Power supply IC brings energy efficiency to non-isolated designs

Kent Wong explains how an integrated IC-based power supply solution offers switching performance and unmatched energy efficiency for very low-power applications, at a cost equal to or less than that of traditional passive solutions, such as capacitive droppers.

Many applications such as appliance control circuits, LED drivers, timers, electricity utility meters and triac-based AC load controllers require 50 - 350mA of non-isolated power. Simple and low cost resistive or capacitive dropper based supplies have traditionally been used in these applications.

However, new appliance features such as electronic displays require more power than passive solutions can cost effectively deliver. Additionally, tomorrow's products will have to meet more stringent energy efficiency standards. Therefore, those older technologies will no longer be viable options.

Power Integrations (PI) has introduced a highly integrated off-line switcher IC, called the LinkSwitch-TN. It has been designed specifically to address the higher load currents and energy efficiency requirements that will be expected and demanded of tomorrow's non-isolated power solutions.

Different topologies

The three members of the LinkSwitch-TN family can be used in a number of different topologies such as Buck, Boost, Buck-Boost, SEPIC and Flyback. Unlike passive solutions, they accept a universal input voltage range and provide system level protection from faults such as a shorted output, overheating, or an open-circuit control loop. Solutions based on the LinkSwitch-TN typically consume very little power (<0.1W) at no-load, even at the highest input line voltage (265VAC).

Having three members in the family make scaling (up or down) the maximum output current of the solution designed around a LinkSwitch-TN very easy. All three devices are available in SMD packages, so that the entire power supply can be manufactured from surface mount components.

And lastly, the package provides a minimum creepage of 3.48mm between the high voltage DRAIN pin and the adjacent low voltage pins, making it an ideal solution for high pollution environments, for example, the dust and lint encountered by clothing washers and dryers.

Seven step design process

Designing a power supply around a LinkSwitch-TN device is easy, and can be summarized briefly as a seven-step process. The following seven steps are described, in all of the detail necessary to create an operational design, in the PI Application Note (AN-37) for the LinkSwitch-TN.

In addition, PI's power supply design software PI-Expert (version 5.0) features a spreadsheet that helps the designer ensure that every important facet of the design has been addressed in the initial paper design.

1. Pick an AC input stage (see AN-37, table 9). If input is already rectified, go to step 2.
2. Pick the Topology to be used (see AN-37, tables 1 and 2).
3. Select the LinkSwitch-TN device and other required components (see AN-37, tables 3 or 4).
4. Select a freewheeling diode, based on the reverse recovery time required (from step 3).
5. Calculate the pre-load requirement – optional applies for direct feedback designs only.
6. Select the output capacitor's voltage and ESR ratings (depends on ripple voltage specification).
7. Construct a prototype, test it, and verify the design or modify it to make it meet specifications.

Because the internal control circuitry of the LinkSwitch-TN consumes so little energy, the chip is powered by a high-voltage current source directly from the Drain of the integrated MOSFET switch. This current source charges a capacitor connected to the BYPASS (BP) pin whenever the MOSFET is switched off (not conducting). The BP pin capacitor must be connected close to the package, between the BP and SOURCE pins.

A capacitance of 0.1µF is sufficient to store the operating energy required by the chip, and to perform high frequency decoupling of the BP pin. An integrated under-voltage (UV) detection and lockout circuit only enables (turns on) the switching of the integrated MOSFET, after the voltage on the BP pin reaches 5.8VDC.

If the voltage on the BP pin falls below 4.85VDC (a line UV event has occurred), MOSFET switching is disabled, and the BP pin voltage must increase back up to 5.8VDC before switching will again be re-enabled. Additionally, an internal 6.3VDC shunt regulator clamps the BP pin voltage, when operating current is provided from an external source (such as a resistor).

Operating the LinkSwitch-TN from an external current source can further decrease the no-load power consumption of the device. Integrating the start-up and UV functions reduces the supply's component count from 5 to 12 parts.

The LinkSwitch-TN has integrated MOSFET current sensing and limiting circuits that terminate the switching cycle every time the drain current exceeds the internal current limit threshold. The current sensing comparator also has a built-in time delay that disables it for the first 215ns after the MOSFET has been switched on. Each time the MOSFET turns on, two phenomena occur.

One is that the output rectifier briefly conducts current in the reverse direction (during its reverse recovery time), as it is in the process of becoming reverse biased. The other is that the parasitic capacitance at the switching node is discharged through the MOSFET.

As the MOSFET first turns on, these two phenomena produce a sharp spike in the drain current that can falsely trigger the current sense comparator. Therefore, the leading edge blanking provided by the 215ns delay prevents that spike from prematurely terminating the switching cycle. Integrating this circuit within the device improves its reliability, while reducing the external component count from 3 to 6 parts.

Over-temperature protection

The integrated over-temperature protection circuit continuously senses the die temperature. If that temperature exceeds the typical trip point of 142˚C, the circuit disables MOSFET switching until the die temperature drops by 75˚C. Once the circuit senses the drop in temperature, MOSFET switching is re-enabled, and the device reinitiates its auto-restart sequence. Again, the integration of this function keeps the discrete component count low without sacrificing the reliability and safety of the power supply.

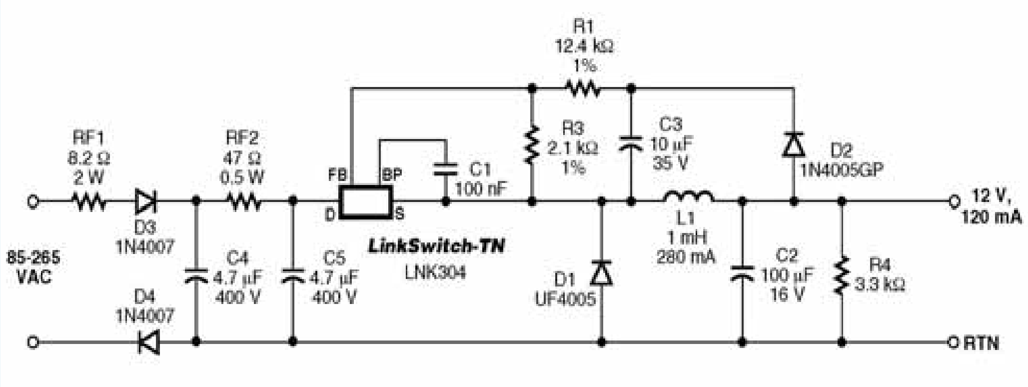
Figure 1 depicts a typical implementation of a 12V, 120mA non-isolated Buck converter, designed around the lowest current member of the LinkSwitch-TN family, the LNK304.

This circuit operates over the universal input voltage range of 85-265 VAC. The input stage is comprised of two fusible resistors RF1 and RF2, two AC input line current rectifiers D3 and D4, and two electrolytic capacitors C4 and C5.

The simple pi-filter made up of C5, RF2, and C4 sufficiently attenuate the conducted EMI noise currents, so that the supply meets the class B equipment requirements of EN55022. This is due to the fact that the switching frequency of the device is modulated ±2kHz, which effectively spreads the switching noise out over a wider frequency range, resulting in lower quasi-peak and average conducted EMI measurements.

Wire-wound resistors RF1 and RF2 are both fusible and flameproof. Resistor RF1 limits the inrush current to a safe level for D3 and D4. Resistor RF2 helps to attenuate the live-line-side differential mode EMI currents and will act as a fuse by failing open-circuit if C5 were to fail in the short-circuit mode.

Fig 1: LinkSwitch-TN based universal input, off-line buck converter delivering 120mA at 12V



Power processing

The power processing stage consists of the LNK304, the freewheeling diode D1, the output inductor (Buck choke) L1, and the output capacitor C2. In this design, the LNK304 and L1 have been selected for mostly discontinuous conduction mode (MDCM) operation, as this keeps the inductor size and cost down, and allows a diode with a reverse recovery time of 75ns to be used for D1.

In this example, the Buck choke is a standard off-the-shelf inductor with an RMS current rating of 280mA. The minimum inductance required to deliver the desired output power in MDCM is calculated by the following formula:

$$L_{1(MIN)} = \frac{2 \cdot V_O \cdot I_O \cdot (V_{MIN} - V_{DS} - V_O)}{I^2_{LIMIT(MIN)} \cdot f_{OSC(MIN)} \cdot (V_{MIN} - V_{DS}) \cdot \frac{1+2\cdot\eta}{3}}$$

where V_{MIN} is the minimum DC bus voltage, V_{DS} is the device drain-to-source voltage (typically 10V), $I_{LIMIT(MIN)}$ is the LNK304 minimum internal current limit (0.24A), $f_{OSC(MIN)}$ is the minimum device switching frequency (62kHz), and η is the estimated supply efficiency (0.7). The factor $(1+2\eta)/3$ takes into account that only 80% to 90% of the energy that is stored in L1 is delivered to the load.

Additionally, all inductance value variation tolerances must also be accounted for [component-to-component inductance variations of (typically) ±10%, and the high current / elevated temperature related inductance drop of (typically) ±10%]. Therefore, in order to compensate for the inductor's energy losses and its inductance value variations, $L_{1(MIN)}$ must be multiplied by a factor of 1.1 to 1.2 (1.15 is OK for the initial calculation) for the design to reliably deliver full load current under all operating conditions. That value should then be used to select the inductance for L1.

The output peak-to-peak noise voltage specification is the primary selection criteria for output capacitor C2. The ESR of the capacitor, not its capacitance value determines how much the noise is attenuated. A circuit that tracks the output voltage and feeds it back to the Feedback (FB) pin of the LNK304 is responsible for output voltage regulation.

This circuit is comprised of the feedback diode D2, the tracking capacitor C3, and resistor divider R1 and R3. The LNK304 FB pin receives current from the junction of R1 and R3, that is proportional to the output voltage. At a first order of approximation, the forward voltage drops of D1 and D2 are identical. Therefore, the voltage developed across C3 tracks the voltage across C2.

The FB pin of each LinkSwitch-TN family member is connected to the input of an integrated low impedance Source-Follower that has a set point of 1.65VDC. When the current being sourced into the FB pin exceeds the turn-off current threshold (typically 49µA), MOSFET switching is disabled for the next switching cycle. If the output voltage rises above the designated set point, the increase in current from the divider (R1/R3) into the FB pin inhibits switching cycles until the output voltage and the current from the divider drop below the turn-off current threshold. This is how the device's ON/OFF control scheme works. The values for the R1/R3 resistor divider network should be chosen so that a current of 825µA flows into R1, at the desired output voltage set point. Therefore, the values for the feedback resistors are calculated using the following formulas:

$$R3 = \frac{V_{FB}}{825\mu A - I_{FB}} = \frac{1.65V}{825\mu A - 49\mu A} = 2126\Omega \text{ (Use 2.1k}\Omega\text{, 1\%)}$$

$$R1 = \frac{R3 \cdot (V_O - V_{FB})}{V_{FB} + I_{FB} \cdot R3} = \frac{2.1k\Omega \cdot (12V - 1.65V)}{1.65V + 49\mu A \cdot 2.1k\Omega} = 12399\Omega \text{ (Use 12.4k}\Omega\text{, 1\%)}$$

This simple feedback approach requires current flow through inductor L1. Otherwise, the voltage across C3 will not accurately represent the voltage across C2 (the output voltage). Therefore, resistor R4 establishes a pre-load of approximately 3.6mA on the output, which keeps the output voltage in regulation, even when no current is being drawn by the load.

From the application example shown, it is clear how easy it is to quickly design a robust, energy efficient, non-isolated power supply around the LinkSwitch-TN IC. The highly integrated LinkSwitch-TN is optimized for the most popular non-isolated converter topologies.

Power supplies designed around it are more than capable of meeting the increased power demands that the more sophisticated digital controllers and display screens of tomorrow's applications are demanding from today's drawing boards.

This cost effective alternative to the highly inefficient, passive power supplies that are currently in use now makes it easy to adopt this new solution, while more strict energy consumption guidelines will make it hard not to adopt it.

Lastly, the design documentation that PI provides (available on-line, at www.powerint.com) for the LinkSwitch-TN, including the data sheet, an application note (AN-37), a Design Accelerator Kit (DAK-48) and a power supply design spreadsheet, make designing tomorrow's demanding solutions today, both quick and easy.

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