

# Primary Side Regulation in Flyback Converters Delivers Low Cost, High Reliability and Energy Efficiency

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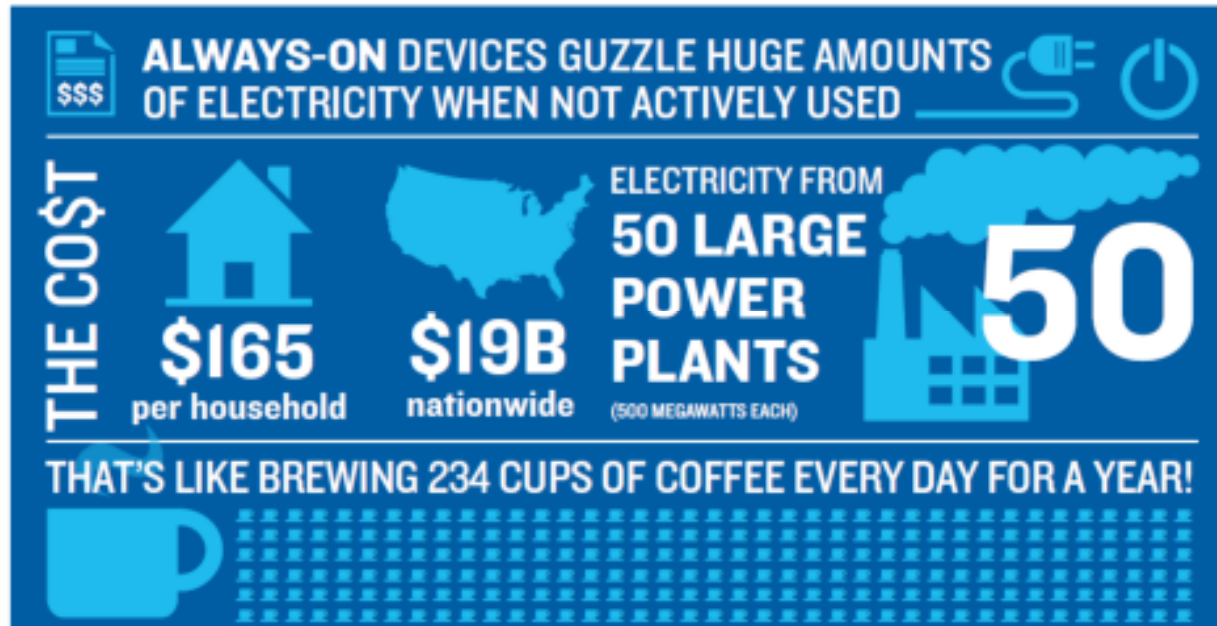
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# Outline

- Background
- Primary side regulation Flyback basics
- Improve PSR performance in CCM Flyback
- PSR with minimum standby power without sacrificing transient
- Summary

# Standby/Vampire/Idle Power Impact



**2. SET-TOP BOX**

WATTS (low to high): 4-30  
 COST (low to high): \$4-30

LOCATION: Living room, bedroom, family room

TYPICAL # DEVICES PER HOME: 2

SOLUTIONS NOW: Unplug seldom-used

SOLUTIONS NEEDED: Manufacturer improvements, Standards, Utility EE incentive programs

**5. AUDIO RECEIVER/STEREO**

WATTS (low to high): <1-22  
 COST (low to high): <\$1-22

LOCATION: Living room, family room

TYPICAL # DEVICES PER HOME: 2

SOLUTIONS NOW: Adjust Settings, Smart strip/smart outlets, Unplug

SOLUTIONS NEEDED: Manufacturer improvements, Stronger standards, Utility EE incentive programs

**8. COFFEE MAKER**

WATTS (low to high): <1-6  
 COST (low to high): <\$1-6

LOCATION: Kitchen

TYPICAL # DEVICES PER HOME: 1

SOLUTIONS NOW: Timer, Settings

SOLUTIONS NEEDED: Standards

**10. GFCI OUTLETS**

WATTS (low to high): 1-1  
 COST (low to high): \$1-1

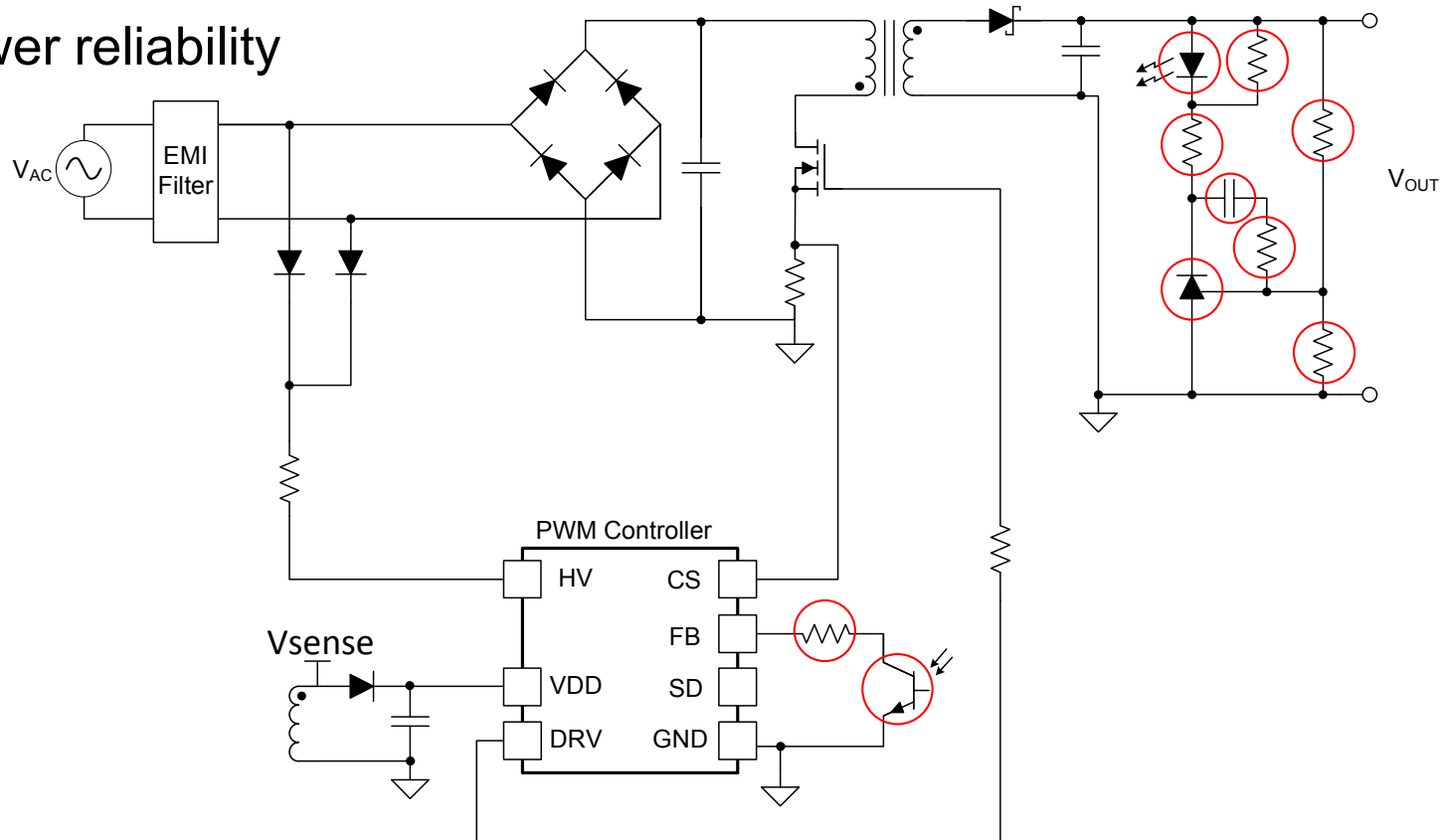
LOCATION: Bathroom (2), kitchen (2), garage (1), outdoor (1)

TYPICAL # DEVICES PER HOME: 6

SOLUTIONS NEEDED: Manufacturer change, Standards, Building codes

# Traditional Opto-Coupler Feedback Flyback

- Traditionally isolated flyback power supplies use opto-couplers to feed regulation information across the isolation barrier
- Higher component count and higher cost
- Lower reliability



# Eliminating Opto-Coupler

- Higher Reliability



- No Opto-coupler

- The aging characteristic of the opto coupler in particular reduces the reliability of the design.

- The opto-coupler CTR reduces over time which reduces the gain of the feedback loop.

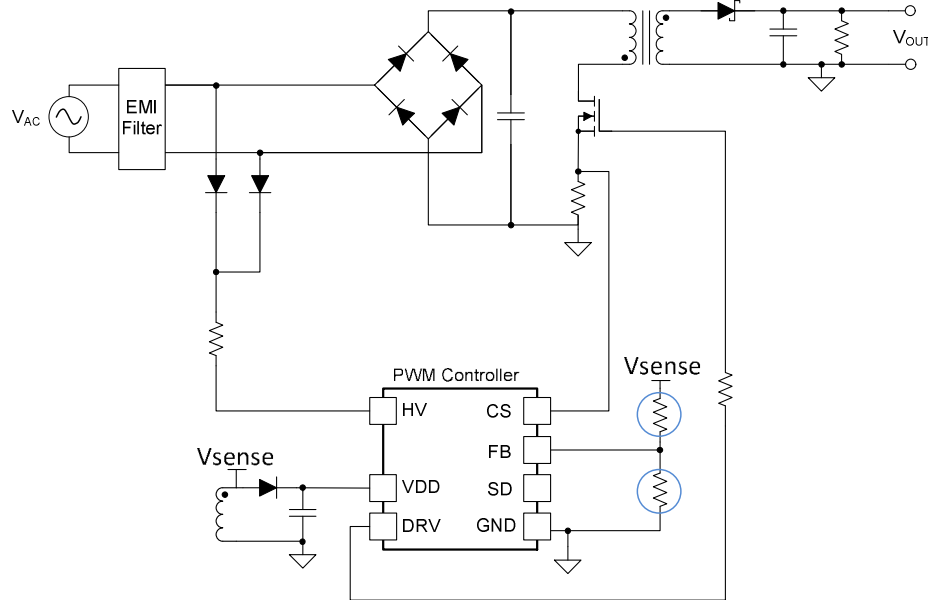
- The loop has to be overdesigned to account for this affect

- Fewer components increases the MTBF of the design.

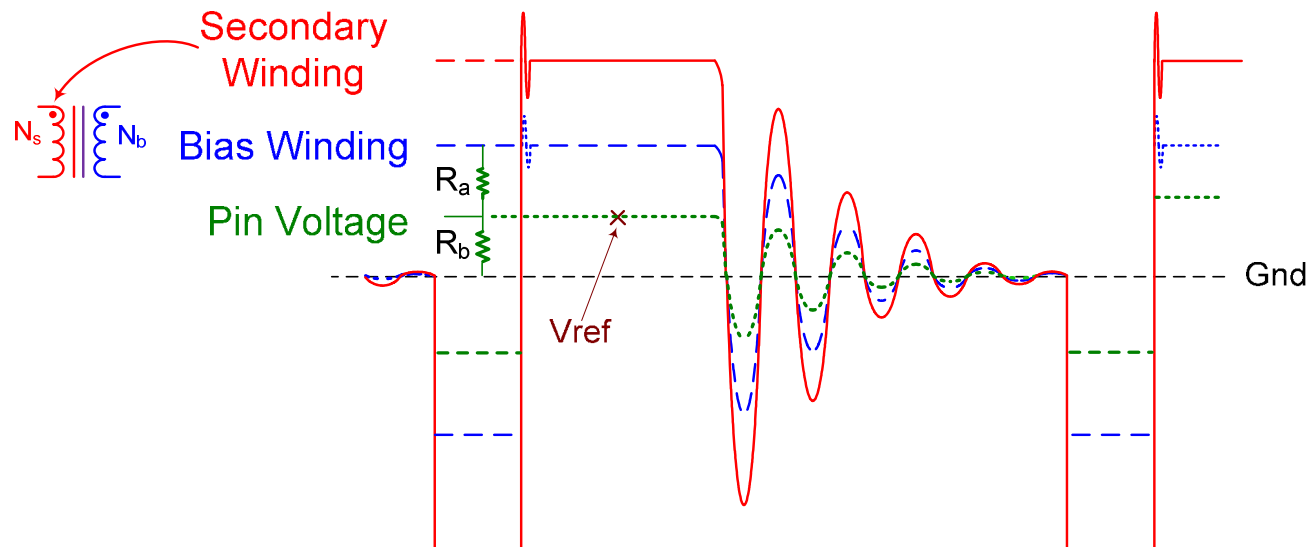
- Better Isolation

- For applications with high surge or isolation voltage requirements, reducing the number of components crossing the isolation barrier reduces the number of areas of potential breakdown.

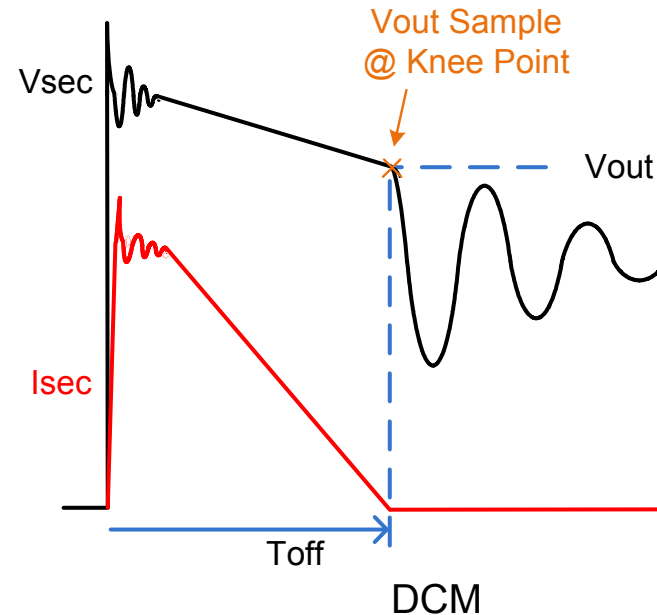
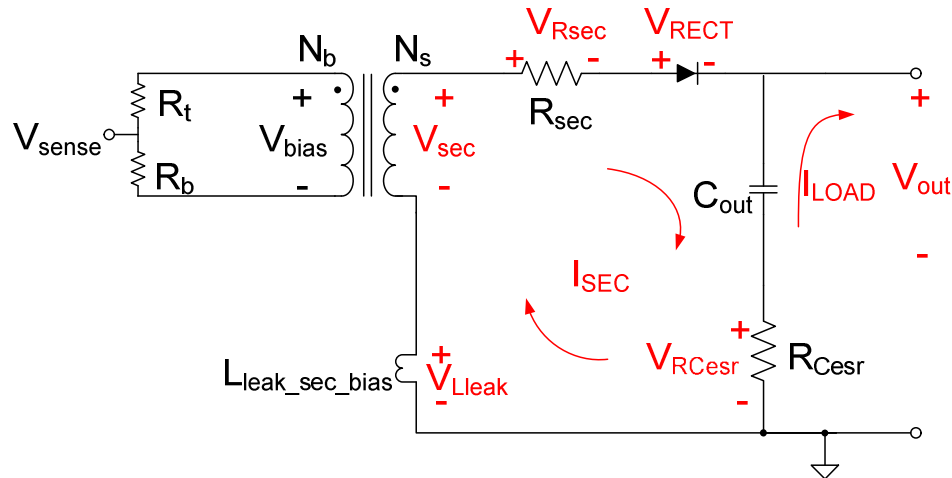
# PSR Flyback Background



- Most flybacks derive their own bias supply from a bias winding which is in phase with the secondary winding
- Bias winding voltage is a scaled replica of the secondary winding voltage and can be sensed via a resistive divider to regulate  $V_{out}$



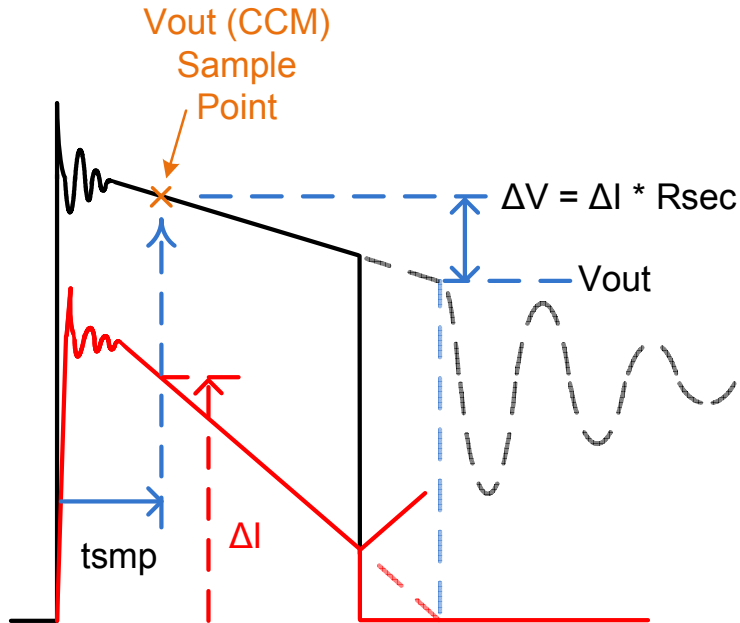
# Output Voltage Sampling in DCM Flyback



$$V_{sense} = \left[ \frac{R_b}{R_t + R_b} \right] \cdot \left[ \frac{N_b}{N_s} \right] \cdot [V_{out} + V_{rect} + V_{Rsec} - V_{Lleak} + V_{RCesr}]$$

- The bias winding voltage is proportional to the output voltage, with some errors
- In DCM condition, the output voltage can be sensed at the knee point and minimize the introduced error
- This sensing method can only be implemented in Boundary Mode or DCM Flybacks.
- For high power designs it is often desirable to operate in CCM

# Output Voltage Sampling in CCM Flyback



The resistors are the major source of sensing error

$$V_{sense} = \left[ \frac{R_b}{R_t + R_b} \right] \cdot \left[ \frac{N_b}{N_s} \right] \cdot [V_{out} + I_{sec} \cdot [R_{sec} + R_{Cesr}]]$$

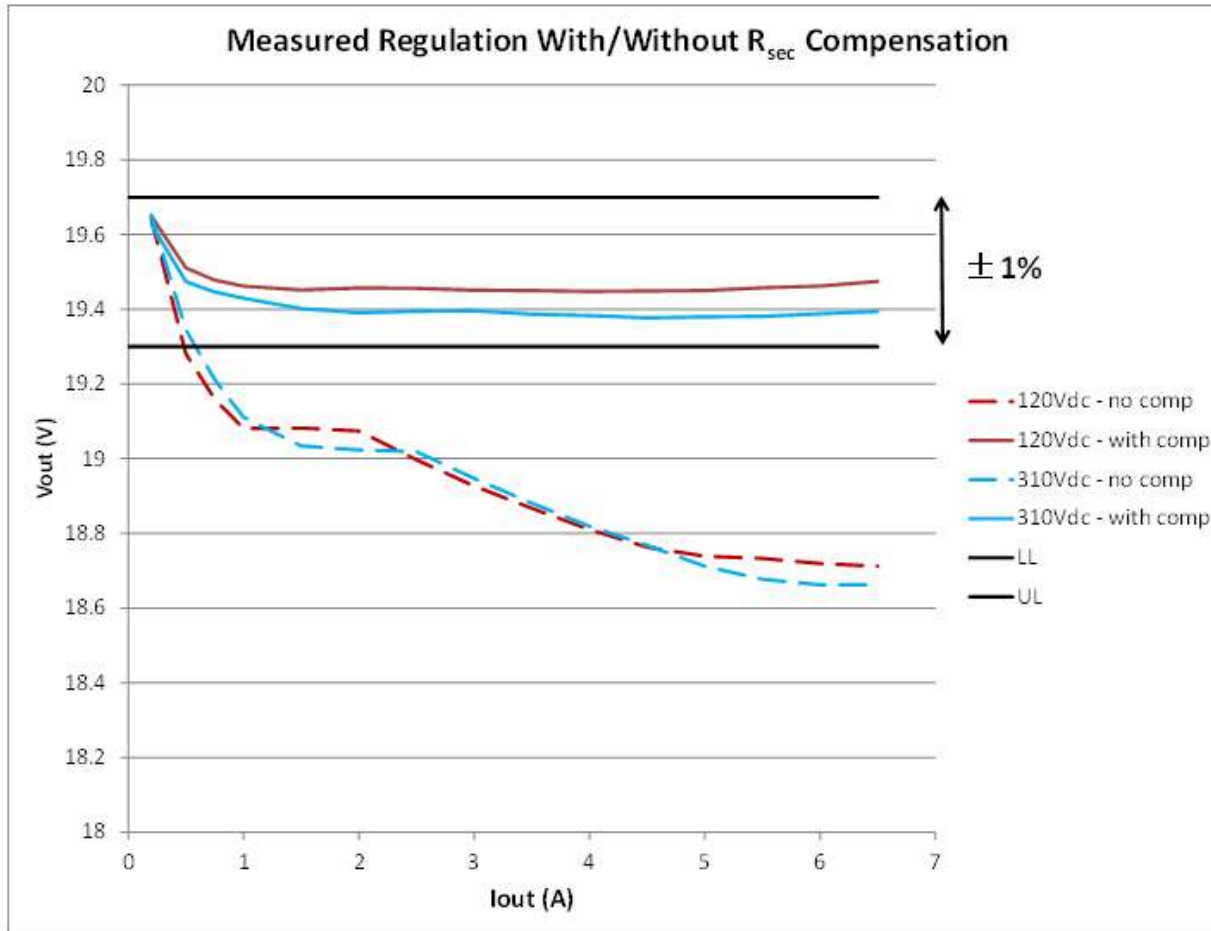
With fixed sampling delay

$$I_{smp} = \left( \frac{V_{cspk}}{R_{cs}} \cdot \left[ \frac{N_p}{N_s} \right] - \left[ \frac{(V_o + V_{rect}) \cdot t_{smp}}{L_{sec}} \right] \right)$$

- For CCM operation the voltage must be sampled during the Off-time, typically a fixed time after turn off (of the Primary FET)
- The error is dominated by the resistive drop
- the current sense demand voltage allows the controller to predict the error in  $V_{sense}$  and used to improve the regulation accuracy



# Output Voltage Regulation for CCM PSR

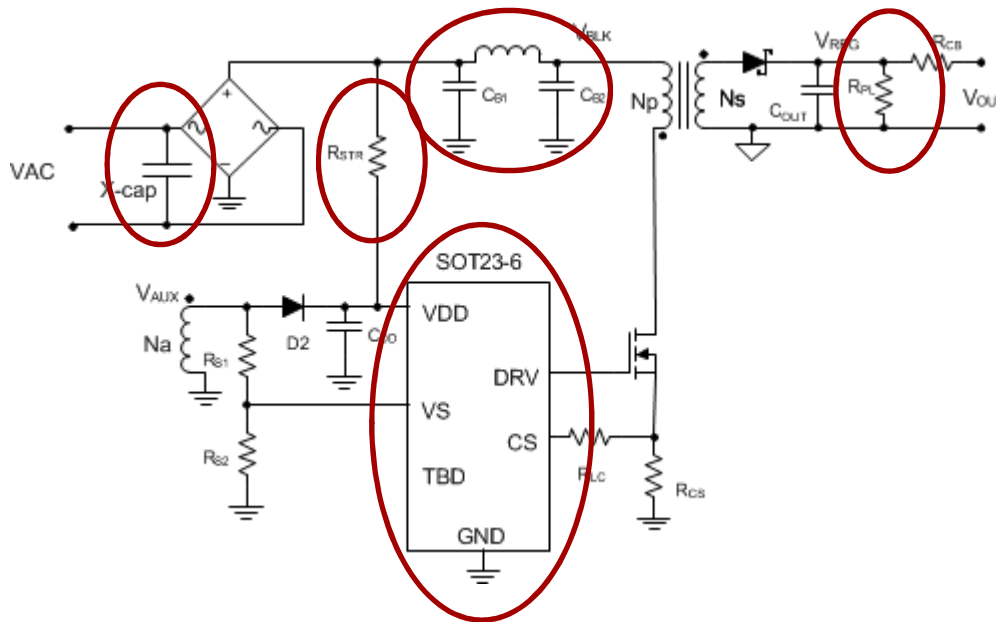


<b>Lpri</b>	260 $\mu$ H	<b>MOSFET</b>	STF13NM60ND
<b>Rcs</b>	200 m $\Omega$	<b>Diode</b>	NTST30100CTG
<b>Np</b>	34	<b>Cbulk</b>	127 $\mu$ F
<b>Ns</b>	6	<b>Cout</b>	1,360 $\mu$ F
<b>Nb</b>	4	<b>Cbias</b>	22 $\mu$ F
<b>Transformer</b>	RM10/I	<b>Rsec</b>	60 m $\Omega$

Measured regulation performance of a 19V, 65 W nominal power stage, operating up to 120 W load, with input bulk capacitor voltage of 120 Vdc and 310 Vdc. Load current was varied from 0 A to 6 A.

The voltage regulation accuracy can be significantly improved by using the error compensation

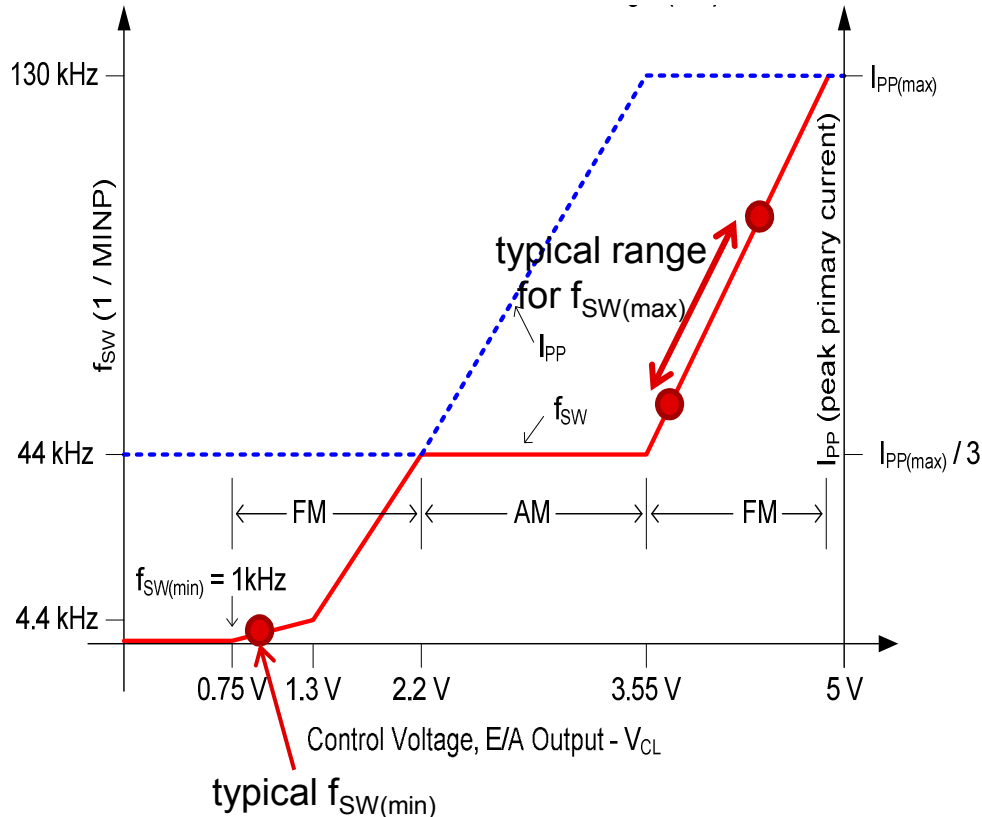
# Standby Power Consumption in Flyback



- Opto coupler consumes most of power during standby mode
- PSR eliminates the feedback components loss but there are plenty of other losses to be considered
- Pre-load is required for PSR Flyback and needs to be minimized

X-cap	IC bias power	Start-up resistor loss	Bulk-cap leakage	Pre-load loss
~5 mW / 330 nF	10~20 mW	10~20 mW	~0.5 mW	1~10 mW

# Typical Control Law for DCM Flyback Controller



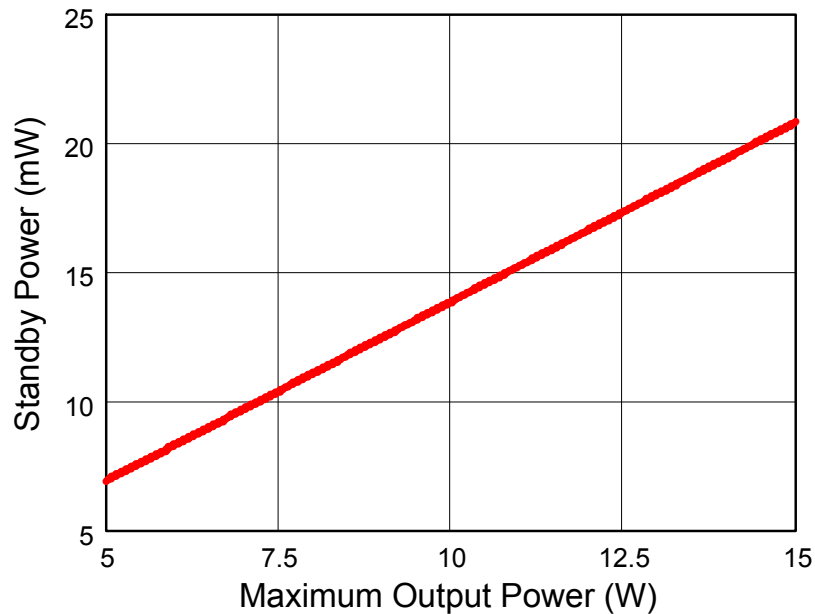
- Frequency modulation
  - Fixed peak current
  - Power is adjusted by switching frequency
- Amplitude modulation
  - Fixed switching frequency
  - Power is adjusted by peak current

- The switching frequency can't be zero since PSR needs the switching to sense the output voltage
- At light load, it is desired to minimize the switching frequency for minimum loss associated with the switching frequency

# Switching Frequency Considerations

- DCM-flyback  $f_{SW}$  follows device Control Law, so  $P_{MAX}$  should predict  $P_{STBY}$
- First-order approximation using  $P_{IN} \approx \frac{1}{2}L_P I_{PP}^2 f_{SW}$  in a ratio:

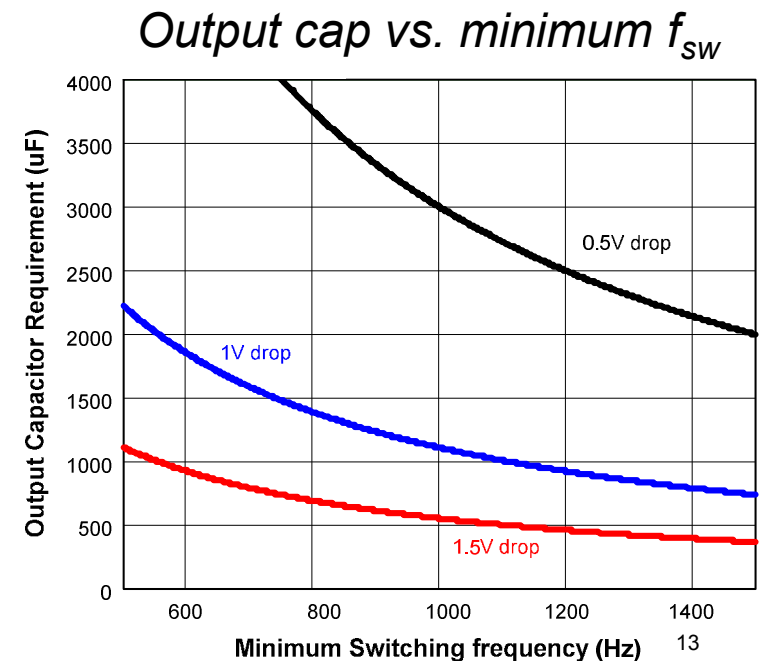
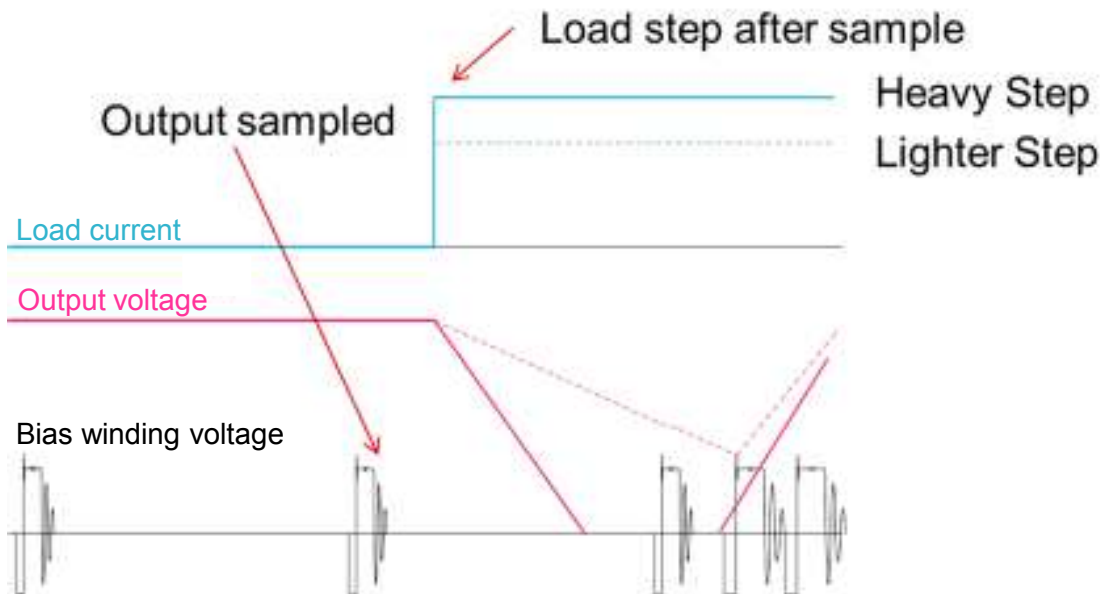
$$\frac{P_{STBY}}{P_{IN(max)}} = \left( \frac{I_{PP(min)}}{I_{PP(max)}} \right)^2 \frac{f_{STBY}}{f_{SW(max)}}$$



- Assume DCM flyback controller with
  - 3:1 peak current ratio
  - 80 kHz max switching frequency
  - 1 kHz min switching frequency
- There are other losses associated with the switching frequency such as the switch node capacitor discharge
- To further reduce the standby power, lower minimum switching frequency is required

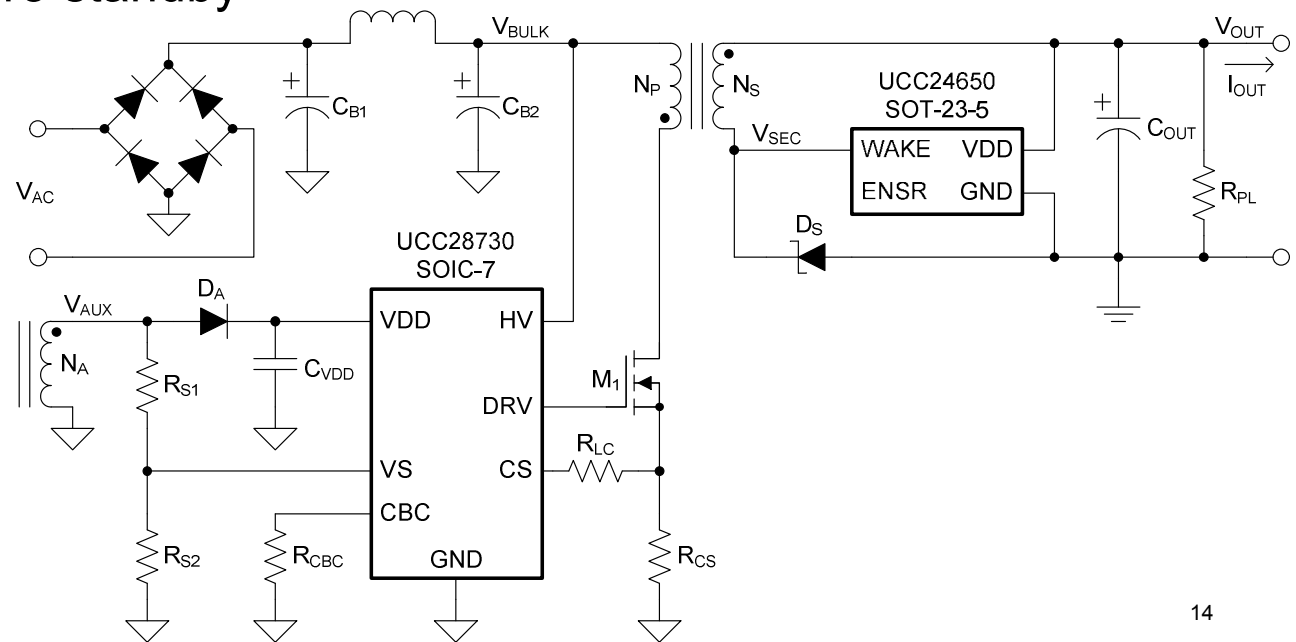
# PSR Slow Transient Response

- PSR is a sample-and-hold control system
- Output voltage is sampled only during output rectifier conduction
- Long idle time between pulses at light-load conditions
- When  $V_{OUT}$  changes between samples
  - Feedback won't respond until next sample
  - Results in excessive droop/under-shoot



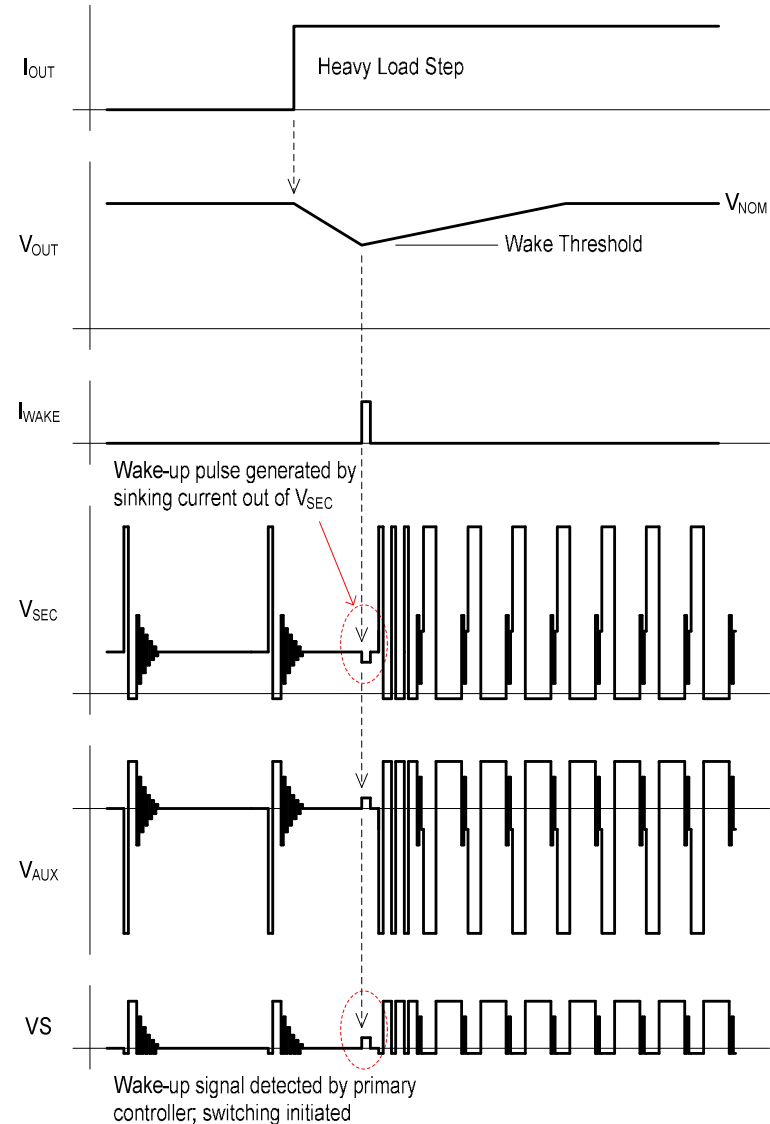
# Fast Transient Response using Output Voltage Monitoring

- Output voltage can be monitored all the time
- Once the output voltage drop is detected, the diode is shorted to send the wakeup signal
  - Speeds up Transient Response during light-load/no-load conditions
    - Even for 100% load steps
- Allows smaller  $C_{OUT}$
- Low bias current for zero standby

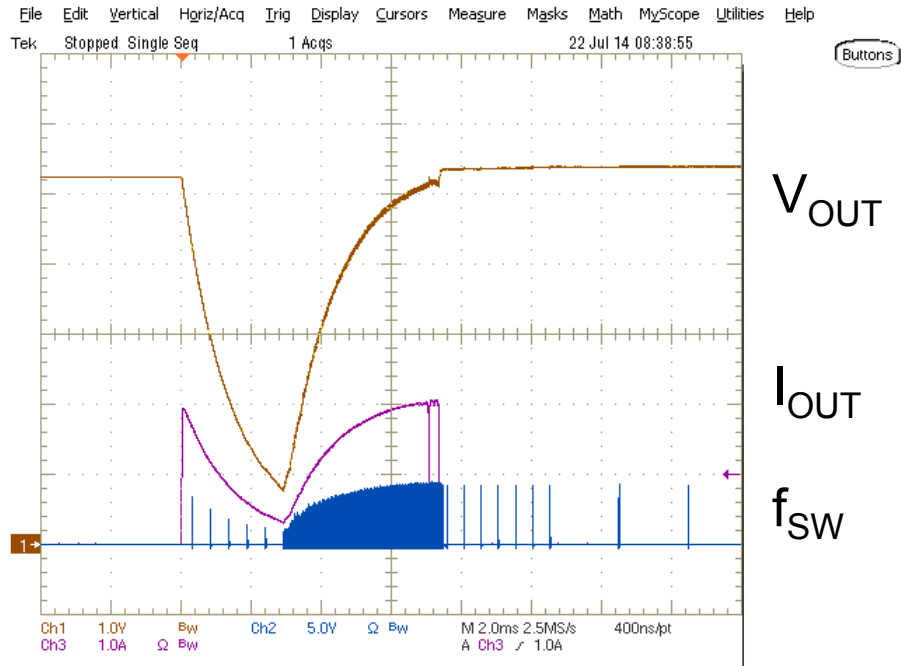


# Improved Transient Response

- $V_{OUT}$  is monitored each cycle
  - If  $V_{OUT} < 97\%$  of previous  $V_{OUT}$ 
    - ✓ Wake-up Pulse is generated
- PSR IC responds to Wake-up Pulse
  - ✓ Generates a few fast pulses to
    - Sample  $V_{OUT}$
    - Adjust  $f_{SW}$  and  $D$
    - Faster recovery to heavy step
    - Avoids overreaction to light step

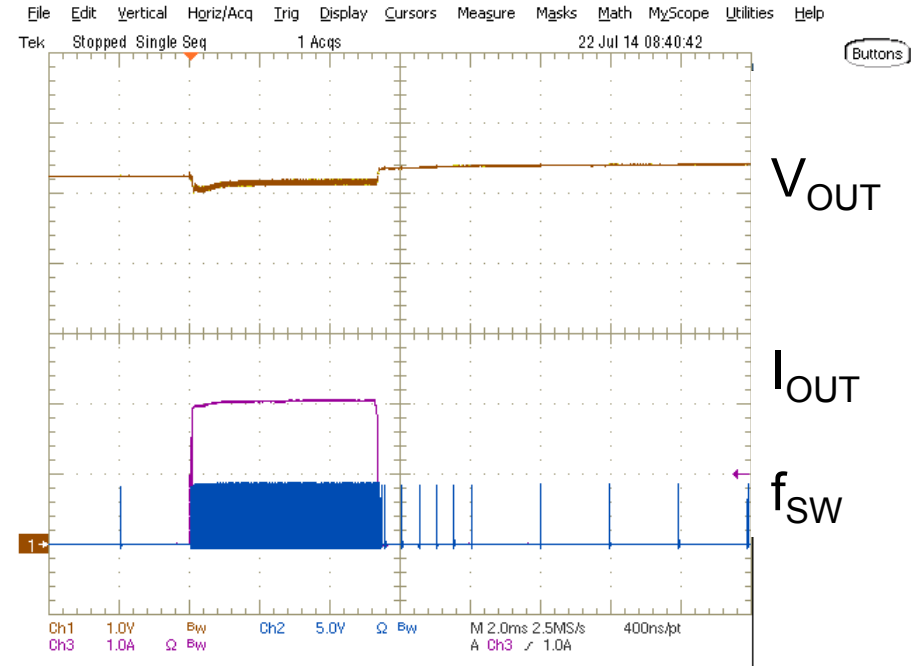


# Compare No-Wake to Wake-Up



Response to 2-A load step on 5 V,  
540  $\mu$ F

- Wake-up function disabled
- $V_{out}$  drops >1 V before detection
  - ✓ Control Loop Can't Respond



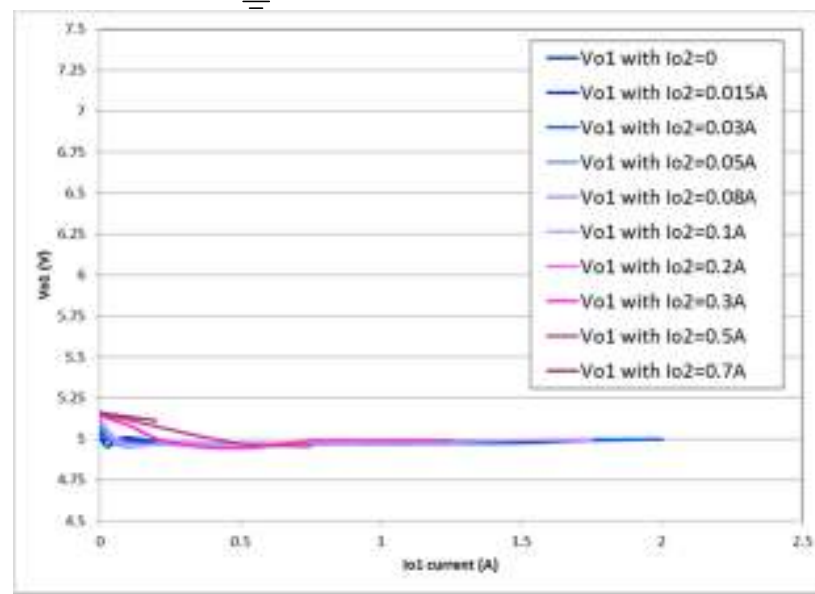
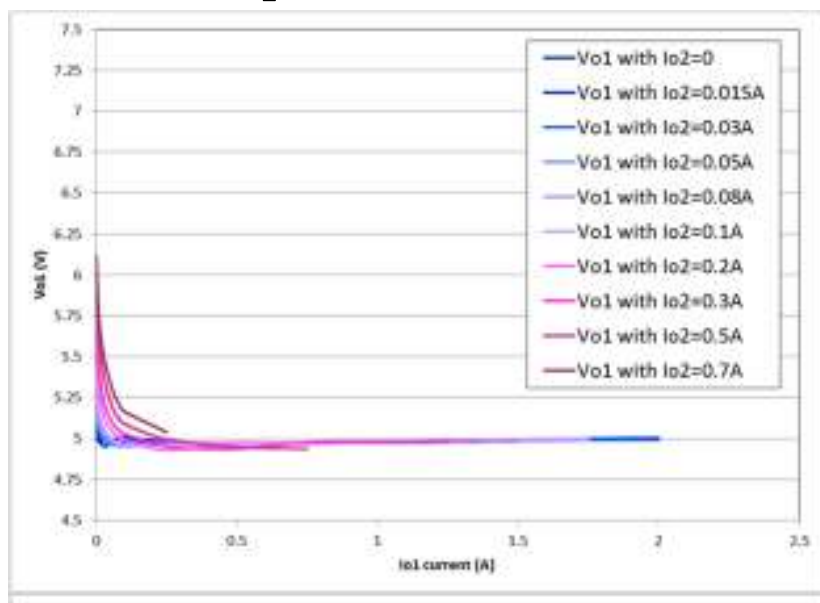
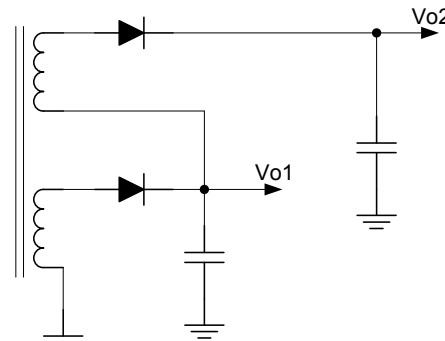
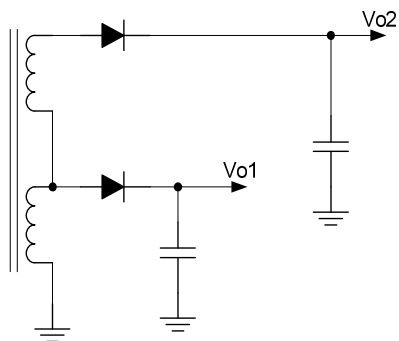
Response to 2-A load step on 5 V,  
540  $\mu$ F

- Wake-up function enabled
- $V_{out}$  droops only 200 mV
  - ✓ Regulation within 2 ms

**Standby power is kept below 4mW for 85V~265VAC input**



# Improve Cross Regulation for Multiple Outputs



- PSR can't assign a dedicated output voltage as regulation target
- Through the DC stacking technique, the output voltage cross regulation can be significantly improved

# Summary

- Standby power savings can be a significant improvement for the electrical efficiency
- Primary side regulation Flyback eliminates the opto coupler and feedback components
  - Improves the reliability
  - Reduces the system cost
  - Reduces the standby power
- The PSR technology can be implemented in CCM Flyback but needs extra compensation
- The PSR technology can achieve minimum standby power without sacrificing the transient performance by using the wakeup concept

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