Accurate Testing of Precision Voltage Reference by DC-AC Conversion

29th IEEE Asian Test Symposium(ATS 2020)

ROHM Co.,Ltd
Keno Sato, Takashi Ishida, Toshiyuki Okamoto,
Tamotsu Ichikawa
Gunma University
Takayuki Nakatani, Anna Kuwana, Kazumi Hatayama,
Haruo Kobayashi

Purpose

To achieve

- ✓ **High accuracy**
- ✓ **Small variation(repeatability)**
- ✓ **Short time testing**
- ✓ **with Auto Test Equipment(ATE)**

- **Target Device**

  Precision voltage reference

  output voltage 2.048V (±0.04%)

- **Requirement**

  Accuracy ±100μV

  Variation ±10μV

  Multi-site measurement

Outline

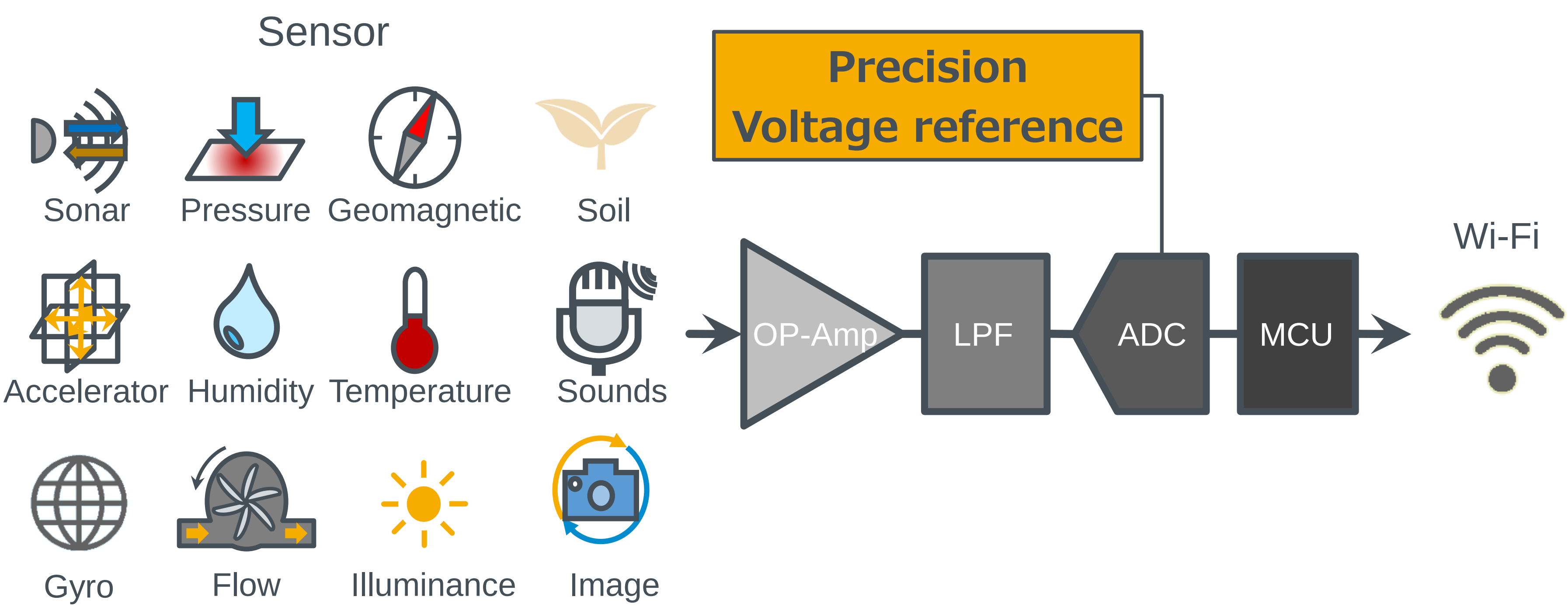
- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Accurate and clean system reference
  - Multi-Site Testing
- **Conclusion**

Outline

- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Accurate and clean system reference
  - Multi-Site Testing
- **Conclusion**

Background

IoT Sensor Network



A precision voltage reference is one of key components of IoT system

Usage of High Accuracy Digital Multimeter

KEYSIGHT 3458A 8½Digit

Outline

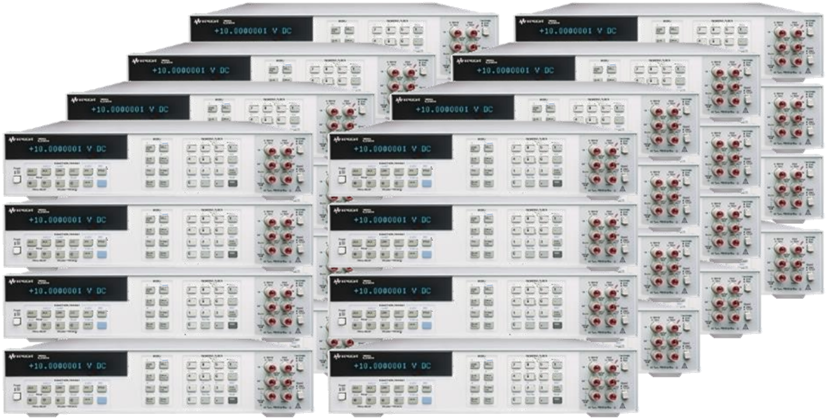
- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Accurate and clean system reference
  - Multi-Site Testing
- **Conclusion**

Difficulty

- **Test time(Multi-Site)**

Single

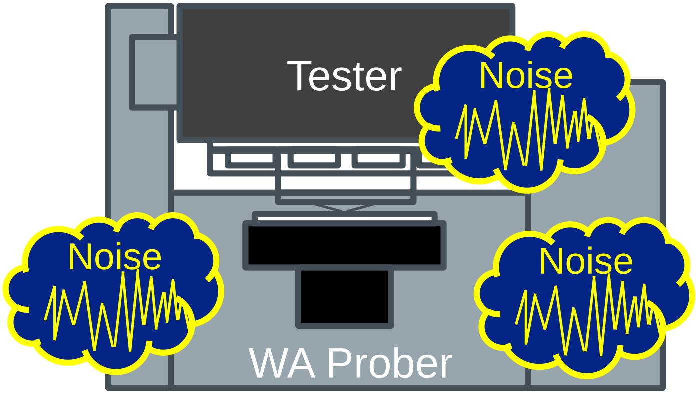
Multi



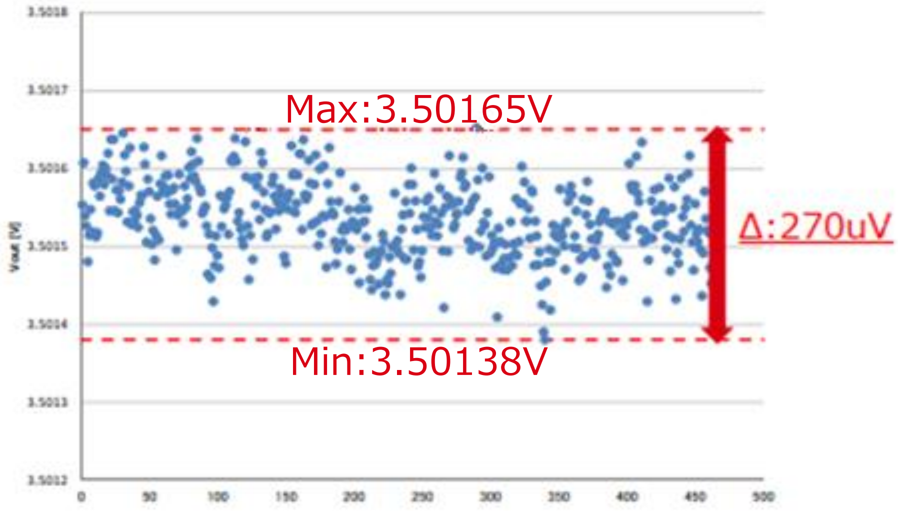
Unrealistic Situation

Difficulty

- **Accuracy of ATE ±809.6μV**
- **Variation 270μV**



Actual situation



Variation with environmental noise

Not satisfy the target

Motivation

We need new test method

To solve the difficulties

- ✓ **High accuracy**
- ✓ **Small variation(repeatability)**
- ✓ **Short time testing**
- ✓ **with Auto Test Equipment(ATE)**

Idea

Chopper technic

+

Fast Fourier Transform(FFT)

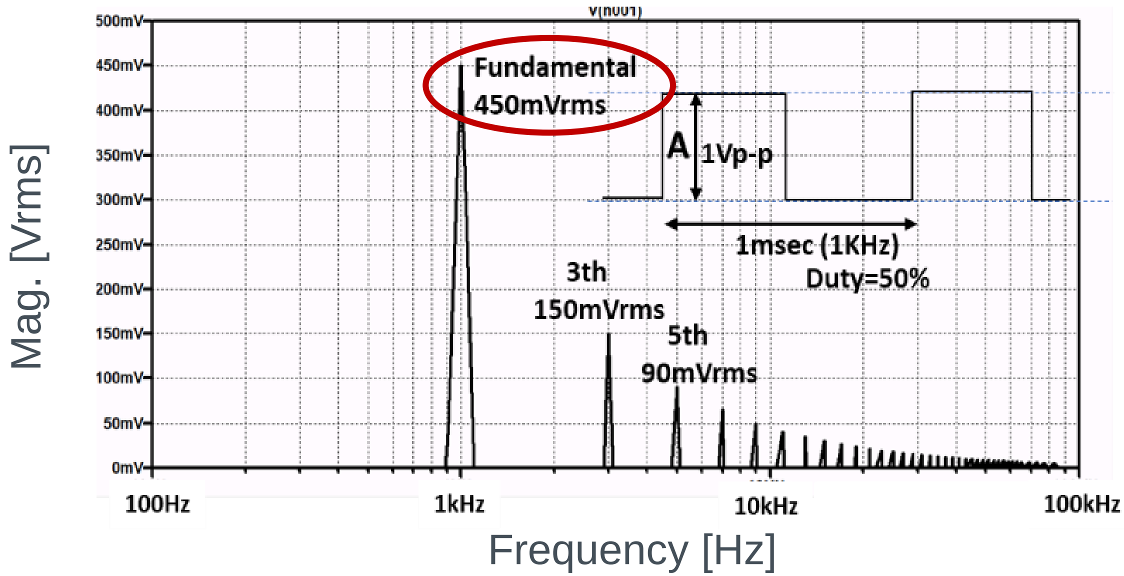
Outline

- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Accurate and clean system reference
  - Multi-Site Testing
- **Conclusion**

DC-AC Conversion and FFT spectrum analysis method

DC Voltage ➡ AC Square Wave ➡ Fast Fourier Transform

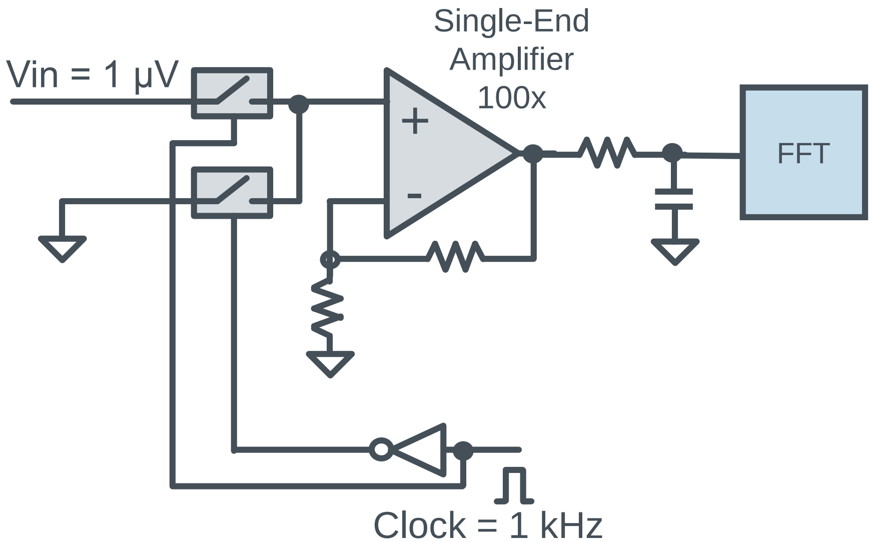
$$V(t) = \frac{2A}{\pi}\left(\sin \omega t + \frac{1}{3}\sin 3\omega t + \frac{1}{5}\sin 5\omega t + \ \ldots\right)$$



DC Voltage is converted to Fundamental Power Spectrum

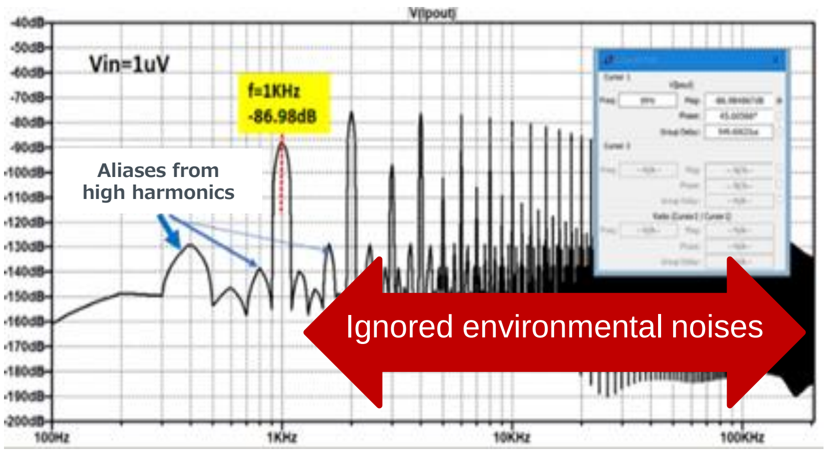
Simulation

Circuit



DC-AC Conversion Clock: 1 kHz (duty 50 %)
CMOS Switch: 4053

FFT result

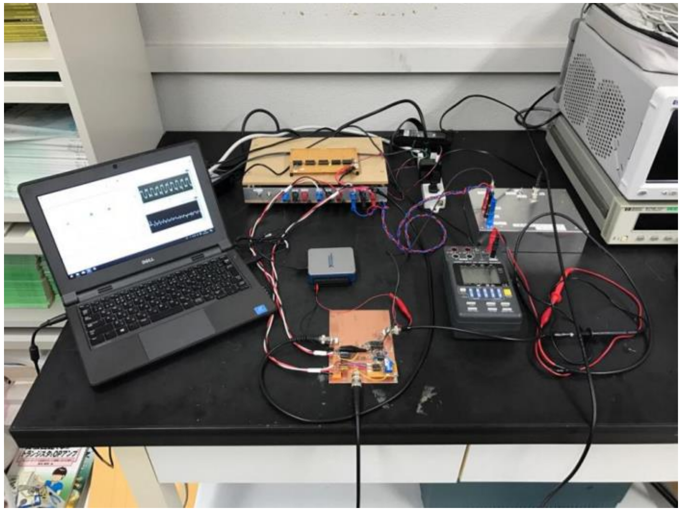


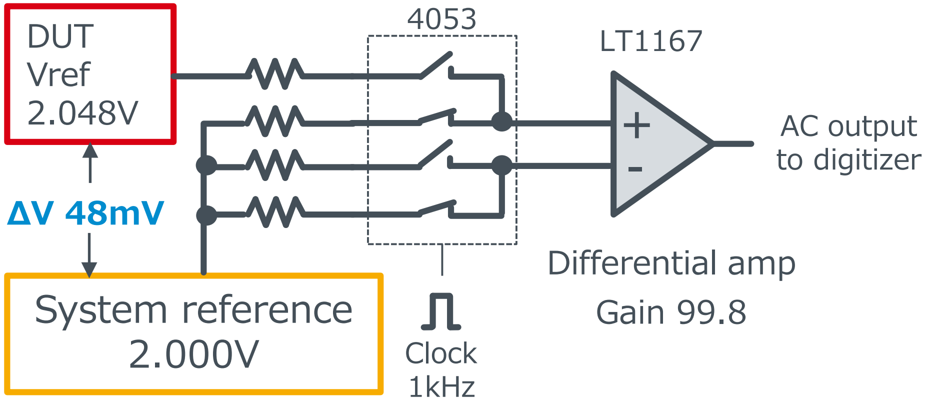
LTspice FFT Condition:
Fs = 409.6 kHz, Fres = 100 Hz, N = 4096,
Rectangle Window

High accuracy for small voltage is feasible

Thanks to FFT, system noises can be ignored

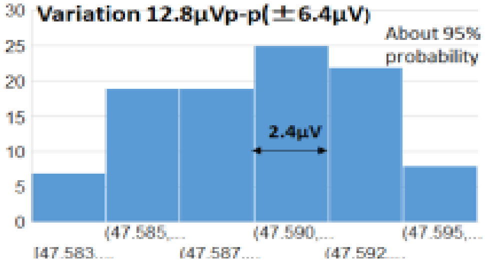
Result of Experiment Environment





Switch: CMOS Analog SW IC (4053)
Environment
- LabVIEW
- NI USB-6003 (16bit ADC,Fs=100kHz)

Result



Measured histogram

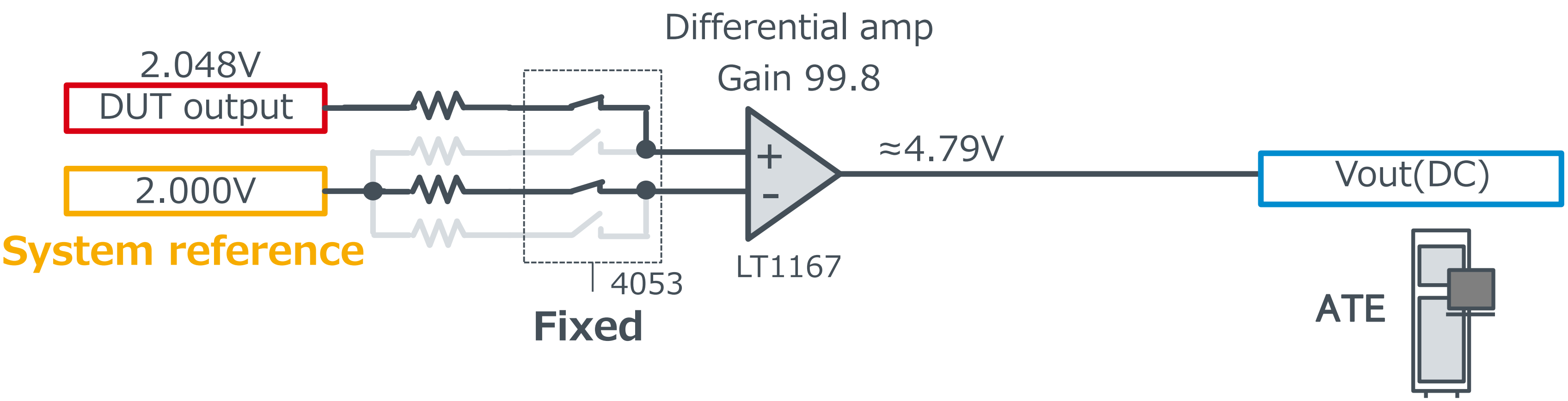
Variation is ±6.4μV

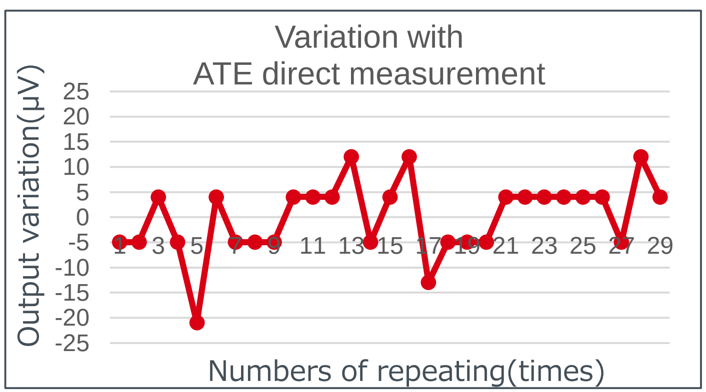
Satisfy the target by system reference

Result with ATE

ATE direct DC measurement

Device : Precision Voltage Reference
Output voltage : 2.048V





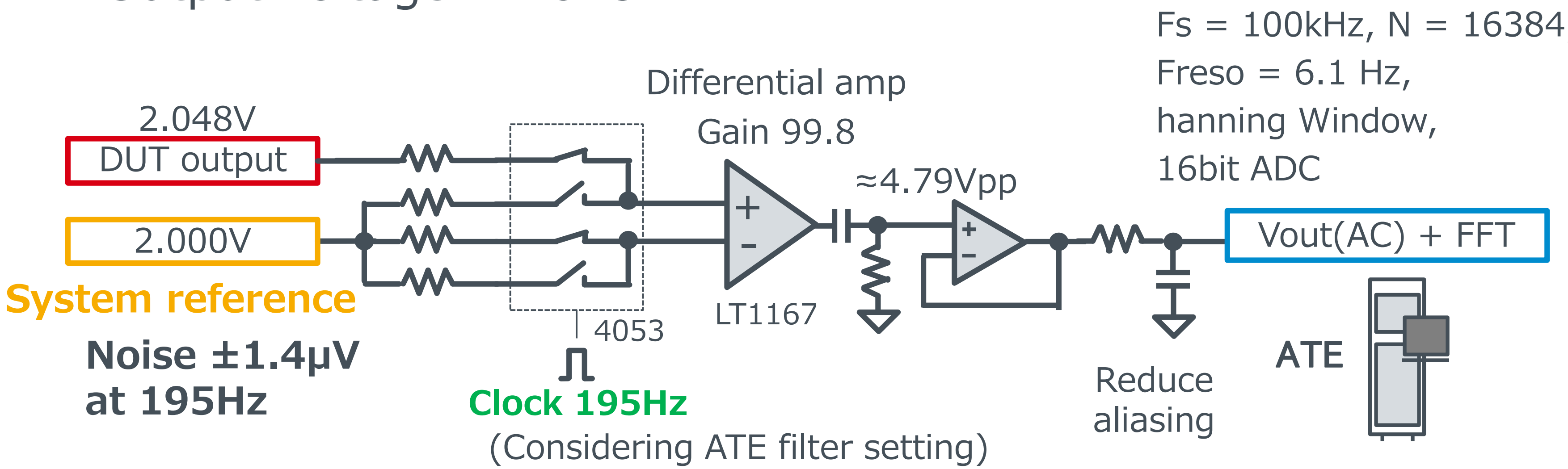
Variation : ±16.5μV

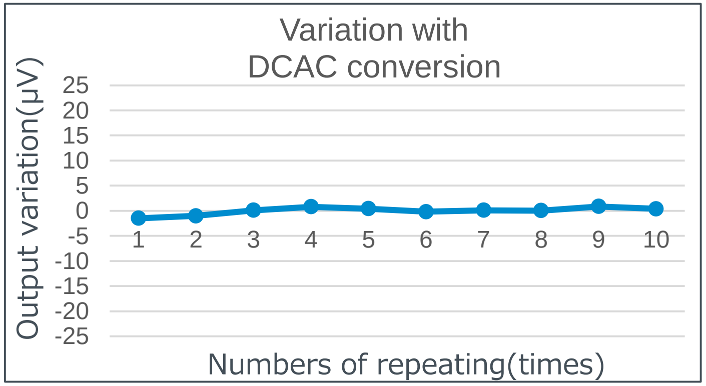
Not satisfy the target

Result with ATE

DC-AC conversion and FFT spectrum analysis

Device : Precision Voltage Reference
Output voltage : 2.048V





Variation : ±2.4μV

Satisfy the target

Result with ATE

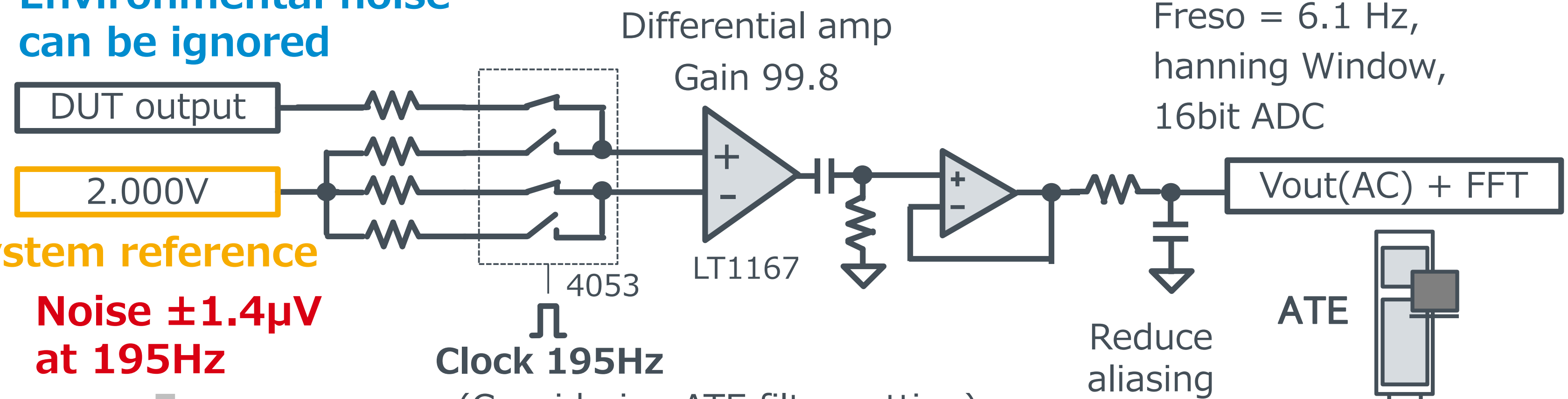
Problem point

Device : Precision Voltage Reference

Output voltage : 2.048V

Environmental noise can be ignored

Fs = 100kHz, N = 16384,
Freso = 6.1 Hz,
hanning Window,
16bit ADC



System reference

Noise ±1.4μV at 195Hz

(Considering ATE filter setting)

can NOT be ignored

Variation : ±2.4μV

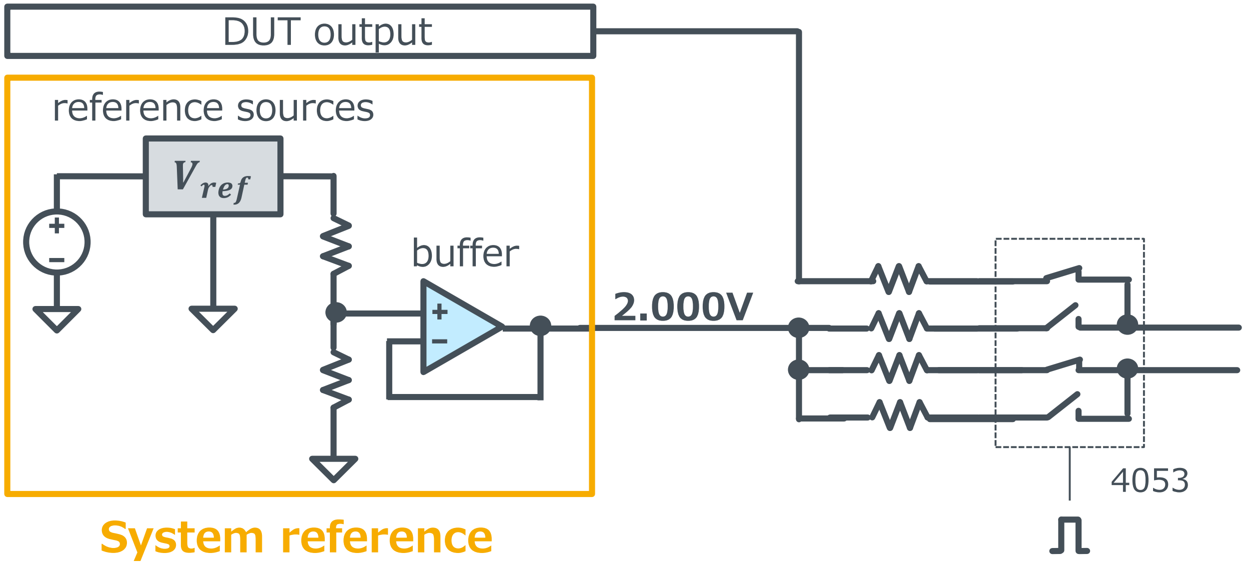
System reference needs improvement

Outline

- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Accurate and clean system reference
  - Multi-Site Testing
- **Conclusion**

Cause of problem in system reference

DC-AC conversion input and system reference circuit



Noise ±1.4µV at 195Hz

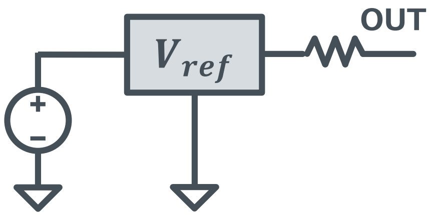
Clock 195Hz

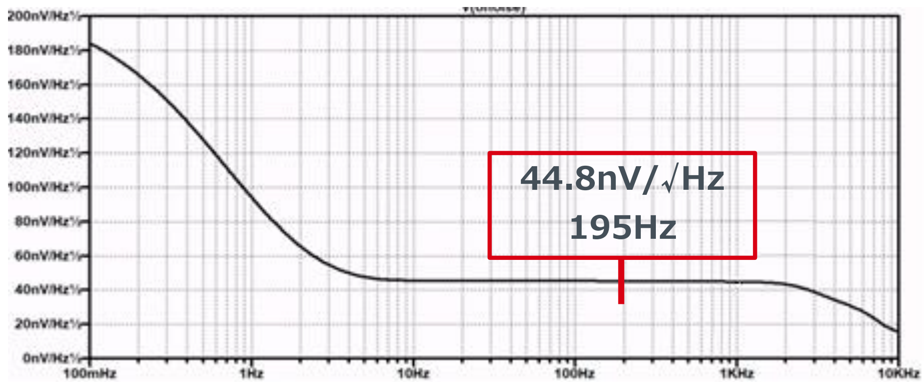
Clock frequency noise is included in system reference

Noise at clock frequency directly affects result

Accurate and clean system reference

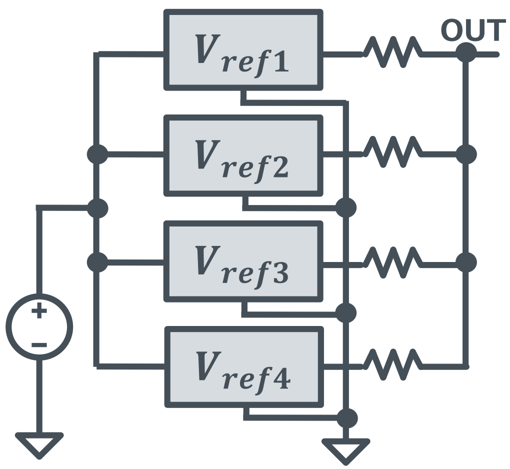
Single reference sources

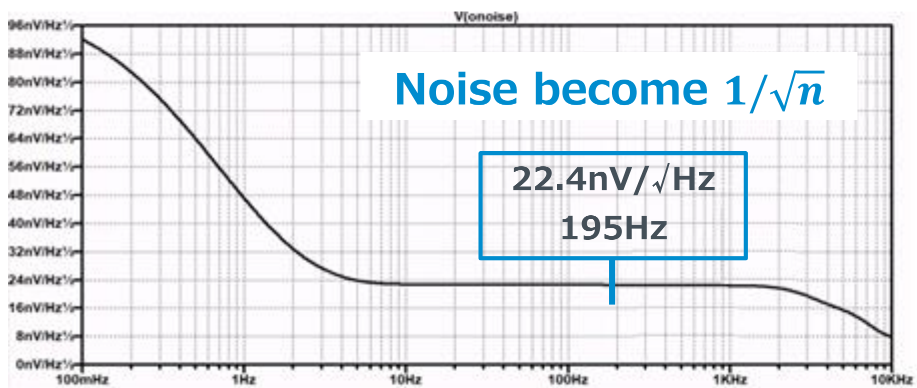




Simulation result of noise density(single)

Parallel reference sources

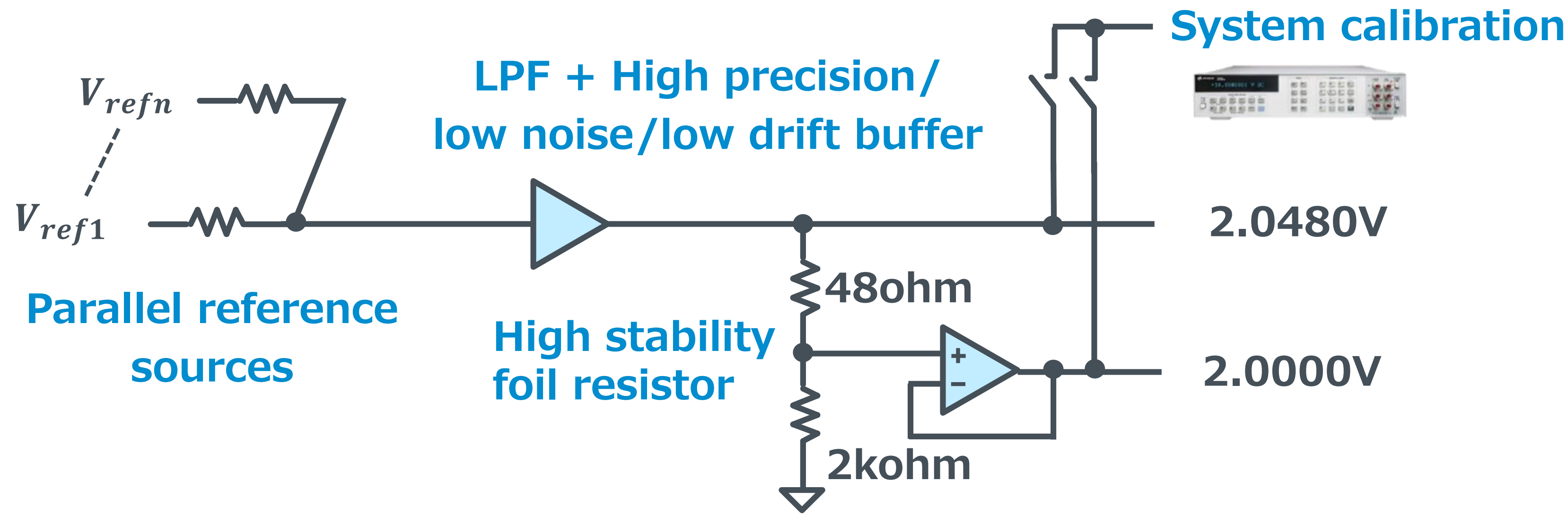




Simulation result of noise density(4parallel)

Parallel sources make very clean voltage

An example of system reference



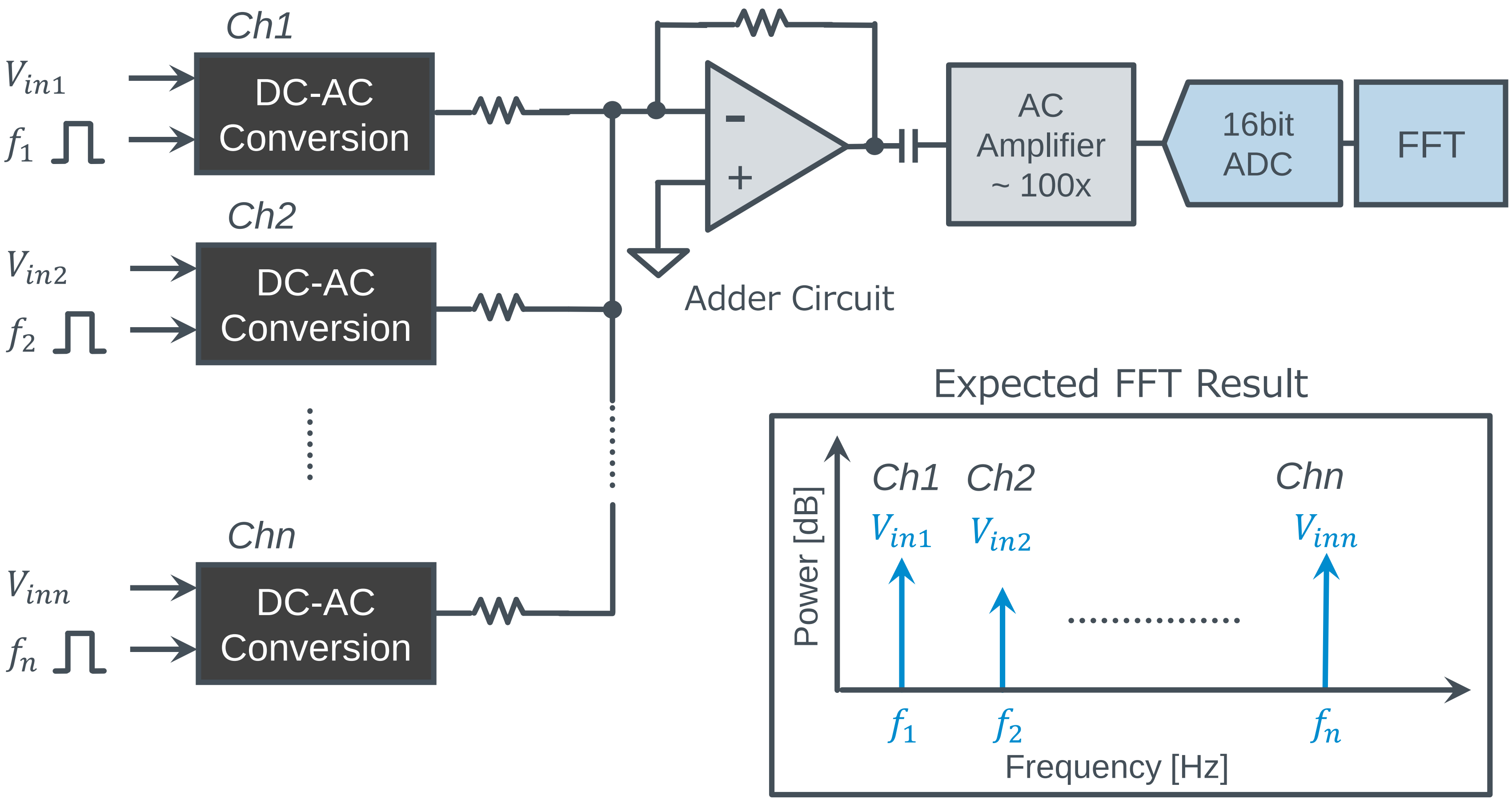
Accurate and clean system reference is produced

Outline

- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Accurate and clean system reference
  - Multi-Site Testing
- **Conclusion**

Multi-Site Testing

Configuration and Operation

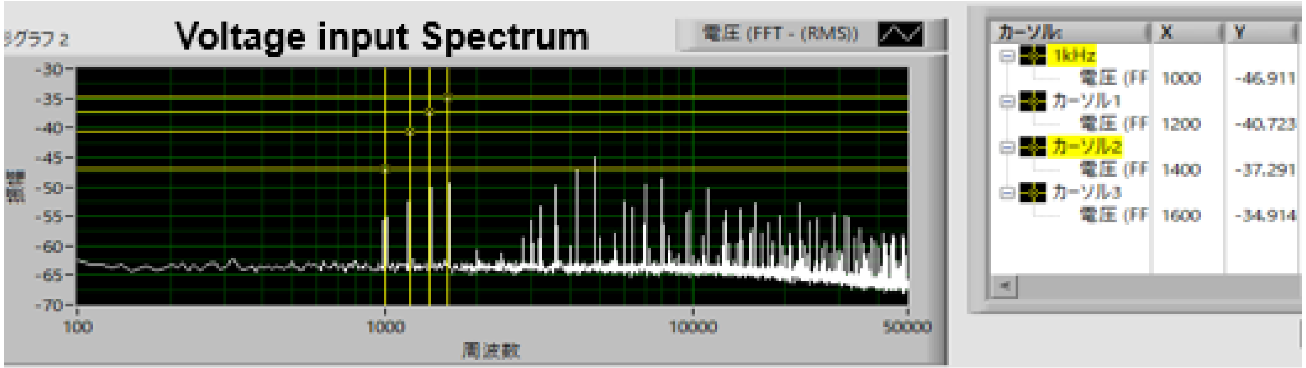


Multi-site testing is possible

Four-Site Testing Measured Spectrum

Sampling Rate: 100 kHz , Sample: 10k, Averaging: 100, Frequency Resolution: 10 Hz
Ch1 =1.0 kHz, Ch2 = 1.2 kHz, Ch3 = 1.4 kHz, Ch4 = 1.6 kHz

Vin1 = 1 μV
Vin2 = 2 μV
Vin3 = 3 μV
Vin4 = 4 μV



Multi-site testing is applicable to small voltage measurement

Usage of System reference voltage

Effective in Precision Voltage Reference

Outline

- **Background and Motivation**
  - Conventional Test Method
  - Difficulty
- **Proposed Method**
  - DC-AC Conversion and FFT spectrum analysis method
  - Very clean system reference voltage
  - Multi-Site Testing
- **Conclusion**

Conclusion

Solved problems

1. Noise at Test Environment

Testing is NOT affected by environmental noise

2. Accuracy and Noise of System Reference

Accuracy and the cause of variation can be improved

3. Test Time

Testing method is applicable to multi-site testing

Proposed DC-AC conversion and FFT analysis method is applicable to Precision Voltage Reference with ATE