# Low-Distortion Single-Tone and Two-Tone Sinewave Generation Using ΣΔ DAC

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This paper describes algorithms for generating low-distortion single-tone and two-tone signals for ADC testing using a multi-bit ΣΔ DAC (Fig.1). The DSP part provides two interleaved signals with the same frequency but different phase to the input of the ΣΔ DAC, in order to precompensate for distortion caused by multi-bit DAC nonlinearity (Fig.1). Theoretical analysis, simulation, and experimental results all show the effectiveness of this approach.

We consider the case that third-order harmonic distortion (HD3) is dominant in the ΣΔ DAC (Figs.1, 2).

For low-HD3 sinusoidal signal generation, we use the following digital input $D_{in}$ to the ΣΔ DAC:

$$D_{in}(n)=\begin{cases} A\sin(\omega_{in} nT_s + \pi/6) & \text{in case } n\text{:even} \\ A\sin(\omega_{in} nT_s - \pi/6) & \text{in case } n\text{: odd.} \end{cases}$$

Fig.3 shows experimental results for single-tone signal generation using a second-order ΣΔ DAC with 4-bit internal DAC: we see that the proposed algorithm suppresses HD3.

For low distortion two-tone signal generation, we use the following $D_{in}$:

$$D_{in}(n)=\begin{cases} A\sin(\omega_1 nT_s + \pi/6) + B\sin(\omega_2 nT_s - \pi/6) & n\text{:even} \\ A\sin(\omega_1 nT_s - \pi/6) + B\sin(\omega_2 nT_s + \pi/6) & n\text{: odd.} \end{cases}$$

Fig.4 shows experimental results for two-tone signal generation using a second-order ΣΔ DAC with 4-bit internal DAC: we see that the proposed algorithm reduces third-order intermodulation distortion (IMD3) components.

We note that: (i) Methods such as dynamic element matching and self-calibration have been used for reducing the effects of multi-bit DAC nonlinearity in ΣΔ modulators [1], but these methods require additional hardware. However, our proposed method needs only a DSP program algorithm change.

(ii) Our proposed method does not require exact identification of the DAC nonlinearity.

(iii) Generalization of the proposed algorithm, e.g. for simultaneous cancellation of HD2 and HD3, is possible [2].

(iv) Our proposed method may be implemented by utilizing existing DSP and DAC cores inside an SoC in test mode.

We thank H. Miyashita, K. Rikino, S. Kishigami and K. Wilkinson for valuable discussions.

REFERENCES

[1] R. Schreier and G. C. Temes, *Undestand Delta-Sigma Data Converters*,IEEE Press (2005).
[2] K. Wakabayashi, et. al., "Low-Distortion Single-Tone and Two-Tone Sinewave Generation Algorithms Using an Arbitrary Waveform Generator," IEEE IMS3TW, Santa Barbara, CA (May 2011).

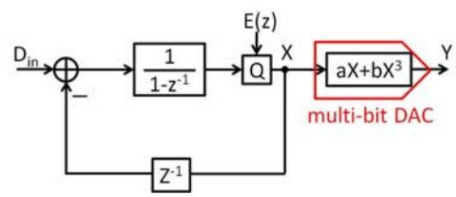



Fig.1. ΣΔ DAC with an internal multi-bit DAC.

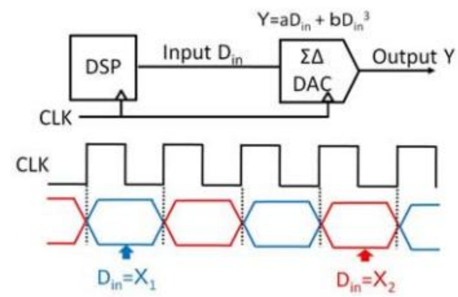
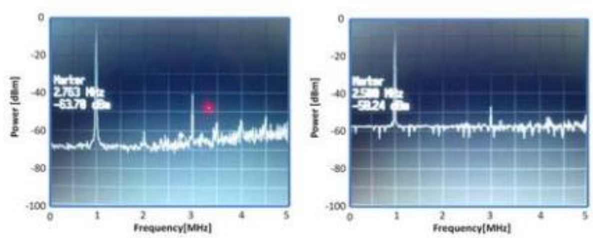
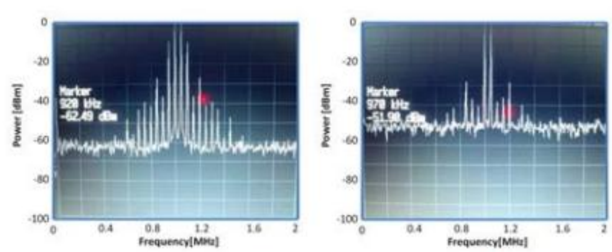



Fig.2. Proposed method to generate low-distortion signal with ΣΔ DAC. DSP provides the input signal X1 and X2 alternatively to the following ΣΔ DAC, and distortion components (such as HD3, IMD3) are cancelled.




(a) (b)

Fig.3. Single-tone generation with ΣΔ DAC. (a) Conventional method. (b) Proposed method.




(a) (b)

Fig.4. Two-tone signal generation with ΣΔ DAC. (a) Conventional method. (b) Proposed method.

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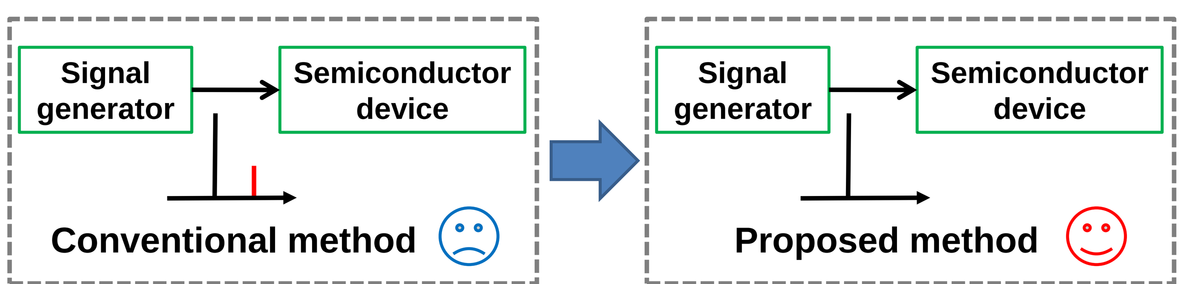
## Introduction

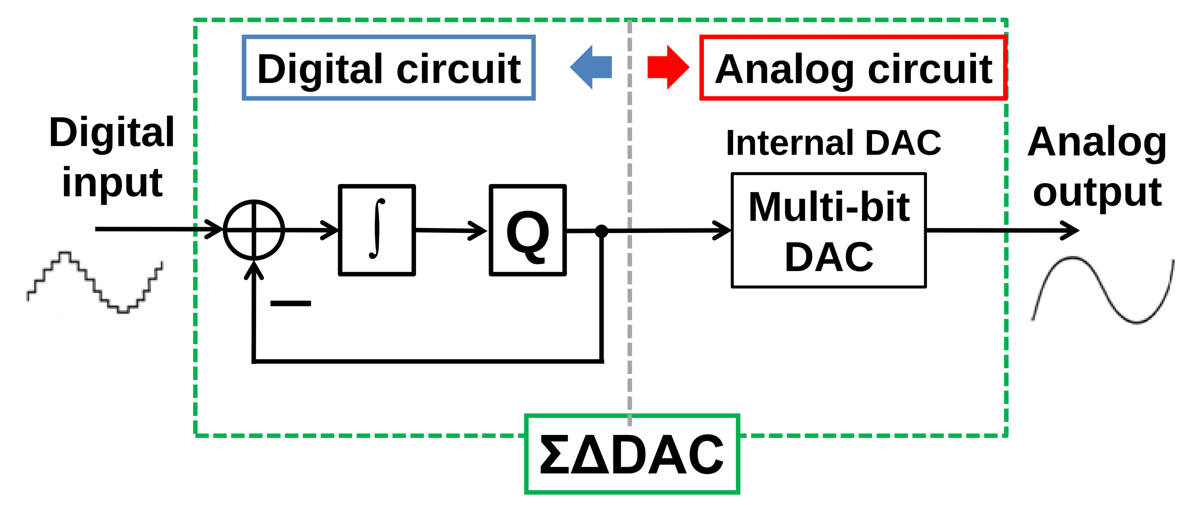
### Research Purpose

Proper-quality low-cost testing of ADCs in SoC

Low-distortion sinusoidal signal generation with DSP and DAC cores in SoC

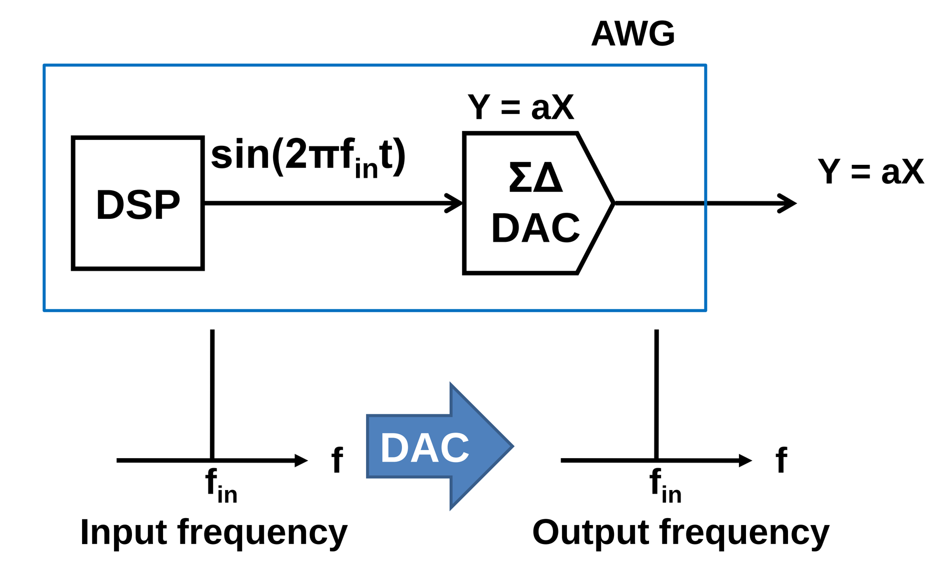



### ΣΔDAC Configuration




ΣΔDAC ⇒ can be implanted with DSP and DAC cores inside SoC in test mode

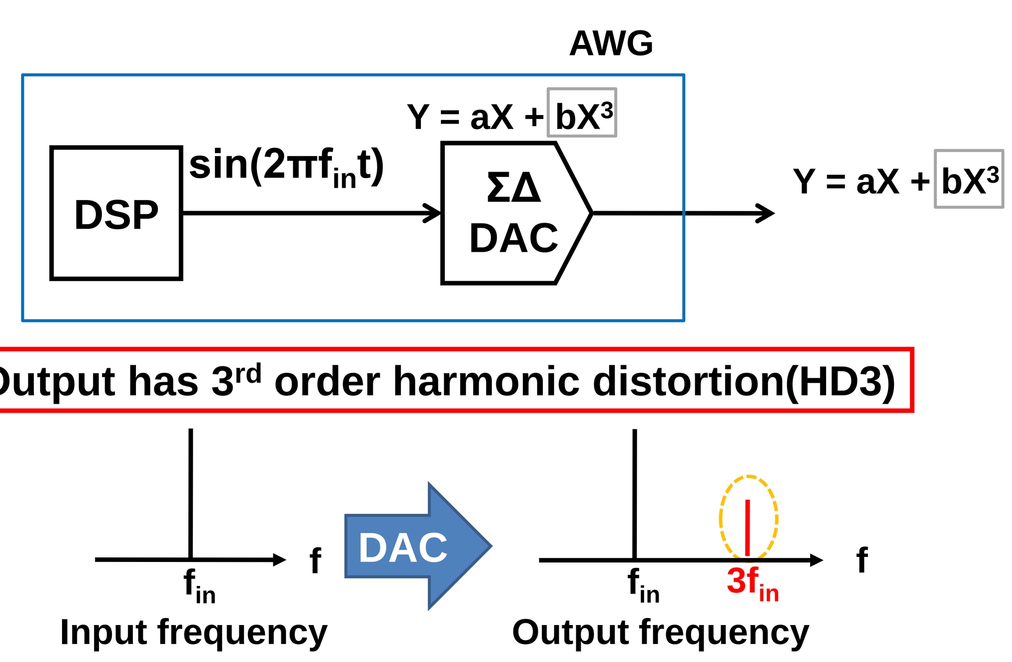
### Ideally Linear ΣΔDAC



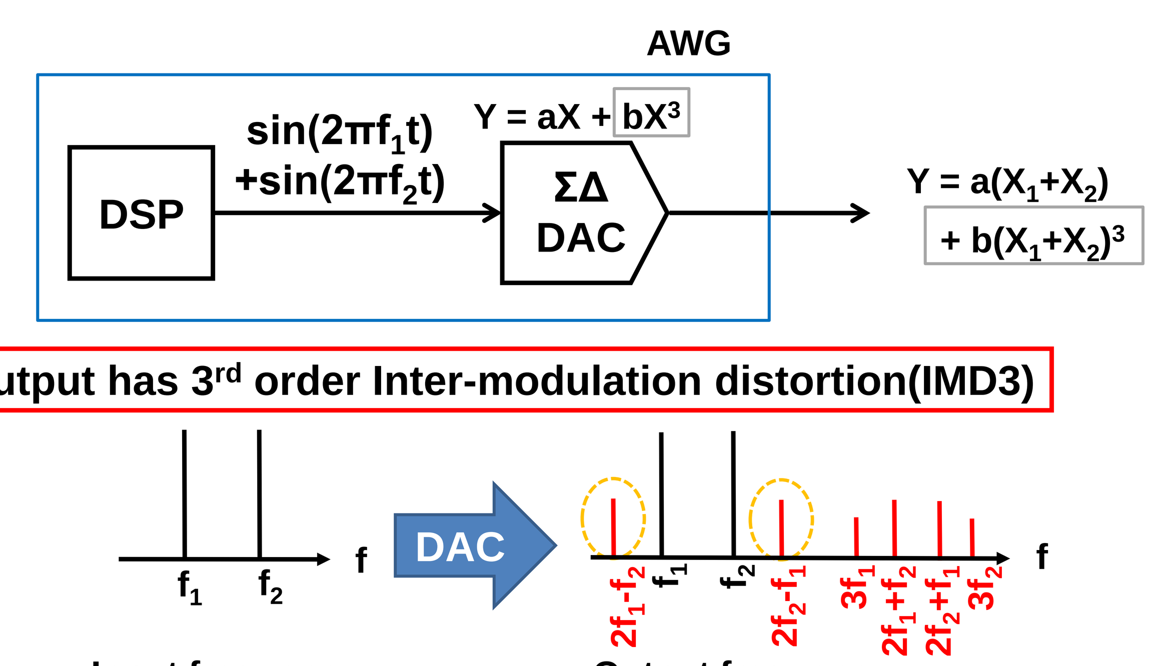

The same frequency of input and output signals

## Proposed test method

### Actual ΣΔ DAC Single-tone Generation

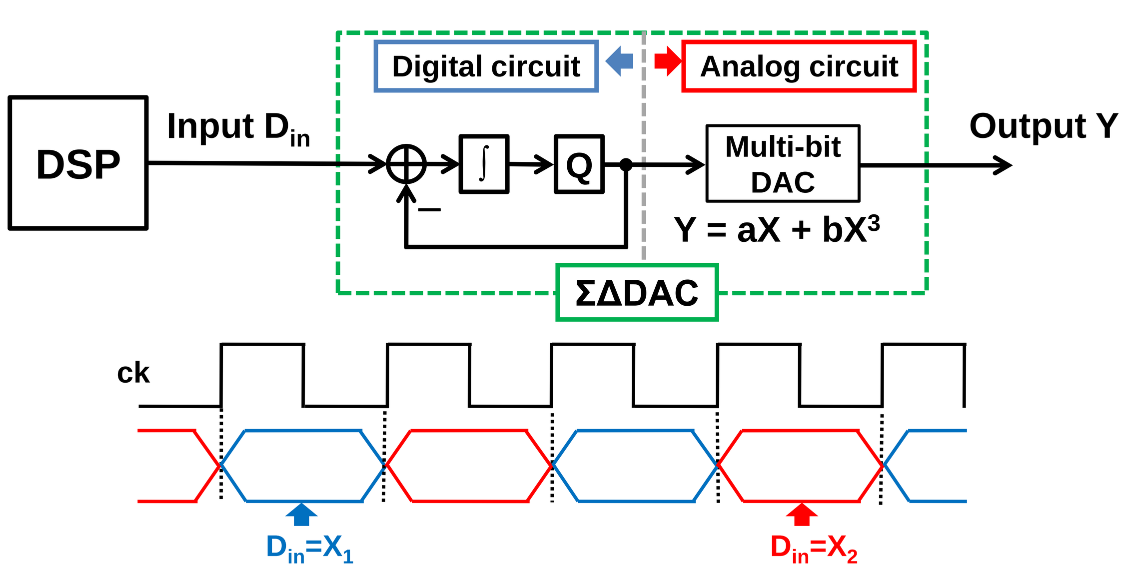



### Actual ΣΔ DAC Two-tone Generation




IMD3 components are difficult to remove by analog filter

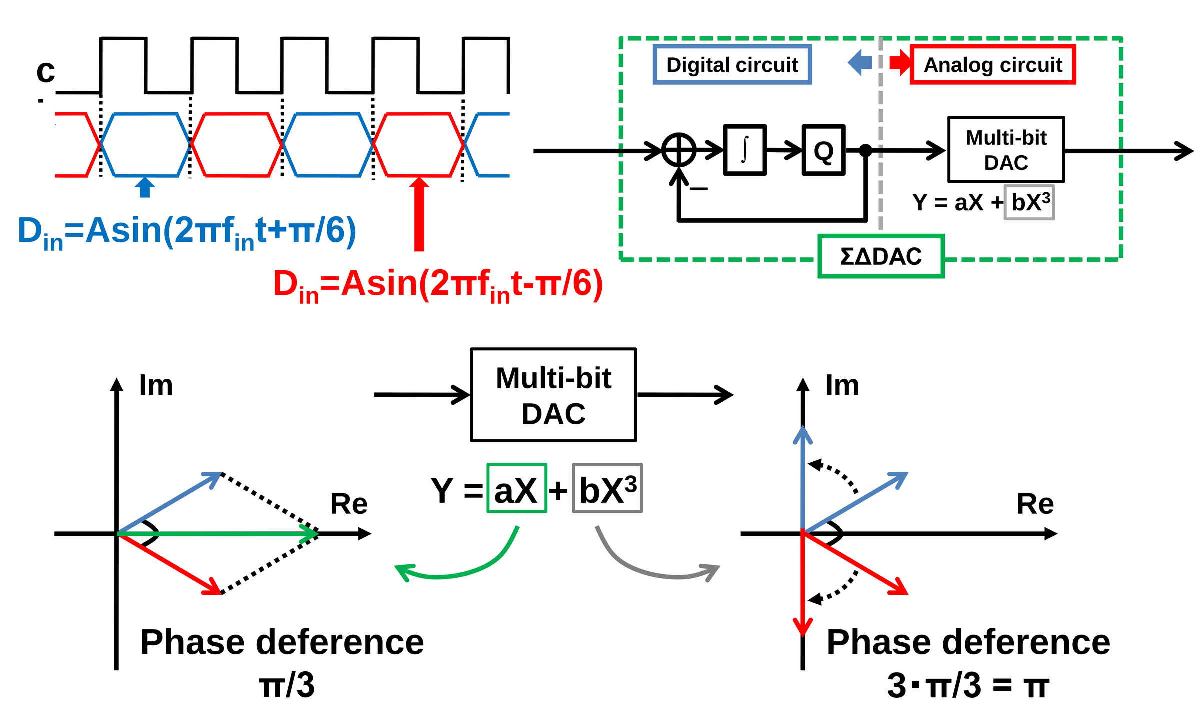
### Proposed Method




Interleaved $X_1$ , $X_2$ generate $D_{in}$

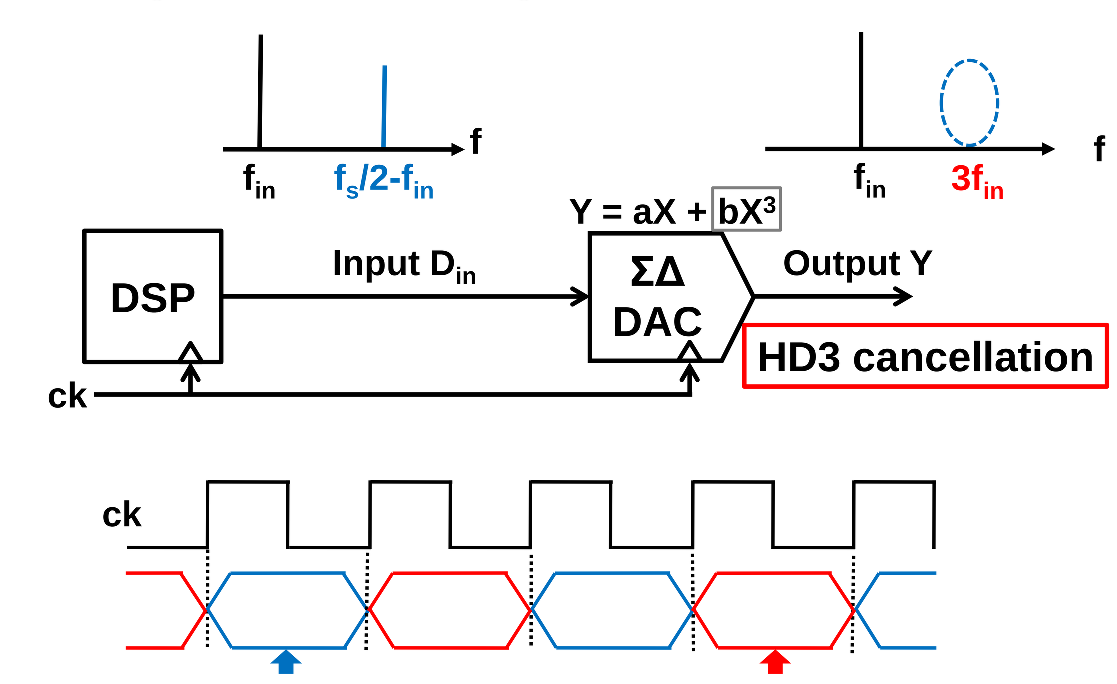
Distortion components cancellation in output Y

### Principle of Proposed Method




Signal component — Distortion component

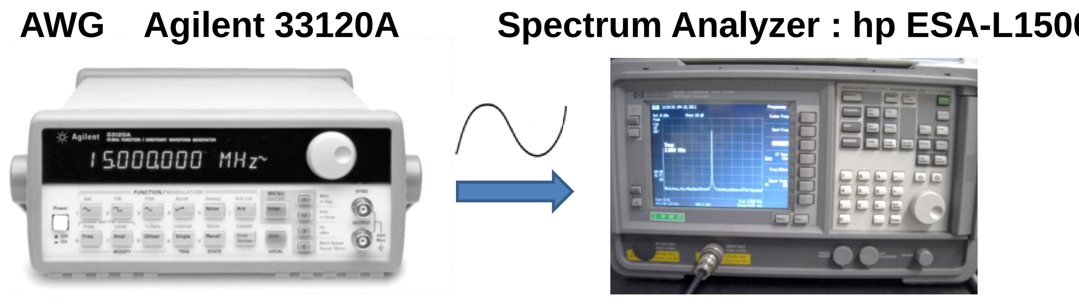
### Single-tone Signal Generation




## Measurement

### Experiment Condition

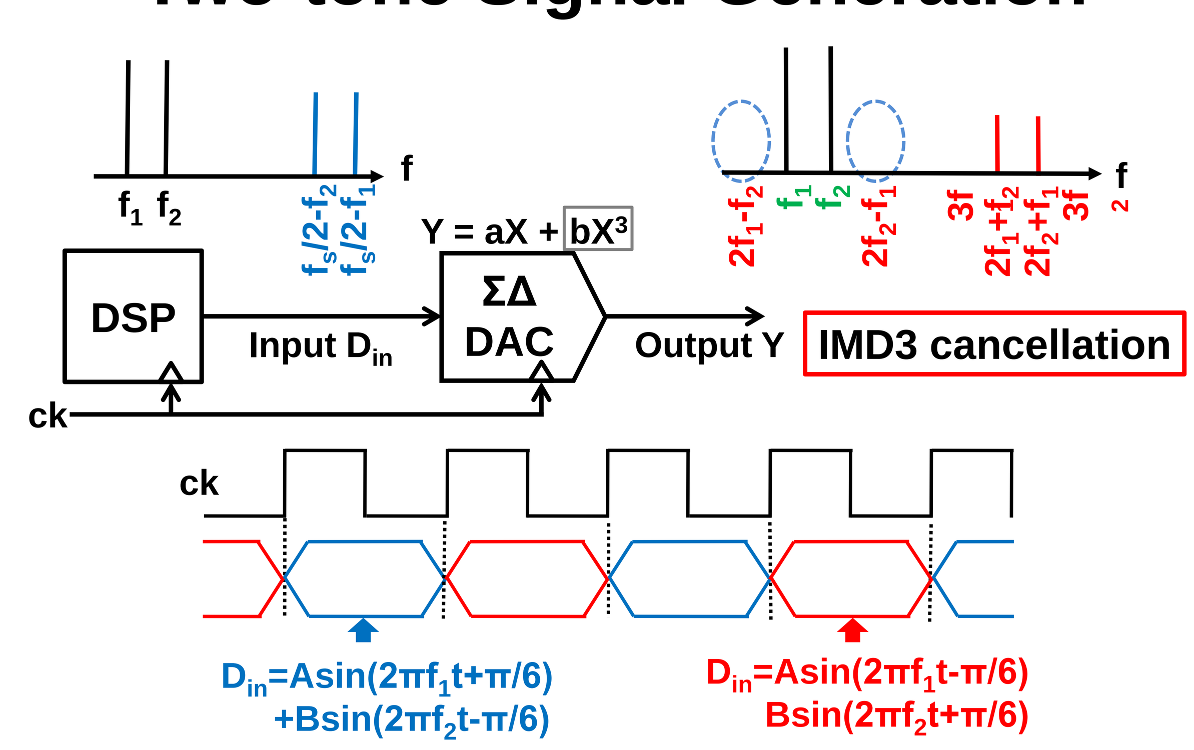
AWG Agilent 33120A — Spectrum Analyzer : hp ESA-L1500A



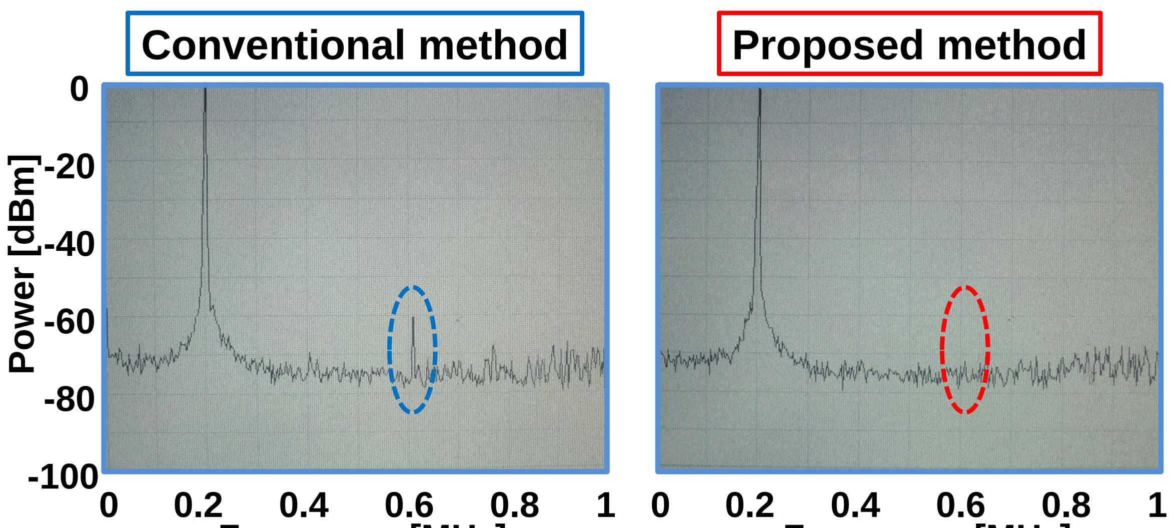
| | |
|---|---|
| Max. Sampling frequency (Hz) | 40M |
| Resolution (bit) | 12 |
| Linearity | △ |
| Input frequency (Hz) | 200k |
| Input amplitude ($V_{pp}$) | 1 |
| Sampling frequency (Hz) | 8M |

| | |
|---|---|
| Frequency range (Hz) | 9k～1.5G |
| Max amplitude (Vpp) | 19.8 |
| RBW : Resolution band width (Hz) | 1k |
| VBW : Video band width (Hz) | 100k |

### Two-tone Signal Generation



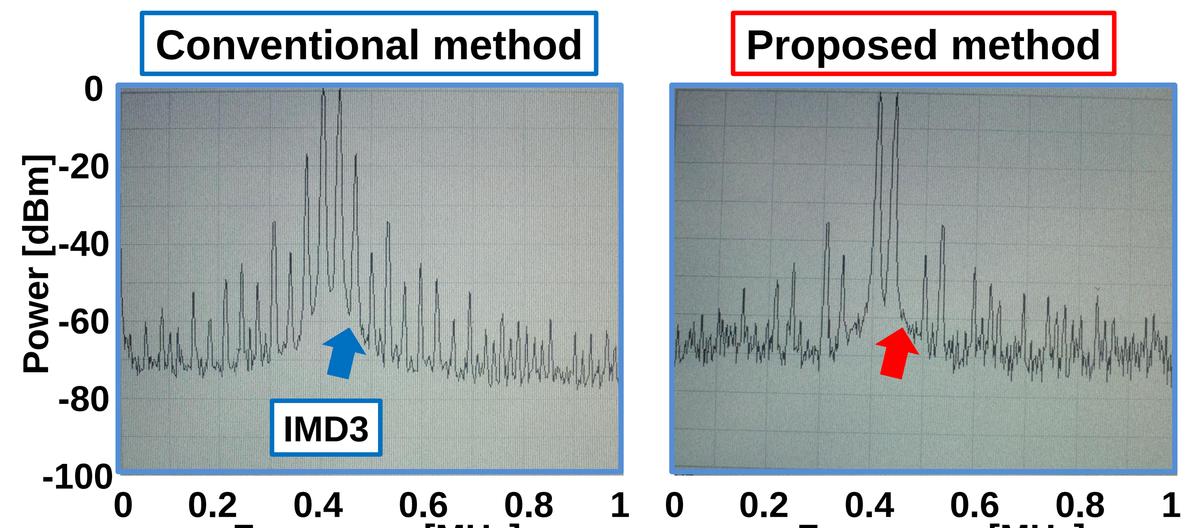

### Single-tone Signal




Fundamental (200kHz) : 3.8 dBm → -1.2 dB → 2.6 dBm

HD3 (600kHz) : -60 dBm → -14 dB → -74 dBm

### Two-tone signal




Fundamental (200kHz) : 0.8 dBm → -1.3 dB → -0.5 dBm

HD3 (600kHz) : -17 dBm → -43 dB → -60 dBm

## Conclusion

- Low-distortion sinewave generation using ΣΔ DAC
  - Single-tone : HD3 cancellation
  - Two-tone : IMD3 cancellation
- Only DSP programming change
- No need for DAC nonlinearity identification
- Effectiveness is verified with theoretical analysis and experiments