

DC/DC Converter, Capacitor Charger Takes Inputs from 4.75V to 400V

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Introduction

High voltage power supplies and capacitor chargers are readily found in a number of applications, including professional photoflashes, security control systems, pulsed radar systems, satellite communication systems, and explosive detonators. The LT3751 makes it possible for a designer to meet the demanding requirements of these applications, including high reliability, relatively low cost, safe operation, minimal board space and high performance.

The LT3751 is a general purpose flyback controller that can be used as either a voltage regulator or as a capacitor charger. The LT3751 operates in boundary-mode, between continuous conduction mode and discontinuous conduction mode. Boundary-mode operation allows for a relatively small transformer and an overall reduced PCB footprint. Boundary-mode also reduces large signal stability issues that could arise from using voltage-mode or PWM techniques. Regulation is achieved with a new dual, overlapping modulation technique using both

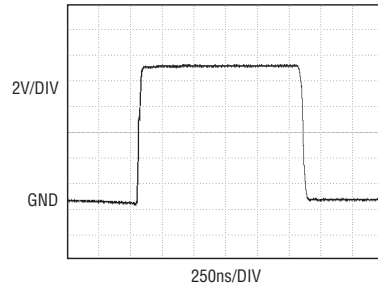


Figure 1. Gate driver waveform in a typical application

peak primary current modulation and duty-cycle modulation, drastically reducing audible transformer noise.

The LT3751 features many safety and reliability functions, including two sets of undervoltage lockouts (UVLO), two sets of overvoltage lockouts (OVLO), no-load operation, over-temperature lockout (OTLO), internal Zener clamps on all high voltage pins, and a selectable 5.6V or 10.5V internal gate driver voltage clamp (no external components needed). The LT3751 also adds a start-up/short-circuit protection circuit to protect against transformer or external FET

damage. When used as a regulator, the LT3751's feedback loop is internally compensated to ensure stability. The LT3751 is available in two packages, either a 20-pin exposed pad QFN or a 20-lead exposed pad TSSOP.

New Gate Driver with Internal Clamp Requires No External Components

There are four main concerns when using a gate driver: output current drive capability, peak output voltage, power consumption and propagation delay. The LT3751 is equipped with a 1.5A push-pull main driver, enough to drive +80nC gates. An auxiliary 0.5A PMOS pull-up only driver is also integrated into the LT3751 and is used in parallel with the main driver for V_{CC} voltages of 8V and below. This PMOS driver allows for rail-to-rail operation. Above 8V, the PMOS driver must be deactivated by tying its drain to V_{CC} .

Most discrete FETs have a V_{GS} limit of 20V. Driving the FET higher than 20V could cause a short in the internal gate oxide, causing permanent

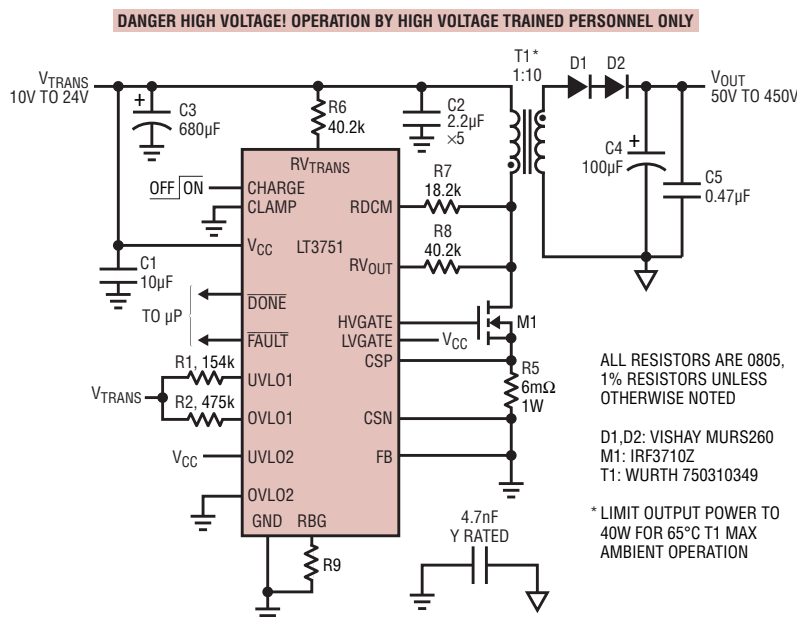


Figure 2. Isolated high voltage capacitor charger from 10V to 24V input

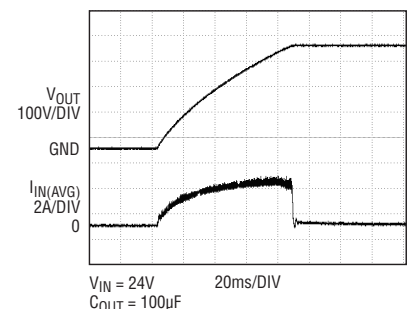


Figure 3. Isolated high voltage capacitor charger charging waveform

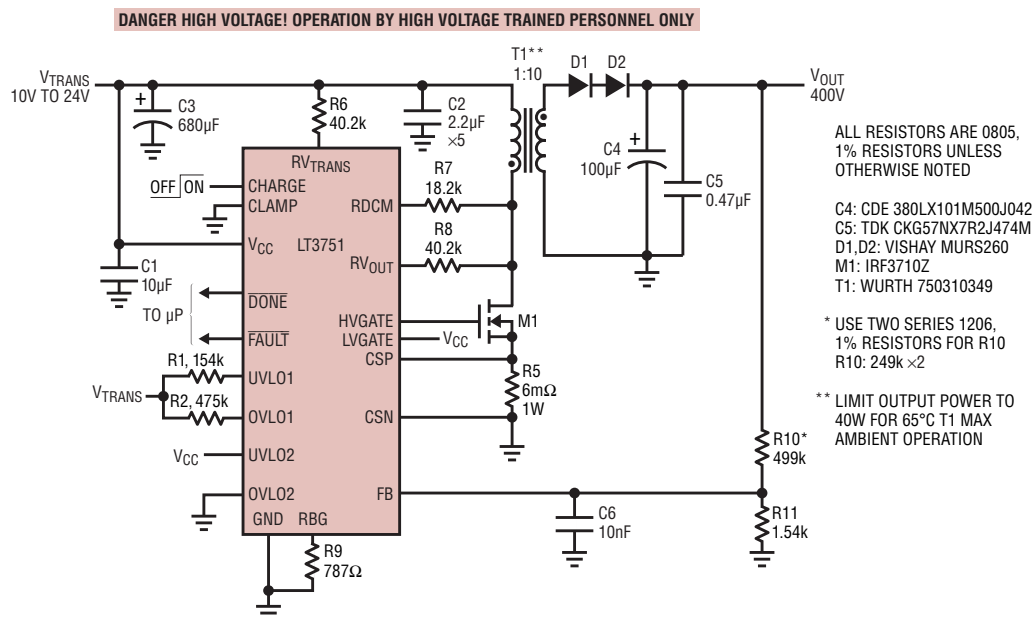


Figure 4. A 10V to 24V input, 400V regulated power supply

damage. To alleviate this issue, the LT3751 has an internal, selectable 5.6V or 10.5V gate driver clamp. No external components are needed, not even a capacitor. Simply tie the CLAMP pin to ground for 10.5V operation or tie to V_{CC} for 5.6V operation. Figure 1 shows the gate driver clamping at 10.5V with a V_{CC} voltage of 24V.

Not only does the internal clamp protect the FET from damage, it also reduces the amount of energy injected into the gate. This increases overall efficiency and reduces power consumption in the gate driver circuit. The gate driver overshoot is very minimal, as seen in Figure 1. Placing the external FET closer to the LT3751 HVGATE pin reduces overshoot.

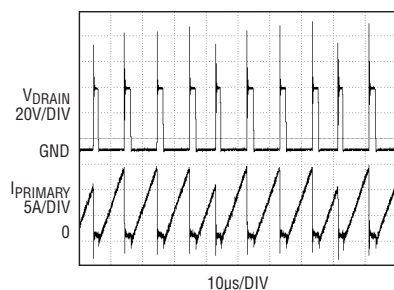
High Voltage, Isolated Capacitor Charger from 10V to 24V Input

The LT3751 can be configured as a fully isolated stand-alone capacitor charger using a new differential discontinuous-conduction-mode (DCM) comparator—used to sense the boundary-mode condition—and a new differential output voltage (V_{OUT}) comparator. The differential operation of the DCM comparator and V_{OUT} comparator allow the LT3751 to accurately operate from high voltage input supplies of greater than 400V. Likewise, the LT3751's DCM comparator and V_{OUT} comparator can work with input supplies down to 4.75V. This accommodates an unmatched range of power sources.

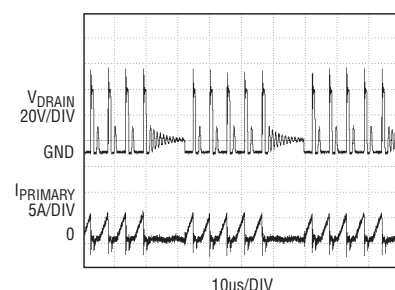
Figure 2 shows a high voltage capacitor charger driven from an input supply ranging from 10V to 24V. Only five resistors are needed to operate the LT3751 as a capacitor charger. The output voltage trip point can be continuously adjusted from 50V to 450V by adjusting R9 given by:

$$R_9 = \left(\frac{0.98 \cdot N}{V_{OUT(TRIP)} + V_{DIODE}} \right) \cdot R_8$$

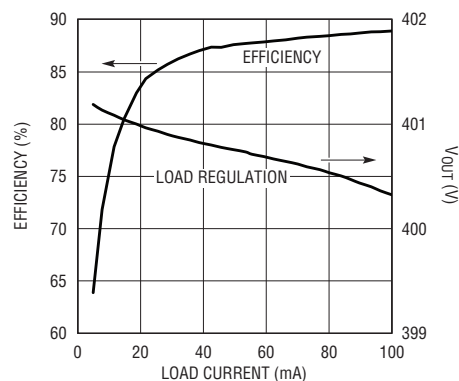
The LT3751 stops charging the output capacitor once the programmed output voltage trip point ($V_{OUT(TRIP)}$) is reached. The charge cycle is repeated by toggling the CHARGE pin. The maximum charge/discharge rate in



a. Switching waveform for $I_{OUT} = 100mA$



b. Switching waveform for $I_{OUT} = 10mA$



c. Efficiency and load regulation

Figure 5. High voltage regulator performance

the output capacitor is limited by the temperature rise in the transformer. Limiting the transformer surface temperature in Figure 2 to 65°C with no air flow requires the average output power to be ≤40W given by:

$$P_{AVG} = \frac{1}{2} C_{OUT} \bullet \text{FREQUENCY} \bullet (2V_{OUT(TRIP)} \bullet V_{RIPPLE} - V_{RIPPLE}^2) \leq 40W$$

where $V_{OUT(TRIP)}$ is the output trip voltage, V_{RIPPLE} is the ripple voltage on the output node, and frequency is the charge/discharge frequency. Two techniques are used to increase the available output power: increase the airflow across the transformer, or increase the size of the transformer itself. Figure 3 shows the charging waveform and average input current for a 100μF output capacitor charged to 400V in less than 100ms ($R_0 = 976\Omega$).

For output voltages higher than 450V, the transformer in Figure 2 must be replaced with one having higher primary inductance and a higher turns ratio. Consult the LT3751 data

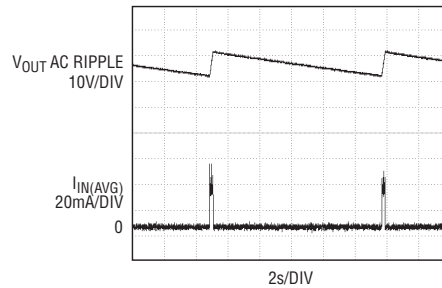


Figure 6. The LT3751 protecting the output during a no-load condition

sheet for proper transformer design procedures.

High Voltage Regulated Power Supply from 10V to 24V Input

The LT3751 can also be used to convert a low voltage supply to a much higher voltage. Placing a resistor divider from the output node to the FB pin and ground causes the LT3751 to operate as a voltage regulator. Figure 4 shows a 400V regulated power supply operating from an input supply range of 10V to 24V.

The LT3751 uses a regulation control scheme that drastically reduces audible noise in the transformer and the input and output ceramic bulk

capacitors. This is achieved by using an internal 26kHz clock to synchronize the primary winding switch cycles. Within the clock period, the LT3751 modulates both the peak primary current and the number of switching cycles. Figures 5a and 5b show heavy-load and light-load waveforms, respectively, while Figure 5c shows efficiency over most of the operating range for the application in Figure 4.

The clock forces at least one switch cycle every period which would over-charge the output capacitor during a no-load condition. The LT3751 handles no-load conditions and protects against over-charging the output node. Figure 6 shows the LT3751 protecting during a no-load condition.

Resistors can be added to RV_{OUT} and RBG to add a second layer of protection, or they can be omitted to reduce component count by tying RV_{OUT} and RBG to ground. The trip level for the V_{OUT} comparator is typically set 20% higher than the nominal regulation voltage. If the resistor divider were to fail, the V_{OUT} comparator would disable switching when the output climbed to 20% above nominal.

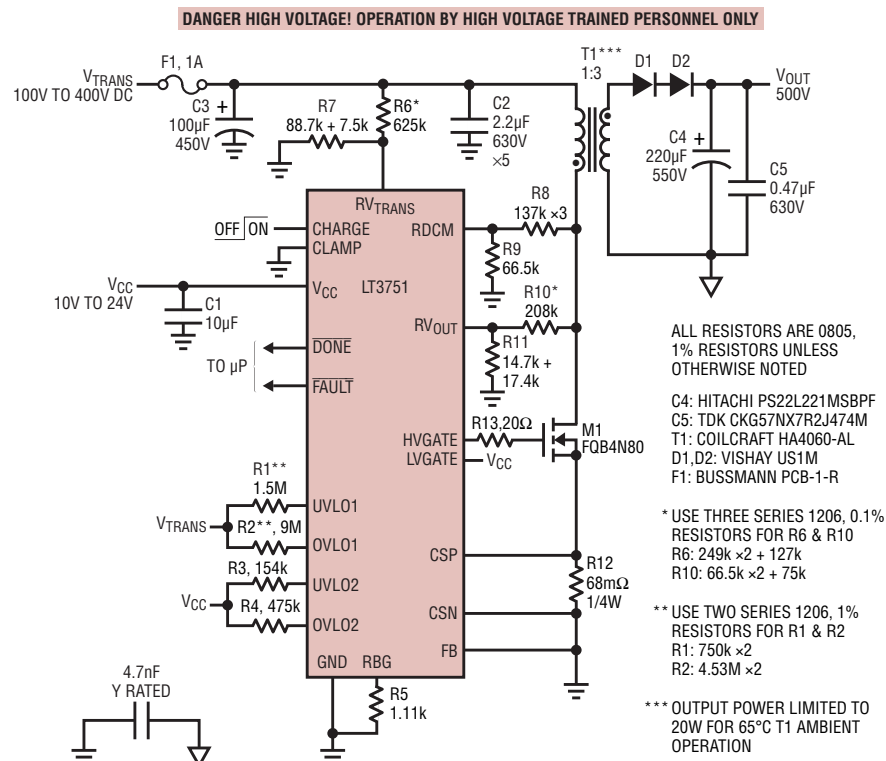


Figure 7. A 100V to 400V input, 500V output, isolated capacitor charger

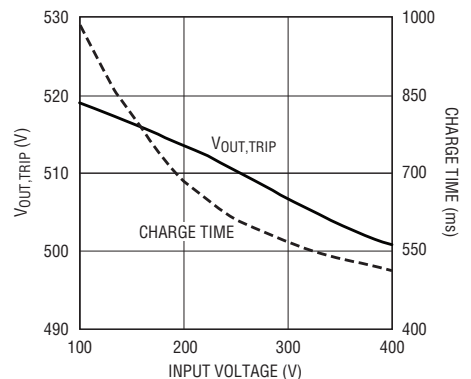


Figure 8. Isolated capacitor charger $V_{OUT(TRIP)}$ and charge time with respect to input voltage

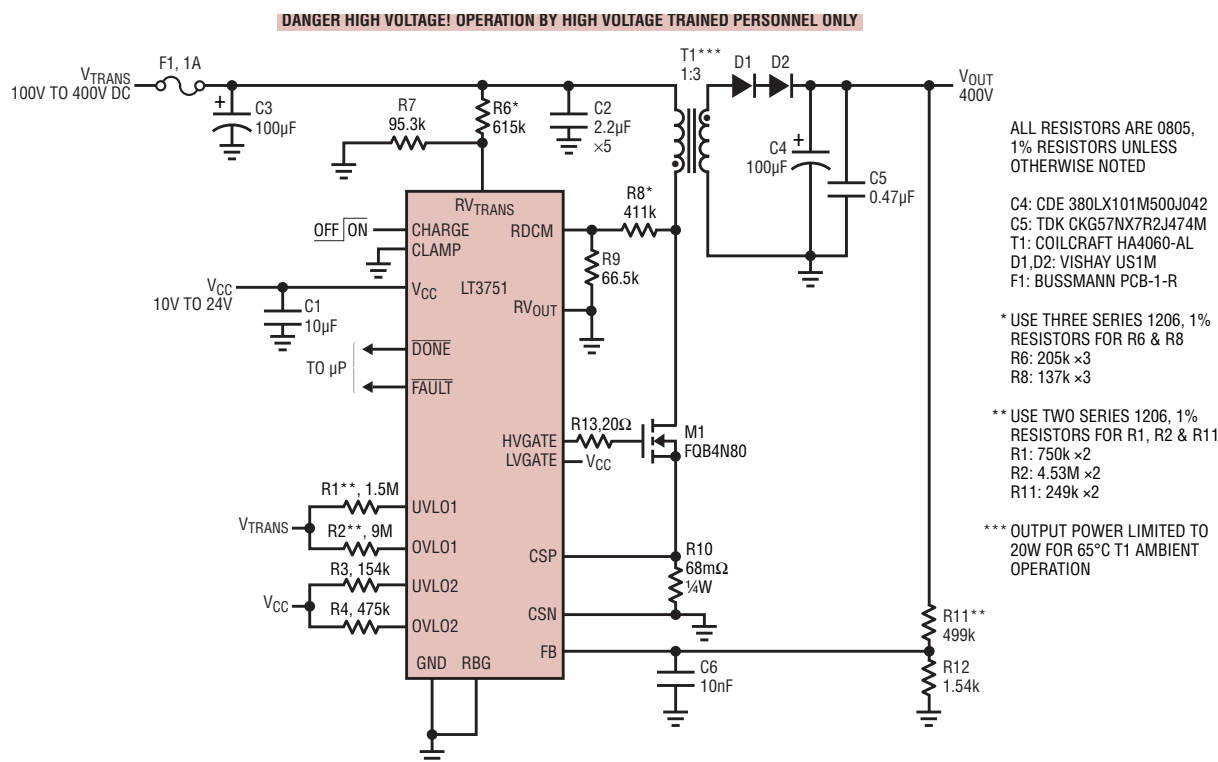


Figure 9. A 100V to 400V input, 400V output, capacitor charger and voltage regulator

Note that the FB pin of the LT3751 can also be used for a capacitor charger. The LT3751 operates as a capacitor charger until the FB pin reaches 1.225V, after which the LT3751 operates as a voltage regulator. This keeps the capacitor topped-off until the application needs to use its energy. The output resistor divider forms a leakage path from the output capacitor to ground. When the output voltage droops, the LT3751 feedback circuit will keep the capacitor topped-

off with small, low current bursts of charge as shown in Figure 6.

High Input Supply Voltage, Isolated Capacitor Charger

As mentioned above, the LT3751 differential DCM and V_{OUT} comparators allow the part to accurately work from very high input supply voltages. An offline capacitor charger, shown in Figure 7, can operate with DC input voltages from 100V to 400V. The transformer provides galvanic isolation from

the input supply to output node—no additional magnetics required.

Input voltages greater than 80V require the use of resistor dividers on the DCM and V_{OUT} comparators (charger mode only). The accuracy of the V_{OUT} trip threshold is heightened by increasing current I_O through R_{10} and R_{11} ; however, the ratio of R_6/R_7 should closely match R_{10}/R_{11} with tolerances approaching 0.1%. A trick is to use resistor arrays to yield the desired ratio. Achieving 0.1% ratio accuracy is not difficult and can reduce the overall cost compared to using individual 0.1% surface mount resistors. Note that the absolute value of the individual resistors is not critical, only the ratio of R_6/R_7 and R_{10}/R_{11} . The DCM comparator is less critical and can tolerate resistance variations greater than 1%.

The 100V to 400VDC input capacitor charger has an overall $V_{OUT(TRIP)}$ accuracy of better than 6% over the entire operating range using 0.1% resistor dividers. Figure 8 shows a typical performance for $V_{OUT(TRIP)}$ and charge time for the circuit in Figure 7.

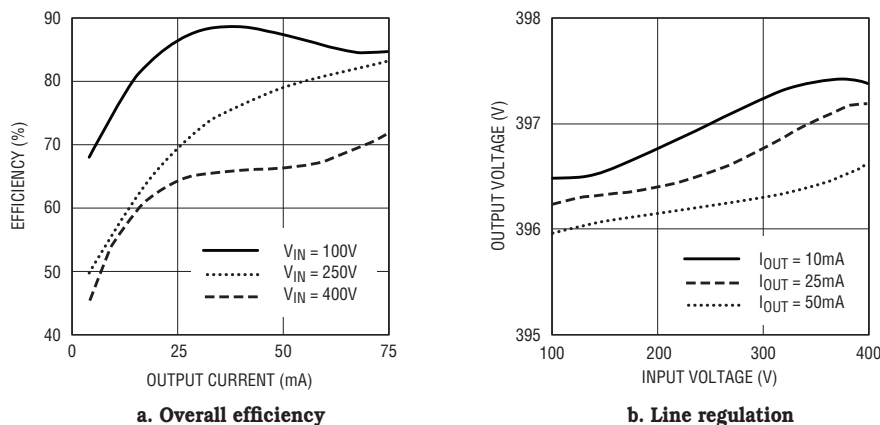


Figure 10. High voltage input and output regulator performance

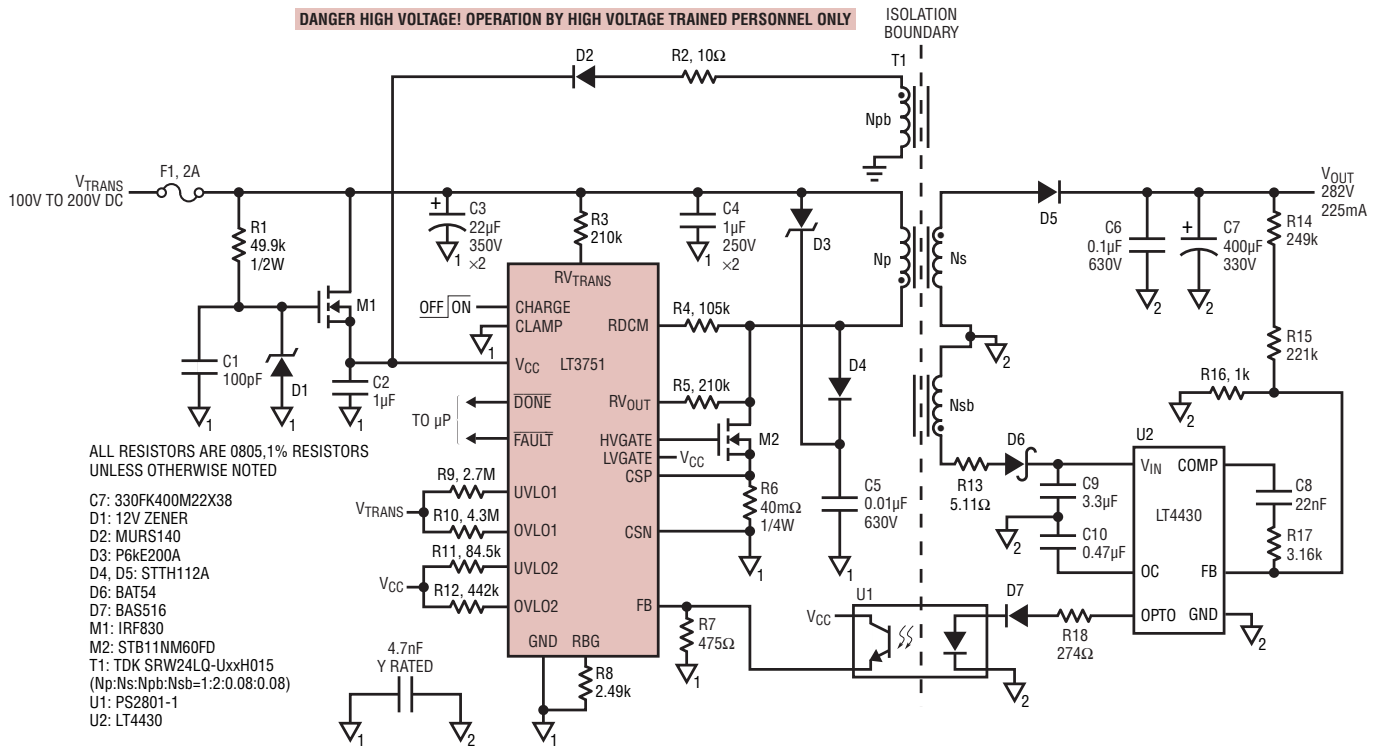


Figure 11. Fully isolated, high output voltage regulator

High Input Supply Voltage, Non-Isolated Capacitor Charger/Regulator

The FB pin of the LT3751 can also be configured for charging a capacitor from a high input supply voltage. Simply tie a resistor divider from the output node to the FB pin. The resistor dividers on the R_{VTRANS} and R_{DCM} pins can tolerate 5% resistors, and all the $R_{V(OUT)}$ and R_{BG} pin resistors are removed. This lowers the number and the tolerance of required components, reducing board real estate and overall design costs. With the output voltage resistor divider, the circuit in Figure 9 is also a fully functional, high-efficiency voltage regulator with load

and line regulation better than 1%. Efficiency and line regulation for the circuit in Figure 9 are shown in Figure 10a and Figure 10b, respectively.

Alternatively, a resistor can be tied from V_{OUT} to the OVLO1 pin or OVLO2 pin. This mimics the V_{OUT} comparator, stopping charging once the target voltage is reached. The FB pin is tied to ground. The CHARGE pin must be toggled to initiate another charge sequence, thus the LT3751 operates as a capacitor charger only. Resistor R_{12} is omitted from Figure 9 and resistor R_{11} is tied from V_{OUT} directly to OVLO1 or OVLO2. R_{11} is calculated using the following equation:

$$R_{11} = \frac{V_{OUT(TRIP)} - 1.225}{50\mu A}$$

Note that OVLO1 or OVLO2 will cause the **FAULT** pin to indicate a fault when the target output voltage, $V_{OUT(TRIP)}$, is reached.

High Voltage Input/Output Regulator with Isolation

Using a resistor divider from the output node to the FB pin allows regulation but does not provide galvanic isolation. Two auxiliary windings are added to the transformer in circuit shown in Figure 11 to drive the FB pin, the

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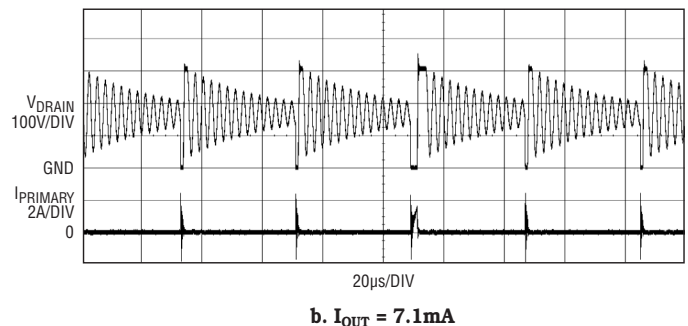
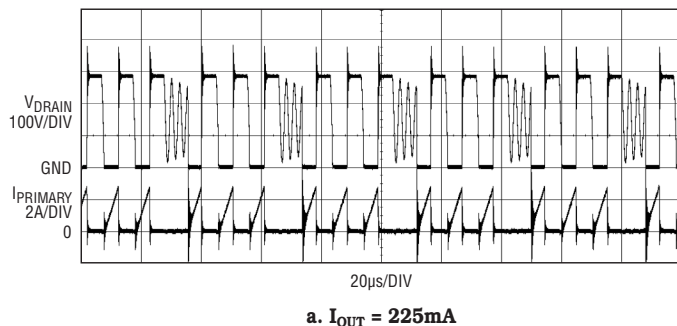


Figure 12. Switching waveforms

battery whether external or internal. Programming the charge current only requires a single external resistor.

The fault management system of the LTC4012 family suspends charging immediately for various conditions. First is battery overvoltage protection, which can occur with the sudden loss of battery load during bulk charge. Second, each IC features internal over-temperature protection to prevent silicon damage during elevated thermal operation.


The LTC4012 family has a logic-level shutdown control input and three open-drain status outputs. First is an input current limit (ICL) status flag to tell the system when V_{IN} is running at over 95% of its current capacity. The input current limit accuracy is typically $\pm 3\%$ and a maximum of $\pm 4\%$ over the full operating temperature range. Next is the AC present status, which indicates when V_{IN} is within a valid range for charging under all modes of operation. The last is a charge status output can indicate bulk or C/10 charge states. The control input and status outputs of the LTC4012, along

with the analog current monitor output, can be used by the host system to perform necessary preconditioning, charge termination and safety timing functions.

4MHz Synchronous Step-Down DC/DC Converter Delivers up to 1.25A from a 3mm \times 3mm DFN

The LTC3565 is a high efficiency synchronous step-down regulator that can deliver up to 1.25A of continuous output current from a 3mm \times 3mm DFN (or MSOP-10E) package. Using a constant frequency of (up to 4MHz) and current mode architecture, the LTC3565 operates from an input voltage range of 2.5V to 5.5V making it ideal for single cell Li-Ion, or multicell Alkaline/NiCad/NiMH applications. It can generate output voltages as low as 0.6V, enabling it to power the latest generation of low voltage DSPs and microcontrollers. An independent RUN pin enables simple turn-on and shutdown. Its switching frequency is user programmable from 400kHz to 4MHz, enabling the designer to

optimize efficiency while avoiding critical noise-sensitive frequency bands. The combination of its 3mm \times 3mm DFN-10 (or MSOP-10) package and high switching frequency keeps external inductors and capacitors small, providing a very compact, thermally efficient footprint.

The LTC3565 uses internal switches with an $R_{DS(ON)}$ of only 0.13 Ω (N-Channel lower FET) and 0.15 Ω (P-Channel upper FET) to deliver efficiencies as high as 95%. It also utilizes low dropout 100% duty cycle operation to allow output voltages equal to V_{IN} , further extending battery run time. The LTC3565 utilizes Automatic Low Ripple ($< 25mV_{P-P}$) Burst Mode[®] operation to offer only 40 μA no load quiescent current. If the application is noise sensitive, Burst Mode operation can be disabled using a lower noise pulse-skipping mode, which still offers only 330 μA of quiescent current. The LTC3565 can be synchronized to an external clock throughout its entire frequency range. Other features include $\pm 2\%$ output voltage accuracy and over-temperature protection. 

LT3751, continued from page 13


LT3751 controller, and the optocoupler on the feedback resistor divider. The auxiliary windings provide the desired galvanic isolation boundary while maintaining an isolated feedback path from the output node to the LT3751 FB pin. Figures 12 and 13 show the regulator's performance.

The fully isolated, high voltage input/output regulator yields over 90% efficiency. Load regulation is excellent as shown in Figure 13b, due mainly to the added gain of the optocoupler circuit.

Conclusion

The ability to run from any input supply voltage ranging from 4.75V to greater than 400V and the abundance of safety features make the LT3751 an excellent choice for high voltage capacitor chargers or high voltage regulated power supplies. In fact, the LT3751 is, for now, the only

boundary-mode capacitor charger controller that can accurately operate from extremely high input voltages. The LT3751 simplifies design by integrating many functions that—due to cost and board real-estate—would otherwise not be realizable. Although several designs are shown here, the

LT3751 includes many more features than we can show in one article. We recommended consulting the data sheet or calling the Linear Technology applications engineering department for more in-depth coverage of all available features. 

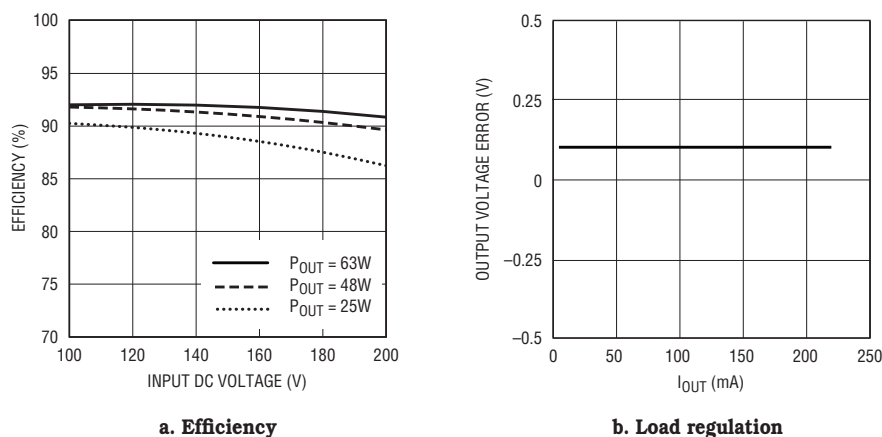


Figure 13. Fully isolated, high voltage regulator performance