

Solving design difficulties associated with flyback converters

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Isolated outputs are required for a broad range of DC/DC converter applications—far beyond the well-known telecom and datacom mandated isolation requirements. Isolation can be necessary for noise-sensitive devices needing ground separation from a noisy input voltage such as a car battery, intermediate bus and industrial inputs. Displays, programmable logic controllers, GPS systems and some medical monitoring devices can all be ill affected by a noisy bus voltage. Many applications also have a safety standard that requires galvanic isolation.

Flyback converters are widely used in isolated DC/DC applications, but they are not necessarily a designer's first choice. Power supply designers grudgingly choose a flyback out of necessity for lower power isolated requirements, not because they are easy to design. A flyback converter requires a significant amount of time devoted to the design of the transformer, a task further complicated by the normally limited selection of off-the-shelf transformers and the possible necessity for a custom transformer. In addition, the flyback converter has stability issues due to the well-known right-half-plane zero in the control loop that is further complicated by the propagation delay, ageing and gain variation of an optocoupler. We'll present a circuit based on the LT3573 isolated monolithic flyback converter IC that solves many of the design difficulties commonly associated with flyback converters and provides an easy means of implementation.

The LT3573 eliminates the need for an optocoupler, external MOSFET, secondary-side reference voltage and extra third winding off

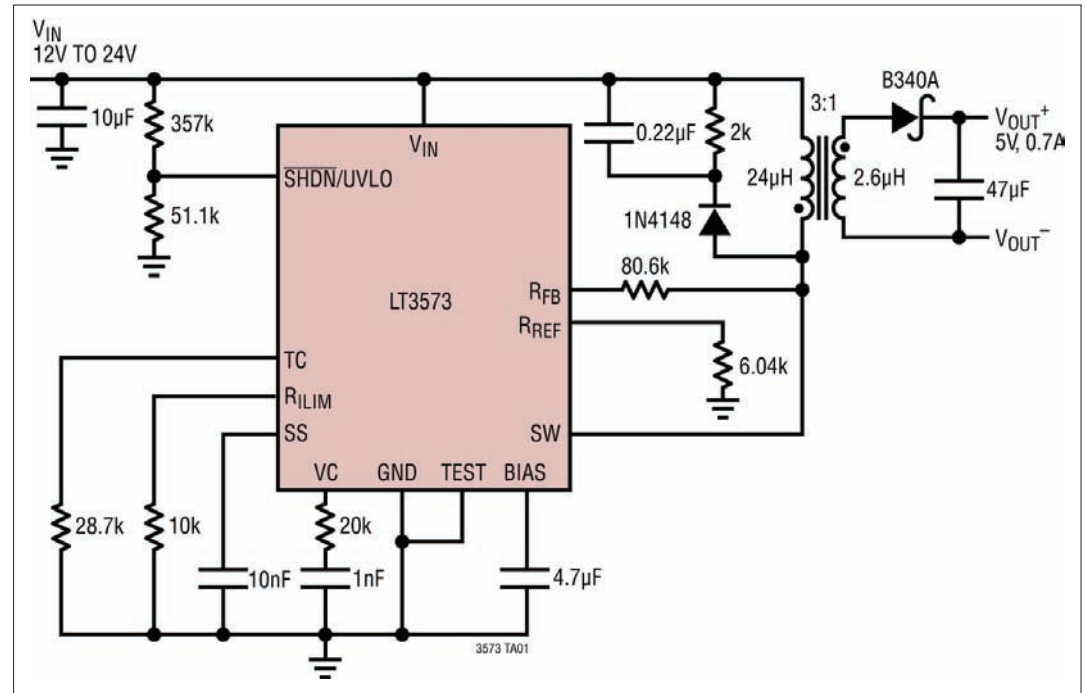


Figure 1: Shown is a flyback converter with primary side output voltage sensing.

the power transformer, all while maintaining isolation between primary and secondary with only one part having to cross the isolation barrier. An on-chip 1.25A, 60V NPN power switch delivers up to 7W of output power from an input voltage ranging from 3V to 40V and employs a primary-side sensing scheme that is capable of detecting the output voltage through the flyback primary-side switching node waveform. During the switch off-period, the output diode delivers the current to the output, and the output voltage is reflected to the primary-side of the flyback transformer. The magnitude of the switch node voltage is the summation of the input voltage and reflected output voltage, with which the LT3573 is able to reconstruct. **Figure 1** shows a flyback converter schematic using the LT3573.

The LT3573 uses boundary mode (BCM) operation, further simplifies system design, reduces converter size and improves load regulation. The LT3573 flyback

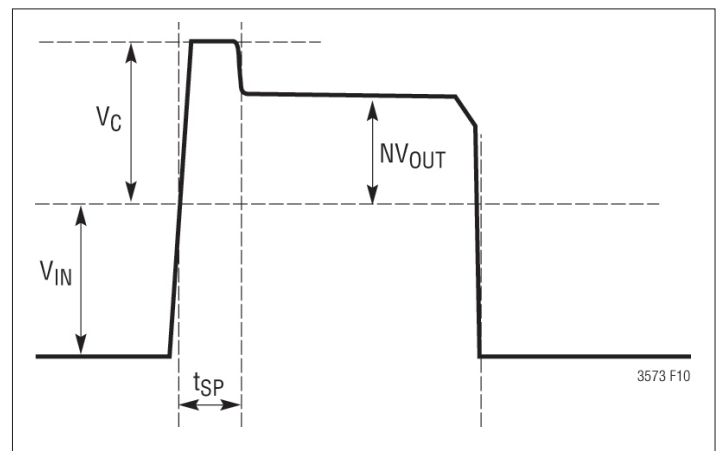


Figure 2: Shown is the typical switch node waveform.

converter turns on its internal switch right after the secondary side current reduces to zero and turns off when the switch current reaches the pre-defined current limit. Thus, it always operates at the transition of continuous conduction mode (CCM) and discontinuous mode (DCM), which is called boundary mode or critical conduction mode. Power supply designers can implement programmable soft-start, adjustable current limit, under-voltage

lockout and temperature compensation features. The designer sets the output voltage via the transformer turns ratio and two external resistors.

Output voltage sensing for an isolated converter normally requires an optocoupler and secondary side reference voltage. An optocoupler transmits the output voltage feedback signal through the optical link while maintaining the isolation barrier. However, an optocoupler transfer ratio

Target Application	Supplier	Size (WxLxH) (mm)	Turns Ratio $N_p:N_s$	Wurth Part Number
5V to 5V @ 0.2A	BH Electronics	9.52 x 9.52 x 4.95	1:1	L10-1019
12V to 3.3V @ 1.5A	Pulse Engineering	15.24 x 13.1 x 11.45	7:1	PA2364NL
12V to 5V @ 1A	Pulse Engineering	15.24 x 13.1 x 11.45	5:1	PA2363NL
12V to 12V @ 0.3A	Pulse Engineering	15.24 x 13.1 x 11.45	1:1	PA2456NL
24V to 3.3V @ 1A	Würth Elektronik	15.24 x 13.3 x 11.43	4:1	750310559
24V to 5V @ 1A	Würth Elektronik	13.35 x 10.8 x 9.14	3:1	750370047
24V to 12V @ 0.5A	Würth Elektronik	15.24 x 13.3 x 11.43	2:1	750310562
24V to 15V @ 0.4A	Würth Elektronik	9.14 x 9.78 x 10.54	1:0.33	750310799
24V to $\pm 5V$ @ 0.5A	Würth Elektronik	15.24 x 13.3 x 11.43	3:1	750310564

Table 1: Here are suitable off-the-shelf transformers.

changes with temperature and ageing, degrading its accuracy. Optocouplers also introduce a propagation delay, resulting in a slower transient response that can be non-linear from unit to unit, which can cause a design to display different characteristics from circuit to circuit. A flyback design employing an extra transformer winding for voltage feedback can also be used to close the feedback loop instead of an optocoupler. This extra transformer winding can increase the transformer size and cost.

The circuit shown eliminates the need for an optocoupler or extra transformer winding by sensing the output voltage on the primary-side of the transformer. The output voltage is accurately measured at the primary-side switching node waveform during the off-time of the power transistor as shown in **Figure 2**, where N is the turns ratio of the transformer, V_{IN} is the input voltage and V_C is the maximum clamped voltage.

Boundary mode operation

Boundary mode control is a variable frequency current mode

switching scheme. When the internal power switch turns on, the transformer current increases until its preset current limit set point is reached. The voltage on the SW pin rises to the output voltage divided by the secondary-to-primary transformer turns ratio plus the input voltage. When the secondary current through the diode falls to zero, the SW pin voltage falls below V_{IN} . The internal DCM comparator detects this event and turns the switch back on, thus repeating the cycle.

Boundary mode returns the secondary current to zero every cycle, resulting in the parasitic resistive voltage drop not causing load regulation errors. Furthermore, the primary flyback switch is always turned on at zero current and the output diode has no reverse recovery loss. This reduction in power loss allows the flyback converter to operate at a relatively high switching frequency, which in turn reduces the transformer size when compared to lower frequency alternative designs. **Figure 3** shows the SW voltage and current along with the current in the output diode.

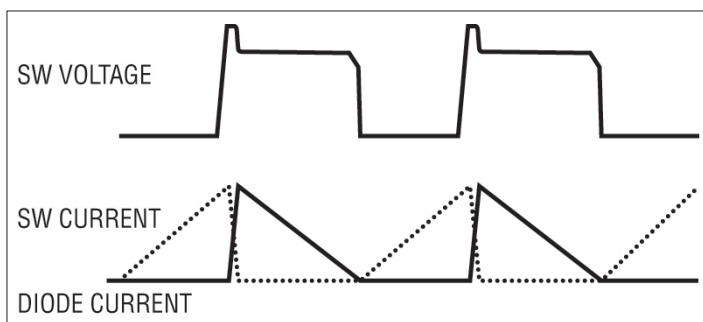


Figure 3: Shown is the flyback converter waveforms in boundary mode.

The load regulation is much improved in boundary mode operation because the reflected output voltage always samples at the diode current zero-crossing. The LT3573 typically provides +/- 3% load regulation.

The transformer specification and design is perhaps the most critical part of successfully applying the LT3573. Linear Technology has worked with magnetic component manufacturers to produce pre-designed flyback transformers, and a complete list is shown in the LT3573 data sheet. **Table 1** shows an abbreviated list of recommended off-the-shelf transformers from Würth Elektronik, Pulse Engineering and BH Electronics. These transformers typically withstand a 1,500VAC breakdown voltage for one minute from primary to secondary. Higher breakdown voltage and custom transformers can also be used.

Linear Technology offers free simulation software called LTSpice that can be downloaded from www.linear.com. The LT3573 can be modelled using any of the transformers listed in Table 1, which produce very realistic simulations to help ease the design of such converters. The simulation circuit includes information on how the circuit starts up; its reaction to load steps for different input voltages and shows how the common mode current flows under varying conditions. It is easy to add filtering and watch the impact this has on common mode and differential mode noise.

Transformer turns ratio

By using an R_{FB}/R_{REF} resistor ratio to set the output voltage, the user has relative freedom in selecting a transformer turns ratio to suit a given application. Typically, the transformers turns ratio is selected to maximise available output power. For low output voltages (3.3V or 5V), an N:1 turns ratio can be used with multiple primary windings relative to the secondary to maximise the transformer's current gain and output power. However, the SW pin sees a voltage that is equal to the maximum input supply voltage plus the output voltage multiplied by the turns ratio. This voltage needs to remain below the ABS MAX rating of the SW pin to prevent breakdown of the internal power switch. Together these conditions place an upper limit on the turns ratio (N) for a given application and needs to satisfy the following equation:

$$N < \frac{50V - V_{IN(MAX)}}{V_{OUT} + V_F}$$

In the equation above, V_F is the output diode voltage drop and V_{OUT} is the output voltage.

For larger N:1 values, a transformer with a larger physical size is needed to deliver additional current and provide a large enough inductance to ensure that the off-time is long enough to accurately measure the output voltage.

For lower output power levels, a 1:1 or 1:N transformer can be chosen for the absolute smallest transformer size. A 1:

N transformer will minimise the transformer size and magnetizing inductance, but will also limit the available output power. A higher 1:N turns ratio makes it possible to have very high output voltages without exceeding the breakdown voltage of the internal power switch.

The transformer leakage inductance on either the primary or secondary side causes a voltage spike to appear at the primary after the power switch turns off. This spike is increasingly prominent at higher load currents where more stored energy must be dissipated. The leakage inductance can be minimised by close coupling of the transformer windings and is measured by reading the inductance on a transformer winding with the other windings shorted out.

A simple RCD (resistor, capacitor and diode) clamp circuit shown in **Figure 4** prevents the leakage inductance spike from exceeding the breakdown voltage on the power device. This cir-

cuit is included in all the LT3573 applications circuits and Schottky diodes are typically the best choice to be used in the snubber due to their fast turn-on time.

Demonstration circuit

A demonstration board using the LT3573 is shown in **Figure 5**. This circuit accepts an input voltage ranging from 10V to 30V and produces an isolated 5V output at up to 1A.

LT3573-based circuit significantly simplifies the design of an isolated flyback DC/DC converter by eliminating the need for an optocoupler, external MOSFET, secondary-side reference voltage and extra third winding of the power transformer. It maintains primary to secondary isolation with only one part crossing the isolation barrier. The LT3573 operates from a 3V to 40V input voltage range and has the ability to deliver up to 7W of continuous output power making it suitable for a wide range of applications. Readily available off-the-

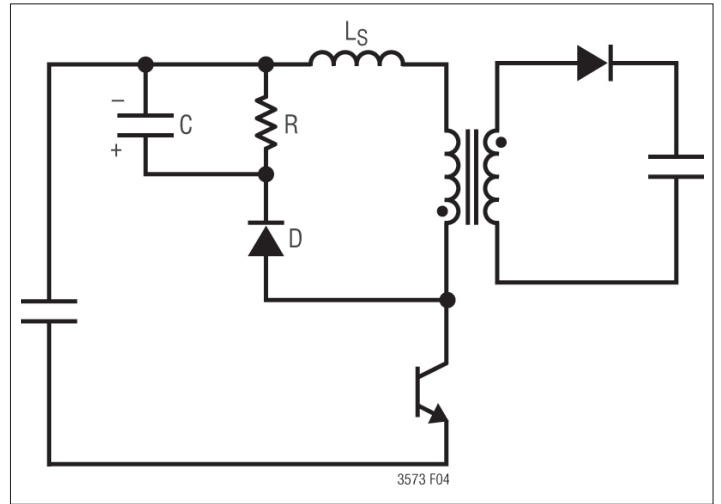


Figure 4: Shown is an RCD clamp circuit.

shelf transformers prevent the need for a custom transformer. Isolated DC/DC converters are being required for a broad range of applications and not just for telecom mandated isolation requirements. Isolation from bus voltages is necessary for noise sensitive applications such as GPS systems, displays, programmable logic controllers and medical monitoring devices.

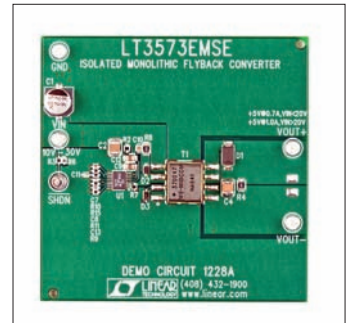


Figure 5: Shown is a demonstration circuit that measures 31mm x 15mm.