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

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発表概要

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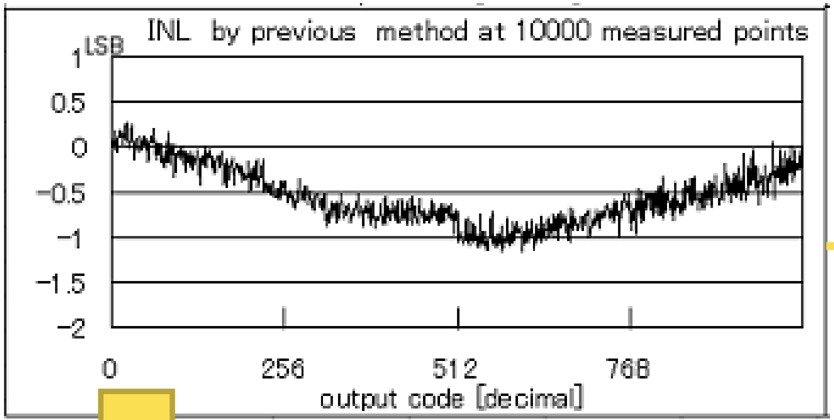
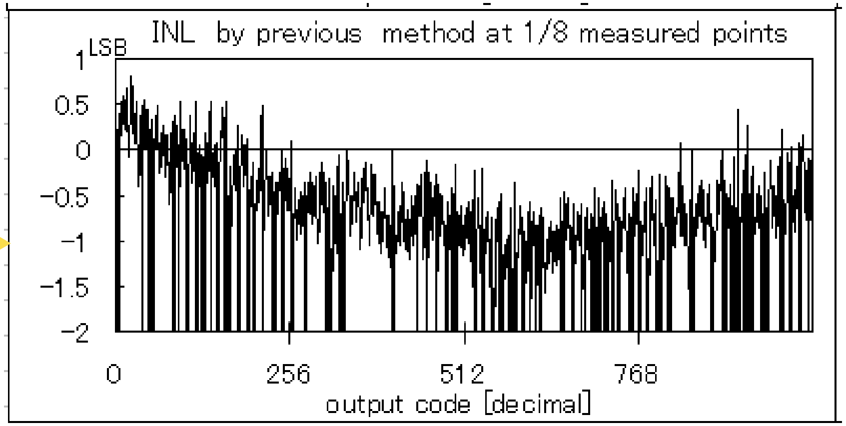
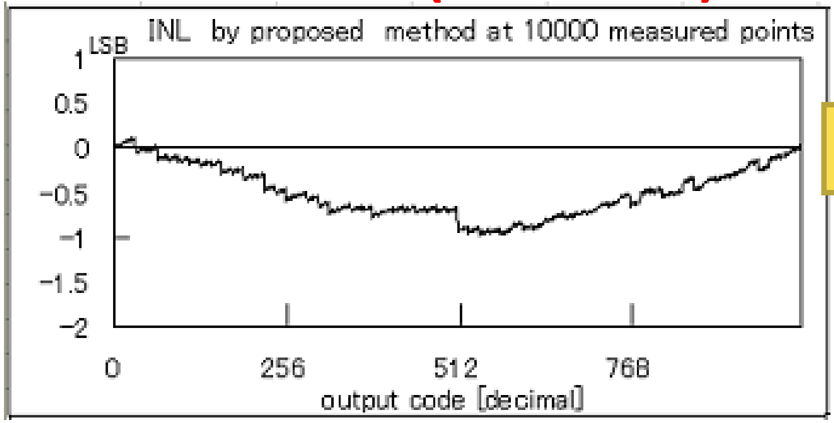
従来



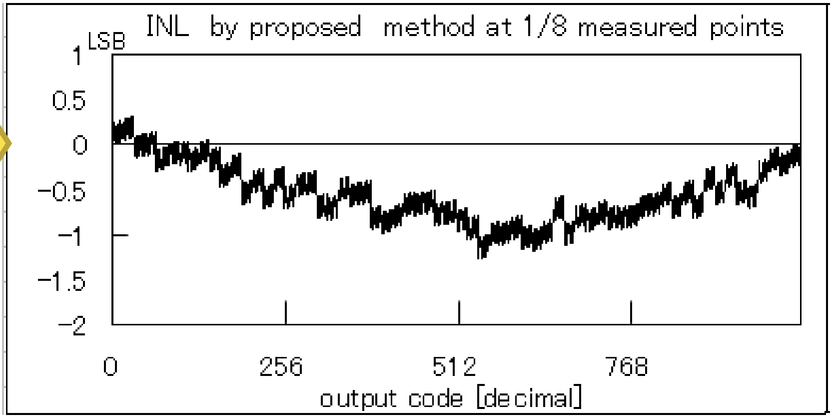
従来手法で1/8に時間短縮



提案1(ノイズ圧縮)



提案2(1/8に時間短縮)

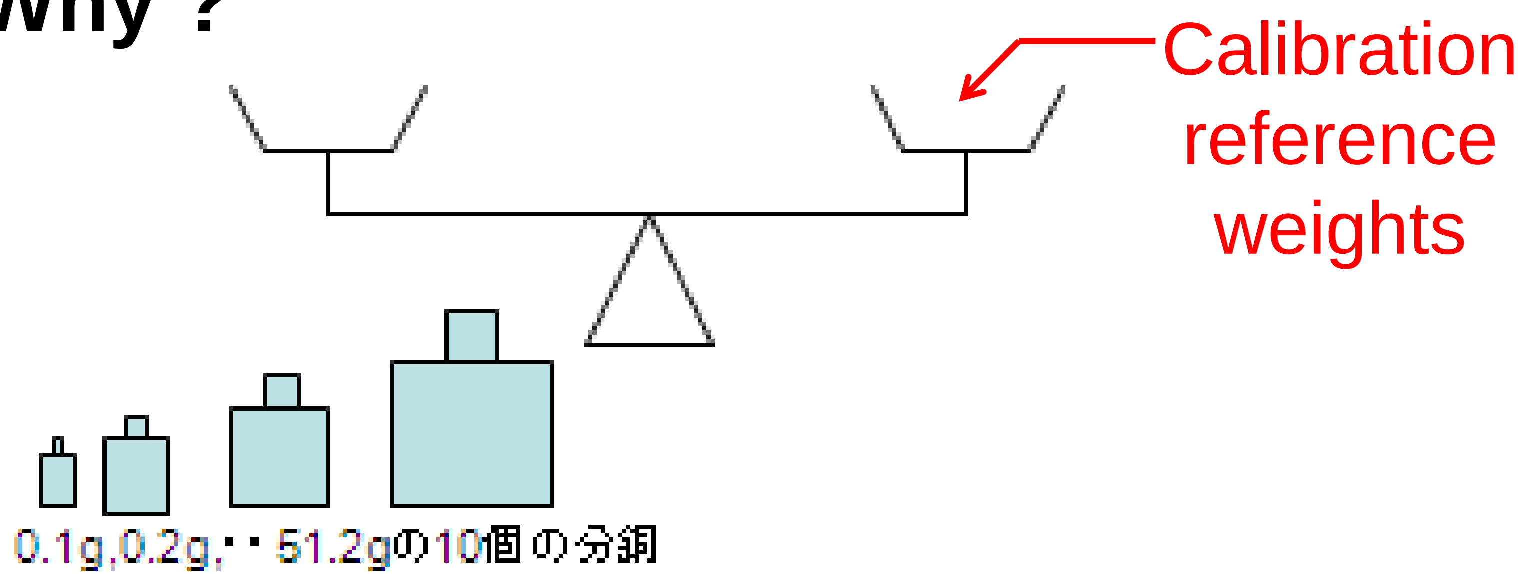


Abstract

- **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 ?**



Why ADC is measured >10,000 times ?

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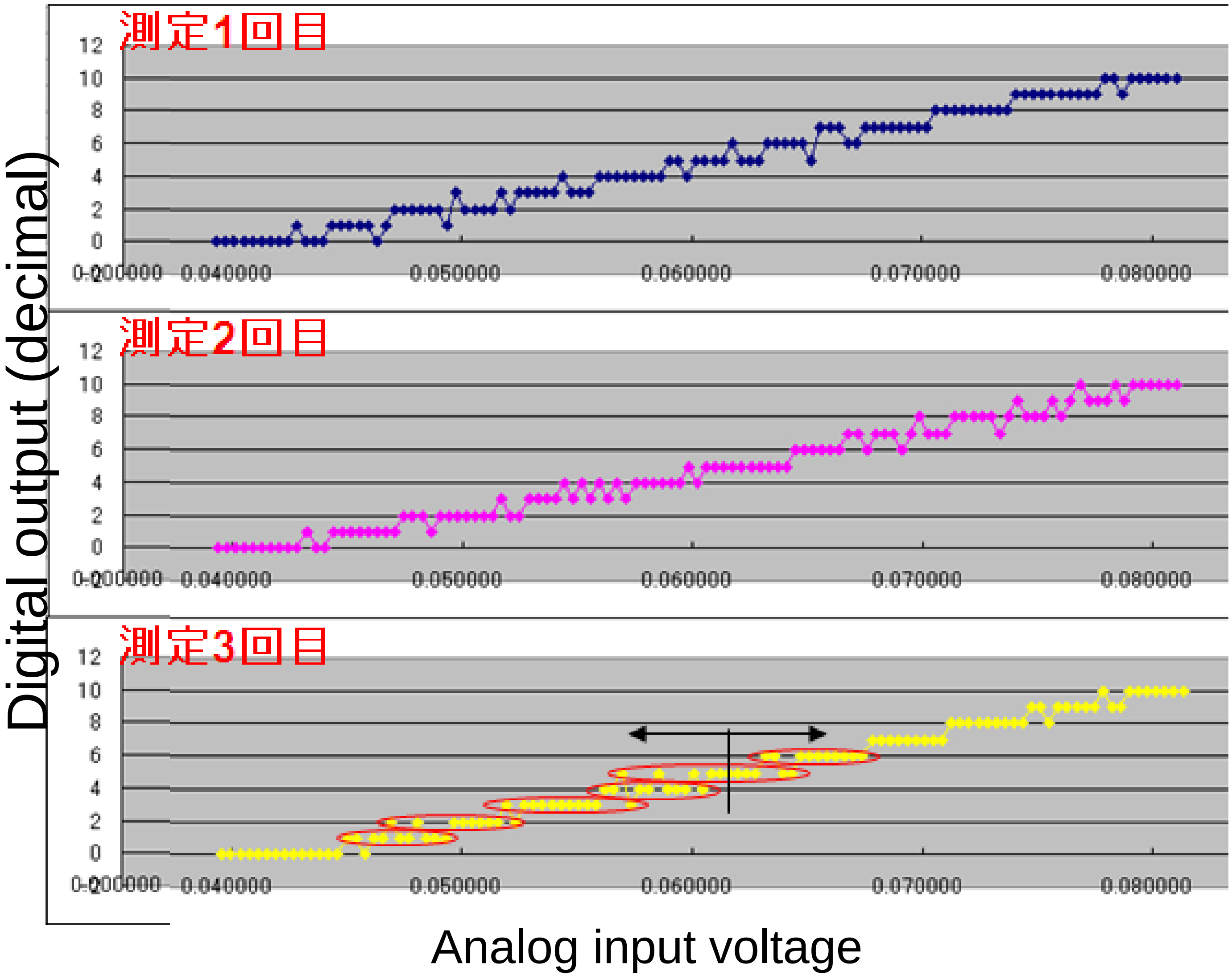
- **"ADC cannot be measured each internal weight directly, thus it is necessary to sweep inputs to find transition points."**
  - To measure 1.6g weight under test, reference weights will be 1.55g,1.56g,・・1.64g,1.65g, to find balance points.
- **"ADC has more than 1LSB noise, therefore need to reduce 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

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**
  - Vi(512C)=Vi(512)-Vi(0)
  - Vi(512C)=Vi(513)-Vi(1)
  - Vi(512C)=Vi(514)-Vi(2)

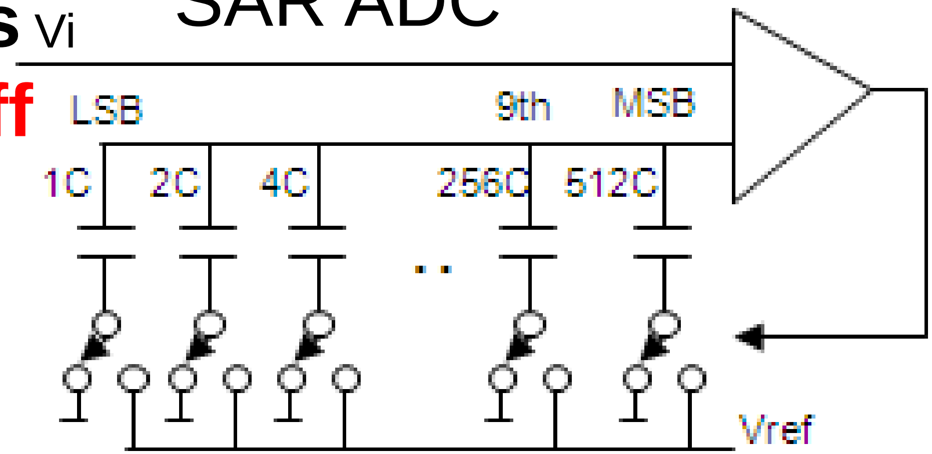
    :
  - Vi(512C)=Vi(1023)-Vi(511)

    Vi(1x xxxx xxxx)

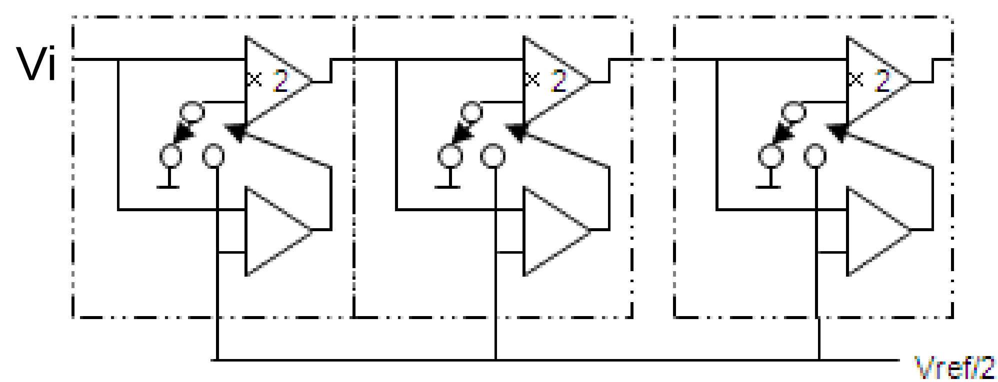
    -) <u>Vi(0x xxxx xxxx)</u>
- **Average above;**
  - $\overline{\text{Vi(512C)}}$
  - Noise sigma becomes $1/\sqrt{512}$=1/22.

    Noise reduced 1/22 !

SAR ADC



Pipelined ADC



Proposed method for binary weighted 2

- **Calculate 9th 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(x1 xxxx xxxx)
-) Vi(x0 xxxx xxxx)

- Average above;
  - $\overline{\text{Vi(256C)}}$
  - Noise sigma becomes $1/\sqrt{512}=1/22$.
- Get each noise-suppressed weight
  - $\overline{\text{Vi(512C)}}$, $\overline{\text{Vi(256C)}}$, ･･$\overline{\text{Vi(1C)}}$
  - Each noise sigma becomes $1/\sqrt{512}=1/22$.

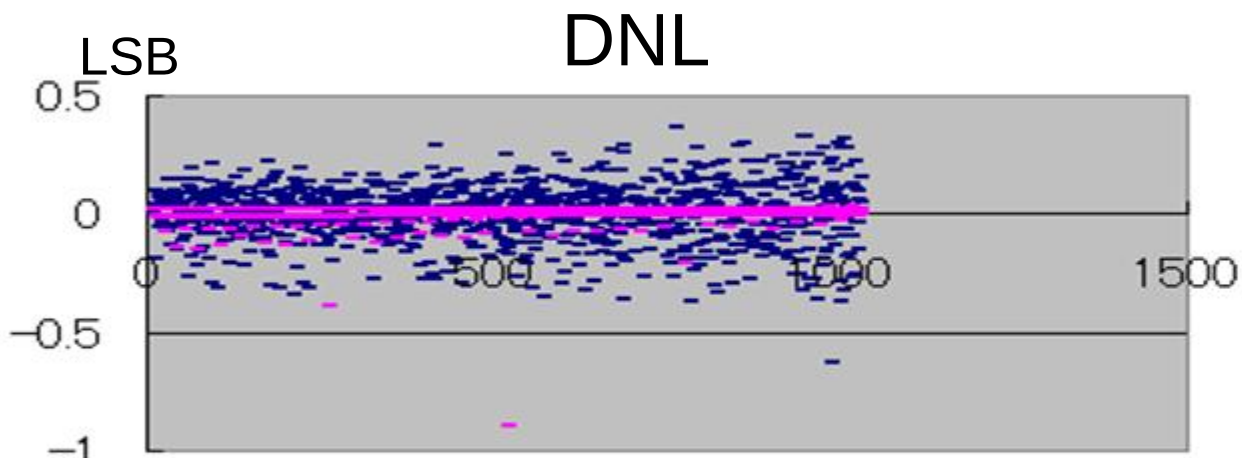
Proposed method for binary weighted 3

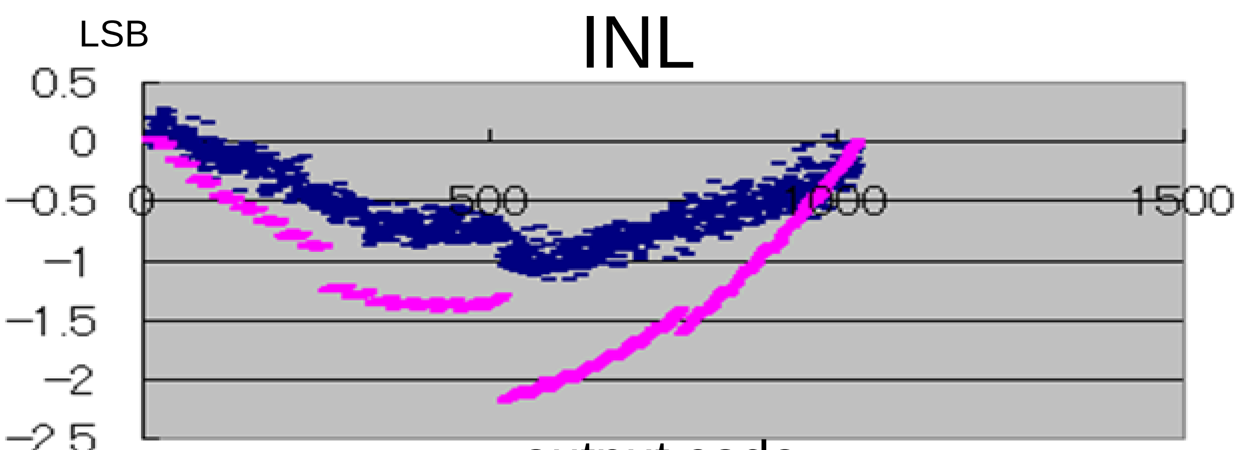
- **Reproduce noise-reduced ADC**
  - Vre(0)=0
  - Vre(1)=$\overline{\text{Vi(LSB)}}$
  - Vre(2)=$\overline{\text{Vi(2}^{\text{nd}}\text{)}}$
  - Vre(3)=$\overline{\text{Vi(2}^{\text{nd}}\text{)}}$+$\overline{\text{Vi(LSB)}}$

    :
  - Vre(513)=$\overline{\text{Vi(MSB)}}$+$\overline{\text{Vi(LSB)}}$

    :
  - Vre(1023)= $\overline{\text{Vi(MSB)}}$+$\overline{\text{Vi(9}^{\text{th}}\text{)}}$+$\overline{\text{Vi(8}^{\text{th}}\text{)}}$+・・+$\overline{\text{Vi(LSB)}}$
- Calculate linearity
  - INL
  - DNL

Calculation results





proposed
previous

I have detected that DUT was not binary coded !

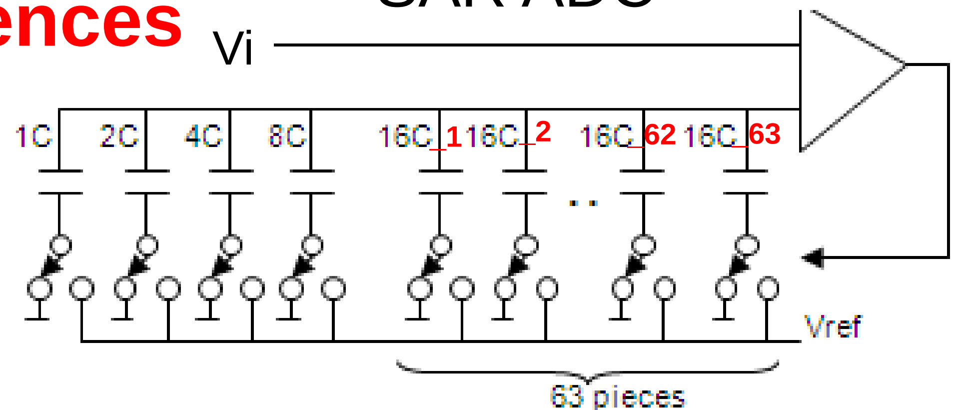
A case of 10bit ADC consists of thermometer coded at top 6bits +binary coded at lower 4bits

Proposed method for thermometer weighted 1

- Calculate top 6bit thermometer coded as differences of each 16C on/off
  - Vi(16C_1)=Vi(16)-Vi(0)
  - Vi(16C_1)=Vi(17)-Vi(1)

    :
  - Vi(16C_1)=Vi(31)-Vi(15)
  - Vi(16C_2)=Vi(32)-Vi(0)
  - Vi(16C_2)=Vi(33)-Vi(1)

    :
  - Vi(16C_63)=Vi(1008)-Vi(0)
  - Vi(16C_63)=Vi(1023)-Vi(15)



- Average above;
  - $\overline{\text{Vi(16C\_1)}}$, $\overline{\text{Vi(16C\_2)}}$, ･･･, $\overline{\text{Vi(16C\_63)}}$
  - Noise sigma becomes $1/\sqrt{16}=1/4$.

    Noise reduced 1/4 !

$$\begin{array}{l} \text{Vi(yy yyyy xxxx)} \\ \underline{\text{-) Vi(zz zzzz xxxx)}} \end{array} \quad \text{yyyyyy} - \text{zzzzzz} = 1$$

Proposed method for thermometer weighted 2

- **Calculate binary weight at lower 4bits**
  - Vi(8C)=Vi(8)-Vi(0)
  - Vi(8C)=Vi(9)-Vi(1)

    :
  - Vi(8C)=Vi(15)-Vi(7)
  - Vi(8C)=Vi(24)-Vi(16)
  - Vi(8C)=Vi(25)-Vi(17)

    :
  - Vi(8C)=Vi(1016)-Vi(1008)
  - Vi(8C)=Vi(1023)-Vi(1015)

Vi(xx xxxx 1xxx)

-) Vi(xx xxxx 0xxx)

- Average above;
  - $\overline{\text{Vi(8C)}}$
  - Noise sigma becomes $1/\sqrt{512}=1/22$.
- Get each noise-reduced weight
  - $\overline{\text{Vi(8C)}},\overline{\text{Vi(4C)}},\overline{\text{Vi(2C)}},\overline{\text{Vi(1C)}}$
  - Each noise sigma becomes $1/\sqrt{512}=1/22$.

Proposed method for thermometer weighted 3

- **Reproduce noise-reduced ADC**
  - $Vre(0)=0$
  - $Vre(1)=\overline{Vi(1C)}$
  - $Vre(2)=\overline{Vi(2C)}$
  - $Vre(3)=\overline{Vi(1C)}+\overline{Vi(2C)}$

    :
  - $Vre(16)=\overline{Vi(16C\_1)}$
  - $Vre(16)=\overline{Vi(16C\_1)}+\overline{Vi(1C)}$

    :
  - $Vre(33)=\overline{Vi(16C\_1)}+\overline{Vi(16C\_2)}+\overline{Vi(1C)}$

    :
  - $Vre(1023)=\overline{Vi(16C\_1)}+\overline{Vi(16C\_2)}+\cdot\cdot+\overline{Vi(8C)}+\cdot\cdot+\overline{Vi(1C)}$

- Calculate linearity
  - INL
  - DNL

Experiment results 1

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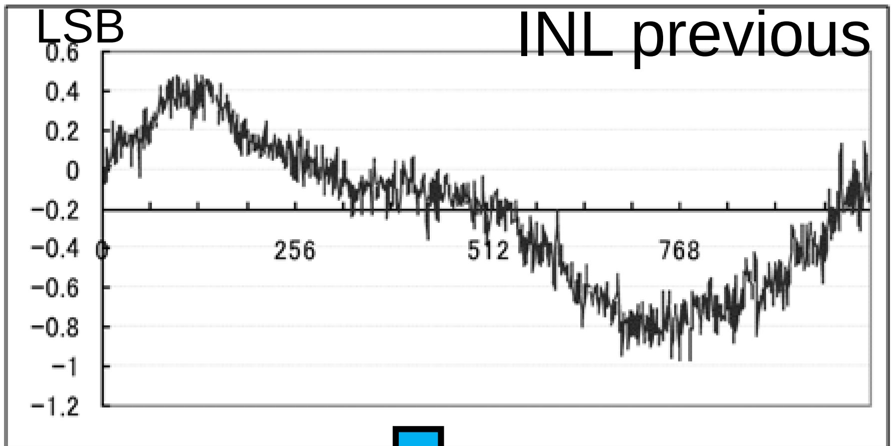
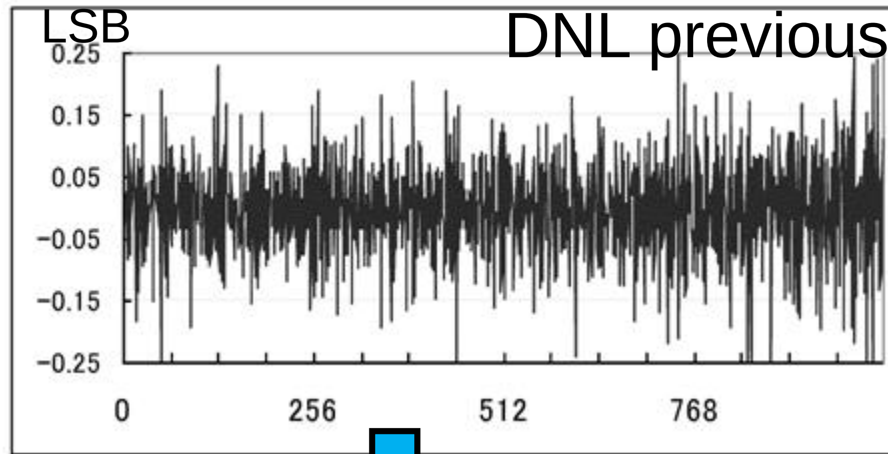
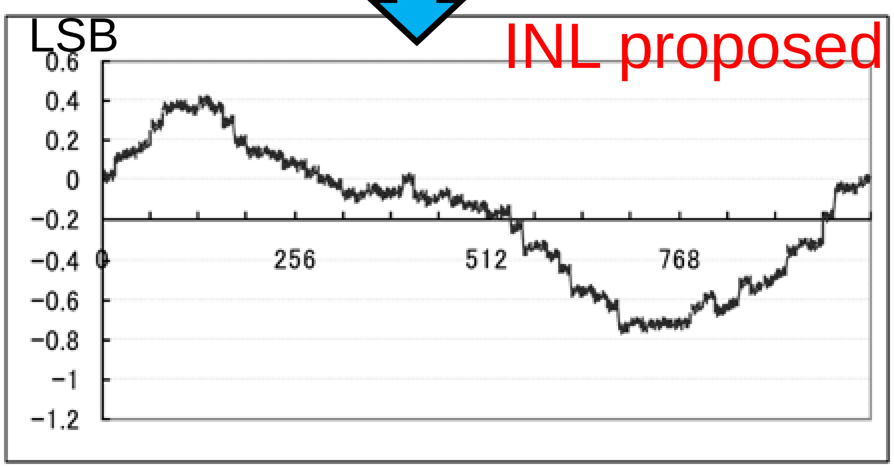
Noise reduction

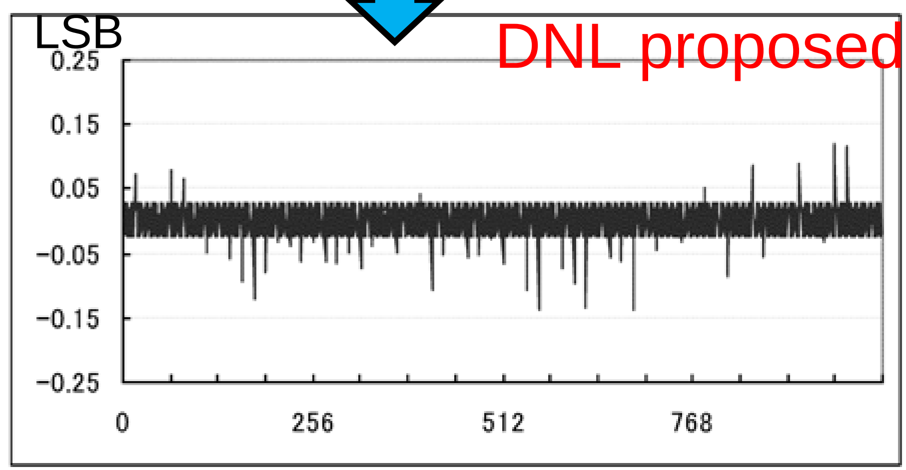
Noise becomes 1/4 ~ 1/22

10bit ADC,
10240 measuring points







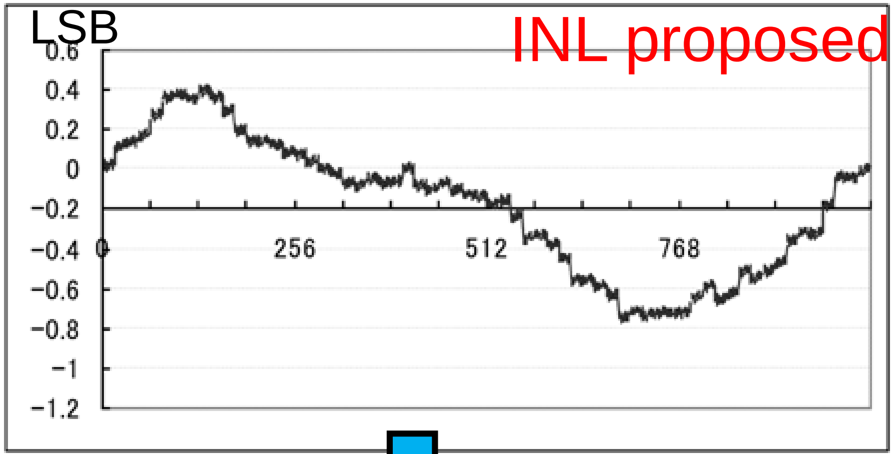


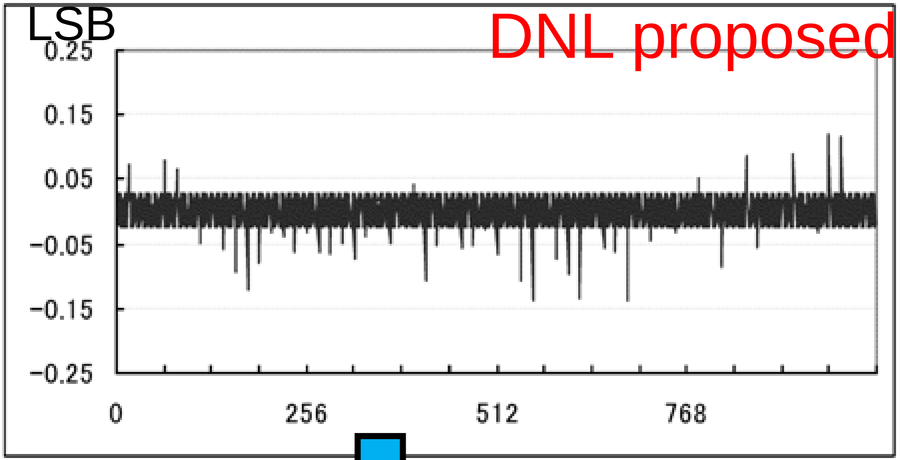
(Equivalence of x16 = 160,000 measuring points or more)

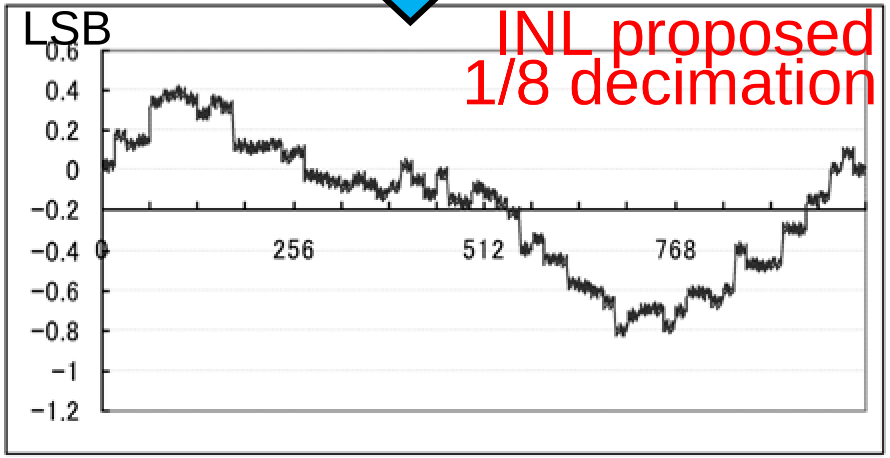
Experiment results 2

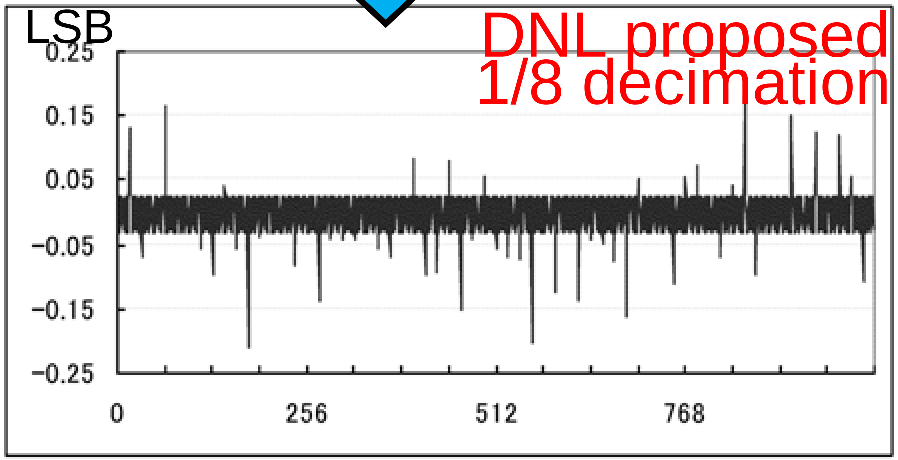
Measurement time reduction

decimated to 1/8 = 1280 measuring points



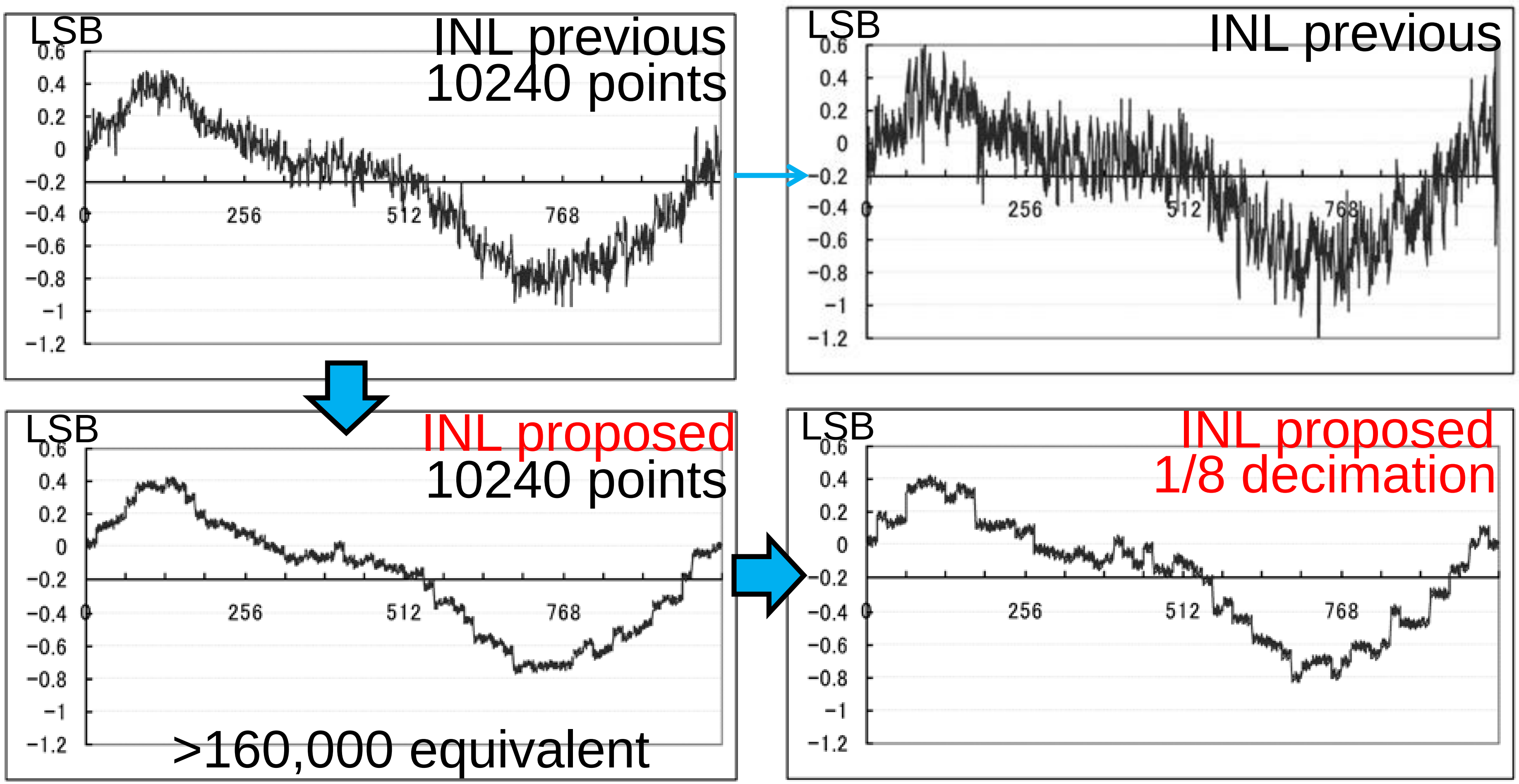






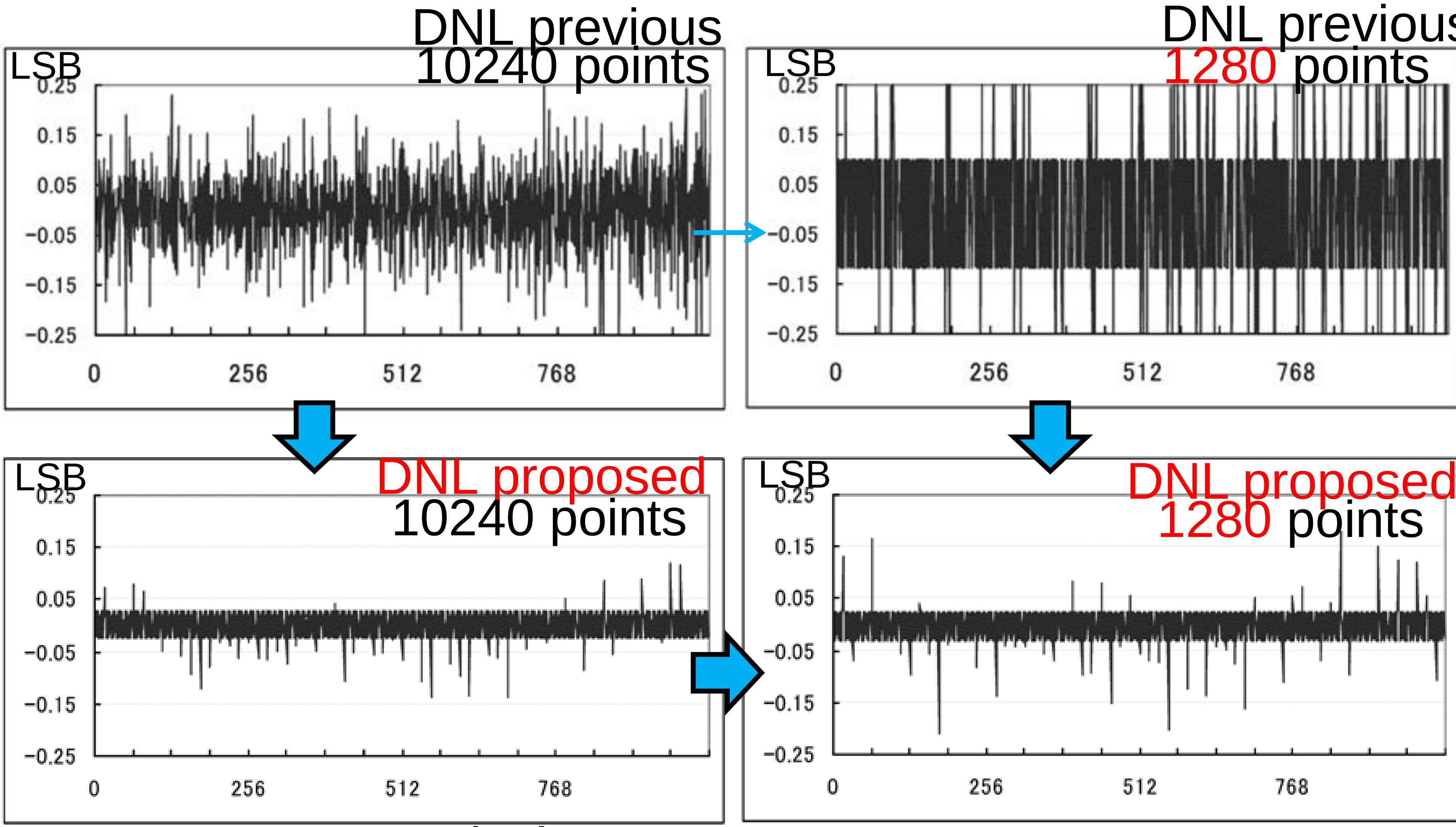
Experiment results 3

Measurement time reduction



Experiment results 4

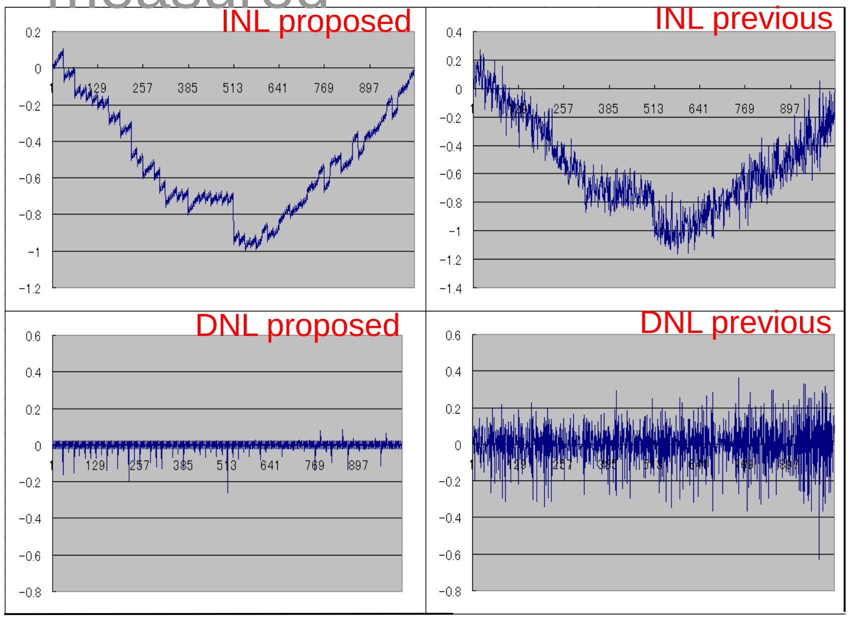
Measurement time reduction



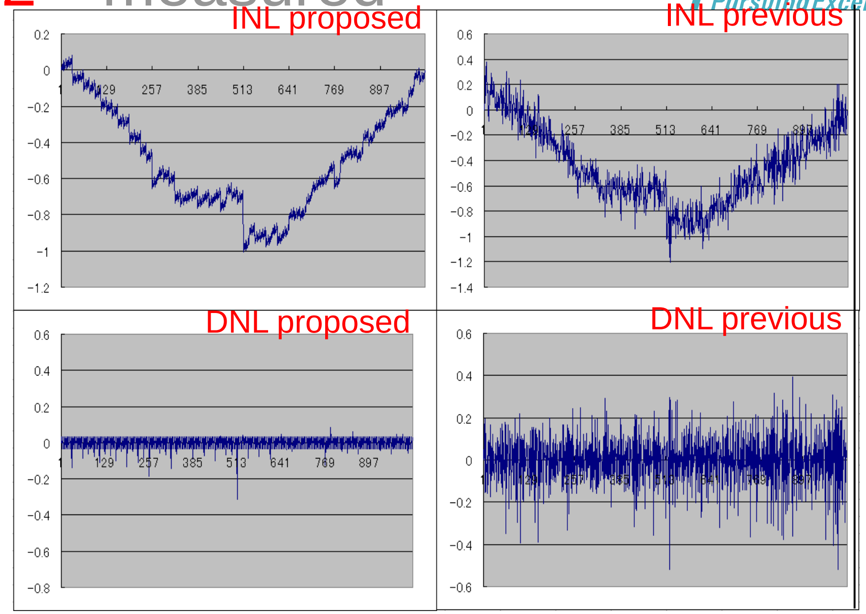
>160,000 equivalent

Experiment results 5

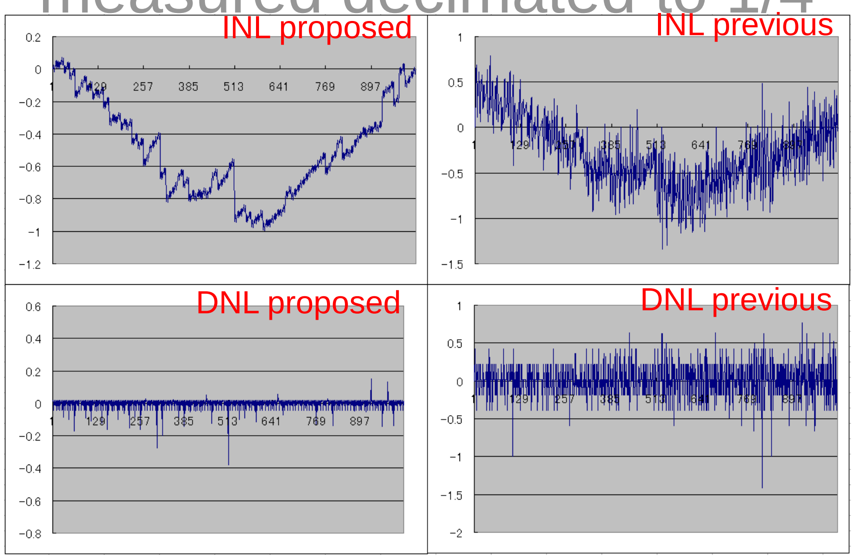
1st measured



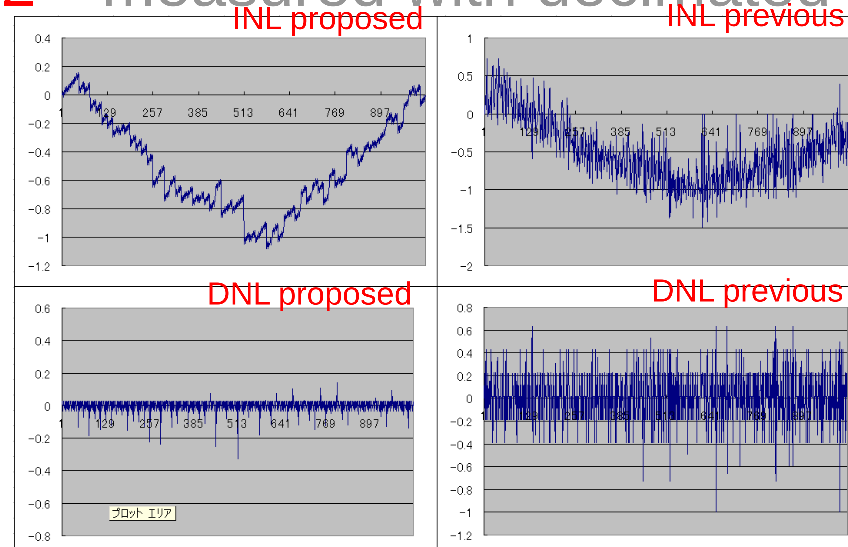
2nd measured



1st measured decimated to 1/4



2nd measured with decimated 1/4



Summery

- **Significant measurement noise reduction to 1/4~1/22**
  - Equivalent x16 (=160,000) measuring point or more
  - Robust data with better repeatability
- **Significant measurement time reduction to1/8**
  - 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;**
  - 1/4~1/22 measurement noise reduction
  - 1/8 measuring time reduction = 1/8 test cost
- **Has been programed with C, BASIC**
  - evaluation use & LSI tester implementation
  - Binary,thermometer & combined ADC/DAC
  - Now applied in volume production

Acknowldgement

I appreciate ex

Renesas Micro Systems Co. Ltd.