InfiniBand Class I Power Supply Using the ISL6160 and HIP6006 ICs

Application Note *September 2001* **AN9959**

Introduction

The InfiniBand architecture represents a significant evolution of high-performance, switched-fabric interconnect systems. The goal is to provide a high-performance, reliable, and scalable way to connect high-end servers to each other and to I/O subsystems, routers and switches that connect to the world outside the data center.

Available from Intersil is the ISL6160, an evolution of IC power sequencing, control and protection for InfiniBand I/O modules (IM). The ISL6160 is designed to address the unique power requirements of the InfiniBand (IB) industry initiative providing independent power control of both the VB (bulk) (+12V) and the VA (auxiliary) (+5V) power rails for a single port. This device can be implemented in both IB Class I (non isolated) and Class II (isolated) Power Topology applications.

Intersil also provides the ISL6160EVAL2 concept evaluation platform. The ISL6160EVAL2 is a complete InfiniBand Class I (non isolated) power topology evaluation platform which highlights the operation of the ISL6160 and the HIP6006 single output PWM controller. See Figure 1 for a simplified block diagram of the ISL6160EVAL2 platform. This evaluation platform allows the InfiniBand Module (IM) power supply designer to evaluate the concept of this design and apply this concept to a specific IM power requirement. The evaluation platform is configured for 5V Vout and 3.5A max Iout capability where it exhibits an efficiency of 85%, all in a small 1.6 sq" area. See Figure 11 for a complete ISL6160EVAL2 schematic.

Using the ISL6160EVAL2 Concept Board

The ISL6160EVAL2 consists of a bus and load boards, representing the IB chassis and IM respectively. The bus board has terminals for VA and VB supplies. The load board with its staggered length connector fingers to emulate the IM connector then hot plugs into the socket as shown in Figure 2.

When the load board is inserted into the bus board, the stagger on the connector fingers, first provides VX_RET, then VX connections, and finally the shortest finger emulates the VBx_En_L line connection.

Once VB_In is connected the VB control portion of the circuit is biased but the VB Secondary Rail (TP1) is held off until the ISL6160 VB_ON pin is signaled high. Local power enable signaling is provided through the LCL_PWR_EN jumper either as a hard tie 'high' with the jumper installed or through an external input signal, on TP6 with the jumper removed. A single logic gate IC, provides for the XORing of the VBxEN _L and local power enable signals into the ISL6160 VB_ON pin. At the time VB_ON is asserted high the ISL6160 turns on the VB Secondary Rail in a soft start mode protecting the primary supply rail from sudden in-rush current. During turn-on, the external gate capacitor of the N-Channel MOSFET, Q3 (VB switch) is charged with a 20µA current source resulting in a programmable ramp (soft start turn-on). An internal charge pump supplies the gate drive for the 12V VB supply switch driving the MOSFET gate to VB +5V. Once the VB Secondary Rail ramps to 10V the DC-DC_En pin is pulled high thus enabling the accompanying voltage converter. The DC-DC converter then provides a well regulated output voltage to the load. For lab evaluation either an electronic or a passive load is suitable for suppling a load current.

The ISL6160 VA undervoltage lockout feature prevents turn-on of VA until VA_In > 2.5V. It then enables the VA soft start and power up. The VA rising voltage output is a current limited ramp so that both the inrush current and voltage slew rate are limited, independent of load. This reduces supply droop due to surge and eliminates the need for additional external EMI filters. During operation, once a VA OC condition is detected the output current is limited to 1A for 12ms to allow transient conditions to pass. If VA is still in current limit after the current limit period has elapsed, the output is then latched off. The VA to the IM circuitry is latched off until reset by the disconnection and reconnection of the IM from the chassis backplane.

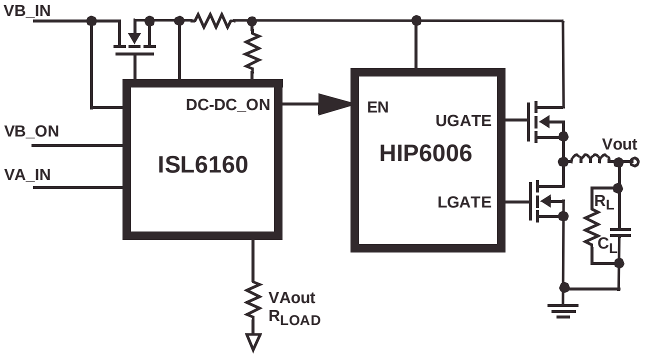

FIGURE 1. ISL6160EVAL2 BLOCK DIAGRAM

The VB Secondary Rail is enabled once the VB_ON (TP7) is signalled high (through the assertion of the local power enable), then the DC-DC En pin (TP2) is pulled high to VB. The RC network of R4, R15 and C14 allows for setting the DC-DC converter enabling signal level and ramp, thus customizing the time to DC-DC enabling. Once the DC-DC is enabled the output (TP3) ramps to 5V. The output is supplied with a banana jack for connecting to an external active or passive load.

Figure 3 illustrates typical operational waveforms of the ISL6160EVAL2. These are accessible through the labeled test points (TPX) on the eval board.

See Figures 4 and 5 for ISL6160EVAL2 turn-on and turn-off output voltage waveforms.

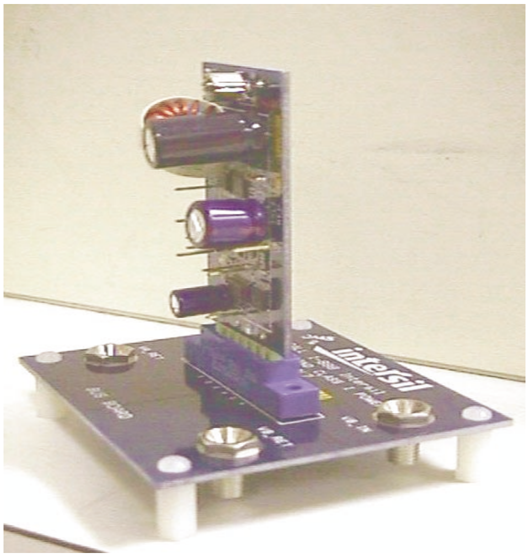

FIGURE 2. ISL6160EVAL2 PHOTOGRAPH

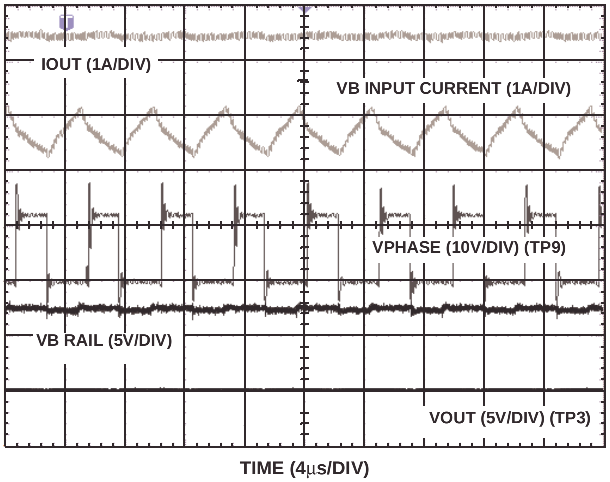

FIGURE 3. ISL6160EVAL2 OPERATIONAL WAVEFORMS

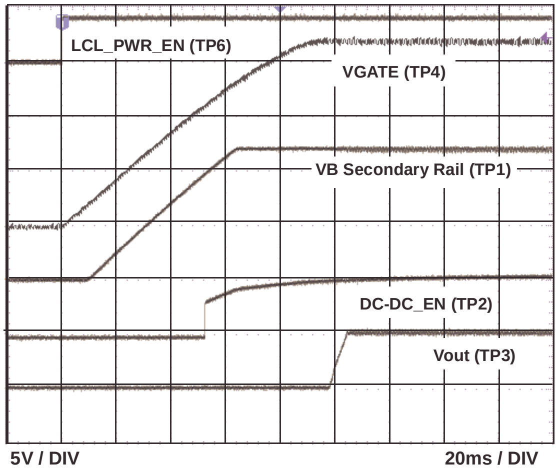

FIGURE 4. ISL6160EVAL2 Vout TURN-ON

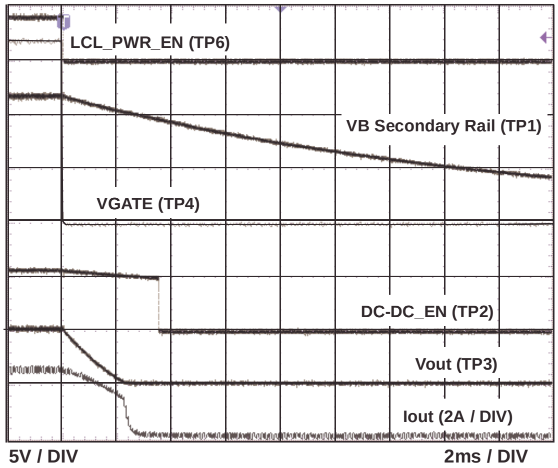

FIGURE 5. ISL6160EVAL2 Vout TURN-OFF

ISL6160EVAL2 Performance

Efficiency

Figure 6 displays the ISL6160EVAL2 efficiency versus load current. It highlights the efficiency advantages of a switching regulator at a higher load current. The designed current limit of this evaluation bd is ~3.5A. The dashed portion of the curve was collected from a modified evaluation board with an increased overcurrent protection limit. The curve indicates maximum efficiency at about 4.5A of output current and approximately 25W of input power.

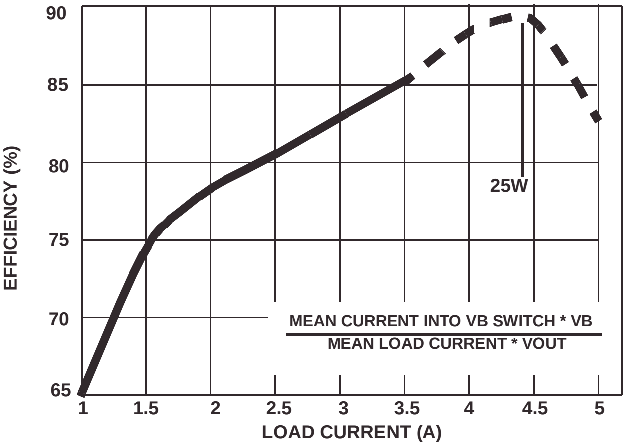

FIGURE 6. ISL6160EVAL2 EFFICIENCY vs LOAD CURRENT

ISL6160 related efficiency improvements can only come from lowering the RDSon of the VB FET (Q3) switch and the threshold voltage across the sense resistor that invokes current regulation and shutdown. HIP6006 related efficiency improvements are explained in the Power Supply Design Considerations section of this document.

Transient Response

Figure 7 shows a laboratory oscillogram of the ISL6160EVAL2 in response to a 0-3.5A, 250A/ms load transient. The output voltage responds rapidly and is within 2% of its nominal value in less than 150µs.

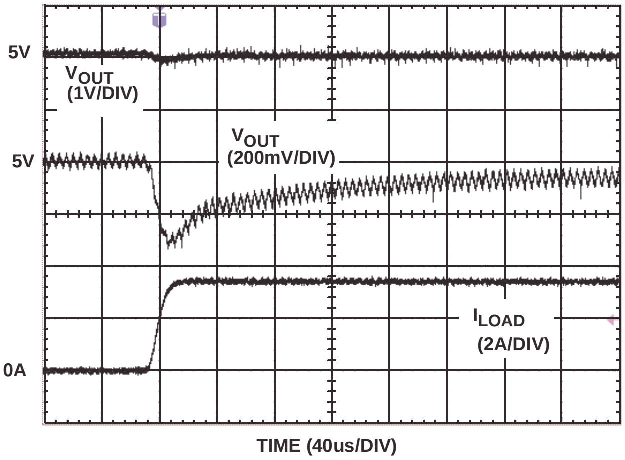

FIGURE 7. ISL6160EVAL2 TRANSIENT RESPONSE

Output Current and Voltage Ripple

The output current and voltage ripple of the HIP6160EVAL2 is shown in Figure 8. The load current is 3.5A for this oscillogram. Peak-to-peak voltage ripple is about 60mV under these conditions.

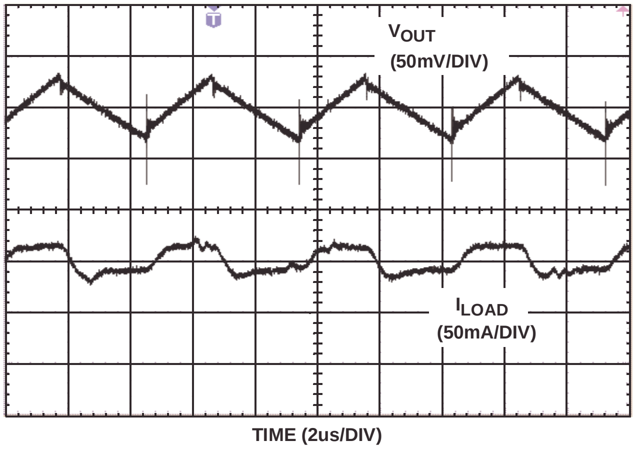

FIGURE 8. ISL6160EVAL2 OUTPUT RIPPLE

OC Protection

With the ISL6160EVAL2 Class I power supply concept there are two areas of OC protection. The ISL6160 limits the current into the port, whereas the HIP6006 will limit current to the load.

ISL6160 OC Protection

The ISL6160EVAL2 is designed to input current limit to 2.8A, the max. specified peak current for a 25W port. This allows a maximum output current of ~3.5A at 5V output voltage. As Iout increases above 3.5A the input current ripple peaks increase and are limited to 2.8A, beyond this point the ISL6160 reduces Q3 gate drive for current regulation (CR), causing a decrease in overall efficiency but protecting the VB primary rail. A lower limit based on the particular IM needs can be implemented to 'tighten' power budget control. This lower limit is based on the achieved efficiency of the down stream converter design and the max. power capability of that converter output. At point of failure, by providing a lower current regulation limit on the I/O module the risk of passing through any rail voltage disruptions is reduced or eliminated by not having to rely on the overhead capacity of the chassis supply.

HIP6006 OC Protection

The HIP6006 has a loss less overcurrent (OC) protection feature. This is accomplished via the current-sense function of the HIP600x family. The HIP6006 senses converter load current by monitoring the drop across the upper MOSFET (Q2a in the Figure 11 schematic) enhancing the converter's efficiency and reducing cost by eliminating a current sensing resistor.

The over-current function cycles the soft-start function in a hiccup mode to provide fault protection. A resistor (R_{OCSET}, R6) programs the over-current trip level. An internal 200µA (typical) current sink develops a voltage across R_{OCSET} that is referenced to the VB secondary rail. When the voltage across the upper MOSFET (also referenced to VB secondary rail) exceeds the voltage across R_{OCSET}, the over-current function initiates a soft-start sequence. The soft-start function discharges C_{SS} with a 10µA current sink and inhibits PWM operation. The soft-start function recharges C_{SS}, and PWM operation resumes with the error amplifier clamped to the SS voltage. Should an overload occur while recharging C_{SS}, the soft start function inhibits PWM operation while fully charging C_{SS} to 4V to complete its cycle. The converter dissipates very little power with this method.

The over-current function will trip at a peak inductor current (I_{PEAK}) determined by:

$$I_{PEAK} = \frac{I_{OCSET} \bullet R_{OCSET}}{r_{DS(ON)}}$$

where I_{OCSET} is the internal OCSET current source (200µA - typical). The OC trip point varies mainly due to the MOSFETs $r_{DS(ON)}$ variations. To avoid over-current tripping in the normal operating load range, find the R_{OCSET} resistor from the equation above with:

1. The maximum $r_{DS(ON)}$ at the highest junction temperature.
2. The minimum I_{OCSET} from the specification table.
3. Determine I_{PEAK} for $I_{PEAK} > I_{OUT(MAX)} + (\Delta I)/2$, where ΔI is the output inductor ripple current.

A small ceramic capacitor should be placed in parallel with R_{OCSET} to smooth the voltage across R_{OCSET} in the presence of switching noise on the input voltage.

Figure 9 illustrates the ISL6160EVAL2 OC operational waveforms. The 5V DC-DC output is shorted and the

HIP6006 current limits it to 5A. When the Secondary Rail voltage decreases to 10V(TP1) the ISL6160 deasserts the DC-DC_EN pin (TP2) and shuts off the converter. The 1.6ms delay prevent spurious events from latching off the power supply.

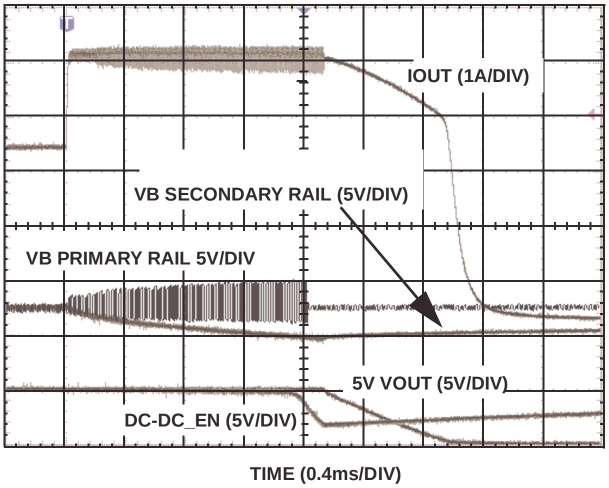

FIGURE 9. ISL6160EVAL2 OVER-CURRENT OPERATION

Power Supply Design Considerations

The concept of the power supply demonstrated by the ISL6160EVAL2 can be scaled across the entire range of 1.3V to 12V of output voltage up to a 50W port power level. To encompass this entire range there are several component variables and trade-offs to consider. These variables and trade-offs are briefly discussed in this document, but for a more detailed and extensive explanation please refer to the several listed documents [2], [4], [5] on page 5.

Input Capacitor Selection

Use a mix of HIP6006 input (VB secondary rail) bypass capacitors to control the voltage overshoot across the MOSFETs. Use small ceramic capacitors for high frequency decoupling and bulk capacitors to supply the current needed each time Q1 turns on. The number of input capacitors and their capacitance are usually determined by their maximum RMS current rating. A conservative approach is to determine the converter maximum input RMS current, and assume it would all have to be supplied from the input capacitors. By providing enough capacitors to meet the required RMS current rating, one usually provides enough capacitance for proper power de-coupling.

MOSFET Selection Effect on Efficiency [4]

This section shows graphically that a larger, lower RDSon) MOSFET does not always improve converter efficiency. Figure 10 shows that smaller RFP25N05 MOSFETs are more efficient over most of the line and load range than larger RFP45N06 MOSFETs. The RFP25N05 has a $r_{DS(ON)}$ of 47mΩ (maximum at 25^{o}C) versus 28mΩ for the RFP45N06. In comparison to the RFP25N05, the RFP45N06's gain in switching losses offsets its decreased conduction losses at load currents up to about 9A. This data reinforces the need to consider both switching and conduction losses of the MOSFETs. This data is taken from the HIP6006EVAL1 platform.

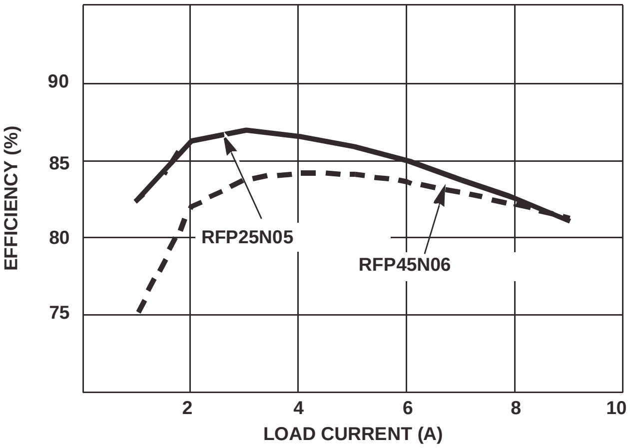

FIGURE 10. HIP6006EVAL1 EFFICIENCY WITH EITHER RFP25N05 OR RFP45N06 MOSFETs

Setting the Output Voltage

Simple resistor value changes allow for outputs as low as 1.3V or as high as the 12V input voltage. The steady-state DC output voltage can be set using the following simple formula:

$$V_{OUT} = V_{REF} \bullet \left(1 + \frac{R8}{R5}\right), \text{ where}$$

V_{OUT} = desired DC output voltage of the converter

V_{REF} = HIP6006 internal reference voltage (typically 1.27V)

Output Capacitor Selection

Output capacitors are required to filter the output and supply the load transient current. The filtering requirements are a function of the switching frequency and the ripple current. The load transient requirements are a function of the slew rate (di/dt) and the magnitude of the transient load current. These requirements are generally met with a mix of capacitors and careful layout. As with the input capacitors, the number of output capacitors is determined by a parameter different than sheer capacitance. Based on the desired output ripple and output transient response, a maximum ESR can be determined. Based on the design's dimensional restraints, an optimum compromise between the number and size of the output capacitors can be reached. Conservative approaches dictate using the data book's maximum values for ESR; this way the design will still meet the initial criteria even at the end of capacitor's active life. High frequency decoupling of the output may not be implemented if the application provides high frequency decoupling components at the load end of the output. In applications requiring good high frequency decoupling, the output should be accordingly decoupled using a few ceramic capacitors. This measure is especially necessary if high ESL output capacitors are used.

Output Inductor Selection

The output inductor is selected to meet the output voltage ripple requirements and minimize the converter's response time to the load transient. The inductor value determines the converter's ripple current and the ripple voltage is a function of the ripple current. Increasing the value of inductance reduces the ripple current and voltage. However, the large inductance values reduce the converter's response time to a load transient. One of the parameters limiting the converter's response to a load transient is the time required to change the inductor current from an initial current value to the transient current level. During this interval the difference between the inductor current and the transient current level must be supplied by the output capacitor. Minimizing the response time can minimize the output capacitance required.

Output Ripple Voltage

The amount of ripple voltage on the output of the DC-DC converter varies with, switching frequency, output inductor, and output capacitors.

Output Load Transient Response

The application of a sudden load requiring the converter to supply maximum output current, most of the energy required by the output load is initially delivered from the output capacitors. This is due to the finite amount of time required for the inductor current to slew up to the level of output current required by the load, and results in a temporary dip (ΔV_{LOW}) in the output voltage, see Figure 7. Conversely, a sudden removal of the same output load, the energy stored in the inductor is dumped into the output capacitors, creating a temporary hump (ΔV_{HIGH}) in the output voltage.

Conclusion

The ISL6160EVAL2 board lends itself well to the evaluation of a complete single fixed voltage IB Class I power supply and providing a conceptual platform for your specific IM power control and supply needs.

In addition, with the availability of multiple output voltage converters such as the IPM6220A coupled with the ISL6160, Intersil provides an application solution for almost every InfiniBand I/O module.

References

For Intersil documents available on the web, see http://www.intersil.com/

[1] *ISL6160 Data Sheet*, Intersil Corporation, FN9028

[2] *HIP6006 Data Sheet*, Intersil Corporation, FN4306.

[3] *IPM6220A Data Sheet*, Intersil Corporation, FN9032

[4] *Application Note*, Intersil Corporation, AN9722.

[5] *Application Note*, Intersil Corporation, AN9761

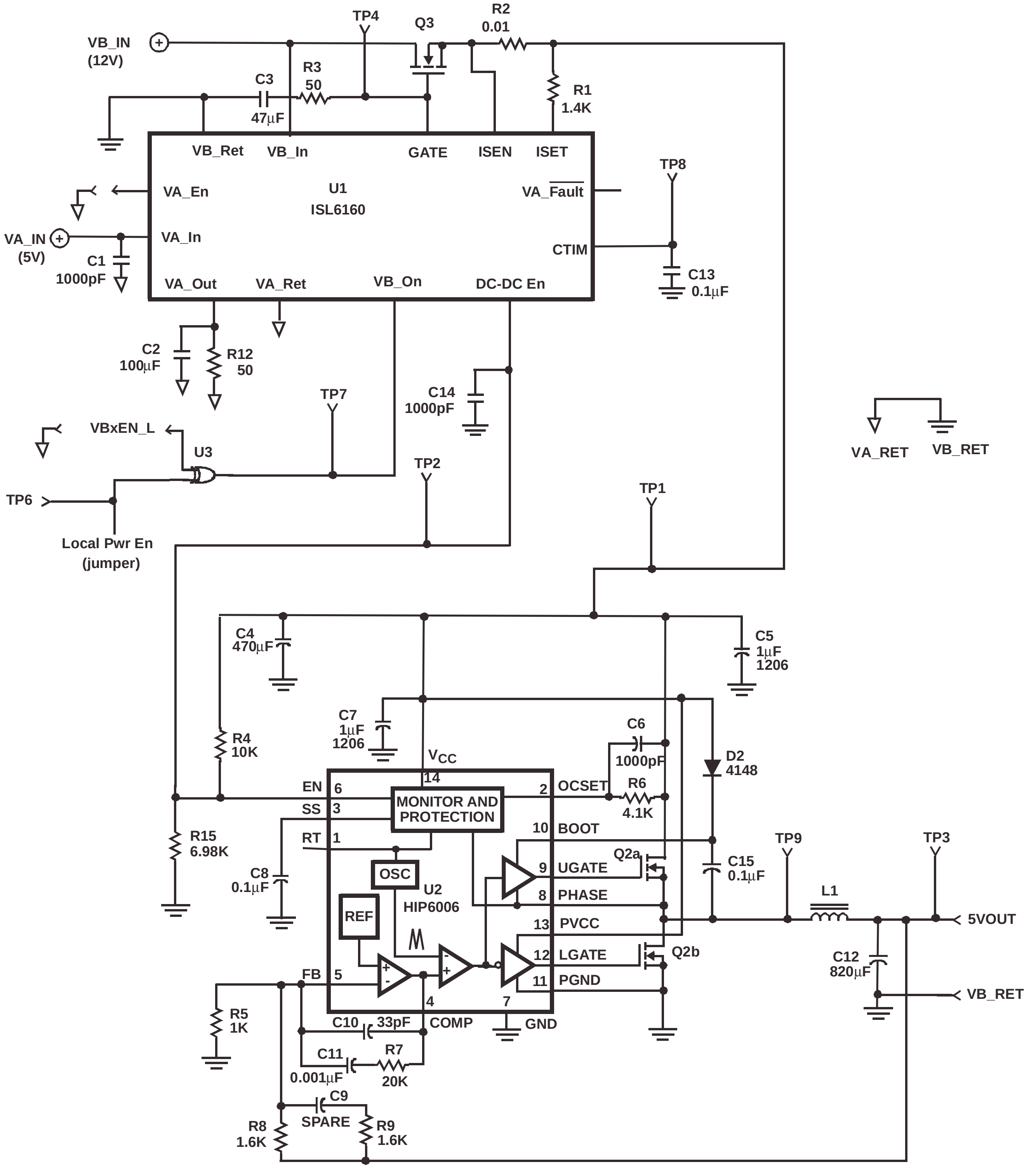

FIGURE 11. ISL6160EVAL2 SCHEMATIC

Bill of Materials for HIP6006EVAL1

PART #	DESCRIPTION	PACKAGE	QTY	REF	VENDOR
ISL6160IB	InfiniBand Power Controller	14NSOIC	1	U1	INTERSIL
HIP6006CV	Synchronous Rectified Buck Controller	14TSSOP	1	U2	INTERSIL
SN74AHC1G86 or equiv	Single XOR gate	5SOT-23	1	U3	Various
Si4922DY or equiv	Dual 8A, 30V, 0.018Ω, N-Channel MOSFET	8SOIC	1	Q2	Various
ITF86130SK8T or equiv	14A, 40V, 0.008Ω, N-Channel MOSFET	8SOIC	1	Q3	Various
1N4148	Rectifier, 100mA, 75V	DO35	1	D2	Various
10µH	Output Filter Inductor	Wound Toroid	1	L1	Various
1.4K	VB Current Set Resistor, 1%, 1/16W	0603	1	R1	Various
0.01Ω	VB Current Sense Resistor, 1%, 1W	2512	1	R2	Various
50Ω	SMD Resistor, 5%, 1/16W	0603	2	R3, R10	Various
10KΩ	SMD Resistor, 5%, 1/16W	0603	1	R4	Various
1KΩ	SMD Resistor, 5%, 1/16W	0603	1	R5	Various
4.1Ω	SMD Resistor, 5%, 1/16W	0603	1	R6	Various
20KΩ	SMD Resistor, 5%, 1/16W	0603	1	R7	Various
3.0KΩ	SMD Resistor, 5%, 1/16W	0603	1	R8	Various
DNP	SMD Resistor, 5%, 1/16W	0603	1	R9	Various
50Ω	Through hole Resistor, 5%, 1W	-	1	R12	Various
6.98KΩ	SMD Resistor, 5%, 1/10W	0805	1	R15	Various
100µF	Electrolytic Aluminum Capacitor, 16V	Radial	1	C2	Various
470µF	Electrolytic Aluminum Capacitor, 16V	Radial	1	C4	Various
820µF	Electrolytic Aluminum Capacitor, 16V	Radial	1	C12	Various
1000pF	Ceramic Capacitor, 50V	0603	2	C1, C6, C14	Various
47µF	Ceramic Capacitor, 50V	0603	1	C3	Various
1µF	Ceramic Capacitor, 50V	0603	2	C5, C7	Various
0.1µF	Ceramic Capacitor, 50V	0603	2	C8, C13, C15	Various
33pF	Ceramic Capacitor, 50V	0603	1	C10	Various
0.001µF	Ceramic Capacitor, 50V	0603	1	C11	Various
-	Local power enable Jumper	-	1	PWR_EN	Various
-	Test Points	-	9	TP1- TP9	Various
1314353-00	Scope Probe Test Point	-	1	TP3, VOUT	Tektronics
-	Banana Jacks	-	4	VB_IN, VA_IN, VB_RET, VA_RET	Various
EZM06DRXH	Edge Connector	-	1	-	Sullins

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