RIC70849EVAL1 user guide

Single phase buck converter with RH GaN HEMTs

About this document

Scope and purpose

RIC70849 is a buck controller with integrated gate drivers and is intended for use in DC/DC power conversion applications such as point of load (PoL) rails and optimized for GaN HEMTs. This evaluation board is designed to help the user evaluate RIC70849 with a Schottky Gate GaN HEMT. It comes prepopulated with two 100V RH IG1NT052N10R GaN HEMT. This user manual includes overview, setup instructions, schematic, printed circuit board layout drawings and bill of material.

Intended audience

The intended audience for this document is design engineers, technicians and developers of DC/DC power converters for PoL applications who are looking to evaluate and design RIC70849 for their application.

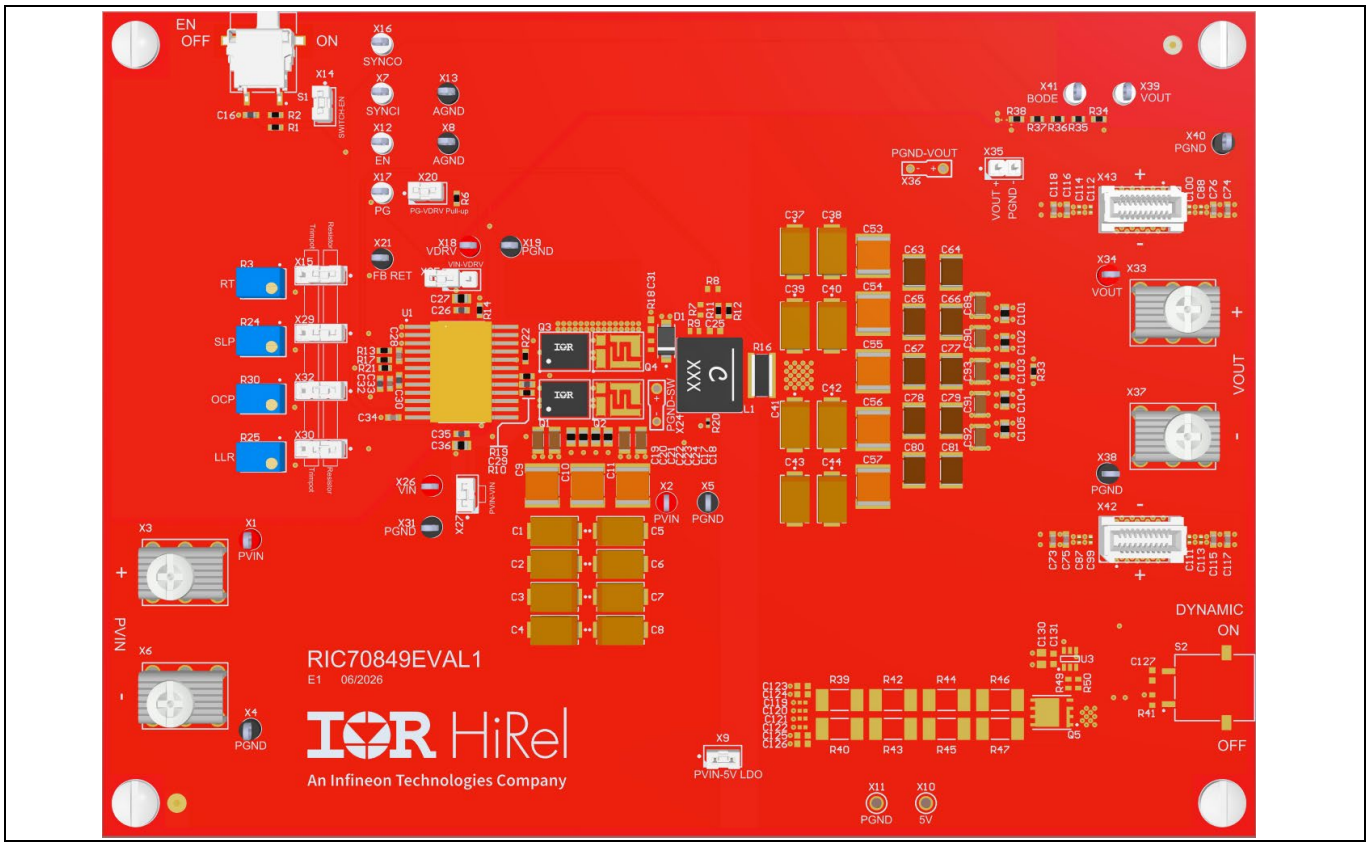

Figure 1 RIC70849EVAL1

Table 1 Safety precautions

	**Warning:** Operation under certain conditions may cause the board to become hot. Ensure that all safety precautions are followed before handling.

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1 Introduction

https://www.infineon.com/part/RIC70847FRIC70849 is a buck controller with integrated 4.8 V half bridge gate driver, and is intended to work with GaN HEMT such as IG1NT052N10R. RIC70849EVAL1 demonstrates the performance of RIC70849 for PoL of space grade FPGA core rails like AMD® Versal XQRV2302 0V80 rail, XQR1902 AI rail, AMD® (former Xilinx®) XQRKU060 VCCINT rail, Microchip® RT PolarFire VDD rail and NanoXplore® NG-Ultra VDDCORE rail. This board is pre-populated with rad hard GaN HEMT IG1NT052N10R.

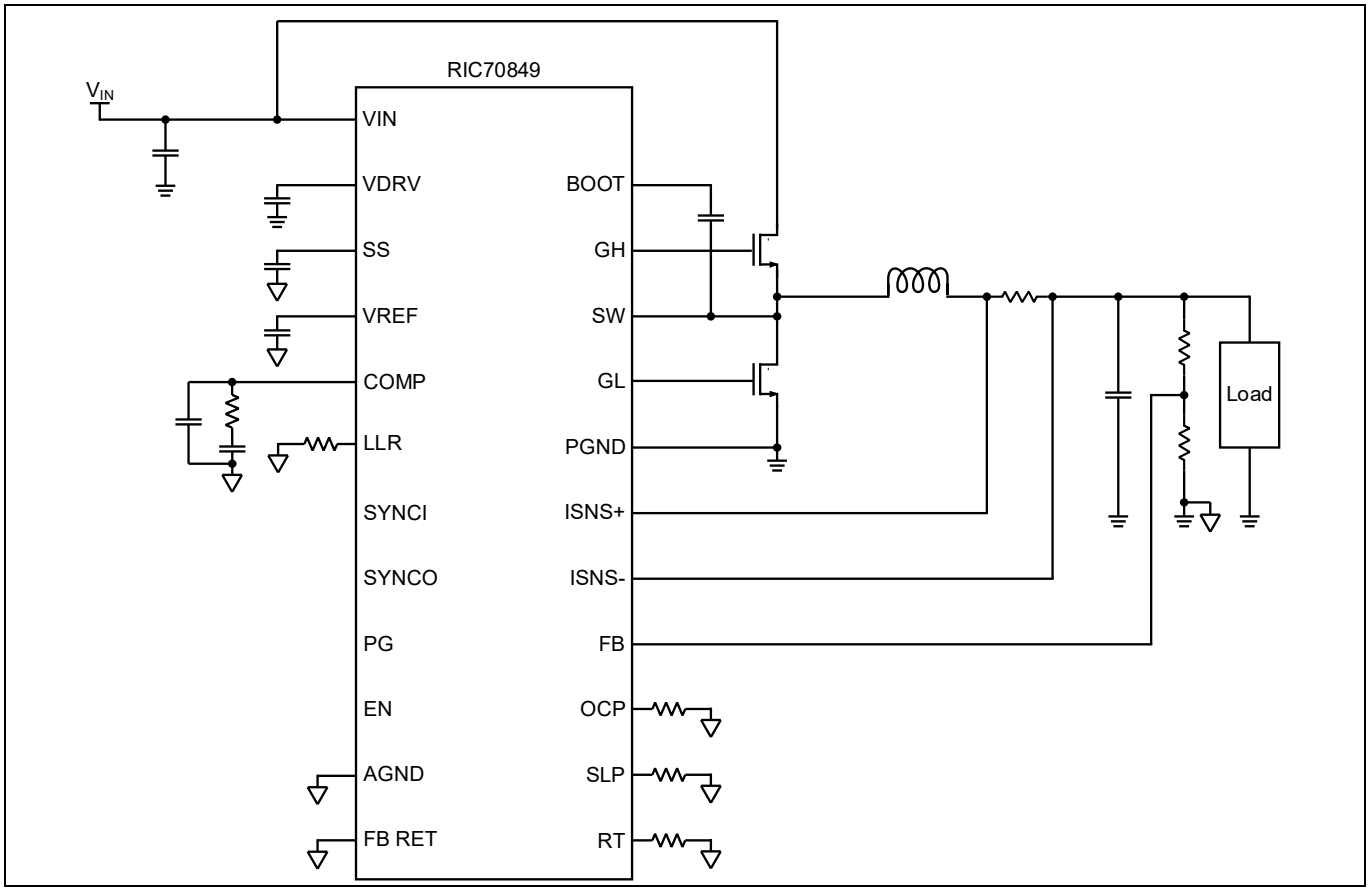

Figure 2 Simplified schematic of RIC70849EVAL1

1.1 Feature list

RIC70849EVAL1 is optimized for ease of use for both measurement in various configurations and modifications. Key features include:

- Easy connection to power source, load and measurement probes to allow for configuration to different states with improved measurement accuracy
- Optional potentiometers for easy adjustment of pin-strap resistor programmed parameters:
  - load line regulation (LLR)
  - Overcurrent limit (OCP)
  - Slope compensation (SLP)
  - Switching frequency (RT)
- Supports a wide range of inductor size and inductance with large footprint
- Supports a wide range of output capacitance values with numerous capacitor footprints in multiple package size

- Simplified ability for transient testing with an on-board dynamic load step circuit which features high slew rates typical of PoL applications
- “Near-flight-like configuration” with commercial off-the-shelf (COTS) equivalent of flight grade components used for key parameters (e.g. output inductor, output capacitor, input capacitor)

1.2 Recommended operating conditions

For proper operation, the device should be used within the recommended operating conditions. All voltage parameters are referenced to PGND=AGND=FB RET unless otherwise stated. Additionally, refer to the RIC70849 datasheet for recommended and maximum operating limits for RIC70849.

Table 2 RIC70849EVAL1 recommended operating conditions

Parameter	Symbol	Values			Unit
		Min.	Typ.	Max.	
Input voltage	V_{IN}		5, 12		V
VDRV voltage	V_{DRV}		4.8		V
EN rising threshold	V_{EN+}		0.92		V
EN falling threshold	V_{EN-}		0.77		V
Overcurrent threshold	V_{OCP}		1.215		V
Reference voltage	V_{REF}		600		mV
Output voltage	V_{OUT}		0.8		V
Output current	I_{OUT}			40	A
Switching frequency	f_{SW}		500		kHz

2 Functional description

2.1 Power input

RIC70849EVAL1 requires power input for the power stage (PVIN), RIC70849 bias (VIN) and the on-board dynamic load (if used).

2.1.1 Power stage (PV_{IN})

High current screw terminals X3 (PVIN) and X6 (PGND) are intended for input power connection for PVIN. Test points X1 (PVIN) and X4 (PGND) are adjacent to these screw terminals for measurement connections, such as the sense inputs for any power supply with 4-wire sensing. Additional test points X2 (PVIN) and X5 (PGND) are recommended for efficiency measurements.

2.1.2 RIC70849 bias (V_{IN})

The bias power for RIC70849 through the VIN pin can be supplied from the power stage (PVIN) or from a separate external supply. To power RIC70849 from PVIN, jumper X27 needs to be populated with a shunt connector. To power RIC70849 from a separate source, jumper X27 needs to be left open and power connection applied from X26 (VIN) to X31 (PGND).

When VIN=4.8V and RIC70849 is under certain bias configurations, the voltage drop of the internal LDO of RIC70849 may cause the VDRV pin voltage to be lower than desired. To overcome this, an external voltage may be applied to the VDRV pin to keep the voltage sufficiently high. If an external voltage is applied to the VDRV pin, it is recommended to apply the same voltage to the VIN pin as well. To connect the VIN pin to the VDRV pin on RIC70849EVAL1, the jumper X25 needs to be populated with a shunt connector.

Attention: The absolute maximum rating of the VDRV pin is lower than the VIN and PVIN pins. If a shunt connector is populated on jumper X26, ensure that the voltage on the VIN pin (and the PVIN pin if jumper X26 has a shunt connector) never exceeds the absolute maximum rating of the VDRV pin.

Table 3 Summary of various input power configuration options for RIC70849EVAL1

Configuration	VDRV power	Recommended operating range	Jumper X27 state	Jumper X25 state
PVIN=VIN	Internal (RIC70849 LDO)	PVIN=VIN=5 V to 12 V	Short	Open
PVIN≠VIN	Internal (RIC70849 LDO)	PVIN =3 V to 12 V VIN =5V to 12V	Open	Open
PVIN=VIN	External (VIN=VDRV)	PVIN = VIN =5 V	Short	Short
PVIN≠VIN	External (VIN=VDRV)	PVIN =3 V to 12 V VIN =5 V	Open	Short

2.1.3 GaN HEMTs parallel operation

RIC70849EVAL1 has Q2 and Q4 placeholders that allow the user to connect a second IG1NT052N10R GaN HEMT at the low and high side of the half bridge of the buck converter. Parallel operation reduces the R_{SDON} of GaN HEMT when is conducting current and spreads the power dissipation heat. This leads to lower conduction losses, higher efficiency and better thermal performance.

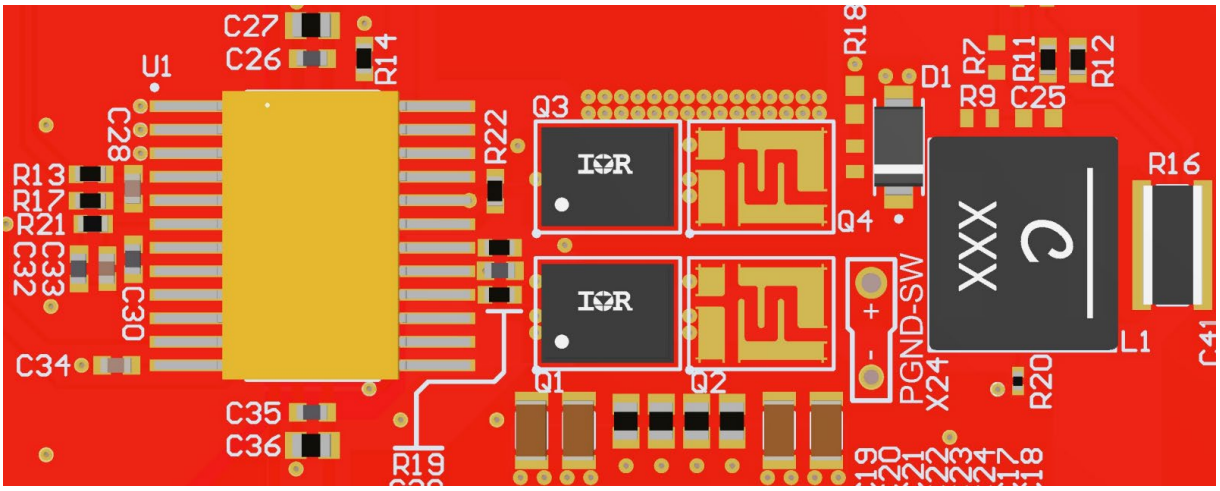

Figure 3 Q2 and Q4 placeholders for parallel operation

2.1.4 On-board dynamic load

The on-board dynamic load requires a 5 V power supply to operate. This 5 V power can either be provided by a separate power supply connected from X10 (5 V) to X11 (PGND), or from PVIN through an LDO (G1) on RIC70849EVAL1. If the on-board dynamic load is used and it is desired to power the circuit from PVIN, a shunt connector needs to be populated on jumper X9. If the on-board dynamic load is not used, or is used with an external power supply, it is recommended to leave jumper X9 open.

Attention: For the most accurate efficiency measurements where transient testing with on-board dynamic load is not used, leave jumper X9 unpopulated (open) and use an external load

2.2 Output

High current screw terminals X33 (VOUT) and X37 (PGND) are intended for output power connection. Test points X34 (VOUT) and X38 (PGND) are adjacent to them and intended for DC measurements. For AC measurements of the output voltage, such as voltage ripple or peak overshoot/undershoot during transient testing, the 100 mil header X35 may be used. This header (X35) allows for direct connection with high bandwidth, low capacitance active differential probes. Additionally, test point X36, which are adjacent to X35, is intended to be used with a typical oscilloscope probe with probe tip ground spring to improve measurement accuracy.

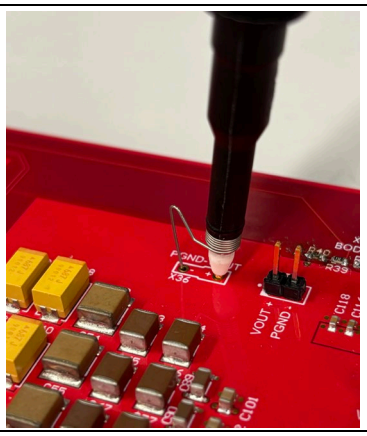

Figure 4 Example probe connection on test point X36

2.2.1 Dynamic load

RIC70849 is intended to power loads, like core rail power for FPGA and ASIC, which have dynamic current load step with high slew rates. These slew rates are typically higher than what external loads connected by cable can achieve. To simplify tests for high slew rate transients, RIC70849EVAL1 supports both on-board and external dynamic load circuits.

2.2.1.1 On-board dynamic load

The on-board dynamic load circuit is designed to pulse a 10 A load step at 1 kHz and 50% duty cycle with a turn on/off slew rate of 10 A/µs. This circuit can be used in conjunction with a DC load on the screw terminals X33 (VOUT) and X37 (PGND) to adjust the DC load. For example, a 20 A DC load with the on-board dynamic load enabled will allow for a load step between 20 A to 30 A. To use this circuit, a 5 V bias power supply needs to be provided, detailed in section 2.1.4. Once powered, to enable the dynamic load the switch S2 needs to be set into the “ON” position as indicated on the PCB silkscreen. The dynamic load can be turned off by setting switch S2 into the “OFF” position as indicated on the PCB silkscreen. It is recommended to keep S2 in the “OFF” position when not actively using the on-board dynamic load to prevent the circuit from interfering with other desired operation.

2.2.1.2 External dynamic load

For enhanced dynamic load tests, RIC70849EVAL1 has connectors X42 and X43 at the output to connect with dynamic load modules such as Intel® Mini-Slammer.

2.3 Switch node, GH, GL measurement

For accurate, high bandwidth measurement of important power stage pulse width modulated (PWM) signals from RIC70849, UMCC connectors are provided on RIC70849EVAL1 for switch node (X23), GH (X22) and GL (X28) signals. All of these connectors are referenced to PGND and are on the bottom side of the PCB. These UMCC connectors are intended to connect to an oscilloscope with a cable such as TE Connectivity 2016682-4 and Amphenol RF 095-850-250-024. All UMCC connectors have a 953 Ω resistor in series with the test point. This 953 Ω resistor is in a 0402 package with 63 mW power rating to increase protection of the oscilloscope. To use these UMCC connectors with an oscilloscope, the oscilloscope must be set to 50 Ω termination with an external attenuation of 20×. This allows for the oscilloscope measurement bandwidth to cover the full range the oscilloscope is capable of over the entire operating range of RIC70849EVAL1.

2.4 Bode plot measurement

For bode plot measurements of control loop bandwidth and stability, RIC70849EVAL1 includes test points and a 10 Ω resistor R34 in series with the output voltage divider network for small signal injection. To run a bode plot measurement, the injected voltage can be applied across R34 through test points X39 and X41. The input can be measured from test point X41 (BODE) to X40 (PGND), and the output can be measured from test point X39 (VOUT) to X40 (PGND).

2.5 LLR, OCP, SLP, RT

For pins LLR, OCP, SLP and RT on RIC70849, the external resistor on each pin can either be set with a fixed resistor or with an adjustable potentiometer resistor. The desired operation can be selected by a shunt connector on the respective jumper, details of which are in Table 4. Operating condition for all four pins can be dynamically adjusted while RIC70849 is operating, allowing for performance to be measured as the parameter value is varied.

Table 4 LLR, OCP, SLP, RT setting details

Pin	Function	Resistor mode	Potentiometer mode
RT	Sets standalone operation switching frequency	Shunt connector on pin 1-2 of X15	Shunt connector on pin 2-3 of X15
SLP	Sets slope compensation slope	Shunt connector on pin 1-2 of X29	Shunt connector on pin 2-3 of X29
OCP	Sets overcurrent protection limit	Shunt connector on pin 1-2 of X32	Shunt connector on pin 2-3 of X32
LLR	Sets load line regulation magnitude	Shunt connector on pin 1-2 of X30	Shunt connector on pin 2-3 of X30

2.6 Current sense

RIC70849EVAL1 current sensing can be configured in two ways, either with a resistor in series with the inductor, or direct current resistance (DCR) current sensing. RIC70849EVAL1 comes pre-configured with a resistor in series with the inductor option.

2.6.1 DCR current sensing

DCR current sensing is a technique to use the equivalent series resistance (ESR) of the inductor to measure the inductor current. This allows for higher efficiency since it eliminates the current sense resistor. To use DCR sensing, following changes need to be made to RIC70849EVAL1

- Replace R17 with high current 0 Ω jumper
- Remove R11 and R12 and leave unpopulated
- Populate R7 and R8 with 0 Ω jumpers
- Populate R9 and C25 with desired resistance and capacitance for DCR current sensing. Refer to section 4.6.1.3 in the RIC70849 datasheet for more information on how to select values

2.6.2 Current sense filter

To prevent EMI into the current sense pins, an RC filter is used to attenuate the high-frequency peaks during the switching transitions. A 0603 1nF C28 capacitor in series with a 100Ω R13 R17 resistors are utilized for the current sense filter.

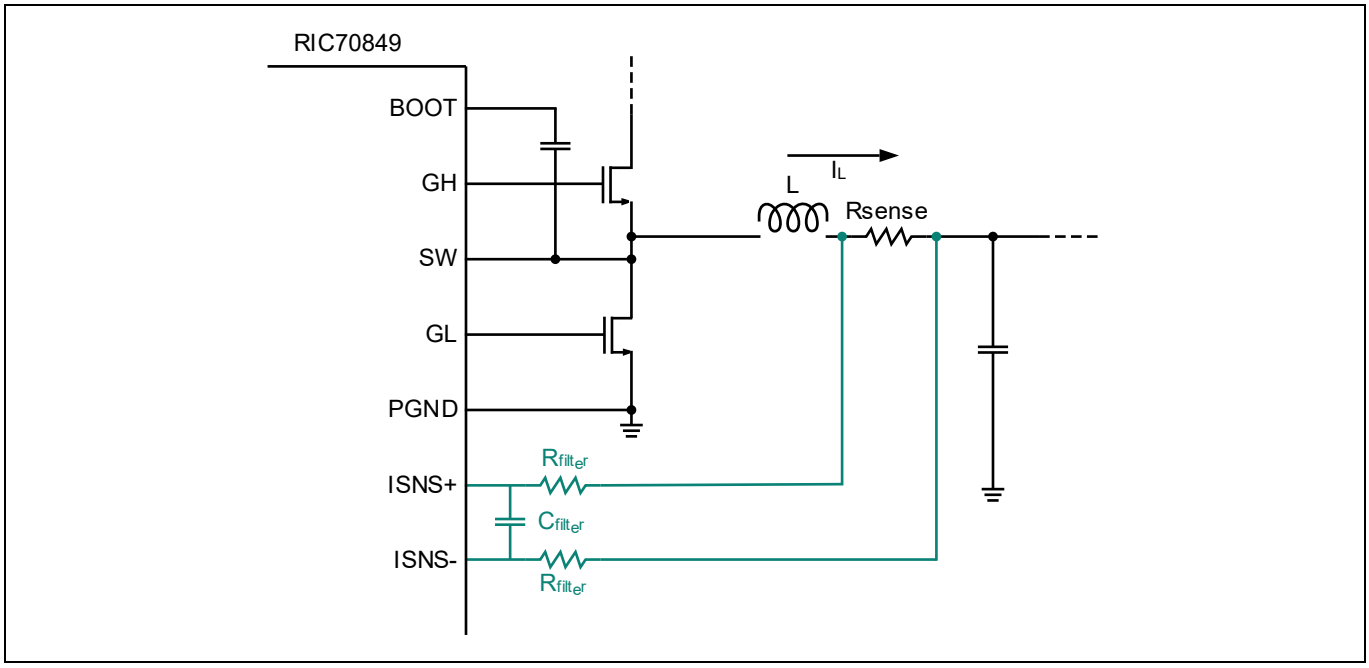

Figure 5 Current sense filter

2.7 External clock operation

The RIC70849EVAL1 switching frequency can either be set by the resistance on the RT pin or an external clock on the SYNCI pin. An external clock can be applied to the RIC70849 SYNCI pin from X7 (SYNCI) to X8 (AGND) or X13 (AGND). Refer to section 4.5.2 in the RIC70849 datasheet for requirements of this external clock signal on SYNCI.

2.8 Enable

RIC70849EVAL1 has an optional 10 kΩ pull up resistor R1 from EN to VDRV that can be used for standalone enabling of operation with a switch S1. If S1 is in the “OFF” position as indicated on the PCB silkscreen, S1 connects EN to AGND and operation of RIC70849 is disabled. If S1 is in the “ON” position as indicated on the PCB silkscreen, S1 is open and EN is pulled up to VDRV through the pull up resistor R1. Switch S1 can be disconnected from the EN pin by removing the shunt connector on jumper X14, allowing external voltage to be applied to EN through X12.

2.9 Power good

RIC70849EVAL1 has an optional 10 kΩ pull up resistor R6 from PG to VDRV. When RIC70849 is operating normally, the PG pin in RIC70849 is open drain and the voltage on PG pin will be pulled up to VDRV. When an event occurs that activates PG, the PG pin in RIC70849 will be pulled to ground. VDRV and the 10 kΩ pull up resistor R6 can be disconnected from PG by removing the jumper populated on X20.

3 Recommended operation

The following equipment is recommended to operate RIC70849EVAL1

- 5 V to 12 V power supply with current capability of at least 10 A at 5 V or 5 A at 12 V
- Electronic load capable of supporting voltage as low as 0.6 V and current of up to 40 A
- Multimeter with voltage and/or current range and accuracy sufficient for desired measurement
- Oscilloscope with a minimum 500 MHz bandwidth

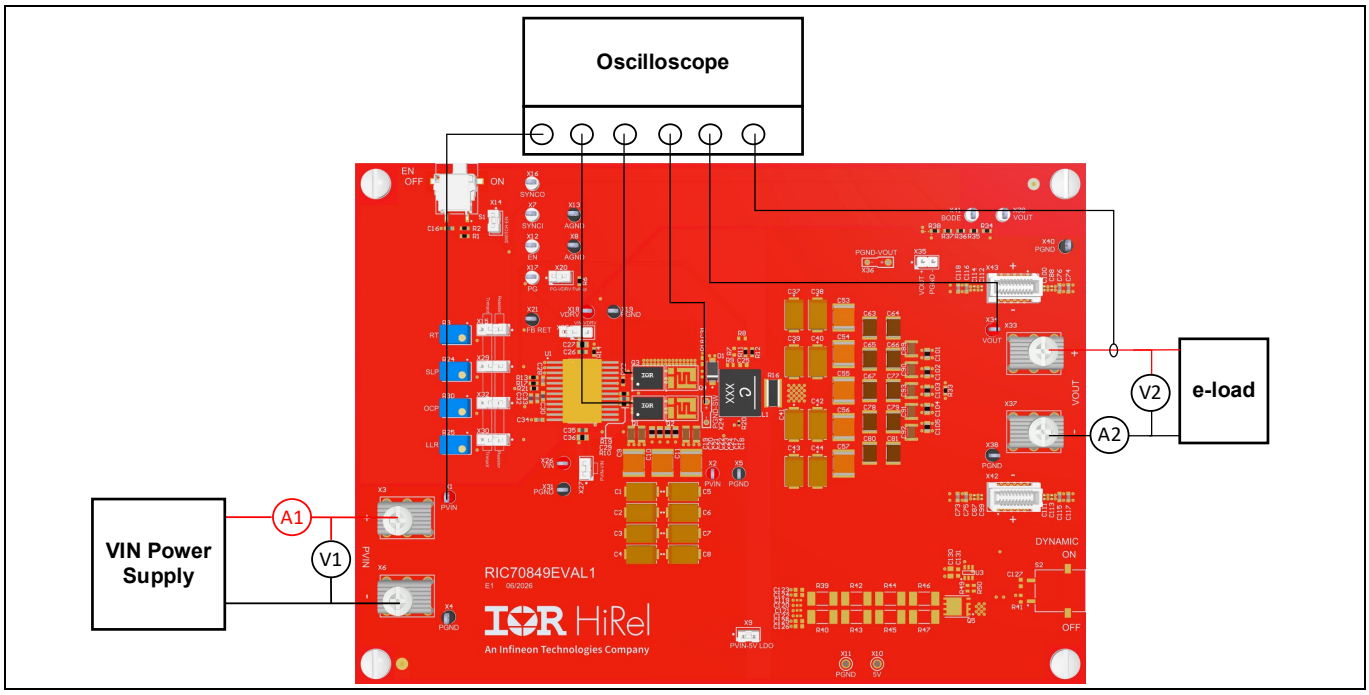

Figure 6 Recommended configuration of RIC70849EVAL1

3.1.1 Power up

The following procedure is recommended for powering up RIC70849EVAL1

1. Connect the PVIN supply, VIN supply (if separate from PVIN), load and measurement probes. Set EN to “OFF” or hold low
2. Enable the PVIN, VIN supplies (if separate from PVIN) and load (if desired)
3. Set EN switch S1 to “ON” or pull EN pin high

3.1.2 Power down

The following procedure is recommended for powering down RIC70849EVAL1

1. Set EN switch S1 to “OFF” or pull EN pin low
2. Disable the PVIN, VIN supplies (if separate from PVIN) and load (if desired)
3. Remove the PVIN supply, VIN supply (if separate from PVIN), load and measurement probes

4 Test Results

4.1 Design notes

RIC70849EVAL1 is designed to support up to 40 A load while meeting voltage regulation requirements in line with space grade FPGAs, such as AMD® Versal XQRV2302 0V80 rail, XQR1902 AI rail, AMD® XQRKU060 VCCINT rails, Microchip® RT PolarFire VDD rail and NanoXplore® NG-Ultra VDDCORE core rail. The target output voltage is 0.8 V ±1% (0.792 V to 0.808 V) but it can be configured to an output voltage range of 0.6 V<Vout<5.25 V. The output filter was designed to be able to handle a load transient with a slew rate of 200 A/us as shown in Figure 16. Load line regulation (LLR) is enabled to improve transient performance.

The output inductor is a 270 nH Coilcraft® XGL1010-271, which is the COTS version of flight grade Coilcraft CPS® AE series. The total output capacitance is 6,994 µF and is split between tantalum and ceramic capacitors. Total capacitance from tantalum capacitors is 6.8 mF and is achieved by paralleling 10 units of 680 µF Kyocera AVX® TPME687M006R0023, which is the COTS version of flight grade Kyocera AVX® TBM family. Total capacitance from ceramic capacitors is 194 µF, which is achieved with a combination of capacitors ranging from 22 µF to 1 uF. All capacitor case sizes, voltage ratings, dielectric materials and capacitances are limited to flight grade units available in Kyocera AVX® MIL-PRF-32535 X7R BME Multi-Layer Ceramic Capacitors (MLCC) family.

4.2 Startup and shutdown results

All tests have parameters PV_{IN}=V_{IN}=5 V and LLR, OCP, SLP and RT set in resistor mode unless otherwise stated. When in resistor mode, LLR is enabled and the switching frequency is set at 500 kHz. GaN HEMTs parallel operation is utilized placing Q2 and Q4 placeholders. For startup and shutdown EN is pulled high and low with an external waveform generator (X14 jumper is removed). A power resistor is used for output load for all tests at full load (I_{OUT}=40 A).

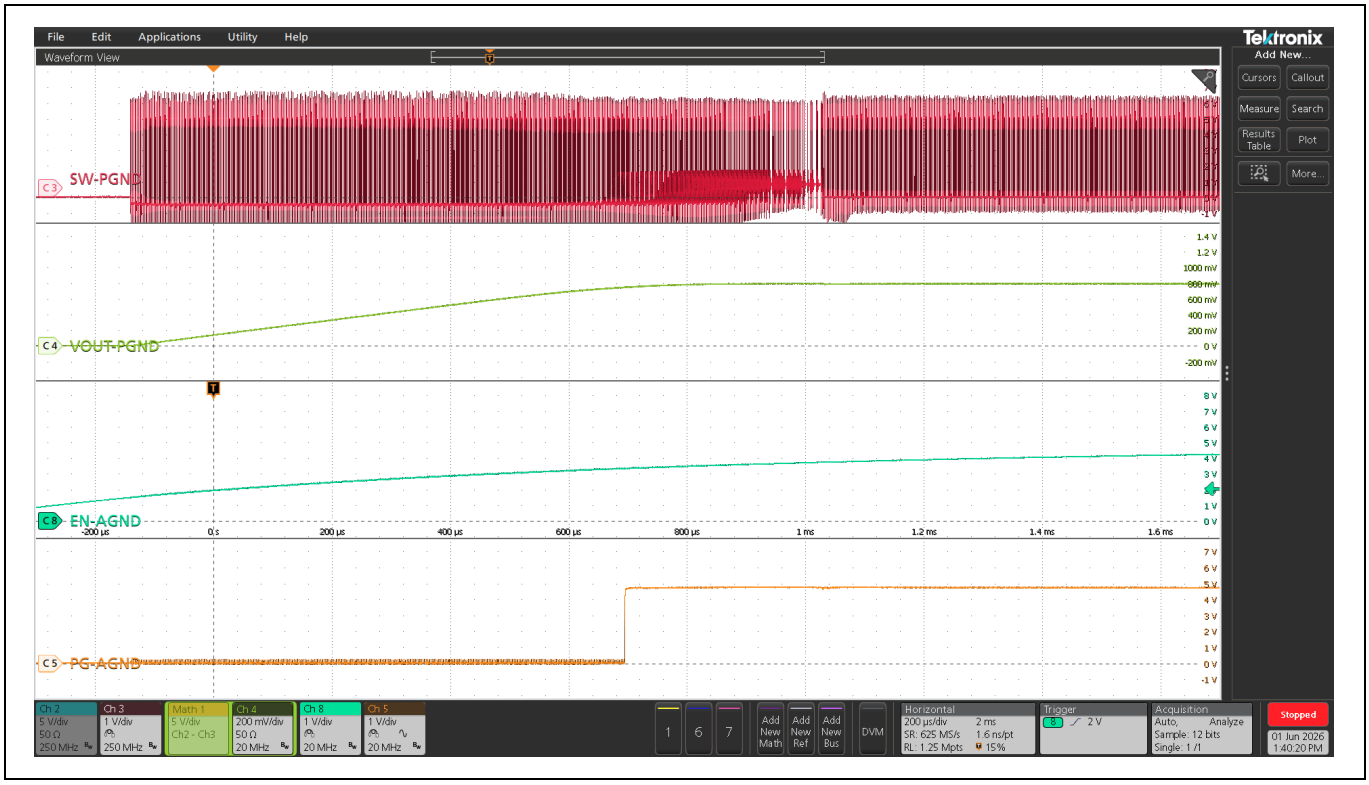

Figure 7 Startup at no load (Iload = 0 A)

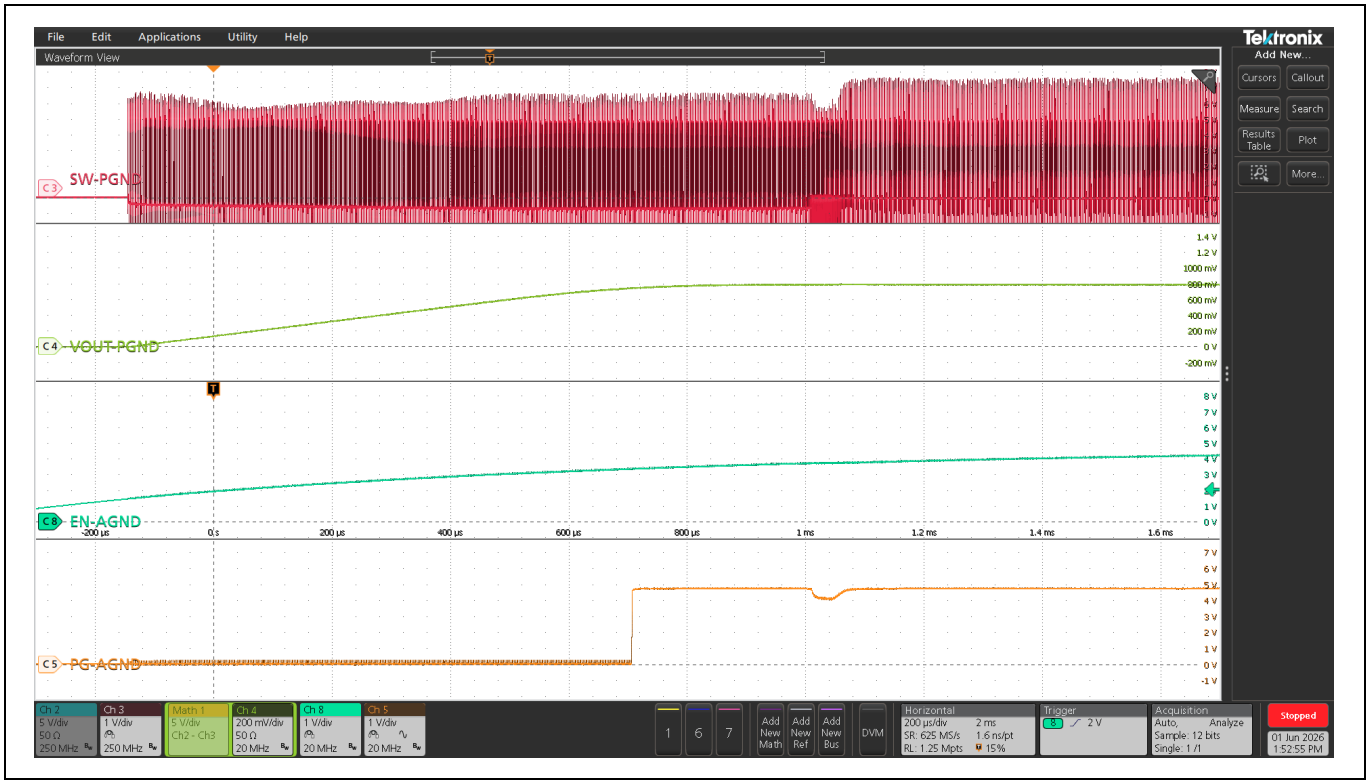

Figure 8 Startup at high load (Iload = 20 A)

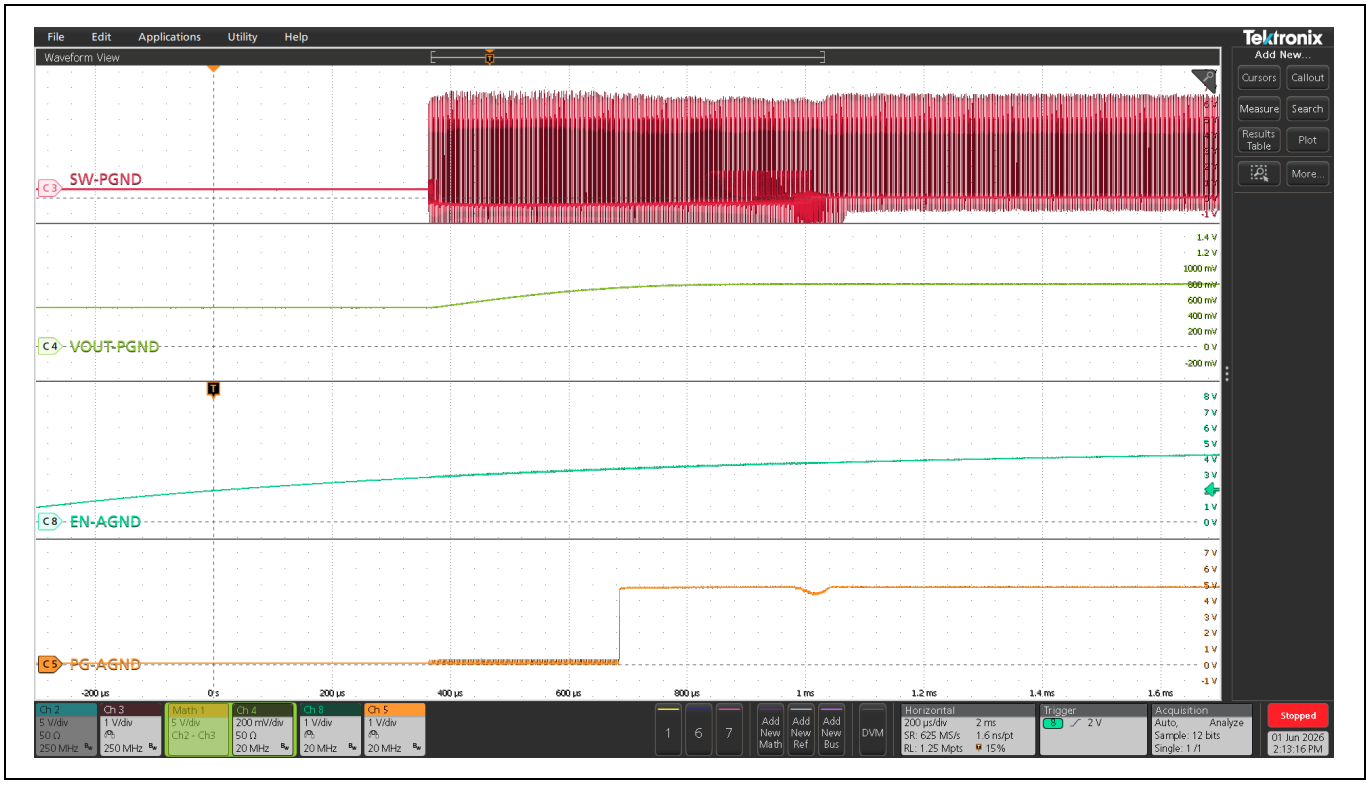

Figure 9 Startup into 0.5 V pre-bias at no load (Iload = 0 A)

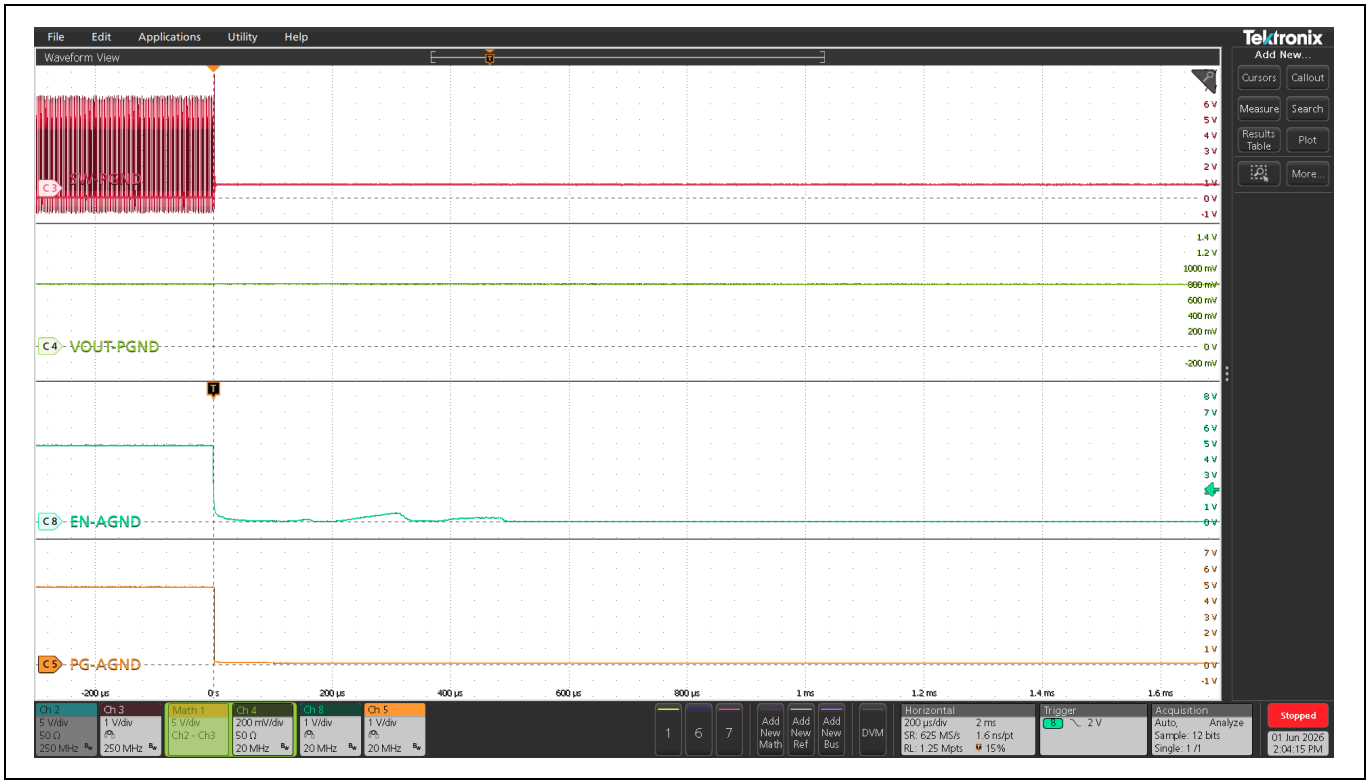

Figure 10 Shutdown at no load (Iload = 0 A)

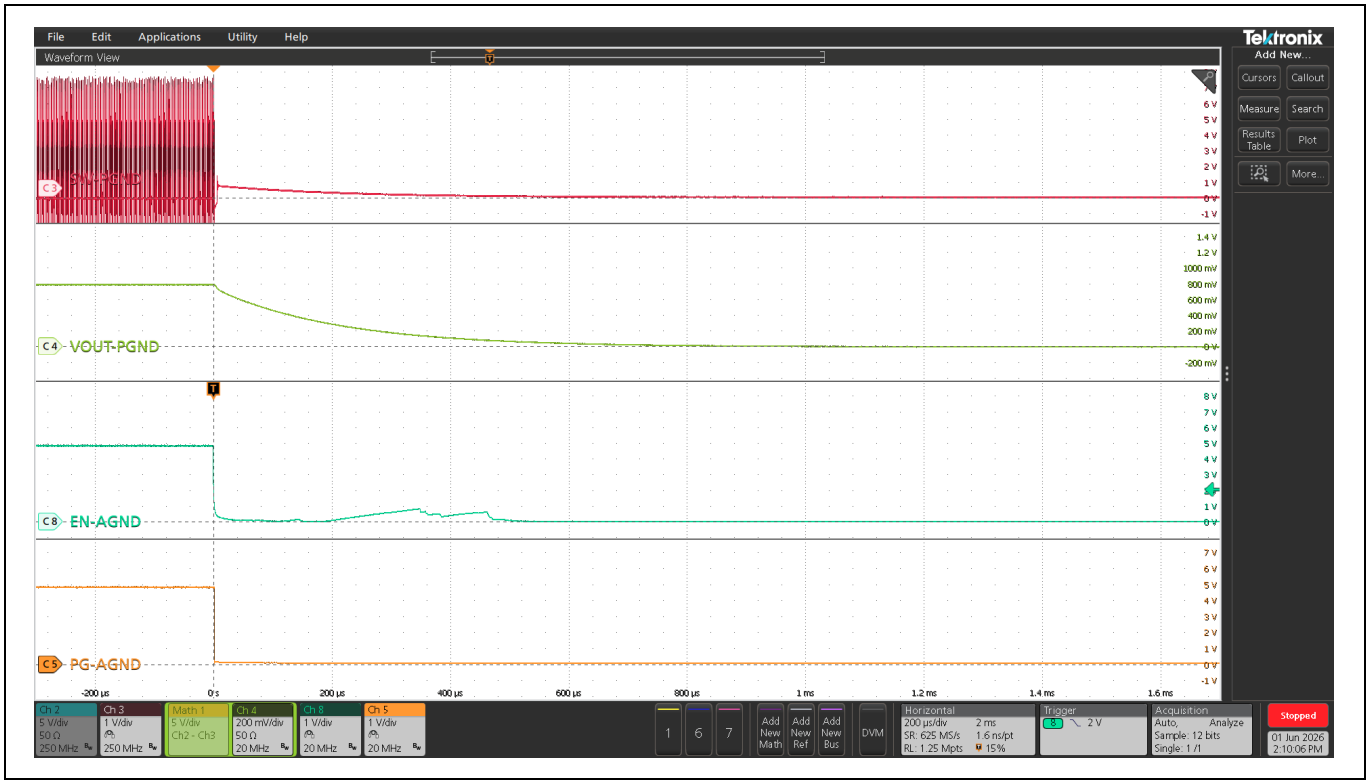

Figure 11 Shutdown at high load (Iload = 20 A)

4.3 Steady State results

All tests have parameters PV_{IN}=V_{IN}=5 V and LLR, OCP, SLP and RT set in resistor mode unless otherwise stated. When in resistor mode, LLR is enabled and the switching frequency is set at 500 kHz. GaN HEMTs parallel operation is utilized placing Q2 and Q4 placeholders. For tests where the LLR feature is disabled, the LLR pin is an open circuit (jumper on X30 is removed).

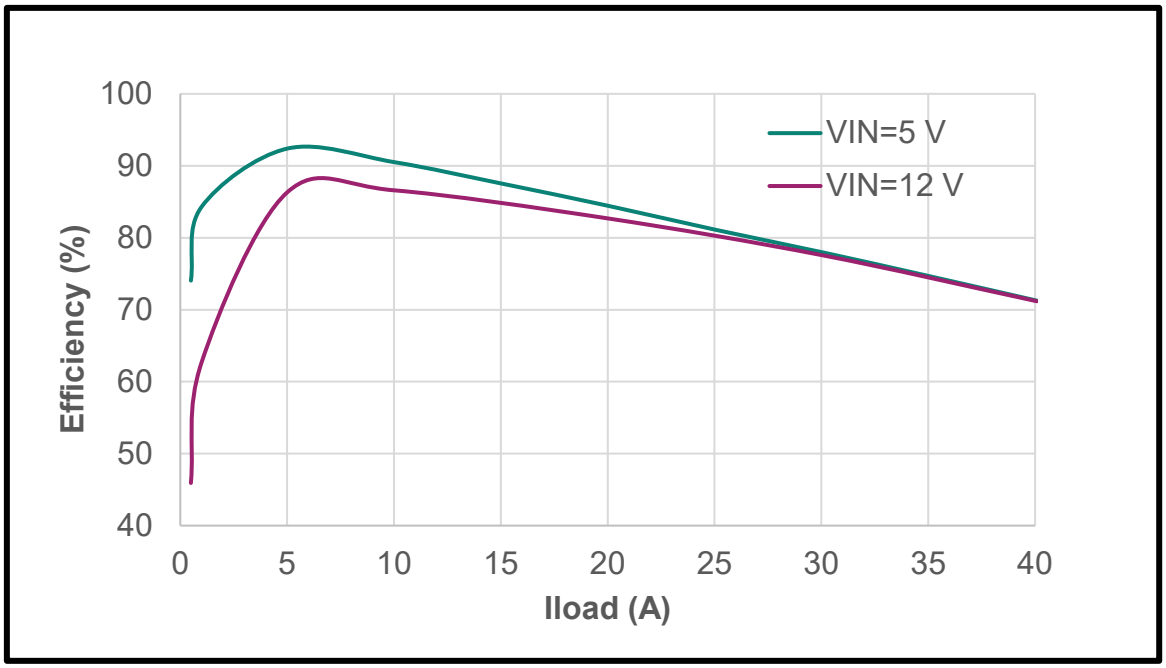

Figure 12 Efficiency over load current

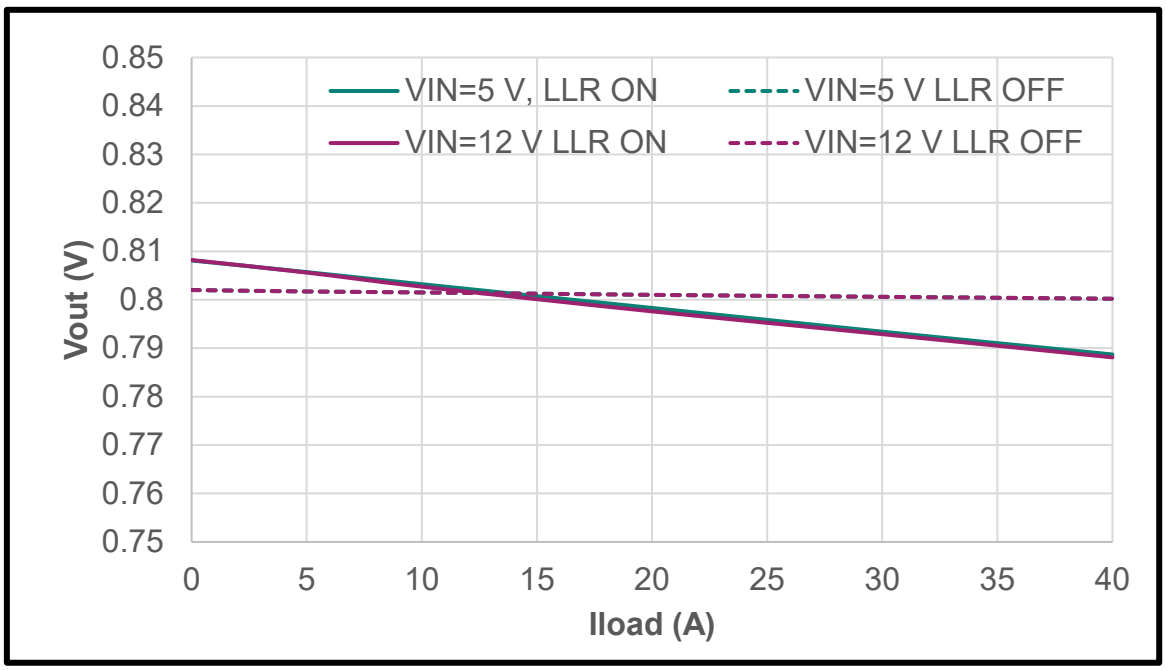

Figure 13 Output voltage over load current

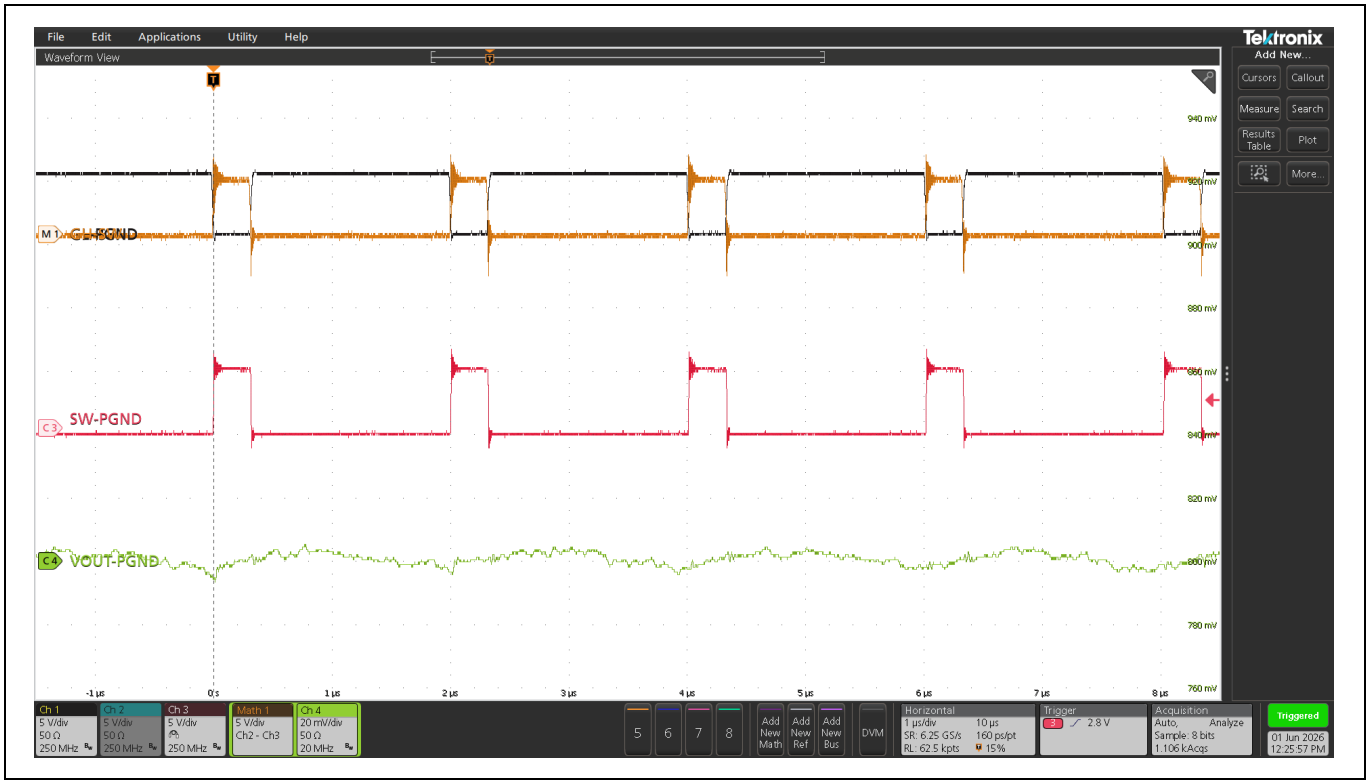

Figure 14 Steady state waveform at no load (Iload=0 A) with LLR enabled

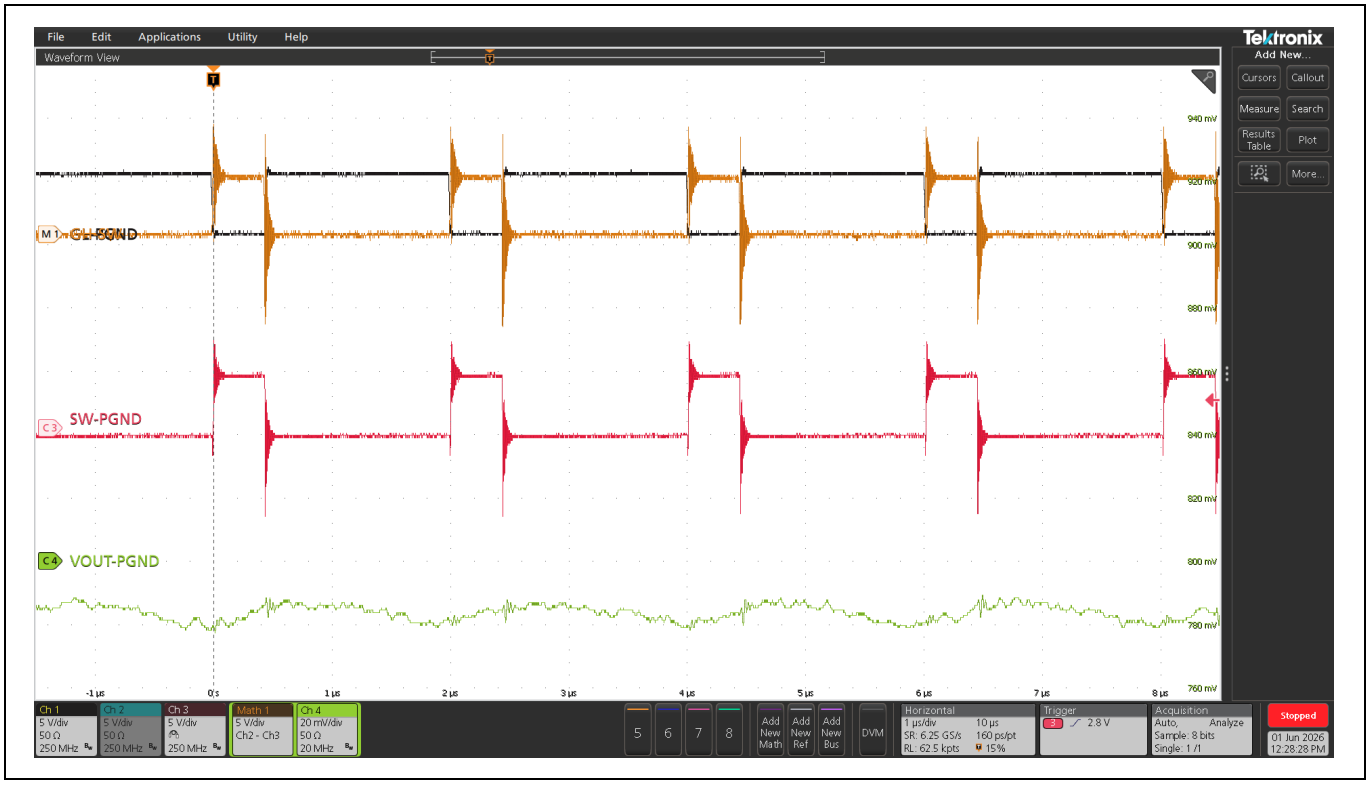

Figure 15 Steady state waveform at high load (Iload=40 A) with LLR enabled

4.4 Transient load step results

All tests have parameters PV_{IN}=V_{IN}=5 V and LLR, OCP, SLP and RT set in resistor mode unless otherwise stated. When in resistor mode, LLR is enabled and the switching frequency is set at 500 kHz. GaN HEMTs parallel operation is utilized placing Q2 and Q4 placeholders. For the load transients, two Intel® 25 A Mini Slammers are used. Figure 16 shows a transient load step that meets the requirements of the AMD XQRV2302 0V80 power rail.

Figure 16 Load transient from Iload=22 A to Iload=37 A with a slew rate of 200 A/us

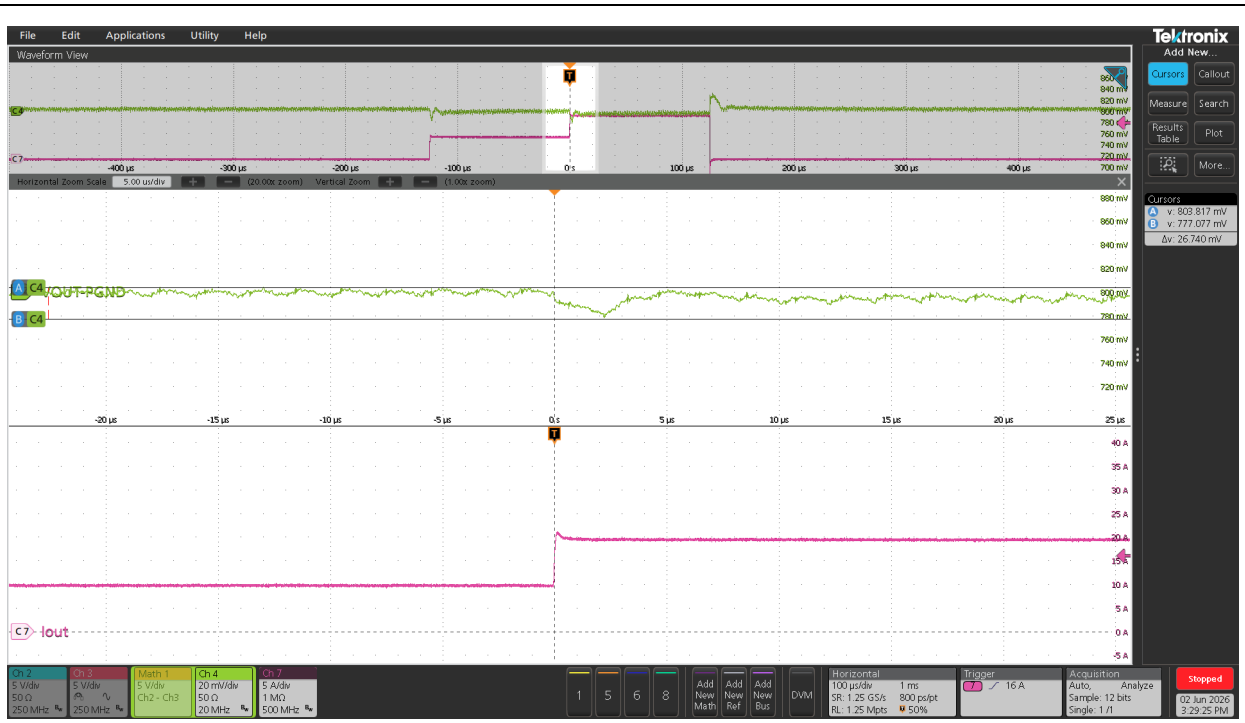

Figure 17 Load transient from Iload=10 A to Iload=20 A with a slew rate of 150 A/us

4.5 Loop gain

All tests have parameters PV_{IN}=V_{IN}=5 V and LLR, OCP, SLP and RT set in resistor mode unless otherwise stated. When in resistor mode, LLR is enabled and the switching frequency is set at 500 kHz. GaN HEMTs parallel operation is utilized placing Q2 and Q4 placeholders. To measure the loop gain, a small signal injection is applied across 10Ω R34 resistor using the Bode 100 hardware and the Bode Analyzer Suite software from Omicron Lab.

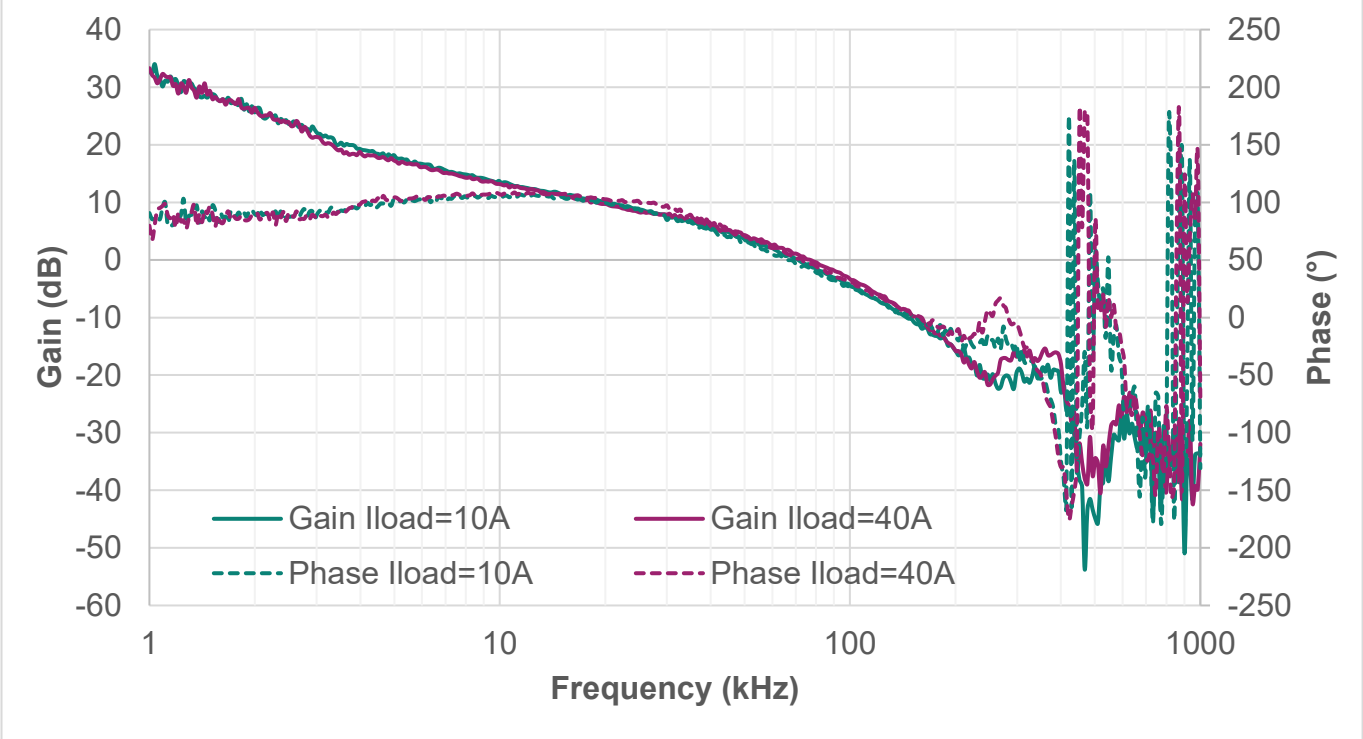

Table 5 Stability parameters

Output current	Cross over frequency	Phase Margin	Gain Margin
10 A	71.1 kHz	46.7°	-11 dB
40 A	76.9 kHz	46.6°	-10.7 dB

4.6 Thermal performance

All tests have parameters PV_{IN}=V_{IN}=5 V and LLR, OCP, SLP and RT set in resistor mode unless otherwise stated. When in resistor mode, LLR is enabled and the switching frequency is set at 500 kHz. GaN HEMTs parallel operation is utilized placing Q2 and Q4 placeholders. The thermal pictures were taken at Ta=25°C and the PCB was running during five minutes so that the temperature of the power devices can settle down.

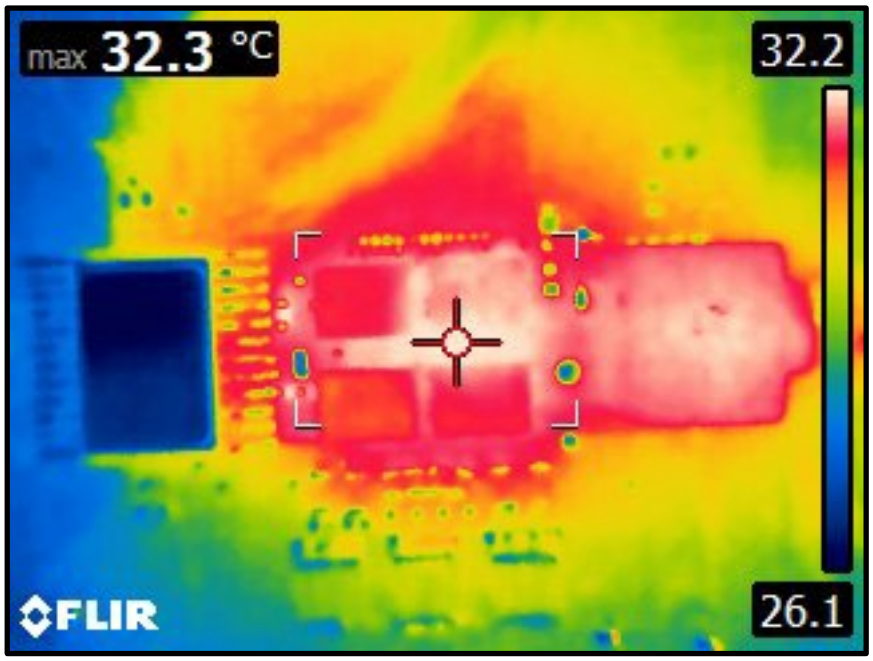

Figure 18 Thermal picture at Iload=10 A

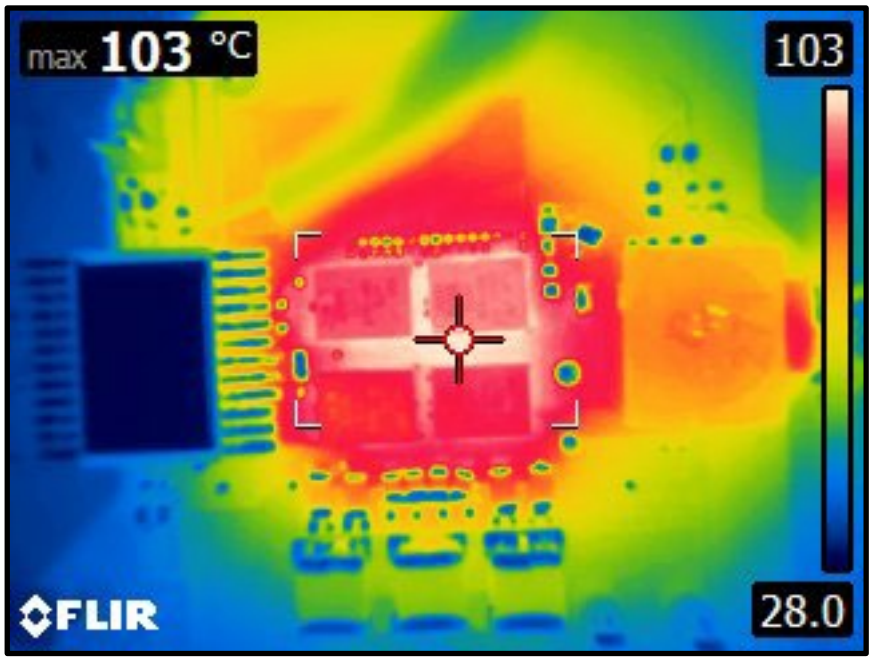

Figure 19 Thermal picture at Iload=40 A

5 Schematic

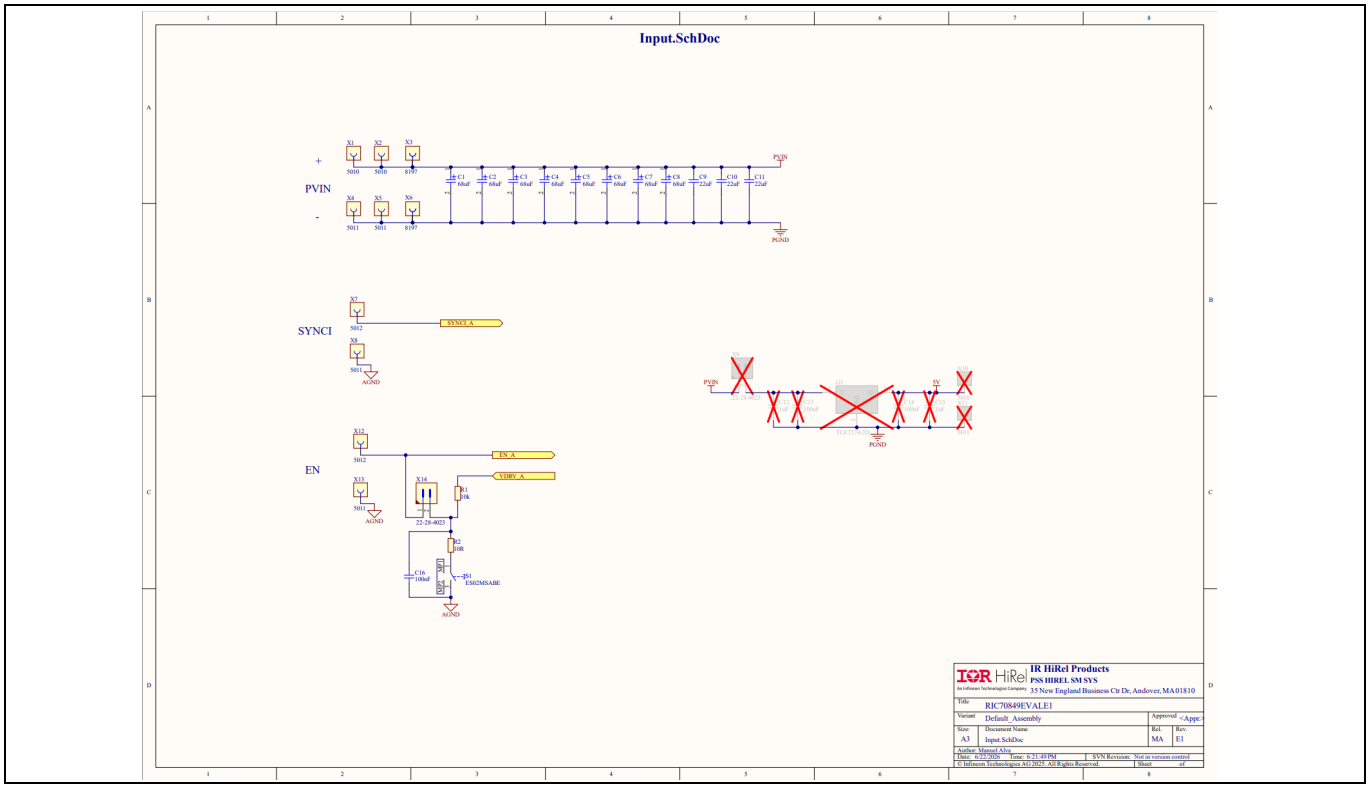

Figure 20 RIC70849EVAL1 schematic (1 of 3)

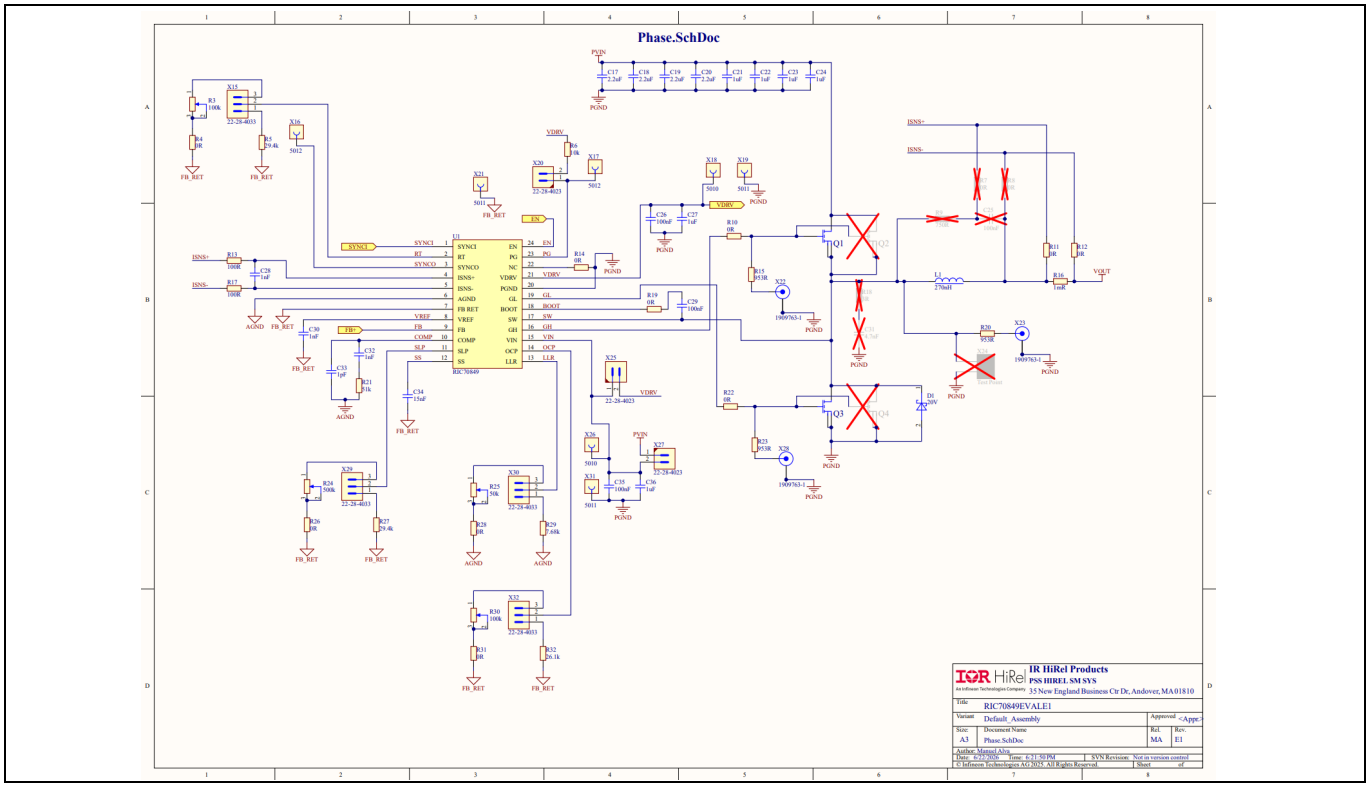

Figure 21 RIC70849EVAL1 schematic (2 of 3)

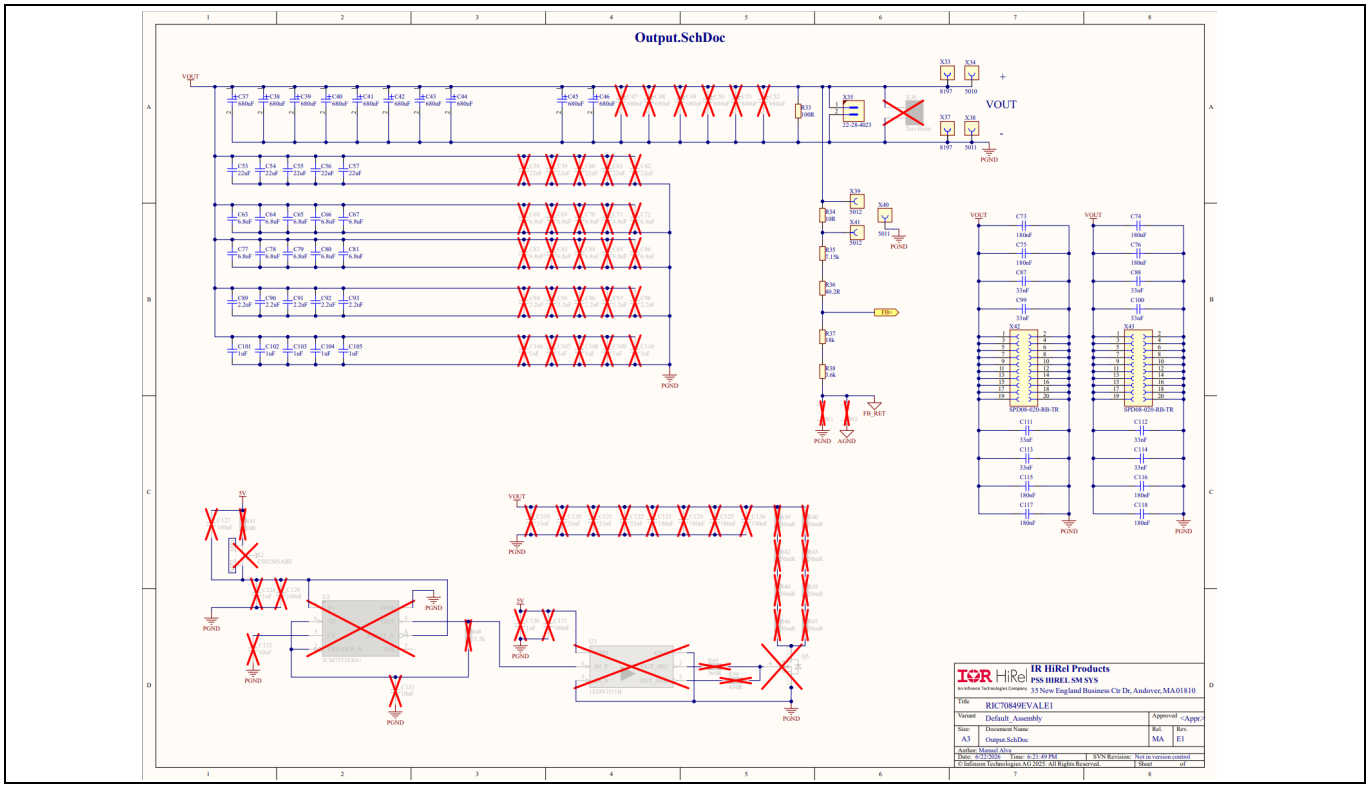

Figure 22 RIC70849EVAL1 schematic (3 of 3)

6 PCB layout

RIC70849EVAL1 is a 62 mil thick, 4 layer PCB with 2 oz copper on all layers.

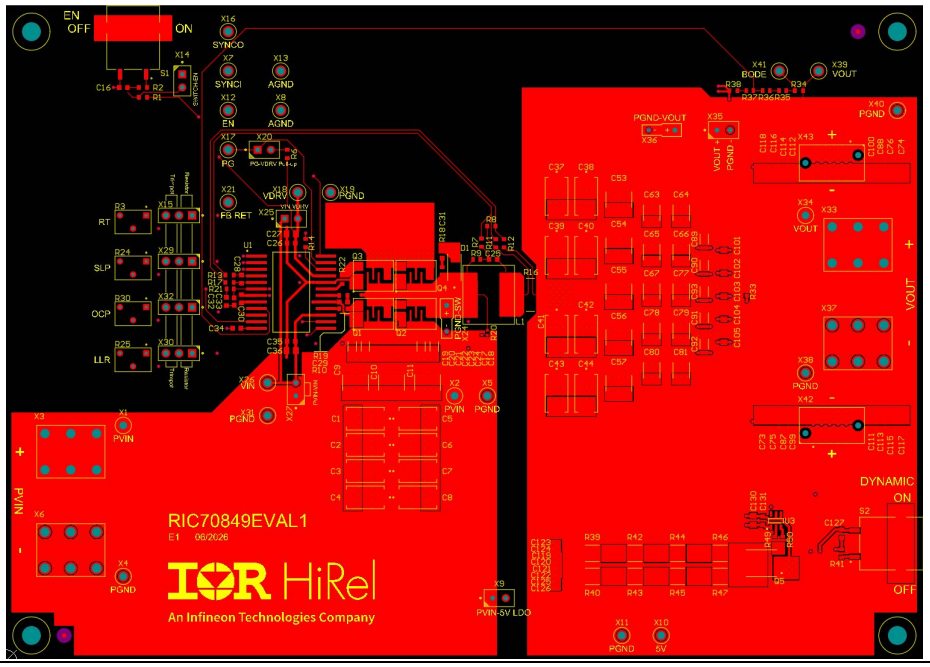

Figure 23 Top view of RIC70849EVAL1 top layer copper and silkscreen

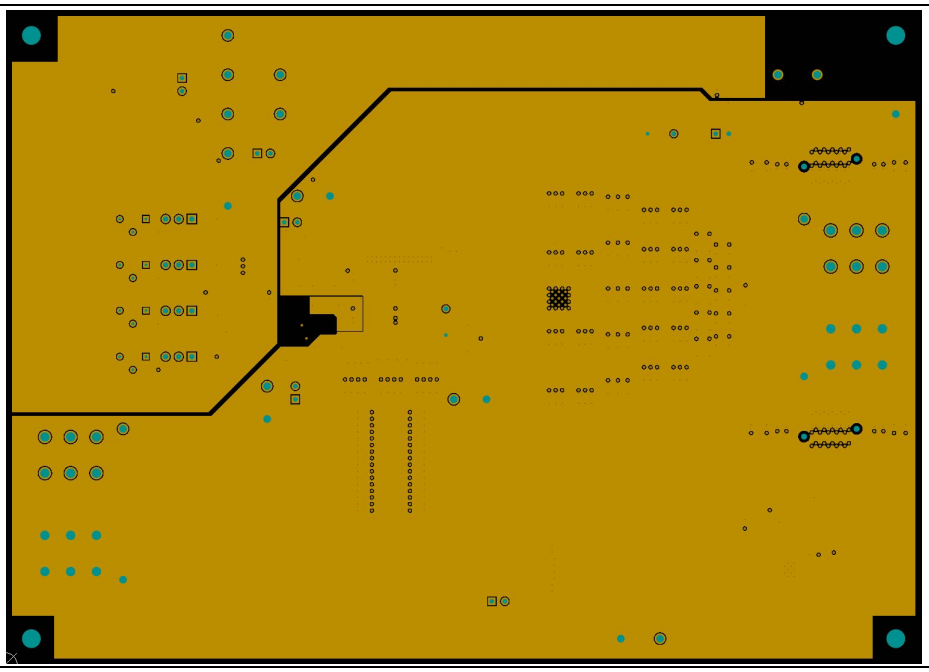

Figure 24 Mid-Layer 1 view of RIC70849EVAL1 copper

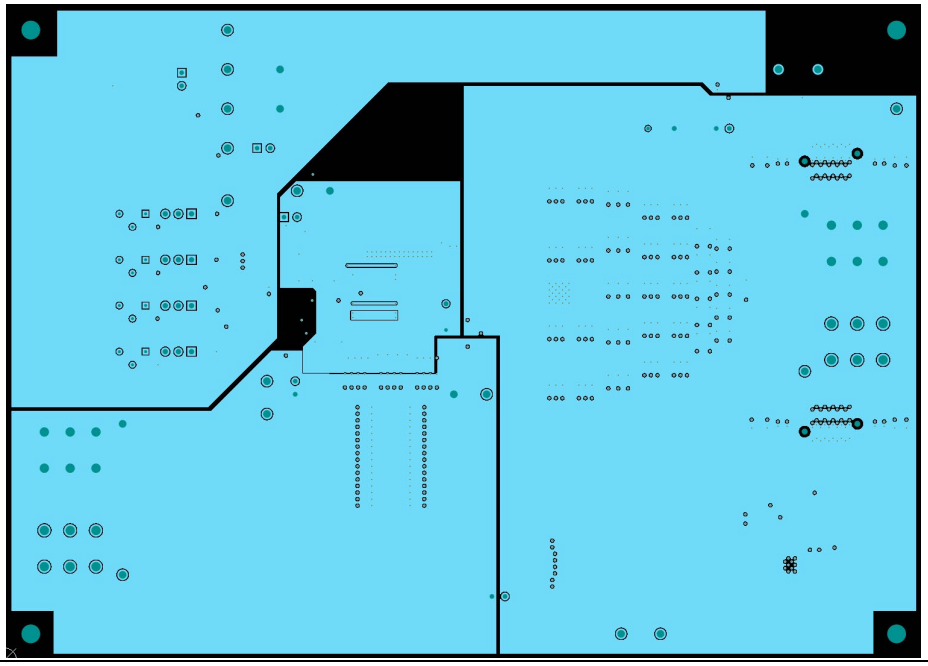

Figure 25 Mid-Layer 2 view of RIC70849EVAL1 copper

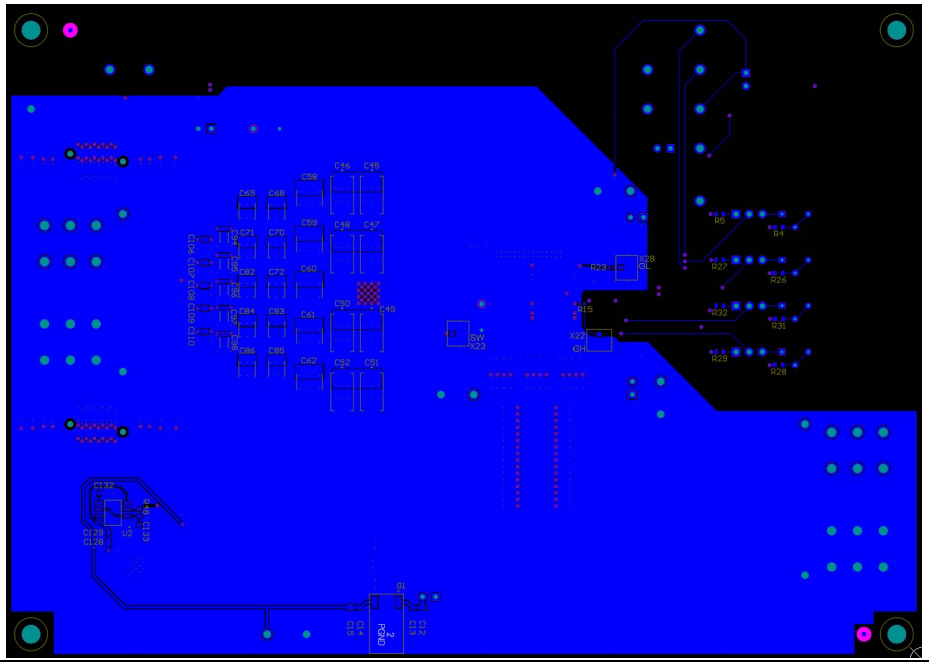

Figure 26 Flipped bottom view of RIC70849EVAL1 bottom layer copper and silkscreen

7 Bill of materials

Designator	Quantity	Manufacturer Part Number	Description	Manufacturer
C1, C2, C3, C4, C5, C6, C7, C8	8	TCJE686M025R0050E	CAP / ELCO / 68uF / 25V / 20% / Tantalum electrolytic / -55°C to 105°C / 2917(7343) / SMD / -	Kyocera
C9, C10, C11, C53, C54, C55, C56, C57	8	22203C226KAZ2A	CAP / CERA / 22uF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 2220(5750) / SMD / -	AVX
C16, C26, C29, C35	4	C0603C104J3RAC	CAP / CERA / 100nF / 25V / 5% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Kemet
C17, C18, C19, C20, C89, C90, C91, C92, C93	9	CGA5L3X7R1V225M160AB	CAP / CERA / 2.2uF / 35V / 20% / X7R (EIA) / -55°C to 125°C / 1206(3216) / SMD / -	TDK Corporation
C21, C22, C23, C24, C27, C36, C101, C102, C103, C104, C105	11	C0805C105K5RACTU	CAP / CERA / 1uF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0805(2012) / SMD / -	Kemet
C28	1	GRM188R72A102JA01	CAP / Ceramic / 1nF / 100V / 5% / X7R (EIA) / -55C to 125C / 0603 (1608) / SMD /	Murata
C30, C32	2	C0603C102F5GAC	CAP / CERA / 1nF / 50V / 1% / C0G (EIA) / NP0 / -55°C to 125°C / 0603(1608) / SMD / -	Kemet
C33	1	CGA3E2C0G1H010C080AA	CAP / CERA / 1pF / 50V / 250fF / C0G (EIA) / NP0 / -55°C to 125°C / 0603(1608) / SMD / -	TDK Corporation
C34	1	GCM188R72A153KA37	CAP / CERA / 15nF / 100V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	MuRata
C37, C38, C39, C40, C41, C42, C43, C44, C45, C46	10	TPME687M006R0023	CAP / ELCO / 680uF / 6.3V / 20% / Tantalumelectrolytic / -55°C to 125°C / 2917(7343) / SMD / -	AVX

C63, C64, C65, C66, C67, C77, C78, C79, C80, C81	10	C4532X7R1H685K250KB	CAP / CERA / 6.8uF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 1812(4532) / SMD / -	TDK Corporation
C73, C74, C75, C76, C115, C116, C117, C118	8	GCM188R71E184JA55	CAP / CERA / 180nF / 25V / 5% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	MuRata
C87, C88, C99, C100, C111, C112, C113, C114	8	GCM155R71E333JA55	CAP / CERA / 33nF / 25V / 5% / X7R (EIA) / -55°C to 125°C / 0402(1005) / SMD / -	MuRata
D1	1	B320A-13-F	3.0A Surface Mount Schottky Barrier Rectifier	Diodes Incorporated
L1	1	XGL1010-271MED	IND / STD / 270nH / 54A / 20% / -40°C to 125°C / 470R / SMD / Inductor,SMD; 2-Leads, 10.00mm L x 11.3mm W x 10.00mm H body / SMD / -	Coilcraft
MP1, MP2, MP3, MP4	4	9434	6-32, Binding Head Screw, Nylon 6/6	Keystone Electronics Corp.
MP5, MP6, MP7, MP8	4	1903C	F-F Nylon Stand, 6-32 Thread Size	Keystone Electronics Corp.
Q1, Q3	2	D101028	Insulated-Gate Field-Effect Transistor (IGFET), N-Channel, Enhancement, Pin 1 Source, 2 Drain, 3 Source, 4 Gate, 4 Pins	Infineon Technologies
R1, R6	2	RC0603FR-0710KL	RES / STD / 10k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo
R2, R34	2	RC0603FR-0710RL	RES / STD / 10R / 100mW / 1% / 200ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo
R3, R30	2	3266W-1-104LF	RES / VAR / 100k / 250mW / 10% / 100ppm/K / -55°C to 125°C / Potentiometer, THT, 4.50mm L X	Bourns

			6.71mm W X 9.02mm H Body / THT / -	
R4, R10, R11, R12, R14, R19, R22, R26, R28, R31	10	RC0603JR-070RL	RES / STD / 0R / 100mW / 0R / 0ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo
R5, R27	2	CRCW060329K4FK	RES / Resistor Chip / 29.4kR / 100mW / 1% / 100 ppm/K / -55C to 155C / 0603 (1608) / SMD /, RES / STD / 29.4k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay
R13, R17, R33	3	RC0603FR-07100RL	RES / STD / 100R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo
R15, R20, R23	3	CRCW0402953RFK	RES / STD / 953R / 63mW / 1% / 100ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay
R16	1	MSMA1225R0010FGM	RES / STD / 1mR / 3W / 1% / 75ppm/K / -55°C to 170°C / 2512(6432) / SMD / -	Cooper Bussmann
R21	1	CRCW060351K0FK	RES / STD / 51k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay
R24	1	3266W-1-504LF	RES / VAR / 500k / 250mW / 10% / 100ppm/K / -55°C to 125°C / Potentiometer, THT, 4.50mm L X 6.71mm W X 9.02mm H Body / THT / -	Bourns
R25	1	3266W-1-503LF	RES / VAR / 50k / 250mW / - / 100ppm/K / -55°C to 125°C / Potentiometer, THT, 4.50mm L X 6.71mm W X 9.02mm H Body / THT / -	Bourns
R29	1	CRCW06037K68FK	RES / STD / 7.68k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay

R32	1	CRCW060326K1FKEA	RES / STD / 26.1k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay
R35	1	CRCW06037K15FK	RES / Resistor Chip / 7.15kR / 100mW / 1% / 100 ppm/K / -55C to 155C / 0603 (1608) / SMD /	Vishay
R36	1	CRCW060340R2FK	RES / Resistor Chip / 40.2R / 100mW / 1% / 100 ppm/K / -55C to 155C / 0603 (1608) / SMD /	Vishay
R37	1	CRCW060318K0FK	RES / STD / 18k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay
R38	1	AC0603FR-073K6L	RES / STD / 3.6k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo
S1	1	ES02MSABE	Sealed Tiny Slide Switches	C&K
U1	1	RIC70849	Radiation Hardened PoL Buck Controller	IR HiRel
X1, X2, X18, X26, X34	5	5010	PC Test Point-Multipurpose THT, Red	Keystone Electronics Corp.
X3, X6, X33, X37	4	8197	Snap In PC Screw Terminal, Unassembled, Rated Current 30A	Keystone Electronics Corp.
X4, X5, X8, X13, X19, X21, X31, X38, X40	9	5011	PC Test Point-Multipurpose THT, Black	Keystone Electronics Corp.
X7, X12, X16, X17, X39, X41	6	5012	PC Test Point-Multipurpose THT, White	Keystone Electronics Corp.
X14, X20, X25, X27, X35	5	22-28-4023	2.54mm Pitch KK header, Breakaway, Vertical, 2 Circuits, 0.38um Gold Selective Plating	Molex
X15, X29, X30, X32	4	22-28-4033	2.54mm Pitch KK Header, Breakaway, Vertical, 3 Circuits, 0.38µm Gold Selective Plating, Mating Pin Length 6.09mm	Molex

X22, X23, X28	3	1909763-1	U.FL (UMCC) Connector Jack, Male Pin	TE Connectivity
X42, X43	2	SPD08-020-RB-TR	SPD08 High Speed Card Edge Connector, 0.8MM Pitch SMD, 20Pins, 1.2A, 250V	3M
X44, X45, X46, X47, X48, X49, X50, X51, X52	9	SNT-100-BK-G	Jumper, 1x2-Positions, Pitch 2,54mm, Body 5,08x2,54mm, black, Au, without handle	Samtec

Revision history

Document revision	Date	Description of changes
1.0	2026-07-13	Initial version

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Edition 2026-07-13

Published by

Infineon Technologies AG

81726 Munich, Germany

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