Novel Measurement-Noise-Suppression and Measurement-Time-Reduction Methodology for ADC/DAC

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発表概要

従来

従来手法で1/8に時間短縮

提案1(ノイズ圧縮)

提案2(1/8に時間短縮)
Abstract

• Previously Histogram-method or Moment method are used for ADC,DAC measurement.

• I am proposing a novel method to reduce noise to $1/22$ at 10bit binary ADC. Or to reduce measurement time $1/8$, when previous noise level is acceptable.
  – First, calculate each physical weight value statistically.
  – Next, reproduce each step using the weights.
Analogy

- On 2pan-balance scale certification, only need to accurately measure each weights.
- On test method of ADC, measured calibration reference weights 0.01g, 0.02g, ..., 102.2g, 102.3g, total 10240 times! Why?

![Diagram showing a balance scale with calibration weights](image)
Why ADC is measured >10,000 times?

• “ADC cannot be measured each internal weight directly, thus it is necessary to sweep inputs to find transition points.”
  – To measure 1.6g weight under test, reference weights will be 1.55g, 1.56g, ⋯ 1.64g, 1.65g, to find balance points.

• “ADC has more than 1LSB noise, therefore need to reduce noise.”
  – Needle fluctuation, or stop at various positions time to time. Need averaging.
Previous Histogram/Moment method

- Sweep input voltage by ramp
- Outputs fluctuate by noise
- Histogram method ignores x-axis positions
  - always monotonic
- Moment method uses averaged x per y value

Digital output (decimal)

Analog input voltage

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A case of 10bit binary coded ADC
Proposed method for binary weighted 1

• Start from same ramp data;

• Calculate 512C weight as differences of MSB on/off

  – \( \text{Vi}(512C) = \text{Vi}(512) - \text{Vi}(0) \)
  
  – \( \text{Vi}(512C) = \text{Vi}(513) - \text{Vi}(1) \)
  
  – \( \text{Vi}(512C) = \text{Vi}(514) - \text{Vi}(2) \)
  
  : 
  
  – \( \text{Vi}(512C) = \text{Vi}(1023) - \text{Vi}(511) \)

\[ \text{Vi}(1x \text{xxxx xxxx}) \]

\[ - \text{Vi}(0x \text{xxxx xxxx}) \]

• Average above;

  – \( \bar{\text{Vi}}(512C) \)

  – Noise sigma becomes

\[
\frac{1}{\sqrt{512}} = \frac{1}{22}.
\]

Noise reduced 1/22 !
Proposed method for binary weighted 2

- **Calculate 9\(^{th}\) bit weight**
  - Vi(256C)=Vi(256)-Vi(0)
  - Vi(256C)=Vi(257)-Vi(1)
    - Vi(256C)=Vi(511)-Vi(255)
    - Vi(256C)=Vi(768)-Vi(512)
    - Vi(256C)=Vi(769)-Vi(513)
    - Vi(256C)=Vi(1023)-Vi(767)

  \[ Vi(256C) = Vi(x1 \text{xxxx xxxx}) \]

  \[ - Vi(0 \text{xxxx xxxx}) \]

- **Get each noise-suppressed weight**
  - Vi(512C), Vi(256C), \cdots Vi(1C)
  - Each noise sigma becomes 
    \[ 1/\sqrt{512}=1/22. \]

- **Average above**
  - Vi(256C)
  - Noise sigma becomes 
    \[ 1/\sqrt{512}=1/22. \]
Proposed method for binary weighted 3

• Reproduce noise-reduced ADC

- \( V_{re}(0) = 0 \)
- \( V_{re}(1) = V_i(\text{LSB}) \)
- \( V_{re}(2) = V_i(2^{nd}) \)
- \( V_{re}(3) = V_i(2^{nd}) + V_i(\text{LSB}) \)
  - \( \vdots \)
- \( V_{re}(513) = V_i(\text{MSB}) + V_i(\text{LSB}) \)
  - \( \vdots \)
- \( V_{re}(1023) = V_i(\text{MSB}) + V_i(9^{th}) + V_i(8^{th}) + \cdots + V_i(\text{LSB}) \)

• Calculate linearity
  - INL
  - DNL
Calculation results

I have detected that DUT was not binary coded!

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A case of 10bit ADC consists of thermometer coded at top 6bits +binary coded at lower 4bits
Proposed method for **thermometer weighted 1**

- Calculate top 6bit thermometer coded as **differences** of each 16C on/off
  - \( V_i(16C_1) = V_i(16) - V_i(0) \)
  - \( V_i(16C_1) = V_i(17) - V_i(1) \)
  - \( V_i(16C_1) = V_i(31) - V_i(15) \)
  - \( V_i(16C_2) = V_i(32) - V_i(0) \)
  - \( V_i(16C_2) = V_i(33) - V_i(1) \)
  - \( V_i(16C_63) = V_i(1008) - V_i(0) \)
  - \( V_i(16C_63) = V_i(1023) - V_i(15) \)

\[ \begin{align*}
V_i(\text{yy yyyy xxxx}) & \\
\text{-) } V_i(\text{zz zzzz xxxx}) & \text{ yyyy} - \text{ zzzzzz} = 1
\end{align*} \]

- Average above;
  - \( \overline{V_i(16C_1)}, \overline{V_i(16C_2)}, \cdots, \overline{V_i(16C_63)} \)
  - Noise sigma becomes \( 1/\sqrt{16} = 1/4 \).
  - Noise reduced 1/4!
Proposed method for thermometer weighted 2

- **Calculate binary weight at lower 4bits**
  - \( V_i(8C) = V_i(8) - V_i(0) \)
  - \( V_i(8C) = V_i(9) - V_i(1) \)
    
  : 
  - \( V_i(8C) = V_i(15) - V_i(7) \)
  - \( V_i(8C) = V_i(24) - V_i(16) \)
  - \( V_i(8C) = V_i(25) - V_i(17) \)
    
  : 
  - \( V_i(8C) = V_i(1016) - V_i(1008) \)
  - \( V_i(8C) = V_i(1023) - V_i(1015) \)

  \[ V_i(\text{xx xxxx 1xxx}) - V_i(\text{xx xxxx 0xxx}) \]

- **Average above;**
  - \( V_i(8C) \)
  - Noise sigma becomes \( 1/\sqrt{512} = 1/22 \).

- **Get each noise-reduced weight**
  - \( V_i(8C), V_i(4C), V_i(2C), V_i(1C) \)
  - Each noise sigma becomes \( 1/\sqrt{512} = 1/22 \).
Proposed method for thermometer weighted 3

- Reproduce noise-reduced ADC
  - $V_{re}(0) = 0$
  - $V_{re}(1) = V_i(1C)$
  - $V_{re}(2) = V_i(2C)$
  - $V_{re}(3) = V_i(1C) + V_i(2C)$
  - $V_{re}(16) = V_i(16C_1)$
  - $V_{re}(16) = V_i(16C_1) + V_i(1C)$
  - $V_{re}(33) = V_i(16C_1) + V_i(16C_2) + V_i(1C)$
  - $V_{re}(1023) = V_i(16C_1) + V_i(16C_2) + \cdots + V_i(8C) + \cdots + V_i(1C)$

- Calculate linearity
  - INL
  - DNL
Experiment results 1

Noise reduction
Noise becomes 1/4 ~ 1/22

10bit ADC, 10240 measuring points

(Equivalence of x16 = 160,000 measuring points or more)

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Experiment results 2

Measurement time reduction
decimated to $1/8 = 1280$ measuring points

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INL proposed

1/8 decimation

DNL proposed
Experiment results 3

Measurement time reduction

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Experiment results 4

Measurement time reduction

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Experiment results 5

1st measured

INL proposed

INL previous

DNL proposed

DNL previous

1st measured decimated to 1/4

INL proposed

INL previous

DNL proposed

DNL previous

2nd measured

INL proposed

INL previous

DNL proposed

DNL previous

2nd measured with decimated 1/4

INL proposed

INL previous

DNL proposed

DNL previous
Summery

• Significant measurement noise reduction to $1/4\sim1/22$
  – Equivalent x16 (=160,000) measuring point or more
  – Robust data with better repeatability

• Significant measurement time reduction to $1/8$
  – Better than previous without decimation
  – Robust data with better repeatability
  – Have realized 1/8 test cost
Conclusion

- Proposed novel method to calculate statistically internal physical weights, and to reproduce noise-suppressed ADC
- Proposed my method has demonstrated;
  - $1/4 \sim 1/22$ measurement noise reduction
  - $1/8$ measuring time reduction = $1/8$ test cost
- Has been programmed with C, BASIC
  - evaluation use & LSI tester implementation
  - Binary, thermometer & combined ADC/DAC
  - Now applied in volume production
I appreciate ex Renesas Micro Systems Co. Ltd.