TI Designs

Three-Phase AC Current Measurement Using Current Transformer Reference Design

Design Overview

This reference design demonstrates high-accuracy, wide-range AC current measurement for a three-phase motor using the zero-drift architecture of the INA199. The design also features a low power consumption of 25 mW for a gain stage of 200 as compared to a discrete solution. The integrated high-precision resistors inside the INA199 device allow for a much smaller design footprint and BOM than with a discrete solution. The design footprint and BOM cost is much smaller than a discrete solution due to the integrated high precision resistors inside the INA199.

Design Resources

TIDA-00753	Design Folder
INA199	Product Folder
TPS717	Product Folder
REF3212	Product Folder

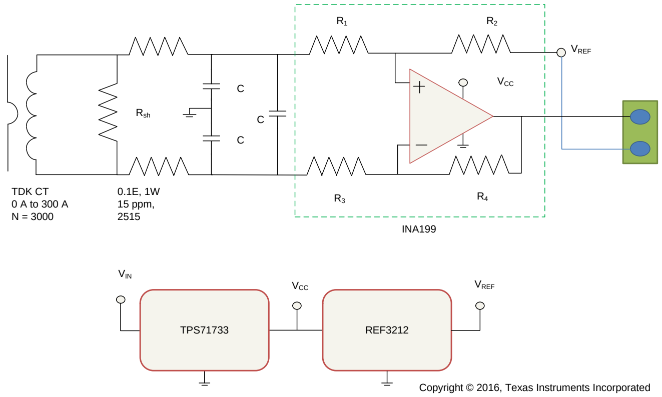
ASK Our E2E Experts

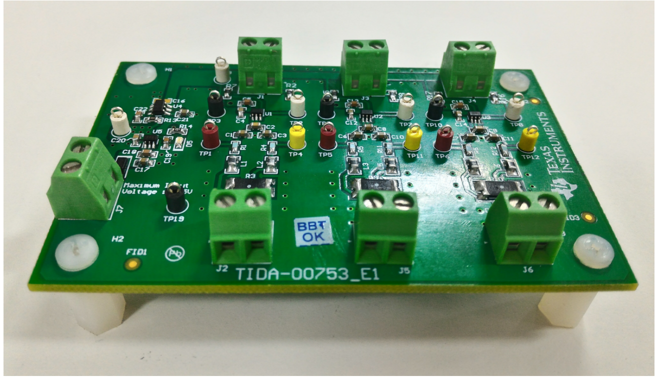
Design Features

- 0.5 % Accuracy (Uncalibrated) for 10% to 100% of Full-Scale Primary Current
- Power Consumption of 25 mW for Gain Stage
- Small Footprint Eliminates Requirement of External Resistors for Amplification

Featured Applications

- Compressors, Chillers, and Blowers (HVAC)
- ID and FD Fans, Screw Feeders, and Feed Pumps (Steam Boiler)
- Traction Motor (Escalator and Elevators)





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

Bluetooth is a registered trademark of Bluetooth SIG, Inc.
All other trademarks are the property of their respective owners.

1 Key System Specifications

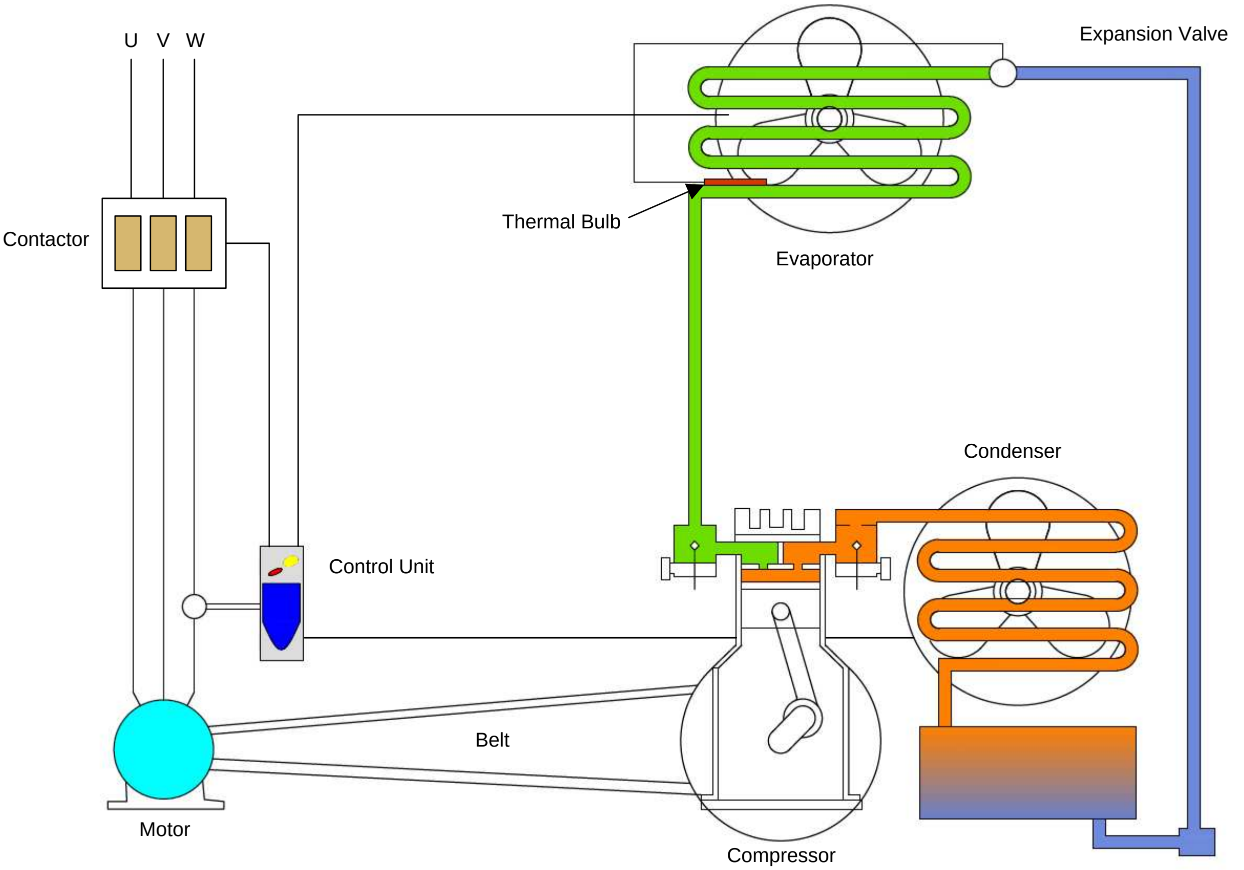
Table 1. Key System Specifications

SYMBOL	PARAMETER	SPECIFICATIONS					DETAILS
		CONDITION	MIN	TYP	MAX	UNIT	
I_{IN}	Input primary current	—	1	—	100	A	As per CT specification
F_{IN}	Input current frequency	—	50	—	60	Hz	As per CT specification
T_e	CT turns ratio	—	—	3000	—	—	As per CT specification
R_{sh}	Burden resistance	—	—	0.1	—	Ω	Section 4.1
% V_{o_Error}	Measured accuracy at INA199 output	Uncalibrated at ambient temperature	–1	0.5	1	%	Section 4.2, Section 4.3, Section 4.4
I_Q	Quiescent current	—	—	—	5	mA	—
V_{IN}	Input power supply (DC)	—	3.5	5	6.5	V	—

2 System Description

An electric motor is an essential moving element of any system. Electric motors are required in pumps, compressors, and blowers in typical heating, ventilation, air conditioning (HVAC), and boiler systems. Problems such as suction, jamming, flood back, and stalling can lead to catastrophic damage to motor and process equipment. Detecting such events is crucial for process controllers to take corrective action.

Because load torque and current are directly proportional to each other, the user can implement a current sense method to indirectly monitor the load profile. The diagram in Figure 1 shows the motor current sensing in an HVAC compressor application.



Copyright © 2016, Texas Instruments Incorporated

Figure 1. Generic HVAC Control System Diagram

The current flowing through a conductor can be detected using a resistive shunt, current transformer (CT), Hall effect sensor, and so forth. CT-based monitoring is the most simple and cost-effective solution for retrofitting systems. This design can be connected to any online system using a split-core CT. When measuring isolated high current, a CT is preferred because of its better stability and dynamic range over Hall effect.

Table 2 compares the various sensor techniques used to measure current. The diagram in Figure 2 provides an overview for testing the TIDA-00753 design with the existing analog-to-digital (ADC) evaluation module (EVM).

Table 2. Current Sensor

SENSOR PARAMETER	RESISTOR	HALL EFFECT(1)	CURRENT TRANSFORMER
Shunt resistive load range	µΩ to mΩ	None	mΩ to Ωs
Linearity over entire range	Very good	Poor	Fair
Offset problem	Yes	Yes	No
Saturation	No	Yes	Yes
Isolation	No	Yes	Yes
Stability over temperature	Fair	Poor	Good

(1) A generic open-loop Hall sensor has been used for comparison.

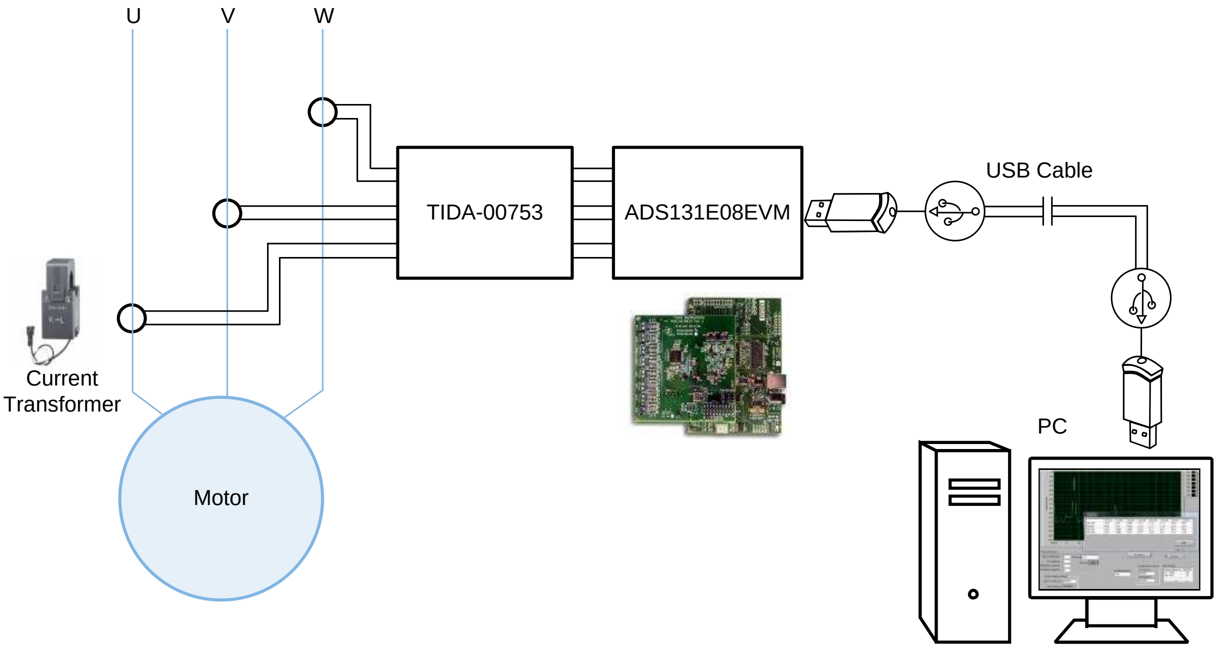


Figure 2. TIDA-00753 System Interface

3 Block Diagram

The TIDA-00753 design focuses on the front end of the CT signal chain, as the block diagram in Figure 3 shows. The reference has been generated using REF3212 for high-precision measurements; however, REF2912 and REF2030 can be used as alternate parts.

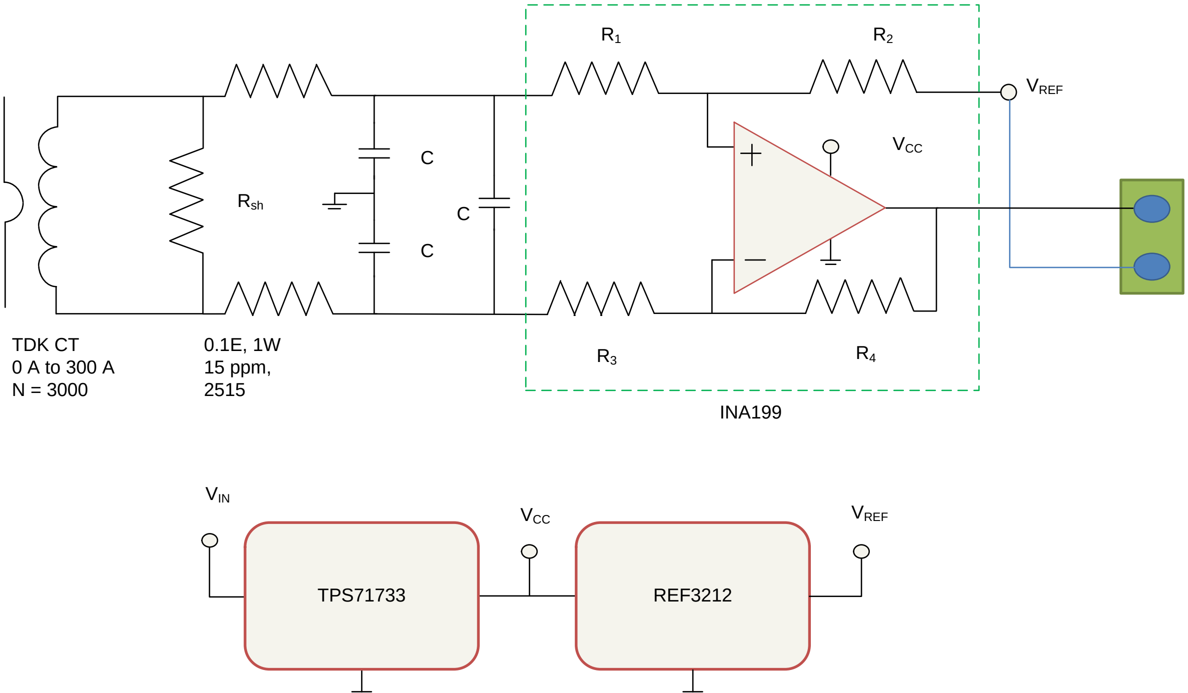


Figure 3. TIDA-00753 Block Diagram

3.1 *Highlighted Products*

The TIDA-00753 reference design features the following devices:

- INA199: 26-V, bidirectional, zero-drift, low- or high-side, voltage output current shunt monitor
- TPS717: Low-noise, high-bandwidth PSRR, low-dropout, 150-mA linear regulator
- REF3212: 4-ppm/°C, 100-µA, SOT23-6 series voltage reference

For more information on each of these devices, see their respective product folders at www.ti.com.

3.1.1 INA199

Features:

- Wide common-mode range: –0.3 V to 26 V
- Offset voltage: ±150 µV (maximum) (Enables shunt drops of 10-mV full-scale)
- Accuracy
  - ±1.5% gain error (maximum over temperature)
  - 0.5-µV/°C offset drift (maximum)
  - 10-ppm/°C gain drift (maximum)
- Choice of Gains:
  - INA199x1: 50 V/V
  - INA199x2: 100 V/V
  - INA199x3: 200 V/V
- Quiescent current: 100 µA (maximum)
- Packages: 6-pin SC70, 10-pin UQFN

Applications

- Notebook computers
- Cell phones
- Qi-compliant wireless charging transmitters
- Telecom equipment
- Power management
- Battery chargers
- Welding equipment

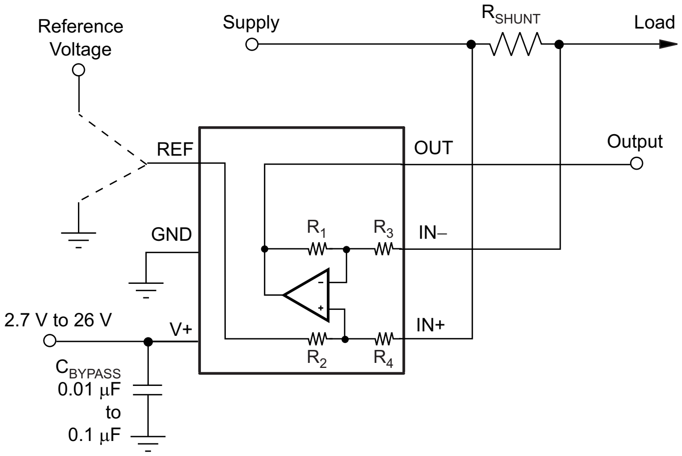


Figure 4. INA199 Simplified Schematic

3.1.2 TPS717

Features

- Input voltage: 2.5 V to 6.5 V
- Available in multiple output versions:
  - Fixed output with voltages from 0.9 V to 5 V
  - Adjustable output voltage from 0.9 V to 6.2 V
- Ultra-high PSRR:
  - 70 dB at 1 kHz and 67 dB at 100 kHz
- Excellent load and line transient response
- Very low dropout: 170 mV typical at 150 mA
- Low noise: 30 μV_{RMS} typical (100 Hz to 100 kHz)
- Small 5-pin SC-70, 2-mm × 2-mm WSON-6, and 1.5-mm × 1.5-mm WSON-6 packages

Applications

- Camera sensor power
- Mobile phone handsets
- PDAs and smartphones
- Wireless LAN, Bluetooth®

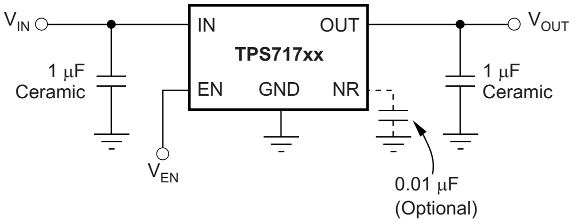


Figure 5. TPS717—Typical Application Circuit for Fixed-Voltage Versions

3.1.3 REF3212

Features:

- Excellent specified drift performance:
  - 7 ppm/°C (max) at 0°C to 125°C
  - 20 ppm/°C (max) at –40°C to 125°C
- Microsize package: SOT23-6
- High output current: ±10 mA
- High accuracy: 0.01%
- Low quiescent current: 100 µA
- Low dropout: 5 mV

Applications:

- Portable equipment
- Data acquisition systems
- Medical equipment
- Test equipment

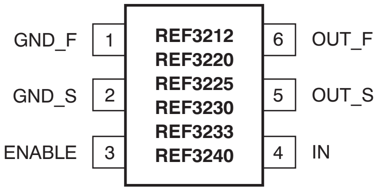


Figure 6. REF32xx Pinout

4 System Design Theory

The TIDA-00753 TI Design has been designed to meet high accuracy demands when measuring wide AC current ranges for motors.

The design uses current transformers (CT), which have a very high turns ratio and are used when measuring the primary current range to achieve better linearity.

As a result of this higher turns ratio, the secondary burden resistor of the design can be specified from mΩ to kΩ depending on the required range of measurement. The signal-to-noise ratio (SNR) is limited because of the lower-value sense resistor. For a wide current range measurement and lower supply rails, the burden resistor must be specified in mΩ, which limits the SNR. By using an amplifier, the SNR can be improved to obtain better accuracy.

4.1 CT Burden Calculations

Burden resistance affects the accuracy of a CT; as burden resistance increases, accuracy decreases.

Figure 7 shows a circuit with CT burden calculations where the magnetic impedance of the core is in parallel with the burden resistance. As the burden resistance increases, the magnetic impedance draws more current, which results in measurement error and nonlinearity for the entire range.

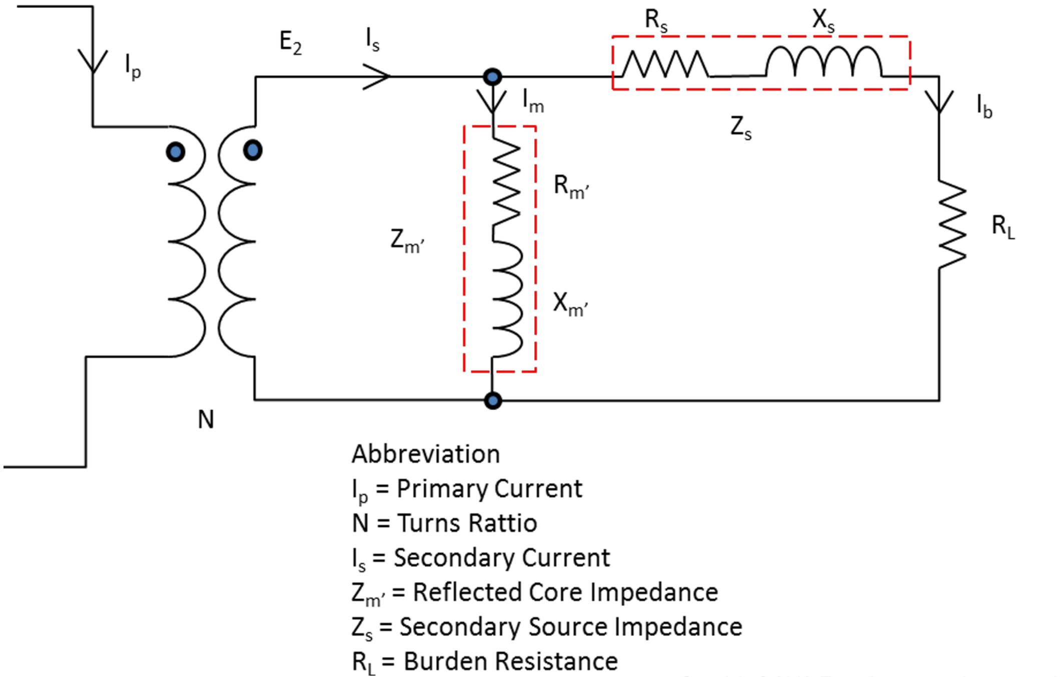


Figure 7. CT Burden Calculations

Use Equation 1, Equation 2, Equation 3, and the CT specifications available from the CT manufacturer to calculate the theoretical error for different burden resistances.

$$E_2 = I_s \times \left(\frac{\left(\left(Z_{m'} \times \left(Z_s + R_L\right)\right)\right)}{\left(\left(Z_{m'} + \left(Z_s + R_L\right)\right)\right)} \right) \quad (1)$$

$$E_2 = I_m \times Z_{m'} \quad (2)$$

$$I_b = I_s - I_m \quad (3)$$

4.2 Discrete Amplifier—Error Budgeting

Because the input full-scale voltage is very low, a gain stage is required to obtain a better SNR. The gain stage can be a simple inverting amplifier or difference amplifier. A discrete, inverting amplifier with external passive components limits the accuracy of a system.

Assume for the sake of this design that a basic inverting amplifier configuration has been used as shown in Figure 8. This example uses an LMV321 amplifier with an R1, R2, and R3 of 1 kΩ, 49.9 kΩ, and 980 Ω with a 0.1% tolerance and drift of 25 ppm.

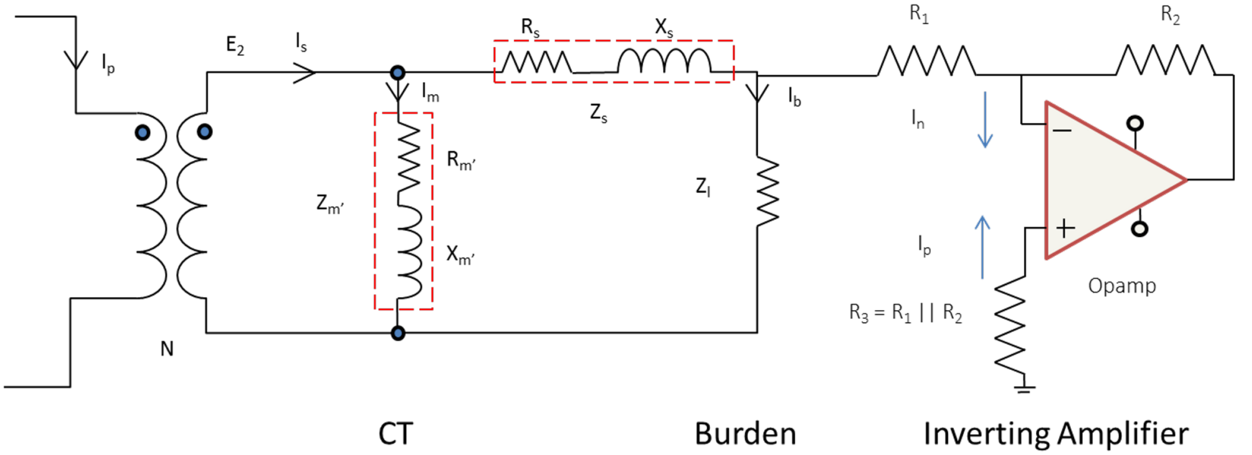


Figure 8. Inverting Amplifier

For lower input voltage range offset voltage, input bias current error dominates, while at higher voltage range gain error dominates. Op amp error budgeting can help to explain the error contribution of an amplifier during input measurement (see Figure 9).

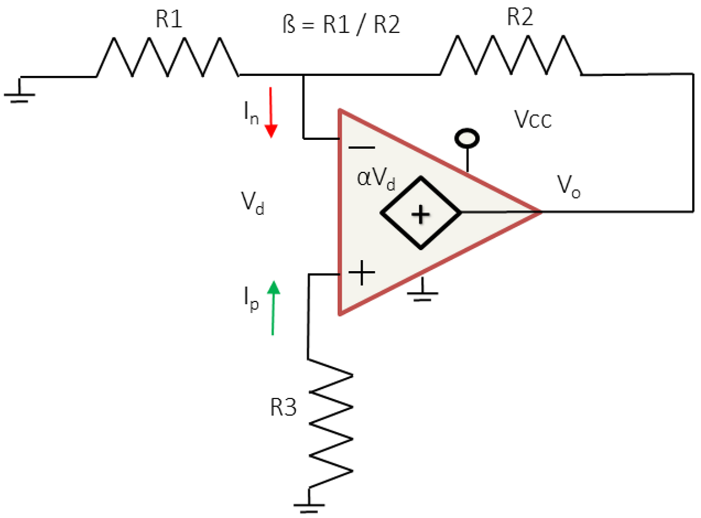


Figure 9. Simplified Model

An error budget requires computing the total loop gain error and bias current error of the discrete amplifier LMV321. Table 3 shows the calculations for the total loop gain and bias current error.

Table 3. Computation of DC Error

REFERENCE NO	PARAMETER	EQUATION	VALUE	UNIT	ERROR
1	Open-loop gain at ambient	A_{open}	15000	—	—
2	Closed-loop gain at ambient	B_{open}	49.800	—	—
3	Ideal gain	$\text{Ideal}_{\text{Gain}} = \left(\frac{A_{\text{open}}}{1 + A_{\text{open}} \times 50}\right)$	0.01999	—	—
3	Total loop gain error at ambient T_{ambient}	$\left(\frac{\left(\left(\frac{A_{\text{open}}}{1 + A_{\text{open}} \times B_{\text{closed}}}\right) - \text{Ideal}_{\text{Gain}}\right)}{\text{Ideal}_{\text{Gain}}}\right) \times 100$	—	%	0.40
4	Open-loop gain drift at max temp	$A_{\text{op\_drift}}$	10000	—	—
5	Closed-loop gain drift at max temp	$B_{\text{cl\_drift}}$	49.651	—	—
6	Total loop gain error at max temp $T_{\text{MAX\_TEMP}}$	$\left(\frac{\left(\left(\frac{A_{\text{op\_drift}}}{1 + A_{\text{op\_drift}} \times B_{\text{cl\_drift}}}\right) - \text{Ideal}_{\text{Gain}}\right)}{\text{Ideal}_{\text{Gain}}}\right) \times 100$	—	%	0.70
7	Input bias current	I_{Bias}	250	nA	—
8	Input offset current	I_{Offset}	50	nA	—
9	I_n	$\frac{\left(2 \times I_{\text{Bias}} - I_{\text{Offset}}\right)}{2}$	225	nA	—
10	I_p	$I_{\text{Offset}} + I_n$	275	nA	—
11	Input bias current error	$V_{\text{IB}} = \left(1 + \frac{R_1}{R_2}\right) \times \left(\left(\left(R_1 \parallel R_2\right) \times I_n\right) - \left(R_3 \times I_p\right)\right)$	—	V	0.00244
12	Input bias current drift	$I_{\text{Bias\_Drift}}$	500	nA	—
13	Input offset current drift	$I_{\text{Offset\_Drift}}$	150	nA	—
14	$I_{\text{n\_Drift}}$	$\frac{\left(2 \times I_{\text{Bias\_Drift}} - I_{\text{Offset\_Drift}}\right)}{2}$	425	nA	—
15	$I_{\text{p\_Drift}}$	$I_{\text{Offset\_Drift}} + I_{\text{n\_Drift}}$	575	nA	—
16	Input bias current drift error	$V_{\text{IB\_Drift}} = \left(1 + \frac{R_1}{R_2}\right) \times \left(\left(\left(R_1 \parallel R_2\right) \times I_{\text{n\_Drift}}\right) - \left(R_3 \times I_{\text{p\_Drift}}\right)\right)$	—	V	0.0074

The user can calibrate the offset voltage, bias current error, and gain error (at ambient temperature) by using software calibration. The user can also calibrate error drifts as a result of temperature change by using software logic for error drift with respect to the temperature; however, the output noise density cannot be calibrated. Table 4 shows the contribution of each error for a full-scale voltage range of 3.33 mV, which corresponds to a full-scale primary current of 100 A.

Table 4. Error Budgeting for Inverting Amplifier—Full-Scale Voltage 3.33 mV

REFERENCE NO	PARAMETER	EQUATION	VALUE	UNIT	ERROR (PPM)	ERROR VOLTAGE
Absolute error						
1	Offset voltage	$\left(\frac{V_{os}}{V_{FS}}\right) \times 10^6$	0.007	V	2100210	—
2	Input bias current error	$\left(\frac{V_{IB}}{V_{FS}}\right) \times 10^6$	0.00244	V	733440	—
3	Gain error	$T_{ambient} \times 10^4$	—	%	4000	—
Absolute best-case error RMS (A)					1284371	0.0042
Absolute worst-case error SUM (A)					2837650	0.0095
Drift error						
4	Offset voltage drift	$\left(\frac{V_{OS} \times V_{OS\_Drift} \times (Temp_{MAX} - 25)}{V_{FS}}\right) \times 10^6$	0.000005	V/C	630.006	—
5	Input bias current drift error	$\left(\frac{V_{IB\_Drift} - V_{IB}}{V_{FS}}\right) \times 10^6$	0.0050	V	1487268	—
6	Gain drift	$T_{MAX\_TEMP} \times 10^4$	0.7	%	7000	—
Drift best-case error RMS (A)					86705	0.0028
Drift worst-case error SUM (A)					157078	0.0049
Resolution						
7	Noise voltage	$\left(\frac{E_{NI(RMS)} \times \sqrt{Bandwidth}}{V_{FS}}\right) \times 10^6$	39 2000	nV Hz	7.45	—
Resolution best-case error (C)					7.45	24.8 nV
Resolution worst-case error (C)					7.45	24.8 nV
Total error						
Best-case error RMS (A + B + C)					1011424	0.0033
Worst-case error SUM (A + B + C)					4332566	0.0144

Table 4 shows that the worst-case error using a discrete amplifier is 14.4 mV. The gain error and noise voltage affect the AC performance and contribute an error of 36 µV in the output.

4.3 INA199 Amplifier—Error Budgeting

Achieving a better performance requires an integrated precision amplifier. The INA199 is one example of the zero-drift, low-power, integrated resistor difference amplifiers that can be used to monitor current shunts in this design.

This amplifier comes with gain variants of 50,100, and 200. The lower offset voltage of 150 µV and typical gain error of 0.03% makes this amplifier a better solution for first-stage amplification. With a lower burden resistance of 0.1 Ω and a lower secondary current, the slew rate of 0.4 V/µs is suitable for detecting high-current amplitude faults.

Table 5 shows that the worst-case error using the INA199 amplifier is 156 µV as compared to the 14.4 mV when using a discrete solution (as shown in Table 4).

The error contributed by gain error, gain drift, gain nonlinearity, and noise voltage is 4.1 µV. Using the INA199 amplifier is the best choice to achieve better accuracy with low power and cost.

Table 5. Error Budgeting for INA199—Full-Scale Voltage 3.33 mV

REFERENCE NO	PARAMETER	EQUATION	VALUE	UNIT	ERROR (PPM)	VOLTAGE ERROR
Absolute error						
1	Offset voltage	$\left(\frac{V_{os}}{V_{FS}}\right) \times 10^6$	0.000150	V	45004	—
2	Input offset current error	$\left(\frac{I_{os} \times (R_+ + R_- + R_{Burden})}{V_{FS}}\right) \times 10^6$	0.00000002	A	12	—
3	CMRR	$\left(\frac{\left(\frac{V_{CM}}{10\left(\frac{CMRR\ (dB)}{20}\right)}\right)}{V_{FS}}\right) \times 10^6$	0.000002 V_{CM} = 0.208	V	625	—
4	Gain error	$\text{Gain error } \% \times 10^4$	0.03	%	300	—
Absolute best-case error RMS (A)					22504	0.000075
Absolute worst-case error SUM (A)					45941	0.00153
Drift error						
5	Gain drift	$\text{Gain Drift}\left(\frac{PPM}{°C}\right) \times (Temp_{MAX} - 25)$	10	ppm	600	—
Drift best-case error RMS (B)					600	1.98 µV
Drift worst-case error SUM (B)					600	1.98 µV
Resolution						
6	Gain nonlinearity	Gain nonlinearity in ppm	1	ppm	1	—
7	Noise voltage	$\left(\frac{E_{NI(RMS)} \times \sqrt{Bandwidth}}{V_{FS}}\right) \times 10^6$	25 2000	nV Hz	335.44	—
Resolution best-case error RMS (C)					237	780 nV
Resolution worst-case error SUM (C)					336	1.1 µV
Total error						
Resolution best-case error RMS (A + B + C)					17012	56 µV
Resolution worst-case error SUM (A + B + C)					46878	156 µV

4.4 Reference for DC Biasing

Most of the integrated analog-to-digital converter (ADC) of the MSP430™ microcontroller (MCU) has a very low reference voltage, which limits the wide dynamic current measurement range; for example, the MSP430I2041 device with an integrated 24-bit delta-sigma (Δ∑) ADC has an input range of 928 mV (peak) for an interval reference of 1.5 V (max) and gain of 1X. Achieving a wide measurement range requires an external reference in this case. Bipolar input signal measurement using a single-supply rail for the INA199 amplifier requires an external reference chip to provide the DC bias voltage.

The REF3212 device has been used in the TIDA-00753 design to obtain very low drift in measurements. The REF3212 is a series voltage reference of 1.25 V and has an accuracy of 0.01% and drift of 4 ppm.

As Table 6 shows, the worst-case error in a DC level change is 5.5 mV, as compared to 39.1 mV of the REF2912 reference.

Table 6. REF3212 Error Budgeting

PARAMETER	REF3212		REF2912	
	VALUE	PPM	VALUE	PPM
Initial accuracy	0.20	2000	2	20000
Noise voltage for bandwidth of 5 KHz	0.000039	2206.173157	0.00019	10748.02
Temperature drift (PPM)	—	20	—	100
Thermal hysteresis (PPM)	—	100	—	100
Line regulation (PPM/V)	—	65	—	410
Worst case (PPM)	—	4391.17	—	31358.02
Worst case (V)	—	0.005488966	—	0.039198

Depending on the requirements of the application, the reference used in this design can either be a simple voltage divider with a buffer (see Figure 10) or a reference chip such as REF2030 or REF2912.

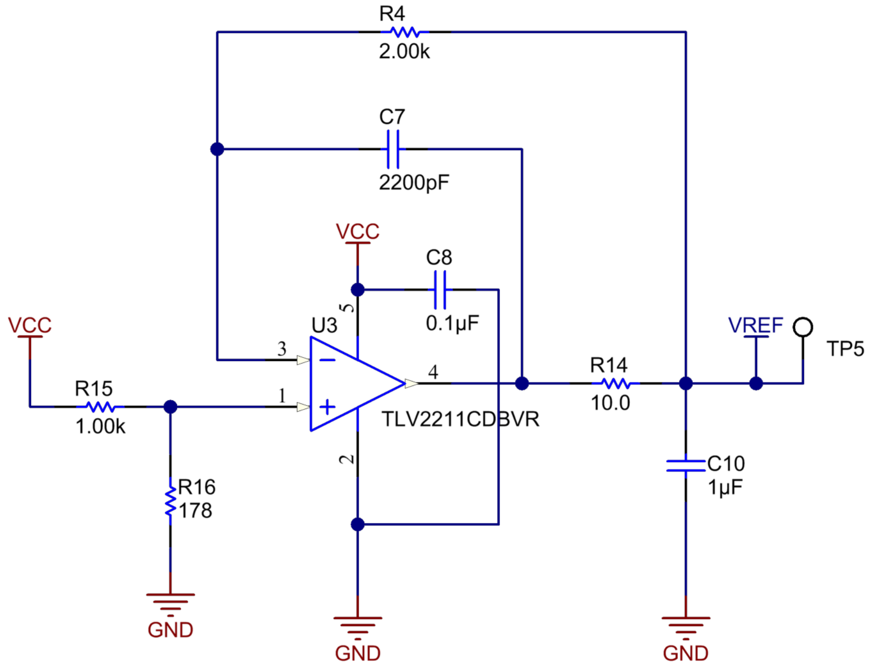


Figure 10. DC Reference

5 Getting Started Hardware

The design is ready to operate directly out of the box. The required test point has been populated for measuring signals at each interface point of the design. Refer to Table 7 for more details.

Table 7. Test Points

TEST POINT NO	DESCRIPTION	VOLTAGE RANGE
TP14	V_{CC}	3.3 V
TP13	V_{REF}	1.25 V
TP1 to TP4	Voltage across burden resistor for channel 1	0 mV to 3.3 mV (RMS)
TP5 to TP11	Voltage across burden resistor for channel 2	0 mV to 3.3 mV (RMS)
TP6 to TP12	Voltage across burden resistor for channel 3	0 mV to 3.3 mV (RMS)
TP2	Output voltage for channel 1 w.r.t. TP13	0 mV to 667 mV (RMS)
TP7	Output voltage for channel 2 w.r.t. TP13	0 mV to 667 mV (RMS)
TP8	Output voltage for channel 3 w.r.t.TP13	0 mV to 667 mV (RMS)
TP3, TP9, TP10, and TP19	GND	0 V

NOTE: Before turning on the power supply and test equipment, make sure that the secondary of the current transformer has been connected to the input connectors J2, J5, and J6.

6 Test Setup

The test setup consists of the TIDA-00753 board, Keithley DC supply, Agilent 6½ digital multimeter (DMM), MTE current source, and TDK current transformer, as Figure 11 shows.

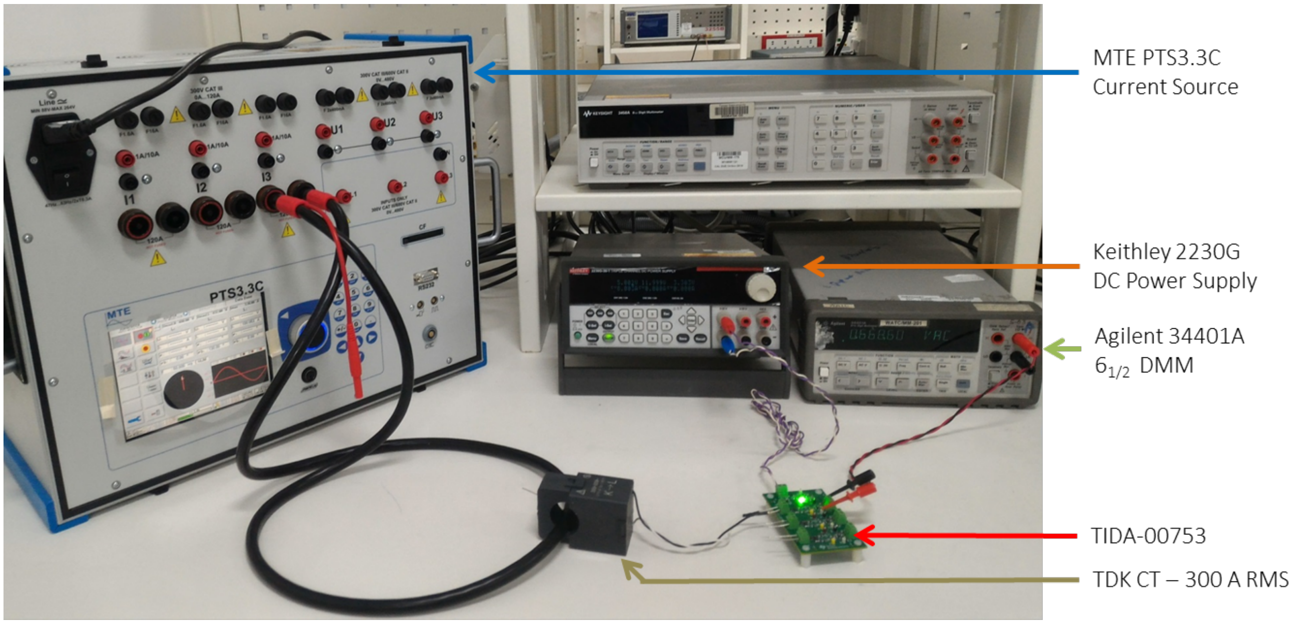


Figure 11. TIDA-00753 Test Setup

The TIDA-00753 design requires performing the following tests:

- Testing the % voltage error across the burden resistor of 0.1 Ω, 1 Ω, and 10 Ω at the full-scale primary current
- Testing the voltage at the difference amplifier output for channel 1 for the primary current range of 1 A to 100 A

Testing the above conditions requires setting the Agilent 6½ DMM with the following settings to average the source and instrument errors:

- Medium filter – 1 seconds/reading
- Number of samples – 60 (approximately 1 minute)

7 Test Results

7.1 Test Table

7.1.1 Burden Resistor Error

As Table 8 shows, the test results for the accuracy across the CT for burden resistors (0.1 Ω, 1 Ω, and 10 Ω) show that the measurement error increases as the burden resistor value increases.

Table 8. Voltage Error

REFERENCE NO	BURDEN RESISTOR ACROSS CURRENT TRANSFORMER	IDEAL VOLTAGE (V)	OBSERVED VOLTAGE (V)	% VOLTAGE ERROR PRIMARY CURRENT = 100 A
1	0.1	0.003335	0.003334	–0.02999
2	1	0.03335	0.03339	0.11994
3	10	0.3335	0.332445	–0.31634

7.1.2 Linearity for 0.1-Ω Burden at 25°C

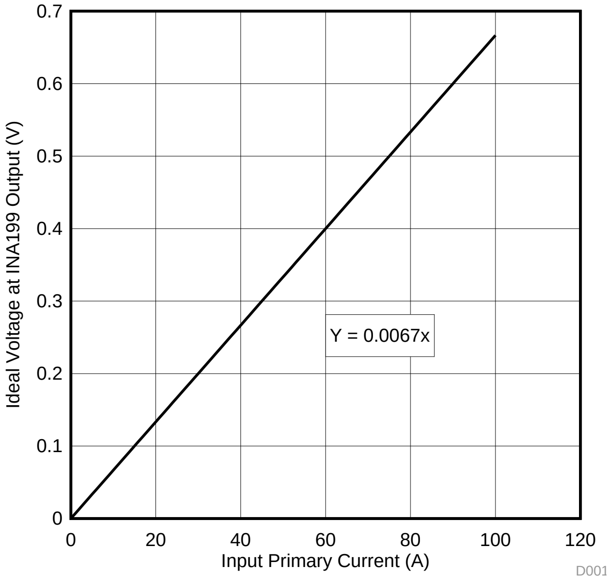


Figure 12. Ideal Linearity

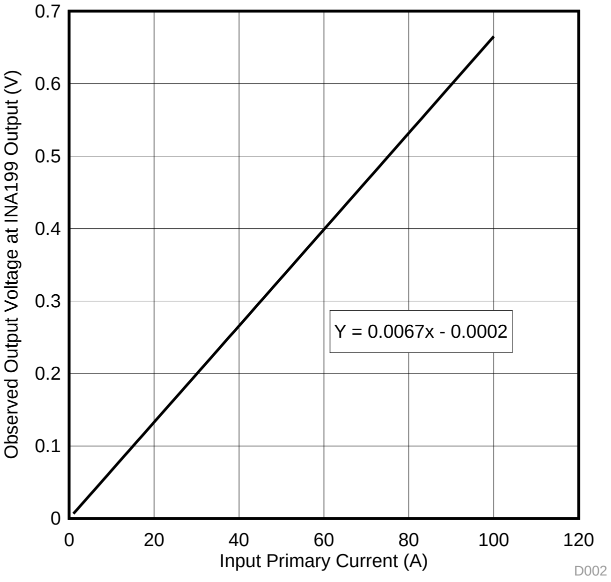


Figure 13. Observed Linearity

7.1.3 Linearity for 0.1-Ω Burden at 85°C

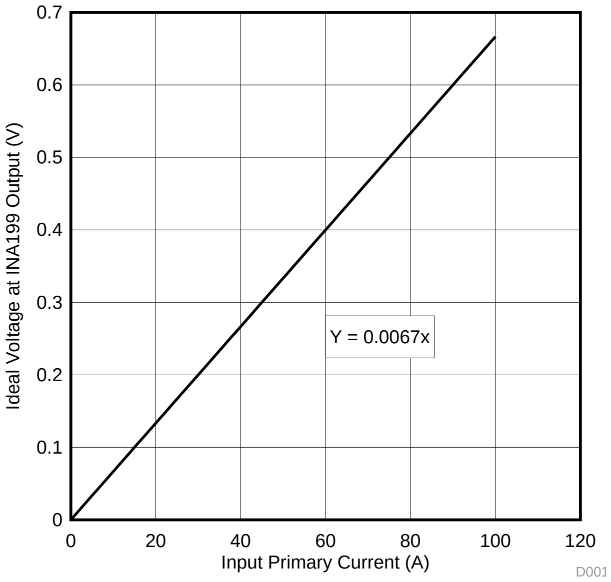


Figure 14. Ideal Linearity

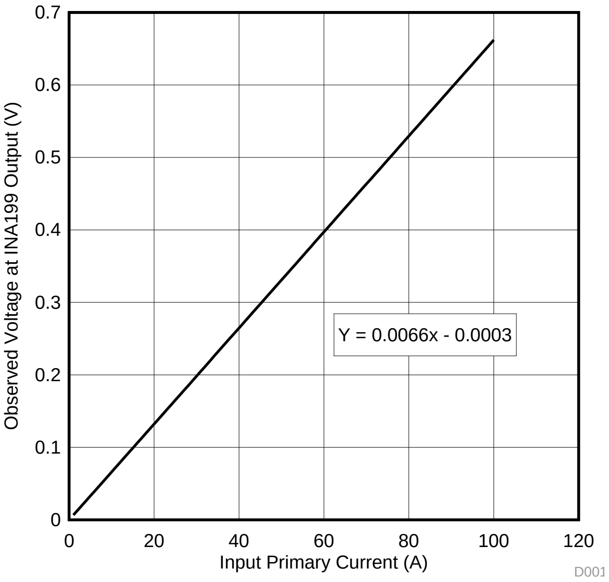


Figure 15. Observed Linearity

7.1.4 Linearity for 0.1-Ω Burden at –25°C

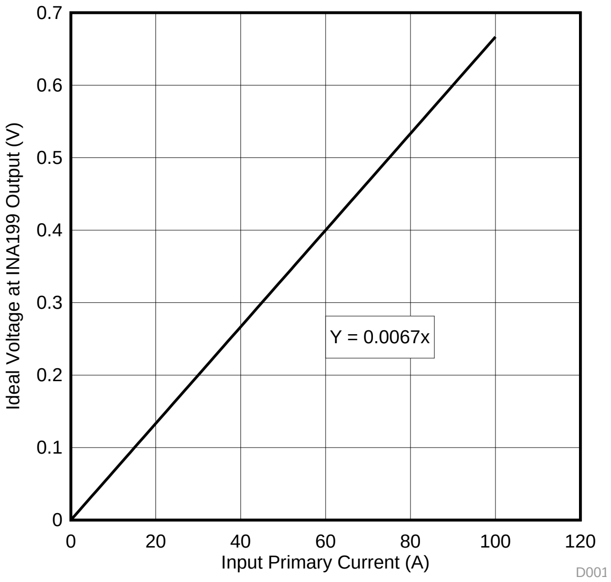


Figure 16. Ideal Linearity

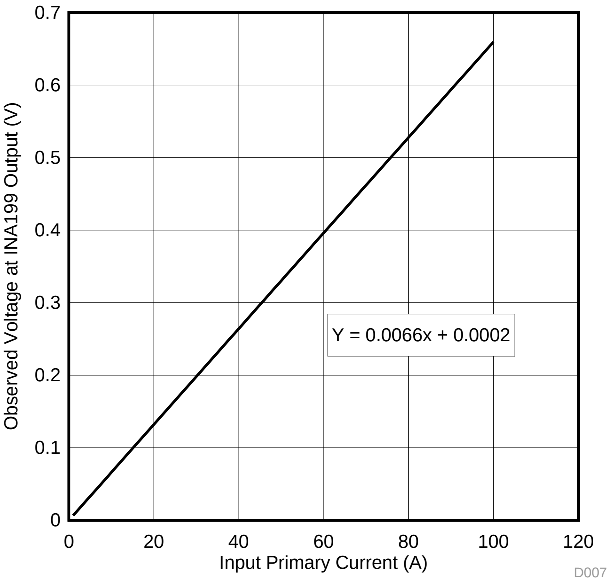


Figure 17. Observed Linearity

7.1.5 Voltage Error at INA199 Output for Current Range of 5 A to 100 A (25°C Uncalibrated)

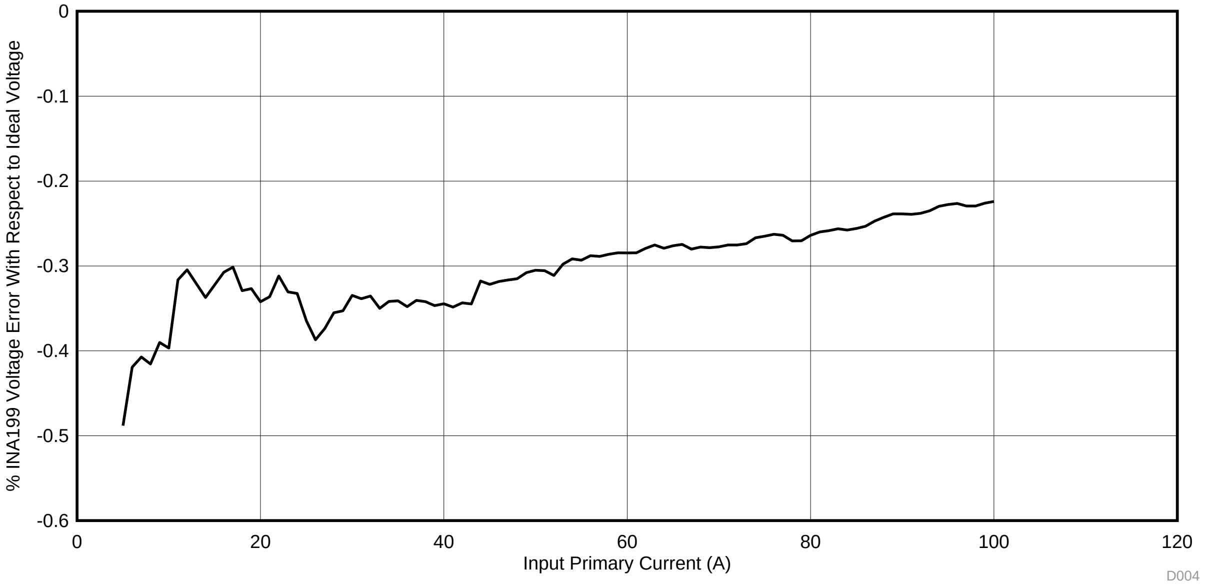


Figure 18. % Voltage Error at 25°C

7.1.6 INA199 Output %Voltage Error for Current Range of 5 A to 100 A (85°C Uncalibrated)

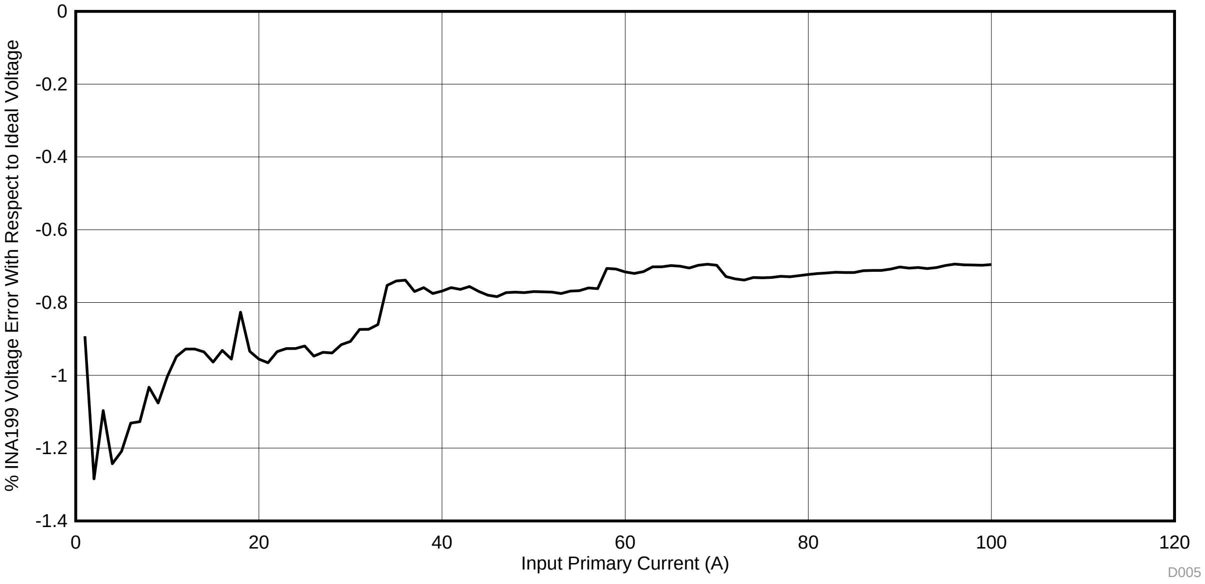


Figure 19. % Voltage Error at 85°C

7.1.7 INA199 Output %Voltage Error for Current Range of 5 A to 100 A (–25°C Uncalibrated)

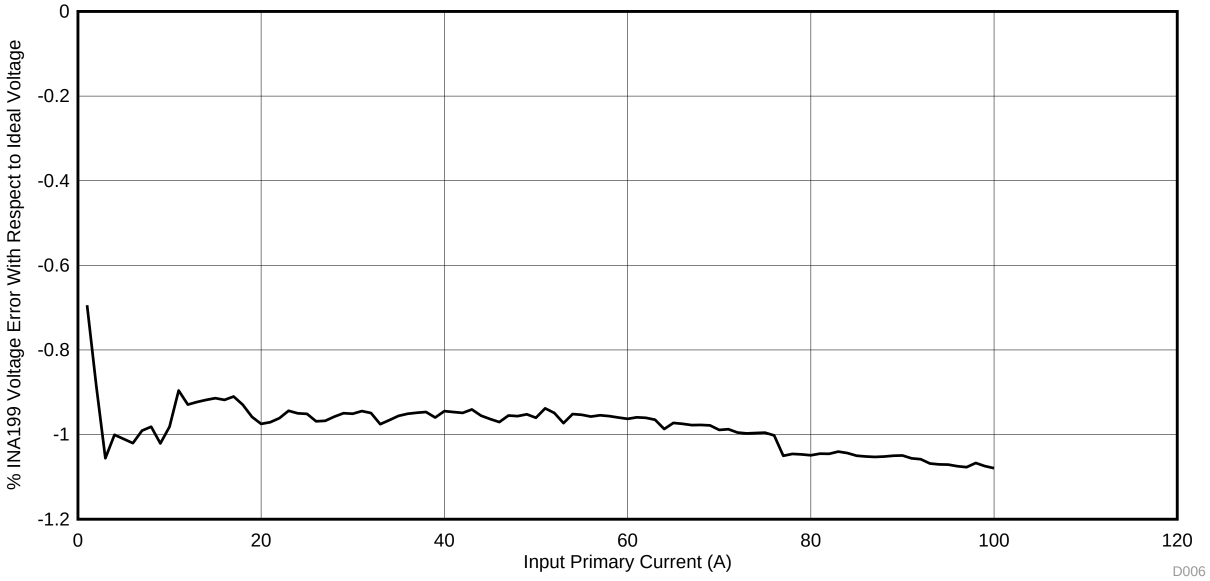
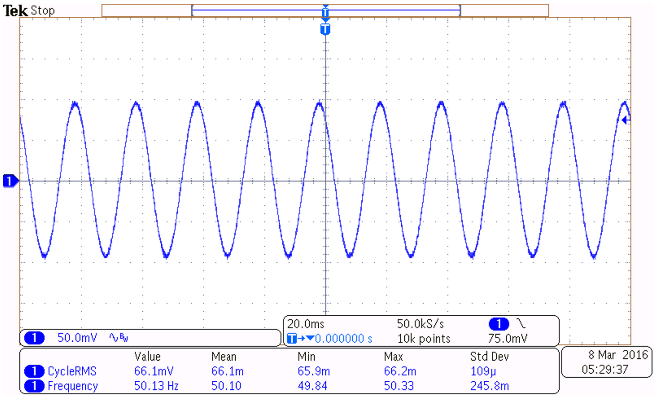


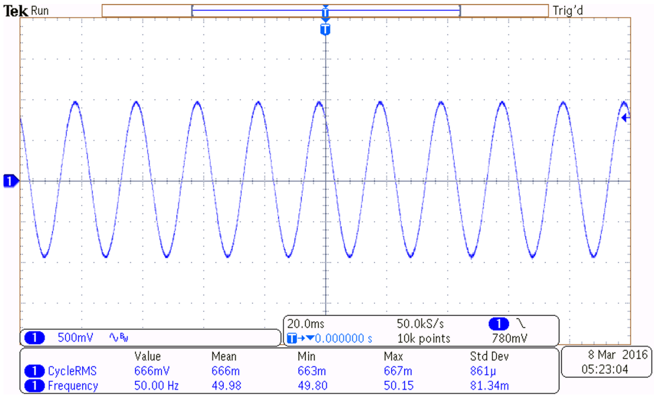
Figure 20. % Voltage Error at –25°C

7.2 Timing Plots



	Value	Mean	Min	Max	Std Dev
1 CycleRMS	66.1mV	66.1m	65.9m	66.2m	109µ
1 Frequency	50.13 Hz	50.10	49.84	50.33	245.8m

Figure 21. Output at INA199 for 1-A Primary Current



	Value	Mean	Min	Max	Std Dev
1 CycleRMS	666mV	666m	663m	667m	861µ
1 Frequency	50.00 Hz	49.98	49.80	50.15	81.34m

Figure 22. Output at INA199 for 100-A Primary Current

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDA-00753.

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00753.

8.3 PCB Layout Recommendations

The PCB layout recommendation is driven by low electromagnetic interference (EMI) and good thermal performance. The layout has been implemented on a two-layer board with 1-oz copper. Figure 23 shows the current path for the kelvin connection of burden resistor R3. The trace length between R3 and U1 (INA199) must be evenly matched to reduce the common-mode voltage error.

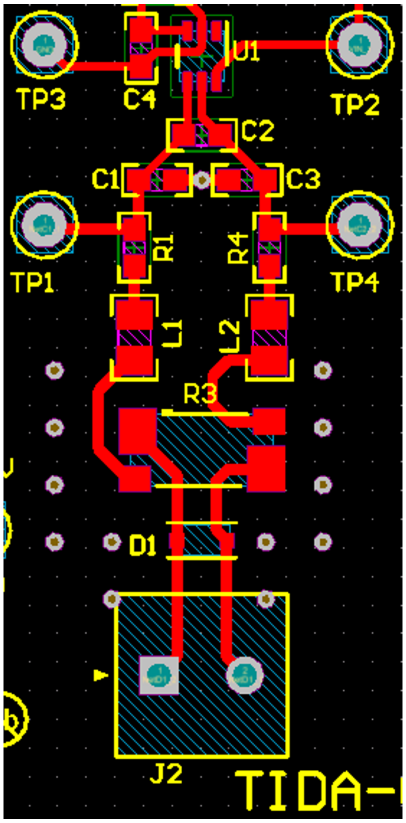


Figure 23. Burden Resistance and INA199 Placement

8.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-00753.

8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00753.

8.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00753.

9 References

1. Texas Instruments, *INA199 26-V, Bidirectional, Zero-Drift, Low- or High-Side, Voltage Output Current Shunt Monitor*, INA199 Datasheet (SBOS469)
2. Texas Instruments, *TPS717 Low-Noise, High-Bandwidth PSRR, Low-Dropout, 150-mA Linear Regulator*, TPS717 Datasheet (SBVS068)
3. Texas Instruments, *4ppm/°C, 100μA, SOT23-6 SERIES VOLTAGE REFERENCE*, REF32xx Datasheet (SBVS058)
4. CR MAGNETICS, *Calculating Ratio Errors: UNDERSTANDING CURRENT TRANSFORMER RATIO ERROR AND EXCITATION CURVES*, Technical Reference (http://www.crmagnetics.com/assets/technical-references/calculating_ratio_errors.pdf)

10 About the Author

Any other important terminology referred to in this documentation.

SRINIVASAN IYER is a Systems Engineer at Texas Instruments India where he is responsible for developing reference design solutions for the building automation applications. Srinivasan has five years of experience in analog circuit designs for field transmitter and signal chain.

MIROSLAV OLJACA is the End Equipment Lead for building automation applications and system solutions. Miro has nearly 30 years of engineering experience and has been granted at least a dozen patents, several related to high performance signal processing, and he has written many articles on the subject. Miro received his BSEE and MSEE from the University of Belgrade, Serbia.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (April 2016) to A Revision	Page
• Changed column title from "SENSOR NO" to "REFERENCE NO"	10
• Changed column title from "SENSOR NO" to "REFERENCE NO"	11
• Changed column title from "SENSOR NO" to "REFERENCE NO"	12
• Changed column title from "SENSOR NO" to "REFERENCE NO"	16

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated (‘TI”) reference designs are solely intended to assist designers (“Designer(s)”) who are developing systems that incorporate TI products. TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.

TI’s provision of reference designs and any other technical, applications or design advice, quality characterization, reliability data or other information or services does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such reference designs or other items.

TI reserves the right to make corrections, enhancements, improvements and other changes to its reference designs and other items.

Designer understands and agrees that Designer remains responsible for using its independent analysis, evaluation and judgment in designing Designer’s systems and products, and has full and exclusive responsibility to assure the safety of its products and compliance of its products (and of all TI products used in or for such Designer’s products) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to its applications, it has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any systems that include TI products, Designer will thoroughly test such systems and the functionality of such TI products as used in such systems. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

Designers are authorized to use, copy and modify any individual TI reference design only in connection with the development of end products that include the TI product(s) identified in that reference design. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of the reference design or other items described above may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS AND OTHER ITEMS DESCRIBED ABOVE ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNERS AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS AS DESCRIBED IN A TI REFERENCE DESIGN OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

TI’s standard terms of sale for semiconductor products (http://www.ti.com/sc/docs/stdterms.htm) apply to the sale of packaged integrated circuit products. Additional terms may apply to the use or sale of other types of TI products and services.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer’s non-compliance with the terms and provisions of this Notice.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated