An Integrated Switching IC Incorporating an Innovative Feedback Method for Switching Power Supplies

Robert MAYELL (BEng. CEng. MIEE)
Manager of Applications Engr.
Power Integrations
Headquarters
477 N.Mathilda Ave.
Sunnyvale, CA 94086
Phone +1 408 523 9200
Fax +1 408 523 9300
email: rmayell@powerint.com

E.H.Quek
Sr. Field Applications Engr.
Power Integrations
Singapore Lab/Office
Blk 248 #24-358
Bishan St. -22
Singapore 570248
Phone +65 453 5523
Fax +65 451 4508
email: quekeh@singnet.com.sg

Abstract *-*
For many years Switched Mode power supplies have used linear PWM feedback for controlling the power supply. This can be used with a multitude of different modes and power supply topologies. However Linear PWM feedback has limitations in bandwidth, cost and the inability to adequately reduce power consumption when operating equipment at low power (or standby mode).

This paper will present a New Technology which will allow high bandwidth (improved regulation), Energy efficiency all at a significantly lower cost than other solutions. The Technology is in the form of TinySwitch, a new product utilizing the EcoSmart technology (ON/OFF Control) from Power Integrations.

Introduction

There are many types of switched-mode power supplies but the majority of them use a proportional feedback method. The most common method is pulse-width modulation (PWM) and Ringing Choke Converters (RCC). These power supplies have many discrete components which use additional board space and require component placement which add to system costs. The PWM and RCC power supplies suffer from low-efficiency at light output loads due to fixed losses in the power supply. Also PWM and RCC power supplies have limited loop bandwidth both in the feedback loop and the method of transmitting signals across safety isolation.

There is a solution to these issues and it is presented in this paper. The solution has improved efficiency at low power, significantly lower component count and high bandwidth. The first part of this paper describes the issues with RCC and PWM power supplies. The second part explains in detail a new type of power supply to offer improved performance.

Typical PWM Feedback Power Supply

This section looks at some of the issues with typical PWM and RCC power supplies.

Loop Bandwidth (Limited For Stability Reasons)

The loop bandwidth is usually limited for reasons of stability when operating in continuous mode (with Fly-back topology). However it should also be pointed out that the use of a **linear error signal** means that spurious noise can also couple into the feedback path. The feedback bandwidth is also reduced in order for such noise to be averaged out.

The main affect of reducing the feedback bandwidth is a reduced ability to respond to transient load conditions (both in time to respond and also in the magnitude of overshoot when load is removed).

Note:- In the case of Voltage Mode continuous mode Fly-back , the right half plane zero requires the feedback bandwidth to be reduced to ensure stability. This prevents the power supply from reaching the region where the right half plane zero would cause problems.

Feedback Isolation (Transformer Bias Winding Required)

Most AC-to-DC power supplies, require isolated output for a safety. This means that the primary side of the power supply is "safety" isolated from the secondary and as such the power supply controller does not have direct access to the voltage which it is trying to regulate.

There are two commonly used ways to transmit the feedback signal across the isolation barrier. These are Opto-Coupler and a "bias winding" (a primary side referenced winding on the transformer).

The Opto-coupler is used to transmit an error signal across the isolation barrier. This is usually done by referencing the Opto-LED cathode to a reference voltage and then applying the actual output voltage to the anode of the Opto-LED. The gain of this error signal can be controlled via the reference using external resistors and depending on the accuracy of the reference, can provide highly accurate voltage regulation (e.g. ±1%).

A "Bias winding" is a winding on the transformer, which for Fly-back power supplies is in-phase with the secondary windings. When the switch is off, the bias winding voltage is proportional to the output voltage on the transformer secondary. However the bias winding voltage is influenced by other parasitic elements (such as primary leakage) and as such can only be used to provide crude output voltage regulation (e.g. ±10-15%) under a limited load range.

In most cases, even Opto-feedback requires a primary bias winding. It is used to provide a DC-voltage from which the Opto-transistor can reconstruct the error signal. It should also be noted that nearly all primary side controllers require a bias winding in order to power the controller itself.

Opto-coupler In The Feedback Loop

In most applications, the bandwidth of the feedback loop is limited in order to improve power supply stability (especially in the case of continuous mode Fly-back). Under these conditions, the speed of the Opto-coupler is sufficient to match the rest of the loop.

The Opto-coupler transmits a linear error signal to the primary side controller. The Opto-coupler has a definite signal to noise ratio (SNR) depending on the level of Opto-LED drive signal (larger the drive the larger SNR). Also the Opto-LED drive level can be increased in order to speed up the Opto-coupler (max. drive level is usually determine as function of required Opto life).

The Opto-transistor cannot respond as quickly at the Opto-LED. The Opto-transistor is actively driven when it is turning on (receiving base drive in the form of photons), but cannot turn-off at the same speed. Instead it relies on leakage of charge away from the base in order to turn off. The speed at which this can occur is a function of two things ; 1) how much charge is trapped on the base (i.e. a function of how hard the Opto-LED was driven), 2) the temperature of the Opto-transistor (which determines charge mobility).

It can be seen, that the Opto-LED drive needs to be high in order to achieve a high SNR, but this has a negative impact on the recovery period of the Opto-transistor. Practical drive levels of 1-10mA are used to achieve acceptable SNR and at these drive levels an Opto-coupler would have a bandwidth of 10kHz or less for practical use.

Minimum Duty Cycle

As mentioned previously, many switched mode power supply controllers require a primary bias winding in order to provide power to the controller itself. Some primary side controllers require a minimum duty cycle in order to guarantee that this bias voltage is maintained at a sufficient level .

The minimum duty cycle requirement, has two significant affects on the overall performance of a power supply. When minimum duty cycle is present, so there is a need for a pre-load (minimum load) on the output of the power supply. Without this minimum load, the output voltage could rise above acceptable limits. When operating in standby mode (i.e. when the power supply is delivering very little power). This is also worst at high input voltage because the fixed minimum duty cycle means highest delivered power at high line.

Low Load Power Supply Efficiency

The efficiency at low loads is often dominated by the Switching Losses of a power supply. The switching losses comprise primarily the discharging of stray capacitance every time the Power MOSFET turns on. At low loads these switching losses soon often exceed the actual power delivered to the load.

For a PWM-based power supply, switching losses (charging/discharging of parasitic capacitance in the power supply) remain constant regardless of load. At lower loads the switching losses become a dominant portion of the efficiency of the power supply. Under no-load the switching losses in a PWM-based supply are in the order of 0.6W. This is because the PWM and RCC solutions continue to switch the Power MOSFET at high frequencies (high f_{Switch}) , when there is zero output load.

$$P_{Switching\_Loss} = 0.5 \cdot C_{Stray} \cdot V_{Input}{}^{2} \cdot f_{Switch}$$

EcoSmart Technology Products

TinySwitch is a breakthrough in switched mode power supply technology. It allows very low power supply consumption at low-load along with superior power supply regulation at normal loads. It does all of this using less components in a power supply which is both cheaper to build and physically smaller.

Current Limit ON/OFF control

This new device uses a version of current mode control called ***current limit ON/OFF control*** (different from conventional current mode control). This new control scheme eliminates many of the normal drawbacks of current mode control while at the same time increasing the feedback bandwidth and improving overall regulation.

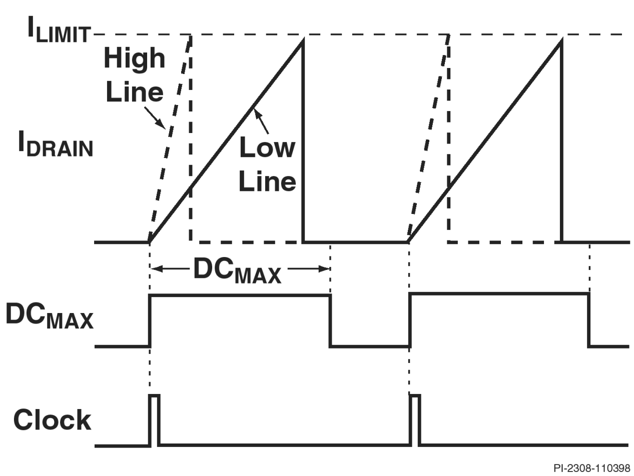


Fig 1. Current Limit ON/OFF control - switching current waveforms

Current limit ON/OFF control works by switching a defined packet of energy per switch cycle. The device has an internal oscillator which controls each cycle. At the beginning of each switching cycle, the device determines whether or not a new packet of energy needs to be switched to the secondary in order to maintain regulation. If the answer is no, then the device will wait for the beginning of the next cycle and repeat the process. If the answer is yes (that a packet of energy needs to be switched), then the switch will turn on. The switch will turn-off again when it reaches either maximum duty cycle (D_{max}) or when the primary current in the transformer reaches the current limit (I_{limit}).

Advantages of EcoSmart Technology Products

There are many advantages of *ON/OFF control* over typical PWM feedback.

- excellent standby power effeciency (power efficiency is constant down to very small loads)
- high feedback bandwidth
- excellent regulation
- switching losses scale with load
- excellent input voltage ripple rejection (current mode)
- low signal to noise ratio requirement for feedback isolation method
- no minimum load requirement

Self Powered From Drain Pin (No Bias Winding Required)

The device is one of the first AC-to-DC power controllers which does not require a Bias winding (auxiliary power winding). Instead the device powers itself, directly from the input voltage applied to the Drain pin of the device.

This eliminates the Bias winding, which allows for a lower cost transformer. A simple two winding approach can be taken when using triple insulated wire (no tape required).

The elimination of the Bias winding is also significant for applications such as battery chargers, where the output voltage can fall to zero. When using a normal PWM controller, this would require using a forward bias winding along with minimum duty cycle and extra circuitry to guarantee enough power to maintain the controller in operation. However with EcoSmart Technology Products, no Bias winding or extra circuitry is required.

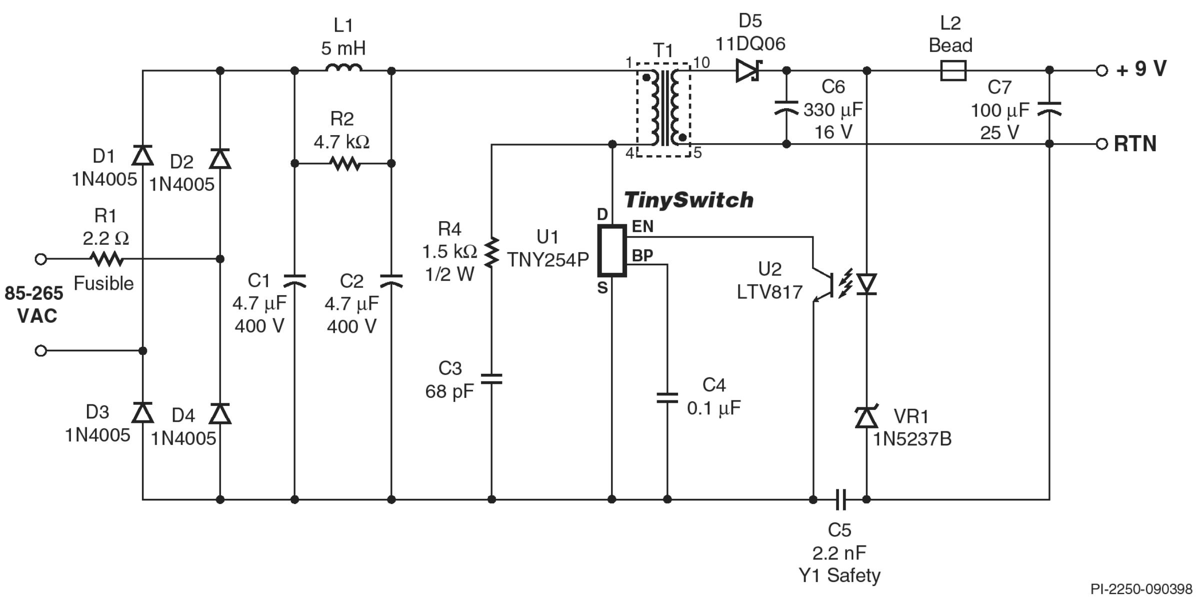


Fig 2. Circuit Schematic For 3W Power Supply With 85Vac to 265Vac Input Voltage, Using EcoSmart Technology

Opto-Coupler Considerations (Low Opto-LED Drive Allows High Bandwidth)

The use of *ON/OFF control* means that signal to noise ratio is no longer a limitation for transmitting the feedback signal. As a result the Opto-LED drive level can be significantly reduced. This in turn has a significant effect on the recovery time of the Opto-transistor, meaning that the overall bandwidth of the Opto-coupler can be increased.

As a comparison, a typical power supply using PWM control might operate at less than 3kHz bandwidth. A typical ***Current Limit ON/OFF Control*** power supply using might operate at 44kHz or 130kHz bandwidth (an increase of 15 to 44 times).

Note: in ***Current Limit ON/OFF Control*** power supply there is no Bias winding required. The Opto-transistor just pulls-down on the Enable pin of the device. Direct feedback (for non-isolated supplies) is also possible using a transistor instead of an Opto-coupler.

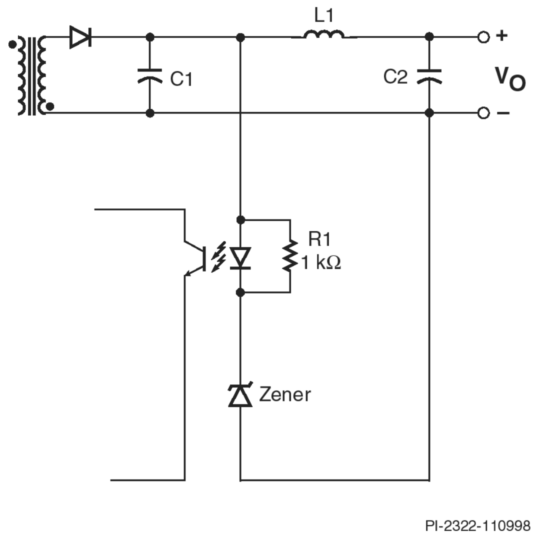


Fig 3. Zener/Optocoupler Feedback

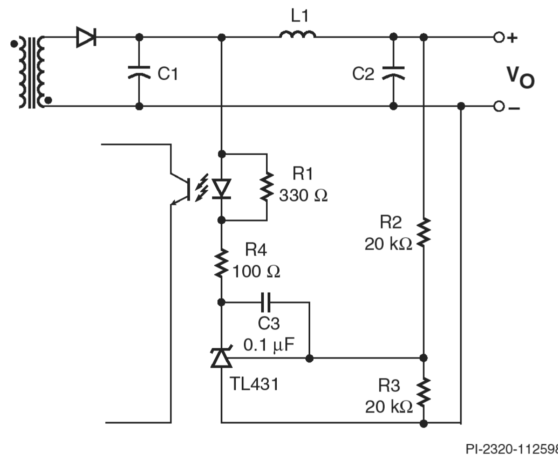


Fig 4. TL431/Optocoupler Feedback

Transient Response (High Bandwidth Provides Good Transient Response)

Due to the extremely high bandwidth of the EcoSmart Technology Products (44kHz or 130kHz) , so the transient response of the power supply is excellent (as can be seen in Fig 5). The output voltage changes by approximately 10mV for a step load change of 75% to 100%. There is extremely small overshoot or undershoot due to the high bandwidth.

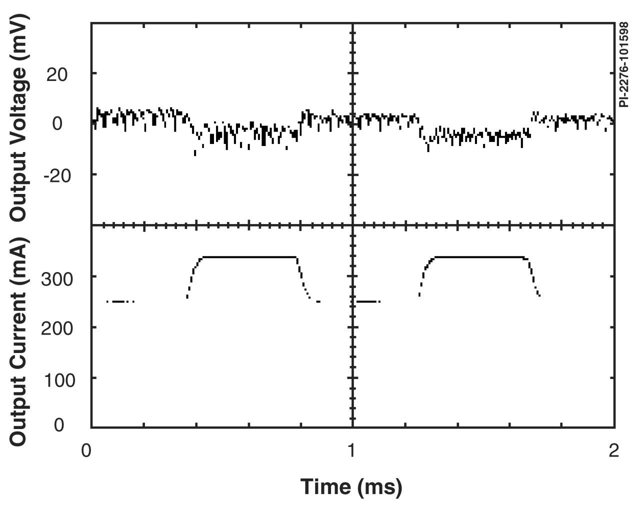


Fig 5. Transient Response (75% to 100% Step Load)

Output Ripple Voltage (Deterministic Ripple Voltage)

The functionality of the device leads to a deterministic ripple voltage. The ripple voltage is determined by the input inductor, the output capacitance and the gain of the Opto-coupler feedback. For a power supply using EcoSmart Technology Products, the ripple voltage is constant for all loads.

For a PWM based power supply, the designer usually has to trade off the frequency response of the power supply, versus the output ripple requirements. If the output requires very small ripple voltage then the output capacitor is usually increased. However the output capacitor is a significant part of the power supply feedback loop and therefore this can significantly affect the frequency response of the power supply.

In a TinySwitch power supply, the frequency response of the power supply is independent of the output capacitor value. Due to the extremely high bandwidth of the power supply, the output ripple voltage is also constant for less stable loads (where frequent step changes in load may occur).

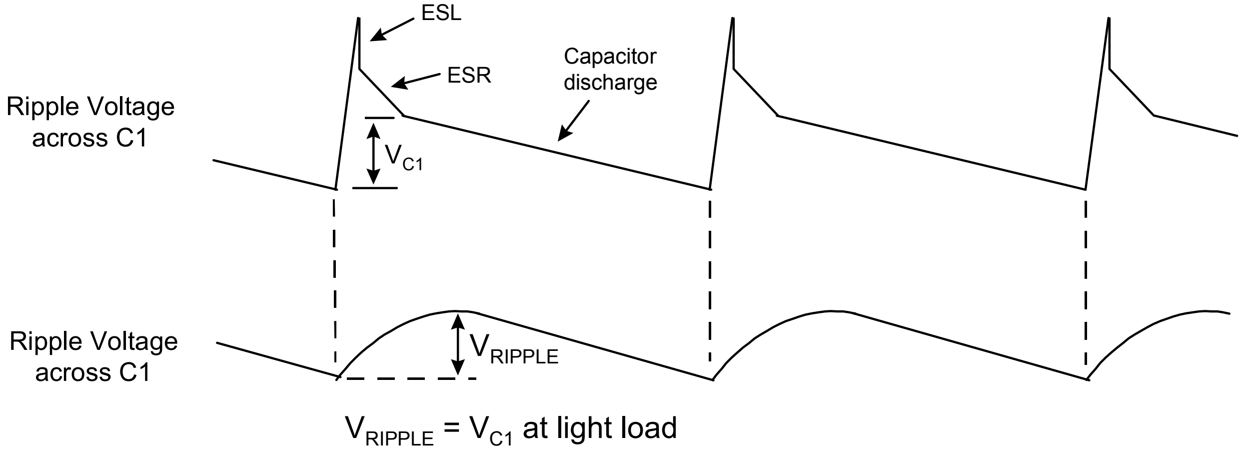
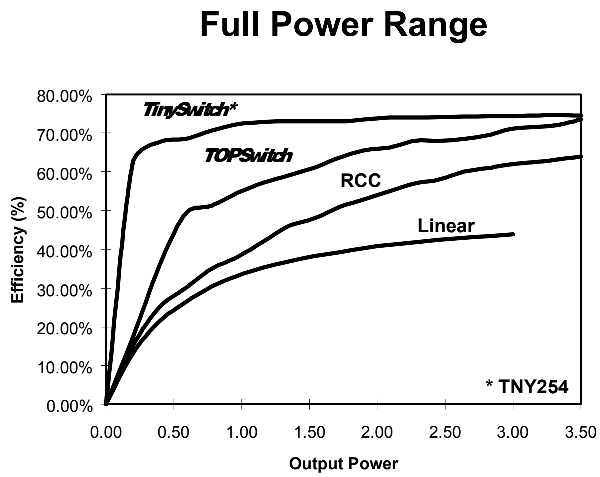


Fig 6. Switching Frequency Ripple At Output

Efficiency (Switching Losses)

The ultra-low controller consumption in EcoSmart Technology Products, allows them to do away with Minimum Duty Cycle requirements. The device can operate close to ZERO switching frequency (when the output load is disconnected the device does not switch for up to 1000 cycles or more).

In a ***TinySwitch*** supply, switching losses are a constant percentage of the output power (down to extremely low load). At ZERO load the switching losses are <0.1W for a 3W (85-265VAC). This has been achieved by minimizing all current consumption within the device controller to the extent that the it consumes less than 30mW at 115VAC (70mW at 230VAC).



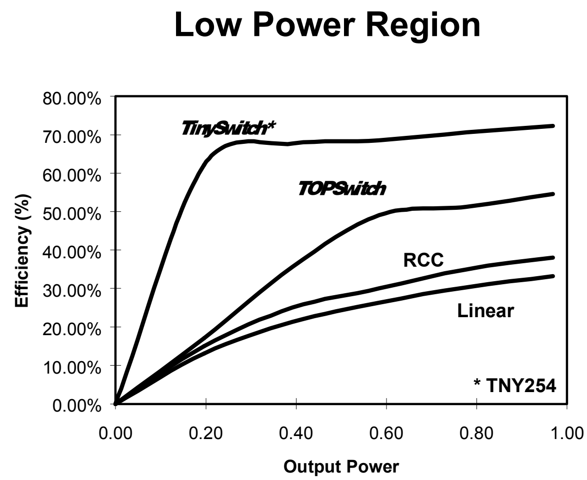


Fig 7. Power Supply Efficiency Comparison - ON/OFF Control Maintain High Efficiency Down To A Fraction Of A Watt

Conclusion

There is a clear advantage of *ON/OFF control* over traditional PWM-based power supplies. This paper has highlight the superior performance in almost all categories (standby power , high feedback bandwidth, excellent regulation, switching losses, excellent input voltage ripple rejection, no minimum load requirement).

TinySwitch forms a fundamental step forward cost/performance equation for power supplies and at the same time enables the new Energy Efficiency standards to be easily achieved at low-cost.

Bibliography

[1.] Marty Brown. "Practical Switching Power Supply Design" , Acedemic Press, Inc. Copyright 1990
[2.] Abraham.I.Pressman. "Switching Power Supply Design", McGraw-Hill, Inc. Copyright 1991
[3.] Power Integrations , "RD5 TOPSwitch II - Reference Design board - 85 to 265VAC Input , 20W(30W Peak) Output", Power Integrations 1997
[4.] Power Integrations "RD7 TOPSwitch II - PC standby reference design board - 90 to 375VDC Input , 3.5W Output" , Power Integrations 1998
[5.] Power Integrations , "RD8 TinySwitch - Reference Design Board - 85 to 265VAC Input, 3W Output", Power Integrations 1998
[6.] Power Integrations, "TNY253/254/255 TinySwitch Family - Energy Efficient, Low Power Off-line Switchers", Power Integrations 1998