Designing AC to DC Converters using TOPSwitch-GX
Agenda

- Introduction

- **TOPSwitch-GX Operation**
  - Built-in Features
  - User Configurable Features

- **Designing AC to DC Flyback Converters using TOPSwitch-GX**
  - Why Flyback?
  - TOPSwitch-GX Flyback Design Methodology
  - Application Examples
  - Hints & Tips

- **Designing AC to DC Forward Converters using TOPSwitch-GX**
  - TOPSwitch-GX Advantages in Forward Converters
  - Forward Basics
  - TOPSwitch-GX Forward Converter Design Methodology
  - Application Examples
  - Hints & Tips
Introduction
Company Overview

- Leader in high voltage monolithic power conversion ICs
- > One billion devices shipped
- Revolutionary products
- Proven quality and delivery performance
  - 3 µ CMOS not capacity limited
- Pioneer in energy efficiency (EcoSmart®)

- Power Integrations was the world’s first semiconductor company to introduce highly energy efficient power conversion ICs, based on its patented EcoSmart® technology
- TinySwitch received the 1999 Discover magazine award for the best technological innovation in their ENVIRONMENT category, for its power saving EcoSmart features
- 10% of the world’s electrical energy is wasted by products that are in standby
- EcoSmart technology practically eliminates standby waste
Technology Leadership

- Integrated high-voltage, high frequency MOSFET
- Patented device structure
- Uses industry standard 3 µ CMOS process
- Widely available capacity
Power Integrations’ ICs integrate the high-voltage MOSFET, PWM controller and:

- The MOSFET gate-drive circuit
- A high-voltage current source (start-up circuit)
- A “loss-less” drain current sensing and limiting function that eliminates external current sense components
- Oscillator timing components
- Feedback loop compensation
- Thermal protection
• The Newest PI product families also feature integrated functions such as:
  – A 10 ms soft-start function
  – A switching frequency modulation (jitter) function that lowers the “annoyance factor” of EMI and makes it easier for a design to reliably meet both average and quasi-peak EMI limits
  – Line Under-Voltage (UV) lockout, Over Voltage (OV) shutdown and maximum duty-cycle reduction ($D_{CMA}\text{X}$) functions
  – An auto-restart function that limits short-circuit and overload power delivery
  – Externally programmable, “loss-less” drain current limiting
  – Remote ON/OFF capability
  – Very low standby and no-load power consumption (PI’s patented EcoSmart Technology)
• PI is on the leading edge of innovation in power conversion, continuously introducing breakthrough topologies and technologies
• Since introducing the original TOPSwitch® device in 1994, PI has continued to innovate with new technologies and circuit topologies
• The newest PI device families can be seen along the right hand side of this slide
Cost Effective Over Wide Power Range

- **Power Integrations’** power conversion ICs cost effectively cover:
  
  - 95% of all AC-DC power supplies, from one watt to 250 watts
    
    - **LinkSwitch-TN**  
      <50 mA to 360 mA (non-isolated)
    
    - **LinkSwitch**  
      <1 W to 4 W (isolated)
    
    - **TinySwitch-II**  
      2 W to 20 W (isolated)
    
    - **TOPSwitch-GX**  
      10 W to 250 W (isolated)

  - 24/48 V DC-DC applications, from one watt to 100 watts
    
    - **DPA-Switch**  
      <1 W to 100 W (isolated)

- This graph only approximates the power capabilities of each product family. For more accurate data, see the output power table on each product family data sheet.
Meeting Global Energy Efficiency Requirements

<table>
<thead>
<tr>
<th>NO LOAD /STANDBY</th>
<th>GEOGRAPHY-APPLICATIONS</th>
<th>PI DEVICE</th>
<th>DESIGN IDEA (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mW</td>
<td>Japan – customer specific</td>
<td>TinySwitch</td>
<td>DI-27</td>
</tr>
<tr>
<td>30 mW</td>
<td>Japan – customer specific</td>
<td>TinySwitch-II</td>
<td>DI-28</td>
</tr>
<tr>
<td>100 mW</td>
<td>Japan – customer specific</td>
<td>TOPSwitch-GX TinySwitch-II</td>
<td>DI-39, DI-33</td>
</tr>
<tr>
<td>300 mW</td>
<td>Global external supplies (EU)</td>
<td>TOPSwitch-GX LinkSwitch TinySwitch-II</td>
<td>DI-13, DI-18, DI-19, DI-21</td>
</tr>
<tr>
<td>1 W</td>
<td>US – Government electronic purchase (PC’s)</td>
<td>TOPSwitch-GX TinySwitch-II</td>
<td>DI-14, DI-17, DI-20, DI-30, DI-38</td>
</tr>
<tr>
<td>5 W</td>
<td>Global – PC’s (Blue Angel)</td>
<td>TOPSwitch-GX TinySwitch-II</td>
<td></td>
</tr>
</tbody>
</table>

Solutions for the presently known (and most future) worldwide requirements

- All PI devices incorporate its patented EcoSmart technology. This enables power supplies based on those ICs to meet all current and projected worldwide requirements.
- The table lists the major Worldwide no-load/standby requirements, the PI device and the Design Idea (DI) which describes the circuits that meet the specific requirement.
- The latest PI Design ideas from can be found at www.powerint.com/appcircuits.htm
Comprehensive Design Support

- **Design Accelerator Kits include:**
  - A fully tested power supply
  - Sample ICs, and a blank PCB, plus
  - Complete design documentation

- **PI Expert** power supply design software

- Technical documents on the PI website: www.powerint.com

- **PI** has the most comprehensive power supply design tools in the industry
PI has fully equipped applications labs located in key geographic areas worldwide: (within a few hours of most of our customers)

- **United States**
  - San Jose, California
  - Chicago, Illinois
  - Atlanta, Georgia

- **Europe**
  - London, UK
  - Munich, Germany
  - Milano, Italy

- **Asia**
  - Taipei, Taiwan
  - Seoul, South Korea
  - Shenzhen, PRC
  - Shanghai, PRC
  - Yokohama, Japan
  - Bangalore, India
Wide Customer Acceptance

- Many major OEMs worldwide use *Power Integrations’* ICs in their products
Presenting the Fourth Generation \textit{TOPSwitch} Family:

\textbf{TOPSwitch}®-GX

Extended Power Range, added Functionality and Flexibility, for Lower System Cost
**TOPSwitch-GX™ Highlights and Packages**

- Scalable: 10 W to over 200 W
- Worldwide input voltage range capability
- Features support Forward/Flyback topologies
- Integrated 700 V MOSFET + PWM controller
- Programmable loss-less current sensing and limiting
- Accurate input UV/OV detection
- Auto-recovering short-circuit/overload, open feedback loop, and thermal fault protections
- Low-power standby mode (<100 mW possible)
- Low-power remote-off function
- Modulated (jitter) switching frequency lowers EMI noise generation
• **TOPSwitch-GX** cost effectively addresses a wide range of end products and applications in the 10 to over 200 watt range
• This slide depicts some of the most popular applications that use **TOPSwitch-GX**. Most of these applications have stringent energy efficiency requirements that are easily met using the **TOPSwitch-GX** EcoSmart features
TOPSwitch-GX Operation
**TOPSwitch-GX Basics**

- **TOPSwitch-GX is a current-to-duty-cycle converter**
  - Feedback current into the CONTROL pin reduces the MOSFET duty cycle

- **TOPSwitch-GX operation is based on the proven, original TOPSwitch technology**
  - Its controller is a fixed frequency, voltage-mode, Pulse Width Modulator (PWM)
    - (It is controlled by duty cycle modulation, not a fixed current limit, like the TinySwitch)
  - Voltage-mode control allows >50% duty cycle, without requiring slope compensation
  - The CONTROL pin is a dual-purpose pin. It supplies input operating current to the device and a feedback current that is proportional to the power supply output voltage. As the current that flows into the pin exceeds the minimum device supply current, the duty cycle of the MOSFET is reduced proportionally

- **The following slides explain how the various TOPSwitch-GX functions operate**
Start-up: Charging CONTROL Pin Capacitor

CONTROL pin capacitor is charged to 5.8 V from DRAIN via fixed high voltage current source

No external start-up resistor required!
Start-up: MOSFET Starts Switching

When CONTROL pin reaches 5.8 V power MOSFET soft-starts with gradually increasing duty cycle

CONTROL pin capacitor is maintained at 5.8 V, during soft-start, by the internal high voltage current source (but only during MOSFET off times)

Output voltage begins to rise
Output Reaches Regulation

As the output voltage reaches its regulation value, opto turns on, closing feedback loop.

When the TOPSwitch-GX is powered from a bias winding, the internal high voltage current source is disabled. CONTROL pin current in excess of the supply current is used as feedback to maintain the output in regulation.
Start-up Control Pin & Drain-node Waveforms

Soft-start
output voltage rises

Charging
CONTROL pin

Output reaches regulation, TOPSwitch-GX
is being powered from the bias winding

5.8 V
4.8 V

VC

VDS

Off

Switching

Normal start-up: CONTROL pin & Drain-node (switching) start-up waveforms

- The internal high-voltage current source charges the CONTROL pin capacitor to 5.8 V
- At 5.8 V, MOSFET switching begins in soft-start mode (10 ms in duration)
- The output voltage rises until it reaches its regulation value and the opto turns on, which allows bias winding current to flow into the CONTROL pin
- The PWM controller modulates the MOSFET duty cycle, based on the value of the CONTROL pin current, maintaining the output voltage within regulation
- The CONTROL pin voltage is set by an internal shunt regulator, making it a current driven input. Any in-circuit testing performed at Incoming Inspection must limit the current supplied to the CONTROL pin, to the range specified in the device data sheet, which also has recommended test circuits
Abnormal start-up: CONTROL pin & Drain-node (switching) waveforms
(occurs during an output overload, short circuit, or an open feedback loop condition)

- If the CONTROL pin receives no current from the opto by the end of the soft-start period (when the internal high-voltage current source is disabled), the CONTROL pin capacitor begins to discharge
- After the CONTROL pin capacitor has discharged to 4.8 V, the MOSFET is disabled, and the CONTROL pin capacitor is charged and allowed to discharge for 7 consecutive clock cycles
- The MOSFET is then enabled after the 7th charge/discharge cycle, and the IC initiates the soft-start function again
- If the CONTROL pin receives no current from the opto by the end of the soft-start period, the entire sequence repeats again
- This overload/open loop protection is very well defined:
  - It does not rely on the loss of the bias winding supply voltage
  - Whenever output regulation is lost, the opto turns off, the CONTROL pin capacitor discharges to 4.8 V, and the auto-restart function is initiated
DIP-8/SMD-8 Packages - Low Power to 34 W

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>Adapter</th>
<th>Open Frame</th>
<th>Adapter</th>
<th>Open Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP242 P or G</td>
<td>9 W</td>
<td>15 W</td>
<td>6.5 W</td>
<td>10 W</td>
</tr>
<tr>
<td>TOP243 P or G</td>
<td>13 W</td>
<td>25 W</td>
<td>9 W</td>
<td>15 W</td>
</tr>
<tr>
<td>TOP244 P or G</td>
<td>16 W</td>
<td>28 W</td>
<td>11 W</td>
<td>20 W</td>
</tr>
<tr>
<td>TOP245 P or G</td>
<td>19 W</td>
<td>30 W</td>
<td>13 W</td>
<td>22 W</td>
</tr>
<tr>
<td>TOP246 P or G</td>
<td>21 W</td>
<td>34 W</td>
<td>15 W</td>
<td>26 W</td>
</tr>
</tbody>
</table>

- Adapter
  - Typical continuous power in a non-ventilated, enclosed adapter, measured at 50 °C (ambient external to adapter)

- Open Frame
  - Maximum practical continuous power in an open frame design, at an internal ambient temperature of 50 °C

See the TOPSwitch-GX data sheet for the detail of the conditions that the power table ratings (in this slide) are based on
D²PAK Package - up to 82 W

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>230 VAC ±15%</th>
<th>85-265 VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adapter</td>
<td>Open Frame</td>
</tr>
<tr>
<td>TOP242 R</td>
<td>21 W</td>
<td>22 W</td>
</tr>
<tr>
<td>TOP243 R</td>
<td>29 W</td>
<td>45 W</td>
</tr>
<tr>
<td>TOP244 R</td>
<td>34 W</td>
<td>50 W</td>
</tr>
<tr>
<td>TOP245 R</td>
<td>37 W</td>
<td>57 W</td>
</tr>
<tr>
<td>TOP246 R</td>
<td>40 W</td>
<td>64 W</td>
</tr>
<tr>
<td>TOP247 R</td>
<td>42 W</td>
<td>70 W</td>
</tr>
<tr>
<td>TOP248 R</td>
<td>43 W</td>
<td>75 W</td>
</tr>
<tr>
<td>TOP249 R</td>
<td>44 W</td>
<td>79 W</td>
</tr>
<tr>
<td>TOP250 R</td>
<td>45 W</td>
<td>82 W</td>
</tr>
</tbody>
</table>
The main power supply in a personal computer (PC) application, with a voltage doubler input stage, has a much wider input voltage range than 230 VAC ±15%, due to the typical hold-up time requirements. Therefore, the device power capability in PC main applications will be closer to that of a universal input (85-265 VAC) range.

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>230 VAC ±15%</th>
<th>85-265 VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adapter</td>
<td>Open Frame</td>
</tr>
<tr>
<td>TOP242 Y or F</td>
<td>10 W</td>
<td>22 W</td>
</tr>
<tr>
<td>TOP243 Y or F</td>
<td>20 W</td>
<td>45 W</td>
</tr>
<tr>
<td>TOP244 Y or F</td>
<td>30 W</td>
<td>65 W</td>
</tr>
<tr>
<td>TOP245 Y or F</td>
<td>40 W</td>
<td>85 W</td>
</tr>
<tr>
<td>TOP246 Y or F</td>
<td>60 W</td>
<td>125 W</td>
</tr>
<tr>
<td>TOP247 Y or F</td>
<td>85 W</td>
<td>165 W</td>
</tr>
<tr>
<td>TOP248 Y or F</td>
<td>105 W</td>
<td>205 W</td>
</tr>
<tr>
<td>TOP249 Y or F</td>
<td>120 W</td>
<td>250 W</td>
</tr>
<tr>
<td>TOP250 Y or F</td>
<td>135 W</td>
<td>290 W</td>
</tr>
</tbody>
</table>
Built-in Features
Fully Integrated 10 ms Soft-start

- **Controlled duty cycle and current limit ramp during startup**
  - Soft-start re-activates after removal of overload/thermal fault

- **Benefits**
  - Reduces component stresses during start-up
  - Helps avoid core saturation during start-up
  - Allows use of RCD clamp

- **Duty Cycle During Soft-Start**

- **DC\(_{\text{MAX}}\)**: Maximum duty cycle
Soft-finish Eliminates Output Overshoot

- Soft-start improves but does not always eliminate output overshoot
- Overshoot can be completely eliminated by using a soft-finish capacitor

A soft-finish capacitor can be used to eliminate output voltage overshoot at turn on
(measurement was made on an 85-265 VAC, 30 W, 12 V TOPSwitch-GX power supply)
When the rising output voltage is high enough to forward bias the opto-LED (U2) and the soft-start diode (D3), the soft-finish capacitor begins charging up.
As current flows through the opto-LED, the opto-transistor lets current flow from the bias winding into the TOPSwitch-GX CONTROL pin, which begins to reduce the switching duty cycle of the MOSFET
By the time the output voltage reaches the regulation set-point, the control loop is already closed and regulating, and there is no output voltage overshoot
The value of C_{SF} can be adjusted to lengthen or shorten the output voltage rise time
D3 isolates C13 (C_{SF}) from the main control loop, once C13 has been fully charged (by R7), in order to avoid influencing the response of the control loop (D3 and R7 may not be required, depending on the performance of the control loop)
R7 discharges C13 (C_{SF}) when the supply turns off, resetting the soft-finish function
• When operating at the full switching frequency (132 kHz), the clock is frequency modulated ± 4 kHz. This causes the switching frequency to vary from 128 kHz to 136 kHz, at a rate of 250 Hz

• When operating at half the switching frequency (66 kHz), the clock is frequency modulated ± 2 kHz. This causes the switching frequency to vary from 64 kHz to 68 kHz, at a rate of 250 Hz

• This “jitter” function can be detected by monitoring the drain-node voltage, using a digital storage oscilloscope with the trace display persistence set to high

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>132 kHz / 66 kHz</td>
</tr>
<tr>
<td>Jitter range</td>
<td>±4 kHz / ±2 kHz</td>
</tr>
<tr>
<td>Jitter repetition</td>
<td>250 Hz</td>
</tr>
</tbody>
</table>
Reducing EMI with Jitter

- Quasi peak (QP) reduced 3 to 5 dB / Average (AV) reduced 10 to 15 dB
- Jitter reduces system cost:
  - Enables the use of a simple ‘π’ filter, for up to 10 W
  - Enables the use of a standard single stage (1 common mode choke and 1 to 2 X capacitors) EMI filter, for up to about 200 W

Left: \textit{TOPSwitch-II} TOP224 power supply (100 kHz switching frequency)
Right: \textit{TOPSwitch-GX} TOP244 power supply (132 kHz switching frequency)
Same board and same load current for both measurements
Without jitter, the switching harmonic peaks are discrete and narrow
With jitter, the switching harmonic peaks are lowered and smoothed. Higher harmonics are smoothed into a more continuous response
**TOPSwitch-GX** Loss-less Current Sense

- No external resistor required
  - No additional losses incurred
- Accuracy ±7% (production trimmed)
- Temperature compensated
  - $R_{REF}$ tracks $R_{DS(ON)}$
- Built-in leading edge blanking
  - $t_{LEB} = 220$ ns typ.
  - Filters turn-on spikes without external components

- The Leading Edge Blanking (LEB) function (not shown) eliminates the need for a low pass filter on the input of the current limit comparator
- This allows very fast current limiting: turns off the MOSFET in ~100 ns
- The drain of the MOSFET is only connected to the low-voltage internal comparator when the MOSFET is on. During the off time, the comparator is isolated from the high drain voltage
The most critical parameters (current limit trip-point and switching frequency) are temperature compensated and trimmed during package level testing, for high accuracy. This allows less expensive power-train components to be selected. Output Diodes and output capacitors need not be specified to accommodate the heavy worst-case overload power that could be demanded of the supply, if these parameters were not tightly controlled. Tightly controlling these parameters makes it easier for the designer to ensure that his or her designs should maintain high yield rates in high volume manufacturing.

### Critical Parameters

#### Current Limit

<table>
<thead>
<tr>
<th>Tolerance at 25 °C</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{\text{LIMIT}} ) (TOP245)</td>
<td>1.68</td>
<td>1.80</td>
<td>1.93</td>
</tr>
</tbody>
</table>

-6.7% ↔ +7.2%

#### Frequency

<table>
<thead>
<tr>
<th>Tolerance at 25 °C</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQUENCY</td>
<td>124</td>
<td>132</td>
<td>140</td>
</tr>
</tbody>
</table>

-6.1% ↔ +6.1%
Frequency Reduction at Low Duty Cycle

- Below 10% duty cycle, operating frequency is reduced

- Retains regulation at light load and reduces standby/no-load consumption

- Typical no-load consumption figures
  - <200 mW at 115 VAC
  - <300 mW at 230 VAC

- <100 mW no-load consumption at 230 VAC is possible using the X pin (M pin on P package) with a simple external circuit configuration
  - See User Configurable Features section

- When in standby, the 10% duty cycle threshold drops the TOPSwitch-GX switching frequency at high line. This automatically compensates for the increased switching losses at high line

- The no-load consumption figures given in this slide represent the latest data, which is not represented in the examples shown later in this presentation. More information is available at www.powerint.com
Hysteretic Thermal Shutdown provides Auto-recovery

- On-chip MOSFET temperature sensing provides robust protection
- Protects entire system: device, PC board and magnetics
  - Wide hysteresis keeps board temperature < 100 °C in fault condition

Wide hysteresis (75 °C) prevents restart unless the ambient temperature is <65 °C. If the ambient >65 °C, the AC input must be cycled off and then back on to restart the device and resume normal operation.

This function protects the entire system, when fault conditions occur at high ambient temperatures, which can help keep the average PCB temperature within safe limits.
**Wide Package DRAIN – SOURCE Creepage**

- **TOPSwitch-GX** has greater creepage than a standard 3-pin TO-220
- Increased creepage reduces probability of arcing
- Important for forced air cooled (high pollution) environments

- The tab of the Y (R and F) package(s) is connected to the source of the Internal MOSFET, not the drain; as normal power MOSFETs are. This helps to reduce EMI noise generation, since the source of the MOFET is a “quiet” (non-switching) node
TO-220/7/6 Lead Formed for Reliability

- The height of the aluminum heatsink changes with temperature, at a different rate than that of the copper lead-frame.
- Package tab is mounted to the heatsink.
- As the heatsink moves, the package moves.
- Formed leads allow legs to absorb movement, which reduces the force on solder joints, and prevents solder pad lifting.
- Heatsink fixed to board or chassis.

- Lead bend prevents PC board damage due to thermal cycling.
- Improves long term reliability.

- Lead forming reduces the mechanical stresses caused by the differences in the coefficients of expansion, between the copper lead-frame and the aluminum heat sink, and minimizes the effects of repetitive stress (from thermal cycling) on solder joints and PCB solder pads.
# Summary of Built-in Features

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>BENEFIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft-start</td>
<td>Reduces component stresses. Prevents transformer saturation.</td>
</tr>
<tr>
<td>Frequency jitter</td>
<td>Reduces EMI</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>132 kHz – reduced transformer and input cap size&lt;br&gt;66 kHz – reduced video noise and no-load consumption</td>
</tr>
<tr>
<td>Tight tolerance over temperature on all critical parameters</td>
<td>Improved design margin for high volume production</td>
</tr>
</tbody>
</table>

- All features are designed to reduce system cost
### Built-in Features (continued)

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>BENEFIT</th>
</tr>
</thead>
</table>
| Frequency reduction (at low duty cycle) | Improved no-load/light load efficiency  
Eliminates need for minimum load |
| High maximum duty cycle (DC<sub>MAX</sub> 78%) | Allows smaller input capacitor to be used saving cost |
| Thermal shutdown with wide hysteresis | Restarts automatically  
Maintains low average temperature during fault condition |
| Package creepage / clearance | Ideal for high pollution (forced air cooled) environments |

- The high maximum duty cycle (DC<sub>MAX</sub>) is an additional built-in feature of the TOPSwitch-GX
- All of the TOPSwitch-GX features and integrated functions were designed to minimize the overall cost of the system
User Configurable Features
Selecting Current Limit (X pin) Resistor

Note: A value of $R_{IL} > 45 \, k\Omega$ may initiate the remote OFF function.

- A single external resistor programs the reduction of the internal current limit.
- The current limit defaults to 100%, when the X pin is shorted to the SOURCE pin.
Programming Output Overload Power
(at a Specific Input Voltage)

- $I_{\text{ILIMIT}} = 100\%$
  - Overload = 4.6 A out
  - Max load = 2.5 A out

- $I_{\text{ILIMIT}} = 86\%$
  - $R_{\text{IL}} = 8.25\, \text{k}\Omega$
  - $R_{\text{IL}}$ programs Ilimit
  - Overload = 3.8 A out
  - Max load = 2.5 A out

- $R_{\text{IL}}$ sets the overload power limit

- In the example shown, the correct choice of $R_{\text{IL}}$ reduces the overload current by 17%
- Reducing the overload current can lower the cost of the output diode and output filter capacitor, since a diode rated for lower current and a lower value of capacitance can be used
For a continuous conduction mode Flyback power supply, the available output power increases as the input voltage increases, if the current limit is fixed.

The maximum output power can be kept almost constant by decreasing the current limit as the input voltage increases.

Limiting output power with increasing input voltage can lower the cost of the output diode, the output filter capacitor and the transformer, since those components will not need to handle the higher worst-case power levels, that they would have to endure without this function.
Using the X Pin to Achieve < 100 mW No-Load

- **TOPSwitch-GX** can be configured as a current mode controlled device

- The X pin is used to control the internal current limit

- Below the minimum internal current limit (~ 30%), the OFF time is extended (by stopping the internal oscillator) to retain output regulation

- At no-load, the lower switching frequency minimizes the switching losses

- For devices in the P package, the M pin combines the X and L pin functions
Current Mode Operation

- Only the minimum device operating current is supplied to the CONTROL pin.
- The X pin is used for output regulation.

Q1 turns on only after 2.2 mA has been supplied to the CONTROL pin. The additional current is then routed to the X pin, as feedback.

Noise decoupling to maintain stable feedback current.

Q2 turns on during forward pulse, charging C6.

Ramp voltage on C6 provides slope compensation allowing >50% duty cycle operation.

D1 protects the Q2 base during the Flyback period.

The X pin current is modulated by feedback from the output, which adjusts the internal current limit.

At the minimum current limit, the off time is extended, lowering the switching frequency.

- This circuit acts as a fixed frequency PWM controlled power supply at medium and high loads, that reduces its switching frequency (further than the TOPSwitch-GX normally does) at lighter loads.
- The auto-restart function works normally (for a shorted output or an open feedback loop fault) in this mode of operation. If the current in the opto-LED drops to zero, the CONTROL pin current will also drop to zero, and the auto-restart mode will be entered.
- For devices in the P package, the M pin combines the X and L pin functions.
- NOTE: 2.2 mA of CONTROL pin current is sufficient to power the device. At 2.2 mA, the MOSFET duty cycle stays very near the maximum of 78%.
### No-Load Consumption

<table>
<thead>
<tr>
<th>Input Power</th>
<th>Standard PWM Fixed Frequency</th>
<th>TOPSwitch-GX CONTROL PIN FEEDBACK (Voltage Mode)</th>
<th>TOPSwitch-GX X or M Pin Feedback (Current Mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>115 VAC</td>
<td>738 mW</td>
<td>247 mW</td>
<td>66 mW</td>
</tr>
<tr>
<td>230 VAC</td>
<td>1310 mW</td>
<td>372 mW</td>
<td>74 mW</td>
</tr>
</tbody>
</table>

- A standard PWM usually requires minimum load to maintain regulation at light loads.
- The **TOPSwitch-GX** does not require a minimum load, since the switching frequency is reduced at light loads.
- The **TOPSwitch-GX** ‘X pin current mode’ frequency reduction provides excellent no-load performance and the inherent characteristics of current mode operation.
- **NOTE:** In the three sample waveforms (going from left to right) shown above, the effective switching frequencies are approximately 132 kHz, 33 kHz and 1.2 kHz.
Programming Input UV/OV Thresholds

- Fixed UV/OV ratio 1: 4.5
  - External parts can be used to adjust the ratio
- Built-in hysteresis prevents accidental restart

Values with $R_{LS} = 2 \, \text{M}\Omega$

Line under voltage lockout
- As the input voltage increases, the supply turns on at about 100 V
- As the input voltage decreases, the supply turns off at about 40 V
- As the input voltage decreases, if regulation is lost before 40 V is reached, the supply will turn off and the input must again increase to about 100 V for the supply to turn on

Line over voltage shutdown
- As the input voltage increases, the supply turns off at about 450 V
- As the input voltage decreases, the supply turns back on at about 434 V

$R_{LS} = \frac{V_{UV} - V_L}{I_{UV}}$

($V_L = 2.5 \, \text{V}$  
$I_{UV} = 50 \, \mu\text{A}$ )

The following describes the UV and OV operation of the example in the slide above
Input UV Prevents Power Down Glitch

The output voltage glitches as the power supply tries to restart from the energy that remains in the input capacitor.

TOPSwitch-GX does not start until 100 VDC. When regulation is lost, does not restart until 100 VDC (no turn off glitches).

- UV lockout prevents ‘glitches’ from occurring on the power supply output when the supply is fed from large input bulk capacitor (i.e., it is an auxiliary or standby supply within a larger power supply)
- UV lockout also prevents the power supply from turning on and off rapidly when the input voltage is too low for the supply to keep the output voltage within regulation at the maximum (PWM) duty cycle (i.e., during a ‘brown out’)

UV Prevents Power Down Glitch
Input OV Extends Surge Withstand to 700 VDC (495 VAC)

- **TOPSwitch-GX** stops switching when the DC rail is > OV threshold
  - Allows surges up to 700 V, with no MOV required to protect the TOPSwitch-GX
  - The input electrolytic capacitor must be rated for the DC rail surge voltage

- Ideal for countries with poor power quality
  - Automatically recovers after the surge is over, with no fuses to replace

The DC rail reaches 592 V with a 47 µF input capacitor, during a 4 kV/2 Ω input surge

- The waveforms depicted above were measured on a TOP244 prototype board, as an input surge of 4 kV/2Ω was applied to it
- OV shutdown not only protects from surges, such as lightning, but also from line regulation problems. For example, in some countries the AC mains voltage may swell to 400 VAC, for up to 100 ms. MOVs cannot protect against line swells of that duration
- OV shutdown keeps costs low by protecting the TOPSwitch-GX, the transformer, and the output components from excessive voltages, without expensive TVS devices
- OV shutdown provides far more robust protection than MOSFET avalanche ratings, which are typically very small (micro-Joules) compared to the amount of energy in a typical input line surge (Joules)
- OV shutdown protects against differential mode surges. For common mode surge protection, route the bias winding return to the input bulk capacitor to keep the surge currents from passing through the TOPSwitch-GX SOURCE traces (see the layout suggestions in the Hints and Tips section)
Surge Performance Without MOV

- 4 kV of surge withstand, without additional protection
- Many TOPSwitch-GX designs with higher withstand (≥6 kV) are currently in production. These use additional protection
- The Flyback Application Section covers this subject in more detail

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>DESCRIPTION</th>
<th>DEVICE</th>
<th>SURGE LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAK-11 / DI-22</td>
<td>70 W laptop</td>
<td>TOP249</td>
<td>4 kV / 2 Ω</td>
</tr>
<tr>
<td>DAK-13 / DI-16</td>
<td>43 W set-top</td>
<td>TOP246</td>
<td>4 kV / 2 Ω</td>
</tr>
<tr>
<td>DI-21</td>
<td>45 W LCD</td>
<td>TOP247</td>
<td>4 kV / 2 Ω</td>
</tr>
</tbody>
</table>

NOTE: The circuit diagrams for DAK-13 and DI-16 contain an MOV. This protects the input components during a 6 kV surge. The TOPSwitch-GX does not require an MOV to survive a 4 kV differential surge.
Duty Cycle ($D_{\text{MAX}}$) Reduction with Input Voltage

- $R_{LS}$ also reduces $D_{\text{MAX}}$ with input voltage
- Prevents transformer saturation under transient/fault conditions in Forward topology converters

Values with $R_{LS} = 2 \, \text{M} \Omega$

When the $D_{\text{MAX}}$ function is operating, the MOSFET duty cycle is about 30% at the OV shutdown threshold
Selecting Frequency: 132/66 kHz (F pin)

- Full frequency (132 kHz)
- Allows smaller magnetics
- Has higher switching losses

- Half frequency (66 kHz)
- Requires larger magnetics
- Allows R-C snubbers (for video noise reduction)

Operating frequency can be chosen to best suit the requirements of the application
Low Power Remote OFF Consumption

<table>
<thead>
<tr>
<th>TECHNIQUES</th>
<th>115 VAC</th>
<th>230 VAC</th>
<th>I_{DRAIN}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using X pin</td>
<td>73 mW</td>
<td>157 mW</td>
<td>490 µA</td>
</tr>
<tr>
<td>Using L pin</td>
<td>135 mW</td>
<td>247 mW</td>
<td>800 µA</td>
</tr>
<tr>
<td>Using external bias</td>
<td>2 mW</td>
<td>2 mW</td>
<td>7 µA</td>
</tr>
</tbody>
</table>

Active ON (X pin)

Active OFF (L pin)

There are multiple ways to implement a remote ON/OFF function.
Two examples are shown using alternate polarity signals.
Remote OFF, with an external bias, is shown on the next slide.
(7 µA is the quiescent current for the internal current source, when it is off)
Reducing Remote OFF Power Consumption using an External Bias Supply

- By default, the TOPSwitch-GX is powered from the high voltage on the DRAIN pin, when it is in the remote OFF state.
- An external bias current will turn off the TOPSwitch-GX's integrated high-voltage current source, minimizing the power consumption of the device.
- This method can be used when a separate standby power supply is available to provide the bias current (example: PC-standby).

In the circuit diagram shown on this slide, R1, D1 and R3 feed the external bias current to the TOPSwitch-GX, which turns off the internal current source and thus eliminates its operating power consumption.

- $R_{IL}$ sets the TOPSwitch-GX drain current limit, and Q1 turns the device on and off, via the X pin. C1 provides noise decoupling, to ensure that the device is not unintentional turned on or off.
- R4 and C4 are the normal CONTROL pin compensation components.
Other X Pin and L Pin Configurations

See data sheet Fig 16-29
The combination of the X and L pin functions onto the M pin limits the use to one or the other function. When using a device with an M pin, both the L pin function and the X pin function cannot be used at the same time.
### User Configurable Features and Functions

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>PIN</th>
<th>BENEFIT</th>
</tr>
</thead>
</table>
| Programmable Current Limit (30% to 100%)     | X pin  | Allows optimum transformer size
|                                              |        | Allows overload protection with line-voltage feed.                                                                                     |
| Frequency Reduction                          | X pin  | Enables <100 mW no-load consumption                                                                                                   |
| Current Mode Control                          |        |                                                                                                                                 |
| Accurate UV/OV                                | L pin  | Single resistor programming                                                                                                            |
| Programmable Duty Cycle Reduction vs Line    | L Pin  | Prevents transformer saturation (useful for Forward converter)                                                                             |
| Selectable Switching Frequency                | F Pin  | 132 kHz - reduced transformer size
|                                              |        | 66 kHz - reduced switching loss.                                                                                                       |
|                                              |        | Allows RC snubber for video noise reduction                                                                                             |
| Remote on/off                                 | L pin/X pin | Low component count
|                                              |        | Allows low off-state consumption                                                                                                       |

- User configurable features and functions provide design flexibility, while reducing system cost
Disabling User Configurable Features and Functions

- Features and functions on user configurable pins can be disabled by connecting those pins to the SOURCE pin.

- All of the built-in features and functions still work, even when used in the three terminal mode.

Built-in features and functions require only the three standard TOPSwitch terminals, DRAIN, SOURCE and CONTROL, and no external components.
Block Diagram

- Accurate adjustable current limit
- Internal 10 ms soft-start
- No external components
- High-voltage Startup Current Source
- Auto-restart for short circuit protection
- Loss-less current sense
- High Speed 700 V Power MOSFET

Accurate UV/OV line sense
Accurate 132/66 kHz clock frequency
Frequency Reduction for no-load regulation (EcoSmart)
Thermal shutdown

See the TOPSwitch-GX data sheet for a detailed description of the block diagram
The TOPSwitch-GX provides the highest level of integration, incorporating the most commonly used primary side functions in a single monolithic device
Appendix
Auto ON/OFF Power Supply using **TOPSwitch-GX** Remote ON/OFF

- The remote ON/OFF function can be configured for automatic operation in networked appliances, to reduce energy consumption
  - Also enables front panel ‘soft-switch’ system ON/OFF control

- The following slides describe the system level, step-by-step operation for a typical network appliance application

- The example uses a ‘P’ package device with an ‘M’ pin
  - To implement this particular scheme with a Y, R or F packaged device, the connections shown should be made to the L pin, instead of the M pin
Auto ON/OFF Power Supply Example
Step 1: No AC Power - Circuit Inactive
Step 2: AC Power Applied

The **TOPSwitch-GX** is in the low-power, remote OFF mode.
Power consumption < 80 mW at 115 VAC, < 160 mW at 230 VAC (typical)

- The M pin current is zero and MOSFET switching is disabled.
Step 3a: User Initiated Turn-on

A user presses switch P1 and current is drawn out of the M pin
MOSFET switching is enabled and begins, in the soft start mode
  – Output voltage starts rising
The opto-coupler LED (U3) is on, while P1 is engaged

As a power supply typically takes < 10 ms to reach regulation, no switch de-bouncing is required (the switch will always be engaged for longer than 10 ms)
If P1 is engaged for less than 10 ms or the supply does not reach regulation (there is a short circuit on the output or the output feedback loop is an open circuit), then the power supply will remain in the off state
Step 3b: External Wake Up

An active (logic high) external wake up signal turns on the opto-LED of U4
The U4 opto-transistor turns on, drawing current out of the M pin
MOSFET switching is enabled and begins, in the soft start mode
  – Output voltage starts rising
Step 4: Processor Takes Control

Current continues to be drawn out of the M pin via U4, and MOSFET switching continues.

Processor takes control:

- P1 is now open circuit.
- Current continues to be drawn out of the M pin via U4, and MOSFET switching continues.
- Processor starts.
- Output reaches regulation.

Processor detects that P1 had closed, via U3.

Processor turns on U4 LED.

- Output voltage reaches regulation.
- Microprocessor starts working.
  - Microprocessor turns the U4 LED on to keep the power supply operating.
- Current continues to be drawn out of the M pin, via U4, even after P1 disengages.
Step 5: Normal Operation

Current out of M pin via U4, switching continues

P1 off

Output in regulation

The processor holds U4 on, which maintains a path for M pin current

- The power supply is kept on by the microprocessor
Step 6: User Requested Shut Down

A user momentarily presses and releases the switch P1
- U3 conveys to the processor that switch P1 was activated
- The processor de-bounces the signal – no de-bounce circuits are required

The processor delays shut down for house keeping
- Example: printer head parking, saving data to memory, etc.

The processor may also initiate a shutdown after a predetermined period of inactivity
Step 7: Processor Shuts Down Supply

- The processor turns off the U4 LED, reducing the current draw from the M pin to zero
- MOSFET switching is disabled
- The output voltage falls, and the microprocessor goes inactive
- The \textit{TOPSwitch-GX} is in its low-power remote off mode
  - Power consumption $< 80$ mW typical at 115 VAC, $< 160$ mW typical at 230 VAC
Auto ON/OFF Power Supply Summary

- **TOPSwitch-GX** is the ideal solution for computer peripherals and networked appliances such as printers, fax machines, scanners, etc.
- **Allows front panel power “soft-switch”**
  - Low cost, low power momentary action switch may be used
- **No on/off latch that could be accidentally triggered during transients**
- **Internal processor always has control over turn OFF**
  - Prevents improper turn off sequence
- **Allows advanced energy saving features**
  - Appliance can automatically turn itself off after a period of inactivity
  - Appliance can automatically wake up via signal on data input or by front panel switch
  - Very low standby consumption
  - No requirement for bias supply
TOPSwitch-GX vs. Discrete Design

30 W, UNIVERSAL INPUT POWER SUPPLY

Soft-start, tight parametric tolerances and power limiting (R1 and R2) optimizes RCD clamp design—up to $0.05 savings

High (132 kHz) frequency and soft-start can reduce transformer core size—up to $0.20 savings

Frequency jittering simplifies EMI filter design reducing development time and component cost—up to $0.20 savings in components plus reduced development costs

Primary power limiting (R1 and R2) and very tight parametric tolerances reduces diode current rating—up to $0.05 savings

Overvoltage shutdown protection (R4) can eliminate input surge protection circuitry (MOV’s etc)—up to $0.10 savings

High max duty cycle (78%) allows smaller input cap—up to $0.25 savings

Current limit control (R2) allows more continuous operation for higher efficiency—up to $0.10 savings

Soft-start reduces output voltage overshoot at turn on—eliminates soft finish capacitor in most applications—up to $0.10 savings

*Cost savings based on high volume quantities (>1 M/yr.). Higher savings possible at lower volumes.