A New Integrated Switcher IC Family -- A Feature Rich Solution for Demanding Power Conversion Applications

Robert MAYELL (BEng. CEng. MIEE)
Manager of Applications Engr.
Power Integrations, Inc.
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, Inc.
China Lab/Office
Rm 1705, Blk A
Bao Hua Bldg
1016 Hua Qiang Bei Lu
Shenzen GuengDong
PRC 518031
email: quekeh@singnet.com.sg

Abstract

The first generation of monolithic integrated switchers were simple, low-cost designs with limited flexibility but have resulted in over half a billion integrated switchers already in the field. New applications and market pressure are requiring a continued reduction in system cost, improvement in performance and flexibility (optimization) in design.

This paper gives a general introduction to some of the added features and performance of the TOPSwitch-FX. The paper explains the overall functionality and goes into a finer level of detail on features such as Frequency jitter, soft-start and Under-voltage lockout. The TOPSwitch-FX builds on the proven technology of TOPSwitch but integrates the flexibility and new features to allow the designer to optimize their design and continue to reduce component count and overall system cost.

Introduction

In 1994 the first family of integrated monolithic switchers was introduced (*TOPSwitch* from Power Integrations). This was a breakthrough in technology allowing the integration of a high voltage MOSFET on the same die as the low-voltage PWM controller. These integrated switchers were extensively used due to low component count and simple power supply design so that most engineers with a little power supply experience could build successful designs. However, the integrated switchers did not have the additional features and flexibility that some designers had come to enjoy working with discrete solutions.

Consider these important factors in a successful design :-
1 – system cost/low component count
2 – optimal solution to a given spec
3 – high reliability
4 – fast time to market (lower design effort for modifications)

TOPSwitch FX addresses the above factors :-
1 – further reduced system component count
2 – flexibility allows the user to optimize a design for a given spec
3 – building on the reliability of the present generation devices
4 – reduced time to market through a family of devices as well as backwards compatibility to first generation devices

This paper presents the key features of the *TOPSwitch-FX* family of integrated switchers which goes beyond the fixed feature set of the present generation devices. The paper describes the available features both the standard features that are inherent in the device and the user configurable features which the design can modify. The new family builds on the strengths of integration while maintaining flexibility in design
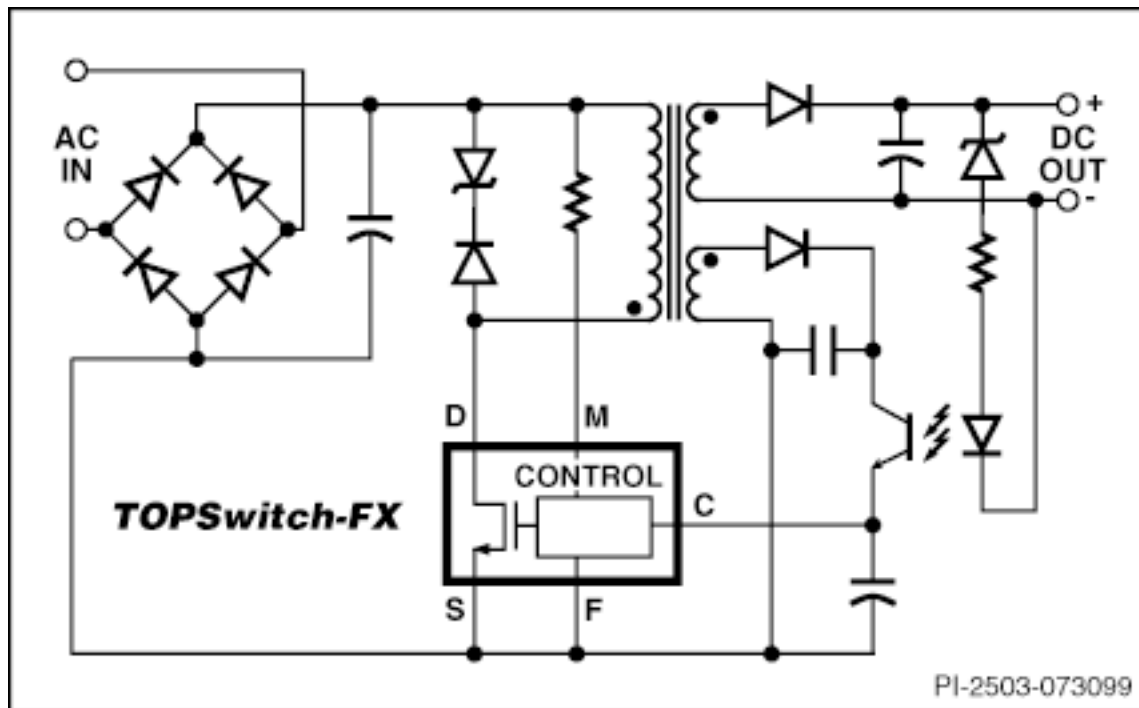
Fig 1. Typical TOPSwitch-FX application circuit

Standard Features
The new features of *TOPSwitch-FX* fall into two categories, standard features and user configurable features. The standard features are present in all applications, where as the configurable features can be controlled by the designer allowing optimization of a power supply design for a given application. This section describes some of the standard features of the device.

Softstart
One of the most stressful events for any power supply is startup. This is because the output voltage is not yet in regulation and therefore the power supply is operating open-loop (at full power) until regulation is established. This can lead to an uncontrolled increase of the reset voltage and sometimes overstress the switching device. Alternately there can be a buildup of primary current in the transformer which if uncontrolled might lead to transformer saturation and associated failures.

In the *TOPSwitch-FX* the soft-start is implemented by linearly increasing the maximum duty cycle from zero to a maximum value over the period of the soft-start (the startup time). This has two major effects. The first is to allow a long period of time for the transformer to fully reset during early cycles, where there is typically very low reflected voltage. The second is to minimize the peak drain current in the switching device during the early cycles thus limiting the amount of energy that would be delivered to an RCD-clamp circuit. This has the effect of limiting the voltage rise on the RCD-clamp to a safe value during startup. Without the softstart feature the RCD-clamp would require a parallel Zener diode to dissipate startup clamp energy.
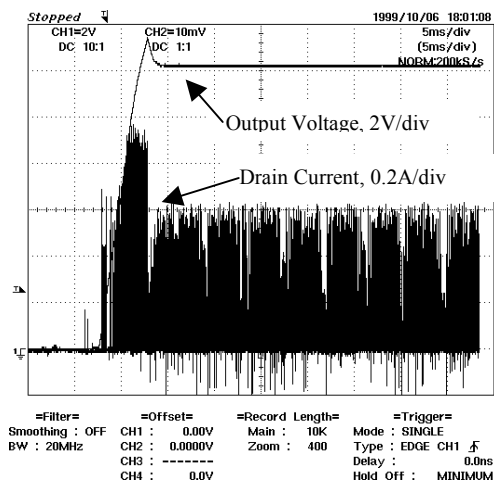
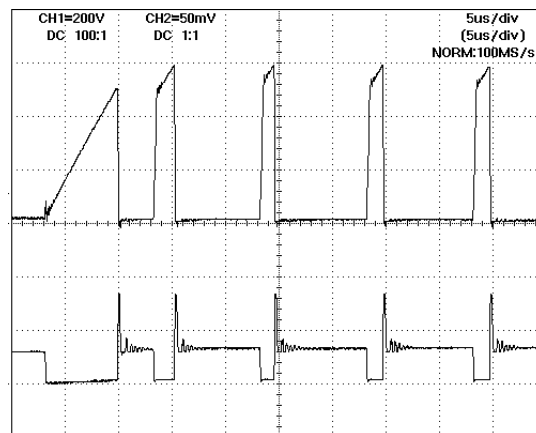Fig 2.1. Startup Drain current and output voltage for TOP234 design

Fig 2.2. Startup Drain current waveform for first generation switcher

Frequency Jitter (EMI)

For a power supply that is directly connected to the AC-mains, the conducted EMI emission of the power supply is required to meet the local or international EMI standards. It is possible to filter out unwanted conducted emissions before they reach the line, however it is preferred to systematically reduce the emissions levels thus reducing the cost of filtering. One way to achieve this is to jitter (modulate) the switching frequency.
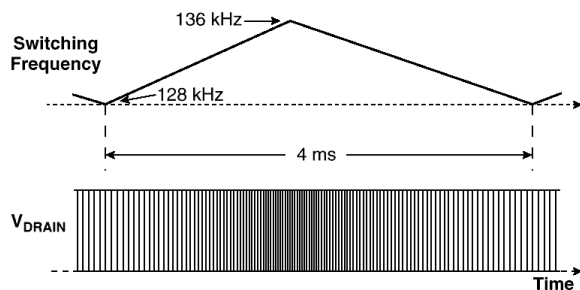

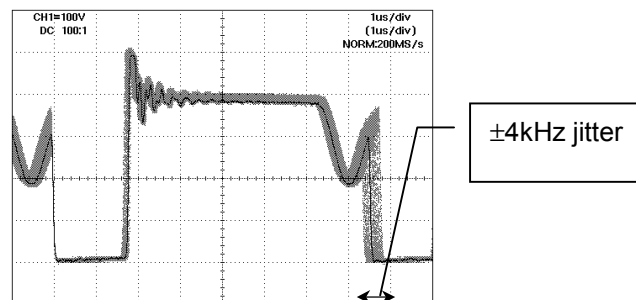Fig 3.1. Diagram shows Switching Frequency Jitter

Fig3.2. Frequency Jitter affect on switching cycle

Frequency jitter has an effect similar to Frequency Modulation, where a switching frequency harmonic is now turned into a band of harmonics in which the peak of the harmonic is still the same but the energy is spread over a larger frequency range. This technique has the effect of reducing both Quasi-peak and Average EMI emissions (see Fig 4.1 and 4.2), both of which are specified in worldwide conducted EMI standards. Reduced Average EMI also leads to a significant reduction in interference with cellphone reception in cellphone charger applications. The frequency jittering feature has been added to the controller and is an inherent feature in the device.
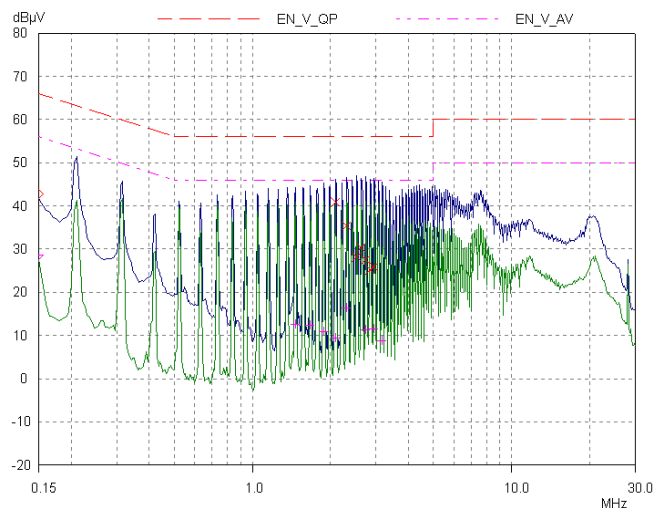
*Fig 4.1. EMI **without jitter** (Quasi-peak upper, Average Lower) – 100kHz switching frequency.*
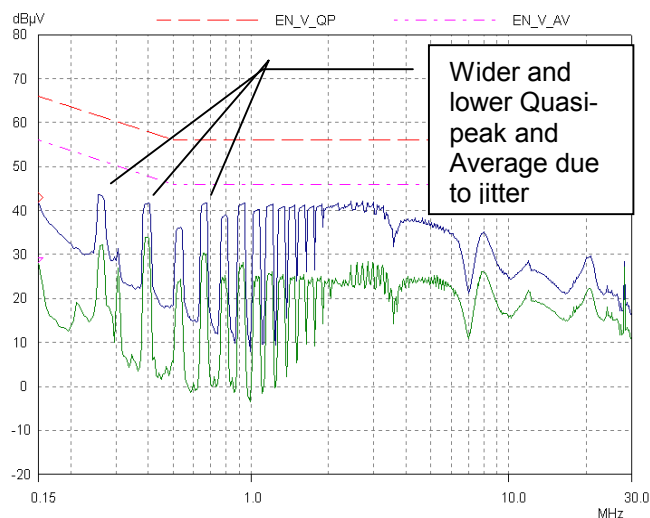

Wider and lower Quasi-peak and Average due to jitter

*Fig 4.2. EMI **with Jitter** (Quasi-peak upper, Average Lower) – 130kHz switching frequency.*

Wider Duty Cycle

Wider duty cycle allows the power supply to operate with a smaller input capacitor compared to earlier products. For most designs the larger duty cycle is only possible when using a higher VOR (reflected voltage). The higher VOR is possible when using an RCD-clamp (Resistor Capacitor Diode) instead of a Zener Clamp. The advantage of an RCD clamp circuit is that it clamps to a voltage very close to the VOR and therefore requires less tolerance allocation than the Zener clamp (which has to be set to roughly 150% of VOR while the RCD-clamp voltage can be set to 110% of VOR).

The wider duty cycle allows Universal input designs (85-265 VAC) to be designed using 2µF per Watt of output power (versus 3µF/Watt required for earlier *TOPSwitch* devices).

Zero Load Regulation

In most PWM controllers, there is a minimum duty cycle in the controller (normally to limit initial current limit issues and also allow supplying of power to the device). The problem is that this minimum duty cycle requires a minimum load to be connected to the output to prevent the output from rising uncontrolled during no-load conditions.

With the new family of integrated switchers, a minimum load is no longer required. Instead the switcher detects when the power supply reaches the minimum duty cycle condition and changes over to cycle-skipping operation. This feature still maintains regulation on the output (all the way down to true zero load). The cycle skipping operation also significantly reduces the input supply consumption.

Power supply no-load consumption is becoming a more and more visible issue and is presently being put into regulations in Europe. By taking advantage of the cycle skipping feature of the new family, the designer can comfortably meet consumption of less than 0.3W in most designs.
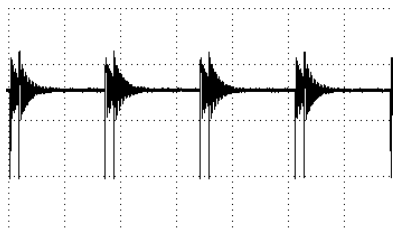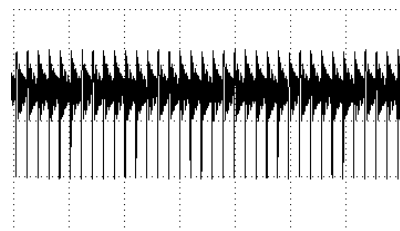
Fig 5.1. Drain voltage waveform for zero output load using first generation switcher (line input consumption = 1.1W)
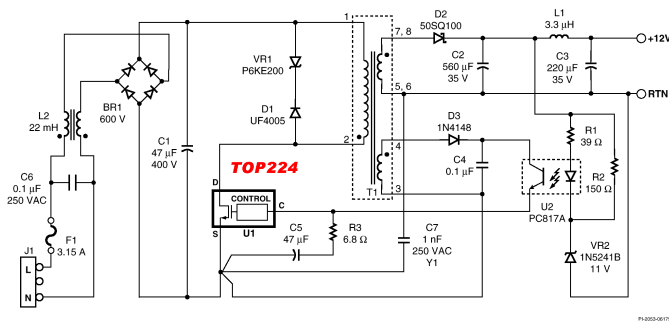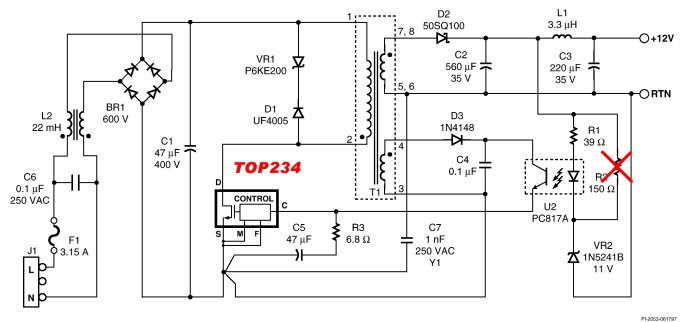
Fig 5.2. Drain voltage waveform for zero output load using TOPSwitch-FX (line input consumption = 0.28W)

Note: - However it should be pointed out that best no-load performance is achieved using Zener clamping instead of RCD-clamp. This is because the RCD voltage clamp voltage decays when the device is skipping cycles and is recharged when the next switch cycle occurs. Recharging the RCD clamp voltage takes energy which would otherwise go to the output. In a zener the clamp voltage does not change when skipping cycles.

Hysteretic Thermal Shutdown

In the original integrated switchers the thermal shutdown was a latched thermal shutdown. This work very well in protecting the PC-board and other components when a component failure occurred. However once the temperature latch was triggered, power had to be removed from the power supply to reset the latch. In the new family of integrated switchers, the thermal shutdown has been changed to a hysteretic shutdown. This means that once the temperature shutdown is triggered, the power supply will wait until the temperature has dropped back down to a lower level before attempting to restart the power supply.

User Configurable Features

This section describes the new *TOPSwitch-FX* features that can be optimized by the designer. These features are for the most part implemented inside the device and therefore require minimal external components in order to control them.

External Current limit

In the original *TOPSwitch* switchers the primary current limit of the device was fixed for a given device. This was done to simplify the circuit design. However if the design did not operate at a peak current close to the primary current limit, then the transformer would end up having to be larger than required for the power level , in order to prevent transformer saturation.

This limitation has now been removed from the new family of integrated switchers. For these devices it is possible to program the safety current limit to a value lower than the default setting with a single resistor. As a result the transformer physical size is no longer dictated by the switching device, but instead is dictated by the power supply design requirements and power level.

The current limit reduction allows the designer to use the same size of transformer and operate much more continuous with the same size core. This is possible because the current limit is reduced to prevent transformer saturation.
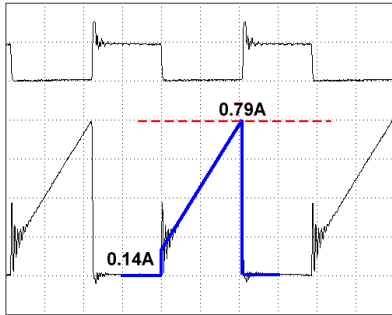
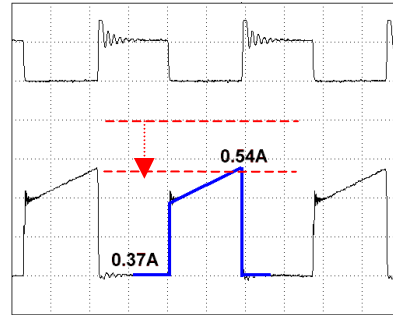*Fig 6.1. Current waveform without current limit reduction*

Fig 6.2. Current waveform with current limit reduction

The second use of external current limit is to control the power delivery during overload conditions. The worst case overload condition occurs at high input line voltage, where the available power from the supply far exceeds the specified output power. The external current limit allows the current limit to be reduced as a function of increasing input line voltage. When optimally conditioned, this feature can assure flat overload power delivery that is independent of input voltage (see Fig 8.). *Note: fig 7 - the area1 and area2 are different, but the energy transferred to the power supply output is more or less constant.*
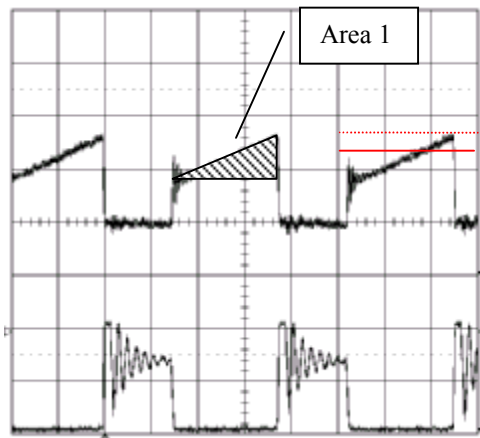

Fig 7.1. Current limit control at 85VAC (Upper: Idrain – 0.5A/Div, Lower: Vdrain – 200V/Div)
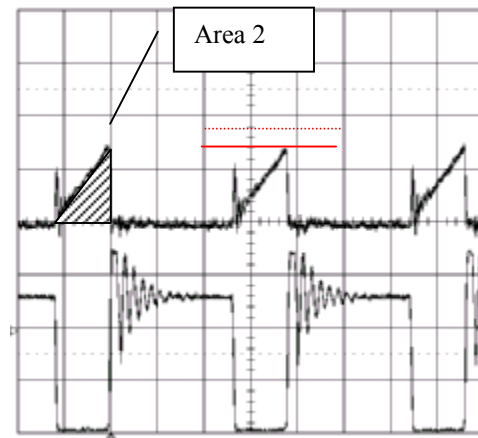

Fig 7.2. Current Limit control at 265VAC (Upper: Idrain – 0.5A/Div, Lower: Vdrain – 200V/Div)
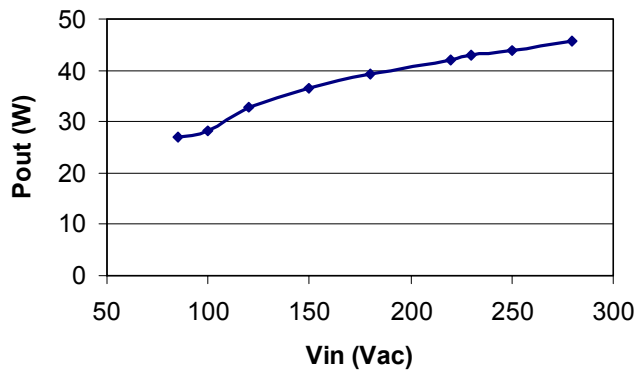
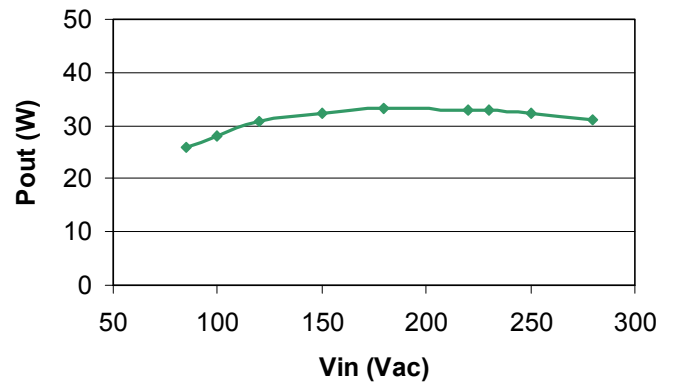Fig 8.1. Output Overload power with first generation switcher

Fig 8.2. Output Overload power with TOPSwitch-FX

Line Under-Voltage

This feature is very useful in bias (standby) power supplies, which are part of a multi-power supply system (such as a PC-power supply that has a bias supply and a main supply).
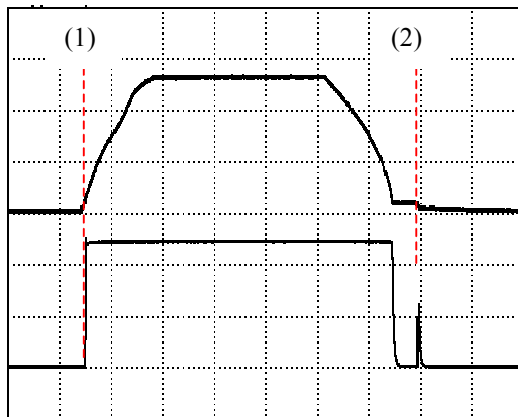

Fig 9.1. DC rail (upper 100V&2s/div) versus Output voltage (lower 5V&2s/div) using first generation switching device. Power supply restart after shutdown
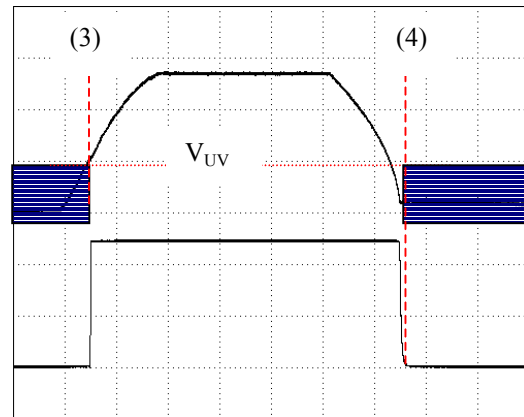

Fig 9.2. DC rail (upper) versus Output voltage (lower) using TOPSwitch-FX switching device. Integrated under-voltage lockout prevents restart after shutdown

(1) Power supply starts up almost instantly for designs without Under-voltage lockout
(2) Power supply restarts after shutdown for designs without Under-voltage lockout
(3) Power supply start prevented until input voltage exceeds Under-voltage lockout (V_{UV}) threshold.
(4) Power supply prevented from restarting once regulation is lost (because input voltage is below Under-voltage lockout (V_{UV}) threshold

The bias supply normally provides the power to the main power supply controller. This means that the main power supply cannot turn-on until the bias supply is running. The bias supply normally has a line under-voltage threshold below which it will not operate, in order to limit the line current drawn by the main supply.

In a first generation monolithic switcher, the line under-voltage feature was implemented using external discrete components and was somewhat problematic since it interfered with the startup circuit for the converter. However in this new device, the line under-voltage feature is included and the threshold is set using a single resistor from the device to the line-voltage.

Line Over-Voltage

In some countries there can be somewhat unreliable line-voltage regulation and this can cause stress on the input to a power supply. The third generation monolithic switcher has an over-voltage shutdown feature. The shutdown threshold can be programmed using a single resistor (the same resistor is used for both under-voltage and over-voltage thresholds). Once this input voltage threshold is exceeded, so the device will stop switching until the input voltage falls back below the threshold voltage. In this way the switching MOSFET only has to survive the fixed DC-input voltage and does not have the additional switching voltage superposed onto the DC-input voltage.

Line Feed Forwad

If a smaller input capacitor is used this can result in increased line-frequency ripple on the output voltage. The line feed-forward feature provides a method of canceling variations in instantaneous input voltage. This is achieved by modulating the feedback duty cycle with a signal derived from instantaneous input voltage. The result is a significant reduction in line frequency ripple on the output voltage.

130kHz and 65kHz operation

With the new family of integrated switchers it is possible to choose the switching frequency. The two possible frequencies are 130kHz and 65kHz. The nominal 130kHz switching frequency was selected to minimize transformer size while keeping the fundamental EMI frequency below 150kHz.

The 65kHz frequency is intended for video and other sensitive applications where all high frequency parasitics ringing need to be damped. The 65kHz frequency allows the use of dissipative snubbers (Resistor-capacitor snubbers) across the switching device. Since these snubbers fully discharge on every switching cycle, all the energy stored in the snubber per cycle is lost. Therefore a snubber is most efficient at the lowest operating frequency.

Conclusion

This paper has highlighted some of the new features of *TOPSwitch-FX*. There is a clear advantage of *TOPSwitch-FX* over previous generations of integrated switcher. This paper has highlighted the superior performance and improved design flexibility in almost all categories (standby power, no minimum load requirement, under-voltage/over-voltage lockout, frequency jitter, soft-start, external current limit).

TOPSwitch-FX forms a fundamental step forward cost/performance equation for power supplies and at the same time allows flexibility of design enabling optimum performance for the lowest system 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, "TOPSwitch-FX Family – Design Flexible, EcoSmart, Integrated Off-line Switcher", Power Integrations 2000
[3.] Power Integrations, "TOPSwitch-FX Flyback – Design Methodology – Application Note AN-25", Power Integrations 2000
[3.] Power Integrations, "TOPSwitch-FX Flyback – Quick Selection Curves – Application Note AN-26", Power Integrations 2000

OUTPUT POWER TABLE

	230 VAC $\pm$15%		85-265 VAC	
	Adapter[1]	**Open Frame[2]**	**Adapter[1]**	**Open Frame[2]**
	9 W	15 W	6.5 W	10 W
	10 W	25 W	7 W	15 W
	13 W	25 W	9 W	15 W
	20 W	50 W	15 W	30 W
	16 W	30 W	11 W	20 W
	30 W	75 W	20 W	45 W

Table 1. Notes: **1.** Typical continuous power in a non-ventilated enclosed adaptor measured at 50 ˚C ambient. **2.** Maximum practical continuous power in an open frame design with adequate heat sinking, measured at 50 ˚C ambient. See key applications section for detailed conditions. **3.** Packages: P: DIP-8B, G: SMD-8B, Y: TO-220-7B.