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

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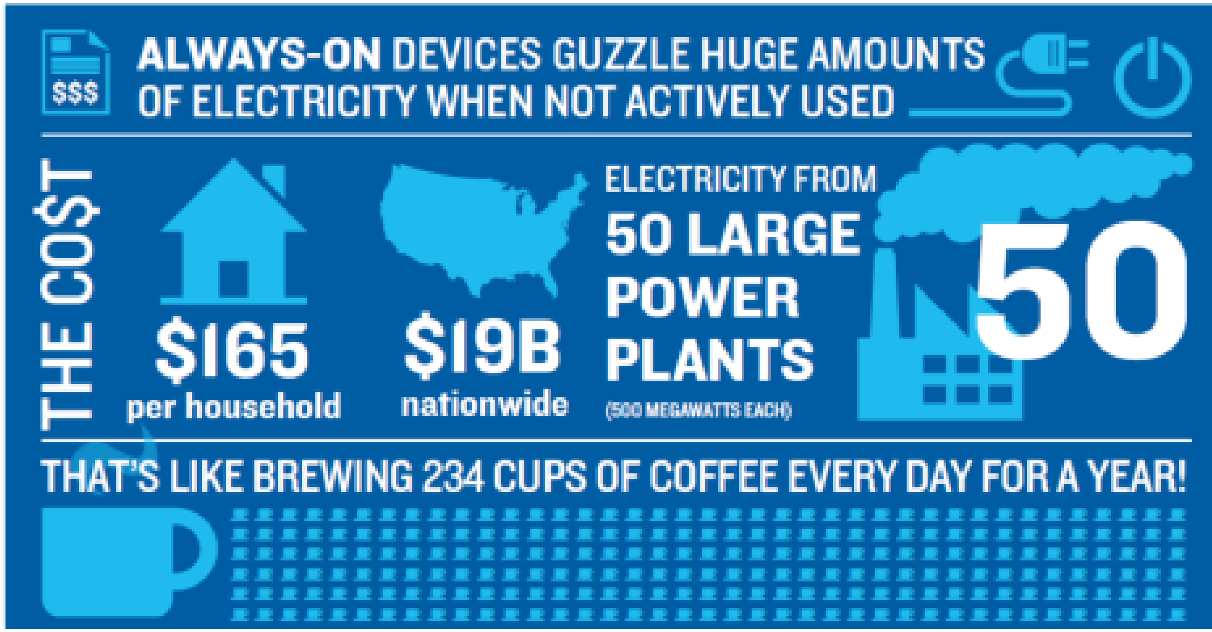
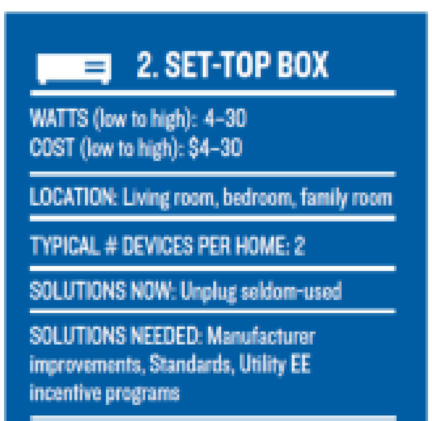
March 2016

# Outline

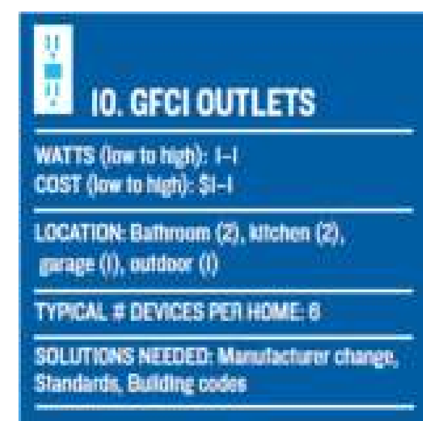
- Background
- Primary side regulation Flyback basics
- Improve PSR performance in CCM Flyback
- PSR with minimum standby power without sacrificing transient
- Summary

# Standby/Vampire/Idle Power Impact



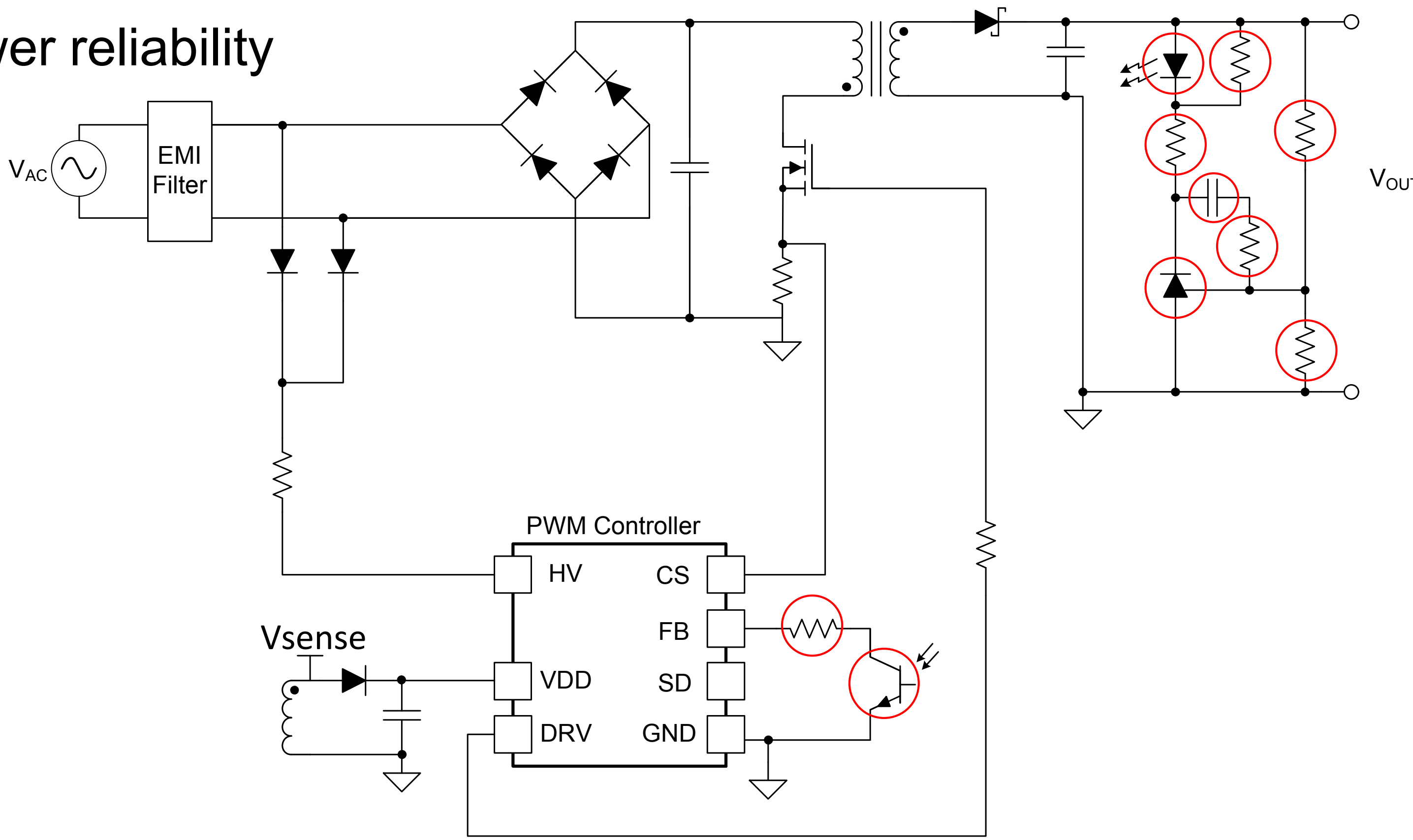


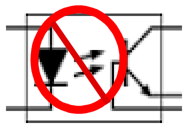

Source NRDC, Home Idle Load Report, May 2015

# 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



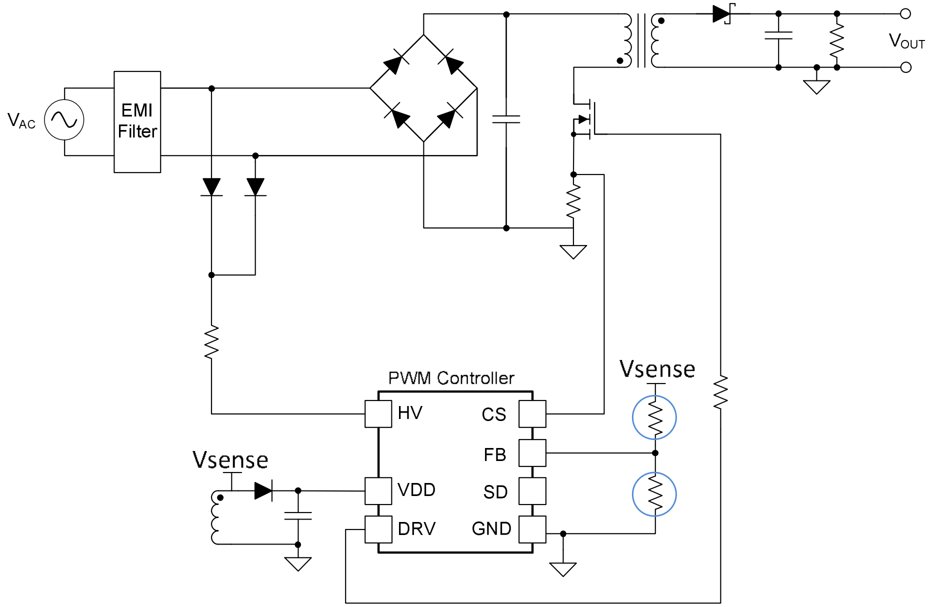
# Eliminating Opto-Coupler



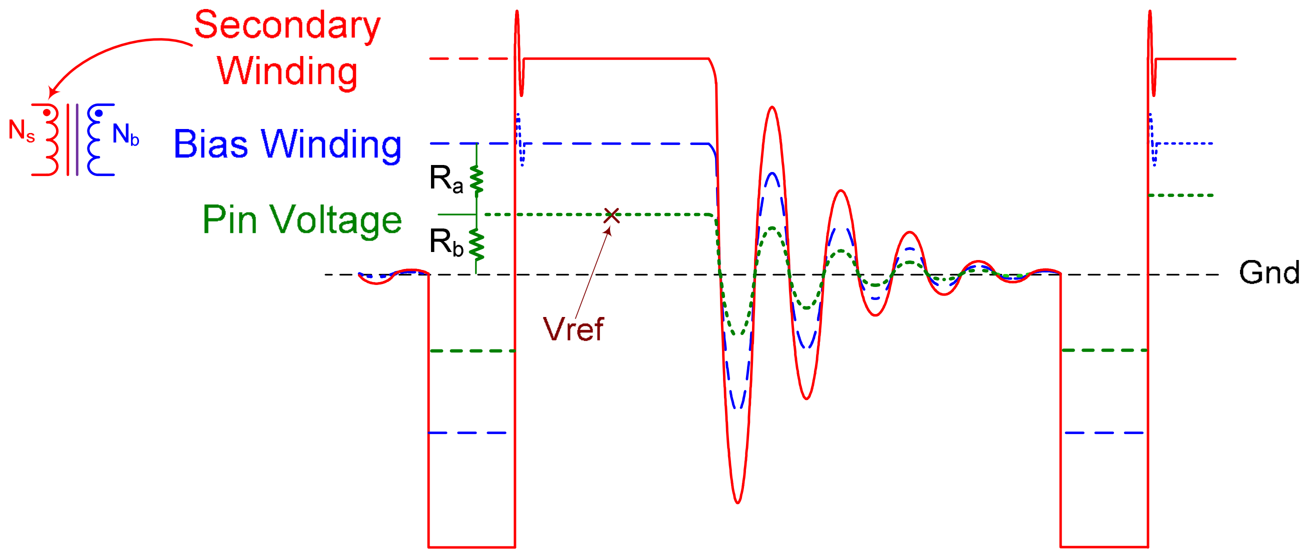
- Higher Reliability
  - No Opto-coupler
    - The aging characteristic of the opto coupler in particular reduces the reliability of the design.
    - The opto-coupler CTR reduces over time which reduces the gain of the feedback loop.
    - The loop has to be overdesigned to account for this affect
  - 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.

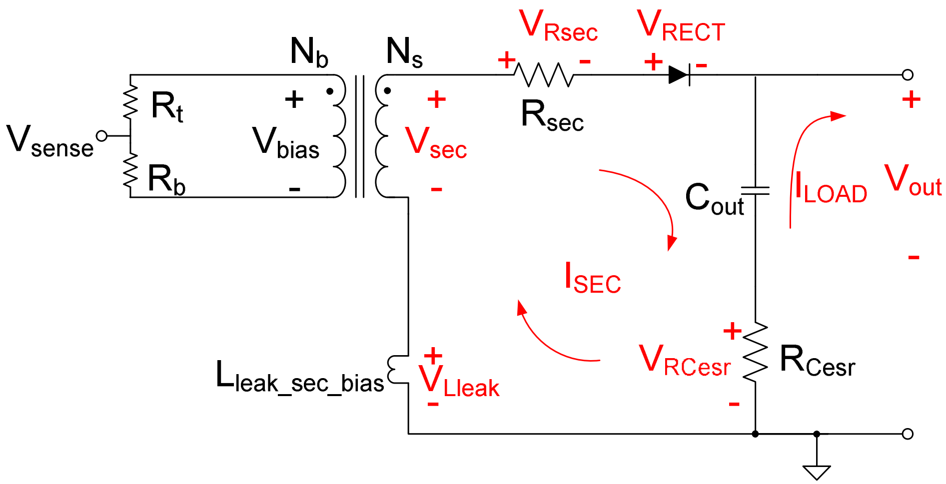
# PSR Flyback Background

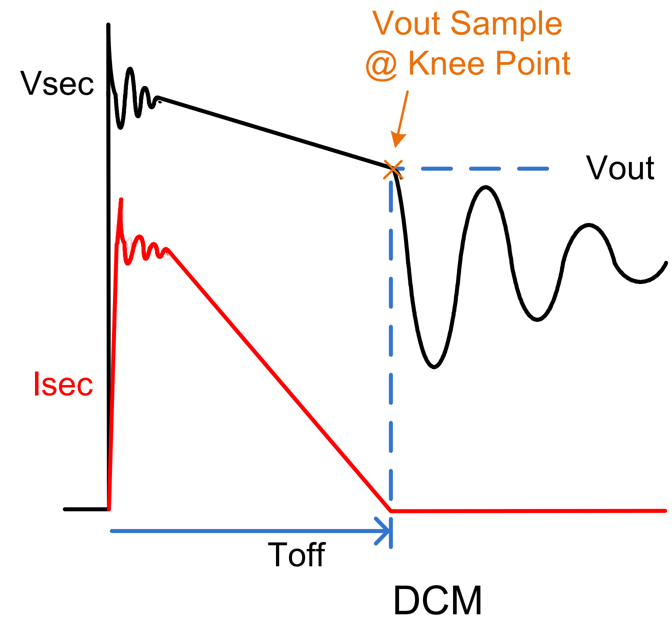



- Most flybacks derive their own bias supply from a bias winding which is in phase with the secondary winding
- Bias winding voltage is a scaled replica of the secondary winding voltage and can be sensed via a resistive divider to regulate Vout



# Output Voltage Sampling in DCM Flyback

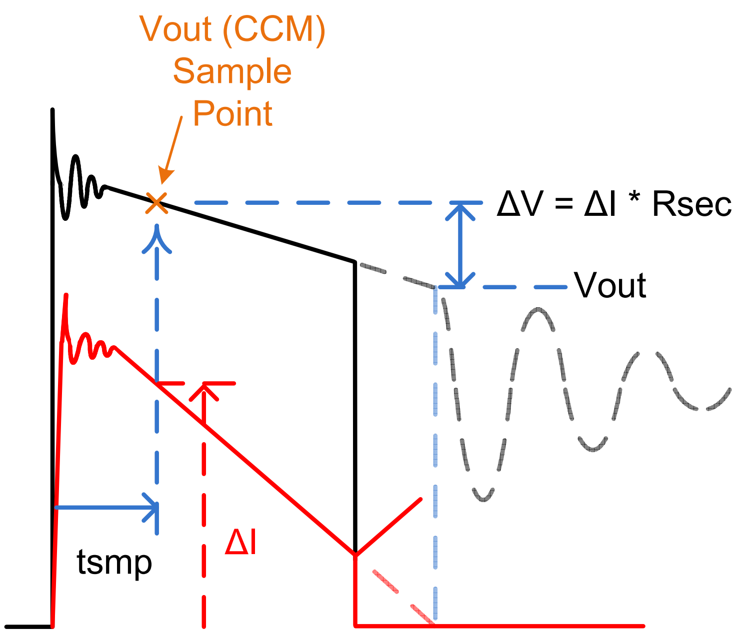



$$V_{sense} = \left[\frac{R_b}{R_t + R_b}\right] \cdot \left[\frac{N_b}{N_s}\right] \cdot \left[V_{out} + V_{rect} + V_{Rsec} - V_{Lleak} + V_{RCesr}\right]$$

- 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

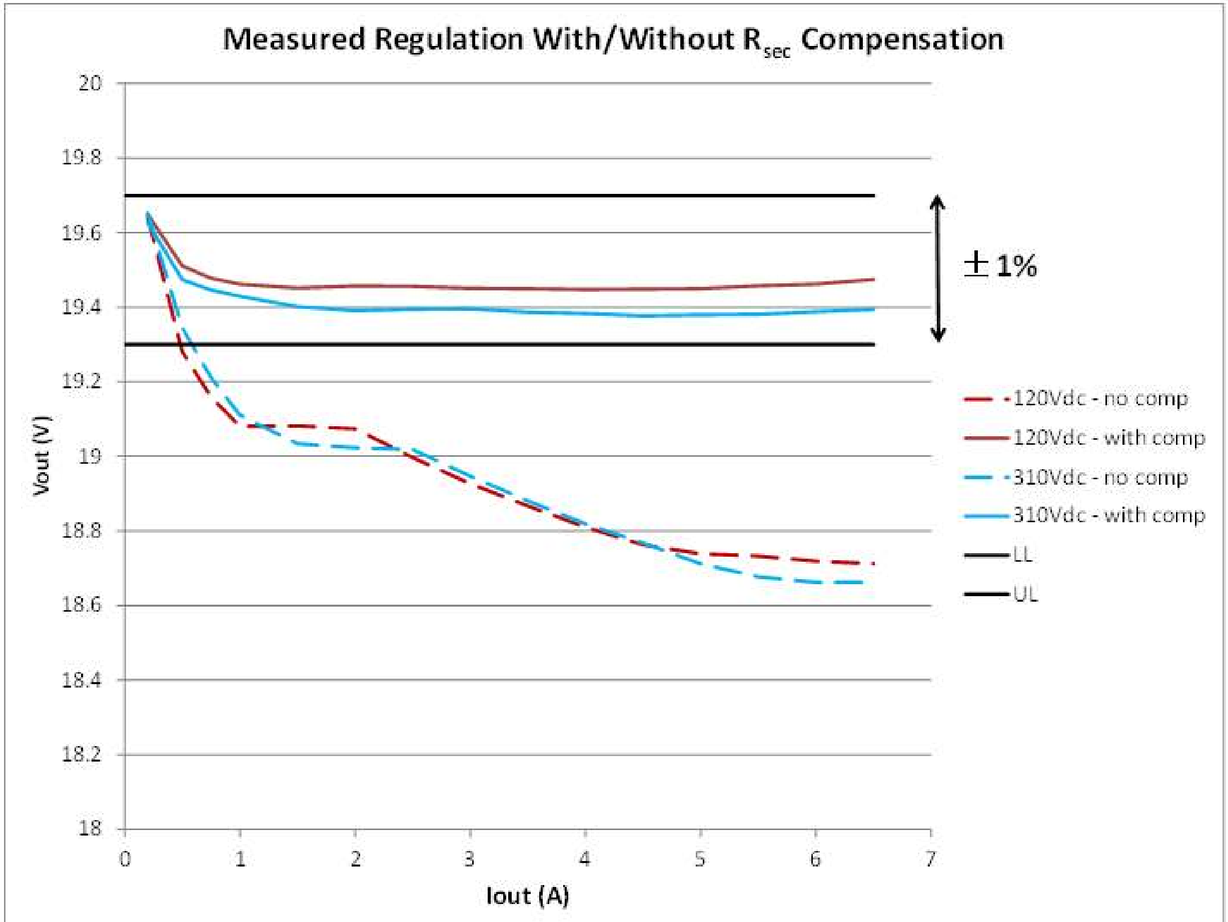
$$V_{sense} = \left[\frac{R_b}{R_t + R_b}\right] \cdot \left[\frac{N_b}{N_s}\right] \cdot \left[V_{out} + I_{sec} \cdot \left[R_{sec} + R_{Cesr}\right]\right]$$

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



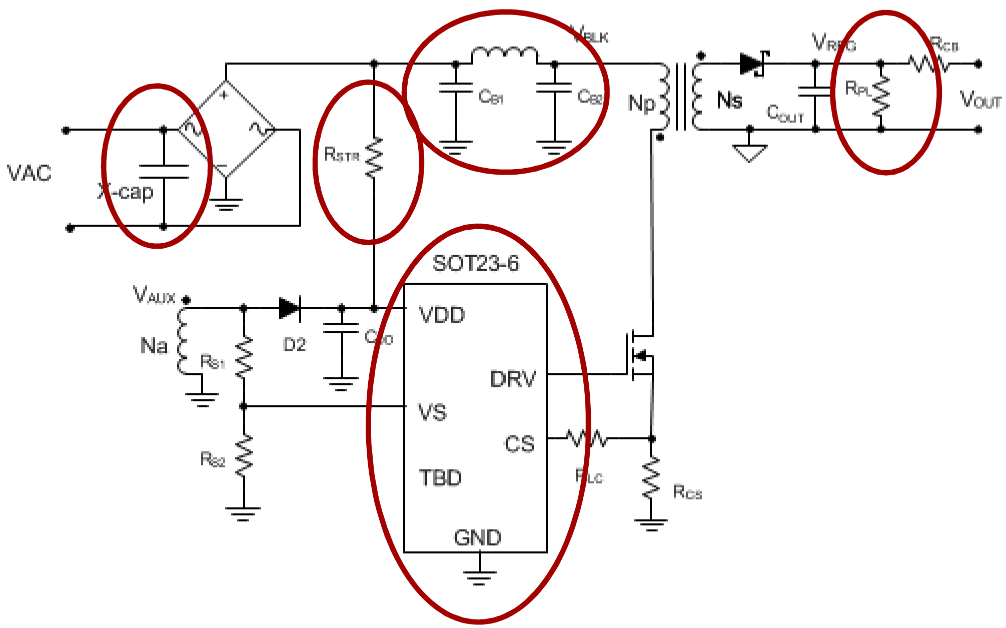

| Lpri | 260 µH | MOSFET | STF13NM60ND |
|---|---|---|---|
| Rcs | 200 mΩ | Diode | NTST30100CTG |
| Np | 34 | Cbulk | 127 µF |
| Ns | 6 | Cout | 1,360 µF |
| Nb | 4 | Cbias | 22 µF |
| Transformer | RM10/I | Rsec | 60 mΩ |

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

Keogh, B.; Long, B. ; Leisten, J., “Design improvements for Primary-Side-Regulated high-power flyback converters in Continuous-Conduction-Mode:, APEC 2015

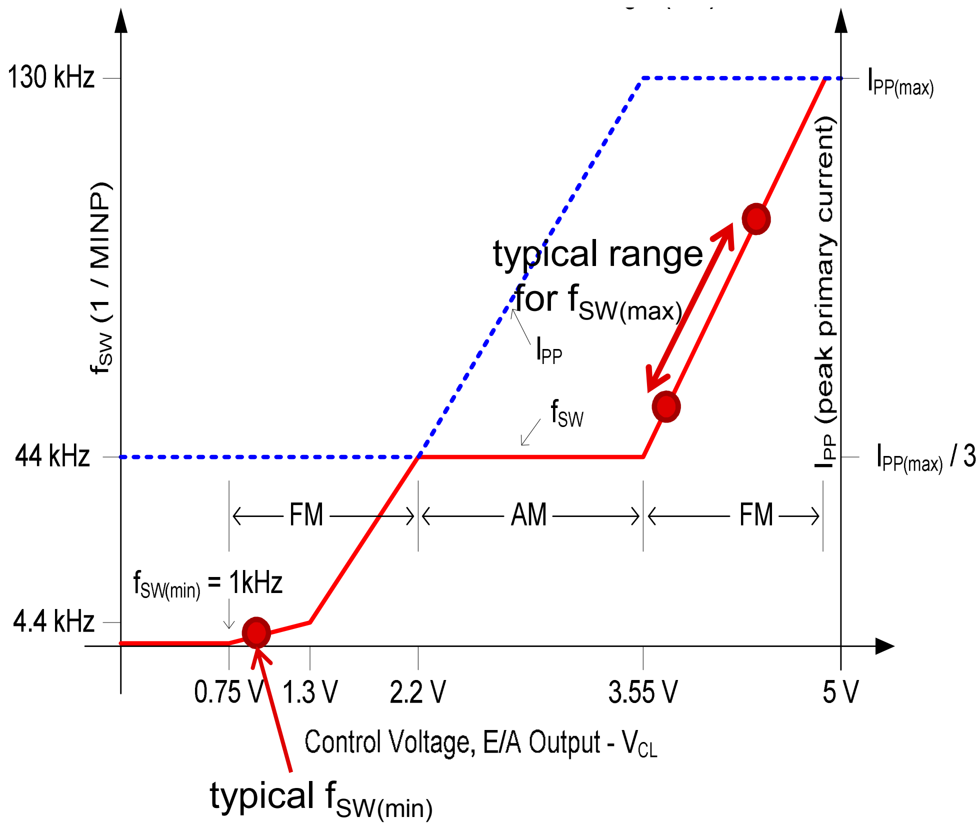
# Standby Power Consumption in Flyback




- 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



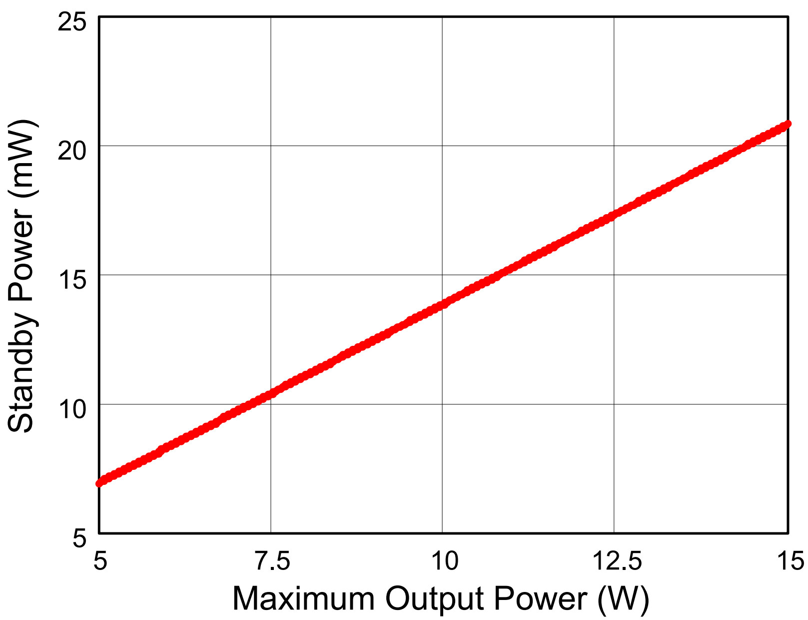

- Frequency modulation
  - Fixed peak current
  - Power is adjusted by switching frequency
- Amplitude modulation
  - Fixed switching frequency
  - Power is adjusted by peak current

- 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:

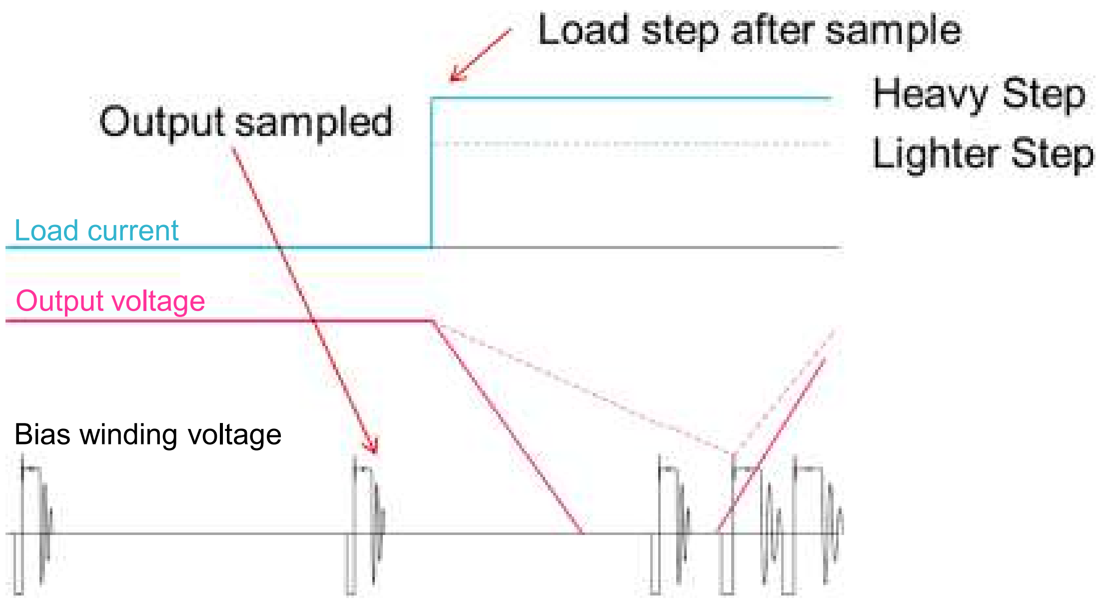
$$\frac{P_{STBY}}{P_{IN(max)}} = \left(\frac{I_{PP(min)}}{I_{PP(max)}}\right)^2 \frac{f_{STBY}}{f_{SW(max)}}$$

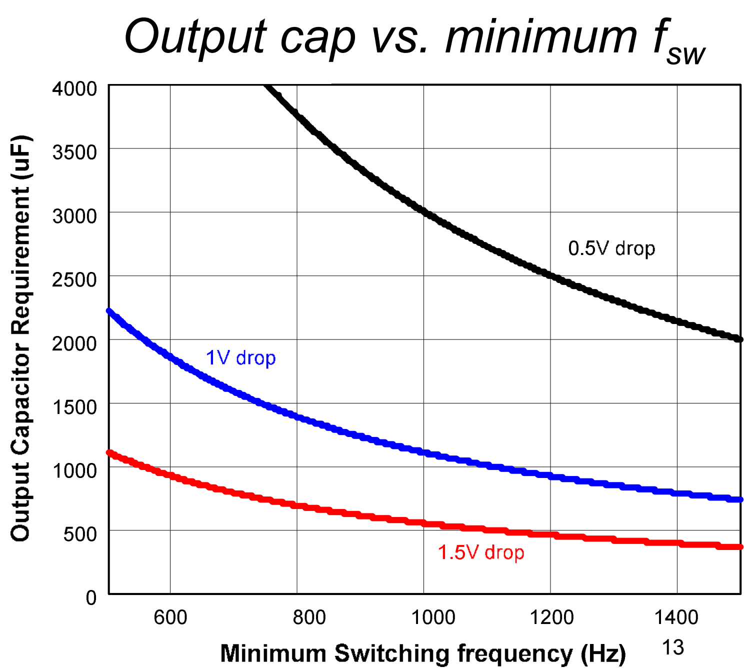



- Assume DCM flyback controller with
  - 3:1 peak current ratio
  - 80 kHz max switching frequency
  - 1 kHz min switching frequency
- There are other losses associated with the switching frequency such as the switch node capacitor discharge
- To further reduce the standby power, lower minimum switching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

# PSR Slow Transient Response

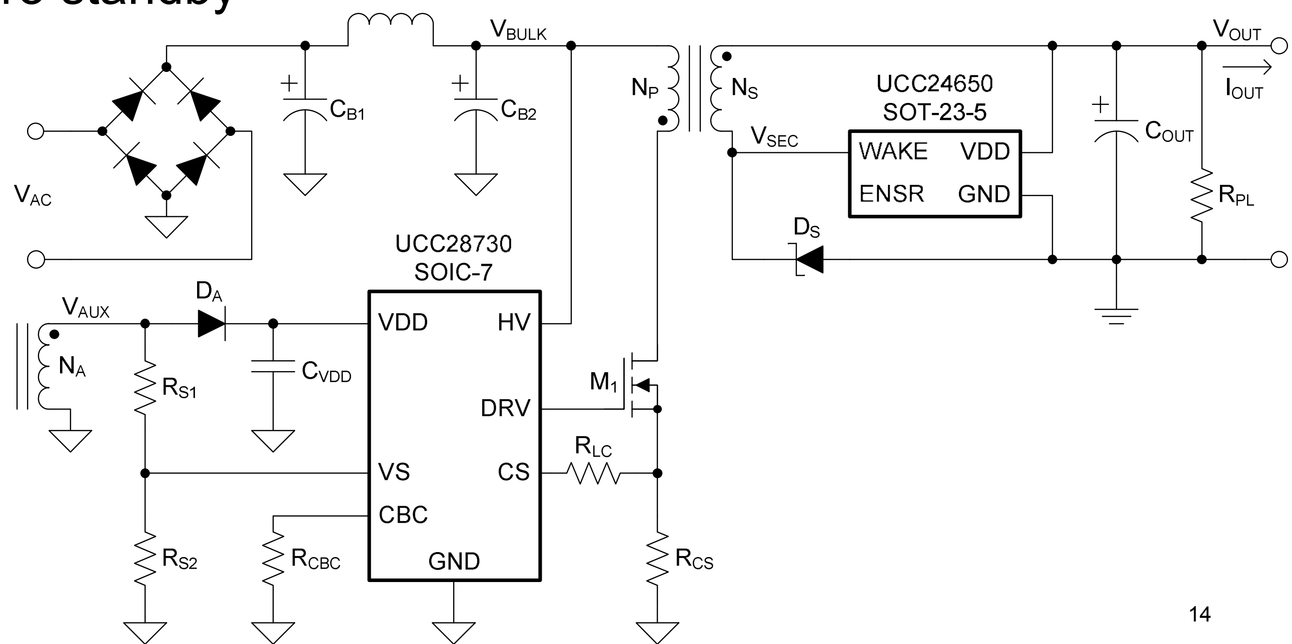
- PSR is a sample-and-hold control system
- Output voltage is sampled only during output rectifier conduction
- Long idle time between pulses at light-load conditions
- When $V_{OUT}$ changes between samples
  - Feedback won't respond until next sample
  - Results in excessive droop/under-shoot



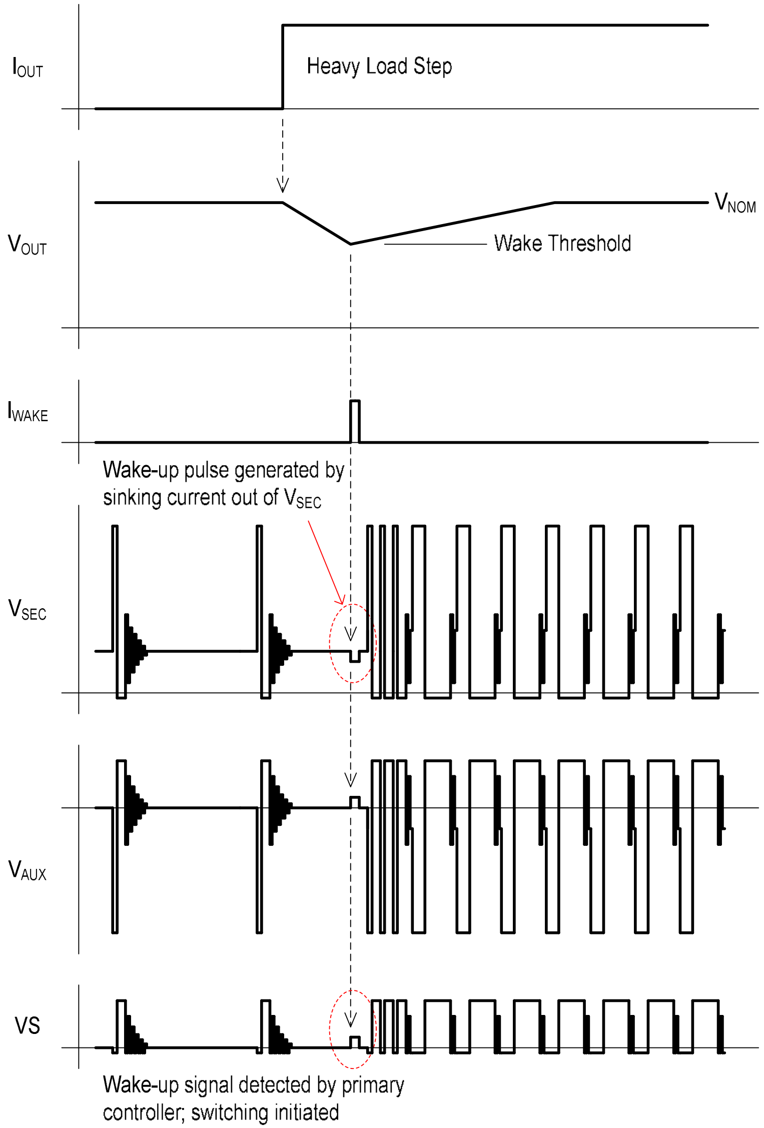
# Fast Transient Response using Output Voltage Monitoring

- 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

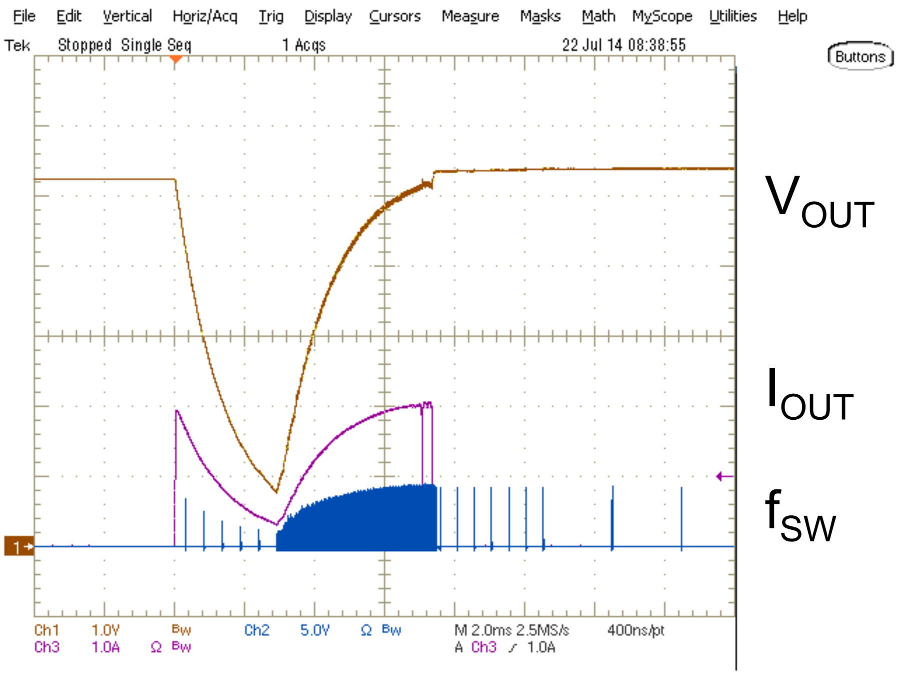


# Improved Transient Response

- $V_{OUT}$ 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

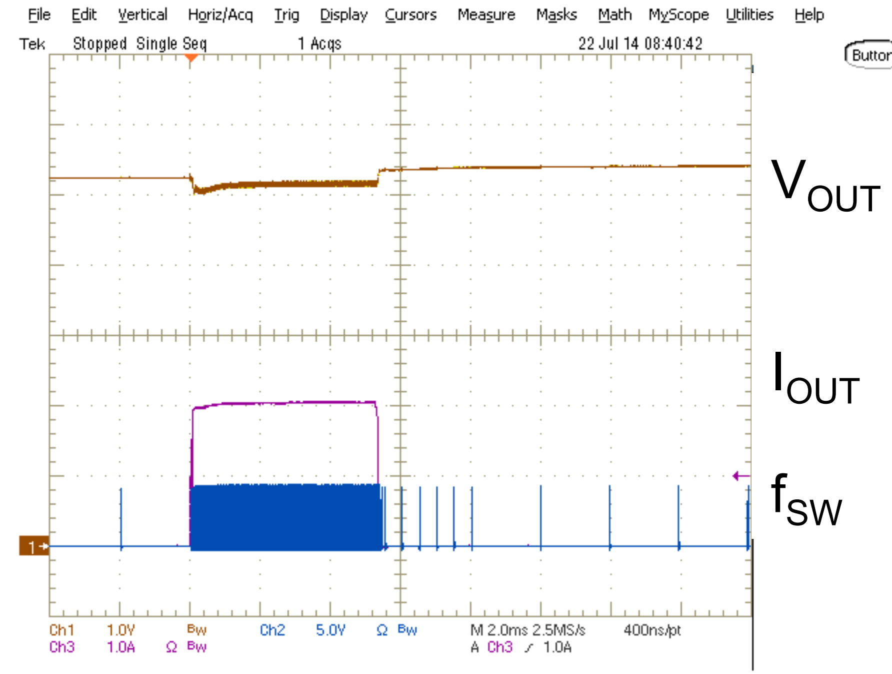


# Compare No-Wake to Wake-Up




Response to 2-A load step on 5 V, 540 µF

- Wake-up function disabled
- Vout drops >1 V before detection
  - ✓ Control Loop Can't Respond

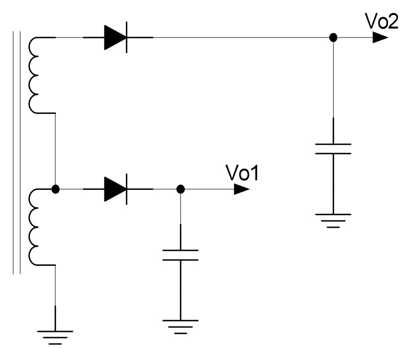


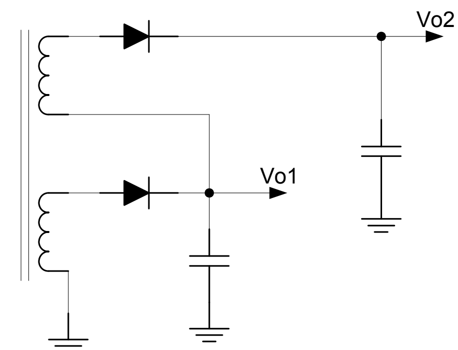

Response to 2-A load step on 5 V, 540 µF

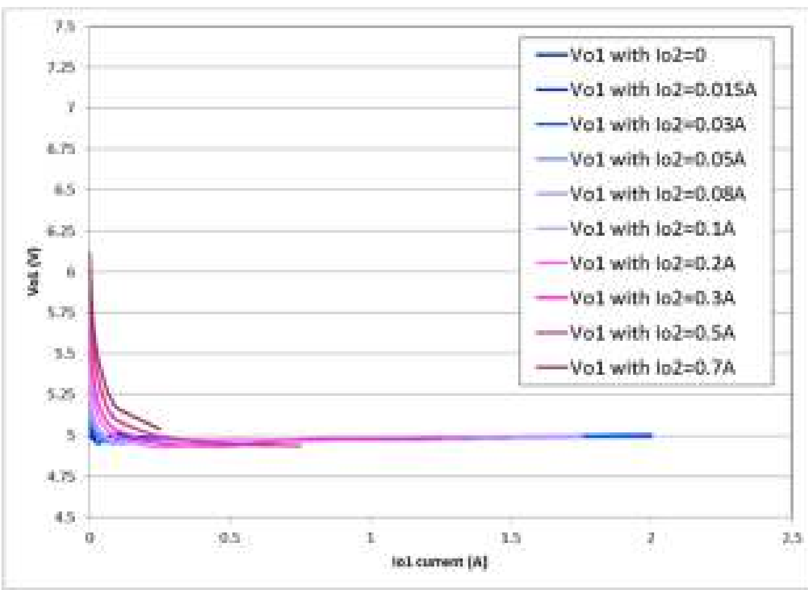
- Wake-up function enabled
- Vout droops only 200 mV
  - ✓ Regulation within 2 ms

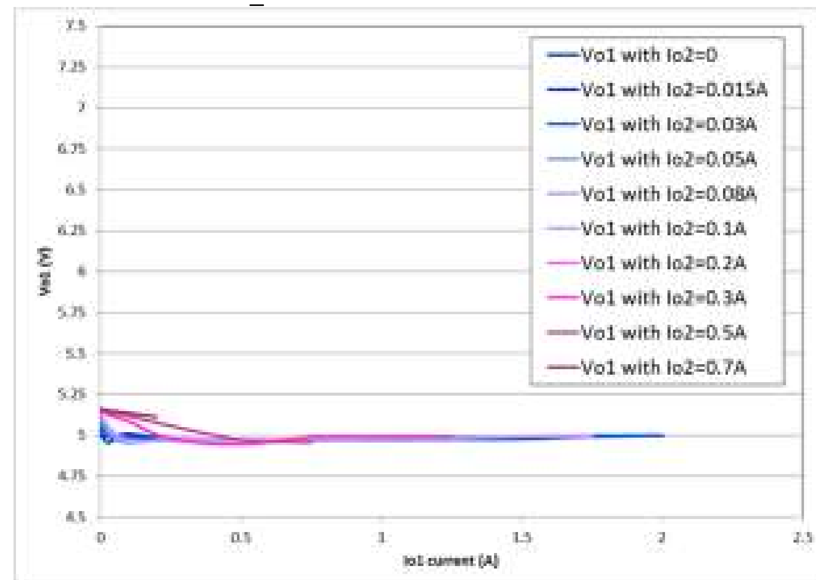
**Standby power is kept below 4mW for 85V~265VAC input**

# 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

## IMPORTANT NOTICE



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