Single Chip Delivers Low Power, Off-Line Switching Converter

Monolithic power IC exhibits high-integration level and design simplicity allowing development of low-component count switching power supplies.

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The old-fashioned linear way of using large line frequency transformers is often the approach employed to design lower power ac-dc power supplies. Although low cost is the main driver for the linear approach, it has definite weight and size drawbacks and does not work everywhere in the world. Further disadvantages of linear power supplies are the low efficiency and the energy waste in no load or standby conditions, a key design consideration as emerging government regulations begin dictating acceptable levels. On the other hand, traditional discrete switching power supplies can address some of these issues. However, the increased cost involved in circuit implementation prevents the prevalence of this approach at levels below a 15W output.

A new generation of highly integrated off-line switcher ICs, TinySwitch-II, offers a high level of integration and circuit simplicity that delivers a low-cost power supply. Its built-in EcoSmart® technology reduces the energy consumption in no load conditions to practically zero.

Based on a proprietary lateral CMOS process, TinySwitch-II incorporates all the required building blocks to form the primary side switching section in a monolithic IC. It contains a 700V power MOSFET, voltage regulator, digital controller with oscillator, and various protection features, such as cycle-by-cycle current limit, auto-restart, and thermal shutdown. The internal regulator supplies the IC from the drain pin, thus saving the extra bias winding and its associated components typically required in traditional switching power supplies. At +135°C junction temperature, it shuts down to prevent any thermal overload in case of a catastrophic failure. The device automatically resumes operation when the temperature falls to +65°C. In a continuous thermal fault condition, this 70°C hysteresis keeps the average temperature of the associated p. c. board at safe levels below +100°C.

With a 132 kHz internal clock frequency, it can deliver as much as 4W to the output with a low-cost EF12.6 or EE13 core. However, under its unique on/off control, the actual load conditions can adjust the effective switching frequency by sampling the output voltage at the rising edge of the internal clock. Each time it detects a high signal at the Enable pin (**Fig. 1**), the device initiates a full switching

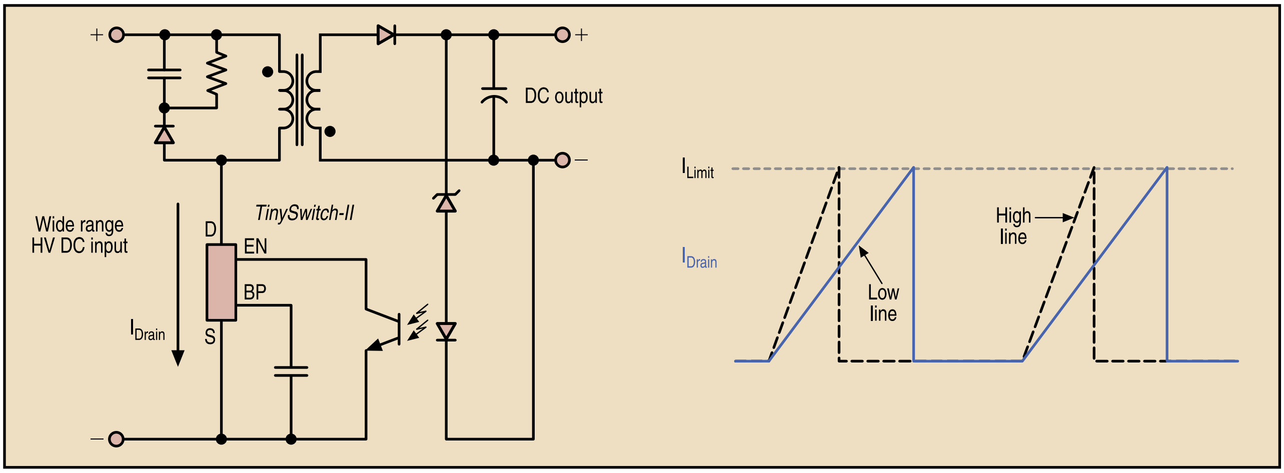

Fig. 1. *TinySwitch-II principle of operation.*

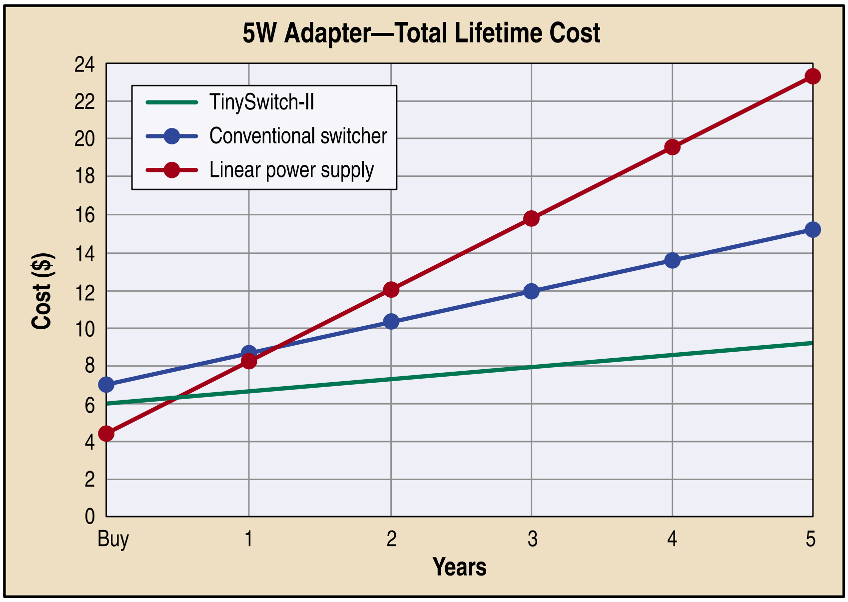

Fig. 2. *Total lifetime cost of three different 5W adapters.*

period. Conversely, if the device detects a low signal at the Enable pin, it skips the switching period. Drawing 240µA from the Enable pin establishes a low signal. When the current in the primary winding reaches the internal current limit, it terminates the switching period on-time. With this current limit mode of on/off control, the device delivers the same amount of energy each switching cycle. In the discontinuous mode, the transformer primary inductance, current limit, switching frequency, and efficiency govern the power delivered to the output:

$$P_{OUT} = \frac{1}{2} \times L \times I^2_{LIMIT} \times f_{SW} \times \eta \qquad (1)$$

P_{OUT} = Output power
f_{SW} = Switching frequency
I_{LIMIT} = Current limit (NOTE: I_{LIMIT} is the current limit, the equation above uses it squared)
η = Efficiency

In light or no load conditions, the IC could decrease its effective switching frequency to within the higher end of the audio range. To prevent transformer audible noise in this mode, the device has an integrated intelligent current limit state machine. This reduces the internal current limit in discrete steps with the load current going down, thus reducing the flux swing in the ferrite core. This technique practically eliminates audible noise with traditionally manufactured transformers using varnish rather than special glue to fix the core halves.

To further reduce system cost, the device introduces a small amount of frequency jitter, typically ±4 kHz, which dramatically reduces EMI emission. On average, it can reduce EMI approximately 5 dB to 10 dB, which allows the use of smaller and less expensive filter components. Tight tolerances of key internal parameters, such as current limit and switching frequency, are mandatory to keep system cost low. Device specifications are a current limit tolerance of only ±7% and a switching frequency tolerance of ±6%. Tight tolerances improve producibility and remove the need to overdesign the transformer, clamp, and output components [2].

The entire family consists of four members (**Table 1**) that can deliver up to 23W output at European mains or up to 10W with a universal input in an adapter application.

EcoSmart Technology

Many consumer electronic systems have a standby mode that offers instant availability. In other cases, like cell phone chargers, the power supply or wall adapter typically remains in the ac outlet—although the load (cell phone) isn't connected most of the time. Both cases consume energy, and yet the product is not in use. A study performed in the United States [3] found that the average household has 19 appliances with standby power. These appliances consume on average 3.5W or in total 67W representing 9% of the annual electricity use of the households investigated. To minimize this energy waste there are many programs that help to reduce this standby power. Probably the most familiar are Energy Star in the United States, Blue Angel in Germany, or the new European "Code of Conduct on Efficiency of External Power Supplies." This code proposes a maximum input power of 300mW for supplies in the sub 15W class in 2005.

To minimize the power consumption, TinySwitch-II has EcoSmart technology built-in that automatically detects a light or no load condition at the output. The device accomplishes this by reducing the switching frequency drastically, thus decreasing the dominant switching losses. With this technique, the power consumption in a no load situation is typically only 110mW or 210mW at 115Vac and 230Vac, respectively. This not only saves energy, but also saves operating costs.

Fig. 2 is an example of a case study that compares the total lifetime cost of three different 5W wall adapters over five years. However, besides the purchase price, it considers the energy cost based on real-life assumptions. Here, the supplied electronic device operates for one hour per day and stays unconnected for the rest of the day, yet the adapter remains in the wall outlet. The TinySwitch-II based adapter offers a full load efficiency of 72% and a no load power consumption of 210mW. A conventional switcher is also 72% efficient, but consumes 1W during no load. The worst case is the regulated linear adapter consuming 2.5W during no load and only 45% efficiency at full load.

Because of its integrated EcoSmart technology, the TinySwitch-II adapter consumes less energy during no load than during the 1-hr operating time of the electronic device. The conventional

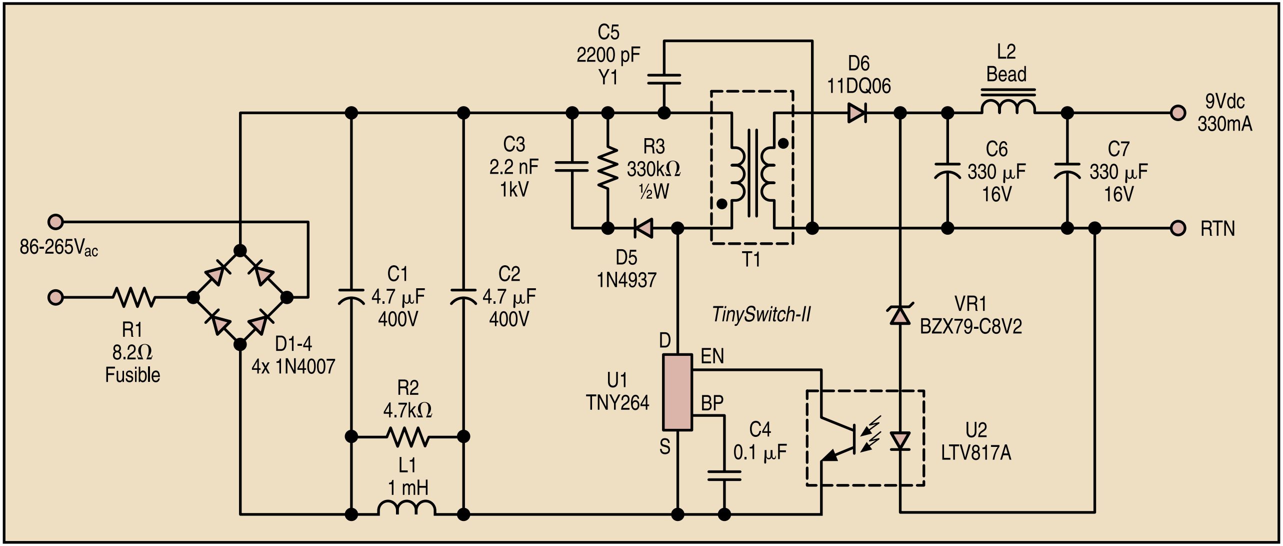

Fig. 3. *Single 9Vdc, 330mA output power supply employing TinySwitch-II.*

switcher consumes more than three times the energy during the no load situation. Obviously, the linear-regulated adapter wastes the most energy by a factor of more than five times. The total annual consumption of the linear adapter is 25.1 kWh, for the conventional switcher 10.9 kWh compared with 4.3 kWh for the TinySwitch-II adapter.

With an assumed energy cost of \$0.15/kWh and despite a slightly higher purchase price compared with the linear adapter, the payback for the TinySwitch-II power supply is only six months. Over the total lifetime of 5 years, the money savings add up to \$14 compared with the linear regulator and up to \$6 compared with the conventional switcher.

Universal 3W adapter

Fig. 3, on page 14, shows a single output flyback converter running from universal mains with TinySwitch-II. This example circuit operates over a universal input voltage range and provides a 9Vdc output at 3W. As with linear power supplies, the transformer only requires two windings, because this device is self-powered from the drain pin.

Compared with traditional switching technology, this saves the bias supply winding and the associated components. The efficiency of this power supply is a minimum 70% at full load and it consumes a maximum of 220mW in a no load condition at 265Vac input.

Rectifiers D1-D4, C1, and capacitor C2 rectify and filter the ac input to create a high voltage dc bus connected to the transformer T1. The fusible, flameproof resistor R1 takes the place of a fuse to reduce system cost; it also provides differential mode noise filtering. It only requires very simple, low-cost filtering thanks to the frequency jitter of TinySwitch-II to meet international standards for conducted EMI, such as CISPR22 class B or EN55022 class B. The circuit requires no common mode choke or X-rated capacitor. A simple π-filter formed by inductor L1 along with C1 and C2, plus the safety rated capacitor C5 is sufficient. Resistor R3, C3, and D5 form a clamp circuit that limits the turn-off voltage spike caused by the leakage inductance of the transformer T1 to a safe level on the TNY264 drain pin. Rectifier D6 and capacitor C6 rectify and filter the output. The second stage output filtering consists of the ferrite bead L2 and the output capacitor C7. This filter eliminates high frequency switching noise and reduces output ripple to below 80mV_{PP}. If required, replacing the ferrite bead with a 3.3-µH inductor can decrease the ripple further.

Zener diode VR1 and optocoupler U2 establish the output voltage. The supply achieves a ±5% voltage tolerance, including load and line regulation with this simple and low-cost feedback circuit.

Another advantage of the digital on/off control loop is

Output Power Table				
	240Vac ±15%		85Vac to 265Vac	
Product	Adapter	Open frame	Adapter	Open frame
TNY264P or G	5.5W	9W	4W	6W
TNY266P or G	10W	15W	6W	9.5W
TNY267P or G	13W	19W	8W	12W
TNY268P or G	16W	23W	10W	15W

TinySwitch-II family.

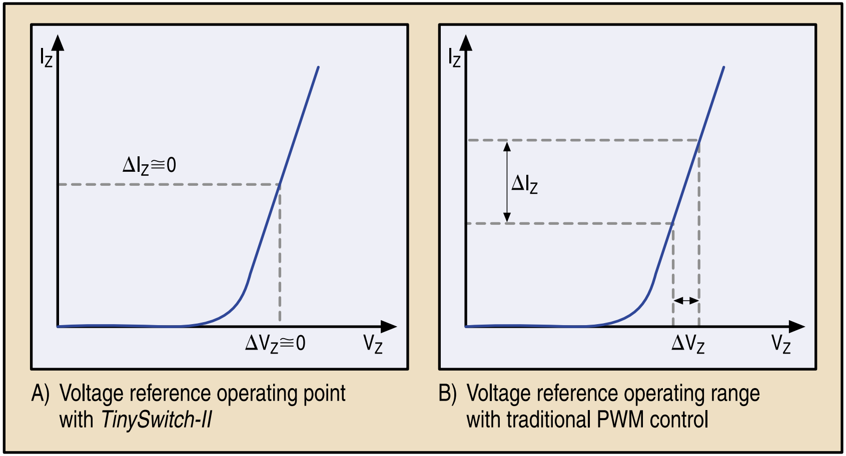

Fig. 4. *Zener diode operating points in TinySwitch-II and PWM controlled power supplies.*

that the Enable pin has a single threshold current of 240µA with no hysteresis to speed up the response time during transient load conditions (see **Fig. 4**). This effectively leads to no current changes through the reference zener diode on the secondary side, cutting down the voltage variation of the zener to zero.

In contrast, a traditional PWM-controlled power supply typically requires a current change in the zener of a couple of mA to generate the error signal for the control loop over the entire load and line range. Because of this, the PWM-controlled supply's associated zener voltage variation forces these designs to use a more sophisticated and expensive voltage reference IC such as a TL431 to achieve the same output tolerance.

References

1. *Power Integrations, Inc., TNY264/266-288 TinySwitch-II Family, Datasheet, March 2001.*
2. *Stefan Bäurle, Controlling the cost of power supply design, PCIM Europe, January/February 2001, p. 36-40.*
3. *Alan Meier, J.P. Ross, Whole-House Measurements of Standby Power Consumption, 2nd Proceedings of the International Conference on Energy Efficiency in Household Appliances, Naples (Italy), September 2000.*

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