ISLSTPMREFEV1Z

Radiation Tolerant Stepper Motor Reference Design

Description

The ISLSTPMREFEV1Z is a radiation-tolerant stepper motor reference design system that provides an efficient driving circuit for a 2-phase bipolar stepper motor at supply voltages up to 12V.

The ISLSTPMREFEV1Z board highlights six main radiation-tolerant components: the ISL71441M half-bridge GaN FET driver, the ISL70024SEH 200V GaN FET, the ISL70100M 40V Current Sense Amplifier (CSA), the ISL71148M 8-channel 14-bit SAR Analog-to-Digital Converter (ADC), the ISL75054M ultra-low-noise, high-PSRR low-dropout regulator, and the ISL71010B25 2.5V Precision Voltage Reference.

The driver circuit uses four ISL71441M half-bridge drivers, two per coil, each controlling a pair of GaN FETs to deliver bidirectional current through each motor coil, as shown in Figure 1.

Features

This reference board demonstrates performance and operation of six system components that deliver:

- 12V 2.5A 30W 2-phase bipolar stepper motor driver
- Precision current-sense monitoring
- High-accuracy analog monitoring
- Adaptable for different motor driver application
- All components available in alternative rad hard flow

Specifications

- +12V power supply input (from a bench top power supply) or a 12V DC wall power supply.
- Main system components support -55°C to +125°C operation
- Supporting components rated for operation from -40°C to +85°C operation

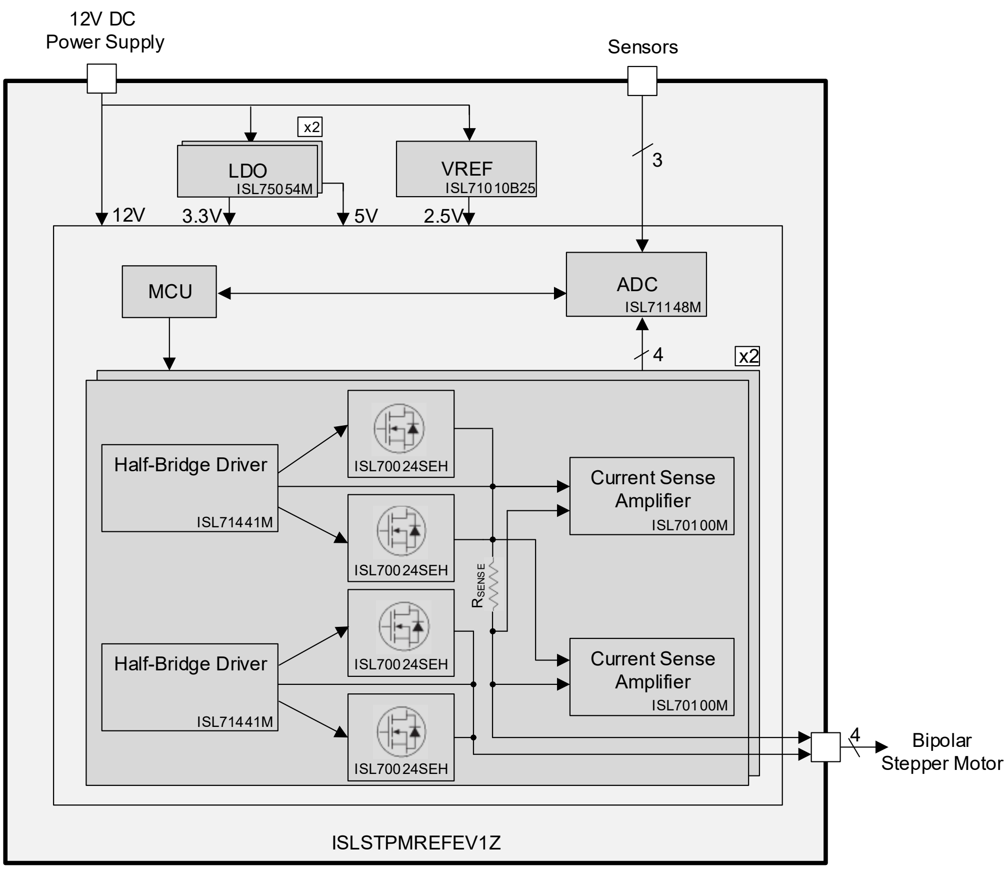

Figure 1. Board Block Diagram

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1. Functional Description

The ISLSTPMREFEV1Z reference design implements a complete radiation-tolerant 2-phase bipolar stepper motor drive circuit, combining dual H-bridge control and high-precision analog monitoring. A 2-phase bipolar stepper motor has two coil pairs that push sequenced current in alternating directions to rotate the motor. Each coil requires an H-bridge to deliver bidirectional switching. One H-bridge is built from two ISL71441M drivers and four ISL70024SEH FETs.

The half-bridge drivers switch the motor coils in a specific four-step sequence. Each step in the sequence shifts the magnetic field inside the motor by one position, causing the motor to follow and advance by one step. Running this sequence continuously produces forward rotation, while reversing the order of the sequence changes the motor direction. The speed of rotation is controlled by how fast the steps are executed, and the direction is controlled by the order in which the coils are energized.

The ISLSTPMREFEV1Z reference design uses the Arduino UNO R4 as the system microcontroller, responsible for generating the stepper motor pulse sequence, acquiring analog measurements through the ISL71148M ADC, and communicating real-time data to the host PC graphical user interface through USB serial. The Arduino UNO R4 is built around the Renesas RA4M1 microcontroller, a 32-bit ARM Cortex-M4-based device operating at 48MHz, providing sufficient computational throughput to manage simultaneous motor control, ADC communication, and high-speed serial data transmission.

The Arduino UNO R4 generates four independent PWM output signals, one per ISL71441M half-bridge driver, to control the switching state of each half-bridge in the dual H-bridge power stage. The four PWM signals are sequenced in the following order to rotate in one direction: CoilA+, CoilB+, CoilA-, CoilB-. For the opposite direction, the sequence reverses its order to: CoilB-, CoilA-, CoilB+, CoilA+. The pulses that drive each coil pair are shown in Figure 2.

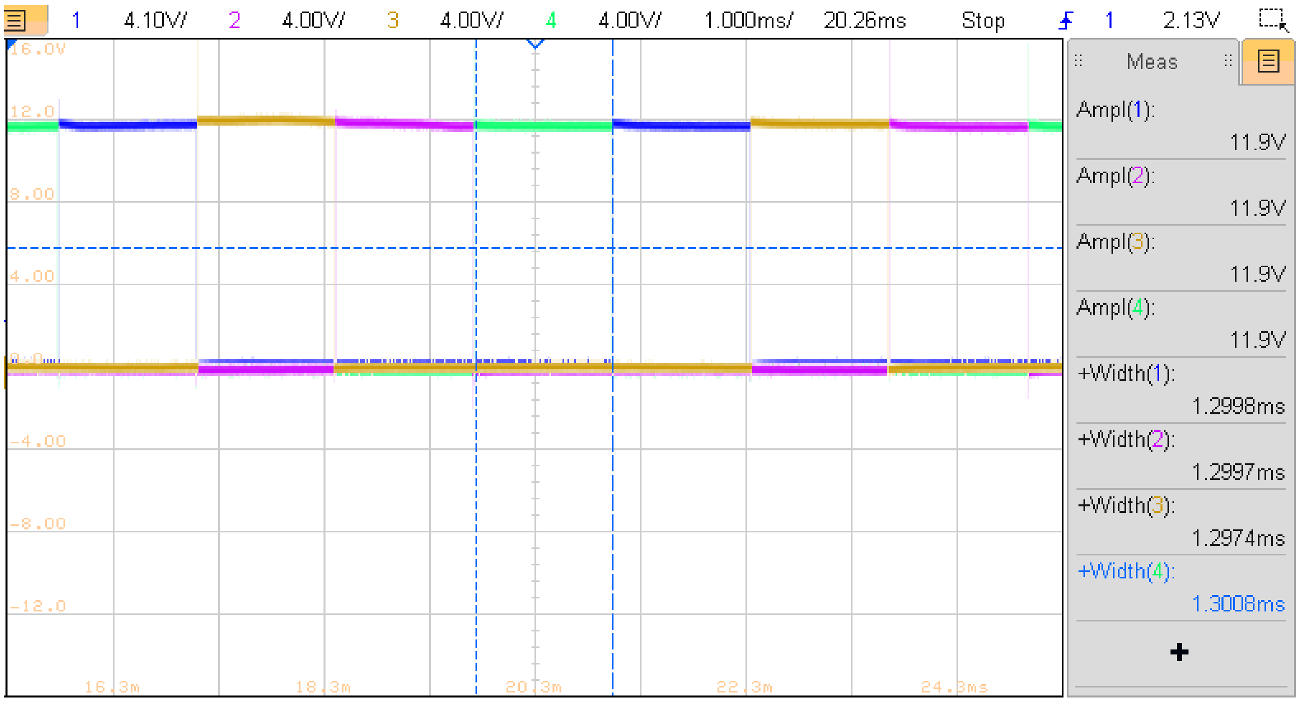

Figure 2. Stepper Motor Coil Waveform - Coil A+ (CH1, Yellow), Coil A- (CH2, Green), Coil B+ (CH3, Blue), Coil B- (CH4, Pink)

A +12V DC supply must be connected to either the VIN_100 and GND_100 banana jack connectors or the J100 DC barrel connector to provide power to the board. The location of these connectors on the board is shown in Figure 3.

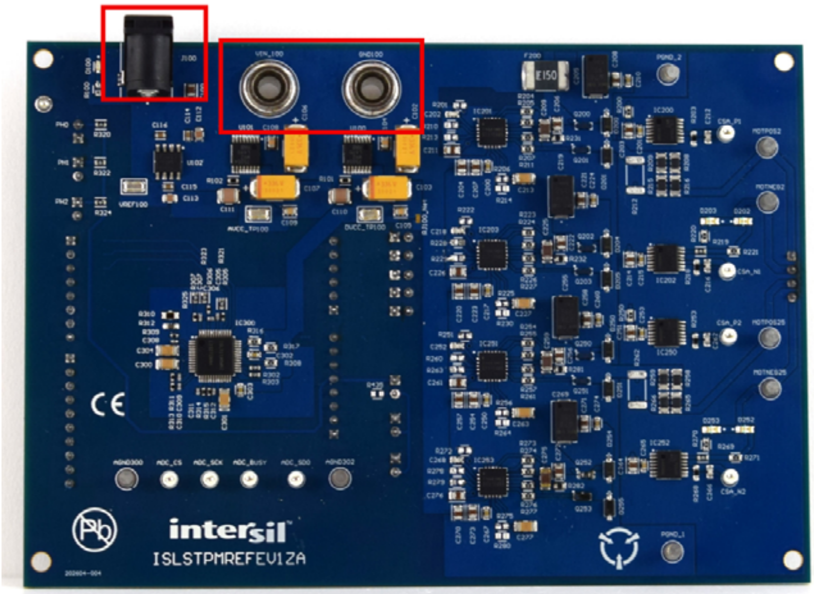

Figure 3. ISLSTPMREFEV1Z Reference Board (Top) - Power Supply Connection Options

The stepper motor is connected to the board through J200_MOT1&2, a 4-pin connector located on the back of the board. The four pins correspond to the two terminal pairs of the 2-phase bipolar stepper motor. The motor connector delivers the switched 12V drive pulses from the dual H-bridge power stage to the stepper motor windings. Because correct wiring polarity must be observed, consult the datasheet for the selected motor to identify the Coil A and Coil B terminal pairs before connection.

Three 2-pin sensor connectors (PH0, PH1, and PH2) are provided on the back of the board for connection of external analog sensors. All three connectors share an identical circuit configuration: a voltage divider network referenced to the Arduino's 5V supply rail.

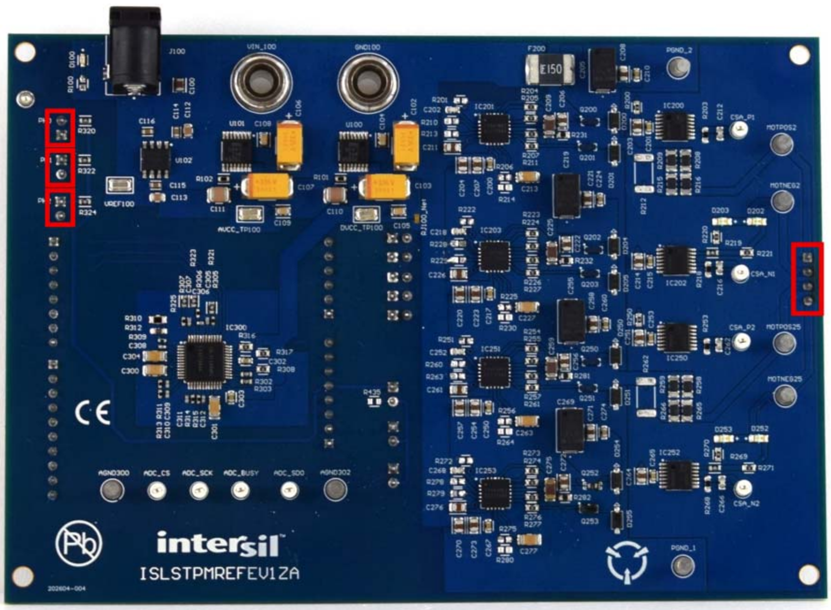

Figure 4. ISLSTPMREFEV1Z Reference Board (Top) - Stepper Motor and Sensor Connections

1.1 Current Sense Amplifiers (CSA)

A 2-phase bipolar stepper motor is driven by two independent H-bridges, each capable of sourcing and sinking current through its respective motor coil in either direction. At any given moment in the stepping sequence, current may be flowing through either the positive or negative side of each H-bridge, depending on which diagonal switch pair is active. To measure current flowing in both directions of each coil, four CSA's must be used. The ISL70100M uses the voltage drop (V_{SEN}) across a dedicated sense resistor network (R_{SEN}), which is set to 100mΩ. The output resistor (R_{OUT}) sets the output gain of the ISL70100M and is populated with a 5kΩ resistor. Applying Equation 1, the maximum CSA output voltage (V_{OUT}) at full scale sense voltage is 1.5V, which falls within the 2.5V ADC input range. To increase the maximum output voltage to 2V and use a greater portion of the ADC dynamic range, R_{OUT} should be replaced with a 6.8kΩ resistor.

(EQ. 1) $$V_{OUT} = R_{OUT} \times V_{SEN}(mV) \times 2\mu A / mA$$

$$V_{SEN}(mV) = R_{SEN}(m\Omega) \times I_{SEN}(A)$$

(EQ. 2) $$R_{OUT} = A_{CSA} / g_m$$

where:

- R_{OUT} is the output load resistance in kΩ.
- A_{CSA} is the required voltage gain.
- g_m is the transconductance of the ISL70100M which is 2µA/mV (typical).

1.2 Bootstrap Capacitor vs PWM

The ISL71441M half-bridge driver employs a bootstrap circuit to generate the floating supply voltage required to drive the high-side GaN FET. The bootstrap capacitor (C_BOOT) stores the charge necessary to sustain the high-side gate drive voltage throughout each switching cycle. The value of C_BOOT, combined with the total current drawn from it during the high-side on-time interval, determines the maximum allowable pulse width that the microcontroller can apply to the high-side switch. Exceeding this maximum on-time causes the bootstrap voltage to drop below the minimum gate drive threshold.

V_{DROP} is the amount of voltage drop allowed across the bootstrap capacitor. For this configuration, a drop of 500mV is allowed. PVCC (the BOOT charge voltage) is 4.5V and the BOOT UVLO rising threshold is 4.0V.

The following design example uses the ISL70024SEH 200V GaN FETs as the high-side FET in nominal conditions:

- Q_{GS1} = 2.5nC gate charge
- ISL71441M I_{Q_BOOT} = 580µA; t_{ON} = 1.3ms; Q_{BOOT} = I_{BOOT} × t_{ON} = 754nC
- For 4.5V gate drive, Q_{GS2} = 4.5V/1kΩ × 1.3ms = 5850nC
- ISL70024SEH specifies 0.8mA gate leakage. Q_{LEAK} = 800µA × 1.3ms = 1040nC
- C_{BOOT} = Q_{TOT}/V_{DROP} = 7647nC / 500mV = 15.3µF

A 22µF bootstrap capacitor is selected for this reference design. A series 10Ω resistor limits the inrush charge current into the 22µF capacitor while a parallel 1µF capacitor supplies the high-frequency gate charge current demand.

1.3 ADC Operation

The Arduino UNO R4 communicates with the ISL71148M using the SPI bus. The ISL71148M is configured to Normal Operation and PGA Bypass mode, enabling the ADC to operate at its maximum sample rate. All three channel selection pins (S2, S1, S0) are driven by the microcontroller to select the active input channel before each conversion. One dummy read is performed to start the ADC pipeline, where the data for a given channel is available on the second consecutive read following the channel selection. The eight channels sampled by the ADC are shown in Table 1.

Table 1. ISL71148M Channels

ADC Channel	Input signal
0	Sensor 1
1	Sensor 2
2	Sensor 3
3	12V Input Supply
4	Current Sense Amp 1
5	Current Sense Amp 2
6	Current Sense Amp 3
7	Current Sense Amp 4

Channel 3 is monitoring the 12V board input supply, and divided by a factor of 7.5 to be within the analog input voltage range of the ADC, which is 2.5V. To read the proper input supply value, it has to be scaled back in SW.

1.4 Driver Circuit Reconfigurability

While this reference design demonstrates stepper motor control, the same ISL71441M half-bridge driver and GaN FET power stage can drive brushed DC motors, solenoids, and brushless DC motors with minimal or no hardware changes.

A brushed DC motor requires a single H-bridge, where a PWM duty cycle controls motor speed and reversing the active switch pair reverses rotation direction. A solenoid requires only a single half-bridge driver, since it operates unidirectionally and requires only on/off or proportional current control rather than bidirectional switching. A brushless DC motor requires three of the four half-bridge drivers arranged as a 3-phase bridge, with SW determining rotor position and sequencing the active phase pair accordingly. In all three cases, the existing ISL70100M current sense amplifiers and the ADC provide real-time current monitoring for protection and closed-loop control, and the programmable dead time of the ISL71441M ensures safe switching across all load types. The primary difference between these applications lies in the switching sequence and PWM control implemented on the microcontroller selected.

2. Board Design

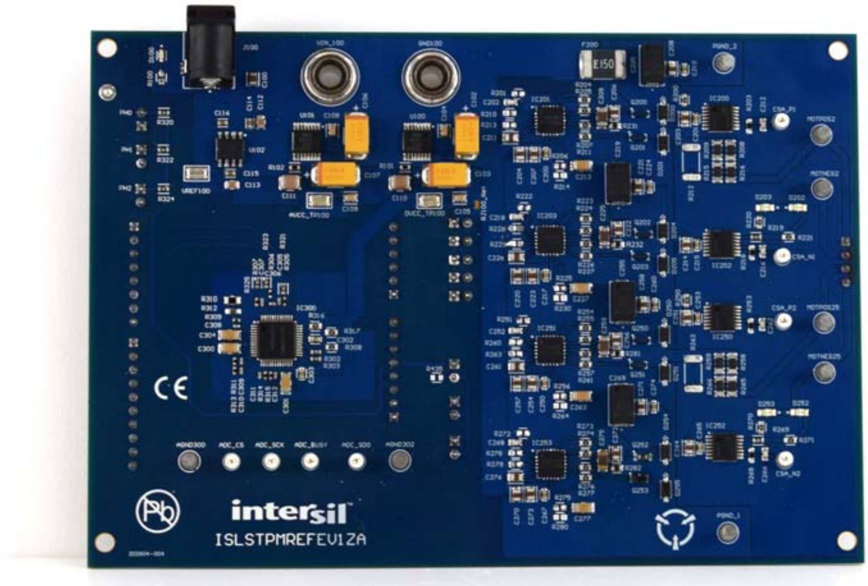

Figure 5. ISLSTPMREFEV1Z Reference Board (Top)

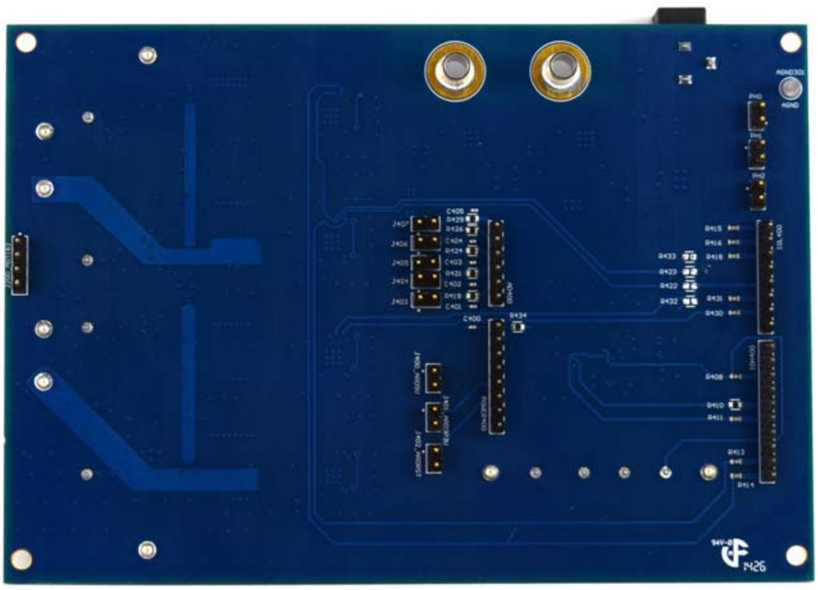

Figure 6. ISLSTPMREFEV1Z Reference Board (Bottom)

2.1 Board Schematics

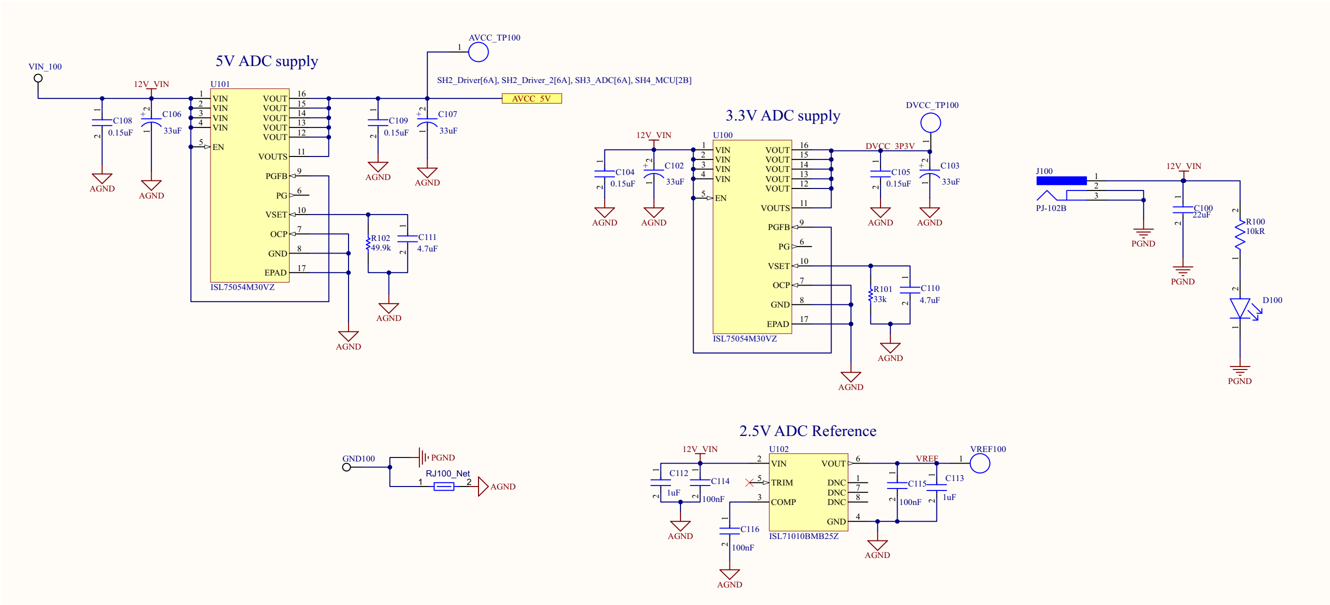

Figure 7. Voltage Reference and LDOs

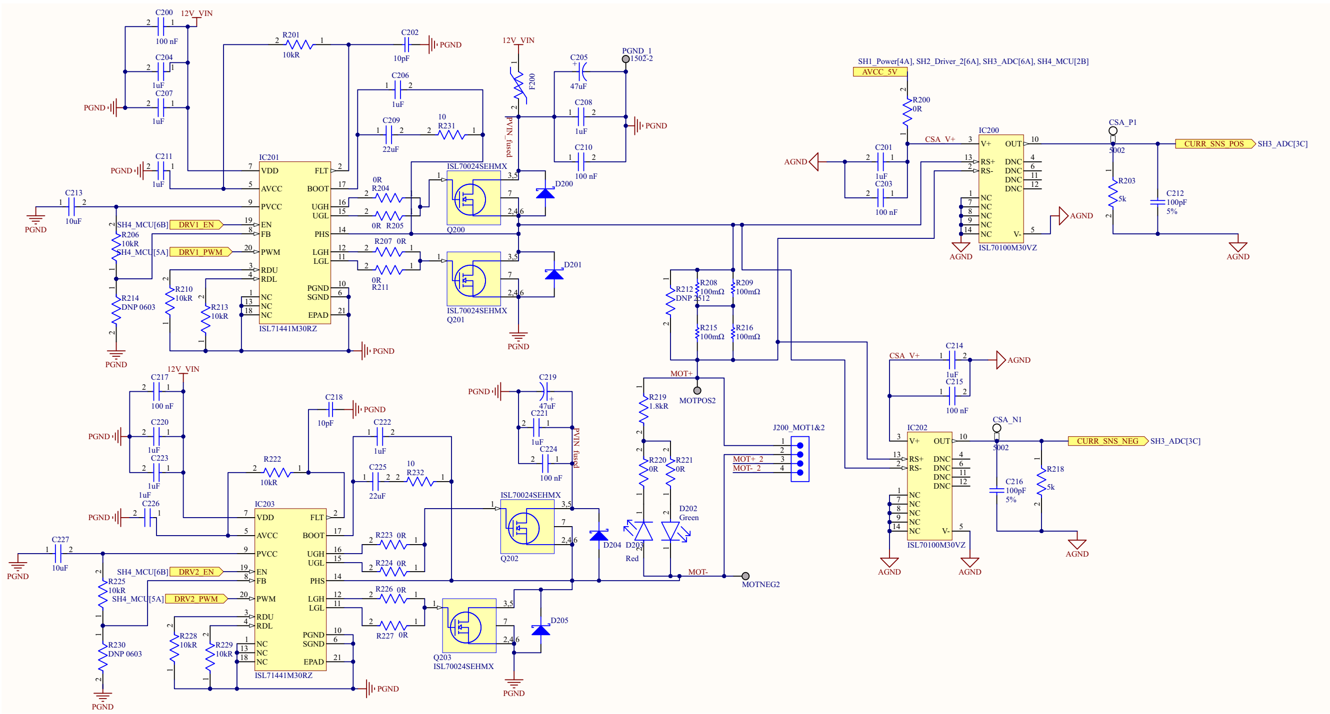

Figure 8. Driver Circuit 1

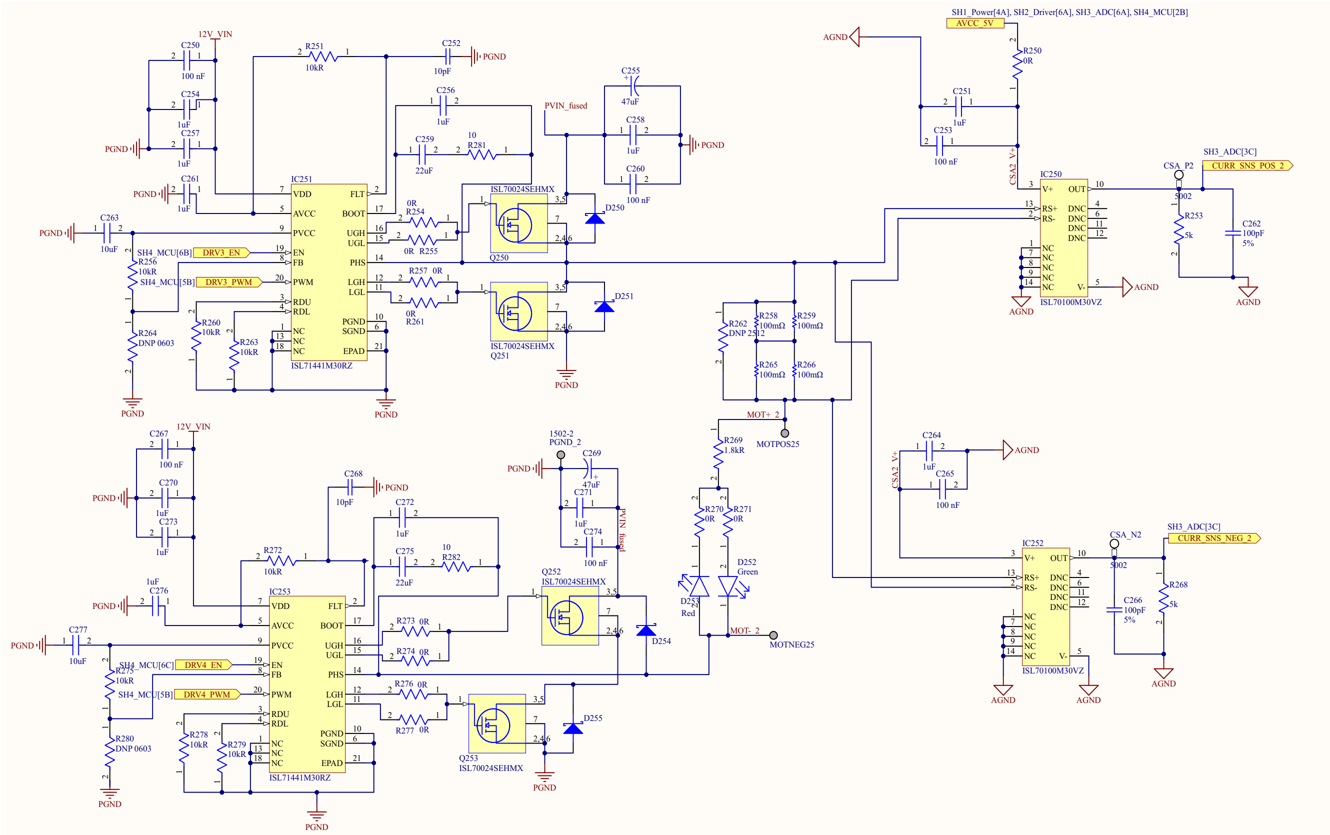

Figure 9. Driver Circuit 2

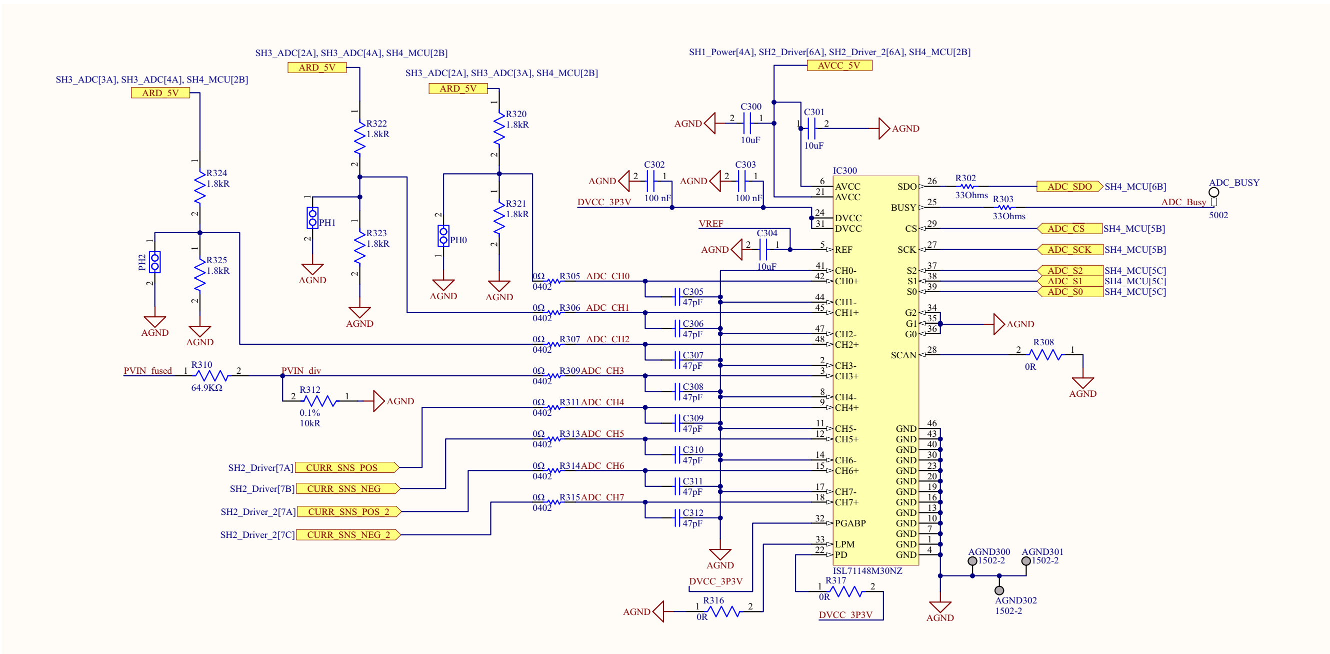

Figure 10. ADC

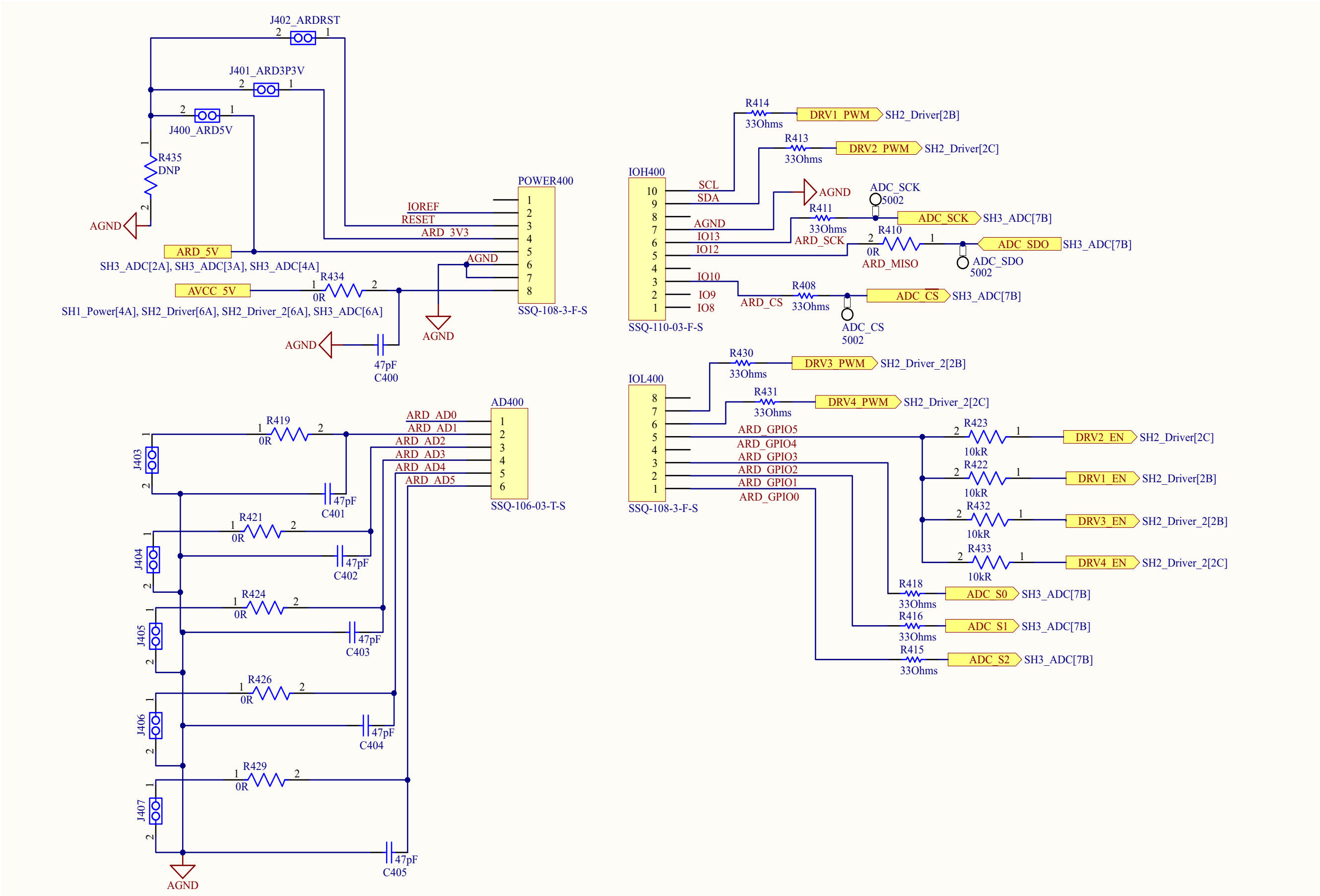

Figure 11. MCU Connections

2.2 Bill of Materials

Qty	Reference Designator	Description	Manufacturer	Manufacturer Part
1	AD400	Conn Header Vert 6POS 2.54MM	Wurth Elektronik	61300611121
1	IOH400	Conn Header Vert 10POS 2.54MM	Wurth Elektronik	61301011121
2	IOL400, POWER400	Conn Header Vert 8POS 2.54MM	Wurth Elektronik	61300811121
9	AGND300, AGND301, AGND302, MOTNEG2, MOTNEG25, MOTPOS2, MOTPOS25, PGND_1, PGND_2	Terminal DBL Turret, Through Hole, RoHS	Keystone Electronics	1502-2
3	AVCC_TP100, DVCC_TP100, VREF100	PC Test Point Miniature	Keystone Electronics	5019
8	ADC_BUSY, ADC_CS, ADC_SCK, ADC_SDO, CSA_N1, CSA_N2, CSA_P1, CSA_P2	PC Test Point Miniature White	Keystone Electronics	5002
1	C100	Ceramic Capacitor 22µF 25V X5R 0805	Murata	GRT21BR61E226ME13L
4	C104, C105, C108, C109	Multilayer Ceramic Capacitors 0.15µF 10% 0805	Kyocera AVX	08055C154KAT2A

Qty	Reference Designator	Description	Manufacturer	Manufacturer Part
4	C102, C103, C106, C107	Tantalum Capacitors - Solid SMD 35V 33µF 10% 2917	Kyocera AVX	TPME336K035R0065
2	C110, C111	General Purpose Ceramic Capacitor, 1210, 4.7µF, 10%, X7R, 15%, 50V	Kyocera AVX	12105C475KAT2A
2	C112, C113	Ceramic Capacitor 1µF 25V X7R 10% Pad SMD 0805 +125°C Automotive T/R	TDK	CGA4J1X8R1E105K125AC
3	C114, C115, C116	Multilayer Ceramic Capacitors 100nF ±10% 75V X7R SMD 0603	TDK	C1608X7R1H104K080AA
14	C200, C203, C210, C215, C217, C224, C250, C253, C260, C265, C267, C274, C302, C303	Ceramic Capacitor 0.1µF 25V X7R 0603	YAGEO	CC0603KRX7R8BB104
24	C201, C204, C206, C207, C208, C211, C214, C220, C221, C222, C223, C226, C251, C254, C256, C257, C258, C261, C264, C270, C271, C272, C273, C276	Multilayer Ceramic Capacitors 1µF ±10% 25V X7R SMD 0805	TDK	C2012X7R1E105K125AB
4	C202, C218, C252, C268	Chip Capacitor, 10 pF, ±5%, 50 V, -55 to 125°C, 0603 (1608 Metric), RoHS, Tape and Reel	Yageo	CC0603JRNPO9BN100
4	C205, C219, C255, C269	Capacitor TANT POLY 47µF 35V 2917	KEMET	T521X476M035ATE030
7	C213, C227, C263, C277, C300, C301, C304	Capacitor Ceramic 10µF 25V X7R ±10% SMD 1206 +125°C Embossed T/R	Samsung	CL31B106KAHNNWE
4	C209, C225, C259, C275	Capacitor Ceramic 22µF 25V X6S 1206	Murata	GRM31CC81E226KE11L
4	C212, C216, C262, C266	Chip Capacitor, 100pF, ±5%, 50V, -55 to 125°C, 0603 (1608 Metric), RoHS, Tape and Reel	Yageo	CC0603JRNPO9BN101
14	C305, C306, C307, C308, C309, C310, C311, C312, C400, C401, C402, C403, C404, C405	Capacitor Ceramic 47pF 50V C0G/NP0 0402	Murata	GRM1555C1H470JA01D
1	D100	LED Green Clear Chip SMD	Lite-On Inc	LTST-C190GKT
8	D200, D201, D204, D205, D250, D251, D254, D255	Diode Schottky 40V 1A SOD123	Diodes Inc.	1N5819HW-7-F
2	D202, D252	LED Green Clear SMD	Lite-On Inc	LTST-C170GKT
2	D203, D253	LED Red Clear SMD	Lite-On Inc	LTST-C170KDKT
1	F200	PTC Reset Fuse 33V 1.5A 2920	Littelfuse Inc.	2920L150DR
2	GND100, VIN_100	Banana Jack, Non-Insulated, 1-Pin THD, RoHS, Bulk	Keystone	575-8
1	J100	2.5 mm Center Pin, 2.5 A, Right Angle, Through Hole, Tapered Pins, DC Power Jack Connector	Same Sky	PJ-102B

Qty	Reference Designator	Description	Manufacturer	Manufacturer Part
1	J200_MOT1&2	Conn Header Vert 4POS 2.54MM	Wurth Elektronik	61300411121
11	J400_ARD5V, J401_ARD3P3V, J402_ARDRST, J403, J404, J405, J406, J407, PH0, PH1, PH2	Conn Header Vert 2POS 2.54MM	Sullins	PBC02SAAN
21	R100, R201, R206, R210, R213, R222, R225, R228, R229, R251, R256, R260, R263, R272, R275, R278, R279, R422, R423, R432, R433	Resistor Thick Film, 10kΩ, 1%, 0.1W, 100ppm/°C, 0603, DNP	Vishay	CRCW060310K0FKEB
1	R101	Resistor SMD 33kΩ 1% 1/10W 0603	Panasonic	ERJ-3EKF3302V
1	R102	Resistor SMD 49.9kΩ 1% 1/10W 0603	Panasonic	ERJ-3EKF4992V
32	R200, R204, R205, R207, R211, R220, R221, R223, R224, R226, R227, R250, R254, R255, R257, R261, R270, R271, R273, R274, R276, R277, R308, R316, R317, R410, R419, R421, R424, R426, R429, R434	Resistor SMD 0Ω JUMPER 1/4W 0603	Vishay Dale	RCS06030000Z0EA
4	R231, R232, R281, R282	Thick Film Resistors - SMD 0.33W 10ohms 1% High Power	Vishay Dale	CRCW060310R0FKEAHP
5	R203, R218, R253, R268, R312	Resistor SMD 10kΩ 0.1% 1/10W 0603	Bourns	CRT0603-BY-1002ELF
8	R208, R209, R215, R216, R258, R259, R265, R266	Resistor 0.1Ω 1% 1/4W 1206	Vishay Dale	WSL1206R1000FEA
8	R219, R269, R320, R321, R322, R323, R324, R325	Resistor SMD 1.8kΩ 1% 1/10W 0603	Yageo	RC0603FR-071K8L
11	R302, R303, R408, R411, R413, R414, R415, R416, R418, R430, R431	Resistor 33Ω 1% 1/10W 0603	Yageo	RC0603FR-0733RL
8	R305, R306, R307, R309, R311, R313, R314, R315	Resistor 0Ω JUMPER 1/16W 0402	Yageo	RC0402JR-070RL
1	R310	Resistor SMD 64.9kΩ 0.1% 1/8W 0805	Yageo	RT0805BRD0764K9L
2	U100, U101	Renesas Radiation-Tolerant Ultra Low Noise LDO	Renesas	ISL75054M30VZ
1	U102	Renesas Ultra Low Noise, 2.5V Precision Voltage Reference	Renesas	ISL71010BMB25Z
4	IC200, IC202, IC250, IC252	Renesas Radiation Hardened 40V Current Sense Amplifier	Renesas	ISL70100M30VZ
4	IC201, IC203, IC251, IC253	Renesas Radiation-Tolerant 12V Half-Bridge GaN FET Driver	Renesas	ISL71441M30RZ
1	IC300	Renesas Radiation-Tolerant 8-Channel 14-Bit 900/480ksps SAR ADC	Renesas	ISL71148M30NZ
8	Q200, Q201, Q202, Q203, Q250, Q251, Q252, Q253	Renesas 200V, 7.5A Enhancement Mode GaN Power Transistor	Renesas	ISL70024SEHMX

2.3 Board Layout

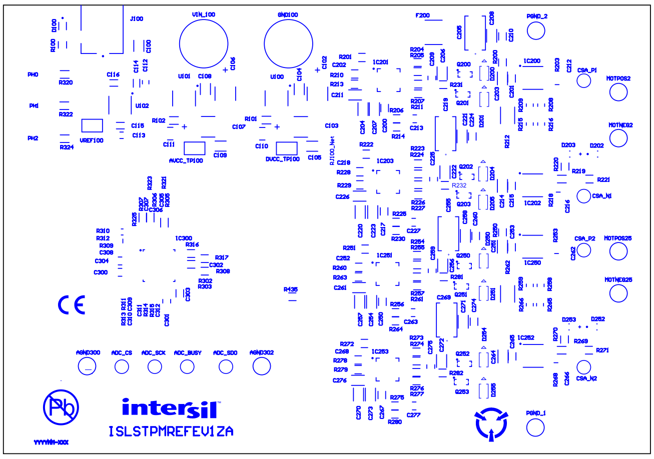

Figure 12. Top Silkscreen

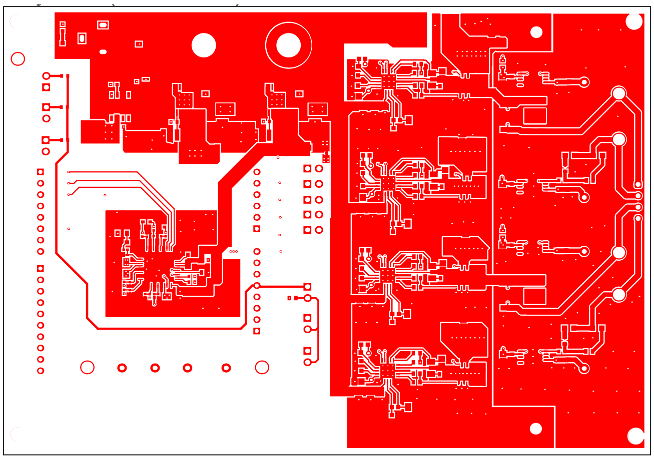

Figure 13. Top Layer

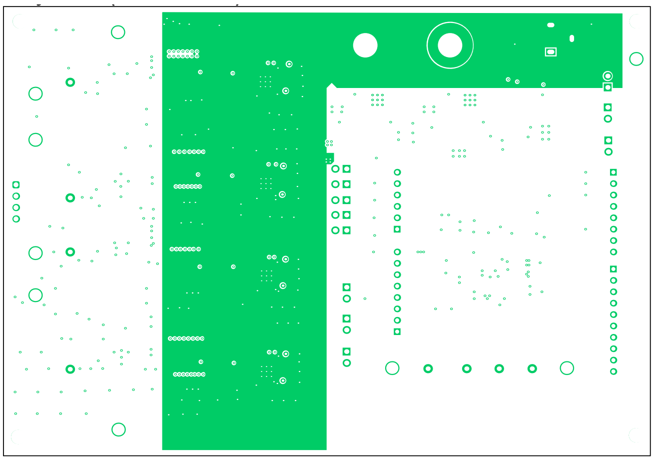

Figure 14. Layer 2

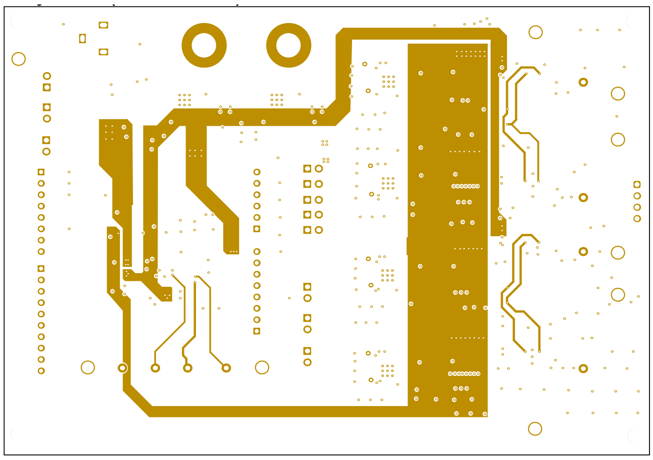

Figure 15. Layer 3

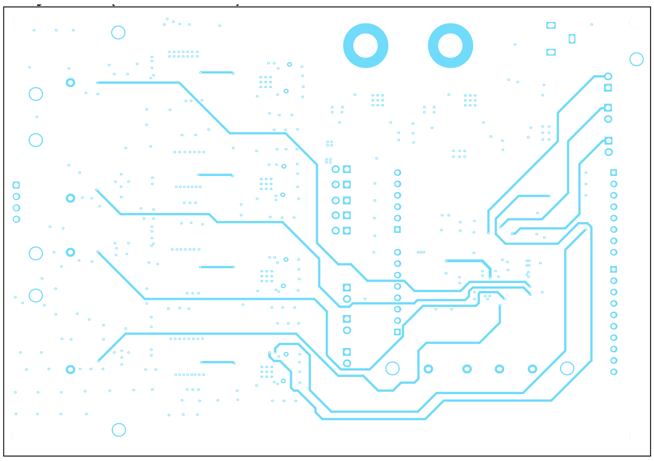

Figure 16. Layer 4

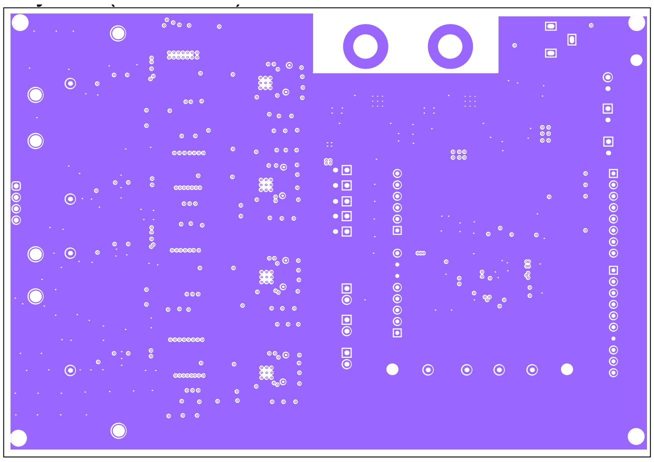

Figure 17. Layer 5

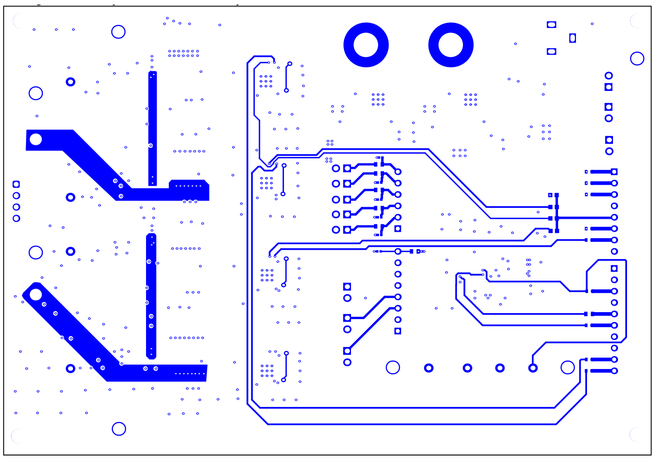

Figure 18. Bottom Layer

3. Ordering Information

Part Number	Description
ISLSTPMREFEV1Z	Radiation Tolerant Stepper Motor Reference Design

4. Revision History

Revision	Date	Description
1.00	Jul 14, 2026	Initial release.

Corporate Headquarters

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