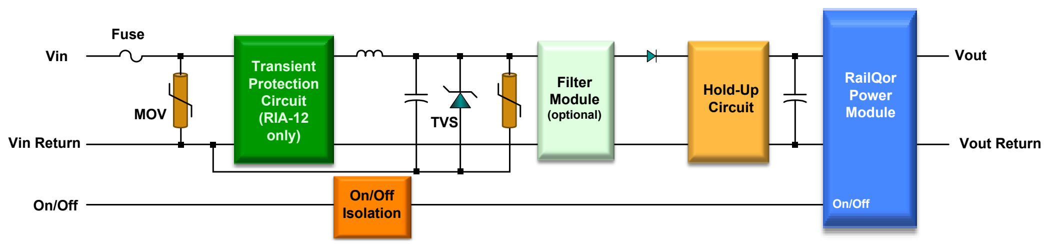
RailQor EN 50155 / RIA-12 Compliance & Evaluation Board Application Note

SynQor has developed the ruggedized RailQor product line for the harsh environments associated with railway transportation electronics. The European standard EN 50155 specifies the required input voltage ranges and input transients for this industry. The RailQor converters are designed to meet or exceed those requirements. Since some equipment is being designed to also comply with RIA-12 surges and transients, those requirements are discussed here as well, along with the supplemental circuitry needed to meet those requirements.



Block diagram of a typical power system, which will be discussed in detail.

Part I: RailQor Power Module Overview

The RailQor power converter modules are designed to meet the requirements of EN 50155 in a typical power system design. They can also be protected from the RIA-12 over-voltage transients with a supplemental transient protection circuit. They are composed of next-generation, board-mountable, isolated, fixed switching frequency dc-dc converters. These converters use synchronous rectification to achieve extremely high power conversion efficiency, even at low output power levels. Power dissipation is so low that many RailQor converters can operate at full output power with no heatsink in an 85°C ambient environment with no forced air cooling.

Each module is supplied completely encased to provide protection from the harsh environments seen in many transportation and industrial applications.

These modules include control features such as remote sense, output voltage trim, and on/off control. They also include protection features such as input under-voltage lockout, output current limit and short circuit protection, active back-bias current limit, output over-voltage protection, and thermal shutdown.

The table below summarizes the input voltage range of each RailQor product family. For more specific details of EN 50155 and RIA-12 input voltage requirements and module performance, please refer to Part II of this document.

RailQor Product Family	Input Voltage Range Continuous (Static) (V)			Transient (1 sec) (V)
	Nom.	Min.	Max.	Max.
RQ18	**18**	**9**	**36**	**40**
RQ68	**68**	**12**	**155**	**170**
RQ72	**72**	**42**	**110**	**up to 150**
RQ1B	**110**	**66**	**160**	**200**

Table 1: RailQor Module Families

EN 50155 requires that electronic equipment be designed and manufactured to operate over different temperature ranges, with -40 to +85ºC ambient the most extreme. These specifications indicate that forced air is not the preferred method of cooling. The RailQor products are designed to operate at baseplate temperatures of -40 to +100ºC. In addition, these products can be directly mounted to a chassis for improved cooling. Many RailQor converters can operate at full output power with no heatsink at ambient temperatures of +85ºC with no forced air cooling. See RailQor product datasheets for further information.

EN 50155 references EN 61373 for shock and vibration requirements. These requirements are for the entire system assembly, including final assembly anti-vibration mounts. The RailQor modules are encased in a permanently elastic thermally conductive compound that enables them to survive rigorous shock and vibration conditions. Please refer to the datasheets for further details.

Part II: Input Voltage Requirements

This section summarizes the EN 50155 and RIA-12 requirements for the dc input voltage. It includes a summary of the dc input voltage range, the surges and spikes, and the input voltage dropout requirements. A comparison is made between the requirements and RailQor performance.

Static Input DC Voltage Range

The EN 50155 nominal input voltage varies for different end-user requirements. The nominal voltages include 24V, 48V, 72V, 96V, and 110V. The EN 50155 static input dc voltage range is a minimum of 0.7 x Vnominal to a maximum of 1.25 x Vnominal. The table below shows which RailQor module family would be used for each nominal voltage.

Static Input Voltage Range (V)			RQ series Input Voltage Rating	
Vnom.	Min. (0.7 x Vnom.)	Max. (1.25 x Vnom.)	RailQor Series	Continuous (V)
24	**16.8**	**30.0**	**RQ18**	**9 - 36**
48	**33.6**	**60.0**	**RQ68**	**12 - 155**
72	**50.4**	**90.0**	**RQ72**	**42 - 110**
96	**67.2**	**120.0**	**RQ68**	**12 - 155**
110	**77.0**	**137.5**	**RQ1B**	**66 - 160**

Table 2: EN 50155 and RIA-12 Nominal Input Voltages

Input Voltage Surges / Spikes

EN 50155 includes input transient voltages of 100mS duration, ranging from 0.6 x Vnominal to 1.4 x Vnominal. The requirement is that these surges shall not cause loss of functionality.

Surge voltages of 1 second duration, ranging from 1.25 x Vnominal to 1.4 x Vnominal, shall not cause damage. However, equipment may not be fully functional during these fluctuations. As can be seen from the Table 3 below, the RailQor module input voltage specifications easily meet these requirements.

Input Voltage Range (V)	EN 50155 Transient 100mS	EN 50155 Transient 1 second Under Nominal	EN 50155 Transient 1 second Over Nominal	RQ series Input Voltage Rating	
Vnom.	0.6 to 1.4 x Vnom. (V)	0.7 to 1.25 x Vnom. (V)	1.25 to 1.4 x Vnom. (V)	RailQor Series	Continuous (1 sec. Transient) (V)
24	**14.4 - 33.6**	**16.8 - 30**	**30 - 33.6**	**RQ18**	**9 - 36 (40)**
48	**28.8 - 67.2**	**33.6 - 60**	**60 - 67.2**	**RQ68**	**12 - 155 (170)**
72	**43.2 - 100.8**	**50.4 - 90**	**90 - 100.8**	**RQ72**	**42 - 110 (up to 150)**
96	**57.6 - 134.4**	**67.2 - 120**	**120 - 134.4**	**RQ68**	**12 - 155 (170)**
110	**66 - 154**	**77 - 137.5**	**137.5 - 154**	**RQ1B**	**66 - 160 (200)**

Table 3: EN 50155 Input Transient Voltages

EN 50155 and RIA-12 specify several different surges and source characteristics as shown in Table 4 below. Power systems are expected to survive and operate through these transients, both positive and negative.

EN 50155 / EN 50121-3-2			RIA-12					
Surge voltage (V)	Duration (uS)	Source impedance (Ohms)	Direct Transient Trapezoidal Test (V)	Direct Transient Alternative Test (V)	Indirect Transient Trapezoidal Test (V)	Indirect Transient Alternative Test (V)	Duration (uS)	Source impedance (Ohms)
			800	**960**			**100**	**5**
2000	**50**	**42**	**1500**	**1800**	**1500**	**1800**	**50**	**5/5/100/100**
			3000	**3600**	**3000**	**3600**	**5**	**100**
			4000	**4800**	**4000**	**4800**	**1**	**100**
2000	**0.05**		**7000**	**8400**	**7000**	**8400**	**0.1**	**100**

Table 4: EN 50155 and RIA-12 Input Spikes and Source Impedance

The RIA-12 input transients include a 20mS high voltage, high energy surge that far exceeds the input rating of the RailQor series converters. These surges are shown in Table 5 below. Protection against these transients will require an external transient protection circuit located before the RailQor converters. An example of this circuit is described in Parts III and IV of this document.

RIA-12 states that, as an alternative to testing, calculations may be used to demonstrate compliance.

Input Voltage Range (V)	RIA-12 Transient 20mS	RIA-12 Transient 1 second	RQ series Input Voltage Rating	
Vnom.	3.5 x Vnom (V)	1.5 x Vnom (V)	RailQor Series	Continuous (1 sec. Transient) (V)
24	**84**	**36**	**RQ18**	**9 - 36 (40)**
48	**168**	**72**	**RQ68**	**12 - 155 (170)**
72	**252**	**108**	**RQ72**	**42 - 110 (up to 150)**
96	**336**	**144**	**RQ68**	**12 - 155 (170)**
110	**385**	**165**	**RQ1B**	**66 - 160 (200)**

Table 5: RIA-12 Input Transient Voltages.

Input Voltage Drop-Out

EN 50155 specifies that interruptions may occur on the input voltage.

For Class S2, a 10mS interruption shall not cause any equipment failure. A temporary malfunction is not considered a failure if the vehicle operating staff cannot notice the dropout, and if the equipment resumes normal operation automatically following the interruption.

For a supply change over, Class C2, the equipment shall operate satisfactorily during a supply break of 30mS.

These input source interruptions require the addition of a hold-up circuit on the input of the power system. An example of this circuit is described in Parts III and IV of this document.

PART III: POWER DESIGN OVERVIEW

This section presents an overview of the power system design using the RailQor power modules. These converters are designed to meet or exceed the requirements of EN 50155. If reverse bias protection, or hold-up through an input voltage drop-out are required, additional circuitry can be included as shown in Figure 1 below. Also, if meeting the extreme input voltage transient requirements of RIA-12 is required, a supplemental transient protection circuit can be included, also shown in the figure below.

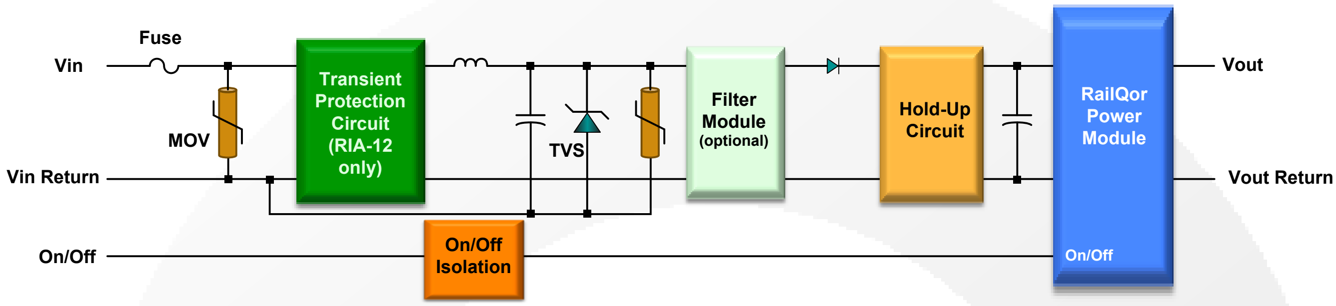


Figure 1: Power System Block Diagram

The discrete components shown between the input and the Filter Module are there to provide protection from the input high voltage spikes, as indicated in Table 4 in Part II of this document. The filter module is present to help meet EMC requirements. The Transient Protection Circuit provides input transient protection from the RIA-12 high voltage, high energy surges, as indicated in Table 5 in Part II of this document. (This circuit is not required to meet EN 50155 specifications). The Hold-up Circuit is there to meet the input voltage drop-out requirements as discussed in Part II of this document, and to provide energy to operate the converter module during the 20ms RIA-12 input over-voltage transient. The diode is provided to direct the hold-up energy to the power module, and keep current from going back to the input source.

The input capacitor of the power module is to ensure input power system stability. Please refer to SynQor's application note "Input System Instability" for further information. If a filter module is included in the circuit, then the input bulk capacitor is not required since a bulk stabilizing capacitor is inside the filter module.

The On/Off signal for the RailQor power converter must be referenced to the MODULE_VIN_RTN (Vin-) pin of that power converter module. However, the incoming On/Off signal is likely referenced to input Vin Return. Due to the ground potential differences from the Transient Protection Circuit and the Input Filter common-mode choke, an On/Off Isolation circuit is required.

TRANSIENT PROTECTION CIRCUIT FOR RIA-12 ONLY

As mentioned before, the input voltages described in EN 50155 are within the input operating voltage range of the RailQor modules. However, protection from RIA-12 transients requires the use of a supplemental transient protection circuit, as discussed in the "Input Voltage Surges / Spikes" section of Part II of this document. Due to the high energy in those input transients, absorbing the transient energy in a transient voltage suppressor (TVS) or in a Varistor (MOV) is not feasible.

For example, in a 110V rail system, the transient energy would be calculated by the following equation, where Energy = transient energy, Vtvs is the clamping voltage of the TVS device, Rs is the source impedance of the power system, and T is the duration of the transient.

$$\text{Energy (Joules)} = \text{Power (Watts)} \times \text{Time (Seconds)} = \text{Current (A)} \times \text{Voltage (V)} \times \text{Time (S)}$$

$$= (((3.5 * Vin) - Vtvs) / Rs) * Vtvs * T = (((3.5 * 110V) - 160V) / 0.2\ \text{Ohm}) * 160V * 20mS = 3600\ \text{Joules}$$

That amount of energy far exceeds typical board-mount component capabilities. It is better to block or disconnect the transient from the input of the power system, rather than try to absorb it. An overview diagram of one approach to an input transient protection circuit is shown in Figure 2.

TRANSIENT PROTECTION CIRCUIT FOR RIA-12 ONLY(CONTINUED)

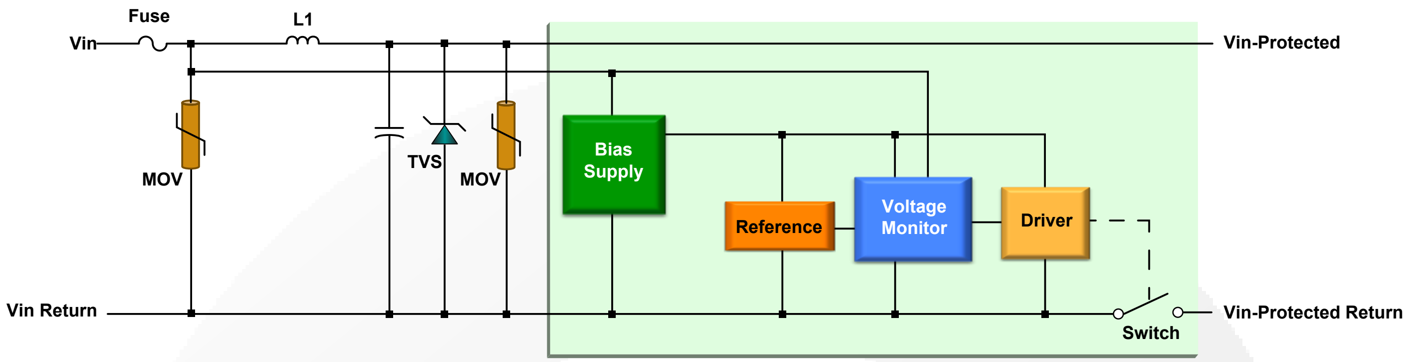


Figure 2: Transient Protection Circuit Block Diagram

A bias supply is generated from the incoming power rail just before inductor L1. This supply powers a reference, voltage monitor, and driver.

When the input voltage is above a minimum level, the Voltage Monitor will turn-on the Switch via the Driver. This Switch will remain on when the input voltage is within the operational ratings of the RailQor power converter.

When a high voltage transient occurs on the input power rail, the Voltage Monitor will quickly turn the Switch off. When the input voltage is back within the RailQor converter input voltage range, the Voltage Monitor will then turn the Switch back on at a controlled rate to limit inrush current.

The inductor-capacitor filter slows the rate of rise of the transient current. To protect the Switch, any high voltage spikes that occur will be clamped by the transient voltage suppressor (TVS) and second MOV. The first MOV, inductor, cap, TVS and second MOV protect the downstream power circuits from the incoming high voltage spikes.

HOLD-UP CIRCUIT

To provide operation through a power drop-out condition, there must be bulk storage capacitance added to the input before the RailQor power module. This functionality is shown in Figure 1 as the hold-up circuit.

Also, since the design of the transient protection circuit shown in this document disconnects the input voltage from the converter module, and the converter is required to operate through the over-voltage transient, a hold-up circuit is required to support continuous operation during the RIA-12 transient of 20mS.

An input power drop-out may be due to an input source open circuit or short circuit. Even if the input source drop-out is due to an open circuit, other loads on that same input rail will actively pull down the source voltage. Since the input will pull down due to a short circuit or pull down due to other loads pulling from the same input power, a circuit is required to keep the hold-up energy in the bulk storage capacitor from discharging through the input. A blocking diode for this purpose is shown in Figure 1.

Part IV: Detailed Circuit Design

This section provides the specific details of the application circuit for a power system using RailQor modules. SynQor's RailQor Evaluation Board information is presented, including the schematic and a circuit description. A supplemental transient protection circuit (for RIA-12 applications) and a hold-up circuit are included in the circuit description. The bill of materials (BOM) and layout are provided in the Appendix.

SynQor offers evaluation boards that allow circuit testing of each of the RailQor module families. RailQor evaluation boards can be used to confirm compliance to EN 50155 and RIA-12 early in the design phase. These evaluation boards are designed in accordance with the Power System Block Diagram shown in Figure 1. Included on the evaluation boards are input and output connectors, input fuse, input transient protection circuitry, hold-up circuitry, input bulk capacitance, sockets for a RailQor power converter module, output voltage trim resistors, output capacitance, and test-point connections.

For detailed application information for each specific RailQor module, please refer to the applications section of the individual datasheets.

RailQor Evaluation Board Circuit Description

There are three versions of this RailQor Evaluation Board; one for the RQ1B and RQ68, one for the RQ72, and one for the RQ18. The evaluation board PCB was designed to support all versions of the RailQor power modules. The schematic and the PCB layout drawing show all parts used for all versions. Please refer to the BOM to determine what specific parts are used or omitted for each specific version of the RailQor Evaluation Board. Figures 3 and 4 make up the schematic for the RailQor Evaluation Board. This schematic is applicable for all versions of the evaluation board. For the following circuit description, please refer to the block diagrams in Figure 1 and 2, and the schematic in Figures 3 and 4.

Input Circuit

Input power is applied as Vin+ through the multi-pin input connector J-INPUT. From J-INPUT the input voltage is applied to the input fuse F1, F2, or F3, indicated as fuseholders FH1, FH2, and FH3. Please refer to the RailQor product datasheets for proper fuse ratings. After the fuse, the input voltage is applied to Z1 (a MOV), C1 and C2, L1 or L2, C3 - C14, D1, and Z2 to provide protection from the input spikes shown in Table 4. A BNC test connector TP1 (J-1) is provided to monitor the input voltage at this node."

Filter Module

Our filter module is not included on this evaluation board. When used in your system design, our filter module provides high differential and common-mode attenuation, low DC resistance, and a stabilizing bulk capacitor. If a filter module is used in the design, an input bulk capacitor is not required before the power module since it is already in the filter module. Please note that meeting system EMC requirements requires a systems approach. Since each application is different, EMC compliance is achieved through whole-system design. Care must be taken in the layout, shielding, and in other system parameters.

Transient Protection Circuit (TPC)

- TPC Bias Supply

The Bias Supply provides power to the Voltage Monitor, Reference, and Driver circuit blocks of the Transient Protection Circuit (TPC). It also provides power to the On/Off Isolator. The bias supply consists of components D2, Q1, R2 - R4, C16, R4, and D3.

When the input voltage is applied, current will flow through D2, Q1, and R3 into the VBIAS node. This is because FET Q1 is a depletion-mode device. It is on, with low impedance, until the source voltage has reached the Q1 turn-off threshold voltage.

As the voltage at the VBIAS node increases, the voltage across zener diode D3 increases and clamps at 8.2V. This clamps the gate of Q1 to 8.2V. As the voltage at VBIAS continues to increase, the voltage across R3 increases, which is the source voltage of Q1. When the source voltage of Q1 has reached the turn-off threshold voltage of Q1, the impedance of Q1 will substantially increase. The impedance of Q1 then limits the voltage to the VBIAS node

The voltage at VBIAS will stabilize at 8.2V plus the Q1 threshold voltage minus the voltage across R3 (due to the VBIAS current). The voltage at VBIAS will vary with the turn-off threshold of Q1. R4 is provided to limit current into zener diode D3. R2 is provided to limit current in Q1 when the input voltage has a positive transition, either at turn-on, or during input over-voltage transients."

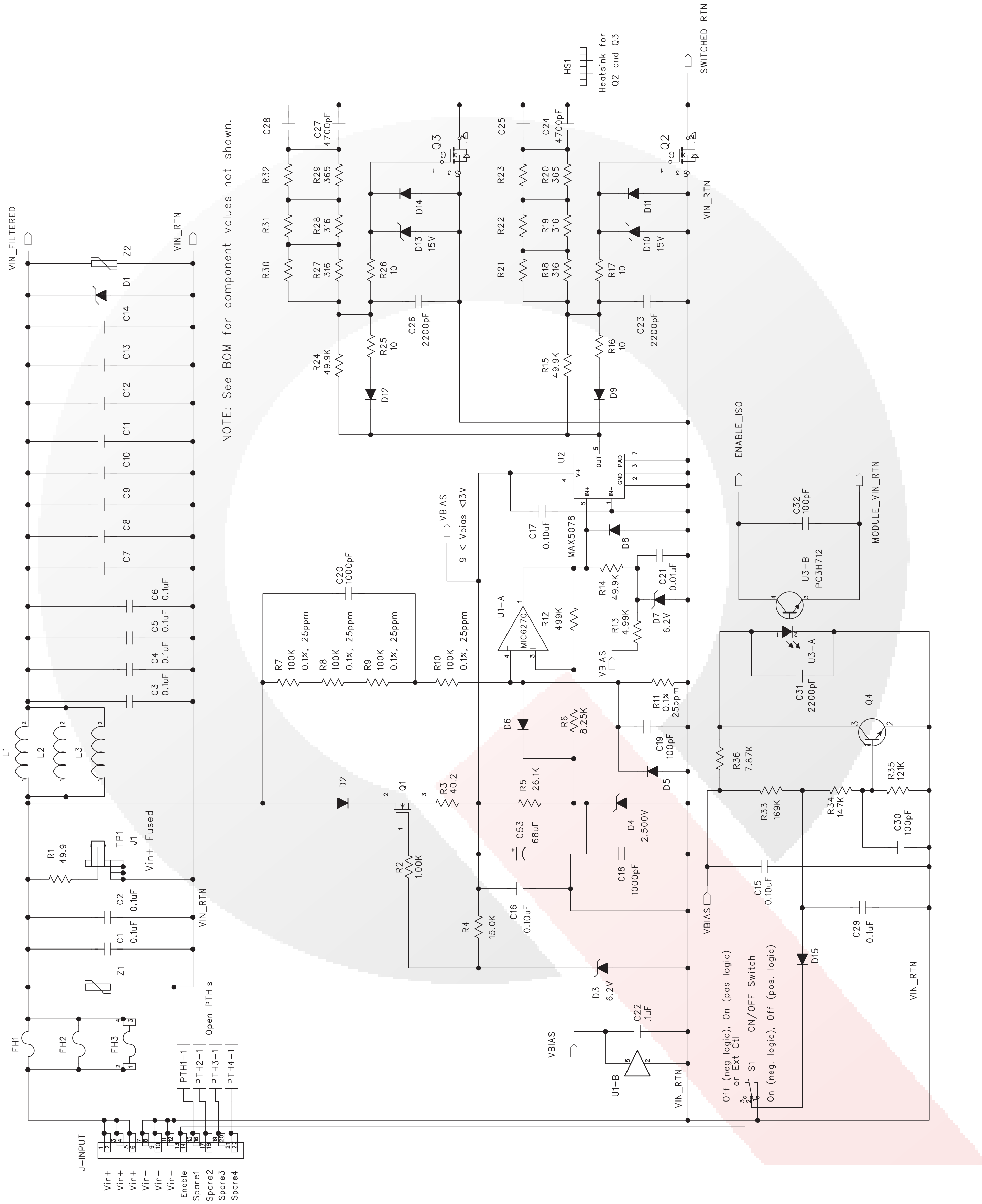


Figure 3: RailQor Evaluation Board Schematic - page one

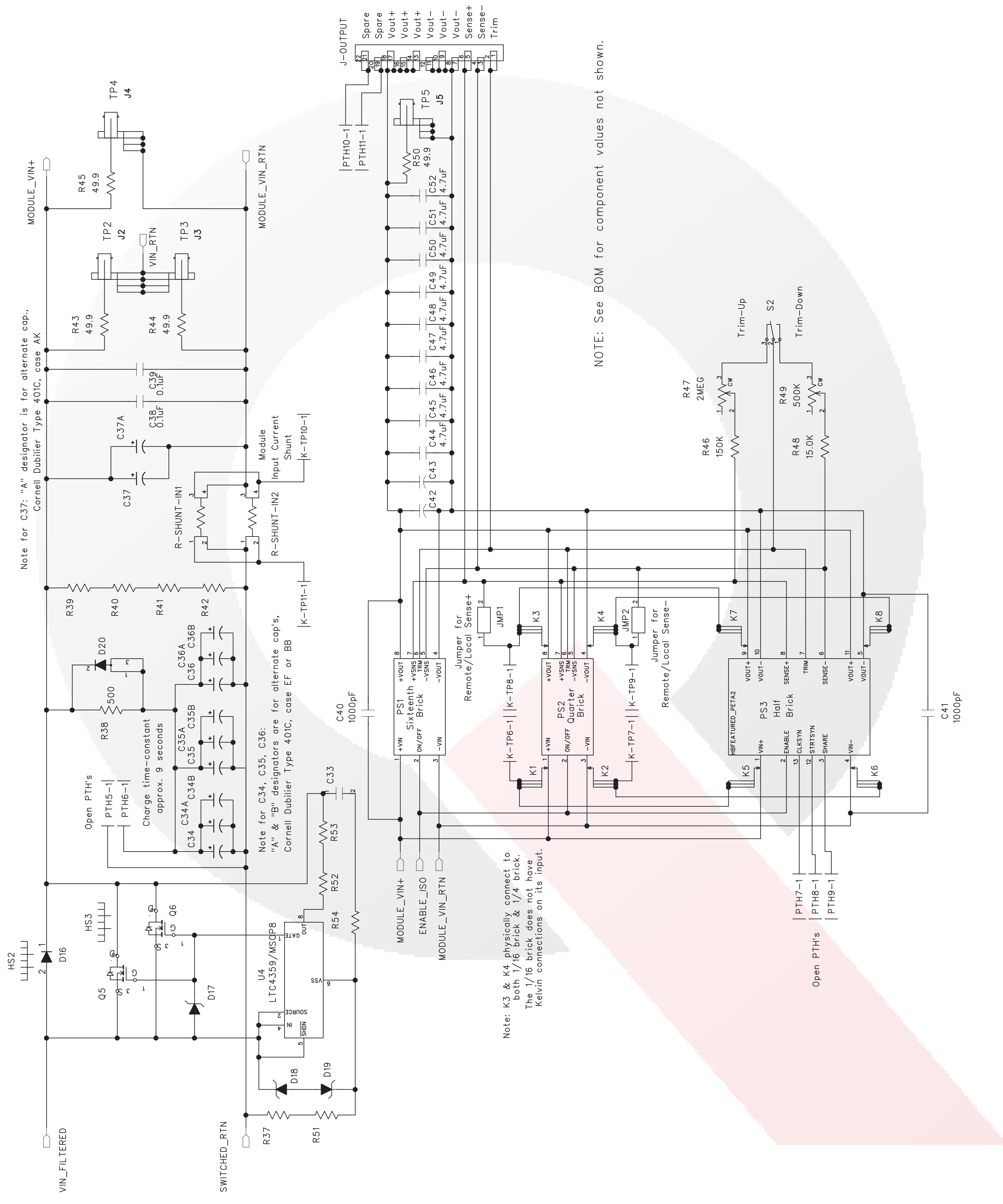


Figure 4: RailQor Evaluation Board Schematic - page two

- TPC Reference

The Reference circuit provides a stable voltage reference to the Voltage Monitor circuit. The reference circuit consists of components D4, R5, and C18. Zener D4 provides an accurate reference voltage. R5 provides the bias and limits the current into D4.

- TPC Voltage Monitor

The Voltage Monitor circuit determines whether the Switch is open or closed. It consists of components U1, R6 - R14, C19 - C21, and D5 - D7. The Voltage Monitor output uses the Driver block to produce sufficient drive to open the Switch quickly, or gradually close the Switch.

This circuit constantly monitors the input voltage. When the input voltage is above the minimum operating voltage and below the over-voltage threshold, the Voltage Monitor asserts its output to close the Switch. The switch is closed gradually by the Driver to reduce inrush current due to the capacitance in the power circuit. When the input voltage exceeds the over-voltage threshold, the Voltage Monitor quickly opens the Switch.

Input voltage is sensed through R7 - R11. The value of R11 sets the threshold voltage for the various RailQor modules. To allow rapid sensing of an input voltage rising edge, C20 is placed around R7 - R9. U1 is a comparator that compares the Reference voltage to the sensed input voltage at R11. D6 is to prevent the input drive to the comparator from exceeding 0.7V above the reference, which avoids saturation, therefore increases the response time of the comparator to a change in input voltage. D5 is provided to protect the comparator input from negative voltages beyond 0.7V. R12 provides hysteresis to avoid chattering on and off when the sensed input voltage is at the reference voltage. The components R13, D7, C21, and R14 provide an accurate reference voltage pull-up to the comparator output stage.

- TPC Driver

The Driver circuit provides the needed circuitry to turn-on the Switch gradually, and to turn it off rapidly. The Driver consists of components U2, D8 - D14, C17, C23 - C28, and R15 - R32. The TPC Driver will turn on Switch Q2, or both Switches Q2 and Q3, depending on the RailQor Evaluation Board version. The description below refers to the drive for Q2, but operates the same for the components supporting Switch Q3.

The driver IC U2 receives the on / off signal from the Voltage Monitor. It then provides the needed drive output to the Switch Q2. The turn-on output drive of U2 to Switch Q2 is provided through R15 and ramped up gradually by charging C23. R15 is a high value resistor to slow the rate of turn-on. The rate of rise of the drive signal is further slowed by R17 charging the input capacitance of the Switch Q2. This gradual turn-on reduces the inrush current into the downstream capacitance in the power circuits.

When the driver IC U2 pulls low to turn-off the Switch Q2, it forward biases D9 which pulls down the input of Q2 through R17 and R16. The resistance value of R16 is low to provide a low impedance path to quickly discharge the gate of Switch Q2, thereby turning it off quickly. D10 is a zener diode to provide over-voltage protection to the gate of Switch Q2. Components R18 - R23, and C24 and C25 are placed across Switch Q2 to provide negative feedback to the Switch input. This slows down the turn-on of Q2 after it has been turned-off by an over-voltage transient event.

- TPC Switch

The Switches Q2 and Q3 are power FETs that provide on/off switching of the input voltage. Closing the Switches completes the circuit path to allow the incoming voltage to be placed across the RailQor power conversion modules. Opening the switches will block incoming high voltage transients, and will isolate the input from the hold-up capacitor and RailQor modules during hold-up events.

These switches are mounted to heatsink HS1, and cooled using airflow directed over this heatsink. Please ensure that a fan is directing air across HS1 during evaluation board operation.

- TPC L1/L2, TVS, and MOV

Inductor L1 or L2 and capacitors C3 - 14, along with the input capacitance of the RailQor power module, slow the rising edge of the input transient as seen by the RailQor power converter module. That network, along with the TVS D1 and MOV's Z1 and Z2 provide over-voltage protection from the high voltage input spikes as described in Table 4 on page 4.

On/Off Isolator

The On/Off Isolator circuit allows the incoming On/Off signal, which is typically referenced to input Vin Return (Vin-, or VIN_RTN), to be used with the RailQor power module, which can have a significant difference in ground potential. The On/Off Isolator consists of components S1, D15, C15, C29 - C32, R33 - R36, Q4, and U3.

When the On/Off signal input is open or logic high, R33 and R34 provide bias to turn-on the base of Q4. Transistor Q4 collector saturates and pulls low, which removes the voltage source from U3 so that U3 input photo-diode is off. This ensures that the U3 output transistor is also off, leaving the Enable Out signal to float high. This high signal will then keep the RailQor power module in the off state.

When the incoming On/Off signal pulls low, it is sensed through D15 and the bias to Q4 base is taken away. Q4 base is turned-off, which causes Q4 collector to open, allowing the VBIAS to forward bias the input photo-diode of U3. This turns-on and saturates the transistor output of U3, pulling the Enable Out signal low. This low signal will turn-on the RailQor power module.

The Enable signal can be applied externally through connector J-INPUT. However, switch S1 can be used to manually turn the power module on and off. Switch S1 is connected for negative logic for the on/off enable signal, since that is the typical configuration of the RailQor power modules. This switch can be used for modules with positive logic by understanding that the on and off indicators will be marked in reverse on the evaluation board.

Hold-Up Circuit

The input voltage drop-out requirements of EN 50155 require the addition of a hold-up circuit. Also, the RIA-12 transient protection circuit shown here provides protection by disconnecting the input voltage from the converter module. Therefore a hold-up circuit is required to support operation during the over-voltage transient. The Hold-Up Circuit consists of components D16 - D20, Q5, Q6, U4, R37, R38, R51 - R54, and C33 - C39.

The input voltage charges the hold-up capacitors C34 - C36 through R36. The resistor R36 is provided to limit the charge current into C34 - C36 so that it does not overstress the input-side components or blow the input fuse. Charge time must be less than ten seconds. Diode D20 is provided so that when input voltage drops out or is disconnected due to an over-voltage transient, sufficient energy is quickly delivered to the power converter (load).

Diode D16 or transistors Q5 and Q6 are there to direct hold-up energy to the input of the power module, and block it from going back out to the input source. The RQ1B, RQ68, and RQ72 evaluation boards use D16 to block reverse current, and do not use the circuitry of Q5 and Q6. The RQ18 evaluation board uses Q5 and Q6 and the associated circuitry to block reverse current, and does not use D16. Q5 and Q6 are controlled using an OR'ing FET Controller IC, U4.

The components D16, Q5, and Q6 are mounted to heatsink HS2 and HS3. They are cooled using airflow directed over these heatsinks. Please ensure that a fan is directing air across HS2 and HS3 during evaluation board operation.

The capacitors chosen for the evaluation board are sized to provide hold-up during the 20mS over-voltage transientof RIA-12. They are not sized for the 30mS input voltage drop-out.

The actual nominal capacitance values for the hold-up function need to be much higher than the nominal calculated value. This is to account for the capacitor's set-point tolerance, and the substantial loss of capacitance at cold temperature. To minimize over-design, a capacitor can be selected that has better stability of capacitance over temperature. An example of a capacitor with improved stability at cold temperatures is the 401C series from Cornell Dubilier Electronics Inc. (www.cde.com). Designers will need to evaluate their particular needs to determine the nominal value of capacitance for this function, the capacitor technology, and the supplier.

Capacitor C37 is provided for input stability (see SynQor application note "Input System Instability"), but will also add to the hold-up time provided by C34 - C36.

Resistors R39 - R42 are placed across the input of the power converter module to ensure that the input voltage will discharge to ground after being disconnected from the input source power for a period of time. Caution: this node may have high voltage applied for a few minutes after input power has been removed. Exercise caution when handling.

- Hold-Up Capacitor Design

To determine the hold-up capacitance needed, add the power delivered to the load to the power burned due to the conversion efficiencies of the RailQor modules. Then calculate the needed hold-up capacitance by using

$$C\ \text{hold-up} = \frac{2 * \text{Power} * \text{Time}}{(\text{Vstart}^2 - \text{Vfinish}^2)}$$

Where Power = Pout + conversion losses, time = drop-out time, Vstart = nominal input voltage, Vfinish = the max UVLO of the RailQor modules plus circuit drops.

Example: for an RQ72 5V output module with a nominal 72Vdc input and a maximum UVLO of 38.4V, determine the hold-up capacitance needed for a 30mS input voltage drop-out.

For an output power of 50W, efficiency is 93%, so total input hold-up power = 50W / 0.93 = 53.8W. The hold-up capacitance needed is determined by the following equation.

$$C\ \text{hold-up} = \frac{2 * 53.8\text{W} * 30\text{ms}}{(72^2 - (38.4\text{V} + 1.5\text{V})^2)} = 898\text{uF}$$

However, the capacitor should be sized bigger to compensate for the set-point tolerance of the capacitor and the loss of capacitance at cold temperatures. Using temperature stabilized capacitors, the set-point tolerance is 20% and the cold temperature loss of capacitance is 20%. This would require a capacitor selection of 1400uF or 1700uF nominal.

RailQor Power Module

The RailQor power module circuit includes sockets to facilitate changing the power module if desired. Input bulk capacitor C37 is installed on the evaluation board, however if using the filter module in your final design then C37 is not required. This is because the filter module includes a stabilizing bulk capacitor inside.

Two BNC test connectors (TP2 and TP3) are provided at the RailQor power module input with the shield connected to Vin Return (Vin-, VIN_RTN), not to the power module return (MODULE_VIN_RTN). This allows simultaneous differential measurements of both Vin at the input connector J-INPUT, and MODULE_VIN+ at the RailQor power module input. This is because the shield connections are at the same potential (Vin Return at the input connector J-INPUT).

A BNC connector is also provided at the RailQor power module input, but with the shield referenced to the power module return (MODULE_VIN_RTN). This facilitates input ripple voltage measurements of the power module."

CAUTION: The input source voltage (Vin+ Fused) BNC test connector TP1 shield is connected to the return of the input source supply voltage (Vin-, VIN_RTN). However, the RailQor power module input (MODULE_VIN+) BNC test connector TP4 shield is at a different ground potential (MODULE_VIN_RTN). Simultaneously connecting oscilloscope probe ground clips or BNC cables to both the source supply input voltage BNC TP1 and to the RailQor input voltage BNC TP4 will place a short around the transient protection circuit. That would result in damage to the RailQor power module during transient tests. When simultaneously monitoring the input voltages to the evaluation board and to the RailQor power module using TP1 and TP4, use a differential probe for one of the measurements, preferably TP4, so only one circuit ground is connected to the oscilloscope ground clip or shield.

Alternatively, one could use standard oscilloscope probes to simultaneously monitor the evaluation board input source voltage and the input voltage to the RailQor converter module by using the following configuration. For the input source voltage, connect one standard oscilloscope probe to the BNC test connector TP1. For the input voltage to the RailQor power module, connect one probe to "MODULE_VIN+" BNC test connector TP2 and one probe to "MODULE_VIN_RTN" BNC test connector TP3. Use the Channel A minus Channel B function of the oscilloscope to view the differential signal. The BNC test connector TP2 has its center pin connected to the positive terminal of the converter module input (MODULE_VIN+), and its shield connected to the input source voltage negative terminal (Vin-, VIN_RTN). The BNC test connector TP3 has its center pin connected to the negative terminal of the converter module input (MODULE_VIN_RTN), and its shield connected to the input source voltage negative terminal (Vin-, VIN_RTN). This configuration connects all three probe grounds to Vin- (VIN_RTN).

The power converter output voltage BNC test connector TP5 can be connected with the either of the above configurations since the converter output is isolated."

Trim resistors are installed to allow trim-up (R46 and trim-pot R47) or trim-down (R48 and trim-pot R49) of the output voltage. Use switch S2 to select between trim-up, trim-down, or no trim.

Kelvin connections to the module input and output voltages are provided with flexible bands (Kelvin connector clips) located on the bottom-side of the evaluation board. There are test points located on the top side of the board to facilitate measuring the voltages on these Kelvin connectors.

For a remote-sense configuration, ensure that jumper shorts across JMP1 and JMP2 are not installed. For a local-sense configuration, install a jumper short across JMP1 and another across JMP2.

A BNC connector TP5 is provided at the RailQor power module output to facilitate output voltage ripple and noise measurements. Please refer to SynQor's application note "Vout Ripple Measurement" for assistance with making accurate ripple and noise measurements.

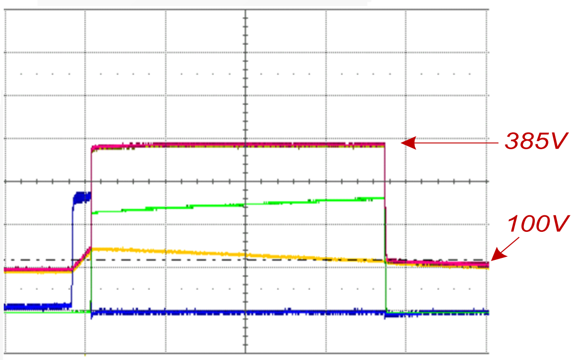
TRANSIENT PROTECTION CIRCUIT EVALUATION TEST RESULTS

The performance of the transient protection circuit to a RIA-12 test waveform with a RQ1B converter is shown below. The surge voltage (red trace) of 385V (3.5 * Vin for 20mS) is applicable to RQ1B with a nominal Vin of 110V.

Initially the Switch, FET Q2, is "closed" (on) with a near zero voltage across it. The protected output voltage (VIN_FILTERED) is equal to the DC input, minus a small voltage drop across the switch FET. As the input voltage transient occurs the voltage on Q2 begins to go up to about 260V when it is opened (turned off), as shown by the green trace.

The protected output momentarily charges up to higher value of about 140V. However, this quickly drops back down as it supports the power draw by the RQ1B converter input as shown by the yellow trace. This is still well below the transient input voltage rating (170V) of RQ1B converter.

The inrush current (blue trace) into the output bulk capacitors is limited to about 14A for 2mS by the inductor L1. When the input voltage transient is over, the circuit returns to normal operation.



Red: Input surge voltage (Va): 100V/ div
Blue: Input current: 5A/div
Green: Voltage across switch FET (Vc): 100V/div
Yellow: Protected output voltage, Vprot: 100V/div
Timebase: 5ms/div

Figure 3: Response of Transient Protection Circuit to RIA-12 Test Transient

Part V: Evaluation Tests

This section provides brief descriptions and guidelines for electrical evaluation tests of the RailQor converters, including tests of the input voltage transients and input voltage drop-out.

The following is a list of evaluation tests discussed in this section.

A) Initial Power-up

B) Input Under-Voltage Turn-On Threshold

C) Input Under-Voltage Turn Off Threshold

D) Input Lockout Hysteresis Voltage

E) Input Voltage Range

F) No Load Input Current

G) Disabled Input Current

H) Line Regulation

I) Load Regulation

J) Output Ripple

K) Output DC Current-Limit Inception

L) Output Voltage Deviation and Response Time Due to Step Change in Input Voltage

M) Output Voltage Deviation and Response Time Due to Step Change in Load Current

N) Soft Start Turn-On Time

O) Efficiency

P) Input Voltage Transient for RIA-12

Q) Input Surge (Spike) Voltage Transients for EN 50155 and RIA-12

R) Hold-Up Time

When setting up and operating electrical equipment, ensure standard safety and ESD guidelines are followed.

During electrical evaluation tests use a fan to blow cooling air over the power converter module, and over the evaluation board heatsinks HS1, HS2, and HS3

Equipment Required

- RailQor Evaluation Board
- Power Supply, (voltage range depends on which RailQor module is being tested.)
- Oscilloscope
- Digital Voltmeters (DVM)
- Load, electronic or resistive
- Two current shunts
- BNC cables
- BNC T-adapter
- BNC to banana plug adapter
- BNC to oscilloscope probe tip adapter (for high frequency measurements)

Set-up

- Connect the positive lead of the input power supply source to Vin+ on J-INPUT on the evaluation board. Connect the return lead of the input power supply source to Vin- on J-INPUT. Size wires according to maximum dc current.
- Connect Vout+ from the evaluation board J-OUTPUT to a current shunt. Connect the other side of this current shunt to the positive lead of the load. Connect Vout- from J-OUTPUT to the return lead of the load. Size wires according to maximum dc current.
- Connect an external switch or control to the Enable pin of J-INPUT. Otherwise, leave the pin open and use the On/Off switch S1 provided on the evaluation board.
- Put output trim switch S2 in desired position for no trim, trim up, or trim down. If trimming, set the trim pot to the desired position.
- Decide on a remote or local sense configuration and connect jumpers JMP1 and JMP2 as needed. For a remote-sense configuration ensure that jumper shorts across JMP1 and JMP2 are not installed. Use a twisted-wire pair to make a connection from J-OUTPUT to the load sense location. For a local-sense configuration, install a jumper short across JMP1 and another across JMP2.
- Kelvin connections are provided for DVM measurements of module input voltage and module output voltage. For the input voltage Kelvin measurements of quarter-brick and half-brick modules use TP6 (+) and TP7 (-). For the output voltage Kelvin measurements of all size modules use TP8 (+) and TP9 (-)

NOTE: Power module input voltage and output voltage measurements should be measured at the power module using Kelvin connections. They should not be measured at the evaluation board connectors J-INPUT or J-OUTPUT, or other locations. Measuring module input or output voltage other than at the provided Kelvin connection test points (TP6, TP7, TP8, TP9) will result in measurement error.

CAUTION: The BNC test connectors do not all have common grounds, please refer to CAUTION on page 13.

CAUTION: The evaluation board can retain high voltage for a few minutes after input power has been removed. Exercise caution when handling.

A) Initial Power-up

1) Ensure the Enable switch (external or evaluation board switch S1) is in the off position. When using the evaluation board switch S1, for a RailQor converter with negative on/off logic, the S1 "on" position is labeled "ON", and the "off" position is labeled "OFF". However, for positive on/off logic the labeling is marked in reverse, i.e. the "on" position is labeled "OFF", and the "off" position is labeled "ON".
2) Turn on the fan
3) Turn on the input source power supply and increase its voltage until the desired value is reached.
4) Put the Enable switch (external or evaluation board switch S1) in the "on" position to enable the DC-DC converter.
5) Verify the proper output voltage is present on the power converter output with a DVM, oscilloscope, or both.
6) The converter can also be turned on by first putting the Enable switch in the "on" position and then either turning on the power supply by ramping up its voltage manually from zero to the desired value, or by presetting the power supply to the desired voltage and then switching it on.
7) Toggle the Enable switch to the "off" position after each test is performed to disable the DC-DC converter, and remove input power.

B) Input Under-Voltage Turn-On Threshold

The input under-voltage turn-on threshold is defined as the input voltage at which the pre-enabled converter first turns on as the input voltage is increased from zero.

1) Set the input voltage source to zero.
2) Turn on the fan.
3) Enable the converter using the Enable signal or switch S1.
4) Slowly increase the input voltage from zero while monitoring the input voltage and output voltage with a DVM and/or oscilloscope. Continue increasing the input voltage until the output voltage appears. Record the input voltage. The input voltage should be within the range given in the datasheet at "Input Characteristics", "Input Under-Voltage Lockout", "Turn-On Voltage Threshold".
5) Toggle the Enable switch to the "off" position and remove input power.

C) Input Under-Voltage Turn-Off Threshold

The input under-voltage turn-off threshold is defined as the input voltage at which the properly operating converter turns itself off as the input voltage is decreased below the operating range.

1) Disable the converter using the Enable signal or switch S1.
2) Set the input voltage source to the minimum input voltage specified in the datasheet.
3) Turn on the fan.
4) Enable the converter using the Enable signal or switch S1.
5) Verify that the output voltage is present.
6) Slowly reduce the input voltage until the converter turns off. Record the input voltage at this point. The input voltage should be within the range given in the datasheet at "Input Characteristics", "Input Under-Voltage Lockout", "Turn-Off Voltage Threshold".
7) Toggle the Enable switch to the "off" position and remove input power.

D) Input Lockout Hysteresis Voltage

The input lockout hysteresis voltage is the difference between the input voltage at which the converter turns on (input under-voltage turn-on threshold) and that at which it turns off (input under-voltage turn-off threshold) with the Enable signal or switch S1 already in the "on" position.

Subtract the result of the "Input Under-Voltage Turn-Off Threshold" test from that of the "Input Under-Voltage Turn On Threshold" test. The result is the hysteresis, which should lie within the range given in the "Input Characteristics", "Input Under-Voltage Lockout", "Lockout Voltage Hysteresis" line of the datasheet.

E) Input Voltage Range

The input voltage range is the span of input voltages within which the converter is designed to operate in order to produce the correct output voltage.

1) Disable the converter using the Enable signal or switch S1.
2) Ensure the load current is set to a value equal to or less than the rated current of the unit.
3) Turn on the fan.
4) Set the input voltage to any value within the operating range.
5) Enable the converter with the Enable signal or switch S1.
6) Ensure that the output voltage is at its correct voltage.
7) Vary the input voltage over the range given in the "Operating Input Voltage Range" line of the datasheet while monitoring the input and output voltage with a DVM and/or oscilloscope. Verify that the output voltage stays at its correct value for all input voltages within the range given in the datasheet.
8) Toggle the Enable switch to the "off" position and remove input power.

F) No Load Input Current

The no load input current is the current that the converter draws from the input voltage supply when it is running with no load connected to its output.

1) Remove the output load.
2) Enable the converter using the Enable signal or switch S1.
3) Adjust the input power supply to the particular operating point of interest.
4) Read and record the input current from the input-side current shunt as measured by a DVM. If the input voltage is set at the value given in the datasheet the reading should not exceed the maximum value given there in the "Input Characteristics", "No-Load Input Current" line.
5) Toggle the Enable switch to the "off" position and remove input power.

G) Disabled Input Current

The disabled input current is the current that the converter draws from the input voltage supply while the converter is in the "off" state.

1) Disable the converter using the Enable signal or switch S1.
2) Adjust the input power supply to the particular voltage of interest.
3) Read and record the input current from input-side current shunt with a DVM. If the input voltage is set at the value given in the datasheet the reading should not exceed the maximum value given in the "Input Characteristics", "Disabled Input Current" line.
4) Toggle the Enable switch to the "off" position and remove input power.

H) Line Regulation

Line regulation is defined as the percentage change in output voltage caused by varying the input voltage over the specified operating range with the output load and temperature remaining constant.

1) Turn on the fan.
2) Enable the converter using the Enable signal or switch S1.
3) Turn on the power supply and set the output current level to the desired operating point.
4) While observing the output voltage on the DVM adjust the input power supply voltage across the converter's input operating voltage range. Record the output voltage at each input voltage.
5) Toggle the Enable switch to the "off" position and remove input power.

Calculate the mean output voltage as VoMEAN = VO1 + VO2 + ... + VON / N, where VO1, VO2, VO3, etc., are each of the N output voltages recorded.

The +/- deviation of any measured value of output voltage (say the j-th measurement) from the mean value can be defined as Voj - VoMEAN

If the load current is within the operating range of the converter, the deviation should not exceed the maximum limits given in the "Output Characteristics", "Output Voltage Regulation", "Over Line" value in the datasheet.

I) Load Regulation

Load regulation is defined as the percentage change in output voltage caused by varying the output load current over the specified range (0 amperes to full load) with the input voltage and ambient temperature remaining constant.

1) Turn on the fan.
2) Enable the converter using the Enable signal or switch S1.
3) Turn on the power supply and set the input voltage level to the desired operating point.
4) While observing the output voltage on a DVM, adjust the load across the converter's operating load range (0 amperes to full load). Record the output voltage at each load current setting.
5) Toggle the Enable switch to the "off" position and remove input power.

To calculate the mean output voltage and deviations use the equations shown in the Line Regulation test section.

If the input voltage is set at the value given in the datasheet, the deviation should not exceed the maximum limits given in the "Output Characteristics", "Output Voltage Regulation", "Over Load" line.

J) Output Ripple

Output ripple is defined as the periodic AC component at the DC-DC converter's output voltage. It is harmonically related to the converter's switching frequency. It is measured in two ways: peak-to-peak and RMS, both done at a specified bandwidth.

For the best accuracy when measuring ripple and noise, please refer to SynQor's application note "Vout Ripple Measurement".

1) Set the time base of the oscilloscope to a value that will allow the switching frequency, as indicated in the datasheet, to be viewed. Limit the bandwidth to 20MHz. If the oscilloscope has the capability, set it to calculate the peak-peak and RMS ripple voltages.
2) Connect the oscilloscope to the RailQor power module output voltage BNC test connector TP5 according to the instructions found in SynQor's application note "Vout Ripple Measurement".
3) Turn on the fan.
4) Enable the converter using the Enable signal or switch S1.
5) Turn on the power supply and set the input voltage and the output load to the desired operating point.
6) Measure the output ripple on the oscilloscope. The peak-to-peak and RMS ripple magnitudes should not exceed the values given in the "Output Voltage Ripple and Noise" section of the datasheet.
7) Toggle the Enable switch to the "off" position and remove input power.

K) Output DC Current-Limit Inception

The output current limit inception point is defined as the current where the converter begins to enter current limit.

1) Turn on the fan.
2) Enable the converter using the Enable signal or switch S1.
3) Turn on the power supply and set the input voltage to the desired operating point and the load current to a value just below the maximum rated output current of the converter.
4) While monitoring the output voltage, increase the load current slowly beyond the rated maximum. The current at which the converter loses regulation, and the output voltage falls to 90% of its steady state value, is the current limit inception point. This current should be greater than the rated current and should be similar to the current given in the "Output Characteristics", "Output DC Current-Limit Inception" line of the datasheet.
5) Toggle the Enable switch to the "off" position and remove input power.

L) Output Voltage Deviation and Response Time Due to Step Change in Input Voltage

The output voltage of the converter may have a temporary deviation due to a step change in input voltage or output current. This section tests the response of the converter due to a step change in input voltage.

The transient response of the converter is characterized by two parameters: the maximum output voltage deviation, and the response time. The output voltage deviation is defined as the response of the converter to a step change in the input voltage. The response time is the length of time it takes for the output voltage to return to within 1% of its final value after a transient.

This section is intended to test transient input voltages within the specifications of the power converter module, which includes input transients specified by EN 50155. However, this section does not test the input transient voltage protection capabilities of the transient protection circuit on the evaluation board, and therefore does not include RIA-12 transients. Please see the separate section below for RIA-12 input voltage transient tests that engage the transient protection circuit.

1) Attach an oscilloscope probe to the output. Set the oscilloscope channel to AC couple. Adjust the oscilloscope to the settings in the "Output Voltage Response to Step Change in Input Voltage" Figure in the datasheet.
2) Turn on the fan.
3) Enable the converter using the Enable signal or switch S1.
4) Turn on the power supply and set its voltage to the desired operating point.
5) Set desired input voltage transient using the input source supply in pulse mode, or a custom test configuration.
6) When set to the same conditions, the maximum output voltage deviation and response time should be similar to that seen in the "Output Voltage Response to Step-Change in Input Voltage" Figure in the datasheet.
7) Toggle the Enable switch to the "off" position and remove input power.

M) Output Voltage Deviation and Response Time Due to Step Change in Load Current

The output voltage of the converter may have a temporary deviation due to a step change in input voltage or output current. This section tests the response due to a step change in load current.

The transient response of the converter is characterized by two parameters: the maximum output voltage deviation, and the response time. The output voltage deviation is defined as the response of the converter to a step change in the load current. The response time is the length of time it takes for the output voltage to return to within 1% of its final value after a transient.

1) Attach an oscilloscope probe to the output. Set the oscilloscope channel to AC couple. Adjust the oscilloscope to the settings in the "Output Voltage Response to Step Change in Load Current" Figure in the datasheet.
2) Turn on the fan.
3) Enable the converter using the Enable signal or switch S1.
4) Turn on the power supply and set its voltage to the desired operating point.
5) Set the desired load transient using the electronic load in pulse mode, or using a custom test configuration.
6) The maximum output voltage deviation and response time should be similar to or better than the values given in the "Output Characteristics", "Output Voltage during Load Current Transient" section of the datasheet and the corresponding "Output Voltage Response to Step-Change in Load Current" Figure in the datasheet.
7) Toggle the Enable switch to the "off" position and remove input power.

N) Soft Start Turn-On Time

Soft Start Turn-On Time is defined as the time it takes for the output to rise to 90% of its final value from the time the converter is enabled. This rise time is deliberately made relatively slow to reduce the inrush current and to eliminate any overshoot in the output voltage.

1) Disable the converter using the Enable signal or switch S1.
2) Connect an oscilloscope probe to the ON/OFF (Enable) pin of the converter. Ground the probe to the Vin(-) (IN RTN) pin of the converter (MODULE_VIN_RTN of the evaluation board).
3) Connect an oscilloscope probe to the output voltage.
4) Adjust the time base of oscilloscope to a slow setting (i.e. mS / div.) to capture the entire start-up waveform.

5) Set the oscilloscope trigger to the probe monitoring the Enable signal, and set the trigger mode to single-shot (one-time event).
6) Turn on the fan.
7) Turn on the power supply and set its voltage to the desired operating point.
8) Enable the converter. Measure the waveforms captured on the oscilloscope.
9) Toggle the Enable switch to the "off" position and remove input power.

The soft-start turn-on time measured should not exceed the interval given in the "Dynamic Characteristics", "Turn-On Transient", "Turn-On Time" line of the datasheet.

Note: Different electronic loads can give dramatically different results on soft start due to their input characteristics during turn-on. If the turn-on appears abnormal, substitute an actual resistive load of the appropriate value.

O) Efficiency

Efficiency is defined as the ratio of the output power Pout (= Vout x Iout) to the input power Pin (= Vin x Iin) expressed as a percentage, under specified operating conditions.

To accurately measure the efficiency of the converter, high accuracy current shunts on the input and output must be used to measure the input and output currents. The input current shunt is provided on the evaluation board as R-SHUNT-IN1 (0.010 Ohm for RQ1B, RQ68, and RQ72) or R-SHUNT-IN2 (0.001 Ohm for RQ18).

Also, the input and output voltages must be measured with Kelvin connections at the module pins, not on the pin sockets or other locations away from the module. Kelvin test points are provided with TP6, TP7, TP8, and TP9.

1) Turn on the fan.
2) Enable the converter using the Enable signal or switch S1.
3) Turn on the power supply and set the input voltage level to the desired operating point.
4) Adjust the load to the desired operating point.
5) Read and record the input voltage Vin, the input current Iin, the output voltage Vout, and the output current Iout.
6) Toggle the Enable switch to the "off" position and remove input power.

Calculate the converter's efficiency with the following formula:

% Efficiency = Power Out * 100 / Power In

The calculated efficiency should be similar to or better than that shown in the Efficiency Figure in the datasheet.

The power dissipation of the converter module is Pin minus Pout.

P) Input Voltage Transient for RIA-12

This test confirms the protection capabilities of the input transient protection circuit against the high voltage transients specified in RIA-12, and the performance of the power converter during these transients.

The input transient protection circuit will block the high voltage transient from exceeding the input voltage specification of the power converter. However, the leading edge of the transient will allow the converter module input voltage to rise until it reaches the input over-voltage protection threshold of the transient protection circuit. The output voltage of the converter may have a temporary deviation due to this step change in input voltage.

Until the transient protection circuit functionality is verified on your test set-up, it is recommended that the RailQor converter not be inserted in the evaluation board. Instead, first connect a load resistor or an electronic load (constant current mode) set to a low power level. When the transient protection circuit functionality is verified, then insert the converter module in the evaluation board and re-test.

Transient Protection Circuit Verification Without the Power Converter Module

1) Remove the power converter module from the evaluation board.
2) At the sockets where the converter module is normally inserted, insert jumpers from the module Vin+ to a separate load positive terminal, and from module Vin- to the separate load negative terminal. Do not jumper to the output sockets where the converter module would insert, or to the load connected on the output of the

evaluation board. Doing so would place an over-voltage stress on evaluation board output components and load.

3) Set the separate load to a low power level at the nominal input voltage.
4) Attach an oscilloscope probe across the input source voltage using BNC test connector TP1, and set the oscilloscope channel to DC couple.
5) Attach a differential oscilloscope probe across the input voltage of the power converter socket using BNC test connector TP4 and set the oscilloscope channel to DC couple. Alternatively, one could use TP2 and TP3, and set the oscilloscope to Channel A minus Channel B. For details see the caution note below. Adjust the oscilloscope settings as required to view the transient.

CAUTION: The BNC test connectors do not have common grounds, please refer to CAUTION on page 13.

6) Set the desired input voltage operating point and transient using the input source supply in pulse mode, or using a custom test configuration. This transient exceeds the input transient specifications of the converter module, but will be blocked by the transient protection circuit.
7) To capture the transient event, set the oscilloscope trigger mode to "single shot" and the trigger source to the channel with the input transient.
8) Turn-on the input source power supply and apply the input voltage transient.
9) Verify that the transient at the power converter input is within the specified input range of the power converter.
10) Remove input power.

Transient Protection Circuit & Converter Module Verification

1) Insert the power converter module in the evaluation board.
2) Attach an oscilloscope probe across the input source voltage using BNC test connector TP1, and set the oscilloscope channel to DC couple.
3) Attach an oscilloscope probe across the output voltage of the power converter using BNC test connector TP5, and set the oscilloscope channel to AC couple.
4) Attach a differential oscilloscope probe across the input voltage of the power converter using BNC test connector TP4 and set the oscilloscope channel to DC couple. Alternatively, one could use TP2 and TP3, and set the oscilloscope to Channel A minus Channel B. For details see the caution note below. Adjust the oscilloscope settings as required to view the transient.

CAUTION: The BNC test connectors do not have common grounds, please refer to CAUTION on page 13.

5) Set the load to the desired power.
6) Turn on the fan.
7) Set the desired input voltage operating point and transient using the input source supply in pulse mode, or using a custom test configuration. This transient is outside the input transient specifications of the converter module, but will be blocked by the transient protection circuit.
8) To capture the transient event, set the oscilloscope trigger mode to "single shot" and the trigger source to the channel with the input transient.
9) Enable the converter using the Enable signal or switch S1.
10) Turn-on the input source power supply and apply the input voltage transient.
11) Verify that the transient at the power converter input is within the specified input range of the power converter. Also verify that the output voltage transient of the power converter is within reasonable limits.
12) Toggle the Enable switch to the "off" position and remove input power.

Q) Input Surge (Spike) Voltage Transients for EN 50155 and RIA-12

High voltage surge testing of transients in the thousands of volts with microsecond durations are typically completed by contractors having specialized knowledge and equipment. Please refer to approved contractors to complete these tests.

RIA-12 states that, as an alternative to testing, calculations may be used to demonstrate compliance. SynQor has completed circuit simulations that demonstrate compliance to RIA-12 Direct Transients and Indirect Transients.

R) Hold-Up Time

Hold-up time is the duration that the power module output will remain in regulation after the nominal input voltage is removed.

1) Connect a 50W load directly on the output of the source input power supply. This load is in parallel with the evaluation board input.
2) Attach an oscilloscope probe across the input source voltage using BNC test connector TP1, and set the oscilloscope channel to DC couple.
3) Attach an oscilloscope probe across the output voltage of the power converter using BNC test connector TP5, and set the oscilloscope channel to DC couple.
4) To capture the transient event, set the oscilloscope trigger mode to "single shot" and the trigger source to the channel with the input voltage.
5) Set the desired load on the power module.
6) Turn on the fan.
7) Enable the converter using the Enable signal or switch S1.
8) Turn on the source input power supply and set its voltage to the nominal operating input voltage.
9) Disable the source input power supply input.
10) Measure the time from when the source input voltage began to fall and when the power module output voltage went out of regulation.
11) Toggle the Enable switch to the "off" position and remove input power.

Appendix

Evaluation Board Bill of Materials (BOM)

RefDes	Value	Tolerance	Package	Description
C1	0.1uF	20%	1812	X7R, 630V
C2	0.1uF	20%	1812	X7R, 630V
C3	0.1uF	20%	1812	X7R, 630V
C4	0.1uF	20%	1812	X7R, 630V
C5	0.1uF	20%	1812	X7R, 630V
C6	0.1uF	20%	1812	X7R, 630V
C7	OPEN	20%	1812	X7R, 630V
C8	OPEN	20%	1812	X7R, 630V
C9	OPEN	20%	1812	X7R, 630V
C10	OPEN	20%	1812	X7R, 630V
C11	OPEN	20%	1812	X7R, 630V
C12	OPEN	20%	1812	X7R, 630V
C13	OPEN	20%	1812	X7R, 630V
C14	OPEN	20%	1812	X7R, 630V
C15	0.10uF	10%	603	X7R 25V
C16	0.10uF	10%	805	X7R 50V
C17	0.10uF	10%	805	X7R 50V
C18	1000pF	5%	603	COG, 100V, 1000pF, 5%, 0603
C19	100pF	5%	603	COG, 100V, 100pF, 5%, 0603
C20	1000pF	10%	1206	X7R 2000V
C21	0.01uF	10%	402	X7R 25V
C22	0.1uF	10%	603	X7R, 50V, 0.1uF, 5%, 0603
C23	2200pF	10%	402	X7R 50V
C24	4700pF	10%	1206	X7R, 1000V
C25	OPEN	10%	1206	X7R, 1000V
C26	2200pF	10%	402	X7R 50V
C27	4700pF	10%	1206	X7R, 1000V
C28	OPEN	10%	1206	X7R, 1000V
C29	0.1uF	10%	805	X7R 50V
C30	100pF	5%	603	C0G 50V
C31	2200pF	10%	402	X7R 50V
C32	100pF	5%	603	COG, 100V, 100pF, 5%, 0603
C33	See BOM Table		1210	Cap, X7R, 100V
C34	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C34A	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C34B	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C35	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C35A	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C35B	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C36	See BOM Table		Radial	Aluminum Electrolytic Capacitor

Appendix

Evaluation Board Bill of Materials (BOM) - continued

RefDes	Value	Tolerance	Package	Description
C36A	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C36B	See BOM Table		Radial	Aluminum Electrolytic Capacitor
C37	150uF		Radial Mount	Al Elec Cap, Nichicon LS Snap-in Terminal 150uF, 400V, Z Case
C37A	Open		Radial	Al Elect Cap Case AK
C38	0.1uF	20%	1812	X7R, 630V
C39	0.1uF	20%	1812	X7R, 630V
C40	1000pF	10%	1812	X1/Y2 Safety Cap, 1500VAC Withstand, 5000V Impulse
C41	1000pF	10%	1812	X1/Y2 Safety Cap, 1500VAC Withstand, 5000V Impulse
C42	OPEN	20%	D case	Low ESR Tantalum
C43	OPEN	20%	D case	Low ESR Tantalum
C44	4.7uF	20%	1210	X7R, 50V
C44	4.7uF	20%	1210	X7R, 50V
C45	4.7uF	20%	1210	X7R, 50V
C46	4.7uF	20%	1210	X7R, 50V
C47	4.7uF	20%	1210	X7R, 50V
C48	4.7uF	20%	1210	X7R, 50V
C49	4.7uF	20%	1210	X7R, 50V
C50	4.7uF	20%	1210	X7R, 50V
C51	4.7uF	20%	1210	X7R, 50V
C52	4.7uF	20%	1210	X7R, 50V
C53	68uF		Radial	Nichicon, Al Elect Cap, Radial, Type PM, 68uF, 16V, 6.3x11mm
D1	See BOM Table		SMC	Bidirectional TVS Diode
D2	600V		SOD-123	Surface Mount Ultra Fast Recovery Silicon Rectifier, 1A, 600V
D3	6.2V		SOD-323	Zener Diode, 6.2V, SOD-323
D4	2.500V	0.1%, 50PPM	SOT-23	Precision Shunt Reference
D5	75V		SOD-523	Low Leakage Diode, 75V, SOD-523
D6	75V		SOD-523	Low Leakage Diode, 75V, SOD-523
D7	6.2V		SOD-323	Zener Diode, 6.2V, SOD-323
D8	75V		SOD-523	Low Leakage Diode, 75V, SOD-523
D9	30V		SOD-523	SBR Diode, SOD-523
D10	15V		SOD-523	Zener Diode, 15V
D11	75V		SOD-523	Low Leakage Diode, 75V, SOD-523
D12	30V		SOD-523	SBR Diode, SOD-523
D13	15V		SOD-523	Zener Diode, 15V
D14	75V		SOD-523	Low Leakage Diode, 75V, SOD-523
D15	200V		SOD-323	Diode
D16	See BOM Table		DO-247	Schottky Diode
D17	See BOM Table		SOD-523	Zener Diode

Appendix

Evaluation Board Bill of Materials (BOM) - continued

RefDes	Value	Tolerance	Package	Description
D18	See BOM Table			TVS Diode
D19	See BOM Table		SMB	Unidirectional TVS Diode
D20	250V, 40A		D2PAK	Schottky Diode MBRB40250TG
HS1	See BOM Table			Heatsink, dual, for TO-247 packages
HS2	See BOM Table			Heatsink, dual, for TO-247 packages
HS3	See BOM Table			Heatsink, dual, for TO-247 packages
L1	See BOM Table			Inductor
L2	See BOM Table			Inductor
L3	See BOM Table			Inductor
JP1				Two-Pin Male Header Sullins GREC002DAAN-RC
JP2				Two-Pin Male Header Sullins GREC002DAAN-RC
JPS1				Shorting Jumper 151-8011-E
JPS2				Shorting Jumper 151-8011-E
Q1	1000V		D PAK	N-CHANNEL MOSFET
Q2	See BOM Table		TO-247	FET, through-hole, TO-247
Q3	See BOM Table		TO-247	FET, through-hole, TO-247
Q4	60V		SOT-23	NPN Transistor
Q5	See BOM Table		TO-247	FET, through-hole, TO-247
Q6	See BOM Table		TO-247	FET, through-hole, TO-247
R1	49.9	1%	805	Resistor
R2	1.00K	1%	603	Resistor
R3	40.2	1%	603	Resistor
R4	15.0K	1%	603	Resistor
R5	26.1K	1%	603	Resistor
R6	8.25K	1%	402	Resistor
R7	100K	0.1%, 25ppm	1206	Resistor, 100K .1% 1206 25ppm
R8	100K	0.1%, 25ppm	1206	Resistor, 100K .1% 1206 25ppm
R9	100K	0.1%, 25ppm	1206	Resistor, 100K .1% 1206 25ppm
R10	100K	0.1%, 25ppm	1206	Resistor, 100K .1% 1206 25ppm
R11	See BOM Table	0.1%, 25ppm	603	Resistor
R12	499K	1%	402	Resistor
R13	4.99K	1%	402	Resistor
R14	49.9K	1%	402	Resistor
R15	49.9K	1%	402	Resistor
R16	10	5%	402	Resistor
R17	10	20%	805	Resistor
R18	316	1%	805	Resistor, 316, 1%, 100ppm, 0805
R19	316	1%	805	Resistor, 316, 1%, 100ppm, 0805
R20	365	1%	805	Resistor
R21	OPEN	1%	805	Resistor, 1%, 100ppm, 0805
R22	OPEN	1%	805	Resistor, 1%, 100ppm, 0805

APPENDIX

Evaluation Board Bill of Materials (BOM) - continued

RefDes	Value	Tolerance	Package	Description
R23	OPEN	1%	805	Resistor, 1%, 100ppm, 0805
R24	49.9K	1%	402	Resistor
R25	10	5%	402	Resistor
R26	10	20%	805	Resistor
R27	316	1%	805	Resistor, 316, 1%, 100ppm, 0805
R28	316	1%	805	Resistor, 316, 1%, 100ppm, 0805
R29	365	1%	805	Resistor
R30	OPEN	1%	805	Resistor, 1%, 100ppm, 0805
R31	OPEN	1%	805	Resistor, 1%, 100ppm, 0805
R32	OPEN	1%	805	Resistor, 1%, 100ppm, 0805
R33	169K	1%	603	Resistor
R34	147K	1%	603	Resistor
R35	121K	1%	603	Resistor
R36	7.87K	1%	603	Resistor
R36	7.87K	1%	603	Resistor
R37	See BOM Table		1206	Resistor
R38	See BOM Table	1%		Resistor
R39	See BOM Table	1%	805	Resistor
R40	See BOM Table	1%	805	Resistor
R41	See BOM Table	1%	805	Resistor
R42	See BOM Table	1%	805	Resistor
R43	49.9	1%	805	Resistor
R44	49.9	1%	805	Resistor
R45	49.9	1%	805	Resistor
R46	150K	1%	805	Resistor
R47	2MEG		3299 - 3/8”	Trimming Potentiometer 2Meg
R48	15.0K	1%	805	Resistor
R49	500K		3299 - 3/8”	Trimming Potentiometer 500K
R50	49.9	1%	805	Resistor
R51	See BOM Table		1206	Resistor
R52	See BOM Table		1206	Resistor
R53	See BOM Table		1206	Resistor
R54	See BOM Table		1206	Resistor
R-SHUNT-IN1	See BOM Table			Current Shunt Resistor, 4 terminal, precision, 0.1%
R-SHUNT-IN2	See BOM Table			Current Shunt Resistor, 4 terminal, precision, 0.1%
U1			SOT-23-5	Comparator
U2	4A		LLP-6	MOSFET Driver, 4A, 20ns
U3			SO-4	Photocoupler, High Isolation Voltage
U4	See BOM Table		MSOP-8	IC
Z1	430V			TVS, ZNR TRANS/SURGE ABSORBERS
Z2	See BOM Table			TVS, ZNR TRANS/SURGE ABSORBERS

APPENDIX

Evaluation Board Bill of Materials — BOM Table

RQ1B / RQ68

RefDes	Value	Tolerance	Package	Description
C33	Open	10%	1210	Capacitor X7R 100V
C34	1800uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
C35	1800uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
C36	Open		Radial C Case	Aluminum Electrolytic Capacitor
D1	480V		SMC	Bidirectional TVS Diode
D16	400V		DO-247	Schottky Diode
D17	Open		SOD-523	Zener Diode
D18	Open		SMC	TVS Diode
D19	Open		SMB	Unidirectional TVS Diode
F1	10A, 450V		6.3 x 32mm	Fast High Voltage Fuse
F2	Open		6.3 x 32mm	Fast High Voltage Fuse
F3	Open		Blade Type	Fuse Automotive
FH1				Fuseholder for cylindrical 10 x 38 mm
FH2	Open			Fuseholder for cylindrical 10 x 38 mm
FH3	Open			Maxi PC Auto-Fuse Socket
HS2				Heatsink 30161B00162G
HS3	Open			Heatsink
L1	4.7uH	20%	IHLP-4040	SM Inductor, Vishay IHLP-4040DZ-01
L2	Open		Through-Hole	
L3	Open		Through-Hole	
Q2	650V, 60A		TO-247	MOSFET Infineon IPW60R045CP
Q3	650V, 60A		TO-247	MOSFET Infineon IPW60R045CP
Q5	Open		TO-247	MOSFET
Q6	Open		TO-247	MOSFET
R11	6.34K	0.1%	603	Resistor 0.1% 25 ppm
R31	Open	1%	805	Resistor 1% 100ppm
R32	Open	1%	805	Resistor 1% 100ppm
R37	Open	1%	1206	Resistor
R38	500	1%	Through Hole	Wire Wound Resistor
R39	30.1K	1%	805	Resistor
R40	30.1K	1%	805	Resistor
R41	30.1K	1%	805	Resistor
R42	30.1K	1%	805	Resistor
R51	Open	5%	1206	Resistor
R52	Open	5%	1206	Resistor
R53	Open	5%	1206	Resistor
R54	Open	5%	1206	Resistor
R-SHUNT-IN1	0.01	0.10%		Current Shunt Resistor, 4 Terminal
R-SHUNT-IN2	Open	0.10%		Current Shunt Resistor, 4 Terminal
U4	Open		MSOP-8	IC
Z2	430V			TVS ZNR Transient/Surge Absorber

APPENDIX

Evaluation Board Bill of Materials — BOM Table

RQ72

RefDes	Value	Tolerance	Package	Description
C33	Open	10%	1210	Capacitor X7R 100V
C34	2700uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
C35	2700uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
C36	2700uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
D1	480V		SMC	Bidirectional TVS Diode
D16	400V		DO-247	Schottky Diode
D17	Open		SOD-523	Zener Diode
D18	Open		SMC	TVS DIODE
D19	Open		SMB	Unidirectional TVS Diode
F1	10A, 450V		6.3 x 32mm	Fast High Voltage Fuse
F2	Open		6.3 x 32mm	Fast High Voltage Fuse
F3	Open		Blade Type	Fuse Automotive
FH1				Fuseholder for cylindrical 10 x 38 mm
FH2	Open			Fuseholder for cylindrical 10 x 38 mm
FH3	Open			
HS2				Heatsink 30161B00162G
HS3	Open			
L1	4.7uH	20%	IHLP-4040	SM Inductor, Vishay IHLP-4040DZ-01
L2	Open		Through-Hole	
L3	Open		Through-Hole	
Q2	650V,60A		TO-247	MOSFET Infineon IPW60R045CP
Q3	650V,60A		TO-247	MOSFET Infineon IPW60R045CP
Q5	Open		TO-247	MOSFET
Q6	Open		TO-247	MOSFET
R11	9.76K	0.1% 25 ppm	603	Resistor
R31	Open	1% 100ppm	805	Resistor
R32	Open	1% 100ppm	805	Resistor
R37	Open	1%	1206	Resistor
R38	221	1%	Through Hole	Wire Wound Resistor
R39	15K	1%	805	Resistor
R40	15K	1%	805	Resistor
R41	10K	1%	805	Resistor
R42	10K	1%	805	Resistor
R51	Open	5%	1206	Resistor
R52	Open	5%	1206	Resistor
R53	Open	5%	1206	Resistor
R54	Open	5%	1206	Resistor
R-SHUNT-IN1	0.01	0.10%		Current Shunt Resistor, 4 Terminal
R-SHUNT-IN2	Open	0.10%		Current Shunt Resistor, 4 Terminal
U4	Open		MSOP-8	IC
Z2	430V			TVS ZNR Transient/Surge Absorber

Appendix

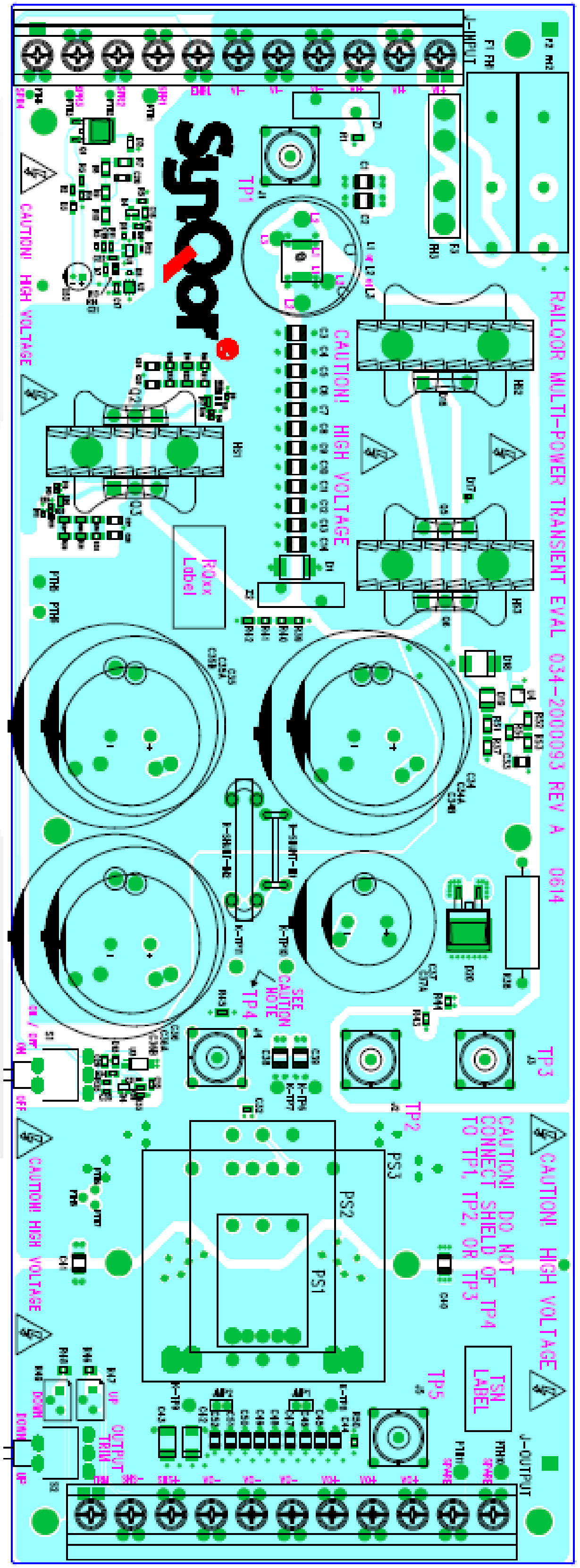
Evaluation Board Bill of Materials — BOM Table

RQ18

RefDes	Value	Tolerance	Package	Description
C33	2.2uF	10%	1210	Capacitor X7R 100V
C34	18000uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
C35	18000uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
C36	18000uF		Radial C Case	Nichicon, Al Elect Capacitor 200V
D1	130V		SMC	Bidirectional TVS Diode
D16	Open		DO-247	Schottky Diode
D17	12V		SOD-523	Zener Diode
D18	93.6V, 32.1A		SMC	TVS DIODE 3.0SMCJ58A
D19	15V		SMB	Unidirectional TVS Diode 15V
F1	Open		6.3 x 32mm	Fast High Voltage Fuse
F2	Open		6.3 x 32mm	Fast High Voltage Fuse
F3	50A, 80V		Blade Type	Fuse Automotive
FH1	Open			Fuseholder for cylindrical 10 x 38 mm
FH2	Open			Fuseholder for cylindrical 10 x 38 mm
FH3				Maxi PC Auto-Fuse Socket
HS2	Open			
HS3				Heatsink 30161B00162G
L1	Open	20%		Inductor
L2	4.7uH		Through-Hole	Vishay, IHTH1125MZEB4R7M5A
L3	Open		Through-Hole	
Q2	150V, 167A		TO-247	MOSFET Fairchild FDH055N15A
Q3	150V, 167A		TO-247	MOSFET Fairchild FDH055N15A
Q5	150V, 167A		TO-247	MOSFET Fairchild FDH055N15A
Q6	150V, 167A		TO-247	MOSFET Fairchild FDH055N15A
R11	30.1K	0.1% 25 ppm	603	Resistor
R31	Open	1% 100ppm	805	Resistor
R32	Open	1% 100ppm	805	Resistor
R37	1.00K	1%	1206	Resistor
R38	33	1%	Through Hole	Wire Wound Resistor
R39	2K	1%	805	Resistor
R40	2K	1%	805	Resistor
R41	2K	1%	805	Resistor
R42	2K	1%	805	Resistor
R51	0	5%	1206	Resistor
R52	0	5%	1206	Resistor
R53	0	5%	1206	Resistor
R54	0	5%	1206	Resistor
R-SHUNT-IN1	Open	0.10%		Current Shunt Resistor, 4 Terminal
R-SHUNT-IN2	0.001	0.10%		Current Shunt Resistor, 4 Terminal
U4	Single		MSOP-8	Ideal Diode Controller IC LTC4359
Z2	100V			TVS ZNR Transient/Surge Absorber

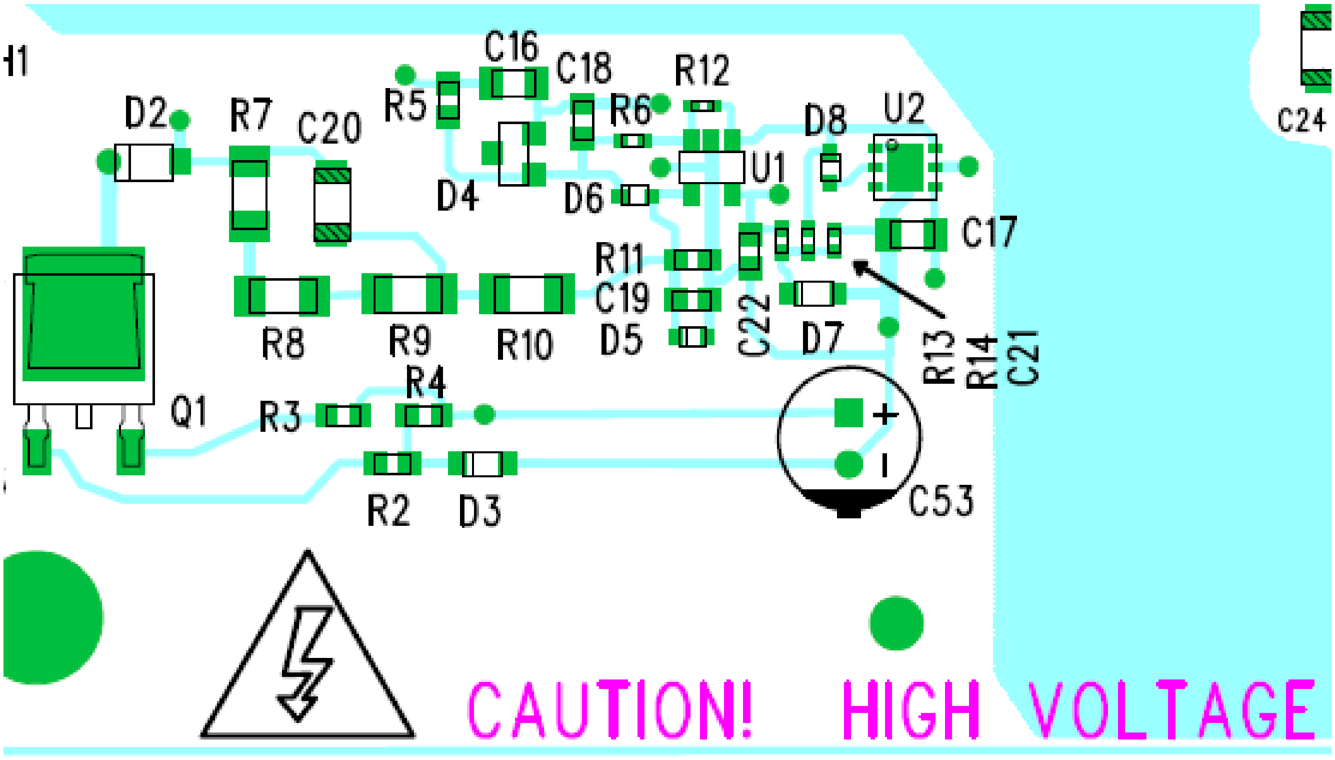
APPENDIX

Evaluation Board Layout *- Component Placement*

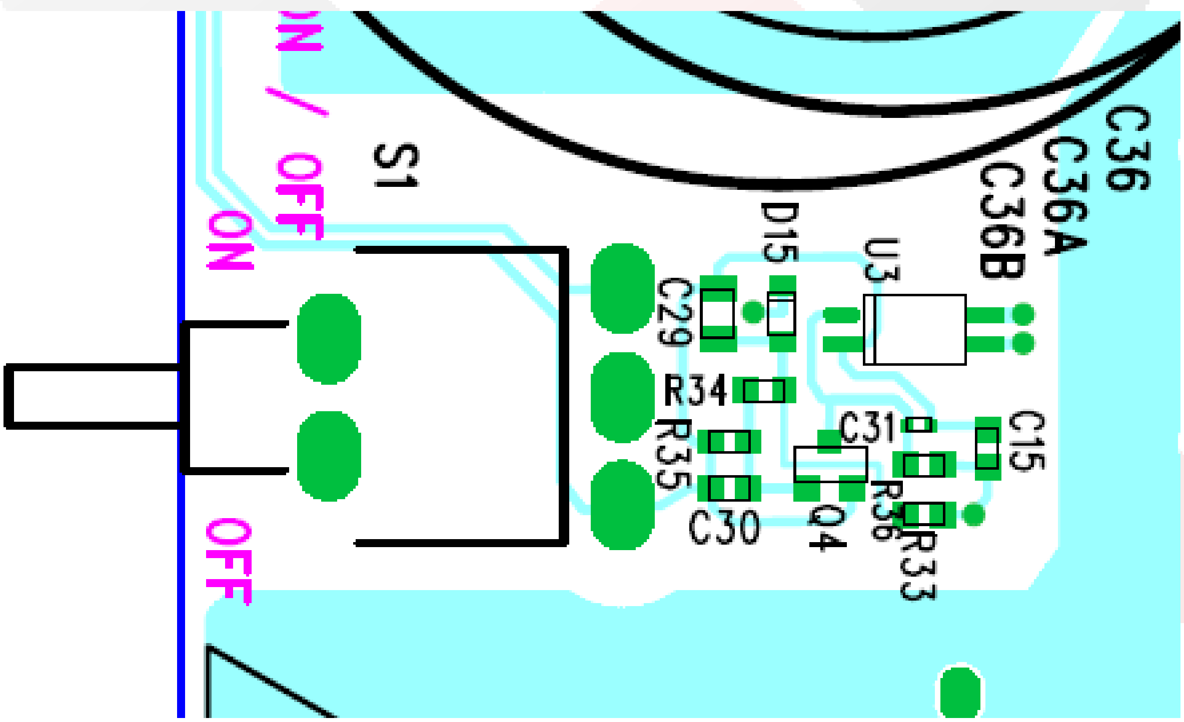


Appendix

Evaluation Board Layout *- Component Placement: Zoom Views*



ZOOM VIEW: Transient Protection Control Circuit



ZOOM VIEW: Enable Circuit