TI Designs
Self/Dual-Powered (Current or Auxiliary DC) Supply for MCCB/ACB/Protection Relay

TEXAS INSTRUMENTS

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Design Resources

TIDA-00229	Tool Folder Containing Design Files
LM5017	Product Folder
CSD18537NKCS	Product Folder
LM293	Product Folder
Tiva™ C Series LaunchPad	Product Folder

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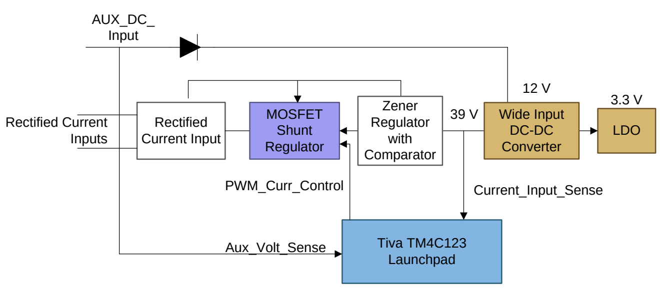
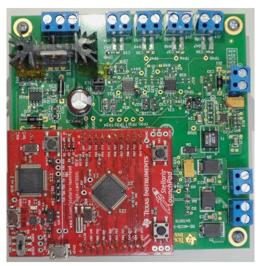
Design Features

- Dual-Powered from Current Circuits and/or Auxiliary DC Input Voltage
- MOSFET Based Output DC Voltage Shunt Regulator
- Wide Input DC-DC Converter to Generate Supply Rails
- Interface to Tiva Launchpad for Quick Evaluation
- Sensing of Auxiliary and Current Inputs

Featured Applications

- MCCB and ACB
- Dual and Self-Powered Protection Relays
- Electronic Overload Relay





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1 System Description

Molded Case Circuit Breaker (MCCB) with Electronic Trip Unit (ETU)

Electronic trip units are true RMS sensing-over-current trip devices, requiring no external supply for their basic functioning. Each MCCB-ETU (microprocessor-based) consists of current sensors, a processing unit, and a trip unit. The trip unit uses microprocessor-based technology to provide the adjustable time-current protection functions.

True RMS sensing circuit protection is achieved by analyzing the secondary current signals received from the circuit breaker current sensors, and initiating trip signals to the circuit-breaker trip actuators with predetermined trip levels and time delays.

Basic ETU Principles

- The current flowing in each phase is monitored by Current Transformer (CT).
- Each phase of the transformed current goes through full wave rectification in the rectifier circuit.
- The largest current is selected for protection.
- A delay circuit calculates the time delay based on the current measured.
- A trigger circuit outputs a trip signal to the trip coil for protection.

Salient ETU Features

- Error free and user friendly settings of current and time delay
- True RMS sensing with immunity to system disturbances
- Higher reliability and repetitive accuracy due to use of a microcontroller (MCU)
- Self-powered by a built-in current transformer
- Three-phase protection and Earth fault protection in the same unit
- LED and LCD indication for all tripping faults

Why to Use MCCB-ETUs

Electronic trip circuit breakers provide the same basic functions as standard thermal magnetic circuit breakers. However, electronic trip circuit breakers offer a variety of additional benefits:

- Provide adjustability for enhanced coordination.
- Provide integral ground fault protection or alarm.
- Measure and report inherent ground-fault leakage.
- Provide capacity for future growth using:
  - Rating plugs.
  - 100% rated full-function trip system.
- Provide zone-selective interlocking to reduce fault stress on the electrical system.
- Provide power monitoring communications.

Self-Powered (Current Transformer) Protection Relay

Self-powered (current transformer) protection relays are self-powered numerical relays, which do not require external auxiliary supply voltage. These self-powered numerical relays operate without auxiliary voltage via an integrated CT power supply. Self-powered numerical relays are an ideal choice for installation, even in remote locations where auxiliary supplies are not available. Self-powered numerical relays derive operating power from current transformers. The standard current transformers secondary outputs are 1 A or 5 A.

These self-powered numerical relays have low power consumption typically, <1.4 VA at IN (of the relay).

The relay can be powered from these three analog phase measuring inputs as indicated in the following list:

- CT input phase L1
- CT input phase L2
- CT input phase L3

Self-powered protection relays increase the availability of the network and are perfectly suited to most applications.

Self-Powered relays are:

- Insensitive to voltage drop due to faults.
- Not dependent on UPS systems, which are a weak point of electrical installations.
- Less dependent on the external environment (due to electromagnetic compatibility [EMC] overvoltages and low-voltage [LV] overvoltages) because self-power protection relays require no external connections.

Current Transformer

Current Transformers (CTs) are instrument transformers that are used to supply a reduced value of current from the bus bar or cables to meters, protective relays, sensors, and other instruments. CTs provide isolation from high current. CTs permit grounding of the secondary for safety. CTs step down the magnitude of the measured current to a value that can be safely handled by the instruments. CT ratios are expressed as a ratio of the rated primary current to the rated secondary current. For example, a 300:5 CT will produce 5 A of secondary current when 300 A flows through the primary. As the primary current changes, the secondary current will vary accordingly. With 150 A through the 300-A rated primary, the secondary current will be 2.5 A (150: 300 = 2.5: 5).

Current sensors energize self-powered protection relays and breakers. Current sensor output is used to generate the required power. MOSFET-based shunt regulators regulate output by shunting input current when the output voltage exceeds a specified voltage amount. The startup delay of a self-powered relay varies as a function of the current through the current transformers (CTs). With a load current above the minimum level required for power-up , there will be no start-up time delay. Then, the relays operate within their normal time settings. In cases where the start-up delay cannot be tolerated or higher output power is required, protection relays and breakers have a provision for power from an auxiliary DC voltage supply. This provision means protection relays and breakers can be up and running before a fault occurs. Standard auxiliary input voltage varies from 18 V to 35 V for a 24-V DC system.

Dual power input ensures faster operation in the following cases:

- Auxiliary power supply is available at the time when a fault occurs.
- Auxiliary power supply has failed, but the load current is above the required minimum value to power the relay.

With self-powered input, the system is energized by CTs and no auxiliary power is needed. With a self-powered system, the CT has to feed more power compared to a device being powered using auxiliary voltage. With reference to the entire measuring range of the protection devices, the input impedance of the individual phases is not linear.

To ensure that the system functions over a wide range of current input (approximately 0.4 times rated current to 10 times rated current), a shunt regulator (MOSFET and comparator) is used to clamp the voltage above 12 V, 18 V, or 24 V. This results in power loss as shown in Figure 1.

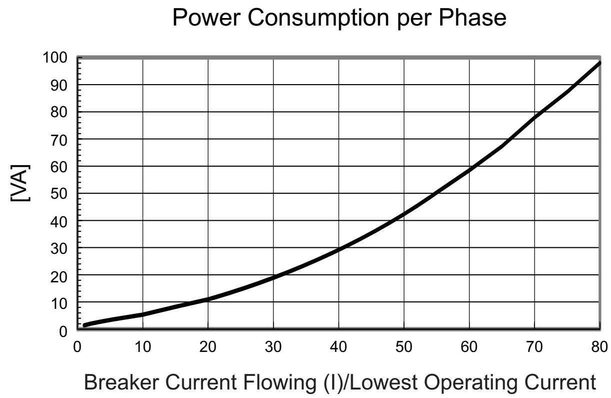

Figure 1. Typical Power Consumption for Current/Lowest Operating Current

By using an LM5017 based power supply, the clamping voltage can be increased as the device input is rated up to 100 V. A power supply with shunt clamping and LM5017 configured in nonisolated output configuration is detailed in this design.

The following systems are generally current transformer powered systems:

- Molded case circuit breakers (MCCBs) are current transformer power electronic trip units.
- Protection relays are self-powered relays supplied by current sensors, requiring no auxiliary power supply.

2 Design Features

Table 1. Design Features

DC-DC Converter	>75-V DC input , <12-V DC output
Zener Regulator	>39-V DC
LDO	3.3-V DC
Comparator Power Supply	Regulated to 16-V DC
DC-DC Converter Temperature	-40 to 125°C

3 Block Diagram

The power supply is powered by two options:

Self-Power (Current Sensor)

The input to the self-power supply input is full wave-rectified input. This rectified input charges the capacitor to generate the output voltage. The regulated DC output voltage is set by a Zener Diode and a MOSFET shunt regulator. The output voltage minus the Zener voltage is compared against a set voltage by the comparator to regulate the output DC voltage. A DC-DC converter is used to generate Relay/FSD trip voltage and electronic circuit control voltages.

Dual-Power (Auxiliary DC or Current Transformer)

An auxiliary DC input voltage also can be applied to generate the required power supply along with the self-powered current inputs. The shunt regulation is bypassed when auxiliary voltage is applied.

The Block Diagram in Figure 2 shows the major blocks in the Self/Dual-Powered Power Supply.

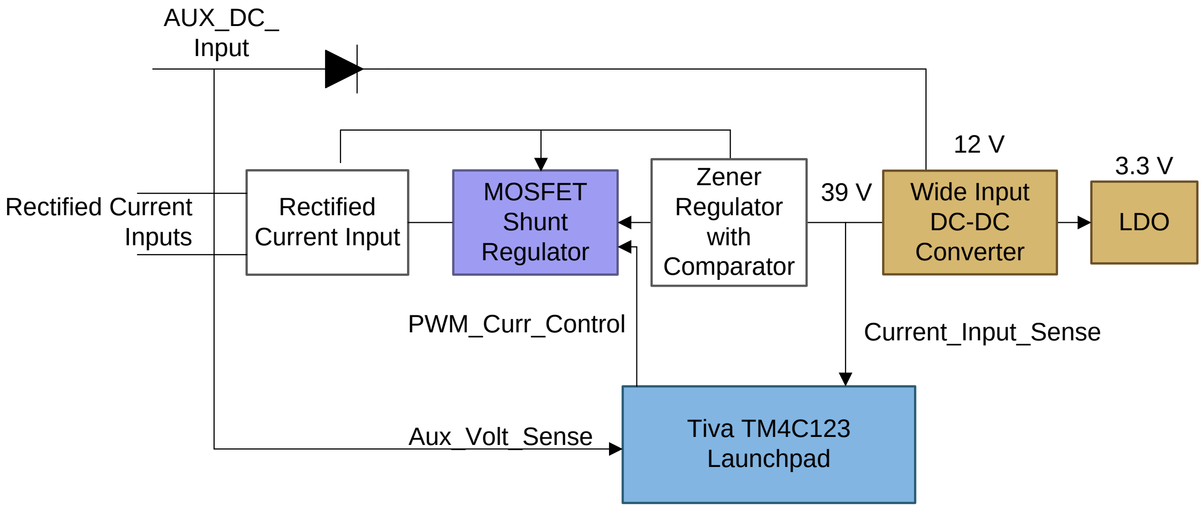

Figure 2. Block Diagram

4 Circuit Design and Component Selection

4.1 LM5017 Wide Input DC-DC Converter

The DC-DC converter is a buck type to generate Relay/FSD trip voltage and the electronic circuit control voltages. The input to the DC-DC converter is the external auxiliary DC input or the output of the shunt regulator.

The DC input to the DC-DC converter is provided by either rectified current input or auxiliary DC input. The DC output is regulated to 39 V. In case both outputs are applied, the current is drawn from the supply that has higher output voltage. The regulated output is given as the input to the DC-DC converter. The DC-DC converter used in this design is LM5017. LM5017 has the following specifications.

- Wide 7.5-V to 100-V Input Range
- Integrated 100-V, High, and Low Side Switches
- No Schottky Diode Required
- Constant On-time Control
- No Loop Compensation Required
- Ultra-Fast Transient Response
- Nearly Constant Operating Frequency
- Intelligent Peak Current Limit
- Adjustable Output Voltage from 1.225 V
- Precision 2% Feedback
- Frequency Adjustable to 1 MHz
- Adjustable Under Voltage Lockout (UVLO)
- Remote Shutdown
- Thermal Shutdown

The wide input capability of LM5017 makes LM5017 the best suited DC-DC converter for this application. The output of the DC-DC converter is programmed for <12 V.

NOTE: The DC 39 V output can be increased up to >70 V based on application requirements.

4.2 CSD18537NKCS Zener Diode Plus MOSFET-Based Shunt Regulation

The combined circuit of Zener diode, comparator, and MOSFET works as a shunt regulator and regulates the output DC voltage to 39 V.

The rectified current sensor input is applied across terminals 3 and 2. The shunt regulator circuit is functional only when the power supply is working in current-sensor powered mode. When the DC output voltage is above the set regulation voltage (39 V), the comparator switches the MOSFET ON. The parallel MOSFET connected across the rectified current outputs shunts the current sensor. The shunt process ensures that the output capacitor does not charge. When the output voltage falls below the regulated voltage (39 V), the comparator switches the MOSFET OFF, allowing the capacitor to charge.

The MOSFET-based shunt regulator is controlled by the following methods:

- By a comparator that regulates the output DC voltage to 39 V.
- By pulse width modulator (PWM) output from the microcontroller. The microcontroller senses the output voltage. Based on the set regulation voltage, the microcontroller regulates the output voltage by controlling the PWM output to the MOSFET.

The PWM output width and frequency is dependent on the application and the power consumption.

The MCCB-ETU uses the TI MOSFET to shunt the current above 39 V. Increased regulation voltage reduces power dissipation and facilitates usage of a 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, as shown in Table 2.

Table 2. 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

4.3 Auxiliary DC Input

The power supply also works with auxiliary DC input. The auxiliary input voltage range is 18-V to 35-V DC.

When no startup delay for fault sensing is required, auxiliary DC input is used. If the protection relay or breaker has functions requiring power >1 W, auxiliary DC input is used. Auxiliary DC input is applied across terminals 1 and 2. Most ETUs with communication and metering functions have a provision for auxiliary DC input.

4.4 TPS7A6533QKVURQ1 Low-Dropout Regulator (LDO)

A low dropout regulator is used to generate the 3.3-V power supply required for the microcontroller and analog signal conditioning amplifiers. The LDO used in this design is TPS7A6533. TPS7A65xx-Q1 is a family of low dropout linear voltage regulators designed for low power consumption and quiescent current less than 25 µA in light-load applications. TPS7A65xx-Q1 devices feature integrated overcurrent protection. TPS7A65xx-Q1 devices are designed to achieve stable operation even with low-ESR ceramic output capacitors. A low-voltage tracking feature allows for a smaller input capacitor.

4.5 DC Input Sensing

A voltage divider is used to sense input voltage to identify if the supply is working from the auxiliary DC input or the current input. The voltage divider sensing is required to stop PWM generation, when the regulator is operated in auxiliary DC input mode.

The auxiliary voltage is given as input to the ADC of the MCU. The MCU measures the DC voltage and the MCU senses that the auxiliary voltage is present. The MCU then switches OFF the PWM. The design of the power supply ensures that the shunt regulation has no effect when operated with auxiliary DC input.

4.6 Comparison of Self-Power Solutions

Table 3. Comparison of Self-Power Solutions

	GENERAL IMPLEMENTATION	PROPOSED IMPLEMENTATION
Regulation Voltage	15 V to 18 V	>39 V and up to 70 V
Power Dissipation	Dissipate power during normal operation	Reduced or no power dissipation during normal operation
Current Transformer Sizing	Higher CT size	Reduced CT size
Heat Sink Design	Larger	Smaller
Linearity	Depends on input current	Linear for nominal current range

5 Test Data

5.1 Functional Testing

Table 4. DC Output Voltage Regulation

EXPECTED – DC V	MEASURED – DC V
39 V	39.4 V

Table 5. LDO Output Voltage

EXPECTED	MEASURED
3.3 V	3.31 V

Table 6. DC-DC Output Voltage

INPUT VOLTAGE (DC-DC CONVERTER)	MEASURED OUTPUT (DC-DC CONVERTER)
15	11.85
18	11.85
20	11.85
25	11.85
30	11.85
35	11.85
39	11.85

Table 7. Comparator Supply Voltage

INPUT VOLTAGE	POWER SUPPLY (COMPARATOR)
15	10.7
18	11.7
20	15.5
25	16
30	16
35	16
39	16

Table 8. Voltage Sensing and Differentiating of Input Supplies

INPUT SUPPLY	MICROCONTROLLER SENSING
Current Input	Ok
Auxiliary Input	Ok

Table 9. Load Regulation

V_{in} (V)	V_{out} (V)	I_{out} (mA)
24	11.88	50
24	11.88	75
24	11.87	100
24	11.86	125
24	11.86	150
24	11.85	175
24	11.84	200
24	11.83	225
24	11.82	250
24	11.81	275
24	11.80	300

Table 10. Efficiency (Measured with Auxiliary Input)

P_{in} – (W)	P_{out} (W)	EFFICIENCY
1.92	1.147	59.7
2.4	1.4325	59.7
2.64	1.719	65.1
3.12	2.00375	64.2
3.36	2.288	68.1
3.84	2.57175	67
4.32	2.855	66.1
4.56	3.13775	68.8
5.04	3.42	67.9

6 Design Files

6.1 Schematics

To download the Schematics, see the design files at TIDA-00229.

Figure 3 and Figure 4 show some of the Schematics for this design.

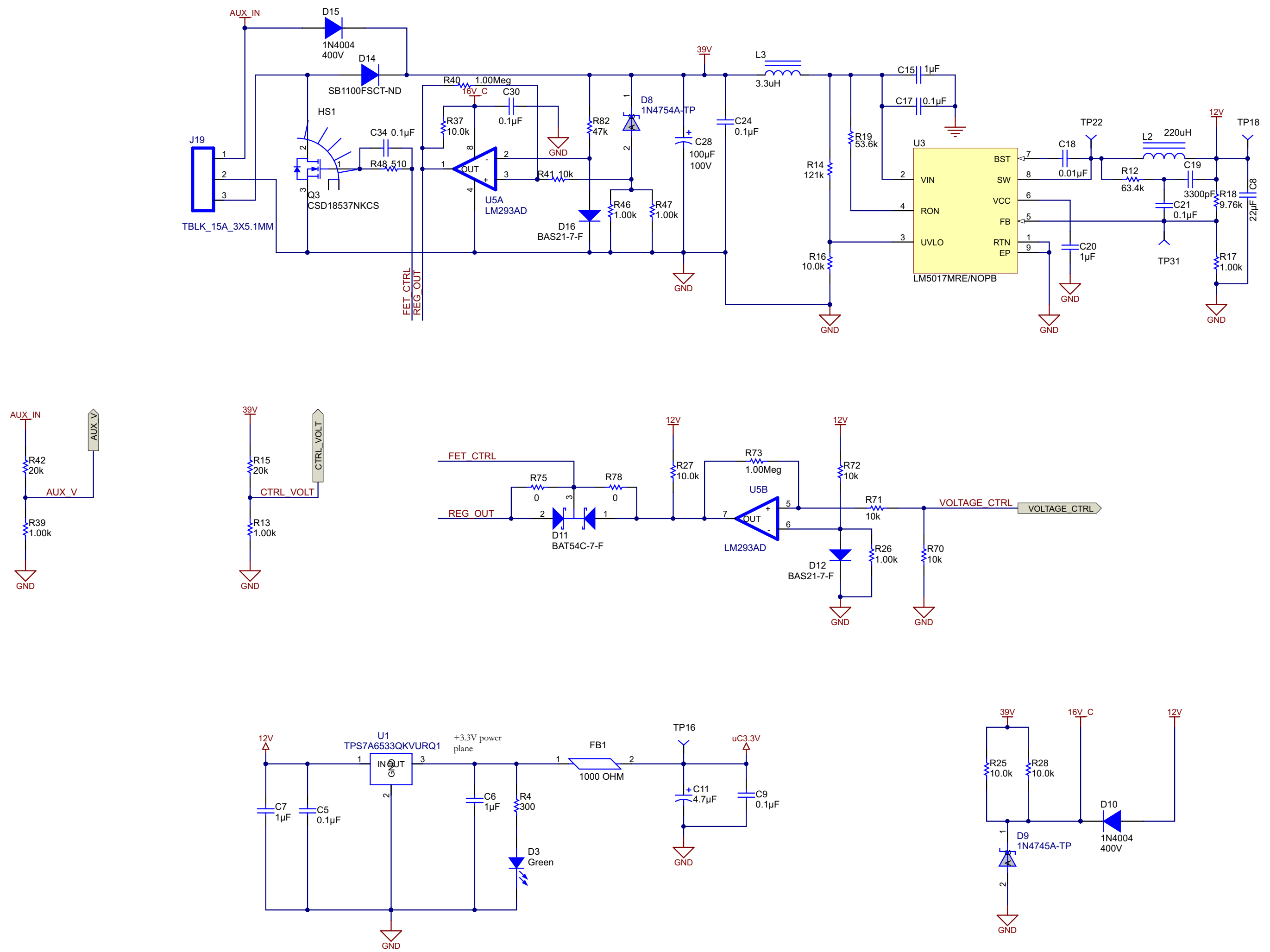

Figure 3. Schematics Page 3

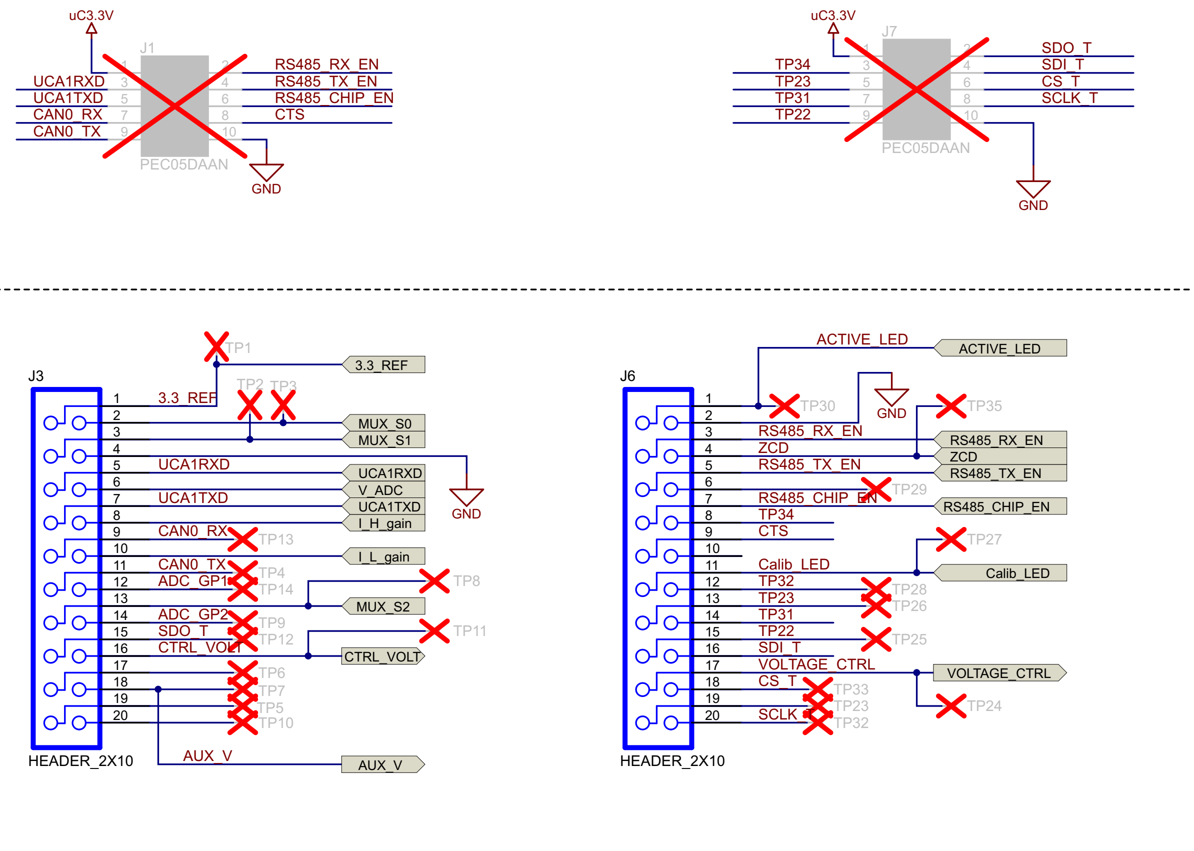

Figure 4. Schematics Page 6 MSP430/TIVA LAUNCH PAD

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00229. To see the BOM for the Fitted category, see Table 11.

Table 11. Bill of Materials

FITTED	DESCRIPTION	DESIGNATOR	PARTNUMBER	QUANTITY	MANUFACTURER	PACKAGEREFERENCE	VALUE
Fitted	CAP, CERM, 0.1uF, 50V, +/-10%, X7R, 0603	C5, C9, C30	C0603C104K5RACTU	3	Kemet	603	0.1uF
Fitted	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0603	C6, C7	C1608X7R1C105K	2	TDK	603	1uF
Fitted	CAP, CERM, 22uF, 16V, +/-10%, X5R, 1206	C8	GRM31CR61C226KE15 L	1	MuRata	1206	22uF
Fitted	CAP, TA, 4.7uF, 35V, +/-10%, 1.9 ohm, SMD	C11	293D475X9035C2TE3	1	Vishay-Sprague	6032-28	4.7uF
Fitted	CAP, CERM, 1uF, 100V, +/-10%, X7R, 1206	C15	GRM31CR72A105KA01L	1	MuRata	1206	1uF
Fitted	CAP, CERM, 0.1uF, 100V, +/-10%, X7R, 0805	C17, C24	C0805C104K1RACTU	2	Kemet	805	0.1uF
Fitted	CAP, CERM, 0.01uF, 25V, +/-5%, C0G/NP0, 0603	C18	C1608C0G1E103J	1	TDK	603	0.01uF
Fitted	CAP, CERM, 3300pF, 50V, +/-10%, X7R, 0603	C19	C0603C332K5RACTU	1	Kemet	603	3300pF
Fitted	CAP, CERM, 1uF, 25V, +/-10%, X5R, 0603	C20	C1608X5R1E105K080A C	1	TDK	603	1uF
Fitted	CAP, CERM, 0.1uF, 25V, +/-5%, X7R, 0603	C21, C34	06033C104JAT2A	2	AVX	603	0.1uF
Fitted	CAP, AL, 100uF, 100V, +/-20%, 0.12 ohm, TH	C28	100YXJ100M10X20	1	Rubycon	10x20mm	100uF
Fitted	LED SmartLED Green 570NM	D3	LG L29K-G2J1-24-Z	1	OSRAM	603	Green
Fitted	Diode, Zener, 39V, 1W, DO41	D8	1N4754A-TP	1	Micro Commercial Co	DO-41	1N4754A-TP
Fitted	Diode, Zener, 16V, 1W, DO41	D9	1N4745A-TP	1	Micro Commercial Co	DO-41	1N4745A-TP

Table 11. Bill of Materials (continued)

FITTED	DESCRIPTION	DESIGNATOR	PARTNUMBER	QUANTITY	MANUFACTURER	PACKAGEREFERENCE	VALUE
Fitted	DIODE, GEN PURPOSE, 400V, 1A, DO-41, TH	D10, D15	1N4004	2	FAIRCHILD SEMICONDUCTOR	DO-41	400V
Fitted	Diode, Schottky, 30V, 0.2A, SOT-23	D11	BAT54C-7-F	1	Diodes Inc.	SOT-23	30V
Fitted	Diode, Switching, 200V, 0.2A, SOT-23	D12, D16	BAS21-7-F	2	Diodes Inc.	SOT-23	200V
Fitted	Diode, P-N, 1100V, 1A, TH	D14	SB1100FSCT-ND	1	Fairchild Semiconductor	DO-41	
Fitted	FERRITE CHIP 1000 OHM 300MA 0603	FB1	MMZ1608B102C	1	TDK Corporation	603	1000 OHM
Fitted	HEATSINK TO-220 W/PINS 1.5TALL"	HS1	513102B02500G	1	Aavid Thermalloy	1.500x1.375in.	513102B02500G
Fitted	Header, Male 2x10-pin, 100mil spacing	J3, J6	PEC10DAAN	2	Sullins	0.100 inch x 10 x 2	PEC10DAAN
Fitted	Terminal Block, 3-pin, 15-A, 5.1mm	J19	ED120/3DS	1	OST	0.60 x 0.35 inch	ED120/3DS
Fitted	Inductor, 220uH .30A SMD	L2	SRR7032-221M	1	Bourns	7x7mm	220uH
Fitted	Inductor, Chip, 3.3uH 770MA 1210 10%	L3	B82422H1332K	1	EPCOS Inc	1210	3.3uH
Fitted	MOSFET, N-CH, 60V, 50A, TO-220AB	Q3	CSD18537NKCS	1	Texas Instruments	TO-220AB	60V
Fitted	RES, 300 ohm, 5%, 0.1W, 0603	R4	CRCW0603300RJNEA	1	Vishay-Dale	603	300
Fitted	RES, 63.4k ohm, 1%, 0.1W, 0603	R12	CRCW060363K4FKEA	1	Vishay-Dale	603	63.4k
Fitted	RES, 1.00k ohm, 1%, 0.25W, 1206	R13, R26, R39, R46, R47	CRCW12061K00FKEA	5	Vishay-Dale	1206	1.00k
Fitted	RES, 121k ohm, 0.1%, 0.125W, 0805	R14	RT0805BRD07121KL	1	Yageo America	805	121k
Fitted	RES, 20k ohm, 5%, 0.25W, 1206	R15, R42	CRCW120620K0JNEA	2	Vishay-Dale	1206	20k
Fitted	RES, 10.0k ohm, 1%, 0.1W, 0603	R16, R27	CRCW060310K0FKEA	2	Vishay-Dale	603	10.0k
Fitted	RES, 1.00k ohm, 1%, 0.1W, 0603	R17	RC0603FR-071KL	1	Yageo America	603	1.00k
Fitted	RES, 9.76k ohm, 1%, 0.1W, 0603	R18	CRCW06039K76FKEA	1	Vishay-Dale	603	9.76k

Table 11. Bill of Materials (continued)

FITTED	DESCRIPTION	DESIGNATOR	PARTNUMBER	QUANTITY	MANUFACTURER	PACKAGEREFERENCE	VALUE
Fitted	RES, 53.6k ohm, 0.1%, 0.125W, 0805	R19	RG2012P-5362-B-T5	1	Susumu Co Ltd	805	53.6k
Fitted	RES, 10.0k ohm, 1%, 0.25W, 1206	R25, R28, R37	CRCW120610K0FKEA	3	Vishay-Dale	1206	10.0k
Fitted	RES, 1.00Meg ohm, 1%, 0.1W, 0603	R40, R73	CRCW06031M00FKEA	2	Vishay-Dale	603	1.00Meg
Fitted	RES, 10k ohm, 0.01%, 0.063W, 0603	R41, R70, R71, R72	RNCF0603TKY10K0	4	Stackpole Electronics Inc	603	10k
Fitted	RES, 510 ohm, 0.1%, 0.1W, 0603	R48	RG1608P-511-B-T5	1	Susumu Co Ltd	603	510
Fitted	RES, 0 ohm, 5%, 0.1W, 0603	R75, R78	CRCW06030000Z0EA	2	Vishay-Dale	603	0
Fitted	RES, 47k ohm, 5%, 0.125W, 0805	R82	ERJ-6GEYJ473V	1	Panasonic	805	47k
Fitted	Test Point, O.040 Hole	TP16, TP18, TP22, TP31	STD	4	STD		STD
Fitted	IC, 300-mA 40-V LOW-DROPOUT REGULATOR WITH 25-uA QUIESCENT CURRENT	U1	TPS7A6533QKVURQ1	1	TI	PFM	TPS7A6533QKVU RQ1
Fitted	100V, 600mA Constant On-Time Synchronous Buck Regulator, DDA0008B	U3	LM5017MRE/NOPB	1	Texas Instruments	DDA0008B	
Fitted	IC, Dual Differential Comparators, 2-36 Vin	U5	LM293AD	1	TI	SO-8	LM293AD

6.3 Layer Plots

To download the layer plots for this design, see the design files at TIDA-00229.

Figure 5 through Figure 10 show the layer plots for this design.

NOTE: All layer plots are viewed from the top side.

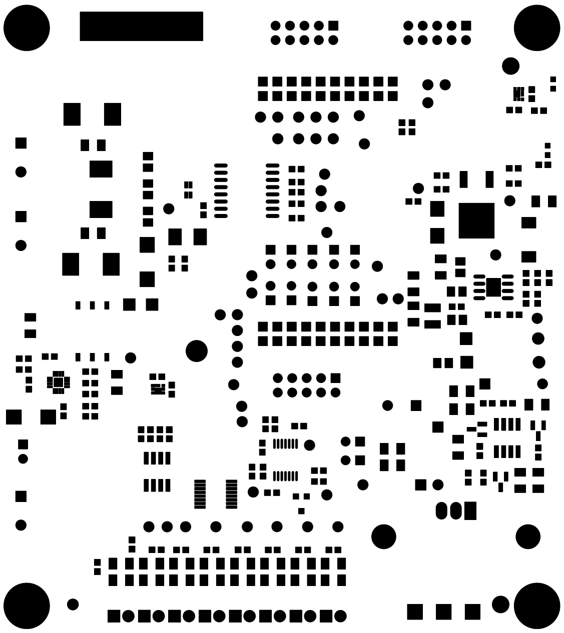

Figure 5. Solder Mask Top

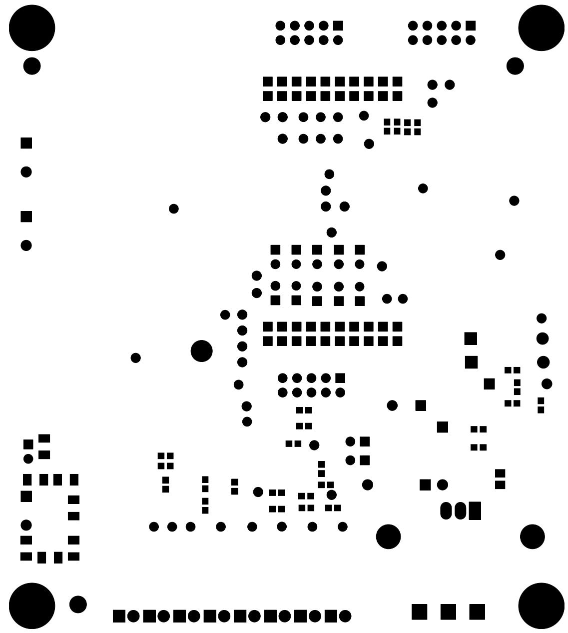

Figure 6. Solder Mask Bottom

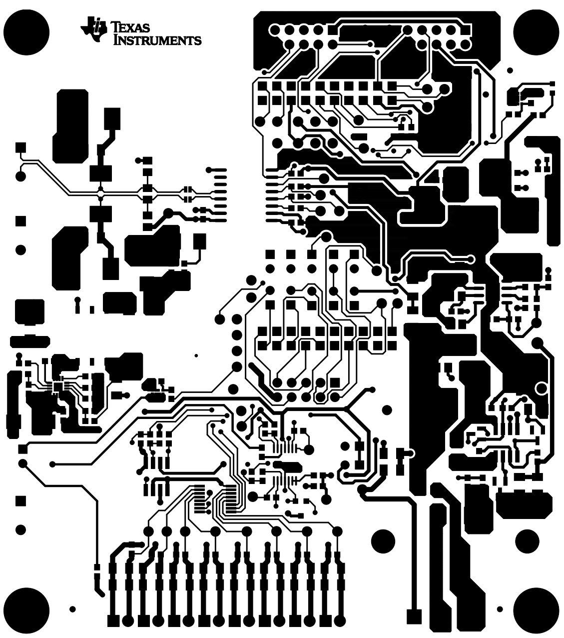

Figure 7. Top Layer

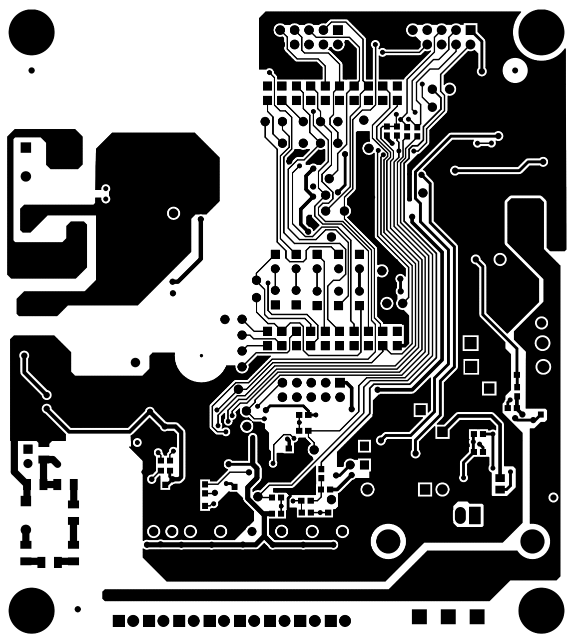

Figure 8. Bottom Layer

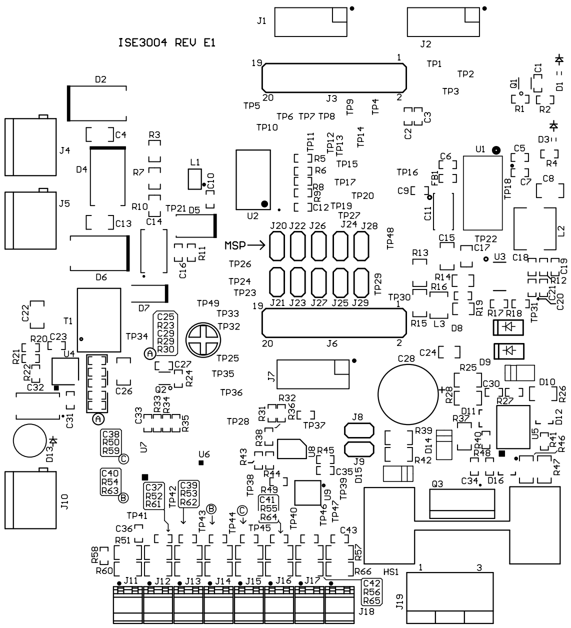

Figure 9. Top Overlay

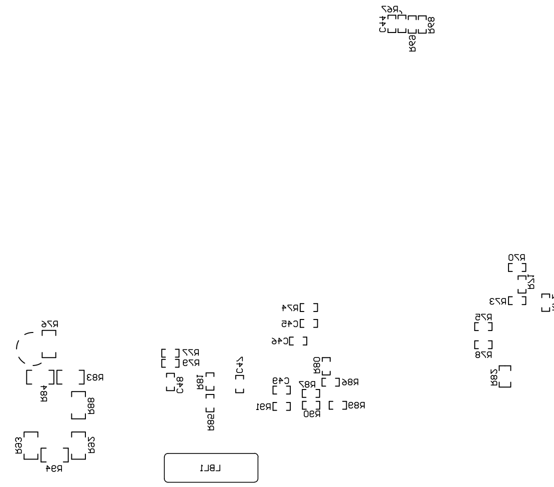

Figure 10. Bottom Overlay

6.4 Multilayer Composite Prints

To download the Multilayer Composite Print files, see the design files at TIDA-00229.

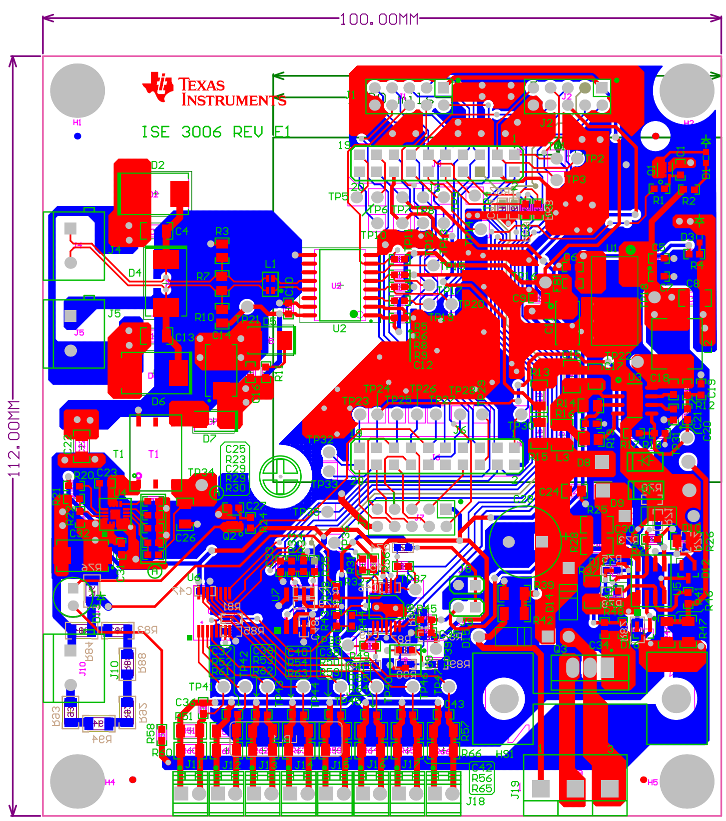

Figure 11. Multilayer Composite Print

6.5 Assembly Drawings

To download the Assembly Drawings, see the design files at TIDA-00229.

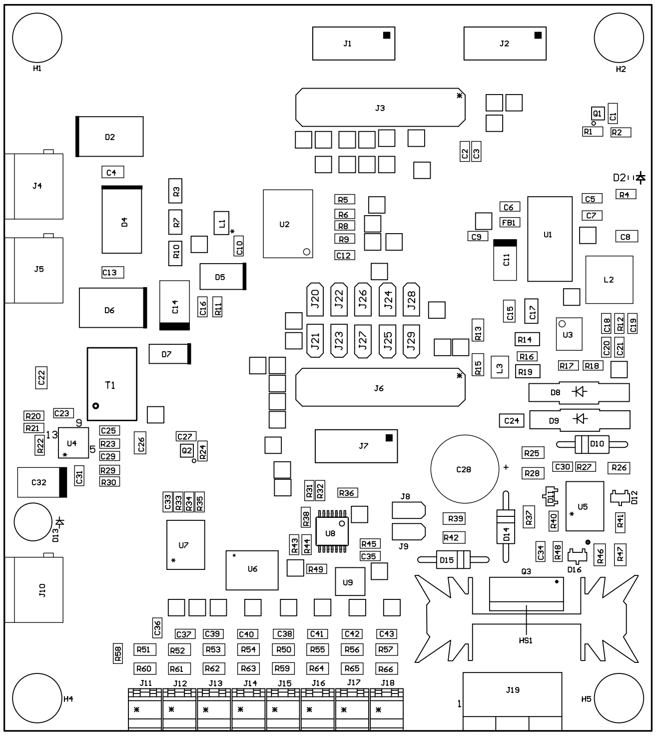

Figure 12. Assembly Drawing 1

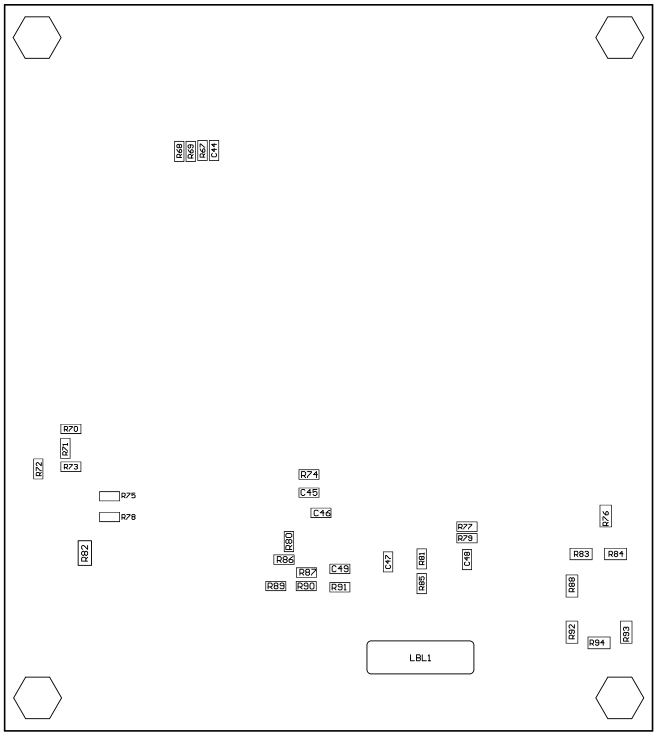

Figure 13. Assembly Drawing 2

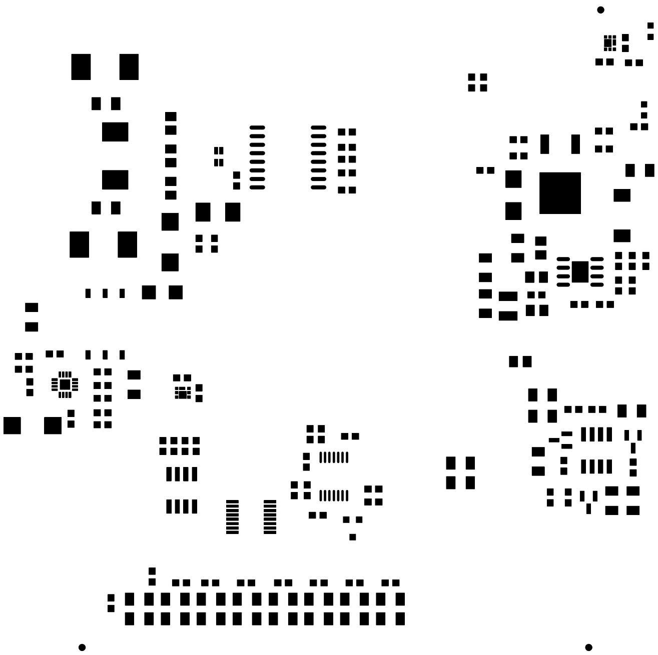

Figure 14. Assembly Drawing 3

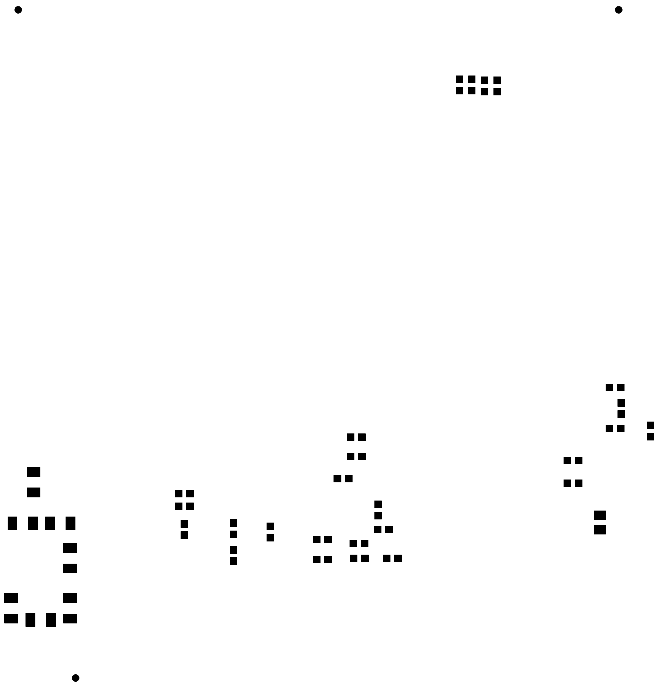

Figure 15. Assembly Drawing 4

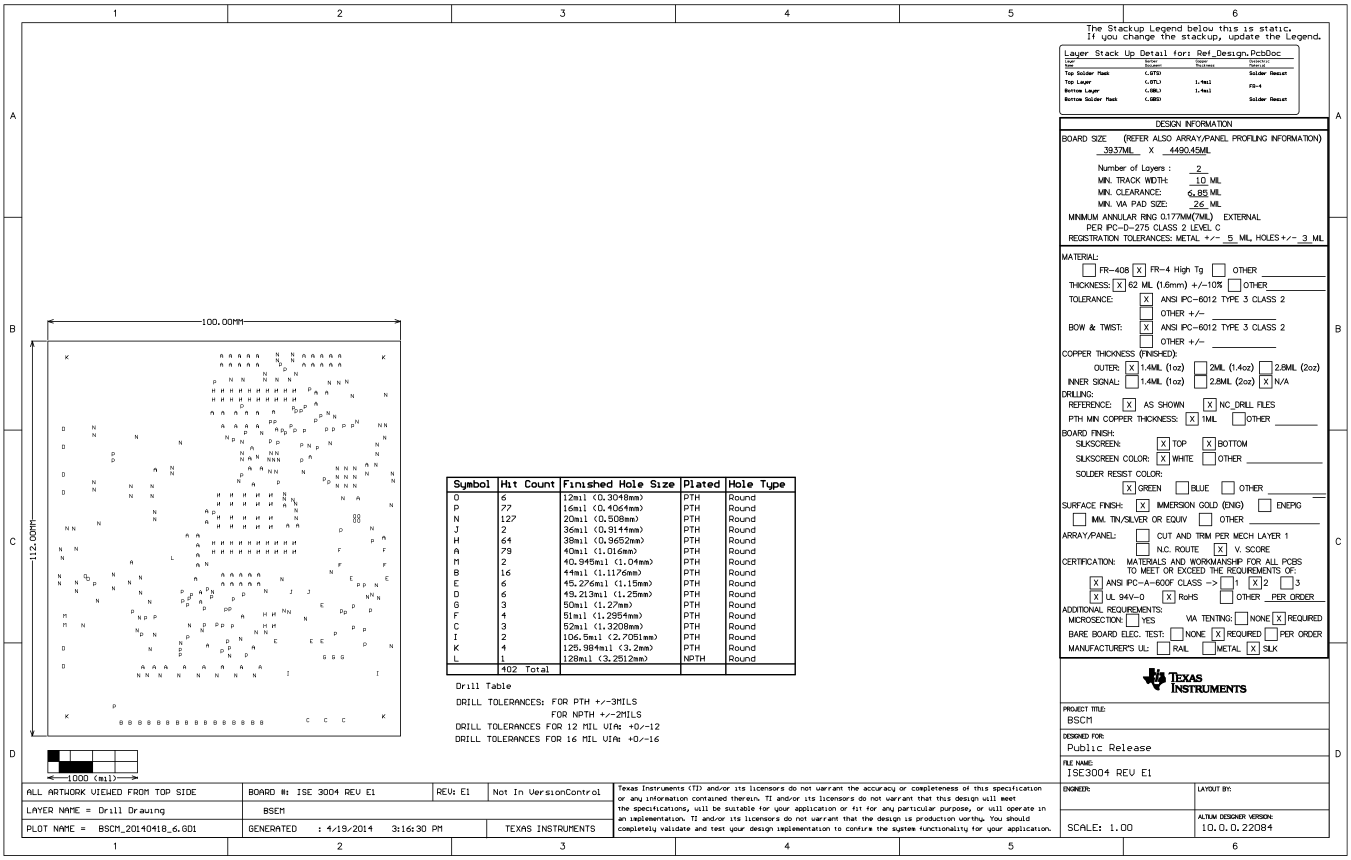

Figure 16. Drill Drawing

6.6 Gerber Files

To download the Gerber files, see the design files at TIDA-00229.

7 About the Author

KALLIKUPPA MUNIYAPPA SREENIVASA is a Systems Architect at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Sreenivasa brings to this role his experience in high-speed digital and analog systems design. Sreenivasa earned his Bachelor of Electronics (BE) in Electronics and communication Engineering (BE-E&C) from VTU, Mysore, India.

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