

# Designing Low Power Switchers with ***LinkSwitch*** and ***TinySwitch-II***

- The focus of this presentation is power supplies of 20 W or less

# Agenda

- **Introduction**
- ***LinkSwitch***
  - Operation
  - Performance
  - Designing with *LinkSwitch*
  - Hints and Tips
  - Application Examples
  - *LinkSwitch* Summary
- ***TinySwitch* and *TinySwitch-II***
  - Why *TinySwitch* Technology
  - Choosing *TinySwitch-II* vs *TinySwitch*
  - Operation
  - Designing with *TinySwitch* Technology
  - Application Examples
  - Hints and Tips
  - *TinySwitch* Technology Summary

# 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*®)



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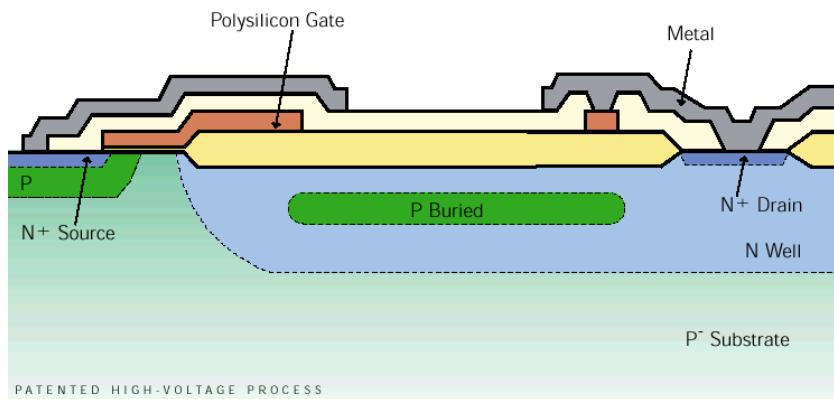
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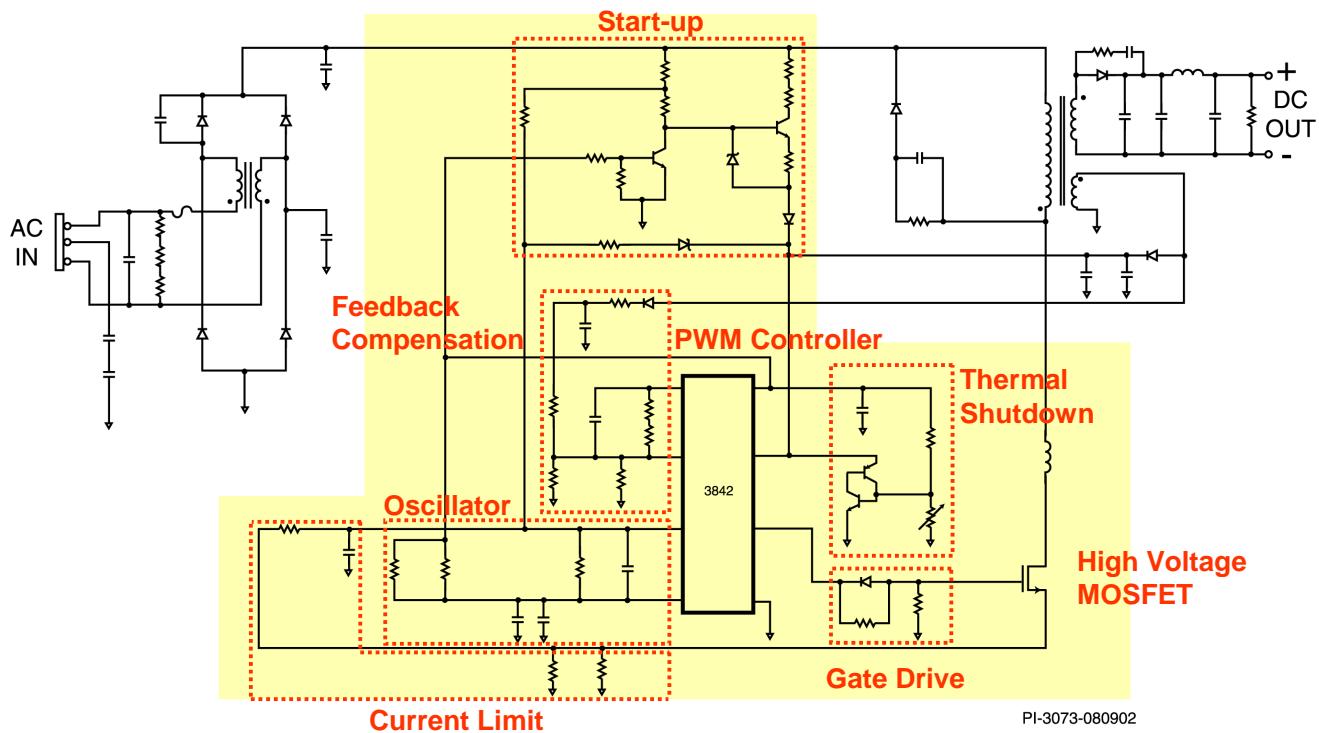
- Power Integrations was the world's first semiconductor company to introduce highly energy efficient products by using *EcoSmart* technology.
- *TinySwitch* received the 1999 Discover award for the best technological innovation in the environment category for its *EcoSmart* features.
- 10% of the world's 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  $\mu$  CMOS process
- Widely available capacity



# Discrete PWM Circuit



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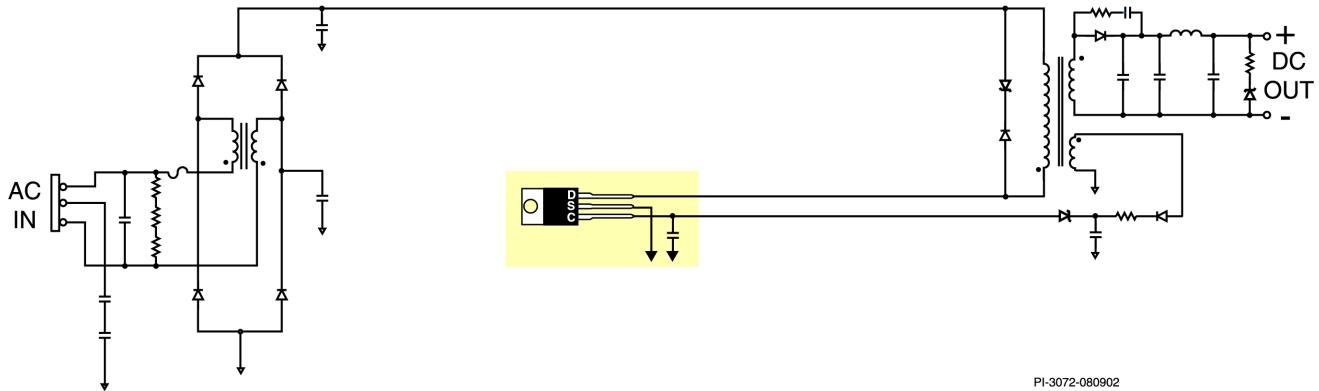
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- In addition to the high voltage MOSFET and controller, Power Integrations' ICs integrate:

- start-up circuit
- lossless current limit
- oscillator timing components
- feedback compensation
- thermal shutdown
- gate driver circuit

# Equivalent Power Integrations Solution

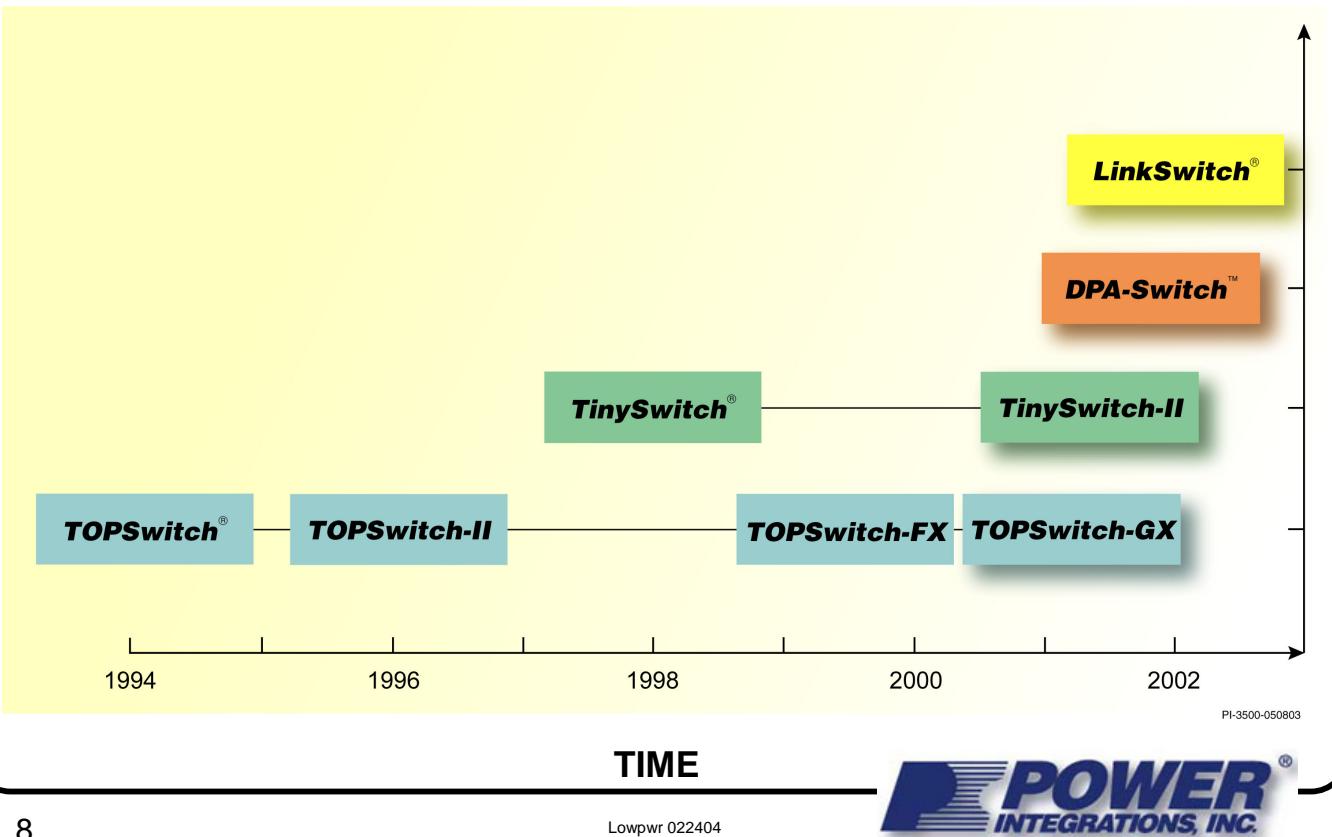


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**20 to 50 components eliminated**

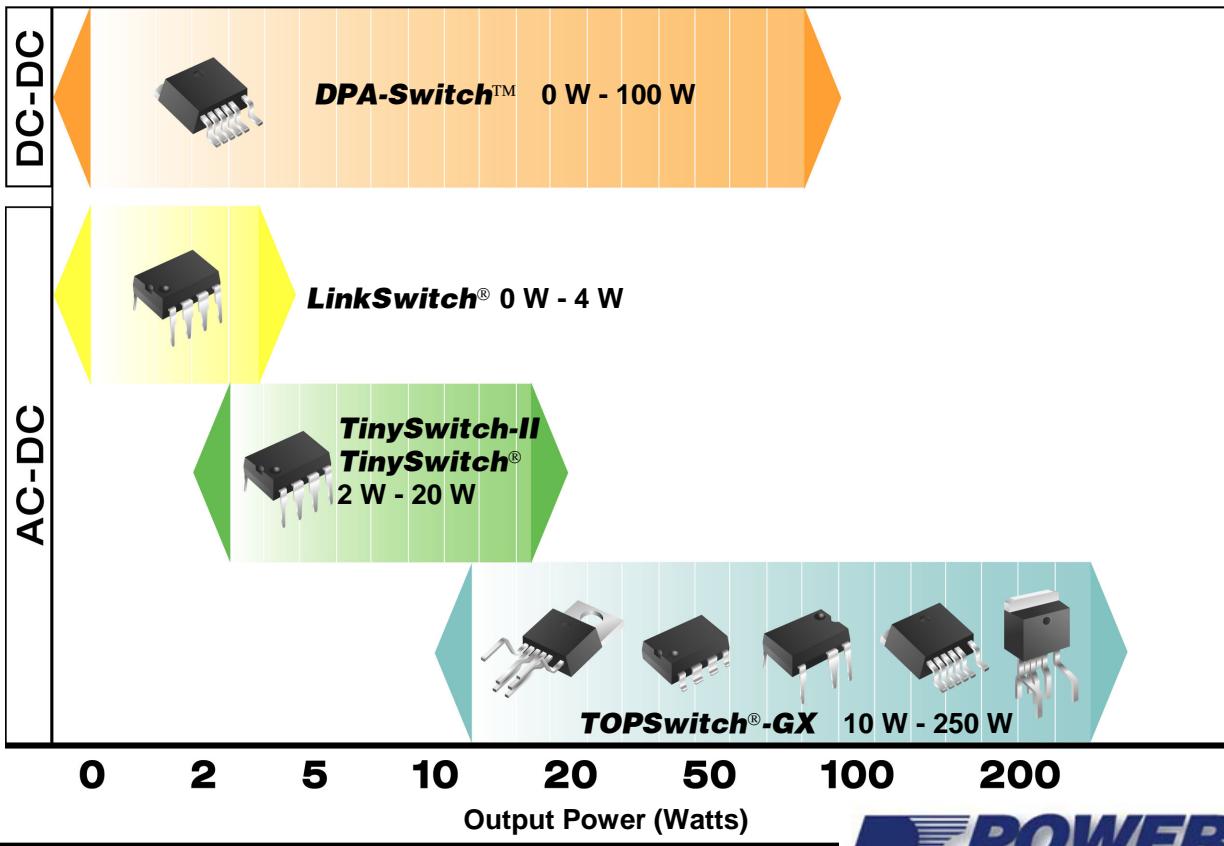
- Newer PI products also integrate functions such as:
  - soft start
  - frequency jittering for low EMI
  - line OV/UV protection
  - programmable lossless current limit
  - remote ON/OFF
  - very low standby/no-load power consumption

# Continuous Innovation



- PI is on the leading edge of innovation in power conversion, continuously introducing breakthrough topologies and technologies.

## Cost Effective Over Wide Power Range



9

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- Power Integrations' products cost effectively cover:

– 95% of all AC-DC power supplies with product families ranging from 0 W to 250 W

<i>LinkSwitch</i>	0 W to 3 W
<i>TinySwitch</i>	2 W to 20 W
<i>TOPSwitch-GX</i>	10 W to 250 W

– High volume 24/48 V DC-DC converter applications ranging from 0 W to 100 W with *DPA-Switch*

- 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.

# Comprehensive Design Support

- **Design Accelerator Kits**
  - Fully tested power supply
  - Product samples
  - Complete design documentation
- **PI Expert design software**
- **Technical documents on website**



- PI has the most comprehensive design tools in the industry

## Global Applications Support



● Fully Equipped Applications Labs

**Fully equipped PI applications labs are located worldwide:**

- **United States**

– San Jose, California	Chicago, Illinois	Atlanta, Georgia
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- **Europe**

– London, UK	Munich, Germany	Milano, Italy
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- **Asia**

– Taipei, Taiwan	Seoul, South Korea	Shenzhen, PRC
– Shanghai, PRC	Yokohama, Japan	Bangalore, India

## Wide Customer Acceptance



- Virtually every major OEM worldwide uses Power Integrations' ICs in their products.

## Low Power (<20 W) Applications



Chargers / Adapters



PC & Monitor  
standby



TV standby



Industrial

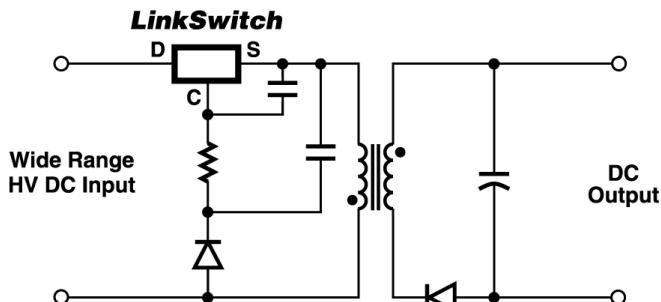


White Goods



- >50% of the AC to DC power supply unit volume is under 20 W, covering a wide range of end products and applications.

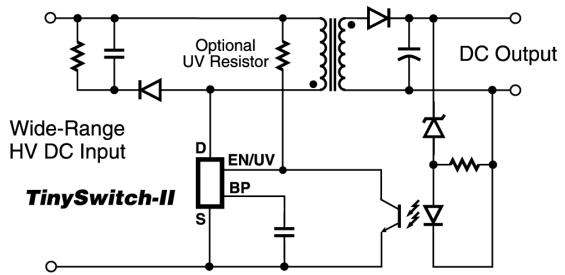
## LinkSwitch



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- 0 W to 3 W
- Replaces linear transformer solutions at equal or lower cost
- Regulation by PWM control
- Primary sensed approximate CV/CC output

## TinySwitch-II



- 2 W to 20 W
- Replaces regulated linear, RCC and other solutions at equal or lower cost
- Regulation by ON/OFF control
- Secondary sensed feedback for accurate CV or CV/CC outputs

Both meet all worldwide energy efficiency standards



- RCC: Ringing choke converter (this is a self oscillating converter)
- CV: Constant Voltage
- CC: Constant Current

# Energy Efficiency Standards Will Make Linear Solutions Obsolete

- **No-load EC requirement for external power supplies**
  - <300 mW by 2005
- **Energy Star requirement for consumer audio and DVD products**
  - < 1 W stand-by, by January 1, 2003
- **US Presidential Executive Order**
  - < 1 W stand-by now on all Federal Government purchases
- **Japanese “Top Runner” program**
  - Promotes lowest standby in consumer products
- **Many other standards and programs worldwide**
  - Blue Angel, China Sustainable Energy Program, etc.



Linears will not be able to cost effectively meet many of these standards

# Introducing **LinkSwitch**<sup>®</sup>

The **Linear Killer** Switch

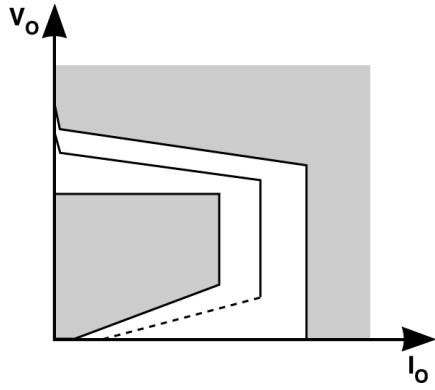
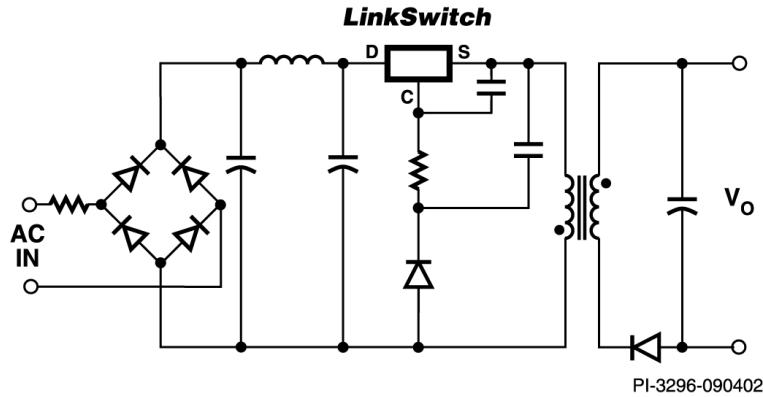
providing

## Switcher Benefits at Linear Cost



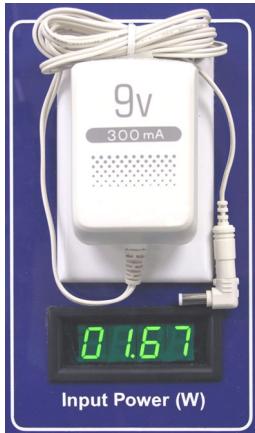
- **LinkSwitch** based solutions are cost competitive, even when compared to low-end, unregulated linear trickle chargers
- Almost 1 Billion low-power (0.5 to 3 W) linear-transformer-based power supplies are produced worldwide, each year
- Driven by energy efficiency requirements, these will convert to switchers
- **LinkSwitch** has enabled cost effective conversion to begin NOW!

# **LinkSwitch: Breakthrough Technology**



- **Extremely simple circuit configuration - easy to design**
- **Only 14 components - low cost**
- **Primary side controlled constant current charging - high efficiency**
  - No primary or secondary side current sense resistor required
- **Fully protected for thermal, short circuit and open loop faults**

- Bridge rectifier is counted as a single component
- An extra resistor is allowed for pre-loading (explained later)



## Linear vs *LinkSwitch*



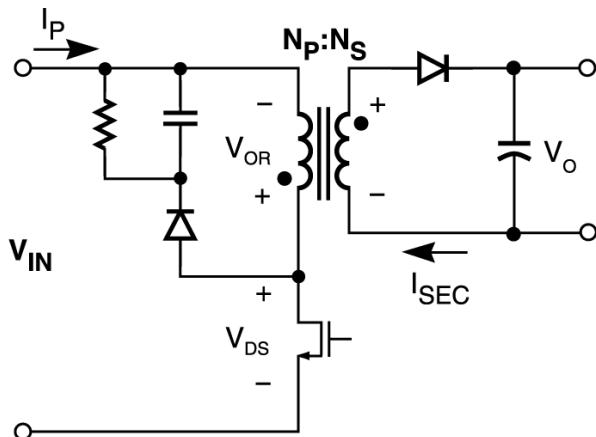
- **Bulky and heavy**
  - Higher shipping costs
  - Covers adjacent outlets
- **Requires multiple designs**
  - Higher inventory costs
- **Energy inefficient**
  - Will not meet most future standards
  - Annual energy waste exceeds cost of power supply
- **Smaller and lighter**
  - Lower shipping costs
  - Occupies single outlet
- **One design works worldwide**
  - Lower inventory costs
- **Extremely Energy efficient**
  - Meets all worldwide standards
  - Saves enough energy to pay for complete power supply in 1 year

- Standby energy loss is reduced by almost an order of magnitude
- Unregulated linear shown, regulated linear would typically have higher zero load consumption
- (*LinkSwitch* is more cost effective than RCC solutions in replacing linears and requires 30-60 fewer components. Therefore RCC comparisons are not included in this presentation.)

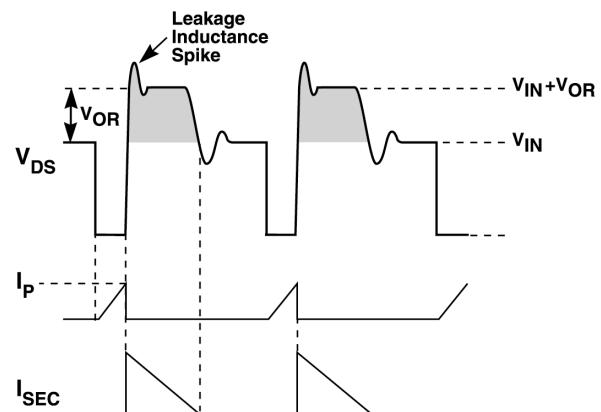
# ***LinkSwitch* Operation**

# Flyback Fundamentals

- **LinkSwitch is designed for discontinuous mode Flyback operation**
  - All energy in transformer transferred to secondary during switch off-time
- **During diode conduction  $V_O$  is transformed to primary as  $V_{OR}$** 
  - $V_{OR} \approx V_O \times N_p/N_s$



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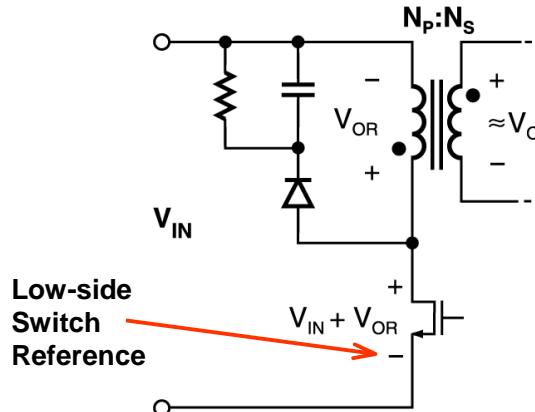


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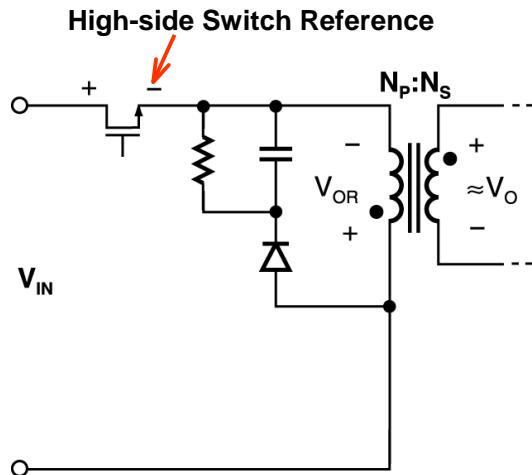
- $V_{OR}$  on the primary side is a close representation of the output voltage for flyback converters
- Unstable operation may result if a **LinkSwitch** device is used in the continuous conduction mode (CCM). Therefore, CCM operation is not recommended.

## High-side MOSFET allows direct $V_{OR}$ sensing



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- Sensing  $V_{OR}$  is difficult with low side MOSFET
  - can only sense  $V_{OR} + V_{IN}$  with respect to source

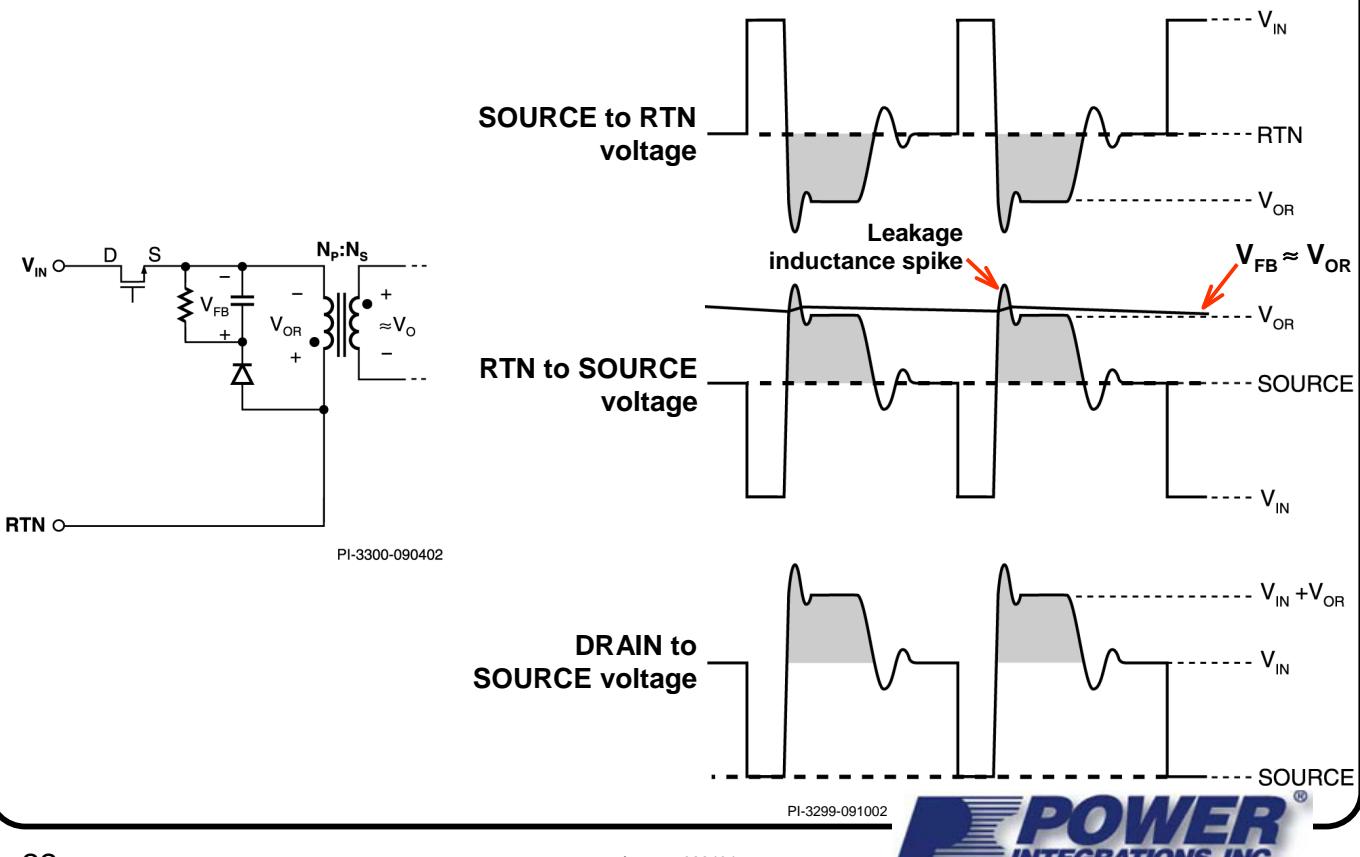


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- Sensing  $V_{OR}$  is easy with high side MOSFET
  - can sense  $V_{OR}$  directly with respect to source

- ( $\approx V_O$  as output diode drop neglected)

# High-side MOSFET Waveforms

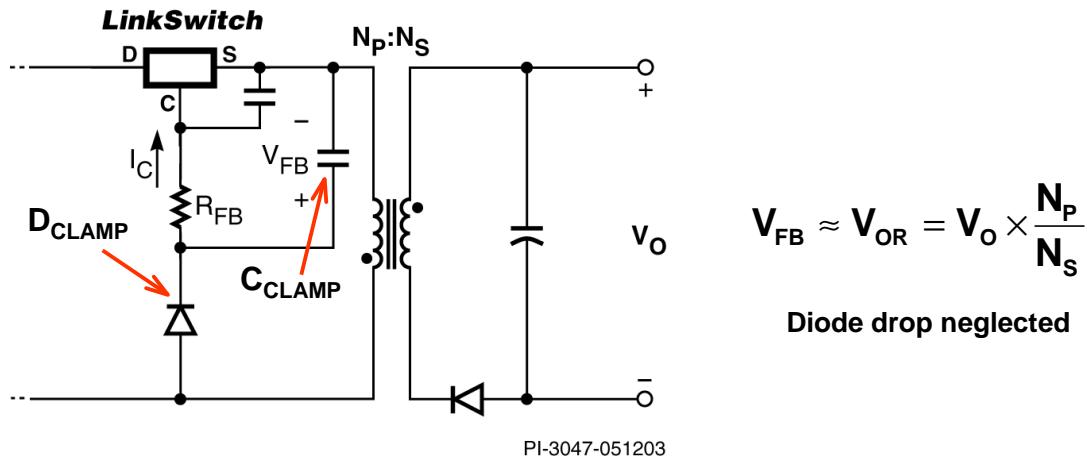


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- Referenced to Source  $V_{FB}$  can be sensed directly
- (Leakage inductance spike causes an error in  $V_{FB}$  (above  $V_{OR}$ ))
- (For illustration, ripple on  $V_{FB}$  exaggerated)

## **LinkSwitch Indirectly Senses $V_O$ from $V_{OR}$**

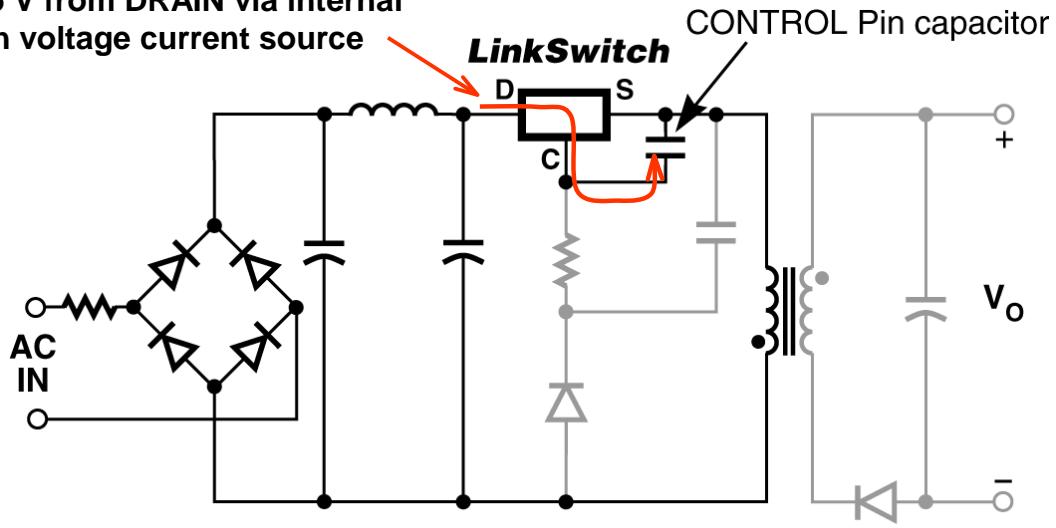


- $C_{CLAMP}$  samples and holds  $V_{FB} \approx V_{OR}$
- $R_{FB}$  converts  $V_{FB}$  into feedback control current  $I_C$
- Clamp circuit ( $D_{CLAMP}$ ,  $C_{CLAMP}$ ,  $R_{FB}$ ) also:
  - Limits voltage across MOSFET due to leakage inductance
  - Provides supply current ( $I_C$ ) to power *LinkSwitch*

- (Leakage inductance energy introduces an error in the feedback voltage meaning that the  $V_{FB}$  is not a perfect representation of  $V_O$ )
- (Electrically, the secondary diode may be placed in upper or lower end of secondary but EMI may be improved by connecting as shown)

## Start-up: Charging CONTROL Pin Capacitor

CONTROL pin capacitor is charged  
to 5.75 V from DRAIN via internal  
high voltage current source

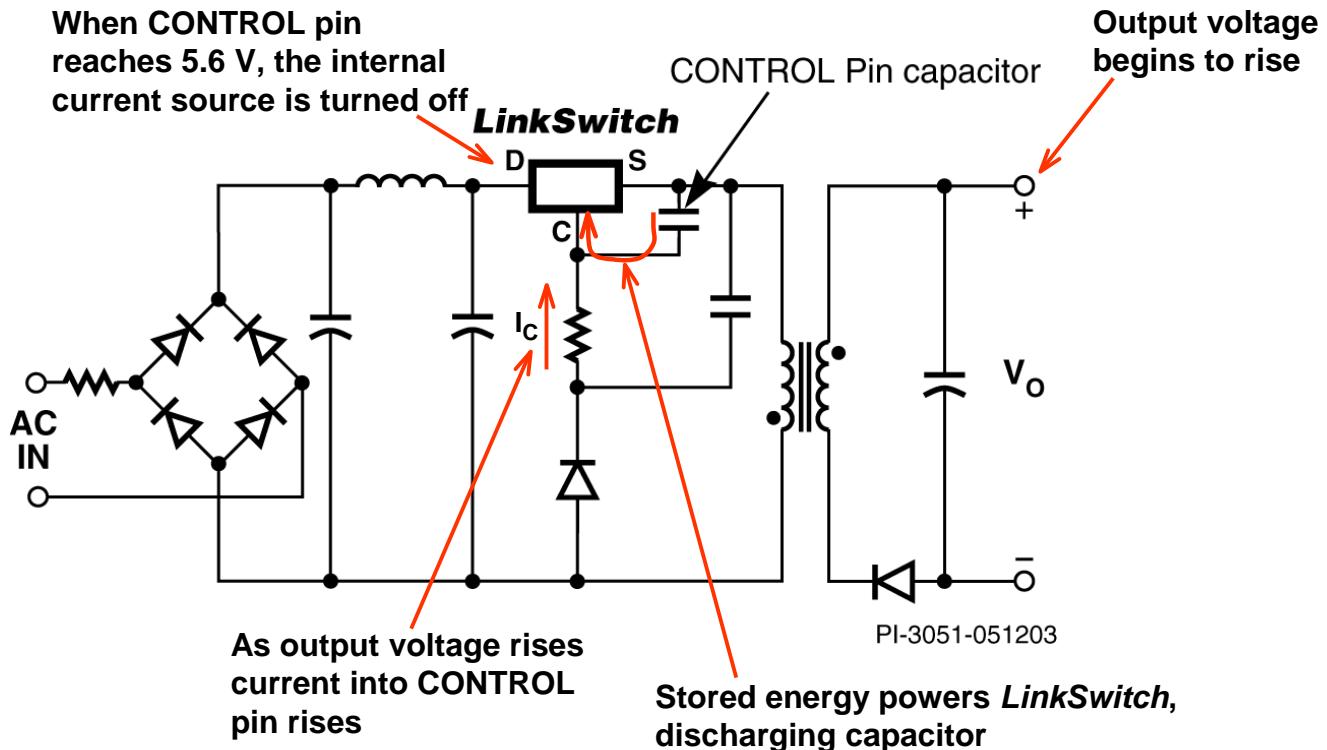


- No external start-up resistor required

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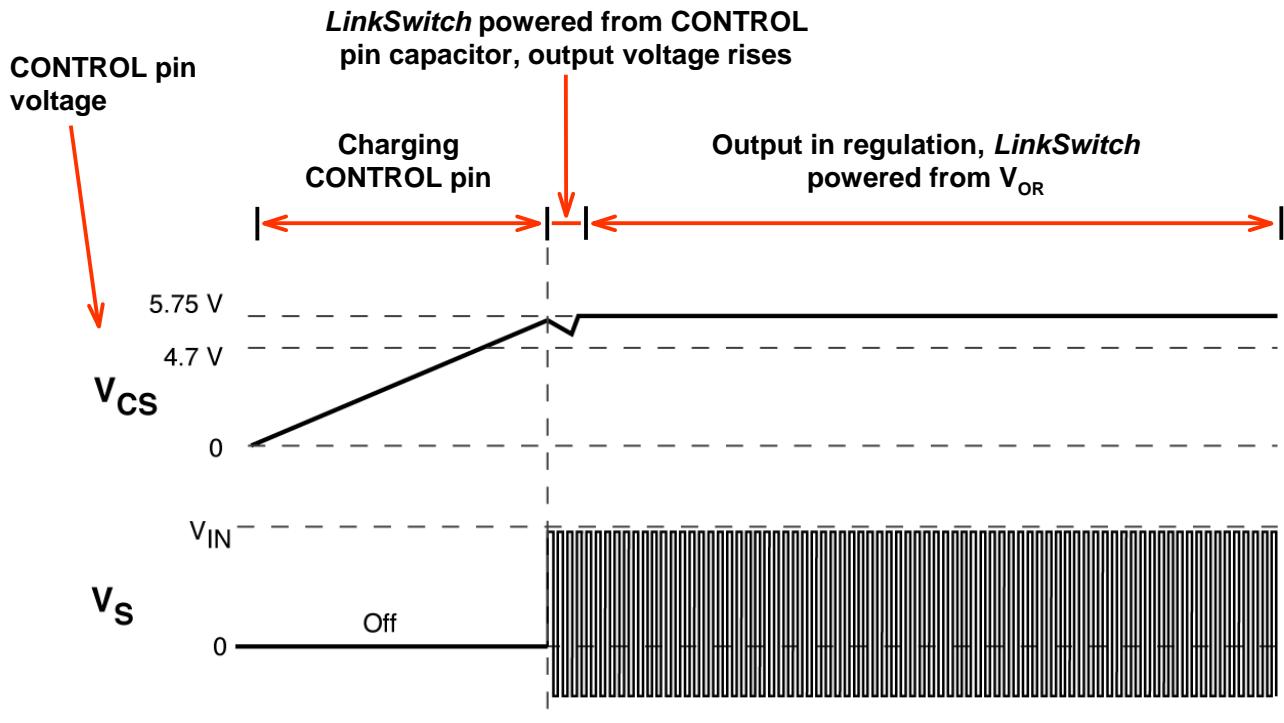
- (Same principal as *TOPSwitch*)

## Start-up: Drain Starts Switching



- CONTROL pin is a current fed pin with an internal voltage clamp
- (Same principal as *TOPSwitch*)

# Start-up Waveforms



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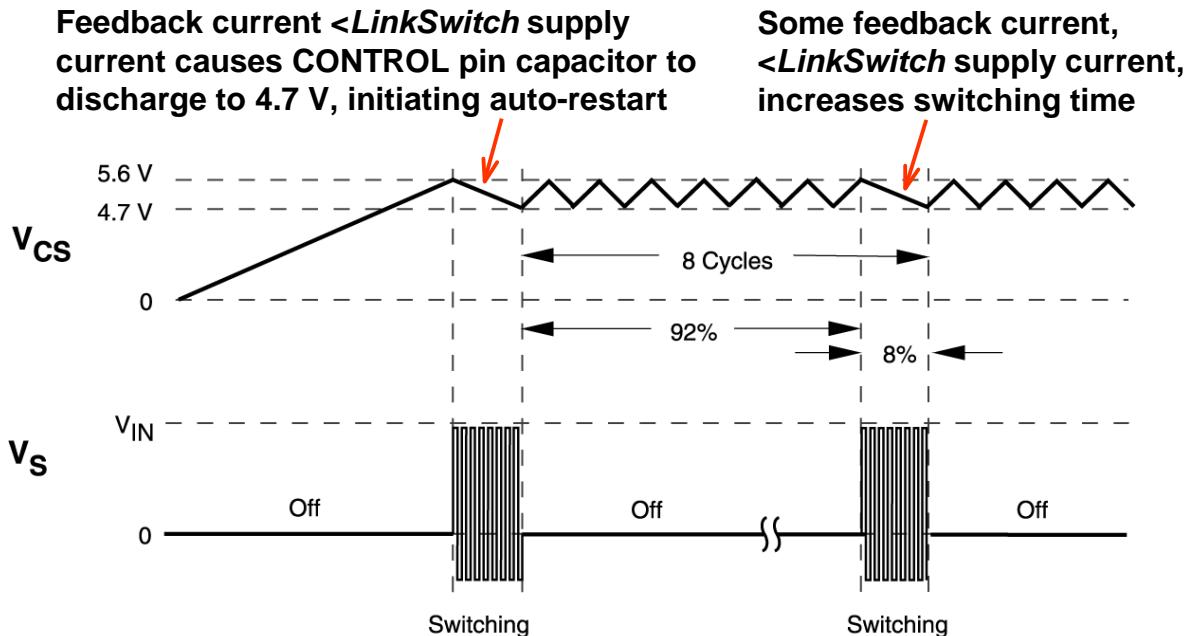
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## Normal start-up: CONTROL pin and SOURCE pin node switching waveforms

- At start-up, the CONTROL pin capacitor is charged to 5.6 V, by the internal, high-voltage current source (from the DRAIN)
- At 5.6 V, the internal current source turns off, and MOSFET switching is enabled
- Energy in the CONTROL pin capacitor powers the *LinkSwitch* device
- The output voltage rises, and reaches its regulation value
- When  $V_{FB}$  exceeds 5.75 V, current flows into the CONTROL pin providing feedback
- The MOSFET duty cycle is modulated to control the CV portion of the output VI curve, the internal current limit is adjusted to maintain the CC portion of the output VI curve (explained in more detail later)
- Due to the (approximate)  $100 \Omega$  impedance of the CONTROL pin, feedback (control) current raises the CONTROL pin voltage from 5.6 V to 5.75 V
- 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.

## Auto-restart Waveforms



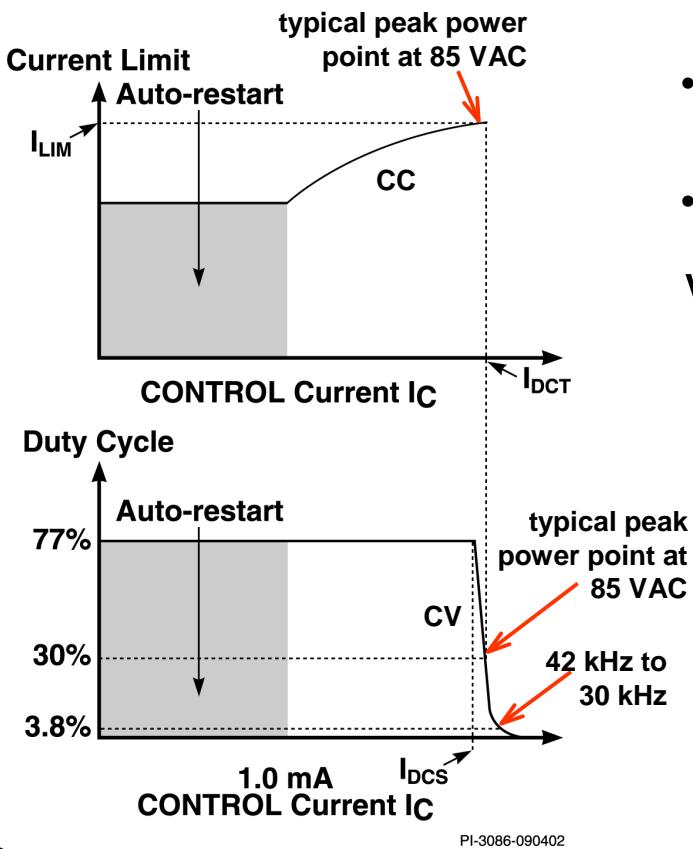
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- Auto-restart limits average output current to 8% of the nominal CC

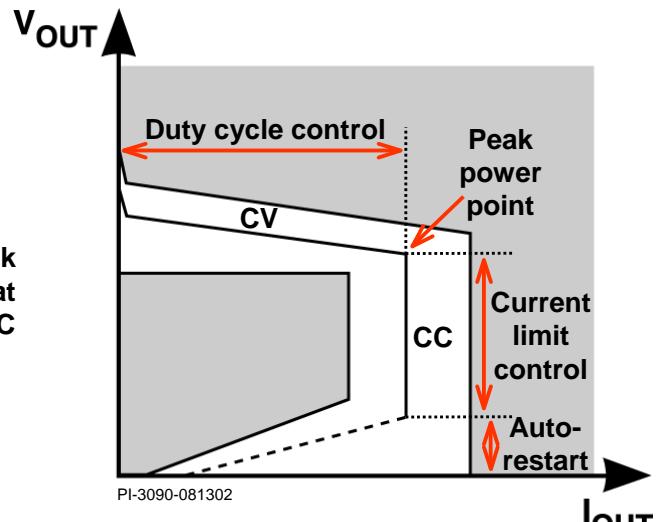


- **Abnormal start-up:** CONTROL pin and SOURCE pin node switching waveforms (during an output overload, short-circuit or an open feedback loop condition)
- Once the CONTROL pin reaches 5.6 V, MOSFET switching is enabled
- Energy in the CONTROL pin capacitor powers the *LinkSwitch* device
- Feedback current  $\sim 1$  mA (the *LinkSwitch* supply current) allows the CONTROL pin capacitor to discharge. When the CONTROL pin reaches 4.6 V, auto-restart is initiated
- With the MOSFET disabled, the CONTROL pin capacitor is charged and discharged for 7 cycles
- MOSFET switching is enabled after the 7th charge/discharge cycle, and the overall sequence repeats (if the overload, short-circuit or open feedback condition still exists)
- While MOSFET switching is occurring, there is usually some feedback current, even under most fault conditions. This slows the discharge rate of the CONTROL pin capacitor, which increases the length of time that switching occurs for, during the start-up attempt

# Primary Based CC/CV Output Regulation

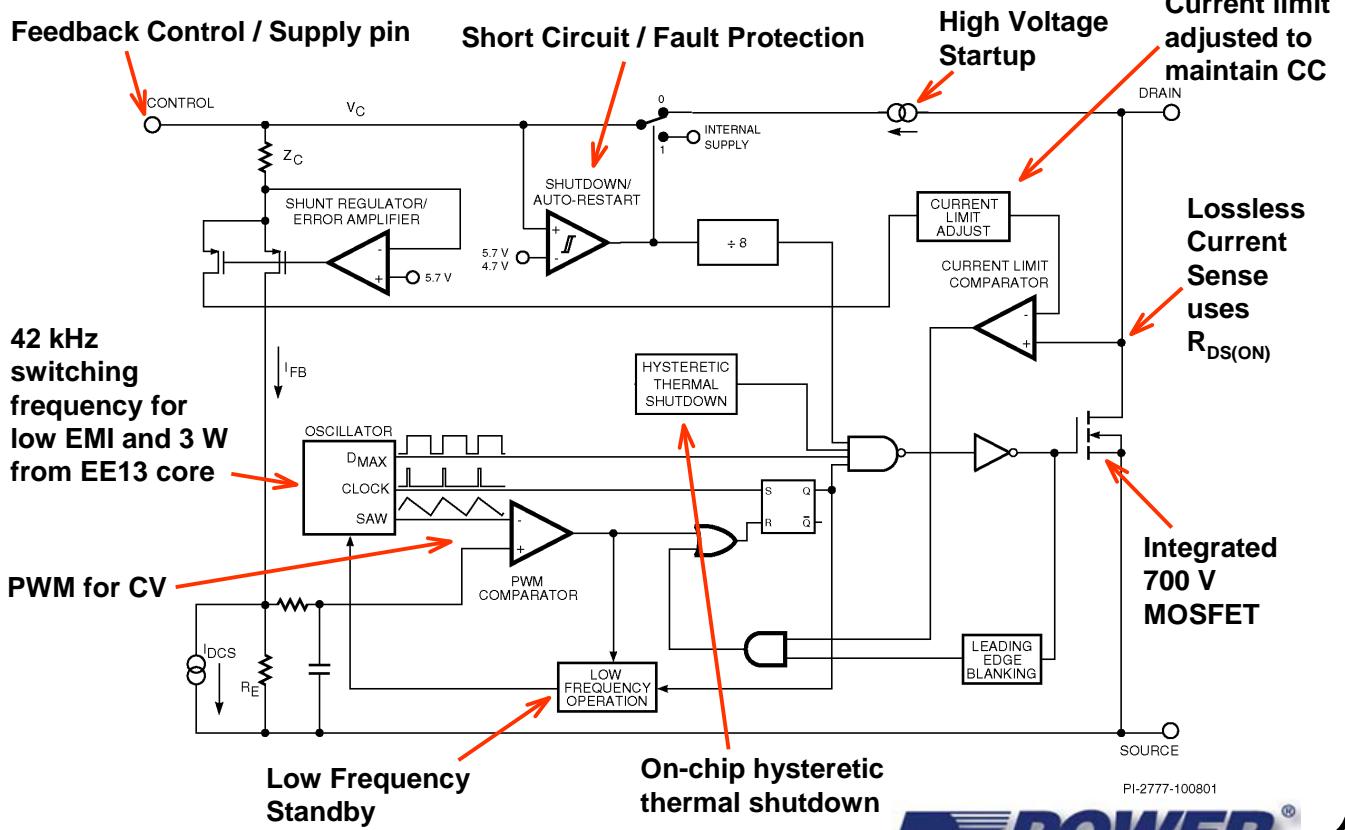


- CC regulated by internal current limit control
- CV regulated by duty cycle control



- $I_C \propto V_{OR} \propto V_O$
- Load <peak power: *LinkSwitch* duty cycle is reduced to maintain an approximate CV output (PWM control)
- At peak power point internal current limit is at maximum
- Loads >peak power:  $V_O$  falls, reducing  $I_C$ . *LinkSwitch* internal current limit is reduced to maintain an approximate CC output down to ~30% of  $V_O$
- Below ~30% of  $V_O$  ( $I_C < \sim 1\text{mA}$ ) *LinkSwitch* enters auto-restart
- At no-load: switching frequency switches from 42 kHz to 30 kHz, reducing no-load power consumption

# LinkSwitch Block Diagram



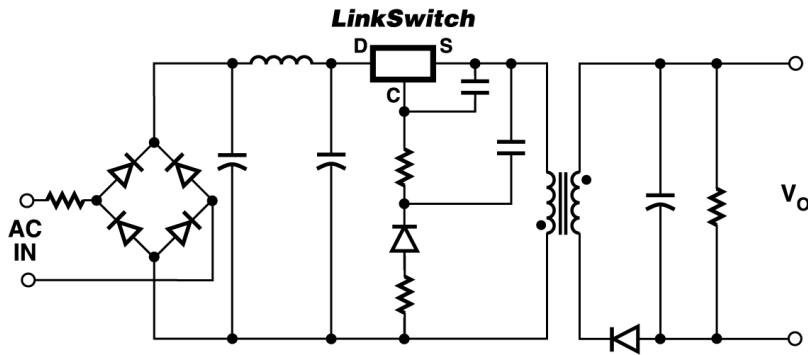
- **LinkSwitch** integrates all of the switcher complexity into just three terminals, making the switching solution as simple as a linear regulator circuit

# Operation Summary

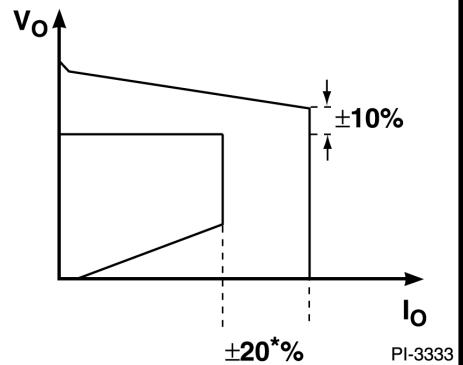
- **Cost equivalent to linears**
- **Provides CV/CC output**
- **Simple transformer**
  - no bias winding
  - powered from primary leakage clamp
  - works to zero output voltage
- **Fault protection**
  - output short circuit
  - hysteretic thermal protection
  - broken feedback loop
- **Low component count**
  - simplest CV/CC solution
  - low manufacturing cost
- **No optocoupler**
  - simple layout
  - low cost
- **Low standby consumption**
  - meets US <1 W and EC <300 mW specifications
- **No current sense resistor**
  - higher efficiency
  - simple design

## ***LinkSwitch* Performance**

# Output CV/CC Tolerances



- **Tolerances achievable in low cost, high volume manufacturing**
  - $\pm 10\%$  estimated CV tolerance at peak power point
  - $\pm 20\%$  estimated CC tolerance\*  
(dominated by transformer inductance tolerance)
  - Includes *LinkSwitch* and other component variations



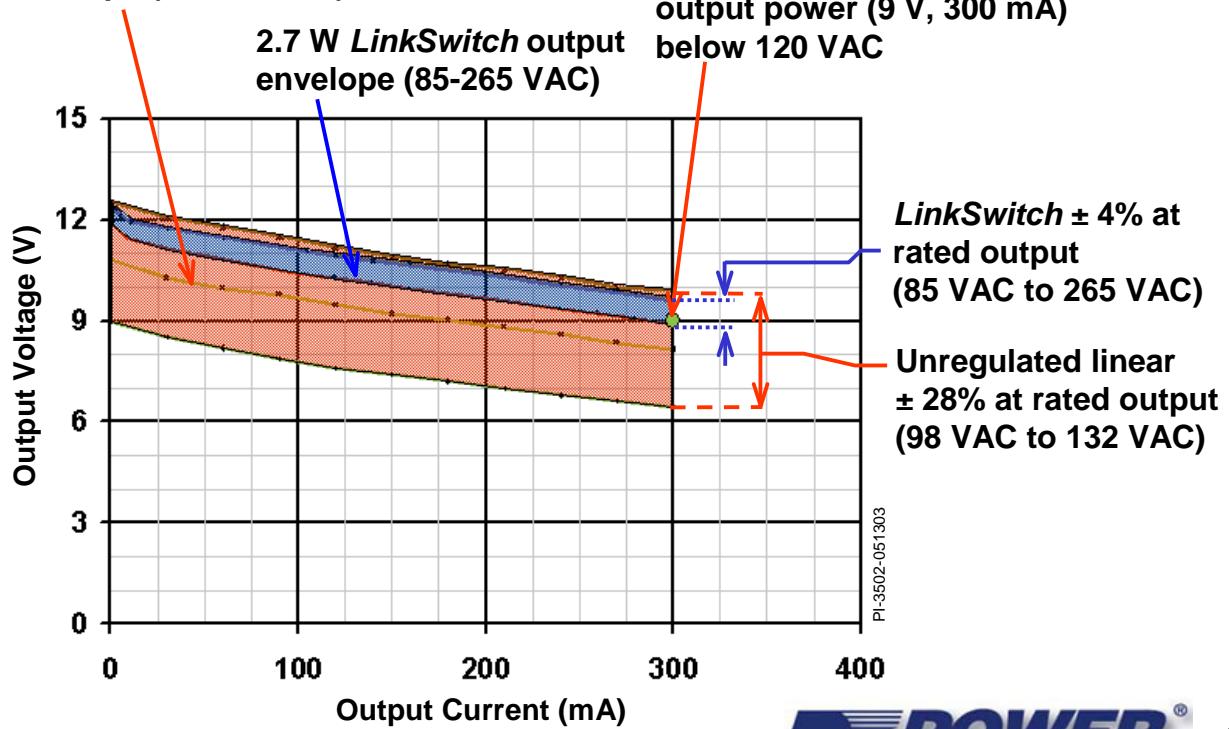
\*with  $\pm 10\%$  primary inductance tolerance

- Tighter primary inductance tolerances produce tighter CC tolerances.  
With no primary inductance variation, the CC tolerance is about  $\pm 12\%$
- From full load to no-load, the output voltage typical increases about +40%

## 2.7 W, 9 V Linear vs **LinkSwitch**: CV

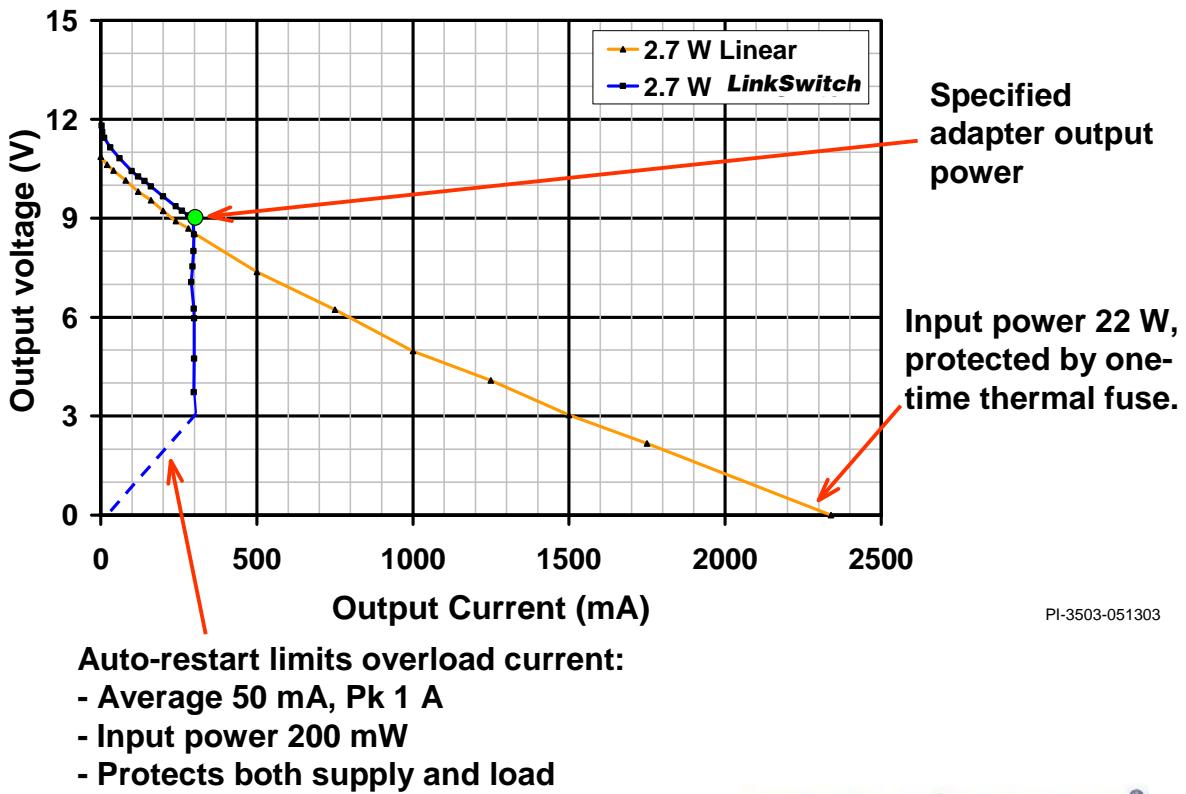
2.7 W Unregulated Linear  
output envelope (98-132 VAC)

Linear does not meet rated  
output power (9 V, 300 mA)  
below 120 VAC



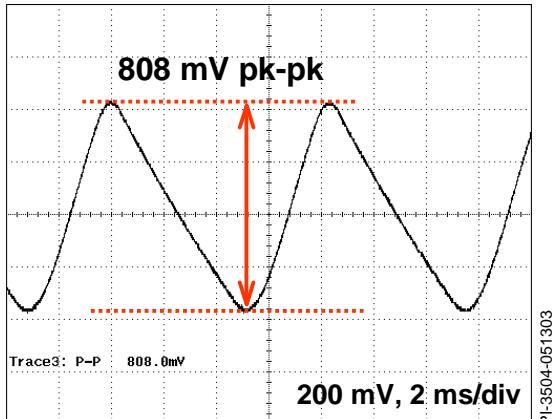
- This linear didn't meet its full specification; at 98 VAC in, it only delivered about 2 W
- In a single unit-to-unit comparison to a typical unregulated linear design...
- The **LinkSwitch** had better regulation
  - Linear regulation: load (0-300 mA) –13%, line  $\pm 28\%$
  - LinkSwitch regulation: load (0-300 mA) –12%, line  $\pm 4\%$
- The **LinkSwitch** provided full power over the entire input range (85-265 VAC)
  - The Linear provided rated power only at 120 VAC and above
- The **LinkSwitch** had a significantly tighter output characteristic
  - Having a tighter peak power point tolerance reduces charging time

## 2.7 W, 9 V Linear vs **LinkSwitch**: CC/Overload

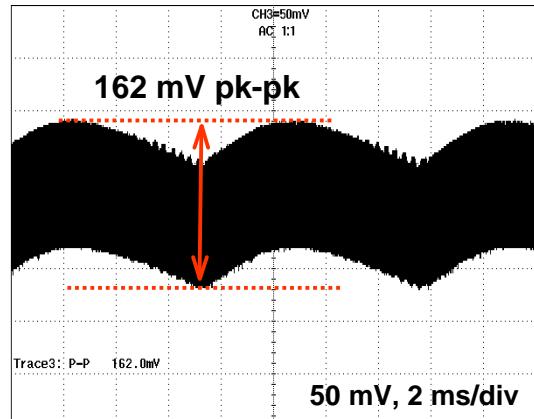


- This comparison was made with a typical unregulated linear design
- The linear may be damaged by an overload or a short circuit on its output
- The **LinkSwitch** CC output characteristic, plus its auto-restart and thermal shut-down functions protect it and the load from damage. Additionally, it will resume normal operation after the fault is removed

## Linear vs **LinkSwitch**: Output Ripple



Unregulated Linear, 9 V, 2.7 W  
adapter 115 VAC, Full Load

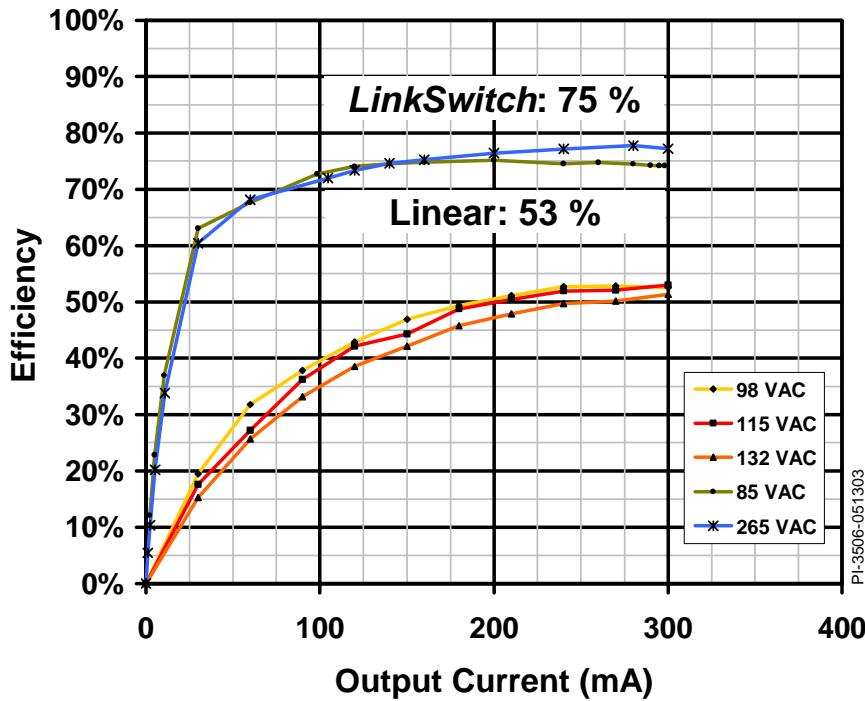


LinkSwitch, 9 V, 2.7 W adapter  
115 VAC, Full Load

Measured with resistive load, at end of cable

- **LinkSwitch** has <20% the output ripple of a typical unregulated linear

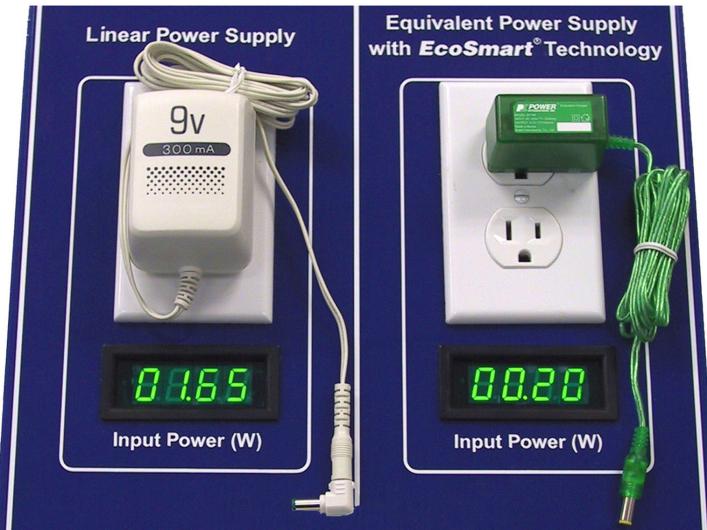
## 1.5 x The Efficiency of Unregulated Linear



- Regulated linear has much poorer efficiency (<25%)

- LinkSwitch efficiency is high, even at light loads (2X the linear's efficiency at 100 mA)

## Linear vs **LinkSwitch**: No-load Consumption



Measurements were made at 115 VAC  
(The no-load consumption at 265 VAC is only 250 mW!)



- The no-load energy savings alone, can pay for the cost of the entire power supply, in less than 1 year

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- The unloaded unregulated linear dissipates 1.65 W at 115 VAC,  
The unloaded *LinkSwitch* only consumes 200 mW at 115 VAC

## Linear vs ***LinkSwitch***: Comparison Summary

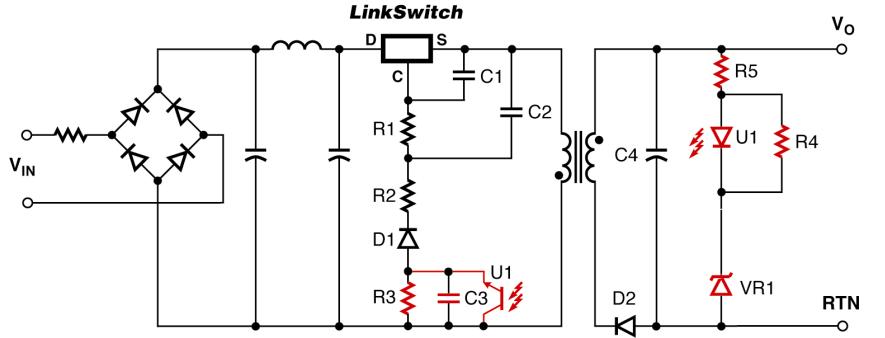
PARAMETER	LINEAR	<b><i>LinkSwitch</i></b>
Output Specification	2.7 W, 9 V	2.7 W, 9 V
BOM Cost	1 ×	1 ×
Input Voltage	98 to 132 VAC	85 to 265 VAC
Full Load Efficiency (115 VAC)	53%	75%
No Load Input Power (115 VAC)	1.6 W	200 mW
Annual Energy Cost (2.7 W load)	\$ 5.34	\$ 3.8
Annual Energy Cost (no-load)	\$ 1.68	\$ 0.22
Short-circuit Current	2.3 A	50 mA
Short-circuit Protection	One time thermal fuse	Self-resetting Auto-restart
Weight	9.4 oz / 267 g	2 oz / 56 g
Volume	11 in <sup>3</sup> / 176 cm <sup>3</sup>	2.45 in <sup>3</sup> / 40 cm <sup>3</sup>
Shipping Cost by Sea (per unit)	1 × (reference)	0.4 ×
Shipping Cost by Air (per unit)	10 ×	4 ×

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- The annual *LinkSwitch* Energy savings, at either full or no-load, exceed the cost of the entire power supply
- A significant portion of overall linear adapter cost is involved in shipping it. The lighter-weight and smaller size of *LinkSwitch* based adapters reduces shipping costs.
- The cost comparisons are referenced to that of shipping a linear adapter by sea (1X)

# Improving CV Tolerance with Opto Feedback

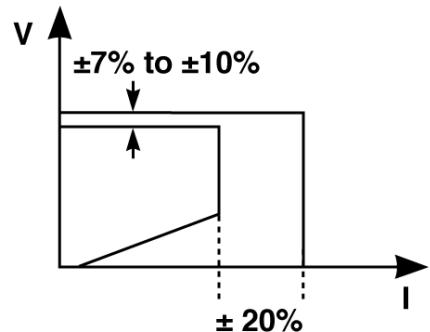


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- Tolerances achievable in low cost, high volume manufacturing**

- $\pm 10\%$  voltage tolerance with Zener reference (VR1)
- $< \pm 5\%$  voltage tolerance with IC reference (TL431)
- $\pm 20\%$  current limit tolerance  
(dominated by transformer inductance tolerance\*)
- Includes the variations of the *LinkSwitch*, other components and the operating temperature range

\* Primary inductance tolerances must be  $\leq \pm 10\%$  for these figures to be valid



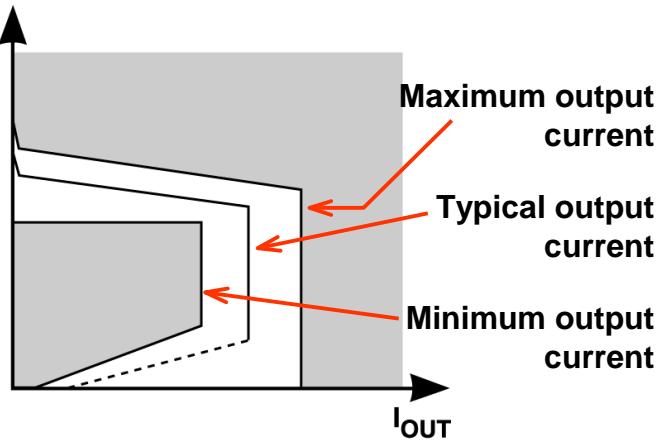
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- Ideal for replacing regulated linears or discrete switching supplies (RCCs)
- CC tolerances can be improved by reducing the primary inductance tolerances.  
(See the Application Example section, for tips on how to improve CC tolerance)
- R5 is only required for output voltages  $> 6$  V, to limit opto-LED current. For outputs  $< 6$  V, the slope resistance of VR1 is typically sufficient to perform this function.

# Designing with ***LinkSwitch***

# Specifying a **LinkSwitch** Design

- A CV/CC (charger) supply is specified at the typical constant output current
- A CV (adapter or auxiliary) supply is specified to deliver a minimum full load output current
- **LinkSwitch design procedure assumes CV/CC**
  - To design for a CV adapter increase full load output current by 20% to ensure full load current delivery with worst case design

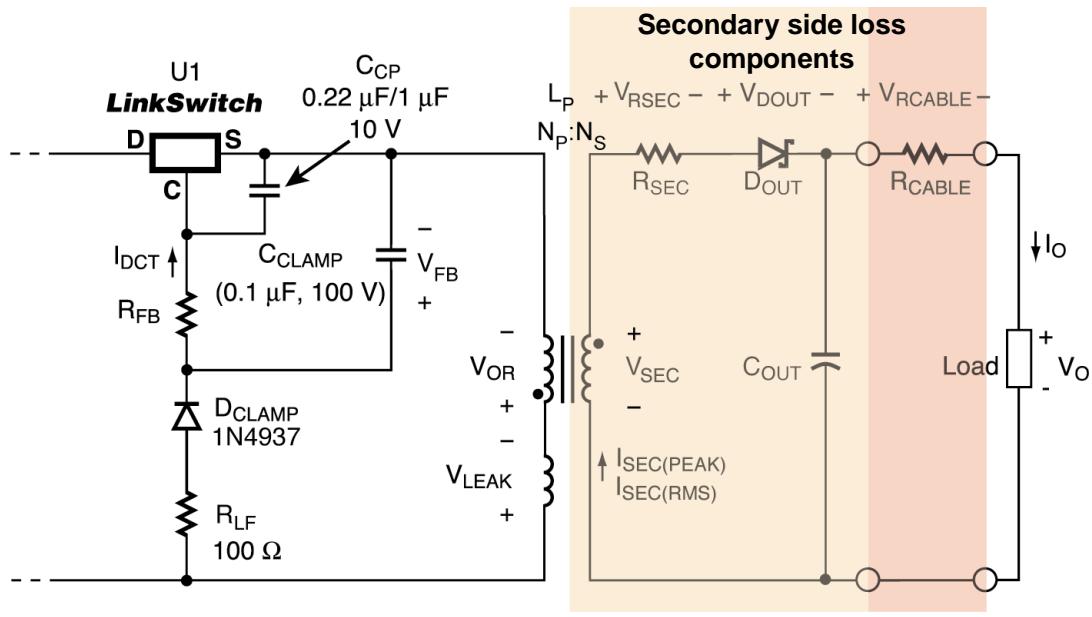


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# Step by Step Design Process

1. Select  $V_{OR}$
  2. Calculate secondary component voltage drops
  3. Calculate transformer turns ratio
  4. Calculate output power
  5. Calculate primary inductance
  6. Design transformer
  7. Select component values
  8. Build prototype
  9. Refine design
- All covered by Application Note AN-35 *LinkSwitch Design Guide*
  - Supported by Design Spreadsheet as part of *PI Expert*

# Definition of Components & Parameters



- All secondary side voltage drops and power losses must be accounted for

- $R_{LF}$  is the leakage inductance filter resistor - improves CV characteristics
- $R_{LF} \sim 100 \Omega$  works well for typical transformer design

## Step 1: Select a Value for the Reflected Output Voltage ( $V_{OR}$ )

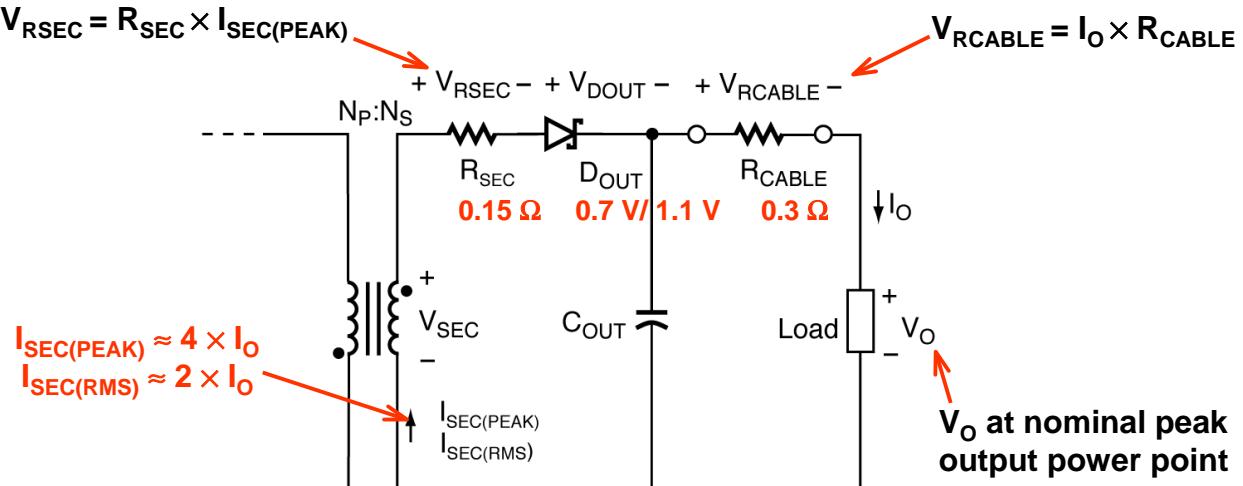
- **$V_{OR}$  determines the feedback voltage ( $V_{FB}$ )**
  - For no-load consumption <300 mW,  $V_{OR}$  should be between 40 – 60 V
  - $V_{OR} > 60$  V may be used, if higher no-load consumption is acceptable
  - Higher  $V_{OR}$  also increases the output power capability of the design
- **For initial design set  $V_{OR} = 50$  V**
  - Default value in design spreadsheet

- For a universal input supply, setting  $V_{OR}$  to 50 V usually gives the best compromise between the no-load power consumption and the maximum available output power
- A low value of  $V_{OR}$  keeps the peak drain voltage of the *LinkSwitch* at a value that is lower than that of a standard switching power supply. If the voltage rating of the input capacitor is sufficient, a *LinkSwitch* design can operate safely during an input over-voltage condition, such as a line surge or voltage swell

## Step 2: Calculate Secondary Voltage ( $V_{SEC}$ )

$$V_{SEC} = V_O + V_{RCABLE} + V_{DOUT} + V_{RSEC}$$

- $V_{DOUT}$  and  $V_{SEC}$  defined at peak secondary current
- If no better measurements available use estimates shown



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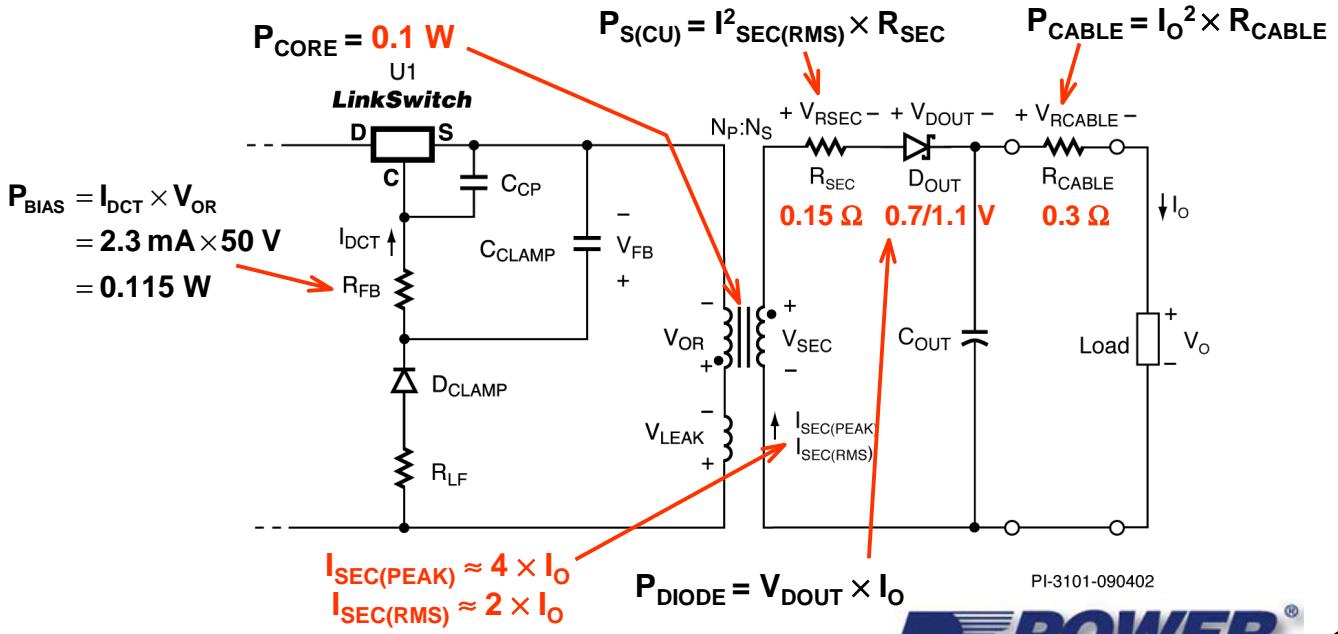
- The peak and RMS secondary current estimates are valid for output voltages near 5 V. Lower output voltages will require higher values.
- The peak  $V_{OR}$  determines the feedback voltage:  $V_{DOUT}$  and  $V_{SEC}$  are determined at the peak secondary current
- $V_{DOUT}$  (at a peak output current of roughly four times the rated  $I_o$ ):
  - A typical Schottky diode forward voltage drop is about 0.7 V
  - A typical ultra-fast diode forward voltage drop is about 1.1 V

## Step 3: Calculate Transformer Turns Ratio

$$\frac{N_p}{N_s} = \frac{V_{OR}}{V_{SEC}}$$
$$= \frac{50}{V_{SEC}}$$

## Step 4: Calculate Power Processed by Transformer $P_{O(EFF)}$

$$P_{O(EFF)} = P_O + P_{CABLE} + P_{DIODE} + P_{BIAS} + P_{S(CU)} + (P_{CORE}/2)$$



- In PI-Expert, the design spreadsheet calculates all of the above parameters, including accurate core losses, which are based on specific core part numbers and geometries
- $P_{CORE}$  is divided by two, since only the core loss that occurs during the transfer of energy to the secondary needs to be considered
- Power loss in  $R_{LF}$  is negligible, and can be ignored
- For a more accurate  $P_{DIODE}$  calculation, use an average voltage drop, if it is known

## Step 5: Calculate Primary Inductance

- $L_P$  is the transformer primary inductance

$$L_{P(NOM)} = \frac{2 \times P_{O(EFF)}}{(I_P^2 \times f_s)} \times \Delta_L$$
$$= \frac{2 \times P_{O(EFF)}}{2710} \times 1.03$$

- $L_P$  tolerance  $\leq \pm 10\%$  to meet  $\leq \pm 20\%$  CC tolerance

- Use the  $I^2f$  parameter (specified in the *LinkSwitch* datasheet)

- Combines the tolerances of both the current limit and the switching frequency
  - 2710 A<sup>2</sup>Hz specifies the nominal primary inductance at the peak power point

- The term  $\Delta_L$  compensates for non-ideal ferrite material

- Inductance falls slightly as flux density increases
  - $\Delta_L$  values of 1 to 1.05 are typical for low-cost ferrite materials

- The  $I^2f$  coefficient is specified in the *LinkSwitch* datasheet with a tolerance of  $\pm 6.2\%$
- $I^2f$  is a useful parameter since *LinkSwitch* based supplies are designed to always operate in the discontinuous conduction mode. Therefore, output power is directly proportional to this term ( $P = 0.5 \cdot L \cdot I^2f$ )

## Step 6: Design the Transformer

- **Secondary turns  $N_s$** 
  - For an initial estimate, use 2.5 turns per volt (of output voltage)
  - If the flux density is too high, increase the number of turns (both  $N_p$  &  $N_s$ )

$$N_s \approx V_{SEC} \times 2.5$$

- **Primary turns  $N_p$**

$$N_p \approx \frac{V_{OR}}{V_{SEC}} \times N_s$$

- The flux density calculation is covered on the next slide

## Step 6: Design the Transformer (cont.)

- **Calculate flux density**

- Flux density < 3300 gauss (330 mT)

$$B_M(\text{gauss}) = \frac{100 \times I_p(\text{A}) \times L_p(\mu\text{H})}{N_p \times A_e(\text{cm}^2)}$$

- **Calculate gap size**

- Transformer manufacturer can calculate  $L_g$  more accurately for a given core material

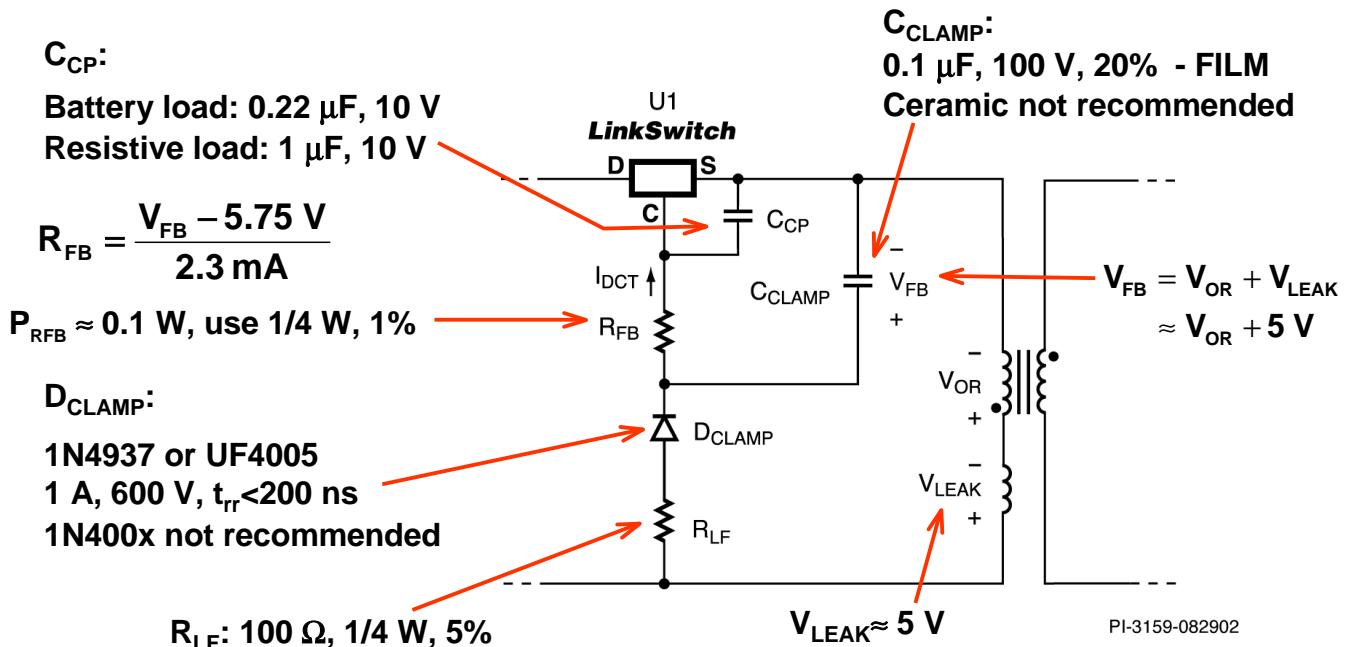
$$\mu_r = \frac{A_L(nH/t^2) \times L_e(\text{cm})}{4\pi \times A_e(\text{cm}^2)} \quad L_g(\text{mm}) = \left[ \frac{4\pi \times N_p^2 \times A_e(\text{cm}^2)}{L_p(\mu\text{H}) \times 100} - \frac{L_e(\text{cm}) \times 10}{\mu_r} \right]$$

- **Gap limits required to maintain a primary inductance tolerance of < ±10%**

- Single (center) leg gap >0.08 mm (accomplished by grinding down the center leg)
  - A gap in all legs >0.05 mm (all 3 legs of an EE core are separated by plastic film)

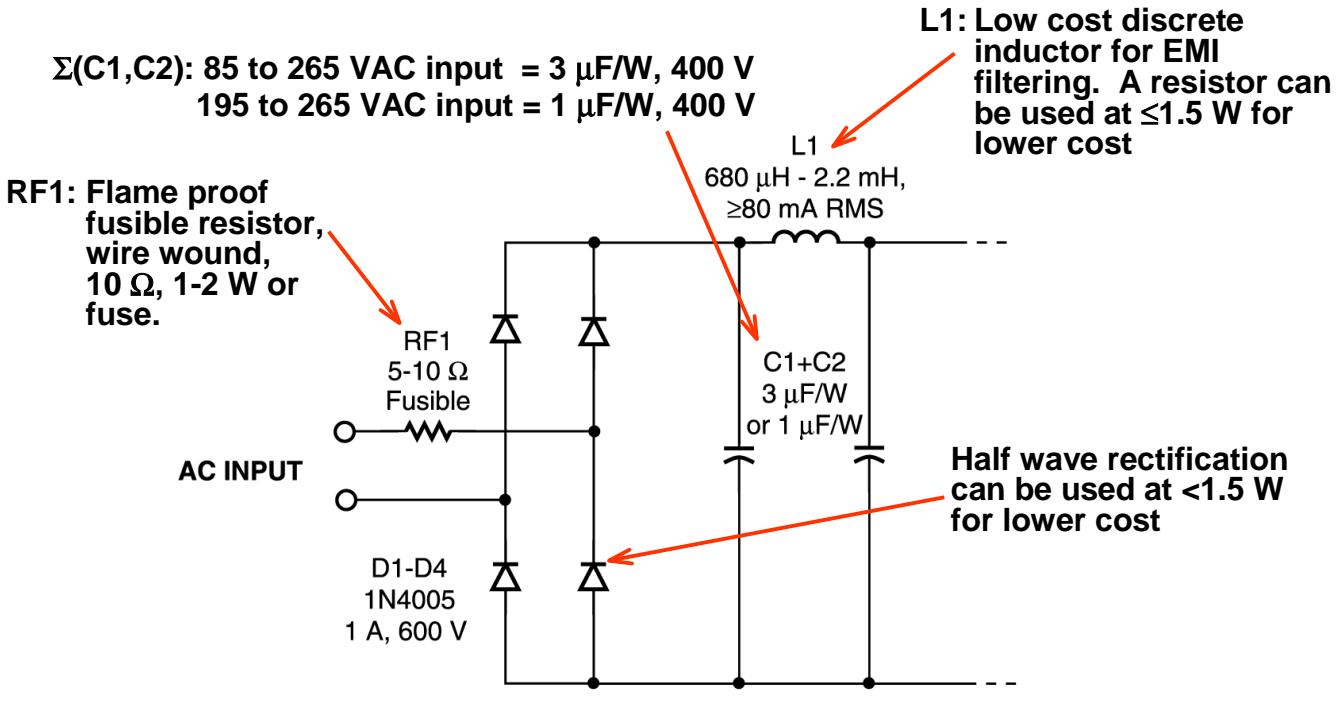
- **Film gapping may provide tighter primary inductance ( $L_p$ ) tolerances (±7%)**
  - check with your magnetics vendor
- **If an EE13 core is used, the guideline in Step 5 will allow these requirements to be met**
- **( $L_p$  is primary inductance in  $\mu\text{H}$ ,  $L_g$  is core center leg gap in mm,  $L_e$  is core effective path length in cm and  $A_e$  is core effective area in  $\text{cm}^2$ )**
- **When film gapping, use film of ½ the gap length: Example, if 0.05 mm is the total gap length, 0.025 mm thick film is inserted between all legs of the core**

## Step 7: Clamp, Bias and Feedback Components



- C<sub>CP</sub>: To allow sufficient time for start-up into a resistive load a 1 μF capacitor should be used
- C<sub>CLAMP</sub>: The value of low cost ceramic capacitors vary with temperature and applied voltage and may cause output oscillation
- (R<sub>LF</sub> = Leakage Filter Resistor)
- I<sub>DCT</sub> = 2.3 mA at peak power point
- V<sub>LEAK</sub>: Note that this is not a real circuit component. It represents the voltage error in the value of V<sub>FB</sub> due to the transformer leakage energy at full load / output peak power point.

## Step 8: Select Input Components



PI-3193-091002



- RF1 should be a fusible, flameproof type (during failure it must not emit incandescent material that may damage transformer insulation)
- Metal film resistor not recommended due to insufficient instantaneous power capability (repeated inrush at high line causes failure)
- A resistor substituted for L1 in the EMI filter should be fusible and flameproof type
- Typically C1 and C2 have the same value
- Input capacitor values below 4.7  $\mu$ F will typically reduce differential surge capability from 2.5 kV. Verify required surge withstand before selecting small values of C1 and C2.

## Step 9: Refine Design

- **Build prototype using nominal primary inductance**
- **Verify output VI characteristic**
  - If necessary adjust  $R_{LF}$  and  $R_{FB}$  to give desired output voltage at peak power point
- **If nominal CC is different from design target recalculate  $L_P$  based on measured parameters on prototype:**
  - Secondary winding resistance
  - Actual secondary peak and RMS currents
  - Diode forward voltage at peak secondary current
  - Output cable resistance
  - Feedback voltage  $V_{FB}$
- **Build next iteration and verify**

# Design Tools

- **AN-35**
  - *LinkSwitch Design Guide*
- **DAK-16A**
  - Includes tested EP-16A board
  - Engineering Report (EPR-16A)
  - Data sheet and device samples
  - Blank PC Board
- **Design Ideas**
  - DI-18, DI-19, DI-58, and DI-59
- **PI Expert**
  - Version 5.0 for PIXls design spreadsheet

**LinkSwitch™**  
**Design Guide**  
Application Note AN-35



**Introduction**

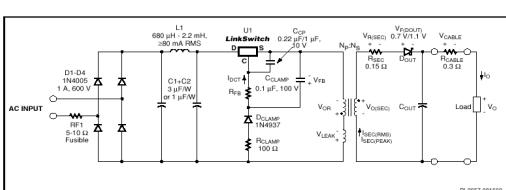
Integrated switching power supply technology, offering small size, low weight and universal AC input voltage operation, has traditionally been limited to high cost, high efficiency IC-based power supplies for low power applications. *LinkSwitch* reduces the cost of switching battery chargers and AC adapters to the level of linear transformer power supplies. *LinkSwitch* also easily meets standby and no-load energy consumption guidelines specified by worldwide regulatory programs such as the USA's Presidential 1 Watt Standby Executive Order and the European Commission's 2005 requirement for 300 milliwatts no-load consumption.

In an AC adapter, normal operation occurs only on the CV portion of the curve, the CC portion providing overload protection and auto-restart short circuit protection.

The feature set of *LinkSwitch* offers the following advantages over other solutions:

- Lowest cost and component count for a constant voltage, constant current (CVCC) solution
- Extremely simple circuit – only 14 components required for a production worthy design
- Primary based CVCC solution eliminates 10 to 20 components found in secondary based designs
- Up to 75% lighter power supply reduces shipping costs
- Fully integrated auto-restart for short circuit and open loop fault protection
- 42 kHz operation simplifies EMI filter design
- 3 W output with EEI-13 core for low cost and small size

**Figure 1. Key Parameters for an Initial LinkSwitch Design**



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August 2002

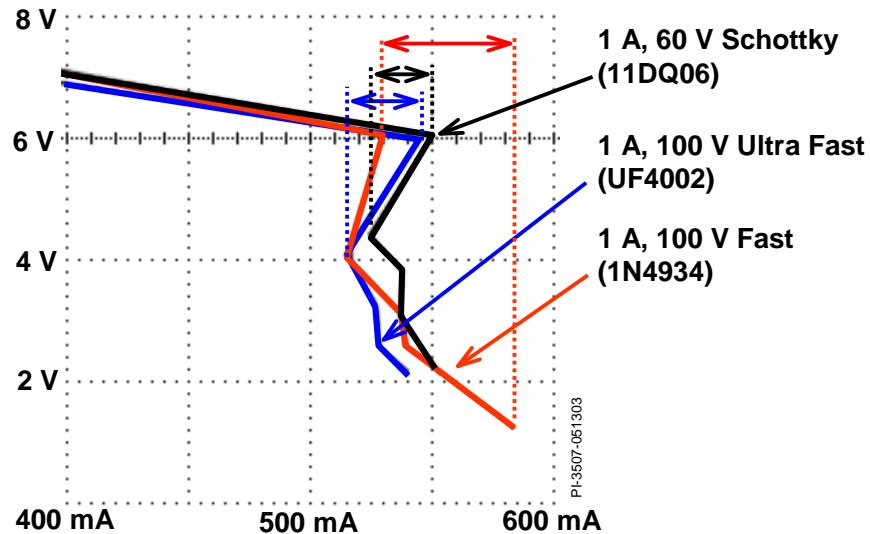


## ***LinkSwitch* Hints and Tips**

# Design Hints and Tips Contents

- **Optimizing output CV/CC characteristics**
  - Effect of output diode choice
  - Compensating for transformer leakage inductance
  - Limiting no-load output voltage
  - Effect of output cable resistance
- **Transformer design considerations**
  - Minimum gap size
  - Gap Uniformity
- **Minimizing no-load consumption**
  - Minimizing transformer capacitance
  - Minimizing external capacitance
  - Selecting lower  $V_{OR}$
- **Layout considerations**
- **Measurement techniques for switching waveform and  $V_{LEAK}$**
- **Output filter selection**
- **Using larger  $V_{OR}$  for higher power**
- **Tighter CV tolerance with opto feedback**
- **Specifying a *LinkSwitch* Design**
- **Estimated Manufacturing Tolerances**

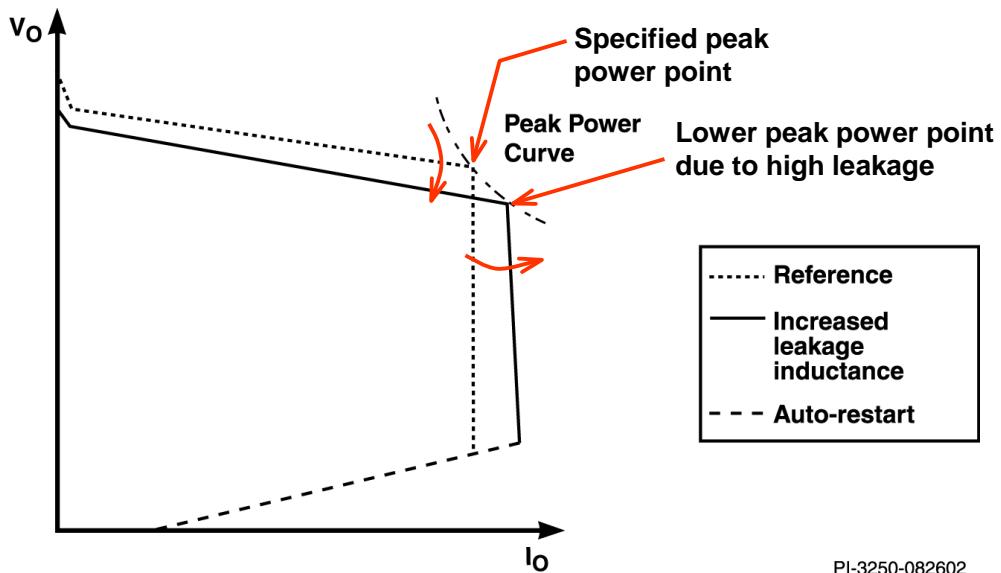
## Effect of Output Diode on CC Linearity



- Schottky and ultra fast ( $t_{rr}=50$  ns) diodes give the best CC linearity
- Fast recovery PN diodes ( $t_{rr}=150$  ns) cause CC region to bend outwards
  - Caused by slower diode forward recovery
  - Designs using fast diodes may not meet +/-20% CC tolerance

- The primary feedback resistor has been adjusted for each diode type to achieve similar peak power output voltage
- The increased forward voltage drop, during the forward recovery time of the fast diode, increases the primary clamp feedback voltage at a given output voltage. The *LinkSwitch* internal current limit is therefore higher for a given output voltage and the CC characteristic bends outwards.

# Effect of High Leakage Inductance $L_{LEAK}$

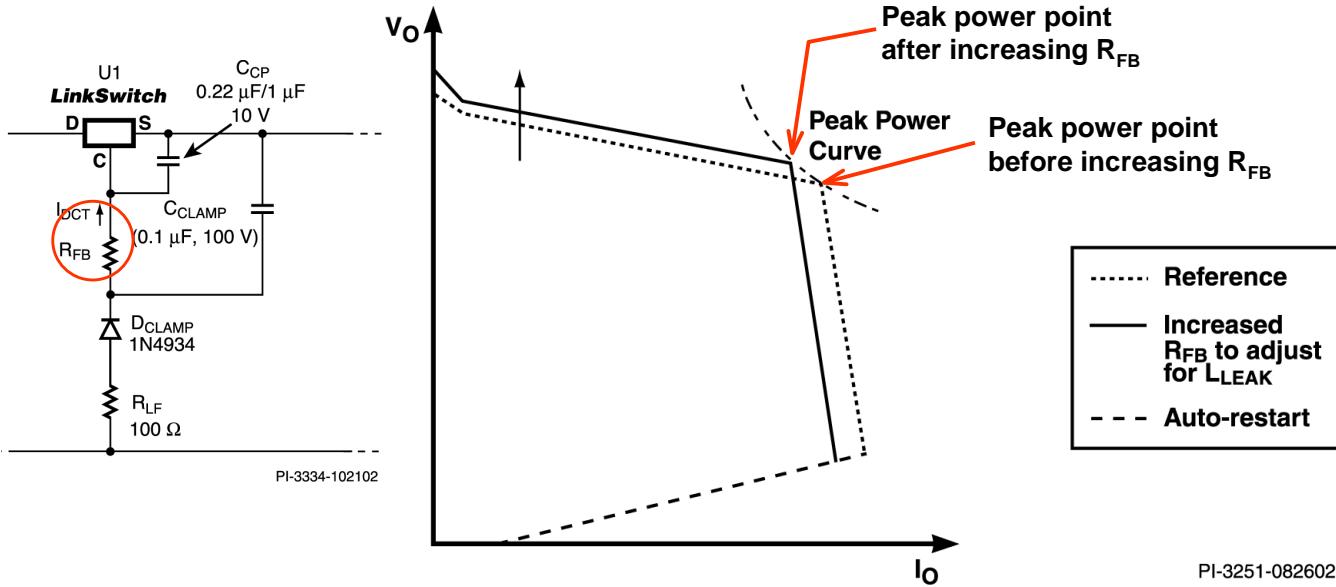


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- Poorer CV regulation
- Moves the CV/CC transition down the peak power curve
- Causes a slight “bowing out” of the CC region

- (Leakage energy degrades the tracking of  $V_{OR}$  ( $V_{FB}$ ) with  $V_O$ )

## Increasing $R_{FB}$ to Compensate for High $L_{LEAK}$

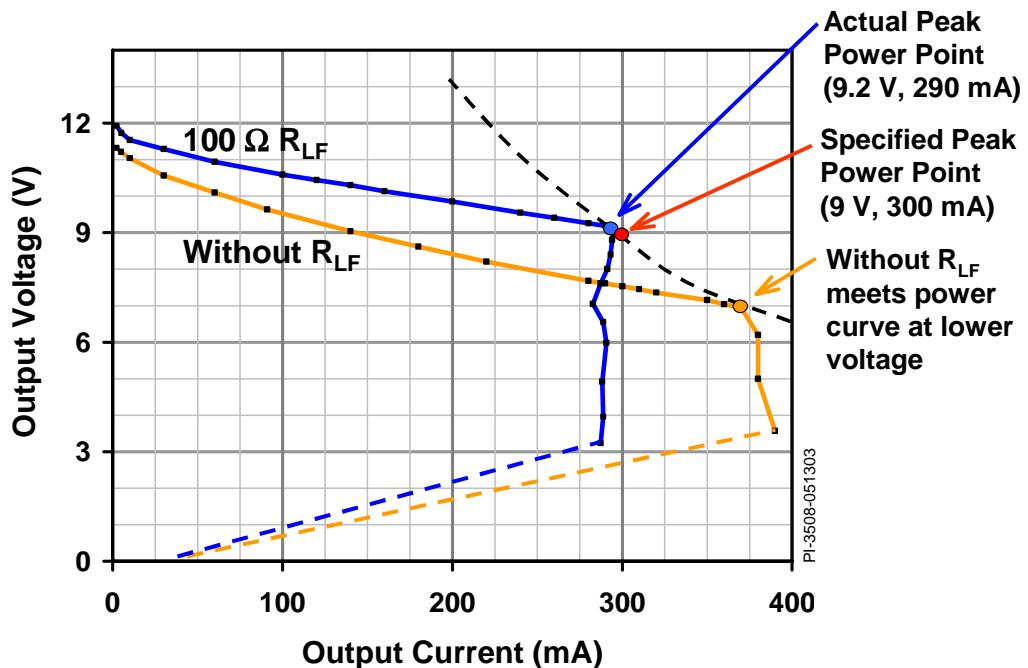
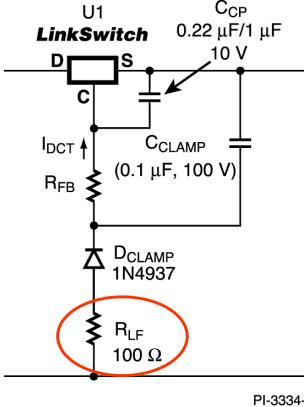


- Moves CV/CC transition up peak power curve
- Does not improve CV or CC regulation
- Increases no-load consumption

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- The peak power curve shown corresponds to the product of the maximum output current and voltage of a discontinuous mode flyback. As the output voltage changes, the output current changes to maintain this product constant.

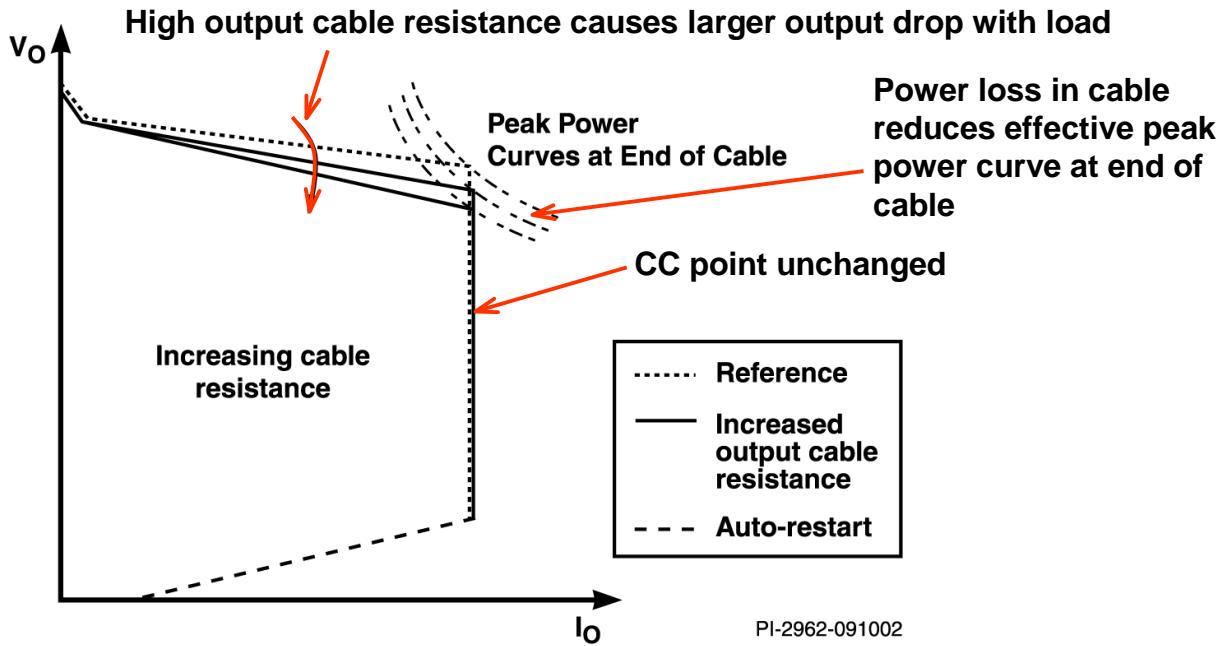
# Benefits of Using $R_{LF}$ : Better CV/CC Characteristics



- $R_{LF}$  filters leakage voltage, improving CV/CC characteristic and decreases zero load voltage and consumption

- $R_{LF}$  also reduces EMI caused by  $D_{CLAMP}$
- Chart shows that without  $R_{LF}$ ,  $R_{FB}$  would need to be increased for the output to meet the specified peak power point. This would cause both the no-load voltage and consumption to increase.

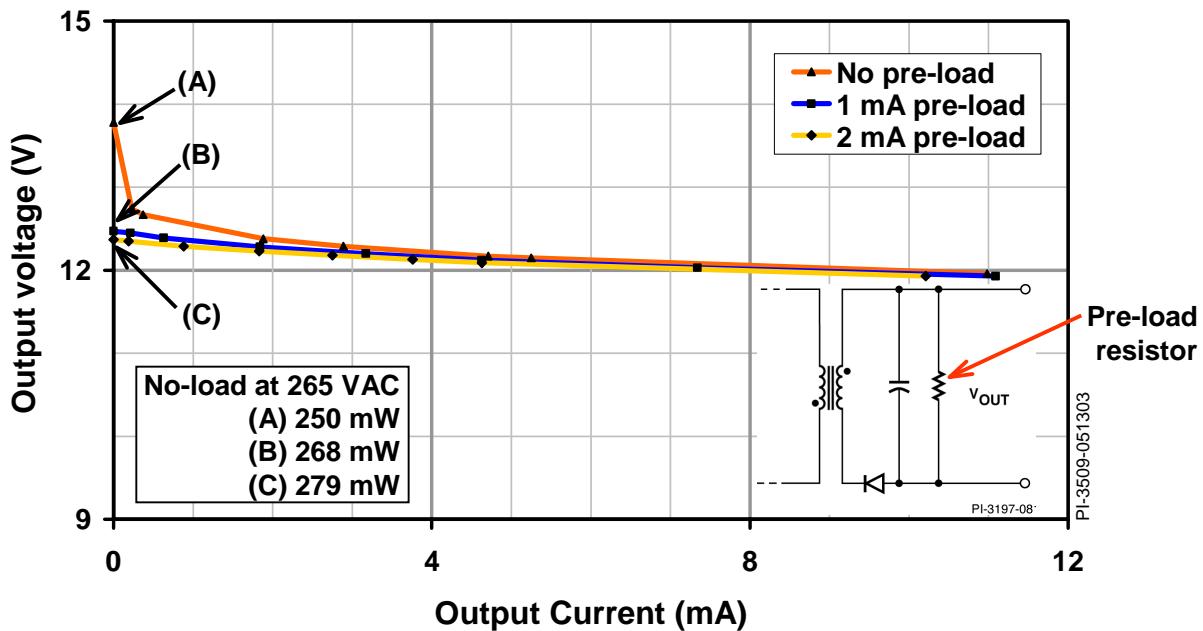
# Effect of High Cable Resistance



- Poorer CV regulation
- Lower Overall Efficiency

- Since the output current of the *LinkSwitch* is limited, once the device transitions from the CV portion of the output VI curve, past the peak power point (onto the CC portion of the output VI curve), the more power that is dissipated in the cable resistance, the lower the voltage will be, at the end of the cable

## Small Pre-load Reduces No-load Voltage



- Secondary peak charging causes output voltage to rise at no-load
  - Small pre-load reduces no-load output voltage by > 1 V
  - Minimal (~20 mW) increase in no-load consumption

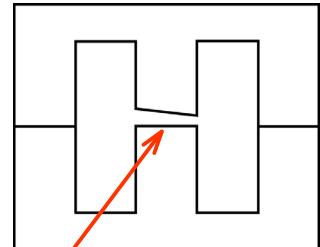
# Transformer Gapping

- **Minimum gap size recommendation**

- Recommendations based on  $\pm 10\%$   $L_p$  tolerance
- Center leg gapping:  $\geq 0.08$  mm
- Film gapping:  $\geq 0.05$  mm
- Verify with magnetics vendor

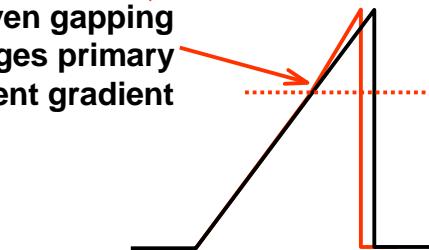
- **Ensure gap is uniform**

- Uneven gapping makes CC portion non-linear
- Verify by measuring  $di/dt$  of transformer current waveform



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Uneven gapping  
changes primary  
current gradient



- The increase in transformer  $di/dt$  only occurs when the current is near the peak. This phenomena is due to the crowding of magnetic lines of flux, in the core, near the narrowest part of the uneven gap, and means that saturation is being approached.
- To measure  $di/dt$  of transformer current waveform, feed power supply from DC source or use large input capacitor ( $100 \mu F$ ). Monitor current using a current probe.
- 0.05 mm is total gap size i.e. the tape or spacer thickness is 0.025 mm between all legs of the EE cores

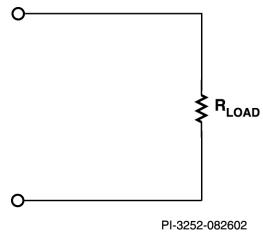
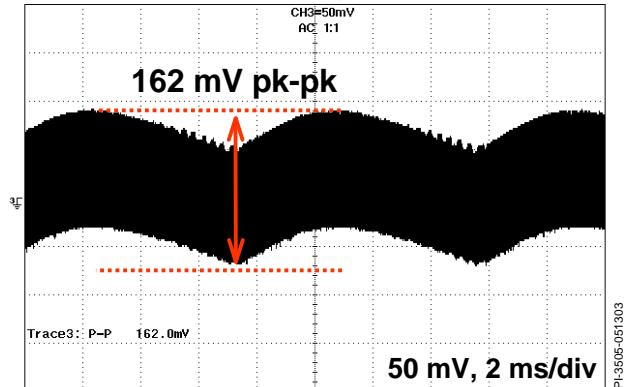
# Minimizing No-load Consumption

- **$40 \text{ V} \leq V_{\text{OR}} \leq 60 \text{ V}$** 
  - 40 V will give the lowest consumption
- **Minimize switching node capacitance**
  - Remove snubbers on *LinkSwitch* and output diode
  - Use double coated/heavy nyleze/L2 magnet wire for primary winding
- **Do not vacuum impregnate transformer**
  - Varnish increases primary capacitance  $\sim 5x$
  - Dip varnishing does not increase capacitance significantly

- **$V_{\text{OR}}$  below 40 V limits output power capability**

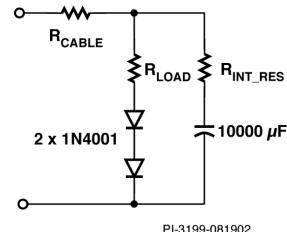
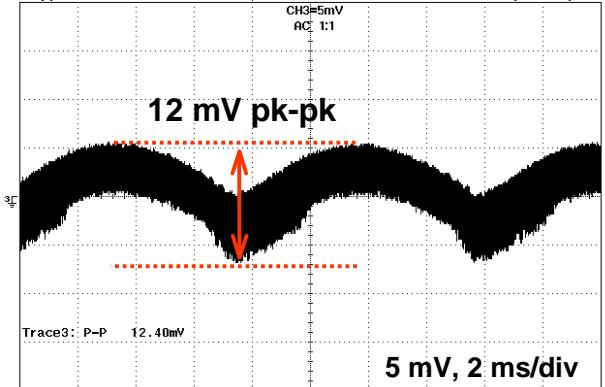
# Battery Loads Do Not Require Output $\pi$ Filter

Output Voltage Ripple



With Resistive Load

Output Voltage Ripple



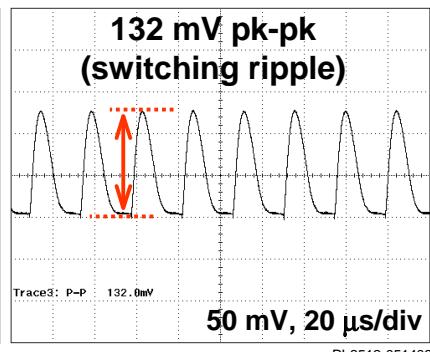
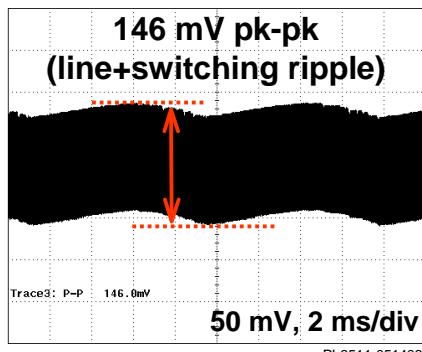
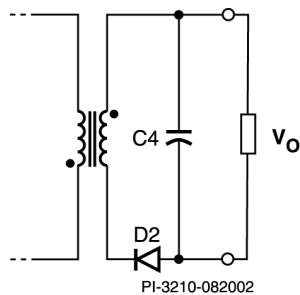
With Battery or Battery Model Load

- Battery acts as a filter capacitor

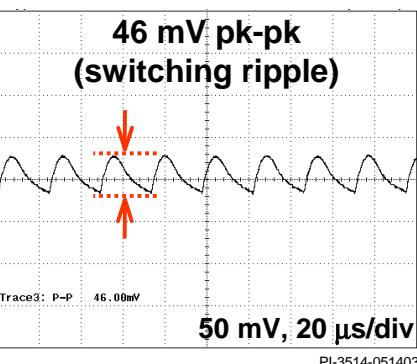
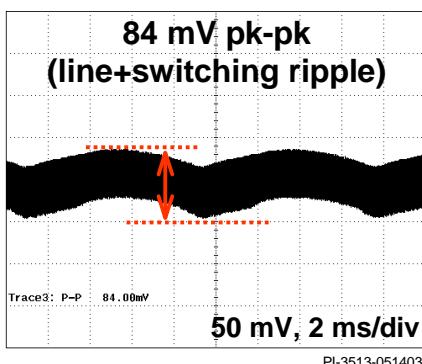
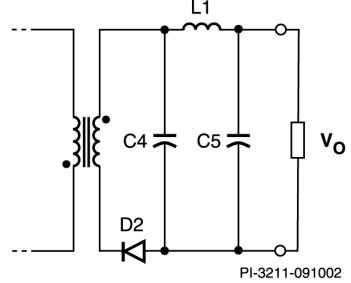
- Measured with x1 probe at end of output cable with parallel 0.1  $\mu$ F and 1  $\mu$ F capacitors and 20 MHz bandwidth
- (Apparent high frequency modulation on falling slope of waveforms is due to digital oscilloscope aliasing)

## Effect of Output $\pi$ Filter

- Without  $\pi$  filter

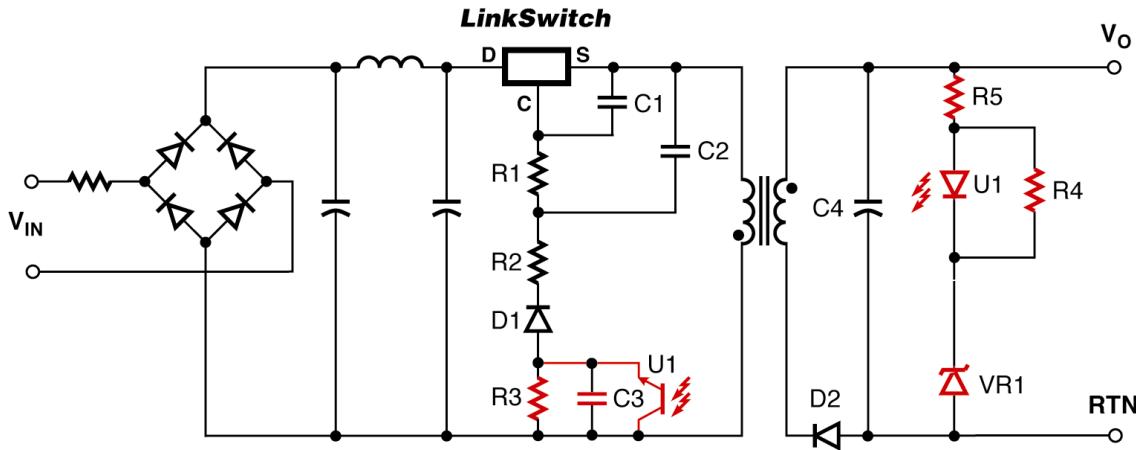


- With  $\pi$  filter



- $\pi$  filter reduces switching ripple
- (Results taken from EP-16, C4: 470  $\mu$ F / 10 V, L1: ferrite bead, C5: 100  $\mu$  F / 10 V)

# Improving CV Tolerance with Optocoupler

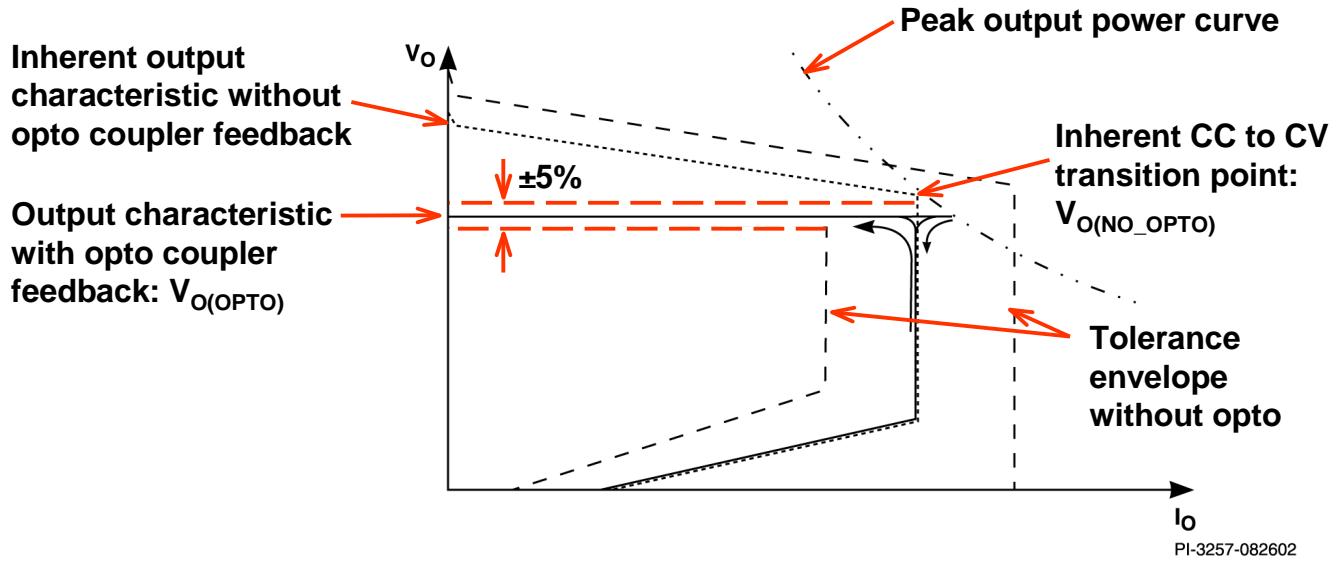


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- **$\pm 2\%$  reference including temperature provides  $\pm 5\%$  CV tolerance**
  - The sense voltage ( $V_{OPTO} + V_{REF}$ ) sets the nominal specified output voltage

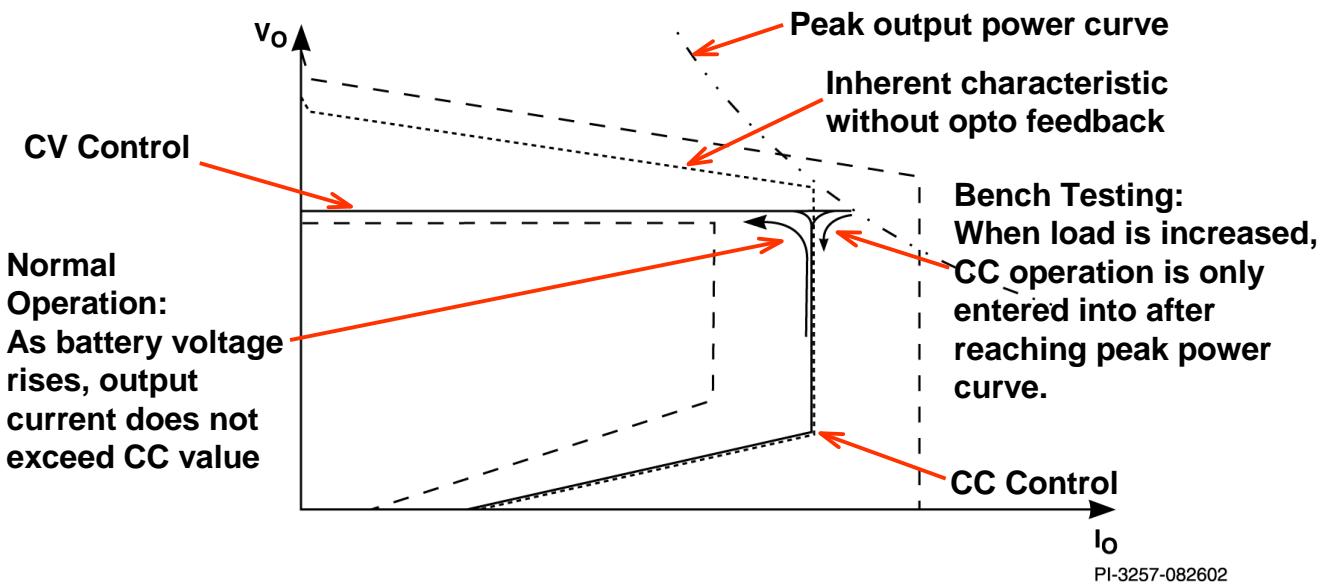
- Typically  $R1=R3=RFB/2$
- Increasing  $R3$ , while keeping  $R1+R3=RFB$ , increases loop gain & improves CV regulation.
- Maximum value of  $R3$  limited by opto transistor dissipation
- For typical transformer leakage inductance values  $R2$  (RLF) is  $100 \Omega$
- $C2, C3$  typically  $0.1 \mu F$ ,  $50 V$ .  $C3$  provides DC voltage for optocoupler
- $R4$  biases  $VR1$  close to its specified test current; a value of  $200 \Omega$  provides  $\sim 5 mA$ .
- $R5$  may be required for Zener voltages above  $5 V$  and for TL431 designs, to limit LED current and ensure stability. Values in the range  $22-68 \Omega$  are typical.
- High CTR optocoupler (200-400%) improves CV regulation, if required.
- See Application Examples section for more information.
- Optocoupler is connected to primary return (non-switching side of  $D1$ ), to reduce common mode EMI, which would result if connected to the switching side of  $D1$ .
- Swapping the positions of  $D1$  and  $R2$  will improve EMI, as  $R2$  would no longer see the switching waveform at the cathode of  $D1$ .

# Designing for Optocoupler Feedback



- The *Linkswitch* circuit should be designed for a nominal inherent (without opto) peak power point voltage that is 5% above the nominal specified voltage
- Example: 5 V output specification,  
 $V_{F(OPTO)} + V_{REF} = V_{O(OPTO)} = 5V$ ,  $V_{O(NO\_OPTO)}$  for *LinkSwitch* design = 5.25 V

# Opto CC Behavior during Bench Test



- During charging, only rising CC characteristic is followed
  - $\pm 20\%$  Output CC tolerance is still maintained with opto-coupler feedback
  - Falling characteristic only seen during lab testing

## Operation during Normal Battery Charging:

- As the battery charges,  $I_o$  is under CC control, as the output voltage rises
- When  $V_o$  reaches the feedback threshold (set by the secondary sense circuit), the opto provides feedback, and the *LinkSwitch* transitions to CV mode (PWM) control

## Operation observed in laboratory bench testing:

- As the load is increased, the output voltage falls when the peak power point is reached. This reduces the current through the secondary sense circuit, which reduces the CONTROL pin current. This reduces the internal current limit of the *LinkSwitch*, which further reduces the output voltage (positive feedback) and transitions the output into CC control mode
- Therefore, a slight overshoot in  $I_o$  may be observed in bench testing (as depicted in the slide), as the load is increased [This will not occur in normal battery charging]
- This effect can be eliminated by setting the sense voltage to 10% above the inherent peak power point voltage
- See the *LinkSwitch* data sheet for more information

# Estimated Manufacturing Tolerances

- Complete analysis of tolerance calculations is provided in AN-35 *LinkSwitch* Design Guide
- **±20% Overall estimated CC tolerance for a 3 W design**
  - Includes all device, external component and temp. variations ( $T_j$ : 25°C to 65°C)
- **Transformer tolerance dominates CC variation**
  - $I^2f$  coefficient tolerance ±6% is the second most dominant
- **At lower power CC tolerance is slightly higher (~± 22% at 1.5 W)**
- **± 10% CV tolerance due to the following variables**
  - Finite gain of *LinkSwitch*
  - Feedback resistor tolerance
  - CONTROL pin voltage tolerance
  - Output diode forward drop variation

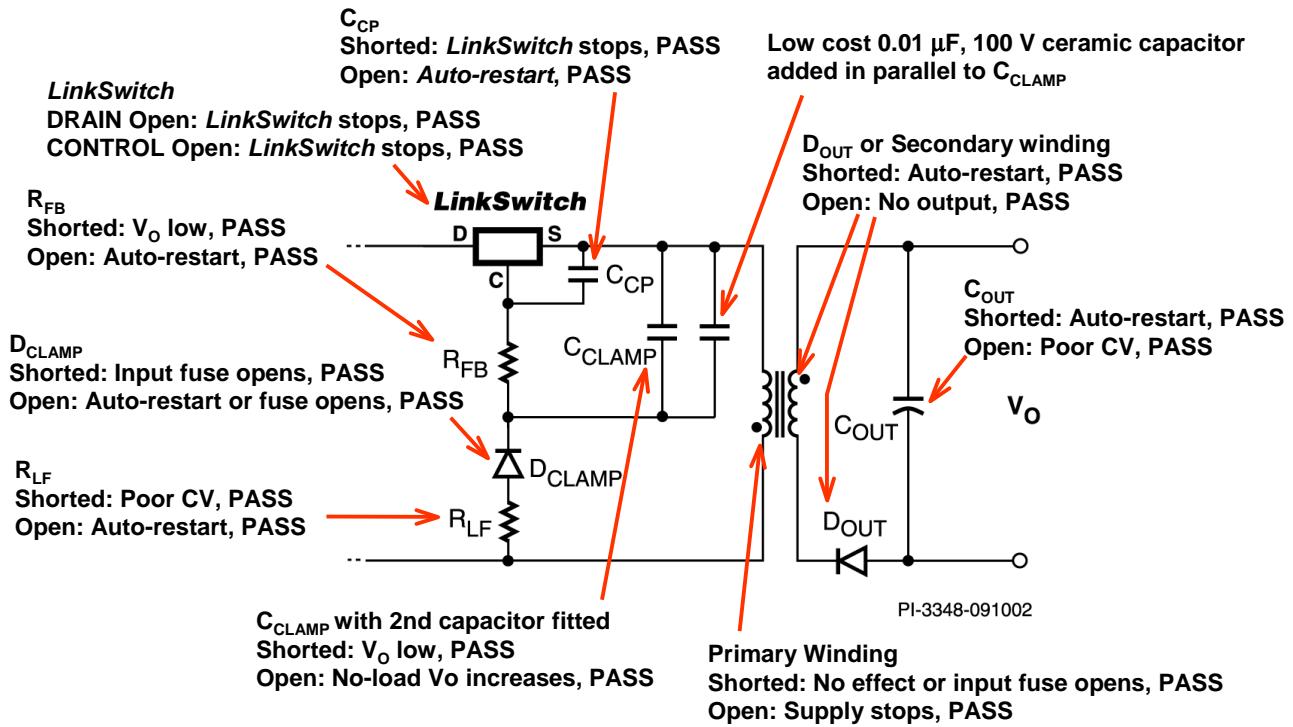
## Higher $V_{OR}$ for Higher Output Power

- **$V_{OR}>60$  V increases power capability for open frame designs**
  - 4.5 W (Universal) with 100  $V_{OR}$ , no-load ~500 mW at 265 VAC (see Note 1)
  - 5 W (230 VAC  $\pm 15\%$ ) with 80  $V_{OR}$ , no-load ~450 mW at 265 VAC (see Note 1)
  - Output power above these levels limited by thermal dissipation constraints
- **Design must still remain fully discontinuous**
  - Continuous mode operation with *LinkSwitch* can cause instability
- **Useful for designs that can accommodate the increased no-load consumption**

Note 1: Ambient temperature must be maintained at a temperature that assures that the device case temperatures do not trip thermal shutdown

- Higher  $V_{OR}$  allows higher duty cycle, increasing power capability

# Single Point Failure Safety Testing

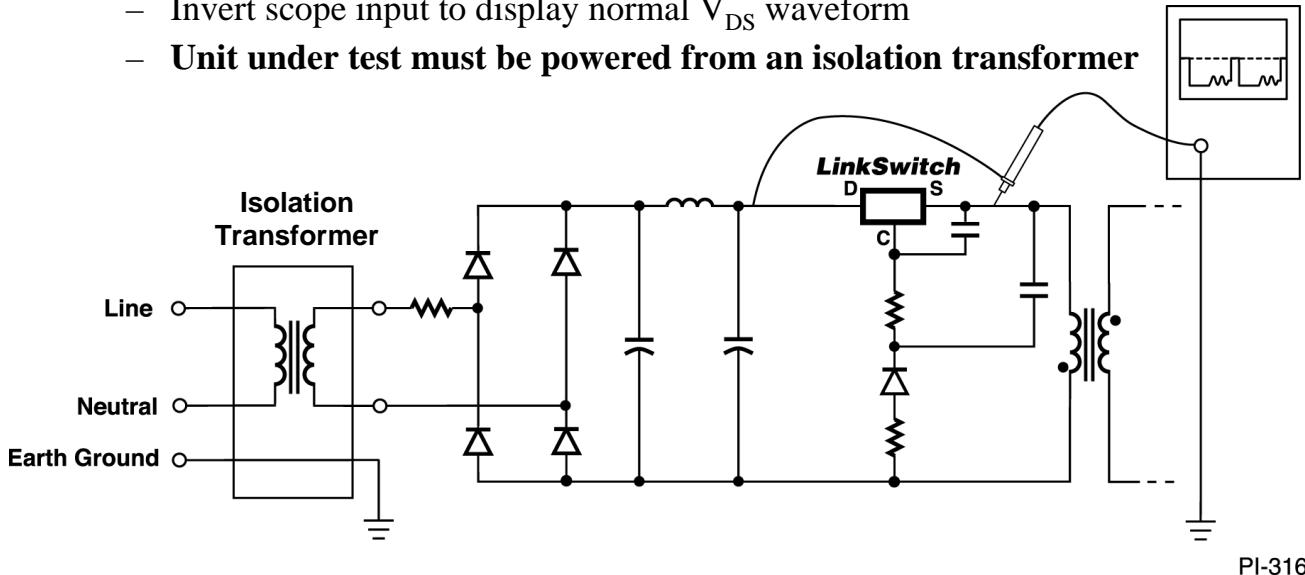


- **LinkSwitch meets single point failure testing with one additional capacitor**

- Shorting of DRAIN to SOURCE pin not required as creepage and clearance of 2.9 mm between pins meets agency requirement (>2.5 mm) with correctly designed PC board.

# Correct Scope Drain Voltage Measurement

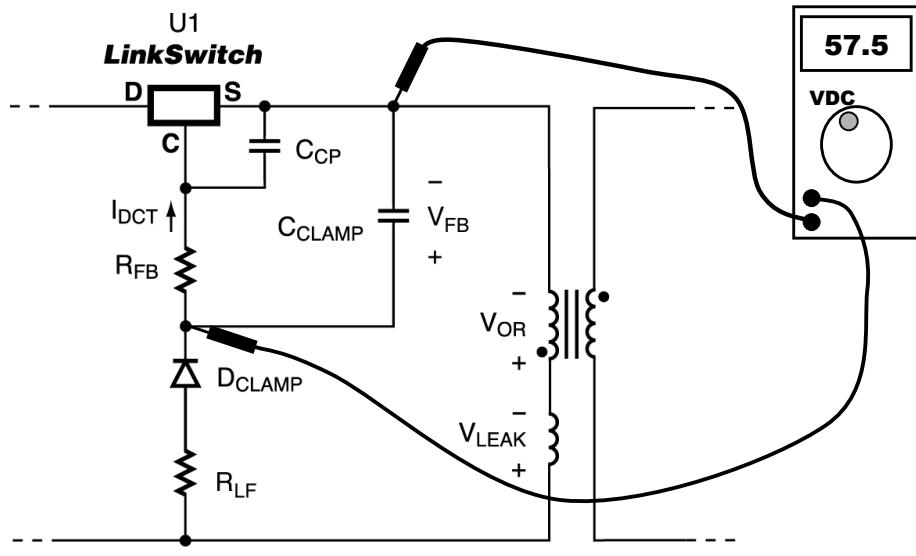
- **Connect scope ground to the DRAIN pin / high voltage DC rail**
  - Do not connect scope ground to SOURCE pin: excess capacitance falsely triggers current limit
  - Invert scope input to display normal  $V_{DS}$  waveform
  - **Unit under test must be powered from an isolation transformer**



PI-3164

# Measuring $V_{FB}$

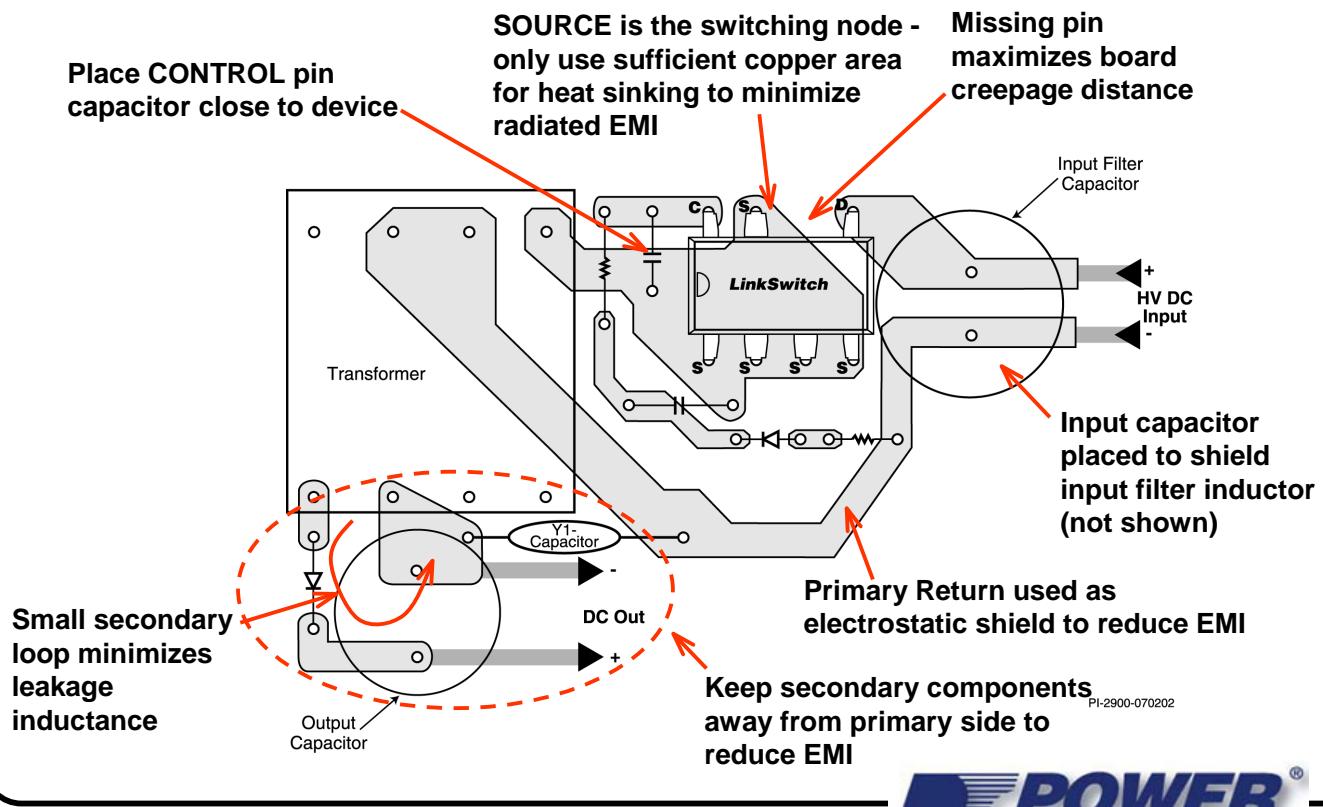
- Connect battery powered DVM directly across  $C_{CLAMP}$ 
  - Sufficient common mode rejection of source switching node to measure  $V_{FB}$  directly



PI-3159-082902



# PC Board Layout Considerations



## ***LinkSwitch* Applications Examples**

## Applications Examples

- **2.75 W, Universal input charger (DI-18)**
  - 5.5 V / 500 mA, CV/CC
- **1.5 W, Universal input charger (DI-19)**
  - 5.5 V / 270 mA, CV/CC
- **2.7 W, Universal input adapter**
  - 9 V / 300 mA, CV
- **1 W, Universal input, portable audio charger**
  - 1.5 V / 700 mA, CV/CC
- **2.6 W, Universal input with opto feedback (DI-44)**
  - 5.2 V / 500 mA, CV/CC
- **4.8 W, 230-375 VDC input, standby / auxiliary supply**
  - 12 V / 400 mA, CV

DI=Design Idea

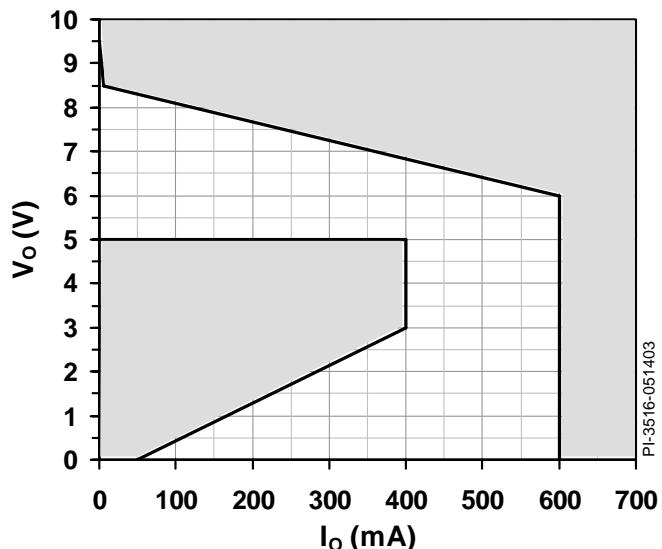
- The latest Design ideas from Power Integrations can be found at [www.powerint.com/appcircuits.htm](http://www.powerint.com/appcircuits.htm)

## 2.75 W Charger Specification (DI-18)

DESCRIPTION	VALUE
Input Voltage	85-265 VAC
Output Voltage	5.5 V
Output Current	500 mA
Output Power	2.75 W
Efficiency	>70%
No load	<300 mW
Conducted EMI	CISPR22B/ EN55022B
Surge	EN1000-4-5 Class 3

PI-3212-091802

Output CV/CC Specification



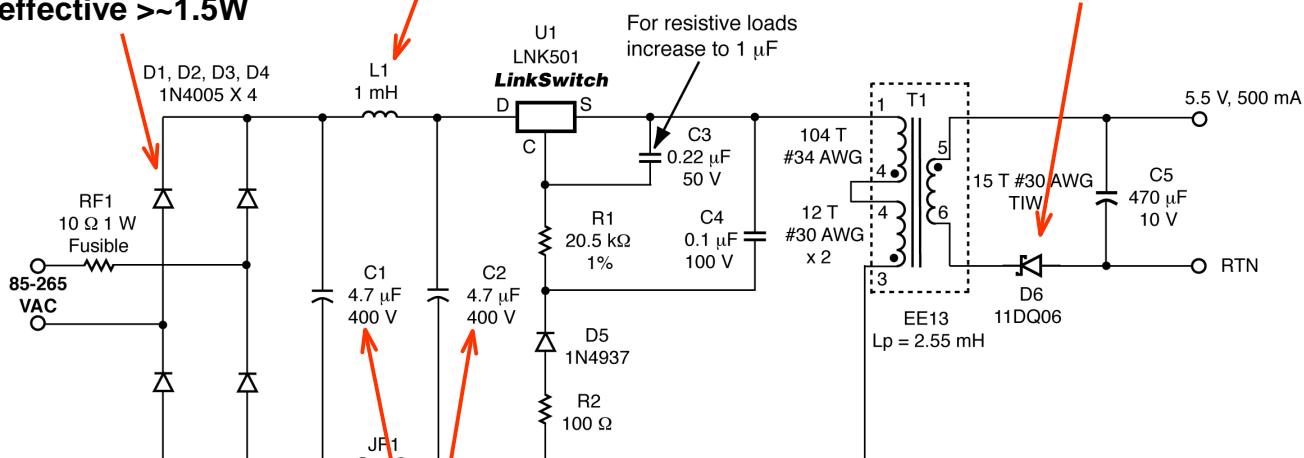
PI-3516-051403

## 2.75 W Charger Schematic

Full wave rectification cost effective >~1.5W

Meets EN55022B/CISPR22B with no Y capacitor. Lower cost resistive  $\pi$  filter possible with lower efficiency

PN diode possible for lower cost with lower efficiency

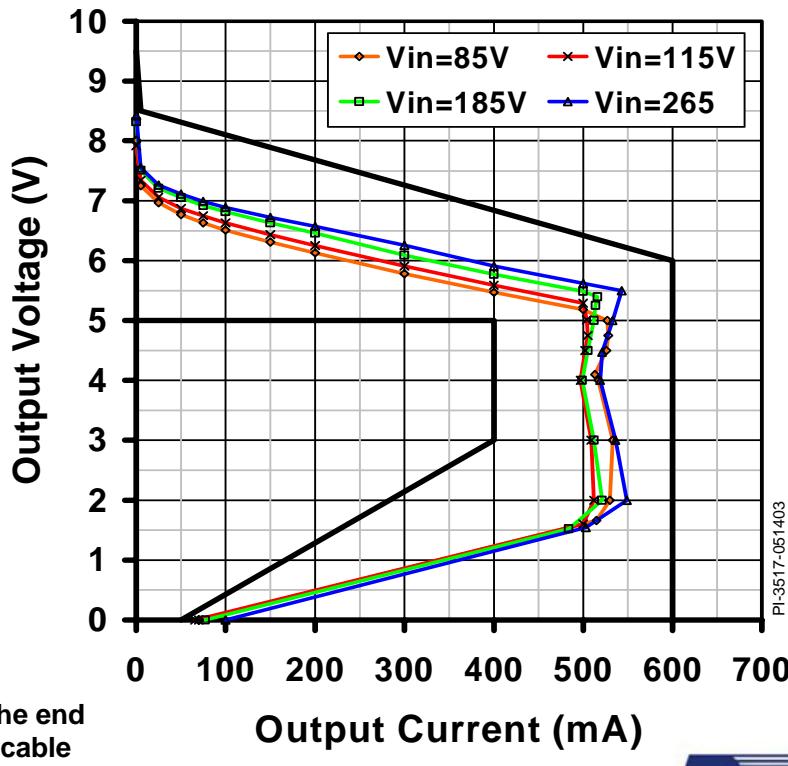


PI-3196-090402

3.3uF can save cost but with lower differential surge withstand rating (<2.5 kV)

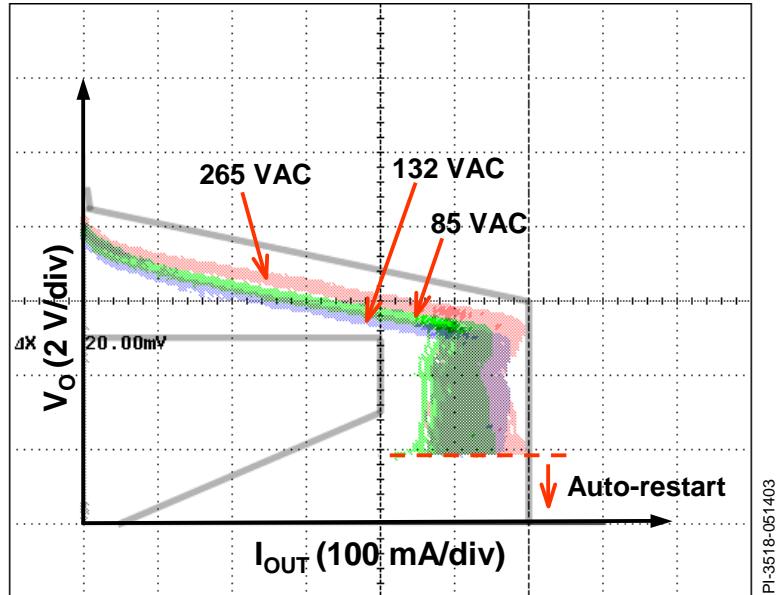
- Resistive  $\pi$  filter reduces efficiency ~10%
- Half wave rectification above ~1.5 W output powers requires larger input capacitors
- (Primary is split as part of primary winding is configured as a shield. This reduces primary to secondary common mode currents and therefore conducted EMI)

## 2.75 W Charger CV/CC Output Characteristic\*



\*Measured at the end  
of the output cable

## Output Characteristic\* of 100 Randomly Selected (2.75 W) Charger Samples



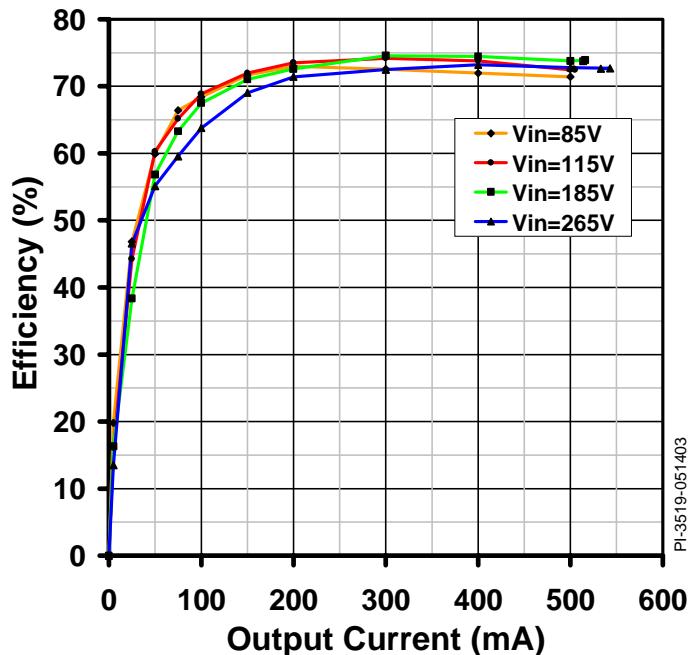
PI-3518-051403

\*Measured at the end of the output cable

- These results show that the CC portion of the output curve could be better “centered” to optimize the manufacturing yield

- “Centering” would require lowering the transformer primary winding inductance

## 2.75 W Charger Efficiency

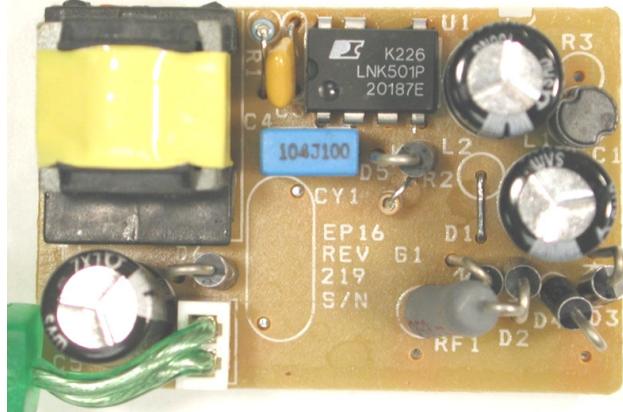
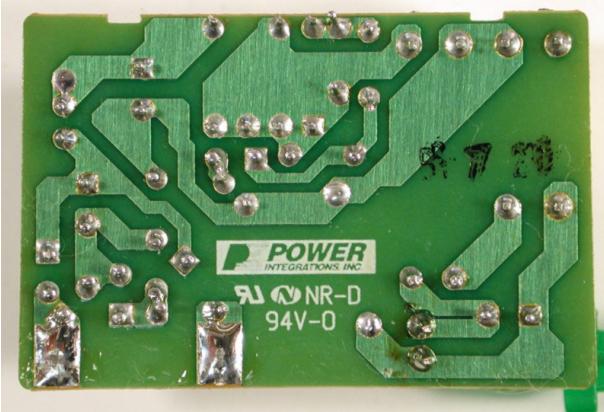


INPUT VOLTAGE	NO-LOAD INPUT POWER
85 VAC	193 mW
115 VAC	210 mW
185 VAC	219 mW
230 VAC	251 mW
265 VAC	274 mW

PI-3249-091802

- High efficiency (71%) due to no current sense losses
- *EcoSmart*: easily meets <300 mW no-load consumption

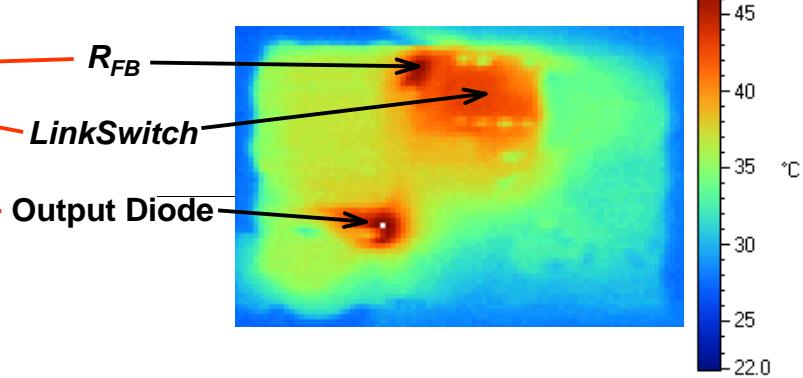
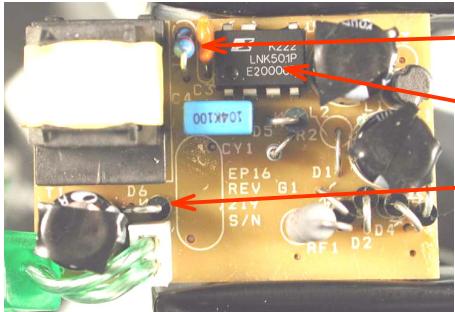
## EP-16A PC Board Layout



1.7 x 1.1 inches (43 x 28 mm)

- **Low cost (CEM1) single sided board**
  - No surface mount components required

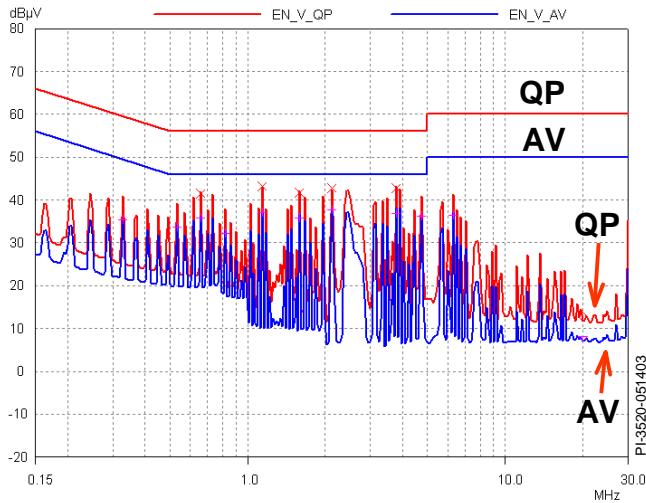
## 2.75 W Charger Thermal Performance



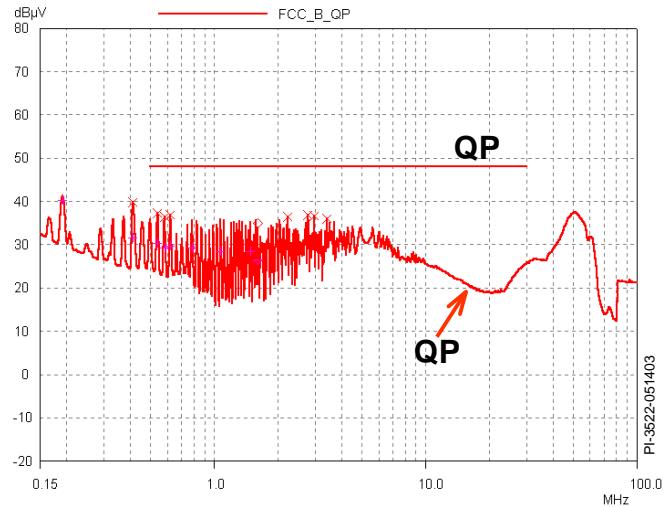
- **High efficiency operation reduces the dissipation of the *LinkSwitch***
  - The absence of a secondary current sense resistor reduces the power, that has to be processed by the transformer, by up to  $\sim 1$  W
  - This also reduces the temperature rise within the charger/adapter enclosure (the enclosure's ambient temperature only rose  $15^{\circ}\text{C}$  above the external ambient)
- **Minimal SOURCE copper-area is needed to heatsink the *LinkSwitch***
  - The *LinkSwitch* temperature rose  $<25^{\circ}\text{C}$  above the ambient within the enclosure
  - Minimizing the area of copper connected to the switching node reduces EMI

- A typical discrete switching supply's sense resistors drop a total of 1.3 secondary-side volts in the process of driving an NPN transistor and an opto-coupler LED. With an operating efficiency of 70% and at an output current of 0.5 A, that represents a loss of 0.65 W of output power, which requires an additional 0.93 W of input power

## 2.75 W Charger EMI Performance



CISPR22-B / EN55022 B

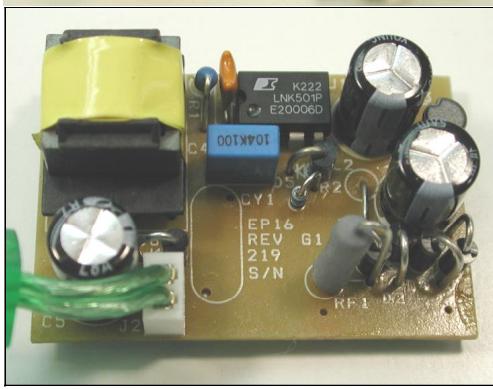
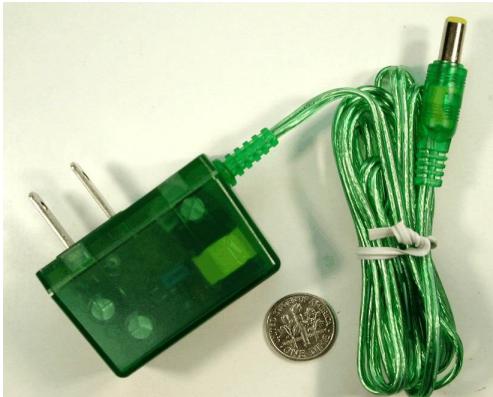


FCC B

Measured with artificial hand connected to output return

- (EMI shown with output return connected to artificial hand connection of LISN. This degrades EMI results by providing a capacitive current path to earth ground. EMI results without artificial hand connected are better than shown above).

## 2.75 W Charger Summary



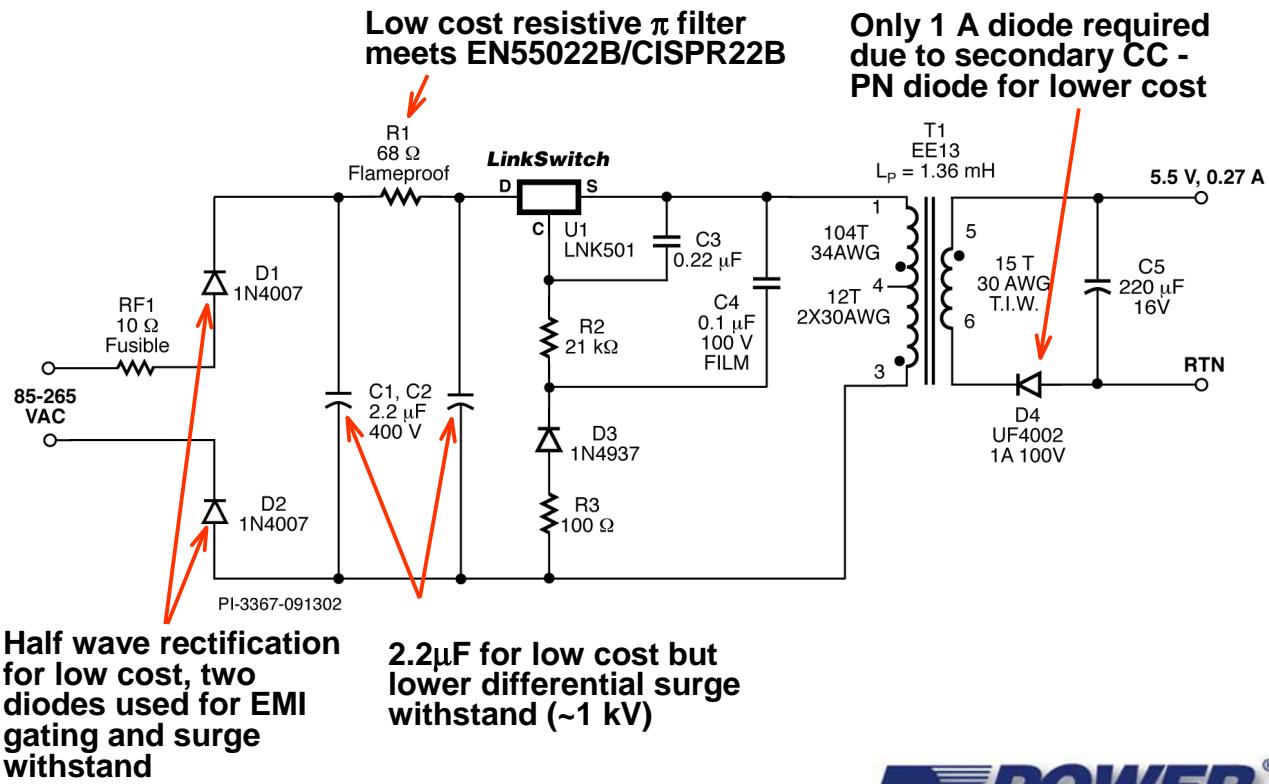
- **Cost competitive even with unregulated linear transformer based chargers with much better performance (CV/CC)**
- **A low parts count solution**
- **Small size and light weight**
- **High efficiency 71%**
- **Meets worldwide standby energy requirements**
- **Meets worldwide EMI standards**
- **Fully fault protected from...**
  - **short circuits or open feedback loops** (by its integrated auto-restart function)
  - **over heating** (by its auto-recovering, hysteretic thermal shutdown function)

Lowpwr 022404



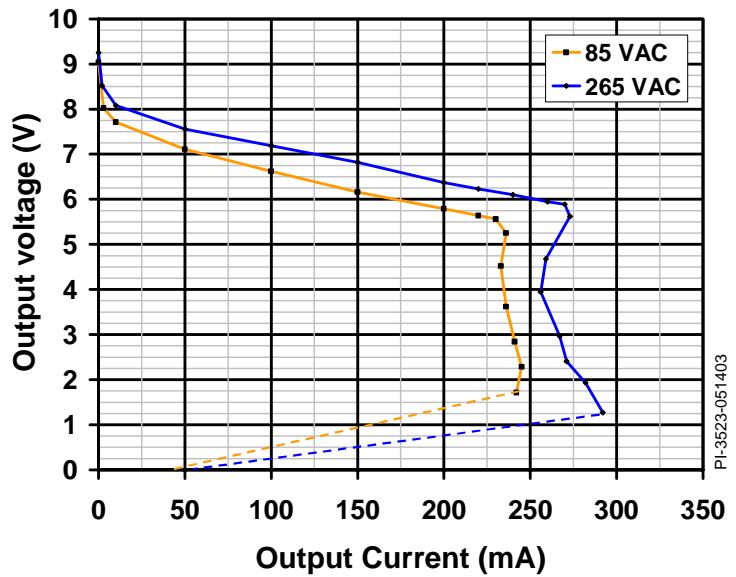
- This 2.75 W charger is available in Design Accelerator Kit DAK-16A. The DAK includes device samples, a second (blank) PCB, and full design documentation

# 1.5 W, 5.5 V Charger Schematic (DI-19)

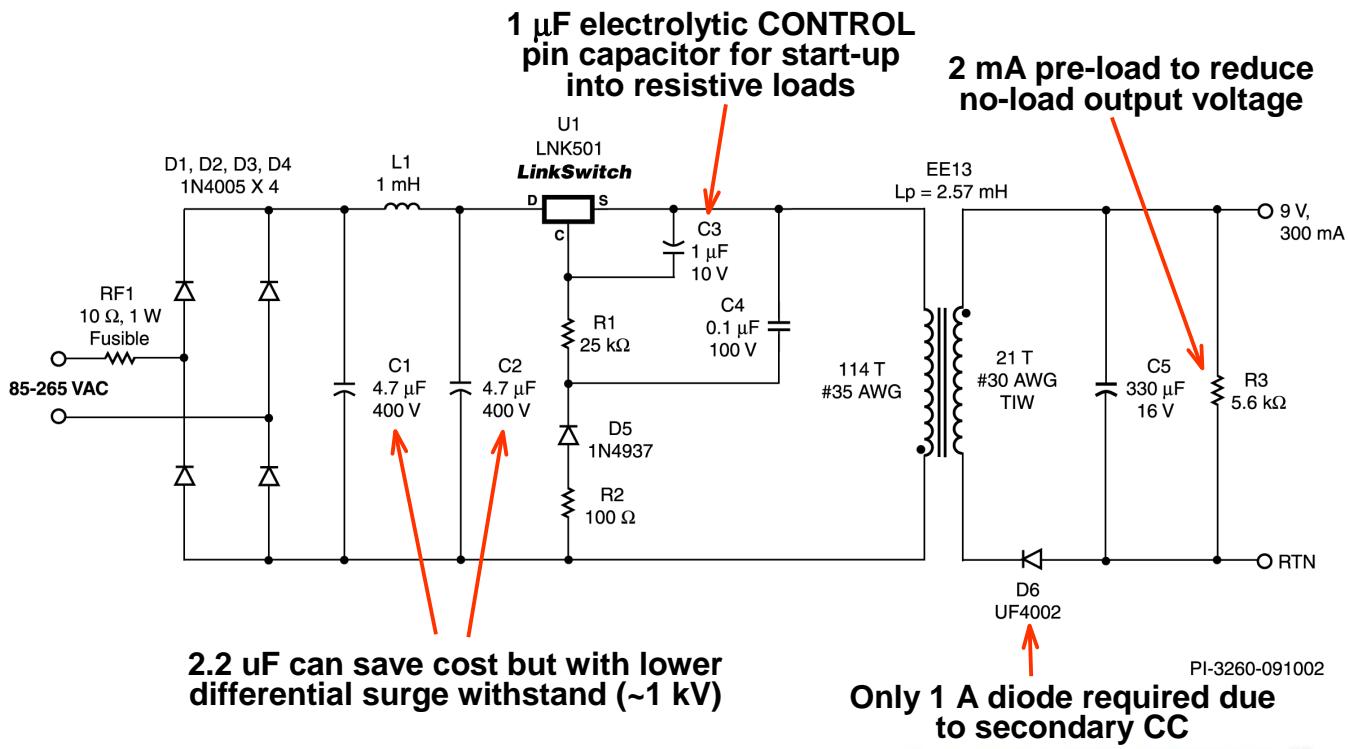


# 1.5 W, 5.5 V Low Cost Charger Performance (DI-19)

- **Universal Input, 5.5 V, 270 mA output**
  - 100/115 VAC only design can lower input capacitor costs
- **Half wave input rectification**
- **Low cost resistive  $\pi$  filter**
- **Efficiency > 62 %**
- **No-load consumption**
  - 219 mW at 115 VAC
  - 282 mW at 265 VAC

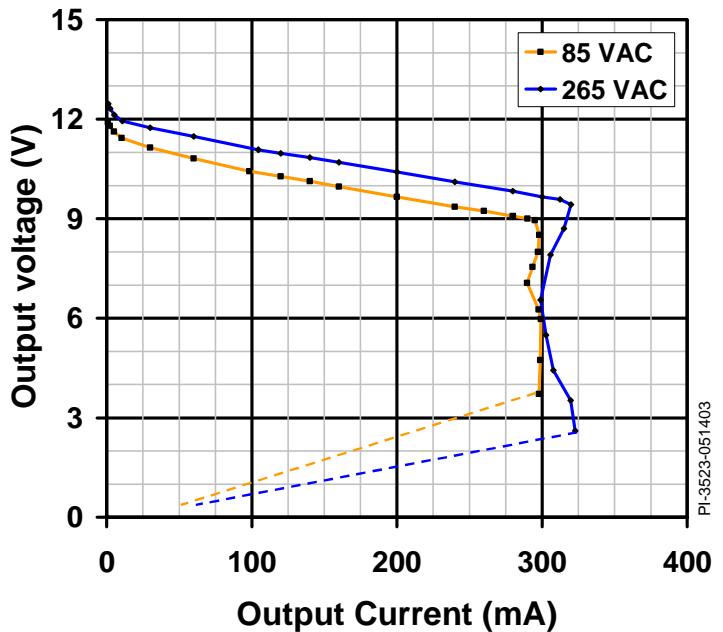


## 2.7 W, 9 V Adapter Schematic

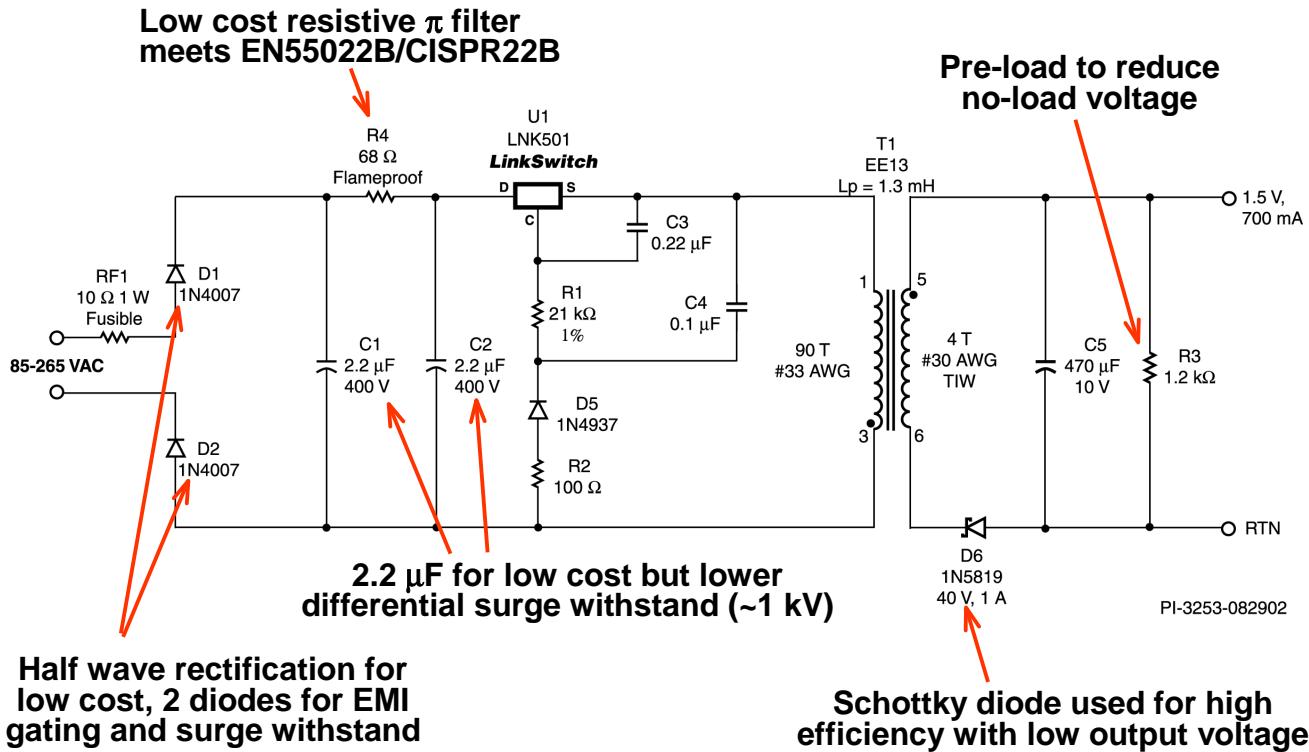


## 2.7 W, 9 V Adapter Performance

- **Universal Input, 9 V, 300 mA nominal output**
  - 100/115 VAC only design can lower input capacitor costs
- **Efficiency >73%**
- **No-load input power**
  - 222 mW at 85 VAC
  - 280 mW at 265 VAC

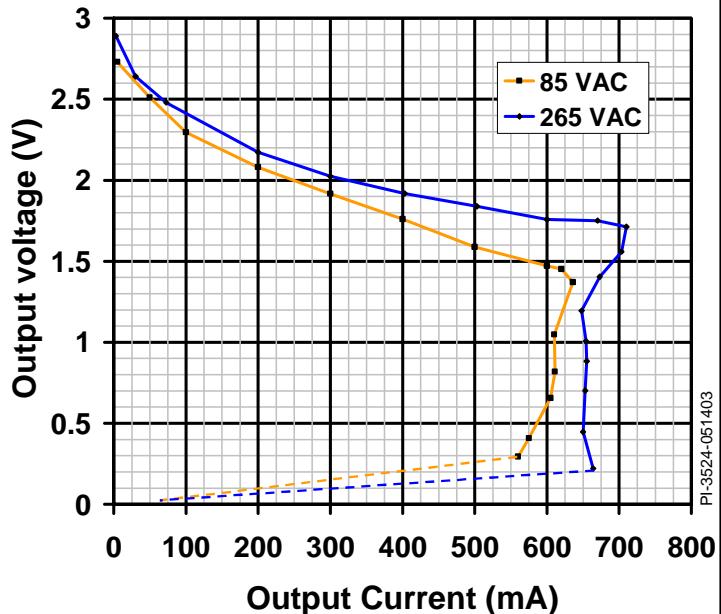


# 1 W, 1.5 V Portable Audio Charger Schematic

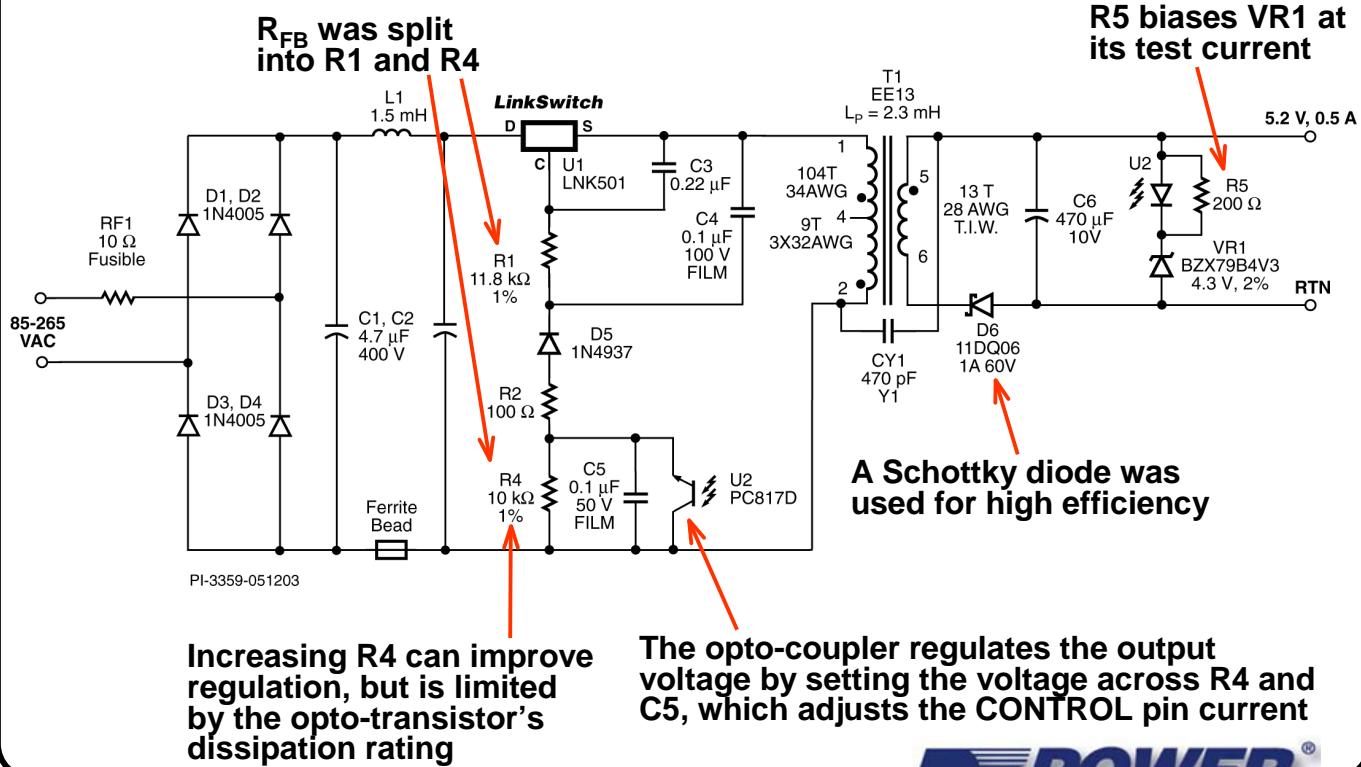


# 1 W, 1.5 V Portable Audio Charger Performance

- **Universal Input, 1.5 V, 700 mA output**
  - 100/115 VAC only design can lower input capacitor costs
- **No-load input power**
  - 235 mW at 110 VAC
  - 264 mW at 265 VAC



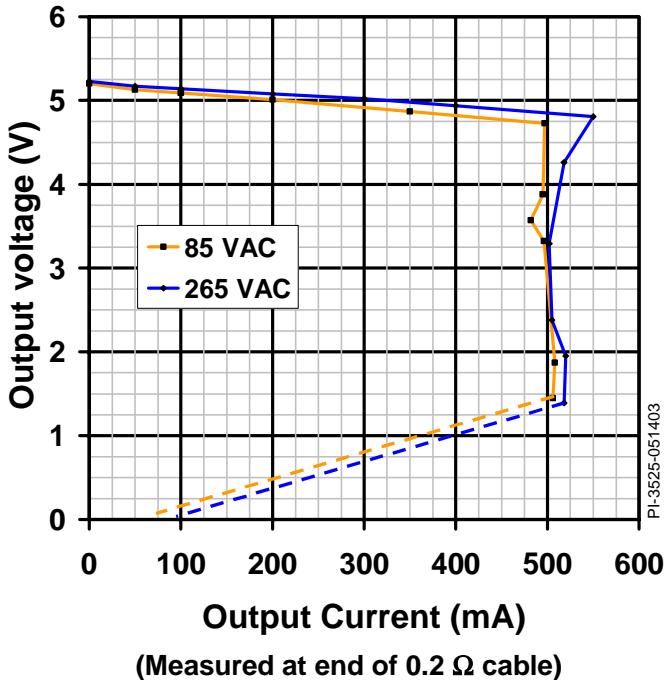
## 2.6 W, 5.2 V Accurate CV Charger (with Opto-coupled Feedback)



- For higher output voltages (i.e., lower Zener impedance) or when using a reference IC (such as a TL431), a series resistor may be required to limit the opto-LED current
- C5 can be a ceramic capacitor, to keep costs low

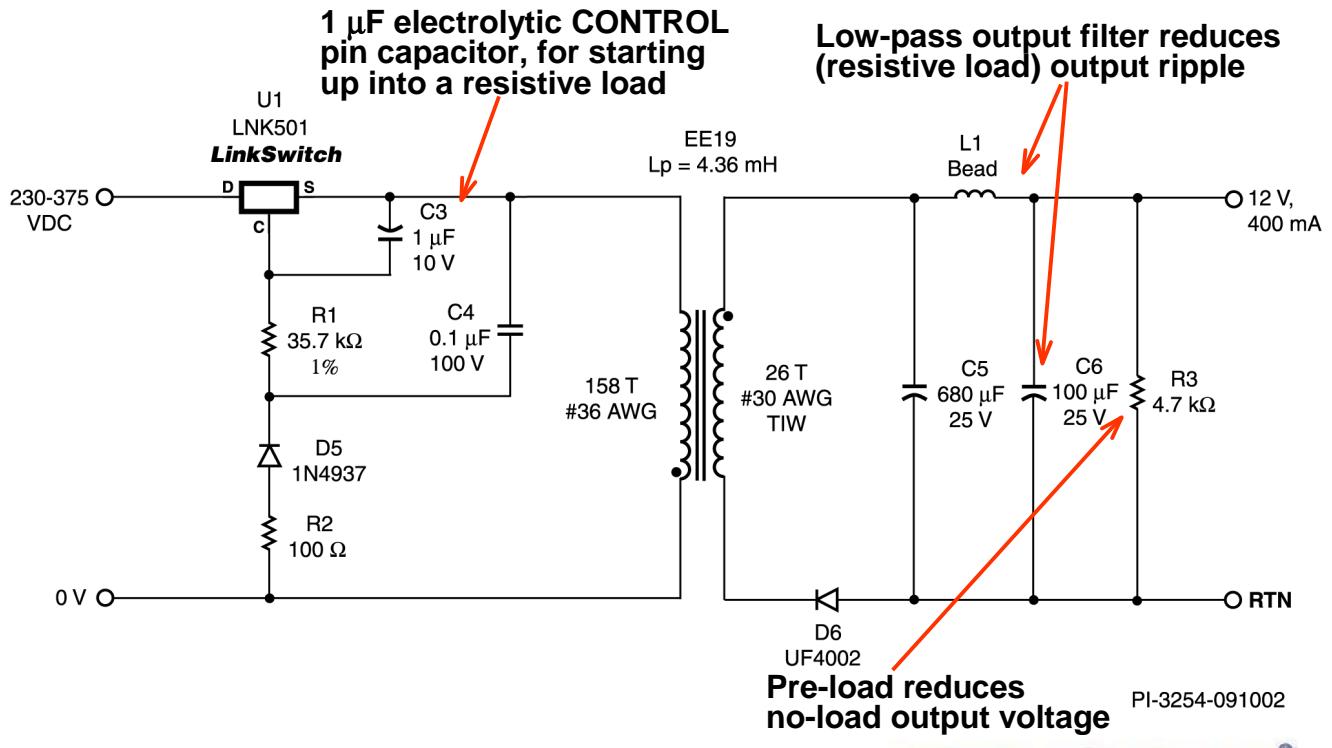
## 2.6 W, 5.2 V Accurate CV Charger Performance

- **Universal Input, 5.2 V, 500 mA output**
  - 5.2 V  $\pm$ 7% at terminals
  - 5.2 V  $\pm$ 8% at end of cable
  - 100/115 VAC only design can lower input capacitor costs
- **Efficiency >68%**
- **No-load input power**
  - 167 mW at 85 VAC
  - 220 mW at 265 VAC



- Output voltage regulation figures include line regulation ( $\pm 1\%$ ), load regulation ( $\pm 2.3\%$ ), Zener tolerance ( $\pm 2\%$ ) and Zener temperature coefficient for 50 °C temperature range ( $\pm 1.7\%$ ).

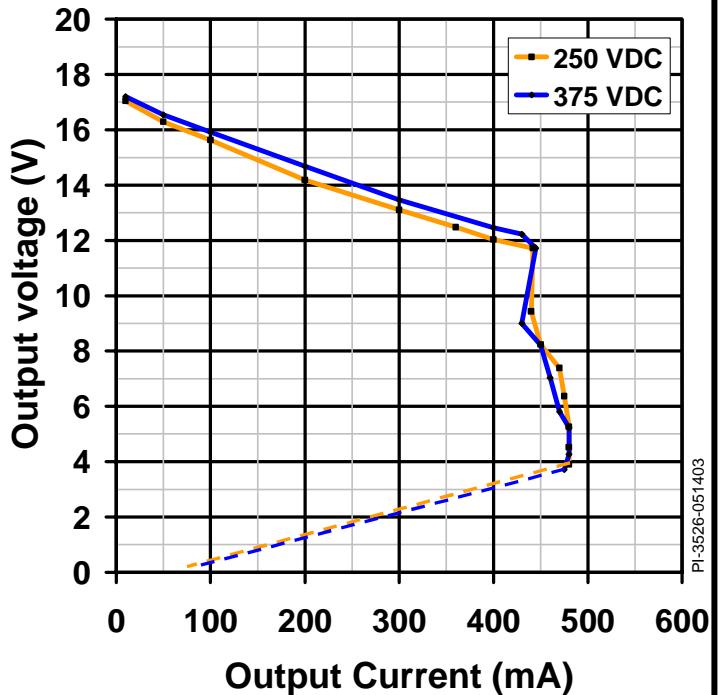
## 4.8 W, 12 V Auxiliary Supply Schematic



- This circuit is ideal for auxiliary supplies in white goods and home appliances

## 4.8 W, 12 V, Auxiliary Supply Performance

- 230 VDC to 375 VDC input, 12 V, 400 mA nominal output
- 80 V<sub>OR</sub>
- Efficiency >78%
- No-load input power
  - 390 mW at 230 VDC
  - 456 mW at 375 VDC



PI-3526-051403

# **LinkSwitch: Switcher Benefits at Linear Cost**

- **Universal input, CV/CC regulated output operation**
  - Higher performance than unregulated linear supplies
  - A single design works worldwide, which simplifies inventory logistics
- **Smaller Size and Weight**
  - Lower shipping costs for both supplier and OEM
  - High tolerance to mechanical shock – easily passes drop testing
  - The power supply matches the state-of-the-art product it powers
  - End user convenience – doesn't block multiple outlets
- **EcoSmart**
  - High operating efficiency
  - Low standby power consumption
  - Meets all worldwide standards
- **Self-Resetting Fault Protections**
  - Fully protected from over heating, short-circuits and open feedback loops



**Linears Will Be Converted**

***LinkSwitch***

**Enables Cost Effective Conversion of  
Up to 1 Billion Linears Built Annually**

**Today!**



# Designing Low Power **EcoSmart**<sup>®</sup> Switchers using **TinySwitch**<sup>®</sup> and **TinySwitch-II**

# Agenda

- Why *TinySwitch* Technology?
- Choosing *TinySwitch-II* vs *TinySwitch*
- Operation
- Designing with *TinySwitch* Technology
- Application Examples
- Hints and Tips
- Summary
- Questions and Answers

## Why **TinySwitch** Technology

- **Most energy efficient**
  - <10 mW no-load consumption at 230 VAC
- **Very simple low cost circuit**
  - ON/OFF regulation

PRODUCT	CONTINUOUS OUTPUT POWER		CONTINUOUS OUTPUT POWER		SWITCHING FREQUENCY (kHz)	AUTO RESTART	FREQUENCY JITTER	LINE UV DETECTION
	ADAPTER	OPEN FRAME	ADAPTER	OPEN FRAME				
<b>TinySwitch-II</b>	230 VAC ±15%		85-265 VAC					
TNY264 P or G	5.5 W	9 W	4 W	6 W	132	Y	Y	Y
TNY266 P or G	10 W	15 W	6 W	9.5 W	132	Y	Y	Y
TNY267 P or G	13 W	19 W	8 W	12 W	132	Y	Y	Y
TNY268 P or G	16 W	23 W	10 W	15 W	132	Y	Y	Y
<hr/>								
<b>TinySwitch</b>	230 VAC ±15%		85-265 VAC					
TNY253 P or G	4 W		2 W		44			
TNY254 P or G	5 W		4 W		44			
TNY255 P or G	10 W		6.5 W		130			

PI-3238-082902



### Continuous Output Power Rating Terms Defined:

- **ADAPTER** – the power supply is in a non-ventilated, close-quarters enclosure, and is delivering a continuous output power [the rating] while the enclosure is in an ambient environment that is at 50 °C (outside the enclosure)
- **OPEN FRAME** – the power supply has adequate heat sinking on the PI device and is subject to some convective air flow, and is delivering a continuous output power [the rating]
- All power ratings in the above table and on the PI device data sheets are for continuous power delivery (peak power or periodic pulsed power ratings are not given, nor dealt with on this slide). Short-term peak power capabilities will be higher, and will be limited only by the maximum current limit of the device in question
- See the PI datasheets for more details
- The TNY253, TNY254, and TNY255 devices target specific very-low-power applications, and are therefore not rated for open frame designs

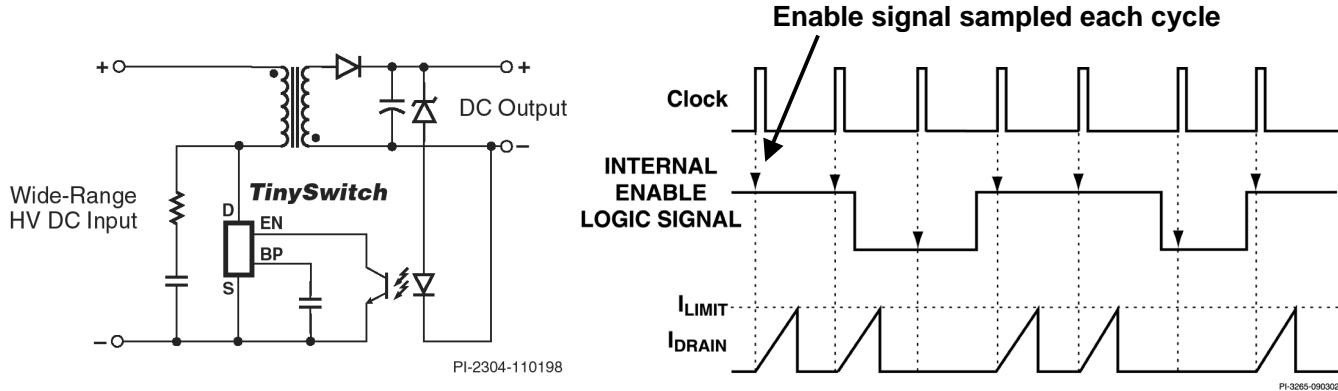
## Choosing **TinySwitch-II** vs **TinySwitch**

- ***TinySwitch-II* is the best choice for most applications**
  - Enhanced features lower system cost
  - Applications up to 23 W (230 VAC), 15 W (85-265 VAC)
  - <30 mW no-load consumption at 230 VAC (with bias winding)
  - <300 mW no-load consumption at 230 VAC (without bias winding)
- ***TinySwitch* is the recommended choice for applications requiring:**
  - <10 mW no-load consumption at 230 VAC (using bias winding)
  - <100 mW no-load consumption at 230 VAC (without bias winding)
  - Low video noise, such as analog TV Standby circuits: the 44 kHz (versus the 132 kHz of *TinySwitch-II*) switching frequency allows the MOSFET Drain node to be heavily snubbed, to suppress EMI noise generation

- The *TinySwitch-II* will still offer superior system cost benefits in TV standby circuits, if heavy Drain-Source snubbing is not necessary to meet EMI noise requirements
- Both *TinySwitch-II* and *TOPSwitch-GX* based circuits can be configured for no-load power consumption of under 100 mW

# Operation

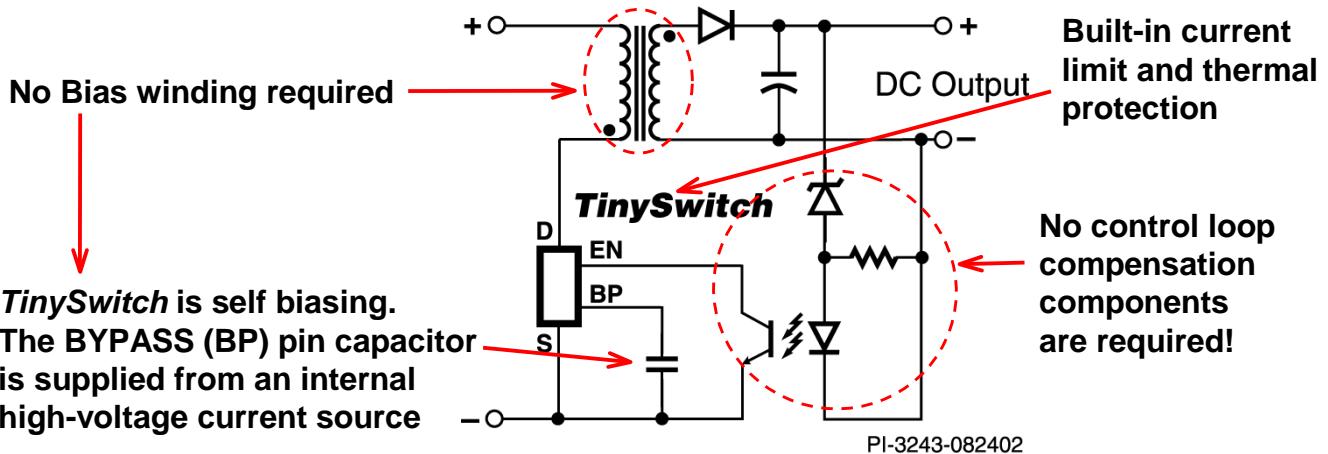
# TinySwitch Regulates by ON/OFF Control



- The MOSFET drain current ramps to a fixed current limit every ON cycle
  - Each ON cycle processes a fixed (maximum) amount of energy
  - Cycles are disabled (OFF cycles) as necessary, to maintain output regulation
  - The effective switching frequency reduces proportionally with load reduction
  - Requires transformer gluing to minimize audible noise at light load conditions
- Maximum energy per cycle ensures lowest no-load frequency/consumption

- The INTERNAL ENABLE LOGIC SIGNAL shown in the above timing diagram is not a signal (nor a voltage) on the IC (package) ENABLE pin
- The ENABLE pin is “current driven,” and is internally fed from a current limited, constant (DC) voltage source. Therefore, the voltage across the collector-emitter of the external opto-coupled transistor—and the current through it—are both virtually constant. This means that the *TinySwitch* responds very quickly to any change in the ENABLE pin current (which renders the supply very responsive to load transients)
- While the value of current being drawn from the ENABLE pin remains below the threshold value (50  $\mu$ A for the *TinySwitch*, and 250  $\mu$ A for the *TinySwitch-II*), the INTERNAL ENABLE LOGIC SIGNAL stays at a logic high. Whenever the current being drawn from the ENABLE pin exceeds the threshold value, the INTERNAL ENABLE LOGIC SIGNAL goes to a logic low
- The INTERNAL ENABLE LOGIC SIGNAL is sampled, before the start of each switching cycle. If it is low, MOSFET switching is disabled (OFF) for that next cycle. If it is high, MOSFET switching is enabled (ON) for that next cycle

## TinySwitch Technology Benefits

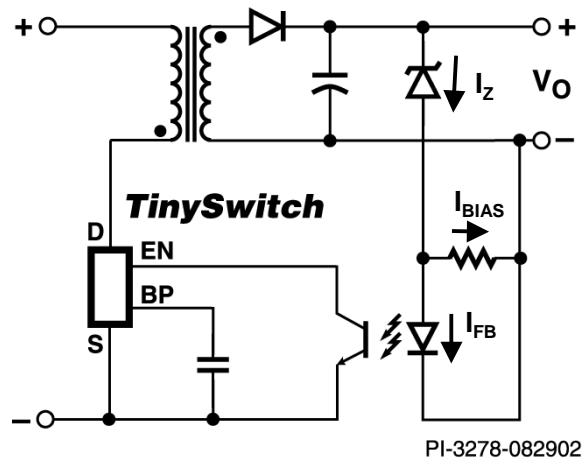
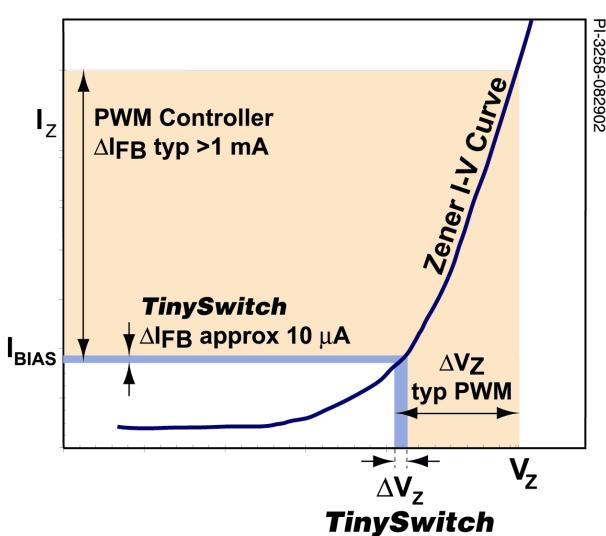


- Can be used in continuous and discontinuous conduction modes
- High bandwidth: excellent transient response, no start-up overshoot
- Using an optional bias winding can further reduce the no-load/standby power consumption
  - <10 mW of no-load power consumption is achievable, even at 265 VAC !

- The output voltage is effectively being sampled each clock cycle. If the output voltage is above the regulation set-point value, switching is disallowed. If the output voltage is below the regulation set-point value, switching is allowed
- This regulation scheme has extremely high bandwidth (half the clock frequency), and therefore requires no control loop compensation
- A low-voltage bias winding on the transformer can be used to supply current into the BYPASS pin, which disables the internal high-voltage current source, further reducing the amount of no-load power the device will consume
- Even without supplemental current from a bias winding, the no-load power consumption of a typical application circuit is usually <100 mW, for a *TinySwitch*, and <300 mW, for a *TinySwitch-II*

## TinySwitch Technology Benefits

- Overall  $\pm 7\%$   $V_o$  tolerance with simple Zener diode feedback (saves cost)
  - The TinySwitch feedback current ( $I_{FB}$ ) is independent of load current
    - The change in Zener voltage ( $\Delta V_z$ ) is almost zero over the range of  $\Delta I_{FB}$
- Typical PWM controllers have  $>1$  mA  $\Delta I_{FB}$  and therefore large  $\Delta V_z$



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- A low-current Zener diode can be used to get optimum regulation, while keeping the Zener bias current low. This will help to minimize the no-load power consumption
- The sample Zener diode I-V curve shown highlights the difference between the TinySwitch technology and conventional PWM operation. For optimum regulation,  $I_{BIAS}$  should be chosen from the Zener diode manufacturer's data sheet
- Less than  $\pm 6\%$  output voltage tolerance may be possible, if a 1% Zener diode is used. This assumes that the operating temperature range will be 0–50 °C, and that the output voltage is about 5 V

## **TinySwitch-II Additional Features/Benefits**

- **Integrated auto-restart fault protection lowers system cost**
  - Output diode needs only be rated to the overload current just prior to auto-restart
  - Open feedback loops and output short circuits are fully protected against
- **Programmable line under-voltage detection prevents turn off glitches**
- **Frequency jittering lowers EMI filter costs**
  - Fully specified, independent of line or load
- **Multi-level current limit practically eliminates audible noise**
  - Standard varnished transformers can be used - no gluing required
- **132 kHz operation reduces transformer size**
- **Tighter current limit/frequency tolerances lower system cost**
- **Increased DRAIN pin creepage, for high pollution environments**
- **Built-in Zener clamp on the BYPASS pin**
  - A simple resistor feed from a low-voltage bias winding enables lower no-load power consumption

- ***TinySwitch does not have a built-in Zener clamp on its BYPASS pin. Therefore, it requires an external Zener clamp diode, when it is fed current from a low-voltage bias winding***
- ***Without auto-restart, the output diode needs to be rated for the full short-circuit current***

# Designing with **TinySwitch** Technology

108

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# Designing with **TinySwitch-II**

- **Design Concept**
  - Choose a transformer inductance value that will deliver full load power, at full frequency and the device current limit
  - Leave margin for tolerances, losses and transient load requirements
- **PI Expert**
  - *PI Expert* automatically calculates all power-train component values, with the above concerns adequately considered



109

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- The design tools mentioned on this slide are specific to *TinySwitch-II*
- *TinySwitch* has separate design tools, that are covered on the next slide
- *PI Expert* provides a full optimization function for *TinySwitch-II* designs. This means that the software fully optimizes the design automatically, without requiring numerous manual reiterations
- Note: within *PI Expert*, efficiency is either a user supplied input value or a software determined estimation. Actual efficiency should always be verified on an early prototype, then that measured efficiency should be entered into *PI Expert*, for the final iterations of the design process
- The names of the parameters *PI Expert* uses are defined in the software's help system

## Designing with ***TinySwitch***

- ***PI Expert*** has a spreadsheet dedicated to ***TinySwitch*** designs
- **Application Note AN-23: ‘*TinySwitch Flyback Design Methodology*’**
  - AN-23 provides a detailed, step-by-step, flowcharted design procedure
- **Application Note AN-24: ‘*Audio Noise Suppression Techniques*’**
  - AN-24 provides techniques for reducing audible noise from Flyback transformers that will be used in an application that may reside in a low-power or standby power mode most of the time
  - Topologies that use single-piece core inductors, such as Buck and Buck-Boost converters, do not require audible noise reduction measures

- The design tools mentioned on this slide are specific to ***TinySwitch***
- The ***TinySwitch-II*** design tools were covered on the previous slide



## ***TinySwitch* and *TinySwitch-II* Application Examples**

**Exceeding**

**Worldwide Energy Efficiency Standards**

# Adapter/Charger Applications with Low No-Load Power Consumption

- **3 W Adapter with:** <300 mW no-load consumption (DI-13)
  - 9 V output, 85-265 VAC input
- **3 W Cell Phone Charger with:** <30 mW no-load consumption (DI-28)
  - 5 V, 600 mA CC output, 85-265 VAC input
- **3 W Adapter with:** <10 mW no-load consumption (DI-27)
  - 12 V output, 85-265 VAC input

DI: Design Idea

112

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- These applications specifically demonstrate the techniques required to meet global no-load consumption standards
- These techniques are not limited to the specific cases presented here
- All of the Design Ideas referred to above, and the newest Design Ideas from Power Integrations are available at [www.powerint.com/appcircuits.htm](http://www.powerint.com/appcircuits.htm)

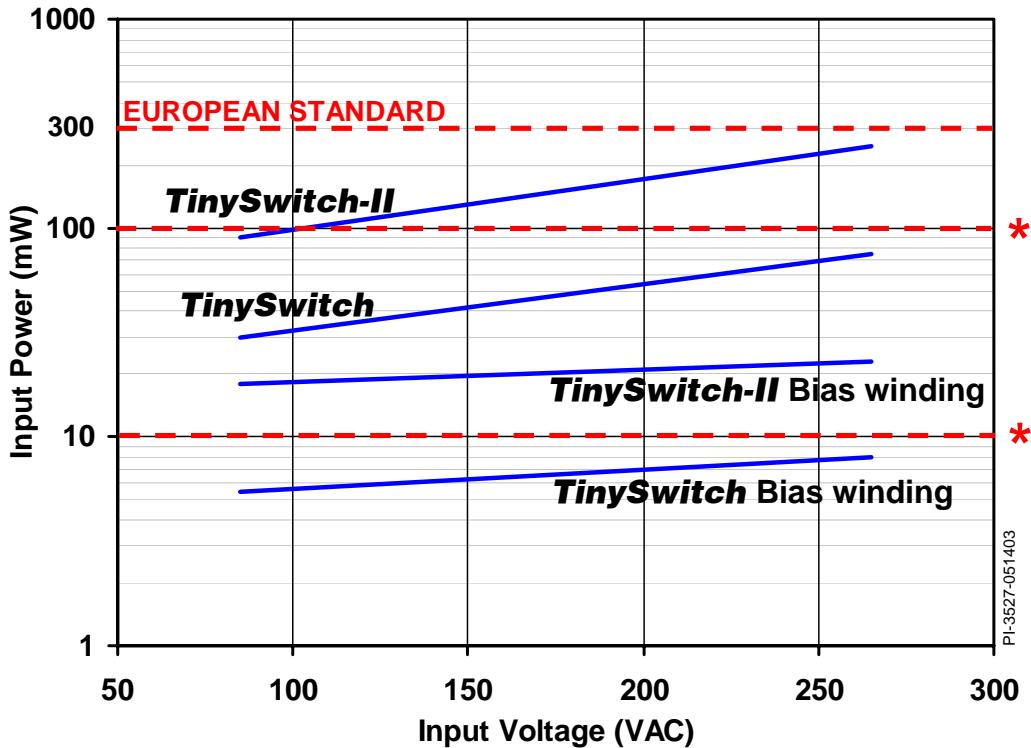
# Applications Requiring High Standby Efficiency

- **10 W Standby Power Supply:**  $P_{OUT} > 600 \text{ mW}$  with  $P_{IN} < 1 \text{ Watt}$ 
  - 5 V, 15 V outputs, 140-375 VDC input
- **15 W Standby Power Supply:**  $P_{OUT} > 600 \text{ mW}$  with  $P_{IN} < 1 \text{ Watt}$ 
  - 5 V, 15 V outputs, 140-375 VDC input
- **1.3 W TV Standby Power Supply:**  $P_{OUT} > 650 \text{ mW}$  with  $P_{IN} < 1 \text{ Watt}$  (DI-7)
  - 7.5 V output, 120-375 VDC input
- **1.2 W Non-Isolated Aux Supply:**  $P_{OUT} > 600 \text{ mW}$  with  $P_{IN} < 1 \text{ Watt}$  (DI-42)
  - 12 V output, 85-265 VAC input
- **11 W Multiple Output DVD Supply:**  $P_{OUT} > 650 \text{ mW}$  with  $P_{IN} < 1 \text{ Watt}$  (DI-33)
  - 3.3 V, 5 V, 12 V, -12 V outputs, 85-265 VAC input

DI: Design Idea

- The  $P_{OUT}$  versus 1 W  $P_{IN}$  data in the above slide is the actual performance of the Design Idea circuits
- These applications specifically demonstrate techniques required to convert power very efficiently, at 1 W of input power and below
- These techniques are not limited to the specific cases presented here
- All of the Design Ideas referred to above, and the newest Design Ideas from Power Integrations are available at [www.powerint.com/appcircuits.htm](http://www.powerint.com/appcircuits.htm)

## Typical No-Load Consumption Curves



- Charger applications with secondary CC circuit add 3 mW to 5 mW
- \* Some OEMs require these limits at 100 VAC

- TinySwitch* technology currently provides solutions that exceed all existing and proposed future global energy efficiency standards
- These solutions use simple techniques that add very little cost to that of standard *TinySwitch* and *TinySwitch-II* designs
- (Charger applications with CV/CC output characteristics normally require additional secondary-side bias current, resulting in slightly higher input power consumption)

## 3 W Adapter: <300 mW No-Load (DI-13)

**Specification Table**

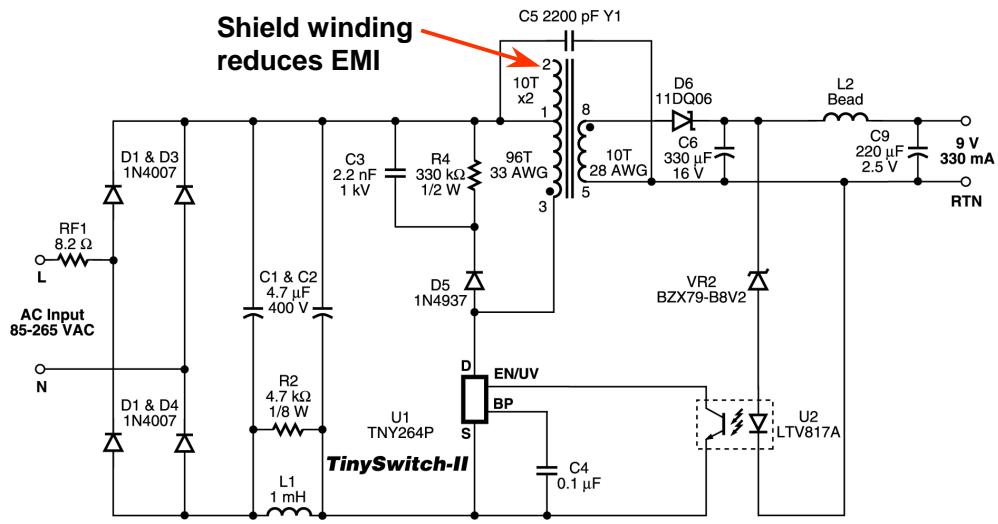
DESCRIPTION	VALUE
Input Voltage	85-265 VAC
Output Voltage	9 V $\pm 7\%$
Output Current	330 mA
Output Power	3 W
Efficiency	>70%
No-load	<300 mW

PI-3248-082702

- Device Choice:**

- Standard *TinySwitch-II* circuit will meet no-load target
- TNY264 is the correct choice based on device power table for adapter applications (enclosed non-ventilated)

## 3 W Adapter: <300 mW No-Load (DI-13)



- No transformer bias winding required**
  - Device powered entirely from DRAIN (D) pin voltage
- Measured no-load consumption: 110/210 mW at 115/230 VAC**
- Measured full load efficiency: 74/72% at 115/230 VAC**

- Addition of Zener bias current improves regulation without exceeding 300 mW**
- (A  $V_{OR}$  of 96 V was used to maximize efficiency)**

# 3 W Cell Phone Charger: <30 mW No-Load (DI-28)

**Specification Table**

DESCRIPTION	VALUE
Input Voltage	85-265 VAC
Output Voltage	5 V $\pm 10\%$
Output Current	600 mA
Output Power	3 W
Efficiency	>60%
No-load	<30 mW
Conducted EMI	CISPR22B EN55022B
50/60 Hz Leakage Current	<5 $\mu$ A

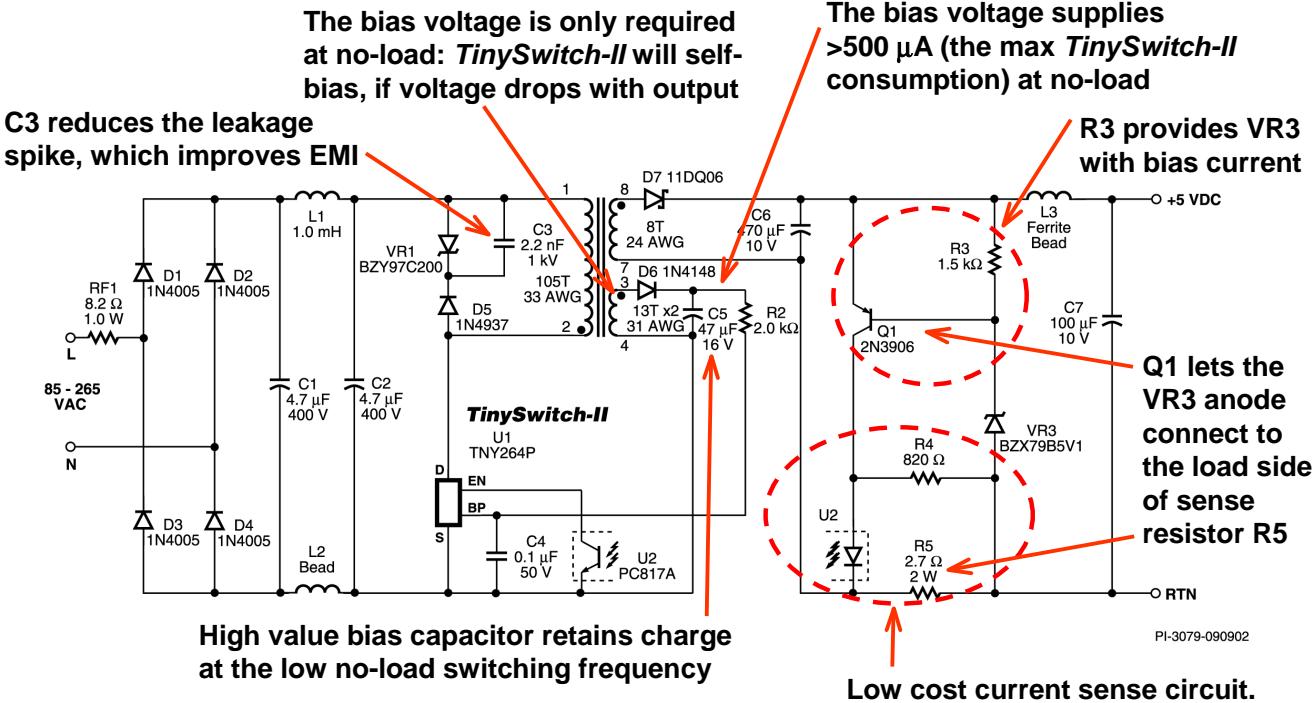
PI-3239-091302

- Device Choice:**

- *TinySwitch-II* with bias winding will meet no-load target
- Secondary CC circuit losses increase effective power delivered by the transformer to approx 4 W
- TNY264 is correct choice based on device power table for adapter applications (enclosed non-ventilated)

- It is important to keep the 50/60 Hz leakage current low in chargers for applications such as cell phones, which may have metallic casings. 50/60 Hz leakage current must be limited to prevent customers from “feeling” the current when touching the unit being charged

# 3 W Cell Phone Charger: <30 mW No-Load (DI-28)



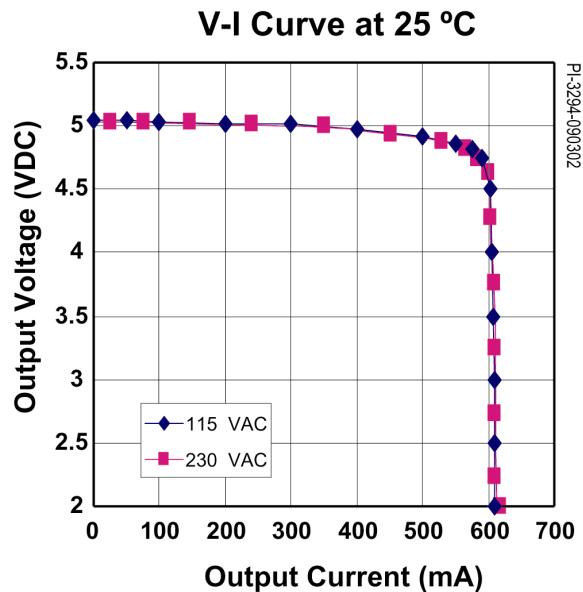
- Meets EMI without a Y capacitor

- The bias winding was designed to work as an electromagnetic shield
- The AC leakage current is very low (<5  $\mu$ A)

- Many CV/CC circuits require a Forward (versus a Flyback) bias winding, to ensure that the bias supply voltage does not collapse if the output voltage drops (when over loaded). However, the *TinySwitch-II* will automatically turn its internal high-voltage current source back on, if the bias winding voltage collapses. Therefore, a simple Flyback winding can be used, since that winding only needs to supply bias current at no-load, to minimize the no-load power consumption
- The built-in Zener clamp on the BYPASS pin of the *TinySwitch-II* eliminates the need for an external Zener diode, as is required in an equivalent *TinySwitch* circuit

# 3 W Cell Phone Charger: <30 mW No-Load (DI-28)

## Measured Output Characteristics



- Measured no-load consumption : 20/25 mW at 115/230 VAC

- Simple secondary CC circuitry provides output current regulation to zero output volts

## 3 W Adapter: <10 mW No-Load (DI-27)

**Specification Table**

DESCRIPTION	VALUE
Input Voltage	85-265 VAC
Output Voltage	12 V $\pm 7\%$
Output Current	250 mA
Output Power	3 W
Efficiency	>70%
No-load	<10 mW

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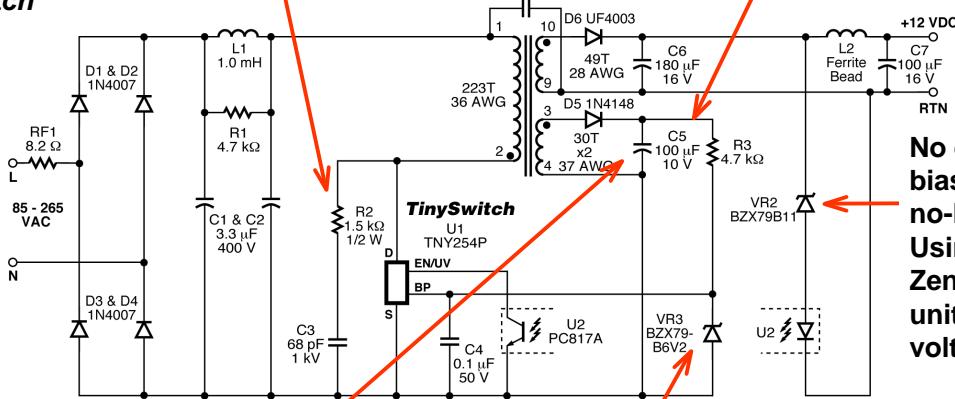
- **Device Choice:**

- Very low no-load target requires *TinySwitch* with bias winding
- TNY254 correct choice based on device power table for adapter applications (enclosed non-ventilated)

## 3 W Adapter: <10 mW No-Load (DI-27)

A simple RC snubber effectively attenuates EMI. The no-load target is still achieved due to the very low no-load switching frequency of the *TinySwitch*

The bias circuit supplies >200  $\mu$ A (the max *TinySwitch* consumption), at no-load



No extra Zener diode bias current keeps no-load power down. Using a low current Zener minimizes the unit-to-unit output voltage variance

High value bias capacitor retains charge at the low no-load switching frequency

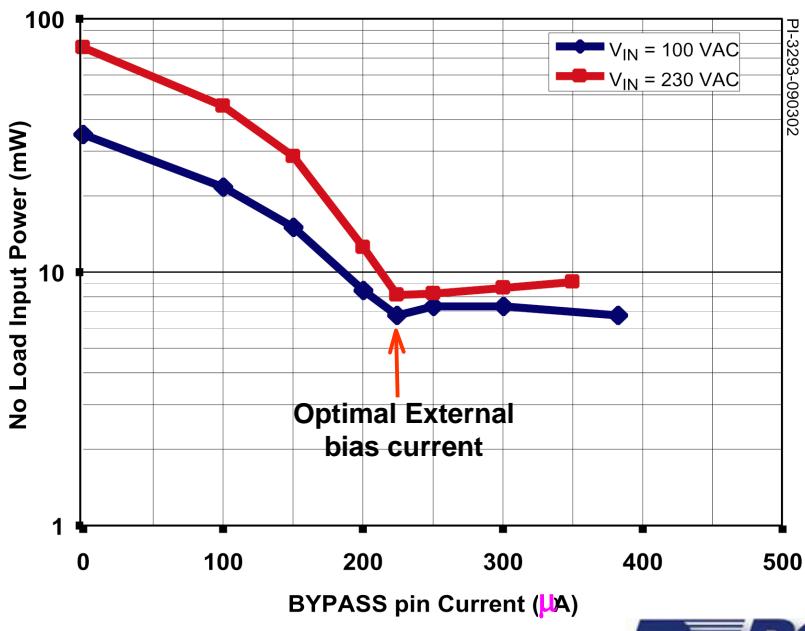
An external Zener clamp is required to protect the *TinySwitch* BYPASS (BP) pin  
PI-3011-091802

- Meets <10 mW no-load, with only 24 components!!
- Measured no-load consumption: 6/8 mW at 115/230 VAC

- Transformer wire gauges were selected to completely fill each winding layer, and the bias winding was used as an electromagnetic shield, to minimize EMI and to eliminate the need for a Y capacitor
- Unlike the *TinySwitch-II*, the *TinySwitch* requires an external Zener diode clamp on the BYPASS pin, whenever an external bias current is fed into the BYPASS pin
- Setting  $V_{OR}$  to 60 V limits the output short circuit current to 1 A

## 3 W Adapter: <10 mW No-Load (DI-27)

- **Influence of the external BYPASS current value on no-load consumption**
  - The bias winding voltage, and the values of C5 and R3 should be calculated to ensure that at no-load, the current into the BYPASS pin is  $>225 \mu\text{A}$ , but  $<250 \mu\text{A}$ , to minimize the no-load power consumption



122

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- Insufficient external bias current ( $<200 \mu\text{A}$ ) significantly increases the no-load power consumption, since the internal high-voltage current source must provide the rest of the supply current
- Excessive external bias current ( $>250 \mu\text{A}$ ) may increase the no-load consumption, as the dissipation of the Zener clamp diode (VR3 in this circuit) increases
- In circuits that are designed around a *TinySwitch-II*, the optimum external bias current is higher (typically  $>500 \mu\text{A}$ ), since the internal power consumption of the device is slightly higher

# 10 W Standby Power Supply

**Specification Table**

DESCRIPTION	VALUE
Input Voltage	140-375 VDC
Output Voltage	
V1	5 V $\pm 5\%$
V2	15 V +6/-20% Primary
Output Current	
I1	2 A
I2	50 mA
Output Power	10 W
P <sub>OUT</sub> at P <sub>IN</sub> = 1 W	>600 mW

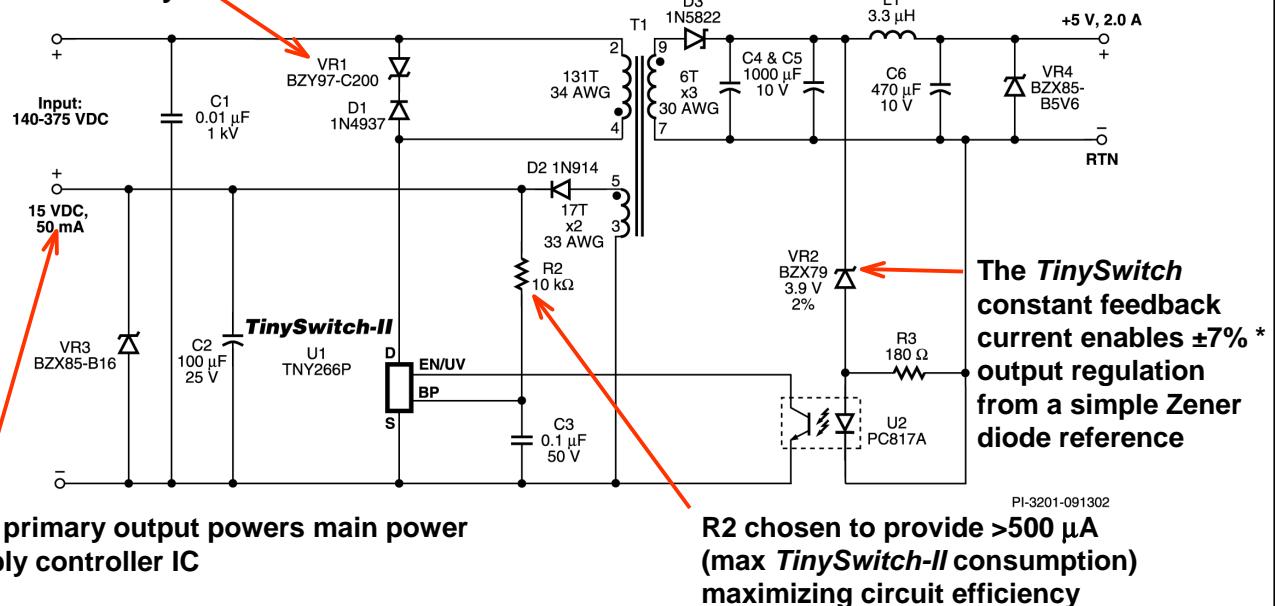
PI-3241-091302

- Device Choice:**

- TNY266 correct choice for a wide input range, open frame power supply

# 10 W Standby Power Supply

Zener clamp reduces losses over RC snubber or RCD clamp to maximize circuit efficiency



- Measured Performance:  $>600 \text{ mW}$  output with  $< 1 \text{ W}$  input power
- Easily meets President Bush's 1 Watt Executive Order

• The  $V_{OR}$  was set to 130 V, to maximize the power capability of the **TinySwitch-II**

• \*  $\leq \pm 5\%$  output voltage tolerance can be obtained by using a TL431 reference in place of the Zener diode

# 15 W Standby Power Supply

## Specification Table

DESCRIPTION	VALUE
Input Voltage	140-375 VDC
Output Voltage	
V1	5 V $\pm 5\%$
V2	15 V +6/-20% primary
Output Current	
I1	3 A
I2	50 mA
Output Power	15 W
P <sub>OUT</sub> at P <sub>IN</sub> = 1 W	>600 mW

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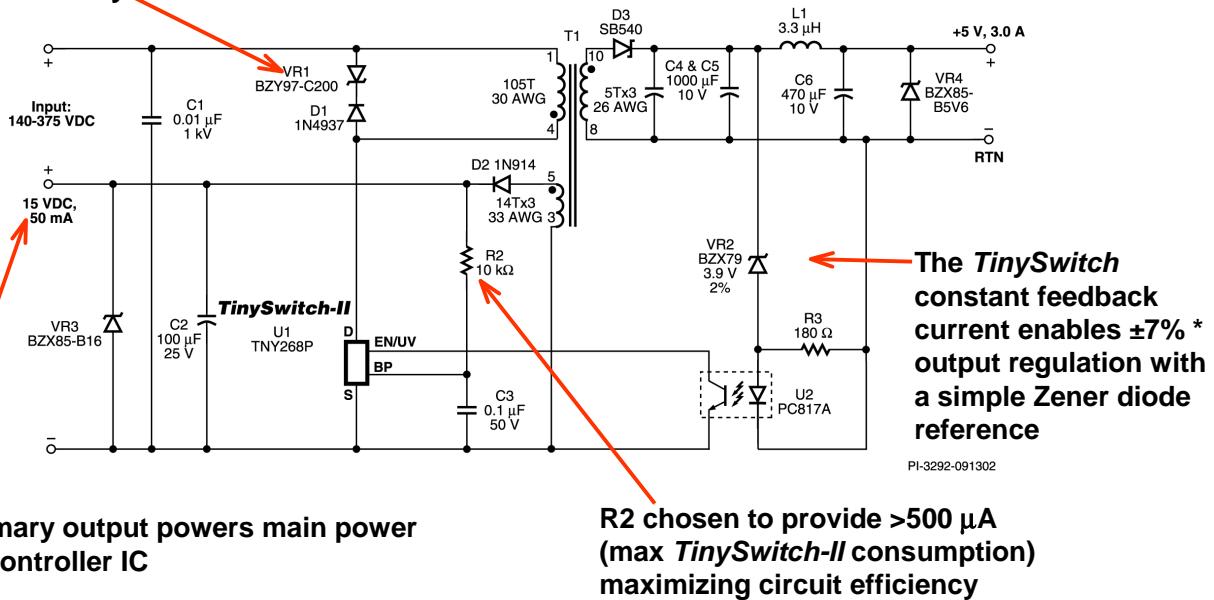
- **Device Choice:**

- TNY268 correct choice for a wide input range, open frame power supply



# 15 W Standby Power Supply

Zener clamp reduces losses over RC snubber or RCD clamp to maximize circuit efficiency



- Measured Performance:  $>600 \text{ mW}$  output with  $< 1 \text{ W}$  input power
  - Easily meets President Bush's 1 Watt Executive Order
- The  $V_{OR}$  was set to 125 V, to maximize the power capability of the TinySwitch-II
  - \*  $\leq \pm 5\%$  output voltage tolerance can be obtained by using a TL431 reference instead of the Zener diode

# 1.3 W TV Standby Supply (DI-7)

Specification Table

DESCRIPTION	VALUE
Input Voltage	120-375 VDC
Output Voltage	7.5 V $\pm$ 5%
Output Current	173 mA
Output Power	1.3 W
Efficiency	>70%
No-load	<100 mW
P <sub>OUT</sub> at P <sub>IN</sub> = 1 W	>600 mW

PI-3245-091302

- **Device Choice:**

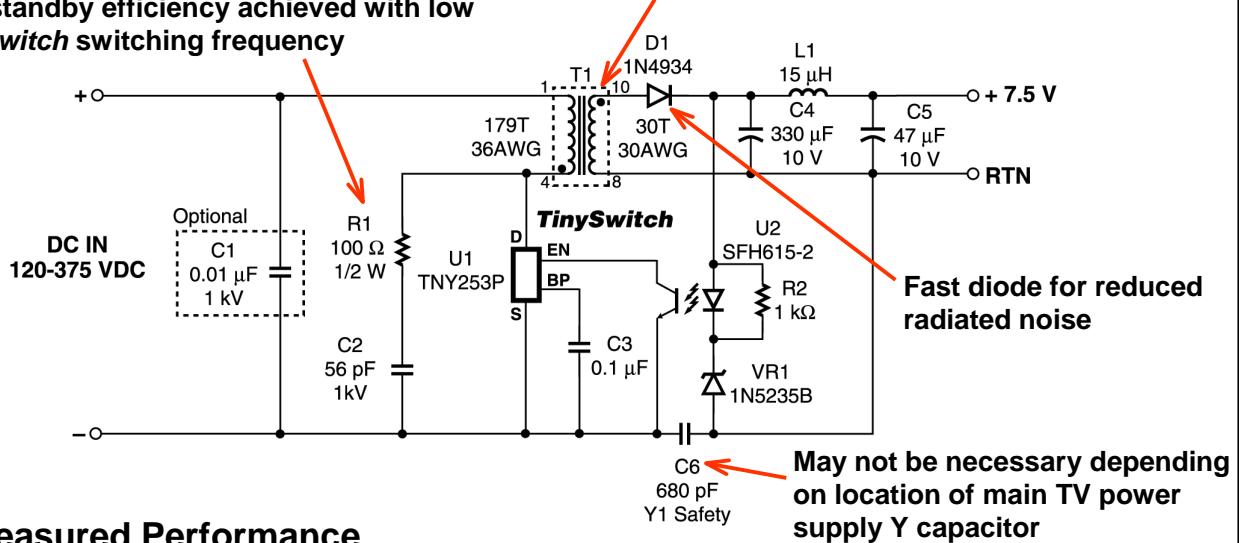
- *TinySwitch* allows RC Drain snubbing to reduce video noise.
- TNY253 correct choice for power level

- *TinySwitch-II* could also be used if lowest video noise is not a requirement - e.g. in digital TVs.

# 1.3 W TV Standby Supply (DI-7)

Simple RC snubber reduces video noise.  
Targets for low no-load consumption and  
high standby efficiency achieved with low  
**TinySwitch** switching frequency

No transformer bias winding: still achieves  
<100 mW no-load, 70% standby efficiency



- **Measured Performance**
  - <100 mW no-load consumption at 375 VDC
  - >650 mW output power with <1 W input power
- **Complete standby supply with as few as 13 components!!**



- (A  $V_{OR}$  of 50 V was used to limit output short circuit current <1 A)

# 1.2 W Non-Isolated Aux Power Supply (DI-42)

## Specification Table

DESCRIPTION	VALUE
Input Voltage	85-265 VAC
Output Voltage	12 V $\pm 7\%$
Output Current	100 mA
Output Power	1.2 W
Efficiency	>60%
$P_{OUT}$ at $P_{IN} = 1$ W	>600 mW
Surge Rating	2 kV IEC1000-4-5

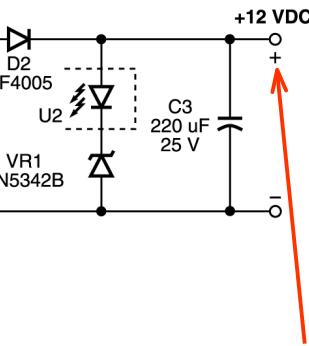
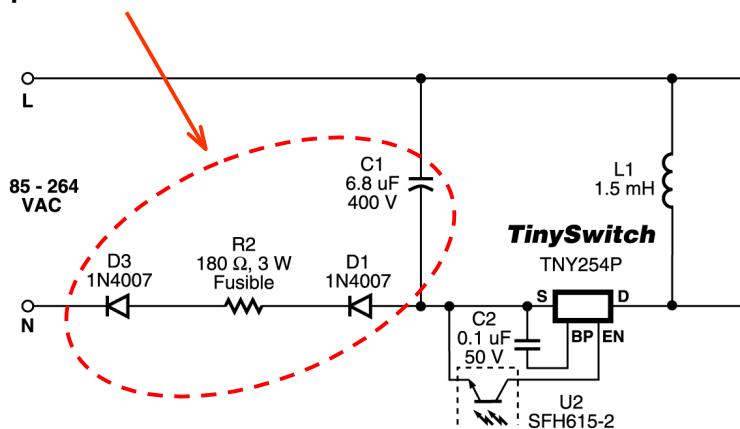
PI-3246-091302

- **Device Choice:**

- Single piece core inductor allows use of *TinySwitch* without audible noise considerations
- TNY254 chosen (See DI-42 Buck-Boost converter)

# 1.2 W Non-Isolated Aux Power Supply: (DI-42)

Simple input stage  
meets 2 kV IEC1000-4-5  
surge requirements



Output reference to Line.  
Typically required for Triacs  
and associated control  
circuitry in appliance and  
industrial motor drives

PI-3280-090502

- **Measured Performance**
  - >650 mW output power with <1 W input power
- **Complete auxiliary supply with as few as 11 components !!**

- L1 should be rated for more than the TNY254 current limit (300 mA is a good choice)
- Two diodes (1N4007s, with PIV ratings of 1000 V) are required, to meet a 2 kV surge voltage withstand rating
- A simple modification to the input circuitry can provide 6 kV of surge voltage withstand rating ( see DI-42, for a description of that circuit modification)
- This circuit is available for evaluation as a Design Accelerator Kit (DAK- 7)
- Many other non-isolated configurations can be designed with the *TinySwitch*, the *TinySwitch-II* or the new *LinkSwitch-TN* (Example: DI-11 Buck converter). The latest new application circuits are available, at [www.powerint.com/appcircuits.htm](http://www.powerint.com/appcircuits.htm)

# 11 W DVD Supply: <50 mW No-Load (DI-33)

**Specification Table**

DESCRIPTION	VALUE
Input Voltage	85-265 VAC
Output V1 V2 V3 V4	3.3 V $\pm 5\%$ 5 V $\pm 5\%$ 12 V $\pm 10\%$ -12 V $\pm 10\%$
Output I1 I2 I3 I4	300-700 mA 300-1600 mA 400 mA 100 mA
Output Power	11 W Cont 17 W Peak
Efficiency	>75%
No-Load	<100 mW
P <sub>OUT</sub> at P <sub>IN</sub> = 1 W	>600 mW

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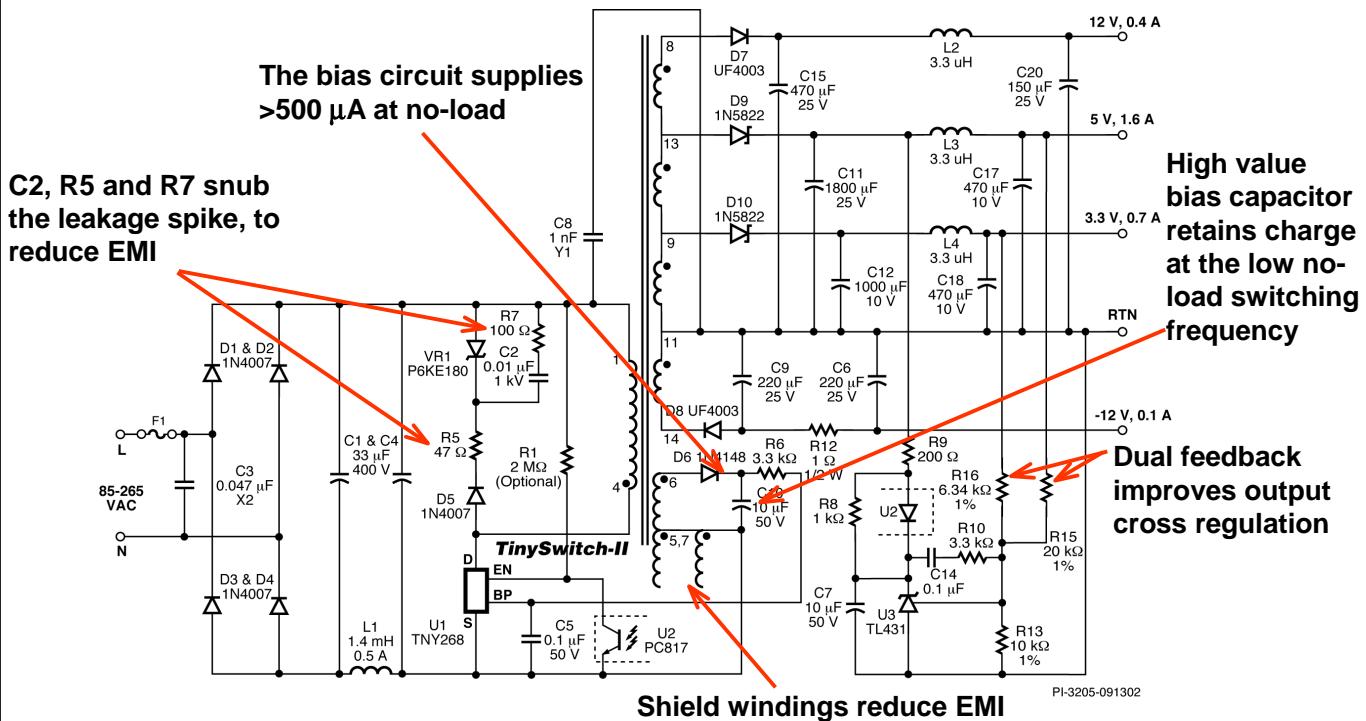
- **Device choice:**

- *TinySwitch-II* with bias winding will meet no-load target
- TNY268 is correct choice for peak power capability

- **Alternative Device choice:**

- At this power level, also consider *TOPSwitch-GX* for additional features
- For higher power levels use *TOPSwitch-GX* (DI-39)

# 11 W DVD Supply: <50 mW No-Load (DI-33)



- **Measured Performance:**

- no-load: 30/41 mW at 115/230 VAC, minimum full load efficiency: 77%
- >650 mW of output power at 1 W of input power

- The standby power consumption was measured at 115 VAC and 230 VAC, with equal loading on both the 3.3 V and 5 V outputs. The other outputs were at zero load
- The transformer shield windings significantly reduce the amount of EMI generated, allowing a simple pi filter (C1, C4 and L1) to adequately attenuate the conducted EMI
- Simple transformer construction (without shield windings) can be used together with a common mode (input) choke. Choices should be made, based on the relative cost of implementing these two options
- The  $V_{OR}$  was set to 120 V in this design. This value allows the power capability of the *TinySwitch-II* to meet the maximum output power requirement while maintaining good cross regulation between the two main outputs and the other two outputs
- The optional line under-voltage lockout function of the *TinySwitch-II* can be activated by simply connecting a resistor between the rectified DC input rail and the EN/UV pin. A 2 MΩ resistor sets a low under-voltage lockout threshold (UVLO) at 100 VDC. This prevents the power down process from producing any glitches on the outputs, as the supply shuts off. The line under-voltage function increases the no-load consumption by approx 50 mW at 230 VAC. However, the circuit can still meet a 100 mW no-load power consumption target

# 11 W DVD Supply: Cross Regulation (DI-33)

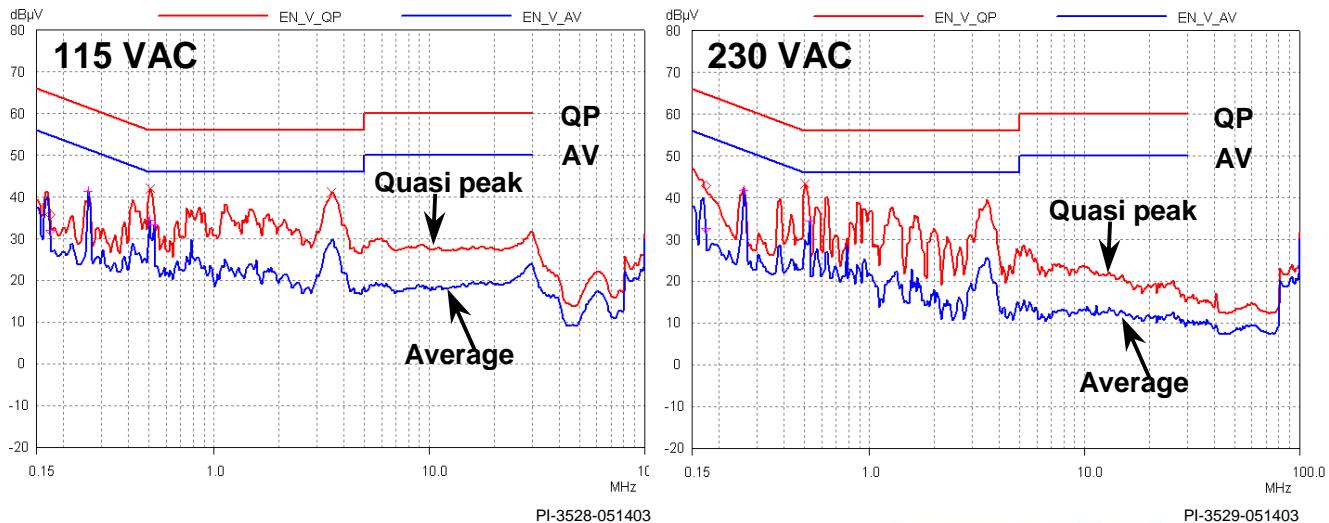
OUTPUT VOLTAGE	VOLTAGE RANGE (VAC)	LOAD RANGE	REGULATION (%)												
			-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
+3.3 V	85-265	40-100%													
+5 V	85-265	20-100%													
+12 V	85-265	100%													
-12 V	85-265	100%													

PI-3255-082702

This table summarizes the worst-case variations of each output voltage. The measurements were recorded across the full input line voltage range, and over the specified load range of each output

# 11 W DVD Supply: Conducted EMI (DI-33)

- **Test Conditions**
  - 11 W output
  - Output grounded through artificial hand (EMI reduced further with floating output)
- **> 10 dB margin (AV and QP) at all frequencies**



134

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- Meets international standards without requiring a common mode choke

## Hints and Tips

# Optimizing Efficiency & No-Load Performance

- **Using Transformer Bias Winding (most significant)**
  - Designed to supply max device current under specified conditions e.g. no-load
  - Use large enough bias capacitor to retain charge at standby or no-load frequency
  - Other load conditions non-critical - devices will self bias if external supply is lost
  - 230 VAC power dissipation reduced by up to 65/160 mW *TinySwitch/TinySwitch-II*
- **Other Transformer Considerations**
  - Reduce capacitance - tape between primary layers
  - Design with low  $V_{OR}$  - reduces clamp losses
  - Reduce leakage inductance - reduces clamp losses

# Optimizing Efficiency & No-Load Performance

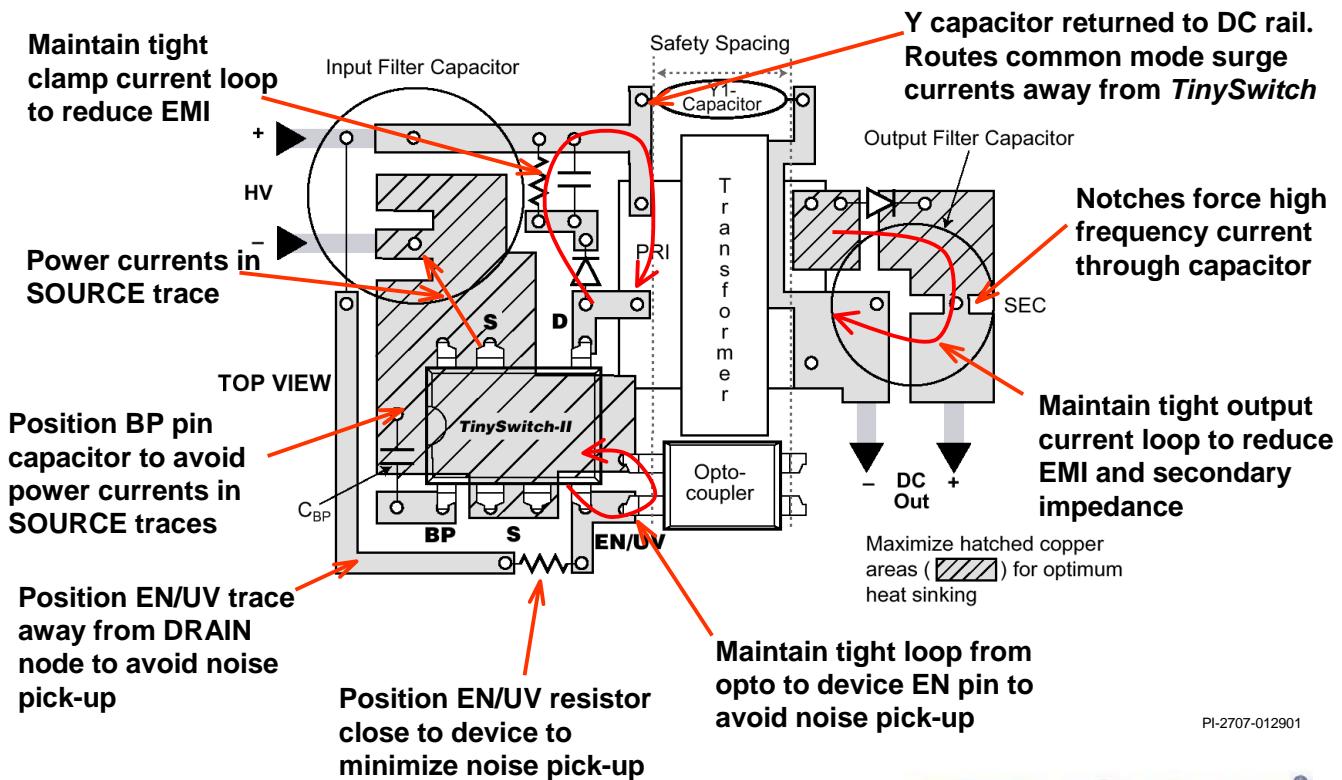
- **Minimize Bias Currents in Secondary Circuits**
  - CV only circuits (adapters/standby), Zeners should be left unbiased if regulation is acceptable - best performance with low current Zeners
  - CV/CC designs (chargers) bias currents should be minimized
- **Choice of primary clamp circuits**
  - Zener clamp for lowest dissipation - dissipates power only during leakage spike
  - RCD clamps often provide acceptable performance with resistor value  $>200\text{ k}\Omega$
  - RC snubber typically used only with *TinySwitch* - switching frequency low at full load and very low at no-load

## Other Hints and Tips

- **Minimizing audible noise in *TinySwitch* designs**
  - Design the transformer for low flux density, <2000 gauss (200 mT), at full load
  - Glue the transformer core halves together, according to the guidelines in AN-24
  - Only dip-varnishing the transformer does not usually produce acceptable results
  - Dip-varnishing the transformer (in addition to gluing) is not necessary
  - Use low-cost Film capacitors in the clamp circuit, as Ceramic capacitors can generate audible noise
- ***TinySwitch-II* practically eliminates audible noise generation**
  - A standard dip-varnished transformer works fine, no gluing is required!
  - Gluing the transformer core halves together (if preferred) also works well

- Varnishing tends to increase transformer capacitance, which results in higher switching losses. This will influence full load efficiency but have only a small effect on standby/no-load consumption, due to the low switching frequency at light loads

# PCB Layout Guidelines



PI-2707-012901



## Summary

- ***TinySwitch and TinySwitch-II based power supplies exceed the requirements of all existing and proposed energy efficiency standards***
- ***TinySwitch-II is the best choice for most applications***
  - Enhanced features lower system cost
  - Applications up to 23 W (230 VAC), 15 W (85-265 VAC)
  - <30 mW no-load consumption at 230 VAC (with bias winding)
  - <300 mW no-load consumption at 230 VAC (without bias winding)
- ***TinySwitch is a better choice for applications requiring:***
  - <10 mW no-load consumption at 230 VAC (using bias winding)
  - <100 mW no-load consumption at 230 VAC (without bias winding)
  - Video noise sensitive applications if RC snubbers are required
- ***TinySwitch Technology provides simple, cost effective, and energy efficient replacements for RCC & Linear solutions in the 2-20 W range***



141

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