TI Designs
High Precision Analog Front End Amplifier and Peripherals for MCCB - Electronic Trip Unit

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Design Resources

TIDA-00128	Design Folder
TINA Spice	Product Folder
LM5017	Product Folder
LM62BIM3	Product Folder
CSD18537NKCS	Product Folder
LM4041B	Product Folder
TPS71533	Product Folder
TPS55010	Product Folder
ISO1176	Product Folder
LM293	Product Folder

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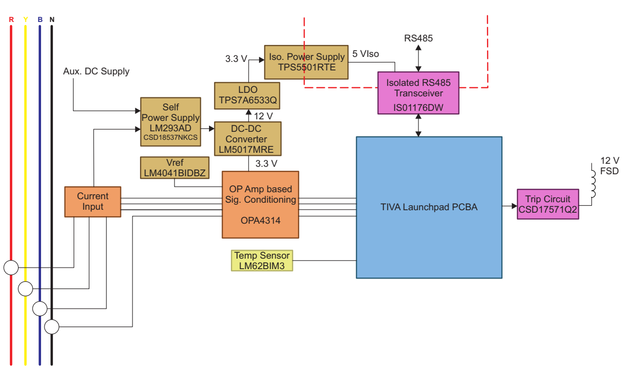
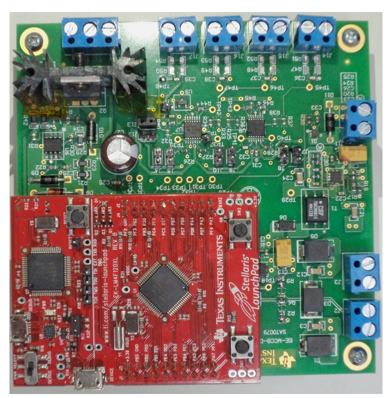
Design Features

- Ambient insensitivity from –10°C to +70°C for global design and worldwide acceptance
- Better trip time repeatability
- Wide input DC-DC converter with undervoltage and overcurrent protection
- Self-Power (CT powered) supply with reduced CT loading and Power loss
- Robust design that prevents phase reversal in overdrive conditions and high electrostatic discharge (ESD) protection (4-kV HBM)
- Device operating temperature of –40°C to 125°C as required for MCCB/ACB

Featured Applications

- MCCB – Electronic trip unit (Electronic Release)
- ACB – Electronic trip unit (Electronic Release)
- Self-Powered Overcurrent, Earth fault, and numerical relays





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1 System Description

Molded Case Circuit Breakers (MCCB) - TI designs Electronic Trip Units (MCCB-ETUs) to react to the magnitude of the current flowing through the circuit breaker. These trip units are Current Sensor-Powered and require some minimum current to be operational. Electronic trip units use digital sampling to determine the RMS value of sinusoidal and nonsinusoidal currents.

Some of the advantages of ETUs are:

- Accurate sensing – pickup and trip timing
- Ambient insensitive from –10°C to 70 ºC
- Adjustable Ir (rated current) for continuous current settings
- Pick-up (A) accuracy ±10% and time-delay(s) accuracy 0 to –20%
- Fault Pickup Current input range for trip adjustable from 0.2 to 10 times Ir

To sense the current input, a low cost op amp is used for signal conditioning.

Some of the limitations of low-cost op amps are:

1. Higher DC output offset and low Rail-to-Rail output, therefore limiting the ADC range.
2. Pickup and trip timing characteristics vary over –10°C to +70°C
3. Suffer from phase reversal problems during short circuit protection resulting in pickup and trip timing repeatability issues
4. Higher input bias current causes loading on the input CT resulting in measurement nonlinearity.
5. TI places the trip units inside the breaker units, subjecting the trip units to higher electromagnetic interference, and requiring external filters.
6. Needs more testing during manufacturing

This reference design provides an analog front end amplifier solution that provides the following advantages:

1. Lower DC offset and improved Rail-to-Rail output voltage improves accuracy
2. Accurate and repeatable over –10°C to +70°C (Less variation in pickup and trip time)
3. Reduced loading on the current transformers due to lower input bias current
4. Does not have phase reversal effects during saturation conditions, resulting in improved repeatability
5. Better Electromagnetic Immunity (EMI)
6. The improvements listed from 1 to 5 also result in reduced manufacturing time, testing time, and improved yield

The MCCB Analog Front End Amplifier reference design is intended as an evaluation platform for easy evaluation of the MCCB - electronic trip characteristics. The following functionalities have been provided on the reference design:

- Current input measurement with two gain stages, based on OPA4314 precision amplifier
- TI MOSFET-based Self-Powered power supply
- DC-DC converter for FSD/Relay supply generation
- Isolated RS-485 communication
- Screw terminals for easy connection
- MCU interface for quick and easy evaluation

The complete design or parts of the design can be used in other Self-Powered or dual powered (Self-Powered or 24-V auxiliary input powered) applications like overcurrent, Earth fault and other protection relays.

The design files include PDF schematics, bill of materials (BOMs), PDF layer plots, Altium files, and Gerber Files.

2 Design Specification

2.1 Precision Op Amp with Low Supply Voltage (3.3 VDC)

Phase Inputs:

Two gains for R, Y, and B inputs. Output to the ADC is selectable with the jumper.

Neutral Inputs:

Single gain for neutral input directly connected to ADC input.

Rail-to-Rail operation

Low output DC offset voltage < 10 mV with high gain.

Note:

Users can configure the required gains for evaluation.

MCCB-ETUs provide burden resistors for CT inputs.

2.2 Power Supply

Power supplies generated:	> 12 VDC for FSD/relay drive ~16 VDC for comparator supply 3.3 VDC for op amp, reference and temperature sensor
Self-Power supply regulation:	39 VDC ±5%
Input supply range for auxiliary input:	20 VDC to 35 VDC

2.3 Measurement Reference (1.65 VDC with ±0.25%)

Engineers can select the reference for input current between 0 V and VCC/2, using jumpers. VCC/2 is generated using precision reference and buffered using op amp. The reference selected is 1.65 V with 0.1% tolerance. Expect a maximum output error less than ±0.25%.

2.4 Temp Sensor

Temp sensor has a 0°C to +90°C temperature range while operating from a single +3.3-V supply with an accuracy of ±3.0°C at 25°C.

2.5 MOSFET Switch

MOSFET switch contains control for FSD/Relay outputs. Additionally, the MOSFET switch can be used for zone selective output (ZSO), thermal memory, and LED indication.

2.6 Communication

The interface provided is an isolated RS-485 communication interface to implement Modbus protocol. The design provides an option to mount failsafe and termination resistors.

2.7 EMI Filter

Integrated RF/EMI rejection filter for improved performance.

2.8 MCU Interface

The current inputs and the temperature inputs interface to Tiva C Series 32-bit MCU. The MCU has an internal 12-bit SAR ADC with multiplexed inputs.

3 Block Diagram

The MCCB-ETU analog front end reference design has the following blocks:

1. Op amp, EMI filters, reference, temperature sensor and current input
2. Self-Power supply
3. Isolated RS-485 interface
4. Relay/FSD control
5. Tiva C series LaunchPad interface

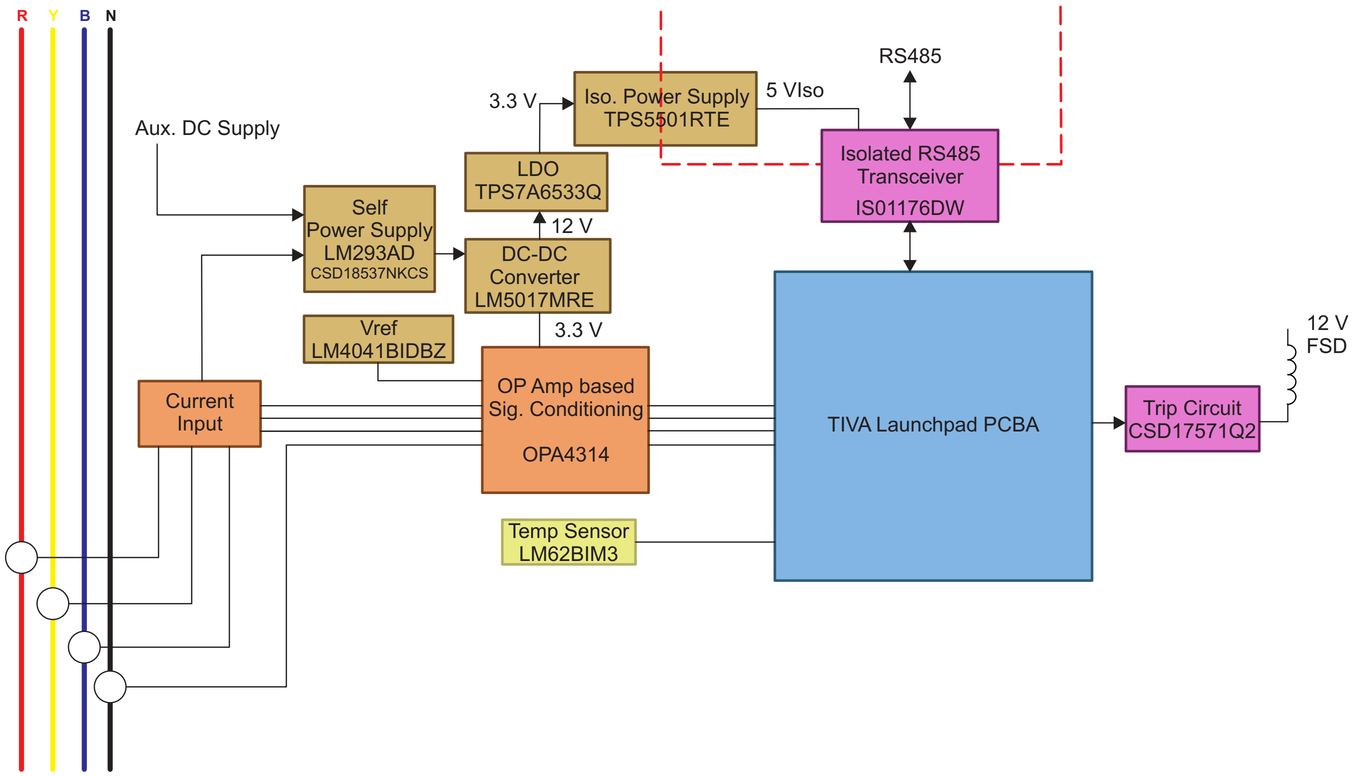


Figure 1. Block Level Diagram

3.1 *Op Amp*

Precision amplifiers amplify the current inputs connected across the burden resistors. Three phase input op-amp sections provide two gains for three phase current inputs and one section with single gain provides Neutral current input. A stable reference with high accuracy is provided for accurate measurement over wide temperature. Screw type terminals are provided to connect CT input. A high accuracy temperature sensor is provided.

3.2 *Self-Power Supply*

The Self-Power supply generates output voltage from the input currents. Three phase input currents generate the required power for the functioning of the electronics. Optionally the ETU can be powered by auxiliary 24-V DC input. The Self-Power output is converted to 12 V and 3.3 V for FSD/relay operation and MCU functioning using a DC-DC convertor and regulator electronics functioning using DC-DC convertors and regulators.

3.3 *Isolated RS-485 Interface*

This MCCBS analog front end amplifier design can also communicate the measured data to the supervisory system through the RS-485.

3.4 Relay/ FSD Control

A MOSFET-based switch provides for Relay/ FSD control. The 12-V supply controls the relay. The output of the DC-DC converter can be adjusted to 15 V or 18 V with programmable resistors. The same MOSFET switch can be used in other applications like ZSO, thermal memory, and LED indication in MCCB.

3.5 Tiva C Series LaunchPad Interface

This reference design uses the Tiva C Series 32-bit CPU LaunchPad for measurement and transfer of the data to PC based GUI by USB interface. The op-amp outputs connect to the 12-bit ADC of TM4C123G.

4 Circuit Design and Component Selection

Table 1 contains a comparison of different op amps with critical characteristics.

Table 1. Comparison of Different Op Amps with Critical Characteristics

Characteristics	Application's Requirement	OPA4314	LMV324	LMV824-N
Iq Total (Max) (mA)	Low	0.720	0.680	1.2 mA
Number of Channels	4	4	4	4
Rail-to-Rail	VCC	In/Out	Out	Out
Operating Temperature Range (C) (Package dependent exception exist)	–40°C to 125°C	–40°C to 125°C	–40°C to 125°C	–40°C to 125°C
Vos (Offset Voltage at 25°C) (Max) (mV)	Min offset	2.5	7	3.5
Offset Drift (Typ) (µV/C)	Min offset drift	1	5	1
Vn at 1 kHz (Typ) (nV/rtHz)	Min noise	14	39	28
CMRR (Min) (dB)/PSRR	Max	94/92	50/50	90/85
IBias (Max) (pA)	Min	10	250000	150
Total Supply Voltage (Max) (+5 V = 5, ±5 V = 10)	3.3	5.5	5.5	5.5
Total Supply Voltage (Min) (+5 V = 5, ±5 V = 10)	2.7	1.8	2.7	2.5
Slew Rate (Typ) (V/µs)	> 1	1.5	1	1.4
GBW (Typ) (MHz)	>1	3	1	5
Pin/Package	14 TSSOP or SOIC	14TSSOP	14SOIC,14TSSOP	14SOIC,14TSSOP
ESD-Human model- kV	High	4	2	2
EMI filter	Integrated	Internal	No	No
Vo (Swing)	Rail-to-Rail	Vcc – 60 mV	Vcc – 400 mV	Vcc – 100 mV
Vcm (Input)	Rail-to-Rail	V–(–0.2 V) , V+ (+0.2 V)	V–(–0.2 V) , 1.9 V	V–(–0.2 V) , 1.9 V
Phase reversal during input overdrive	No reversal	No	TBD	TBD

With the comparison shown in Table 1, OPA4314 offers the most optimal cost versus performance for the MCCB-ETU.

4.1 Op Amp with Internal EMI Filter and Reference

This reference design uses OPA4314. The quad channel OPA4314 is offered in a TSSOP-14 package. The robust design of the OPA314 devices provides unity-gain stability with capacitive loads of up to 300 pF, an integrated RF/EMI rejection filter, no phase reversal in overdrive conditions, and high electrostatic discharge (ESD) protection (4-kV HBM).

Some of the critical features are:

- Wide supply range: 1.8 V to 5.5 V
- Low noise: 14 nV/MHz at 1 kHz
- Gain bandwidth: 3 MHz
- Low input bias current: 0.2 pA
- Low offset voltage: 0.5 mV
- Unity-gain stable
- Internal RF/EMI filter
- Extended temperature range: –40°C to +125°C

TI configures the op amp as a noninverting amplifier with two gains. The engineer configures the gains with gain resistors. The op amp can take AC input and rectified half wave input. The input is configured with the jumper setting shown in Figure 2 and is explained in Table 2.

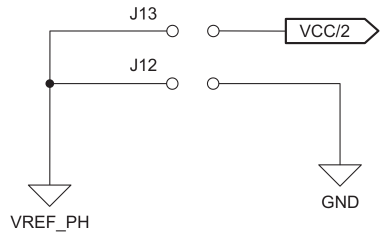


Figure 2. OPA4314 Input Jumper Configuration

Table 2. Input Jumper Configuration for OPA4314

Jumper J13 is mounted	Op amp accepts AC input
Jumper J12 is mounted	Op amp accepts rectified input

1. The neutral input is always configured for AC input.
2. Do not mount both the jumpers together.
3. During DC offset measurement ensure that the Phase inputs and neutral inputs are looped separately when the J12 is mounted.

The OPA4314 operational amplifier family incorporates an internal input low-pass filter that reduces the amplifier response to EMI. This filter provides both common-mode and differential mode filtering. The filter design has a cutoff frequency of approximately 80 MHz (–3 dB), with a roll-off of 20 dB per decade.

The reference design has LM4041-N/LM4041-N-Q1 precision micro power shunt voltage reference for providing the level shifting when the PGA is configured for AC input.

Key Specifications (LM4041-N/LM4041-N-Q1 1.2) include:

- 0.1% output voltage tolerance
- 20-µV RMS output noise
- Low temperature coefficient of < 100 PPM/°C

Using the reference design parameters from the previous list along with the op amp guarantees the trip accuracy over a wide temperature range.

A temperature sensor is provided for thermal overload trip and gain compensation functions, as required. The temperature sensor is rated for 0°C to +90°C range.

4.2 Self-Power Supply

4.2.1 Current Inputs

Figure 3 shows the current input schematics.

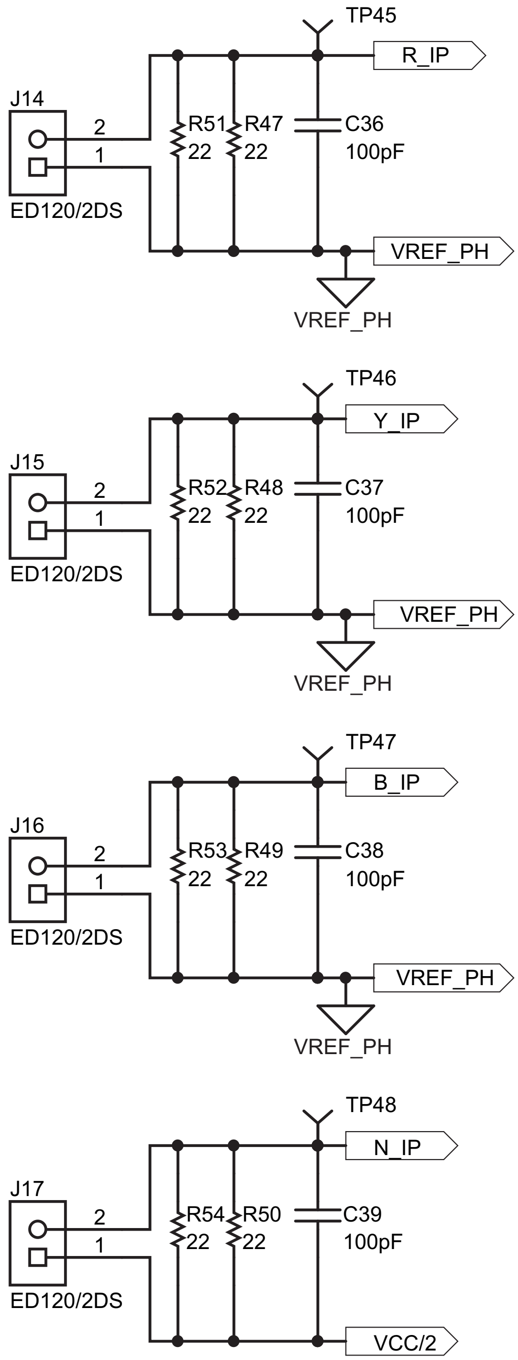


Figure 3. Current Inputs

The board provides the ability to connect up to 4 current inputs. The current input can be AC or half-wave rectified input. The design includes the ability to mount two 22R burdens. The reference design includes a screw type terminal to connect the current input. Based on the secondary current and transformer performance, the design engineer can change the burden resistor. A Rogowski coil cannot be connected directly and the output from the integrator has to be applied at the current inputs. When the integrator output is applied, burden resistors must be made as do not populate.

> **CAUTION**
>
> Do not leave the current terminal open and apply current during testing.
>
> Ensure the current inputs are connected and the terminal screws are tightened before applying current for testing.

Figure 4 illustrates the self-power supply schematic.

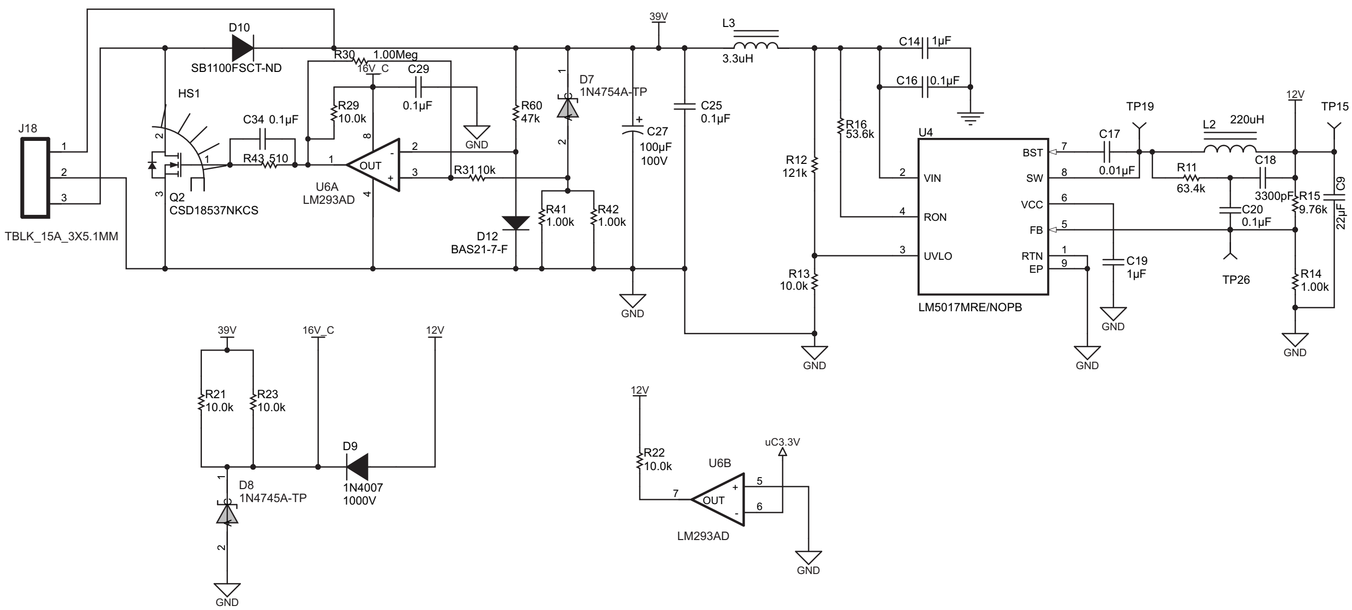


Figure 4. Self-Power Supply

The Self-Power section has provision for two inputs:

1. Half-wave rectified current inputs
2. Auxiliary DC voltage inputs

TI configures the Self-Power regulator to regulate the voltage at 39 V. The MCCB-ETU uses TI MOSFETs to shunt the current above 39 V. Increased regulation voltage reduces power dissipation and facilitates usage of lower VA current transformer. TI has a wide range of MOSFETs that can be selected for current shunting based on the application and the configured regulation voltage.

The Self-Power supply generates output voltage from the input currents. The input to the self-power generation circuit is half-wave rectified output from current transformers. The design engineer must connect the rectifier diodes externally. Optionally, power the ETU by auxiliary 24-V input. The Zener diode reference regulates the self-power to 39 V. If the output voltage exceeds 39 V, the comparator switches the MOSFET on and the MOSFET shunts the input current. When the output voltage reduces, the comparator switches the MOSFET off and the input current charges the output capacitor. The 39-V Self-Power output is converted to 12 V and 3.3 V for FSD/relay operation and electronic circuit functioning using DC-DC convertors and LDO. **The advantage of the self-power circuit is to reduce CT loading.** The critical component in the Self-Power circuit is the shunt regulation MOSFET. A wide range of MOSFETs are available and are listed in Table 3.

Table 3. TI MOSFETs with Current Shunting

Product Description	Product Link
60-V, N-Channel NexFET™ Power MOSFET	CSD18537NKCS
60-V, N-Channel NexFET Power MOSFET	CSD18534KCS
80-V, N-Channel NexFET Power MOSFET	CSD19506KCS
80-V, 7.6-mΩ, N-Channel TO-220 NexFET Power MOSFET	CSD19503KCS
100-V, N-Channel NexFET Power MOSFET	CSD19535KCS
100-V, 6.4-mΩ, TO-220 NexFET Power MOSFET	CSD19531KCS

The graph in Figure 5 indicates the power loss in a typical Self-Power supply.

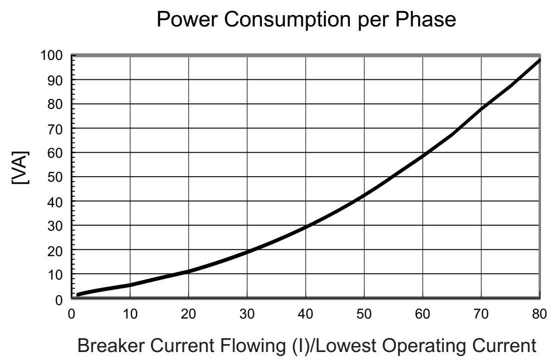


Figure 5. Typical Power Consumption for Current/Lowest Operating Current

CAUTION

Do not leave the current terminal open and apply current for testing.

Ensure the current inputs are connected and the terminal screws are tightened before applying current for testing.

By using LM5017, the clamping voltage can be increased as the device input is rated up to 100 V. The MCCB-ETU analog front end reference design details shunt clamping, with LM5017 configured in nonisolated output configuration.

4.3 Isolated RS-485 Communication Interface

The reference design provides an EMC-compliant isolated 1-Mbps, 3.3 V to 5 V RS-485 interface using an ISO1176 transceiver and the TPS55010. This board provides signal and power isolation with reduced board space and power consumption. The TPS55010 has a higher efficiency and better regulation accuracy since its Fly-Buck™ topology uses primary side feedback that provides excellent regulation over line and load. The TPS55010 provides 3.3 V to 5 V and isolation levels using off-the-shelf Fly-Buck transformers. The transformer chosen here for the design has a 475-µH primary inductance and a dielectric strength of 2500 VAC. The ISO1176 transceiver is an ideal device for long transmission lines since the ground loop is broken to provide for operation with a much larger common mode voltage range. The symmetrical isolation barrier provides 2500 VRMS of isolation between the line transceiver and the logic level interface. The RS-485 bus is available on screw type terminals and connectors.

The RS-485 bus provides an external failsafe biasing that uses external resistor biasing to ensure failsafe operation during an idle bus. If none of the drivers connected to the bus are active, the differential voltage (VAB) approaches zero or in between ±250 mV, allowing the receivers to assume random output states. To force the receiver outputs into a defined state, the design introduces failsafe biasing resistors with terminating resistors of 120 Ω. The RS-485 bus is also protected against EFT, ESD, and surges with the help of transient voltage suppressor diodes (SMCJ15CA, 1500-W series).

4.4 FSD/Relay Control

TI has a wide range of MOSFETs that can be used for driving Relay, FSD, ZS0, or LEDs. TI provides a wide range of MOSFETs with a tiny SON2x2 package. CSD17571Q2 is installed in the reference design.

Table 4. TI MOSFETs for Driving Relay, FSD, ZS0, or LEDs

Product Description	Product Link
30-V, N-Channel NexFET Power MOSFETs	CSD17571Q2
N-Channel Power MOSFET, CSD13202Q2, 12-V VDS, 9.3 mΩ, $R_{DS(on)}$ 4.5 (max)	CSD13202Q2
20-V, N-Channel NexFET Power MOSFET	CSD15571Q2
Automotive 30-V, N-Channel NexFET Power MOSFET	CSD17313Q2Q1
30-V, N-Channel NexFET Power MOSFET	CSD17313Q2
N-Channel, NexFET Power MOSFET	CSD16301Q2

4.5 Tiva C Series LaunchPad Interface

The Tiva™ C Series LaunchPad (EK-TM4C123GXL) is a low-cost evaluation platform for ARM® Cortex™ M4F-based microcontrollers. The Tiva C Series LaunchPad design highlights the TM4C123GH6PMI microcontroller USB 2.0 device interface, hibernation module, and motion control pulse-width modulator (MC PWM) module. The Tiva C Series LaunchPad also features programmable user buttons and an RGB LED for custom applications. The stackable headers of the Tiva C Series LaunchPad BoosterPack XL interface demonstrate how easy it is to expand the functionality of the Tiva C Series LaunchPad when interfacing to other peripherals on many existing BoosterPack add-on boards as well as future products. Figure 6 shows a photo of the Tiva C Series LaunchPad.

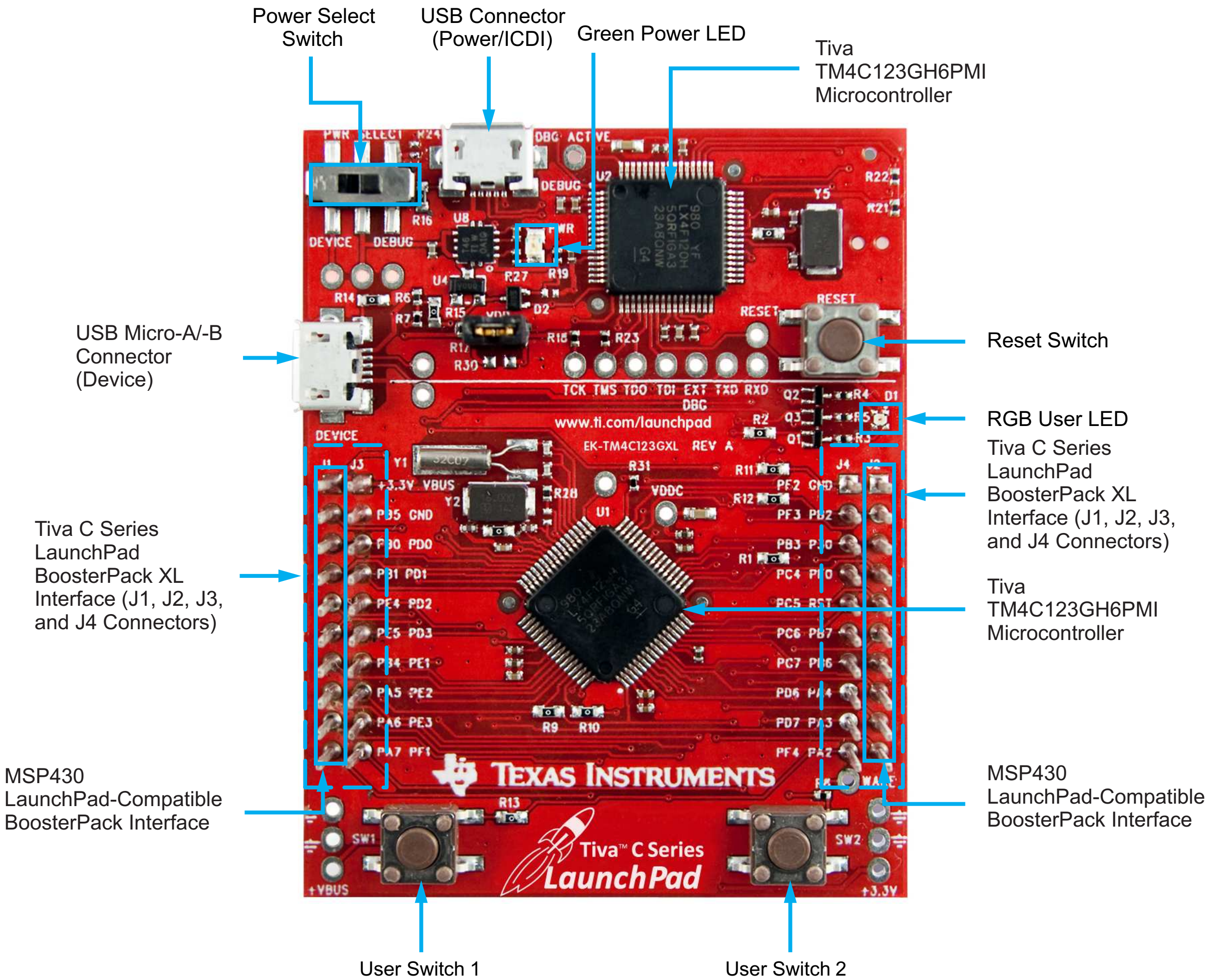


Figure 6. Tiva C Series LaunchPad

For details, refer to EK-TM4C123GXL.

Care must be taken while aligning the Tiva C Series LaunchPad with the reference design board.

Table 5. Mapping Tiva C Series LaunchPad and Reference Design Connectors

Tiva C Series LaunchPad connector	Reference design connector
J1,J3	J1
J4,J2	J4

5 Test Results

This section contains descriptions of Self-Power supply rail, offset variation over temperature, accuracy testing results, and a summary of the test results.

5.1 Self-Power Supply Rail

Table 6 includes the self-power supply rail measured results.

Table 6. Self-Power Supply Rail Measured Results

Rails	Measured
39 V	39.8 V
16 V	16.12 V
12 V	12.2 V
3.3 V	3.301 V
Vref (VCC/2)	1.6554 V

5.2 Offset Variation Over Temperature

The offset voltage of an op amp increases with an increase in temperature. The offset voltage is measured by keeping the PCB in an oven and the temperature is varied, over time. The results are shown in Table 7.

Table 7. Offset Variation Over Temperature Op-Amp DC Offset Drift(1)(2)

Amplifier	Offset Drift at -10ºC (µV)	Expected Op-Amp Drift –µV (Without Resistor Drift)	Offset Drift at +55 ºC (µV)	Expected Op-Amp Drift –µV (Without Resistor Drift)
OPA4314-1	300	270	-300	231
OPA4314-1	200	270	-100	231
LMV324-1	1600	1350	-1200	1155
LMV324-1	1500	1350	-1600	1155

(1) Reference to 25ºC with 7.7 Gain
(2) The measured value is the total drift of the amplifier including op amp and the gain resistors.

5.3 Accuracy Testing

This section contains test results including the test setup, measurement for high and low gain, and a summary of the test results.

5.3.1 Test Setup

Figure 7 illustrates the TIDA-00128 test setup.

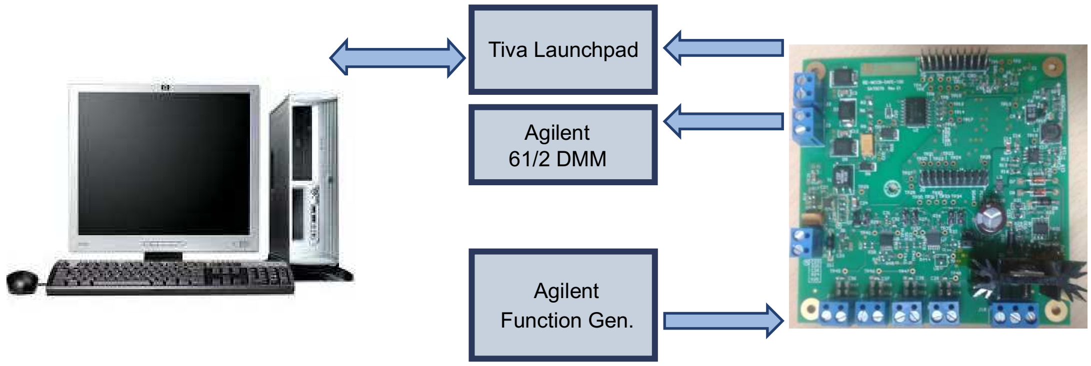


Figure 7. TIDA-00128 Test Setup

These test results are documented using the following parameters:

- The tests were performed with two different gains:
  - High Gain — for low level signals, gain is set at 7.7.
  - Low Gain — gain is reduced for higher current inputs so the op-amp output does not saturate, gain is set to 2.
- Input Signal Frequency: 50 Hz.

NOTE: All the voltages mentioned in Figure 8 through Figure 12 are Root Mean Square Values (RMS).

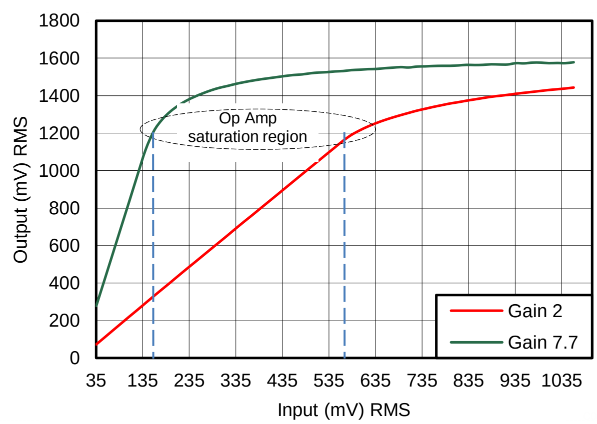


Figure 8. Saturation Level of Op-Amp Outputs for Gain 2 and Gain 7.7

5.3.2 Measurement for High Gain

The graphs in Figure 9 through Figure 10 show the results for the OPA4314 op amp designated as Op Amp1 and Op Amp2.

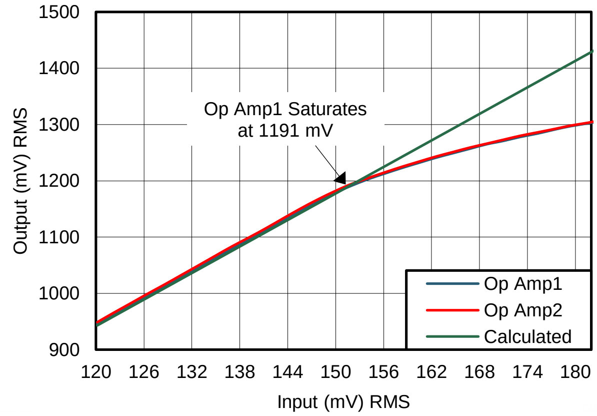


Figure 9. Saturation Level of Op-Amp Outputs (RMS)

Total error (RMS) due to ADC and op amp together is as plotted in Figure 10.

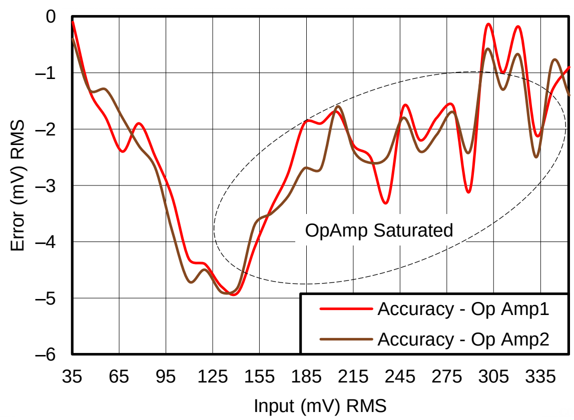


Figure 10. Total Error due to 12-bit Internal ADC and Op Amp

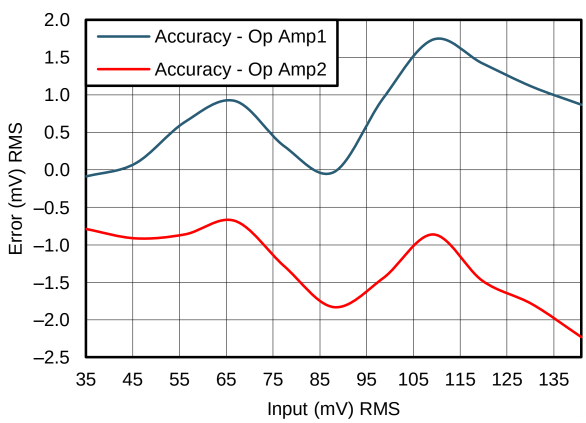


Figure 11. Error in mV RMS-Measured versus Theoretical Value

5.3.3 Measurement for Low Gain

Figure 12 through Figure 14 show the results for the op amps within OPA4314 designated as Op Amp1 and Op Amp2. These results are all obtained at a low gain: 2.

Graph over entire range (RMS) with respect to input as compared to the calculated (ideal) curve.

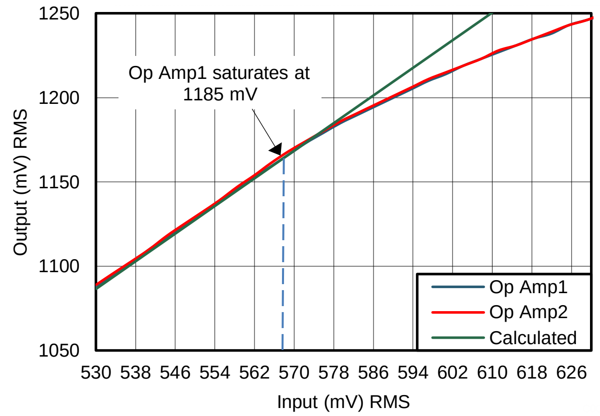


Figure 12. Saturation Level of Op Amp Output (RMS)

Total error (RMS) due to ADC and op amp together is as plotted in Figure 13.

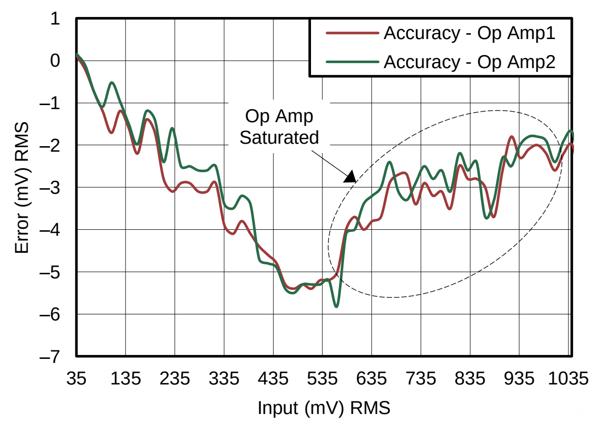


Figure 13. Total Error due to 12-bit Internal ADC and Op Amp

Figure 14 illustrates the accuracy (error in mV RMS) measured versus calculated value: for the input range before op amp saturates:

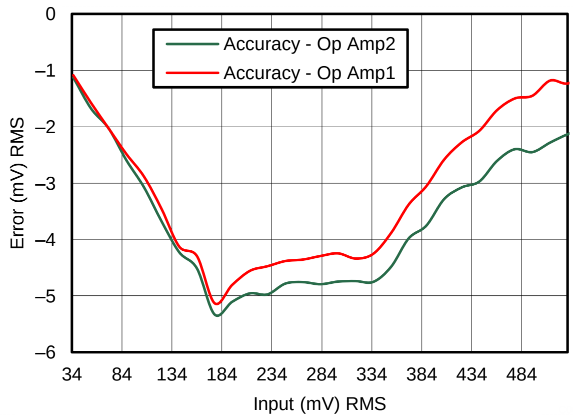


Figure 14. Error in mV RMS-Measured versus Theoretical Value

5.4 Results Summary

Table 8 presents a summary of accuracy and saturation level for the two op amps for different gain.

Table 8. Accuracy and Saturation Measurement Results Summary

	Accuracy (Error Before Op-Amp Saturation)		Saturation level	
	Gain 2	**Gain 7.7**	**Gain 2**	**Gain7.7**
Op Amp1	~5 mV RMS	~ +1.8 mV RMS	1184 mV RMS	1191 mV RMS
Op Amp2	~5 mV RMS	~ –2.0 mV RMS	1185 mV RMS	1194 mV RMS

6 Schematics

Figure 15 through Figure 21 represent the schematics for the high precision analog front end amplifier and peripherals for MCCB.

Figure 15. Schematics (1 of 7)

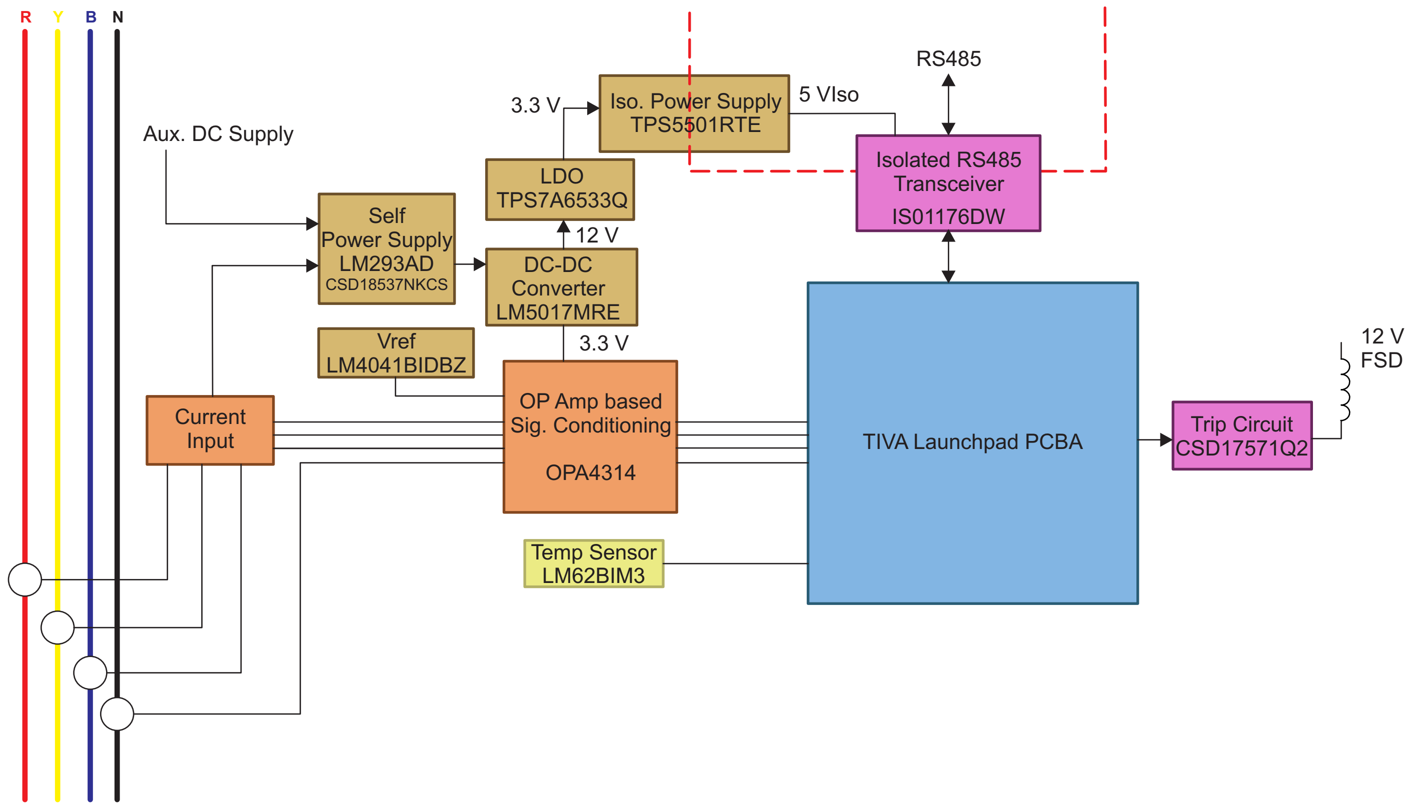


Figure 16. Schematics (2 of 7)

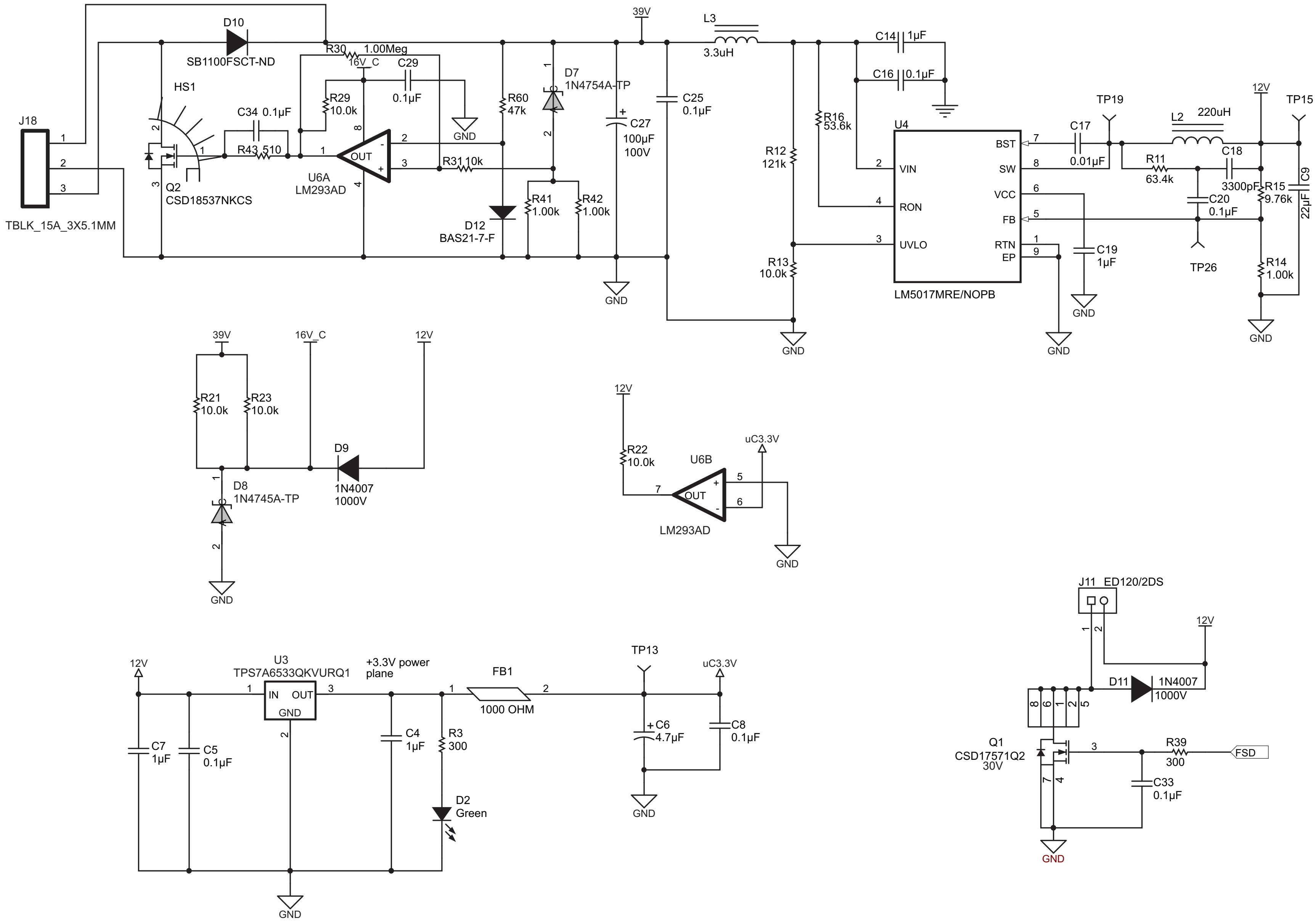


Figure 17. Schematics (3 of 7)

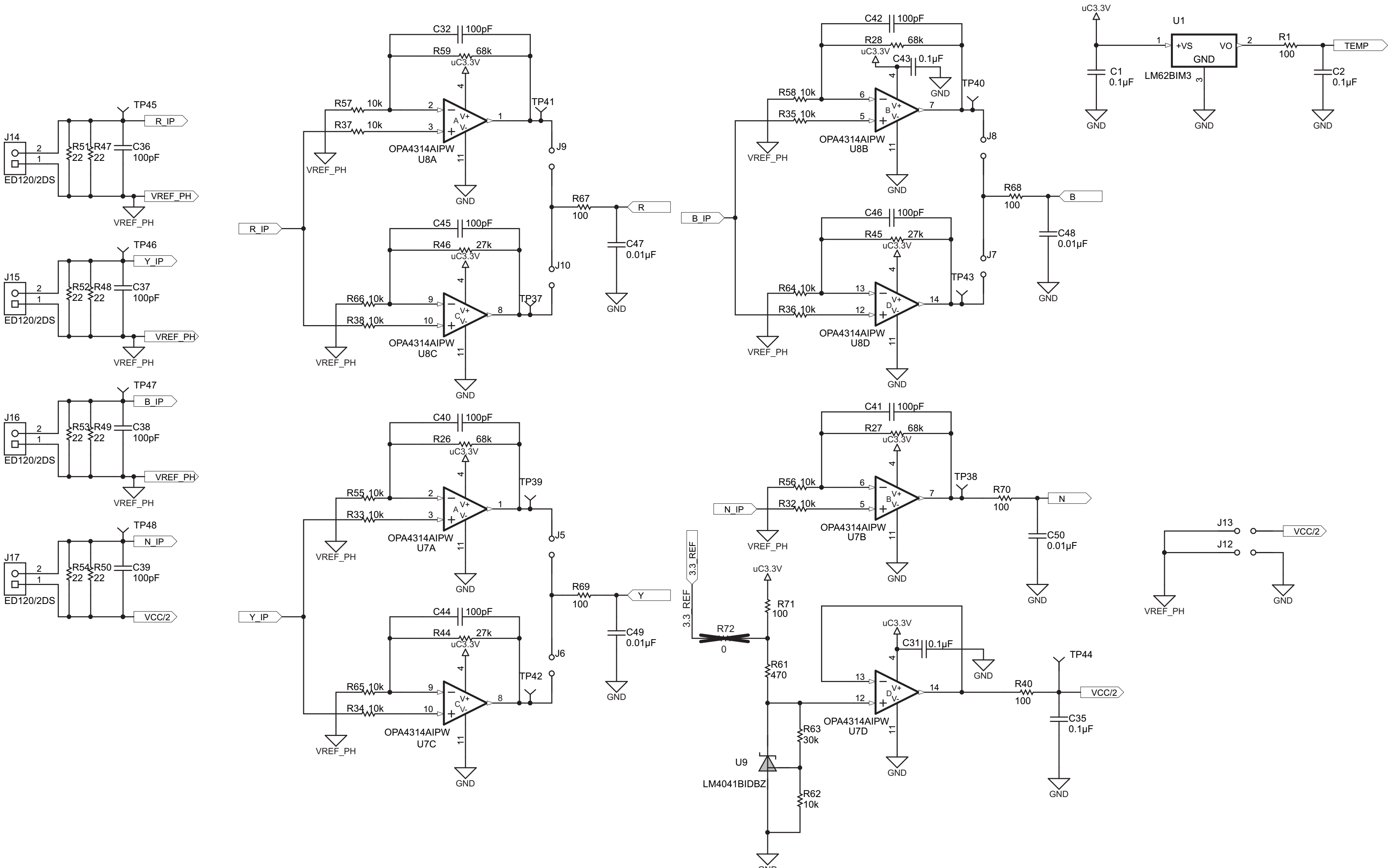


Figure 18. Schematics (4 of 7)

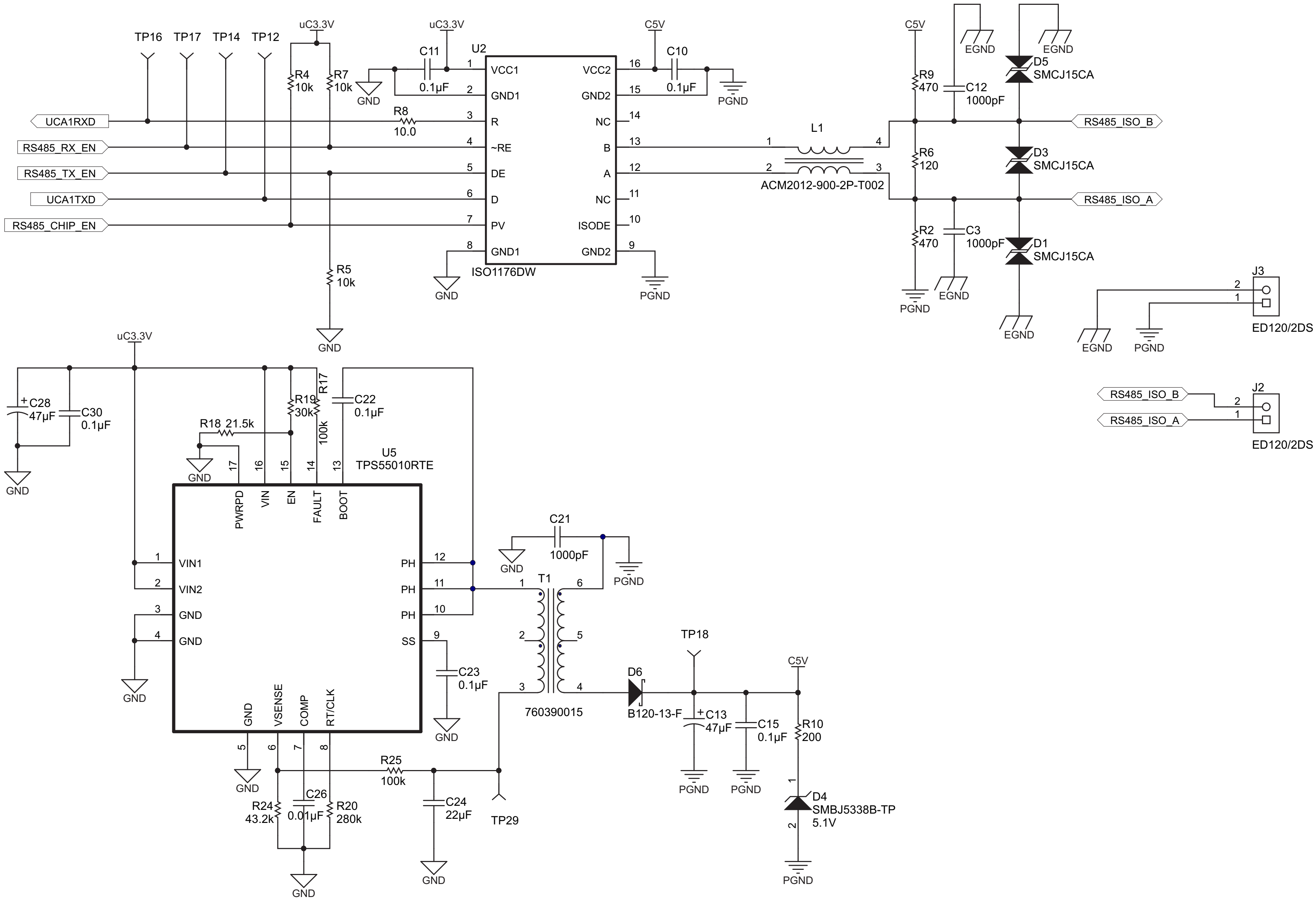


Figure 19. Schematics (5 of 7)

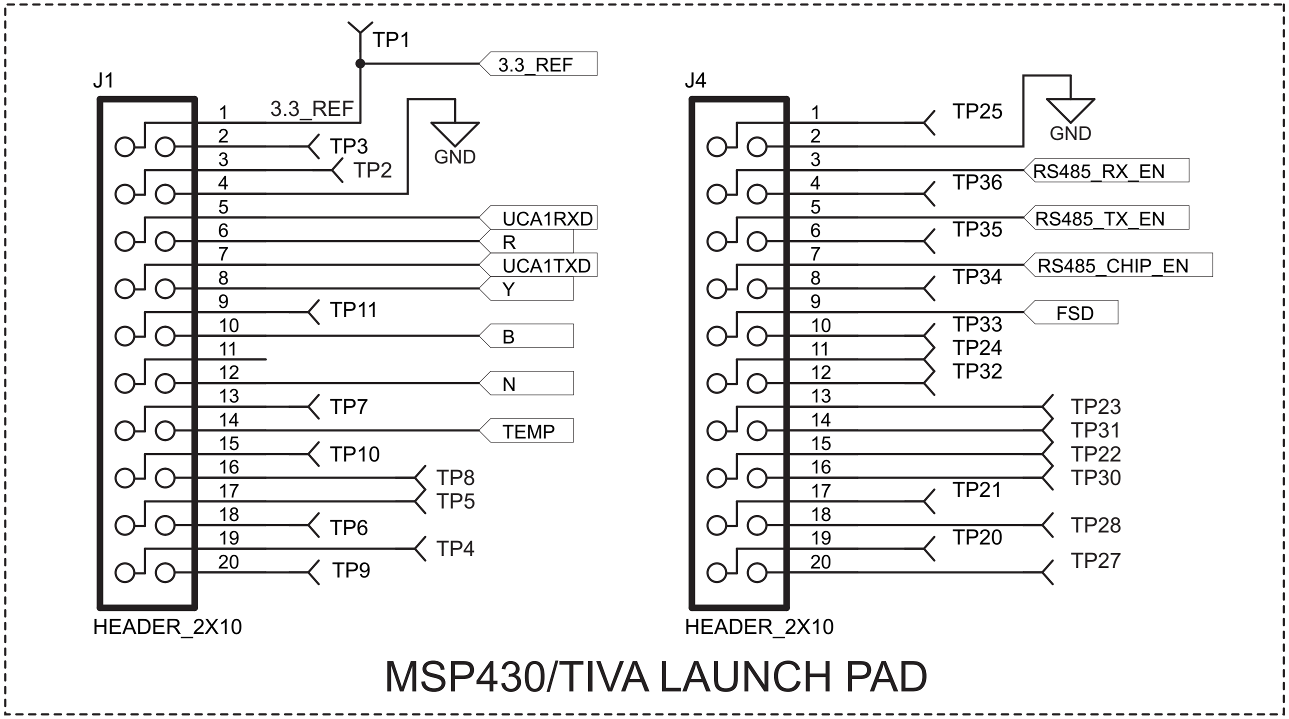


Figure 20. Schematics (6 of 7)

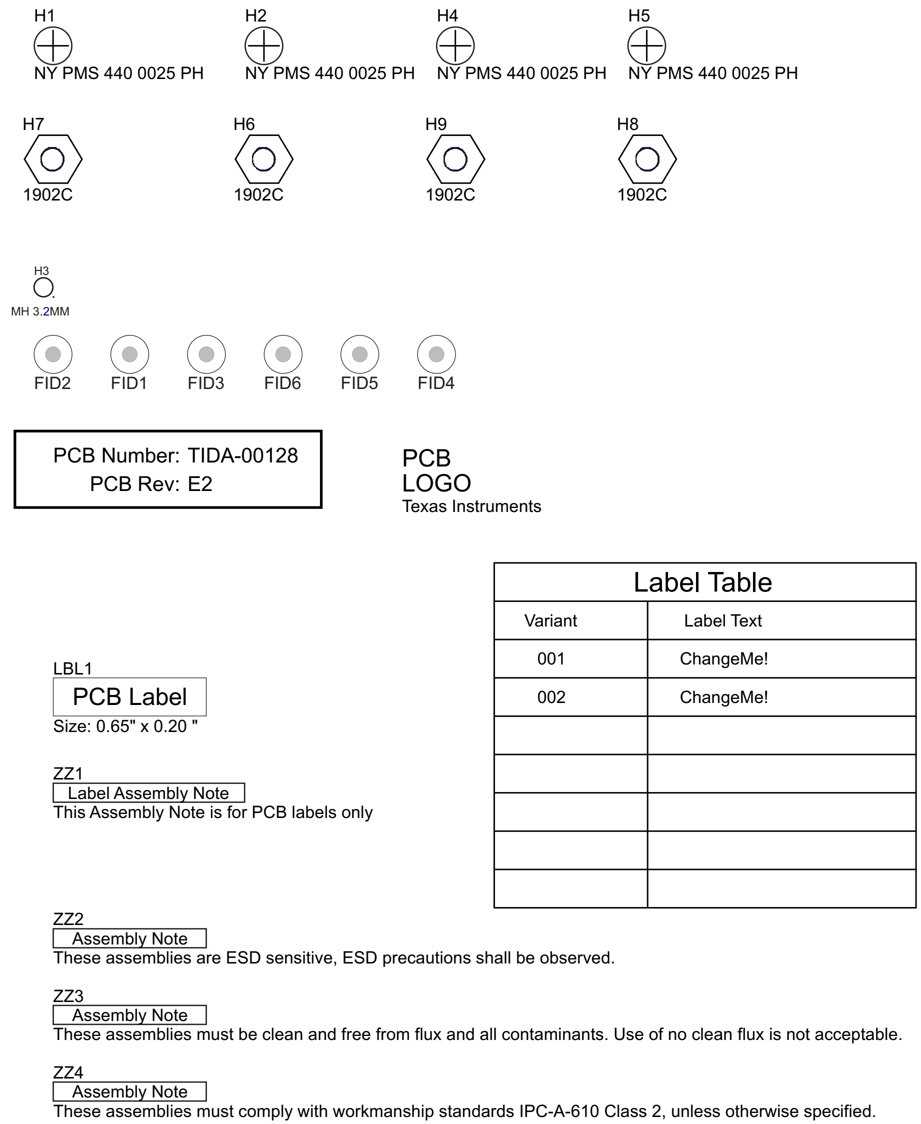


Figure 21. Schematics (7 of 7)

7 Bill of Materials

The BOM for the high precision analog front end amplifier and peripherals for MCCB is listed in Table 9.

Table 9. Bill of Materials

Fitted	Description	Designator	Manufacturer	Part Number	Quantity	RoHS	Package Reference
Fitted	Printed Circuit Board	!PCB1	Any	TIDA-00128	1	O	
Fitted	CAP, CERM, 0.1 µF, 25 V, ±5%, X7R, 0603	C1, C2, C10, C11, C15, C20, C22, C23, C30, C31, C33, C34, C35, C43	AVX	06033C104JAT2A	14	Y	0603
Fitted	CAP, CERM, 1000 pF, 1000 V, ±10%, X7R, 1206	C3, C12, C21	Yageo America	CC1206KKX7RCBB102	3	Y	1206
Fitted	CAP, CERM, 1 µF, 16 V, ±10%, X7R, 0603	C4, C7	TDK	C1608X7R1C105K	2	Y	0603
Fitted	CAP, CERM, 0.1 µF, 50 V, ±10%, X7R, 0603	C5, C8, C29	Kemet	C0603C104K5RACTU	3	Y	0603
Fitted	CAP, TA, 4.7 µF, 35 V, ±10%, 1.9 Ω, SMD	C6	Vishay-Sprague	293D475X9035C2TE3	1	Y	6032-28
Fitted	CAP, CERM, 22 µF, 16 V, ±10%, X5R, 1206	C9	MuRata	GRM31CR61C226KE15L	1	Y	1206
Fitted	CAP, TA, 47 µF, 35 V, ±10%, 0.3 Ω, SMD	C13, C28	Kemet	T495X476K035ATE300	2	Y	7343-43
Fitted	CAP, CERM, 1 µF, 100 V, ±10%, X7R, 1206	C14	MuRata	GRM31CR72A105KA01L	1	Y	1206
Fitted	CAP, CERM, 0.1 µF, 100 V, ±10%, X7R, 0805	C16, C25	Kemet	C0805C104K1RACTU	2	Y	0805
Fitted	CAP, CERM, 0.01 µF, 25 V, ±5%, C0G/NP0, 0603	C17, C26, C47, C48, C49, C50	TDK	C1608C0G1E103J	6	Y	0603
Fitted	CAP, CERM, 3300 pF, 50 V, ±10%, X7R, 0603	C18	Kemet	C0603C332K5RACTU	1	Y	0603
Fitted	CAP, CERM, 1 µF, 25 V, ±10%, X5R, 0603	C19	TDK	C1608X5R1E105K080AC	1	Y	0603
Fitted	CAP, CERM, 22 µF, 16 V, ±20%, X5R, 1206	C24	AVX	1206YD226MAT2A	1	Y	1206
Fitted	CAP, AL, 100 µF, 100 V, ±20%, 0.12 Ω, TH	C27	Rubycon	100YXJ100M10X20	1	Y	10 mm × 20 mm
Fitted	CAP, CERM, 100 pF, 25 V, ±10%, X7R, 0603	C32, C36, C37, C38, C39, C40, C41, C42, C44, C45, C46	AVX	06033C101KAT2A	11	Y	0603
Fitted	Diode, TVS 15 V 1500 W BIDIR 5% SMC	D1, D3, D5	Littelfuse Inc	SMCJ15CA	3	Y	SMC
Fitted	LED SmartLED Green 570NM	D2	OSRAM	LG L29K-G2J1-24-Z	1		0603
Fitted	Diode, Zener, 5.1 V, 5 W, SMB	D4	Micro Commercial Components	SMBJ5338B-TP	1	Y	SMB
Fitted	Diode, Schottky, 20 V, 1A, SMA	D6	Diodes Inc.	B120-13-F	1	Y	SMA
Fitted	Diode, Zener, 39 V, 1 W, DO41	D7	Micro Commercial Co	1N4754A-TP	1		DO-41
Fitted	Diode, Zener, 16 V, 1 W, DO41	D8	Micro Commercial Co	1N4745A-TP	1		DO-41
Fitted	Diode, P-N, 1000 V, 1A, TH	D9, D11	Fairchild Semiconductor	1N4007	2	Y	DO-41
Fitted	Diode, P-N, 1100 V, 1A, TH	D10	Fairchild Semiconductor	SB1100FSCT-ND	1	Y	DO-41
Fitted	Diode, Switching, 200 V, 0.2A, SOT-23	D12	Diodes Inc.	BAS21-7-F	1	Y	SOT-23
Fitted	FERRITE CHIP 1000 OHM 300MA 0603	FB1	TDK Corporation	MMZ1608B102C	1	Y	0603
Fitted	Fiducial mark. There is nothing to buy or mount.	FID1, FID2, FID3, FID4, FID5, FID6	N/A	N/A	6		Fiducial
Fitted	Machine Screw, Round, #4-40 × 1/4, Nylon, Philips panhead	H1, H2, H4, H5	B&F Fastener Supply	NY PMS 440 0025 PH	4	Y	Screw
Fitted	Mountin hole, NPTH Drill 3.2 mm	H3			1		
Fitted	Standoff, Hex, 0.5"L #4-40 Nylon	H6, H7, H8, H9	Keystone	1902C	4	Y	Standoff
Fitted	HEATSINK TO-220 W/PINS 1.5"TALL	HS1	Aavid Thermalloy	513102B02500G	1		1.500 × 1.375in.
Fitted	Header, Male 2 × 10-pin, 100mil spacing	J1, J4	Sullins	PEC10DAAN	2		0.100 inch × 10 × 2

Table 9. Bill of Materials (continued)

Fitted	Description	Designator	Manufacturer	Part Number	Quantity	RoHS	Package Reference
Fitted	TERMINAL BLOCK 5.08MM VERT 2POS, TH	J2, J3, J11, J14, J15, J16, J17	On-Shore Technology	ED120/2DS	7	Y	TERM_BLK, 2pos, 5.08 mm
Fitted	Header, Male 2-pin, 100mil spacing,	J5, J6, J7, J8, J9, J10, J12, J13	Sullins	PEC02SAAN	8		0.100 inch × 2
Fitted	Terminal Block, 3-pin, 15-A, 5.1 mm	J18	OST	ED120/3DS	1		0.60 × 0.35 inch
Fitted	Inductor, Common Mode Filter SMD	L1	TDK	ACM2012-900-2P-T002	1		2.00 mm × 1.20 mm
Fitted	Inductor, 220 µH .30A SMD	L2	Bourns	SRR7032-221M	1	Y	7×7 mm
Fitted	Inductor, Chip, 3.3 µH 770MA 1210 10%	L3	EPCOS Inc	B82422H1332K	1		1210
Fitted	Thermal Transfer Printable Labels, 0.650" W × 0.200" H - 10,000 per roll	LBL1	Brady	THT-14-423-10	1	Y	PCB Label 0.650"H × 0.200"W
Fitted	MOSFET, N-CH, 30 V, 22 A, SON 2×2 MM	Q1	Texas Instruments	CSD17571Q2	1	Y	DQK
Fitted	MOSFET, N-CH, 60 V, 50 A, TO-220AB	Q2	Texas Instruments	CSD18537NKCS	1	Y	TO-220AB
Fitted	RES, 100 Ω, 1%, 0.1 W, 0603	R1, R40, R67, R68, R69, R70, R71	Vishay-Dale	CRCW0603100RFKEA	7	Y	0603
Fitted	RES, 470 Ω, 1%, 0.125 W, 0805	R2, R9	Vishay-Dale	CRCW0805470RFKEA	2	Y	0805
Fitted	RES, 300 Ω, 5%, 0.1 W, 0603	R3, R39	Vishay-Dale	CRCW0603300RJNEA	2	Y	0603
Fitted	RES, 10 kΩ, 5%, 0.1 W, 0603	R4, R5, R7	Vishay-Dale	CRCW060310K0JNEA	3	Y	0603
Fitted	RES, 120 Ω, 5%, 0.125 W, 0805	R6	Vishay-Dale	CRCW0805120RJNEA	1	Y	0805
Fitted	RES, 10.0 Ω, 1%, 0.1 W, 0603	R8	Vishay-Dale	CRCW060310R0FKEA	1	Y	0603
Fitted	RES, 200 Ω, 1%, 0.1 W, 0603	R10	Vishay-Dale	CRCW0603200RFKEA	1	Y	0603
Fitted	RES, 63.4 kΩ, 1%, 0.1 W, 0603	R11	Vishay-Dale	CRCW060363K4FKEA	1	Y	0603
Fitted	RES, 121 kΩ, 0.1%, 0.125 W, 0805	R12	Yageo America	RT0805BRD07121KL	1	Y	0805
Fitted	RES, 10.0 kΩ, 1%, 0.1 W, 0603	R13, R22	Vishay-Dale	CRCW060310K0FKEA	2	Y	0603
Fitted	RES, 1.00 kΩ, 1%, 0.1 W, 0603	R14	Yageo America	RC0603FR-071KL	1	Y	0603
Fitted	RES, 9.76 kΩ, 1%, 0.1 W, 0603	R15	Vishay-Dale	CRCW06039K76FKEA	1	Y	0603
Fitted	RES, 53.6 kΩ, 0.1%, 0.125 W, 0805	R16	Susumu Co Ltd	RG2012P-5362-B-T5	1	Y	0805
Fitted	RES, 100 kΩ, 1%, 0.1 W, 0603	R17, R25	Vishay-Dale	CRCW0603100KFKEA	2	Y	0603
Fitted	RES, 21.5 kΩ, 1%, 0.1 W, 0603	R18	Vishay-Dale	CRCW060321K5FKEA	1	Y	0603
Fitted	RES, 30 kΩ, 5%, 0.1 W, 0603	R19, R63	Vishay-Dale	CRCW060330K0JNEA	2	Y	0603
Fitted	RES, 280 kΩ, 1%, 0.1 W, 0603	R20	Vishay-Dale	CRCW0603280KFKEA	1	Y	0603
Fitted	RES, 10.0 kΩ, 1%, 0.25 W, 1206	R21, R23, R29	Vishay-Dale	CRCW120610K0FKEA	3	Y	1206
Fitted	RES, 43.2 kΩ, 1%, 0.1 W, 0603	R24	Vishay-Dale	CRCW060343K2FKEA	1	Y	0603
Fitted	RES, 68 kΩ, 5%, 0.1 W, 0603	R26, R27, R28, R59	Vishay-Dale	CRCW060368K0JNEA	4	Y	0603
Fitted	RES, 1.00 MΩ, 1%, 0.1 W, 0603	R30	Vishay-Dale	CRCW06031M00FKEA	1	Y	0603
Fitted	RES, 10 kΩ, 0.01%, 0.063 W, 0603	R31, R32, R33, R34, R35, R36, R37, R38, R55, R56, R57, R58, R62, R64, R65, R66	Stackpole Electronics Inc	RNCF0603TKY10K0	16	Y	0603
Fitted	RES, 1.00 kΩ, 1%, 0.25 W, 1206	R41, R42	Vishay-Dale	CRCW12061K00FKEA	2	Y	1206
Fitted	RES, 510 Ω, 0.1%, 0.1 W, 0603	R43	Susumu Co Ltd	RG1608P-511-B-T5	1	Y	0603
Fitted	RES, 27 kΩ, 5%, 0.1 W, 0603	R44, R45, R46	Yageo America	RC0603JR-0727KL	3	Y	0603
Fitted	RES, 22 Ω, 5%, 0.25 W, 1206	R47, R48, R49, R50, R51, R52, R53, R54	Vishay-Dale	CRCW120622R0JNEA	8	Y	1206
Fitted	RES, 47 kΩ, 5%, 0.125 W, 0805	R60	Panasonic	ERJ-6GEYJ473V	1	Y	0805
Fitted	RES, 470 Ω, 5%, 0.1 W, 0603	R61	Vishay-Dale	CRCW0603470RJNEA	1	Y	0603

Table 9. Bill of Materials (continued)

Fitted	Description	Designator	Manufacturer	Part Number	Quantity	RoHS	Package Reference
Fitted	Transformer 475 µH SMD	T1	Wurth Electronics Midcom	760390015	1	Y	10.05 mm L × 6.73 mm W
Fitted	Test Point, O.040 Hole	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12, TP13, TP14, TP15, TP16, TP17, TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP25, TP26, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP36, TP37, TP38, TP39, TP40, TP41, TP42, TP43, TP44, TP45, TP46, TP47, TP48	STD	STD	48		
Fitted	2.7 V, 15.6 mV/°C, Temperature Sensor, 3-pin SOT-23	U1	National Semiconductor	LM62BIM3	1	N	MF03A
Fitted	IC, ISOLATED RS-485 PROFIBUS TRANSCEIVER	U2	TI	ISO1176DW	1		SO-16
Fitted	IC, 300-mA 40-V LOW-DROPOUT REGULATOR WITH 25-uA QUIESCENT CURRENT	U3	TI	TPS7A6533QKVURQ1	1		PFM
Fitted	100 V, 600mA Constant On-Time Synchronous Buck Regulator, DDA0008B	U4	Texas Instruments	LM5017MRE/NOPB	1	Y	DDA0008B
Fitted	IC, DC-DC Converter	U5	TI	TPS55010RTE	1		QFN-16
Fitted	IC, Dual Differential Comparators, 2-36 Vin	U6	TI	LM293AD	1		SO-8
Fitted	LOW-VOLTAGE RAIL-TO-RAIL OUTPUT OPERATIONAL AMPLIFIERS, PW0014A	U7, U8	Texas Instruments	OPA4314AIPW	2	Y	PW0014A
Fitted	IC, Micropower Shunt Voltage Reference 100 ppm/°C, 45 µA–12 mA, Adjustable	U9	TI	LM4041BIDBZ	1		SOT23
Not Fitted	RES, 0 Ω, 5%, 0.1W, 0603	R72	Vishay-Dale	CRCW06030000Z0EA	0	Y	0603

8 PCB Layout

This design is implemented in 2 layers PCB. For optimal performance of this design follow standard PCB layout guidelines: including providing decoupling capacitors close to all ICs and adequate power and ground connections with large copper pours. Additional considerations must be made for providing robust EMC and EMI immunity. All protection components should be placed as close to the output connectors as possible to provide a controlled return path for transient currents that does not cross sensitive components. For best performance, low impedance thick traces should be used along the protection circuits. Pour copper where ever possible.

8.1 Layout Recommendations

In order to achieve a high performance, the following layout guidelines are recommended:

1. Ensure that protection elements such as TVS diodes and capacitors are placed as close to connectors as possible.
2. Use large and wide traces to ensure a low-impedance path for high-energy transients.
3. Place the decoupling capacitors close to the supply pin of the IC.
4. Use multiple vias for power and ground for decoupling caps.
5. Place the reference capacitor close to the voltage reference.

9 Layout Prints

Figure 22 through Figure 29 illustrate the layout prints and some mechanical layout information for the high precision analog front end amplifier and peripherals for MCCB.

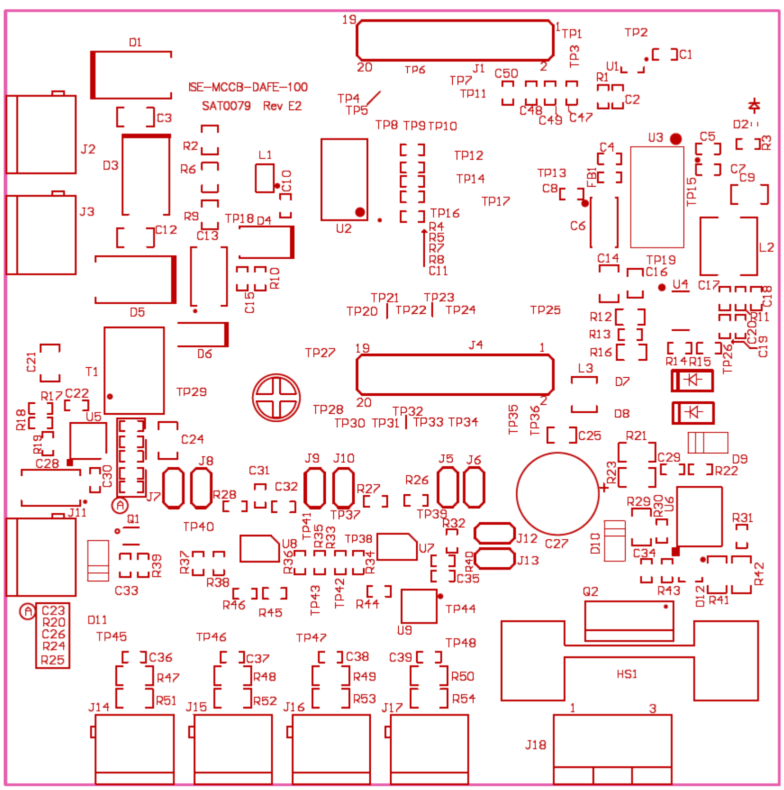


Figure 22. Top Silk Screen

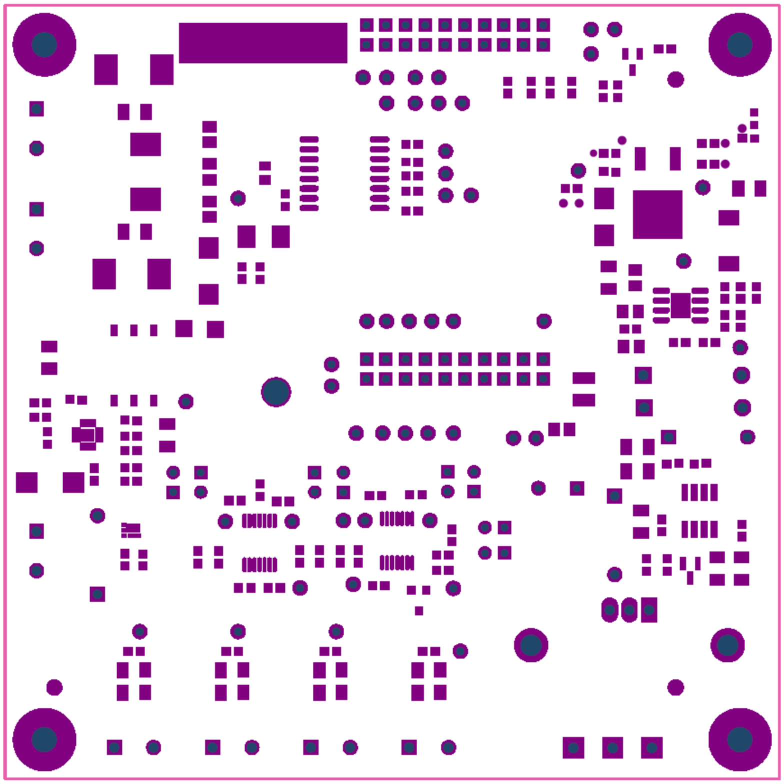


Figure 23. Top Solder Mask

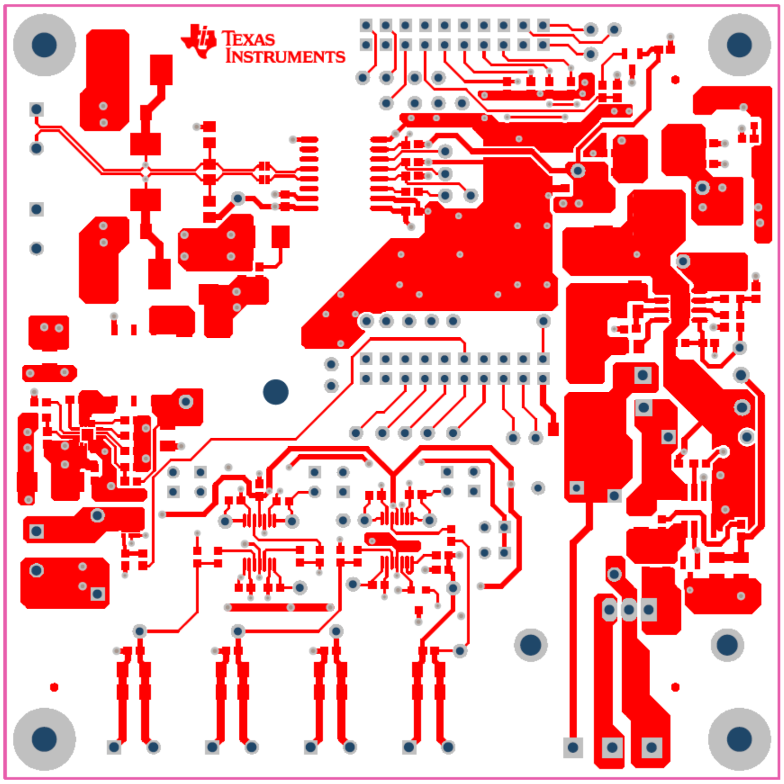


Figure 24. Top Layer

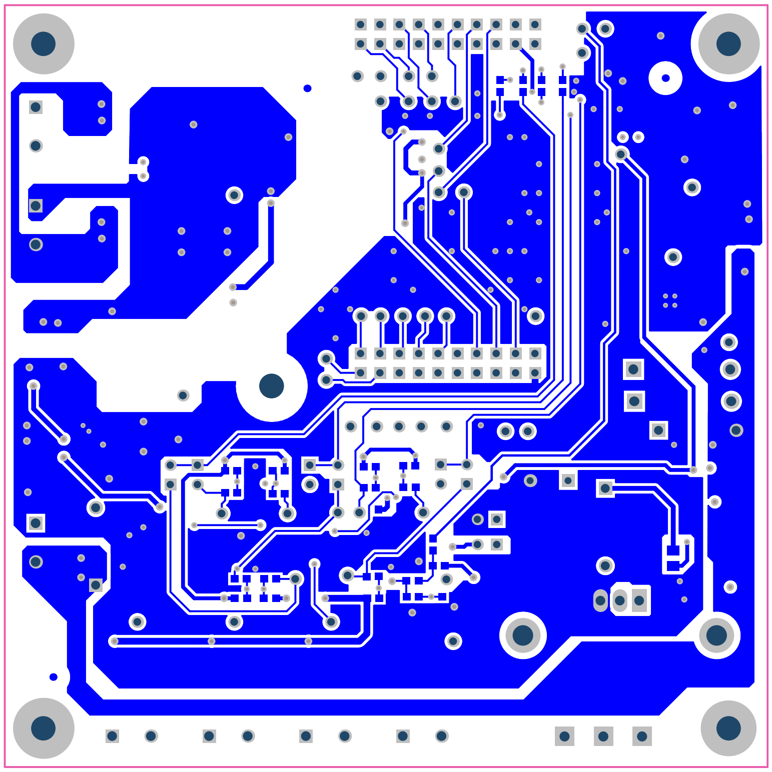


Figure 25. Bottom Layer

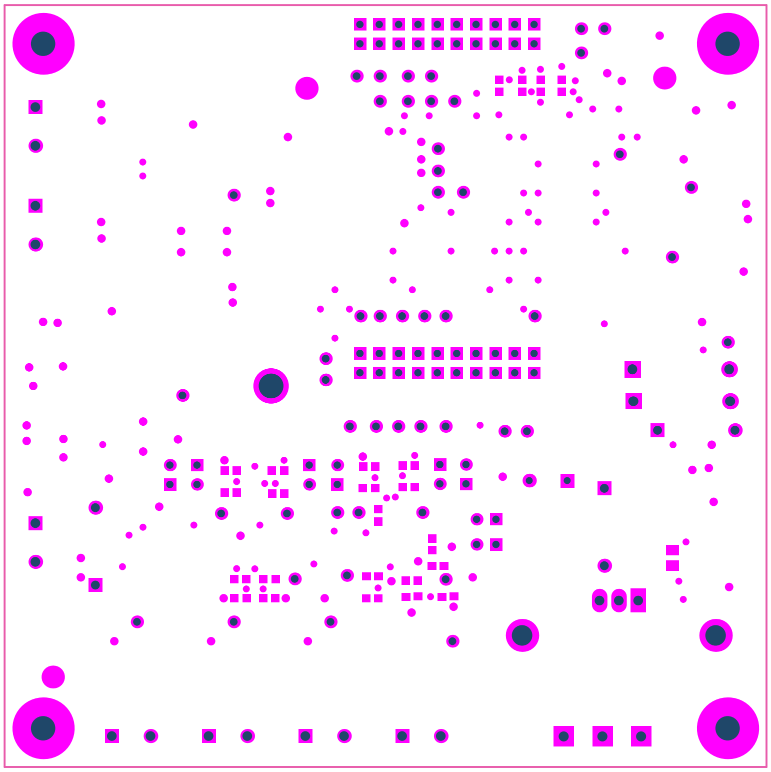


Figure 26. Bottom Solder Mask

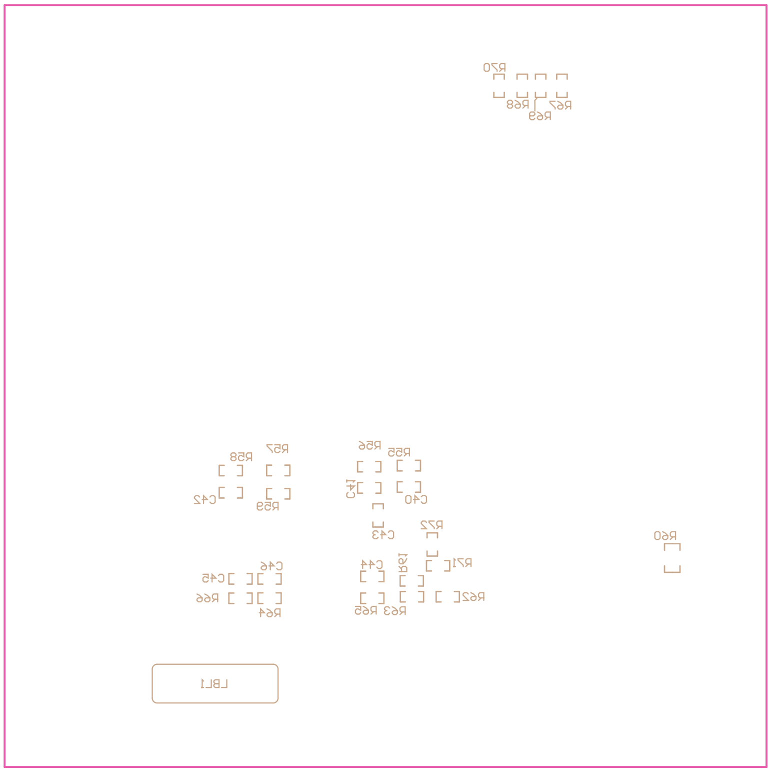
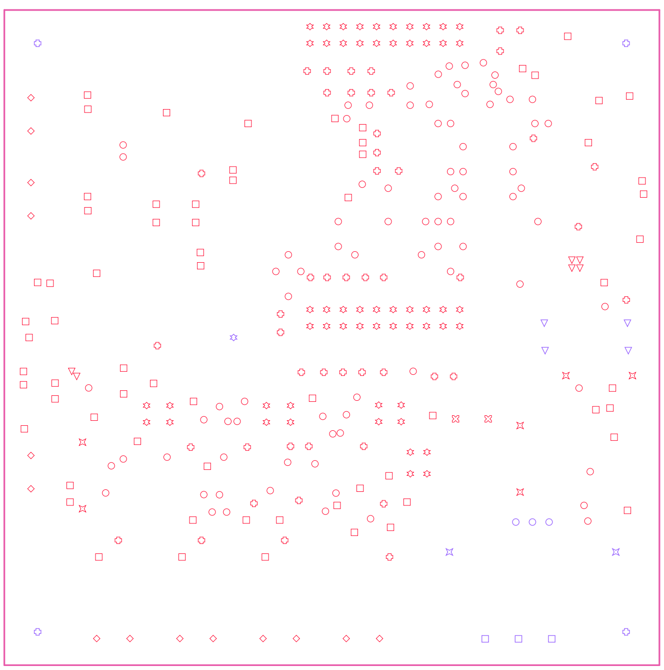


Figure 27. Bottom Silk Screen



Symbol	Hit Count	Tool Size	Plated	Hole Type
▽	6	12mil (0.305mm)	PTH	Round
○	85	16mil (0.406mm)	PTH	Round
□	68	20mil (0.508mm)	PTH	Round
⊠	2	36mil (0.914mm)	PTH	Round
✲	56	38mil (0.965mm)	PTH	Round
⬡	48	40mil (1.016mm)	PTH	Round
⌘	6	45.276mil (1.15mm)	PTH	Round
◇	14	49.213mil (1.25mm)	PTH	Round
○	3	50mil (1.27mm)	PTH	Round
▽	4	51mil (1.295mm)	PTH	Round
□	3	52mil (1.321mm)	PTH	Round
⌘	2	106.5mil (2.705mm)	PTH	Round
⬡	4	125.984mil (3.2mm)	PTH	Round
✡	1	128mil (3.251mm)	NPTH	Round
	302 Total			

Drill Table

DRILL TOLERANCES: FOR PTH +/-3MILS
FOR NPTH +/-2MILS

Figure 28. Drill Drawing

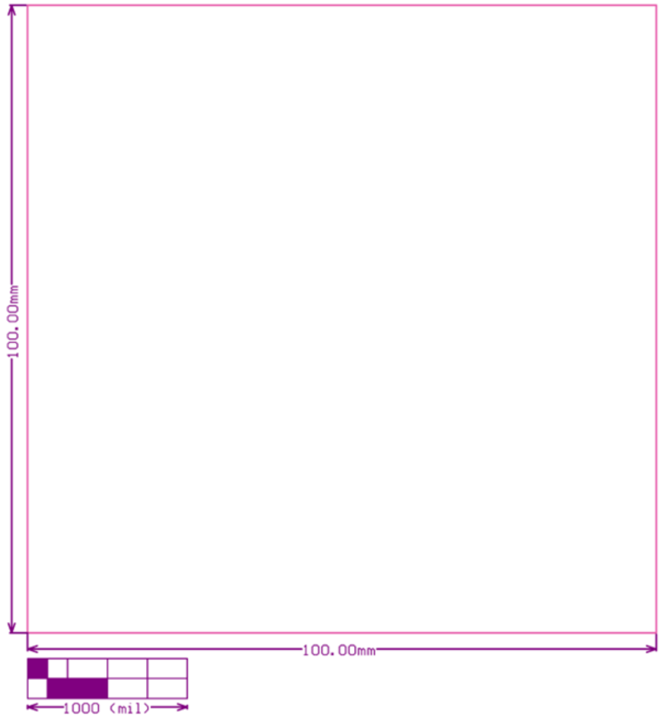


Figure 29. Mechanical Dimensions

10 Altium Project

To download the Altium Project files for the board, see the design files at: www.ti.com/tool/TIDA-00128.

11 Gerber files

To download the Gerber files for the board, see the design files at: www.ti.com/tool/TIDA-00128.

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