LM5000

High voltage, single chip DC/DC regulator optimized for flyback, boost, or forward power converter applications

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High voltage, single chip DC/DC regulator optimized for flyback, boost, or forward power converter applications

Application Brief 126

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Highlights

- **1.25 MHz current-mode regulator integrated with 80 V @ 2 A power MOSFET**
- **Single chip family of SIP modules**

Telecom and industrial applications such as local area networks (LAN), telephone interfaces (SLICs), ISDN, and xDSL terminals often require low-power multi-output, non-isolated power supplies operating from a non-regulated 12-36 V bus.

The flyback converter is often the preferred solution because of its simplicity, size, low cost, and low part count. National Semiconductor's newest high-voltage, single-chip, DC/DC regulator (LM5000) is a monolithic integrated circuit specially designed and optimized for flyback, boost, or forward power converter applications. Having integrated a complete current-mode PWM controller with a high voltage power switch (80 V @ 2 A), a highly efficient, low-cost regulator can be easily designed to operate from an unregulated (wide input range) DC voltage source.

Consider the typical example of a 3.3 V at 2 A output from an unregulated 28 V bus, with an input of 20 V to 55 V. *(see Figure 1)*

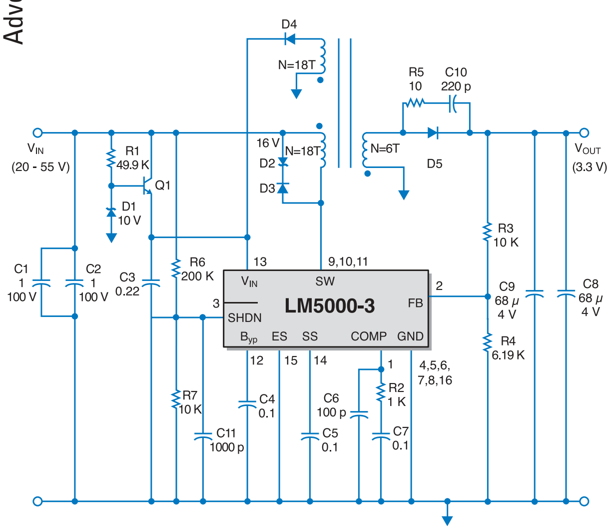

Figure 1: LM5000 flyback converter

During the ON-time of the internal power switch, a fixed voltage is applied across the primary winding of the power transformer and the current ramps linearly at the rate of dI/dT = (V_{IN})/Lp, where Lp is the primary magnetizing inductance. Energy stored in the magnetic field of the core is equal to $E = Lp * Ip^2_{peak} /2$. When the power switch turns off, the current in the primary inductance forces a reversal of polarities on all windings, and all energy from the primary winding is transferred to the secondary winding. The peak secondary current is equal to $I_{s(peak)} = I_{p(peak)} * N$, where N is the turns ratio between primary and secondary (Np/Ns).

The power delivered to the output is:
$P = E/T = (V_{IN} * T_{ON})^2/2 * T * Lp$. The feedback loop maintains constant output voltage by keeping the product $V_{IN} * T_{ON}$ constant.

Current mode control circuitry is integrated in the LM5000 regulator and offers users the advantage of being able to tightly regulate the output current and voltage together. Pulse-width-modulation (PWM) of the duty cycle (ON/OFF-time) of the power transistor is used to correct for input line voltage transients and variations in the primary switch current. The output will not see these transients because duty cycle modulation in a current-mode controller is based on an error signal proportional to output voltage regulation. This is super-imposed across a sawtooth waveform that is representative of the output inductor current. The power switch is turned ON, allowing current to ramp up through the primary until the sawtooth crosses the DC error voltage, then shuts OFF and discharges the stored energy into the output. This current mode control scheme is preferred over an older voltage mode control scheme because it provides superior bandwidth and transient response as well as cycle by cycle and overload current limiting to prevent thermal hazards.

The LM5000 can operate at four different selectable switching frequencies: 300 kHz/700 kHz (LM5000-3), 600 kHz/1.25 MHz (LM5000-6). The high switching frequency options allow the system to be "tuned" to a preferred operating frequency band. This reduces the size of output capacitance and inductance of the primary and secondary windings, and similarly reduces the total unit volume of the transformer and cost of the power supply. However, higher switching frequencies lead to increasing transformer core losses and total AC switching losses. Here, a frequency of 300 kHz is often used to keep core losses and size of the flyback transformer to a minimum.

Flyback converters can operate in discontinuous and continuous modes. In discontinuous mode, all the energy stored in the primary during the ON-time is delivered to the secondary and the load before the next cycle. In the continuous mode of operation, a small amount of energy remains in the secondary at the beginning of the next cycle.

In the LM5000 typical application of *Figure 1*, a continuous mode operation with maximum duty cycle of 33% was used to reduce the AC output current, thereby reducing the output voltage ripple. A 3:1 turns ratio between primary and secondary windings maintains the maximum stress voltage below the breakdown voltage of the integrated 80 V FET:

$$V_{SW_{off}} = (V_{IN_{max}} + (V_{OUT} + V_{DIODE}) * N_{pri})/N_{sec}$$

To reduce voltage spikes across the FET caused by transformer leakage inductance and the output rectifier recovery time, a transient voltage suppressor (clamp) in series with a diode is inserted across the transformer primary.

To achieve maximum performance in a high switching frequency design, particular attention needs to be paid to the principal magnetic component, the power transformer. Flyback transformers are more like multiple inductors on the same core rather than typical transformers. Most power supply topologies avoid storing energy in the transformer. Ideally all energy is transferred instantaneously from the primary to the secondary during the ON-time of the power transistor. Uniquely, flyback transformers store energy during the ON-time, and deliver it to the secondary during the OFF-time. In this way, currents never flow on the primary and secondary winding at the same time.

Flyback transformers are designed with minimal leakage inductance, minimal winding and core losses with an air gap added to avoid saturation. High frequency operation causes electrons to flow only on the outermost diameter of the windings (known as a "skin effect"), increasing resistance to current flow, power dissipation, and heating of the transformer. High-frequency transformers are designed using multiple strands of windings (or Litz wire) to gain cross sectional area for current to flow while reducing the AC power losses.

The window shape of the transformer core used for the winding area should be as wide as possible to minimize the number of layers, winding losses, and the leakage inductance. E-type or Pot cores with an internal air-gap are the best choice for low cost and lower leakage inductance. Core losses depend on the core materials selected and the amount of flux swing allowed without use of saturation and switching frequency. To reduce core losses, it is necessary to adjust the flux density to limit increases in the core temperature rise. Limiting core loss density to 100-300 mW/cm^3 keeps the temperature rise at approximately 40°C. Generally, Ferrite-P and -K material are the preferred materials for flyback transformers.

To assist you in the design of a flyback power supply, a Mathcad file containing equations needed to calculate all external components can be found at the National Semiconductor Web site: http://power.national.com

Additional Information

power.national.com
www.national.com/appinfo/power/hv.html

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