LT3751 Design Notes

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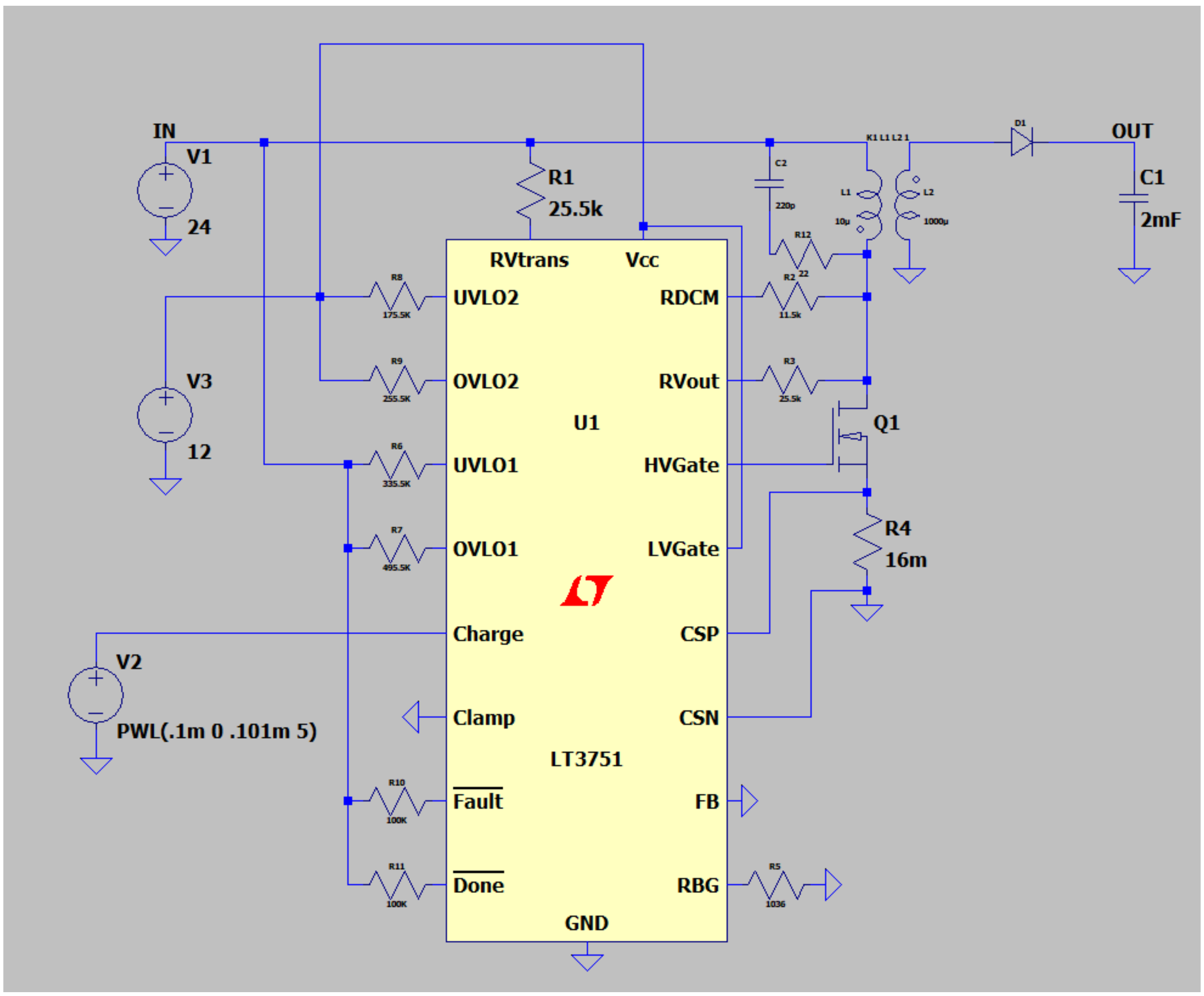
This document will contain the design process for the LT3751 flyback converter. It is to be used alongside (not in place of) the LT3751 data sheet. Thunderbots uses this converter as a 24V - 240V capacitor charger.



The following variables were selected as design parameters:

Parameter	Description	Value
V_{trans}	Transformer supply voltage	24V
V_{out}	Output voltage	240V
C_{out}	Output capacitance	2mF
I_{pk}	Peak transformer primary current	10A
VCC	Supply Voltage	12V

1 Pins

This section will briefly describe each pin and the calculations of any necessary components.

Note: Resistor values are calculated values and need to be updated with standard resistor values

1.1 RVtrans

RVtrans is used as the transformer supply sense pin. The resistor R_{trans} is placed between V_{trans} and the pin. See Section 2 for instructions on setting RV_{out}.

1.2 UVLO1, OVLO1, UVLO2, OVLO2

These four pins serve similar purposes, so they will be covered in the same section. UVLO1 and OVLO1 are the V_{trans} undervoltage/overvoltage detection pins and will raise a fault signal when V_{trans} drops below 18V or goes above 26V. They are connected to V_{trans} via R_{UVLO1} and R_{OVLO1}, which are calculated as per page 7 of the data sheet:

$$R_{UVLO1} = \frac{V_{UVLO1} - 1.225V}{50\mu A} = \frac{18V - 1.225V}{50\mu A} = 335.5k\Omega$$

$$R_{OVLO1} = \frac{V_{OVLO1} - 1.225V}{50\mu A} = \frac{26V - 1.225V}{50\mu A} = 495.5k\Omega$$

UVLO2 and OVLO2 are the VCC undervoltage/overvoltage detection pins and will raise a fault signal when VCC drops below 10V or goes above 14V. They are connected to VCC via R_{UVLO2} and R_{OVLO2} which are calculated as follows:

$$R_{UVLO2} = \frac{V_{UVLO2} - 1.225V}{50\mu A} = \frac{10V - 1.225V}{50\mu A} = 175.5k\Omega$$

$$R_{OVLO2} = \frac{V_{OVLO2} - 1.225V}{50\mu A} = \frac{14V - 1.225V}{50\mu A} = 255.5k\Omega$$

1.3 Fault

This (active low) pin goes low when an undervoltage or overvoltage condition occurs and all switching will be disabled. The charge pin must be toggled to reset this signal. This pin must be pulled up to V_{trans} or VCC via a 100kΩ resistor.

1.4 Done

This (active low) pin goes low when the target output voltage is reached or the fault pin goes low. The charge pin must be toggled to reset this signal. This pin must be pulled up to V_{trans} or VCC via a 100kΩ resistor.

1.5 Charge

Drive pin higher than 1.5V to start charging. Bring to below 0.3V to stop charging. This pin is directly controlled by the microcontroller.

1.6 Clamp

Clamps the gate driver pin voltage. Clamp is set to 5.6V if this pin is connected to VCC and 10.5V if connected to ground. In our implementation, V_{GS} of our NMOS transistor is 10V so Clamp is connected to GND.

1.7 FB

Feedback regulation pin. The voltage of this pin determines whether the LT3571 is used as a no-load voltage regulator, heavy load voltage regulator, or capacitor charger. We connect this pin to ground for capacitor charger mode.

1.8 CSN and CSP

Negative and positive NMOS source current sense pins. Connect CSP to the source of the external transistor and CSN to ground, then connect a source resistor between CSP and CSN to complete the circuit. The value of this sense resistor is important as it sets the maximum value of the source current through the transistor, which by extension is the current through the transformer primary (I_{pk}). This resistor is calculated as follows:

$$R_{CS} = \frac{106mV}{I_{pk}} = \frac{106mV}{10A} = 16m\Omega$$

1.9 VCC

12V input from the voltage regulator. Bypass with a XR5 ceramic cap because the data sheet says so.

1.10 LVGate

Low voltage gate pin. If VCC is less than 8V, connect to external transistor gate. Otherwise connect to VCC. Our VCC is 12V so this pin is connected to VCC.

1.11 HVGate

High voltage gate pin. Connect to external transistor gate. Will drive gate voltage to within VCC-2V. Gets clamped based on the state of the Clamp pin.

1.12 RBG

This pin is really important because it sets the output voltage! Connect to ground via the R_{BG} resistor. See section 2 for instructions on setting this resistor value.

1.13 RVout

Output voltage sense pin. Pretty self-explanatory. Connect to the external NMOS drain via the R_{out} resistor. See section 2 for instructions on setting this resistor value.

1.14 RDCM

Discontinuous mode sense pin. Determines when to initiate the next switch cycle. Connect to the external NMOS drain via the R_{DCM} resistor. See section 2 for instructions on setting this resistor value.

1.15 GND

Don't worry about it.

2 External Resistors

2.1 RTrans, Rout, and RDCM

The values of R_{trans}, R_{out}, and R_{DCM} are set based on V_{trans} and ΔV_{Drain}, where ΔV_{Drain} is the difference between V_{Drain} (the drain of the external NMOS) and V_{trans}. I couldn't figure out how to analytically find V_{Drain}, but simulations showed that it peaked at 48V in our setup and was dependant on V_{out}. We use this value for ΔV_{Drain}:

$$\Delta V_{Drain} = V_{Drain} - V_{trans} = 48V - 24V = 24V$$

and compare it to Table 2 in the data sheet (pg 17):

Table 2. Suggested RV_{TRANS}, RV_{OUT}, and R_{DCM} Values

V_{TRANS} Range (V)	ΔV_{DRAIN} RANGE (V)	RV_{TRANS} (kΩ)	RV_{OUT} (kΩ)	R_{DCM} (kΩ)
4.75 to 55	0 to 5	5.11	5.11	2.32
4.75 to 60	2.5 to 50	25.5	25.5	11.5
	5 to 80	40.2	40.2	18.2
8 to 80	8 to 160	80.6	80.6	36.5
80 to 200	$2mA \bullet RV_{OUT}$	$\frac{V_{TRANS} - 55V}{0.25}$	$\frac{V_{TRANS} - 55V}{0.25}$	$0.86 \bullet RV_{TRANS}$
>200	Resistor Divider Dependent	Use Resistor Divider	Use Resistor Divider	Use Resistor Divider

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Based on the table, $R_{trans} = 25.5k\Omega, R_{out} = 25.5k\Omega,$ and $R_{DCM} = 11.5k\Omega$. These are also the values RoboJackets use so that's probably a good sign.

2.2 RBG

With the other resistors selected, R_{BG} is calculated as follows (as per pg 45 of the data sheet):

$$R_{BG} = 0.98N \frac{RV_{out}}{V_{out} + V_{diode}} = 0.98(10)\frac{25.5k\Omega}{240V + 1.7V} = 1033.9\Omega$$

Where N is based on the flyback transformer (section 3.1) and V_{diode} is the forward voltage of the output diode (section 3.2).

3 External Components

3.1 Flyback Transformer

I_{pk} is the main criteria for selecting the transformer. The CoilCraft DA-2034-AL is one of the transformers recommended by the LT3751 manufacturers (table 1 of the data sheet). It is the current frontrunner because of its ability to handle up to 10A on the primary, 1:10 ratio, and relatively small size. **Not available on digikey though (is available on Mouser).** This transformer is currently used by RoboJackets, while the similar CoilCraft DA-2032-AL is used by Mannheim ($I_{pk} = 5A$ for this transformer).

3.2 Output Diode

The output diode is selected based on the maximum repetitive reverse voltage (V_{RRM}) and the average forward current I_{Av}. The diode must meet the following requirements:

$$V_{RRM} > V_{out} + N * V_{trans} = 240V + 10(24V) = 480V$$

$$I_{Av} > \frac{I_p k}{2N} = \frac{10A}{2 * 20} = 0.5A$$

The Fairchild ES3J is one of the diodes recommended by the LT3751 manufacturers (table 4 in the data sheet). It meets our requirements and has a low t_{rr}.

3.3 External NMOS

The Fairchild FDS2582 is one of the transistors recommended by the LT3751 manufacturers (table 3 in the data sheet).

3.4 RC Snubber Circuit

The purpose of the RC snubber circuit is to reduce the effect of the transformer leakage inductance. The transformer is not ideal; not all energy will be transferred from one coil to the other. When the MOSFET turns off, this energy needs to go somewhere. Otherwise, we will have a large voltage spike on the drain of the MOSFET, which may be enough to damage it. The voltage spike could also be enough for the comparator to think the capacitor bank is done charging, even if it's actually nowwhere near the charge voltage.

Simulating the LT3751 with the non-ideal transformer was challenging, where seemingly impossible voltage spikes were noticed. After talking with Will from RoboJackets, I think that the spice model for the LT3751 is simply not designed to model a non-ideal transformer. Additionally, this simulation (and possibly the LT3751 itself) is incompatible with industry standard RCD or Zener snubber circuits.

For the time being, our approach is to leave footprints for the RC snubber on the PCB and populate as needed. Will said that the transformer leakage inductance was small compared to the inductances caused by the high currents, and they were able to test different combinations of R and C in the snubber. We will use the same approach for the time being.