IRHYS9A97034EVAL1 user guide

Inrush current limiter using R9 P-channel MOSFET

About this document

IRHYS9A97034EVAL1 is an evaluation board to help evaluate radiation hardened (rad hard) R9 P-channel MOSFETs in linear mode application. This evaluation board is designed to help the user evaluate P-channel MOSFETs in TO-257AA package in an inrush current limiter circuit configuration. IRHYS9A97034EVAL1 uses 60 V R9 P-channel MOSFET in hermetic TO-257AA low ohmic package. Passive components on the board can be adjusted to change inrush current peak and/or charging time.

This user manual includes overview, setup instructions, test results, schematic, printed circuit board layout drawings and bill of material. More information on the rad hard R9 MOSFETs is available on our website.

Intended audience

This document is intended for engineers who are familiar with MOSFET based converters and inverters looking to evaluate and design R9 P-channel MOSFETs into their application.

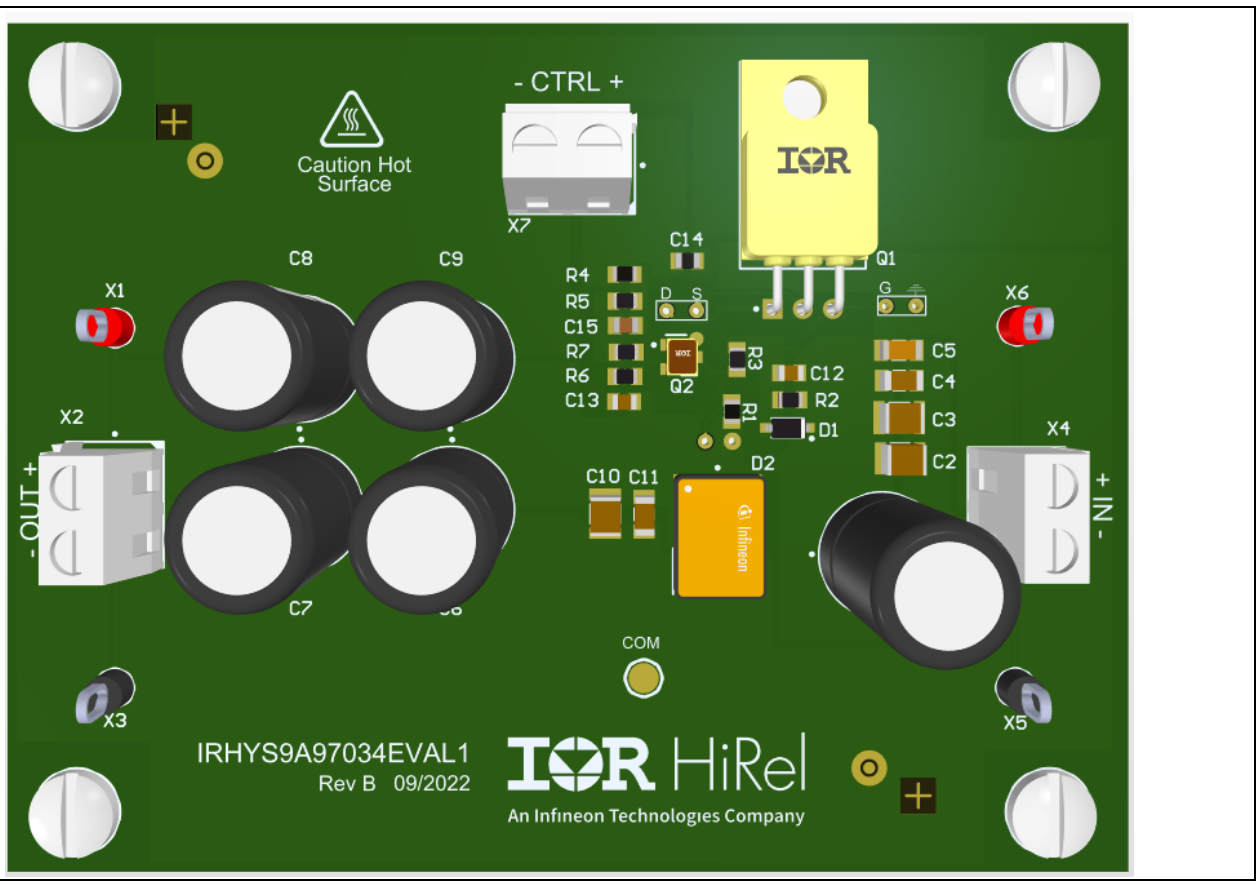


Figure 1 IRHYS9A97034EVAL1 – Evaluation board for rad hard R9 P-channel MOSFET

Table 1 Safety warning

	**Warning:** IRHYS9A97034EVAL1 has a large amount of bulk capacitance across VOUT connector on board. If high voltages are applied to VOUT please be sure to follow all safety precautions and ensure that the bulk capacitor voltage is fully discharged before handling.
	**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

IRHYS9A97034EVAL1 is an inrush current limiting application board, where it can be used as a circuit block in front of a DC-DC converter, motor drive or to understand the P-channel FET operation in linear mode application. It comes populated with 60 V rad hard R9 P-channel MOSFET (IRHYS9A97034CM) driven by a small signal N-channel FET (IRHLUB770Z4) as a control switch. The default configuration allows for a 5 V control input. The board has an optional footprint for a rectifier diode in SMD-0.5/SMD-0.5e package at the output which may be used for inductive loads.

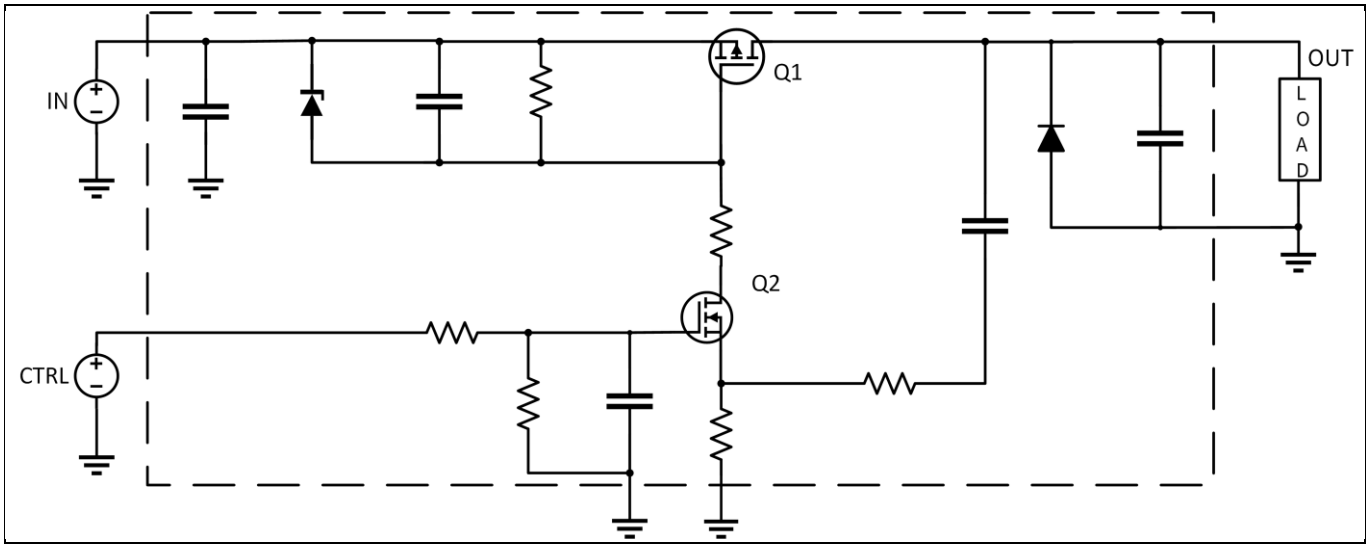


Figure 2 Simplified schematic of IRHYS9A97034EVAL1

1.1 Feature list

- Inrush current limiter power stage populated with 60 V/30 A rad hard R9 P-channel Si MOSFET in low ohmic TO-257AA package
- Supports 28 V bus input
- Supports control input of 5 V
- Adjustable inrush current peak and charging time with passive components
- On-board rectifier diode footprint for inductive loads
- PCB layout and test points optimized for ease of use in engineering evaluation

1.2 Applications

- Inrush current limiter
- Load switching
- Load sequencing
- Load redundancy

1.3 Highlighted products

The low-ohmic TO-257AA package coupled with R9 technology platform offers high current capability of 30 A with a footprint of 145 mm^2. Besides significant improvements in electrical switching performance (lower figure of merit), IR HiRel's R9 P-channel have substantially improved electrical linear mode and Single Event Effects (SEE) safe operating area compared to the previous generation of R5 planar MOSFETs (See Figure 3). The

improvements in linear mode safe operating area enable higher power density as well as higher reliability of power distribution circuits of space power systems.

IR HiRel's R7 MOSFETs in UB package are ideal for use as a control transistor in driving high side P-channel MOSFET.

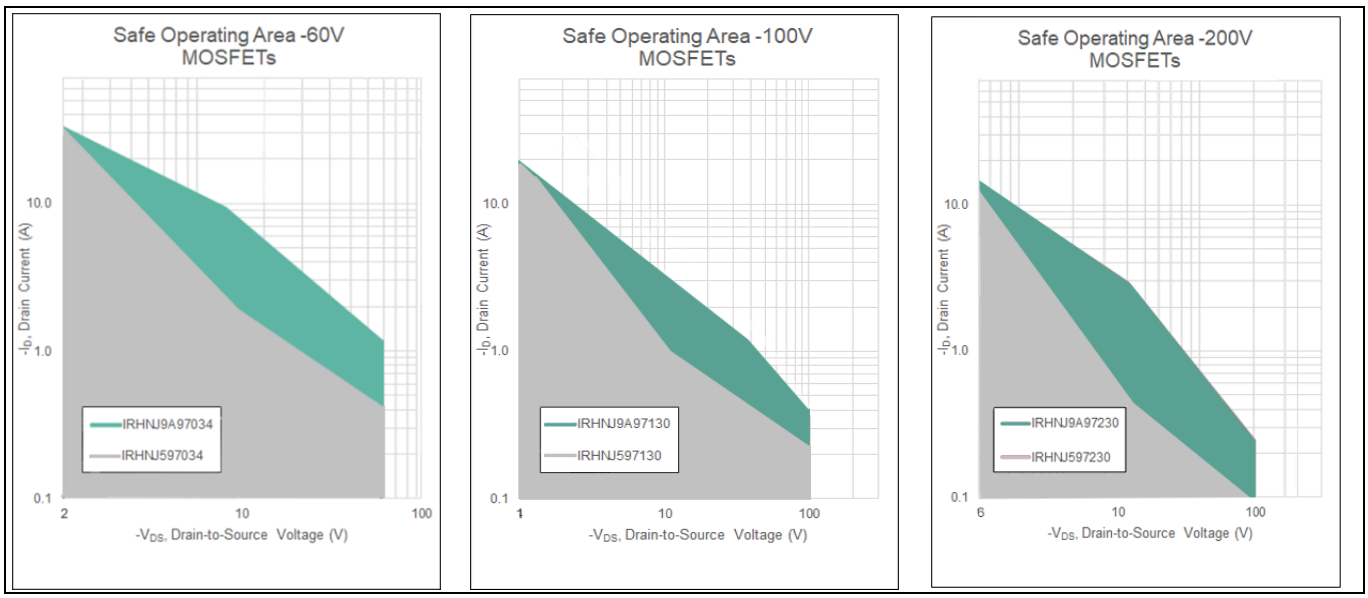


Figure 3 R9 P-channel MOSFETs expand the envelope for DC safe operating area

For information about the released products, please visit the Infineon web pages linked below:

- IRHYS9A97034CM (JANSR2N7659T3): https://www.irf.com/part/_/A~IRHYS9A97034CM
- IRHYB9A97034CM (JANSR2N7659D5): https://www.irf.com/part/_/A~IRHYB9A97034CM
- IRHYS9A97130CM (JANSR2N7660T3): https://www.irf.com/part/_/A~JANSR2N7660T3
- IRHYB9A97130CM (JANSR2N7660D5): https://www.irf.com/part/_/A~IRHYB9A93130CM
- IRHLUB770Z4 (JANSR2N7616UB): https://www.irf.com/part/_/A~IRHLUB770Z4
- IRHLUBC770Z4 (JANSR2N7616UBC): https://www.irf.com/part/_/A~IRHLUBC770Z4

1.4 Design specifications

For proper operation the device should be used within the recommended operating conditions. All voltage parameters are absolute voltages referenced to COM unless otherwise stated.

Table 2 IRHYS9A97034EVAL1 recommended operating conditions

Symbol	Definition	Min	Typical	Max	Units
V_{IN}	Power stage voltage on IN		28	40	V
V_{OUT}	Power stage voltage on OUT		28	40	V
I_D	Steady state current through IN/OUT			8[1]	A
V_{CTRL}	CTRL bias voltage to COM	3.3[2]	5[2]	12[2]	V
P_{OUT}	Power stage output power (Q1, Q2: $T_J \leq 110$ °C)			200[1]	W

[1] Limits dependent on application configuration, $T_J \leq 110$ °C

[2] Biasing resistors R4, R5 should be changed to accommodate required V_{CTRL} and ensure that the control transistor fully turns on

2 Functional description

2.1 Power stage

IRHYS9A97034EVAL1 is a load switching circuit, where a P-channel MOSFET driven via control transistor can connect or disconnect the load from bus. The specific application is targeted for inrush current limiting where a large amount capacitance is present at the front end of a load, such as DC-DC converter. The P-channel MOSFET turns-on in a controlled manner to reduce the peak inrush current and gradually charging the bulk capacitance thereby protecting bus voltage regulation, minimizing EMI and providing load protection. By using a P-channel MOSFET, gate drive circuit is simplified as it does not require level-shift circuitry. The source terminal of P-channel MOSFET is connected to the input or bus, drain is connected to the output and the gate is controlled via N-channel FET. Zener diode is used to clamp the V_{GS} to -12 V, once the P-channel FET fully turns-on.

The absolute maximum input voltage of the power stage is 40 V although the P-channel MOSFET is rated for 60 V BV_{DSS}. If operation is close to device BV_{DSS} limit, it is recommended to slowly bring up the voltage during initial power up to insure any voltage overshoot or ringing does not exceed this threshold. To demonstrate high inrush current limiting capability with R9, four 100 µF bulk capacitors are used at the output. We suggest the user to perform evaluation for typical bulk capacitance used in their applications.

Attention: ***IRHYS9A97034EVAL1 has a large amount of bulk capacitance across OUT connector on board. If high voltages are applied to OUT please be sure to follow all safety precautions and ensure that the bulk capacitor voltage is fully discharged before handling.***

2.2 Adjusting peak inrush current and charging time

The inrush current and its peak are strongly dependent on the amount of capacitance present at the output ($i_C = C\frac{dv}{dt}$). For a given capacitance, the inrush current peak and charging time changes as the bus voltage can vary from 18 V to 40 V. For higher bus voltage, larger inrush current and smaller charging time can be observed. The charging time of output capacitance is also the time period when the P-channel FET is operating in linear mode.

Resistor R7 can be replaced with appropriate value to adjust peak inrush current and charging time as needed. Reducing the value of R7 decreases charging time while increasing peak inrush current. By adjusting these two parameters, the user can make sure the device operates under the safe operating area (SOA) of the MOSFET.

A summary of effect of such circuit values on peak inrush current and charging time is listed in Table 3.

Table 3 Effect of values on peak inrush current and charging time

Values	Increase / Decrease	Peak inrush current	Charging time
V_{IN}	↑	↑	↓
V_{CTRL}	↑	↑	↓
R7	↑	↓	↑
C13	↑	↓	↑
C15	↑	↓	↑

2.3 Test points

To simplify measurement and improve accuracy, several test points are provided. For waveform measurements, it is recommended that V_{IN}, V_{OUT}, VDS and VG are measured from the corresponding test point to prevent cable and connector loss from impacting measurement. For Q1 gate to source measurement, a math function on the oscilloscope may be used (VG – V_{IN}). For Q1 drain to source measurement, a HV differential probe can be directly used across VDS test point or test points across IN and OUT can be used with math function on scope to measure VDS. A current probe can be used to measure the input current / drain current ID through the FET.

To measure the power dissipation through the FET, VDS and ID can be multiplied using math function on the scope.

Table 4 Test points

Net (Test points)	Description
IN	Input or bus voltage
OUT	Output or load voltage
VDS	P-channel FET drain-to-source voltage
VG	P-channel FET gate voltage

Note: Test points IN, OUT and VG are referenced to COM

3 Test configuration and results

3.1 Equipment

The following equipment is recommended to operate IRHYS9A97034EVAL1 over the full range

- 3.3 V to 12 V power supply capable of at least 10 mA for CTRL connector
- Input (IN) supply up to 40 V capable of enough output current for power level of planned test
- Oscilloscope and probes for measurement with at least 500 MHz bandwidth to capture high slew rate and high frequency ringing

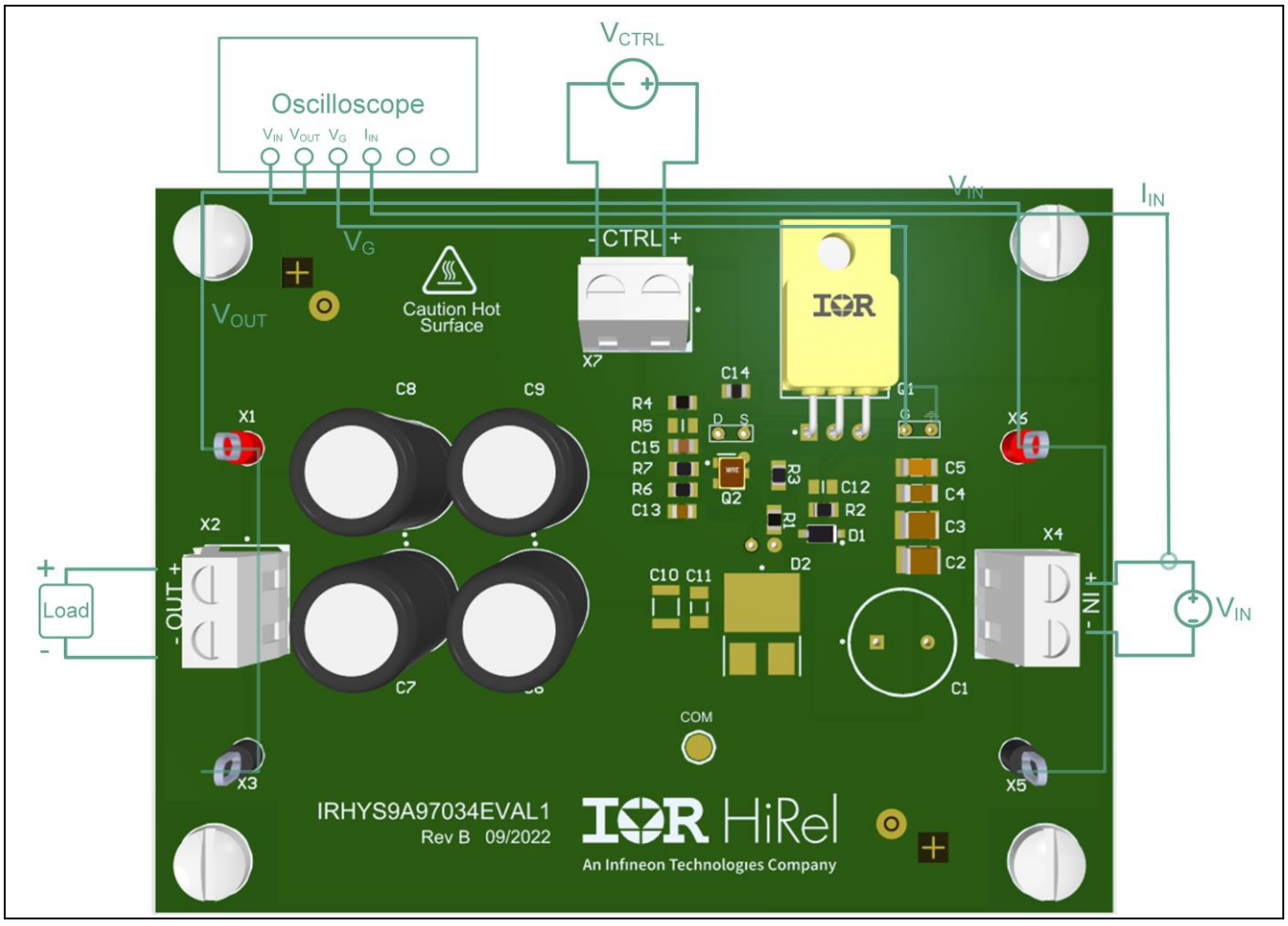


Figure 4 Recommended configuration of IRHYS9A97034EVAL1

3.2 Configuration – inrush current limiting

The following section shows test results in inrush current limiting with resistive e-load configuration, where a DC voltage is applied to V_{IN} (V_{IN} = 18 V / 28 V / 40 V) and a 5 A load is connected. When the input capacitance is charged to input voltage, a V_{CTRL} input of 5 V is applied to connect the load to input / bus voltage.

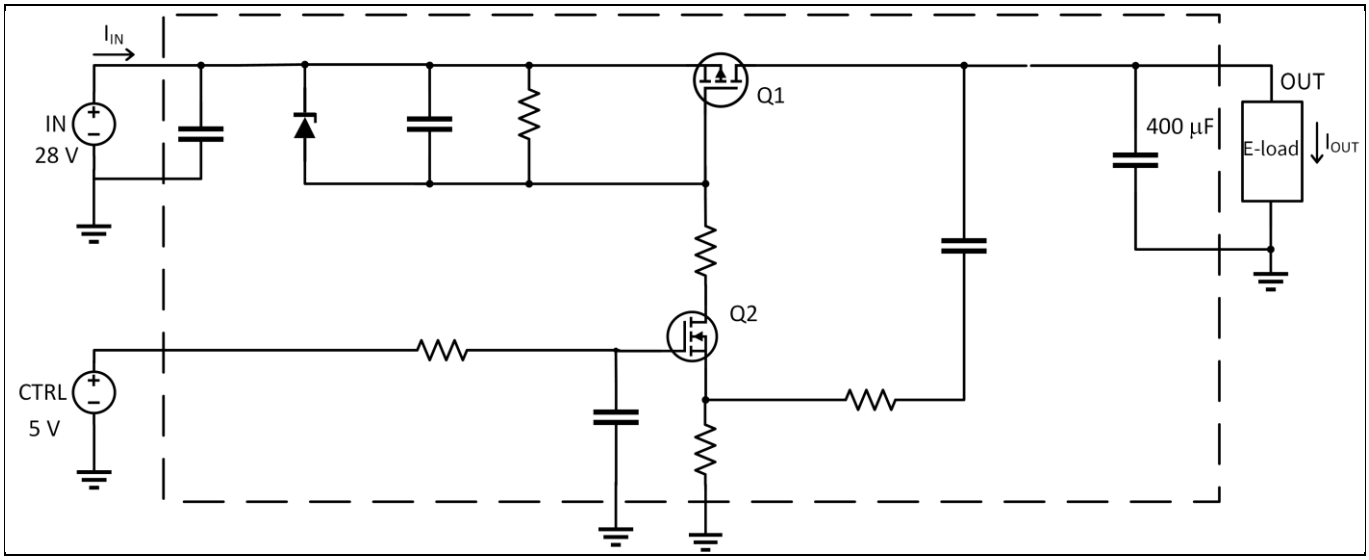


Figure 5 Simplified schematic of IRHYS9A97034EVAL1 configured with e-load

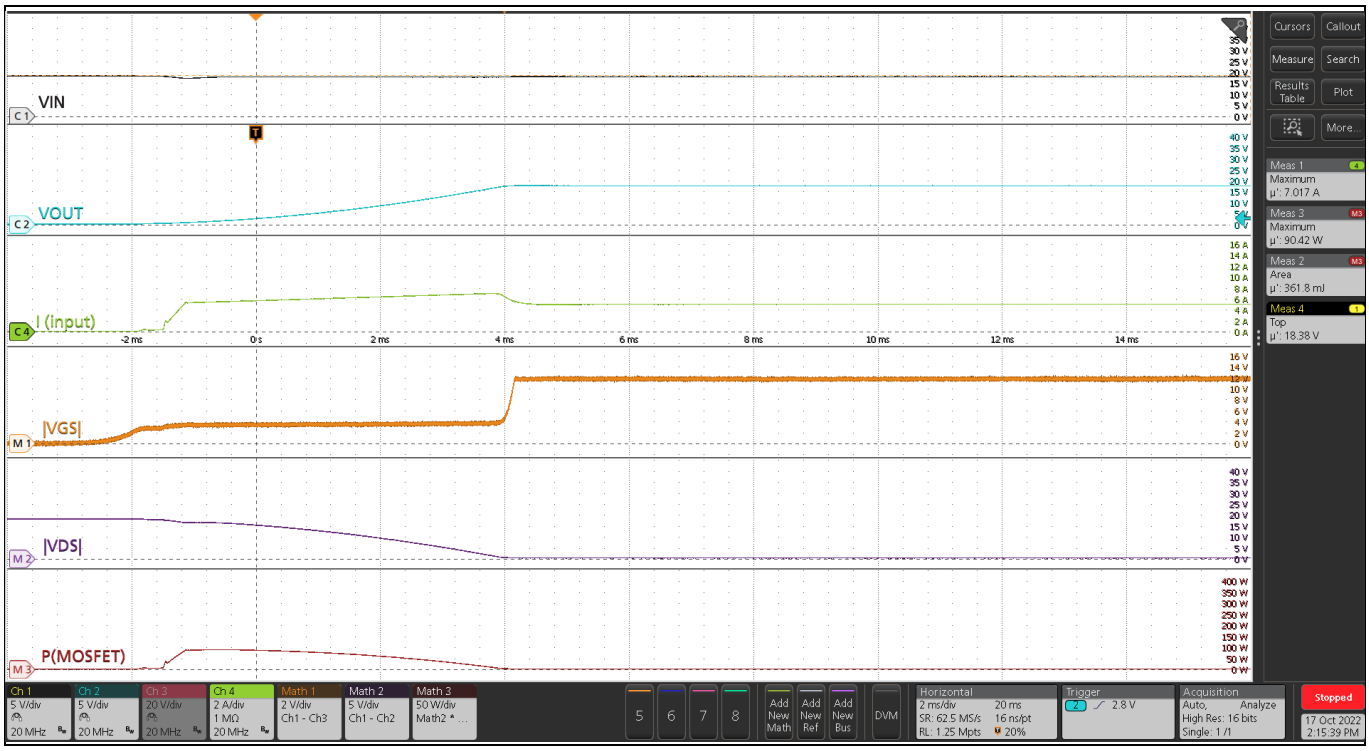


Figure 6 Measured waveforms at V_{IN} = 18 V, I_{OUT} = 5 A (T_A = 25 °C)

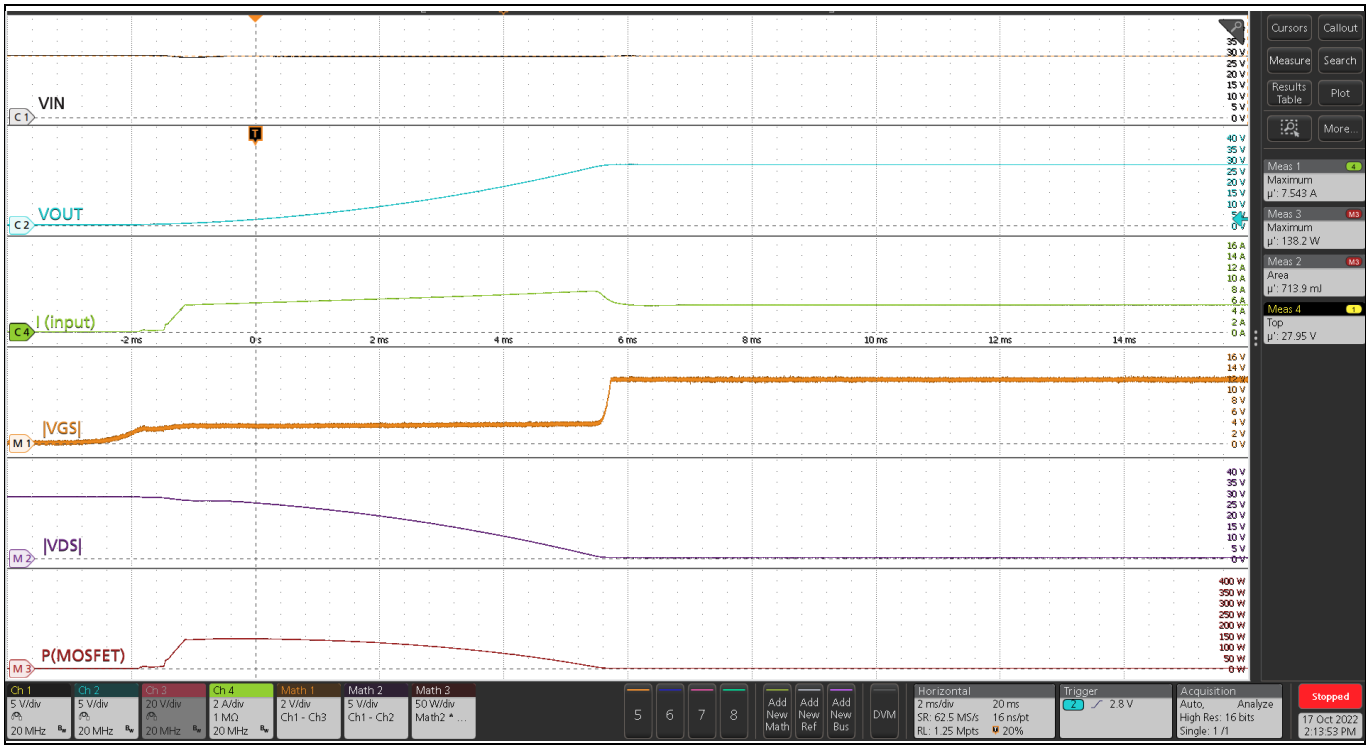


Figure 7 Measured waveforms at V_{IN} = 28 V, I_{OUT} = 5 A (T_A = 25 °C)

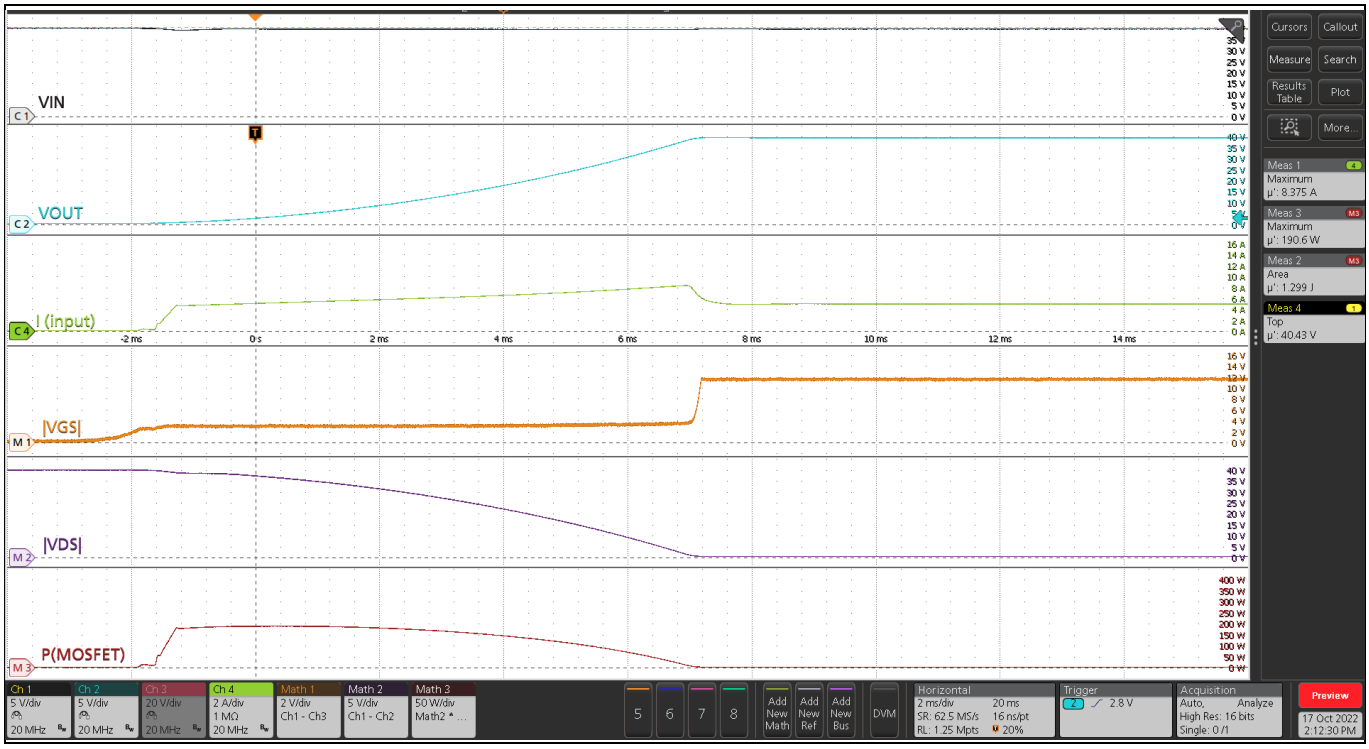


Figure 8 Measured waveforms at V_{IN} = 40 V, I_{OUT} = 5 A (T_A = 25 °C)

3.2.1 Effect of circuit values on inrush current limiter

This section discusses how changing circuit values such as of components R7, C13 and C15 changes inrush current limiter performance. The default circuit values are R7 = 1 kΩ, C13 = 100 nF and C15 = 0 (open). As shown in Figure 7, inrush current peak $I_{D(max)}$ = 7.5 A at V_{IN} = 28 V, I_{OUT} = 5 A.

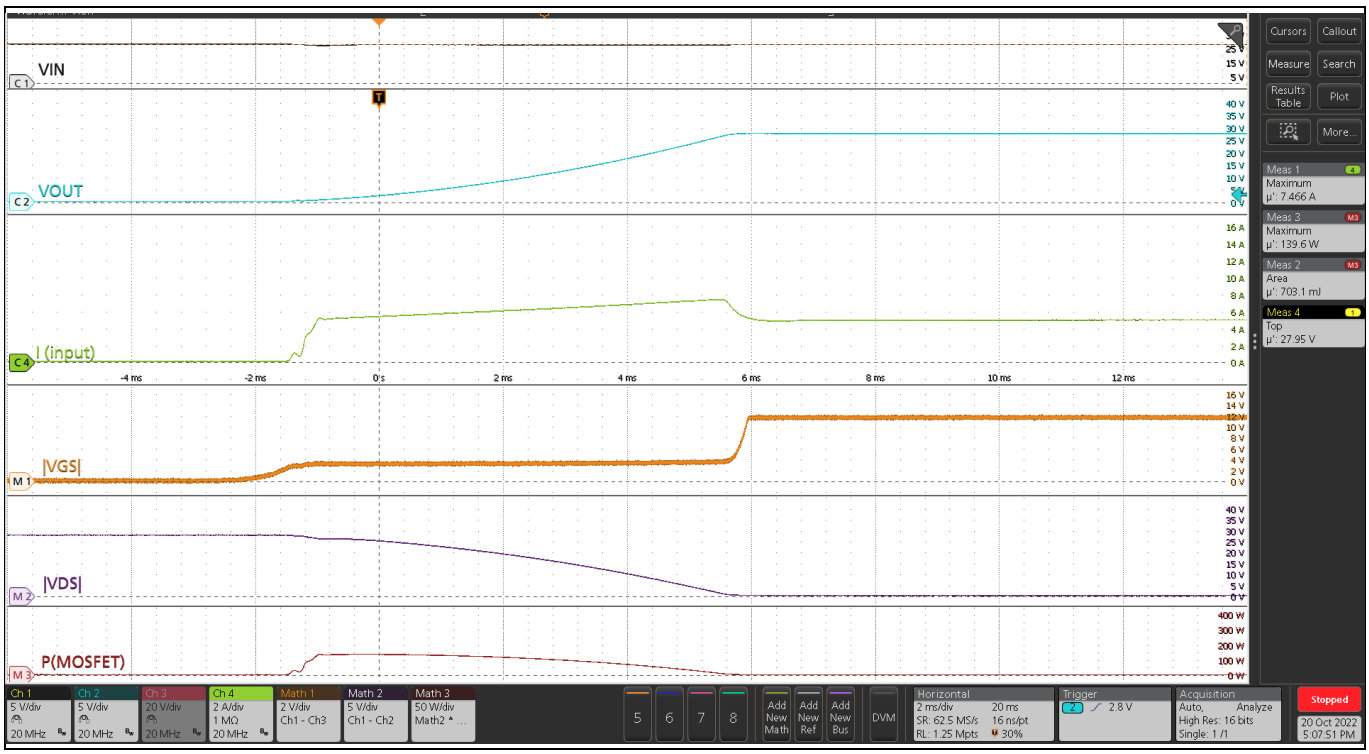


Figure 9 Measured waveforms at V_{IN} = 28 V, I_{OUT} = 5 A (T_A = 25 °C) and R7 = 5 kΩ

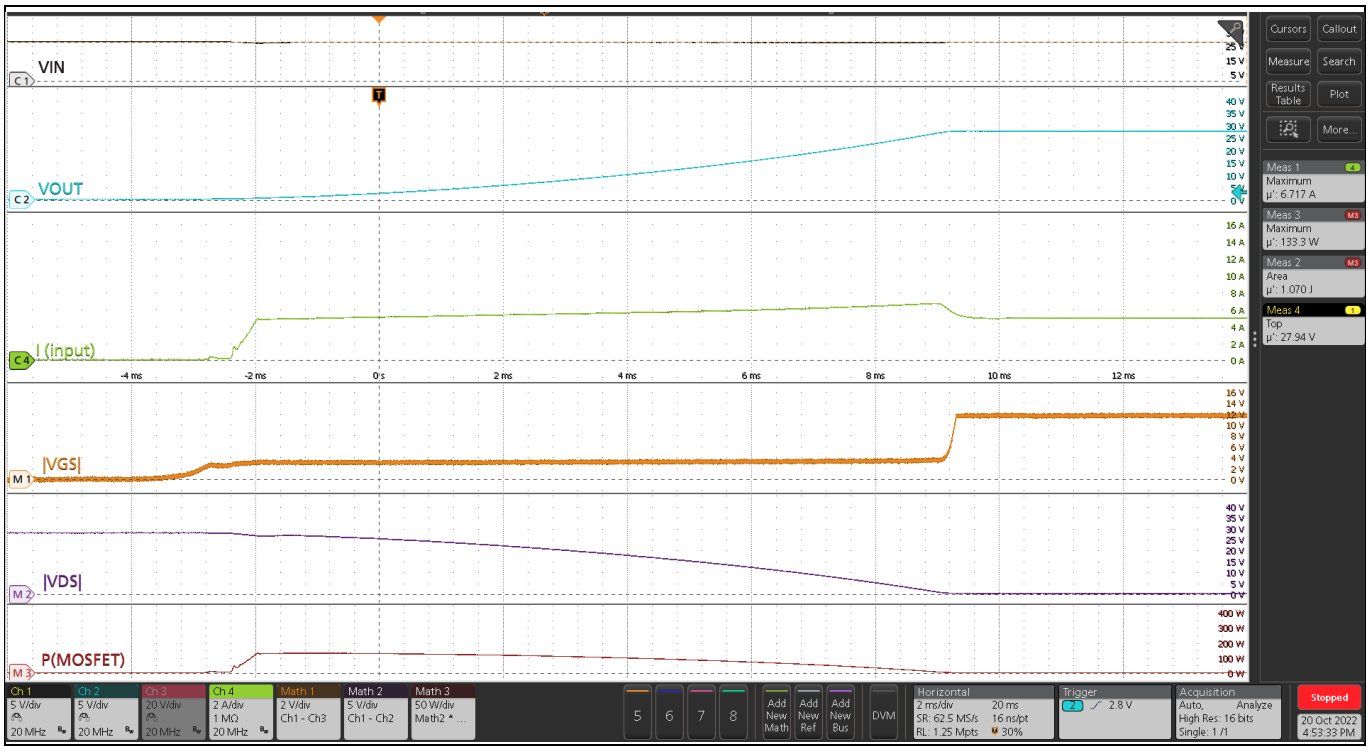


Figure 10 Measured waveforms at V_{IN} = 28 V, I_{OUT} = 5 A (T_A = 25 °C) and C13 = 220 nF

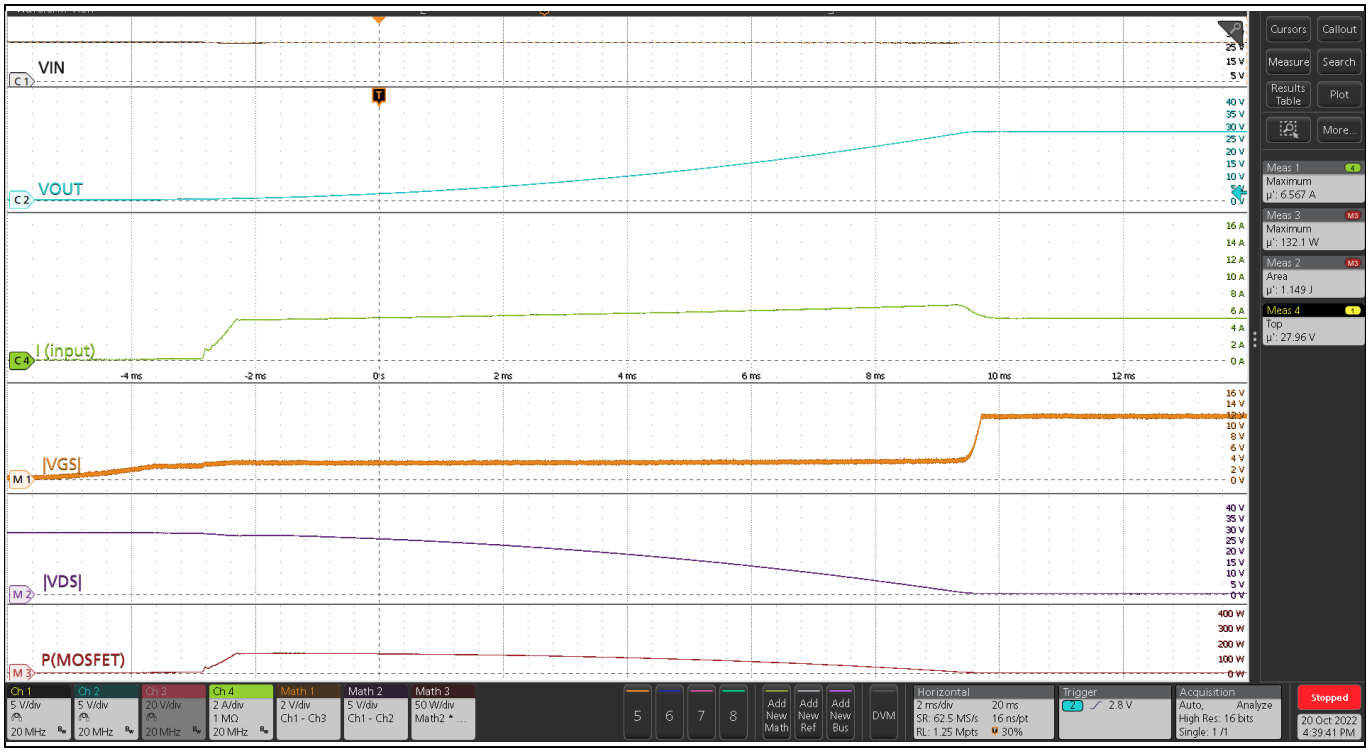


Figure 11 Measured waveforms at V_{IN} = 28 V, I_{OUT} = 5 A (T_A = 25 °C) and C15 = 4.7 µF

In Figure 9, R7 value is increased from 1 kΩ to 5 kΩ. R6 and R7 form a voltage divider where if R7 value increases then that reduces VGS across Q2. This reduces the drive current through the main FET (Q1) decreasing peak inrush current and increasing linear mode duration. Likewise, as C13 value is increased similar event occurs.

When C15 = 4.7 µF is used, a time delay is added to the turn on duration of control transistor Q2 also called “soft turn-on”. This results in reduced peak inrush current and increased charging time.

Table 5 Effect of circuit values on peak inrush current and charging time

V_{IN} (V)	Circuit values	I_{OUT} (A)	Peak inrush current (A)	Charging time (ms)
28	R7 = 1 kΩ, C13 = 100 nF, C15 = Open	5	7.54	5.17
28	**R7 = 5 kΩ,** C13 = 100 nF, C15 = Open	5	7.47	5.04
28	R7 = 1 kΩ, **C13 = 220 nF,** C15 = Open	5	6.72	8.03
28	R7 = 1 kΩ, C13 = 100 nF, **C15 = 4.7 µF**	5	6.57	8.70

4 Schematic

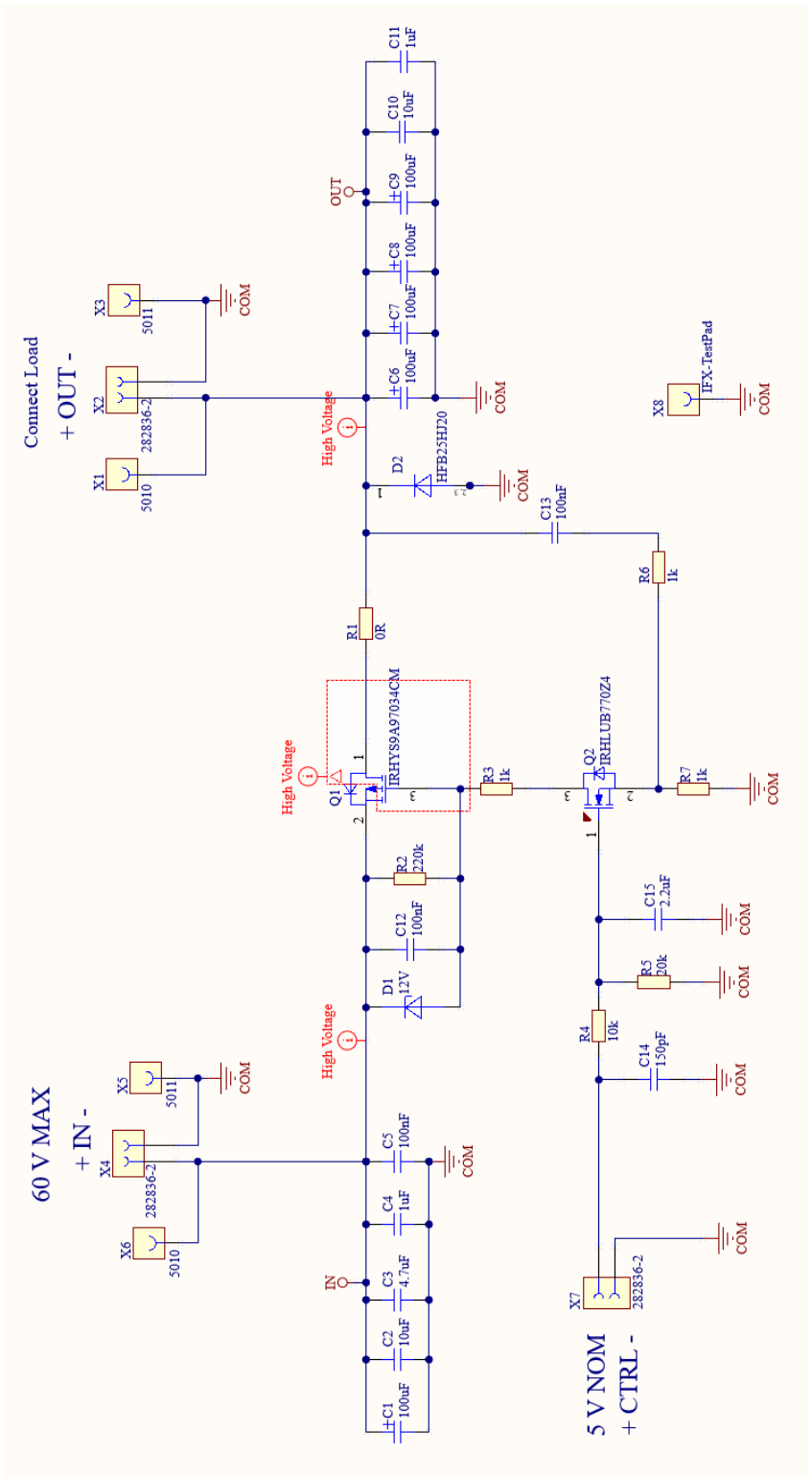


Figure 12 IRHYS9A97034EVAL1 schematic

5 PCB layout

IRHYS9A97034EVAL1 is a 62-mil thick, 4 layer PCB with 2 oz copper on outer layers and 1 oz copper on inner layers. Components are only on top layer. Altium design files and fabrication files are made available on the website.

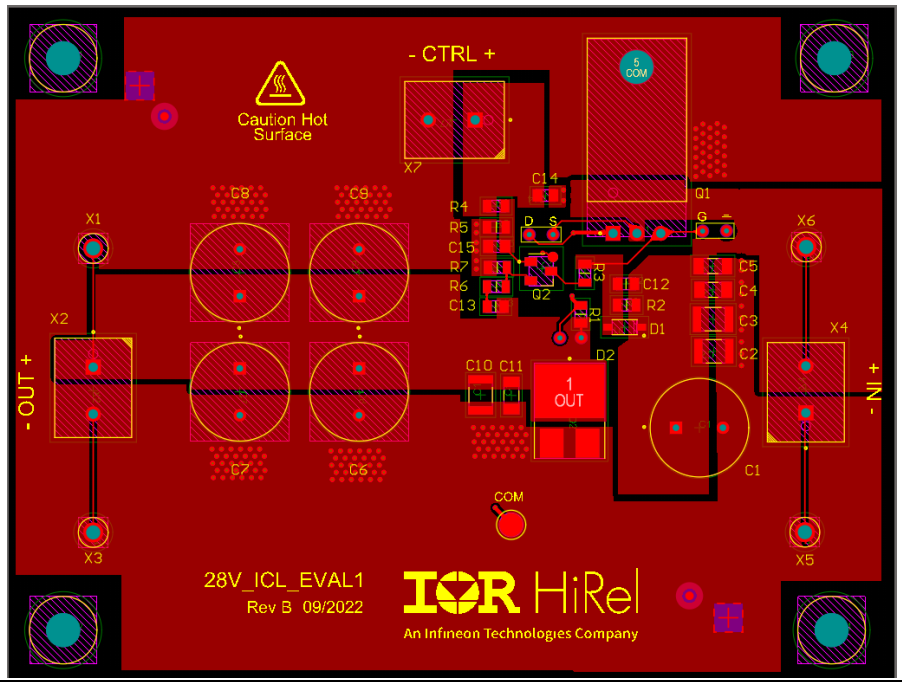


Figure 13 Layer 1 of IRHYS9A97034EVAL1

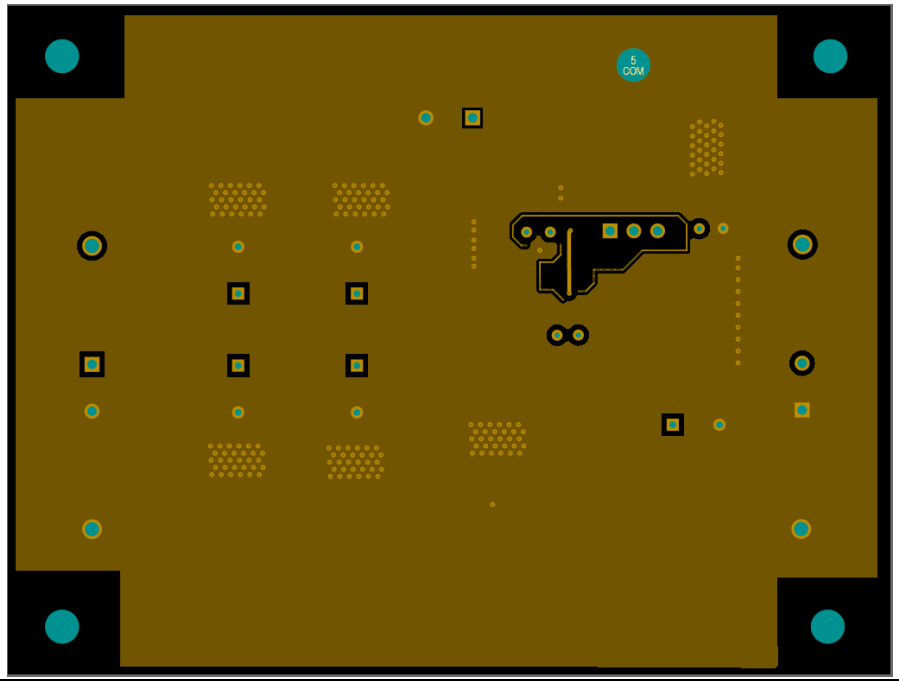


Figure 14 Layer 2 of IRHYS9A97034EVAL1

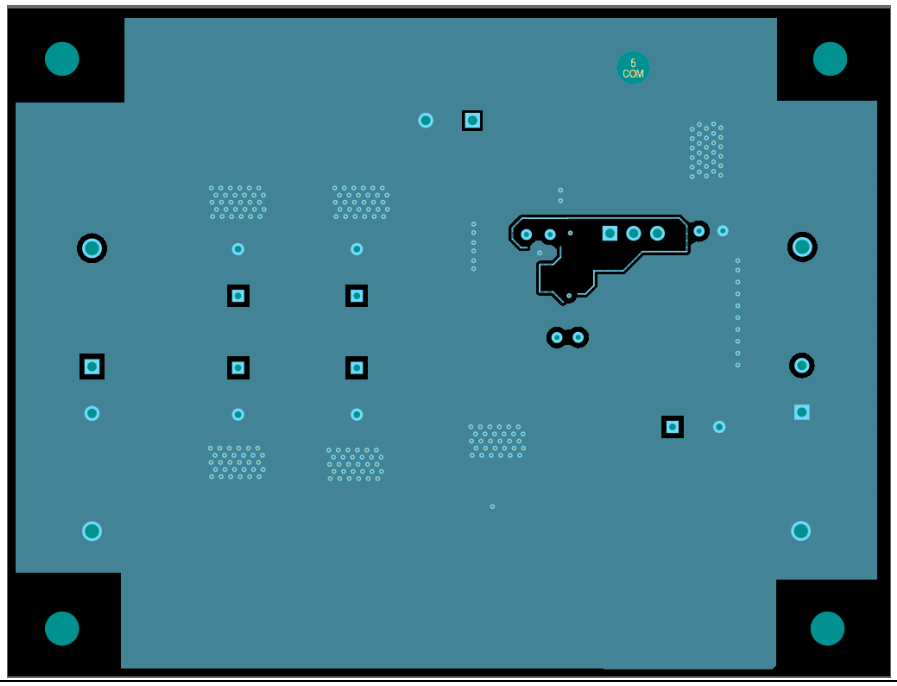


Figure 15 Layer 3 of IRHYS9A97034EVAL1

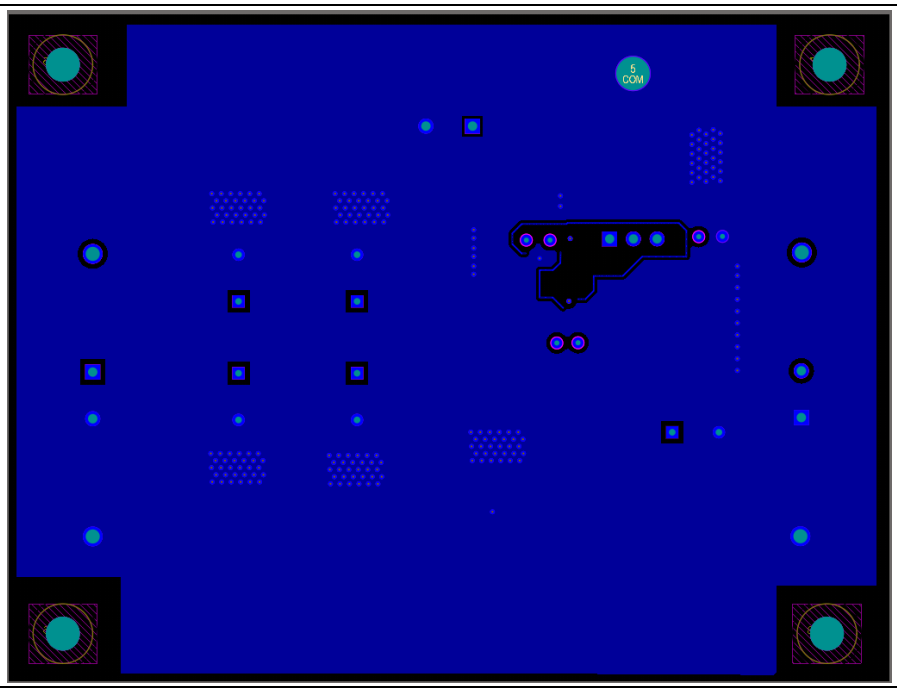


Figure 16 Layer 4 of IRHYS9A97034EVAL1

6 Bill of materials

Components used on IRHYS9A97034EVAL1 are listed below. Alternate parts of equivalent value, tolerance, size may be used.

Table 6 Bill of materials

Quantity	Designator	Description	Manufacturer	Part number
5	C1, C6, C7, C8, C9	CAP / ELCO / 100uF / 100V / 20% / Aluminiumelectrolytic / -40°C to 105°C / 5.00mm C X 0.60mm W 10.50mm Dia X 22.00mm H / - / -	Rubycon	100ZLH100MEFC10X20
2	C2, C10	CAP / CERA / 10uF / 100V / 10% / X7S (EIA) / -55°C to 125°C / 1210 (3225) / SMD / -	MuRata	GRM32EC72A106KE05L
1	C3	CAP / CERA / 4.7uF / 100V / 10% / X7S (EIA) / -55°C to 125°C / 1210(3225) / SMD / -	Taiyo Yuden	HMK325C7475KM-PE
2	C4, C11	CAP / CERA / 1uF / 100V / 10% / X7R (EIA) / -55°C to 125°C / 1206(3216) / SMD / -	TDK Corporation	CGA5L2X7R2A105K160AA
1	C5	CAP / CERA / 100nF / 250V / 10% / X7R (EIA) / -55°C to 125°C / 1206(3216) / SMD / -	Kemet	C1206C104KARAC7800
2	C12, C13	CAP / CERA / 100nF / 100V / 5% / X7R (EIA) / -55°C to 125°C / 0805(2012) / SMD / -	KYOCERA AVX	08051C104JAT2A
1	C14	CAP / CERA / 150pF / 100V / 1% / C0G (EIA) / NP0 / -55°C to 125°C / 0805 / SMD / -	KYOCERA AVX	08051A151JAT2A
1	C15	CAP / CERA / 2.2uF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0805(2012) / SMD / -	YAGEO	CC0805KKX7R9BB225
1	D1	Zener Voltage Regulator,12V	Micro Commercial Co	MMSZ5242B-TP
1	D2	Ultrafast, Soft Recovery Diode	Infineon Technologies	HFB25HJ20
4	MP1, MP2, MP3, MP4	6-32, Binding Head Screw, Nylon 6/6	Keystone Electronics Corp.	9434
4	MP5, MP6, MP7, MP8	F-F Nylon Stand, 6-32 Thread Size	Keystone Electronics Corp.	1903C
1	Q1	Radiation Hardened Power MOSFET	Infineon Technologies	IRHYS9A97034CM
1	Q2	Radiation Hardened Logic Level Power MOSFET Surface Mount	Infineon Technologies	IRHLUB770Z4

Bill of materials

Quantity	Designator	Description	Manufacturer	Part number
1	R1	RES / STD / 0R / 500mW / - / - / - 55°C to 155°C / 0805(2012) / SMD / -	Stackpole Electronics Inc	HCJ0805ZT0R00
1	R2	RES / STD / 220k / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805 / SMD / -	Vishay	CRCW0805220KFKEAC
3	R3, R6, R7	RES / STD / 1k / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805 / SMD / -	Vishay	CRCW08051K00FKEAC
1	R4	RES / STD / 10k / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Yageo	RC0805FR-0710KL
1	R5	RES / STD / 20k / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805 / SMD / -	Vishay	CRCW080520K0FK
2	X1, X6	PC Test Point-Multipurpose THT, Red	Keystone Electronics Corp.	5010
3	X2, X4, X7	Terminal Block PCB Mount, 2 Pin	TE Connectivity	282836-2
2	X3, X5	PC Test Point-Multipurpose THT, Black	Keystone Electronics Corp.	5011

Revision history

Document version	Date of release	Description of changes
1.0	01/2023	Initial release

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