Designing Power Supplies with

*TinySwitch®-III*
Seminar Agenda

• **Introduction**
  – Power Integrations

• **Introducing TinySwitch-III**
  – Features and Operation
  – Performance
  – Designing with TinySwitch-III
  – Hints and Tips
  – Design Examples
  – *PI* Device Quick Design Checklist

• **External Power Supply (EPS)**
  Energy Efficiency Standards
Power Integrations Overview
Company Overview

- Leader in high voltage monolithic power conversion ICs
- > 1.6 billion devices shipped
- Revolutionary products
- Proven quality and delivery performance
- Pioneers in energy efficiency (EcoSmart®)
Global Applications Support

- Fully Equipped Applications Labs
- 55+ Application Engineers Worldwide
24-Hour Design Documentation Support

http://www.powerint.com
Design Examples Page Has > 150 Supplies

### Design Examples

**Design Example Reports (DER)**
Design Example Reports contain a power supply design specification, schematic, bill of materials, transformer documentation, and PCB layout. This design has been built and bench-tested to provide performance data and typical operating characteristics.

**Design Ideas (DI)**
Design Ideas are concise two-page documents describing a design for a specific application. Key design points are highlighted.

**Engineering Prototype Reports (EPR)**
Engineering Prototype Reports contain a power supply reference design specification, schematic, bill of materials, transformer documentation, and PCB layout. Performance data and typical operating characteristics are included. The design has been put into production for use in our DAKEs.

The documents are organized by application, starting from the most recent document. To sort by a different column, position your cursor over an undelined column heading and click once with your left mouse button.

**CEC “Green Design.”** Sample designs that can be used to meet the efficiency requirements set by the California Energy Commission (CEC) and ENERGY STAR®, as well as many other regulations worldwide. For information on global energy-efficiency standards and EcoSmart® solutions, visit our Green Room.

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#### Quick Access (please note: more using this feature)

- **Select Your Application**
  - Appliances
    - Cordless Phone
    - DC-DC Converters/Communications
    - DC-DC Converters/PoE
    - DC-DC Converters/VoIP Phone
    - DC-DC Power Supply
    - Digital Video Recorder
  - Appliance
    - General Purpose
    - High Speed Modem
    - Industrial
    - Laptop Adapter
    - LCD Monitor
    - LCD TV Standy
    - LED
    - Motor Control
    - Network Interface
  - Appliances
    - TOP80Wx/80V
    - 207-400 VAC
  - 24V
  - 5V
  - 12V

### Table

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<th>Output Voltage</th>
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<th>Schematic</th>
<th>Topology</th>
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[http://www.powerint.com/appcircuits.htm](http://www.powerint.com/appcircuits.htm)
> 15 Working Reference Designs Available

[Image of a website interface with a table and text]

**Reference Designs**

Reference Designs (OAKs) provide the essential materials to get started on your next power supply design. All kits include samples, a fully functional reference board and complete documentation. To purchase a OAK, contact your local sales representative or distributor.

- **KEC** - "Green Design": Sample designs that can be used to meet the efficiency requirements set by the California Energy Commission (CEC) and ENERGY STAR®, as well as many other regulations worldwide. For information on global energy-efficiency standards and EcoSmart® solutions, visit our [Green Room](http://www.powerint.com/dak.htm).

<table>
<thead>
<tr>
<th>DESIGN ACCELERATOR KIT</th>
<th>ENGINEERING PROTOTYPE BOARD</th>
<th>SAMPLES</th>
<th>DOCUMENTATION</th>
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<tbody>
<tr>
<td>DA9-93 PeakSwitch</td>
<td>EP-93 PK6801Y 90-265 VAC</td>
<td>30 W</td>
<td>EPS-93, AN-41</td>
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</table>

[Image of a website interface with a table and text]

**http://www.powerint.com/dak.htm**
World-Wide Technical Support

http://www.powerint.com/techsupport.htm
Introducing the TinySwitch®-III IC Family
The *TinySwitch®-III* IC Family

- A family of highly integrated, off-line switching power conversion ICs
  - Enables low component count, high reliability power supply solutions
  - New functions and features offer greater flexibility
  - Easily meets all current and proposed energy efficiency standards
  - System-level protection improves reliability
  - Scalable family of devices covers a wide power range up to 36.5 W
  - Optimized pin-out simplifies layout and maximizes heat transfer to PCB
TinySwitch-III Features / System Cost Benefits

- 132 kHz operation minimizes transformer size
- ON/OFF control allows output voltage regulation using a Zener diode reference
- Tight $I^2f$ tolerance minimizes MOSFET, transformer and output diode size
- Internal, high-voltage, current source eliminates start-up circuitry
- Internal current sense circuit eliminates sense resistor
- ON/OFF control: no frequency compensation components required
TinySwitch-III Features / System Cost Benefits

- Single resistor UVLO prevents output glitches during power up and shut down.
- Selectable current limit through BP/M capacitor value for greater flexibility.
- Latching output overvoltage protection using simple Zener diode eliminates additional opto-coupler.
- On-time extension extends hold-up time to reduce input bulk capacitance.
- Switching frequency jitter enables simple EMI filter.
- <50 mW no-load consumption with optional bias winding and resistor.
TinySwitch®-III

Features and Operation
TinySwitch-III Pin Function Descriptions

- **DRAIN (D) Pin:**
  - Power MOSFET drain connection and high-voltage startup

- **BYPASS / Multi-function (BP/M) Pin:**
  - Connection point for bypass capacitor
  - Selects internal current limit level
  - Provides latching shutdown

- **ENABLE / UNDER-VOLTAGE (EN/UV) Pin:**
  - Feedback input for ON/OFF control
  - Senses under-voltage condition

- **SOURCE (S) Pin:**
  - Power MOSFET source connection and controller ground reference
Optimized Package Pin Arrangement
Eases Layout For Heatsinking and EMI

- All SOURCE pins along one side of the package enables use of an additional PCB mounted heatsink
- Electrically quiet MOSFET SOURCE is connected to heatsink pins: Lowers EMI generation
Wide Creepage Distances

- **Extended package and PCB creepage**
  - Industry standard 8 pin package with pin 3 removed
  - Provides adequate high voltage spacing for high humidity and high pollution environments, both at the IC package and on the PCB
  - Meets safety agency functional insulation spacing requirements (3 mm)
    - Eliminates need to short circuit DRAIN pin to any other pin of the IC package

Compare to TO-92 package with < 0.9 mm package creepage
Start-up: Charging BP Pin Capacitor

- No external resistor string or start-up circuit required
- Value of bypass capacitor selects one of three internal current limits

BP pin capacitor is charged to 5.85 V before MOSFET switching is enabled
Start-up: MOSFET Starts Switching

The BP pin capacitor energy powers the IC while MOSFET is on; the internal high-voltage current source recharges the BP pin capacitor while MOSFET is off.

As output voltage rises, no switching cycles are skipped until Zener reference conduction.

At 5.85 V, MOSFET starts switching.

The BP pin capacitor energy powers the IC while MOSFET is on; the internal high-voltage current source recharges the BP pin capacitor while MOSFET is off.

The BP pin capacitor energy powers the IC while MOSFET is on; the internal high-voltage current source recharges the BP pin capacitor while MOSFET is off.
Start-up: Output Reaches Regulation

Once output reaches regulation, EN/UV is pulled low, disabling MOSFET switching and regulating the output.
TinySwitch-III Start-up Waveforms

MOSFET switching enabled when BP pin reaches 5.85 V

TinySwitch-III skipping switching cycles to keep output voltage in regulation
ON/OFF Control Operation and Benefits

- MOSFET current ramps to a fixed limit every enabled (ON) switch cycle
  - Switching cycles are disabled to maintain regulation
- Effective switching frequency is proportional to load
  - Efficiency is virtually constant over entire load range, even in standby mode
  - Multi-level MOSFET current limit practically eliminates audible noise
- No loop compensation components required
ON/OFF Control Benefit: Output Regulation

- Overall $\pm 7\%$ $V_o$ tolerance with $(\pm 2\%)$ Zener feedback (saves cost)
  - Feedback current ($I_{FB}$) virtually independent of changes in Zener bias point
- Zener voltage change ($\Delta V_Z$) is very small with ON/OFF control
- Typical PWM controllers have $>1\ mA$ $\Delta I_{BIAS}$, so $\Delta V_Z$ affects accuracy

\[
IZ = IFB + IBIAS
\]
Current Limit State Machine Operation

- **Light Load**
  - $I_{\text{LIMIT}} = 40\%$

- **Mid Load**
  - $I_{\text{LIMIT}} = 70\%$

- **Full Load**
  - $I_{\text{LIMIT}} = 100\%$

- The controller sets the MOSFET current limit ($I_{\text{LIMIT}}$) to keep the effective switching frequency above the audible range.
TinySwitch-III Auto-restart Waveforms

When switching cycles are not skipped (<115 μA is drawn from the EN/UV pin) for >64 ms, auto-restart initiates, and MOSFET switching is disabled for ≈ 2.5 s, then re-enabled for 64 ms. Auto-restart ends when >115 μA is drawn from the EN/UV pin while MOSFET switching is enabled (cycle skipping is occurring).

- Auto-restart limits average output power to < 3% of maximum power.
## Selectable MOSFET Current Limit Provides Design Flexibility

<table>
<thead>
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<th>DEVICE</th>
<th>CURRENT LIMIT (mA)</th>
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<tbody>
<tr>
<td></td>
<td>BP/M cap 1 µF</td>
<td>BP/M cap 0.1 µF</td>
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<tr>
<td>TNY274*</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td>TNY275</td>
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<td>650</td>
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<tr>
<td>TNY280</td>
<td>650</td>
<td>750</td>
</tr>
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</table>

- $I_{\text{LIMITred}}$ equals the standard $I_{\text{LIMIT}}$ of the next smaller device
- $I_{\text{LIMITinc}}$ equals the standard $I_{\text{LIMIT}}$ of the next larger device
- Optimum device and current limit by simply changing the value of the BP/M pin capacitor
  - $I_{\text{LIMITinc}} = \text{highest power solution}$
  - $I_{\text{LIMITred}} = \text{highest efficiency}$
- Enables same supply to be used in applications with different ambient temperatures

* 250 mA is max current limit of the TNY274

All BP/M capacitor values $\geq 1$ µF select $I_{\text{LIMITred}}$
Selectable MOSFET Current Limit
Provides Design Flexibility

• 3 current limit levels available for each device (except TNY274)
  – Current limit levels selected by BP/M pin capacitor value

• Standard current limit ($I_{LIMIT}$)
  – Normal choice for sealed enclosure (adapter) applications

• Higher current limit ($I_{LIMITinc}$)
  – Extends maximum continuous power in open frame applications
  – Boosts peak power capability in all applications

• Lower current limit ($I_{LIMITred}$)
  – Lowers RMS currents and $R_{DS\_ON}$ based $I^2R$ losses
    • Lowers the operating temperature of the IC and the supply
    • Improves the active-mode efficiency of the supply

• Different devices can be used in the same design
  – A sealed adapter uses one device larger than open frame but with $I_{LIMITred}$
MOSFET On-Time Extension Operation

- Controller extends ON-time when $I_{\text{LIMIT}}$ is not reached by $\text{DC}_{\text{MAX}}$
  - Enables current limit to be reached independent of DC bus voltage
- Maximizes power capability at very low DC bus voltages
  - Improves power delivery during line sags, brown-outs and shutdown

**Without On-Time Extension**

- $I_{\text{LIMIT}} = 550 \, \text{mA}$
- $I_{\text{PK}} = 140 \, \text{mA}$
- $\delta = 65\%$

**With On-Time Extension**

- $I_{\text{PK}} = I_{\text{LIMIT}} = 550 \, \text{mA}$
- $\delta = 81\%$
MOSFET On-Time Extension Benefit: Longer Holdup Time

- ON-time extension increases typical output holdup time
- All the energy stored in the bulk capacitance is delivered to output
- May enable smaller values of bulk capacitance to be used

<table>
<thead>
<tr>
<th>Without On-Time Extension</th>
<th>With On-Time Extension</th>
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</thead>
<tbody>
<tr>
<td>t_{HOLDUP}</td>
<td>17 ms</td>
</tr>
<tr>
<td>V_{ACIN}: 200 V/div, V_{OUT}: 10 V/div</td>
<td>V_{ACIN}: 200 V/div, V_{OUT}: 10 V/div</td>
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</table>
Latching Shutdown for Output Overvoltage Protection (OVP)

- Latching shutdown triggers when BP/M pin current >6 mA for >30 µs
  - 30 µs filter prevents false triggering due to noise or line transients
- Allows simple, low cost, primary side design
  - Zener diode connected to bias supply senses output overvoltage
    - Protects against open loop due to component failure or open pin faults

- Removal of AC input allows input capacitor to discharge
  - Latch resets when BP/M pin voltage falls below 4.8 V
Auto-Restart Function

- Delivers < 3% of maximum output power during a fault condition
  - Lowers dissipation in primary clamp, MOSFET, transformer, and output diode
  - Reduces size and cost of the output-clamp Zener diode, if one is used for output overvoltage protection

Typical waveform during auto-restart (AR)
If Parameter Simplifies Design

Conventional designs must deliver power at minimum $I_{\text{LIMIT}}$, $f_{\text{OSC}}$ at $V_{\text{MIN}}$.

Conventional designs must survive overload at maximum $I_{\text{LIMIT}}$, $f_{\text{OSC}}$ and $V_{\text{MAX}}$.

$I^2f$ eliminates worst case design corners.

$I^2f$ Parameter Simplifies Design
$I^2f$ Parameter Lowers Cost

- Increases power delivery capability
  - Compared to designs with independent $I_{\text{LIMIT}}$ (±7%) and $f_{\text{OSC}}$ (±6%) tolerances:
    - Up to 5% more output power with a given core size
    - Up to 3% lower device conduction losses in a given design

- Improves power supply manufacturability
  - Tight tolerances improve production yields and manufacturing efficiency

- $I^2f$ is specified for the TinySwitch-III family of devices
  - Trimmed to be within –10% to +12% at final test
  - Primary inductance calculations in the PI Xls design tool are based on $I^2f$
Integrated Thermal Shutdown Function

- **Accurate, integrated, hysteretic, thermal shutdown (+142 °C, ± 5%)**
  - Normal operation resumes after junction temperature drops 75 °C (hysteresis)

- **Wide hysteresis keeps average PCB temperature below 100 °C**
  - Allows use of low cost PCB material
  - Protects IC, transformer, PCB and minimizes case temperature rise

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**Die temperature during a thermal fault**

- **Shutdown** 142 °C
- **Fault applied**
- **75 °C Hysteresis**
- **Fault removed**

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**Power Integrations**
UVLO Function Prevents Output Voltage Glitches

- MOSFET switching is kept disabled until VIN reaches the UVLO threshold
  - MOSFET switching is only enabled after EN/UV pin current ($I_{LUV}$) exceeds 25 $\mu$A
- If UV resistor is absent ($I_{LUV} < 1$ $\mu$A), the UVLO function is disabled

Typical waveforms during power up with a UV resistor in circuit

$I_{LUV} > 25$ $\mu$A MOSFET switching enabled

$V_{OUT}: 10$ V/div
$V_{BP}: 5$ V/div
$V_{DRAIN}: 200$ V/div

1 s/div
Switching Frequency Jitter Function

- ± 4 kHz modulation of switching frequency (at a 1 kHz rate)
  - Reduces size, cost and number of EMI filter components
  - Lowers average conducted EMI up to 10 dBμV
TinySwitch-III

Power Supply Performance
EP-91 12 V, 12 W Universal Input Example

R5 and R8 are optional components

C7 is configurable to adjust U1 current limit, see circuit description
Self Biased: < 150 mW No-Load Consumption

• IC is self powered from its internal, high-voltage current source
  – Meets all harmonized, world-wide, no-load power consumption standards
Bias Winding: < 50 mW No-Load Consumption

- Utilizing a bias winding can reduce no-load consumption to < 50 mW
  - Also allows implementation of OVP shutdown
High Active Mode Efficiency

- ON/OFF control results in consistently high efficiency across load
  - Meets all harmonized, active-mode, energy efficiency standards

![Graph showing efficiency across output current for different voltages.](image)
High Standby Power Availability

- ON/OFF control keeps efficiency high in standby and sleep modes
TinySwitch-III Conducted EMI Results

- **Worst-case measurement**
  - 230 VAC input, line measurement, artificial hand connected to output return
Designing with
TinySwitch-III
A Simple 12-Step Process

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>PI XIs used?</th>
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<tbody>
<tr>
<td>1</td>
<td>Choose feedback circuit type: constant voltage (CV) or constant current (CC)</td>
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<tr>
<td>2</td>
<td>Enter application variables: $V_{AC_{MIN}}, V_{AC_{MAX}}, f, V_O, I_O, \eta, Z, t_C, C_{IN}$</td>
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<td>3</td>
<td>Enter device variables: P/N, $V_{OR}, V_{DS}, V_D$</td>
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<td>4</td>
<td>Enter bias winding &amp; UVLO variables if used: $V_B, V_{ZOV}, V_{UV_TARGET}, R_{UV_ACTUAL}$</td>
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<td>5</td>
<td>Select transformer core and bobbin (variables: $A_E, L_E, A_L, BW, M, L, N_S$)</td>
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<td>6</td>
<td>Iterate the design (alter adjustable values) to eliminate spreadsheet warnings</td>
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<td>7</td>
<td>Build transformer prototype or pass PI XIs outputs to a magnetics vendor</td>
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<td>Select primary clamp components</td>
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<td>9</td>
<td>Select output rectifier diode: use PIVS from spreadsheet</td>
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<td>10</td>
<td>Select output capacitor(s): use IRIPPLE from spreadsheet</td>
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<td>11</td>
<td>Build and test a prototype of the power supply</td>
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<tr>
<td>12</td>
<td>Use the test results to refine &amp; document the design in the PI XIs spreadsheet</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- **PI XIs** enables engineers to quickly and easily optimize a transformer and complete a power supply design in very little time.
Step 1: Choose Feedback Circuit Type

- **Constant voltage (CV) only feedback circuits**
  - Either simple CV feedback circuit or enhanced CV feedback circuit

- **Constant voltage and constant current (CV/CC) feedback circuit**
**Simple Optocoupled CV Feedback Circuit**

\[ V_{RFB} = V_{OUT} - (V_{RA} + V_{F(UFB)}) \]

At \( V_{OUT} \), current flows through \( V_{RFB} \) and \( U_{FB} \) LED.

- \( R_A \) adjusts output voltage and limits feedback current during output transients.
- \( U_{FB} \) (200%-600% (PC817D))
- \( L_A \) (Bead)
- \( C_A \) (100 \( \mu \)F 16 V)
- \( R_B \) (390 \( \Omega \))
- \( L_A \) and \( C_A \) optional for lower switching ripple
- \( R_B \) sets bias current through \( V_{RFB} \)

- **Practical tolerance ± 7%, with 2%, low-current Zener (BZX79 series)**
  - Values shown in parentheses are for a 5 V output power supply.
RA adjusts output voltage, sets DC gain, and limits feedback current during output load transients.

Accurate Optocoupled CV Feedback Circuit

- \( R_D \) provides \( \approx 1 \) mA bias for \( U_{REF} \)
- \( R_A \) adjusts output voltage, sets DC gain, and limits feedback current during output load transients.
- \( C_{COMP} \) rolls off high frequency gain of \( U_{REF} \)
- \( U_{REF} \) provides output accuracy of \( \pm 2\% \)

\[ U_{REF}, R_B \text{ and } R_C \text{ tolerances determine accuracy of } V_{OUT} \]
  \[ \text{Values shown in parentheses are for a 5 V output power supply} \]

\( L_A \) and \( C_A \) optional for lower switching ripple

Resistor divider \( R_B \) and \( R_C \) sets output voltage
LowDrop-CC™ (0.3 V) CV/CC Feedback Circuit

At $I_{OUT}$, Q2 turns on, turning on Q1 and driving LED of U4A.

Q3, R11 and R8 bias Q2 to give 0.3 V threshold, using U4A LED as reference. Value of R11 sets threshold voltage.

$V_{BE}$ of Q2 and Q3 cancel for excellent temperature stability.

$R9 = 0.3 / I_{OUT}$

VR1 and U4A set CV output. Select Zener with low test current ($I_{ZT}$).

$R7$ and $R5$ determine when auto-restart is entered (at 2 V as shown).

**Example of the value of PI external intellectual property**

- This circuit can be employed with no royalty to PI when PI parts are used in the circuit.
Recommended First-Pass $\eta$ and Z Values

• Efficiency ($\eta$)
  – For constant voltage (CV) only operation, use a value of 0.75
  – For CV/CC designs with the CC threshold voltage values below (based on $V_O = 5$ V)
    • 1.1 V threshold, use 0.64
    • 0.7 V threshold, use 0.66
    • 0.3 V threshold, use 0.68
  Note: After actual efficiency has been measured on a prototype, it should be entered into the spreadsheet to refine and document the design

• Loss Allocation Factor (Z)
  – For opto-coupled CV only feedback, use 0.5
  – For opto-coupled CV/CC (1.1, 0.7, 0.3 V threshold), use 0.75, 0.66, 0.57 respectively

\[ Z = \frac{\text{Secondary Side Losses}}{\text{Total Losses}} \]
Step 2: Enter Variables into *PI XIs* Spreadsheet

<table>
<thead>
<tr>
<th>AC input voltage range</th>
<th>Line frequency</th>
<th>Main output voltage</th>
<th>Output current (increase to match total output power in multi-output designs)</th>
<th>Efficiency estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACDC_TinySwitch-III_020706; Rev.1.6; (c) Power Integrations 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENTER APPLICATION VARIABLES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VACMIN</td>
<td>85</td>
<td>Volts</td>
<td>Minimum AC Input Voltage</td>
<td></td>
</tr>
<tr>
<td>VACMAX</td>
<td>265</td>
<td>Volts</td>
<td>Maximum AC Input Voltage</td>
<td></td>
</tr>
<tr>
<td>fL</td>
<td>50</td>
<td>Hertz</td>
<td>AC Mains Frequency</td>
<td></td>
</tr>
<tr>
<td>VO</td>
<td>12.00</td>
<td>Volts</td>
<td>Output Voltage (at continuous power)</td>
<td></td>
</tr>
<tr>
<td>IO</td>
<td>1.00</td>
<td>Amps</td>
<td>Power Supply Output Current (corresponding to peak power)</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td>12 Watts</td>
<td>Continuous Output Power</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td></td>
<td>0.71</td>
<td>Efficiency Estimate at output terminals. Enter 0.7 if no better data available</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td></td>
<td>0.50</td>
<td>Z Factor. Ratio of secondary side losses to the total losses in the power supply. Use 0.5 if no better data available</td>
<td></td>
</tr>
<tr>
<td>tC</td>
<td></td>
<td>3.00</td>
<td>Bridge Rectifier Conduction Time Estimate</td>
<td></td>
</tr>
<tr>
<td>CIN</td>
<td></td>
<td>33.00</td>
<td>Input Capacitance</td>
<td></td>
</tr>
</tbody>
</table>

**Loss allocation factor (Z):** 0.5 for CV, 0.75 for CV/CC

**PI XIs** Spreadsheet

**Seminar Example**
# TinySwitch-III Device Selection

## OUTPUT POWER TABLE

<table>
<thead>
<tr>
<th>PRODUCT $^3$</th>
<th>230 VAC ±15%</th>
<th>85-265 VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adapter$^1$</td>
<td>Peak or Open Frame$^2$</td>
</tr>
<tr>
<td>TNY274 P or G</td>
<td>6 W</td>
<td>11 W</td>
</tr>
<tr>
<td>TNY275 P or G</td>
<td>8.5 W</td>
<td>15 W</td>
</tr>
<tr>
<td>TNY276 P or G</td>
<td>10 W</td>
<td>19 W</td>
</tr>
<tr>
<td>TNY277 P or G</td>
<td>13 W</td>
<td>23.5 W</td>
</tr>
<tr>
<td>TNY278 P or G</td>
<td>16 W</td>
<td>28 W</td>
</tr>
<tr>
<td>TNY279 P or G</td>
<td>18 W</td>
<td>32 W</td>
</tr>
<tr>
<td>TNY280 P or G</td>
<td>20 W</td>
<td>36.5 W</td>
</tr>
</tbody>
</table>

*Table 1.* Notes: 1. Minimum continuous power in a typical non-ventilated enclosed adapter measured at 50 °C ambient. Use of an external heatsink will increase power capability. 2. Minimum peak power capability in any design or minimum continuous power in an open frame design (see Key Application Considerations). 3. Packages: P: DIP-8C, G: SMD-8C. See Part Ordering Information.

- Actual continuous power capability depends on thermal constraints
**Step 3: Enter TinySwitch-III device and VOR**

Enter selected *TinySwitch-III* device part number

Enter current limit choice: STD, RED, or INC

---

<table>
<thead>
<tr>
<th>ENTER TinySwitch-III VARIABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TinySwitch-III</td>
</tr>
<tr>
<td>Chosen Device</td>
</tr>
</tbody>
</table>

Chose Configuration

- **ILIMITMIN** | 0.512 Amps | Minimum Current Limit |
- **ILIMITTYP** | 0.550 Amps | Maximum Current Limit |
- **ILIMITMAX** | 0.588 Amps |
- **fSmin** | 124000 Hertz | Minimum Device Switching Frequency |
- **I^2fmin** | 35.937 A^2kHz | I^2f (product of current limit squared and frequency is trimmed for tighter tolerance) |
- **VOR** | 100.00 Volts | Reflected Output Voltage (VOR < 135 V Recommended) |
- **VDS** | 10 Volts | TinySwitch-III on-state Drain to Source Voltage |
- **VD** | 0.7 Volts | Output Winding Diode Forward Voltage Drop |
- **KP** | 0.64 | Ripple to Peak Current Ratio (KP < 6) |
- **KP_TRANSIENT** | 0.38 | Transient Ripple to Peak Current Ratio. Ensure KP_TRANSIENT > 0.25 |

**VPOR default value is 120 V**

**Output diode forward voltage drop, can be manually changed for Schottky diodes**

**KP is the ripple-to-peak primary current ratio (0.6 < KP < 1). KP_TRANSIENT must be ≥ 0.25 to prevent false triggering of current limit**
Continuous Conduction Mode (CCM) $K_p$

- When the MOSFET switch turns on before the secondary current has reduced to zero, the supply is operating in CCM.

\[ K_p = K_{RP} = \frac{I_R}{I_P} \]

(a) Continuous, $K_p < 1$

(b) Borderline Continuous/Discontinuous, $K_p = 1$
Discontinuous Conduction Mode (DCM) $K_p$

\[
K_p = K_{DP} = \frac{(1-D) \times T}{t}
\]

(a) Discontinuous, $K_p > 1$

(b) Boarderline Discontinuous/Continuous, $K_p = 1$

- In DCM, secondary current is zero when the MOSFET turns on
Transient vs Steady State $K_p$

Steady state switching cycle sequence (a)

Feedback requires a skipped cycle (b)

On-time of next enabled cycle longer as primary current ramps from zero (c)

Secondary current ramps to zero: all energy in transformer delivered to load (b)

Reduced off-time of following cycle causes much lower transient $K_p$ value (d)
Input Stage Selection

4 W to 10 W

10 W to 15 W

> 15 W
Input Capacitance Value

<table>
<thead>
<tr>
<th>Total Input Capacitance Required</th>
<th>μF per Watt of Output Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Input Voltage</td>
<td></td>
</tr>
<tr>
<td>85–265</td>
<td>2 to 3</td>
</tr>
<tr>
<td>100/115</td>
<td>2 to 3</td>
</tr>
<tr>
<td>230</td>
<td>1</td>
</tr>
</tbody>
</table>

- Check rectified input voltage $V_{\text{MIN}}$ at low-line (AC input) and full load
  - $V_{\text{MIN}}$ should be $\geq 70$ VDC
    - $PI XIs$ calculates the minimum input capacitance value for $V_{\text{MIN}} \geq 70$ VDC
- On-time extension feature minimizes value of $C_{\text{IN}}$
  - Maximizes energy delivery and holdup time during power down and brownout
Step 4: Enter Bias Winding and UVLO Variables

A user specified bias winding voltage can be entered in the over-ride cell

<table>
<thead>
<tr>
<th>ENTER BIAS WINDING VARIABLES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VB</td>
<td>22.00 Volts</td>
</tr>
<tr>
<td>VDB</td>
<td>0.70 Volts</td>
</tr>
<tr>
<td>NB</td>
<td>6.93</td>
</tr>
<tr>
<td>VZOV</td>
<td>28.00 Volts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UVLO VARIABLES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>V_UV_TARGET</td>
<td>93.85 Volts</td>
</tr>
<tr>
<td>V_UV_ACTUAL</td>
<td>92.20 Volts</td>
</tr>
<tr>
<td>RUV_IDEAL</td>
<td>3.67 Mohms</td>
</tr>
<tr>
<td>RUV_ACTUAL</td>
<td>3.60 Mohms</td>
</tr>
</tbody>
</table>

- Entering resistor value will calculate the actual UV voltage
- Enter specific target value of the DC input startup voltage
- Enter the value of the Zener diode if it differs from the calculated value

- A bias voltage of 22 V and a 28 V Zener gives good OVP performance
  - For 12 V output, OVP limits peak voltage to \( \approx 15 \) V during open loop fault
Step 5: Select Transformer Core and Bobbin

Select the desired core from drop down menu

Grey, over-ride cells can be used to enter custom core / bobbin types

**ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES**

<table>
<thead>
<tr>
<th>Core Type</th>
<th>EF20</th>
<th>EF20</th>
<th>User-Selected transformer core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>EF20</td>
<td>P/N: PC40EF20-Z</td>
<td></td>
</tr>
<tr>
<td>Bobbin</td>
<td>EF20</td>
<td>P/N: EF20_BOBBIN</td>
<td></td>
</tr>
</tbody>
</table>

- **AE**: Core Effective Cross Sectional Area: 0.335 cm²
- **LE**: Core Effective Path Length: 4.49 cm
- **AL**: Ungapped Core Effective Inductance: 1570 nH/T²
- **BW**: Bobbin Physical Winding Width: 12.2 mm
- **M**: Safety Margin Width (Half the Primary to Secondary Creepage Distance): 0 mm
- **L**: Number of Primary Layers: 3
- **NS**: Number of Secondary Turns: 6

Enter half of total required margin (enter 3 mm for 6 mm total margin)

The number of secondary turns are calculated to keep the flux density < 3000 Gauss (300 mT). Other values can be entered in over-ride cell.

Enter number of primary winding layers ($L \leq 4$) if different from that calculated by $PI$ XIs
Step 6: Iterate Design to Eliminate Warnings

<table>
<thead>
<tr>
<th>Transformer Primary Design Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>966 uHenries</td>
</tr>
<tr>
<td>LP_TOLERANCE</td>
<td>+/- 12% to ensure a minimum primary inductance of 862 uH</td>
</tr>
<tr>
<td>NP</td>
<td>38 Primary Winding Number of Turns</td>
</tr>
<tr>
<td>ALG</td>
<td>676 nH/T^2</td>
</tr>
<tr>
<td>BM</td>
<td>4485 Gauss</td>
</tr>
<tr>
<td>BAC</td>
<td>1661 Gauss</td>
</tr>
<tr>
<td>ur</td>
<td>1675 Relative Permeability of Ungapped Core</td>
</tr>
<tr>
<td>LG</td>
<td>0.04 mm</td>
</tr>
<tr>
<td>BWE</td>
<td>36.6 mm Effective Bobbin Width</td>
</tr>
<tr>
<td>OD</td>
<td>0.97 mm Maximum Primary Wire Diameter including insulation</td>
</tr>
<tr>
<td>INS</td>
<td>0.08 mm Estimated Total Insulation Thickness (= 2 * film thickness)</td>
</tr>
<tr>
<td>DIA</td>
<td>0.89 mm Bare conductor diameter</td>
</tr>
<tr>
<td>AWG</td>
<td>20 AWG Primary Wire Gauge (Rounded to next smaller standard AWG value)</td>
</tr>
<tr>
<td>CM</td>
<td>1024 Cmils Bare conductor effective area in circular mils</td>
</tr>
<tr>
<td>CMA</td>
<td>3341 Cmils/Amp</td>
</tr>
</tbody>
</table>

- Follow PI Xls guidance in comments column to bring design within acceptable best practice limits
Step 6a: Iterating Design Details

• **VOR recommendations**
  - Highest efficiency typically occurs with a VOR value of:
    • 90-110 V for 85-265 VAC (universal) input (or multiple outputs)
    • 120-135 V for 185-265 VAC (single) input
  - A value of 135 V delivers maximum power from a given device

• **Relationship between primary layers (L), secondary turns ($N_S$), core size, flux density ($B_M$), core gap ($L_g$) and current density (CMA)**

<table>
<thead>
<tr>
<th></th>
<th>$B_M$</th>
<th>$L_g$</th>
<th>CMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>↑</td>
<td>-</td>
<td>↑</td>
</tr>
<tr>
<td>$N_S$</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>core size</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

↑= Value increases  
↓= Value decreases  
- = No change
### Key Outputs From PI Xls Spreadsheet

#### Transformer Primary Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>966 uH</td>
<td>Typical Primary Inductance. +/- 12% to ensure a minimum primary inductance of 862 uH</td>
</tr>
<tr>
<td>LP_TOLERANCE</td>
<td>12 %</td>
<td>Primary inductance tolerance</td>
</tr>
<tr>
<td>NP</td>
<td>57</td>
<td>Primary Winding Number of Turns</td>
</tr>
<tr>
<td>ALG</td>
<td>300 nH/T²</td>
<td>Gapped Core Effective Inductance</td>
</tr>
<tr>
<td>BM</td>
<td>2990 Gauss</td>
<td>Maximum Operating Flux Density, BM&lt;3000 is recommended</td>
</tr>
<tr>
<td>BAC</td>
<td>1107 Gauss</td>
<td>AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)</td>
</tr>
<tr>
<td>ur</td>
<td>1675</td>
<td>Relative Permeability of Ungapped Core</td>
</tr>
<tr>
<td>LG</td>
<td>0.11 mm</td>
<td>Gap Length (Lg &gt; 0.1 mm)</td>
</tr>
<tr>
<td>BWE</td>
<td>24.4 mm</td>
<td>Effective Bobbin Width</td>
</tr>
<tr>
<td>OD</td>
<td>0.43 mm</td>
<td>Maximum Primary Wire Diameter including insulation</td>
</tr>
<tr>
<td>INS</td>
<td>0.06 mm</td>
<td>Estimated Total Insulation Thickness (= 2 * film thickness)</td>
</tr>
<tr>
<td>DIA</td>
<td>0.37 mm</td>
<td>Bare conductor diameter</td>
</tr>
<tr>
<td>AWG</td>
<td>27 AWG</td>
<td>Primary Wire Gauge (Rounded to next smaller standard AWG value)</td>
</tr>
<tr>
<td>CM</td>
<td>203 Cmils</td>
<td>Bare conductor effective area in circular mils</td>
</tr>
<tr>
<td>CMA</td>
<td>663 Cmils/Amp</td>
<td>CAN DECREASE CMA &lt; 500 (decrease L (primary layers), increase NS, use smaller core)</td>
</tr>
</tbody>
</table>

#### Transformer Secondary Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISP</td>
<td>4.84 Amps</td>
<td>Peak Secondary Current</td>
</tr>
<tr>
<td>ISRMS</td>
<td>2.29 Amps</td>
<td>Secondary RMS Current</td>
</tr>
<tr>
<td>IRIPPLE</td>
<td>2.07 Amps</td>
<td>Output Capacitor RMS Ripple Current</td>
</tr>
<tr>
<td>CMS</td>
<td>459 Cmils</td>
<td>Secondary Bare Conductor minimum circular mils</td>
</tr>
<tr>
<td>AWGS</td>
<td>23 AWG</td>
<td>Secondary Wire Gauge (Rounded up to next larger standard AWG value)</td>
</tr>
</tbody>
</table>

#### Voltage Stress Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDRAIN</td>
<td>647 Volts</td>
<td>Maximum Drain Voltage Estimate (Assumes 20% zener clamp tolerance and an additional 10% temperature tolerance)</td>
</tr>
<tr>
<td>PIVS</td>
<td>52 Volts</td>
<td>Output Rectifier Maximum Peak Inverse Voltage</td>
</tr>
</tbody>
</table>

Besides the list of primary and secondary design parameters, the slide also highlights:

- Provides key information for component selection and transformer design
Step 7: Use PI Xls Outputs to Build A Transformer Prototype

- All data needed to build a transformer prototype is provided, such as:
  - Primary Inductance $L_p$
    - default tolerance $\pm 12\%$, adjust based on vendor input
  - Core gap length ($L_g$) and gapped core effective inductance ($A_{LG}$) values
  - Number of primary, secondary and bias winding turns ($N_P$, $N_S$ and $N_B$)
  - Wire diameter sizes for each winding

- **PI Xls helps in selecting other TinySwitch-III support components by calculating:**
  - Output capacitor ripple current ($I_{RIPPLE}$) value
  - Output diode reverse voltage stress value
  - Zener diode voltage for OVP implementation
  - UVLO resistor value
Step 8: Primary Clamp Component Selection

<table>
<thead>
<tr>
<th>MOSFET Drain Clamp</th>
<th>RCD</th>
<th>Zener</th>
<th>RCD / Zener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component cost</td>
<td>Lowest</td>
<td>Higher</td>
<td>Highest</td>
</tr>
<tr>
<td>No-load input power</td>
<td>Highest</td>
<td>Lowest</td>
<td>Low</td>
</tr>
<tr>
<td>Light-load efficiency</td>
<td>Lowest</td>
<td>Highest</td>
<td>High</td>
</tr>
<tr>
<td>EMI generation</td>
<td>Lowest</td>
<td>Highest</td>
<td>Low</td>
</tr>
</tbody>
</table>
Step 9: Output Diode Selection

<table>
<thead>
<tr>
<th>Series Number</th>
<th>Type</th>
<th>$V_{\text{REVERSE Range (V)}}$</th>
<th>$F_{\text{Forward Current (A)}}$</th>
<th>Package</th>
<th>Manf</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB120 – 1100</td>
<td>Schottky</td>
<td>20–100</td>
<td>1</td>
<td>Axial Lead</td>
<td>Vishay</td>
</tr>
<tr>
<td>SB320 – 3100</td>
<td>Schottky</td>
<td>20–100</td>
<td>3</td>
<td>Axial Lead</td>
<td>Vishay</td>
</tr>
<tr>
<td>SB520 – 5100</td>
<td>Schottky</td>
<td>20–100</td>
<td>5</td>
<td>Axial Lead</td>
<td>Vishay</td>
</tr>
<tr>
<td>MBR735 – 745</td>
<td>Schottky</td>
<td>35–45</td>
<td>7.5</td>
<td>TO-220AC</td>
<td>Vishay</td>
</tr>
<tr>
<td>MBR1045 – 1060</td>
<td>Schottky</td>
<td>45–60</td>
<td>10</td>
<td>TO-220AC</td>
<td>Vishay</td>
</tr>
<tr>
<td>MBR2045CT</td>
<td>Schottky</td>
<td>45</td>
<td>20</td>
<td>TO-220AB</td>
<td>Vishay</td>
</tr>
<tr>
<td>UF4002 – 4006</td>
<td>Ultrafast</td>
<td>100–600</td>
<td>1</td>
<td>Axial Lead</td>
<td>Vishay</td>
</tr>
<tr>
<td>UF5401 – 5408</td>
<td>Ultrafast</td>
<td>100–800</td>
<td>3</td>
<td>Axial Lead</td>
<td>Vishay</td>
</tr>
<tr>
<td>MUR620</td>
<td>Ultrafast</td>
<td>200</td>
<td>6</td>
<td>TO-220AB</td>
<td>On Semi</td>
</tr>
<tr>
<td>MUR820 – 840</td>
<td>Ultrafast</td>
<td>200–400</td>
<td>8</td>
<td>TO-220AC</td>
<td>On Semi</td>
</tr>
<tr>
<td>ES2A – ES2D</td>
<td>Ultrafast</td>
<td>50–200</td>
<td>2</td>
<td>SMD</td>
<td>Vishay</td>
</tr>
</tbody>
</table>

- Sample Schottky and Ultrafast diodes for use in *TinySwitch-III* designs
  - Output diode current rating should be ≥ rated output current
Step 10: Output Capacitor Selection

- Capacitor voltage rating should be $> 1.25 \times V_o$
- Capacitor ripple current rating should be $> I_{RIPPLE}$
  - Output capacitor $I_{RIPPLE}$ ratings are inversely proportional to temperature
    - Example: A 105°C capacitor working at 85°C has an $I_{RIPPLE}$ factor of 1.7
    - Check manufacturer’s datasheet for specific factors

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Value (μF)</th>
<th>$I_{RIPPLE}$ (A) (at rated life, 105°C)</th>
<th>UCC Series</th>
<th>Size (dxl mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>470</td>
<td>0.76</td>
<td>KZE</td>
<td>8 x 11.5</td>
</tr>
<tr>
<td>10 V</td>
<td>1000</td>
<td>1.25</td>
<td>KZE</td>
<td>8 x 20</td>
</tr>
<tr>
<td>10 V</td>
<td>1500</td>
<td>2.15</td>
<td>KZE</td>
<td>10 x 25</td>
</tr>
<tr>
<td>16 V</td>
<td>470</td>
<td>1.03</td>
<td>KZE</td>
<td>10 x 12.5</td>
</tr>
<tr>
<td>16 V</td>
<td>1000</td>
<td>1.82</td>
<td>KZE</td>
<td>10 x 20</td>
</tr>
<tr>
<td>25 V</td>
<td>470</td>
<td>1.25</td>
<td>KZE</td>
<td>8 x 20</td>
</tr>
<tr>
<td>25 V</td>
<td>1000</td>
<td>2.36</td>
<td>KZE</td>
<td>12.5 x 20</td>
</tr>
<tr>
<td>35 V</td>
<td>330</td>
<td>1.43</td>
<td>KZE</td>
<td>10 x 16</td>
</tr>
<tr>
<td>35 V</td>
<td>470</td>
<td>1.82</td>
<td>KZE</td>
<td>10 x 20</td>
</tr>
<tr>
<td>50 V</td>
<td>220</td>
<td>1.37</td>
<td>KZE</td>
<td>10 x 16</td>
</tr>
<tr>
<td>50 V</td>
<td>330</td>
<td>1.87</td>
<td>KZE</td>
<td>10 x 25</td>
</tr>
<tr>
<td>63 V</td>
<td>100</td>
<td>0.535</td>
<td>LXZ</td>
<td>8 x 15</td>
</tr>
<tr>
<td>63 V</td>
<td>220</td>
<td>1.05</td>
<td>LXZ</td>
<td>10 x 25</td>
</tr>
</tbody>
</table>
Steps 11–12: Test Prototype & Refine Design

• Build and test prototype of power supply
• Measure peak drain voltage at maximum input voltage, the minimum DC bus voltage ($V_{MIN}$) and efficiency at low line
• Verify that $V_{MIN}$ is $\geq 70$ V
  – Increase input capacitance value if necessary
• Verify peak drain voltage <650 V at maximum line voltage
• Enter measured parameters into the PI Xls spreadsheet
  – Efficiency ($\eta$)
  – Measured value of $V_{MIN}$
TinySwitch-III Design Tools

• Reference Design
  (Design Accelerator Kit)
  DAK-91:
  – Built and tested 12 W power
    supply (EP-91)
  – Engineering report (EPR-91)
  – Blank PCB and IC samples
  – PI Expert Suite power supply
    design software
  – Datasheet
  – Design Idea DI-91
TinySwitch-III

Hints and Tips
Low-cost RCD Clamp Circuit

- **R<sub>CLAMP</sub>**: 47 kΩ to 200 kΩ, ½ W to 3 W
- **C<sub>CLAMP</sub>**: 330 pF to 3.3 nF, ≥ 400 V ceramic or film (ceramic capacitors may produce audible noise)
- **D<sub>CLAMP</sub>**: FR107, 1N4937, or UF4005. FR107 gives best EMI and efficiency

For applications where lowest cost and EMI are most important
Low-cost RCD Clamp Design Guidelines

- **Minimize value of** $C_{\text{CLAMP}}$ **and maximize value of** $R_{\text{CLAMP}}$
  - Maximizes efficiency and minimizes no-load input power consumption
  - Reduce value of $R_{\text{CLAMP}}$ to improve conducted EMI in the 1-2 MHz region
    - Increases damping of leakage inductance ringing
  - Dissipation of $P_{R_{\text{CLAMP}}} = \frac{V_{\text{CCLAMP}}^2}{R_{\text{CLAMP}}}$
    - Measure voltage across $C_{\text{CLAMP}}$ at full load, low line using a DVM
    - Select suitable resistor power rating
- $R_{\text{CLAMP2}}$ dampens ringing when a 500 ns diode (FR107) is used
- Keep $V_{\text{DRAIN}} < 650$ V to provide margin for unit-to-unit variation
High-Efficiency Zener Clamp Circuit

**DCLAMP:**
FR107, 1N4937 or UF4005. FR107 gives best EMI and efficiency

**VRCLAMP:**
1.4 × V_{OR} ≤ VR_{CLAMP} ≤ 200 V
0.5 W to 1 W rating
Part number series P6KExxx, BZY97Cxxx, BZX55

**R_{CLAMP3}:**
Optional to reduce zener dissipation and EMI
47 kΩ to 330 kΩ

**VR_{CLAMP}:**

**R_{CLAMP2}:**
50 Ω to 330 Ω, ¼ W

**D_{CLAMP}:**
For applications where lower no-load consumption and higher light load efficiency are most important
High-Efficiency Zener Clamp Design Guidelines

- Improved efficiency and lower no-load consumption than RCD clamp
- Generates higher EMI than RCD clamp
  - Placing $R_{ \text{CLAMP3}}$ (47 k$\Omega$ to 330 k$\Omega$) in parallel with $V_{R_{ \text{CLAMP}}}$ can reduce EMI and decrease zener dissipation
- $R_{ \text{CLAMP2}}$ dampens ringing when a 500 ns diode (FR107) is used
RCD/Zener Clamp Circuit

- **R\text{CLAMP}:** 47 kΩ to 200 kΩ, ½ W
- **C\text{CLAMP}:** 330 pF to 3.3 nF, ≥ 400 V ceramic or film (ceramic capacitors may produce audible noise)
- **VR\text{CLAMP}:**
  \[ 1.4 \times V_{OR} \leq VR\text{CLAMP} \leq 200 \text{ V} \]
  0.5 W to 1 W rating
  Part number series P6KExxx, BZY97Cxxx, BZX55

- **R\text{CLAMP2}:** 50 Ω to 330 Ω, ¼ W
- **D\text{CLAMP}:** FR107, 1N4937 or UF4005. FR107 gives best EMI and efficiency

- For applications where lowest no-load consumption, highest light load efficiency and low EMI are most important
Combo RCD/Zener Clamp Design Guidelines

- Highest efficiency and lowest no-load consumption clamp circuit
- Parallel capacitor softens Zener turn-on
  - A 330 pF to 3.3 nF capacitor can lower EMI and increase efficiency
  - Allows low cost 1 W Zener (BZY97-C200) to be used in high power designs
- $R_{\text{CLAMP}_2}$ dampens ringing and limits diode reverse recovery current
- Set initial value of $R_{\text{CLAMP}_2}$ at 200 $\Omega$
  - Adjust value for optimum EMI and efficiency
- Fast diodes produce higher efficiency and lower EMI than ultra-fast
  - Avoid general purpose rectifier diodes (1N400x) due to excessive ringing
Bias Winding Reduces No-Load Input Power

- A bias winding reduces the no-load consumption to <50 mW
  - IC supply current is no longer provided from the DRAIN pin
  - Select resistor value to provide the supply current ($I_{S2}$) specified in the TinySwitch-III datasheet
  - Internal clamp limits maximum BP/M pin voltage
Primary Side Sensed OVP Guidelines

• \( V_{BIAS} \approx (V_{OUT} \cdot N_B/N_S) \)
  - High bias voltage improves accuracy by reducing the effect of leakage inductance
  - 12 V to 22 V works well

• Zener voltage
  - \( V_{VR(OVP)} > V_{BAIS} + 6.2 \text{ V} \) (\( V_{BP\_PIN} \))

• \( R_{OVP1} \) filters leakage spikes

• \( R_{OVP2} \) can be used to adjust trip point

• Verify that OVP does not falsely trigger
  - Test at low line, maximum load where leakage energy is highest
  - Perform startup at highest line, zero load, where output overshoot is maximum

• Monitor VR\(_{OVP} \) current to determine design margin to 6 mA threshold
Secondary Side Sensed OVP Guidelines

- **Bias voltage:** 12 V  
  - Insensitive to bias variation
- **Zener voltage:**  
  \[ V_{VR(OVP)} > V_{OUT(MAX)} + V_{F(OPTO)} \]  
  - 1 kΩ resistor biases Zener close to test current for improved accuracy
- **OVP latch triggered when output voltage exceeds** \( V_{ROVP} \) **plus forward drop of opto LED**
Under-voltage Lock-Out (UVLO) Guidelines

- \( R_{UV} = \frac{(V_{UV} - V_{EN})}{25 \mu A} \)
  - \( V_{EN} = 2.2 \) V at \( I_{EN} = 25 \mu A \)
  - \( V_{UV} \) is typically 100 VDC for universal input, 200 VDC for 230 VAC input designs
    - 3.9 M\( \Omega \) for 100 VDC, 8.2 M\( \Omega \) for 200 VDC

- **Voltage rating of >400 V required**
  - 0.5 W resistor or 2 series 0.25 W parts
    - Actual dissipation \( \approx 35 \) mW

- **With no \( R_{UV} (I_{LUV} < 1 \mu A) \), UVLO is disabled**
  - Install a 390 k\( \Omega \) resistor from the EN/UV pin to the SOURCE pin, in open frame designs
    - Prevents PCB leakage current from the BP/M pin to the EN/UV pin, which can cause false UVLO resistor detection and keep the power supply from starting up
Audible Noise Design Guidelines

- Flux density > 3000 Gauss may produce perceptible audible noise
- Long cores (EEL types) increase noise due to “tuning fork” effect
  - Can be reduced by lowering flux density
- 35 dBA is the typical acceptable limit for audible noise
  - Sealed enclosures attenuate audible noise by ≈10 dBA

3000 Gauss (300 mT) Short Core

35 dBA limit

3000 Gauss (300 mT) Long Core

Measured 1 inch (25 mm) from transformer
TinySwitch-III Layout Recommendations

- Keep input stage away from IC DRAIN pin to minimize noise coupling.
- Keep drain trace short.
- Maximize source area for good heatsinking.
- Keep traces above source potential away from EN/UV pin.
- Place BP pin capacitor near the IC.
- Connect Y capacitor to the plus bulk rail on the primary side for better surge immunity.
- Keep Y capacitor traces short.
- Keep output diode to output capacitor traces short.
- Route bias winding currents back to the bulk cap.
TinySwitch-III

Design Examples
EP91 – 12 V, 12 W Universal Input Supply

- No-load with R8:  < 50 mW
- No-load without R8:  < 140 mW
- Average efficiency:  > 80%
- Component count:  33

Available standby power @ 230 VAC
- 2.2 W for 3 W input power
- 1.4 W for 2 W input power
- 0.65 W for 1 W input power
7.5 W Multiple Output (DVD) Supply

- No-load consumption: <140 mW
- Average efficiency: >70%
- Component count: 42

Available standby power @ 230 VAC
- 2.1 W for 3 W input power
- 1.3 W for 2 W input power
- 0.6 W for 1 W input power
21 W Dual Output PC Standby Supply

- No-load consumption: < 50 mW
- Average efficiency: > 80%
- Component count: 42

Available standby power @ 230 VAC
- 2.3 W for 3 W input power
- 1.48 W for 2 W input power
- 0.67 W for 1 W input power
PI Device Quick Design Checklist
Quick Design Checklist

• **Maximum (peak) drain voltage**
  – $V_{DS}$ should not exceed 650 V at $V_{IN(MAX)}$ and peak (overload) power
    • Provides 50 V margin to the 700 V $BV_{DSS}$ rating

• **Maximum (peak) drain current**
  – Observe drain current waveforms for signs of transformer saturation at maximum ambient temperature, $V_{IN(MAX)}$ and peak (overload) power
  – Peak drain current must remain below the specified absolute maximum specifications under all operating conditions

• **Leading Edge Blanking**
  – Observe the leading-edge current spike on the drain current waveform and verify that it is below $I_{LIMIT(MIN)}$ at the end of the $t_{LEB(MIN)}$
Leading Edge Blanking Verification

*PeakSwitch* datasheet specified minimum blanking time \( t_{LEB} \) = 170 ns

Drain current well below \( I_{INIT(MIN)} \) after \( t_{LEB(MIN)} \)

\[ I_{INIT(MIN)} = 0.75 \cdot I_{LIMIT(MIN)} \]

\[ I_{INIT(MIN)} = 1.95 \text{ A} \]
External Power Supply (EPS)
Energy Efficiency Standards

Appendix A
The Problem of Energy Waste

- **Energy waste is a major concern around the world**
  - Fossil fuel energy sources are finite
  - Fossil fuel consumption side effects: pollution, green-house gases
  - Energy costs are increasing, while alternative energy sources are not mature enough to provide relief

- **The growing demand for personal electronics has dramatically increased the number of External Power Supplies (EPS)**

- **How much energy do EPS actually consume each year?**
The Magnitude of Energy Waste

- Estimated EPS sold annually: >1 billion units
- Estimated EPS currently in use: >10 billion units
- % of EPS that are inefficient linears: ~ 45%
- Yearly EPS energy waste in the US: 30 – 60 B kW-hours
- Cost of annual US EPS waste: 2.5 – 5 billion dollars

Although EPS waste is only 1-2% of annual US energy consumption, it equals the output of 26 average sized power plants!
### Regulations Emerge to Reduce Energy Waste

<table>
<thead>
<tr>
<th>Regulation Name Description</th>
<th>Geographic Region Affected</th>
<th>Effective Date</th>
<th>Compliance Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY STAR</td>
<td>United States</td>
<td>January 2005</td>
<td>voluntary</td>
</tr>
<tr>
<td>EU Code of Conduct</td>
<td>Europe</td>
<td>January 2007*</td>
<td>voluntary</td>
</tr>
<tr>
<td>China Certification Center for Energy Conservation Products (CECP)</td>
<td>Mainland China</td>
<td>January 2005</td>
<td>voluntary</td>
</tr>
<tr>
<td>California Appliance Efficiency Regulations (Title 20)</td>
<td>California</td>
<td>January 2007**</td>
<td>mandatory</td>
</tr>
<tr>
<td>Australia Greenhouse Office (AGO)</td>
<td>Australia</td>
<td>October 2007</td>
<td>mandatory</td>
</tr>
<tr>
<td>HB 3363</td>
<td>Oregon</td>
<td>January 2007</td>
<td>mandatory</td>
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<tr>
<td>Energy and Consumer Savings Act</td>
<td>Rhode Island</td>
<td>January 2007</td>
<td>mandatory</td>
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<tr>
<td>SB 6840</td>
<td>Washington</td>
<td>January 2008</td>
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<tr>
<td>HB 2390</td>
<td>Arizona</td>
<td>January 2008</td>
<td>mandatory</td>
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</table>

*Standards have been in effect since 2001. In January 2007, it plans to harmonize EPS active-mode efficiency standard with the others shown. ** Additional products covered in July 2007.

<table>
<thead>
<tr>
<th>Nameplate Output (W)</th>
<th>Minimum Efficiency in Active Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 Watt</td>
<td>0.49 * Nameplate Output</td>
</tr>
<tr>
<td>≥ 1 (W) ≤ 49 Watts</td>
<td>(0.09 * Ln(Nameplate output)) + 0.49</td>
</tr>
<tr>
<td>&gt; 49 Watts</td>
<td>0.84</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum Energy Consumption in No-Load Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to &lt; 10 Watts</td>
</tr>
<tr>
<td>≥ 10 to &lt; 250 Watts</td>
</tr>
</tbody>
</table>

Where Ln (Nameplate output) = Natural Logarithm of the output power in Watts

Note: Active-mode efficiency is the average of the 25%, 50%, 75%, and 100% load points.

In 2008, the minimum active-mode efficiency for EPS > 51 watts will be 0.85, and the maximum no-load consumption for all EPS < 250 watts will be 0.5 watts.
Additional Energy Efficiency Programs

- US 1W Standby Executive Order
- Japan Top Runner Program
- Korea Energy Saving Office Equipment & Home Electronics Program
- Germany Blue Angel
- US Ecos Consulting 80-Plus Program
- European Group for Energy Efficient Appliances
Meeting Worldwide Requirements

• PI solutions enable conformance to ALL worldwide energy efficiency standards including standards with tighter no-load consumption limits
  – European Union Code of Conduct requires < 300 mW
  – Some Japanese and European OEMs require < 150 mW
  – Other Japanese OEMs require < 50 mW
Stay Informed with PI’s Green Room

- The PI Green Room contains information and links to the latest worldwide standards
  - www.powerint.com/greenroom
  - View regulations and standards for your design:
    - By agency (ENERGY STAR, CEC, CECP, AGO, etc.)
    - By application (external adapter/charger, TV, DVD player, etc.)
    - By region (China, Asia, Europe, US, etc.)
Links to Key Documents

• Current version of the CEC Appliance Efficiency Regulations
  http://www.energy.ca.gov/appliances/

• US EPA ENERGY STAR power supply efficiency specification
  http://www.energystar.gov/index.cfm?c=prod_development.power_supplies

• US EPA test method for calculating the efficiency of single voltage external AC-DC and AC-AC power supplies

• EU Code of Conduct external power supply efficiency web page