ON Semiconductor®

# Driving Efficient Power Solutions from Standby to Active Mode

# (from line to load)

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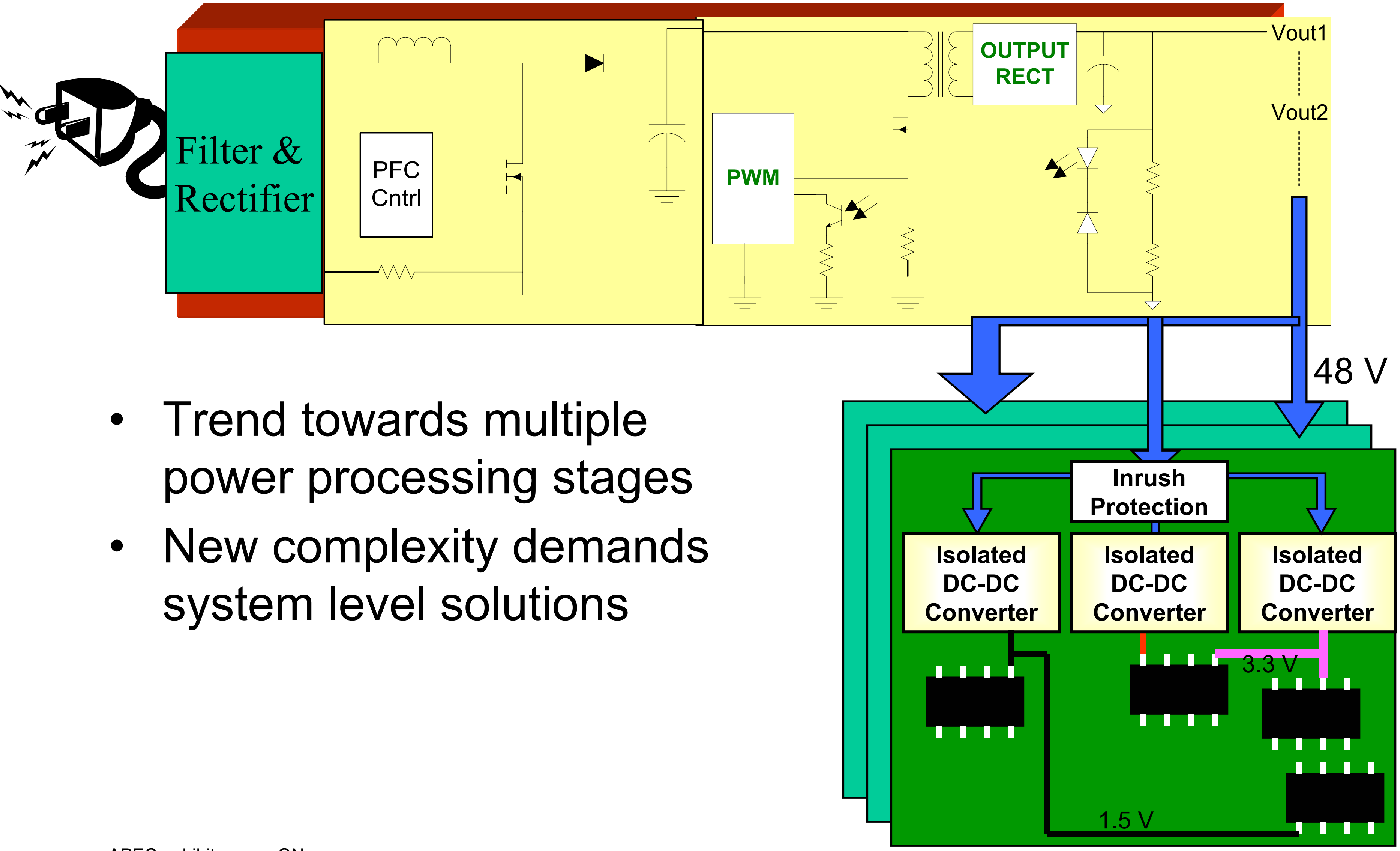
# Agenda

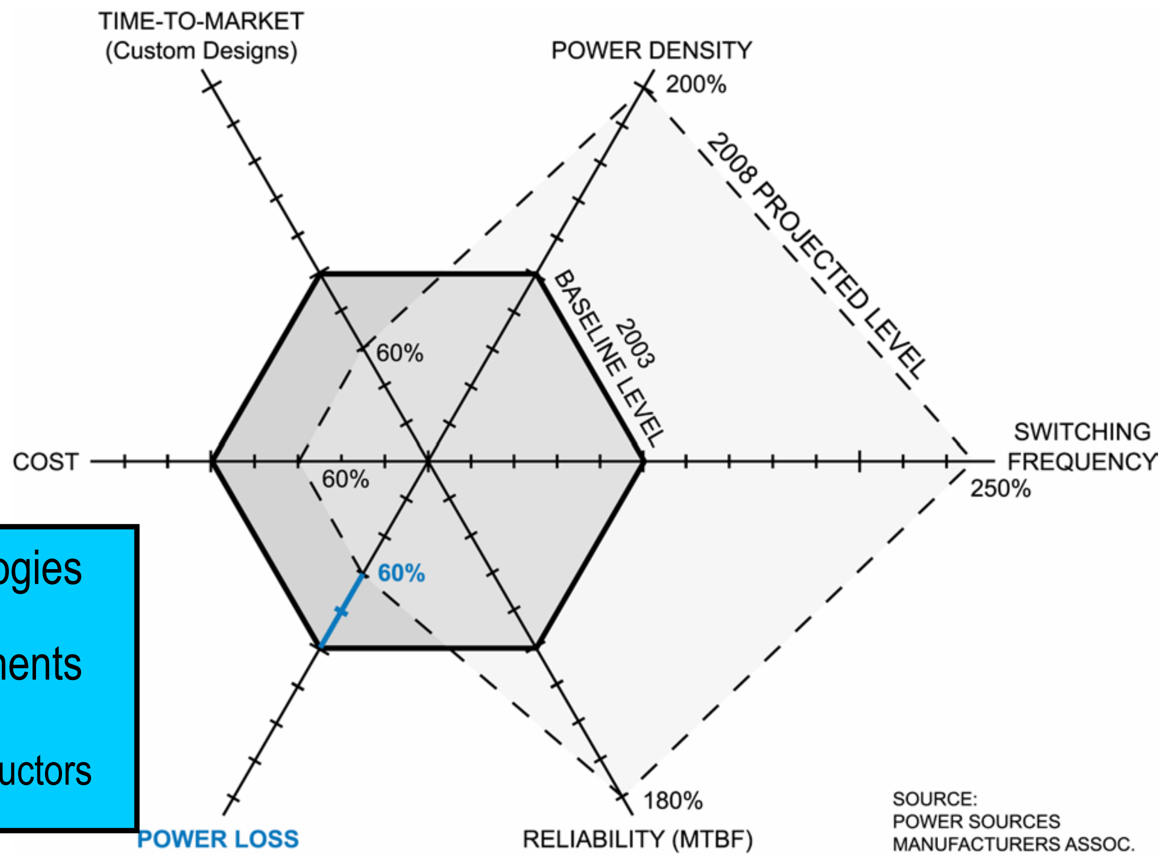
- Power train overview – new complexities
- Challenges (PSMA roadmap, energy standards)
- Solutions for standby power savings
- Solutions for active mode savings
- Conclusions/Questions

# The Power Train – Line to Load




- Trend towards multiple power processing stages
- New complexity demands system level solutions

# Challenges – A PSMA Perspective




Optimal Topologies

Better Components
ICs
Power Semiconductors

# Regulatory Trends

- Standby power requirements in effect in various parts of the world
  - IEA, Energy-star, Blue Angel, CECP
  - Requirements depend on type of equipment
  - Input power levels are reducing
  - Only 25% of energy consumed in standby
- Active mode efficiency is the next frontier
  - Test methodology defined (CEC)
  - EPA/CEC sponsored contest
  - Some OEMs driving their own standards

# Lowering *standby* power
# Skip-cycle or Frequency foldback?

Christophe Basso, application manager
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# What is standby power…?

- A supply is left connected to the line without load, the power drawn from the mains shall be minimum.

➔ battery chargers, AC/DC wall adapters etc.

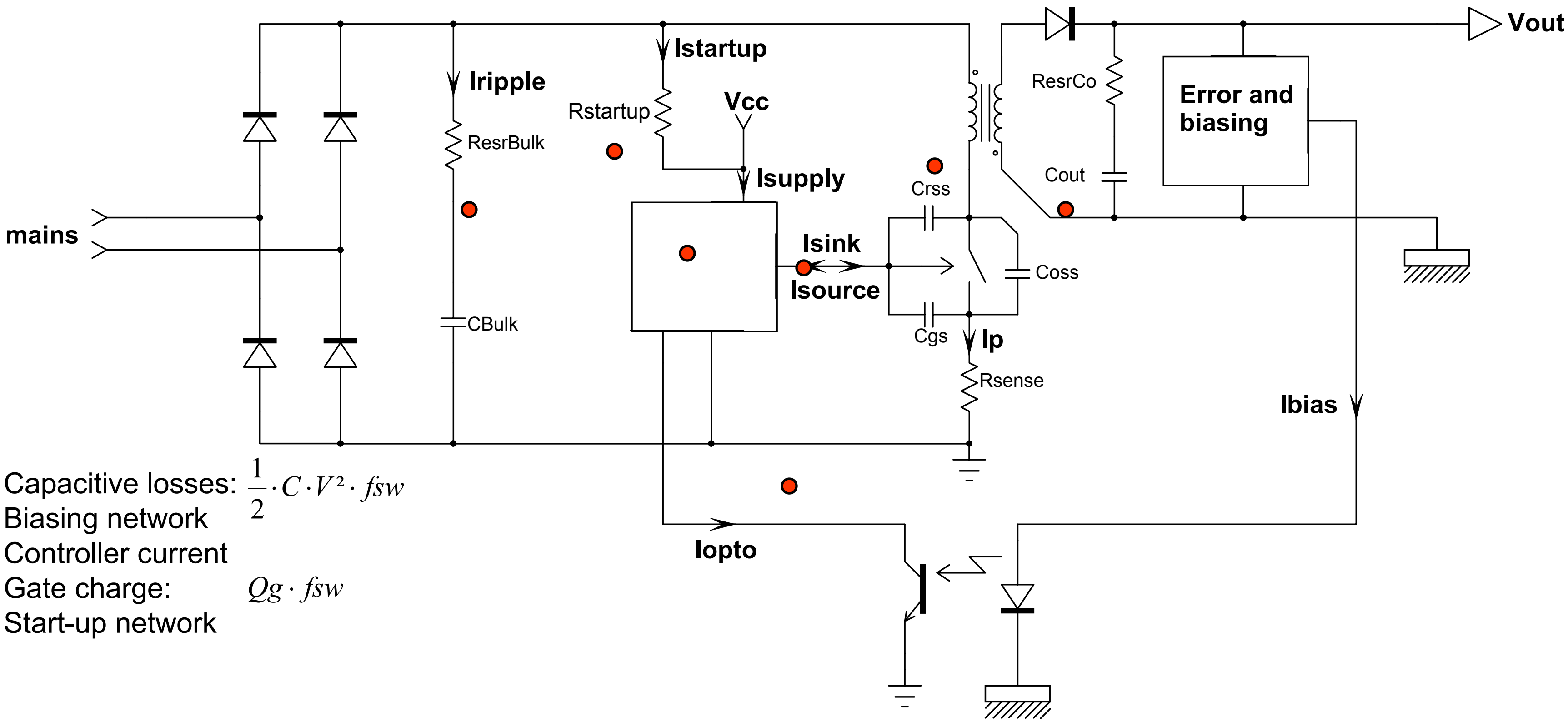
- A system goes into sleep-mode while still having some intelligent activity.

➔ TV sets (LED is on, µP waiting for remote control), VCRs

EC recommendations:

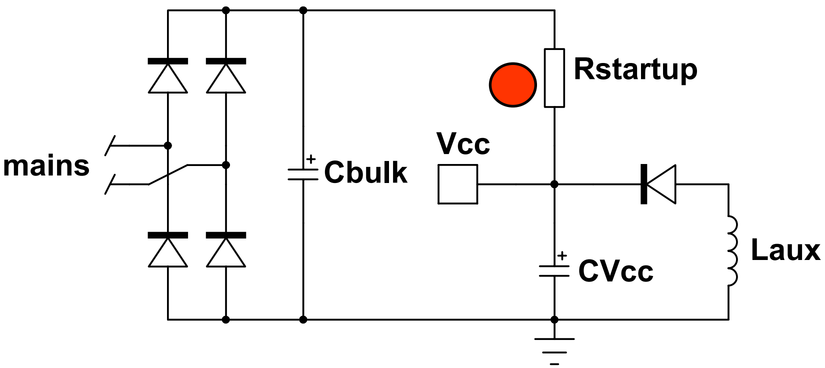
| Rated Input Power | No-load power consumption | | |
|---|---|---|---|
| | **Phase 1 1.1.2001** | **Phase 2 1.1.2003** | **Phase 3 1.1.2005** |
| ≥ 0.3 W and < 15 W | 1.0 W | 0.75 W | 0.30 W |
| ≥ 15 W and < 50 W | 1.0 W | 0.75 W | 0.50 W |
| ≥ 50 W and < 75 W | 1.0 W | 0.75 W | 0.75 W |

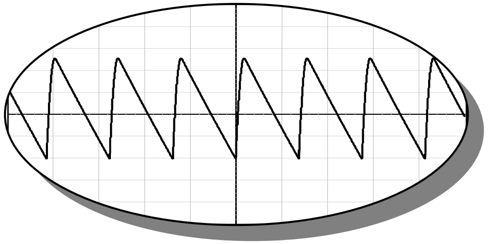
# Where are the *losses* coming from?



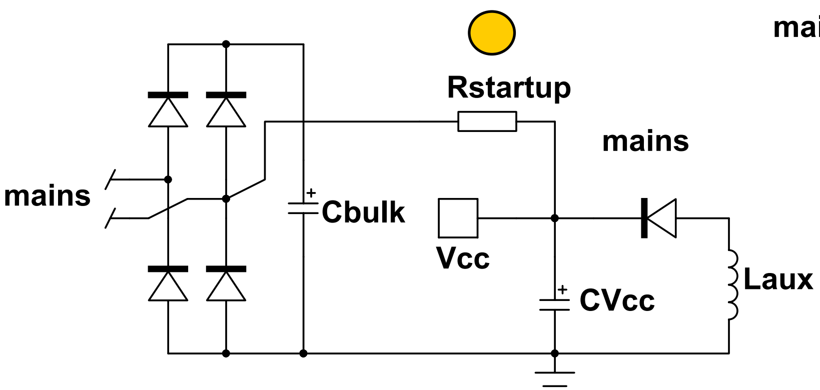

1. Capacitive losses: $\frac{1}{2} \cdot C \cdot V^2 \cdot fsw$
2. Biasing network
3. Controller current
4. Gate charge: $Qg \cdot fsw$
5. Start-up network

No-load losses can easily go up to 1W!



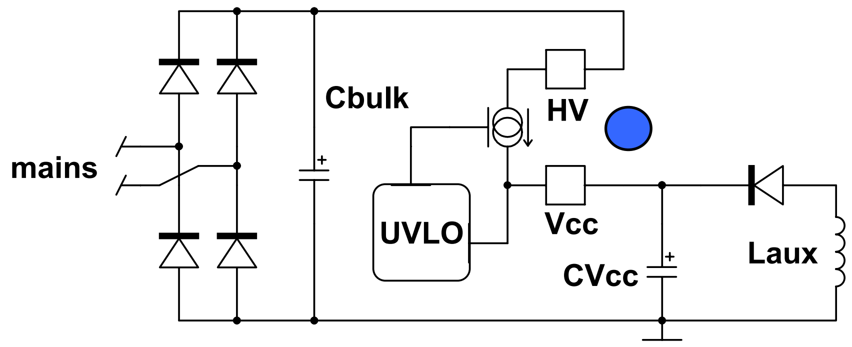



## Standard connection

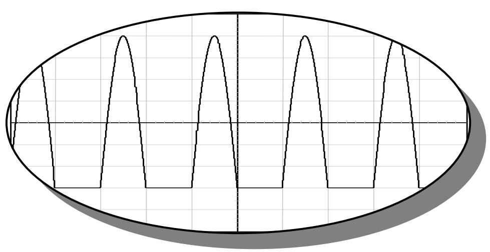



## Half-wave connection

Only *27%* in gain ☹




## High-Voltage Technology



Suppose we want to start-up in 250ms with:
CVcc = 22µF, UVLO = 12V
Istartup total (IC + capacitor) = 50µA
Universal mains input, 100 – 370VDC
A 250ms time sequence imposes a current of: $i = \frac{12 \cdot 22\mu}{250m} = 1mA$

- **Standard connection**: R = (100-12)/1m=88kΩ

→P@370VDC = 1.55W!

$$P = \frac{(Vbulk)^2}{Rstartup}$$

- **Half-wave connection**: 28kΩ

→P@370VDC = 1.22W!

$$P = \frac{(Vac)^2}{2 \cdot Rstartup}$$

- **High-voltage technology**:

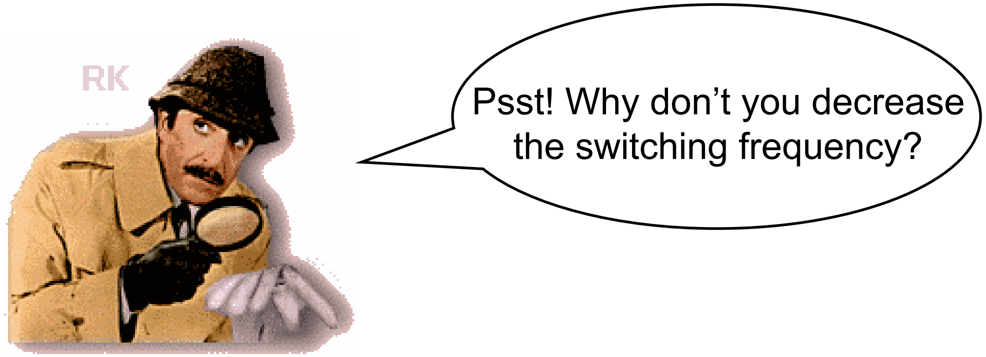
→Isource = 4mA, then startup time equals 66ms
→P@370VDC = 13mW!

$$P = 35\mu \cdot VDC$$

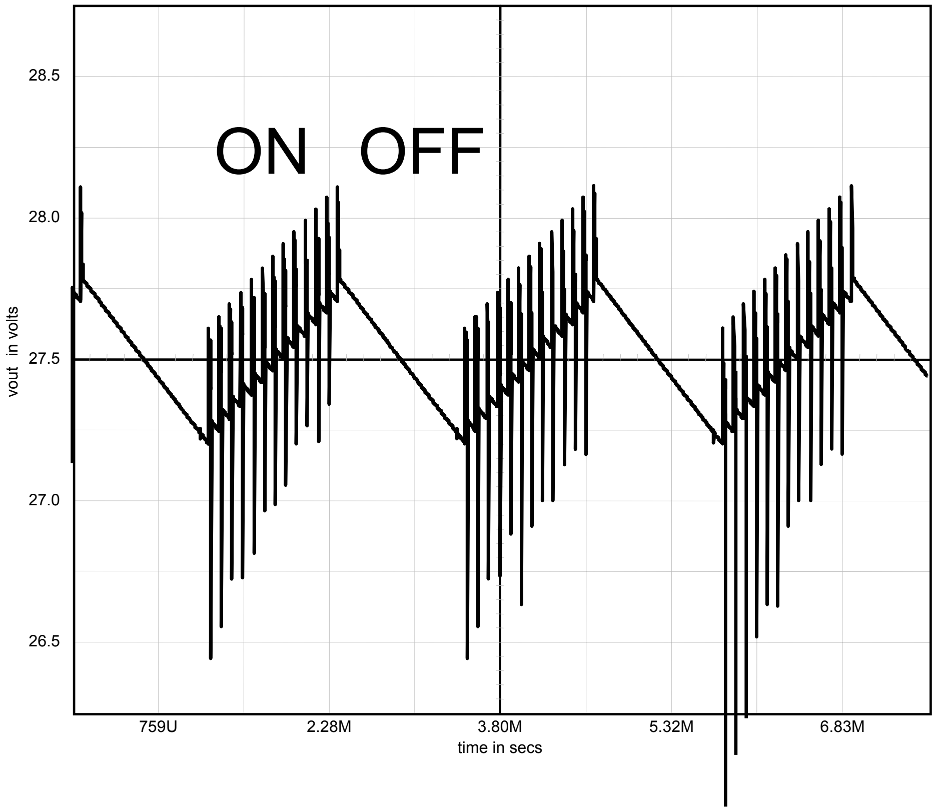
# **Switching frequency**: *THE* actor in the low-standby tragedy…

« Why not further reducing the duty-cycle? »

- Gate-charge losses are almost independent of duty-cycle
- MOSFET drain-node capacitive losses are not eliminated
- Controller internal activity is still important (all blocks active)
- Minimum duty-cycle is also limited to LEB + prop. delay



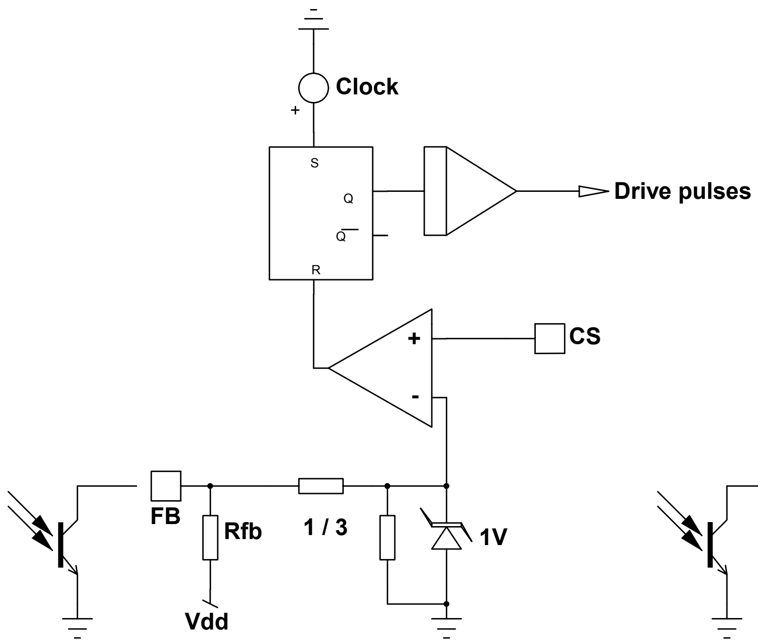
# The *first* approach: hysteretic regulation



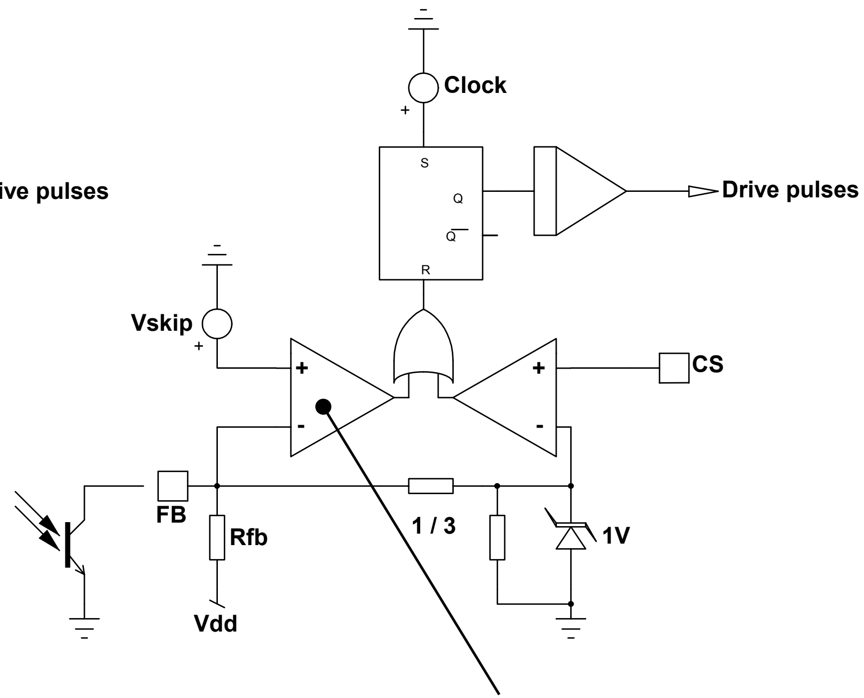

***Slicing the switching pattern…***

- introduced 20 years ago with the MC33063…
- also called…ripple regulator!
- generates a lot of noise
- Excellent natural standby!

## *Novel* approach: mixing ***fixed frequency*** and ***skip cycle***…



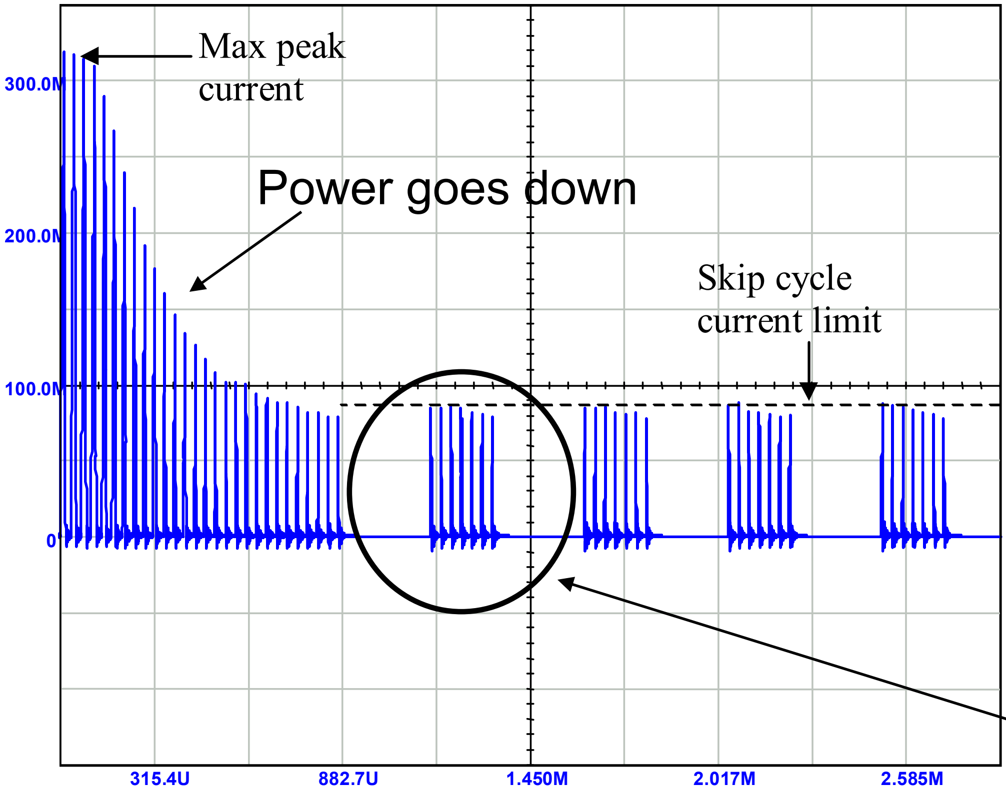

Standard CM controller

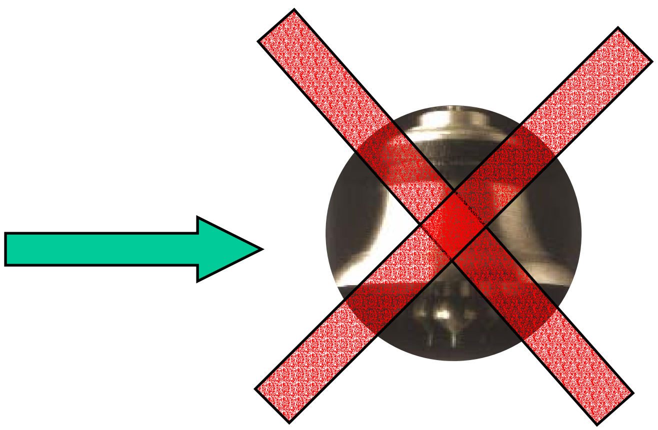



CM controller + skip comparator

NCP120X

# NCP120X for noise free operation in standby...

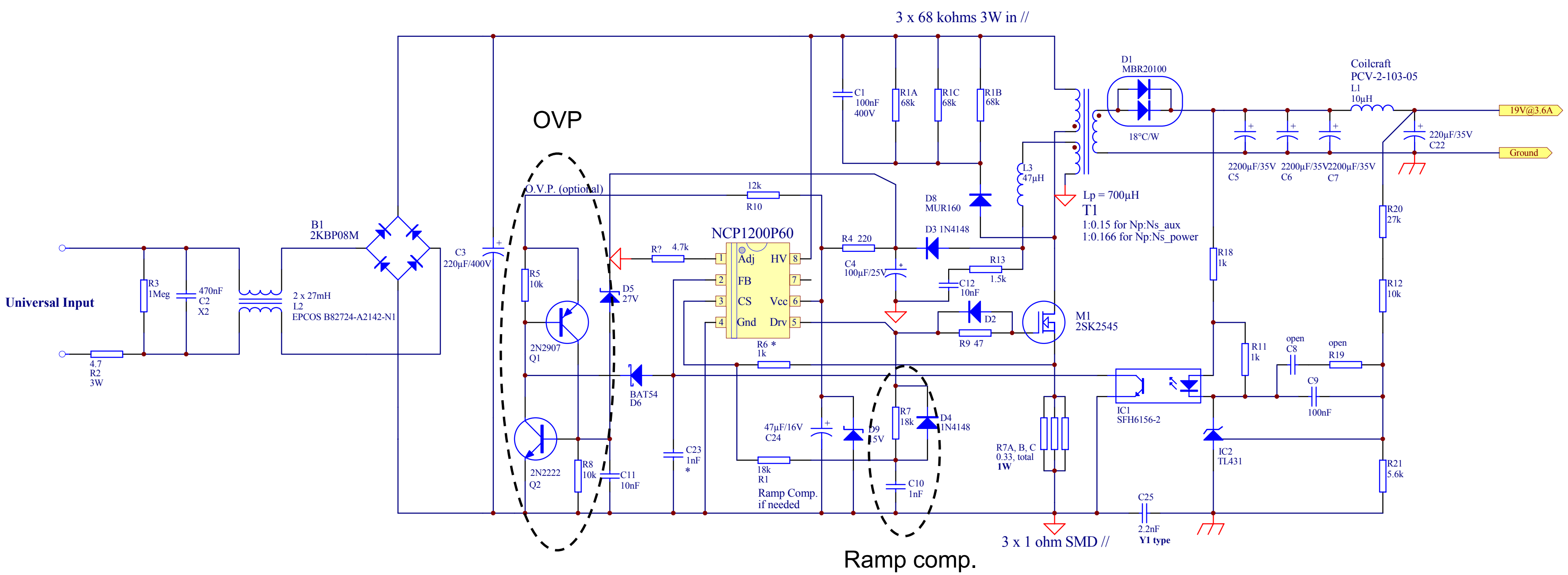


Cycle skipping in standby
Low peak current!

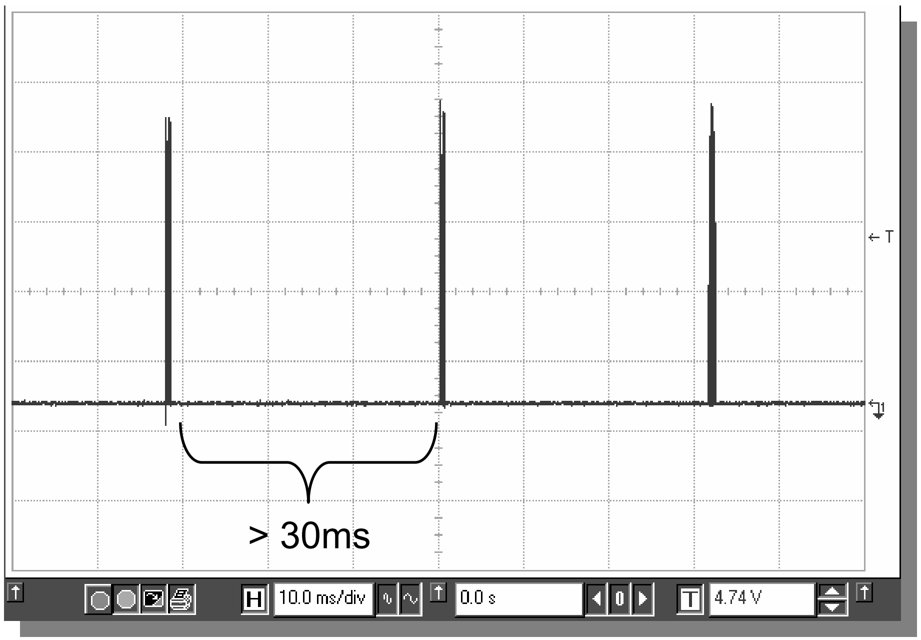
NCP120X

# A practical solution using *NCP1203/1217*…

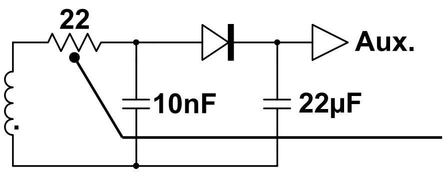



A 84mW@230VAC standby power at no-load was measured!

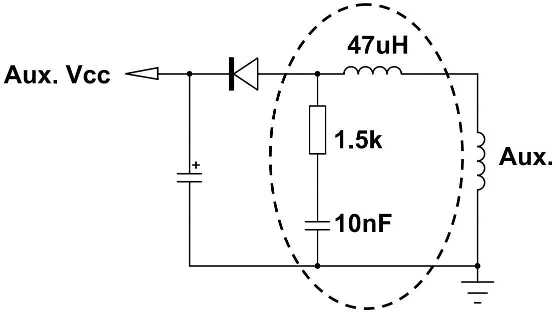
# The controller self-supply: a designer's *nightmare*




- burst frequency is low
- pulse packet is narrow
- can't afford to lose energy…



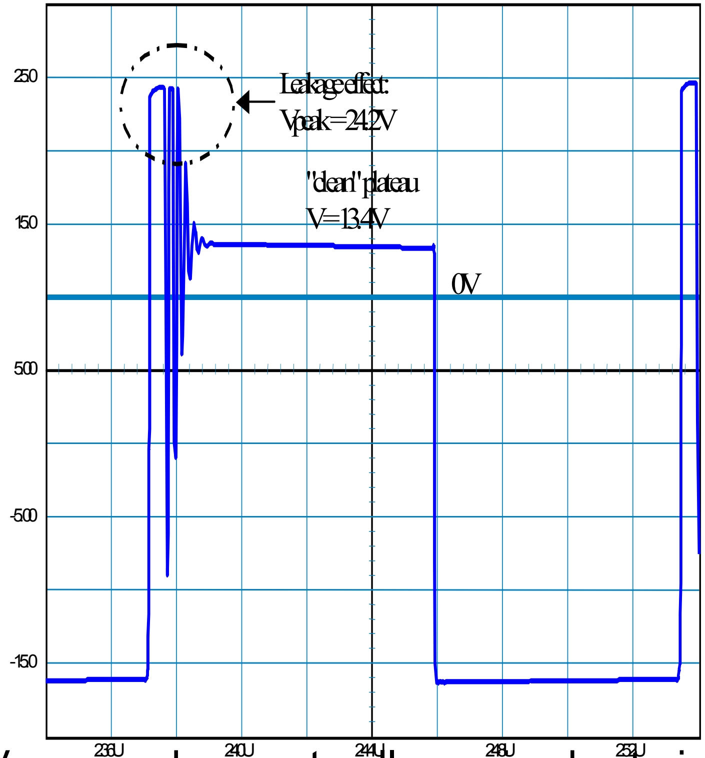

Too lossy!



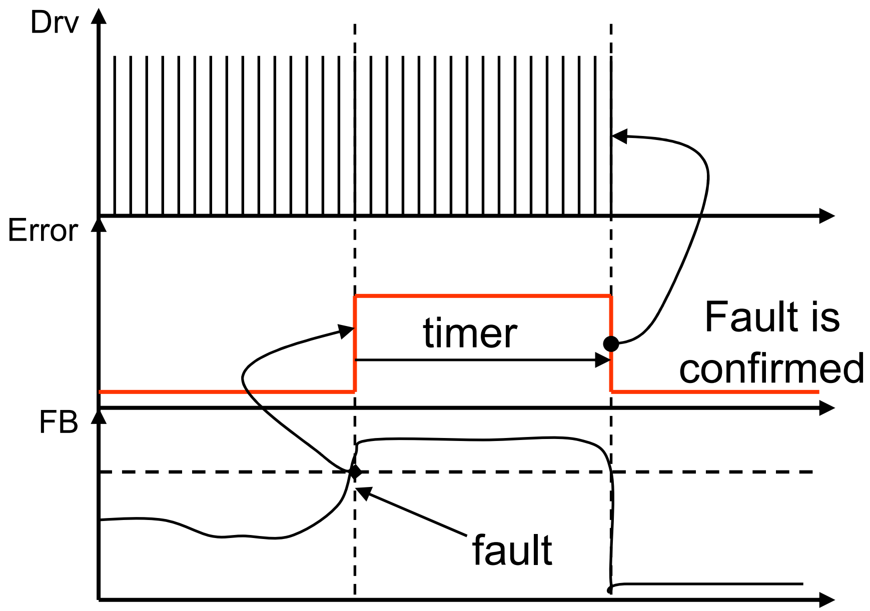

Damped LC filter

- increase the aux. turn ratio → degrades overload protection
- decrease the aux. turn ratio → can't self-supply the IC

# Fault detection ***independent*** of Vcc..




Vcc aux. does not collapse in short-circuit!




Decision point is *independent* of Vcc!

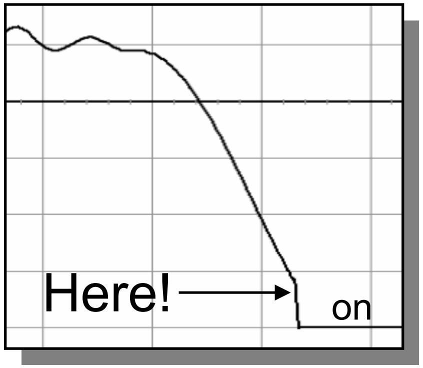
NCP1230

# Frequency reduction via ***Q***uasi-***R***esonance

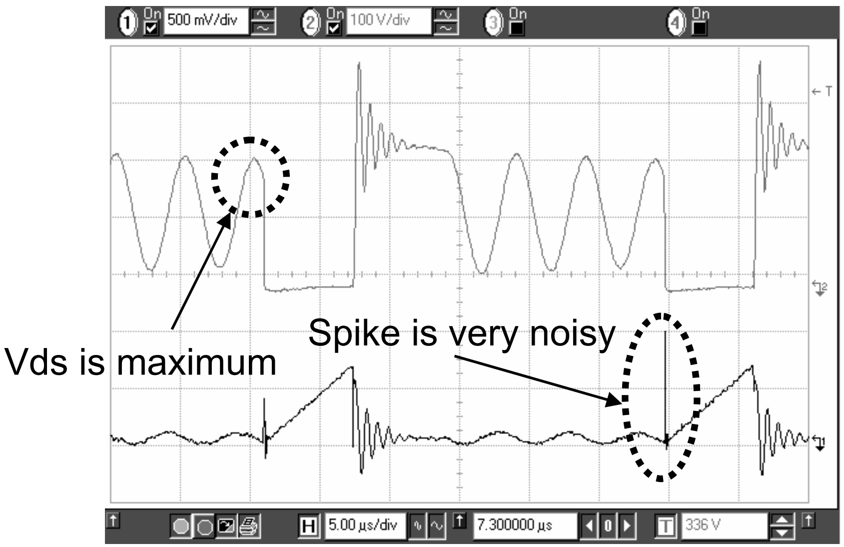
"Switching ON at the *minimum* drain-source voltage..."

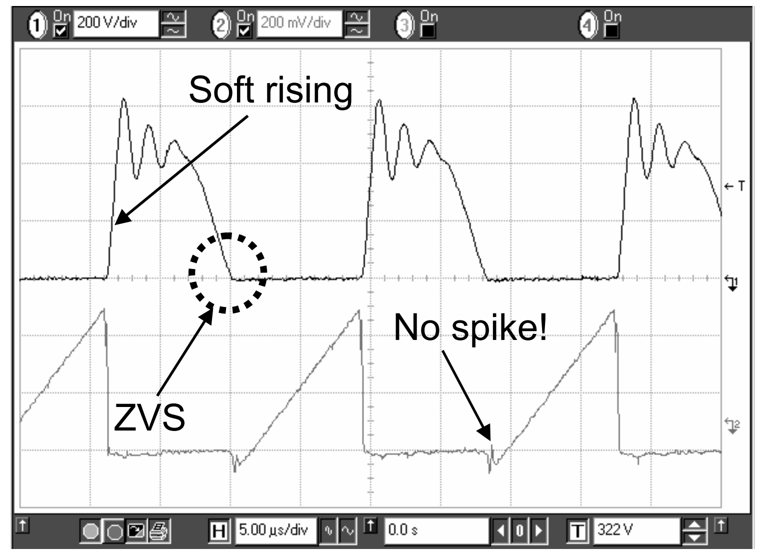
**It brings**:

- Soft switching ⇨ smaller MOSFET...
- ZVS ⇨ reduced Miller effect on Qg
- Less EMI noise ⇨ RF friendly
- Discontinuous conduction only ⇨ easy to stabilize
- Core reset offers better short-circuit performance
- With good transformers ⇨ no RCD clamp!

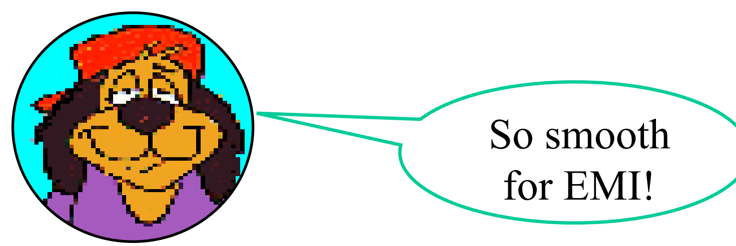


# What are *Hard* and Soft switching SMPS??

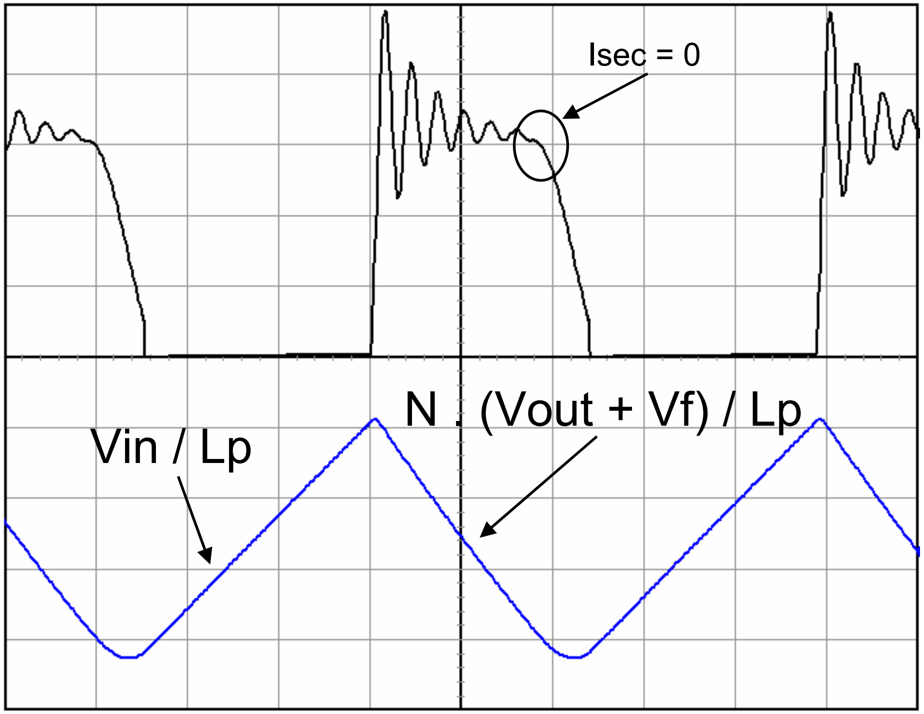






# Core reset detection ensures ***BCM****** operation



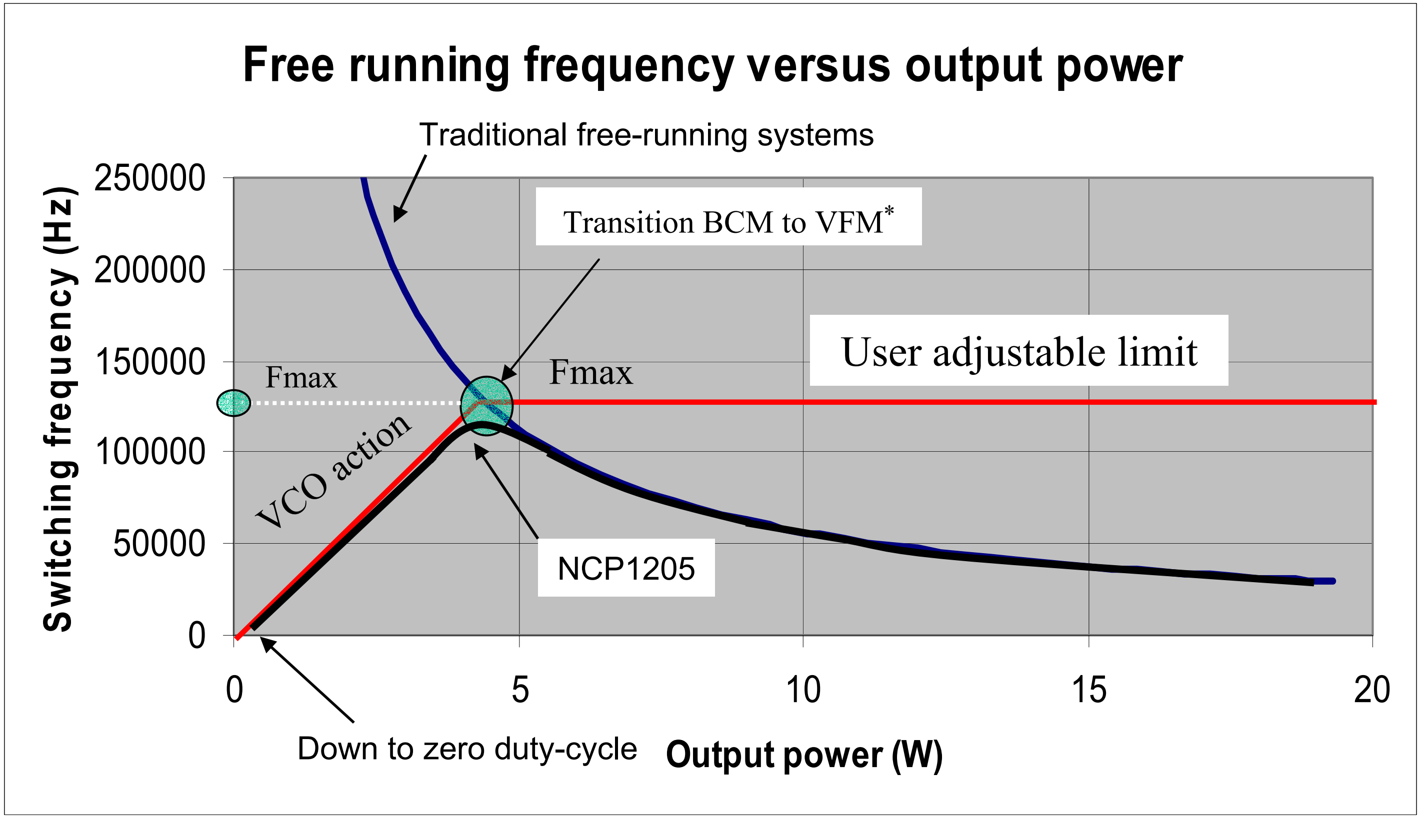

Switching period moves
w. line and load variations:

$$Tsw = Ip \cdot Lp \cdot \left[ \frac{1}{Vin_{DC}} + \frac{1}{\left[ \frac{Np}{Ns} \cdot (Vout + Vf) \right]} \right]$$

Bulk ripple introduces
natural EMI jittering!!

* BCM = Borderline Conduction Mode

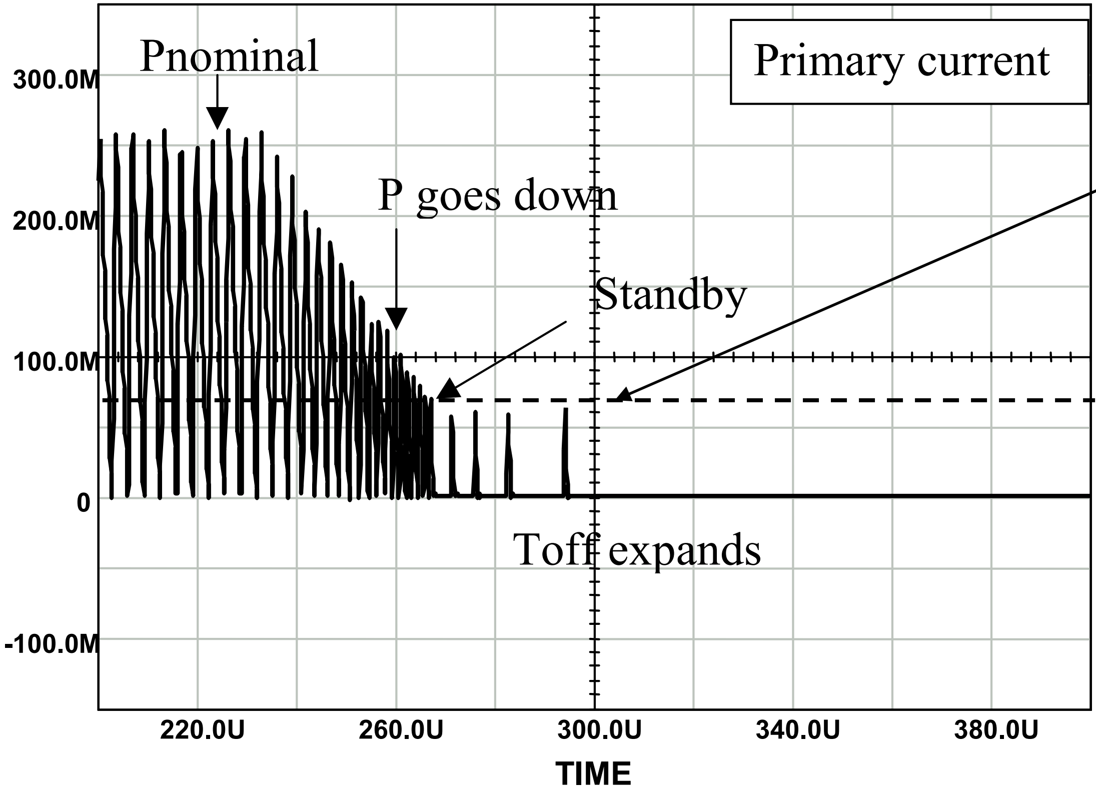
# Free-running operation **needs** a frequency clamp!




* VFM = Variable Frequency Mode

NCP1205

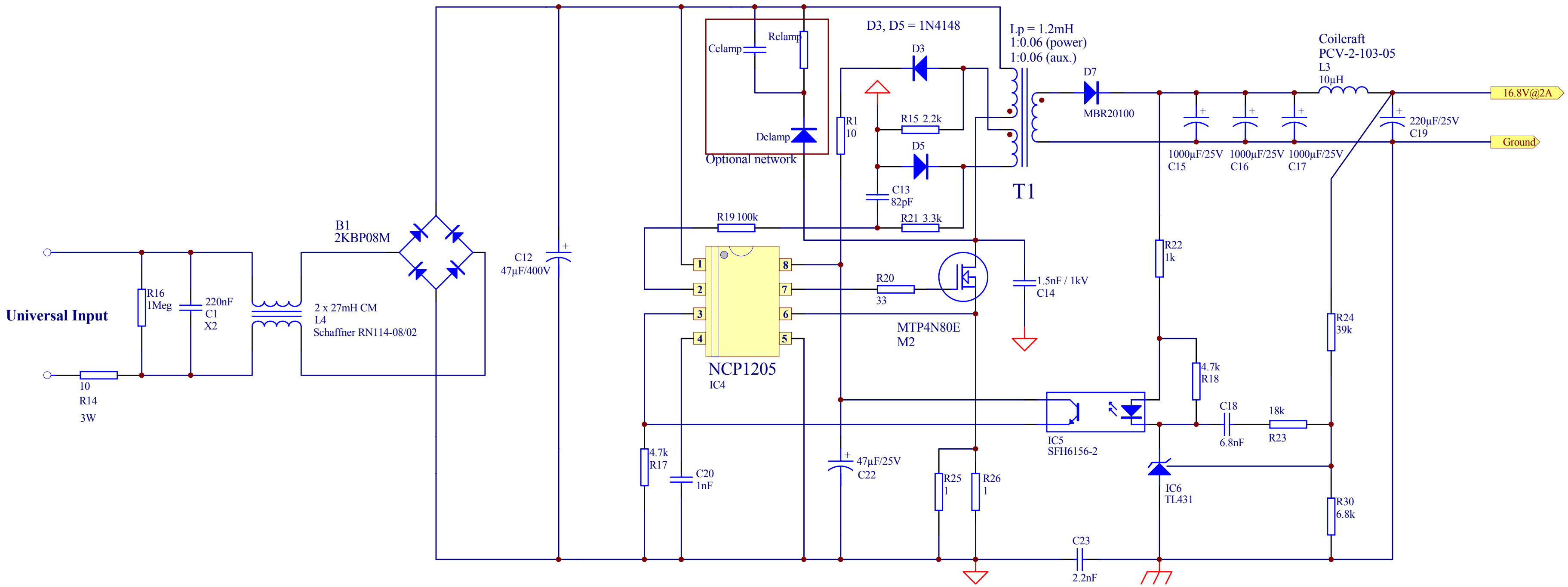
# The *Feedback* voltage determines the operating mode




Frequency foldback takes place at 1/3rd of the max. Ip
No noise!

NCP1205

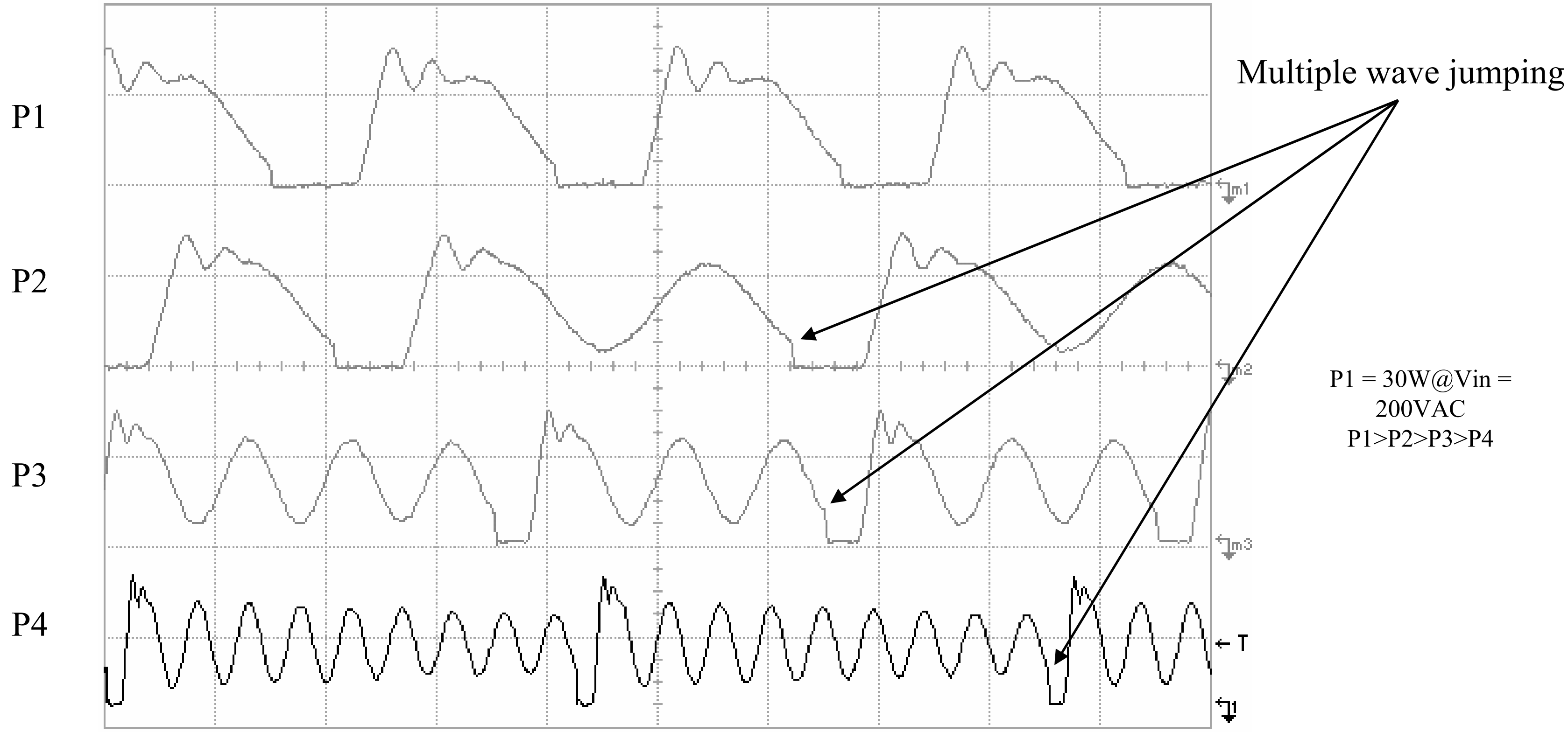
# A *30W* universal mains demonstration board




Pin @ no-load = 108mW@240VAC!!

NCP1205

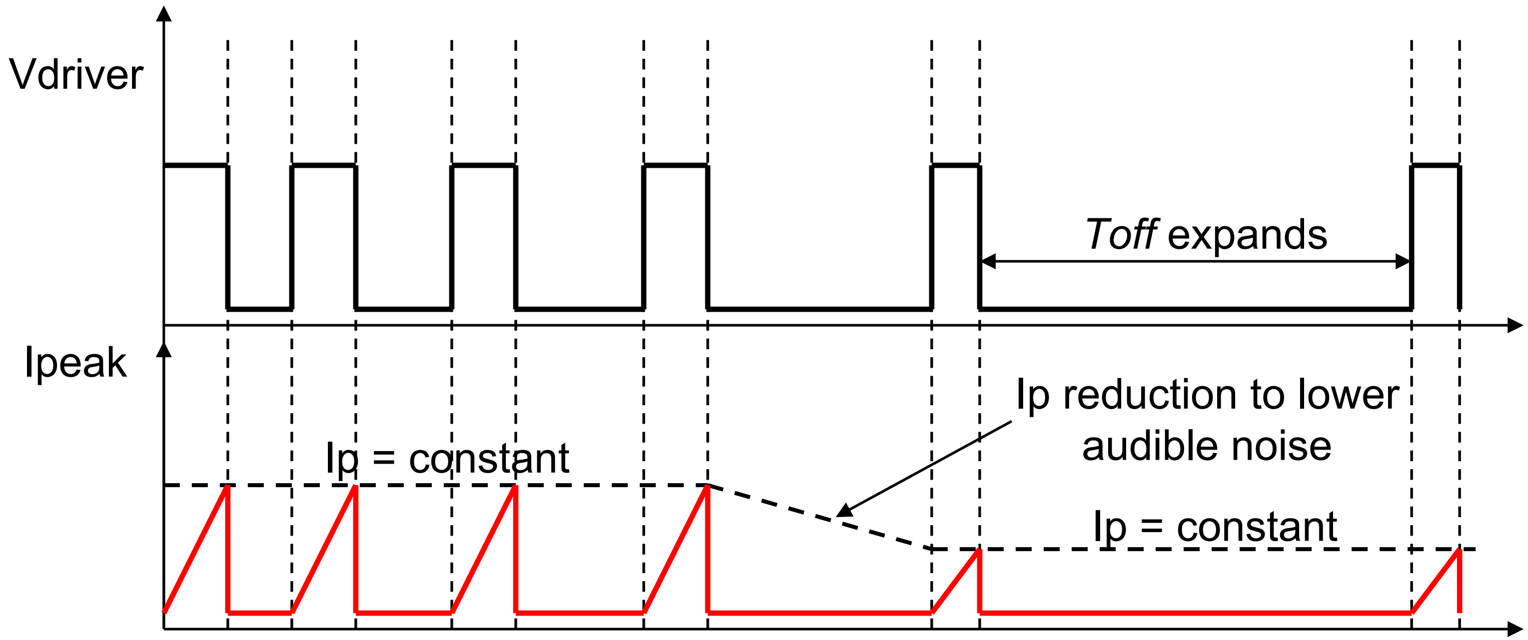
# Drain-source waveforms at different power levels




P1 = 30W@Vin = 200VAC
P1>P2>P3>P4

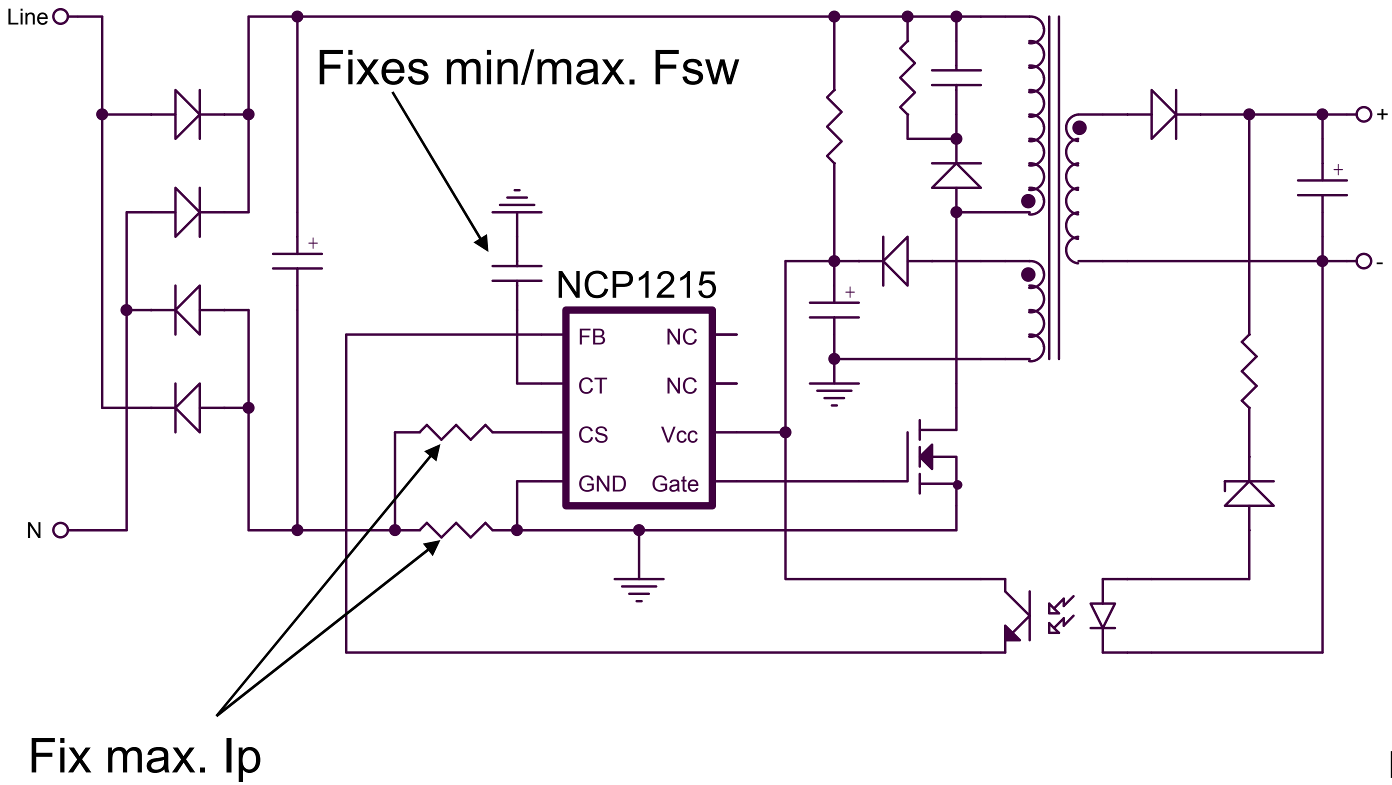
NCP1205

# Frequency reduction via ***Toff*** expansion



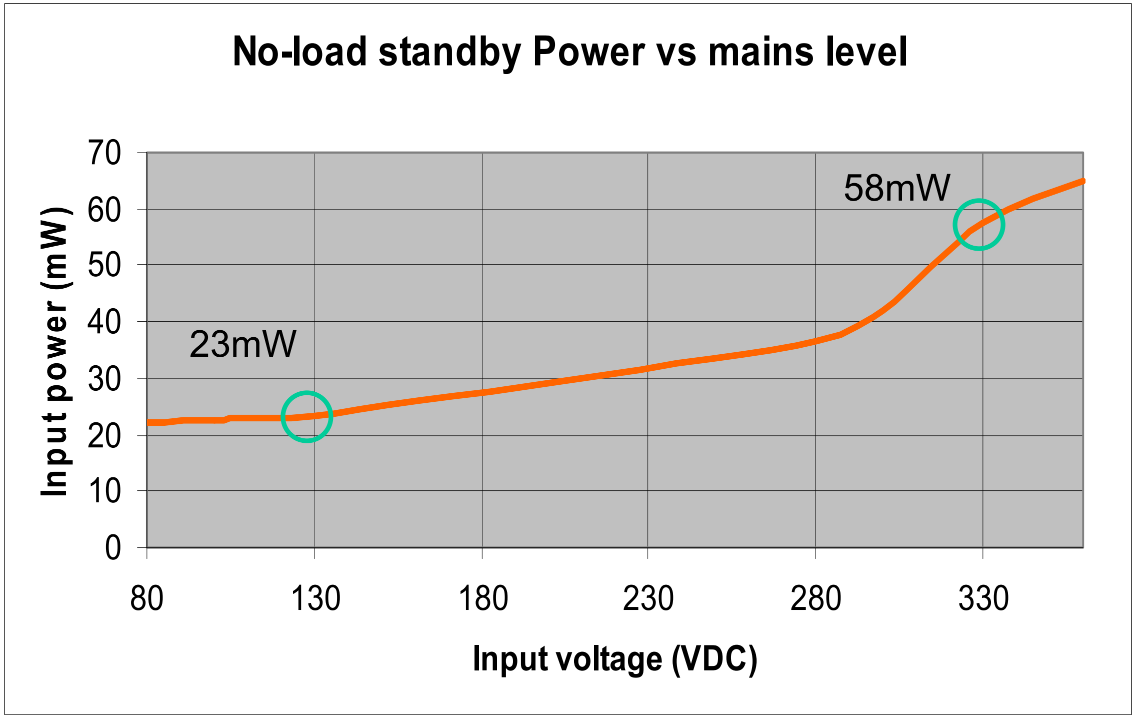

NCP1215

# Frequency reduction via *Toff* expansion



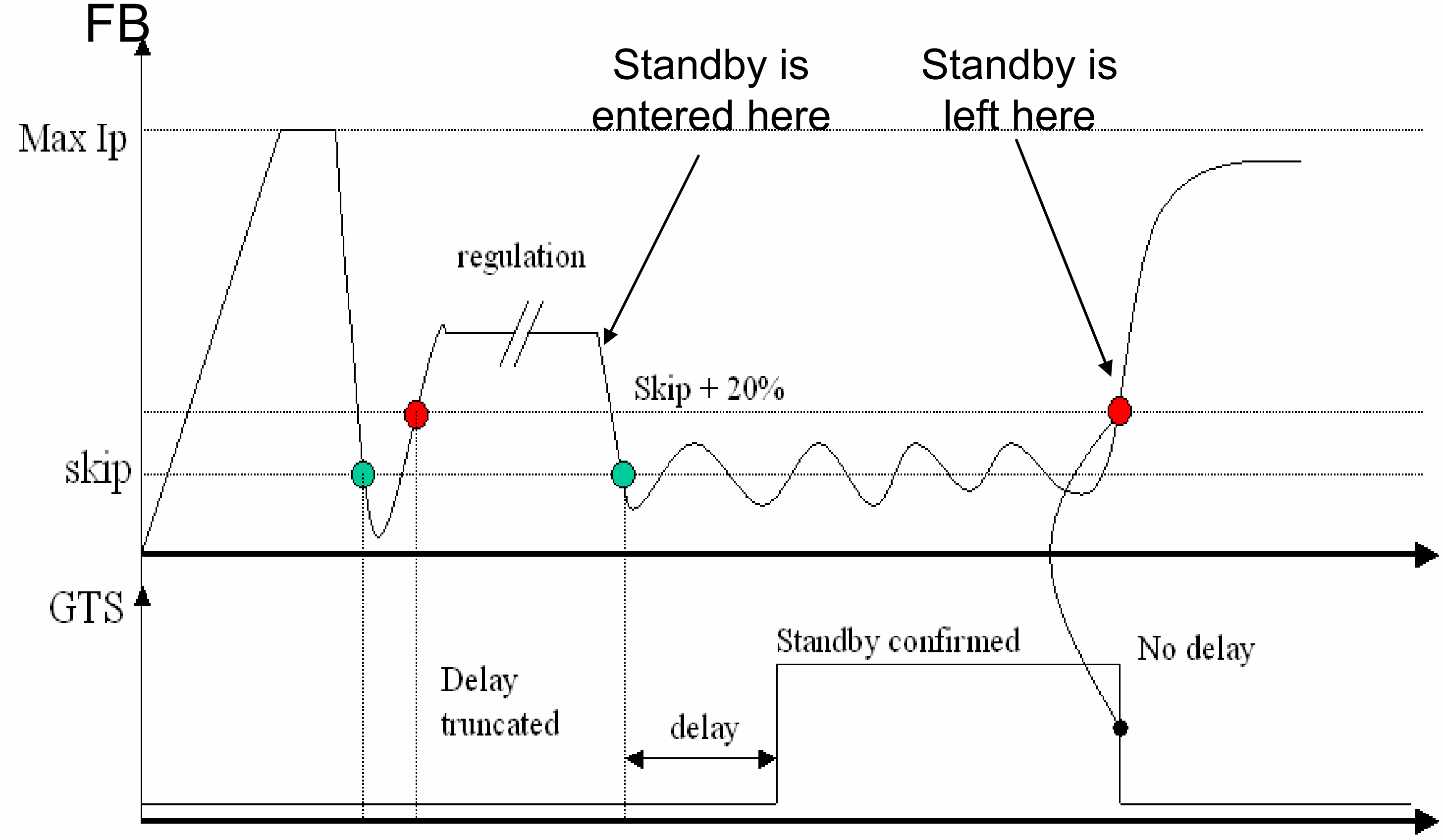

NCP1215

# *Toff* expansion brings *extremely* low standby…



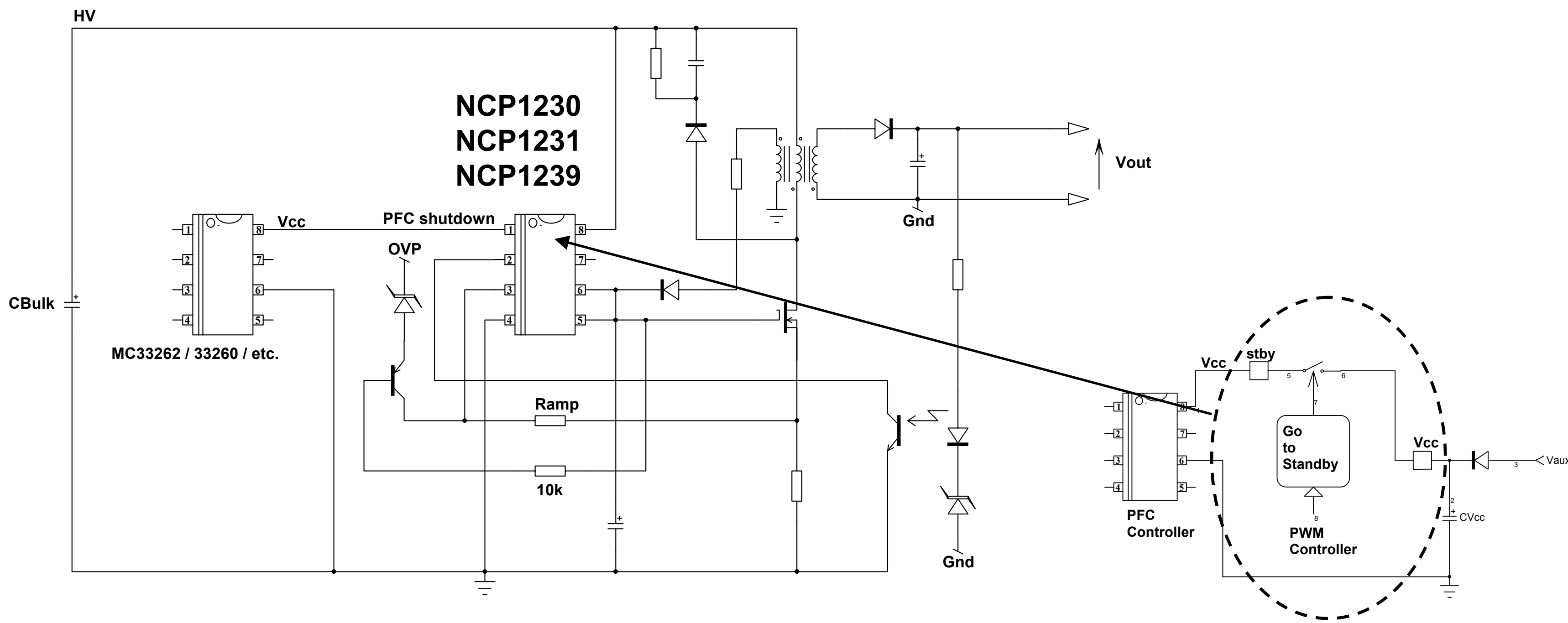

NCP1215

# **P**ower **F**actor **C**orrection – observing the **FB** signal



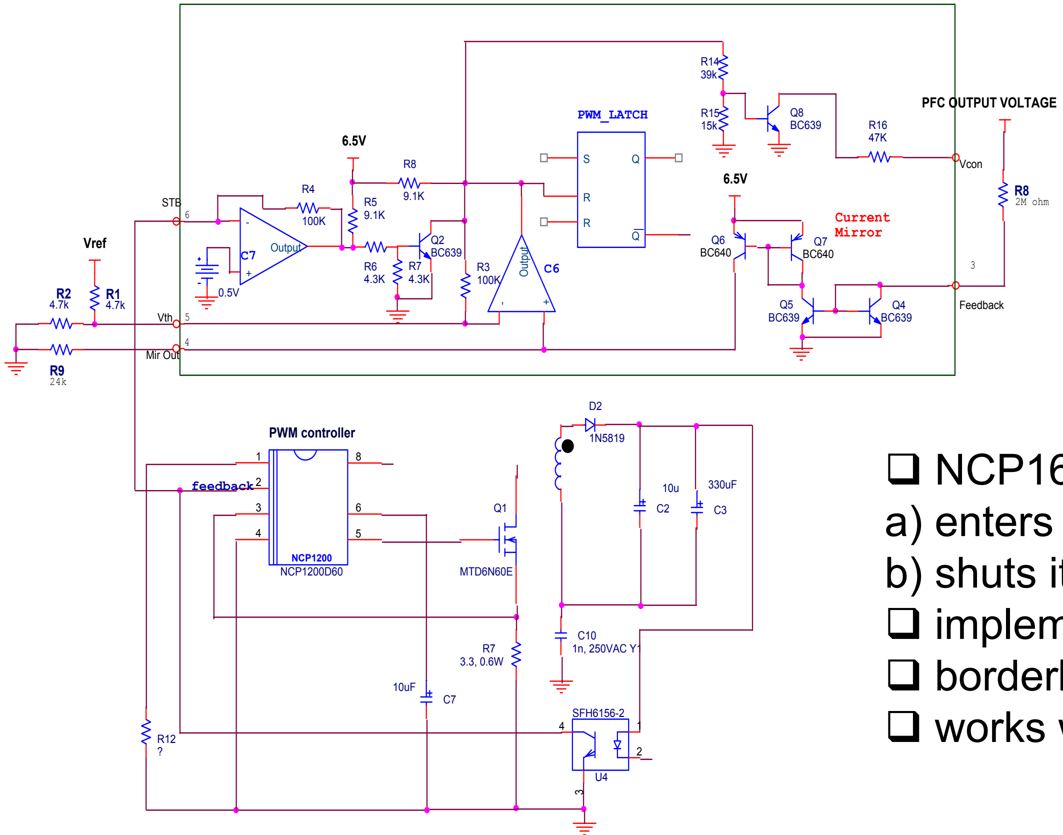

NCP1230

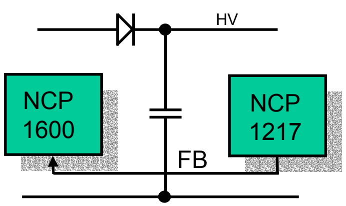
# Power Factor Correction – standby improvement




Shut-down your PFC in standby-mode and pass the 100mW barrier…

# Power Factor Correction – auto-shutdown controller

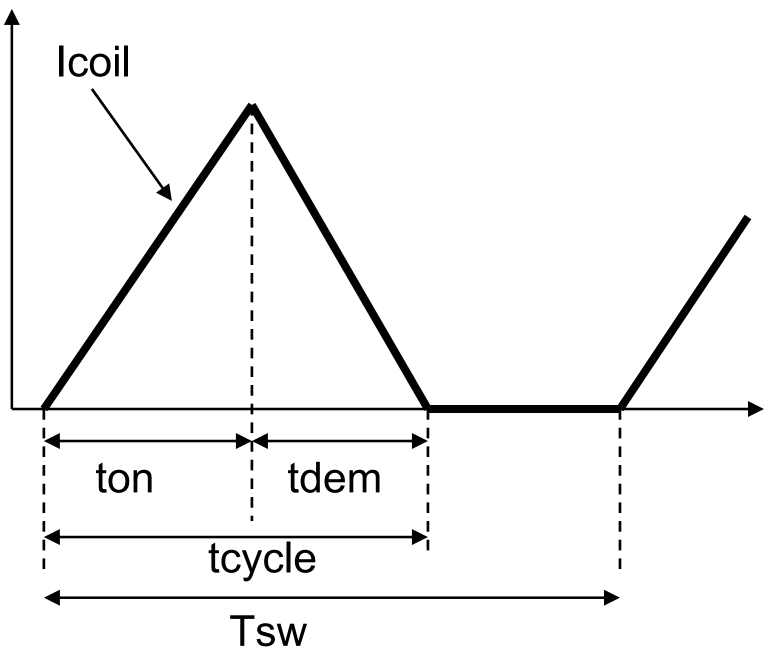



- ❑ NCP1600 observes the FB signal:
- a) enters skip mode and maintains Vout
- b) shuts itself off until normal mode
- ❑ implements follow-boost mode
- ❑ borderline operation with Fsw clamp
- ❑ works with any PWM controllers!

NCP1600

# **P**ower **F**actor **C**orrection – **first** fixed frequency DCM!




$$d_{cycle} = \frac{t_{cycle}}{Tsw} = \frac{ton + t_{dem}}{Tsw}$$

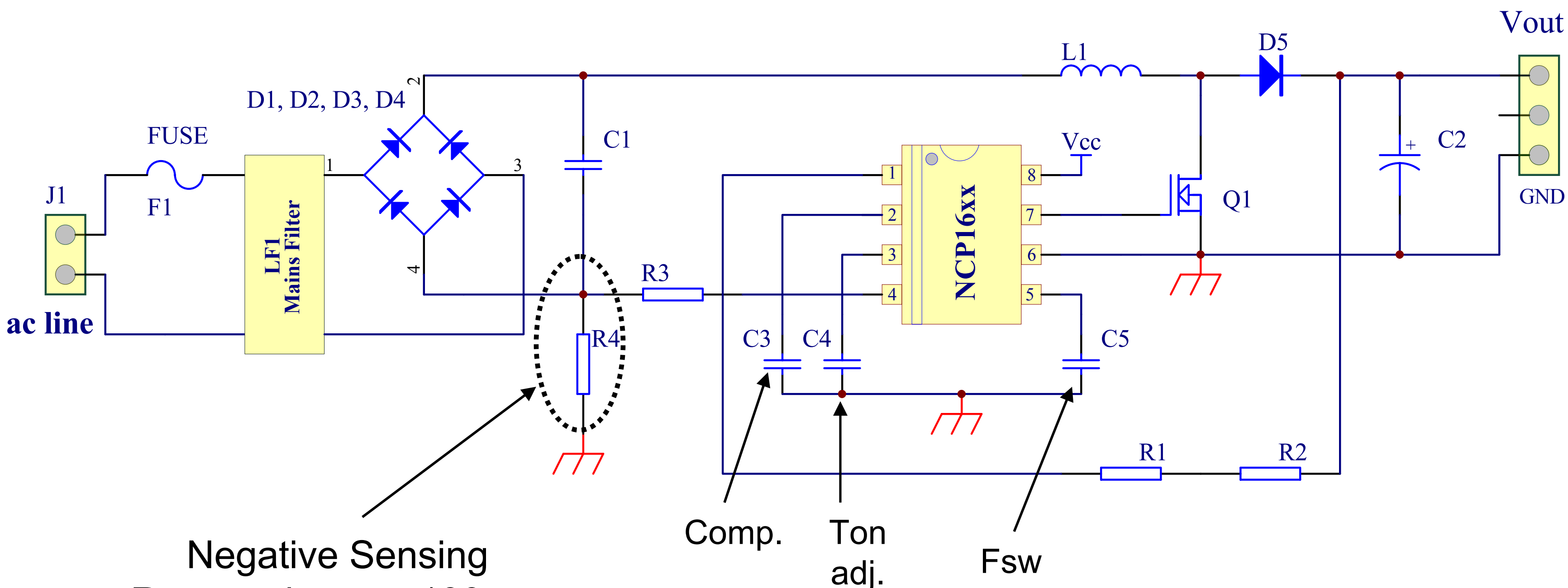
$$\langle Icoil \rangle_{Tsw} = \frac{Vin}{2 * L} \boxed{* \left( ton * d_{cycle} \right)}$$

Keeping this term constant
<Icoil> follows Vin…

**NCP1601** principle of operation (patented by ON)

NCP1601

# Power Factor Correction – **ease** of implementation

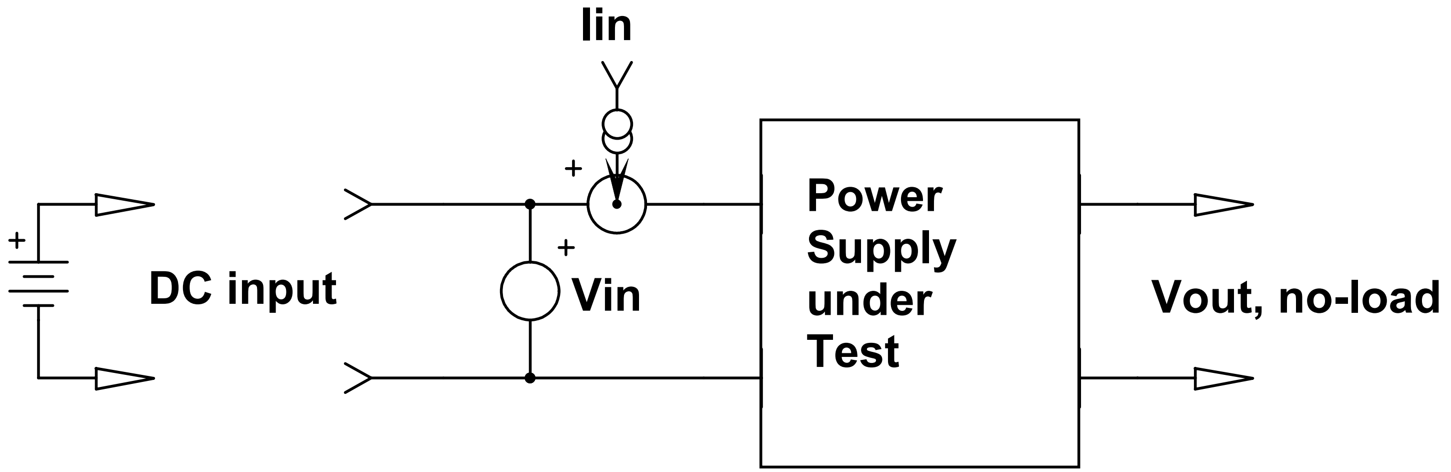



Negative Sensing
Rsense down to 100mΩ
Secured start-up

**NCP1601** a truly simple application schematic!!

NCP1601

# How to measure *low* standby power?



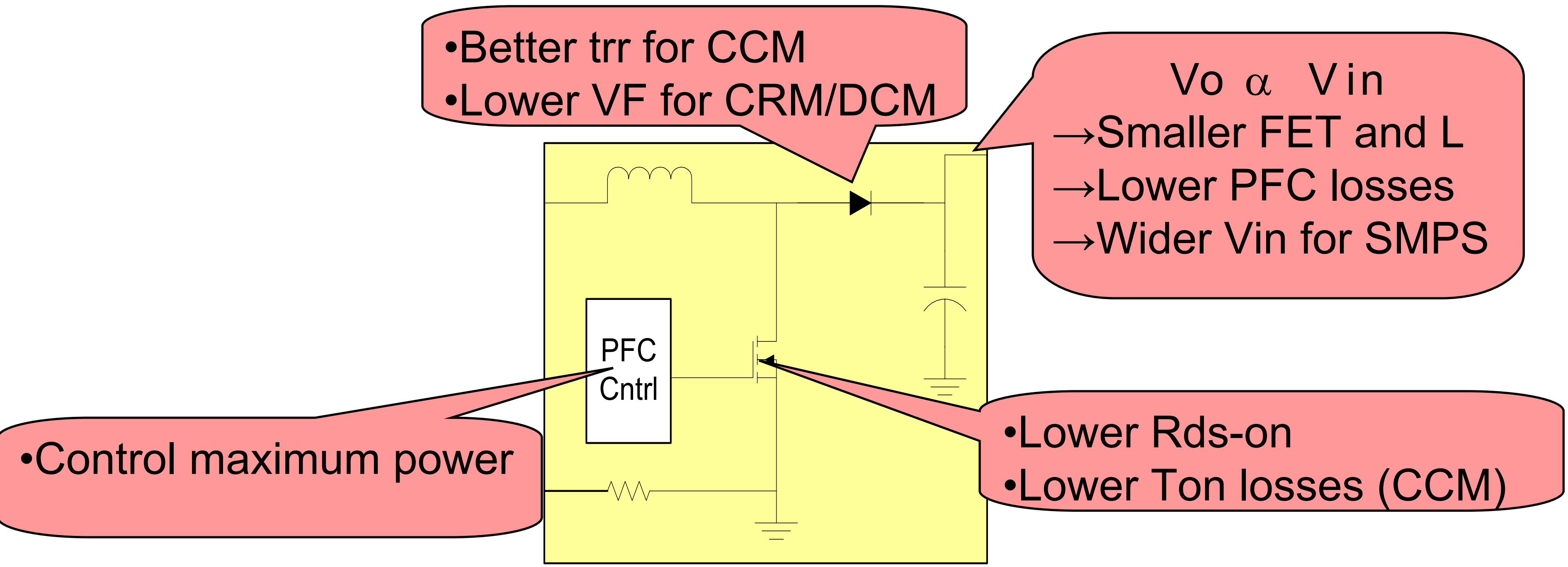

• using a DC supply (e.g. 325V) and measuring incoming I and V
→ the best is to use a good old needle amp-meter which mechanically integrates bursts…
→ the difference between DC results and AC results is around 10-15% more for AC.
• use a wattmeter (highest current sens.) toggled in accumulation mode and integrate W-hours.

# Summary

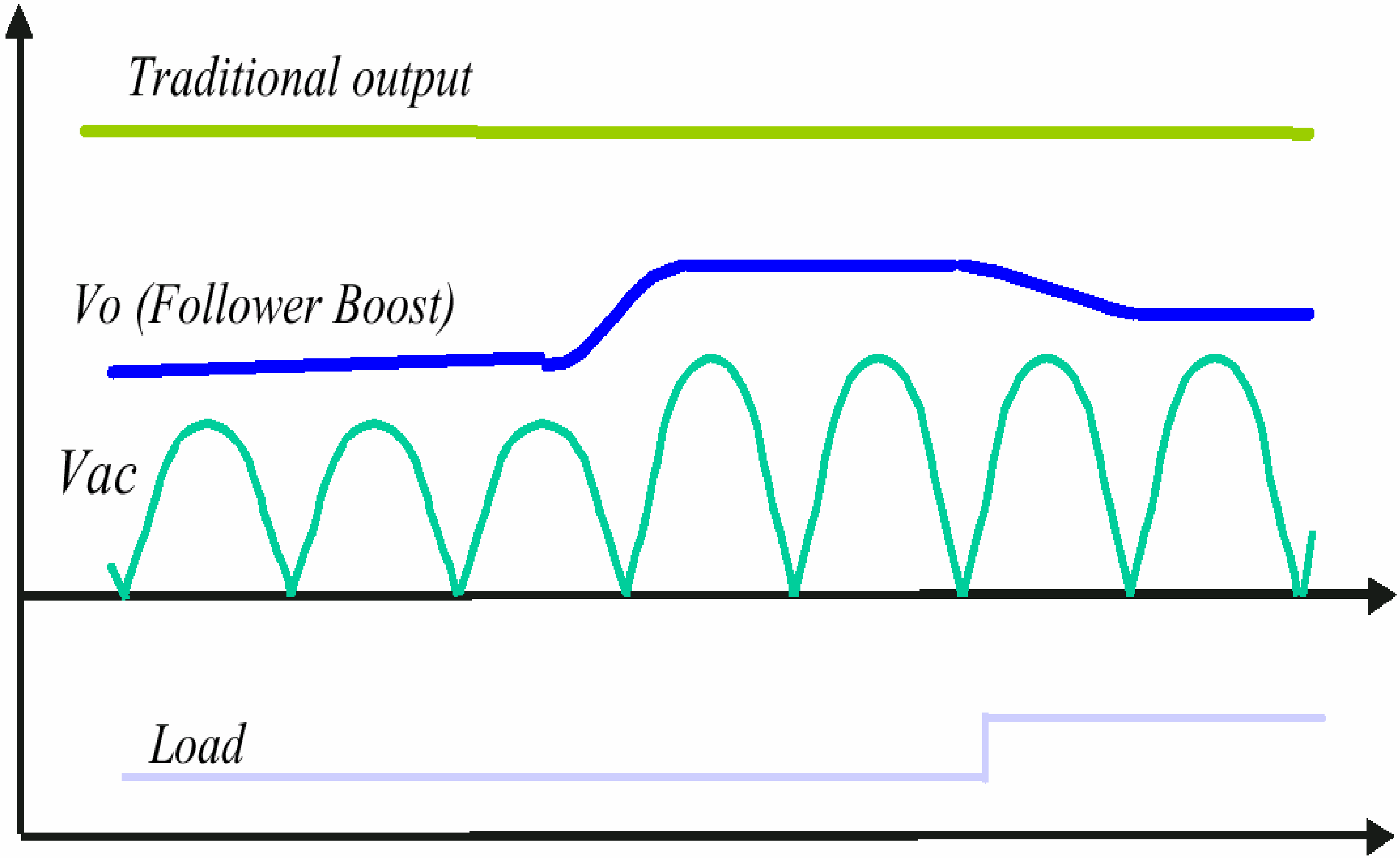
• **Skip cycle** offers a simple mean to improve standby:
❖ cheapest method to slice the switching pattern
❖ combined with a startup source, it gives good results
→ It generates some output ripple
→ If the skip occurs at high peak, acoustical noise can be heard
• **Free-running Frequency foldback** requires a more complex controller:
❖ implement ZVS operation
❖ offers soft transition between normal operation and light load
❖ generates lower ripple level compared to skip
→ The controllers gains in complexity
→ Discrete valley jumps can make noise
• **Quasi-fixed Ton, Toff expansion** further simplies the control section:
❖ ease of implementation, both on silicon and final circuit
→ Audio range operation requires peak compression

# Improving PFC Efficiency

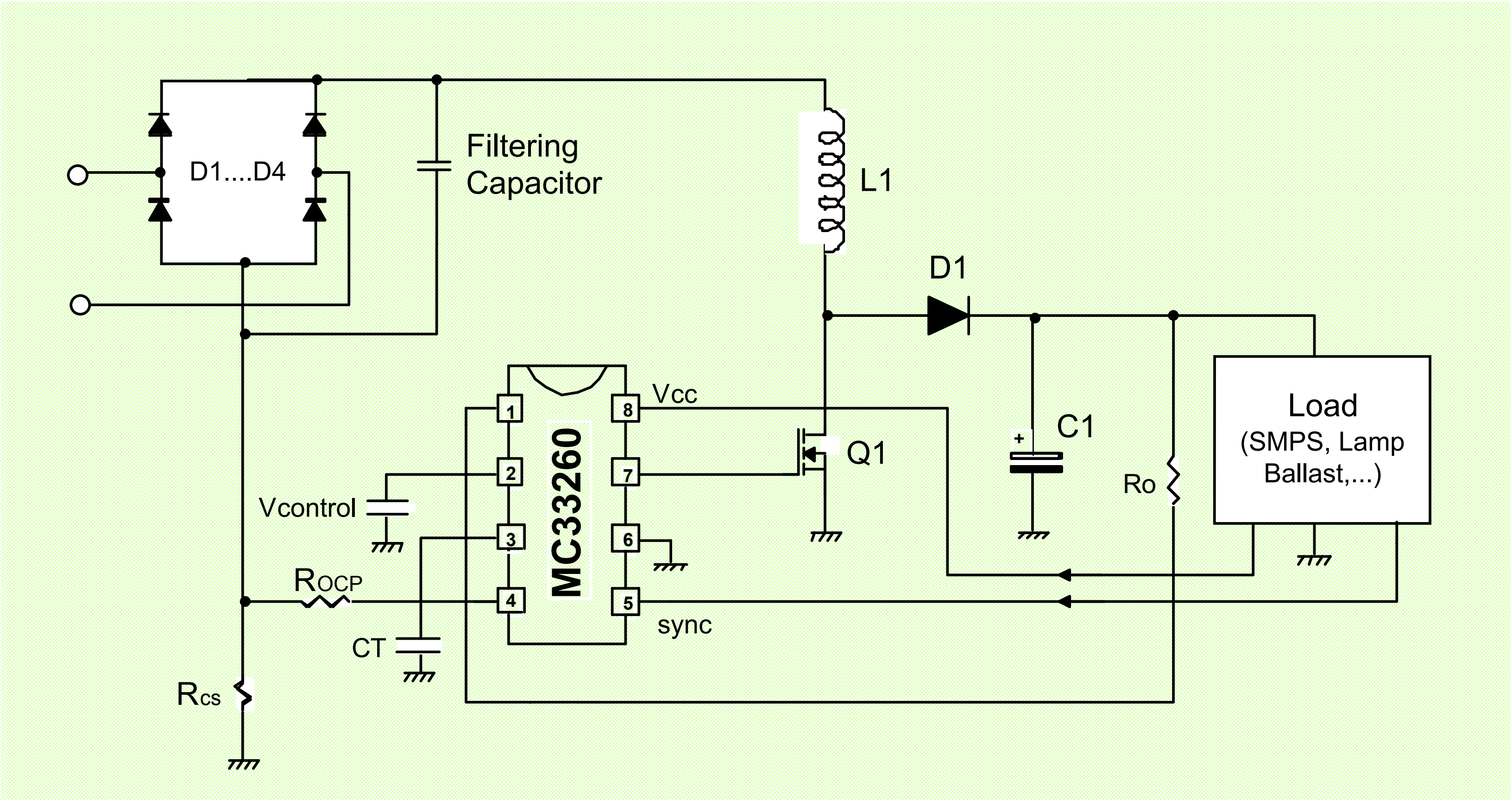
- CCM for higher power, CRM/DCM for lower power
- Topology improvements drive component changes



# Follower Boost Waveform (MC33260, NCP1600)



# MC33260 – Apps Diagram




Vo: 200-400 V => •33% Reduction in Conduction Losses
•43% Reduction in Inductor Size

# NCP1650 - CCM PFC Control


### Typical Applications

- *power up to 5 kW*
- Server Power Converters
- Front end for Distributed Power Systems
- Desktop Power Systems

| Features | Benefits |
|---|---|
| • Average Current Mode PWM | Unity Power Factor |
| • Fixed Frequency Operation | Predictable Filtering Requirements |
| Continuous or discontinuous mode operation | User Flexibility |
| Shutdown Function | Helps Meet Standby Regulations |
| ***Fast Line/Load Transient Compensation*** | Better Performance to Line or Load Changes |
| • Over Voltage Protection | High Reliability |
| • ***Accurate Power Limit*** | Allows use of smaller power components |
| • Current Limit | Avoids excessive heating |
| • Brownout Protection | |

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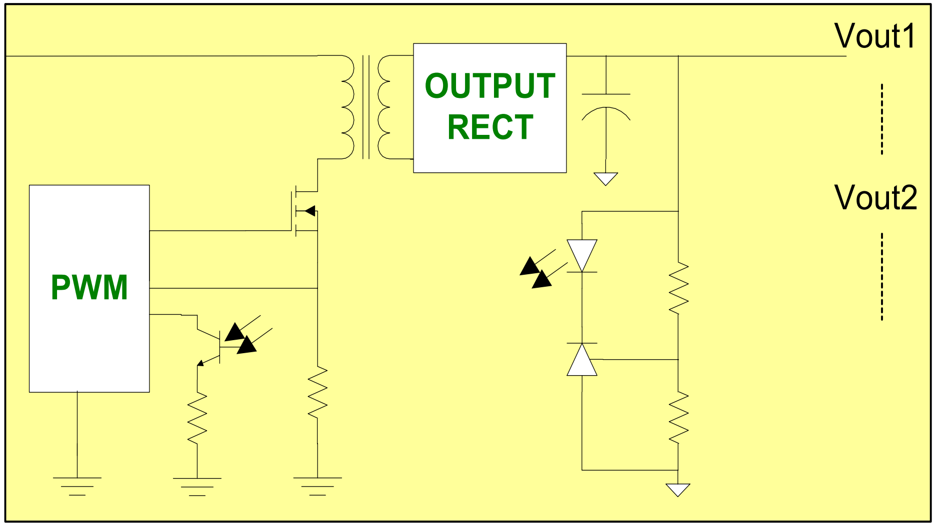
# NCP1650 - Competition

| Power Limit Specs | Min | Typ | Max | Unit |
|---|---|---|---|---|
| **NCP1650** Power Multiplier Gain (-40 to 125 deg C) | 11.8 | 12.8 | 13.3 | 1/V |
| | 100 | 108.5 | 112.7 | % |
| UCCxxxx Power Limit (-40 to 85 deg C) (based on $V^2$ scheme) | 375 | 420 | 485 | µW |
| | 100 | 112 | 129.3 | % |

- NCP1650 cuts the excess power requirement by more than 50% (from 29.3% to 12.7%)
  - These numbers come directly from spec tables
- Other PFC controllers have NO power limiting or offer less accuracy compared to the above

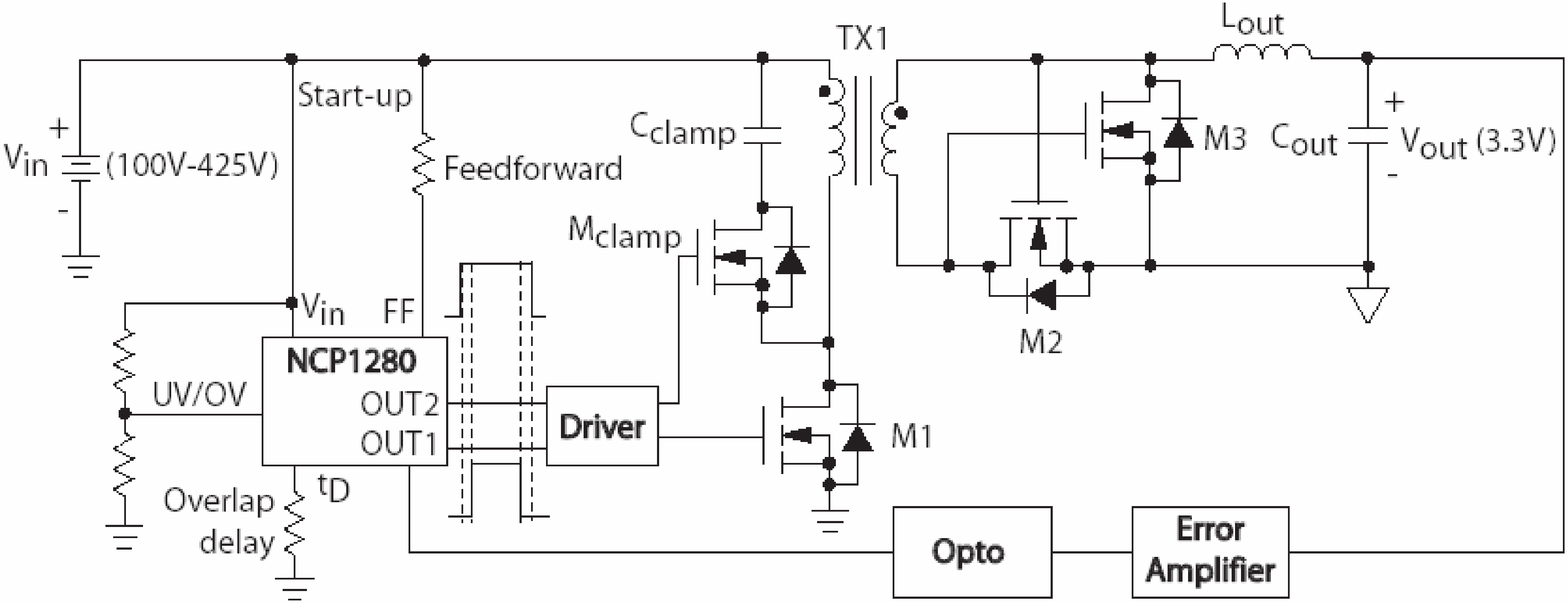
# Improving SMPS Efficiency

- Topology Upgrade (Flyback -> Forward -> Bridge)
- Soft-switching extends range (QR, Active clamp etc)
- Component level improvements (FET, sync rec etc)



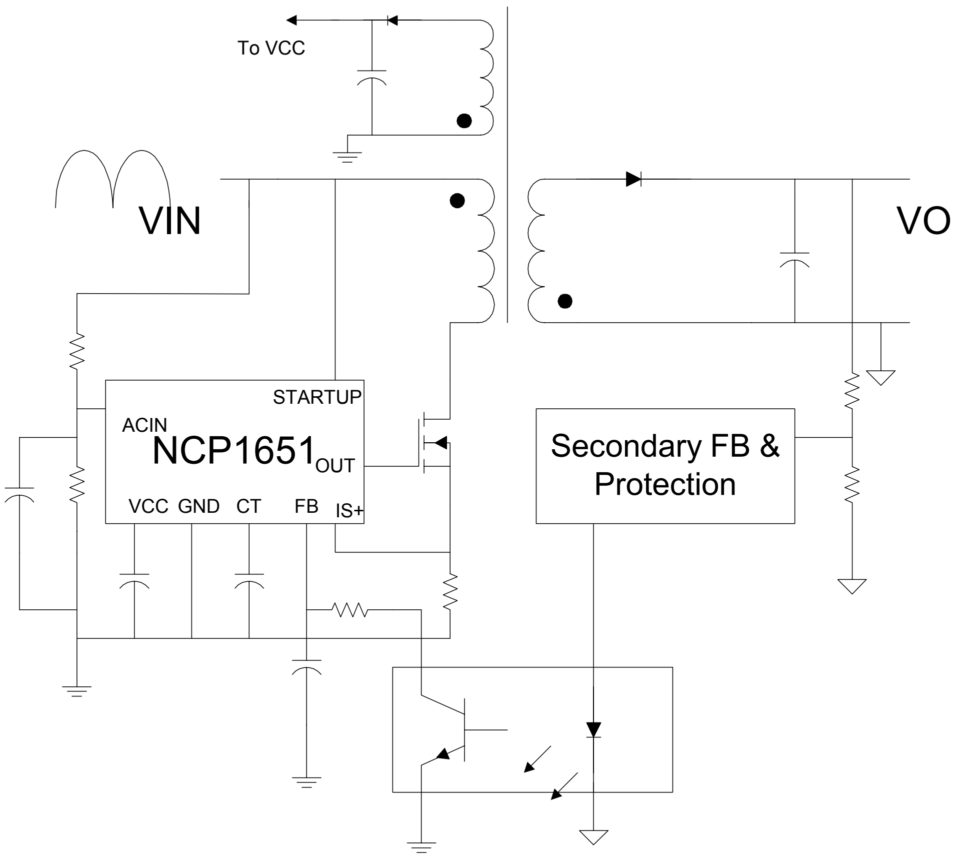
# Active Clamp Topology

- Off-line Active Clamp Forward Converters
  - *Clamp Circuit (Switch and cap) resets the core*
  - *This topology allows soft-switching*
  - Synchronous Rectification available naturally



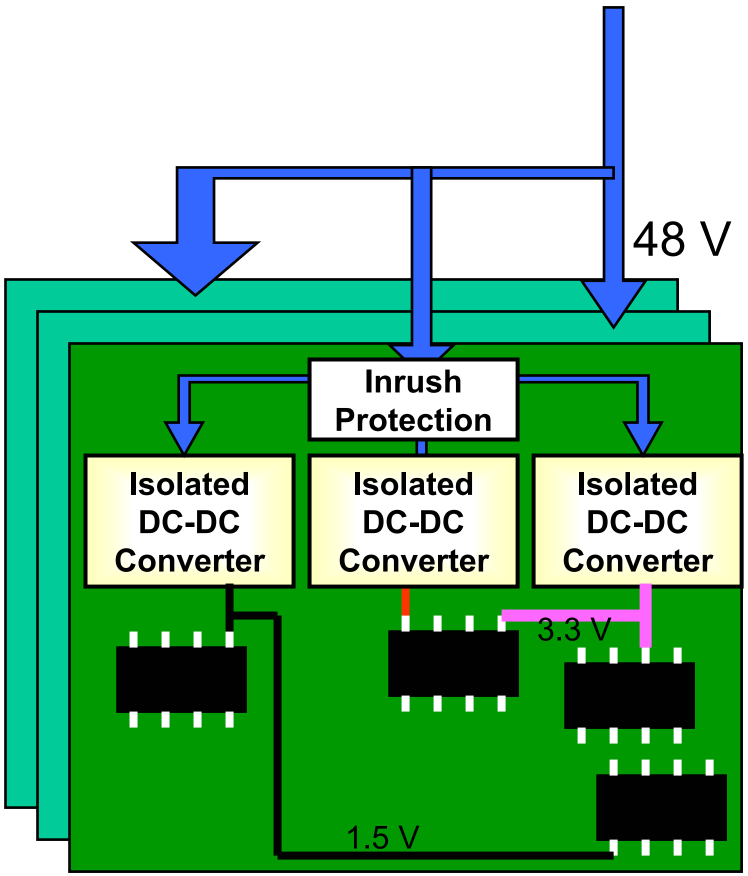
# Single Stage Option

- Elimination of a power processing stage
- Requires single switch, single magnetic, single rectifier & single cap
- Low frequency output ripple can be high
- Ideal for mid-high (12-150) voltage output systems

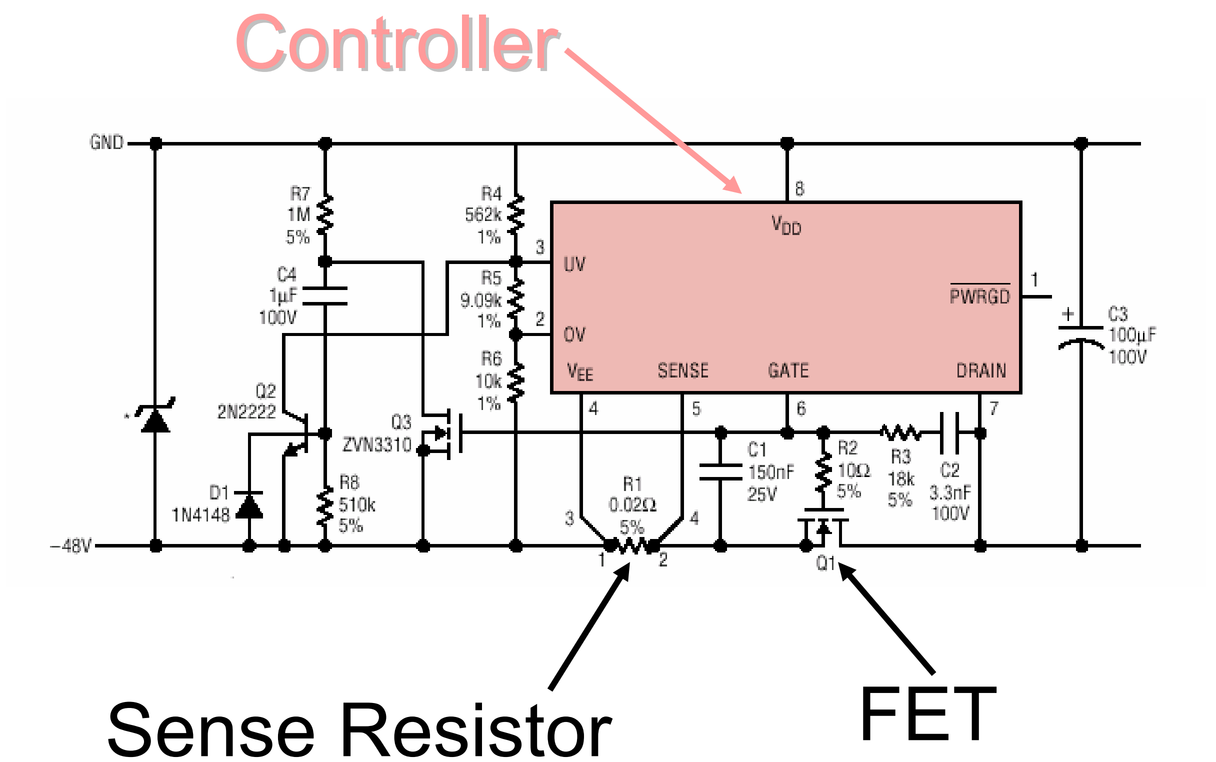


# On-Board Power Conversion

- Need efficient in-rush protection
- Isolated dc-dc module size shrink drivers
  - Topology
  - Packaging
  - Integration
  - Components
- Architecture shift to IBCs
- Evolution of point of load solutions



# Hot Swap Controller and FET



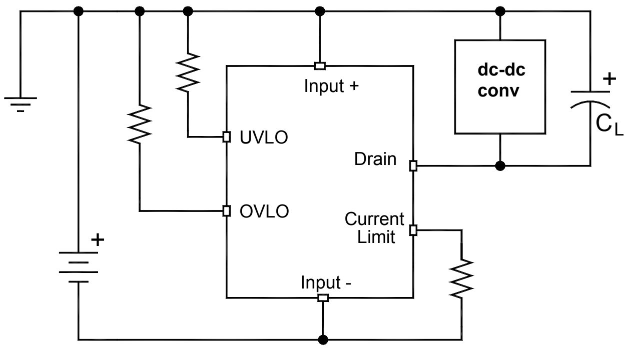

This approach is complex

Power resistor increases cost and losses

## Current Solution

# NIS5101 - SMART HotPlug™

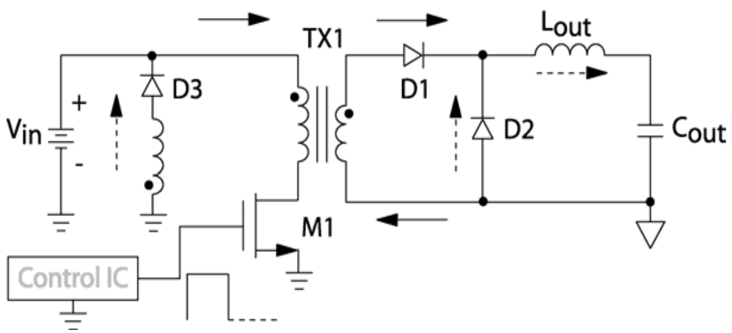
Fully Integrated controller and FET



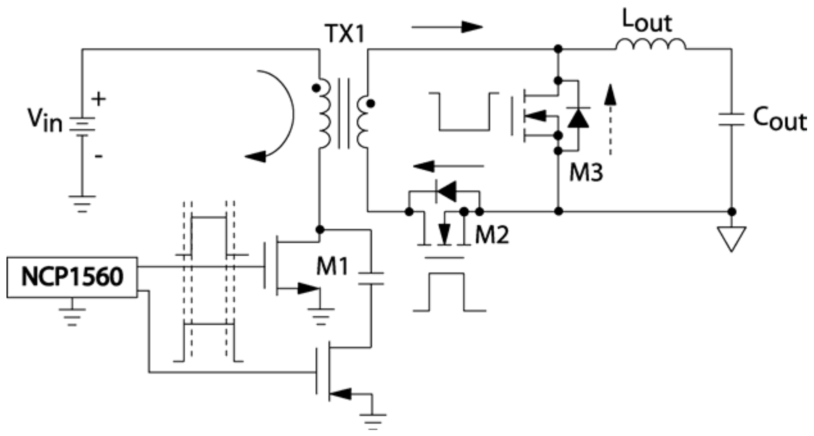

- Linear Current Limit
- Thermal Protection
- SOA Operation Guaranteed
- 40 mΩ, 110 Volt FET
- Extremely Simple to Design
- Cost Effective

# NCP1560 Demo Board

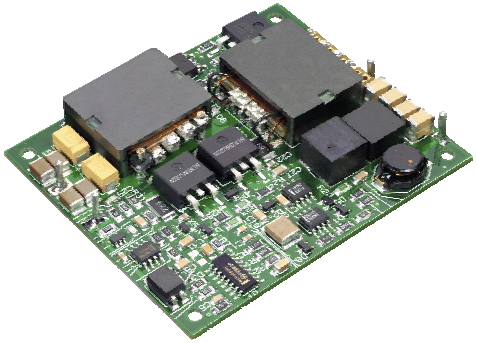
## Basic Forward Converter:

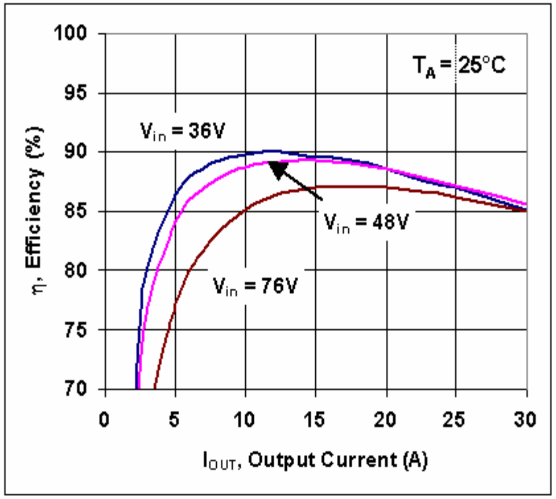



## High Efficiency Forward Converter Implemented Using NCP1560:

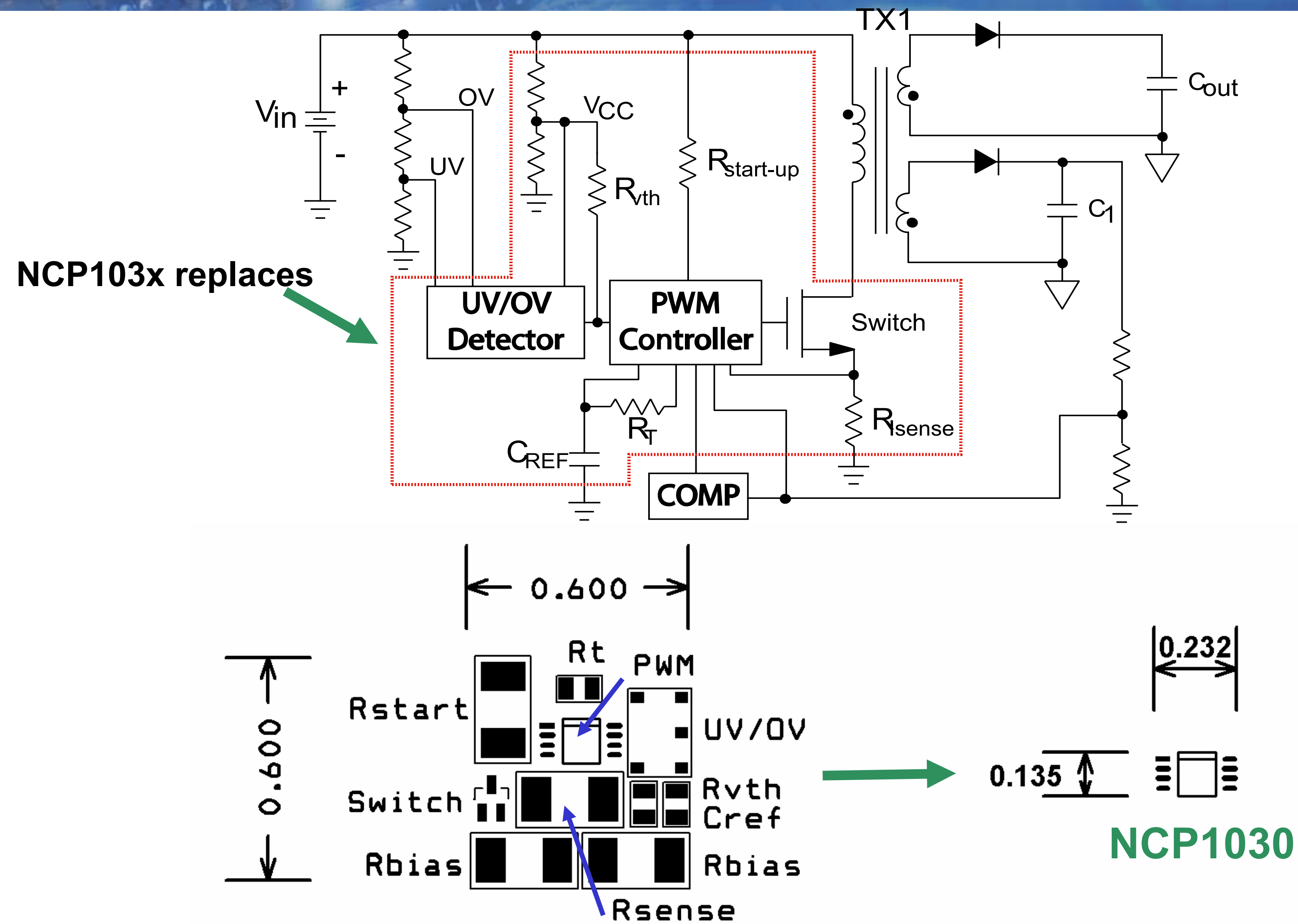



- Vin: 35-75 V (Telecom Input)
- Vout: 3.3 V @ 30 A (100 W)
- Dimensions: 2.5" x 3.0" x 0.4"



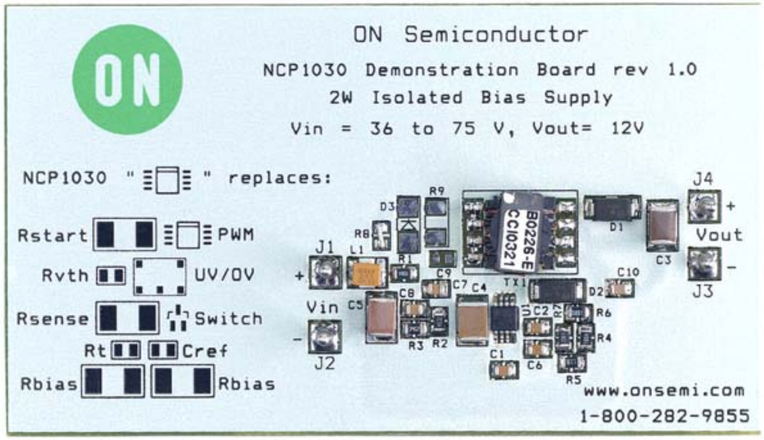


# NCP1030 – Low power regulator

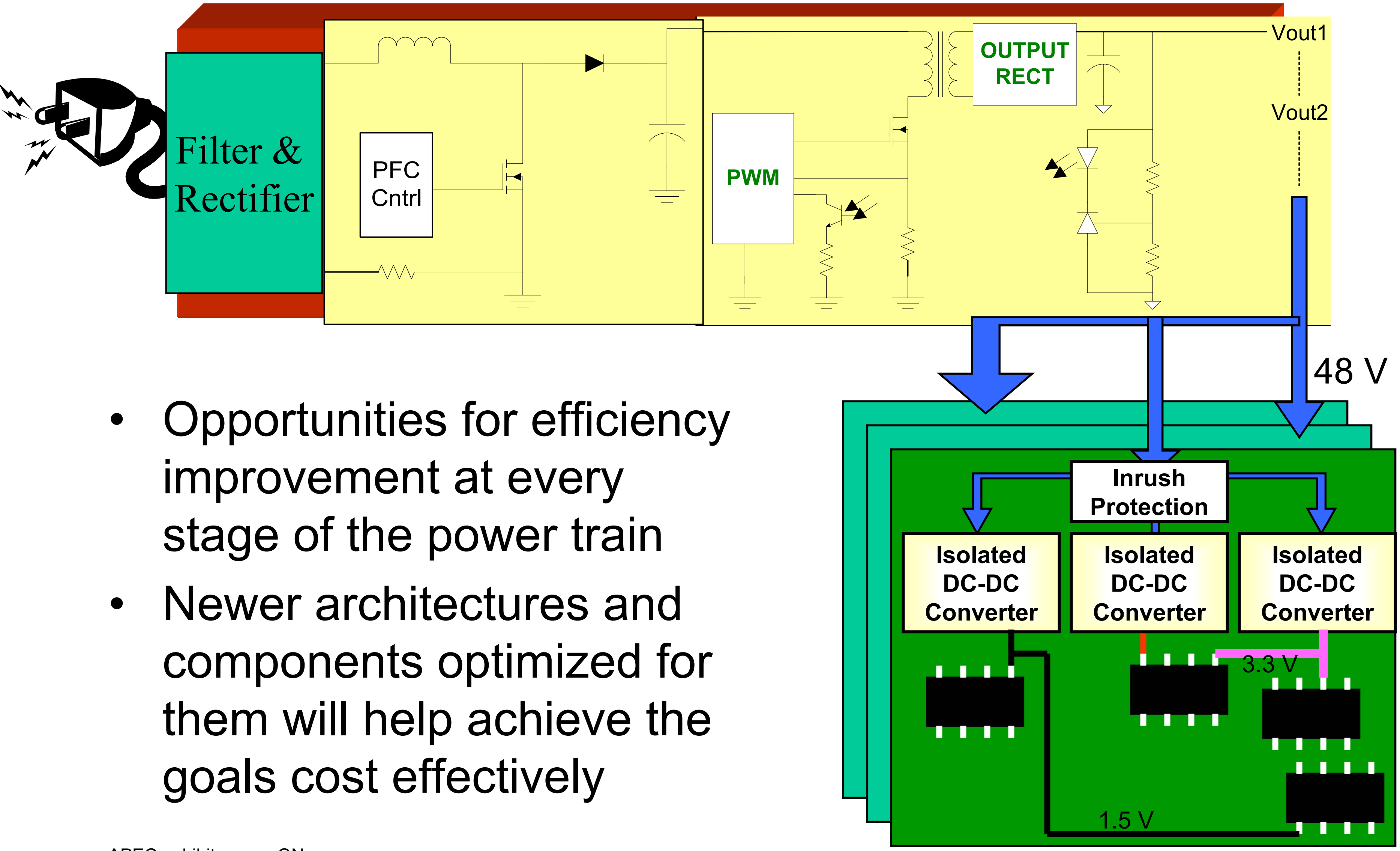


# NCP1030 Demonstration Board

- An isolated bias supply for a telecom system was built using the NCP1030. The supply delivers 2 W at 12 V.
- The supply is ideal for biasing a secondary side controller.
- A discontinuous flyback topology is used.
- Application Note AND8119/D describes the bias supply design.
- Please contact your sales representative for availability of demonstration boards.



# Conclusions




- Opportunities for efficiency improvement at every stage of the power train
- Newer architectures and components optimized for them will help achieve the goals cost effectively