ASIAN TEST SYMPOSIUM 2021
November 22–25, 2021—Virtual Event Hosted by Japan—

High Precision Measurement of Sub-Nano Ampere Current in ATE Environment

ROHM Co,. Ltd.

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To achieve measurement of Sub-Nano Ampere Current w/ Automatic Test Equipment(ATE)

- **Requirements**
  - **Fast Testing**
  - **High Accuracy**
  - **High Stability**
- **Proposed Method**
  - **FFT-Based DC-AC Conversion for Current measurement**

Outline

- Research Background
- Sub-Nano Ampere Current Testing
- Proposed Method
- Experiment of DC-AC Current Measurement
- Verification with Actual DUT
- Conclusion

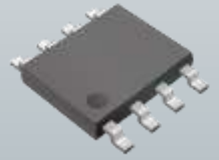
Mobile and Wearable devices

Requirement

Long battery life

⇩ Development

Low power consumption LSI



Low power consumption is a key performance

Outline

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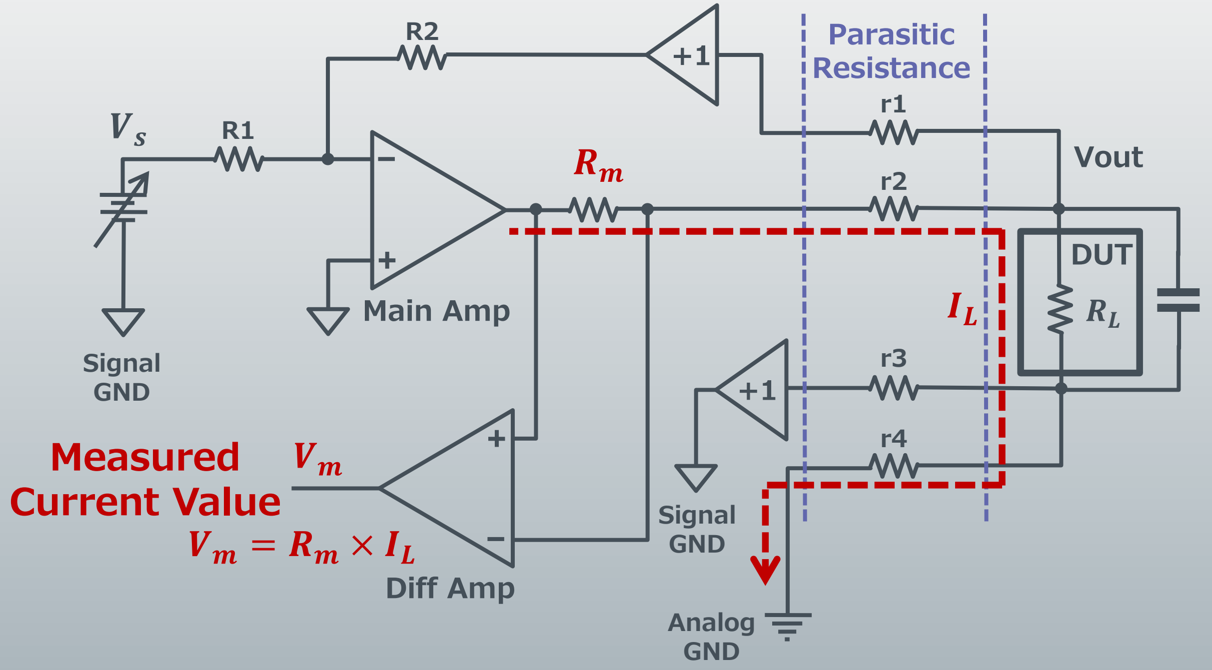
Difficulty of Sub-Nano Ampere Current Testing (1/2)

Slow Testing

Voltage Source/Current measurement (VSIM) in ATE system



Sub-Nano Ampere Current Testing

⇩

Large current sense resistor

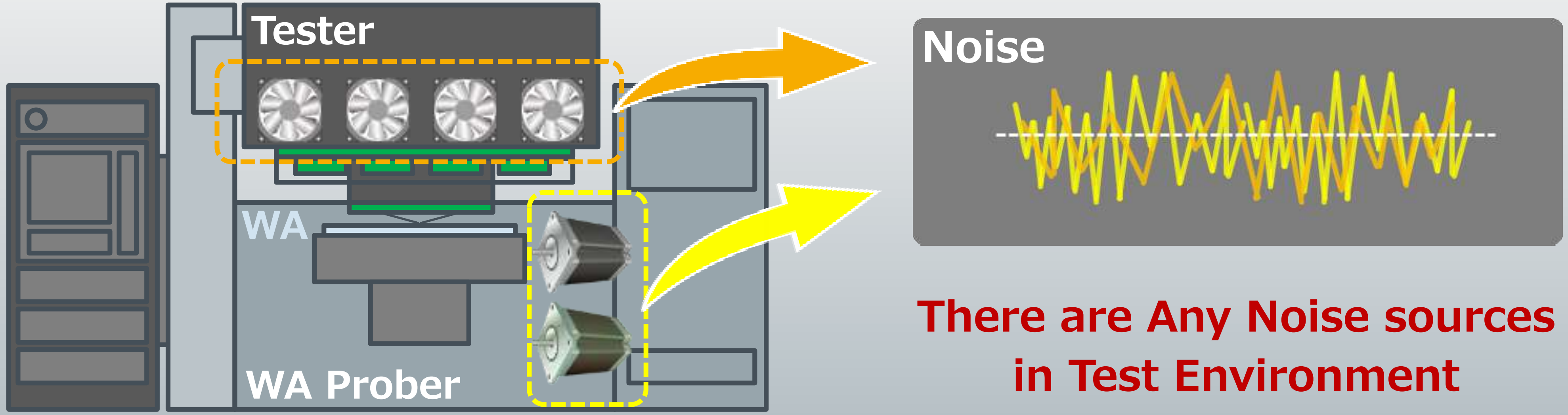
R_m : $M\Omega$ order

Large current sense resistor "Rm" will affect Test Time

Difficulty of Sub-Nano Ampere Current Testing (2/2)

Environmental Noises

Actual Test Environment



There are Any Noise sources in Test Environment

System noises will affect Sub-Nano Ampere Current Testing

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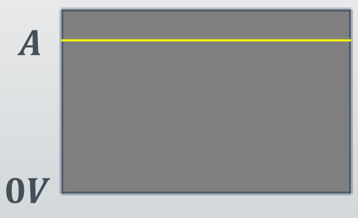
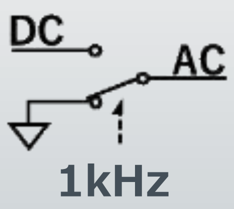
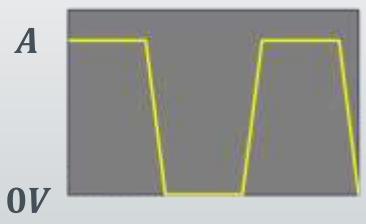
FFT-based DC-AC Conversion

Overview

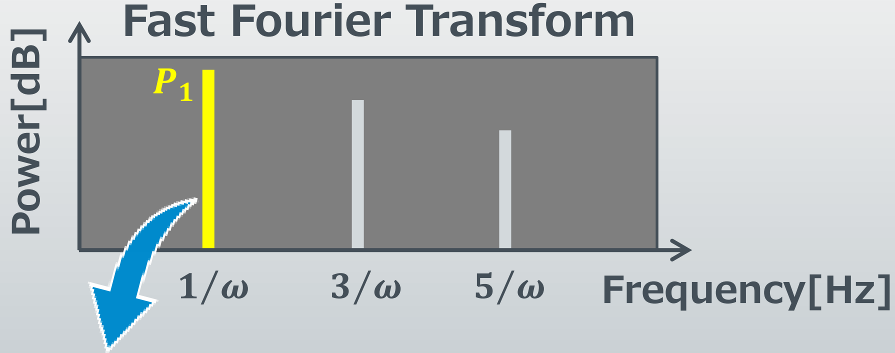


$V_{(t)} = A$





$$V_{(t)} = \frac{4}{\pi}\left\{\sin(\omega t) + \frac{1}{3}\sin(3\omega t) + \frac{1}{5}\sin(5\omega t) + \cdots\right\}$$



Fundamental Power Spectrum

$$A = \frac{10^{\wedge}\left(\frac{P_1}{20}\right)\cdot 2\sqrt{2}}{\frac{4}{\pi}}$$

DC Voltage is converted to Fundamental Power Spectrum

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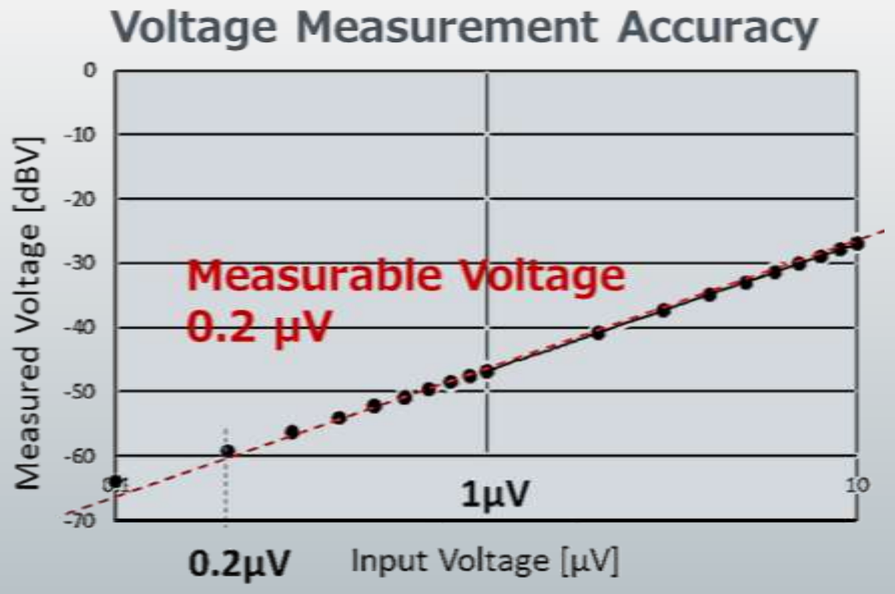
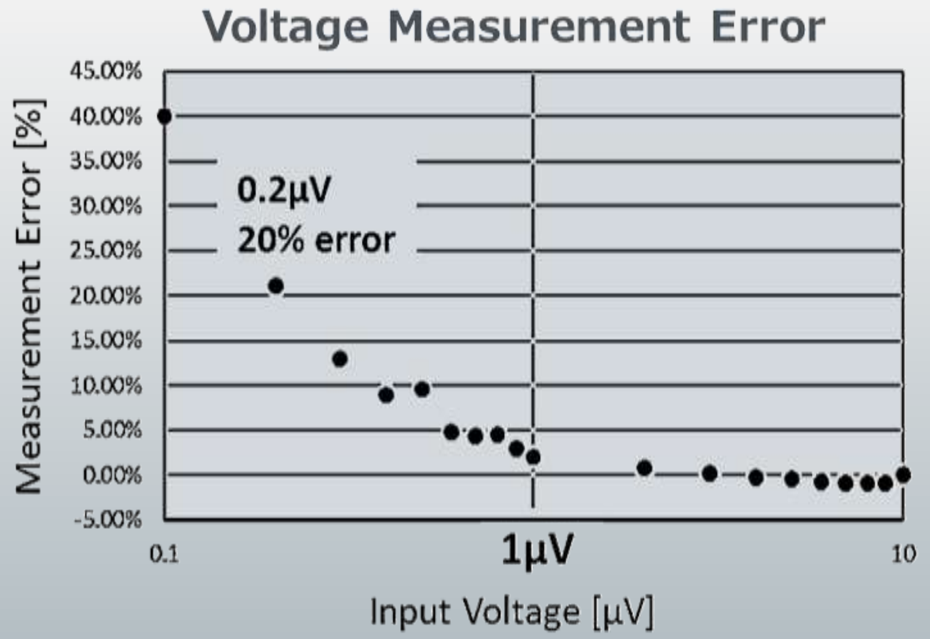
FFT-based DC-AC Conversion

Feature



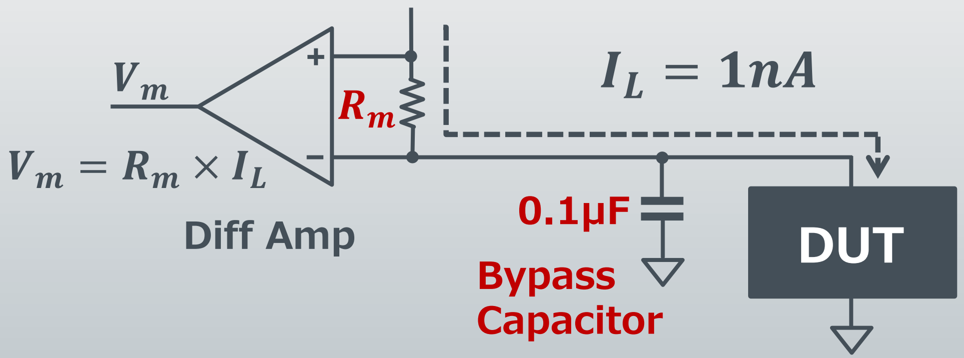


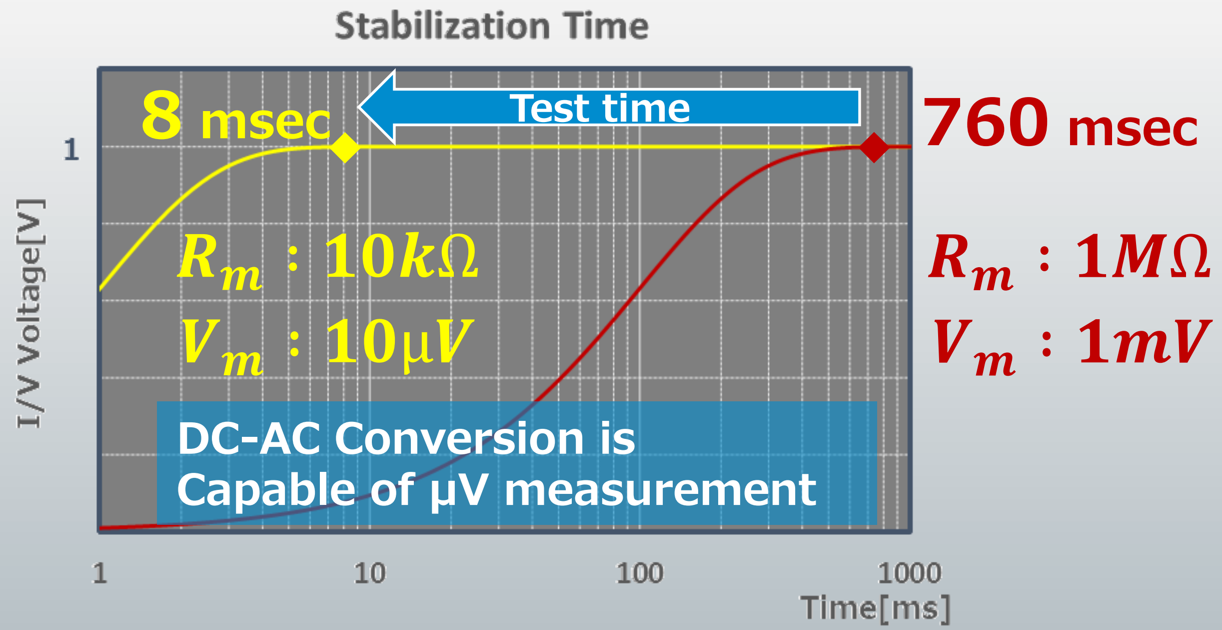
DC Voltage measurement accuracy is less than 1μV

Advantage of FFT-based DC-AC Conversion (1/2)

Test Time reduction

I/V Conversion



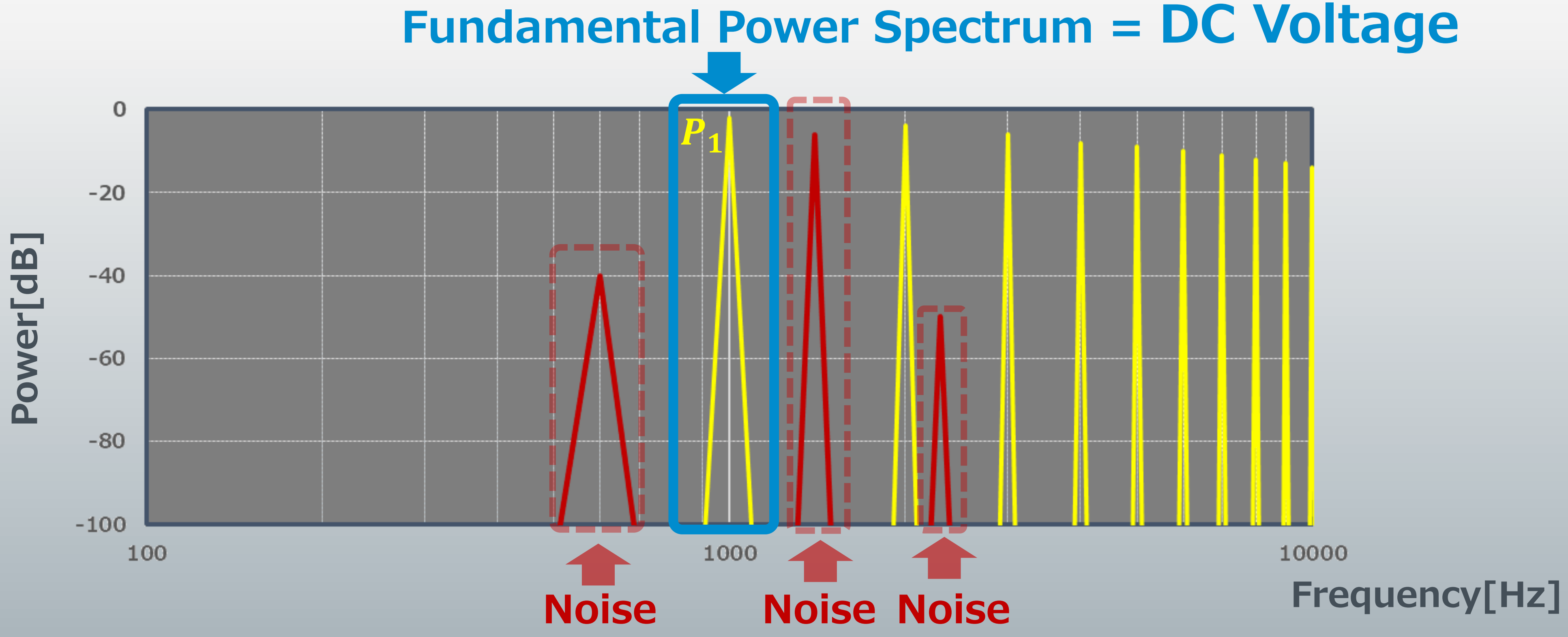


"Rm" and "Bypass Capacitor" affect stabilization time

Test time can be reduced for Sub-Nano Ampere Measurement

Advantage of FFT-based DC-AC Conversion (2/2)

Disregard of Environmental Noise



Can be ignored Noise Power Spectrum

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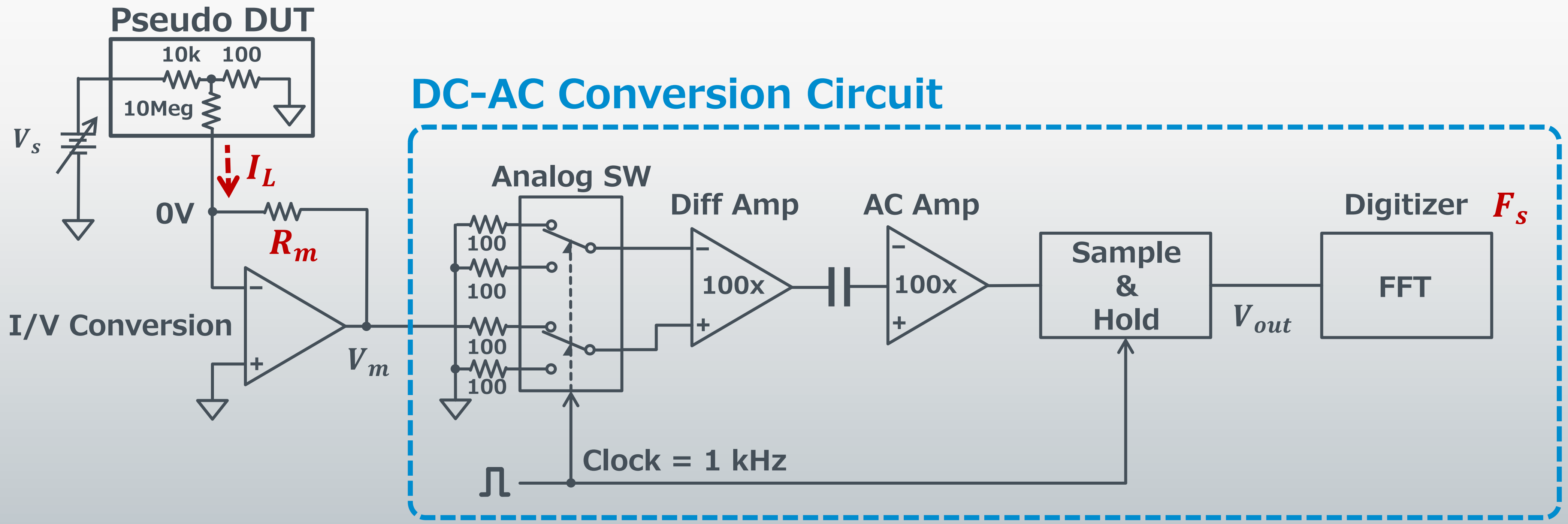
Experiment Setup

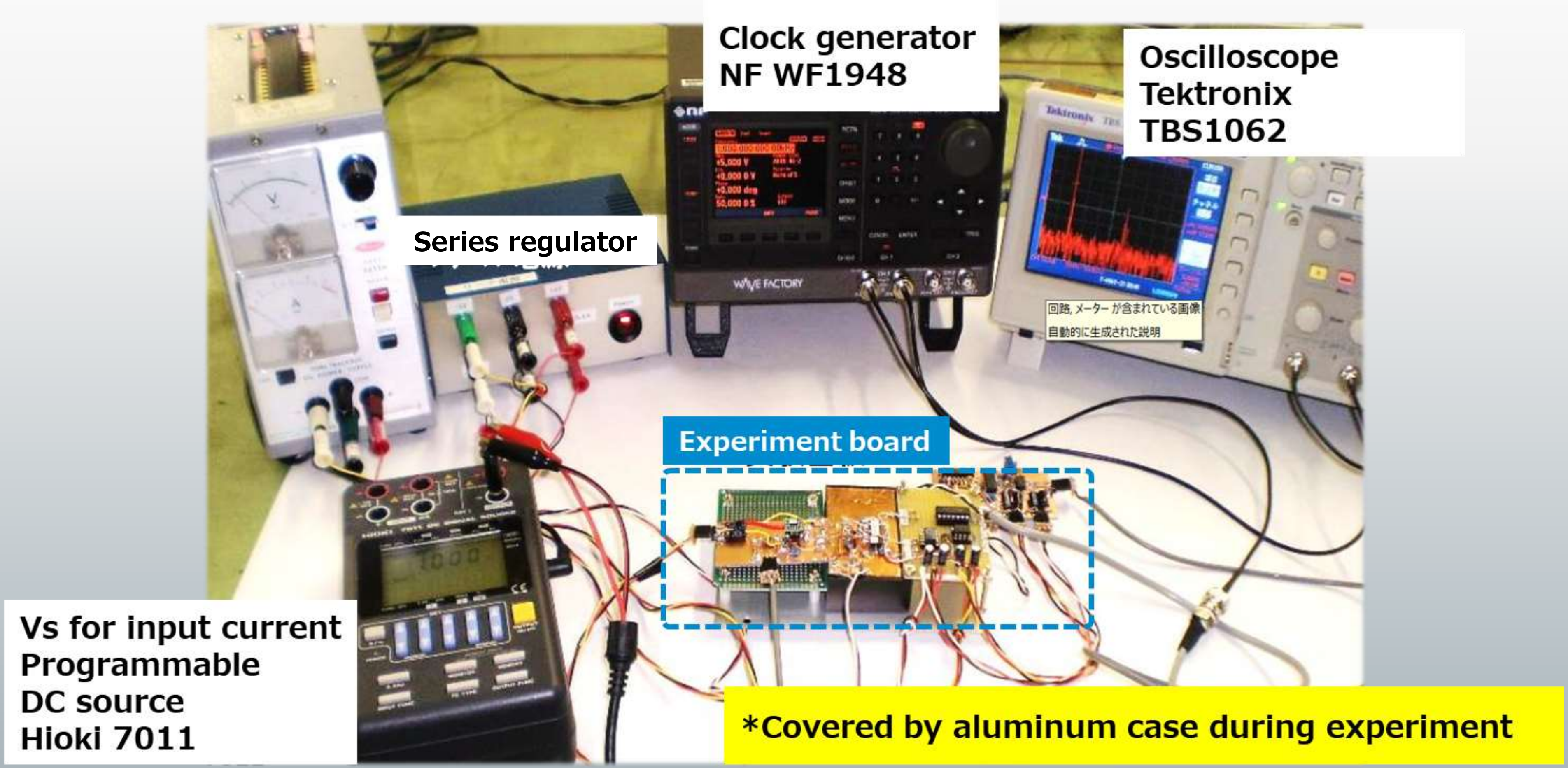


Condition

- I_L (Input current) : 1nA, 10nA
- R_m (Feedback register) : 10kΩ, 100kΩ
- F_s (Digitizer Sampling Rate) : 25.6ksps, 51.2ksps, 102.4ksps

Experiment of DC-AC Current Measurement

Overall Experiment Environment



*Covered by aluminum case during experiment

Experiment of DC-AC Current Measurement

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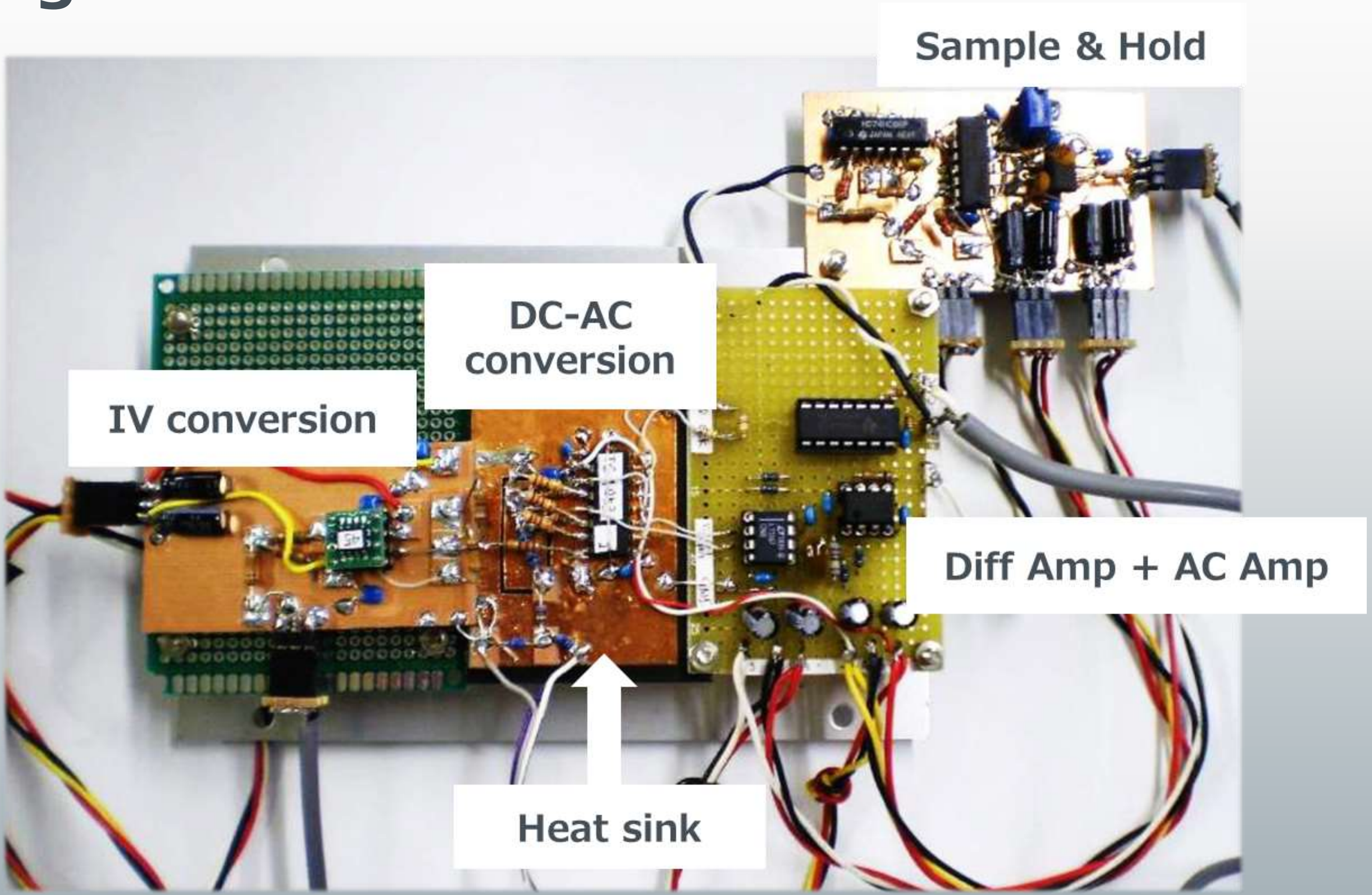
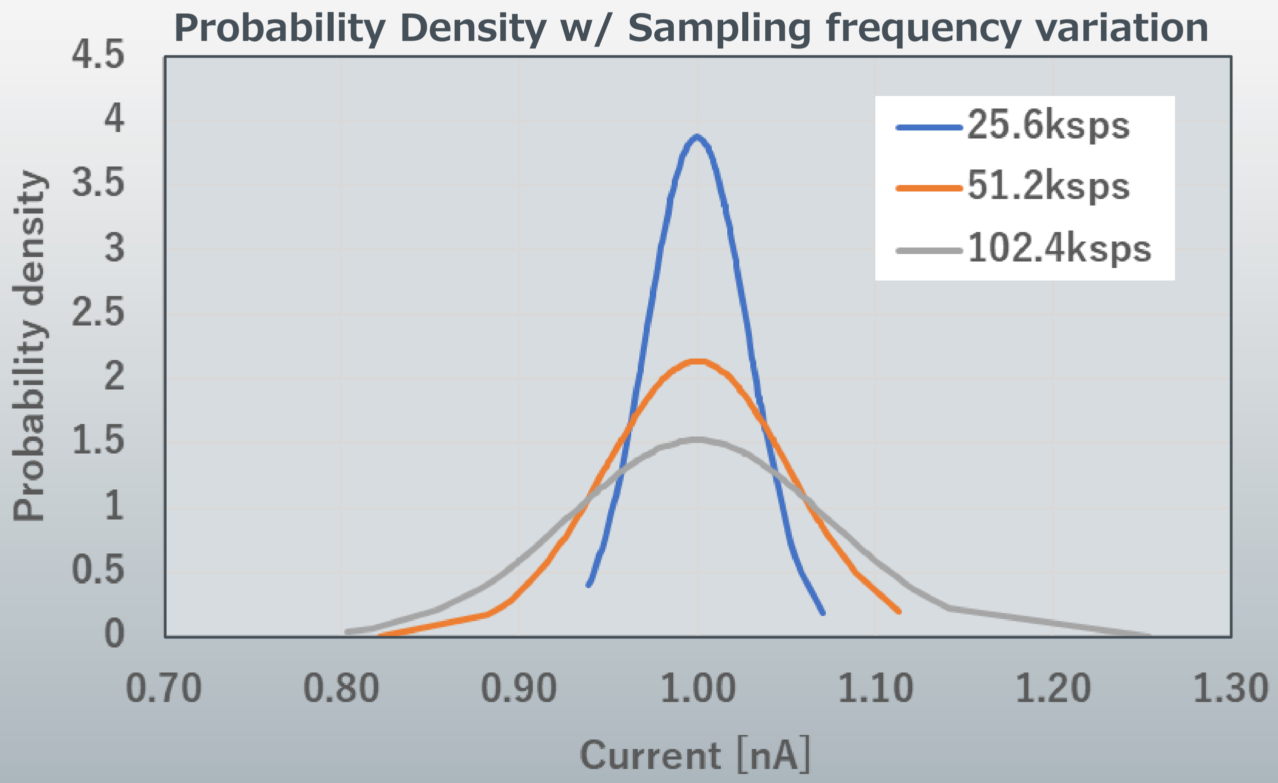
Board Configuration



Experiment of DC-AC Current Measurement

Comparison of probability density

DC-AC Conversion result of 1nA measurement



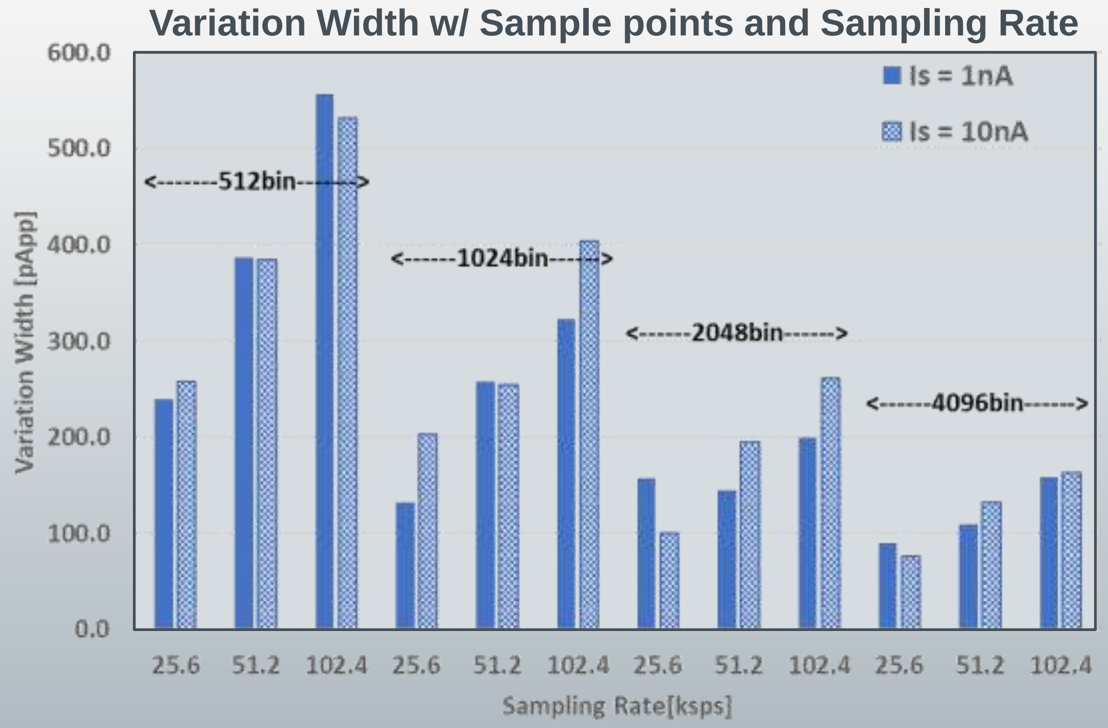
Condition

- I_L : 1nA
- R_m :10kΩ
- Sample points
  - ✓ 1024 bins
- Sampling Rate
  - ✓ 25.60ksps (40msec)
  - ✓ 51.20ksps (20msec)
  - ✓ 102.4ksps (10msec)

The longer the sampling time, the smaller the data variance

Comparison of variation width

Current variation of 1nA and 10nA



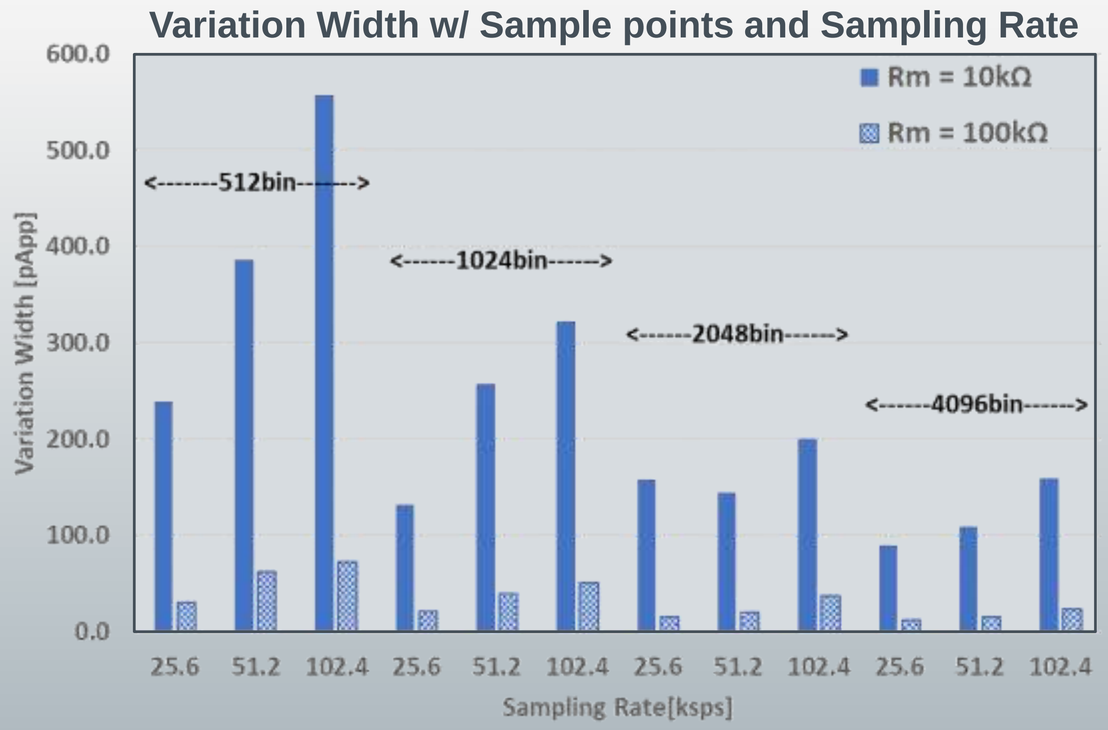
Condition

- I_L : **1nA, 10nA**
- R_m :10kΩ
- Sample points
  - ✓ 512 bins
  - ✓ 1024 bins
  - ✓ 2048 bins
  - ✓ 4096 bins
- Sampling Rate
  - ✓ 25.60ksps
  - ✓ 51.20ksps
  - ✓ 102.4ksps

Input current does not affect data variation

Comparison by probability density

Rm value of 10kΩ and 100kΩ



Condition

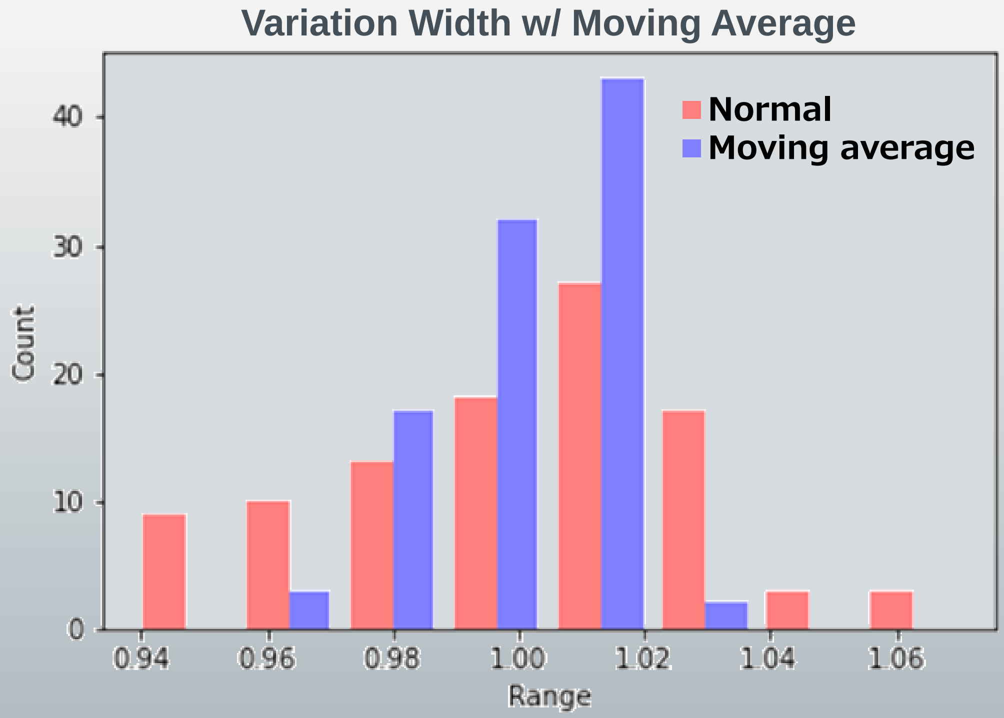
- I_L : 1nA
- R_m :10kΩ, 100kΩ
- Sample points
  - ✓ 512 bins
  - ✓ 1024 bins
  - ✓ 2048 bins
  - ✓ 4096 bins
- Sampling Rate
  - ✓ 25.60ksps
  - ✓ 51.20ksps
  - ✓ 102.4ksps

The larger Rm, the smaller the data variance

Experiment of DC-AC Current Measurement

Smoothing effect

Moving Average (4 times)



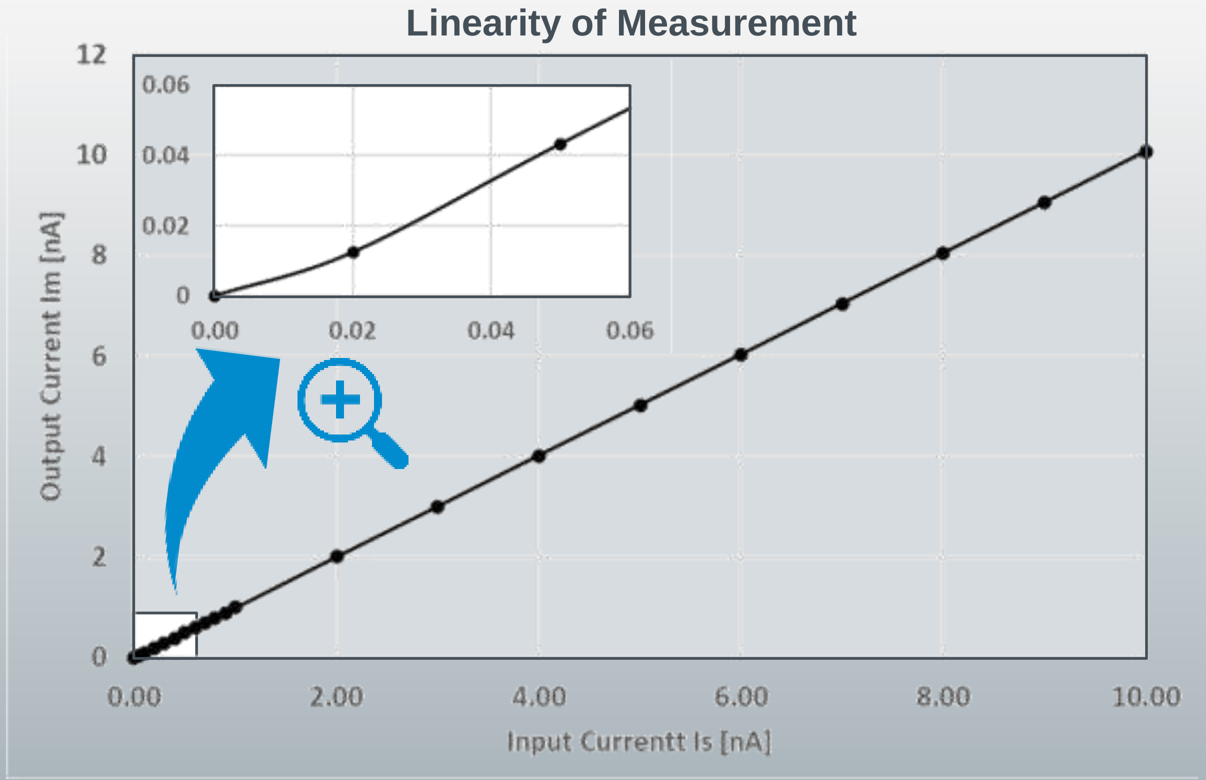
Condition

- I_L : 1nA
- R_m :10kΩ
- Sample points
  - ✓ 1024 bins
- Sampling Frequency
  - ✓ 25.60ksps (40ms)

Variation reduction by about 50%

Limit of measurable current value

Moving Average (4 times)



Condition

- I_L : 1nA
- R_m :100kΩ
- Sample points
  - ✓ 1024 bins
- Sampling Frequency
  - ✓ 25.60ksps (40ms)

Maintains linearity as low as measured current of 0.02nA

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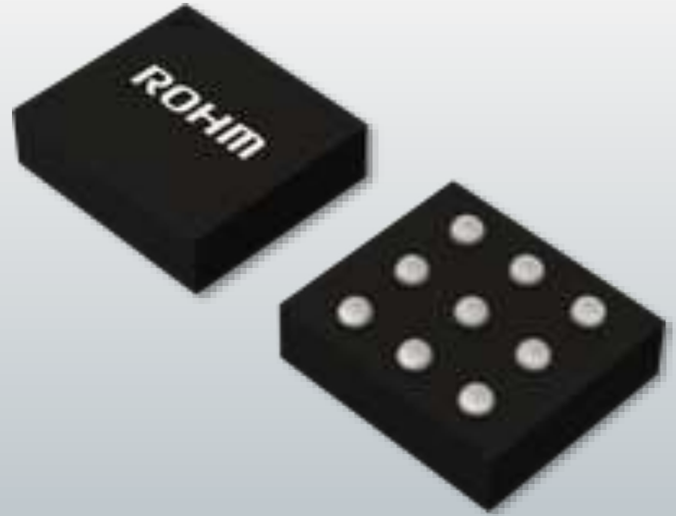
Verification with Actual DUT

BD70522GUL

Nano Energy™ Ultra Low Iq Buck Converter



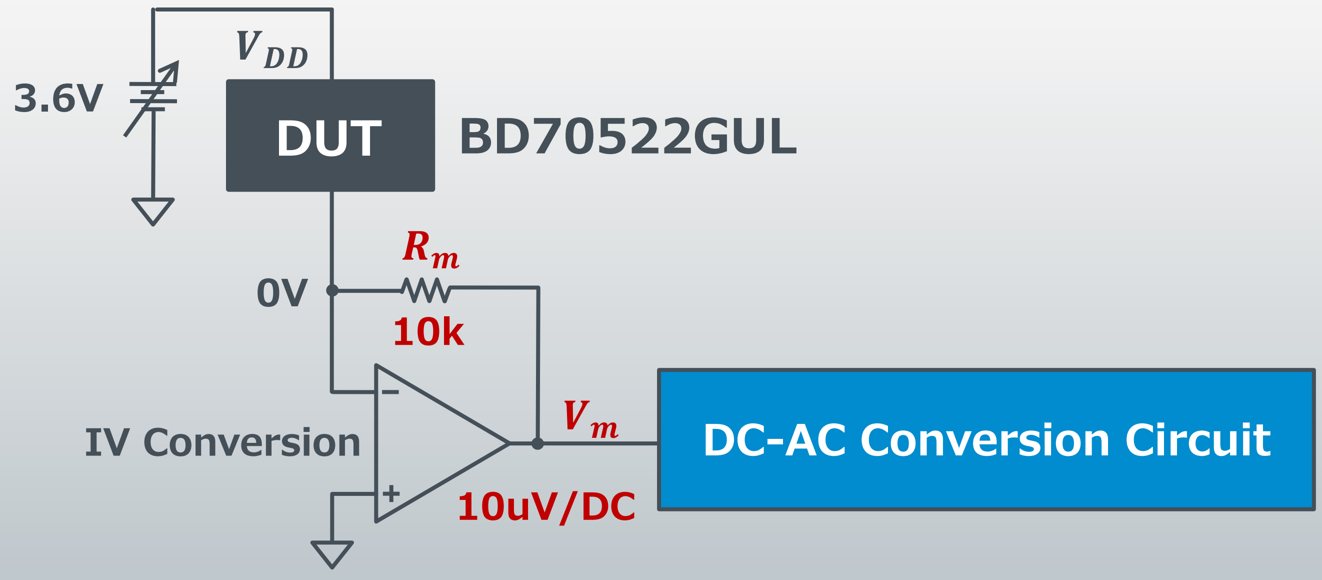
Nano Energy

Datasheet

- Standby Current **Ist : 50nA**
- Operating Quiescent Current **Iq : 180nA**

DC-AC Conversion Circuit for Current Measurement

GND Side



Verification with 5 samples

GND Side

Condition

- R_m :10kΩ
- Sample points :1024bins
- Sampling Rate :25.60ksps

Test time :50msec

Stabilization time :10msec

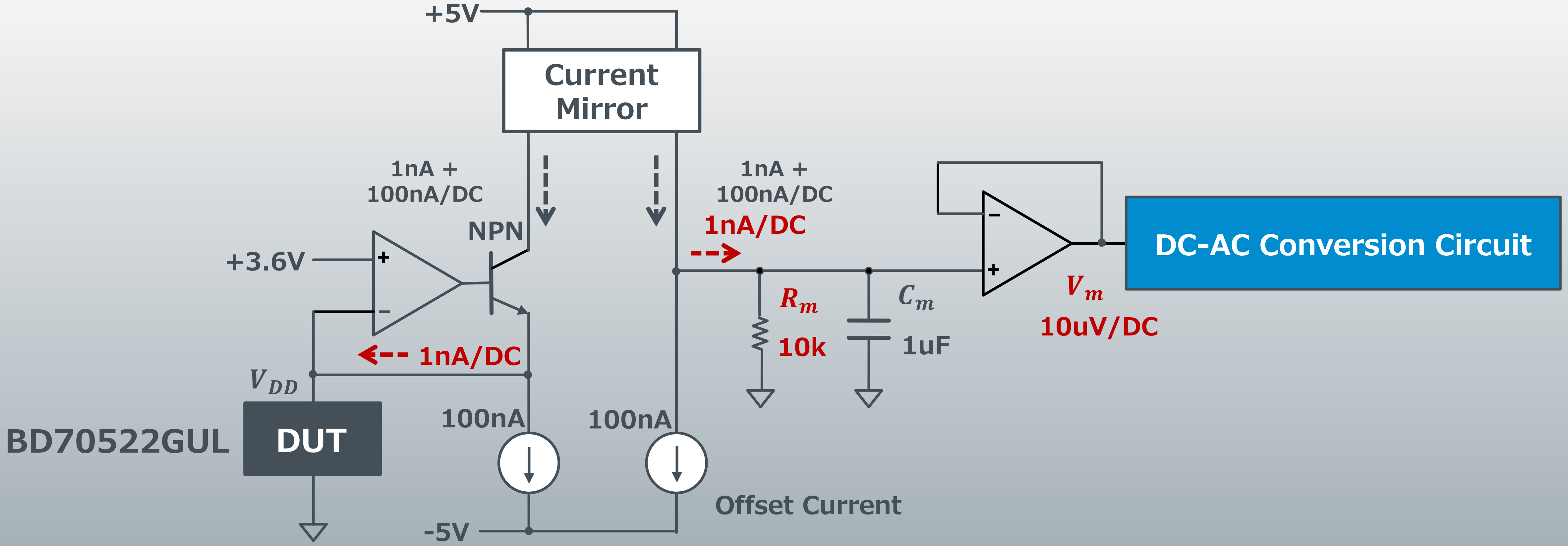
Measurement time :40msec

Device	No.1	No.2	No.3	No.4	No.5	Average
Ist [nA]	12.30	4.27	4.15	2.53	2.25	5.10
Variation width [nApp]	3.62	3.32	3.66	4.29	3.66	3.71
Iq [nA]	147.1	150.7	143.8	134.7	140.1	143.3
Variation width [nApp]	3.95	8.64	3.77	3.64	3.85	4.77

Need to improve variation width

DC-AC Conversion Circuit for Current Measurement

VDD Side



Verification with Actual DUT

Verification with 5 samples

VDD Side

Condition

- R_m :10kΩ
- Sample points :1024bins
- Sampling Rate :25.60ksps

Test time :50msec

Stabilization time :10msec
Measurement time :40msec

Device	No.1	No.2	No.3	No.4	No.5	Average
Ist [nA]	9.27	7.23	3.26	3.52	2.36	5.13
Variation width [nApp]	0.546	0.393	0.513	0.446	0.388	0.457
Iq [nA]	143.7	149.0	141.7	133.2	138.6	141.2
Variation width [nApp]	0.248	0.346	0.305	0.332	0.201	0.286

Variation width smaller than 1nA

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Conclusion

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Sub-Nano Ampere Current Testing

“FFT Based DC-AC Conversion for Current measurement” meets the requirements

- **Fast Testing**
  Sub-Nano Ampere testing time is approximate **50msec**
- **High Accuracy**
  Current measurement range is **20pA**
- **High Stability**
  Current variation width is less than **1nA**

Thank you very much