

## Flexible Double Ended Voltage and Current Mode PWM Controllers

The ISL6740-41 family of adjustable frequency, low power, pulse width modulating (PWM) voltage mode (ISL6740) and current mode (ISL6741) controllers is designed for a wide range of power conversion applications using half-bridge, full bridge, and push-pull configurations. These controllers provide an extremely flexible oscillator that allows precise control of frequency, duty cycle, and deadtime.

This advanced BiCMOS design features low operating current, adjustable switching frequency up to 1 MHz, adjustable soft start, internal and external over temperature protection, fault annunciation, and a bi-directional SYNC signal that allows the oscillator to be locked to paralleled units or to an external clock for noise sensitive applications.

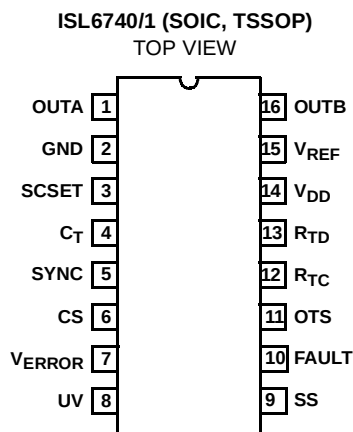
## Ordering Information

| PART NUMBER | TEMP. RANGE (°C) | PACKAGE     | PKG. NO. |
|-------------|------------------|-------------|----------|
| ISL674xIB   | -40 to 105       | 16 Ld SOIC  | M16.15   |
| ISL674xIV   | -40 to 105       | 16 Ld TSSOP | M16.173  |

Add -T suffix to part number for tape and reel packaging

| x = | Control Mode |
|-----|--------------|
| 0   | Voltage Mode |
| 1   | Current Mode |

## Pinout



## Features

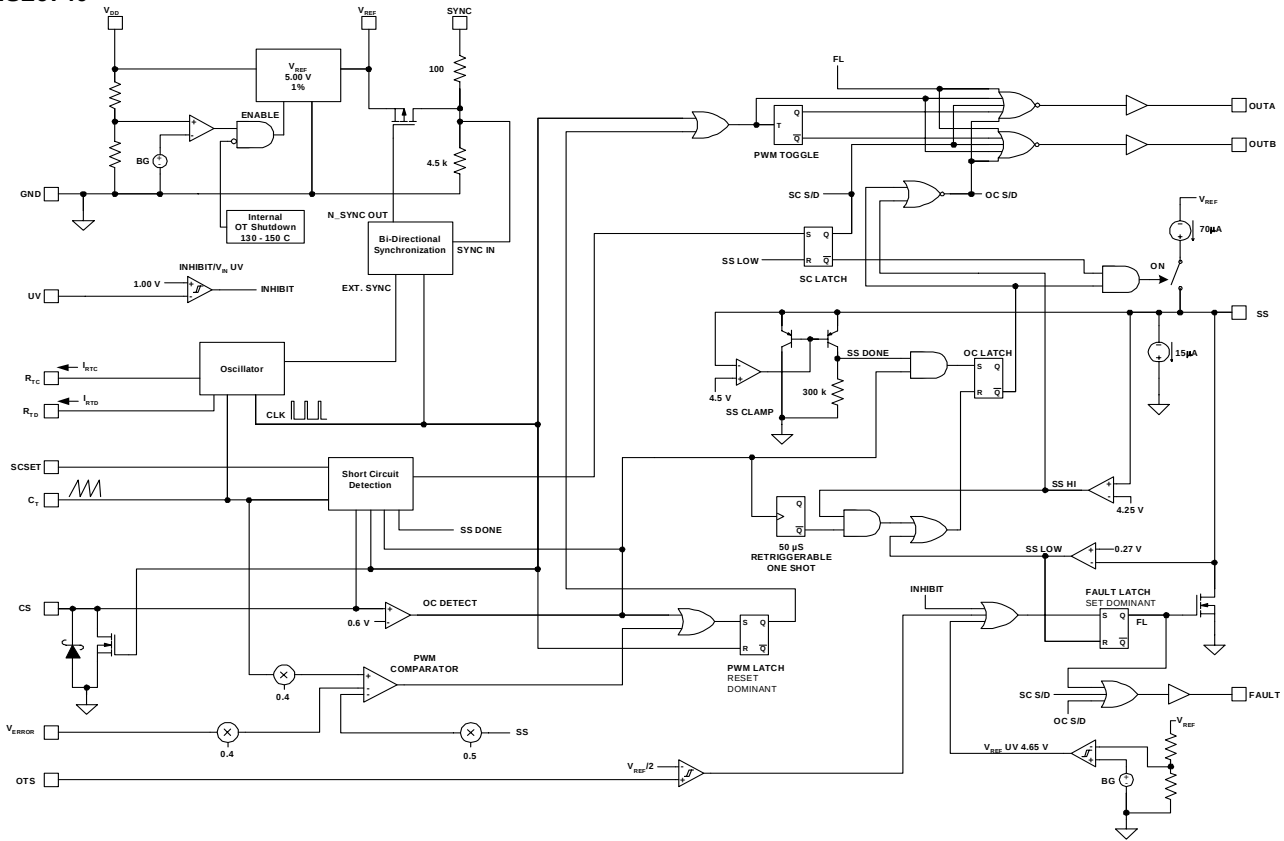
- Precision Duty Cycle and Deadtime Control
- 95  $\mu$ A Startup Current
- Adjustable Delayed Over Current Shutdown and Re-Start (ISL6740)
- Adjustable Short Circuit Shutdown and Re-Start
- Adjustable Oscillator Frequency Up to 2 MHz
- Bi-Directional Synchronization
- Inhibit Signal
- Internal Over Temperature Protection
- System Over Temperature Protection Using a Thermistor or Sensor
- Adjustable Soft Start
- Adjustable input Under Voltage Lockout
- Fault Signal
- Tight Tolerance Voltage Reference Over Line, Load, and Temperature

## Applications

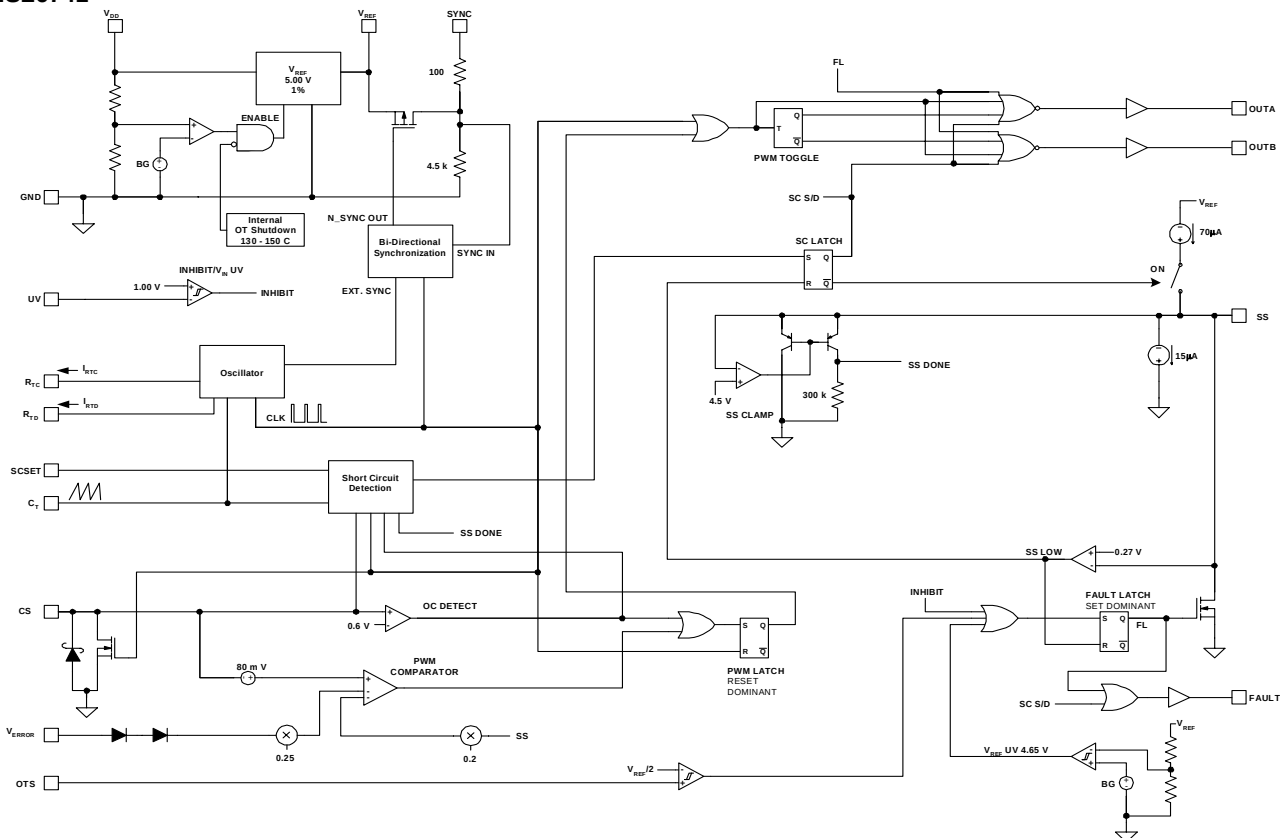
- Telecom and Datacom Power
- Wireless Base Station Power
- File Server Power
- Industrial Power Systems
- DC Transformers and Buss Regulators

## Functional Block Diagrams

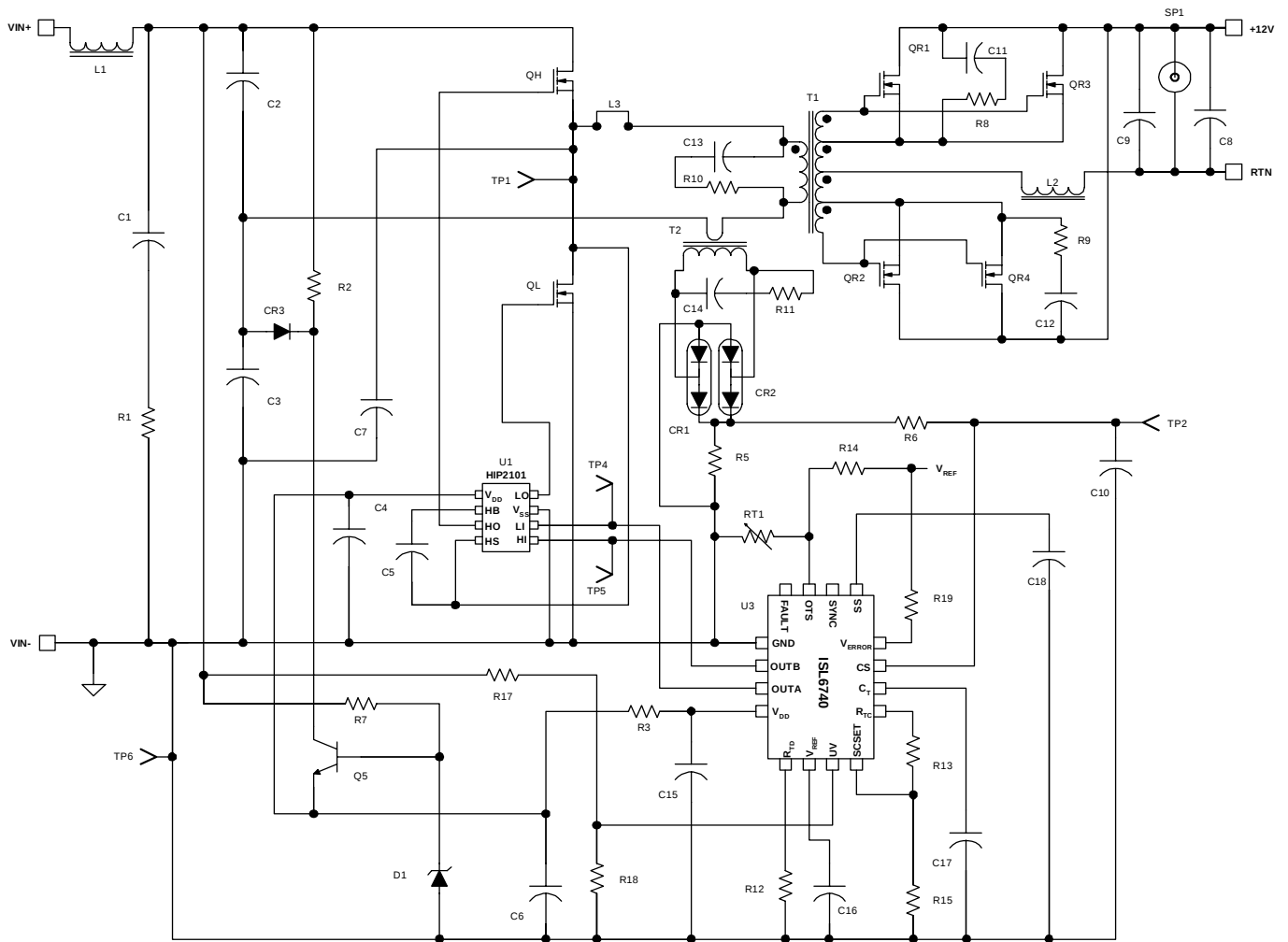
ISL6740



ISL6741



**Typical Application (ISL6740)- 48V Input DC Transformer, 12V @ 8A Output**



## Absolute Maximum Ratings

Supply Voltage,  $V_{DD}$  . . . . . GND - 0.3V to +20.0V  
 OUTA, OUTB, Signal Pins . . . . . GND - 0.3V to  $V_{REF}$   
 $V_{REF}$  . . . . . GND - 0.3V to 6.0V  
 Peak GATE Current . . . . . 0.5A  
 ESD Classification  
   Human Body Model (Per MIL-STD-883 Method 3015.7) . . .1500V  
   Charged Device Model (Per EOS/ESD DS5.3, 4/14/93) . .1000V

## Thermal Information

Thermal Resistance Junction to Ambient (Typical)  $\theta_{JA}$  ( $^{\circ}\text{C/W}$ )  
 16 Lead SOIC (NOTE 1) . . . . . 77  
 16 Lead TSSOP (NOTE 1). . . . . 102  
 Maximum Junction Temperature . . . . . -55 $^{\circ}\text{C}$  to 150 $^{\circ}\text{C}$   
 Maximum Storage Temperature Range. . . . . -65 $^{\circ}\text{C}$  to 150 $^{\circ}\text{C}$   
 Maximum Lead Temperature (Soldering 10s) . . . . . 300 $^{\circ}\text{C}$   
 (SOIC, TSSOP- Lead Tips Only)

## Operating Conditions

Temperature Range  
 ISL674x1x . . . . . -40 $^{\circ}\text{C}$  to 105 $^{\circ}\text{C}$   
 Supply Voltage Range (Typical). . . . . 9-16 VDC

**CAUTION:** Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

### NOTES:

1.  $\theta_{JA}$  is measured with the component mounted on a high effective thermal conductivity test board in free air. See Tech Brief TB379 for details.
2. All voltages are with respect to GND.

Electrical Specifications Recommended operating conditions unless otherwise noted. Refer to Block Diagram and Typical Application schematic. 9 V <  $V_{DD}$  < 20 V,  $R_{TD} = 51.1 \text{ k}\Omega$ ,  $R_{TC} = 10 \text{ k}\Omega$ ,  $C_T = 470 \text{ pF}$ ,  $T_A = -40^{\circ}\text{C}$  to 105 $^{\circ}\text{C}$  (Note 4), Typical values are at  $T_A = 25^{\circ}\text{C}$

| PARAMETER                                   | TEST CONDITIONS                                   | MIN   | TYP   | MAX   | UNITS         |
|---------------------------------------------|---------------------------------------------------|-------|-------|-------|---------------|
| <b>SUPPLY VOLTAGE</b>                       |                                                   |       |       |       |               |
| Start-Up Current, $I_{DD}$                  | $V_{DD} < \text{START Threshold}$                 | -     | 95    | 140   | $\mu\text{A}$ |
| Operating Current, $I_{DD}$                 | $R_{LOAD}, C_{OUTA,B} = 0$                        | -     | 5.0   | 8.0   | mA            |
|                                             | $C_{OUTA,B} = 1\text{nF}$                         | -     | 7.0   | 12.0  |               |
| UVLO START Threshold                        |                                                   | 6.50  | 7.25  | 8.00  | V             |
| UVLO STOP Threshold                         |                                                   | 6.00  | 6.75  | 7.50  | V             |
| Hysteresis                                  |                                                   | 0.75  | 1.00  | 1.25  | V             |
| <b>REFERENCE VOLTAGE</b>                    |                                                   |       |       |       |               |
| Overall Accuracy                            | $V_{REF} = 0 - -20\text{mA}$ (Note 4)             | 4.900 | 5.000 | 5.050 | V             |
| Long Term Stability                         | $T_A = 125^{\circ}\text{C}$ , 1000 hours (Note 4) | -     | 3     | -     | mV            |
| Fault Voltage                               |                                                   | 4.10  | 4.55  | 4.75  | V             |
| $V_{REF}$ Good Voltage                      |                                                   | 4.50  | 4.75  | 4.95  | V             |
| Hysteresis                                  |                                                   | 75    | 165   | 250   | mV            |
| Operational Current (source)                |                                                   | -20   | -     | -     | mA            |
| Operational Current (sink)                  |                                                   | 5     | -     | -     | mA            |
| Current Limit                               |                                                   | -25   | -     | -100  | mA            |
| <b>CURRENT SENSE</b>                        |                                                   |       |       |       |               |
| Current Limit Threshold                     | $V_{ERROR} = V_{REF}$                             | 0.55  | 0.6   | 0.65  | V             |
| CS to OUT Delay                             |                                                   | -     | 35    | 50    | nS            |
| CS Sink Current                             |                                                   | -     | 10    | -     | mA            |
| Input Bias Current                          |                                                   | -500  | -     | 500   | nA            |
| CS to PWM Comparator Input Offset (ISL6741) |                                                   | TBD   | 80    | TBD   | mV            |
| Gain (ISL6741)                              | $A_{CS} = \Delta V_{ERROR} / \Delta V_{CS}$       | TBD   | 4     | TBD   | V/V           |
| SCSET Input Impedance                       |                                                   | 1     | -     | -     | M $\Omega$    |
| SC Setpoint Accuracy                        |                                                   | -     | 10    | -     | %             |
| <b>PULSE WIDTH MODULATOR</b>                |                                                   |       |       |       |               |
| $V_{ERROR}$ Input Impedance                 |                                                   | 400   | -     | -     | k $\Omega$    |
| Minimum Duty Cycle                          | $V_{ERROR} < \text{CS Offset (ISL6741)}$          | -     | -     | 0     | %             |
|                                             | $V_{ERROR} < C_T \text{ Offset (ISL6740)}$        | -     | -     | 0     |               |

# ISL6740/1

## Electrical Specifications

Recommended operating conditions unless otherwise noted. Refer to Block Diagram and Typical Application schematic.  $9\text{ V} < V_{DD} < 20\text{ V}$ ,  $R_{TD} = 51.1\text{ k}\Omega$ ,  $R_{TC} = 10\text{ k}\Omega$ ,  $C_T = 470\text{ pF}$ ,  $T_A = -40^\circ\text{C}$  to  $105^\circ\text{C}$  (Note 4), Typical values are at  $T_A = 25^\circ\text{C}$  (Continued)

| PARAMETER                                            | TEST CONDITIONS                                                                                                      | MIN               | TYP  | MAX          | UNITS                     |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-------------------|------|--------------|---------------------------|
| Maximum Duty Cycle                                   | $V_{ERROR} > 4.75\text{V}$                                                                                           | -                 | 83   | -            | %                         |
| $V_{ERROR}$ to PWM Comparator Input Offset (ISL6741) |                                                                                                                      | 0.4               | 1.0  | 1.25         | V                         |
| $V_{ERROR}$ to PWM Comparator Input Gain (ISL6740)   |                                                                                                                      | -                 | 0.4  | -            | V/V                       |
| $C_T$ to PWM Comparator Input Gain (ISL6740)         |                                                                                                                      | -                 | 0.4  | -            | V/V                       |
| SS to PWM Comparator Input Gain (ISL6740)            |                                                                                                                      | -                 | 0.5  | -            | V/V                       |
| (ISL6741)                                            |                                                                                                                      | -                 | 0.2  | -            |                           |
| <b>OSCILLATOR</b>                                    |                                                                                                                      |                   |      |              |                           |
| Frequency Accuracy                                   | $T_A = 25^\circ\text{C}$                                                                                             | 333               | 351  | 369          | kHz                       |
| Frequency Variation with $V_{DD}$                    | $T = 105^\circ\text{C}$ ( $F_{20V} - F_{9V}$ )/ $F_{9V}$<br>$T = -40^\circ\text{C}$ ( $F_{20V} - F_{9V}$ )/ $F_{9V}$ | -                 | 2    | 3            | %                         |
| Temperature Stability                                | (Note 4)                                                                                                             | -                 | 8    | -            | %                         |
| Charge Current Gain                                  |                                                                                                                      | 1.88              | 2.0  | 2.12         | $\mu\text{A}/\mu\text{A}$ |
| Discharge Current Gain                               |                                                                                                                      | 45                | 55   | 65           | $\mu\text{A}/\mu\text{A}$ |
| $C_T$ Valley Voltage                                 |                                                                                                                      | 0.75              | 0.80 | 0.85         | V                         |
| $C_T$ Peak Voltage                                   |                                                                                                                      | 2.70              | 2.80 | 2.90         | V                         |
| <b>SYNCHRONIZATION</b>                               |                                                                                                                      |                   |      |              |                           |
| Input High Threshold (VIH), Minimum                  |                                                                                                                      | 4.0               | -    | -            | V                         |
| Input Low Threshold (VIL), Maximum                   |                                                                                                                      | -                 | -    | 0.8          | V                         |
| Input Impedance                                      |                                                                                                                      |                   | 4.5  | -            | k $\Omega$                |
| Input Frequency Range                                | (Note 4)                                                                                                             | 0.6x Free Running | -    | Free Running | Hz                        |
| High Level Output Voltage (VOH)                      | $I_{LOAD} = -1\text{mA}$                                                                                             | -                 | 4.5  | -            | V                         |
| Low Level Output Voltage (VOL)                       | $I_{LOAD} = 10\mu\text{A}$                                                                                           | -                 | -    | 100          | mV                        |
| SYNC Output Current                                  | $VOH > 2.0\text{V}$ (Note 4)                                                                                         | -10               | -    | -            | mA                        |
| SYNC Output Pulse Duration (minimum)                 | (Note 4, 5)                                                                                                          | 250               | -    | 400          | nS                        |
| SYNC Advance                                         | SYNC rising edge to GATE falling edge, $C_{GATE} = C_{SYNC} = 100\text{pF}$ (Note 4)                                 | -                 | 5    | -            | nS                        |
| <b>SOFTSTART</b>                                     |                                                                                                                      |                   |      |              |                           |
| Charging Current                                     | SS = 2V                                                                                                              | -45               | -55  | -75          | $\mu\text{A}$             |
| SS Clamp Voltage                                     |                                                                                                                      | 4.35              | 4.5  | 4.65         | V                         |
| Sustained Over Current Threshold Voltage (ISL6740)   | Charged Threshold minus:                                                                                             | 0.20              | 0.25 | 0.30         | V                         |
| Over Current/Short Circuit Discharge Current         | SS = 2V                                                                                                              | 13                | 18   | 23           | $\mu\text{A}$             |
| Fault SS Discharge Current                           | SS = 2V                                                                                                              | -                 | 10.0 | -            | mA                        |
| Reset Threshold Voltage                              |                                                                                                                      | 0.25              | 0.27 | 0.33         | V                         |
| <b>FAULT</b>                                         |                                                                                                                      |                   |      |              |                           |
| Fault High Level Output Voltage (VOH)                | $I_{LOAD} = -10\text{mA}$                                                                                            | 2.85              | 3.5  | -            | V                         |
| Fault Low Level Output Voltage (VOL)                 | $I_{LOAD} = 10\text{mA}$                                                                                             | -                 | 0.4  | 0.9          | V                         |
| Fault Rise Time                                      | $C_{LOAD} = 100\text{pF}$ (Note 4)                                                                                   | -                 | 15   | -            | nS                        |
| Fault Fall Time                                      | $C_{LOAD} = 100\text{pF}$ (Note 4)                                                                                   | -                 | 15   | -            | nS                        |
| <b>OUTPUT</b>                                        |                                                                                                                      |                   |      |              |                           |
| High Level Output Voltage (VOH)                      | $V_{REF} - O_{UTA}$ or $O_{UTB}$ , $I_{OUT} = -50\text{mA}$                                                          | -                 | 0.5  | 1.0          | V                         |
| Low Level Output Voltage (VOL)                       | $O_{UTA}$ or $O_{UTB} - GND$ , $I_{OUT} = 50\text{mA}$                                                               | -                 | 0.5  | 1.0          | V                         |
| Rise Time                                            | $C_{GATE} = 1\text{nF}$ , $V_{DD} = 15\text{V}$ (Note 4)                                                             | -                 | 50   | 100          | nS                        |
| Fall Time                                            | $C_{GATE} = 1\text{nF}$ , $V_{DD} = 15\text{V}$ (Note 4)                                                             | -                 | 40   | 80           | nS                        |
| <b>THERMAL PROTECTION</b>                            |                                                                                                                      |                   |      |              |                           |
| Thermal Shutdown                                     | (Note 4)                                                                                                             | 135               | 145  | 155          | $^\circ\text{C}$          |
| Thermal Shutdown Clear                               | (Note 4)                                                                                                             | 120               | 130  | 140          | $^\circ\text{C}$          |
| Hysteresis, Internal Protection                      | (Note 4)                                                                                                             | -                 | 15   | -            | $^\circ\text{C}$          |

Electrical Specifications

Recommended operating conditions unless otherwise noted. Refer to Block Diagram and Typical Application schematic.  $9\text{ V} < V_{DD} < 20\text{ V}$ ,  $R_{TD} = 51.1\text{ k}\Omega$ ,  $R_{TC} = 10\text{ k}\Omega$ ,  $C_T = 470\text{ pF}$ ,  $T_A = -40^\circ\text{C}$  to  $105^\circ\text{C}$  (Note 4), Typical values are at  $T_A = 25^\circ\text{C}$  (Continued)

| PARAMETER                              | TEST CONDITIONS | MIN   | TYP  | MAX   | UNITS            |
|----------------------------------------|-----------------|-------|------|-------|------------------|
| Reference, External Protection         |                 | 2.375 | 2.50 | 2.625 | V                |
| Hysteresis, External Protection        |                 | 18    | 25   | 30    | $\mu\text{A}$    |
| <b>SUPPLY UVLO/INHIBIT</b>             |                 |       |      |       |                  |
| Input Voltage Low/Inhibit Threshold    |                 | 0.97  | 1.00 | 1.03  | V                |
| Hysteresis, Switched Current Amplitude |                 | 7     | 10   | 15    | $\mu\text{A}$    |
| Input High Clamp Voltage               |                 | 4.8   | -    | -     | V                |
| Input Impedance                        |                 | 1     | -    | -     | $\text{M}\Omega$ |

NOTE:

- Specifications at  $-40^\circ\text{C}$  and  $105^\circ\text{C}$  are guaranteed by design, not production tested.
- Guaranteed by design, not 100% tested in production.
- SYNC pulse width is the greater of this value or the  $C_T$  discharge time.

Typical Performance Curves

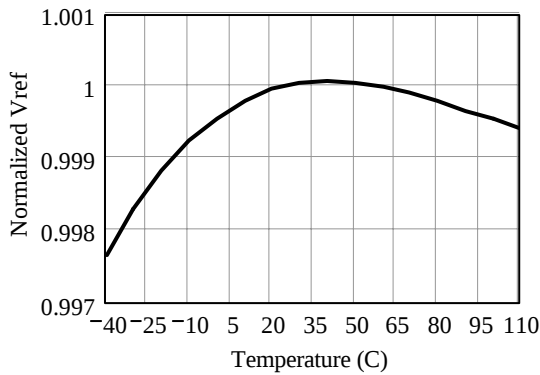


FIGURE 1. REFERENCE VOLTAGE vs. TEMPERATURE

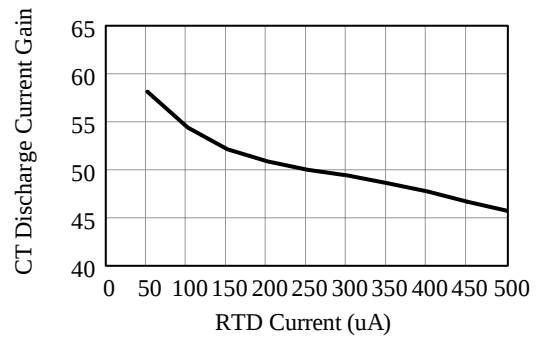


FIGURE 2. OSCILLATOR CT DISCHARGE CURRENT GAIN

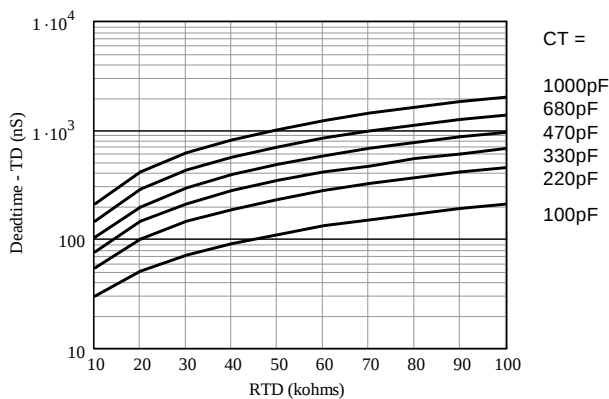


FIGURE 3. DEADTIME (TD) vs. CAPACITANCE

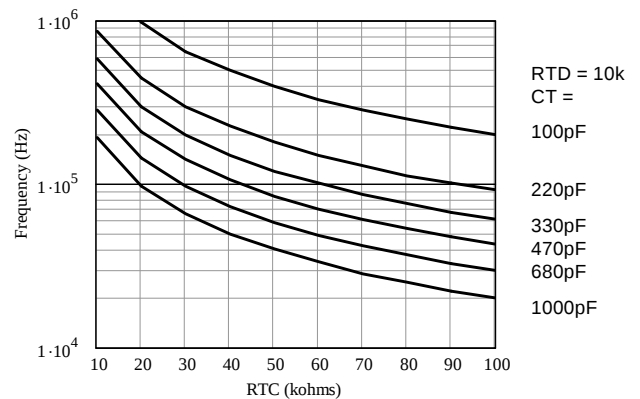


FIGURE 4. CAPACITANCE vs. FREQUENCY

Pin Descriptions

$V_{DD}$  -  $V_{DD}$  is the power connection for the IC. To optimize noise immunity, bypass  $V_{DD}$  to GND with a ceramic capacitor as close to the  $V_{DD}$  and GND pins as possible.

The total supply current,  $I_{DD}$ , will be dependent on the load applied to outputs OUTA and OUTB. Total  $I_{DD}$  current is the sum of the quiescent current and the average output current. Knowing the operating frequency,  $F_{sw}$ , and the output

loading capacitance charge,  $Q$ , per output, the average output current can be calculated from:

$$I_{OUT} = 2 \cdot Q \cdot F_{SW} \quad A \quad (EQ. 1)$$

**SYNC** - A bi-directional synchronization signal used to coordinate the switching frequency of multiple units. Synchronization may be achieved by connecting the SYNC signal of each unit together or by using an external master clock signal. The oscillator timing capacitor,  $C_T$ , is always required regardless of the synchronization method used. The paralleled unit with the highest oscillator frequency assumes control.

**R<sub>TC</sub>** - This is the oscillator timing capacitor charge current control pin. A resistor is connected between this pin and GND. The current flowing through the resistor determines the magnitude of the charge current. The charge current is nominally twice this current. The PWM maximum ON time is determined by the timing capacitor charge duration.

**R<sub>TD</sub>** - This is the oscillator timing capacitor discharge current control pin. A resistor is connected between this pin and GND. The current flowing through the resistor determines the magnitude of the discharge current. The discharge current is nominally 50x this current. The PWM deadtime is determined by the timing capacitor discharge duration.

**C<sub>T</sub>** - The oscillator timing capacitor is connected between this pin and GND.

**V<sub>ERROR</sub>** - The inverting input of the PWM comparator. The error voltage is applied to this pin to control the duty cycle. Increasing the signal level increases the duty cycle. The node may be driven with an external error amplifier or opto-coupler.

The ISL6740/1 features a built-in soft start. Soft start is implemented as a clamp on the error voltage input.

**OTS** - The non-inverting input to the over temperature shutdown comparator. The signal input at this pin is compared to an internal threshold of  $V_{REF}/2$ . If the voltage at this pin exceeds the threshold, the Fault signal is asserted and the outputs are disabled until the condition clears. There is a nominal 25  $\mu A$  switched current source used for hysteresis. The amount of hysteresis is adjustable by varying the source impedance of the signal into this pin.

**FAULT** - The Fault signal is asserted high whenever the outputs, OUTA and OUTB, are disabled. This occurs during an over temperature fault, an input UV fault, a  $V_{REF}$  UV fault, or during an over current (ISL6740) or short circuit shutdown fault.

**UV** - Undervoltage monitor input pin. A resistor divider between the input source voltage and GND sets the under voltage lock out threshold. The signal is compared to an

internal 1.00V reference to detect an under voltage or inhibit condition.

**CS** - This is the input to the current sense comparator(s). The IC has the PWM comparator for peak current mode control (ISL6741) and an over current protection comparator. The over current comparator threshold is set at 0.600V nominal. A short circuit condition occurs when the threshold set by the SCSET pin is exceeded. The CS pin is shorted to GND at the end of each switching cycle. Depending on the the current sensing source impedance, a series input resistor may be required due to the delay between the internal clock and the external power switch. This delay may allow the CS input

**ISL6740** - Exceeding the over-current threshold will start a delayed shutdown sequence. Once an over current condition is detected, the soft start charge current source is disabled. The soft start capacitor begins discharging through a 25  $\mu A$  current source, and if it discharges to less than 4.25V (Sustained Over Current Threshold), a shutdown condition occurs and the OUTA and OUTB outputs are forced low. When the soft start voltage reaches 0.27V (Reset Threshold) a soft start cycle begins.

If the over current condition ceases, and then an additional 50  $\mu S$  period elapses before the shutdown threshold is reached, no shutdown occurs. The SS charging current is re-enabled and the soft start voltage is allowed to recover.

**ISL6741** - The ISL6741 current mode controller does not shutdown due to an overcurrent condition. The pulse-by-pulse current limit characteristic of peak current mode control limits the output current to acceptable levels.

**GND** - Reference and power ground for all functions on this device. Due to high peak currents and high frequency operation, a low impedance layout is necessary. Ground planes and short traces are highly recommended.

**OUTA and OUT B** - Alternate half cycle output stages. Each output is capable of 0.5A peak currents for driving logic level power MOSFETs or MOSFET drivers. Each output provides very low impedance to overshoot and undershoot.

**V<sub>REF</sub>** - The 5.00V reference voltage output. 1% tolerance over line, load and operating temperature. Bypass to GND with a 0.01  $\mu F$  or larger ceramic capacitor.

**SS** - Connect the soft start timing capacitor between this pin and GND to control the duration of soft start. The value of the capacitor determines the rate of increase of the duty cycle during start up, controls the over current shutdown delay (ISL6740), and the over current and short circuit hiccup restart period.

**SCSET** - Sets the duty cycle threshold that corresponds to a short circuit condition. A resistive divider between  $R_{TC}$  and GND or  $R_{TD}$  and GND may be used to adjust the SCSET threshold. In either case, the impedance to GND from either

$R_{TC}$  or  $R_{TD}$  affects the oscillator timing and should be considered when determining the oscillator timing components. Connecting SCSET to GND disables short circuit shutdown and hic-cup.

## Functional Description

### Features

The ISL6740 and ISL6741 PWMs are an excellent choice for low cost bridge and push-pull topologies for applications requiring accurate duty cycle and deadtime control. With its many protection and control features, a highly flexible design with minimal external components is possible. Among its many features are current mode control (ISL6741), adjustable soft start, over current protection, thermal protection, bi-directional synchronization, fault indication, and adjustable frequency.

### Oscillator

The ISL6740/1 have an oscillator with a programmable frequency range to 2MHz, which can be programmed with two resistors and capacitor. The use of three timing elements,  $R_{TC}$ ,  $R_{TD}$ , and  $C_T$  allow great flexibility and precision when setting the oscillator frequency.

The switching period may be considered the sum of the timing capacitor charge and discharge durations. The charge duration is determined by  $R_{TC}$  and  $C_T$ . The discharge duration is determined by  $R_{TD}$  and  $C_T$ .

$$T_C \approx 0.5 \cdot R_{TC} \cdot C_T \quad S \quad (EQ. 2)$$

$$T_D \approx 0.02 \cdot R_{TD} \cdot C_T \quad S \quad (EQ. 3)$$

$$T_{SW} = T_C + T_D = \frac{1}{f_{SW}} \quad S \quad (EQ. 4)$$

where  $T_C$  and  $T_D$  are the charge and discharge times, respectively,  $T_{SW}$  is the oscillator free running period, and  $f$  is the oscillator frequency. One output switching cycle requires two oscillator cycles. The actual times will be slightly longer than calculated due to internal propagation delays of approximately 10 nS / transition. This delay adds directly to the switching duration, but also causes overshoot of the timing capacitor peak and valley voltage thresholds, effectively increasing the peak-to-peak voltage on the timing capacitor. Additionally, if very low charge and discharge currents are used, there will be increased error due to the input impedance at the  $C_T$  pin.

The maximum duty cycle,  $D$ , and percent deadtime,  $DT$ , can be calculated from:

$$D = \frac{T_C}{T_{SW}} \quad (EQ. 5)$$

$$DT = 1 - D \quad (EQ. 6)$$

### Implementing Synchronization

The oscillator can be synchronized to an external clock applied to the SYNC pin or by connecting the SYNC pins of multiple ICs together. If an external master clock signal is used, the free running frequency of the oscillator should be ~10% slower than the desired synchronous frequency. The external master clock signal should have a pulse width greater than 20nsec. The SYNC circuitry will not respond to an external signal during the first 60% of the oscillator switching cycle. Should.

The SYNC input is edge triggered and its duration does not affect oscillator operation. However, the deadtime is affected by the SYNC frequency. A higher frequency signal applied to the SYNC input will shorten the deadtime. The shortened deadtime is the result of the timing capacitor charge cycle being prematurely terminated by the external SYNC pulse. Consequently, the timing capacitor is not fully charged when the discharge cycle begins. This effect is only a concern when an external master clock is used, or if units with different operating frequencies are paralleled.

### Soft Start Operation

The ISL6740/1 feature a soft start using an external capacitor in conjunction with an internal current source. Soft start reduces stresses and surge currents during start up.

Upon start up, the soft start circuitry clamps the error voltage input ( $V_{ERROR}$  pin) indirectly to a value equal to the soft start voltage. The soft start clamp does not actually clamp the error voltage input as is done in many implementations. Rather the PWM comparator has two inverting inputs such that the lower voltage is in control.

The output pulse width increases as the soft start capacitor voltage increases. This has the effect of increasing the duty cycle from zero to the regulation pulse width during the soft start period. When the soft start voltage exceeds the error voltage, soft start is completed. Soft start occurs during start-up, after recovery from a Fault condition or over current/short circuit shutdown. The soft start voltage is clamped to 4.5V.

### Gate Drive

The ISL6740/1 are capable of sourcing and sinking 0.5A peak current, but are primarily intended to be used in conjunction with a MOSFET driver due to the 5V drive level. To limit the peak current through the IC, an external resistor may be placed between the totem-pole output of the IC (OUTA or OUTB pin) and the gate of the MOSFET. This

small series resistor also damps any oscillations caused by the resonant tank of the parasitic inductances in the traces of the board and the FET's input capacitance.

### Under Voltage Monitor and Inhibit

The UV input is used for input source under voltage lockout and inhibit functions. If the node voltage falls below 1.00V a UV shutdown fault occurs. This may be caused by low source voltage or by intentional grounding of the pin to disable the outputs. There is a nominal 10  $\mu$ A switched current source used to create hysteresis. The current source is active only during an UV/Inhibit fault; otherwise, it is inactive and does not affect the node voltage. The magnitude of the hysteresis is a function of the external resistor divider impedance. If the resistor divider impedance results in too little hysteresis, a series resistor between the UV pin and the divider may be used to increase the hysteresis. A soft start cycle begins when the UV/Inhibit fault clears.

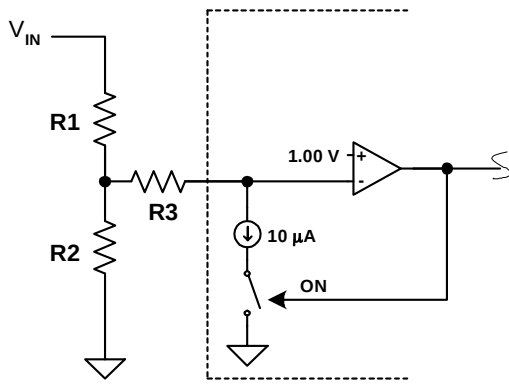


FIGURE 5. UV Hysteresis

As  $V_{IN}$  decreases to a UV condition, the threshold level is:

$$V_{IN(DOWN)} = \frac{R1 + R2}{R2} V \quad (EQ. 7)$$

The hysteresis voltage,  $\Delta V$ , is:

$$\Delta V = 10^{-5} \cdot \left( R1 + R3 \cdot \left( \frac{R1 + R2}{R2} \right) \right) V \quad (EQ. 8)$$

Setting R3 equal to zero results in the minimum hysteresis, and yields:

$$\Delta V = 10^{-5} \cdot R1 V \quad (EQ. 9)$$

As  $V_{IN}$  increases from a UV condition, the threshold level is:

$$V_{IN(UP)} = V_{IN(DOWN)} + \Delta V V \quad (EQ. 10)$$

### Over Current Operation

**ISL6740** - Over current delayed shutdown is enabled once the soft start cycle is complete. If an over current condition is detected, the soft start charging current source is disabled and the soft start capacitor is allowed to discharge through a 15  $\mu$ A source. At the same time a 50 $\mu$ S re-triggerable one-shot timer is activated. It remains active for 50 $\mu$ S after the over current condition ceases. If the soft start capacitor discharges by more than 0.25V to 4.25V, the output is disabled and the Fault signal asserted. This state continues until the soft start voltage reaches 270mV, at which time a new soft start cycle is initiated. If the over current condition stops at least 50 $\mu$ S prior to the soft start voltage reaching 4.25V, the soft start charging currents revert to normal operation and the soft start voltage is allowed to recover.

**ISL6741** - Over current results in pulse-by-pulse duty cycle reduction as occurs in any peak current mode controller. This results in a well controlled decrease in output voltage with increasing current beyond the over current threshold. An over current condition in the ISL6741 will not cause a shutdown.

### Short Circuit Operation

A short circuit condition is defined as the simultaneous occurrence of current limit and a reduced duty cycle. The degree of reduced duty cycle is user adjustable using the SCSET input. A resistor divider between either  $R_{TD}$  or  $R_{TC}$  and GND to RCSET sets a threshold that is compared to the voltage on the timing capacitor,  $C_T$ . The resistor divider percentage corresponds to the maximum duty cycle percentage below which a short circuit may exist. If the timing capacitor voltage fails to exceed the threshold before an over current pulse is detected, a short circuit condition exists. A shutdown and soft start cycle will begin if 8 short circuit events occur within 32 oscillator cycles.

Since the current sourced from both  $R_{TC}$  and  $R_{TD}$  determine the charge and discharge currents for the timing capacitor, the effect of the SCSET divider must be included in the timing calculations. Typically the resistor between  $R_{TC}$  and GND is formed by two series resistors with the center node connected to SCSET.

Alternatively, SCSET may be set using a voltage between 0 and 2 volts. This voltage divided by 2 determines the percentage of the maximum duty cycle that corresponds to a short circuit when current limit is active. For example, if the maximum duty cycle is 95% and 1 volt is applied to SCSET, then the short circuit duty cycle is 50% of 95% or 47.5%.

### Fault Conditions

A Fault condition occurs if  $V_{REF}$  falls below 4.65V, the UV input falls below 1.00V, or the thermal protection is triggered (internal or external). When a Fault is detected, OUTA and OUTB outputs are disabled, the Fault signal is asserted, and the soft start capacitor is quickly discharged. When the Fault condition clears and the soft start voltage is below the reset threshold, a soft start cycle begins.

An over current condition that results in shutdown (ISL6740), or a short circuit condition also cause assertion of the Fault signal. The difference between a current fault and the faults described earlier is that the soft start capacitor is not quickly discharged. The initiation of a new soft start cycle is delayed while the soft start capacitor is discharged at a 15  $\mu$ A rate. This keeps the average output current to a minimum.

### Thermal Protection

Two methods of over temperature protection are provided. The first method is an on board temperature sensor that protects the device should the junction temperature exceed 145°C. There is approximately 15°C of hysteresis.

The second method uses an internal comparator with a 2.5V reference ( $V_{REF}/2$ ). The non-inverting input to the comparator is accessible through the OTS pin. A thermistor or thermal sensor located at or near the area of interest may be connected to this input. There is a nominal 25  $\mu$ A switched current source used to create hysteresis. The current source is active only during an OT fault; otherwise, it is inactive and does not affect the node voltage. The magnitude of the hysteresis is a function of the external resistor divider impedance. Either a positive temperature coefficient (PTC) or a negative temperature coefficient (NTC) thermistor may be used. If a NTC is desired, position R1 may be substituted.

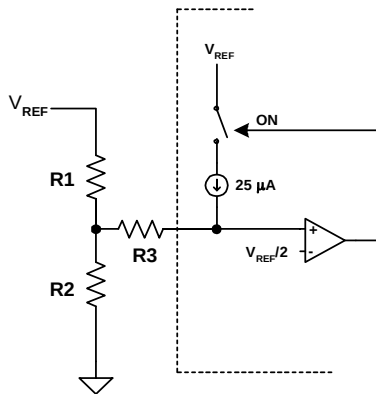


FIGURE 6. OTS Hysteresis

If a PTC is desired, then position R2 may be substituted. The threshold with increasing temperature is set by making the fixed resistance equal in value to the thermistor resistance at the desired trip temperature.

$$V_{TH} \uparrow = 2.5 \text{ V and } R1 = R2 \text{ (HOT)}$$

To determine the value of the hysteresis resistor, R3, select the value of thermistor resistance that corresponds to the desired reset temperature.

$$R3 = \frac{10^5 \cdot (R1 - R2) - R1 \cdot R2}{R1 + R2} \quad \Omega \quad (\text{EQ. 11})$$

If the hysteresis resistor, R3, is not desired, the value of the thermistor resistance at the reset temperature can be determined from:

$$R1 = \frac{2.5 \cdot R2}{2.5 - 10^{-5} \cdot R2} \quad \Omega \quad (\text{NTC}) \quad (\text{EQ. 12})$$

$$R2 = \frac{2.5 \cdot R1}{2.5 + 10^{-5} \cdot R1} \quad \Omega \quad (\text{PTC}) \quad (\text{EQ. 13})$$

The OTS comparator may also be used to monitor signals other than suggested above. It may also be used to monitor any voltage signal for which an excess requires a response as described above. Input or output voltage monitoring are examples of this.

### Ground Plane Requirements

Careful layout is essential for satisfactory operation of the device. A good ground plane must be employed.  $V_{DD}$  should be bypassed directly to GND with good high frequency capacitance.

### Typical Application

The Typical Application Schematic features the ISL6740 in an unregulated half-bridge DC-DC converter configuration, often referred to as a DC Transformer or Bus Regulator. The ISL6740EVAL1 demonstration unit implements this design and is available for evaluation.

The input voltage range is from 36 to 75 volts DC. The output is a nominal 12V when the input voltage is at 48V. Since this is an unregulated topology, the output voltage will vary proportionately with input voltage. The load regulation is a function of resistance between the source and the converter output. The output is rated at 10A.

### Circuit Element Descriptions

The converter design may be broken down into the following functional blocks:

Input Filtering: L1, C1, R1

Half-Bridge Capacitors: C2, C3

Isolation Transformer: T1

Primary Snubber: C13, R10

Start Bias Regulator: CR3, R2, R7, C6, Q5, D1

Supply Bypass Components: R3, C15, C4, C5

Main MOSFET Power Switch: QH, QL

Current Sense Network: T2, CR1, CR2, R5, R6, R11, C10, C14

Control Circuit: U3, RT1, R14, R19, R13, R15, R17, R18, C16, C18, C17

Output Rectification and Filtering: QR1, QR2, QR3, QR4, L2, C9, C8

Secondary Snubber: R8, R9, C11, C12

FET Driver: U1

ZVS Resonant Delay (Optional): L3, C7

### Design Criteria

The following design requirements were selected:

Switching Frequency,  $F_{sw}$ : 235 kHz

$V_{IN}$ :  $48 \pm 10\%$  V

$V_{OUT}$ : 12 V (nominal) @  $I_{OUT} = 8$  A

$P_{OUT}$ : 100 W

Efficiency: 95%

Ripple: 1%

### Transformer Design

The design of a transformer for a half-bridge application is a straight forward affair, although iterative. It is a process of many compromises, and even experienced designers will produce different designs when presented with identical requirements. The iterative design process is not presented here for clarity.

The abbreviated design process follows:

- Select a core geometry suitable for the application. Constraints of height, footprint, mounting preference, and operating environment will affect the choice.
- Determine the turns ratio.
- Select suitable core material(s).
- Select maximum flux density desired for operation.
- Select core size. Core size will be dictated by the capability of the core structure to store the required energy, the number of turns that have to be wound, and the wire gauge needed. Often the window area (the space used for the windings) and power loss determine the final core size.
- Determine maximum desired flux density. Depending on the frequency of operation, the core material selected, and the operating environment, the allowed flux density must be determined. The decision of what flux density to allow is often difficult to determine initially. Usually the highest flux density that produces an acceptable design is used, but often the winding

geometry dictates a larger core than is indicated based on flux density alone.

- Determine the number of primary turns.
- Select the wire gauge for each winding.
- Determine winding order and insulation requirements.
- Verify the design.

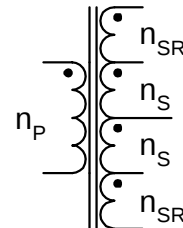


FIGURE 7. Transformer Schematic

For this application we have selected a planar structure to achieve a low profile design. A PQ style core was selected because of its round center leg cross section, but there are many suitable core styles available.

Since the converter is operating open loop at nearly 100% duty cycle, the turns ratio,  $N$ , is simply the ratio of the input voltage to the output voltage divided by 2.

$$N = \frac{V_{IN}}{V_{OUT} \cdot 2} = \frac{48}{12 \cdot 2} = 2 \quad (\text{EQ. 14})$$

The factor of 2 divisor is due to the half-bridge topology. Only half of the input voltage is applied to the primary of the transformer.

A PC44HPQ20/6 "E-Core" plus a PC44PQ20/3 "I-Core" from TDK were selected for the transformer core. The ferrite material is PC44.

The core parameter of concern for flux density is the effective core cross sectional area,  $A_e$ . For the PQ core pieces selected:

$$A_e = 0.62 \text{ cm}^2 \text{ or } 6.2 \text{ e } -5 \text{ m}^2$$

Using Faraday's Law,  $V = N \frac{d\Phi}{dt}$ , the number of primary turns can be determined once the maximum flux density is set. An acceptable  $B_{max}$  is ultimately determined by the allowable power dissipation in the ferrite material and is influenced by the lossiness of the core, core geometry, operating ambient temperature, and air flow. The TDK datasheet for PC44 material indicates a core loss factor of  $\sim 400 \text{ mW/cm}^3$  with a  $\pm 2000$  gauss 100 kHz sinusoidal excitation. The application uses a 235 kHz square wave excitation, so no direct comparison between the application and the data can be made. Interpolation of the data is

required. The core volume is approximately  $1.6 \text{ cm}^3$ , so the estimated core loss is

$$P_{\text{loss}} = \frac{\text{mW}}{\text{cm}^3} \cdot \text{cm}^3 \cdot \frac{f_{\text{act}}}{f_{\text{meas}}} = 0.4 \cdot 1.6 \cdot \frac{200\text{kHz}}{100\text{kHz}} = 1.28 \quad \text{W} \quad (\text{EQ. 15})$$

1.28 watts of dissipation is significant for a core of this size. Reducing the flux density to 1200 Gauss will reduce the dissipation by about the same percentage, or 40%. Ultimately, evaluation of the transformer's performance in the application will determine what is acceptable.

From Faraday's Law and using 1200 gauss peak flux density ( $\Delta B = 2400 \text{ gauss}$  or  $0.24 \text{ tesla}$ )

$$N = \frac{V_{\text{IN}} \cdot T_{\text{ON}}}{2 \cdot A_e \cdot \Delta B} = \frac{53 \cdot 2 \cdot 10^{-6}}{2 \cdot 6.2 \cdot 10^{-5} \cdot 0.24} = 3.56 \quad \text{turns} \quad (\text{EQ. 16})$$

Rounding up yields 4 turns for the primary winding. The peak flux density using 4 turns is ~1100 gauss. From EQ. 1, the number of secondary turns is 2.

The volts/turn for this design ranges from 5.4 volts at  $V_{\text{IN}} = 43 \text{ volts}$  to 6.6 volts at  $V_{\text{IN}} = 53 \text{ volts}$ . Therefore, the synchronous rectifier (SR) windings may be set at 1 turn each with proper FET selection. Selecting 2 turns for the synchronous rectifier windings would also be acceptable, but the gate drive losses would increase.

The next step is to determine the equivalent wire gauge for the planar structure. Since each secondary winding conducts for only 50% of the period, the RMS current is

$$I_{\text{RMS}} = I_{\text{OUT}} \cdot \sqrt{D} = 10 \cdot \sqrt{0.5} = 7.07 \quad \text{A} \quad (\text{EQ. 17})$$

where D is the duty cycle. Since an FR-4 PWB planar winding structure was selected, the width of the copper traces is limited by the window area width, and the number of layers is limited by the window area height. The PQ core selected has a usable window area width of 0.165 inches. Allowing one turn per layer and 0.020 inches clearance at the edges allows a maximum trace width of 0.125 inches. Using 100 circular mils(c.m.)/amp as a guideline for current density, and from EQ. 17, 707 c.m. are required for each of the secondary windings (a circular mil is the area of a circle 0.001 inches in diameter). Converting c.m. to square mils yields 555 mils<sup>2</sup> (0.785 sq. mils/c.m.). Dividing by the trace width results in a copper thickness of 4.44 mils (0.112 mm). Using 1.3 mils/oz. of copper requires a copper weight of 3.4 oz.. For reasons of cost, 3 oz. copper was selected.

One layer of each secondary winding also contains the synchronous rectifier winding. For this layer the secondary trace width is reduced by 0.025 inches to 0.100 inches (0.015 inches for the SR winding trace width and 0.010 inches

spacing between the SR winding and the secondary winding).

The choice of copper weight may be validated by calculating the DC copper losses of the secondary winding as follows. Ignoring the terminal and lead-in resistance, the resistance of each layer of the secondary may be approximated using EQ. 18.

$$R = \frac{2\pi\rho}{t \cdot \ln\left(\frac{r_2}{r_1}\right)} \quad \Omega \quad (\text{EQ. 18})$$

where

R = Winding resistance

$\rho$  = Resistivity of copper =  $669\text{e-}9 \text{ } \Omega\text{-inches}$  at  $20^\circ \text{ C}$

t = Thickness of the copper (3 oz.) =  $3.9\text{e-}3 \text{ inches}$

$r_2$  = Outside radius of the copper trace = 0.324 or 0.299 inches

$r_1$  = Inside radius of the copper trace = 0.199 inches

The winding without the SR winding on the same layer has a DC resistance 2.21 m $\Omega$ . The winding that shares the layer with the SR winding has a DC resistance of 2.65 m $\Omega$ . With the secondary configured as a 4 turn center tapped winding (2 turns each side of the tap), the total DC power loss for the secondary at  $20^\circ \text{ C}$  is 486 mW.

The primary windings have an RMS current of approximately 5 A ( $I_{\text{OUT}} \times N_S/N_P$  at ~ 100% duty cycle). The primary is configured as 2 layers, 2 turns per layer to minimize the winding stack height. Allowing 0.020 inches edge clearance and 0.010 inches between turns yields a trace width of 0.0575 inches. Ignoring the terminal and lead-in resistance, and using EQ. 18, the inner trace has a resistance of 4.25 m $\Omega$ , and the outer trace has a resistance of 5.52 m $\Omega$ . The resistance of the primary then is 19.5 m $\Omega$  at  $20^\circ \text{ C}$ . The total DC power loss for the secondary at  $20^\circ \text{ C}$  is 489 mW.

Improved efficiency and thermal performance could be achieved by selecting heavier copper weight for the windings. Evaluation in the application will determine its need.

The order and geometry of the windings affects the AC resistance, winding capacitance, and leakage inductance of the finished transformer. To mitigate these effects, interleaving the windings is necessary. The primary winding

is sandwiched between the two secondary windings. The winding layout appears below.

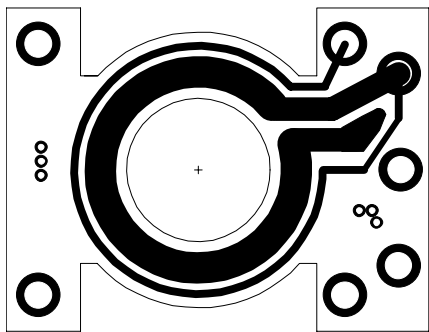


FIGURE 7A. Top Layer: 1 Turn Secondary and SR Windings

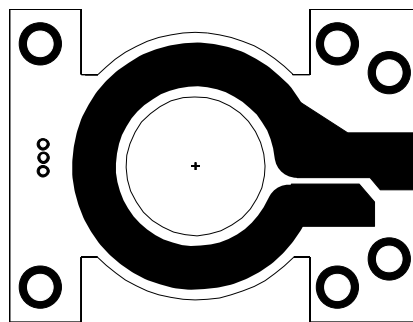


FIGURE 7E. Int. Layer 4: 1 Turn Secondary Winding

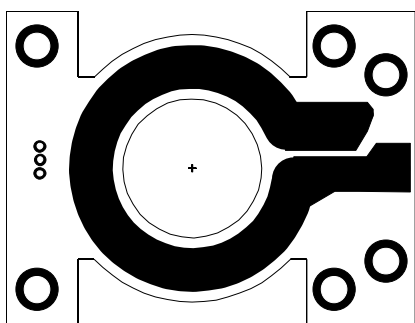


FIGURE 7B. Int. Layer 1: 1 Turn Secondary Winding

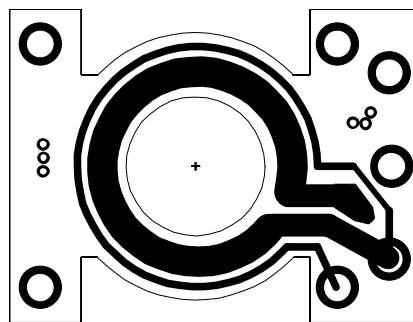


FIGURE 7F. Bottom Layer: 1 Turn Secondary and SR Windings

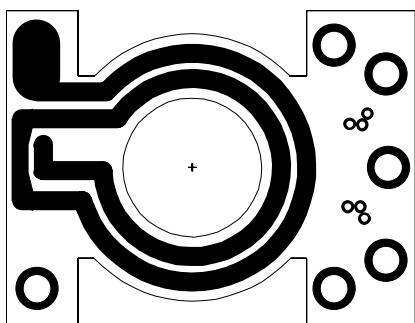


FIGURE 7C. Int. Layer 2: 2 Turns Primary Winding

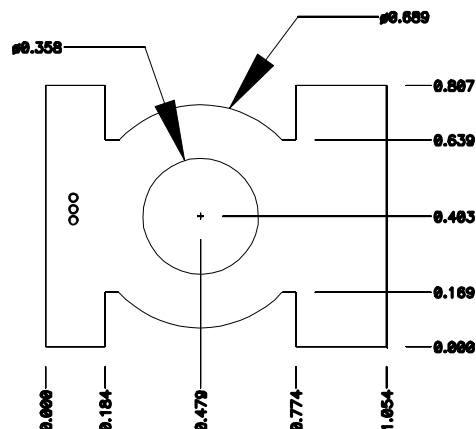


FIGURE 7G. PWB Dimensions

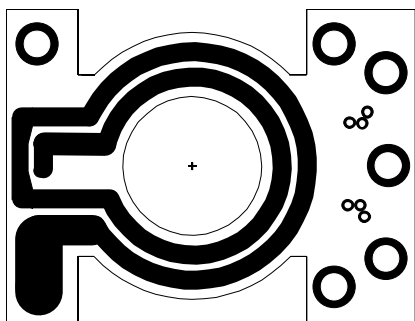


FIGURE 7D. Int. Layer 3: 2 Turns Primary Winding

### MOSFET Selection

The criteria for selection of the primary side half-bridge FETs and the secondary side synchronous rectifier FETs is largely based on the current and voltage rating of the device. However, the FET drain-source capacitance and gate charge cannot be ignored.

The zero voltage switch (ZVS) transition timing is dependent on the transformer's leakage inductance and the capacitance at the node between the upper FET source and the lower FET drain. The node capacitance is comprised of the drain-source capacitance of the FETs and the transformer parasitic capacitance. The leakage inductance

and capacitance form an LC resonant tank circuit which determines the duration of the transition. The amount of energy stored in the LC tank circuit determines the transition voltage amplitude. If the leakage inductance energy is too low, ZVS operation is not possible and near or partial ZVS operation occurs. As the leakage energy increases, the voltage amplitude increases until it is clamped by the FET body diode to ground or  $V_{IN}$ , depending on which FET conducts. When the leakage energy exceeds the minimum required for ZVS operation, the voltage is clamped until the energy is transferred. This behavior increases the time window for ZVS operation. This behavior is not without consequences, however. The transition time and the period of time during which the voltage is clamped reduces the effective duty cycle.

The gate charge affects the switching speed of the FETs. Higher gate charge translates into higher drive requirements and/or slower switching speeds. The energy required to drive the gates is dissipated as heat.

The maximum input voltage,  $V_{IN}$ , plus transient voltage, determines the voltage rating required. With a maximum input voltage of 53 volts for this application, and if we allow a 10% adder for transients, a voltage rating of 60 volts or higher will suffice.

The RMS current through the each primary side FET can be determined from EQ. 17, substituting 5 A of primary current for  $I_{OUT}$ . The result is 3.5 A RMS. Fairchild FDS3672 FETs, rated at 100 V and 7.5 A ( $R_{dson} = 22 \text{ m}\Omega$ ), were selected for the half-bridge switches.

The synchronous rectifier FETs must withstand approximately one half of the input voltage assuming no switching transients are present. This suggests a device capable of withstanding at least 30 V is required. Empirical testing in the circuit revealed switching transients of 20 V were present across the device indicating a rating of at least 60 V is required.

The RMS current rating of 7.07 A for each SR FET requires a low  $R_{dson}$  to minimize conduction losses, which is difficult to find in a 60 V device. It was decided to use two devices in parallel to simplify the thermal design. Two Fairchild FDS5670 devices are used in parallel for a total of four SR FETs. The FDS5670 is rated at 60V and 10 A ( $R_{dson} = 14 \text{ m}\Omega$ ).

### Oscillator Component Selection

The desired operating frequency of 235 kHz for the converter was established in the **Design Criteria** section. The oscillator frequency operates at twice the frequency of the converter because two clock cycles are required for a complete converter period.

During each oscillator cycle the timing capacitor,  $C_T$ , must be charged and discharged. Determining the required discharge time to achieve zero voltage switching (ZVS) is

the critical design goal in selecting the timing components. The discharge time sets the deadtime between the two outputs, and is the same as ZVS transition time. Once the discharge time is determined, the remainder of the period becomes the charge time.

The ZVS transition duration is determined by the transformer's primary leakage inductance,  $L_{lk}$ , by the FET  $C_{oss}$ , by the transformer's parasitic winding capacitance, and by any other parasitic elements on the node. The parameters may be determined by measurement, calculation, estimate, or by some combination of these methods.

$$t_{zvs} = \frac{\pi \sqrt{L_{lk} \cdot (2C_{oss} + C_{xfrmr})}}{2} \quad S \quad (EQ. 19)$$

Device output capacitance,  $C_{oss}$ , is non-linear with applied voltage. To find the equivalent discrete capacitance,  $C_{fet}$ , a charge model is used. Using a known current source, the time required to charge the MOSFET drain to the desired operating voltage is determined and the equivalent capacitance is calculated.

$$C_{fet} = \frac{I_{chg} \cdot t}{V} \quad F \quad (EQ. 20)$$

Once the estimated transition time is determined, it must be verified directly in the application. The transformer leakage inductance was measured at 125 nH and the combined capacitance was estimated at 2000 pF. Calculations indicate a transition period of ~ 25 nS. Verification of the performance yielded a value of  $T_D$  closer to 45 nS.

The remainder of the switching half-period is the charge time,  $T_C$ , and can be found from

$$T_C = \frac{1}{2 \cdot F_S} - T_D = \frac{1}{2 \cdot 235 \cdot 10^3} - 45 \cdot 10^{-9} = 2.08 \quad \mu S \quad (EQ. 21)$$

where  $F_S$  is the converter switching frequency.

Using Fig. 4, the capacitor value appropriate to the desired oscillator operating frequency of 470 kHz can be selected. A  $C_T$  value of 100, 220, or 330 pF is appropriate for this frequency. A value of 220 pF was selected.

To obtain the proper value for  $R_{TD}$ , EQ. 3 is used. Since there is a 10 nS propagation delay in the oscillator circuit, it must be included in the calculation. The value of  $R_{TD}$  selected is 8.06 k $\Omega$ .

A similar procedure is used to determine the value of  $R_{TC}$  using EQ. 2. The value of  $R_{TC}$  selected is the series combination of 17.4 k $\Omega$  and 1.27 k $\Omega$ . See section **Over Current Component Selection** for further explanation.

### Output Filter Design

The output filter inductor and capacitor selection is simple and straightforward. Under steady state operating conditions the voltage across the inductor is very small due to the large duty cycle. Voltage is applied across the inductor only during the switch transition time, about 45 nS in this application. Ignoring the voltage drop across the SR FETs, the voltage across the inductor during the on time with  $V_{IN} = 48$  V is

$$V_L = V_S - V_{OUT} = \frac{V_{IN} \cdot N_S \cdot (1-D)}{2N_P} \approx 250 \quad \text{mV (EQ. 22)}$$

where

$V_L$  is the inductor voltage

$V_S$  is the voltage across the secondary winding

$V_{OUT}$  is the output voltage

If we allow a current ramp,  $\Delta I$ , of 5% of the rated output current, the minimum inductance required is

$$L \geq \frac{V_L \cdot T_{ON}}{\Delta I} = \frac{0.25 \cdot 2.08}{0.5} = 1.04 \quad \mu\text{H} \quad \text{(EQ. 23)}$$

An inductor value of 1.4  $\mu\text{H}$ , rated for 18 A was selected.

With a maximum input voltage of 53 V, the maximum output voltage is about 13 volts. The closest higher voltage rated capacitor is 16 V. Under steady state operating conditions the ripple current in the capacitor is small, so it would seem appropriate to have a low ripple current rated capacitor. However, a high rated ripple current capacitor was selected based on the nature of the intended load, multiple buck regulators. To minimize the output impedance of the filter, a SANYO OSCON 16SH150M capacitor in parallel with a 22  $\mu\text{F}$  ceramic capacitor were selected.

### Over Current Component Selection

There are two circuit areas to consider when selecting the components for over current protection, current limit and short circuit shutdown. The current limit threshold is fixed at 0.6 V while the short circuit threshold is set to a fraction of the duty cycle the designer wishes to define as a short circuit.

The current level that corresponds to the over current threshold must be chosen to allow for the dynamic behavior of an open loop converter. In particular, the low inductor

ripple current under steady state operation increases significantly as the duty cycle decreases.

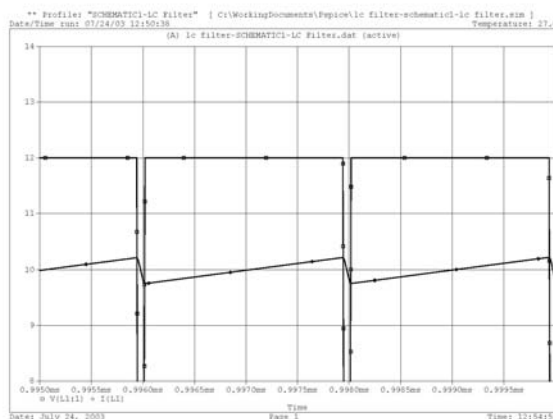


FIGURE 8. Steady State Secondary Winding Voltage and Inductor Current

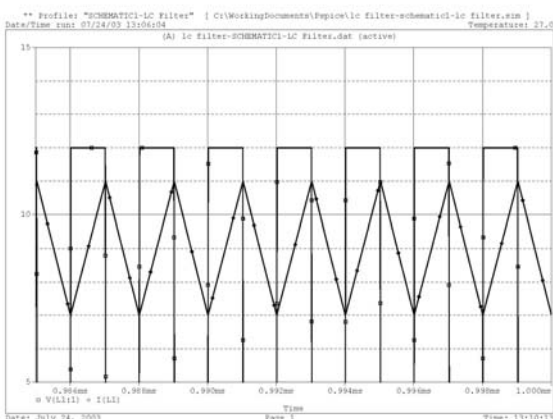


FIGURE 9. Secondary Winding Voltage and Inductor Current During Over Current

Fig. 8 and 9 show the behavior of the inductor ripple under steady state and over current conditions. In this example, the peak current limit is set at 11 A. The peak current limit causes the duty cycle to decrease resulting in a reduction of the average current through the inductor. The implication is that the converter can not supply the same output current in current limit that it can supply under steady state conditions. The peak current limit setpoint must take this behavior into consideration. A 3.32  $\Omega$  current sense resistor was selected for the rectified secondary of current transformer T2, corresponding to a peak current limit setpoint of 16.5 A.

The short circuit protection involves setting a voltage between 0 and 2 volts on the SCSET pin. The applied voltage divided by 2 is the percent of maximum duty cycle that corresponds to a short circuit when the peak current limit is active. A divider from RTC to ground provides an easy method to achieve this. The divider between RTC and GND formed by R13 and R15 determines the percent of

maximum duty cycle that corresponds to a short circuit. The divider ratio formed by R13 and R15 is

$$\frac{R13}{R13 + R15} = \frac{1.27k}{1.27k + 17.4k} = 0.068 \quad (\text{EQ. 24})$$

Therefore, the duty cycle that corresponds to a short circuit is 6.8% of D max (97.9%), or ~6.6%.

### Performance

The major performance criteria for the converter are efficiency, and to a lesser extent, load regulation. Efficiency, load regulation and line regulation performance are demonstrated in the following Figures.

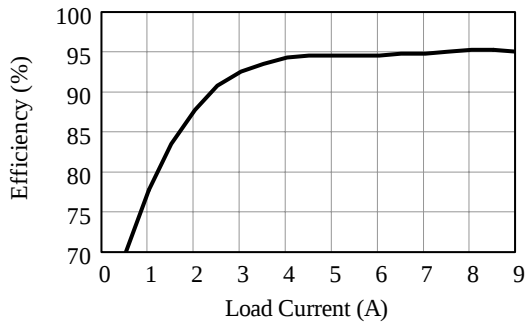


FIGURE 10. Efficiency vs. Load VIN = 48 Vt

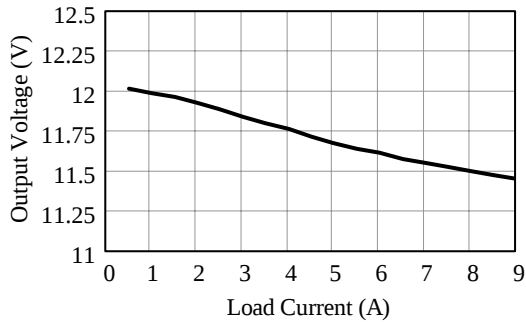


FIGURE 11. Load Regulation at VIN = 48 V

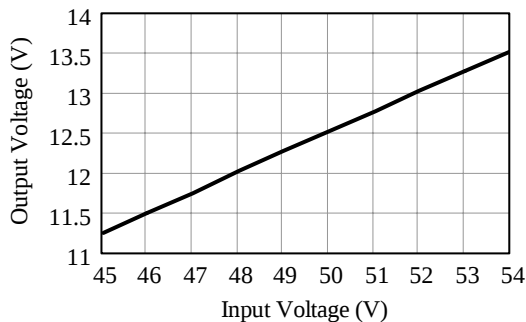


FIGURE 12. Line Regulation at Iout = 1 A

As expected, the output voltage varies considerably with line and load when compared to an equivalent converter with

closed loop feedback. However, for applications where tight regulation is not required, such as those application that use downstream DC-DC converters, this design approach is viable.

### Waveforms

Typical waveforms can be found in the following Figures. Figure 13 shows the output voltage during start up.

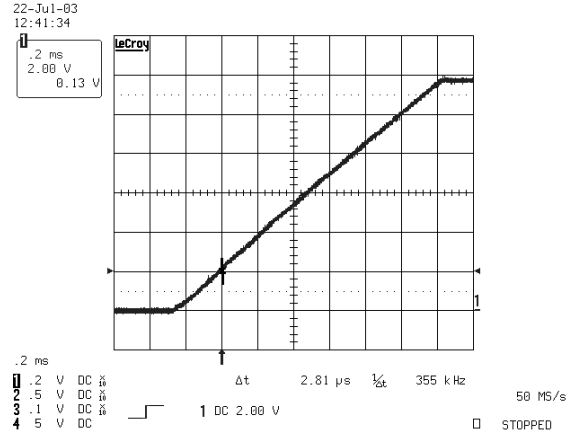


FIGURE 13. Output Soft Start

Figure 14 shows the output voltage ripple and noise at a 5 A load.

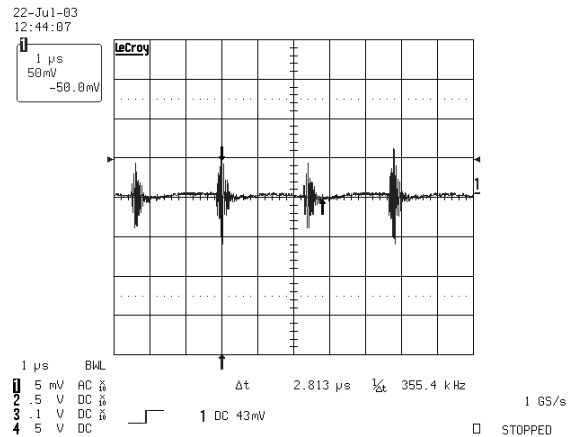


FIGURE 14. Output Ripple and Noise - 20 MHz BW

Figures 15 and 16 show the voltage waveforms at the switching node shared by the upper FET source and the lower FET drain. In particular, Figure 16 shows near ZVS operation at 8 A of load when the upper FET is turning off and the lower FET turning on. There is insufficient energy stored in the leakage inductance to allow complete ZVS operation. However, since the energy stored in the node capacitance is proportional to  $V^2$ , a significant portion of the energy is still recovered. Figure 17 shows the switching transition between outputs, OUTA and OUTB during steady state operation. The deadtime duration of 48.6 nS is clearly shown.

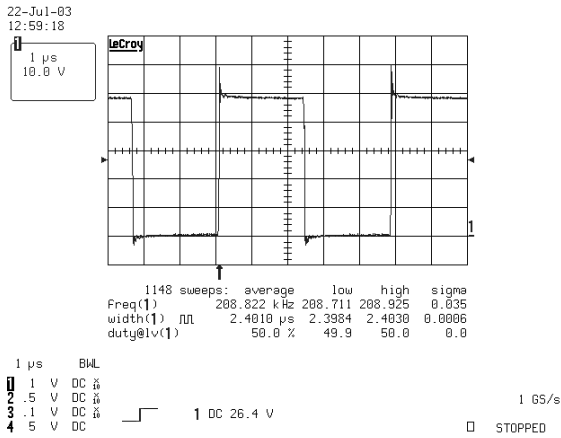


FIGURE 15. FET Drain-Source Voltage

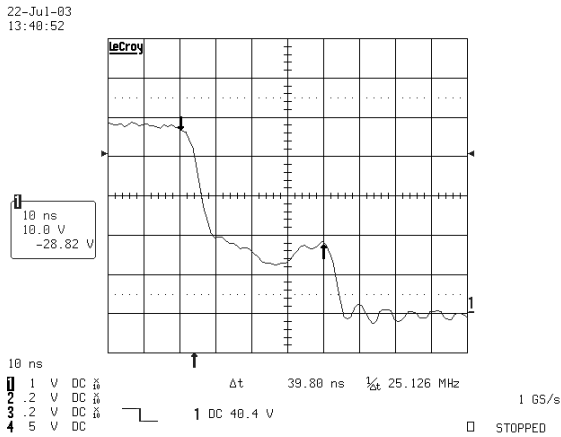


FIGURE 16. FET D-S Voltage Near-ZVS Transition

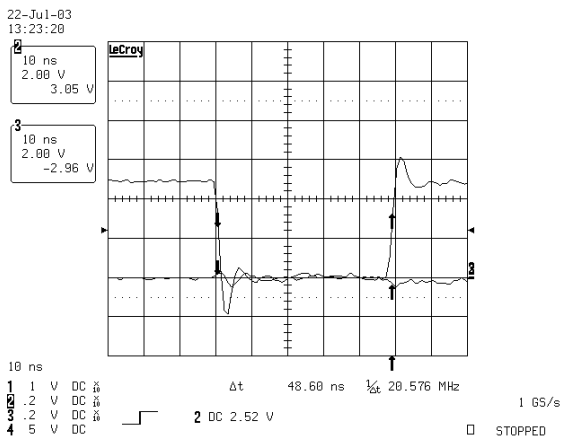


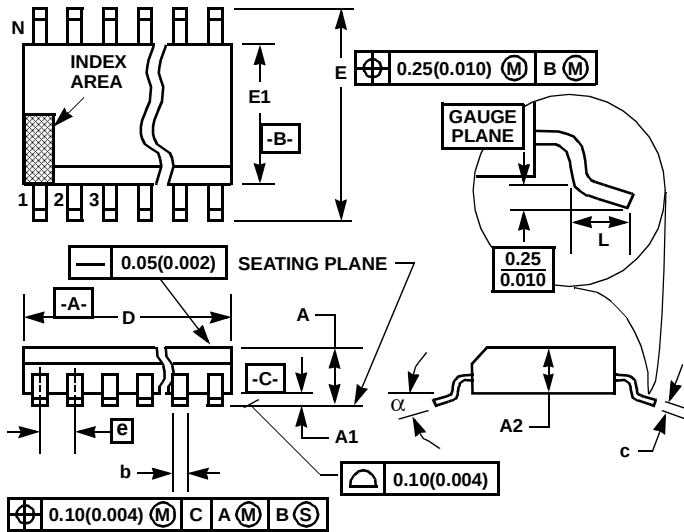
FIGURE 17. OUTA - OUTB Transition

### Component List

| Reference Designator | Value | Description                     |
|----------------------|-------|---------------------------------|
| C1                   | 1.0uF | Capacitor, 1812, X7R, 100V, 20% |
| C2, C3               | 3.3uF | Capacitor, 1812, X5R, 50V, 20%  |
| C4, C6               | 1.0uF | Capacitor, 0805, X5R, 16V, 10%  |
| C5, C15, C16         | 0.1uF | Capacitor, 0603, X7R, 50V, 10%  |

| Reference Designator    | Value   | Description                                    |
|-------------------------|---------|------------------------------------------------|
| C7                      | OPEN    | Capacitor, 0603, OPEN                          |
| C8                      | 22uF    | Capacitor, 1812, X5R, 16V, 20%                 |
| C9                      | 150uF   | Capacitor, Radial, SANYO 16SH150M              |
| C10, C11, C12, C13, C14 | 1000pF  | Capacitor, 0603, X7R, 50V, 10%                 |
| C17                     | 220pF   | Capacitor, 0603, COG, 16V, 5%                  |
| C18                     | 0.047uF | Capacitor, 0603, X7R, 16V, 10%                 |
| C8                      | 330pF   | Capacitor, 0603, COG, 50V, 5%                  |
| CR1, CR2                |         | Diode, Schottky, BAT54S                        |
| CR3                     |         | Diode, Schottky, BAT54                         |
| D1                      |         | Zener, 10V, Zetex BZX84C10ZXCT-ND              |
| L1                      | 190nH   | PULSE, P2004T                                  |
| L2                      | 1.5uH   | PULSE, PG0077.142                              |
| L3                      | SHORT   | Jumper or Optional Discrete Leakage Inductance |
| Q5                      |         | Transistor, ON MJD31C                          |
| QL, QH                  |         | FET, Fairchild FDS3672                         |
| QR1, QR2, QR3, QR4      |         | FET, Fairchild FDS5670                         |
| R1, R10                 | 3.3     | Resistor, 2512, 5%                             |
| R2                      | 3.01K   | Resistor, 2512, 1%                             |
| R3, R6                  | 10.0    | Resistor, 0603, 1%                             |
| R5                      | 3.32    | Resistor, 0603, 1%                             |
| R7                      | 75.0K   | Resistor, 0805, 1%                             |
| R8, R9                  | 20.0    | Resistor, 0805, 1%                             |
| R11                     | 100     | Resistor, 0603, 1%                             |
| R12                     | 8.06K   | Resistor, 0603, 1%                             |
| R13                     | 17.4K   | Resistor, 0603, 1%                             |
| R14                     | OPEN    | Resistor, 0603, OPEN                           |
| R15                     | 1.27K   | Resistor, 0603, 1%                             |
| R17                     | 97.6K   | Resistor, 0603, 1%                             |
| R19, RT1                | 10.0K   | Resistor, 0603, 1%                             |
| T1                      |         | MIDCOM 31718                                   |
| T2                      |         | PULSE P8205T                                   |
| U1                      |         | INTERSIL HIP2101IB                             |
| U3                      |         | ISL6740IB                                      |

## Thin Shrink Small Outline Plastic Packages (TSSOP)



## NOTES:

- These package dimensions are within allowable dimensions of JEDEC MO-153-AB, Issue E.
- Dimensioning and tolerancing per ANSI Y14.5M-1982.
- Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion and gate burrs shall not exceed 0.15mm (0.006 inch) per side.
- Dimension "E1" does not include interlead flash or protrusions. Interlead flash and protrusions shall not exceed 0.15mm (0.006 inch) per side.
- The chamfer on the body is optional. If it is not present, a visual index feature must be located within the crosshatched area.
- "L" is the length of terminal for soldering to a substrate.
- "N" is the number of terminal positions.
- Terminal numbers are shown for reference only.
- Dimension "b" does not include dambar protrusion. Allowable dambar protrusion shall be 0.08mm (0.003 inch) total in excess of "b" dimension at maximum material condition. Minimum space between protrusion and adjacent lead is 0.07mm (0.0027 inch).
- Controlling dimension: MILLIMETER. Converted inch dimensions are not necessarily exact. (Angles in degrees)

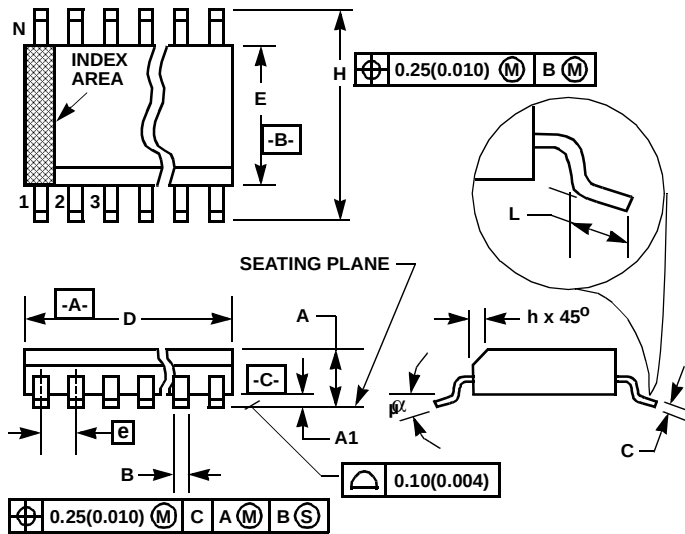
## M16.173

## 16 LEAD THIN SHRINK SMALL OUTLINE PLASTIC PACKAGE

| SYMBOL   | INCHES    |        | MILLIMETERS |      | NOTES |
|----------|-----------|--------|-------------|------|-------|
|          | MIN       | MAX    | MIN         | MAX  |       |
| A        | -         | 0.047  | -           | 1.20 | -     |
| A1       | 0.002     | 0.006  | 0.05        | 0.15 | -     |
| A2       | 0.031     | 0.051  | 0.80        | 1.05 | -     |
| b        | 0.0075    | 0.0118 | 0.19        | 0.30 | 9     |
| c        | 0.0035    | 0.0079 | 0.09        | 0.20 | -     |
| D        | 0.193     | 0.201  | 4.90        | 5.10 | 3     |
| E1       | 0.169     | 0.177  | 4.30        | 4.50 | 4     |
| e        | 0.026 BSC |        | 0.65 BSC    |      | -     |
| E        | 0.246     | 0.256  | 6.25        | 6.50 | -     |
| L        | 0.0177    | 0.0295 | 0.45        | 0.75 | 6     |
| N        | 16        |        | 16          |      | 7     |
| $\alpha$ | 0°        | 8°     | 0°          | 8°   | -     |

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## Small Outline Plastic Packages (SOIC)



### NOTES:

1. Symbols are defined in the "MO Series Symbol List" in Section 2.2 of Publication Number 95.
2. Dimensioning and tolerancing per ANSI Y14.5M-1982.
3. Dimension "D" does not include mold flash, protrusions or gate burrs. Mold flash, protrusion and gate burrs shall not exceed 0.15mm (0.006 inch) per side.
4. Dimension "E" does not include interlead flash or protrusions. Interlead flash and protrusions shall not exceed 0.25mm (0.010 inch) per side.
5. The chamfer on the body is optional. If it is not present, a visual index feature must be located within the crosshatched area.
6. "L" is the length of terminal for soldering to a substrate.
7. "N" is the number of terminal positions.
8. Terminal numbers are shown for reference only.
9. The lead width "B", as measured 0.36mm (0.014 inch) or greater above the seating plane, shall not exceed a maximum value of 0.61mm (0.024 inch).
10. Controlling dimension: MILLIMETER. Converted inch dimensions are not necessarily exact.

### M16.15 (JEDEC MS-012-AC ISSUE C) 16 LEAD NARROW BODY SMALL OUTLINE PLASTIC PACKAGE

| SYMBOL   | INCHES    |        | MILLIMETERS |       | NOTES |
|----------|-----------|--------|-------------|-------|-------|
|          | MIN       | MAX    | MIN         | MAX   |       |
| A        | 0.0532    | 0.0688 | 1.35        | 1.75  | -     |
| A1       | 0.0040    | 0.0098 | 0.10        | 0.25  | -     |
| B        | 0.013     | 0.020  | 0.33        | 0.51  | 9     |
| C        | 0.0075    | 0.0098 | 0.19        | 0.25  | -     |
| D        | 0.3859    | 0.3937 | 9.80        | 10.00 | 3     |
| E        | 0.1497    | 0.1574 | 3.80        | 4.00  | 4     |
| e        | 0.050 BSC |        | 1.27 BSC    |       | -     |
| H        | 0.2284    | 0.2440 | 5.80        | 6.20  | -     |
| h        | 0.0099    | 0.0196 | 0.25        | 0.50  | 5     |
| L        | 0.016     | 0.050  | 0.40        | 1.27  | 6     |
| N        | 16        |        | 16          |       | 7     |
| $\alpha$ | 0°        | 8°     | 0°          | 8°    | -     |

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