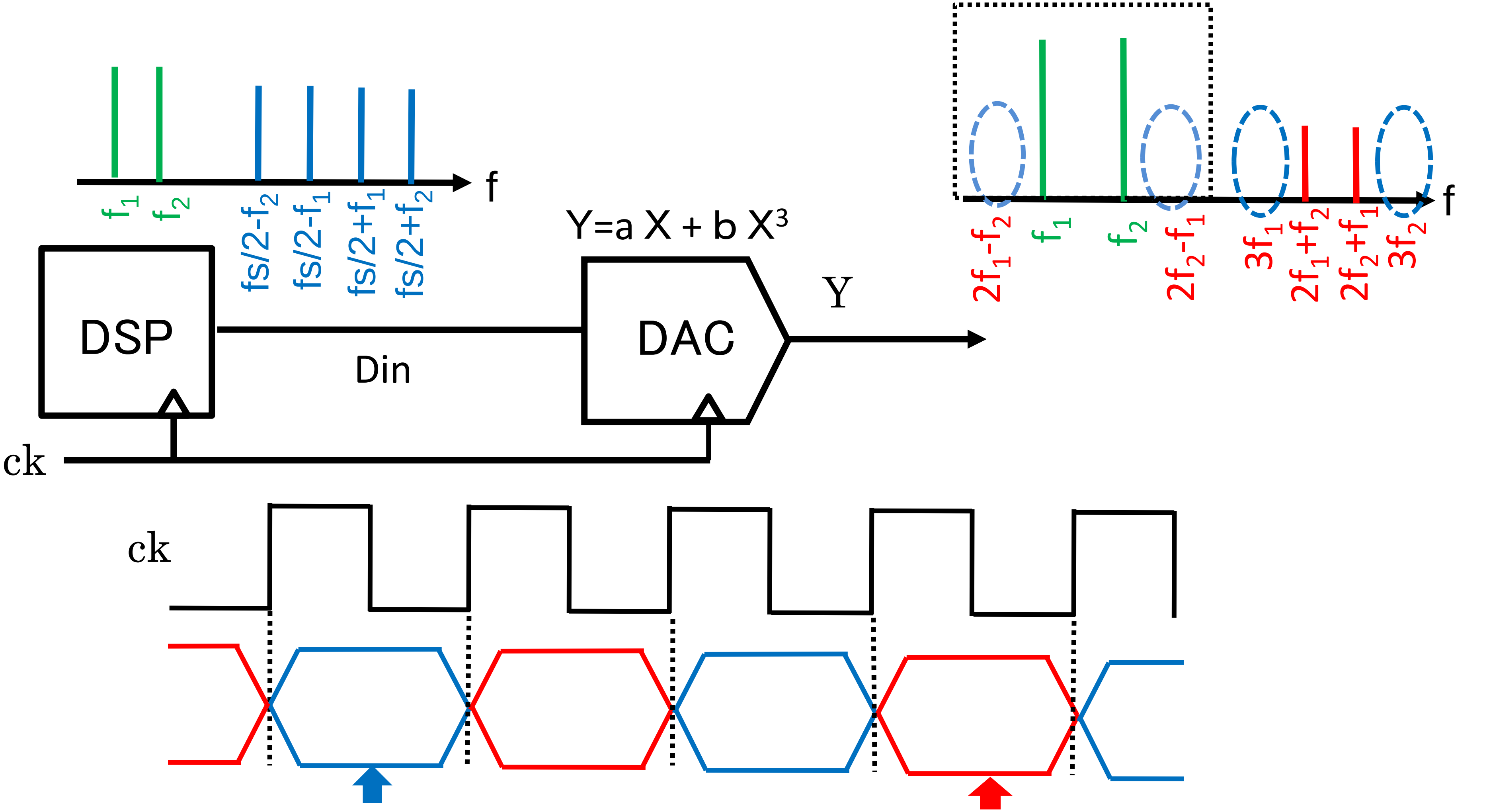
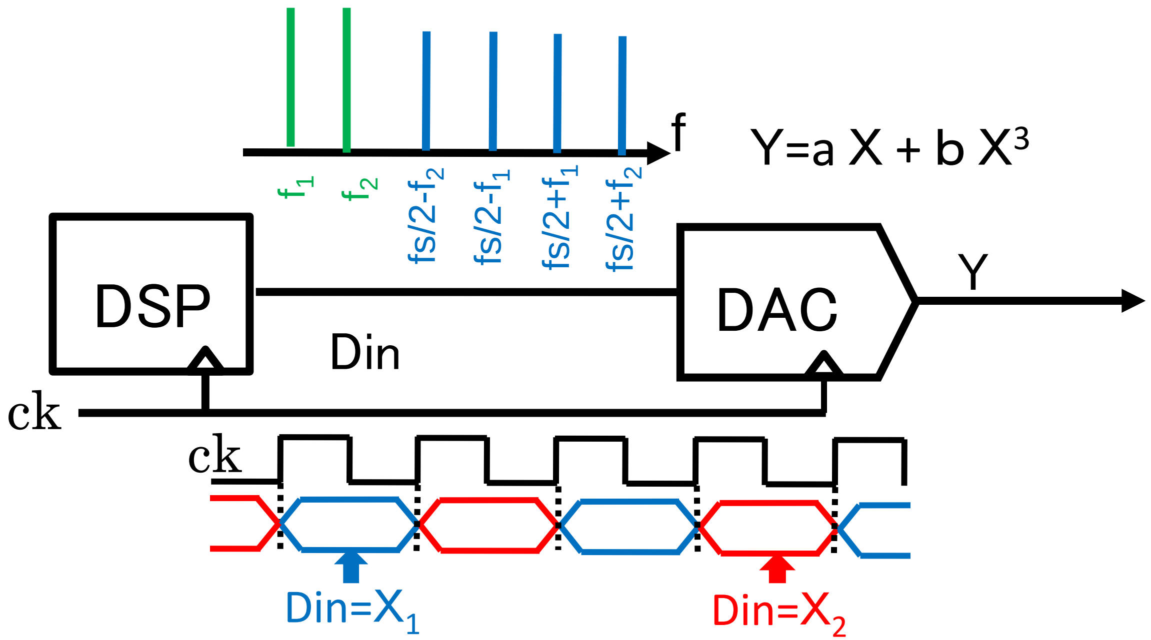
Proposed Method (Two-tone signal)



Din= Asin($2\pi f_1\, t + \pi/6$)
+Bsin($2\pi f_2\, t - \pi/6$)

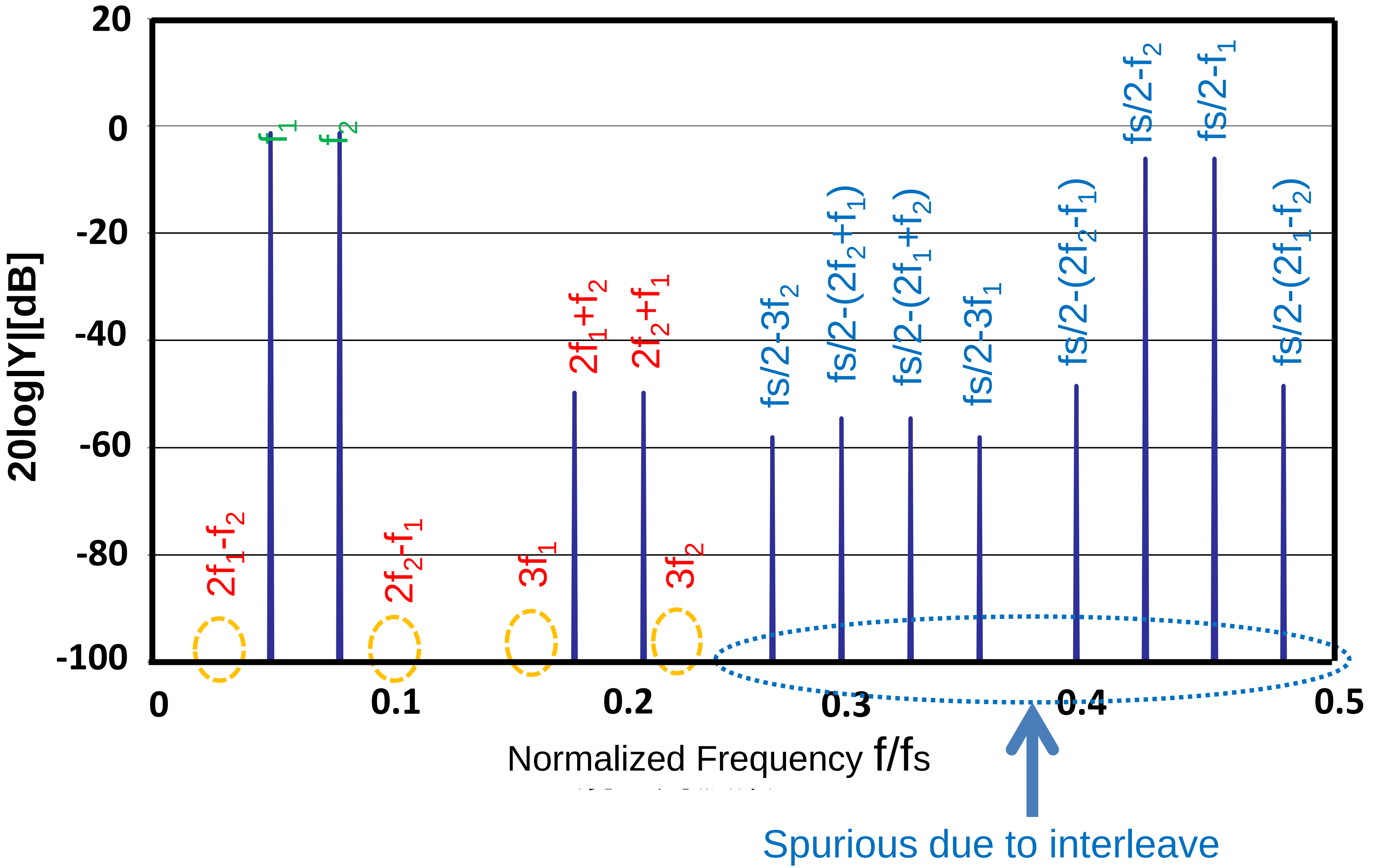
Din= Asin($2\pi f_1\, t - \pi/6$)
+Bsin($2\pi f_2\, t + \pi/6$)

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

Output Power Spectrum（Two-tone Input）



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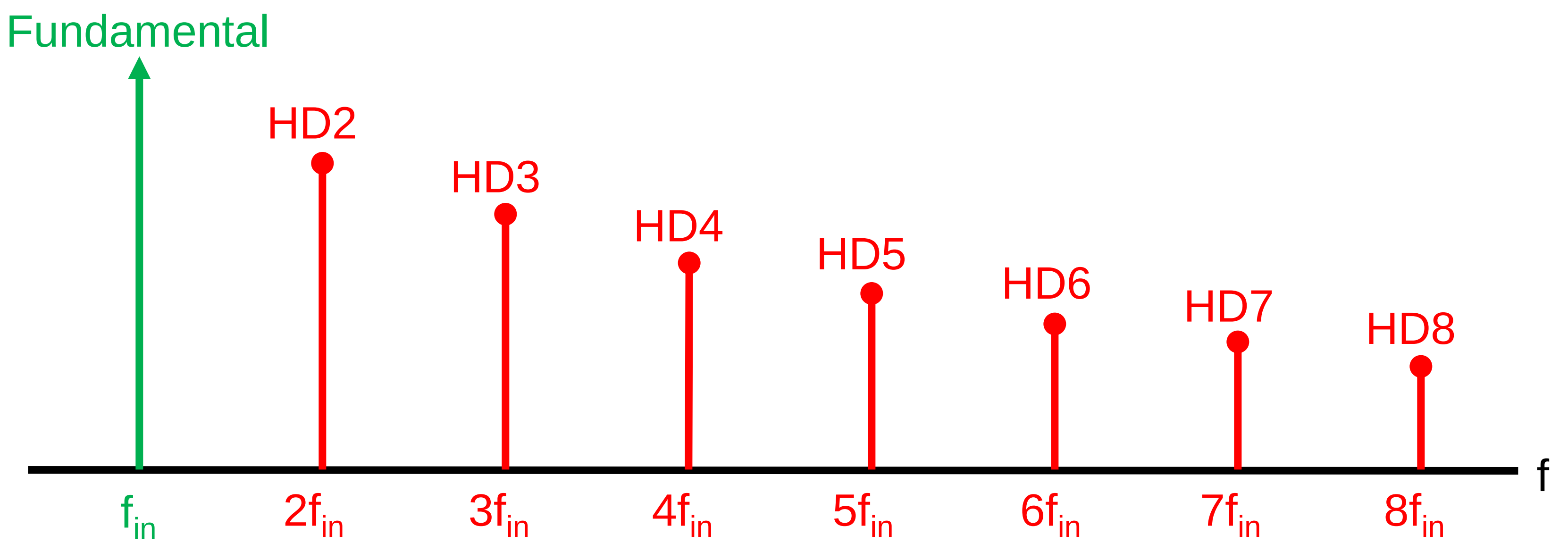
Algorithm Generalization

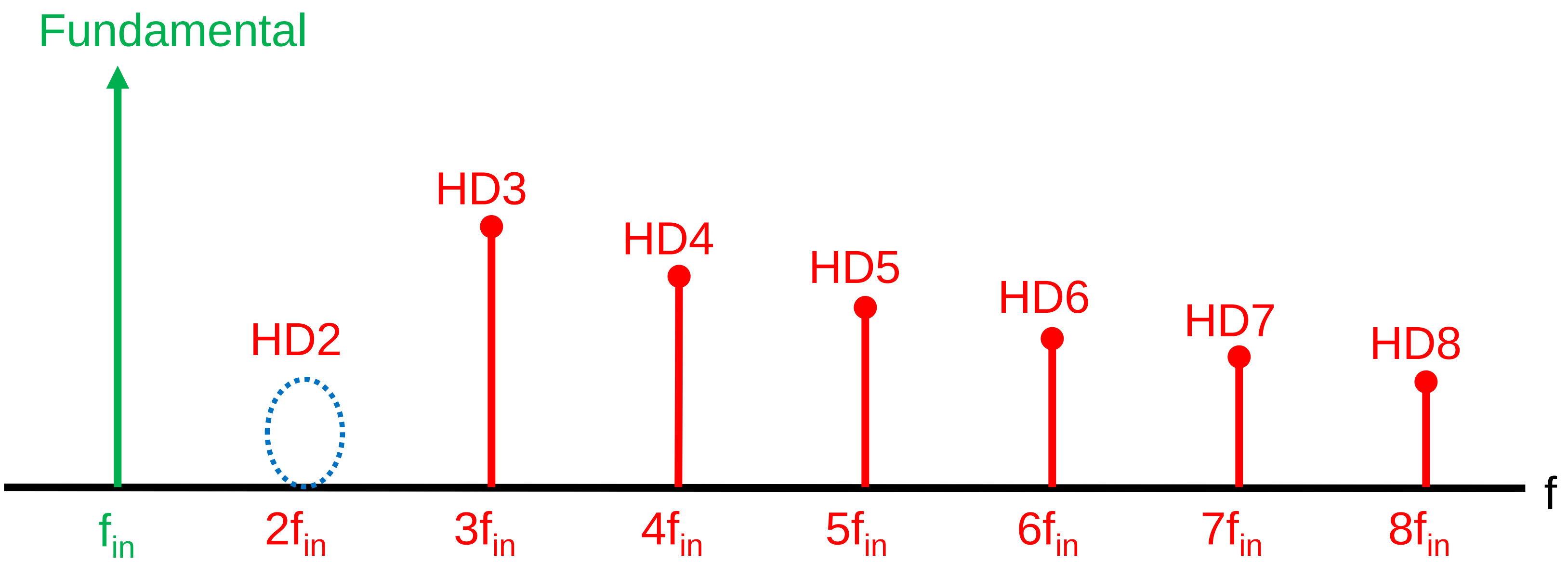


① HD2 cancellation

② HD2 & HD3 cancellation

③ HD3, HD5 & HD7 cancellation

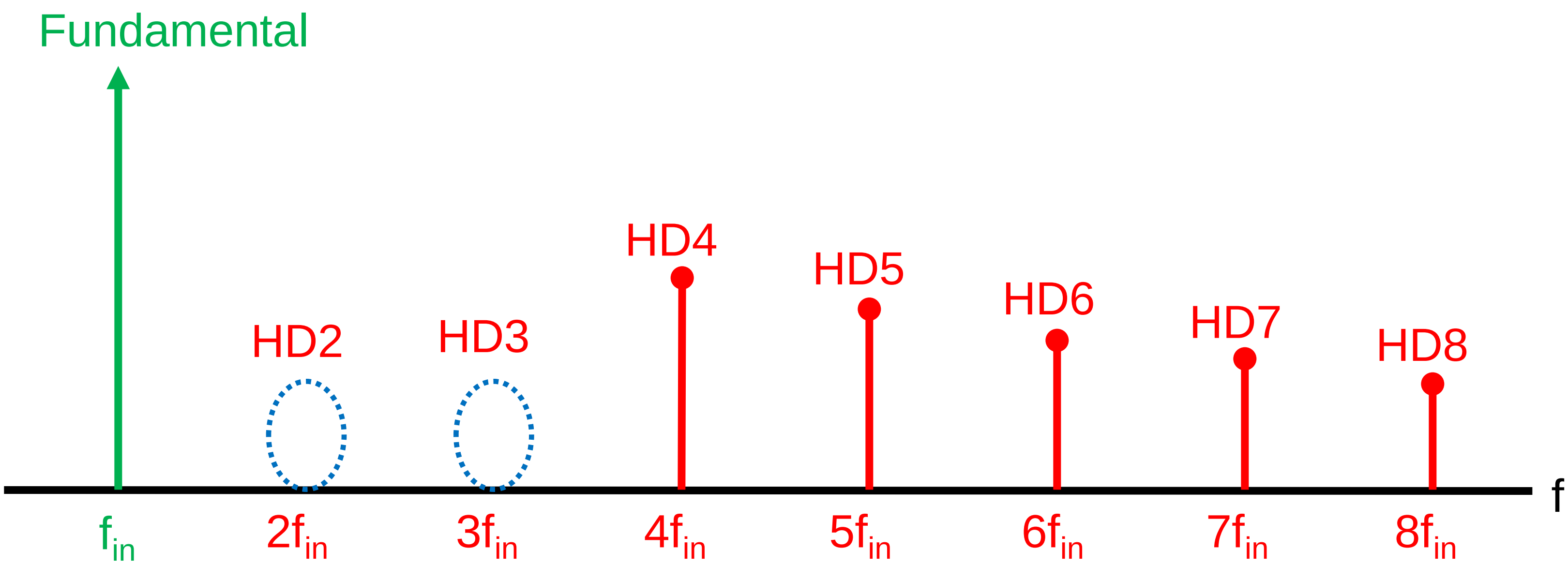
HD2 Cancellation



2-way interleave cancels HD2.

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

HD2, HD3 Cancellation

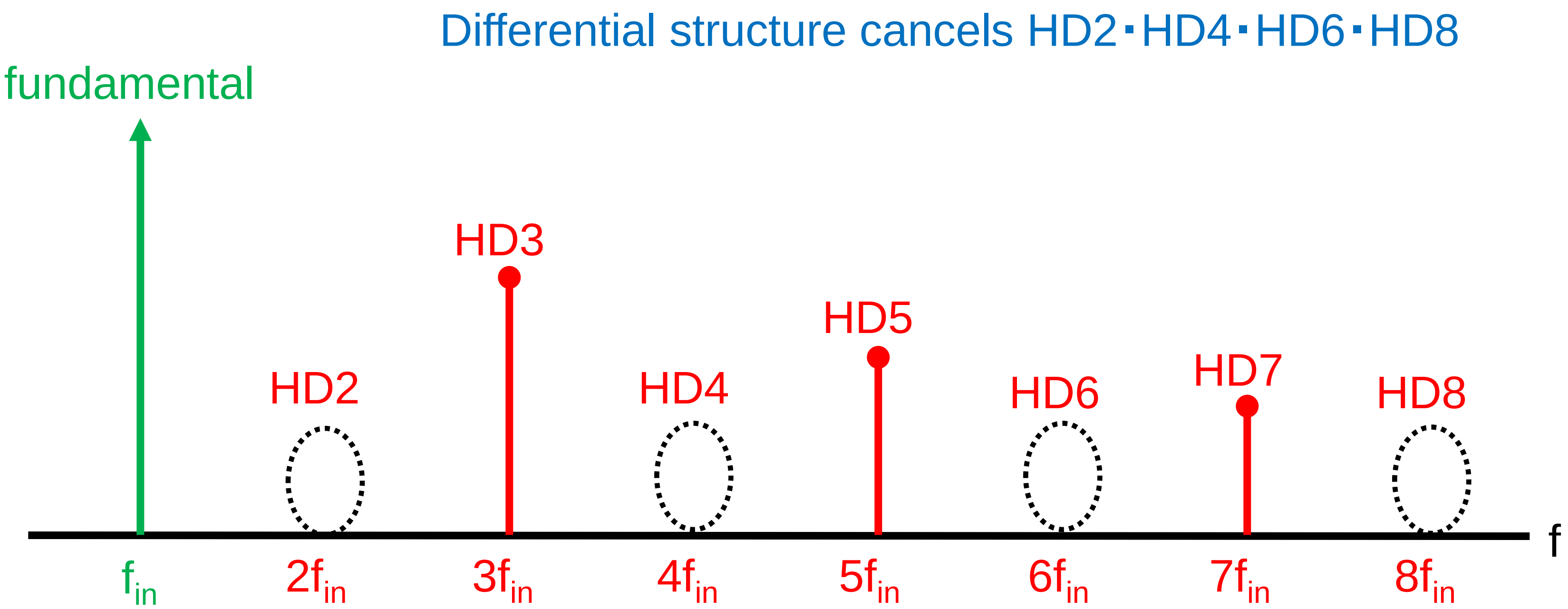


4-way interleave cancels HD2 & HD3.

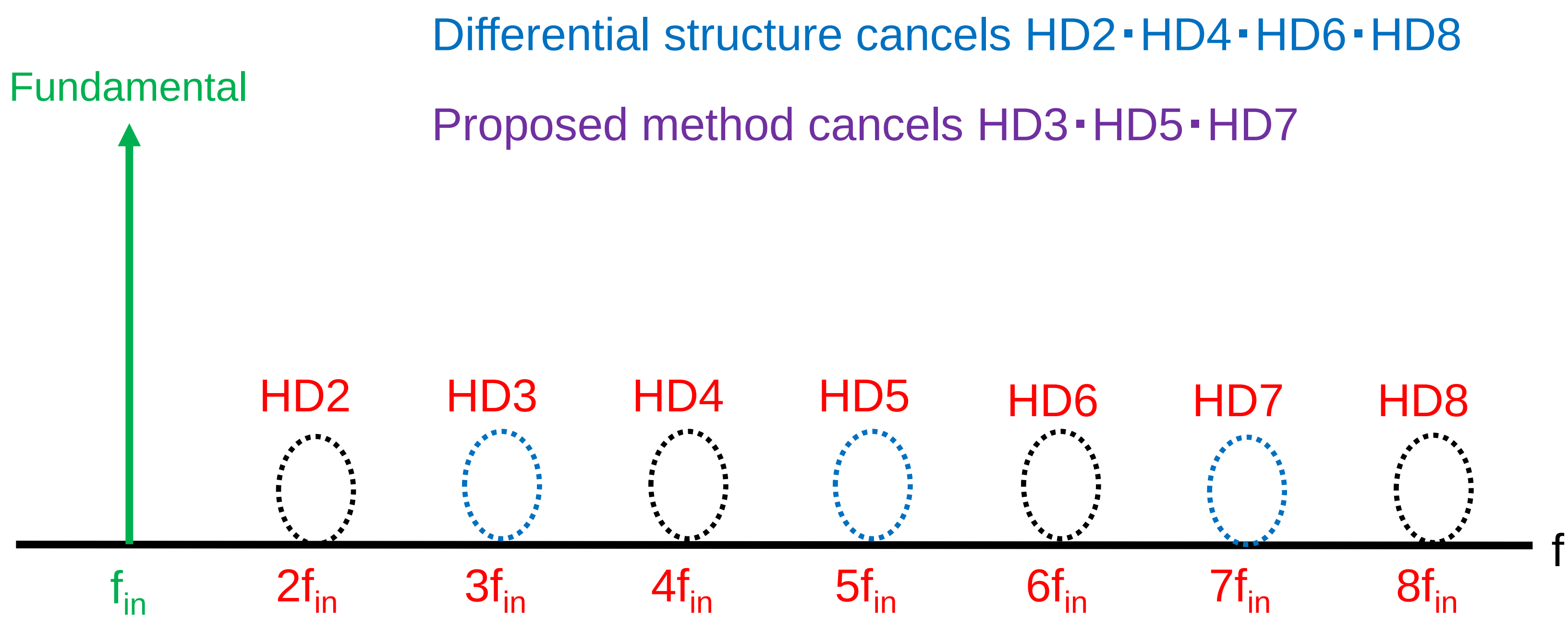
$X_1 = A\sin(2\pi f_{in} t - \pi/4 - \pi/6)$ $X_2 = A\sin(2\pi f_{in} t - \pi/4 + \pi/6)$

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

Even Harmonic Cancellation



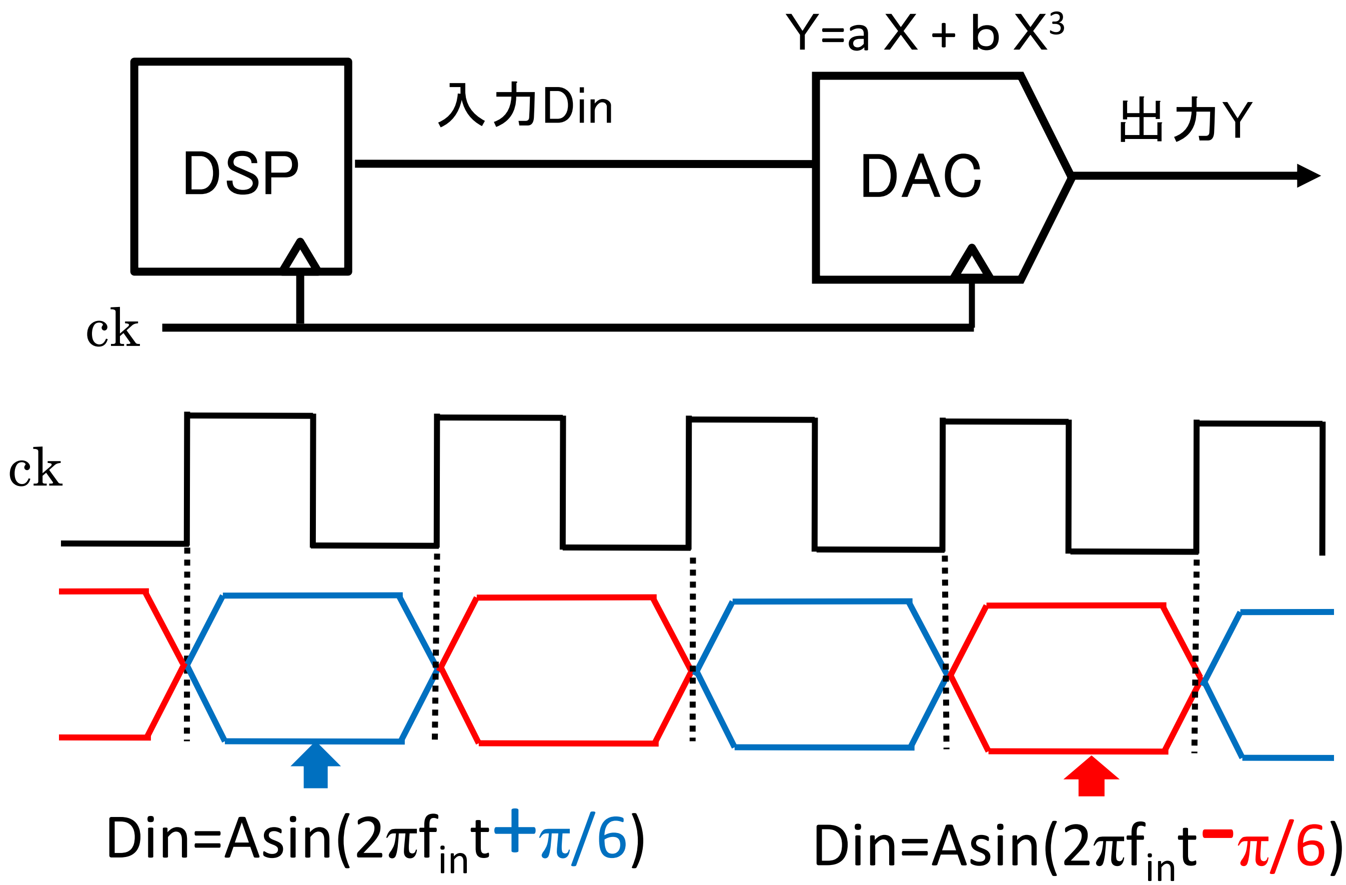
HD3, HD5, HD7 cancellation



8-interleave cancels HD3, HD5 & HD7.

Contents

Experimental Verification

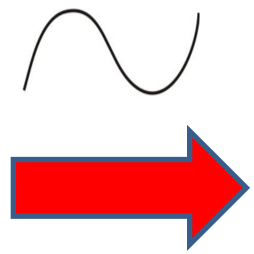


- Only DSP algorithm change in conventional AWG
- Single-tone generation with HD3 cancellation

Experiment Instrumentation

AWG
(Agilent 33120A)

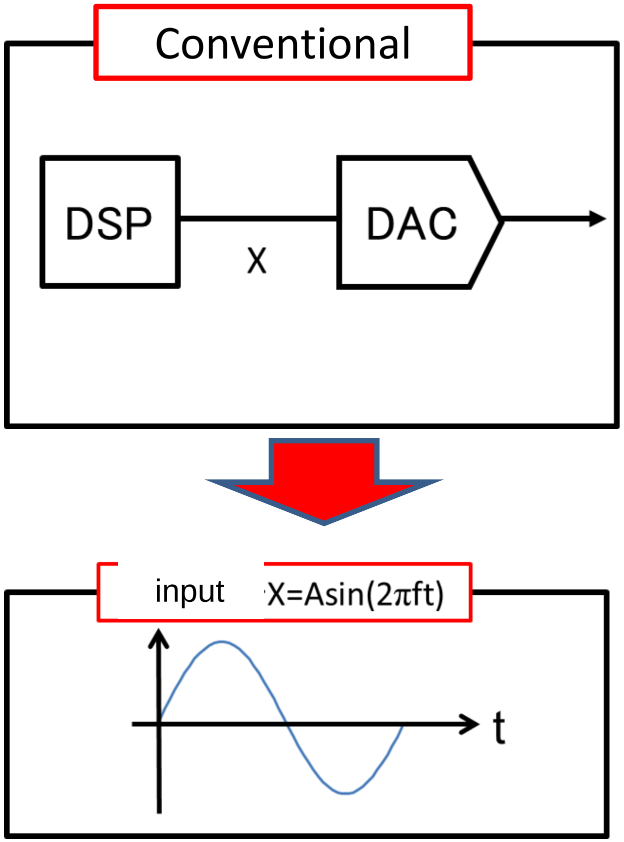
Max. Sampling frequency (Hz)	40M
Resolution (bit)	12
Linearity	△

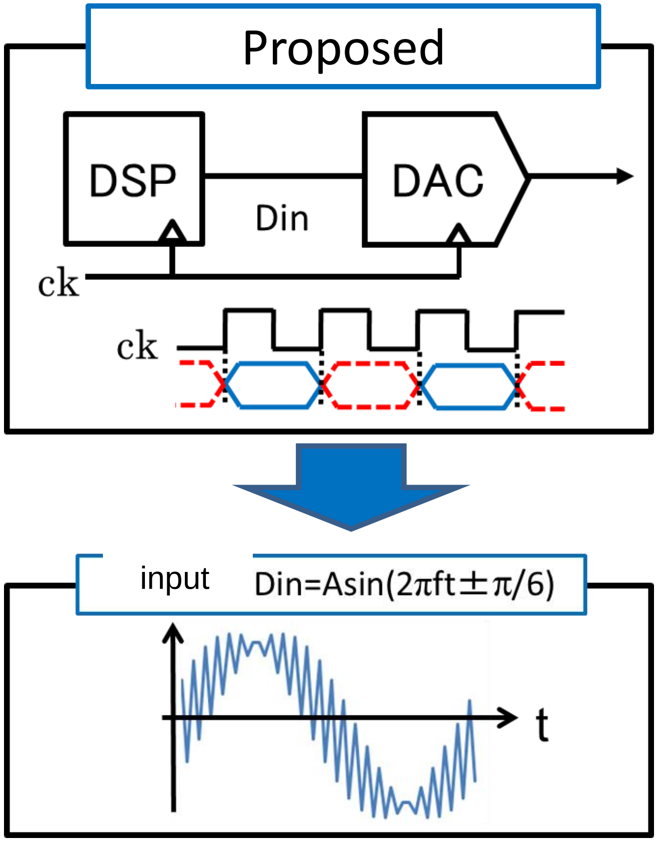


Spectrum Analyzer
(HP ESA-L1500A)

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

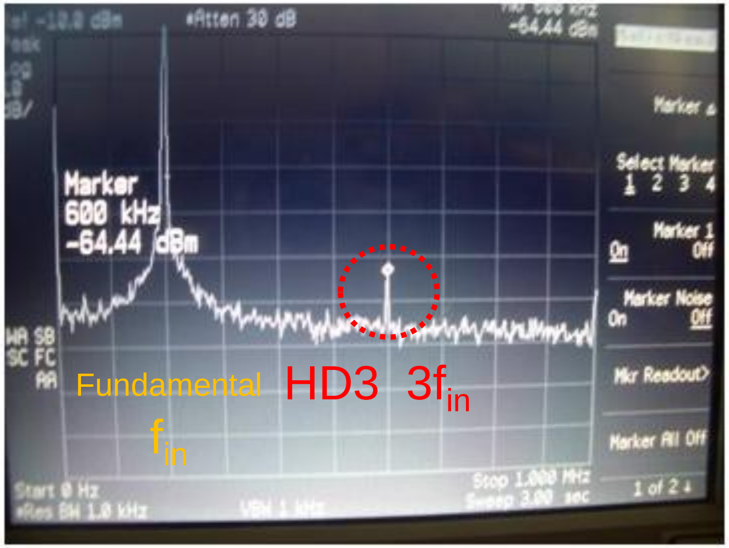
Experiment Condition





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

Conventional



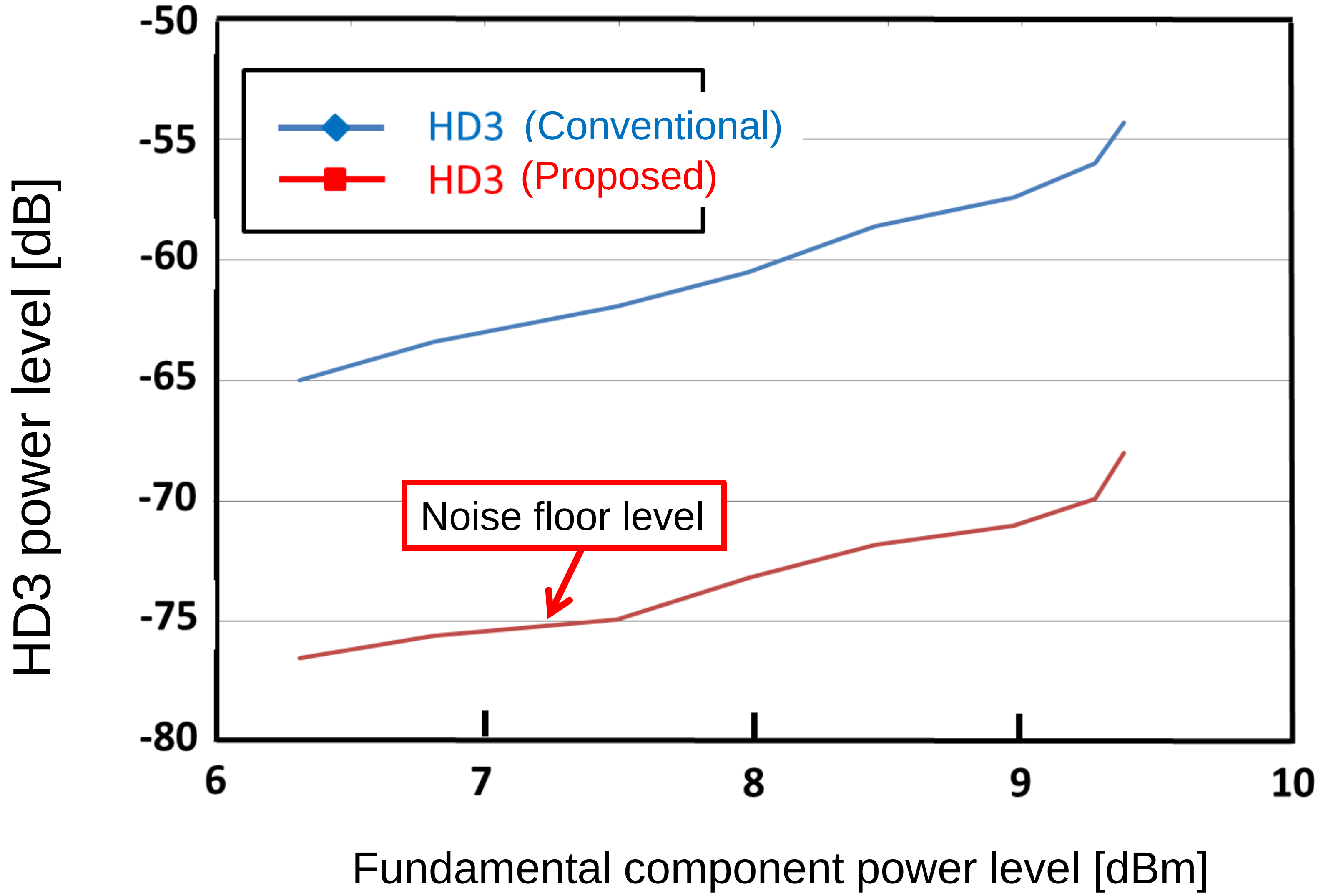
Proposed

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

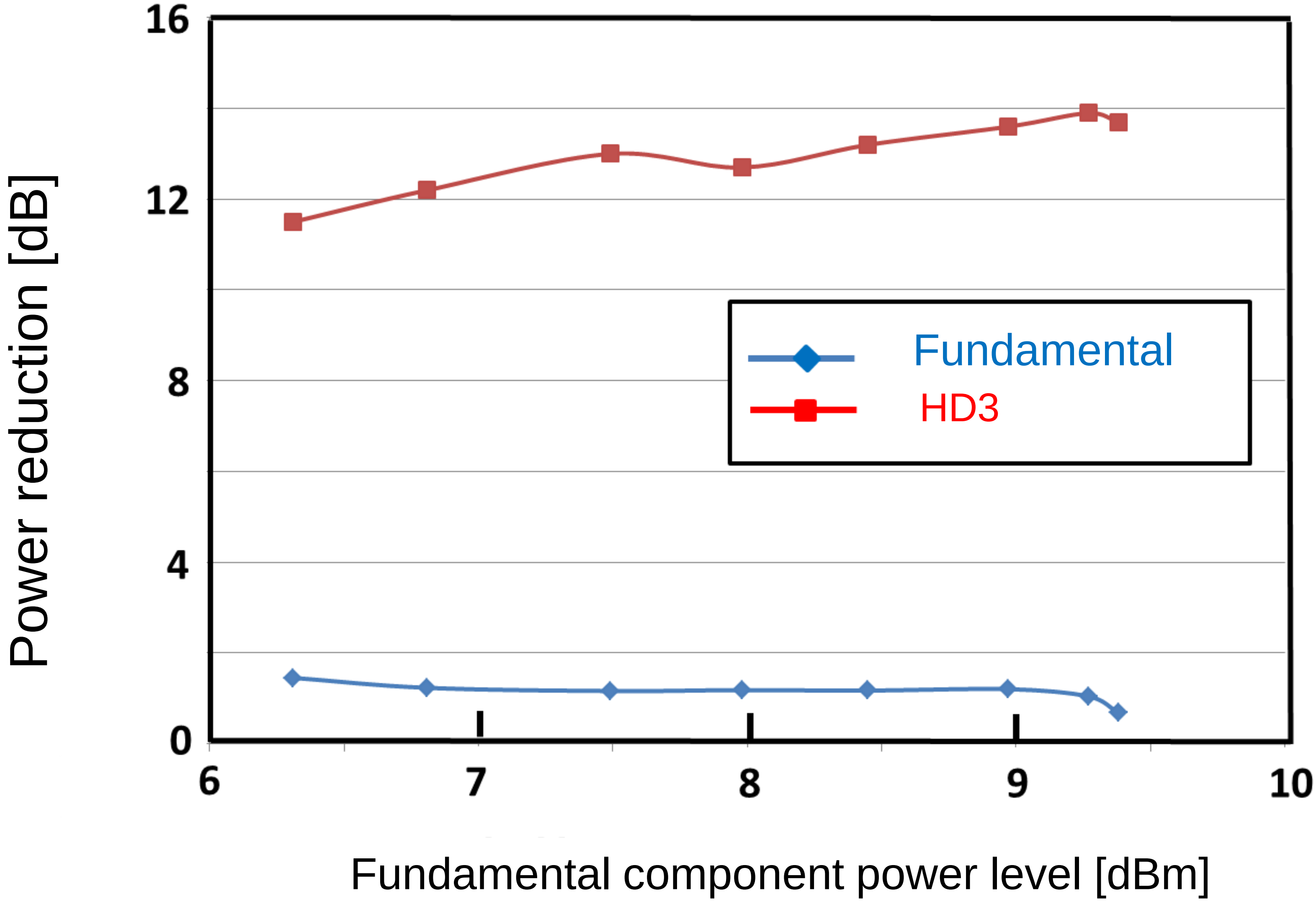
reduction

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