

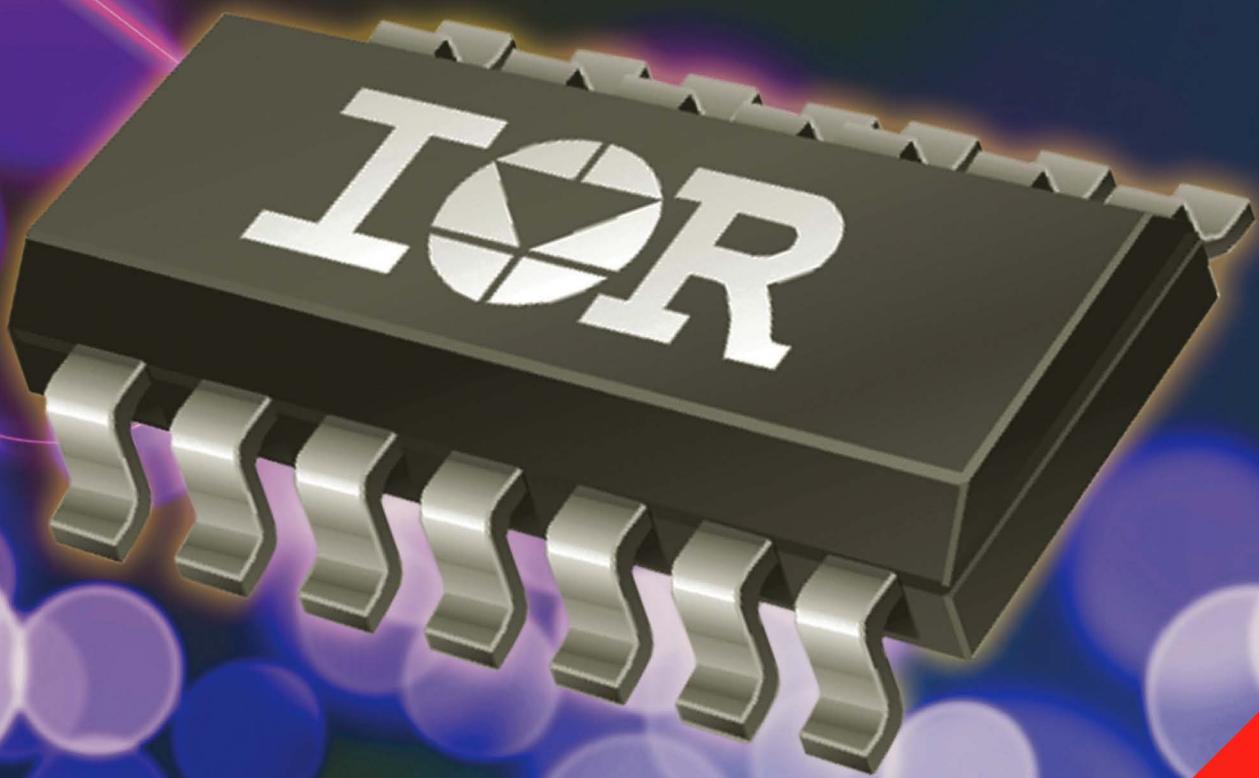


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April 2010
Supplement to EPN
Nº 04

power management

Power Factor
Correction Key to
Meeting Energy
Star Rating
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LED

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Cover: International Rectifier's IRS2548D Front end and half bridge with dimming charge pump.

Energy management and alternative energy sources are both giving impetus to advances in power electronics. EPN is pleased to bring you this Power Management supplement to look at some of these topics. To enquire about any advertisements or products covered in this supplement, you may use the reader enquiry card or enquire online at www.epn-online.com.

power management

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Power Factor Correction Key to Meeting Energy Star Rating

By Peter B. Green, International Rectifier

A non-dimming LED driver with no power factor correction generally consists of an off line switching power supply configured to regulate the output at a constant current. This is not much different from a standard off line switching power supply such as the types commonly used in AC/DC adaptors. On December 3 2009 the US (DOE) Department of Energy released the final version of Energy Star Program requirements for Integral LED lamps, which mandates that power factor must be better than 0.7 for domestic applications for LED drivers. The requirement for industrial applications is expected to be better than 0.9.

There are two basic approaches to power factor correction, each of which requires some additional circuitry at the front end of the converter; the simple low cost passive PFC and the more complex active PFC. Before exploring these methods in greater depth it should be mentioned that in order to gain Energy Star rating the LED driver must also be dimmable. This generally means dimmable from existing wall dimmers based on the phase cut principle of operation originally designed to work with purely resistive incandescent lamps.

Fluorescent lamps

The adoption of LED lighting in off line applications such as office lighting, public buildings and street lighting is increasing and is predicted to continue to do so for the next few years. In these

applications high power LEDs replace linear or high power CFL fluorescent lamps, HID (metal halide and high pressure sodium) lamps as well as incandescent lamps. These applications require an LED driver, which will typically range from 25W to 150W. In many cases the LED load is comprised of an array of high brightness white LEDs often packaged in multiple die form. In LED light fixtures galvanic isolation is required to prevent electric shock risk where LEDs are accessible, which is in most cases. This is because, unlike for example fluorescent light fixtures which do not need to be isolated for safety, the LED die need to be connected to a metal heatsink. It is therefore the best option to provide isolation within the LED driver itself and this dictates the power converter topologies that are suitable. The two possibilities are the flyback converter or a multi stage converter that includes

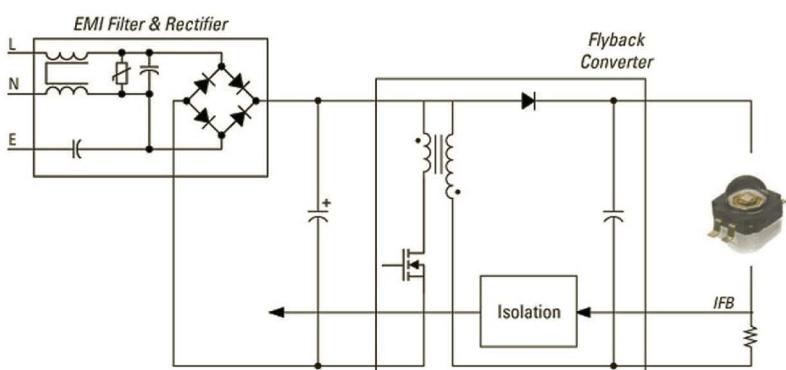


Figure 1: Flyback converter – simple diagram.

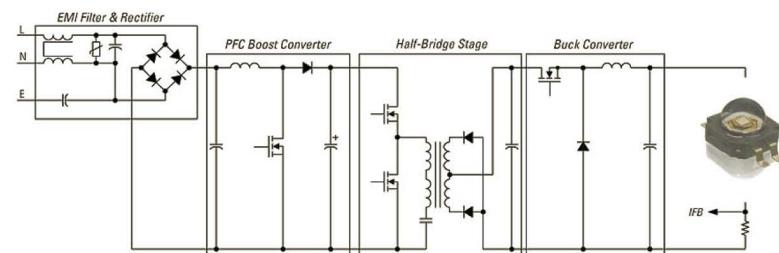


Figure 2: Multi stage Converter – simple diagram.

a PFC stage, followed by an isolation and step down stage and finally a back end current regulation stage. Of the two the flyback is the more popular due to its relative simplicity and low cost. The flyback converter offers a good solution for many applications; however it has the following limitations: 1) Limited power factor correction ability, 2) Limited efficiency over wide input voltage range, 3) Output ripple at twice the line frequency (<150Hz) cannot be easily eliminated and, 4) Additional circuitry is required for dimming.

Output ripple

The multi stage design can overcome these problems, although its additional cost limits its adoption to higher end products. High power factor and low total harmonic distortion (THD) can be achieved over a wide AC input voltage range allowing the same LED driver to operate from a 110, 120, 220, 240 or 277V mains supply. Efficiency can be maintained over this range rather than peak at a specific line load point and drop off significantly under different conditions. It is also much easier to minimise output ripple under 150Hz and the multi stage system lends itself more effectively to the different methods of dimming.

The multi stage LED driver in this example will be broken down into three sections: 1) The front end, (PFC) power factor correction section, 2) The isolation and step down section, 3) The back end, current regulation section. The front end section consists of a boost converter configured as a power factor correcting pre-regulator that delivers a high voltage DC bus. Since the regulat-

ing control loop response is slow and takes many cycles of AC line frequency to react to line load changes, it draws an essentially sinusoidal line input current. This circuit typically operates in critical conduction mode otherwise known as transition mode. In this mode the PWM off period and therefore the switching frequency is variable such that the new switching cycle begins at the point when all of the energy stored in the boost inductor has been transferred to the output. This resonant mode of operation is widely used and offers high efficiency due to minimal switching losses. The middle stage converts the high voltage DC bus voltage (typically around 475V) to a low voltage output suitable for driving LED loads.

Transformer primary

For safety reasons LED loads are normally driven from low voltage and therefore drive current is often at least 1A. The configuration of the isolation and step down stage recommended here is a resonant half bridge consisting of a pair of switching MOSFETs driven in anti-phase with each other. The mid point of these switches supplies one end of the primary winding of a high frequency step down transformer and the other end is connected to a capacitive divider network from the DC bus to the zero volt return. In this way the transformer primary sees a square wave voltage of equal positive and negative amplitude. The secondary winding will be center tapped in order that a two diode rectifier can be used to convert the output back to DC. Where the output current is sufficiently high the rectifying diodes can be re-

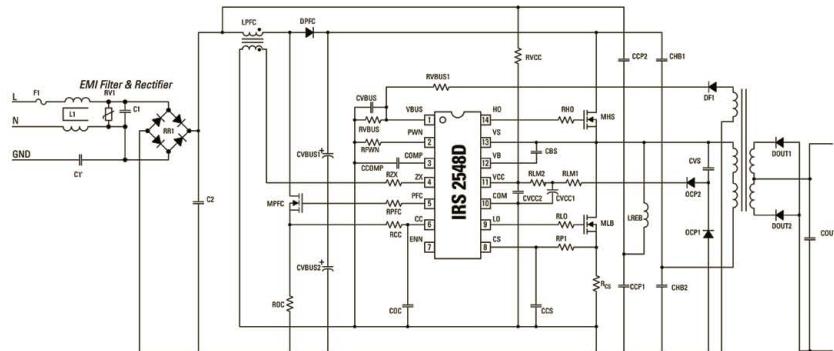


Figure 3: Front end and half bridge with dimming charge pump.

placed with MOSFETs operating as a synchronous rectification system. In a typical application running at 3 Amps, the surface temperature of synchronous MOSFETs was measured at 30 degrees C lower than Schottky diodes having the same package. It can be seen that as the current requirement increases the thermal benefits of synchronous rectification become very significant. Finally a smoothing capacitor is required to produce an isolated DC voltage with low ripple. This can be in the order of tens of micro-Farads and therefore ceramic capacitors can be used.

In order for the half bridge stage to operate efficiently it should be designed to operate in resonant mode where the MOSFETs switch at zero voltage (ZVS). This is accomplished by ensuring that there is a short delay between the time when one MOSFET switches off and its counterpart switches on and that during this time the voltage at the mid point commutes from one rail to the other. This happens due to the release of energy stored in the inductor conducting through the integral body diodes of the MOSFETs. It is necessary for the primary of the transformer to possess sufficient leakage inductance in order for sufficient energy to be stored to allow commutation to take place.

Dimming operations

This makes the transformer design rather more complicated and one easy way to get around this difficulty is to use a standard high frequency

transformer design without additional leakage inductance added into its design and to simply add another inductor in parallel with the primary solely to facilitate commutation. This extra inductor can also be used to aid dimming operations from triac-based dimmers, therefore adding justification for the extra cost and space. The back end stage of the LED driver consists of a current regulating circuit with short circuit protection. This compensates for variations in total LED forward voltage over temperature and device tolerance and also limits the current in the event of a short circuit or other fault condition thereby protecting the driver against damage. A multi channel approach is also possible where several output stages are connected to a single isolated DC voltage supplied by the previous stage. Most dimmers commonly available operate by means of leading edge phase cutting using a very simple circuit based around a triac. The principle of operation consists of firing the triac at a point in the AC line cycle so that it conducts until the end of the cycle at which point the line voltage drops to zero and consequently so does the current flowing through the triac, which causes it to switch off again. Triac devices have a minimum rated holding current below which will switch off. Adjusting a potentiometer in the circuit controls the firing point of the triac in the dimmer circuit and changes the overall average AC current passed through enabling dimming.

Additional current

LED converters and other power supplies or electronic ballasts however do not represent a purely resistive load to the dimmer even when they include a power factor correcting front end. To overcome this limitation, instead of returning the commutating inductor from the primary side of the step down transformer to the mid point of the capacitive divider, the current can be fed through a DC blocking capacitor back to the line input. This provides a small amount of additional current which will keep the triac from switching off before the end of the AC line cycle and allow it to operate as required over the range of dimming.

Dimming in this way works because as the dimmer level is reduced the output bus voltage from the front end stage also drops. This results in the secondary voltage also dropping and since LED loads have a fixed total voltage drop a small variation in voltage causes a large variation in current and therefore light output. In this way linear dimming of LEDs is realised, which circumvents the need for more complicated PWM dimming circuitry as well as avoiding possible patent infringement.

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