ROHM SEMICONDUCTOR

Electronics for the Future

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群馬大学
GUNMA UNIVERSITY

High Precision Voltage Measurement System Utilizing Low-End ATE Resource and BOST

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Research Objective

To realize High Precision Voltage Measurement w/ Automatic Test Equipment (ATE)

Requirements

- High Accuracy
- Fast Testing
- Low Test Cost

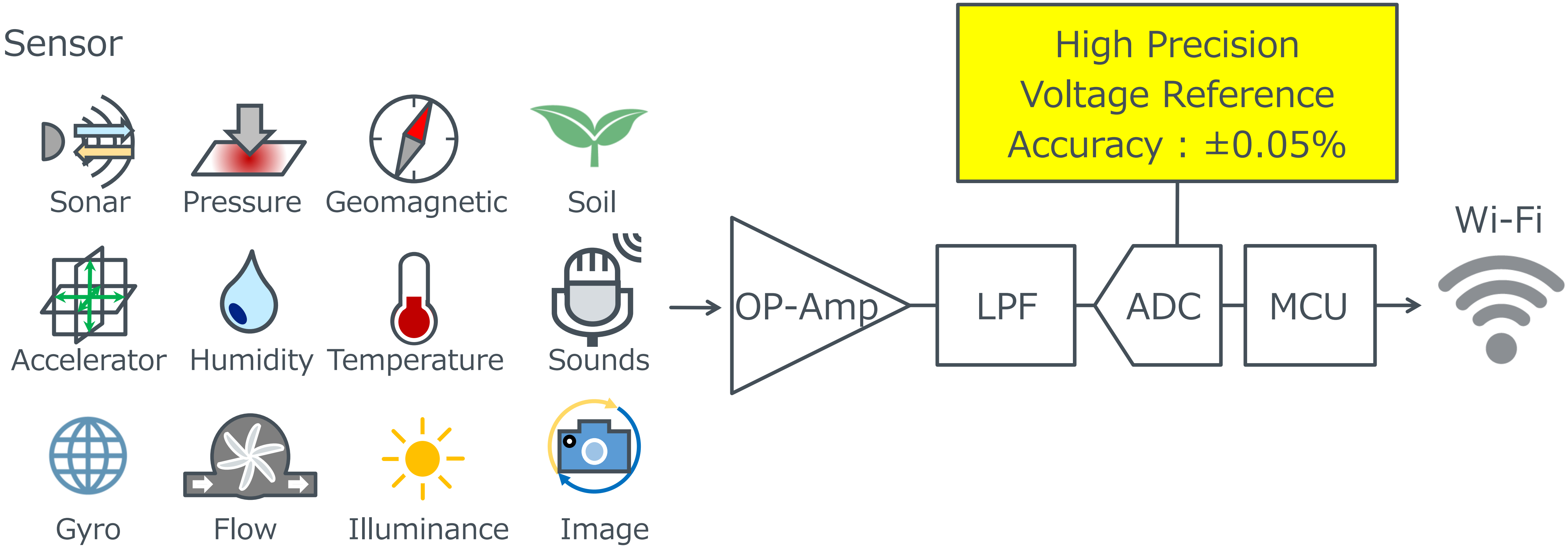
Proposed Method

BOST Circuit + ATE Digitizer

Outline

1. Background

IoT Sensor Network



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

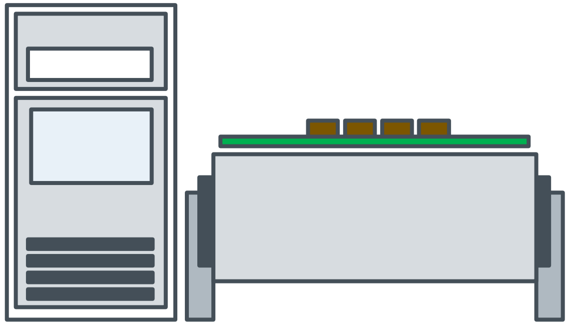
Outline

2. High Precision Voltage Measurement

Conventional Method

Use of External Instruments

ATE



KEYSIGHT 3458A 8½Digit

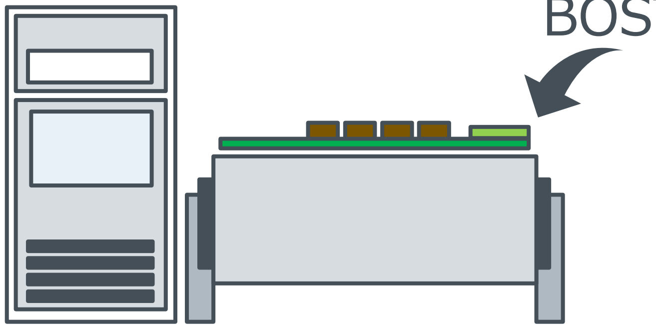
- High Accuracy
- Fast Testing
- Low Test Cost

Proposed Method

Use of BOST Circuit

ATE

BOST Circuit



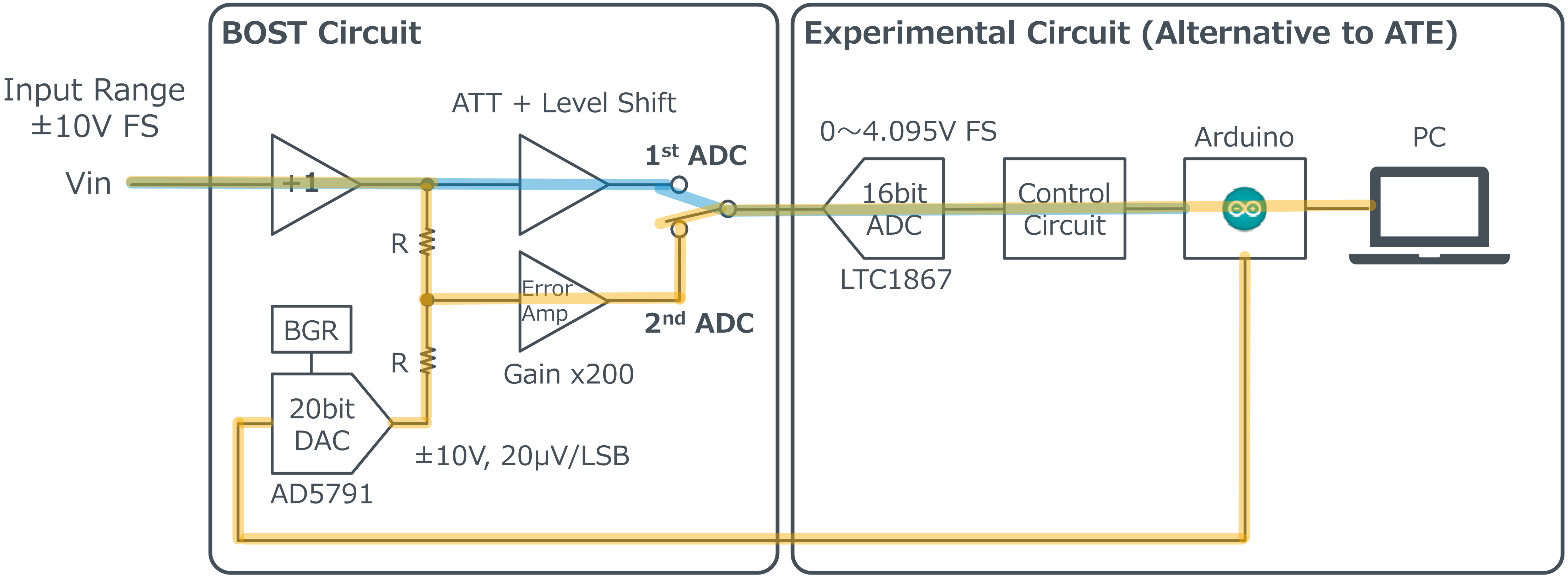
BOST Circuit + ATE Digitizer

- High Accuracy
- Fast Testing
- Low Test Cost

Outline

3. Proposed Method

Sub-Ranging Architecture



Sub-Ranging

1st ADC : 12bit

2nd ADC : 8bit + Over Range

ATE resource usage

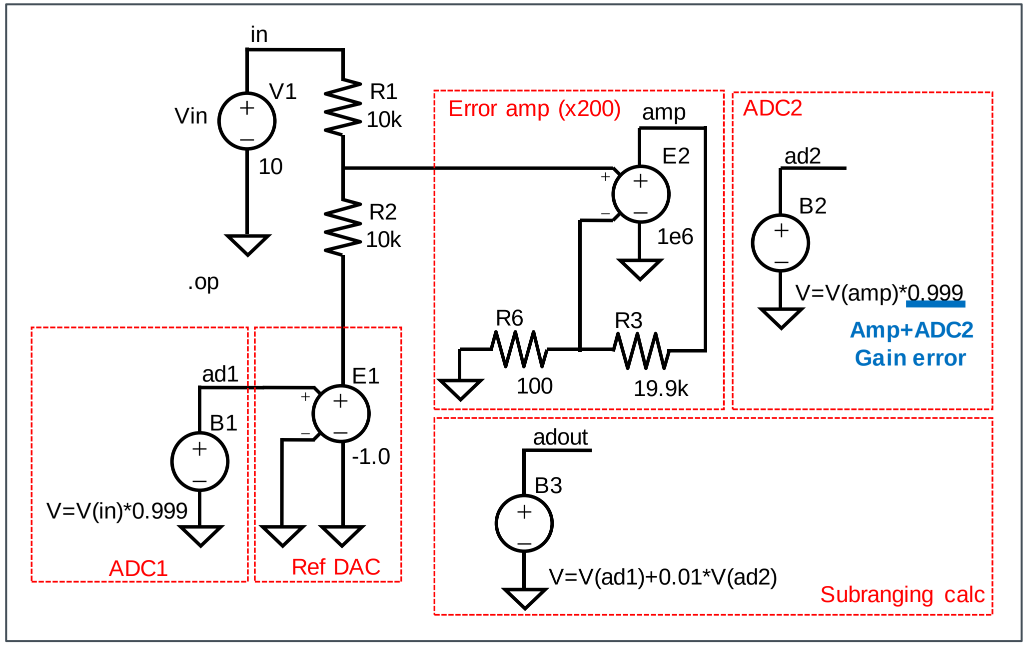
- ✓ Waveform digitizer (more than 16bit)
- ✓ 20bit DAC control and system calibration

Outline

Gain Error Effect

Simulate gain error of the error amplifier and 2nd ADC

Testbench



Simulation results

	Error amp+ADC2 gain error=0.1%		Error amp+ADC2 gain error=1%	
V(ad1)	9.99	V	9.99	V
V(ad2)	0.9988	V	0.989802	V
V(in)	10.0	V	10.0	V
V(n003)	-9.99	V	-9.99	V
V(n001)	0.005	V	0.005	V
V(amp)	0.9998	V	0.9998	V
V(n002)	0.0049999	V	0.0049999	V
	2nd ADC Error 1ppm		**2nd ADC Error 10ppm**	

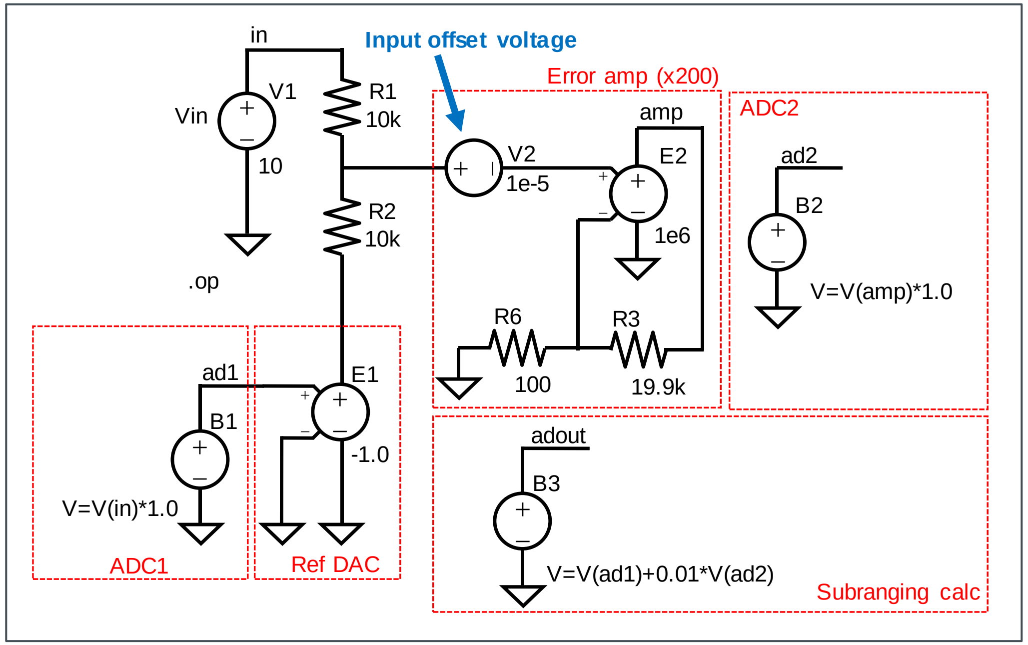
Remarks

Gain error should be smaller than 0.1%

Offset Error Effect

Simulate offset error of the error amplifier

Testbench



Simulation results

	Error amp+ADC2 Offset error=5μV		Error amp Input Offset error=10μV	
V(ad1)	10.0	V	10.0	V
V(ad2)	-0.0009998	V	-0.0019996	V
V(in)	10.0	V	10.0	V
V(n004)	-10.0	V	-10.0	V
V(n001)	0.0	V	0.0	V
V(amp)	-0.0009998	V	-0.0019996	V
V(n002)	-5×10^{-6}	V	-1×10^{-5}	V
V(n003)	-4.999×10^{-6}	V	-9.998×10^{-6}	V
	2nd ADC Error 1ppm		**2nd ADC Error 2ppm**	

Remarks

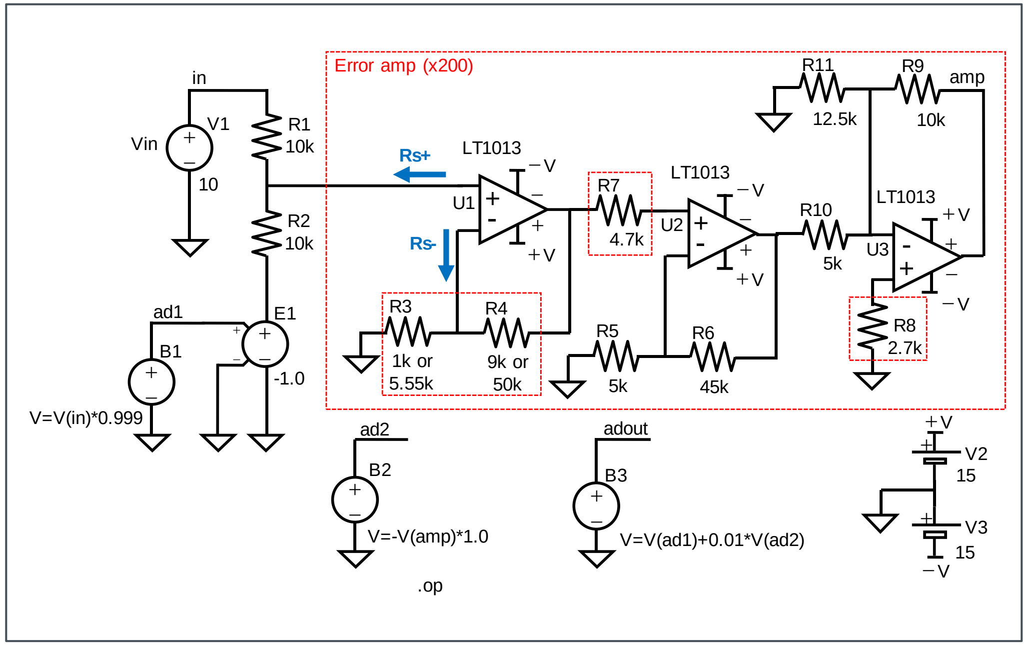
Offset error should be smaller than 10μV

4. Verification

Bipolar Transistor Input Stage

Simulate the bias current compensation in the error amplifier using bipolar transistor input stage

Testbench



Simulation results

	Rs+ = Rs- (R3=5.55k, R4=50k)		Rs+ ≠ Rs- (R3=1k, R4=9k)	
V(ad1)	9.99	V	9.99	V
V(ad2)	0.999133	V	1.00887	V
V(in)	10.0	V	10.0	V
V(n009)	-9.99	V	-9.99	V
V(n002)	0.00506	V	0.00506	V
V(n004)	0.0500045	V	0.0504919	V
V(n006)	0.00505999	V	0.00505999	V
	ADC Error 1ppm		**ADC Error 10ppm**	

Remarks

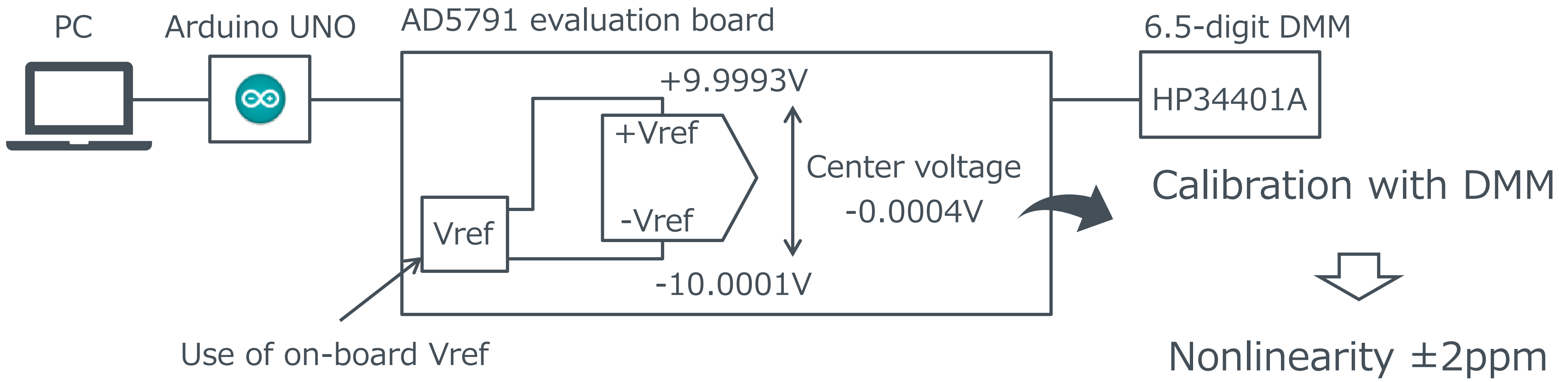
Rs+ and Rs- are not equal ⇨ Overall error is 10ppm

Outline

20bit DAC Evaluation

AD5791 DAC Linearity

Measurement Circuit



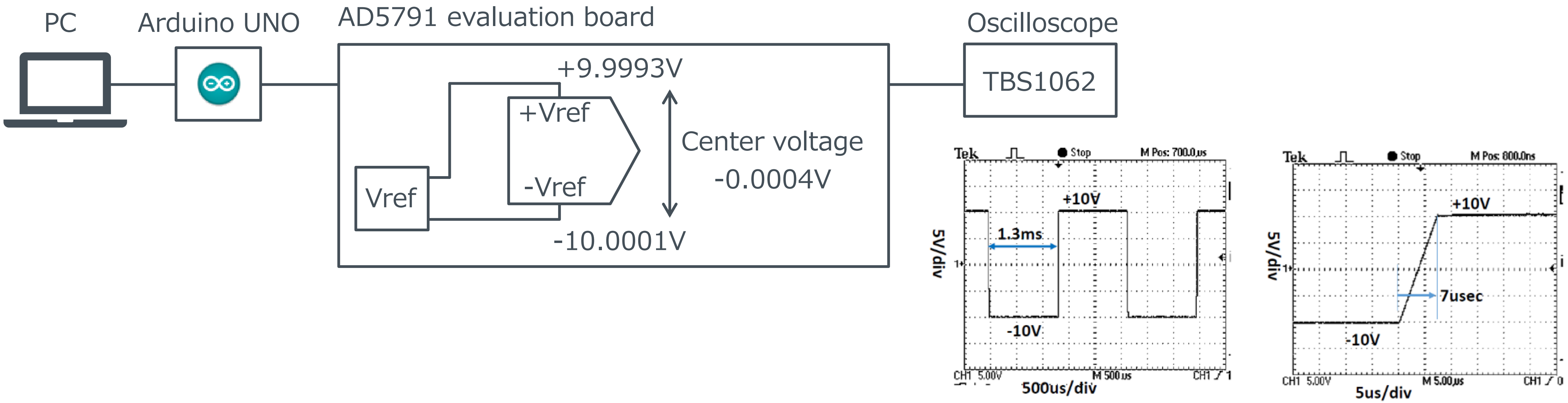
Remarks

AD5791 evaluation board ⇨ Enough accuracy for BOST

20bit DAC Evaluation

AD5791 Evaluation Board AC Response

Measurement Circuit



7μsec for 20Vp-p full scale response

Slew-rate 2.86V/μs

Remarks

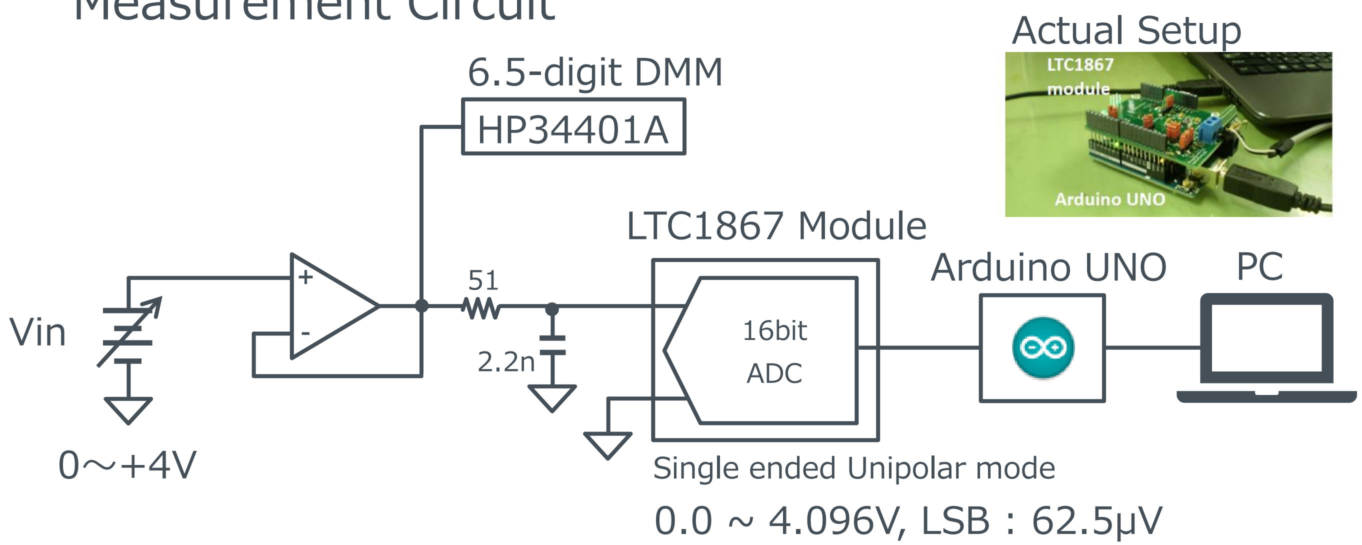
Slew-rate does not affect test time

5. Evaluation

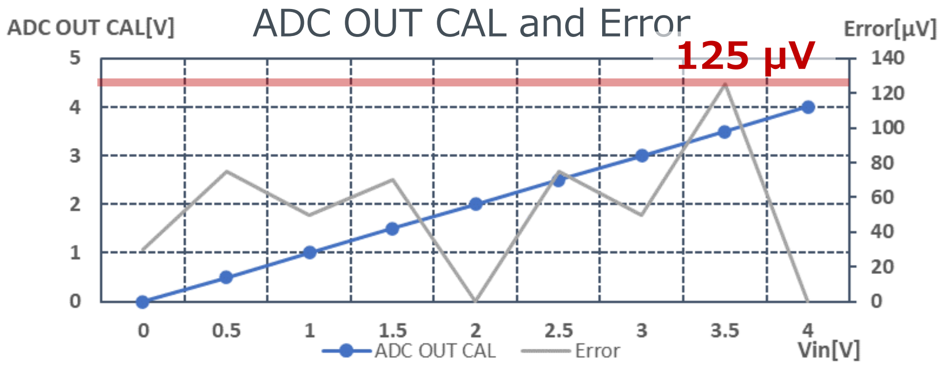
16bit ADC Evaluation (Alternative to ATE Digitizer)

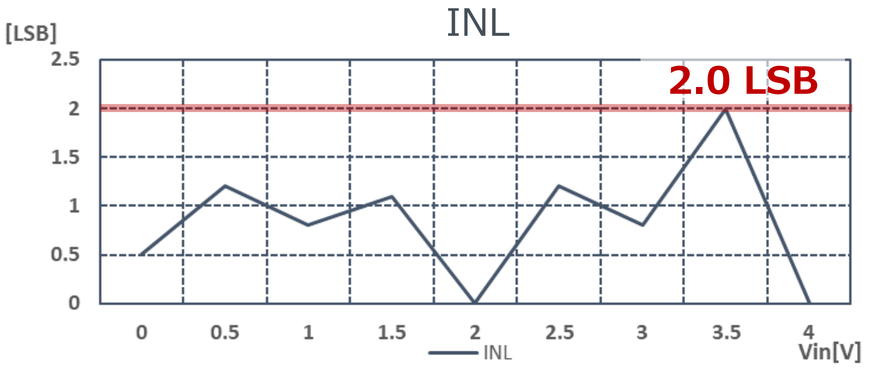
LTC1867 ADC Linearity

Measurement Circuit



Measurement Result





Remarks

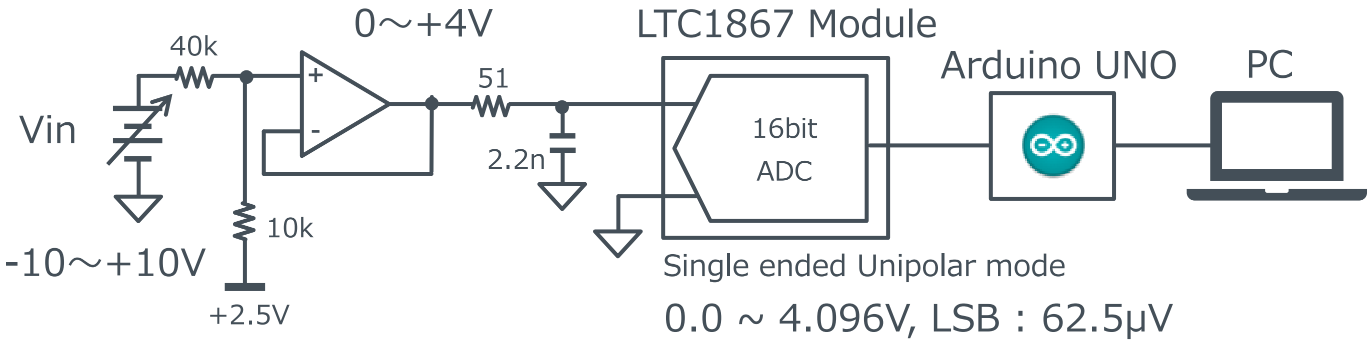
Moderate data as alternative to ATE digitizer

5. Evaluation

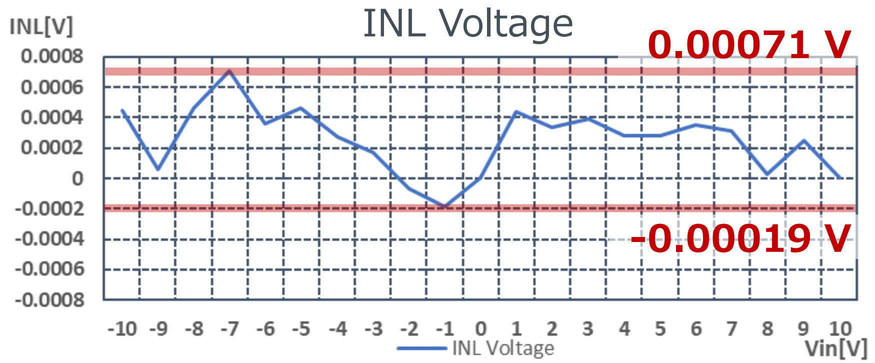
Voltage Input Circuit 1st ADC

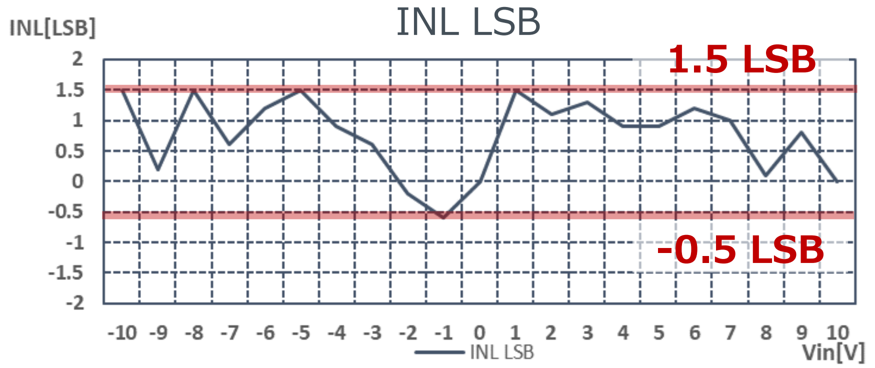
Linearity and variation of ±10V

Measurement Circuit



Measurement Result





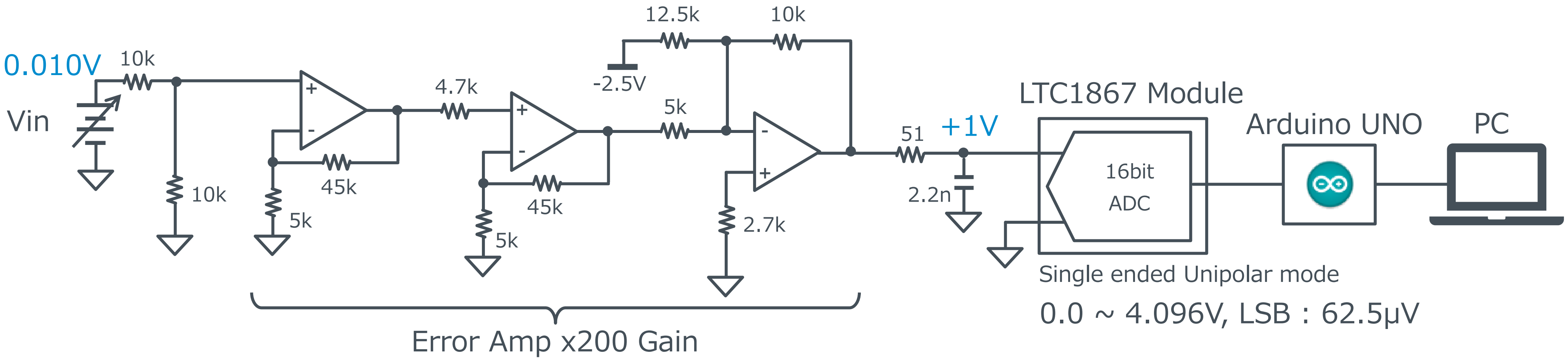
Remarks

INL is acceptable for the measurement

Voltage Input Circuit 2nd ADC

Error amplifier variation with gain of x200

Measurement Circuit



Measurement Result

LTC1867 variation : 5.9mVp-p (=±47LSBp-p)

Remarks

- 5.9mVp-p corresponds to the error amp input referred voltage of 59μV, which is 6ppm variation for ±10V full scale.
- Noise can be further reduced by using low noise operational amplifier.

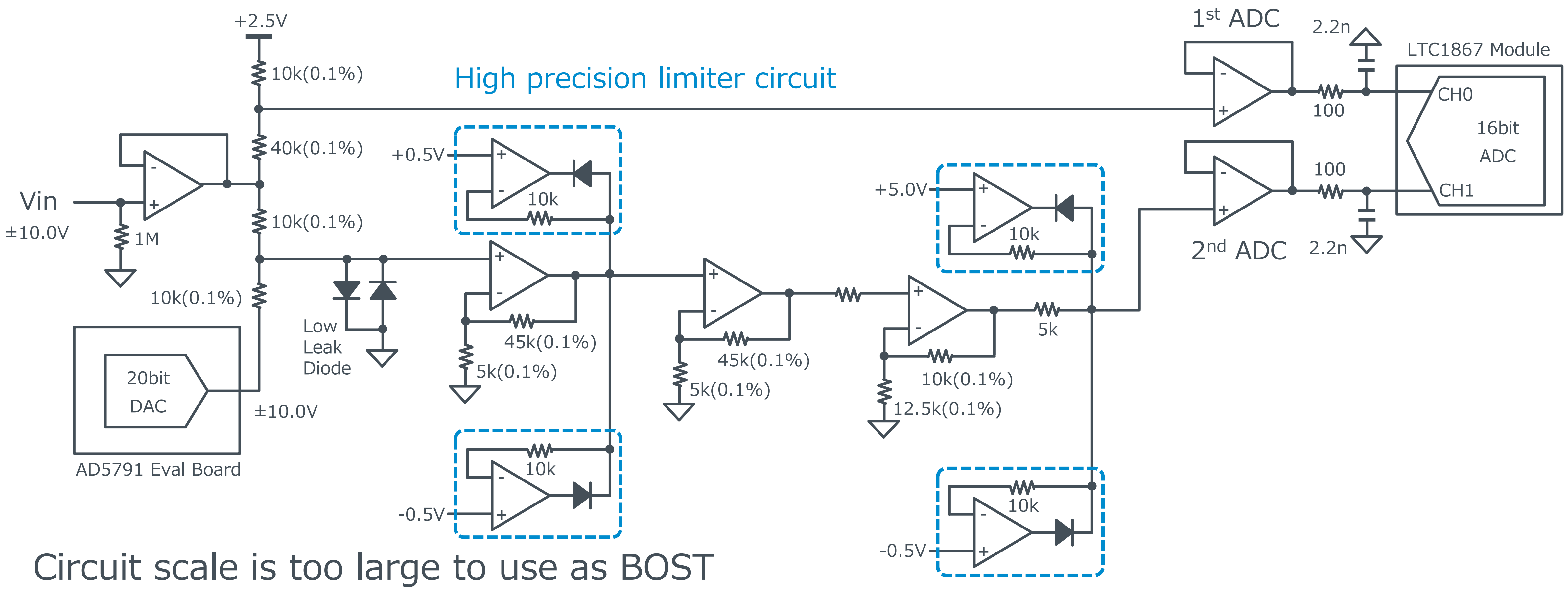
Outline

1. Background
2. High Precision Voltage Measurement
3. Proposed Method
4. Verification
5. Evaluation
6. Experiment
7. Conclusions and Future Works

6. Experiment

Experimental Circuit

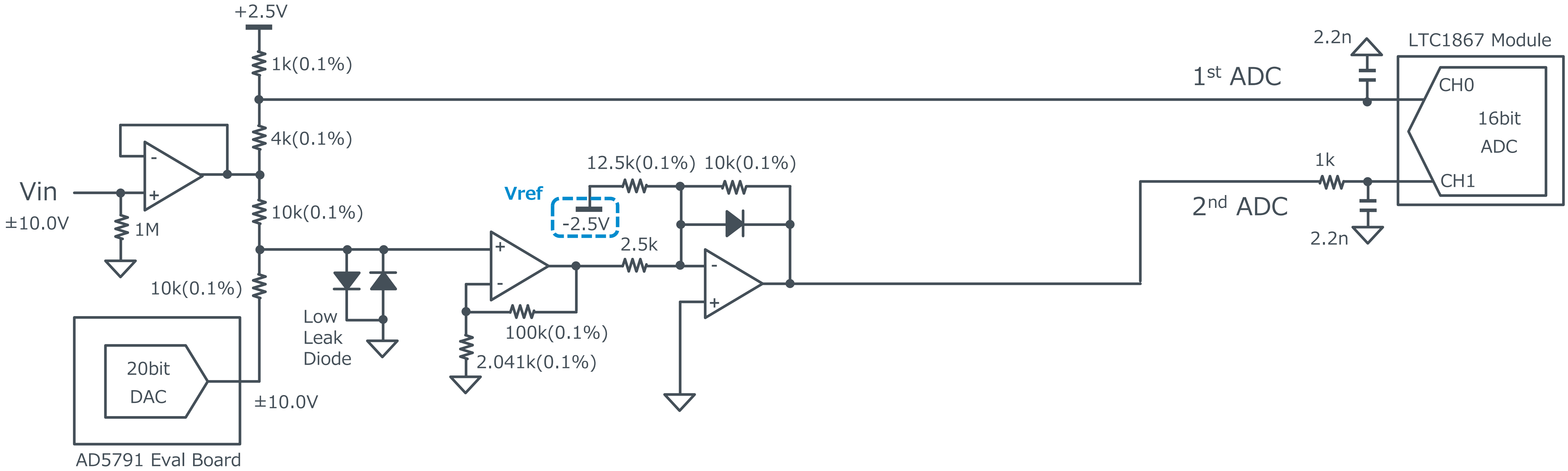
Initial consideration



Circuit scale is too large to use as BOST

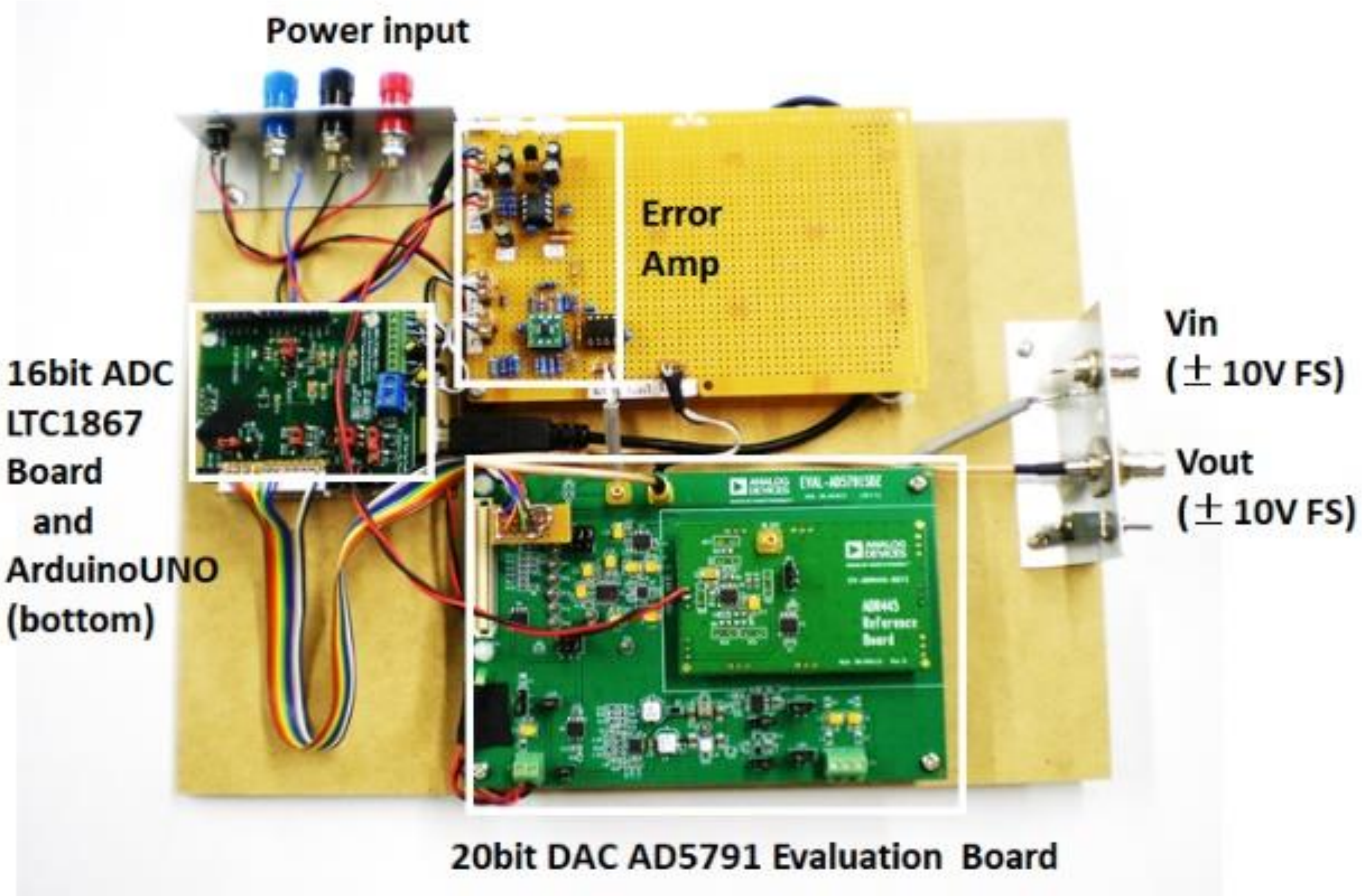
Experimental Circuit

Optimized Circuit



Simplified error amplifier circuit is acceptable

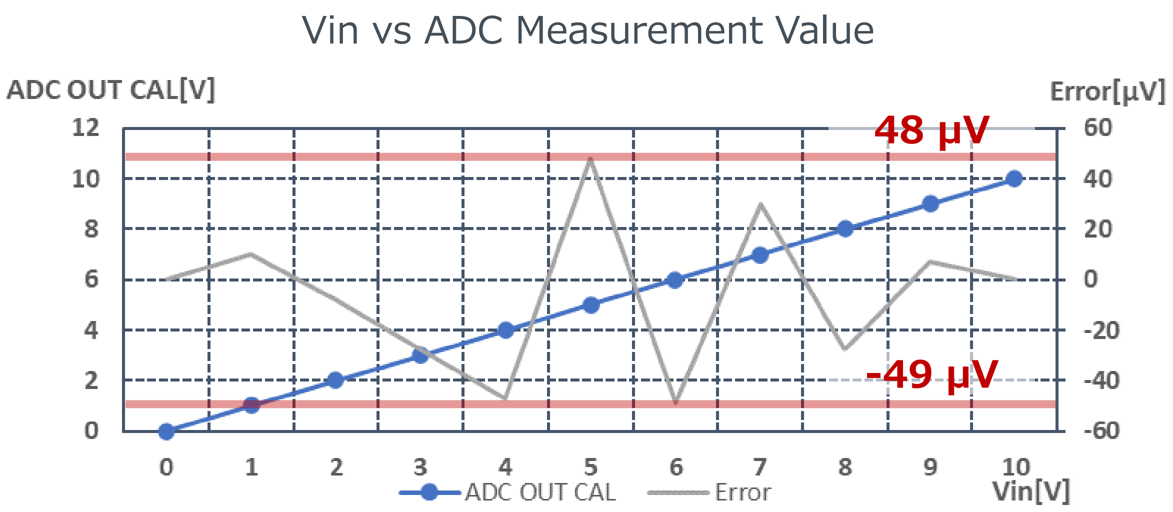
Experimental Setup

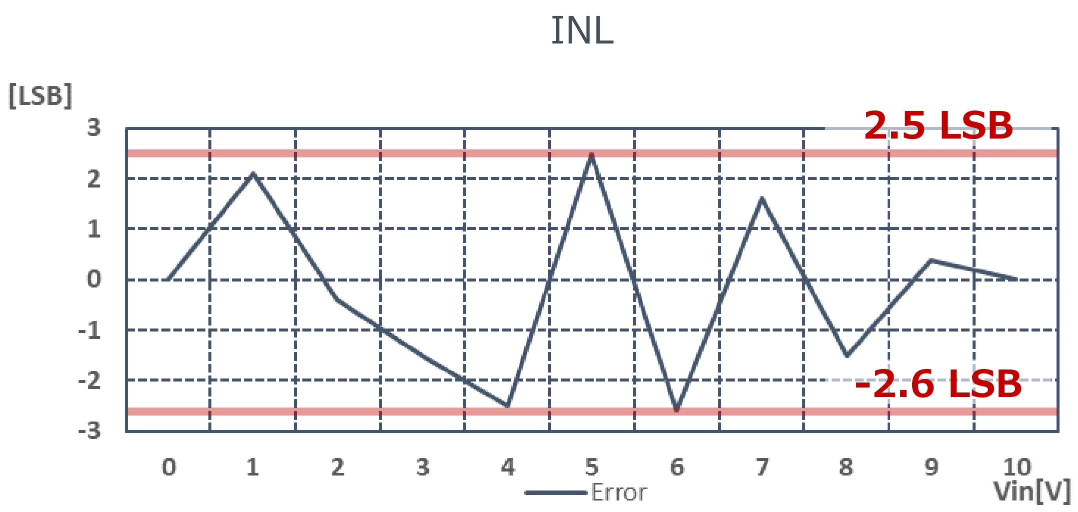


High Precision Voltage Measurement System Prototype

Experimental Result

Linearity Evaluation





19.1μV/LSB

Remarks

Voltage measurement accuracy ⇨ Better than ±2.6LSB

Experimental Result

Variation Evaluation

Vin (V)	Variation W/O averaging		Variation W/ 16 times averaging	
	(μV)	(LSB)	(μV)	(LSB)
1.000	118.0	6.2	32.0	1.7
0.000	74.0	3.9	22.0	1.2
-1.000	89.0	4.7	24.0	1.3

Remarks

Variation is 2LSB (2 ppm) with 16 times averaging

Test time Consideration

ADC2 Averaging	AD conversion time (ms)	
	W/O display on PC	W/ display on PC
1	2.7	10.4
10	7.9	10.4
×100	59.5	60.0

Remarks

Variation is ±2LSB (2 ppm) with 100 times averaging

Outline

7. Conclusions and Future Works

Conclusions

To realize High Precision Voltage Measurement

Meet the Requirements

- High Accuracy : Accuracy is better than ±50μV
- Fast Testing : Test time is 60ms with 100 times averaging
- Low Test Cost : No need for external instruments

BOST circuit + ATE digitizer is effective for high precision voltage measurement

Future Works

- The proposed system will be integrated on the actual ATE system
- To consider calibration method of absolute voltage

多謝你！

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