



## LM3150 Wide-VIN Synchronous Buck Controller

### 1 Features

- PowerWise™ Step-Down Controller
- 6-V to 42-V Wide Input Voltage Range
- Adjustable Output Voltage Down to 0.6 V
- Programmable Switching Frequency up to 1 MHz
- No Loop Compensation Required
- Fully WEBENCH® Enabled
- Low External Component Count
- Constant On-Time (COT) Control
- Ultra-Fast Transient Response
- Stable With Low ESR Capacitors
- Output Voltage PreBias Startup
- Valley Current Limit
- Programmable Soft-Start

### 2 Applications

- Telecom
- Networking Equipment
- Routers
- Security Surveillance
- Power Modules

### 3 Description

The LM3150 SIMPLE SWITCHER® controller is an easy-to-use and simplified step-down power controller capable of providing up to 12 A of output current in a typical application. Operating with an input voltage range of 6 V to 42 V, the LM3150 controller features an adjustable output voltage down to 0.6 V. The switching frequency is adjustable up to 1 MHz and the synchronous architecture provides for highly efficient designs. The LM3150 controller employs a constant on-time (COT) architecture with a proprietary emulated ripple mode (ERM) control that allows for the use of low ESR output capacitors, which reduces overall solution size and output voltage ripple. The COT regulation architecture allows for fast transient response and requires no loop compensation, which reduces external component count and reduces design complexity.

Fault protection features such as thermal shutdown, undervoltage lockout, overvoltage protection, short-circuit protection, current limit, and output voltage prebias start-up allow for a reliable and robust solution.

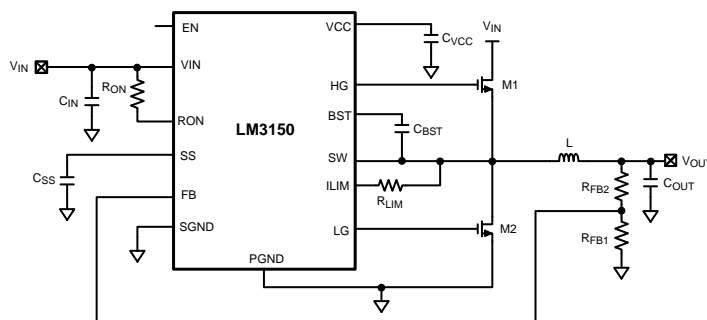
The LM3150 concept provides for an easy-to-use complete design using a minimum number of external components and TI's WEBENCH online design tool. WEBENCH provides design support for every step of the design process and includes features such as external component calculation with a new MOSFET selector, electrical simulation, thermal simulation, and Build-It boards for prototyping.

#### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE     | BODY SIZE (NOM)   |
|-------------|-------------|-------------------|
| LM3150      | HTSSOP (14) | 5.00 mm × 4.40 mm |

(1) For all available packages, see the orderable addendum at the end of the datasheet.

### 4 Typical Application Schematic



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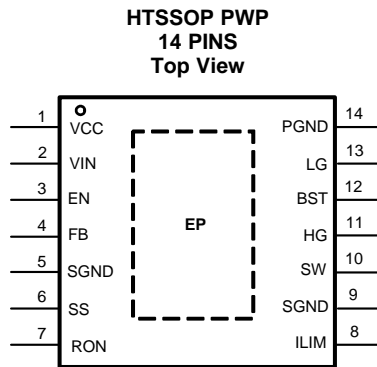
## 5 Revision History

### Changes from Revision E (November 2012) to Revision F

Page

- Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section ..... **4**

## 6 Pin Configuration and Functions



### Pin Functions

| PIN  |     | I/O | DESCRIPTION                        | FUNCTION   |
|------|-----|-----|------------------------------------|--|
| NAME | NO. |     |                                    |  |
| VCC  | 1   | O   | Supply Voltage for FET Drivers     | Nominally regulated to 5.95 V. Connect a 1.0-μF to 4.7-μF decoupling capacitor from this pin to ground.  |
| VIN  | 2   | I   | Input Supply Voltage               | Supply pin to the device. Nominal input range is 6 V to 42 V.  |
| EN   | 3   | I   | Enable                             | To enable the IC, apply a logic high signal to this pin greater than 1.26-V typical or leave floating. To disable the part, ground the EN pin.   |
| FB   | 4   | I   | Feedback                           | Internally connected to the regulation, overvoltage, and short-circuit comparators. The regulation setting is 0.6 V at this pin. Connect to feedback resistor divider between the output and ground to set the output voltage.                         |
| SGND | 5,9 | —   | Signal Ground                      | Ground for all internal bias and reference circuitry. Should be connected to PGND at a single point.   |
| SS   | 6   | I   | Soft-Start                         | An internal 7.7-μA current source charges an external capacitor to provide the soft-start function.  |
| RON  | 7   | I   | On-time Control                    | An external resistor from VIN to this pin sets the high-side switch on-time.   |
| ILIM | 8   | I   | Current Limit                      | Monitors current through the low-side switch and triggers current limit operation if the inductor valley current exceeds a user defined value that is set by $R_{LIM}$ and the Sense current, $I_{LIM-TH}$ , sourced out of this pin during operation. |
| SW   | 10  | O   | Switch Node                        | Switch pin of controller and high-gate driver lower supply rail. A boost capacitor is also connected between this pin and BST pin  |
| HG   | 11  | O   | High-Side Gate Drive               | Gate drive signal to the high-side NMOS switch. The high-side gate driver voltage is supplied by the differential voltage between the BST pin and SW pin.  |
| BST  | 12  | I   | Connection for Bootstrap Capacitor | High-gate driver upper supply rail. Connect a 0.33 to 0.47-μF capacitor from SW pin to this pin. An internal diode charges the capacitor during the high-side switch off-time. Do not connect to an external supply rail.                              |
| LG   | 13  | O   | Low-Side Gate Drive                | Gate drive signal to the low-side NMOS switch. The low-side gate driver voltage is supplied by VCC.  |
| PGND | 14  | G   | Power Ground                       | Synchronous rectifier MOSFET source connection. Tie to power ground plane. Should be tied to SGND at a single point.   |
| EP   | —   | —   | Exposed Pad                        | Exposed die attach pad should be connected directly to SGND. Also used to help dissipate heat out of the IC.   |

## 7 Specifications

### 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) <sup>(1)(2)</sup>

|                                      | MIN  | MAX | UNIT |
|--------------------------------------|------|-----|------|
| V <sub>IN</sub> , RON to GND         | −0.3 | 47  | V    |
| SW to GND                            | −3   | 47  | V    |
| BST to SW                            | −0.3 | 7   | V    |
| BST to GND                           | −0.3 | 52  | V    |
| All Other Inputs to GND              | −0.3 | 7   | V    |
| T <sub>stg</sub> Storage temperature | −65  | 150 | °C   |

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Ratings*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

### 7.2 ESD Ratings

|  | VALUE | UNIT |
|--|-------|------|
| V <sub>(ESD)</sub> Electrostatic discharge Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup> | ±2000 | V    |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

### 7.3 Recommended Operating Ratings

over operating free-air temperature range (unless otherwise noted)

|  | MIN | NOM | MAX | UNIT |
|--|-----|-----|-----|------|
| V <sub>IN</sub>                              | 6   |     | 42  | V    |
| Junction Temperature Range (T <sub>J</sub> ) | −40 |     | 125 | °C   |
| EN   | 0   |     | 5   | V    |

### 7.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |  | LM3150  | UNIT |
|-------------------------------|--|---------|------|
|                               |  | PWP     |      |
|                               |  | 14 PINS |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 42.5    | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 28.7    |      |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 24.2    |      |
| ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 0.9     |      |
| ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 23.9    |      |
| R <sub>θJC(bot)</sub>         | Junction-to-case (bottom) thermal resistance | 4.4     |      |

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

## 7.5 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted)

| PARAMETER                             |   | TEST CONDITIONS   | T <sub>J</sub> = 25°C |     |     | T <sub>J</sub> = -40°C to 125°C |       |     | UNIT |
|---------------------------------------|---|---|-----------------------|-----|-----|---------------------------------|-------|-----|------|
|                                       |   |   | MIN                   | TYP | MAX | MIN                             | TYP   | MAX |      |
| START-UP; REGULATOR, VCC              |   |   |                       |     |     |                                 |       |     |      |
| VCC                                   |   | C <sub>VCC</sub> = 1 μF, 0 mA to 40 mA                                    | 5.95                  |     |     | 5.65                            | 6.25  |     | V    |
| VIN - VCC                             | VIN - VCC Dropout Voltage                 | I <sub>VCC</sub> = 2 mA, V <sub>IN</sub> = 5.5 V                          | 40                    |     |     |                                 |       |     | mV   |
|                                       |   | I <sub>VCC</sub> = 30 mA, V <sub>IN</sub> = 5.5 V                         | 330                   |     |     |                                 |       |     |      |
| I <sub>VCC</sub> L                    | VCC Current Limit <sup>(1)</sup>          | VCC = 0V  | 100                   |     |     | 65                              |       |     | mA   |
| VCC <sub>UVLO</sub>                   | VCC Undervoltage Lockout Threshold (UVLO) | VCC Increasing  | 5.1                   |     |     | 4.75                            | 5.40  |     | V    |
| VCC <sub>UVLO-HYS</sub>               | VCC UVLO Hysteresis                       | VCC Decreasing  | 475                   |     |     |                                 |       |     | mV   |
| t <sub>CC-UVLO-D</sub>                | VCC UVLO Filter Delay                     |   | 3                     |     |     |                                 |       |     | μs   |
| I <sub>IN</sub>                       | Input Operating Current                   | No Switching, V <sub>FB</sub> = 1 V                                       | 3.5                   |     |     | 5                               |       |     | mA   |
| I <sub>IN-SD</sub>                    | Input Operating Current, Device Shutdown  | V <sub>EN</sub> = 0 V   | 32                    |     |     | 55                              |       |     | μA   |
| GATE DRIVE                            |   |   |                       |     |     |                                 |       |     |      |
| I <sub>Q-BST</sub>                    | Boost Pin Leakage                         | V <sub>BST</sub> – V <sub>SW</sub> = 6 V                                  | 2                     |     |     |                                 |       |     | nA   |
| R <sub>DS-HG-Pull-Up</sub>            | HG Drive Pullup On-Resistance             | I <sub>HG</sub> Source = 200 mA   | 5                     |     |     |                                 |       |     | Ω    |
| R <sub>DS-HG-Pull-Down</sub>          | HG Drive Pulldown On-Resistance           | I <sub>HG</sub> Sink = 200 mA   | 3.4                   |     |     |                                 |       |     | Ω    |
| R <sub>DS-LG-Pull-Up</sub>            | LG Drive Pullup On-Resistance             | I <sub>LG</sub> Source = 200 mA   | 3.4                   |     |     |                                 |       |     | Ω    |
| R <sub>DS-LG-Pull-Down</sub>          | LG Drive Pulldown On-Resistance           | I <sub>LG</sub> Sink = 200 mA   | 2                     |     |     |                                 |       |     | Ω    |
| SOFT-START                            |   |   |                       |     |     |                                 |       |     |      |
| I <sub>SS</sub>                       | SS Pin Source Current                     | V <sub>SS</sub> = 0 V   | 7.7                   |     |     | 5.9                             | 9.5   |     | μA   |
| I <sub>SS-DIS</sub>                   | SS Pin Discharge Current                  | Current Limit   | 200                   |     |     |                                 |       |     | μA   |
| I <sub>LIM-TH</sub>                   | Current Limit Sense Pin Source Current    |   | 75                    | 85  | 95  |                                 |       |     | μA   |
| ON/OFF TIMER                          |   |   |                       |     |     |                                 |       |     |      |
| t <sub>ON</sub>                       | ON Timer Pulse Width                      | V <sub>IN</sub> = 10V, R <sub>ON</sub> = 100 kΩ, V <sub>FB</sub> = 0.6V   | 1.02                  |     |     |                                 |       |     | μs   |
|                                       |   | V <sub>IN</sub> = 18V, R <sub>ON</sub> = 100 kΩ, V <sub>FB</sub> = 0.6 V  | 0.62                  |     |     |                                 |       |     |      |
|                                       |   | V <sub>IN</sub> = 42 V, R <sub>ON</sub> = 100 kΩ, V <sub>FB</sub> = 0.6 V | 0.36                  |     |     |                                 |       |     |      |
| t <sub>ON-MIN</sub>                   | ON Timer Minimum Pulse Width              | See <sup>(2)</sup>  | 200                   |     |     |                                 |       |     | ns   |
| t <sub>OFF</sub>                      | OFF Timer Minimum Pulse Width             |   | 370                   |     |     | 525                             |       |     | ns   |
| ENABLE INPUT                          |   |   |                       |     |     |                                 |       |     |      |
| V <sub>EN</sub>                       | EN Pin Input Threshold Trip Point         | V <sub>EN</sub> Rising  | 1.20                  |     |     | 1.14                            | 1.26  |     | V    |
| V <sub>EN-HYS</sub>                   | EN Pin Threshold Hysteresis               | V <sub>EN</sub> Falling   | 120                   |     |     |                                 |       |     | mV   |
| REGULATION AND OVERVOLTAGE COMPARATOR |   |   |                       |     |     |                                 |       |     |      |
| V <sub>FB</sub>                       | In-Regulation Feedback Voltage            | V <sub>SS</sub> > 0.6 V   | 0.600                 |     |     | 0.588                           | 0.612 |     | V    |
| V <sub>FB-OV</sub>                    | Feedback Overvoltage Threshold            |   | 0.720                 |     |     | 0.690                           | 0.748 |     | V    |
| I <sub>FB</sub>                       | Feedback Bias Current                     |   | 20                    |     |     |                                 |       |     | nA   |

(1) VCC provides self bias for the internal gate drive and control circuits. Device thermal limitations limit external loading.

(2) See [Detailed Description](#) section for minimum on-time when using MOSFETs connected to gate drivers.

**LM3150**

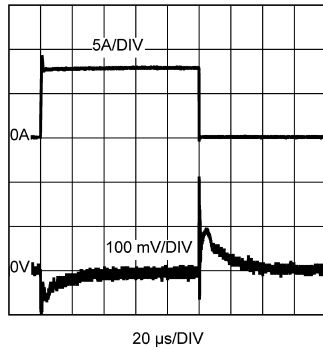
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**Electrical Characteristics (continued)**

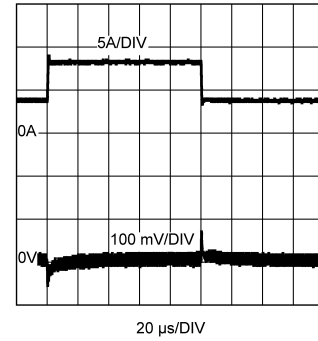
over operating free-air temperature range (unless otherwise noted)

| PARAMETER               |                             | TEST CONDITIONS          | T <sub>J</sub> = 25°C |     |     | T <sub>J</sub> = -40°C to 125°C |     |     | UNIT |
|-------------------------|-----------------------------|--------------------------|-----------------------|-----|-----|---------------------------------|-----|-----|------|
|                         |                             |                          | MIN                   | TYP | MAX | MIN                             | TYP | MAX |      |
| BOOST DIODE             |                             |                          |                       |     |     |                                 |     |     |      |
| V <sub>f</sub>          | Forward Voltage             | I <sub>BST</sub> = 2 mA  | 0.7                   |     |     |                                 |     |     | V    |
|                         |                             | I <sub>BST</sub> = 30 mA | 1                     |     |     |                                 |     |     |      |
| THERMAL CHARACTERISTICS |                             |                          |                       |     |     |                                 |     |     |      |
| T <sub>SD</sub>         | Thermal Shutdown            | Rising                   | 165                   |     |     |                                 |     |     | °C   |
|                         | Thermal Shutdown Hysteresis | Falling                  | 15                    |     |     |                                 |     |     | °C   |

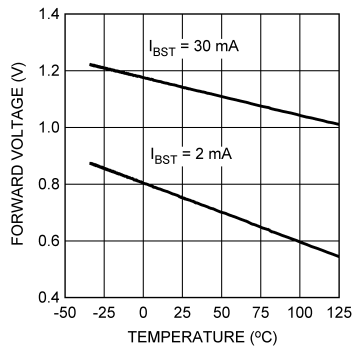
## 7.6 Typical Characteristics



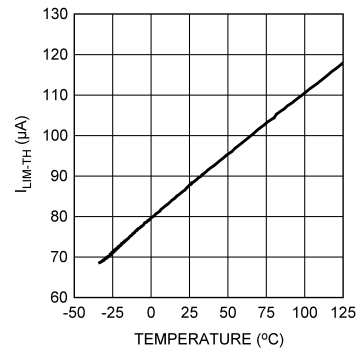
**Figure 1. 500-kHz Full Load Transient**



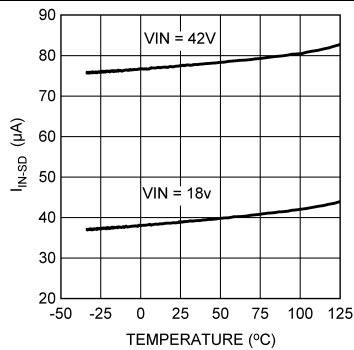
**Figure 2. 500-kHz Partial Load Transient**



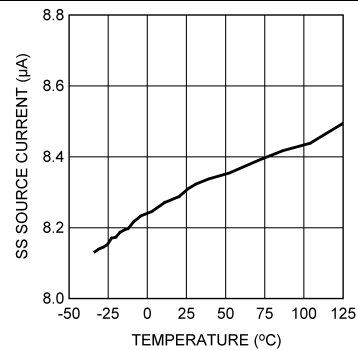
**Figure 3. Boost Diode Forward Voltage vs Temperature**



**Figure 4.  $I_{LIM-TH}$  vs Temperature**

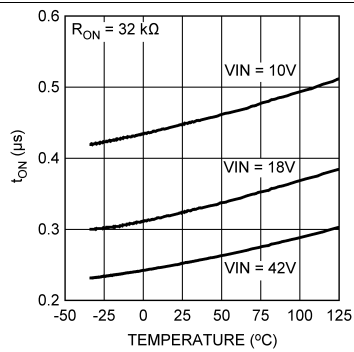


**Figure 5. Quiescent Current vs Temperature**

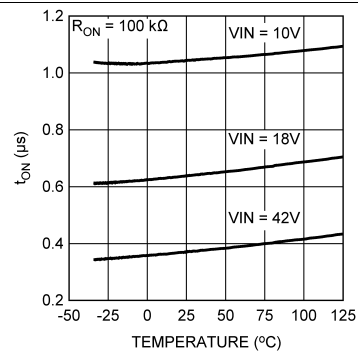


**Figure 6. Soft-Start Current vs Temperature**

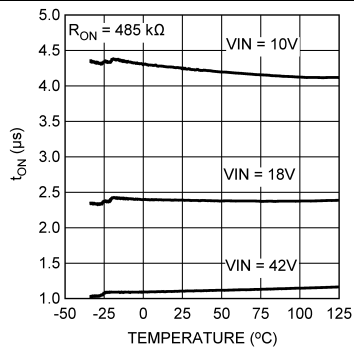
## Typical Characteristics (continued)



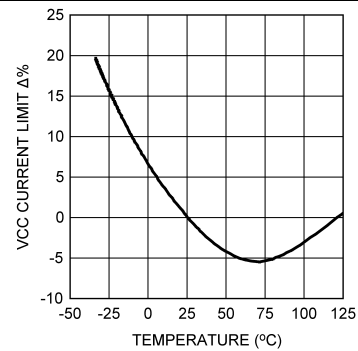
**Figure 7.  $t_{ON}$  vs Temperature**



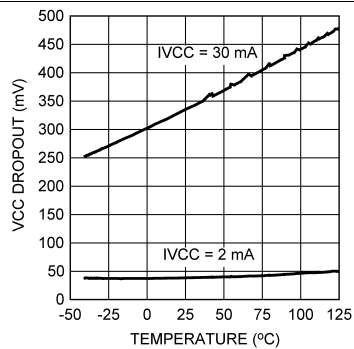
**Figure 8.  $t_{ON}$  vs Temperature**



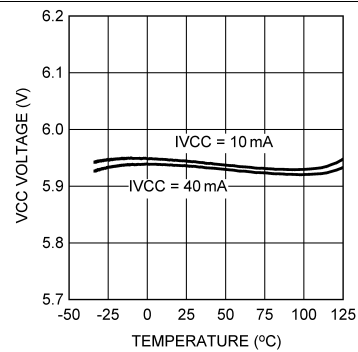
**Figure 9.  $t_{ON}$  vs Temperature**



**Figure 10. VCC Current Limit vs Temperature**



**Figure 11. VCC Dropout vs Temperature**



**Figure 12. VCC vs Temperature**



## 8 Detailed Description

### 8.1 Overview

The LM3150 synchronous step-down controller uses a COT architecture which is a derivative of the hysteretic control scheme. COT relies on a fixed switch on-time to regulate the output. The on-time of the high-side switch can be set manually by adjusting the size of an external resistor ( $R_{ON}$ ). To maintain a relatively constant switching frequency as  $V_{IN}$  varies, the LM3150 controller automatically adjusts the on-time inversely with the input voltage. Assuming an ideal system and  $V_{IN}$  is much greater than 1 V, the following approximations can be made:

The on-time,  $t_{ON}$ :

$$t_{ON} = \frac{K \times R_{ON}}{V_{IN}}$$

where

- constant  $K = 100 \text{ pC}$  (1)

The  $R_{ON}$  resistance value can be calculated as follows:

$$R_{ON} = \frac{V_{OUT}}{K \times f_s}$$

where

- $f_s$  is the desired switching frequency (2)

Control is based on a comparator and the on-timer, with the output voltage feedback (FB) compared with an internal reference of 0.6 V. If the FB level is below the reference, the high-side switch is turned on for a fixed time,  $t_{ON}$ , which is determined by the input voltage and the resistor  $R_{ON}$ . Following this on-time, the switch remains off for a minimum off-time,  $t_{OFF}$ , as specified in the [Electrical Characteristics](#) table or until the FB pin voltage is below the reference, then the switch turns on again for another on-time period. The switching will continue in this fashion to maintain regulation. During continuous conduction mode (CCM), the switching frequency ideally depends on duty-cycle and on-time only. In a practical application however, there is a small delay in the time that the HG goes low and the SW node goes low that also affects the switching frequency that is accounted for in the typical application curves. The duty-cycle and frequency can be approximated as:

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = t_{ON} \times f_s \approx \frac{V_{OUT}}{V_{IN}} \quad (3)$$

$$f_s = \frac{V_{OUT}}{K \times R_{ON}} \quad (4)$$

Typical COT hysteretic controllers need a significant amount of output capacitor ESR to maintain a minimum amount of ripple at the FB pin in order to switch properly and maintain efficient regulation. The LM3150 controller, however, uses a proprietary Emulated Ripple Mode control scheme (ERM) that allows the use of low ESR output capacitors. Not only does this reduce the need for high output capacitor ESR, but also significantly reduces the amount of output voltage ripple seen in a typical hysteretic control scheme. The output ripple voltage can become so low that it is comparable to voltage-mode and current-mode control schemes.



## Feature Description (continued)

The  $R_{LIM}$  value can be approximated as follows:

$$I_{CL} = I_{OCL} - \frac{\Delta I_L}{2} \quad (6)$$

$$R_{LIM} = \frac{I_{CL} \times R_{DS(ON)max}}{I_{LIM-TH}}$$

where

- $I_{OCL}$  is the user-defined average output current limit value
- $R_{DS(ON)max}$  is the resistance value of the low-side FET at the expected maximum FET junction temperature
- $I_{LIM-TH}$  is an internal current supply of 85  $\mu A$  typical

**Figure 13** illustrates the inductor current waveform. During normal operation, the output current ripple is dictated by the switching of the FETs. The current through the low-side switch,  $I_{valley}$ , is sampled at the end of each switching cycle and compared to the current limit,  $I_{CL}$ , current. The valley current can be calculated as follows:

$$I_{valley} = I_{OUT} - \frac{\Delta I_L}{2}$$

where

- $I_{OUT}$  is the average output current
- $\Delta I_L$  is the peak-to-peak inductor ripple current

If an overload condition occurs, the current through the low-side switch will increase which will cause the current limit comparator to trigger the logic to skip the next on-time cycle. The IC will then try to recover by checking the valley current during each off-time. If the valley current is greater than or equal to  $I_{CL}$ , then the IC will keep the low-side FET on and allow the inductor current to further decay.

Throughout the whole process, regardless of the load current, the on-time of the controller will stay constant and thereby the positive ripple current slope will remain constant. During each on-time the current ramps-up an amount equal to:

$$\Delta I_L = \frac{(V_{IN} - V_{OUT}) \times t_{ON}}{L} \quad (9)$$

The valley current limit feature prevents current runaway conditions due to propagation delays or inductor saturation because the inductor current is forced to decay following any overload conditions.

Current sensing is achieved by either a low value sense resistor in series with the low-side FET or by utilizing the  $R_{DS(ON)}$  of the low-side FET. The  $R_{DS(ON)}$  sensing method is the preferred choice for a more simplified design and lower costs. The  $R_{DS(ON)}$  value of a FET has a positive temperature coefficient and will increase in value as the temperature of the FET increases. The LM3150 controller will maintain a more stable current limit that is closer to the original value that was set by the user, by positively adjusting the  $I_{LIM-TH}$  value as the IC temperature increases. This does not provide an exact temperature compensation but allows for a more tightly controlled current limit when compared to traditional  $R_{DS(ON)}$  sensing methods when the  $R_{DS(ON)}$  value can change typically 140% from room to maximum temperature and cause other components to be over-designed. The temperature compensated  $I_{LIM-TH}$  is shown below where  $T_J$  is the die temperature of the LM3150 controller in Celsius:

$$I_{LIM-TH}(T_J) = I_{LIM-TH} \times [1 + 3.3 \times 10^{-3} \times (T_J - 27)] \quad (10)$$

To calculate the  $R_{LIM}$  value with temperature compensation, substitute [Equation 10](#) into  $I_{LIM-TH}$  in [Equation 7](#).

### 8.3.5 Short-Circuit Protection

The LM3150 controller will sense a short-circuit on the output by monitoring the output voltage. When the feedback voltage has fallen below 60% of the reference voltage,  $V_{ref} \times 0.6$  ( $\approx 0.36$  V), short-circuit mode of operation will start. During short-circuit operation, the SS pin is discharged and the output voltage will fall to 0 V. The SS pin voltage,  $V_{SS}$ , is then ramped back up at the rate determined by the SS capacitor and  $I_{SS}$  until  $V_{SS}$  reaches 0.7 V. During this re-ramp phase, if the short-circuit fault is still present the output current will be equal to the set current limit. Once the soft-start voltage reaches 0.7 V, the output voltage is sensed again and if the  $V_{FB}$  is still below  $V_{ref} \times 0.6$  then the SS pin is discharged again and the cycle repeats until the short-circuit fault is removed.

## Feature Description (continued)

### 8.3.6 Soft-Start

The soft-start (SS) feature allows the regulator to gradually reach a steady-state operating point, which reduces start-up stresses and current surges. At turnon, while VCC is below the undervoltage threshold, the SS pin is internally grounded and V<sub>OUT</sub> is held at 0 V. The SS capacitor is used to slowly ramp V<sub>FB</sub> from 0 V to 0.6 V. By changing the capacitor value, the duration of start-up can be changed accordingly. The start-up time can be calculated using the following equation:

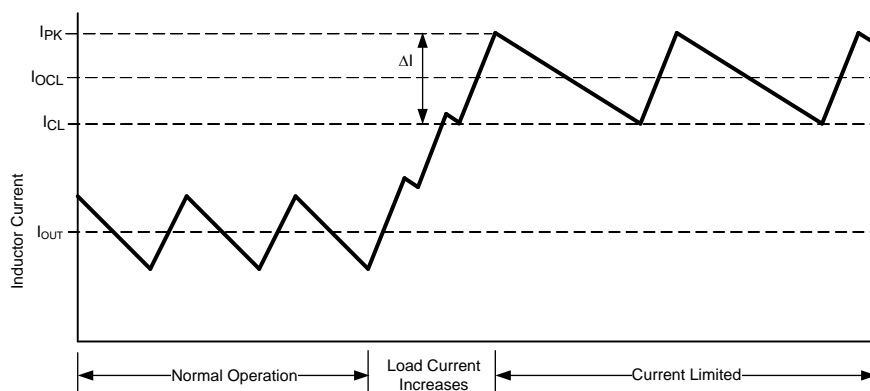
$$t_{SS} = \frac{V_{ref} \times C_{SS}}{I_{SS}}$$

where

- t<sub>SS</sub> is measured in seconds
- V<sub>ref</sub> = 0.6 V
- I<sub>SS</sub> is the soft-start pin source current, which is typically 7.7 μA (refer to [Electrical Characteristics](#))

An internal switch grounds the SS pin if VCC is below the undervoltage lockout threshold, if a thermal shutdown occurs, or if the EN pin is grounded. By using an externally controlled switch, the output voltage can be shut off by grounding the SS pin.

During startup the LM3150 controller will operate in diode emulation mode, where the low-side gate LG will turn off and remain off when the inductor current falls to zero. Diode emulation mode will allow start-up into a pre-biased output voltage. When soft-start is greater than 0.7 V, the LM3150 controller will remain in continuous conduction mode. During diode emulation mode at current limit the low-gate will remain off when the inductor current is off.



**Figure 13. Inductor Current - Current Limit Operation**

The soft-start time should be greater than the input voltage rise time and also satisfy the following equality to maintain a smooth transition of the output voltage to the programmed regulation voltage during start-up.

$$t_{SS} \geq (V_{OUT} \times C_{OUT}) / (I_{OCL} - I_{OUT}) \quad (12)$$

### 8.3.7 Thermal Protection

The LM3150 controller should be operated such that the junction temperature does not exceed the maximum operating junction temperature. An internal thermal shutdown circuit, which activates at 165°C (typical), takes the controller to a low-power reset state by disabling the buck switch and the on-timer, and grounding the SS pin. This feature helps prevent catastrophic failures from accidental device overheating. When the junction temperature falls back below 150°C the SS pin is released and device operation resumes.

## 8.4 Device Functional Modes

The EN pin can be activated by either leaving the pin floating due to an internal pullup resistor to VIN or by applying a logic high signal to the EN pin of 1.26 V or greater. The LM3150 controller can be remotely shut down by taking the EN pin below 1.02 V. Low quiescent shutdown is achieved when VEN is less than 0.4 V. During low quiescent shutdown the internal bias circuitry is turned off.

The LM3150 controller has certain fault conditions that can trigger shutdown, such as short circuit, undervoltage lockout, or thermal shutdown. During shutdown, the soft-start capacitor is discharged. Once the fault condition is removed, the soft-start capacitor begins charging, allowing the part to start-up in a controlled fashion. In conditions where there may be an open drain connection to the EN pin, it may be necessary to add a 1-nF bypass capacitor to this pin. This will help decouple noise from the EN pin and prevent false disabling.

## 9 Application and Implementation

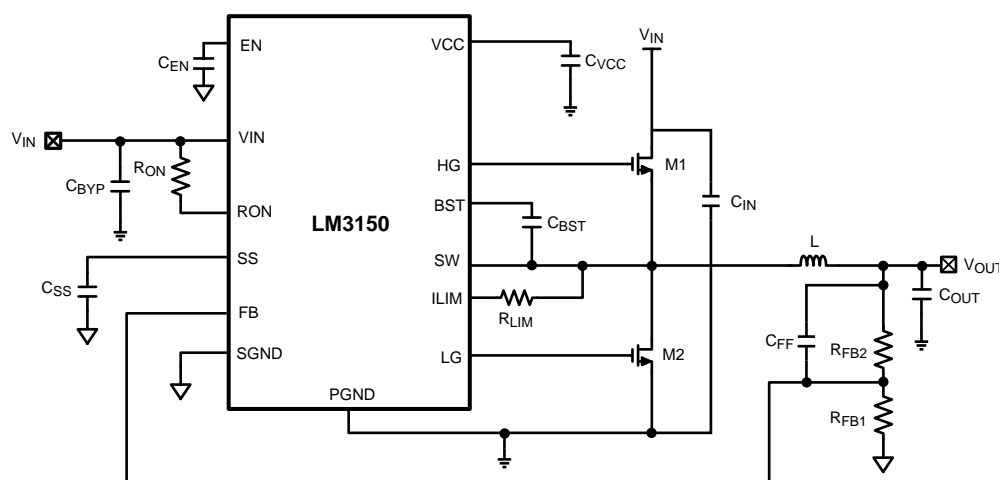
### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 9.1 Application Information

The LM3150 controller employs a COT architecture with ERM (emulated ripple mode) control. This allows for fast transient response, reduction in output voltage ripple, and low external component count. A typical application of this part is described in the following section.

### 9.2 Typical Application



**Figure 14. Design Example Schematic**

#### 9.2.1 Design Requirements

To properly size the components for the application, the designer needs the following parameters: Input voltage range, output voltage, output current range and required switching frequency. To summarize briefly, these four main parameters will affect the choices of component available to achieve a proper system behavior.

For the power supply, the input impedance of the supply rail should be low enough that the input current transient does not cause drop below the UVLO value. To maintain a relatively constant switching frequency as the input voltage varies, the LM3150 controller automatically adjusts the on-time inversely with the input voltage. The available frequency range for a given input voltage range, is determined by the duty-cycle,  $D = V_{OUT}/V_{IN}$ , and the minimum  $t_{ON}$  and  $t_{OFF}$  times. The feedback resistor values can be calculated based on the value of required output and feedback voltage. Regarding the output capacitor, its voltage rating must be greater than or equal to the output voltage. Similarly, the voltage rating for the input capacitor must be greater than the input voltage to be used in the application. Also, a feed-forward capacitor may be required for improved stability, based on the application.

The following sections describe in detail the design requirements for a typical LM3150 application.

## Typical Application (continued)

### 9.2.2 Detailed Design Procedure

To properly size the components for the application, the designer needs the following parameters: Input voltage range, output voltage, output current range and required switching frequency. These four main parameters will affect the choices of component available to achieve a proper system behavior.

**Table 1. Bill of Materials**

| DESIGNATOR                            | VALUE           | PARAMETERS                                     | MANUFACTURER        | PART NUMBER        |
|---------------------------------------|-----------------|--|---------------------|--------------------|
| C <sub>BST</sub>                      | 0.47 $\mu$ F    | Ceramic, X7R, 16 V, 10%                        | TDK                 | C2012X7R1C474K     |
| C <sub>BYP</sub>                      | 0.1 $\mu$ F     | Ceramic, X7R, 50 V, 10%                        | TDK                 | C2012X7R1H104K     |
| C <sub>EN</sub>                       | 1000 pF         | Ceramic, X7R, 50 V, 10%                        | TDK                 | C1608X7R1H102K     |
| C <sub>FF</sub>                       | 270 pF          | Ceramic, C0G, 50 V, 5%                         | Vishay-Bccomponents | VJ0805A271JXACW1BC |
| C <sub>IN1</sub> , C <sub>IN2</sub>   | 10 $\mu$ F      | Ceramic, X5R, 35 V, 20%                        | Taiyo Yuden         | GMK325BJ106KN-T    |
| C <sub>OUT1</sub> , C <sub>OUT2</sub> | 150 $\mu$ F     | Polymer Aluminum, 6.3 V, 20%                   | Panasonic           | EEF-UE0J151R       |
| C <sub>SS</sub>                       | 0.068 $\mu$ F   | Ceramic, 0805, 25 V, 10%                       | Vishay              | VJ0805Y683KXXA     |
| C <sub>VCC</sub>                      | 4.7 $\mu$ F     | Ceramic, X7R, 16 V, 10%                        | Murata              | GRM21BR71C475KA73L |
| L1                                    | 1.65 $\mu$ H    | Shielded Drum Core, 2.53 m $\Omega$            | Coilcraft           | HA3778–AL          |
| M1, M2                                | 30 V            | 8 nC, R <sub>DS(ON)</sub> @4.5 V=10 m $\Omega$ | Renesas             | RJK0305DPB         |
| R <sub>FB1</sub>                      | 4.99 k $\Omega$ | 1%, 0.125 W                                    | Vishay-Dale         | CRCW08054k99FKEA   |
| R <sub>FB2</sub>                      | 22.6 k $\Omega$ | 1%, 0.125 W                                    | Vishay-Dale         | CRCW080522k6FKEA   |
| R <sub>LIM</sub>                      | 1.91 k $\Omega$ | 1%, 0.125 W                                    | Vishay-Dale         | CRCW08051K91FKEA   |
| R <sub>ON</sub>                       | 56.2 k $\Omega$ | 1%, 0.125 W                                    | Vishay-Dale         | CRCW080556K2FKEA   |
| U1                                    | LM3150          |  | Texas Instruments   | LM3150             |

#### 1. Define Power Supply Operating Conditions

- V<sub>OUT</sub> = 3.3 V
- V<sub>IN-MIN</sub> = 6 V, V<sub>IN-TYP</sub> = 12 V, V<sub>IN-MAX</sub> = 24 V
- Typical Load Current = 12 A, Max Load Current = 15 A
- Soft-Start time t<sub>SS</sub> = 5 ms

#### 2. Set Output Voltage with Feedback Resistors

$$R_{FB2} = R_{FB1} \left( \frac{V_{OUT}}{V_{FB}} - 1 \right) \quad (13)$$

$$R_{FB2} = 4.99 \text{ k}\Omega \left( \frac{3.3\text{V}}{0.6\text{V}} - 1 \right) \quad (14)$$

$$R_{FB2} = 22.455 \text{ k}\Omega \quad (15)$$

R<sub>FB2</sub> = 22.6 k $\Omega$ , nearest 1% standard value.

#### 3. Determine R<sub>ON</sub> and f<sub>s</sub>

$$D_{min} = V_{OUT}/V_{IN-MAX} \quad (16)$$

$$D_{min} = 3.3\text{V}/24\text{V} = 0.137 \quad (17)$$

$$D_{max} = 3.3\text{V} / 6\text{V} = 0.55 \quad (18)$$

$$f_{smax} = 0.137 / 200 \text{ ns} = 687 \text{ kHz} \quad (19)$$

$$D_{max} = V_{OUT}/V_{IN-MIN} \quad (20)$$

$$t_{OFF} = (1-0.55)/687 \text{ kHz} = 654 \text{ ns} \quad (21)$$

t<sub>OFF</sub> should meet the following criteria:

$$t_{OFF} > t_{OFF-MIN} + 200 \text{ ns} \quad (22)$$

$$t_{OFF} > 725 \text{ ns} \quad (23)$$

At the maximum switching frequency of 687 kHz, which is limited by the minimum on-time, the off-time of 654 ns is less than 725 ns. Therefore the switching frequency should be reduced and meet the following criteria:

$$f_s < (1 - D)/725 \text{ ns} \quad (24)$$

$$f_s < (1 - 0.55)/725 \text{ ns} = 620 \text{ kHz} \quad (25)$$

A switching frequency is arbitrarily chosen at 500 kHz which should allow for reasonable size components and satisfies the requirements above.

$$f_s = 500 \text{ kHz}$$

Using  $f_s = 500 \text{ kHz}$   $R_{ON}$  can be calculated as follows:

$$R_{ON} = [(V_{OUT} \times V_{IN}) - V_{OUT}] / (V_{IN} \times K \times f_s) + R_{OND} \quad (26)$$

$$R_{OND} = - [(V_{IN} - 1) \times (V_{IN} \times 16.5 + 100)] - 1000 \quad (27)$$

$$R_{OND} = - [(12 - 1) \times (12 \times 16.5 + 100)] - 1000 \quad (28)$$

$$R_{OND} = -4.3 \text{ k}\Omega \quad (29)$$

$$R_{ON} = [(3.3 \times 12) - 3.3] / (12 \times 100 \text{ pC} \times 500 \text{ kHz}) - 4.3 \text{ k}\Omega \quad (30)$$

$$R_{ON} = 56.2 \text{ k}\Omega \quad (31)$$

Next, check the desired minimum input voltage for  $R_{ON}$  using . This design will meet the desired minimum input voltage of 6 V.

#### 4. Determine Inductor Required

$$(a) \text{ ET} = (24 - 3.3) \times (3.3 / 24) \times (1000 / 500) = 5.7 \text{ V } \mu\text{s}$$

(b) From the inductor nomograph a 12-A load and 5.7 V  $\mu\text{s}$  calculation corresponds to a L44 type of inductor.

(c) Using the inductor designator L44 in [Table 2](#) the Coilcraft HA3778–AL 1.65- $\mu\text{H}$  inductor is chosen.

#### 5. Determine Output Capacitance

The voltage rating on the output capacitor should be greater than or equal to the output voltage. As a rule of thumb most capacitor manufacturers suggests not to exceed 90% of the capacitor rated voltage. In the case of multilayer ceramics the capacitance will tend to decrease dramatically as the applied voltage is increased towards the capacitor rated voltage. The capacitance can decrease by as much as 50% when the applied voltage is only 30% of the rated voltage. The chosen capacitor should also be able to handle the rms current which is equal to:

$$I_{rmsco} = I_{OUT} \times \frac{r}{\sqrt{12}} \quad (32)$$

For this design the chosen ripple current ratio,  $r = 0.3$ , represents the ratio of inductor peak-to-peak current to load current  $I_{OUT}$ . A good starting point for ripple ratio is 0.3 but it is acceptable to choose  $r$  between 0.25 to 0.5. The nomographs in this datasheet all use 0.3 as the ripple current ratio.

$$I_{rmsco} = 12 \times \frac{0.3}{\sqrt{12}} \quad (33)$$

$$I_{rmsco} = 1 \text{ A} \quad (34)$$

$$t_{ON} = (3.3\text{V}/12\text{V})/500 \text{ kHz} = 550 \text{ ns} \quad (35)$$

Minimum output capacitance is:

$$C_{Omin} = 70 / (f_s^2 \times L) \quad (36)$$

$$C_{Omin} = 70 / (500 \text{ kHz}^2 \times 1.65 \mu\text{H}) = 169 \mu\text{F} \quad (37)$$

The maximum ESR allowed to prevent overvoltage protection during normal operation is:

$$ESR_{max} = (80 \text{ mV} \times L \times A_f) / \text{ET} \quad (38)$$

$$A_f = V_{OUT} / 0.6 \text{ without a feed-forward capacitor} \quad (39)$$

$$A_f = 1 \text{ with a feed-forward capacitor} \quad (40)$$

For this design a feed-forward capacitor will be used to help minimize output ripple.

$$ESR_{max} = (80 \text{ mV} \times 1.65 \mu\text{H} \times 1) / 5.7 \text{ V } \mu\text{s} \quad (41)$$

$$ESR_{max} = 23 \text{ m}\Omega \quad (42)$$

The minimum ESR must meet both of the following criteria:

$$ESR_{min} \geq (15 \text{ mV} \times L \times A_f) / \text{ET} \quad (43)$$

$$ESR_{min} \geq [ \text{ET} / (V_{IN} - V_{OUT}) ] \times (A_f / C_O) \quad (44)$$

$$ESR_{min} \geq (15 \text{ mV} \times 1.65 \mu\text{H} \times 1) / 5.7 \text{ V } \mu\text{s} = 4.3 \text{ m}\Omega \quad (45)$$

$$ESR_{min} \geq [5.7 \text{ V } \mu\text{s} / (12 - 3.3) ] \times (1 / 169 \mu\text{F}) = 3.9 \text{ m}\Omega \quad (46)$$



Based on the above criteria two 150-μF polymer aluminum capacitors with a ESR = 12 mΩ each for a effective ESR in parallel of 6 mΩ was chosen from Panasonic. The part number is EEF-UE0J101P.

## 6. Determine Use of Feed-Forward Capacitor

From Step 5 the capacitor chosen in ESR is small enough that we should use a feed-forward capacitor. This is calculated from:

$$C_{ff} = \frac{V_{OUT}}{V_{IN-MIN} \times f_s} \times \frac{R_{FB1} + R_{FB2}}{R_{FB1} \times R_{FB2}}$$

$$C_{ff} = \frac{3.3V}{6V \times 500 \text{ kHz}} \times \frac{4.99 \text{ k}\Omega + 22.6 \text{ k}\Omega}{4.99 \text{ k}\Omega \times 22.6 \text{ k}\Omega} = 269 \text{ pF} \quad (47)$$

Let  $C_{ff} = 270 \text{ pF}$ , which is the closest next standard value.

## 7. MOSFET and $R_{LIM}$ Selection

The LM3150 controller is designed to drive N-channel MOSFETs. For a maximum input voltage of 24 V we should choose N-channel MOSFETs with a maximum drain-source voltage,  $V_{DS}$ , greater than  $1.2 \times 24 \text{ V} = 28.8 \text{ V}$ . FETs with maximum  $V_{DS}$  of 30 V will be the first option. The combined total gate charge  $Q_{gtotal}$  of the high-side and low-side FET should satisfy the following:

$$Q_{gtotal} \leq I_{VCC} / f_s \quad (48)$$

$$Q_{gtotal} \leq 65 \text{ mA} / 500 \text{ kHz} \quad (49)$$

$$Q_{gtotal} \leq 130 \text{ nC} \quad (50)$$

Where  $I_{VCC}$  is the minimum current limit of VCC, over the temperature range, specified in the [Electrical Characteristics](#) table. The MOSFET gate charge  $Q_g$  is gathered from reading the  $V_{GS}$  vs  $Q_g$  curve of the MOSFET datasheet at the  $V_{GS} = 5 \text{ V}$  for the high-side, M1, MOSFET and  $V_{GS} = 6 \text{ V}$  for the low-side, M2, MOSFET.

The Renesas MOSFET RJK0305DPB has a gate charge of 10 nC at  $V_{GS} = 5 \text{ V}$ , and 12 nC at  $V_{GS} = 6 \text{ V}$ . This combined gate charge for a high-side, M1, and low-side, M2, MOSFET  $12 \text{ nC} + 10 \text{ nC} = 22 \text{ nC}$  is less than 130 nC calculated  $Q_{gtotal}$ .

The calculated MOSFET power dissipation must be less than the max allowed power dissipation,  $P_{dmax}$ , as specified in the MOSFET data sheet. An approximate calculation of the FET power dissipated  $P_d$ , of the high-side and low-side FET is given by:

### High-Side MOSFET

$$P_{cond} = I_{out}^2 \times R_{DS(ON)} \times D$$

$$P_{sw} = \frac{1}{2} \times V_{in} \times I_{out} \times Q_{gd} \times f_s \times \left( \frac{8.5}{V_{CC} - V_{th}} + \frac{6.8}{V_{th}} \right)$$

$$P_{dh} = P_{cond} + P_{sw}$$

$$P_{cond} = 12^2 \times 0.01 \times 0.275 = 0.396 \text{ W}$$

$$P_{sw} = \frac{1}{2} \times 12 \times 12 \times 1.5 \text{ nC} \times 500 \text{ kHz} \times \left( \frac{8.5}{6 - 2.5} + \frac{6.8}{2.5} \right) = 0.278 \text{ W}$$

$$P_{dh} = 0.396 + 0.278 = 0.674 \text{ W} \quad (51)$$

The max power dissipation of the RJK0305DPB is rated as 45 W for a junction temperature that is 125°C higher than the case temperature and a thermal resistance from the FET junction to case,  $\theta_{JC}$ , of 2.78°C/W. When the FET is mounted onto the PCB, the PCB will have some additional thermal resistance such that the total system thermal resistance of the FET package and the PCB,  $\theta_{JA}$ , is typically in the range of 30°C/W for this type of FET package. The max power dissipation,  $P_{dmax}$ , with the FET mounted onto a PCB with a 125°C junction temperature rise above ambient temperature and  $\theta_{JA} = 30^\circ\text{C/W}$ , can be estimated by:

$$P_{dmax} = 125^\circ\text{C} / 30^\circ\text{C/W} = 4.1 \text{ W} \quad (52)$$

The system calculated  $P_{dh}$  of 0.674 W is much less than the FET  $P_{dmax}$  of 4.1 W and therefore the RJK0305DPB max allowable power dissipation criteria is met.

### Low-Side MOSFET

Primary loss is conduction loss given by:

$$P_{dl} = I_{out}^2 \times R_{DS(ON)} \times (1-D) = 12^2 \times 0.01 \times (1-0.275) = 1 \text{ W} \quad (53)$$

$P_{dl}$  is also less than the  $P_{dmax}$  specified on the RJK0305DPB MOSFET data sheet.

However, it is not always necessary to use the same MOSFET for both the high-side and low-side. For most applications it is necessary to choose the high-side MOSFET with the lowest gate charge and the low-side MOSFET is chosen for the lowest allowed  $R_{DS(ON)}$ . The plateau voltage of the FET  $V_{GS}$  vs  $Q_g$  curve must be less than  $V_{CC} - 750 \text{ mV}$ .

The current limit resistor,  $R_{LIM}$ , is calculated by estimating the  $R_{DS(ON)}$  of the low-side FET at the maximum junction temperature of  $100^\circ\text{C}$ . By choosing to go into current limit when the average output load current is 20% higher than the output load current of 12A while the inductor ripple current ratio is 1/3 of the load current will make  $I_{CL} = 10.4 \text{ A}$ . Then the following calculation of  $R_{LIM}$  is:

$$R_{LIM} = (10.4 \times 0.014) / (75 \times 10^{-6}) = 1.9 \text{ k}\Omega \quad (54)$$

Let  $R_{LIM} = 1.91 \text{ k}\Omega$  which is the next standard value.

## 8. Calculate Input Capacitance

The input capacitor should be chosen so that the voltage rating is greater than the maximum input voltage which for this example is 24 V. Similar to the output capacitor, the voltage rating needed will depend on the type of capacitor chosen. The input capacitor should also be able to handle the input rms current, which is a maximum of approximately  $0.5 \times I_{OUT}$ . For this example the rms input current is approximately  $0.5 \times 12 \text{ A} = 6 \text{ A}$ .

The minimum capacitance with a maximum 5% input ripple  $\Delta V_{IN-MAX} = (0.05 \times 12) = 0.6 \text{ V}$ :

$$C_{IN} = [12 \times 0.275 \times (1-0.275)] / [500 \text{ kHz} \times 0.6] = 8 \text{ }\mu\text{F} \quad (55)$$

To handle the large input rms current 2 ceramic capacitors are chosen at  $10 \text{ }\mu\text{F}$  each with a voltage rating of 50 V and case size of 1210. Each ceramic capacitor is capable of handling 3 A of rms current. A aluminum electrolytic of 5 times the combined input capacitance,  $5 \times 20 \text{ }\mu\text{F} = 100 \text{ }\mu\text{F}$ , is chosen to provide input voltage filter damping because of the low ESR ceramic input capacitors.

$C_{BYP} = 0.1 \text{ }\mu\text{F}$  ceramic with a voltage rating greater than maximum  $V_{IN}$

## 9. Calculate Soft-Start Capacitor

The soft start-time should be greater than the input voltage rise time and also satisfy the following equality to maintain a smooth transition of the output voltage to the programmed regulation voltage during startup. The desired soft-start time,  $t_{ss}$ , of 5 ms also must satisfy the equality in [Equation 12](#), by using the chosen component values through the previous steps as shown below:

$$5 \text{ ms} > (3.3\text{V} \times 300 \text{ }\mu\text{F}) / (1.2 \times 12\text{A} - 12\text{A}) \quad (56)$$

$$5 \text{ ms} > 0.412 \text{ ms} \quad (57)$$

Because the desired soft-start time satisfies the equality in [Equation 12](#), the soft start capacitor is calculated as:

$$C_{SS} = (7.7 \text{ }\mu\text{A} \times 5 \text{ ms}) / 0.6\text{V} = 0.064 \text{ }\mu\text{F} \quad (58)$$

Let  $C_{SS} = 0.068 \text{ }\mu\text{F}$ , which is the next closest standard value. This should be a ceramic cap with a voltage rating greater than 10 V.

## 10. $C_{VCC}$ , $C_{EN}$ , and $C_{BST}$

$C_{VCC} = 4.7\text{-}\mu\text{F}$  ceramic with a voltage rating greater than 10 V

$C_{EN} = 1000\text{-pF}$  ceramic with a voltage rating greater than 10 V

$C_{BST} = 0.47\text{-}\mu\text{F}$  ceramic with a voltage rating greater than 10 V

### 9.2.2.1 Design Guide

The design guide provides the equations required to design with the LM3150 controller. WEBENCH design tool can be used with or in place of this section for a more complete and simplified design process.

#### 1. Define Power Supply Operating Conditions

- Required Output Voltage
- Maximum and Minimum DC Input Voltage
- Maximum Expected Load Current during Normal Operation
- Soft-Start Time

#### 2. Set Output Voltage With Feedback Resistors

$$V_{OUT} = V_{FB} \times \frac{(R_{FB1} + R_{FB2})}{R_{FB1}}$$

where

- $R_{FB1}$  is the bottom resistor
- $R_{FB2}$  is the top resistor

(59)

#### 3. Determine $R_{ON}$ and $f_s$

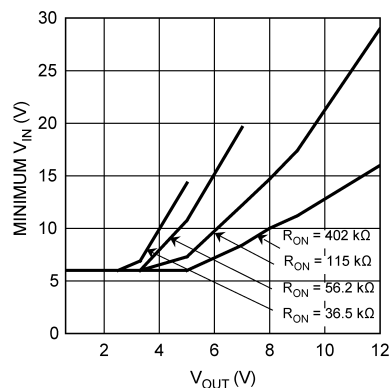
The available frequency range for a given input voltage range, is determined by the duty-cycle,  $D = V_{OUT}/V_{IN}$ , and the minimum  $t_{ON}$  and  $t_{OFF}$  times as specified in the [Electrical Characteristics](#) table. The maximum frequency is thus,  $f_{smax} = D_{min}/t_{ON-MIN}$ . Where  $D_{min} = V_{OUT}/V_{IN-MAX}$ , is the minimum duty-cycle. The off-time will need to be less than the minimum off-time  $t_{OFF}$  as specified in the [Electrical Characteristics](#) table plus any turnoff and turnon delays of the MOSFETs which can easily add another 200 ns. The minimum off-time will occur at maximum duty cycle  $D_{max}$  and will determine if the frequency chosen will allow for the minimum desired input voltage. The requirement for minimum off-time is  $t_{OFF} = (1 - D_{max})/f_s \geq (t_{OFF-MIN} + 200 \text{ ns})$ . If  $t_{OFF}$  does not meet this requirement it will be necessary to choose a smaller switching frequency  $f_s$ .

Choose  $R_{ON}$  so that the switching frequency at your typical input voltage matches your  $f_s$  chosen above using the following formula:

$$R_{ON} = [(V_{OUT} \times V_{IN}) - V_{OUT}] / (V_{IN} \times K \times f_s) + R_{OND} \quad (60)$$

$$R_{OND} = -[(V_{IN} - 1) \times (V_{IN} \times 16.5 + 100)] - 1000 \quad (61)$$

Use to determine if the calculated  $R_{ON}$  will allow for the minimum desired input voltage. If the minimum desired input voltage is not met, recalculate  $R_{ON}$  for a lower switching frequency.



**Minimum  $V_{IN}$  vs.  $V_{OUT}$   
 $I_{OUT} = 10 \text{ A}$**

#### 4. Determine Inductor Required Using [Figure 15](#)

To use the nomograph in [Figure 15](#), calculate the inductor volt-microsecond constant ET from the following formula:

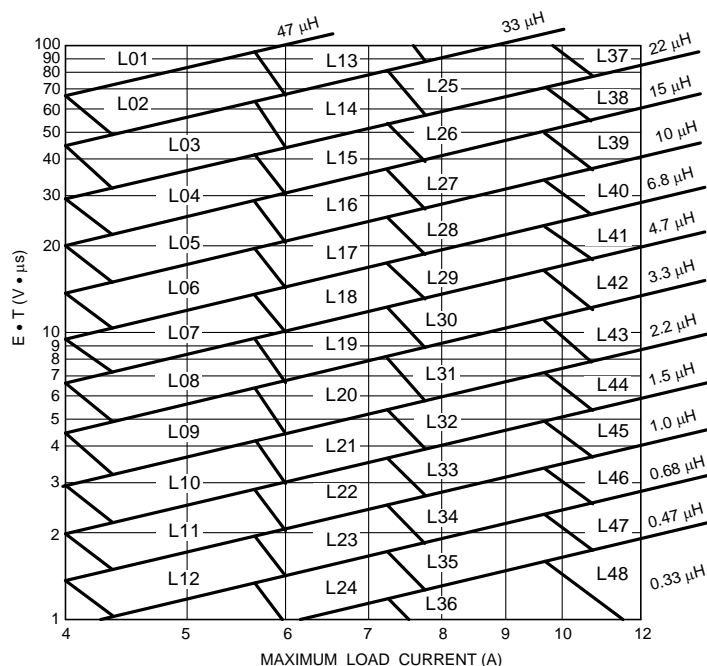
$$ET = (V_{inmax} - V_{OUT}) \times \frac{V_{OUT}}{V_{inmax}} \times \frac{1000}{f_s} \quad (\text{V} \times \mu\text{s})$$

where

- $f_s$  is in kHz units

(62)

The intersection of the Load Current and the Volt-microseconds lines on the chart below will determine which inductors are capable for use in the design. [Figure 15](#) shows a sample of parts that can be used. The offline calculator tools and WEBENCH will fully calculate the requirements for the components needed for the design.


**Figure 15. Inductor Nomograph**
**Table 2. Inductor Selection Table**

| INDUCTOR DESIGNATOR | INDUCTANCE (μH) | CURRENT (A) | PART NAME         | VENDOR    |
|---------------------|-----------------|-------------|-------------------|-----------|
| L01                 | 47              | 7-9         |                   |           |
| L02                 | 33              | 7-9         | SER2817H-333KL    | COILCRAFT |
| L03                 | 22              | 7-9         | SER2814H-223KL    | COILCRAFT |
| L04                 | 15              | 7-9         | 7447709150        | WURTH     |
| L05                 | 10              | 7-9         | RLF12560T-100M7R5 | TDK       |
| L06                 | 6.8             | 7-9         | B82477-G4682-M    | EPCOS     |
| L07                 | 4.7             | 7-9         | B82477-G4472-M    | EPCOS     |
| L08                 | 3.3             | 7-9         | DR1050-3R3-R      | COOPER    |
| L09                 | 2.2             | 7-9         | MSS1048-222       | COILCRAFT |
| L10                 | 1.5             | 7-9         | SRU1048-1R5Y      | BOURNS    |
| L11                 | 1               | 7-9         | DO3316P-102       | COILCRAFT |
| L12                 | 0.68            | 7-9         | DO3316H-681       | COILCRAFT |
| L13                 | 33              | 9-12        |                   |           |
| L14                 | 22              | 9-12        | SER2918H-223      | COILCRAFT |
| L15                 | 15              | 9-12        | SER2814H-153KL    | COILCRAFT |
| L16                 | 10              | 9-12        | 7447709100        | WURTH     |
| L17                 | 6.8             | 9-12        | SPT50H-652        | COILCRAFT |
| L18                 | 4.7             | 9-12        | SER1360-472       | COILCRAFT |
| L19                 | 3.3             | 9-12        | MSS1260-332       | COILCRAFT |
| L20                 | 2.2             | 9-12        | DR1050-2R2-R      | COOPER    |

**Table 2. Inductor Selection Table (continued)**

| INDUCTOR DESIGNATOR | INDUCTANCE (μH) | CURRENT (A) | PART NAME      | VENDOR    |
|---------------------|-----------------|-------------|----------------|-----------|
| L21                 | 1.5             | 9-12        | DR1050-1R5-R   | COOPER    |
| L22                 | 1               | 9-12        | DO3316H-102    | COILCRAFT |
| L23                 | 0.68            | 9-12        |                |           |
| L24                 | 0.47            | 9-12        |                |           |
| L25                 | 22              | 12-15       | SER2817H-223KL | COILCRAFT |
| L26                 | 15              | 12-15       |                |           |
| L27                 | 10              | 12-15       | SER2814L-103KL | COILCRAFT |
| L28                 | 6.8             | 12-15       | 7447709006     | WURTH     |
| L29                 | 4.7             | 12-15       | 7447709004     | WURTH     |
| L30                 | 3.3             | 12-15       |                |           |
| L31                 | 2.2             | 12-15       |                |           |
| L32                 | 1.5             | 12-15       | MLC1245-152    | COILCRAFT |
| L33                 | 1               | 12-15       |                |           |
| L34                 | 0.68            | 12-15       | DO3316H-681    | COILCRAFT |
| L35                 | 0.47            | 12-15       |                |           |
| L36                 | 0.33            | 12-15       | DR73-R33-R     | COOPER    |
| L37                 | 22              | 15-         |                |           |
| L38                 | 15              | 15-         | SER2817H-153KL | COILCRAFT |
| L39                 | 10              | 15-         | SER2814H-103KL | COILCRAFT |
| L40                 | 6.8             | 15-         |                |           |
| L41                 | 4.7             | 15-         | SER2013-472ML  | COILCRAFT |
| L42                 | 3.3             | 15-         | SER2013-362L   | COILCRAFT |
| L43                 | 2.2             | 15-         |                |           |
| L44                 | 1.5             | 15-         | HA3778-AL      | COILCRAFT |
| L45                 | 1               | 15-         | B82477-G4102-M | EPCOS     |
| L46                 | 0.68            | 15-         |                |           |
| L47                 | 0.47            | 15-         |                |           |
| L48                 | 0.33            | 15-         |                |           |

## 5. Determine Output Capacitance

Typical hysteretic COT converters similar to the LM3150 controller require a certain amount of ripple that is generated across the ESR of the output capacitor and fed back to the error comparator. Emulated Ripple Mode control built into the LM3150 controller will recreate a similar ripple signal and thus the requirement for output capacitor ESR will decrease compared to a typical Hysteretic COT converter. The emulated ripple is generated by sensing the voltage signal across the low-side FET and is then compared to the FB voltage at the error comparator input to determine when to initiate the next on-time period.

$$C_{Omin} = 70 / (f_s^2 \times L) \quad (63)$$

The maximum ESR allowed to prevent overvoltage protection during normal operation is:

$$ESR_{max} = (80 \text{ mV} \times L \times A_f) / ET_{min} \quad (64)$$

$ET_{min}$  is calculated using  $V_{IN-MIN}$

$A_f = V_{OUT} / 0.6$  if there is no feed-forward capacitor used

$A_f = 1$  if there is a feed-forward capacitor used

The minimum ESR must meet both of the following criteria:

$$ESR_{min} \geq (15 \text{ mV} \times L \times A_f) / ET_{max} \quad (65)$$

$$ESR_{min} \geq [ET_{max} / (V_{IN} - V_{OUT})] \times (A_f / C_O) \quad (66)$$

$ET_{max}$  is calculated using  $V_{IN-MAX}$ .

Any additional parallel capacitors should be chosen so that their effective impedance will not negatively attenuate the output ripple voltage.

## 6. Determine The Use of Feed-Forward Capacitor

Certain applications may require a feed-forward capacitor for improved stability and easier selection of available output capacitance. Use the following equation to calculate the value of  $C_{ff}$ .

$$Z_{FB} = (R_{FB1} \times R_{FB2}) / (R_{FB1} + R_{FB2}) \quad (67)$$

$$C_{ff} = V_{OUT} / (V_{IN-MIN} \times f_s \times Z_{FB}) \quad (68)$$

## 7. MOSFET and $R_{LIM}$ Selection

The high-side and low-side FETs must have a drain to source ( $V_{DS}$ ) rating of at least  $1.2 \times V_{IN}$ .

Use the following equations to calculate the desired target value of the low-side FET  $R_{DS(ON)}$  for current limit.

$$R_{LIM}(T_j) = \frac{I_{CL} \times R_{DS(ON)max}}{I_{LIM-TH}(T_j)} \quad (69)$$

$$I_{LIM-TH}(T_j) = I_{LIM-TH} \times [1 + 3.3 \times 10^{-3} \times (T_j - 27)] \quad (70)$$

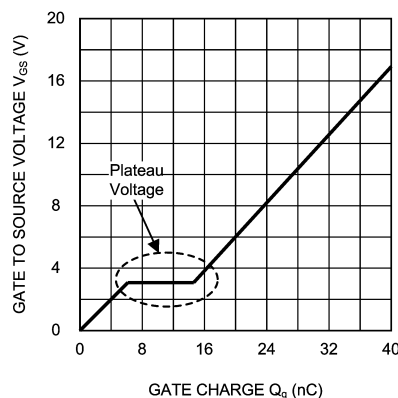
The gate drive current from VCC must not exceed the minimum current limit of VCC. The drive current from VCC can be calculated with:

$$I_{VCCdrive} = Q_{gtotal} \times f_s$$

where

- $Q_{gtotal}$  is the combined total gate charge of the high-side and low-side FETs (71)

The plateau voltage of the FET  $V_{GS}$  vs  $Q_g$  curve, as shown in [Figure 16](#), must be less than  $V_{CC} - 750 \text{ mV}$ .



**Figure 16. Typical MOSFET Gate Charge Curve**

See following design example for estimated power dissipation calculation.

## 8. Calculate Input Capacitance

The main parameters for the input capacitor are the voltage rating, which must be greater than or equal to the maximum DC input voltage of the power supply, and its rms current rating. The maximum rms current is approximately 50% of the maximum load current.

$$C_{IN} = \frac{I_{omax} \times D \times (1-D)}{f_s \times \Delta V_{IN-MAX}}$$

where

- $\Delta V_{IN-MAX}$  is the maximum allowable input ripple voltage. A good starting point for the input ripple voltage is 5% of  $V_{IN}$  (72)

When using low ESR ceramic capacitors on the input of the LM3150 controller, a resonant circuit can be formed with the impedance of the input power supply and parasitic impedance of long leads/PCB traces to the LM3150 input capacitors. TI recommends using a damping capacitor under these circumstances, such as aluminum electrolytic that will prevent ringing on the input. The damping capacitor should be chosen to be approximately five times greater than the parallel ceramic capacitors combination. The total input capacitance should be greater than 10 times the input inductance of the power supply leads/PCB trace. The damping capacitor should also be chosen to handle its share of the rms input current which is shared proportionately with the parallel impedance of the ceramic capacitors and aluminum electrolytic at the LM3150 switching frequency.

The  $C_{BYP}$  capacitor should be placed directly at the VIN pin. The recommended value is 0.1  $\mu\text{F}$ .

#### 9. Calculate Soft-Start Capacitor

$$C_{SS} = \frac{I_{SS} \times t_{SS}}{V_{ref}}$$

where

- $t_{SS}$  is the soft-start time in seconds
- $V_{ref} = 0.6\text{V}$

(73)

#### 10. $C_{VCC}$ , $C_{BST}$ , and $C_{EN}$

$C_{VCC}$  should be placed directly at the VCC pin with a recommended value of 1  $\mu\text{F}$  to 4.7  $\mu\text{F}$ .  $C_{BST}$  creates a voltage used to drive the gate of the high-side FET. It is charged during the SW off-time. The recommended value for  $C_{BST}$  is 0.47  $\mu\text{F}$ . The EN bypass capacitor,  $C_{EN}$ , recommended value is 1000 pF when driving the EN pin from open-drain type of signal.

### 9.2.3 Application Curves

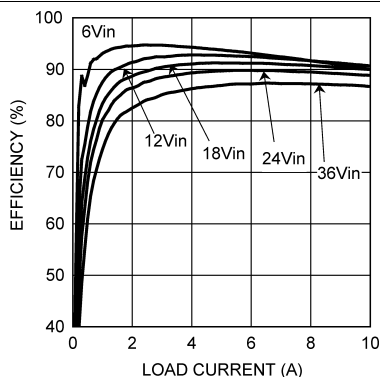


Figure 17. 250-kHz Efficiency vs Load

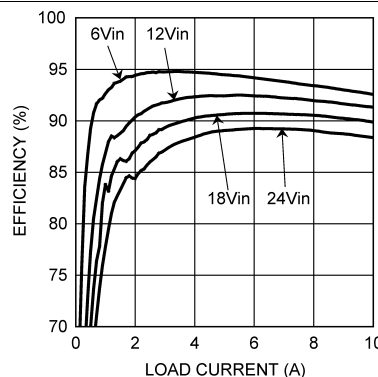


Figure 18. 500-kHz Efficiency vs Load

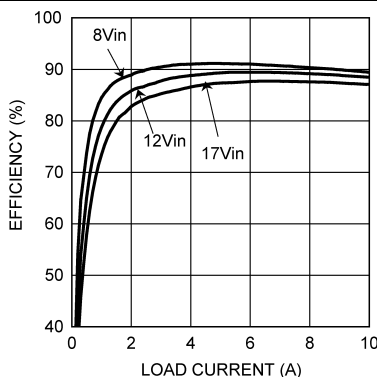


Figure 19. 750-kHz Efficiency vs Load

## 10 Power Supply Recommendations

The LM3150 controller is designed to operate from various DC power supplies. VIN input should be protected from reversal voltage and voltage dump over 42 volts. The impedance of the input supply rail should be low enough that the input current transient does not cause drop below VIN UVLO level. If the input supply is connected by using long wires, additional bulk capacitance may be required in addition to normal input capacitor.

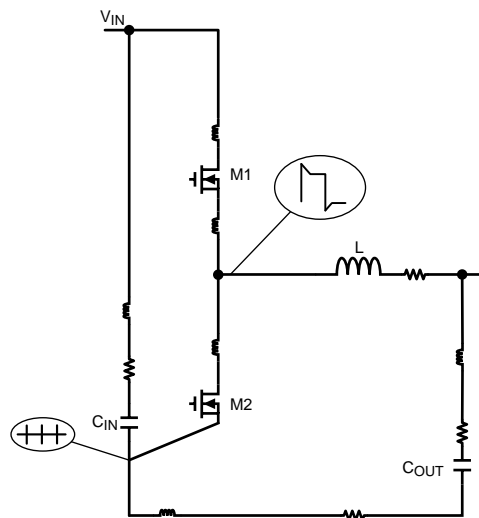
## 11 Layout

### 11.1 Layout Guidelines

It is good practice to layout the power components first, such as the input and output capacitors, FETs, and inductor. The first priority is to make the loop between the input capacitors and the source of the low-side FET to be very small and tie the grounds of the low-side FET and input capacitor directly to each other and then to the ground plane through vias. As shown in Figure 20 when the input capacitor ground is tied directly to the source of the low-side FET, parasitic inductance in the power path, along with noise coupled into the ground plane, are reduced.

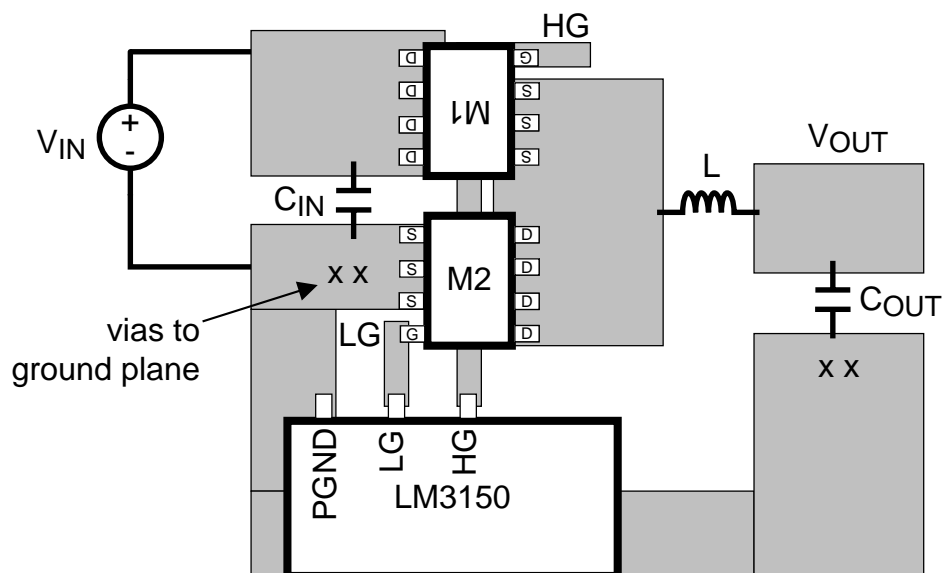
The switch node is the next item of importance. The switch node should be made only as large as required to handle the load current. There are fast voltage transitions occurring in the switch node at a high frequency, and if the switch node is made too large it may act as an antennae and couple switching noise into other parts of the circuit. For high power designs, it is recommended to use a multilayer board. The FETs are going to be the largest heat generating devices in the design, and as such, care should be taken to remove the heat. On multilayer boards using exposed-pad packages for the FETs such as the power-pak SO-8, vias should be used under the FETs to the same plane on the interior layers to help dissipate the heat and cool the FETs. For the typical single FET Power-Pak type FETs, the high-side FET DAP is VIN. The VIN plane should be copied to the other interior layers to the bottom layer for maximum heat dissipation. Likewise, the DAP of the low-side FET is connected to the SW node and the SW node shape should be duplicated to the other PCB layers for maximum heat dissipation.

See the Evaluation Board application note AN-1900 (SNVA371) for an example of a typical multilayer board layout, and the Demonstration Board Reference Design Application Note for a typical 2-layer board layout. Each design allows for single-sided component mounting.



**Figure 20. Schematic of Parasitics**





### Figure 21. PCB Placement of Power Stage

## 12 Device and Documentation Support

### 12.1 Documentation Support

#### 12.1.1 Third-Party Products Disclaimer

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#### 12.1.2 Related Documentation

For related documentation see the following:

- *AN-1900 LM3150 Evaluation Boards* [SNVA371](#)

### 12.2 Trademarks

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### 12.3 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### 12.4 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

## PACKAGING INFORMATION

| Orderable Device | Status<br>(1) | Package Type | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| LM3150MH/NOPB    | ACTIVE        | HTSSOP       | PWP                | 14   | 94             | Green (RoHS<br>& no Sb/Br) | CU SN                   | Level-1-260C-UNLIM   | -40 to 125   | LM3150<br>MH            | <a href="#">Samples</a> |
| LM3150MHE/NOPB   | ACTIVE        | HTSSOP       | PWP                | 14   | 250            | Green (RoHS<br>& no Sb/Br) | CU SN                   | Level-1-260C-UNLIM   | -40 to 125   | LM3150<br>MH            | <a href="#">Samples</a> |
| LM3150MHX/NOPB   | ACTIVE        | HTSSOP       | PWP                | 14   | 2500           | Green (RoHS<br>& no Sb/Br) | CU SN                   | Level-1-260C-UNLIM   | -40 to 125   | LM3150<br>MH            | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

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**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

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**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

| Device         | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| LM3150MHE/NOPB | HTSSOP       | PWP             | 14   | 250  | 178.0              | 12.4               | 6.95    | 5.6     | 1.6     | 8.0     | 12.0   | Q1            |
| LM3150MHX/NOPB | HTSSOP       | PWP             | 14   | 2500 | 330.0              | 12.4               | 6.95    | 5.6     | 1.6     | 8.0     | 12.0   | Q1            |

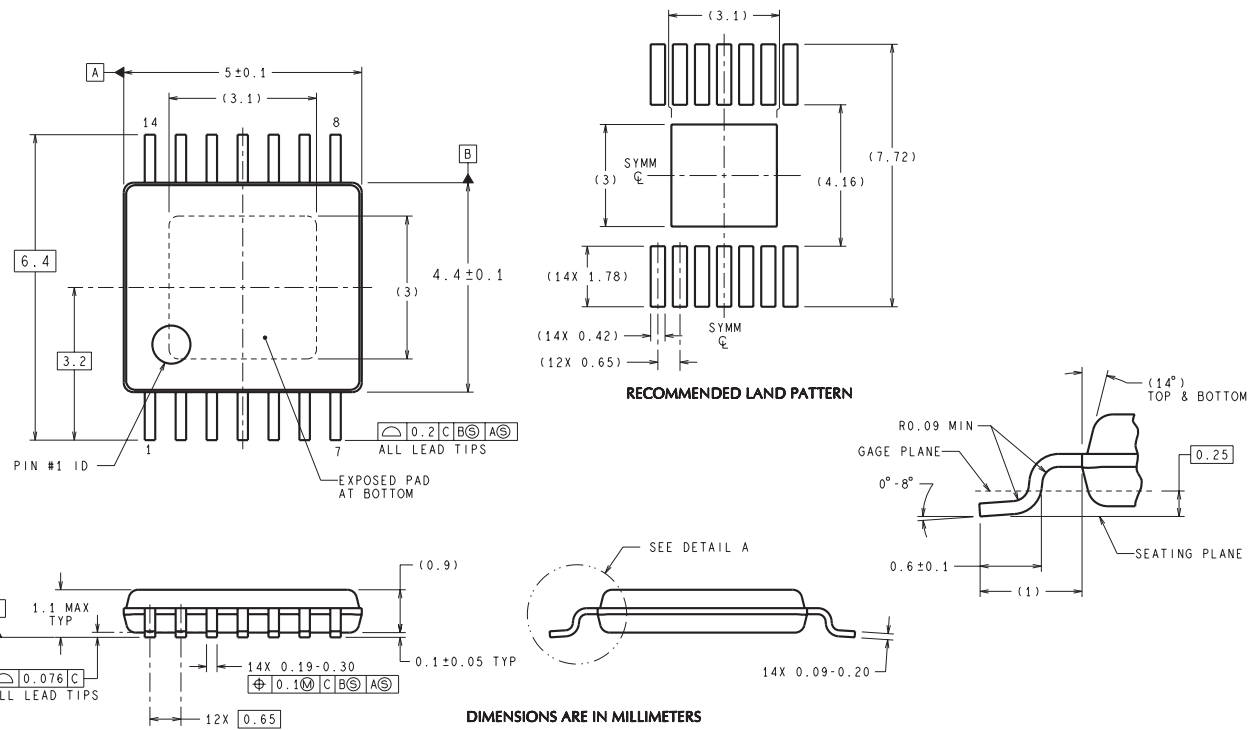
## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device         | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| LM3150MHE/NOPB | HTSSOP       | PWP             | 14   | 250  | 210.0       | 185.0      | 35.0        |
| LM3150MHX/NOPB | HTSSOP       | PWP             | 14   | 2500 | 367.0       | 367.0      | 35.0        |

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