Accurate Testing of Precision Voltage Reference by DC-AC Conversion

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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

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• **Conclusion**
A precision voltage reference is one of key components of IoT system.
Conventional Method

Usage of High Accuracy Digital Multimeter

KEYSIGHT 3458A 8½Digit
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Difficulty

- Test time (Multi-Site)

Unrealistic Situation
Difficulty

- Accuracy of ATE: $\pm 809.6\mu V$
- Variation: $270\mu V$

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)
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Proposed Method

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

Vin = 1 μV

Single-End Amplifier 100x

Clock = 1 kHz

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

Satisfy the target by system reference

Variation is ±6.4μV
Result with ATE

ATE direct DC measurement

Device: Precision Voltage Reference
Output voltage: 2.048V

DUT output: 2.048V
System reference: 2.000V

Differential amp
Gain 99.8
LT1167

\[ \text{Vout(DC)} \approx 4.79V \]

Variation with ATE direct measurement

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

2.048V
DUT output

2.000V
System reference

Noise ±1.4μV at 195Hz

Clock 195Hz
(Considering ATE filter setting)

Variation with DCAC conversion

Variation: ±2.4μV
Satisfy the target

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

≈4.79Vpp

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Result with ATE

**Problem point**

**Device**: Precision Voltage Reference  
**Output voltage**: 2.048V

**Environmental noise can be ignored**

DUT output  
2.000V  

**System reference**  
Noise ±1.4μV at 195Hz

**Noise ±1.4μV at 195Hz**

Clock 195Hz  
(Considering ATE filter setting)

**Reduction of aliasing**

**Variation**: ±2.4μV

**System reference needs improvement**

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

Device: Precision Voltage Reference  
Output voltage: 2.048V  

**ATE**  
Vout(AC) + FFT

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Accurate and clean system reference

Cause of problem in system reference

DC-AC conversion input and system reference circuit

- **DUT output**
- **Reference sources**
  - $V_{ref}$
  - Buffer

System reference

- 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

\[ V_{\text{ref}} \]

Parallel reference sources

\[ V_{\text{ref1}}, V_{\text{ref2}}, V_{\text{ref3}}, V_{\text{ref4}} \]

Simulation result of noise density(single)

\[ 44.8 \text{nV/}\sqrt{\text{Hz}} \quad 195\text{Hz} \]

Simulation result of noise density(4parallel)

\[ 22.4 \text{nV/}\sqrt{\text{Hz}} \quad 195\text{Hz} \]

Parallel sources make very clean voltage
An example of system reference

Accurate and clean system reference is produced

Parallel reference sources

LPF + High precision/low noise/low drift buffer

High stability foil resistor

System calibration

2.0480V

2.0000V
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Multi-Site Testing

Configuration and Operation

Multi-site testing is possible
Multi-Site Testing

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
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• 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