ON Semiconductor®

Selection. Service. Support.

ON Semiconductor®

Standby Power Reduction Techniques

TND324/D Rev.1 – September 2007

Agenda

- Regulatory requirements
- Sources for standby power losses
- Methods to lower the standby power consumption
- Measured results versus calculated results
- Conclusion

Agenda

- **Regulatory requirements**
- Sources for standby power losses
- Methods to lower the standby power consumption
- Measured results versus calculated results
- Conclusion

Regulatory challenges

- Standby Power Reduction
  - 25% of total energy consumption is in low power/sleep/standby mode
  - Concerted effort by CECP, Energy Star, IEA and other international agencies to limit standby power
- Active Mode Efficiency Improvement
  - 75% of total energy consumption is in active mode
  - Changing efficiency from 60% to 75% can result in 15% energy savings
  - Next focus area for agencies
- Power Factor Correction (or Harmonic Reduction)
  - Applicable with IEC 1000-3-2 (Europe, Japan)
  - Some efficiency specifications also require >0.9 PF

Standby certification programs

(external power supplies)

Code	**Region/Country & Timing**	**No Load Power Consumption**
CUC1	CECP (China) & Energy Star (US) From January, 2005 (Tier 1)	≤ 0.50 W for 0-<10 W ≤ 0.75 W for ≥10-250 W
CUC2	CECP and Energy Star From July 1, 2006 (Tier 2)	≤ 0.30 W for 0-<10 W ≤ 0.50 W for ≥10-250 W
CE1	Europe (EC Code of Conduct) From January 1, 2005	≤ 0.30 W for <15 W ≤ 0.50 W for 15-50 W ≤ 0.75 W for 50-60 W ≤ 1.00 W for 60-150 W
CE2	Europe (EC Code of Conduct) From January 1, 2007	≤ 0.30 W for non-PFC ≤ 0.50 W for PFC
CA1	Australia (High Efficiency) From April, 2006	≤ 0.50 W For 0-180 W

Standby mandatory programs

Code	Region/Country & Timing	No Load Power Consumption
MU0	US – FEMP DOE (Final 2011)	≤ 1.00 W for most applications ?
MC1	China GB (Guo Biao) Standards (From January, 2005)	≤ 0.75 W for 0-10 W ≤ 1.00 W for 10-250 W
MC2	China GB (Guo Biao) Standards (From October, 2007)	≤ 0.50 W for 0-10 W ≤ 0.75 W for 10-250 W
MA1	Australia (MEPS) From April, 2006	≤ 0.75 W for 0-180 W
MA2	Australia (MEPS) From 2008/9	≤ 0.50 W for 0-180 W

Agenda

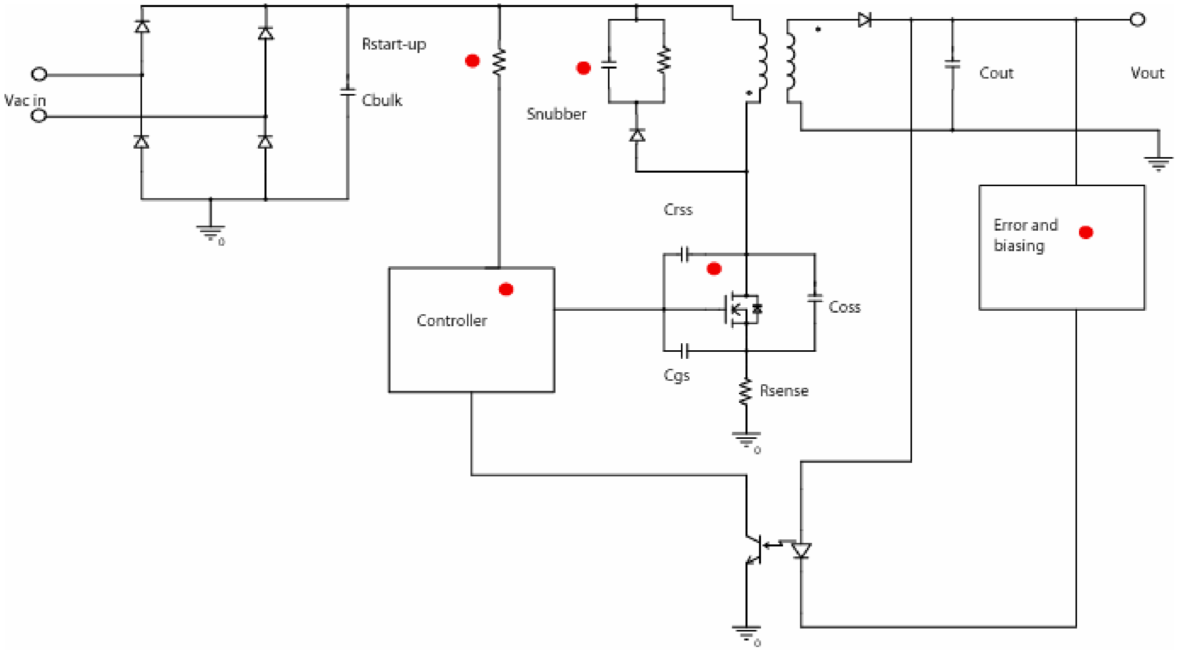
- Regulatory requirements
- **Sources for standby power losses**
- Methods to lower the standby power consumption
- Measured results versus calculated results
- Conclusion

Application overview

- One application was selected.
- Notebook adaptor operating in a flyback topology.
    - Universal input 85 -265 Vac
    - Vout 19 Vdc @ 90 W
    - Frequency 65 kHz
    - No power factor correction pre-regulation stage.
- Standby power losses calculations
    - Start-up resistors 70 Vac, or 100 Vdc
    - Standby power calculations 230 Vac (required)
- Standby power measured data
    - Measured data 230 Vac, or 325 Vdc
- Goal to have a standby power < 0.5 W minimum
- Desired < 0.3 W

What are the sources for standby power losses?

- Switching losses
- Gate charge losses
- Start-up circuits
- Bias circuits
- Snubbers



Switching losses

- Switching losses are associated with the controller turning on the power MOSFET each oscillator cycle

$$P = \frac{1}{2} \bullet C_{OSS} \bullet V_{DS}{}^{2} \bullet Freq$$

$$P = \frac{1}{2} \bullet 390\ pF \bullet 325\ V^{2} \bullet 65\ kHz = 1.33\ W$$

Where:
Operating frequency = 65 kHz

230 Vac • 1.414 = 325 V

MOSFET Characteristics
V_{DS} = 650 V
I_D = 11 A
C_{OSS} = 390 pF
Q = Gate Charge = 45 nC

Gate charge loss

- The loss due to the controller charging and discharging the power MOSFET's gate

$$P = Vg \bullet Q \bullet Fsw = 13\,V \bullet 45\,nC \bullet 65\,kHz = 38\,mW$$

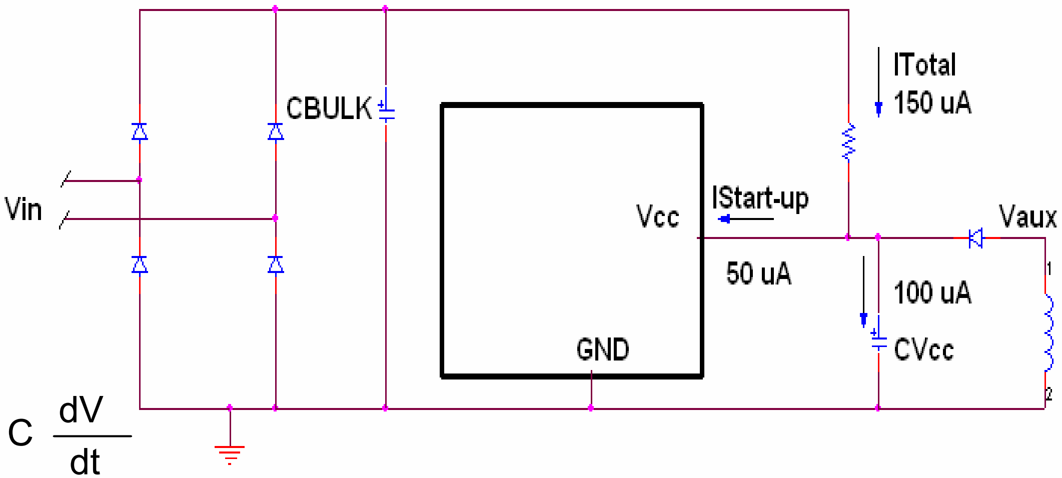
Q = Gate Charge = 45 nC

Lower gate charge devices are available, but they typically have a higher R_{DSON}, decreasing the active efficiency of the SMPS at full load

Start-up circuits

- Start-up circuits are used in SMPS to start the controller when the input power is first applied to the power supply .

The start-up time is 5 s
CVcc 39 µF,
Vccon 12 V
50 µA is the start-up current of the controller



- The start-up current:

$$I_{TOTAL} = I_{START\text{-}UP\ Controller} + C\frac{dV}{dt}$$

I_{TOTAL} = 50 µA + 94 µA > 144 µA (Use 150 µA)

Where:
dV = 12 V the controller turn-on threshold (VCCON)
dt = 5 s (the start-up time)
C = CVcc = 39 µF

Start-up circuits continued

$$R_{START-UP} = \frac{Vdc\ \min}{I_{Total}}$$

$$R_{START-UP} = \frac{100\ Vdc}{150\ \mu A} = 667\ k\Omega$$

$$P_{START-UP} = \frac{VBulk^{2}}{R_{START-UP}} = \frac{325^{2}}{667\ k\Omega}$$ **= 160 mW**

P_{START_UP} is calculated at 230 Vac

Start-up time vs. standby power

Changing the start-up time to 500 ms
CVcc 39 µF,
Vccon 12 V
I_{Vcc} =50 µA is the start-up current of the controller

$$I_{VCC} = C_{VCC} \frac{VCC_{ON}}{T_{start-up}} = 39\ \mu F \frac{12\,V}{500\ ms} = 936\ \mu A$$

$$I_{Total} = I_{VCC} + I_{controller} = 936\,\mu A + 50\,\mu A = 986\,\mu A$$

$$R_{START-UP} = \frac{Vdc\ \min}{I_{Total}} = \frac{100\ Vdc}{986\ \mu A} = 100.4\ \text{k}$$

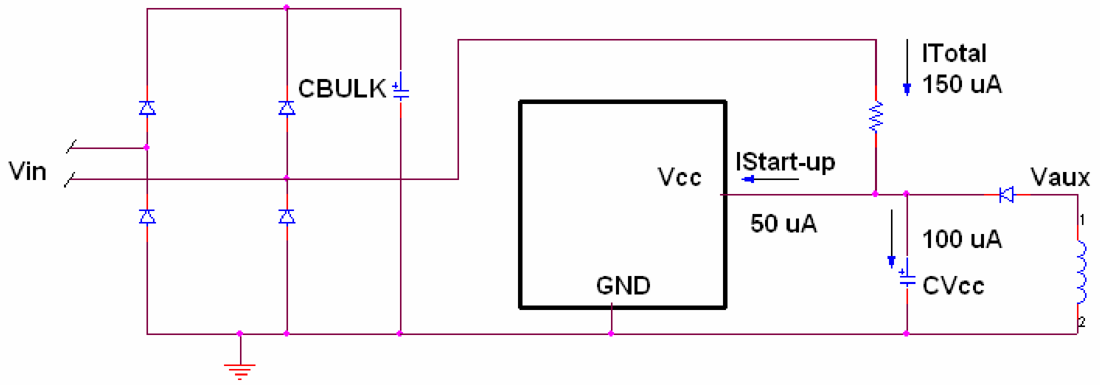
$$P_{START-UP} = \frac{VBulk^2}{R_{START-UP}} = \frac{325\ V^2}{101.4\,k} = 1.04\ \text{W}$$

To increase the start-up time, $R_{start-up}$ must be lowered increasing the standby power

Half-wave connection

$$\text{Rstart} - \text{up} = \frac{100\ \text{Vpk}}{150\ \mu\text{A} \bullet \pi} = 212\ \text{k}\Omega$$

$$Pstart - up = \frac{Vin^2}{2 \bullet Rstart - up} = \frac{230\,Vac^2}{2 \bullet 212\ k\Omega} = 125\ mW$$

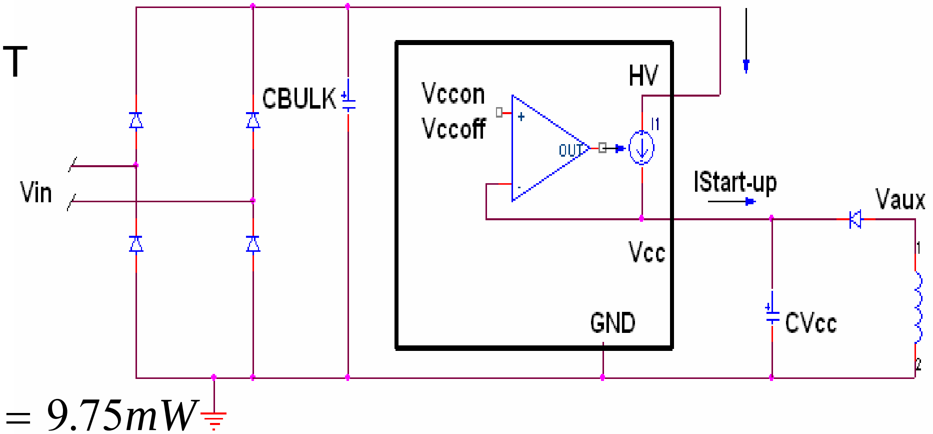


Pstart-up@ 230 Vac = 125 mW, a 22% reduction

Integrated high voltage start-up MOSFETs

- The high voltage MOSFET is used as a current source that charges up the controllers Vcc capacitor when the input ac power is applied to the Power Supply.

Controller with a High Voltage Start-Up FET
Typical Isource 4 mA
The Start-Up time is 118 ms
Typical ILeakage 30 µA



$$Pd = I_{Leakge} \bullet VBulk = 30\mu A \bullet 325Vdc = 9.75mW$$

Advantages:

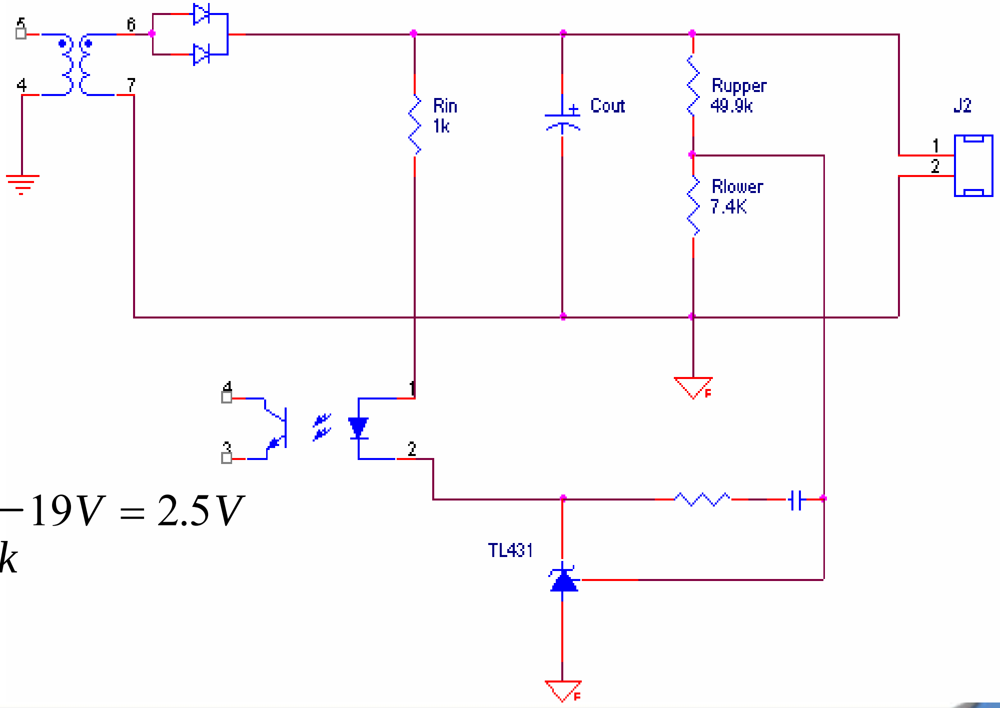
- Can reduce the standby power consumption by approximately **150 mW** (compared to a SMPS with the start-up resistors connected to the bulk capacitor) down to **9.75 mW**

- Faster start-up time.

Bias currents

- In any power supply there are a number of circuits that, if not carefully selected, can consume a significant amount of standby power.
  - TL431 Shunt Regulator (TL431 needs a minimum of 1 mA of cathode
  - current).
  - Optocoupler for the output feedback signal.
  - Resistive dividers

- Output sensing and divider network impedance needs to be as high as possible



$$Vsense = \frac{Rlower}{Rupper + Rlower} Vout = \frac{7.4\,k}{49.0\,k + 7.4\,k} 19V = 2.5V$$

Bias networks

The goal was to keep the bias current losses on the secondary to less than 20 mW.

$$Psense = \frac{Vo^2}{Rupper + Rlower} = \frac{19^2}{57.3k} = 6.3\ mW$$

V_{Rin} = 1 mA • 1 kΩ = 1 V

PRin = 1 mA² • 1 kΩ = **1 mW**

PTL431=(Vo-VRin-Vopto)•1 mA =(19 V- 1 V- 1V)•1 mA = **17 mW**

$PT_{SECONDARY\ Side}$ = 24.3 mW

The primary side controller bias current = 2 mA

Pcontroller = ICC • Vcc= 2 mA • 13 V = **26 mW**

The total losses due to bias currents are:

PTotal = Psense + PRin + PTL431 + PController

6.3 mW + 1 mW + 17 mW + 26 mW = **50.3 mW**

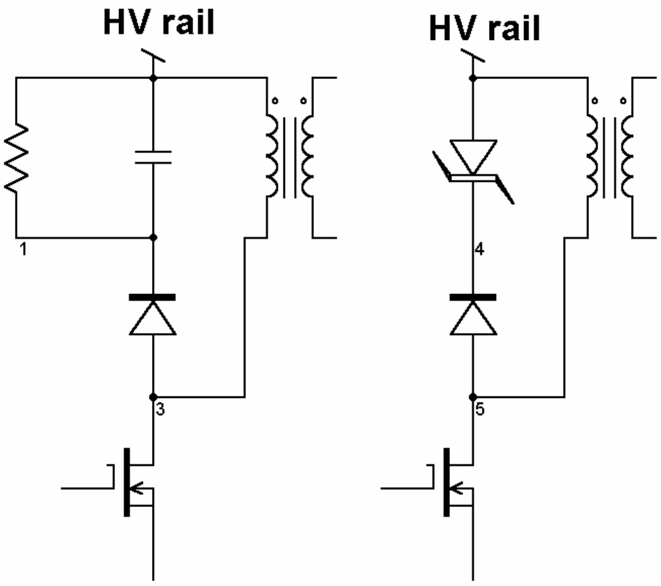
Snubber/clamp losses

RDC snubber

$$P_R = \frac{1}{2} L_{LK} \bullet Ipk^2 \bullet Freq \bullet \frac{V_{clamp}}{V_{clamp} - V_{out} \bullet n}$$

Zener clamp

$$P_Z = \frac{1}{2} Ipk^2 L_{LK} \bullet Freq \frac{Vdc - Vz}{Vz - Vout \bullet n}$$



Where:

L_{LK} is the transformer leakage inductance

Ipk is the transformer peak primary current

Freq is the SMPS operating frequency

Vdc is the SMPS HV dc bus

VZ is the zener break down voltage
Vclamp is the RDC snubber clamp voltage
Vout is the output voltage
N is the transformer turns ratio

Losses summary

$$PT_{stand\text{-}by} = P_{Switching}+P_{Gate}+P_{Start\text{-}up}+P_{Bias}$$

With 667 kΩ start-up resistors.

$$PT_{stand\text{-}by} = 1.33\ W + 38\ mW + 160\ mW + 50.3\ mW = 1.58\ W$$

With HV start-up

$$PT_{stand\text{-}by} = 1.33\ W + 38\ mW + 9.75\ mW + 50.3\ mW = 1.43\ W$$

Using Fixed frequency will not get us to the low standby power requirements.

Agenda

- Regulatory requirements
- Sources for standby power losses
- **Methods to lower the standby power consumption**
- Measured results versus calculated results
- Conclusion

Methods to lower the standby power consumption

- Switching losses
    - Frequency foldback
    - Skip cycle operation
- Startup circuits
- Bias circuits

Frequency foldback

Operating frequency =65 kHz → 24 kHz

$$P = \frac{1}{2} \bullet 390\ \text{pF} \bullet 325\ \text{V}^{2} \bullet 24\ \text{kHz} = 494\ \text{mW}$$

☺ ***62% reduction in standby power losses, compared to Example 1 where the P_{SW} = 1.33 W***

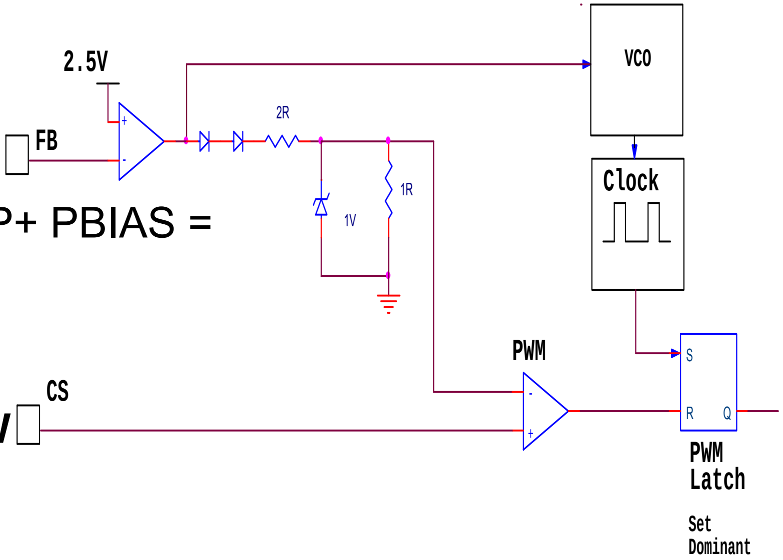
With 667 kΩ start-up resistor

$PT_{STANDBY}$ = PSWITCHING + PGATE + PSTART_UP+ PBIAS =

494 m W + 14 mW + 160 mW + 50.3 mW = **720 mW**

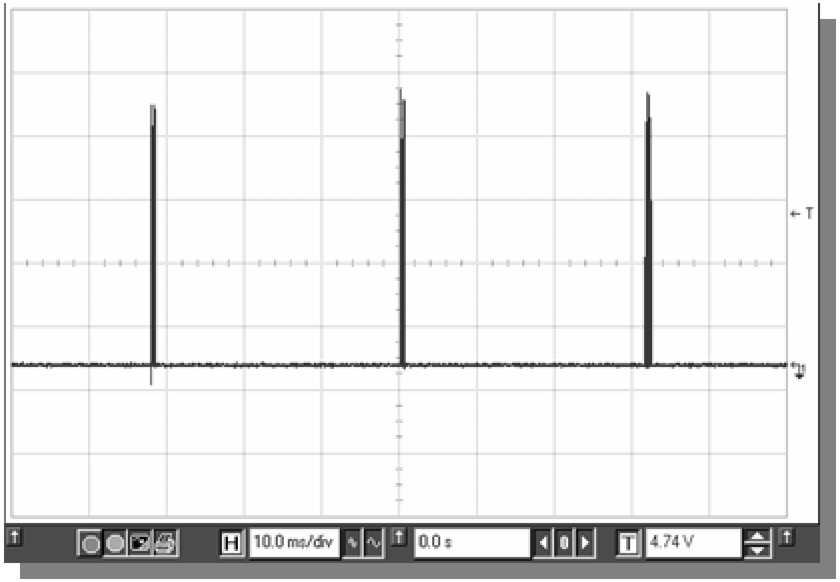
With HV start-up

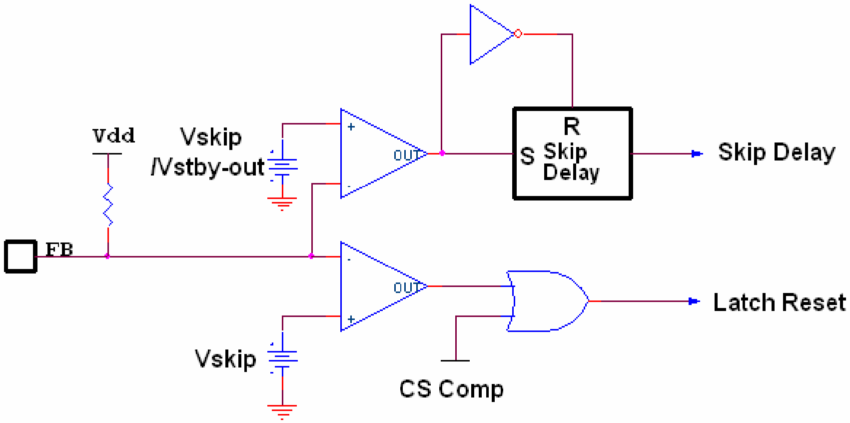
494 m W + 14 mW + 9.75 mW + 50.3 mW = **568 mW**



Skip cycle

$$P = 1/2 \bullet C_{OSS} \bullet V_{DS}^{2} \bullet Freq \bullet D_{SKIP\_CYCLE}$$





Skip cycle with start-up resistors

Skip cycle switching loss calculation

D_{SKIP_CYCLE}= 7% (measured)

$$P = \frac{1}{2} \bullet 390\text{pF} \bullet 325\text{V}^2 \bullet 65\text{kHz} \bullet 0.07 = 93\text{mW}$$

EQ 18: (With 667 kΩ start-up resistors)

$P_{TSTANDBY\_Skip} = P_{SWITCHING} \bullet D + P_{GATE} \bullet D + P_{START\_UP} + P_{BIAS} =$

93 mW + 1.4 mW + 160 mW + 50.3 mW = **304 mW**

With HV start-up
93 mW + 1.4 mW + 9.75 mW + 50.3 mW = **155 mW**

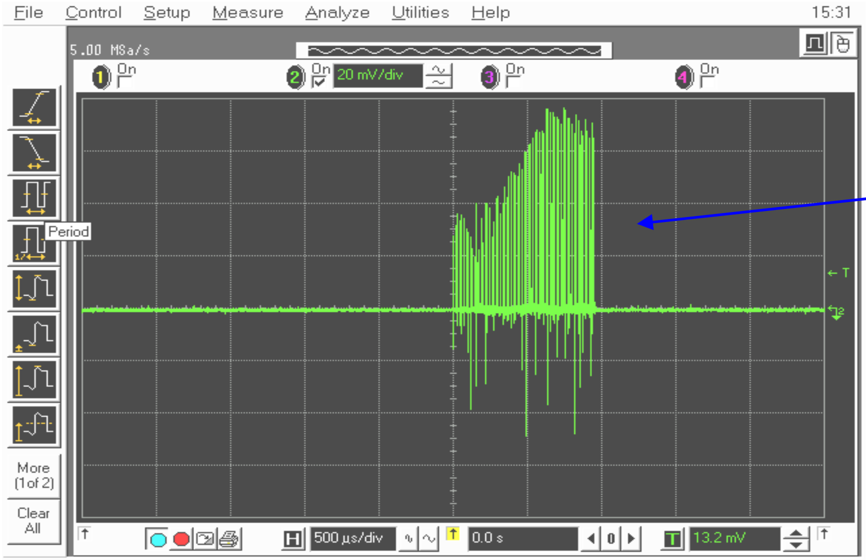
Frequency foldback with HV start-up
PTSTANDBY frequency foldback = **568 mW**

Frequency foldback with 667 kΩ start-up resistor
PTSTANDBY = **720 mW**

Soft skip cycle

Skip cycle operation can lead to audible noise due to the instantaneous peak current which causing a mechanical resonance with the snubber capacitor and magnetic winding, and core .

Soft skip primary current waveform



- •Soft skip reduces the high instantaneous peak current by ramping up the primary current
- • This reduces the audible noise
- •This increases the skip duty cycle
- •Increasing the standby power

Agenda

- Regulatory requirements
- Sources for standby power losses
- Methods to lower the standby power consumption
- **Measured results versus calculated results**
- Conclusion

Standby power results with start-up resistors

667 kΩ start-up resistors

Vin	Fixed Frequency (65 kHz)	Frequency Foldback (65 kHz→24 kHz)	Skip cycle (65 kHz)
230 Vac	Calculated- 1.58 W Measured-1.7 W	Calculated- 720 mW Measured- 710 mW	Calculated- 304 mW Measured- 320 mW

Standby power results with a HV start-up

Vin	Skip with HV Start-Up (65 kHz)	Soft Skip with HV Start-Up (65 kHz)
230 Vac	Calculated-155 mW Measured- 160 mW	Measured- 190 mW

Conclusion

- **Regulatory requirements worldwide are driving the reduction of standby power consumption**

- **Identification of sources for standby power losses:**
  - Switching losses
  - Gate charge losses
  - Start-up circuits
  - Bias circuits
  - Snubbers

- **Identification of methods to lower the standby power**
  - Switching losses
    - Frequency foldback
    - Skip cycle operation
  - Startup circuits
  - Bias circuits

- **Very good correlation between calculated and measured results**