EVM User's Guide: AMC-AMP-200A-EVM

AMC-AMP-200A-EVM

Description

The AMC-AMP-200A-EVM is an isolated current-sensing evaluation module designed for ±200A shunt-based current sensing. This EVM allows users to sense up to ±200A peak current through an external bus-bar shunt resistor while measuring the isolated output through the isolation barrier of the AMC3302. The AMC3302 is a precision, isolated amplifier optimized for shunt-based current measurements and is paired with the Vishay™ WSBS8518 bus-bar shunt resistor. This EVM features via stitching to facilitate with heat dissipation at large currents and can perform within ±5% (typical) accuracy.

Get Started

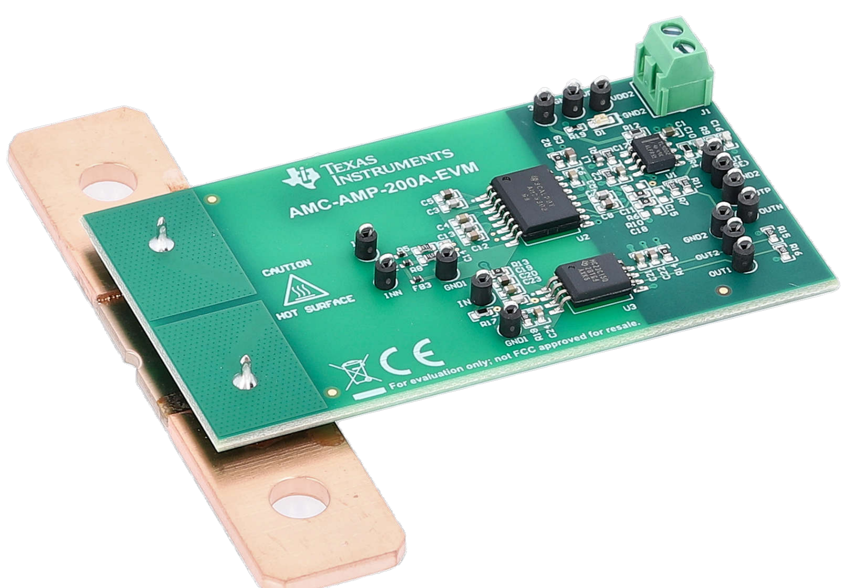
1. Order the AMC-AMP-200A-EVM on ti.com.
2. Download the comprehensive reference design files.
3. Evaluate performance on the bench.

Features

- ±200A isolated current sensing
- 250μΩ bus-bar shunt resistor
- Lug connection compatibility
- Heat dissipation design up to 180°C at 2 minutes
- Test points for easy evaluation
- Differential to single-ended signal chain

Applications

- Motor drives
- Power delivery
- Onboard chargers (OBCs)
- Traction inverters
- DC/DC converters
- Energy storage systems (ESS)
- EV charging
- Solar inverters



1 Evaluation Module Overview

1.1 Introduction

Throughout this document, the abbreviation *EVM* and the term *evaluation module* are synonymous with the AMC-AMP-200A-EVM. This document includes how to set up and evaluate the EVM, the printed circuit board (PCB) layout, schematics, and bill of materials (BOM).

1.2 Kit Contents

Table 1-1 details the contents included in the AMC-AMP-200A-EVM kit.

Table 1-1. Kit Contents

Item	Description	Quantity
AMC-AMP-200A-EVM	PCB	1

1.3 Specification

The AMC-AMP-200A-EVM provides the ability to evaluate high currents up to ±200A. Refer to the data sheets of the AMC3302, AMC23C15, TLV9002IDR, and WSBS8518 for detailed device specifications.

1.4 Device Information

The AMC-AMP-200A-EVM is designed to provide ease-of-use and high accuracy in large current applications. The current-sensing device, AMC3302, is an isolated amplifier intended for shunt-based current sensing with reinforced isolation and an integrated DC/DC converter. Overcurrent detection is configurable using the AMC23C15, a reinforced, adjustable threshold isolated comparator. Both isolated current-sensing products sense across the WSBS8518 shunt resistor. The EVM features an additional unpopulated shunt resistor footprint in parallel to extend the current sensing range flexibility. See Section 2.7 for details.

2 Hardware

This section summarizes the AMC-AMP-200A-EVM components, assembly instructions, interfaces, power requirements, and test point information.

2.1 Hardware Overview

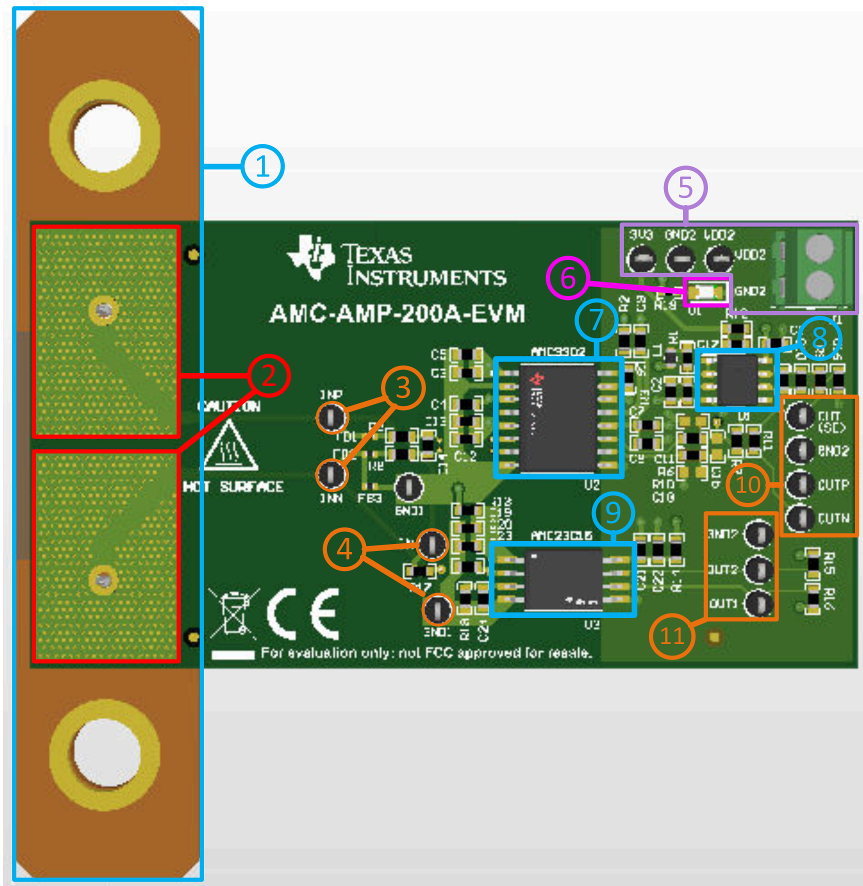


Figure 2-1. AMC-AMP-200A-EVM Hardware Labels

The AMC-AMP-200A-EVM has many hardware features, allowing the user to access and assess the EVM from many points in the signal chain. The default configuration is one 250µΩ shunt listed as R20 to sense ±200A applications.

Note

This EVM is an example high current-sensing design and further designs can be modified per system requirements. Considerations included in definition table.

1. Vishay WSBS8518 Busbar Shunt Resistor

- 250µΩ, ±5% tolerance shunt resistor for accurate current sensing. The PCB is not designed for more than ±200A. *If alternate current sensing range is desired, consider alternate shunt resistor values.*
- *Design Considerations for Isolated Current Sensing*
- *Shunt Resistor Selection for Isolated Data Converters*

2. Via Stitch Via stitching provides aeration to dissipate heat further.

3. AMC3302 Input AMC3302 differential analog input.

4. AMC23C15 Input AMC23C15 analog input.

5. Low-Side Power Supply Low-side power supply connectors: terminal block J6 or test point connections.

6. LED LED on to indicate device powered.

7. AMC3302	Isolated current-sensing amplifier with integrated DC/DC converter. *If smaller footprint desired or if high-side supply is available in the application such as from a gate driver or additional transformer winding, consider the AMC1302 isolated current-sensing amplifier.*
8. TLV9002	Operational amplifier for differential to single-ended conversion.
9. AMC23C15	• Isolated comparator with adjustable threshold for overcurrent detection; 280ns propagation delay (typical). *If <3µs latency is not required, consider omitting isolated comparator.* • *Isolated Overcurrent Protection Circuit*
10. AMC3302 Outputs	AMC3302 differential and single-ended outputs.
11. AMC23C15 Outputs	AMC23C15 analog outputs.

2.2 Assembly Instructions

This section has step-by-step instructions on how to assemble the AMC-AMP-200A-EVM. Lugs are not included. If the user desires to use lugs during evaluation, follow step one.

1. Connect high-current input lugs to R20 with screw and hexnut.
    a. The lugs must not touch when secured.
    b. Make sure that the lugs are positioned such that the lugs make contact with the maximum amount of surface area of the shunt.
    c. The connectors must be tightly fastened to the current carrying cables such that the connectors can not be moved by hand. A torque wrench is recommended to provide symmetrical connection. A torque of approximately 40in-lbs is recommended.
2. Modify isolated comparator adjustable trip threshold resistor (R18) if desired. The default trip voltage is ±288A. Refer to the AMC23C15 data sheet for more information.

2.3 Interfaces

The AMC-AMP-200A-EVM features analog input circuitry to the isolated amplifier AMC3302 and to the isolated comparator AMC23C15. The EVM output contains two output sections: isolated amplifier (AMC3302) analog output circuitry and isolated comparator (AMC23C15) analog output circuitry.

2.3.1 Analog Input

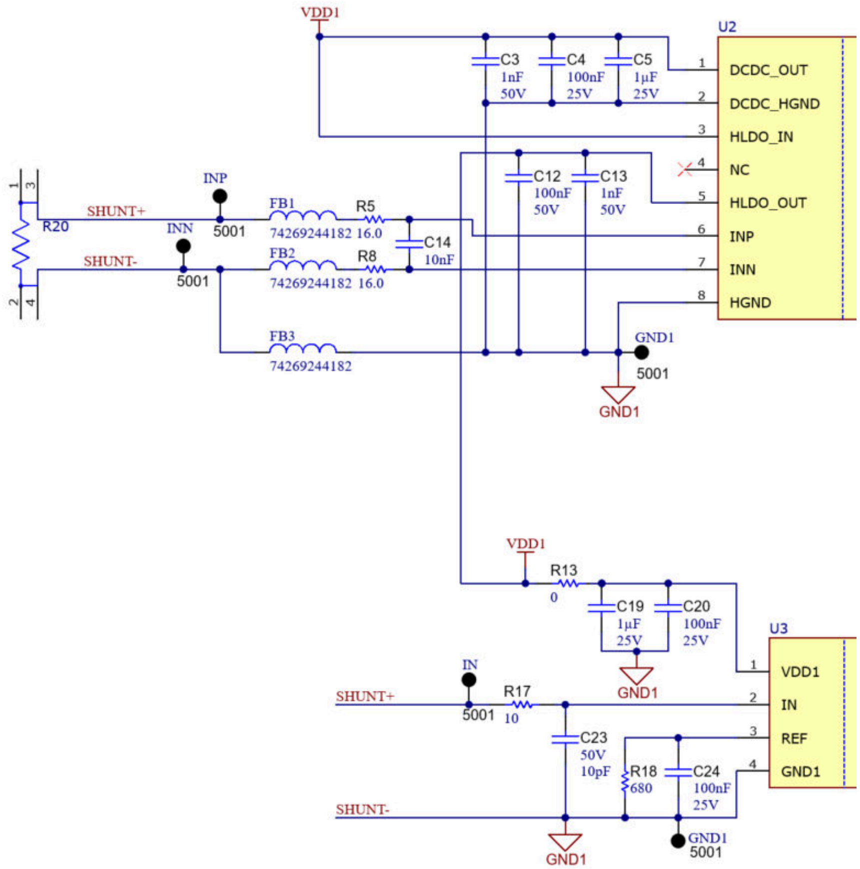


Figure 2-2. AMC-AMP-200A-EVM Analog Input

Figure 2-2 shows the analog input circuit for the AMC-AMP-200A-EVM.

The input is supplied through high current input lugs, connected to either end of R20. The input current is sensed through the bus-bar shunt resistor R20 and is carried into the analog inputs of the AMC3302 and into the analog input of the AMC23C15. The AMC3302 input is accessible to the user through test-points INP and INN. The AMC23C15 input is accessible to the user through test-points IN and REF.

For the AMC3302 input, the passive components R5, R8, and C14 make a differential anti-aliasing filter with a cutoff frequency of 497kHz. Ferrite beads FB1, FB2, and FB3 help to suppress high frequency signals on the signal lines. See the *Best Practices to Attenuate AMC3302 Family Radiated Emissions EMI* application note for more information. Capacitors C3, C4, C5, C12, and C13 serve as decoupling capacitors.

For the AMC23C15 input, the passive components R17 and C23 make an RC filter with a cutoff frequency of 1.59GHz. Passive components R18 and C24 define the adjustable threshold voltage determined by the desired overcurrent value. See the AMC23C15 data sheet for more details. Capacitors C19 and C20 serve as decoupling capacitors.

2.3.2 Isolated Amplifier (AMC3302) Analog Output

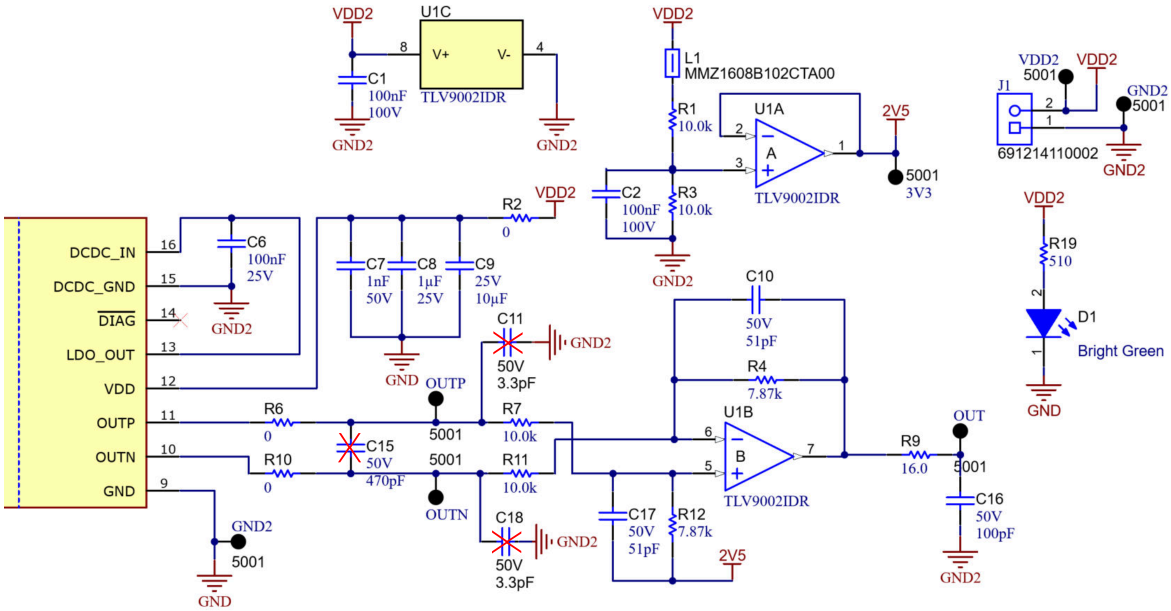


Figure 2-3. AMC-AMP-200A-EVM Isolated Amplifier (AMC3302) Analog Output

Figure 2-3 shows the analog output circuit for the AMC-AMP-200A-EVM AMC3302 signal chain.

The AMC3302 differential output is accessible to the user through test-points OUTP and OUTN. The passive components R6, R10, and C15 give a footprint for a differential anti-aliasing filter. R6 and R10 are 0Ω by default configuration and C15 is unpopulated by default configuration.

The AMC3302 single-ended output is accessible to the user through test point OUT(SE), with respect to GND. A two-channel operational amplifier TLV9002 is used to transform the differential output signal to a single-ended signal. Passive components R4, R7, R11, R12, C10, and C17 serve as differential to single-ended filtering and set the gain of the operational amplifier. C11 and C18 are unpopulated by default configuration. See the *Isolated Current-Sensing Circuit with ±250mV Input Range and Single-Ended Output Voltage* application note for more information on differential to single-ended signal conversion.

Passives R1, R3, and C2 derive a common-mode voltage that is buffered by the second channel of the TLV9002 at the midpoint from the power supply to prevent common-mode shifting.

Passive components R9 and C16 make an RC filter on the single-ended output with a cutoff frequency of 99.5MHz.

Capacitors C7, C8, and C9 serve as decoupling capacitors. Capacitor C6 is a feedback capacitor for the integrated DC/DC converter.

2.3.3 Isolated Comparator (AMC23C15) Analog Output

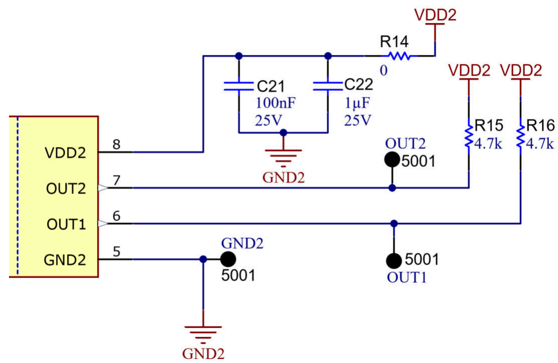


Figure 2-4. AMC-AMP-200A-EVM Isolated Comparator (AMC23C15) Analog Output

Figure 2-4 shows the analog output circuit for the AMC-AMP-200A-EVM AMC23C15 signal chain.

The analog output of the AMC23C15 provides the overcurrent protection response of the circuitry.

The AMC23C15 output is accessible to the user through test-points OUT1 and OUT2. OUT1 connects to window comparator 1, adjustable threshold. OUT2 connects to window comparator 2, fixed threshold. OUT1 transitions from high to low at approximately ±288A input current with default configurations. OUT2 transitions from high to low at ±60mV at the input of the device. Resistors R15 and R16 are pullup resistors. Capacitors C21 and C22 serve as decoupling capacitors.

2.4 Power Requirements

The EVM requires one external power rail for VDD2. VDD2 is the low-voltage side power supply. The AMC3302 includes an integrated DC/DC converter which acts as the high-voltage side power supply. This power is extended to the high-voltage side of the AMC23C15 from the AMC3302 HLDO_OUT pin.

2.4.1 VDD2 Input

The EVM provides access to VDD2 by terminal block J1 and test-points VDD2 and GND2. The power supply must be between the devices recommended operating conditions with respect to ground (3.3V-5V). LED lights up when powered.

2.5 Test Points

The AMC-AMP-200A-EVM includes 12 test-points throughout the EVM signal chain. These connections allow for full evaluation of the current sensing circuitry. External equipments, such as power supplies and digital multimeters (DMMs) with hook clips, are intended to attach to the surface mounted test points for easy evaluation.

2.6 Lug Information

The input connectors labeled IN+ and IN- correspond to the high-current rated load connector lugs supplied with the EVM kit. To make contact, securely screw these components to the board. The acceptable continuous load input maximum for the included connectors is ±200A for DC and AC measurements. Continuous allowable current is also limited by the maximum operating conditions of the shunt resistor.

2.7 Best Practices

Do not apply more than ±200A continuous load to this EVM. The AMC-AMP-200A-EVM is defined to measure the ±200A range. For best reliability with standard FR4 based PCB, the temperature must not exceed 180°C.

3 Implementation Results

3.1 Evaluation Procedure

To evaluate the function of the board, TI recommends to run a test procedure - Section 3.1.2. For more in depth signal chain evaluation, reference Section 3.1.3.

3.1.1 Equipment Setup

1. One 5V source limited to 50mA.
2. High current electronic load (for example, Agilent™ N3300A).
3. DC Current Source.
4. High current carrying cables.
5. One (or more) oscilloscopes or digital mulitmeters (DMM) with at least 6.5 digits of resolution. *Optional:* Use five DMMs for full signal chain evaluation.
6. Signal generator or data collection equipment.
7. *Optional:* High current supply control shunt for full signal chain evaluation.

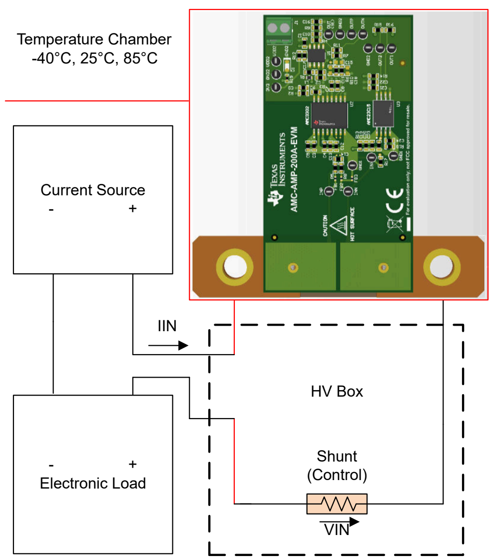


Figure 3-1. Positive Current Equipment Setup

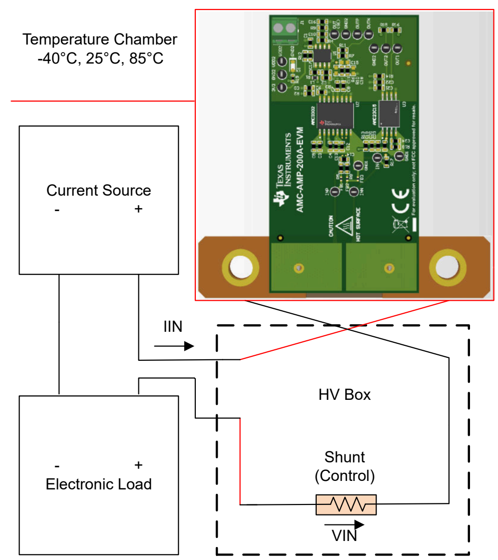


Figure 3-2. Negative Current Equipment Setup

3.1.2 Test Procedure

Note

Verify that the outputs of the connected supplies are disabled before connecting or disconnecting equipment.

1. Set the 5V (±10%) source and limit the current to 50mA as noted in Section 3.1.1. Connect the EVM voltage source to the VDD pin of the connector, referenced to GND2. Turn on the power source and make sure there is no more than the specified current limit in the device data sheet drawn.
2. Tie inputs together and to HGND. Use the oscilloscope or the DMM to verify that isolated power is present on both supplies. Measure test point OUTP referenced GND and test point OUTN referenced to GND. Verify the isolated voltage is at the common-mode output voltage (typical 1.44V) to confirm device functionality.
3. Connect the oscilloscope or the DMM to the AMC3302 differential output.
4. Connect the high current carrying cables to the positive and negative lugs, IN+ and IN-. For high-side measurement of positive current, IN– sources to the electronic load; for negative current, IN+ sources to the load. Set current bounds if supplies allow. Turn on all connected supplies.
5. Apply the appropriate full-scale linear input signal: ±200A.
6. Measure the AMC3302 differential output with the oscilloscope or the DMM. Verify that the differential output voltage swings between the specified range in the device data sheet: ±2.05V.

3.1.3 Full Signal Chain Evaluation Procedure

Note

Verify that the outputs of the connected supplies are disabled before connecting or disconnecting equipment.

1. Set the 5V (±10%) source and limit the current to 50mA as noted above. Connect the EVM voltage source to the VDD pin of the connector, referenced to GND2. Turn on the power source and verify that there is no more than the specified current limit in the device data sheet drawn.
2. Connect DMMs to the following test points. Refer to Figure 3-1, Figure 3-2, and Figure 2-1 for test procedure setup and connection mapping.
   a. High current power supply control shunt: V_{IN}
   b. AMC3302 input, INP and INN: $V_{INP/INN}$
   c. AMC3302 differential output, OUTP and OUTN: V_{OUT_DIFF}
   d. AMC3302 single-ended output, OUT(SE) and GND: V_{OUT_SE}
   e. AMC23C15 output, OUT1 *(or OUT2)*, and GND: V_{OUT1}
3. Connect the high-current carrying cables to the positive and negative lugs, IN+ and IN–. For high-side measurement of positive current, IN– sources to the electronic load; for negative current, IN+ sources to the load. Set current bounds if supplies allow. Turn on all connected supplies.
4. Apply the appropriate full-scale linear input sweep ±200A range. Incrementing 0.5A every 0.2s is appropriate for evaluation.
5. Record the five DMM outputs for the entire full-scale linear input sweep.
6. To evaluate the current sensing performance of the EVM, calculate the following errors across the entire current sweep. Equations *i* calculate the error at a given input current and equations *ii* calculate the error over a specified current range at a given input current. An example range is ±50A.
   a. Default Values:

$$R_{IND} = 4.9k\Omega$$

$$I_B = 36\mu A$$

$$GAIN_{AMC3302} = 41$$

$$V_{OFFSET} = 2.5V$$

Shunt Resistor Error:

$$\text{i. } E_{SHUNT} = V_{IN} \times \frac{R_{IND}}{R_{IND} + R_5 + R_8} + I_B \times R_{20} - V_{INP/INN}$$

$$\text{ii. } E_{SHUNT\ \%FS} = \frac{E_{SHUNT}}{E_{SHUNT}(I_{IN} = -200A) - E_{SHUNT}(I_{IN} = 200A)} \times 100$$

   b. AMC3302 Error:

$$\text{i. } E_{AMC3302} = V_{OUT\_DIFF} - V_{INP/INN} \times \frac{R_{IND}}{R_{IND} + R_5 + R_8} \times GAIN_{AMC3302}$$

$$\text{ii. } E_{AMC3302\ \%FS} = \frac{E_{AMC3302}}{E_{AMC3302}(I_{IN} = -200A) - E_{AMC3302}(I_{IN} = 200A)} \times 100$$

   c. Differential to Single-Ended Error:

$$\text{i. } E_{DIFF \to SE} = V_{OUT\_SE} - V_{OUT\_DIFF} \times \frac{R_4}{R_7} + V_{OFFSET}$$

$$\text{ii. } E_{DIFF \to SE\ \%FS} = \frac{E_{DIFF \to SE}}{E_{DIFF \to SE}(I_{IN} = -200A) - E_{DIFF \to SE}(I_{IN} = 200A)} \times 100$$

d. Total Error:

i. $E_{TOTAL} = V_{OUT\_SE} - V_{OFFSET} + \left(V_{IN} \times \frac{R_{IND}}{R_{IND} + R_5 + R_8} + I_B \times R_{20}\right) \times GAIN_{AMC3302} \times \frac{R_4}{R_7}$

ii. $E_{TOTAL\ \%FS} = \frac{E_{TOTAL}}{E_{TOTAL}(I_{IN} = -200A) - E_{TOTAL}(I_{IN} = 200A)} \times 100$

7. Plot calculated results against input current, $I_{IN.}$ Results shown in Figure 3-3 are taken over temperature from two samples.

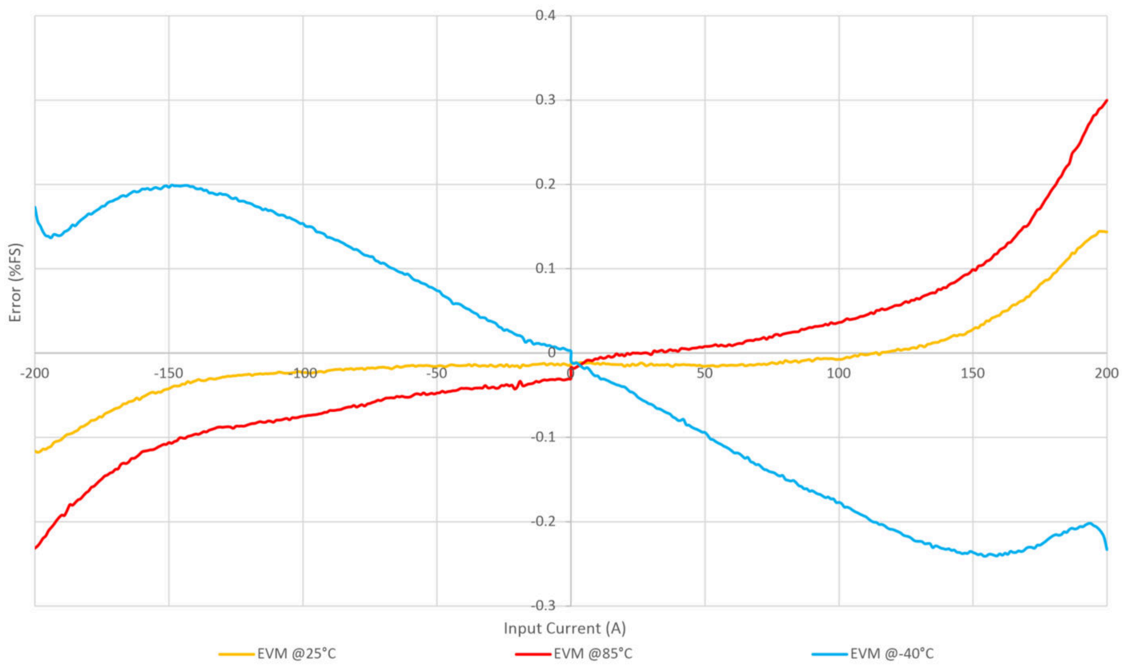


Figure 3-3. AMC-AMP-200A-EVM Total Error %FS Results

8. To evaluate the overcurrent detection performance, measure V_{OUT1} or V_{OUT2}. By default, V_{OUT1} is low at I_{IN} = ±288A or V_{IN} = ±72mV ± 2.5mV and V_{OUT2} toggles at V_{IN} =±60mV.
9. Repeat these steps at hot and cold temperatures. Calibrate if necessary.

3.2 Performance Data and Results

3.2.1 Shunt Selection Calculations

Consider desired input range and power dissipated when selecting a shunt resistor for high current applications.

- The following equation calculates the ideal shunt resistance:

$$R_{SHUNT} = \frac{V}{I} = \frac{50mV(Input\ \ Range\ \ of\ \ AMC3302)}{200A(Current\ \ Range)} = 250\mu\Omega$$

- The following equation calculates the amount of power dissipated:

$$P = I^2R = 200A^2 \times 250\mu\Omega = 10W$$

Power dissipated must be ⅔ of the shunt resistor power rating for heat dissipation at high currents. See application note, *Shunt Resistor Selection for Isolated Data Converters*, for more information.

3.2.2 Filter Selection

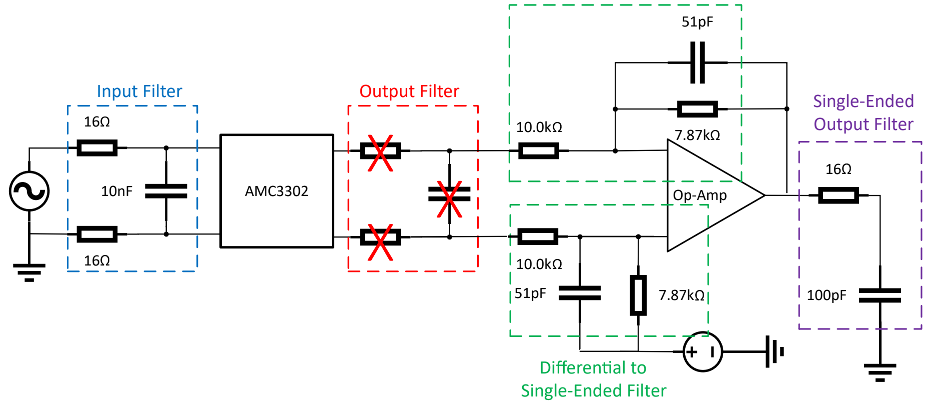


Figure 3-4. AMC-AMP-200A-EVM Filter Diagram

The AMC-AMP-200A-EVM performance can be adjusted among four circuit filters. With each filter, there is a tradeoff between noise and propagation delay. The weaker the filter, the shorter the propagation delay.

- Input Filter:

$$F_C = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 32\Omega \times 10nF} = 497kHz$$

  – Selecting a shunt resistor with high inductance when measuring a high frequency signal can cause overshoot in AC measurements. Compensate for overshoot caused by parasitic inductance with proper design of the differential RC filter. Best input filter design is dependent on inductance of resistor and PCB design. An example simulation is shown below for TINA-TI.

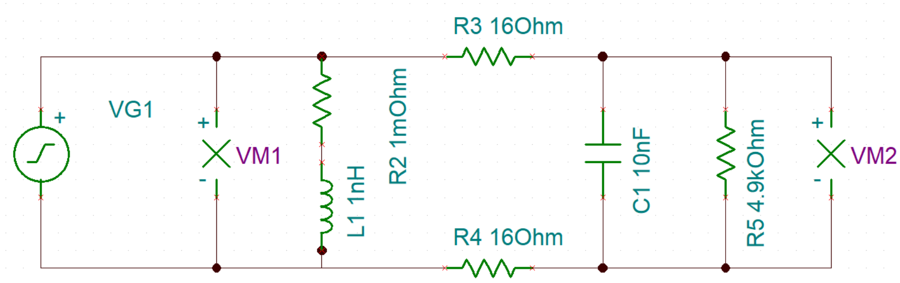


Figure 3-5. Input Filter TINA-TI

- Output filter (unpopulated):

$$F_C = \frac{1}{2\pi RC}$$

  – Size for additional filtering as desired.
- Differential to single-ended filter:

$$F_C = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 7.87k\Omega \times 51pF} = 397kHz$$

  – Sized to allow 340kHz AMC3302 output bandwidth. Modify as needed for bandwidth limitations.
- Single-ended output filter:

$$F_C = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 16\Omega \times 100pF} = 99.5MHz$$

  – Modify as needed for single-ended output signal.

4 Hardware Design Files

4.1 Schematics

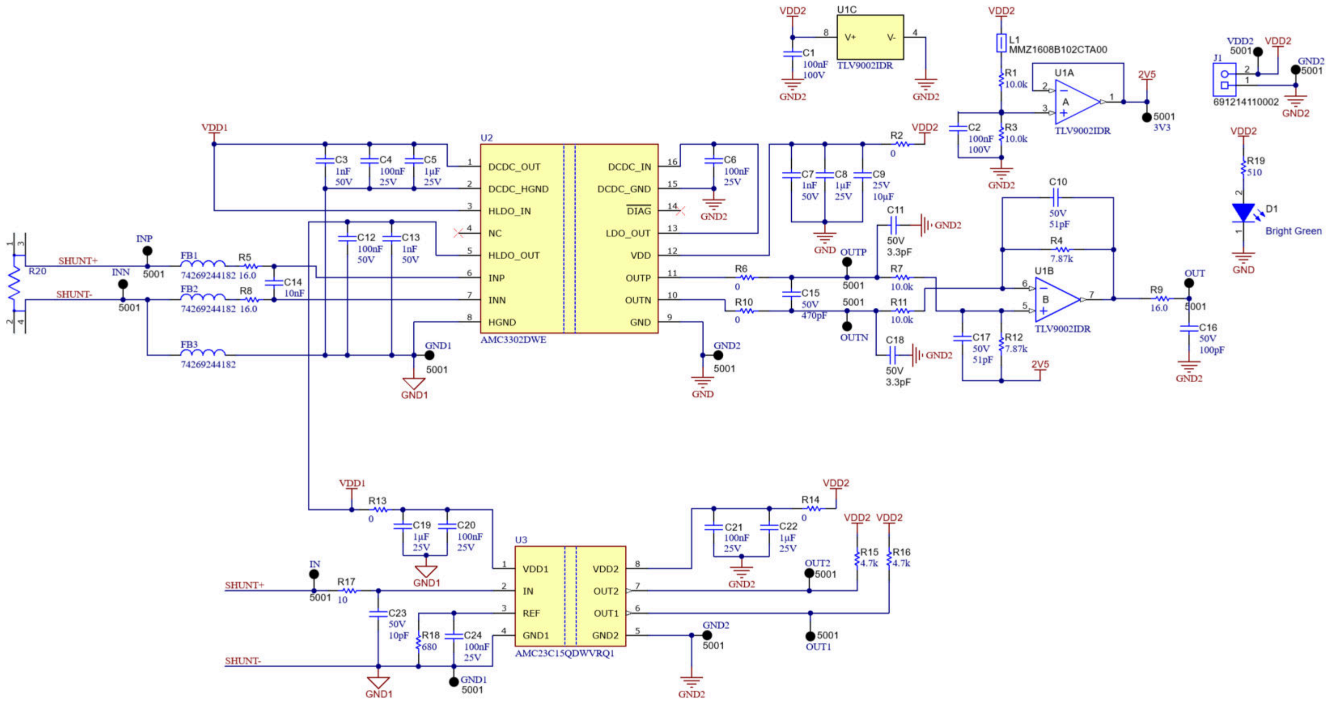


Figure 4-1. AMC-AMP-200A-EVM Schematic

4.2 PCB Layouts

Figure 4-2 and Figure 4-3 show the top and bottom printed circuit board (PCB) drawings of the AMC-AMP-50A-EVM respectively.

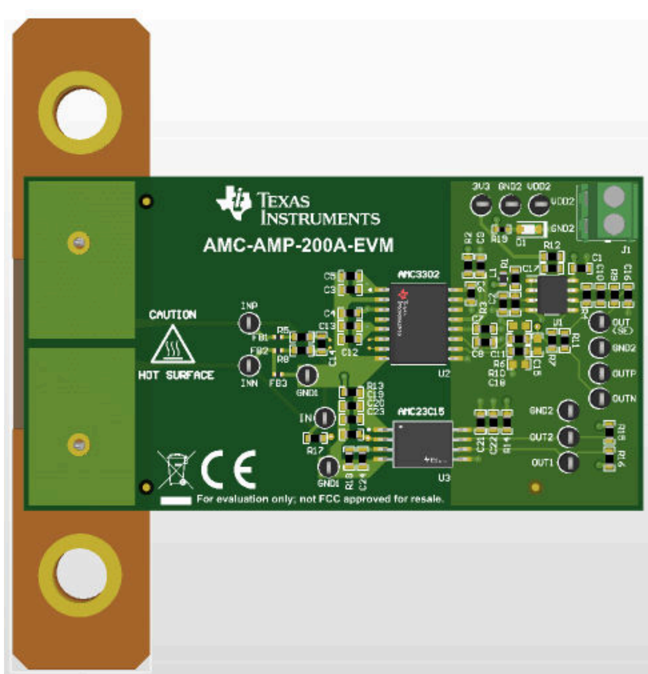


Figure 4-2. AMC-AMP-200A-EVM Top PCB Drawing

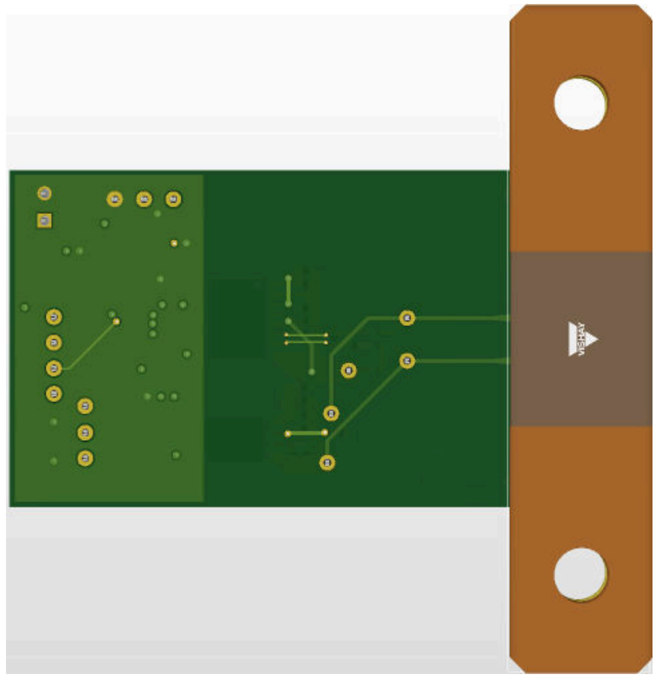


Figure 4-3. AMC-AMP-200A-EVM Bottom PCB Drawing

4.3 Bill of Materials (BOM)

Designator	Description	Manufacturer	Part Number
3V3, GND1, GND2, IN, INN, INP, OUT, OUT1, OUT2, OUTN, OUTP, VDD2	Test Point, Miniature, Black, TH	Keystone Electronics	5001
C1, C2	CAP, CERM, 0.1 uF, 100 V, +/- 10%, X7R, 0603	MuRata	GRM188R72A104KA35J
C3, C7, C13	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0603	Kemet	C0603C102K5RACTU
C4, C6, C20, C21, C24	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X7R, 0603	AVX	06033C104KAT2A
C5, C8	CAP, CERM, 1 µF, 25 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	TDK	CGA3E1X7R1E105K080AC
C9	CAP, CERM, 10 µF, 25 V,+/- 10%, X5R, 0603	MuRata	GRM188R61E106KA73D
C10, C17	CAP, CERM, 51 pF, 50 V, +/- 5%, C0G/NP0, AEC-Q200 Grade 1, 0603	MuRata	GCM1885C1H510JA16D
C12	CAP, CERM, 0.1 µF, 50 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	Kemet	C0603C104K5RACAUTO
C14	CAP, CERM, 0.01 µF, 25 V,+/- 10%, X7R, 0603	Presidio Components	SR0603X7R103K1NT95(F)#M123A
C16	CAP, CERM, 100 pF, 50 V,+/- 1%, C0G/NP0, 0603	Kemet	C0603C101F5GACTU
C19, C22	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, 0603	AVX	06033C105KAT2A
C23	CAP, CERM, 10 pF, 50 V, +/- 5%, C0G/NP0, 0603	Kemet	C0603C100J5GACTU
D1	LED, Bright Green, SMD	Wurth Elektronik	150080VS75000
FB1, FB2, FB3	WE-TMSB Tiny Multilayer Suppression Bead, size 0402, 1800Ohm, 0.21A	Wurth Elektronik	74269244182
J1	Terminal Block, 3.5mm, 2x1, Tin, TH	Wurth Elektronik	691214110002
L1	Ferrite Bead, 1000 ohm @ 100 MHz, 0.3 A, 0603	TDK	MMZ1608B102CTA00
R1, R3, R7, R11	RES, 10.0 k, 0.1%, 0.1 W, 0603	Yageo America	RT0603BRD0710KL
R2, R6, R10, R13, R14	RES, 0, 5%, 0.1 W, 0603	Yageo	RC0603JR-070RL
R4, R12	RES, 7.87 k, 0.1%, 0.1 W, 0603	Yageo America	RT0603BRD077K87L
R5, R8, R9	RES, 16.0, 0.5%, 0.1 W, 0603	Yageo America	RT0603DRE0716RL
R15, R16	RES, 4.7 k, 5%, 0.1 W, 0603	Yageo	RC0603JR-074K7L
R17	RES, 10, 5%, 0.1 W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW060310R0JNEA
R18	RES, 680, 1%, 0.1 W, 0603	Yageo	RC0603FR-07680RL
R19	RES, 510, 5%, 0.1 W, AEC-Q200 Grade 0, 0402	Panasonic	ERJ-2GEJ511X

Designator	Description	Manufacturer	Part Number
R20	250 µOhms ±5% 36W Shunt, Battery Specialized Resistor Metal Element ±110ppm/°C Shunt Fixture, 60mm Pitch	Vishay	WSBS8518L2500JK20-ND
U1	2-Channel, 1MHz, RRIO, 1.8V to 5.5V Operational Amplifier for Cost-Optimized Systems, D0008A (SOIC-8)	Texas Instruments	TLV9002IDR
U2	High-Precision, ±50-mV Input, Reinforced Isolated Amplifier With Integrated DC/DC Converter	Texas Instruments	AMC3302DWE
U3	Dual, Fast Response, Reinforced Isolated Window Comparator with Adjustable Threshold, SOICW8	Texas Instruments	AMC23C15QDWVRQ1

5 Additional Information

5.1 Trademarks

Vishay™ is a trademark of Vishay Intertechnology, Inc.
Agilent™ is a trademark of Agilent Technologies, Inc.
ISA-WELD™ is a trademark of Isabellenhütte USA.
All trademarks are the property of their respective owners.

6 Related Documentation

- Texas Instruments, *AMC3302 High-Precision, ±50mV Input, Reinforced Isolated Amplifier With Integrated DC/DC Converter*, data sheet
- Texas Instruments, *AMC23C15 Dual, Fast Response, Reinforced Isolated Window Comparator With Adjustable Threshold* , data sheet
- Texas Instruments, *TLV900x Low-Power, RRIO, 1MHz Operational Amplifier for Cost-Sensitive Systems* , data sheet
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