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Low-IMD Two-Tone Signal Generation for ADC Testing

K. Kato, F. Abe, K. Wakabayashi, T. Yamada,

H. Kobayashi, O. Kobayashi, K. Niitsu

Gunma University

Semiconductor Technology Academic Research Center

Presented by
Fumitaka ABE (安部文隆)

Outline

- Research Background
- Conventional Method
- Proposed Method
- Experimental Results
- Extension to ΔΣDAC
- Conclusion

Outline

- ***Research Background***
- **Conventional Method**
- **Proposed Method**
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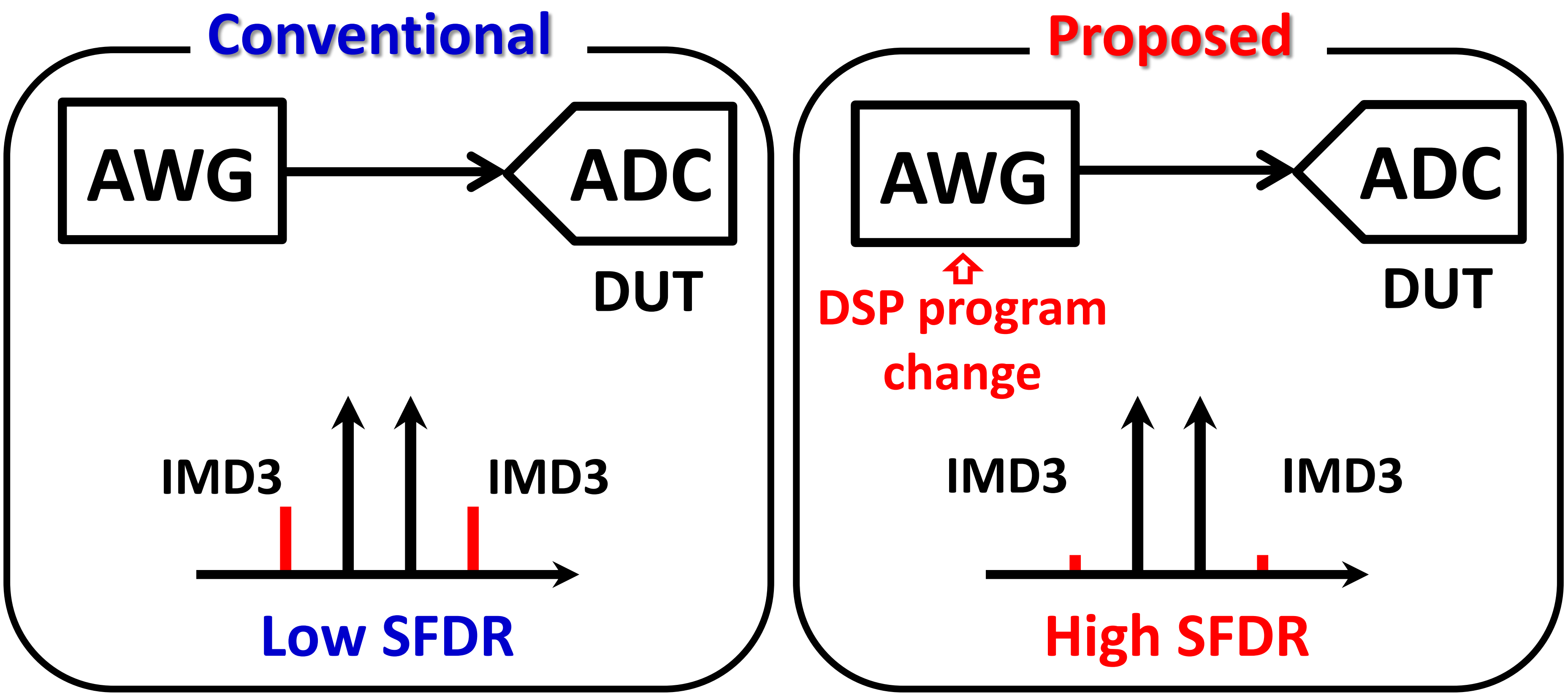
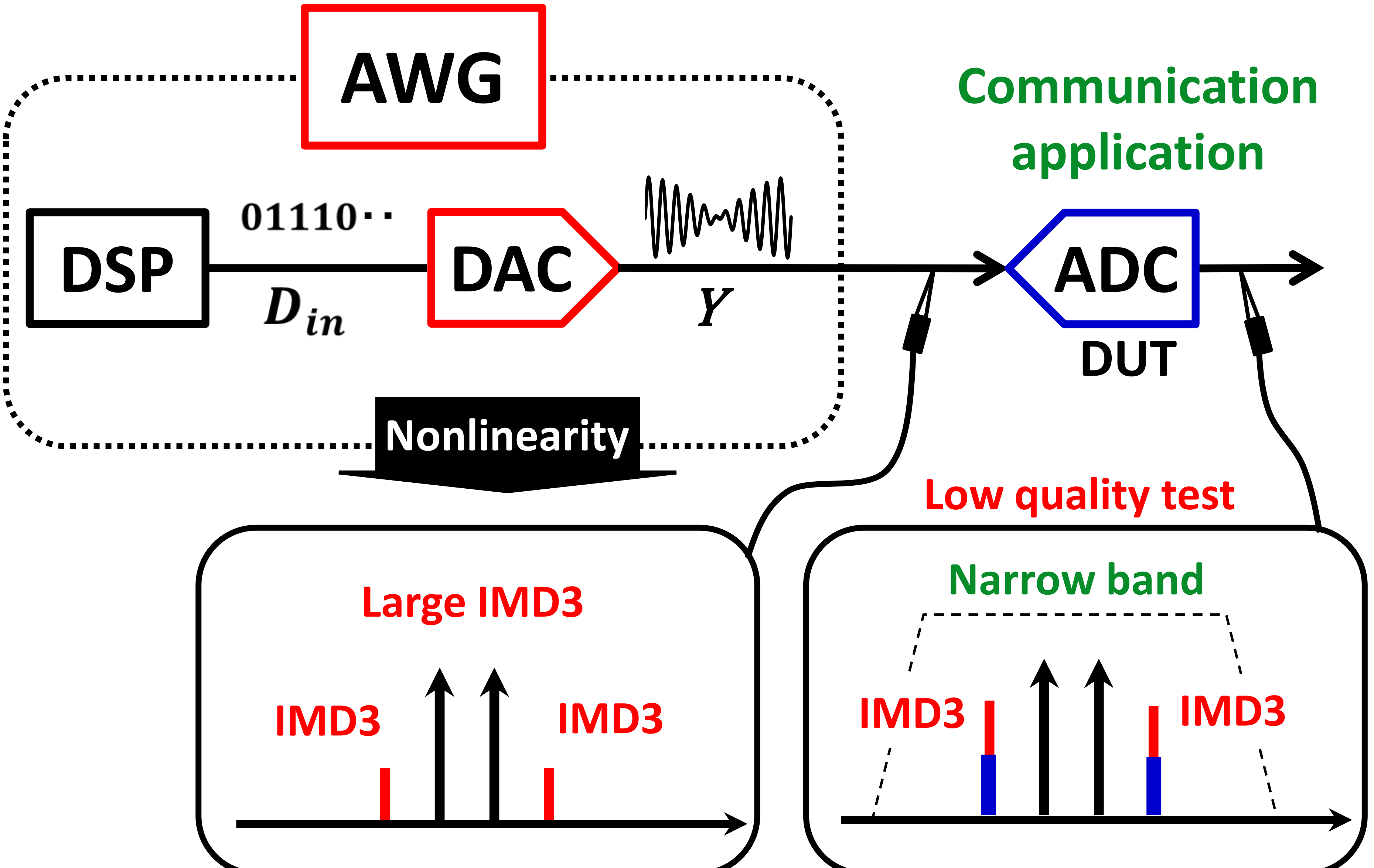
- **Conclusion**

Research Goal

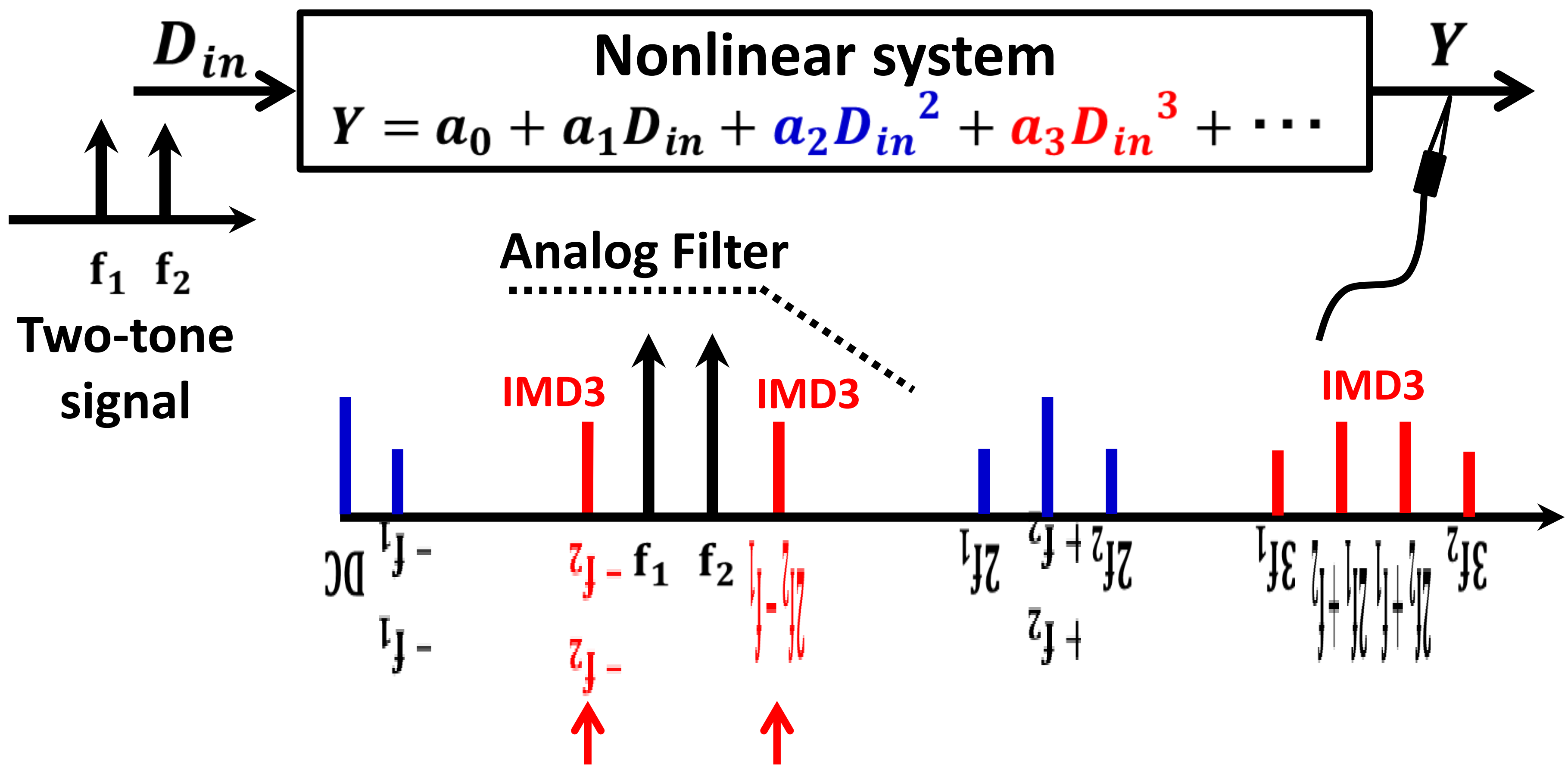
Low distortion two-tone signal generation for communication application ADC testing with low cost AWG by only changing DSP program



Two-Tone Generation with AWG



IMD3 is important for two tone signal !



Cannot remove with analog filter

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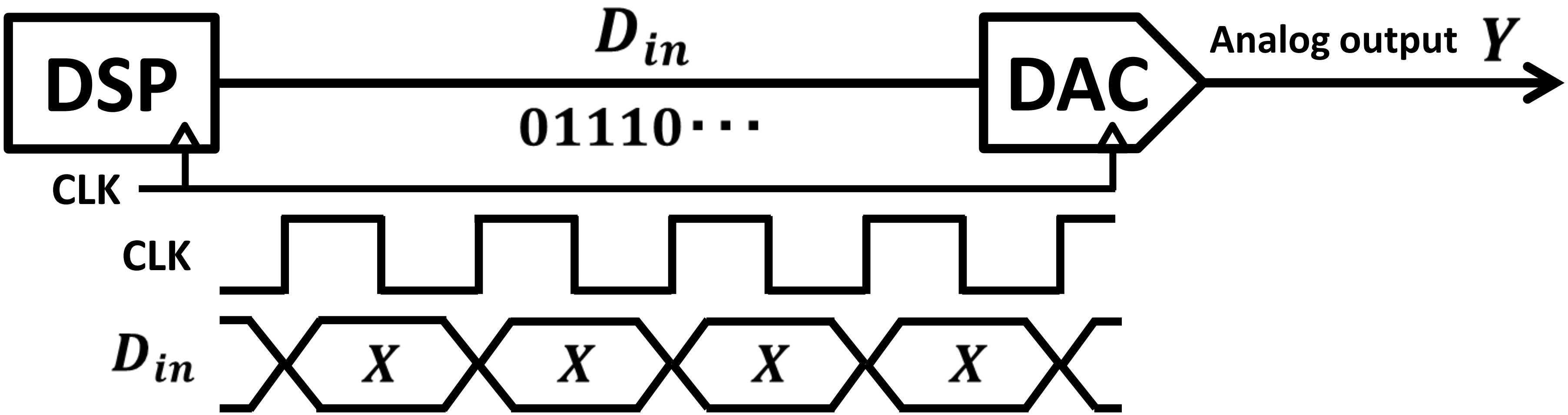
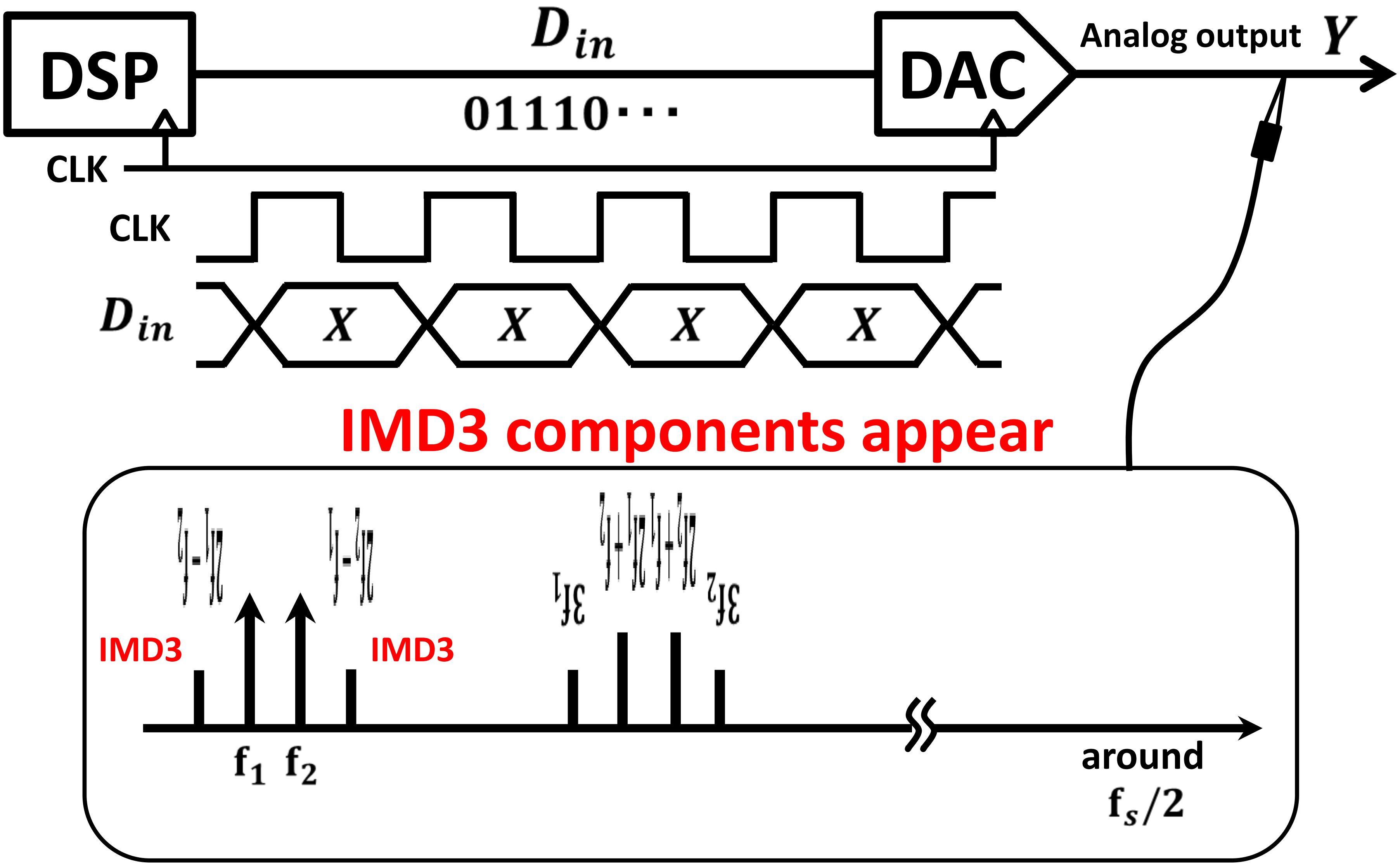
Conventional Method



$$X = A\cdot cos(2\pi f_1 nT_s) + A\cdot \cos(2\pi f_2 nT_s)$$

DAC Nonlinearity & IMD3

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



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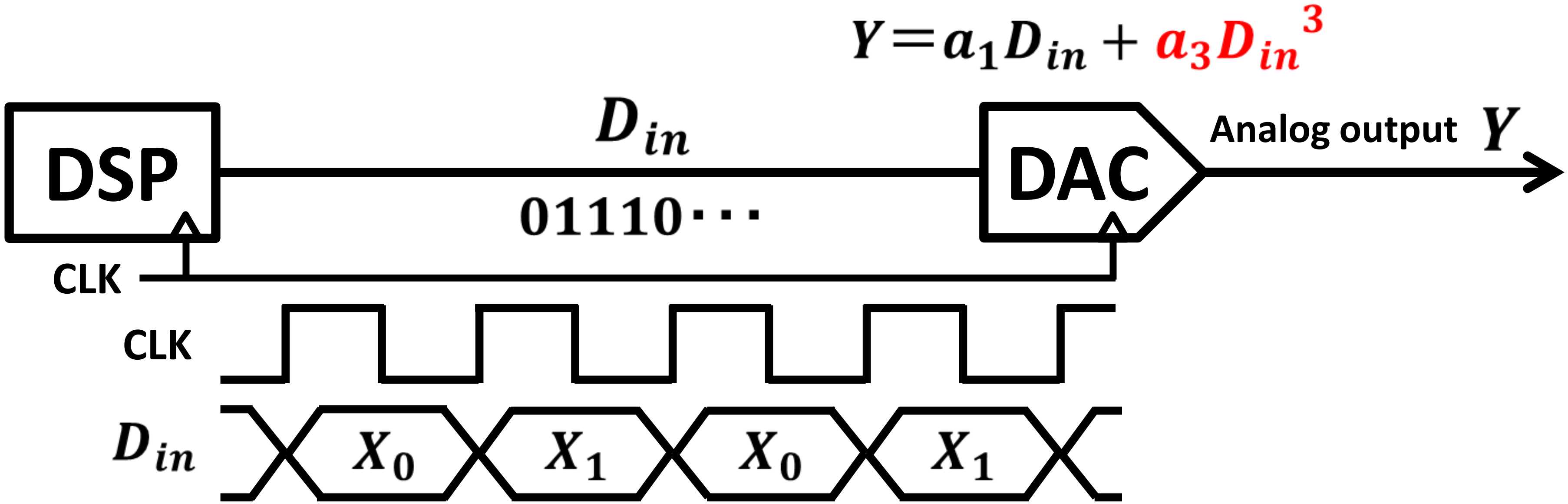
Four Proposed Techniques

- Phase Switching
- Frequency Switching
- Phase Frequency Switching
- Pre-Distortion

Four Proposed Techniques

- **Phase Switching**
- Frequency Switching
- Phase Frequency Switching
- Pre-Distortion

Phase Switching

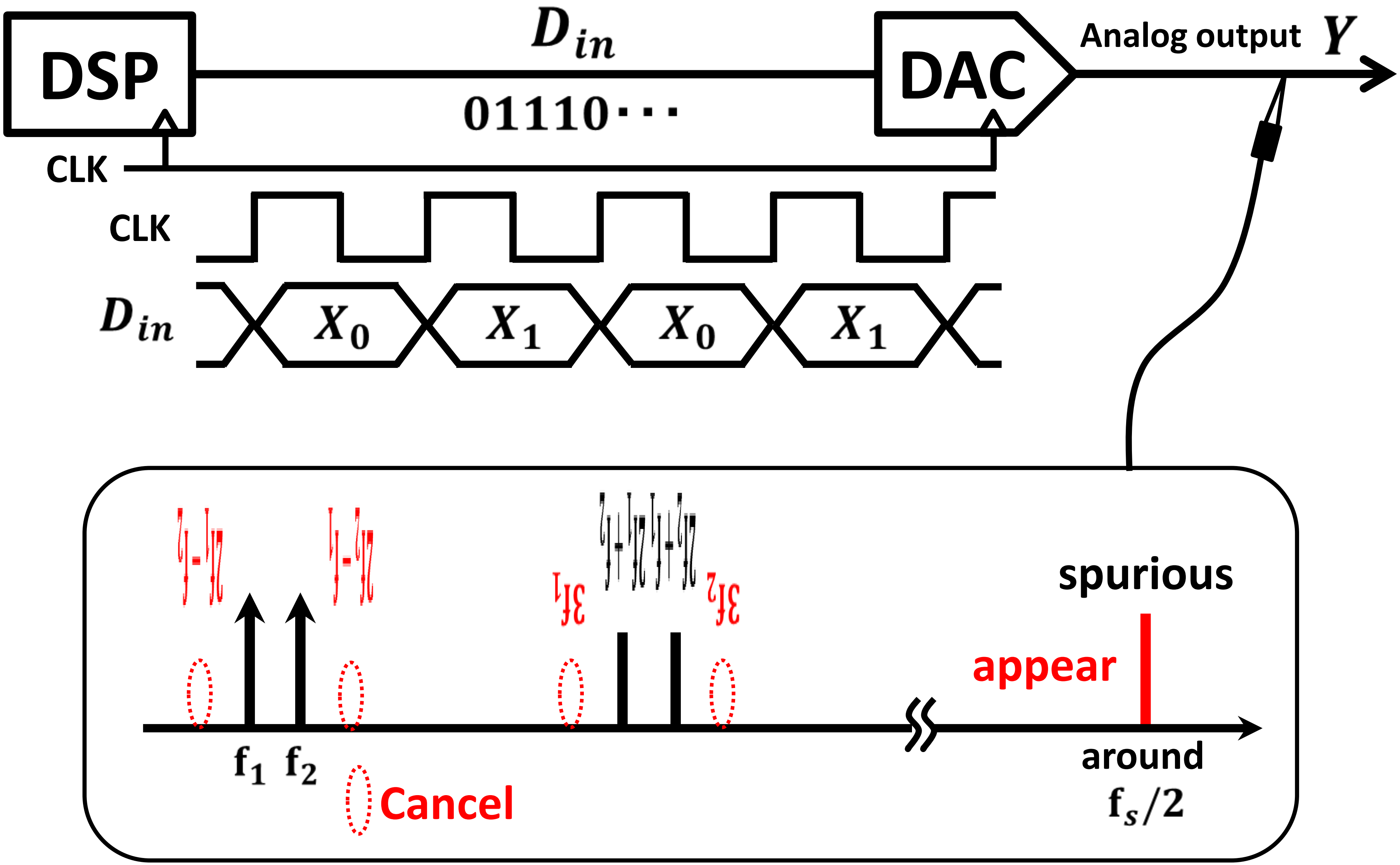


$$X_0 = A \cdot cos(2\pi f_1 (n-1)T_s) + A \cdot \cos(2\pi f_2 (n-1)T_s)$$

$$X_1 = A \cdot cos(2\pi f_1 n T_s + \pi/3) + A \cdot \cos(2\pi f_2 n T_s - \pi/3)$$

Phase Switching Effects

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

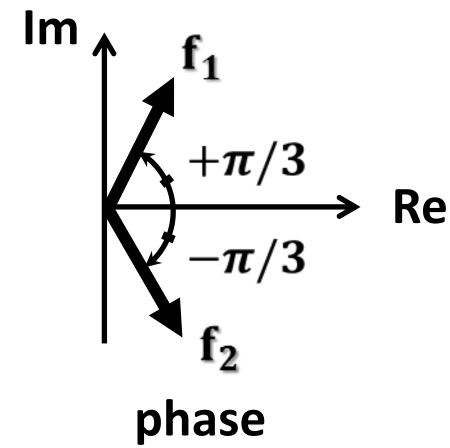


Principle of Phase Switching

Fundamental

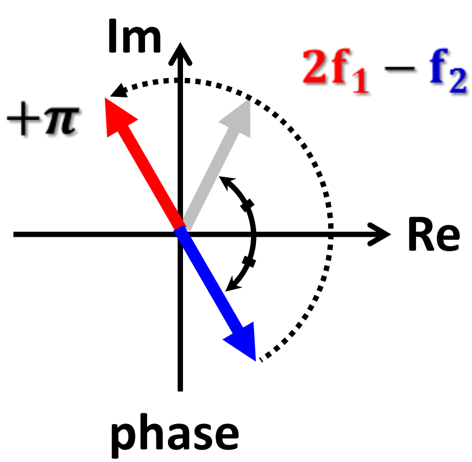
$$\mathbf{f_1} \ : \ \text{phase} \quad +\frac{\pi}{3}$$

$$\mathbf{f_2} \ : \ \text{phase} \quad -\frac{\pi}{3}$$



Inter-Modulation

IMD3 $\quad \mathbf{2f_1 - f_2} \ : \ \text{phase} \quad 2 \times \left(+\frac{\pi}{3}\right) - \left(-\frac{\pi}{3}\right) = +\pi$



Phase difference by π

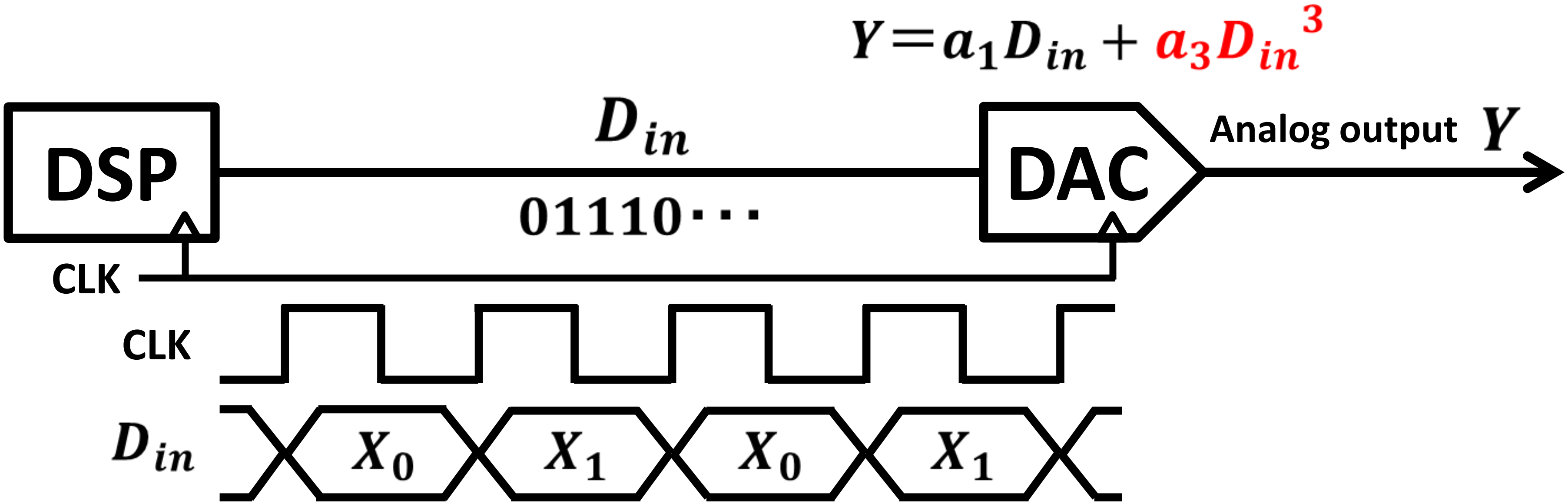
Cancel

$$\mathbf{2f_1 - f_2}$$

Four Proposed Techniques

- Phase Switching
- **Frequency Switching**
- Phase Frequency Switching
- Pre-Distortion

Frequency Switching

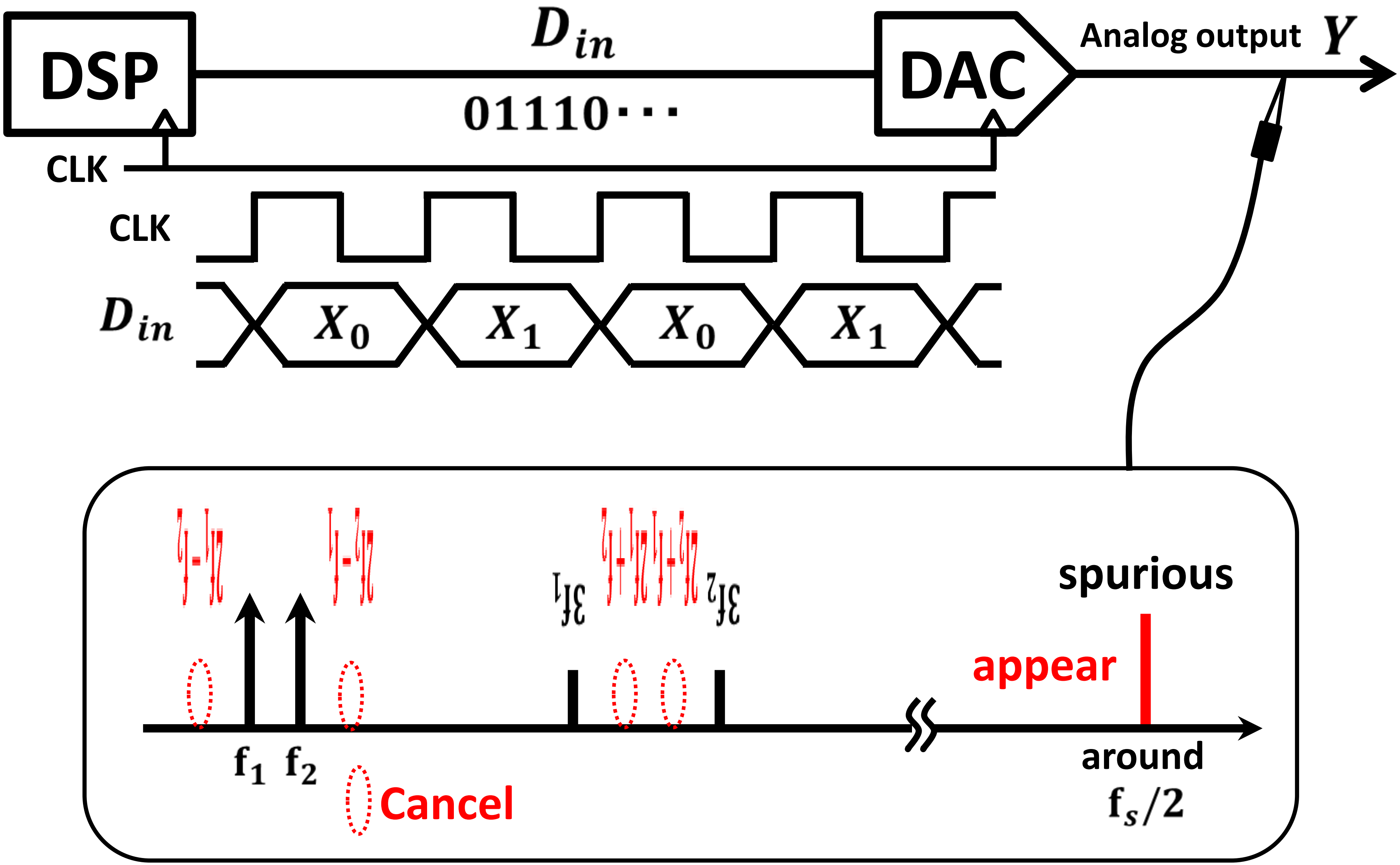


$$X_0 = 2A \cdot cos(2\pi f_1 (n-1) T_s)$$

$$X_1 = 2A \cdot cos(2\pi f_2 n T_s)$$

Frequency Switching Effects

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

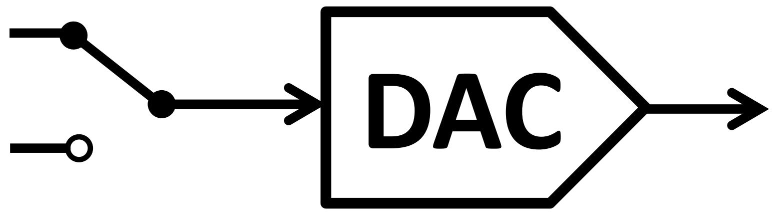


Principle of Frequency Switching

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

$2A\sin(\omega_1 n T_s)$

$2A\sin(\omega_2 n T_s)$



$2A'\sin(\omega_1 n T_s)$

$2A'\sin(\omega_2 n T_s)$

$B\sin(3\omega_1 n T_s)$

$B\sin(3\omega_2 n T_s)$

$+ \alpha$

α : around $f_s/2$ Spurious components

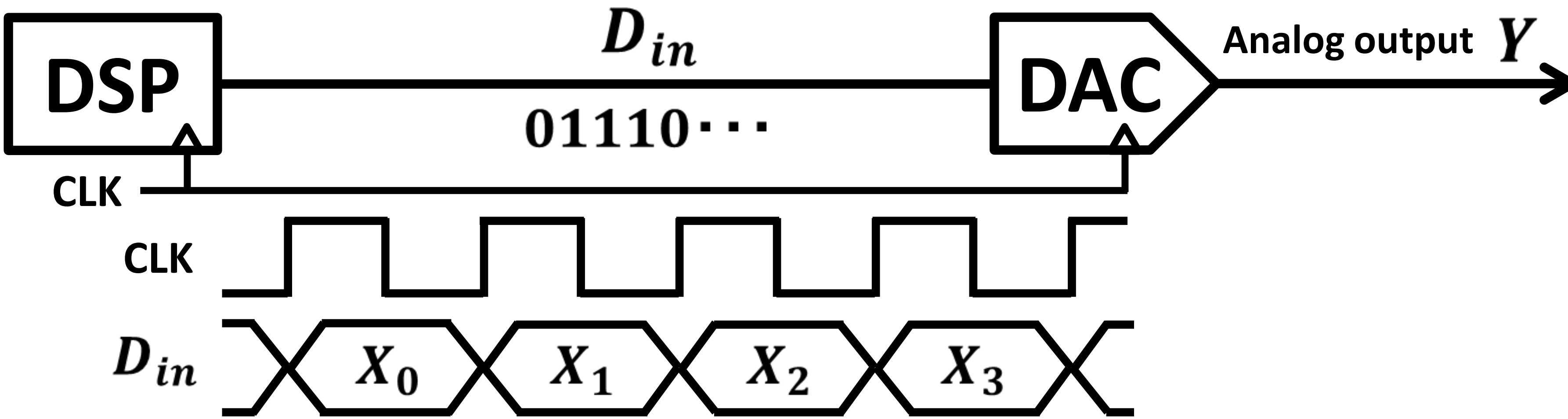
In principle, IMD components do not appear

Four Proposed Techniques

- Phase Switching
- Frequency Switching
- **Phase Frequency Switching**
- Pre-Distortion

Phase Frequency Switching

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



$$X_0 = A \cdot cos(2\pi f_1 (n-3) T_s)$$

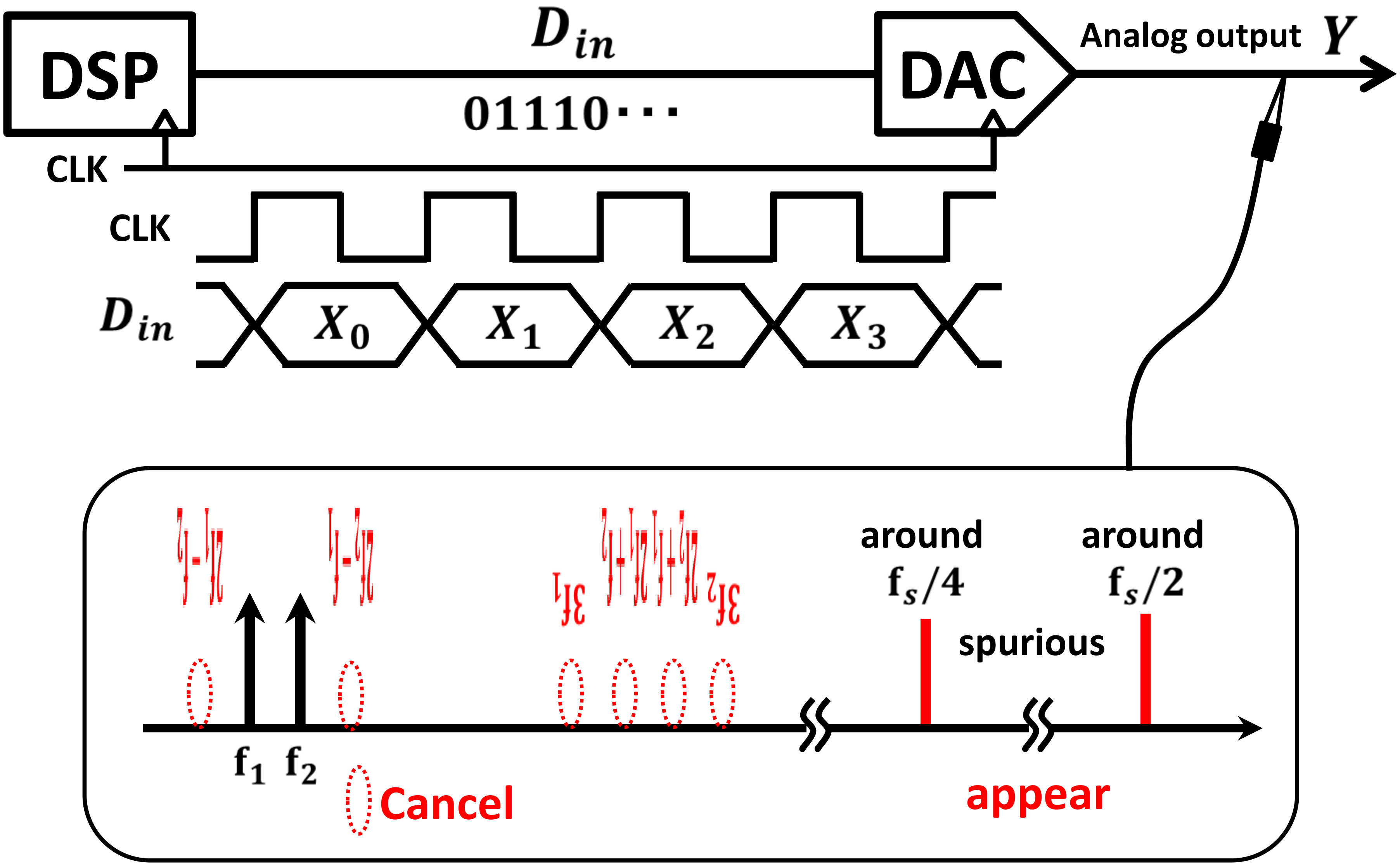
$$X_1 = A \cdot cos(2\pi f_1 (n-2) T_s + \pi/3)$$

$$X_2 = A \cdot cos(2\pi f_2 (n-1) T_s)$$

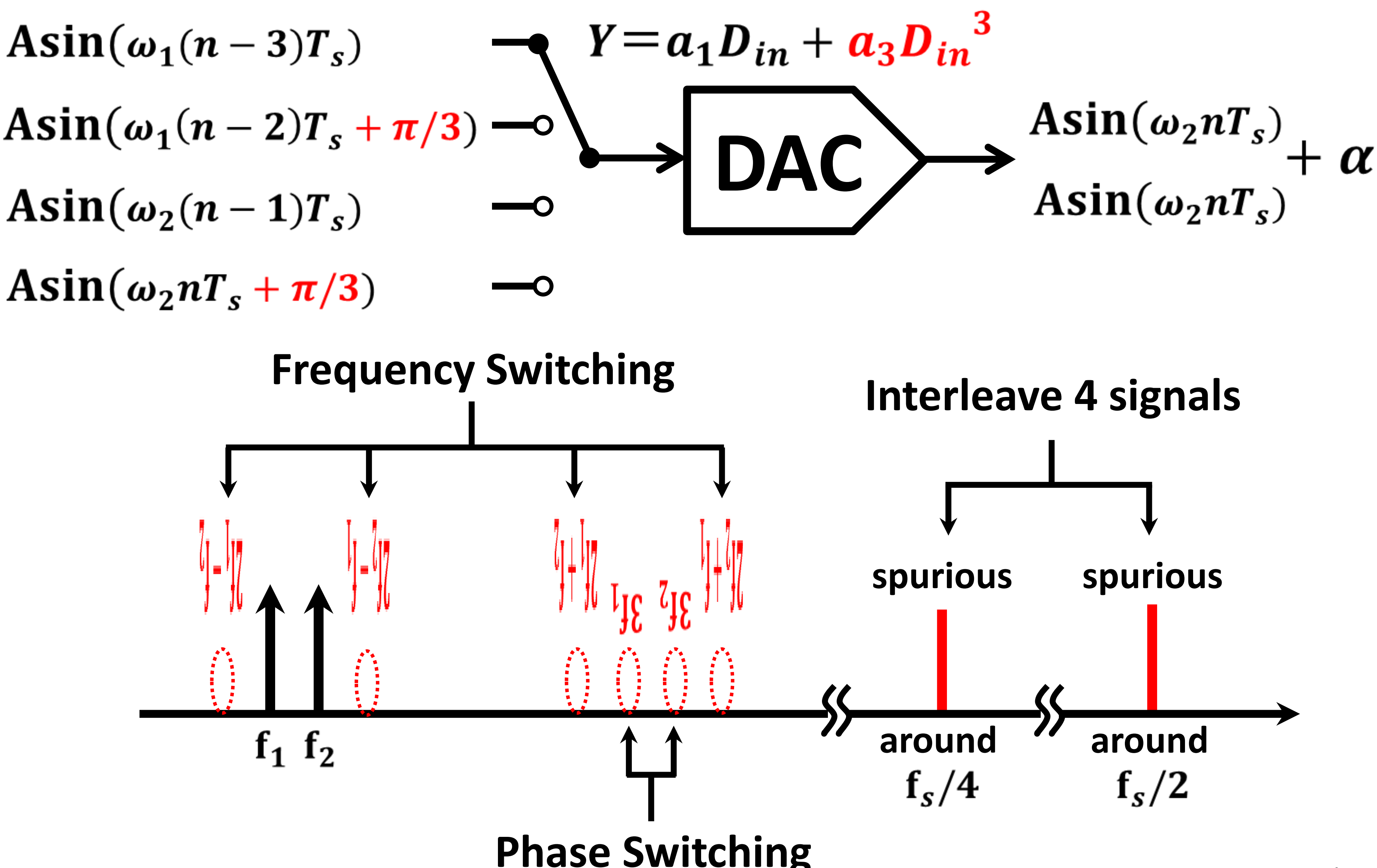
$$X_3 = A \cdot cos(2\pi f_2 n T_s + \pi/3)$$

Phase Frequency Switching Effects

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



Principle of Phase Frequency Switching

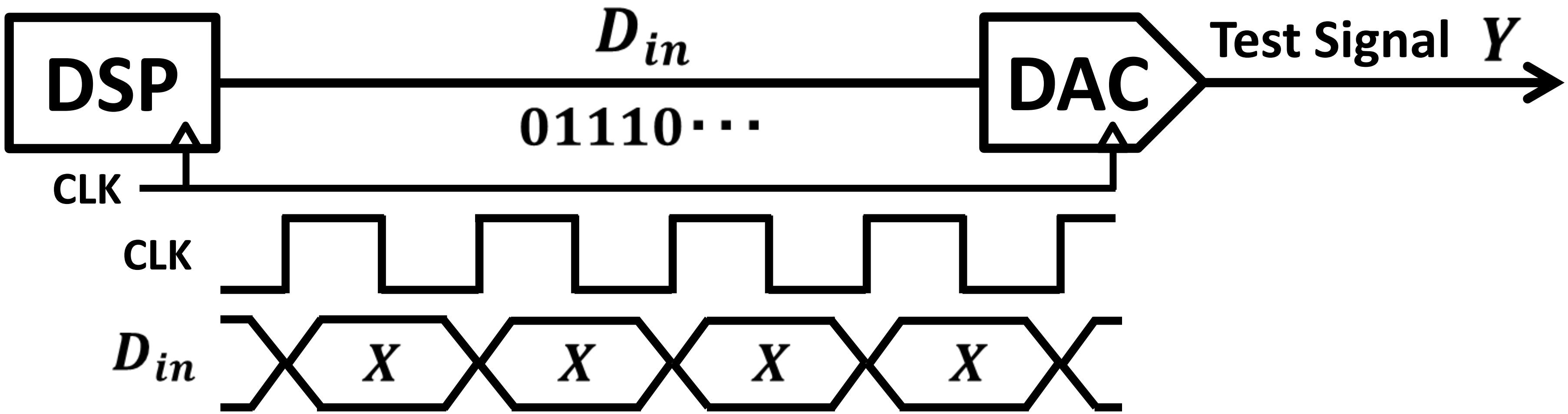


Four Proposed Techniques

- Phase Switching
- Frequency Switching
- Phase Frequency Switching
- **Pre-Distortion**

Pre-Distortion

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

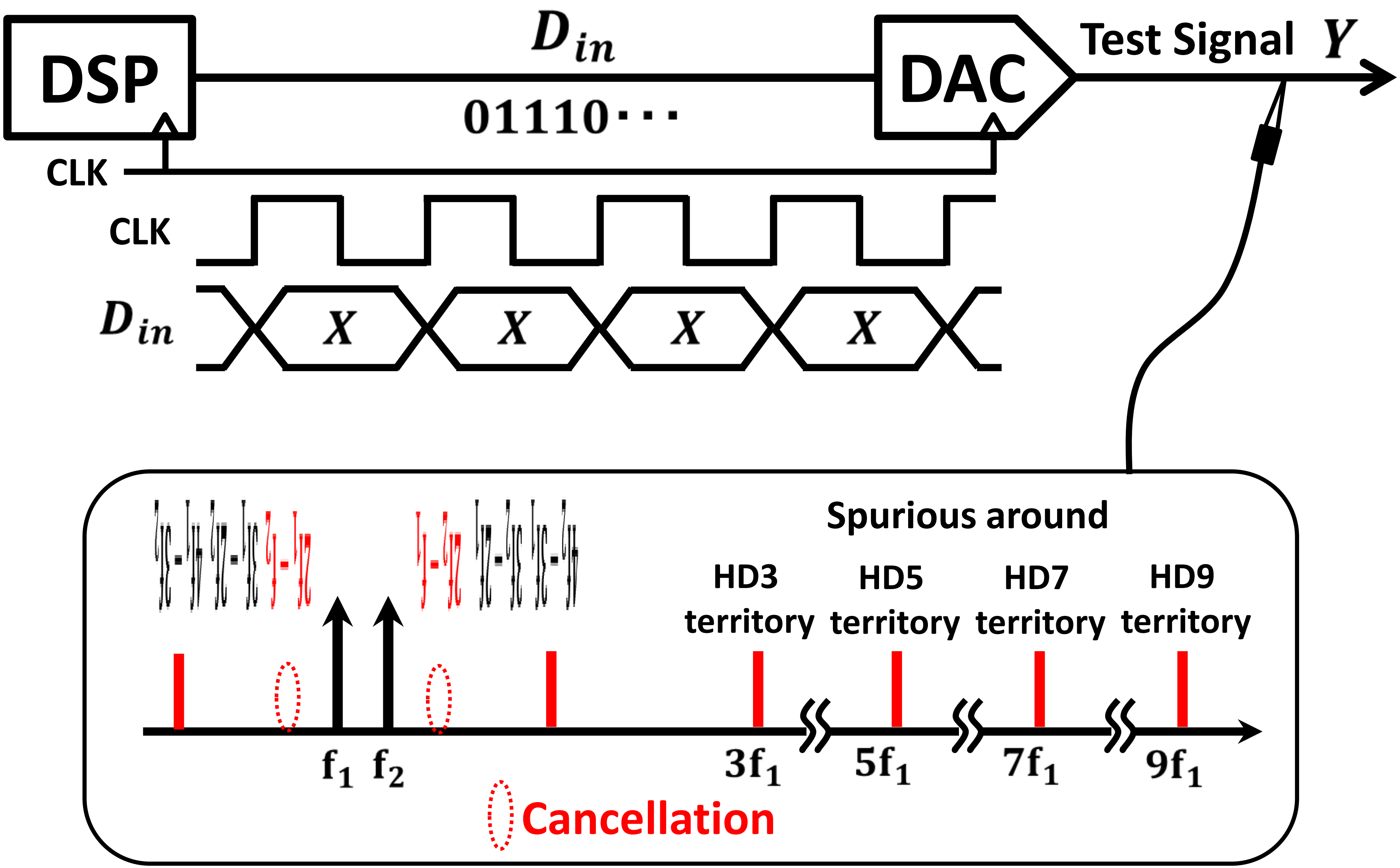


Add HD3 components in Din.

$$X = A \cdot cos(2\pi f_1 nT_s) + A \cdot cos(2\pi f_1 nT_s)$$
$$+ A/2 \cdot cos(2\pi (3f_1) nT_s) + A/2 \cdot cos(2\pi (3f_2) nT_s)$$

Effect of Pre-Distortion

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



Principle of Pre-Distortion

D_{in}

$A\sin(\omega_1 nT_s)$

$+$

$A\sin(\omega_2 nT_s)$

$+$

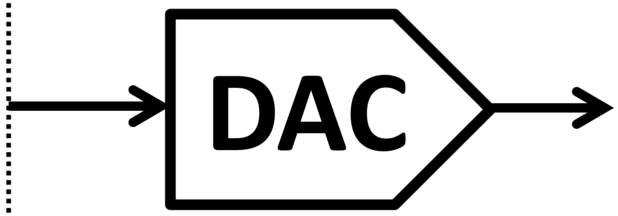
$B\sin(3\omega_1 nT_s)$

$+$

$C\sin(3\omega_2 nT_s)$

Pre-Distortion Components

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



$$\left(\frac{3A^3 a_3}{4}\right)\sin(2\omega_1 - \omega_2)nT_s$$

$+$

$$\left(-\frac{3A^2 B a_3}{2}\right)\sin(2\omega_1 - \omega_2)nT_s$$

$+$

$$\left(\frac{3A^3 a_3}{4}\right)\sin(2\omega_2 - \omega_1)nT_s$$

$+$

$$\left(-\frac{3A^2 C a_3}{2}\right)\sin(2\omega_2 - \omega_1)nT_s$$

$+$

Fundamental
& Spurious

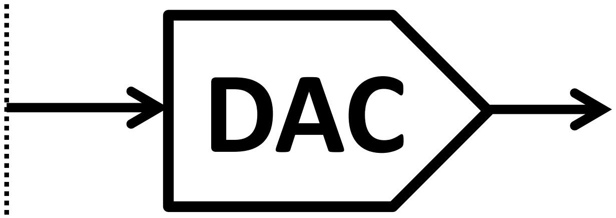
Principle of Pre-Distortion

D_{in}

$A\sin(\omega_1 nT_s)$
$+$
$A\sin(\omega_2 nT_s)$
$+$
$B\sin(3\omega_1 nT_s)$
$+$
$C\sin(3\omega_2 nT_s)$

Pre-Distortion Components

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



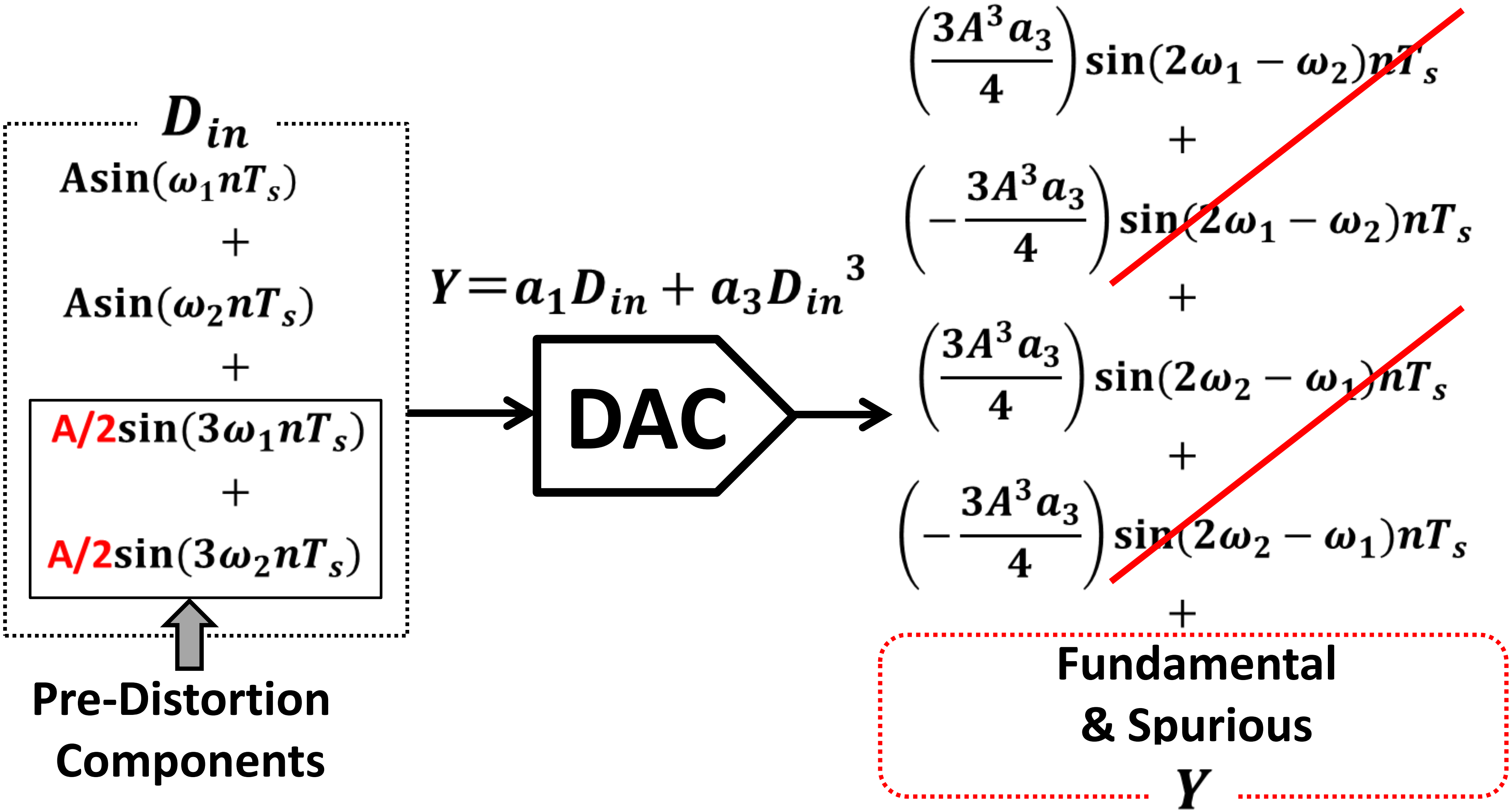
$$\left(\frac{3A^3 a_3}{4}\right)\sin(2\omega_1 - \omega_2)nT_s$$
$$+$$
$$\left(-\frac{3A^2 B a_3}{2}\right)\sin(2\omega_1 - \omega_2)nT_s$$
$$+$$
$$\left(\frac{3A^3 a_3}{4}\right)\sin(2\omega_2 - \omega_1)nT_s$$
$$+$$
$$\left(-\frac{3A^2 C a_3}{2}\right)\sin(2\omega_2 - \omega_1)nT_s$$
$$+$$

Fundamental & Spurious

IMD3 Cancel

$$B = C = \frac{A}{2}$$

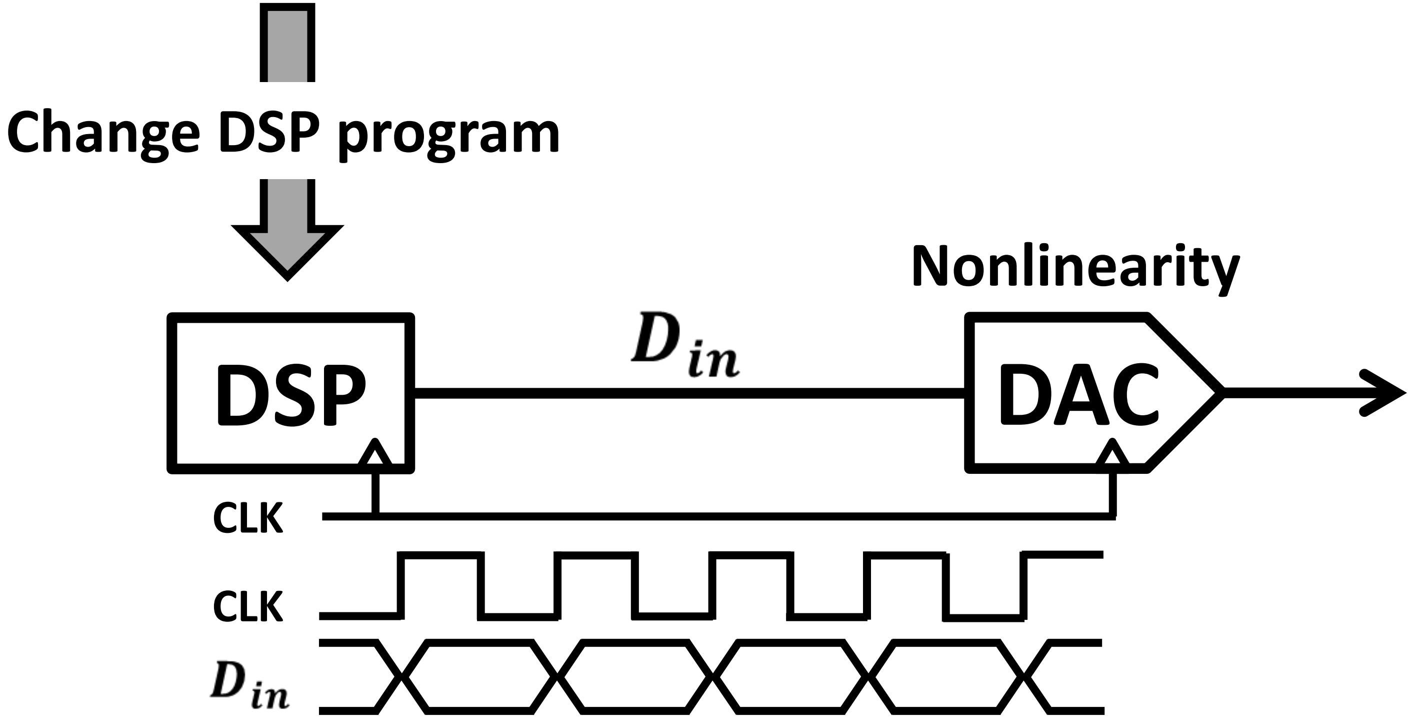
Principle of Pre-Distortion



IMD3 components disappear

Proposed Low IMD3 Two-tone Generation

$$D_{in} = X = A \cdot cos(2\pi f_1 n T_s) + A \cdot cos(2\pi f_2 n T_s)$$

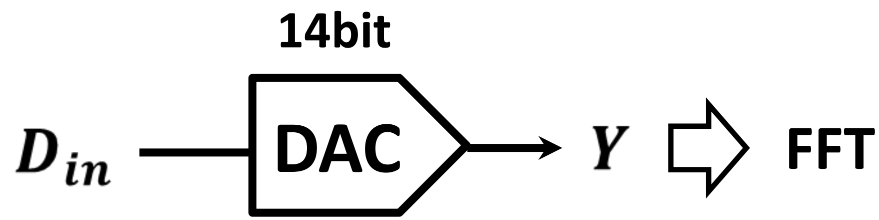


- **No hardware change**
- **No need for calibration**
- **No need for DAC nonlinearity identification**

Simulation Conditions

D_{in}

- Conventional Test Signal
- 4 Proposed Test Signal

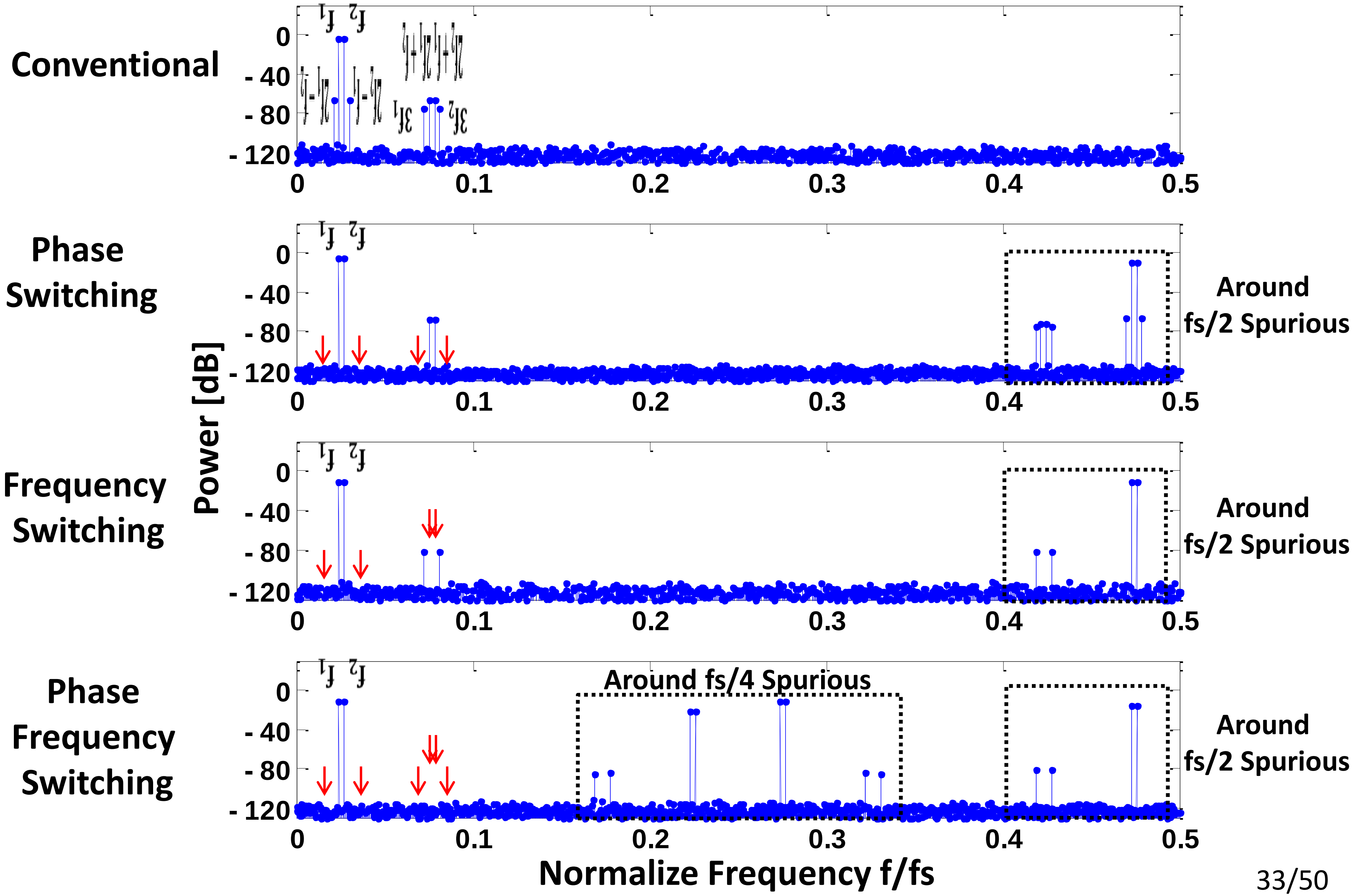


$$Y = D_{in} - 0.003{D_{in}}^3$$

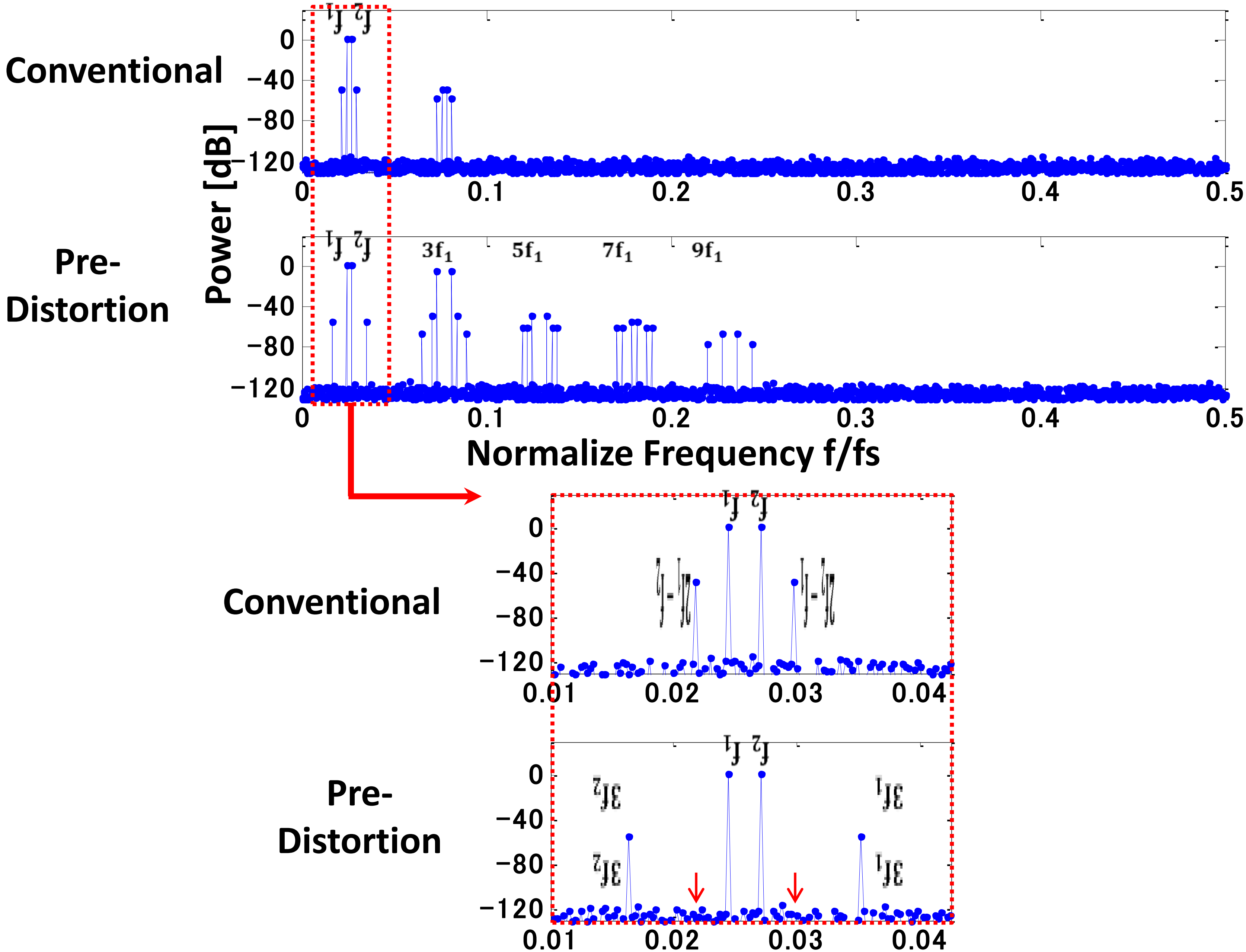
D_{in} $Signal$ Parameter

Sampling Points	4096
Two-tone Signal	$\mathrm{f}_1 = 99$ $\mathrm{f}_2 = 111$
Amplitude (peak-to-peak)	1.2

Phase, Frequency, Phase Freq. Switching



Pre-Distortion



Output Power Spectrum Comparison

	Disappear	Appear
Conventional		$2f_1 - f_2$ $2f_2 - f_1$
Phase Switching	$2f_1 - f_2$ $2f_2 - f_1$ $3f_1$ $3f_2$	Around $f_s/2$
Frequency Switching	$2f_1 - f_2$ $2f_2 - f_1$ $2f_1 + f_2$ $2f_2 + f_1$	Around $f_s/2$
Phase & Freq. Switching	$2f_1 - f_2$ $2f_2 - f_1$ $2f_1 + f_2$ $2f_2 + f_1$ $3f_1$ $3f_2$	Around $f_s/2$ $f_s/4$
Pre-Distortion	$2f_1 - f_2$ $2f_2 - f_1$	$4f_1 - 3f_2$ $4f_2 - 3f_1$ Around $3f_1$ $5f_1$ $7f_1$ $9f_1$

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Experimental Conditions

AWG

Agilent 33220A

Signal →

Spectrum analyzer

ADVANTEST R3267

Frequency characteristic	1μHz~6MHz
Amplitude Resolution	14bits
Maximum Sampling Rate	50MSa/s

Frequency band	100Hz~8GHz
RBW	10Hz~30MHz

※ RBW : Resolution Band Width

Test Signal

Two-tone Signal	200kHz , 220kHz
Sampling rate	10MSa/s
Input Voltage	0.8~2.0V_{pp} (0.2V steps)
Offset	0

Experimental Results

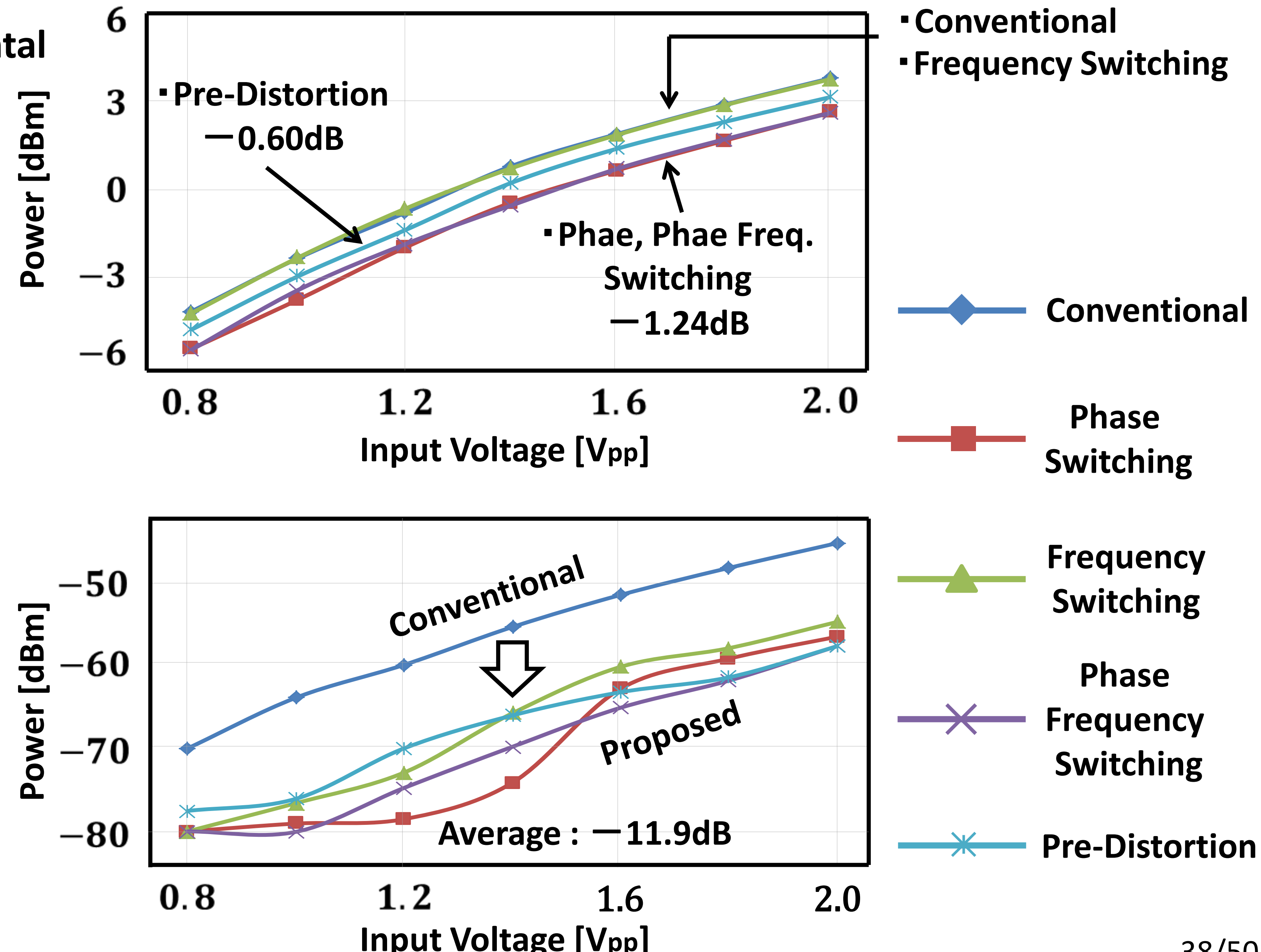
Fundamental

f_1 f_2

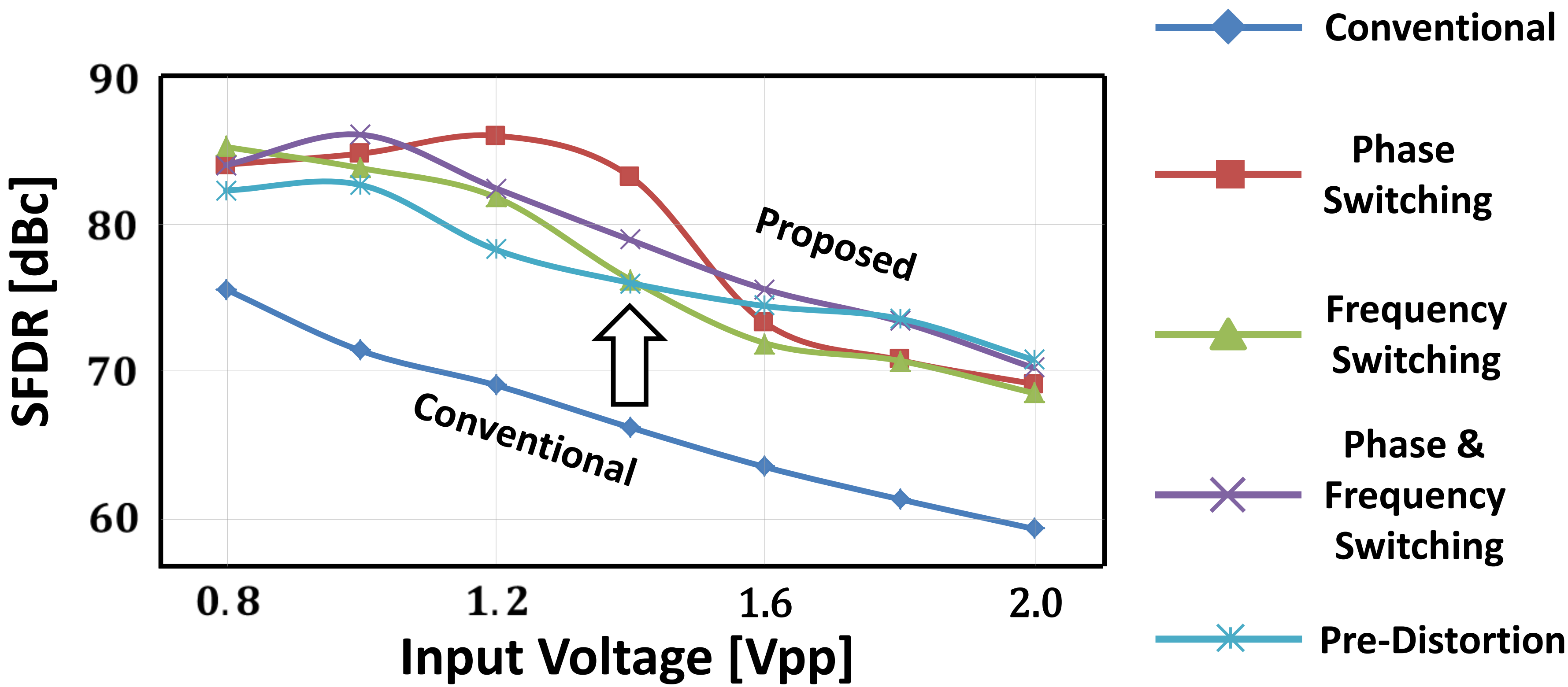
IMD3

$2f_1 - f_2$

$2f_2 - f_1$

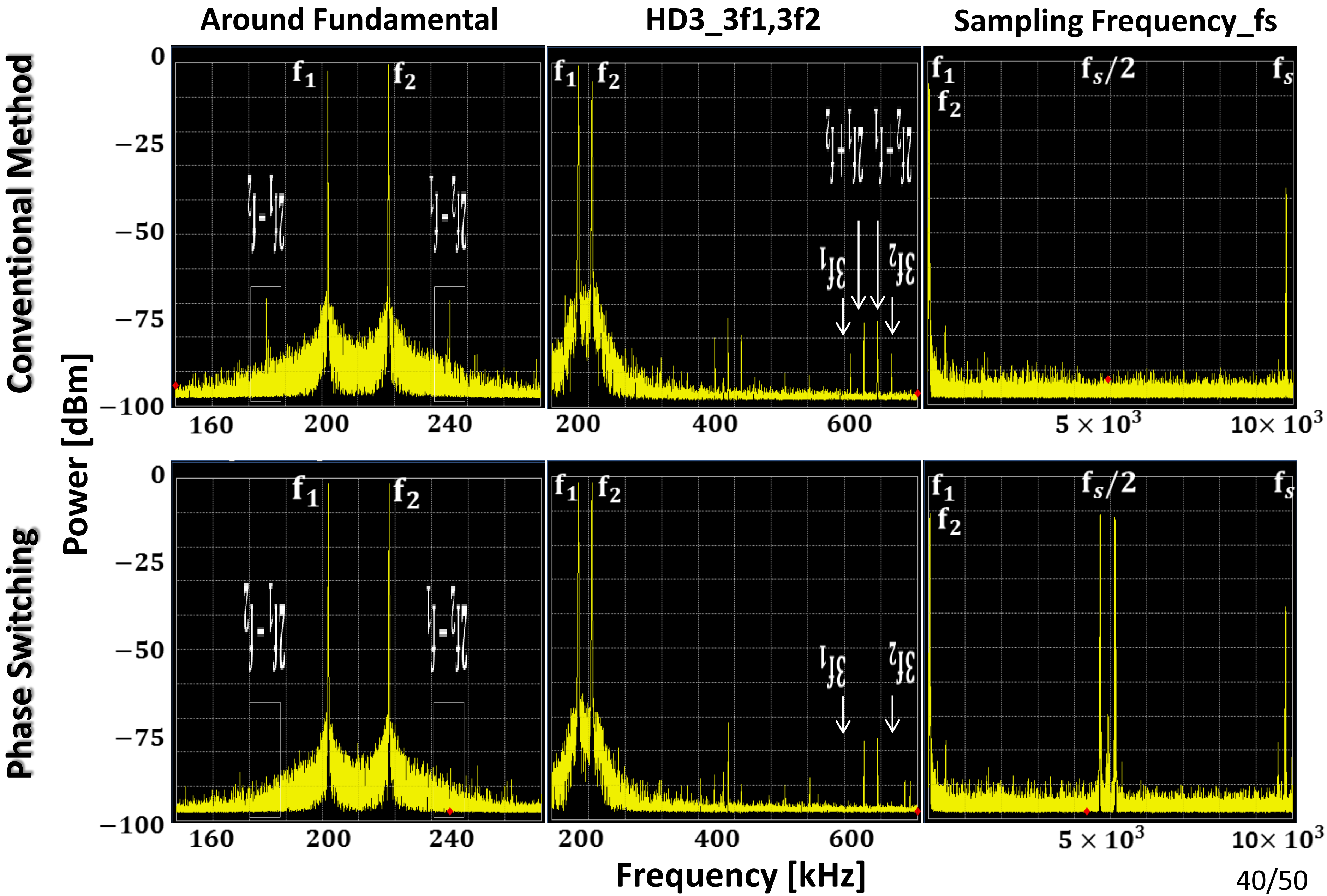


SFDR Improvement

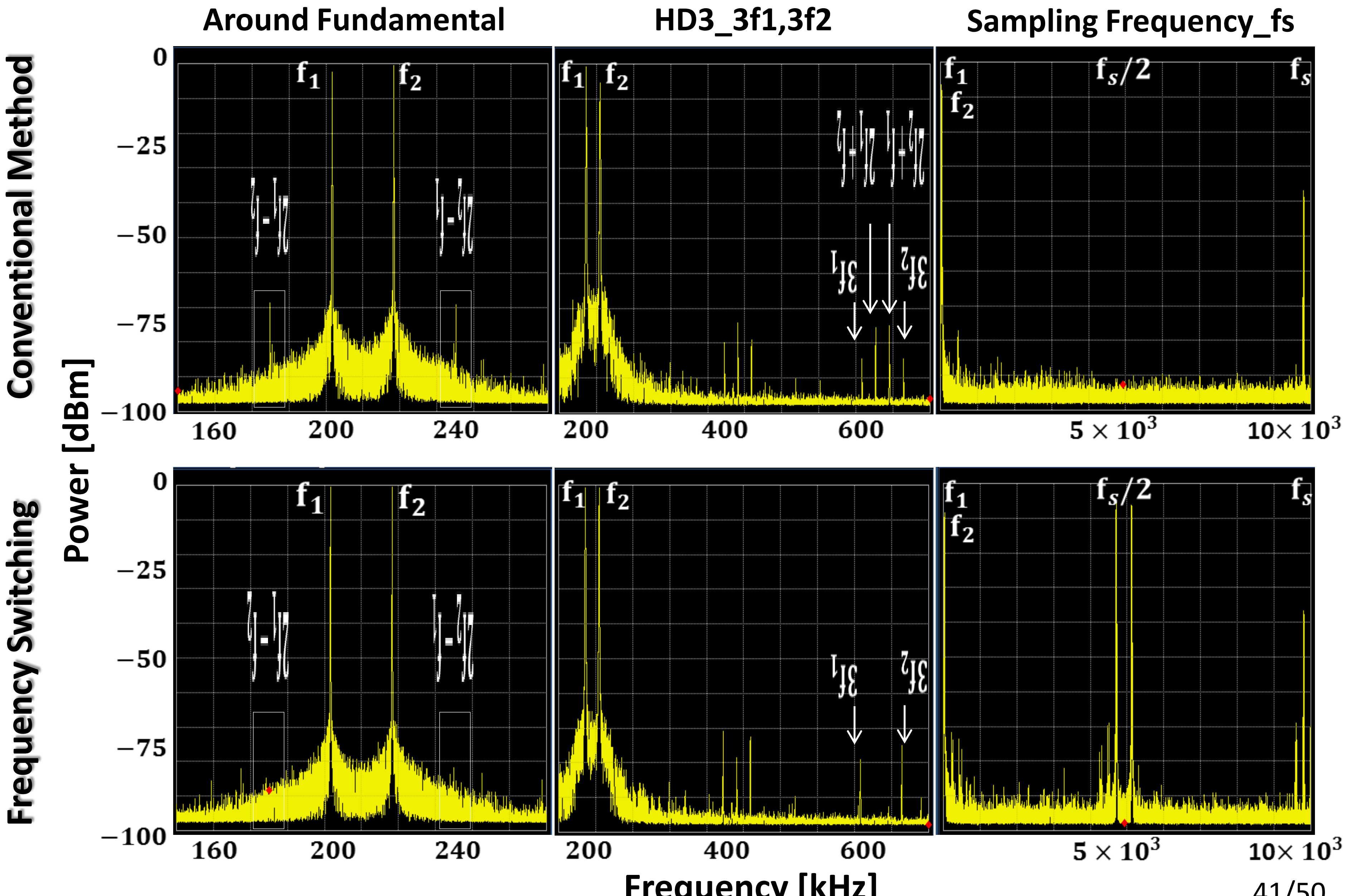


Phase Switching	Frequency Switching	Phase Frequency Switching	Pre-Distortion
+ 12.5 dB	+ 10.6 dB	+ 12.4 dB	+ 10.5 dB

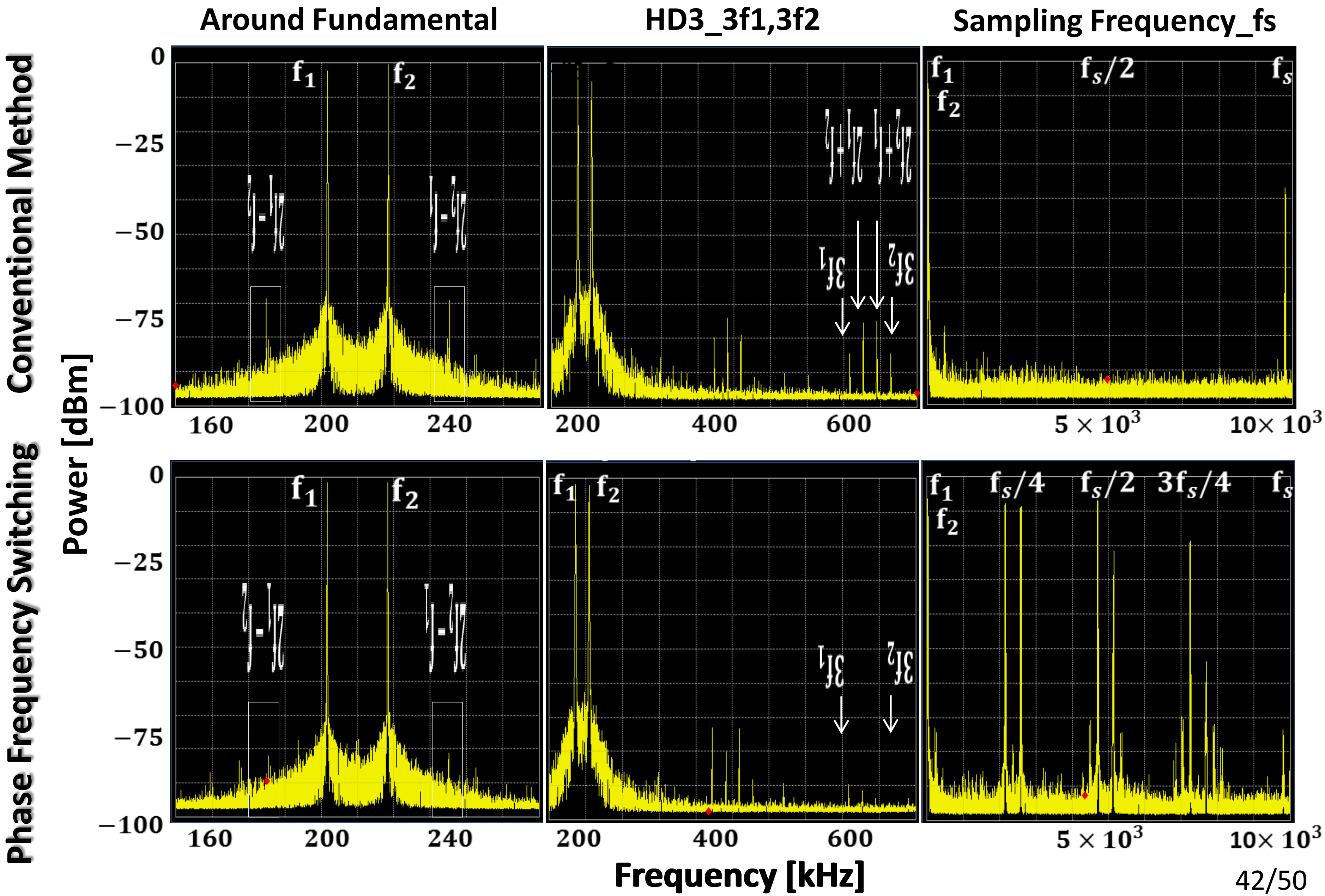
Phase Switching



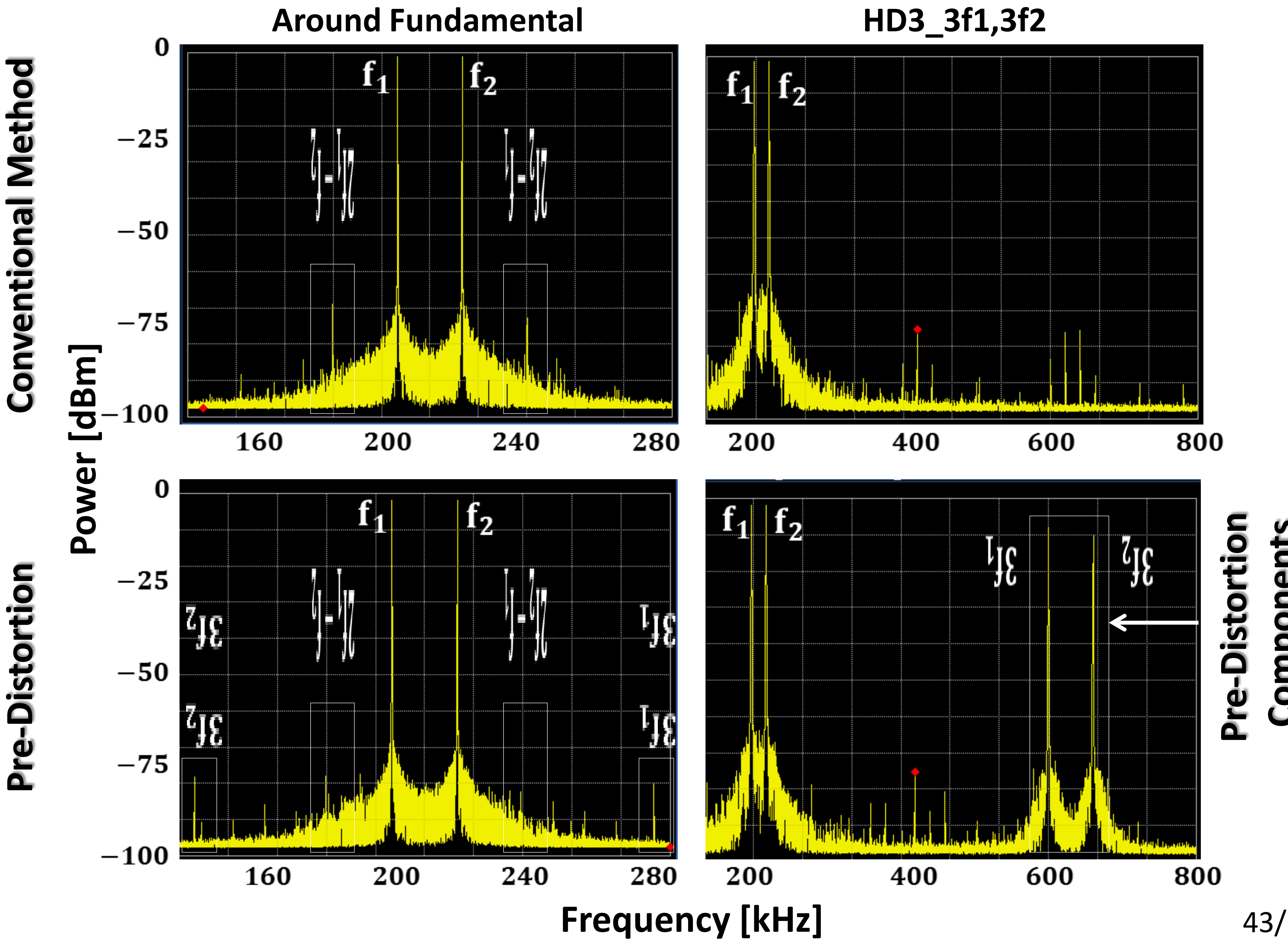
Frequency Switching



Phase Frequency Switching



Pre-Distortion



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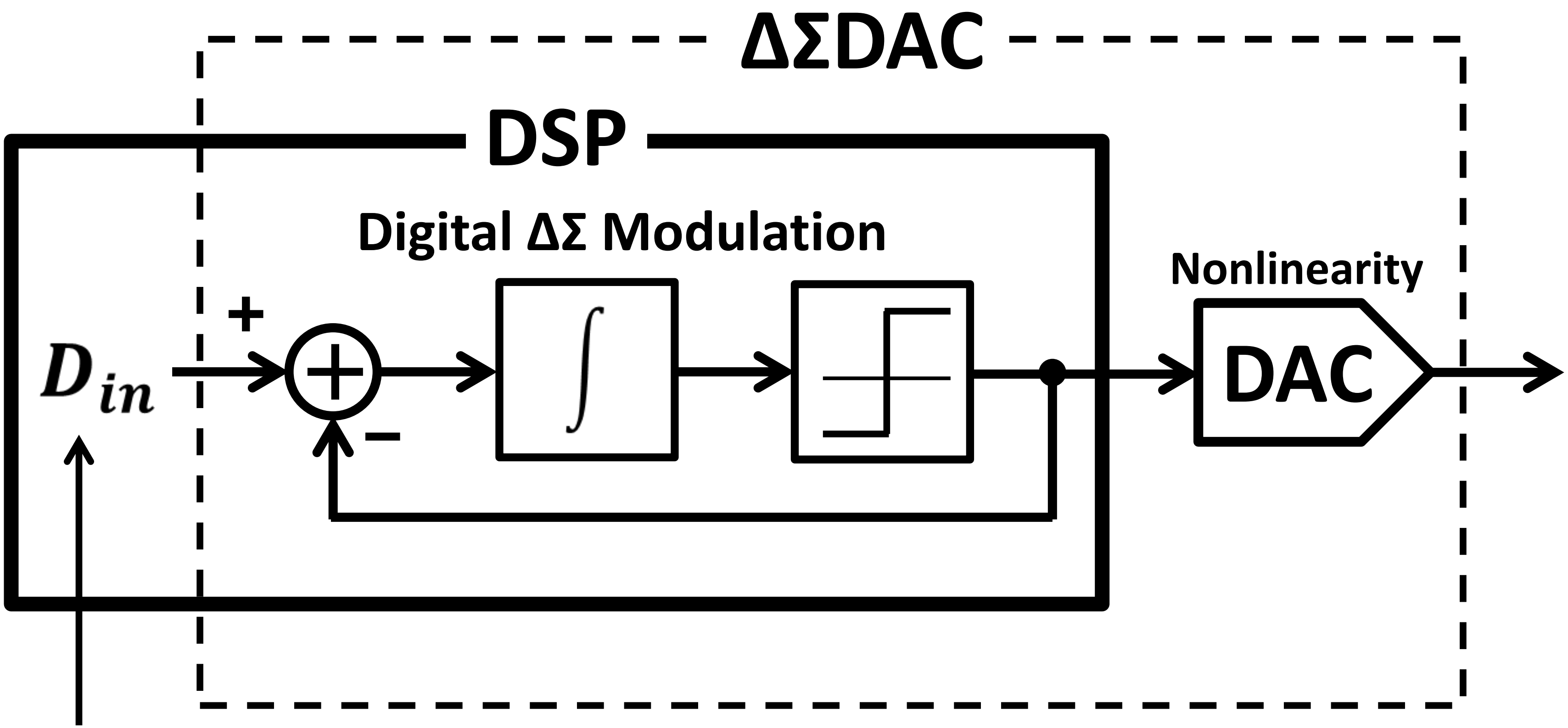
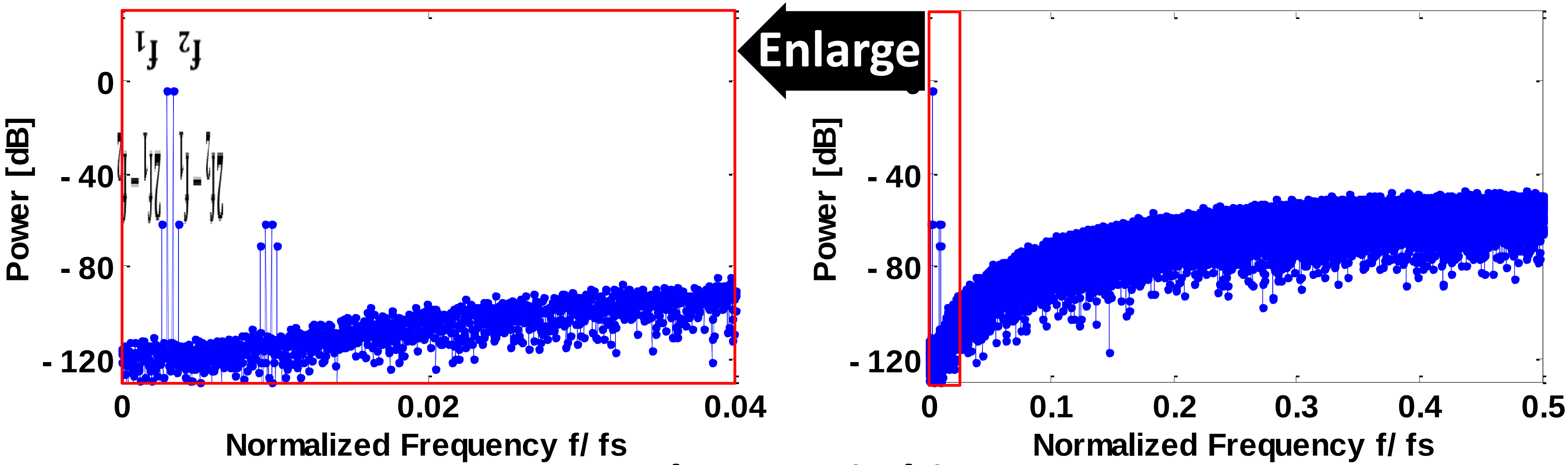
Proposed Techniques using ΔΣDAC



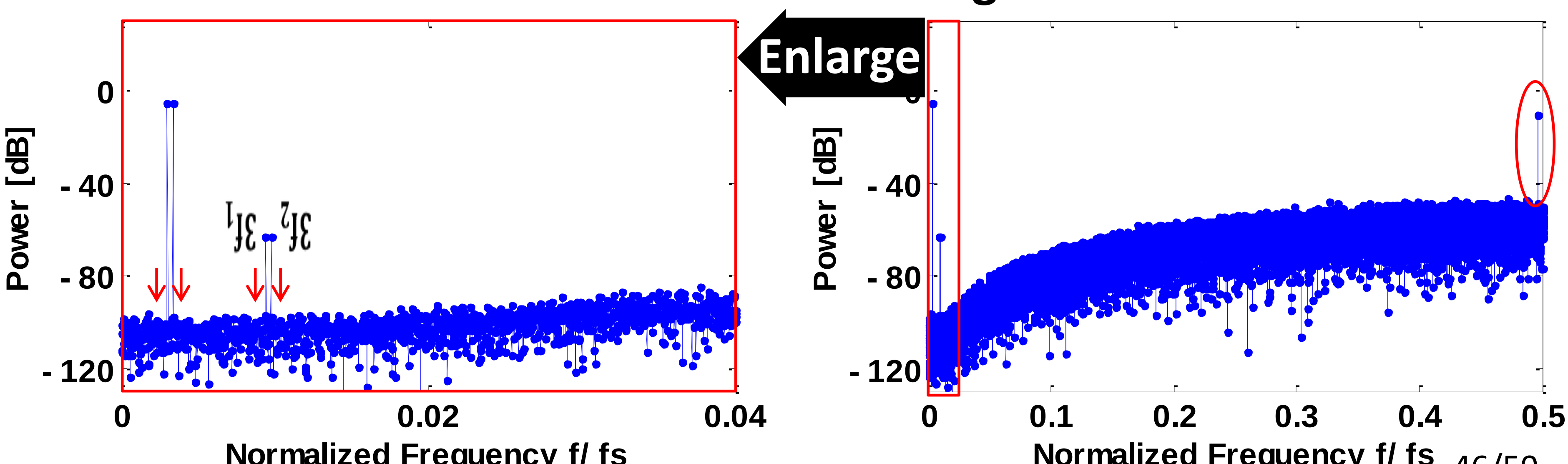
Conventional and Proposed digital input signal

Phase Switching using ΔΣDAC

Conventional

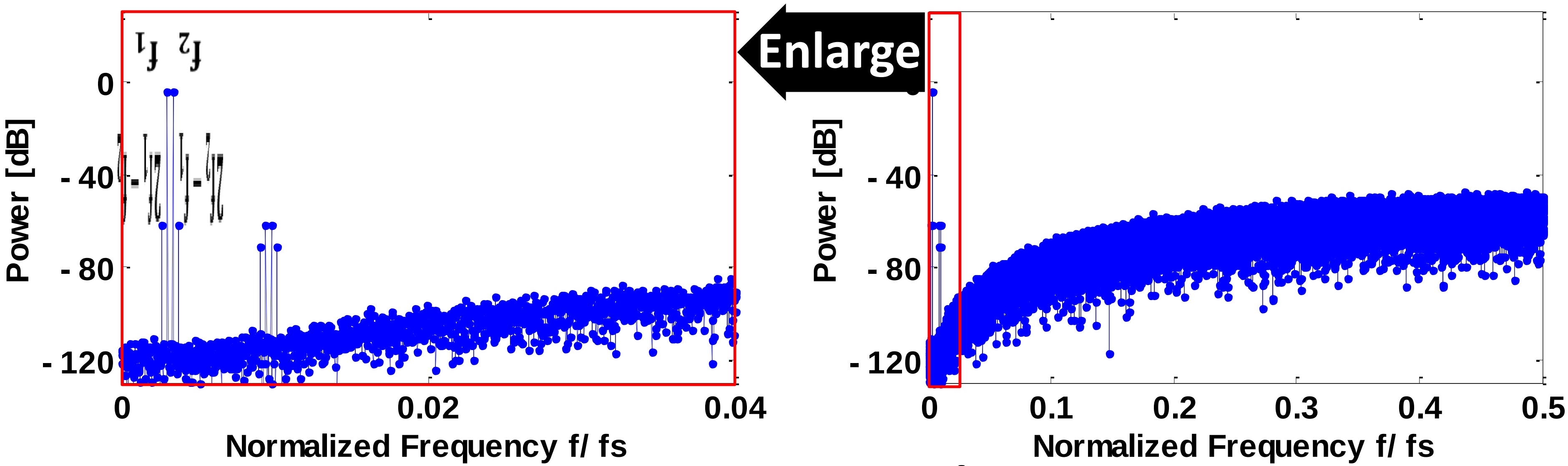


Phase Switching

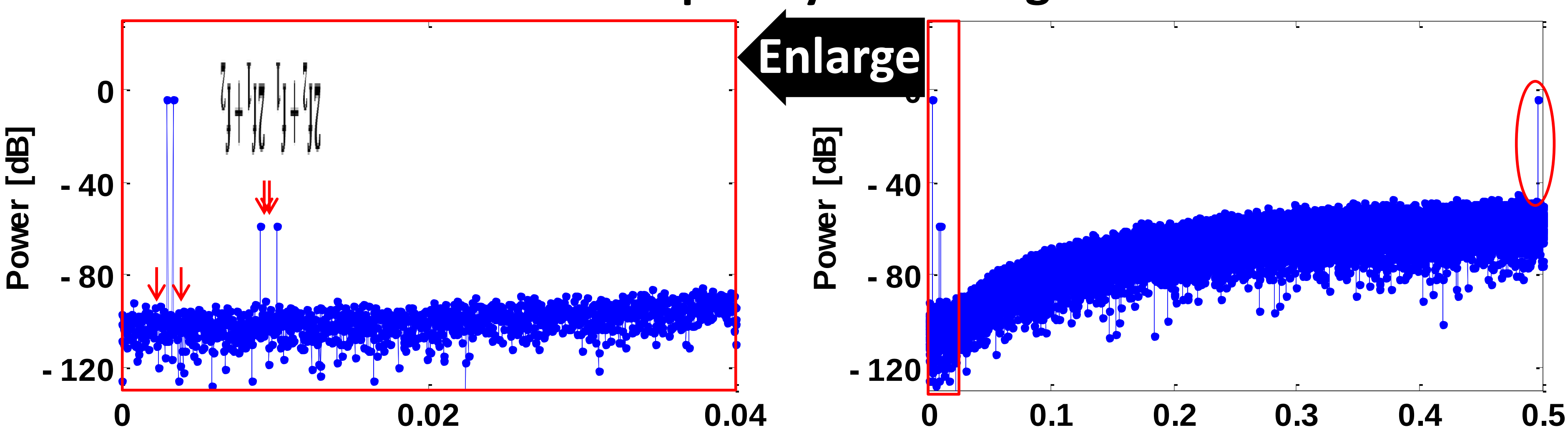


Frequency Switching using ΔΣDAC

Conventional

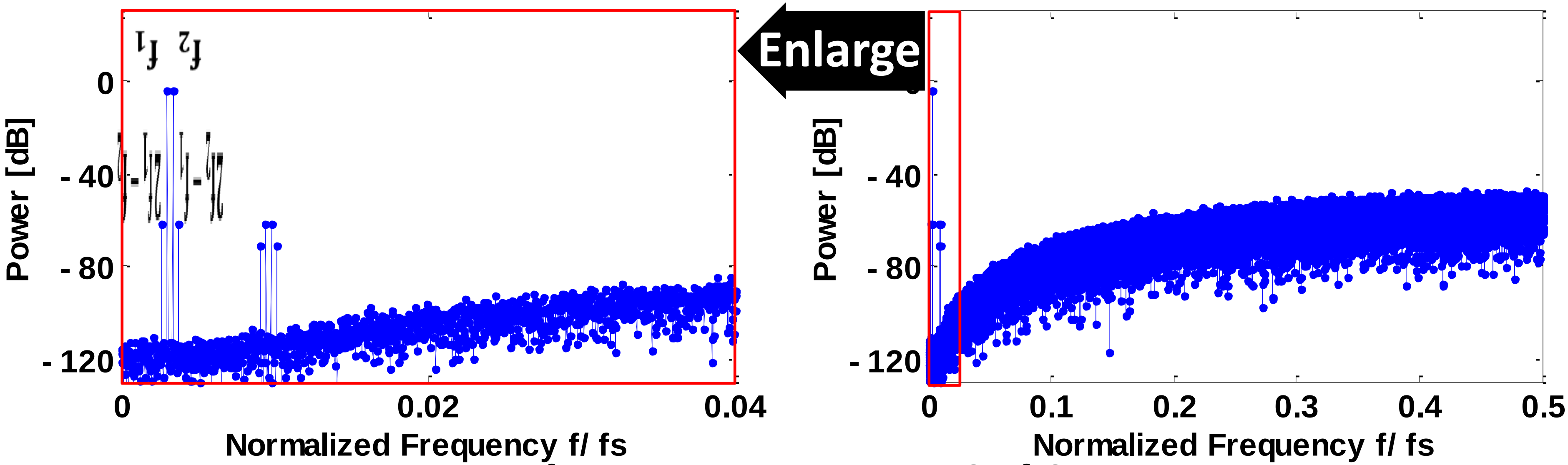


Frequency Switching

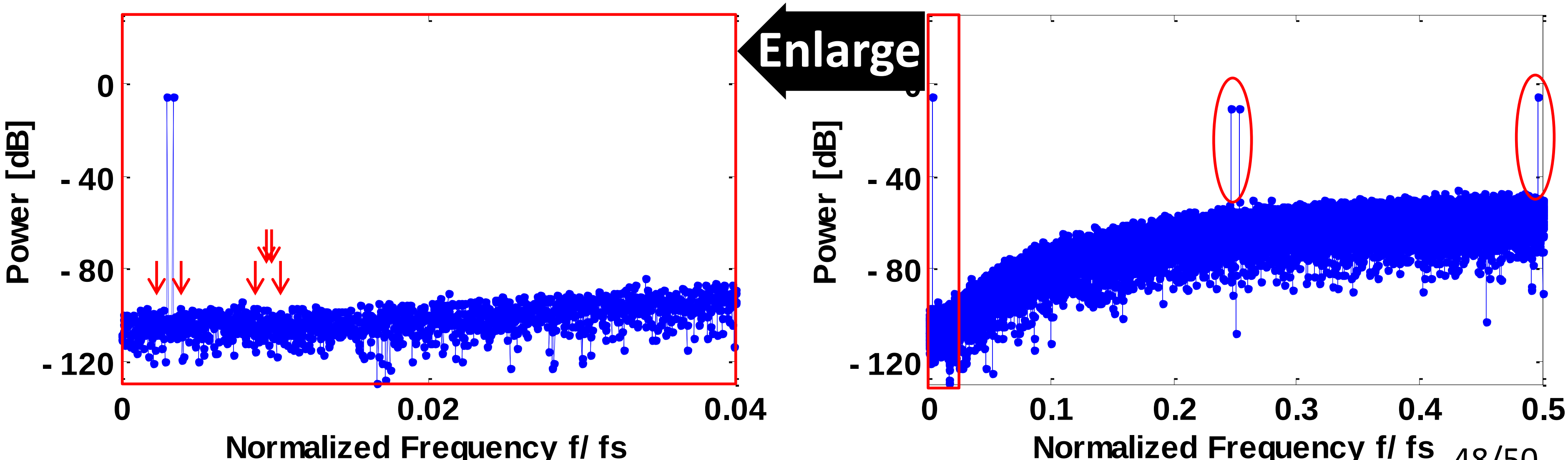


Phase Frequency Switching using ΔΣDAC

Conventional

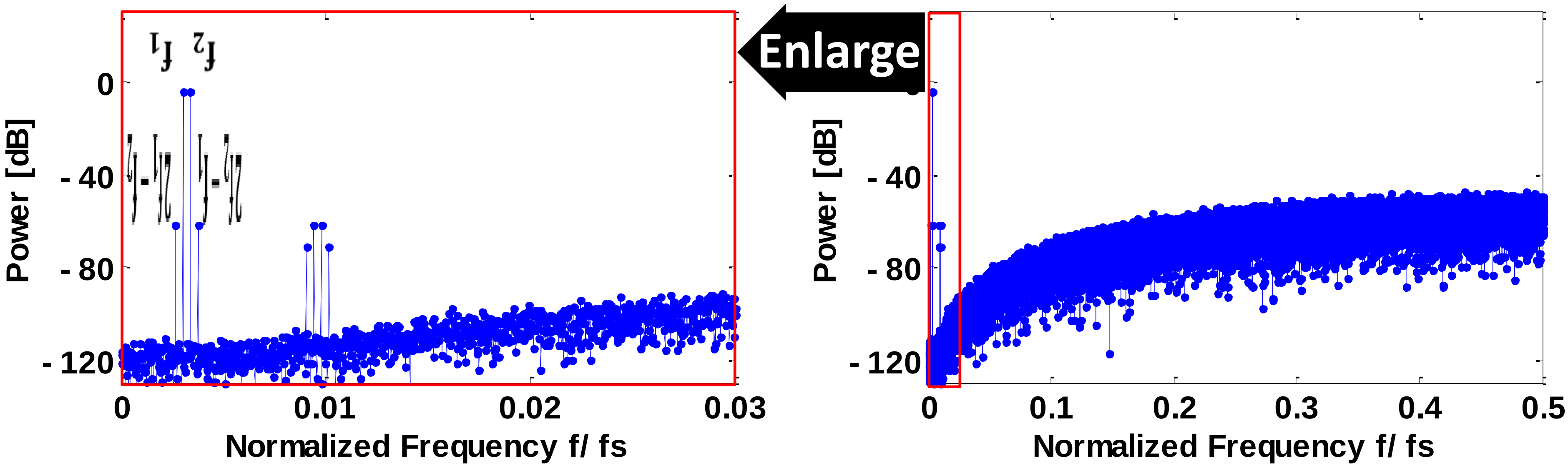


Phase Frequency Switching

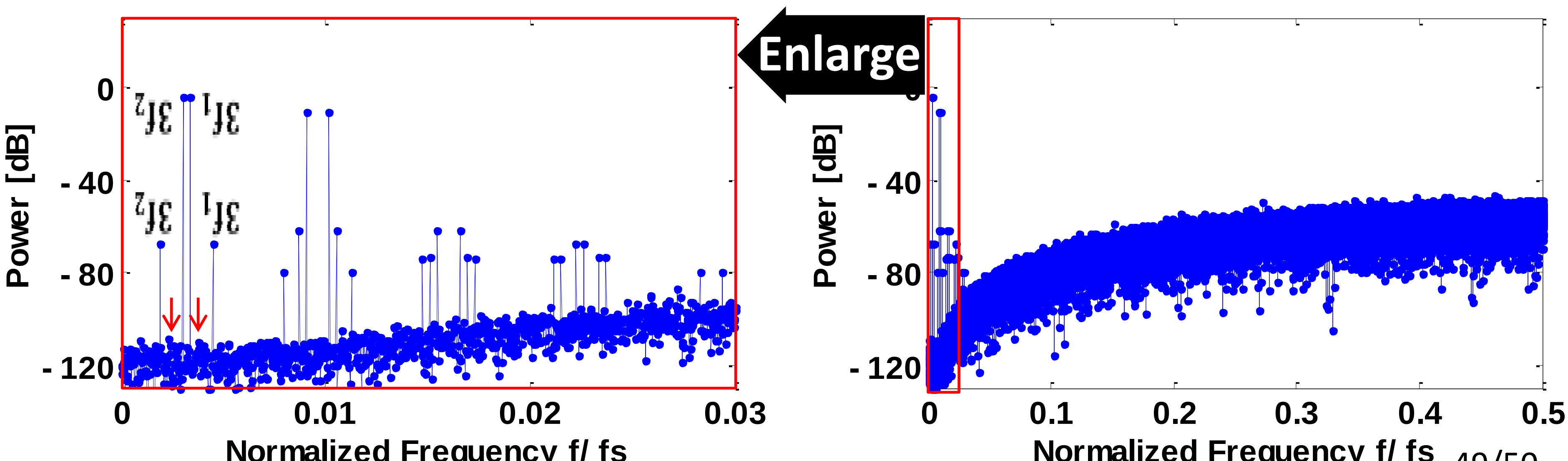


Pre-Distortion using ΔΣDAC

Conventional



Pre-Distortion



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Conclusion

- **Low IMD3 signal generation with low-cost AWG**
  - **Only program change, No hardware change**
  - **No need for calibration**
  - **No need for AWG nonlinearity identification**
- **4 proposed techniques cancel IMD3**
- **Applicable to Nyquist-rate DAC and ΔΣDAC**

Low cost testing of communication application ADCs can be realized