High VOLT Interactive

Where power supply design meets collaboration

A new way to PFC and an even better way to LLC

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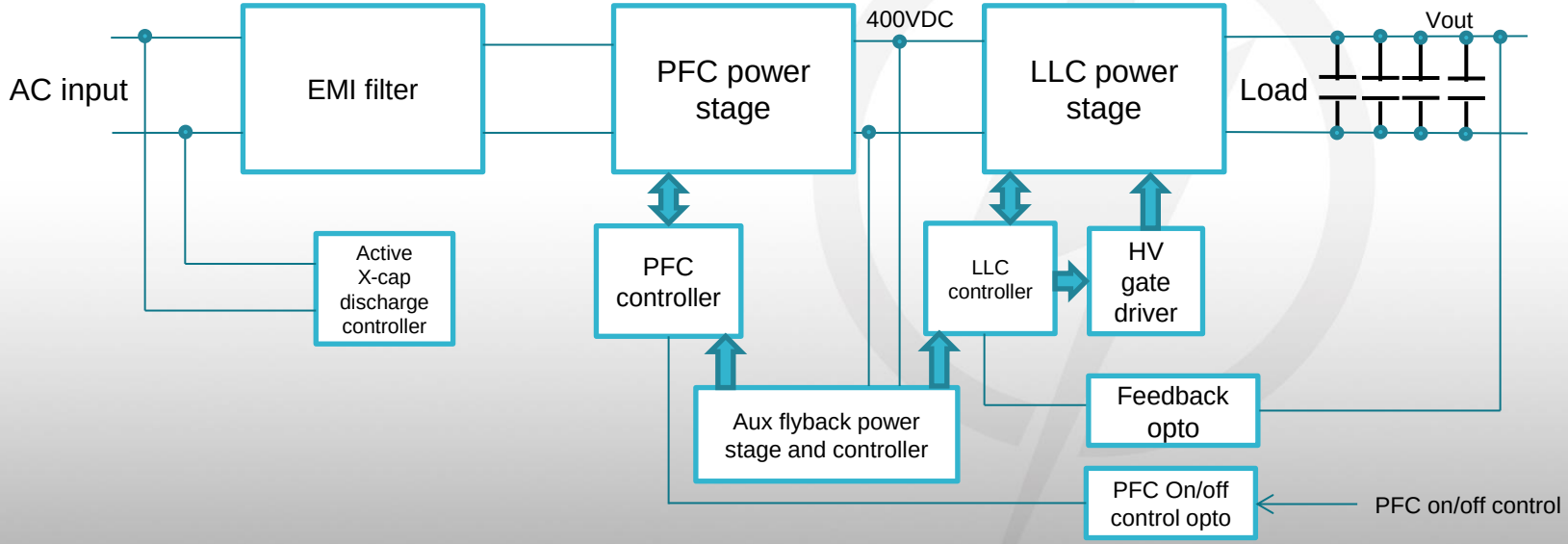
What will I get out of this session?

- Purpose:

  To introduce a recently developed advanced PFC + LLC solution with extremely low stand by power, superior light load efficiency, excellent THD and PF, best in class transient response, as well as low system cost

- Part numbers mentioned:
  - UCC28056
  - UCC25630x
- Relevant End Equipment:
  - Digital TV
  - Adapters
  - Lighting
  - Power tools
  - Computing power supplies

System Block Diagram for AC/DC Application

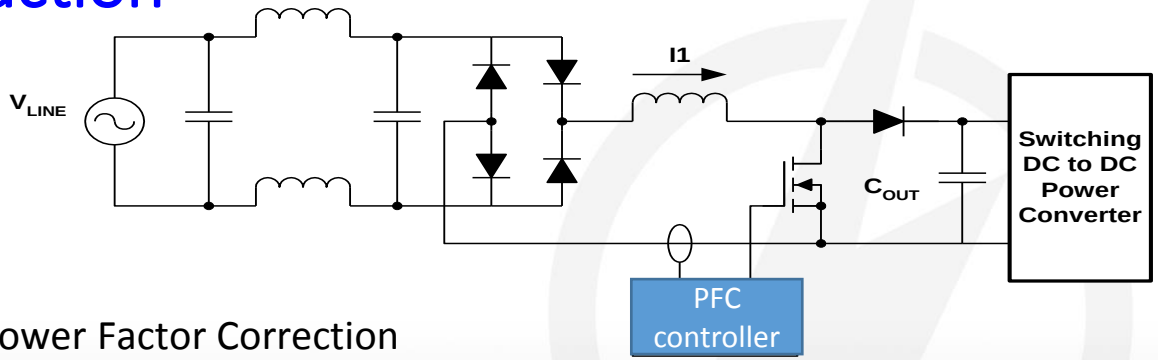


Question #1: What is most important for PFC?

- A)Low standby power and good light load efficiency
- B)low THD and good PF
- C)Low total system cost
- D)Easy to use

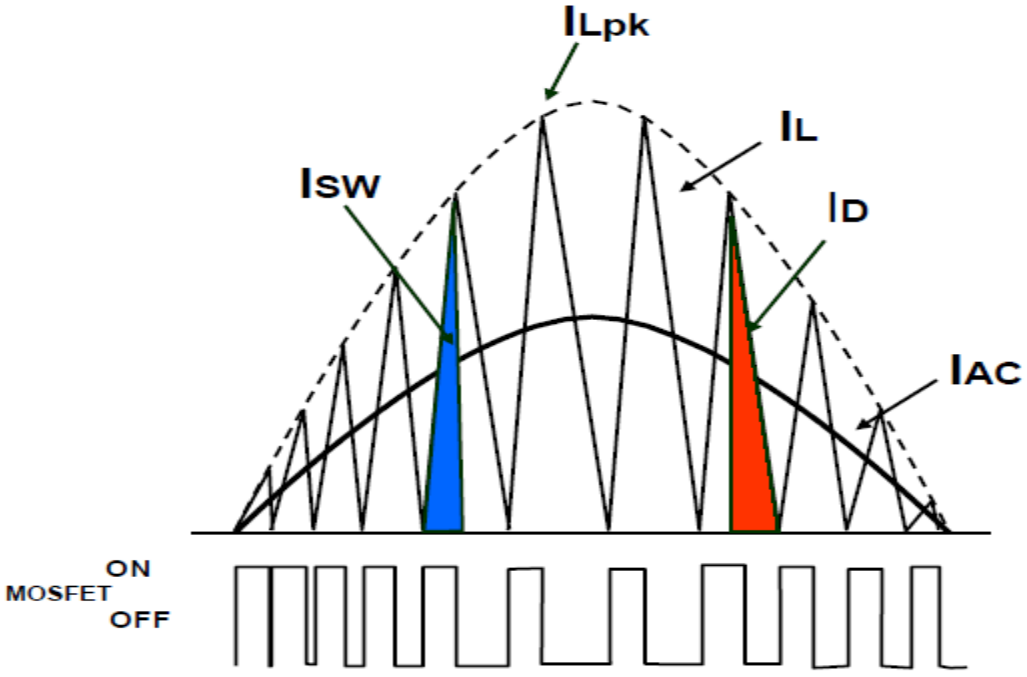
TI has addressed all of them with our new PFC controller UCC28056!

PFC Introduction



- PFC stands for Power Factor Correction
- It is used to force the input current to follow the input voltage so that any electrical load appears like a resistor
- Front-End Converter interfaces directly with the utility line
- Universal Voltage Range: 85-264V AC (50/60 Hz)
- Fixed DC output voltage (~400V)

How Transition Mode PFC Works



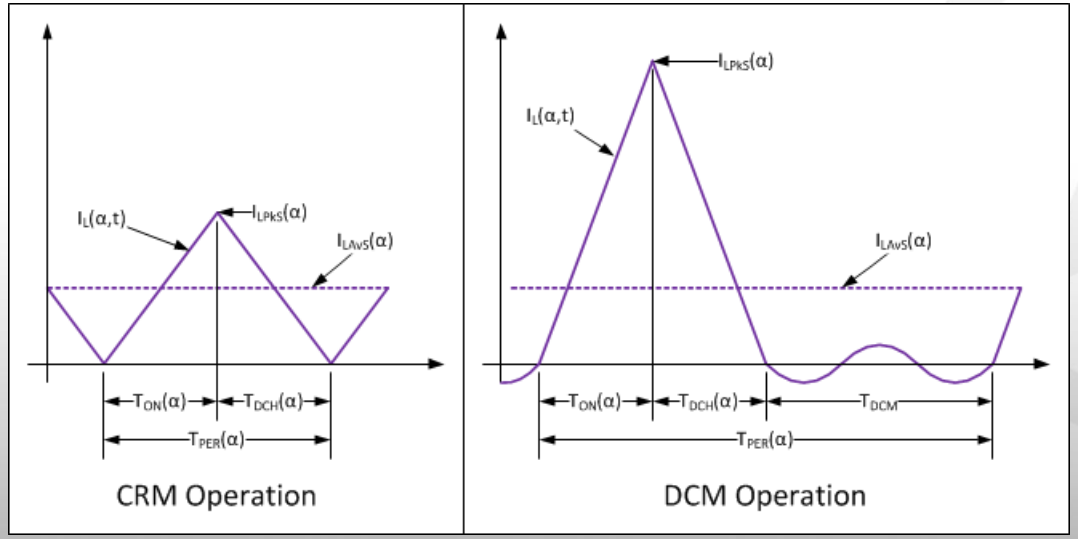
$$I_{LPK} = \frac{Vin * Ton}{L}$$

$$I_{AC} = \frac{I_{PLK}}{2} = \frac{Vin * Ton}{2L}$$

- Ton is controlled by voltage loop, it is almost a constant since voltage loop is slow
- I_{AC} is proportional to Vin, a good PF is achieved

However, when load reduce:

- When load reduce, switching frequency increase
- Switching frequency cannot go to infinite, will be clamped to some value
- Once it reaches the clamp limit, PFC enters DCM mode



In DCM:

$$I_{AC} = \frac{V_{in} \cdot T_{ON}}{2 \cdot L} \cdot \delta_{ONDCH}$$

Where:

$$\delta_{ONDCH} = \frac{T_{ON} + T_{DCH}}{T_{ON} + T_{DCH} + T_{DCM}}$$

I_{AC} is not solely proportional to Vin any more, PF reduce, THD increase

UCC28056: Maintain good PF in entire load range by calculating TON

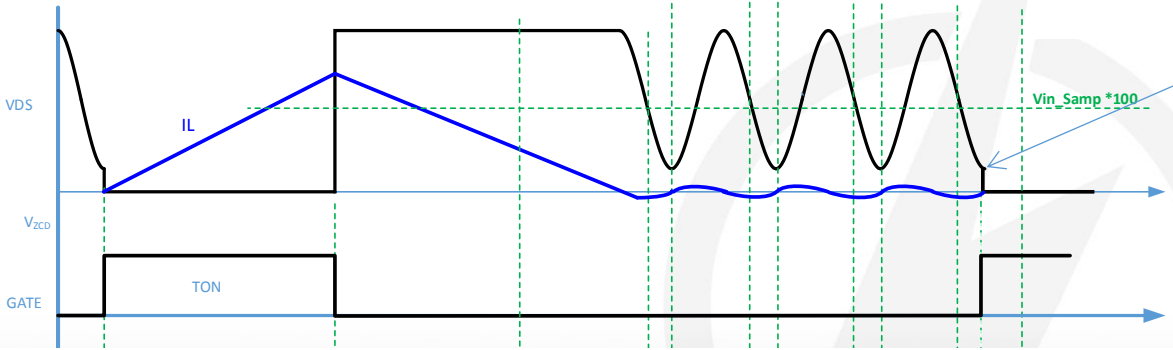
- $I_{AC} = \frac{V_{in} \cdot T_{ON}}{2 \cdot L} \cdot \delta_{ONDCH}$, $\delta_{ONDCH} = \frac{T_{ON} + T_{DCH}}{T_{ON} + T_{DCH} + T_{DCM}}$
- In UCC28056, TON is calculated such that $T_{ON} \cdot \delta_{ONDCH}$ is held constant across each AC Half-Cycle
- Now I_{AC} is proportional to Vin again, unity PF is achieved

UCC28056: Improve light load efficiency

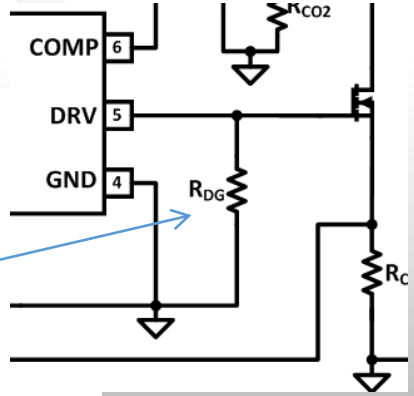
- When load reduces, switching frequency increases.
- High switching frequency leads to the low RMS current flowing in the power stage and therefore reducing conduction power loss
- On the other hand, high switching frequency leads to high switching power loss

- UCC28056 has an advanced control algorithms to improve light load efficiency:
  1. At full load, where conduction loss dominates, UCC28056 always operates in TM.
  2. As load decreases, UCC28056 increases switching frequency to remain in TM
  3. Further reduces load will result in UCC28056 goes to DCM mode, TDCM is calculated such that the efficiency is optimized (Patent pending).
  4. Moreover, UCC28056 does valley switching in DCM mode.

UCC28056: Valley Switching in DCM mode



Valley switching

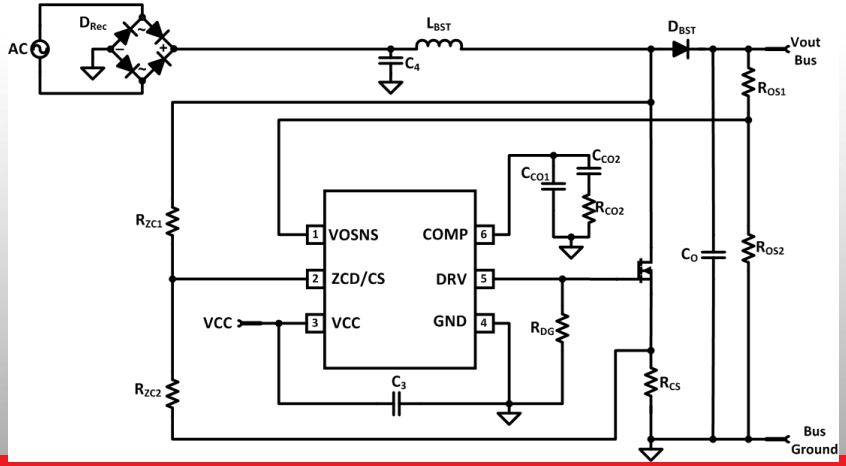


- Once in DCM, the switch is always turn on when the switching node voltage is at its valley.
- Switching loss reduced, light load efficiency improved
- The valley delay is adjustable through a resistor on pin 5

UCC28056: No need aux winding for ZCD

CS/ZCD pin multiplexed for 4 different functions:

1. Zero current detection
2. Current sense
3. Input voltage sense
4. 2nd OVP



Customer Benefit

- Aux winding is labor intensive due to manual termination of windings, tape etc
  - Cost does not scale down well with volume
- No aux winding also means easier layout due to eliminating 2 holes in high density portion of layout
- In low power applications, eliminates need for custom magnetics
  - Off the shelf magnetics can be as much as 50% cheaper than custom magnetics
- Accelerate design

UCC28056: No need to turn off PFC during standby

Problem

- To meet the standby power requirement, the PFC is turned off to reduce the power loss
- The PFC turn off command comes from secondary side, need opto-coupler control to shut off PFC during standby

Solution

- UCC28056 + UCC25630 has less than 80mW standby power
- PFC can keep always ON – eliminates opto-coupler control to shut off PFC during standby

Customer Benefit

- Opto-coupler ~ $0.03-$0.08
  - 1Mu pricing
- Accelerate design
- Fast load turn on response

UCC28056: Audibility Performance

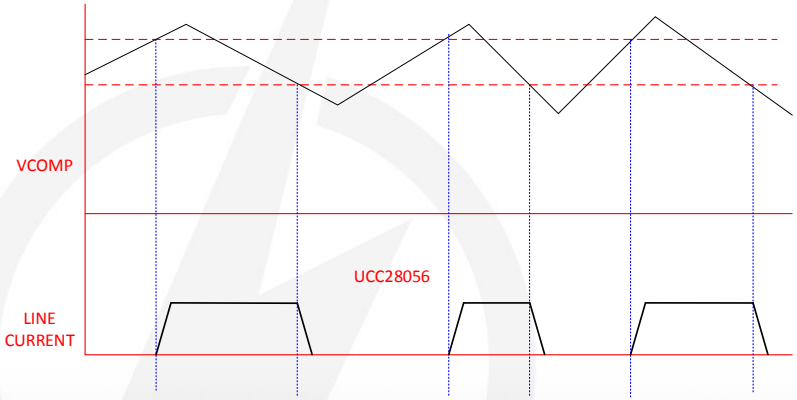
Problem

- Burst Mode is often audible
- In DCM, the transition from 1st valley to 2nd can cause audible noise

Customer Benefit

- Best in class audibility performance

Solution #1: Soft Burst mode transitions



Solution #2: Constant TDCM and valley locking

- DCM time is constant for a line cycle
- Hysteresis prevents transitioning from 1st valley to another eliminating major source of audible noise

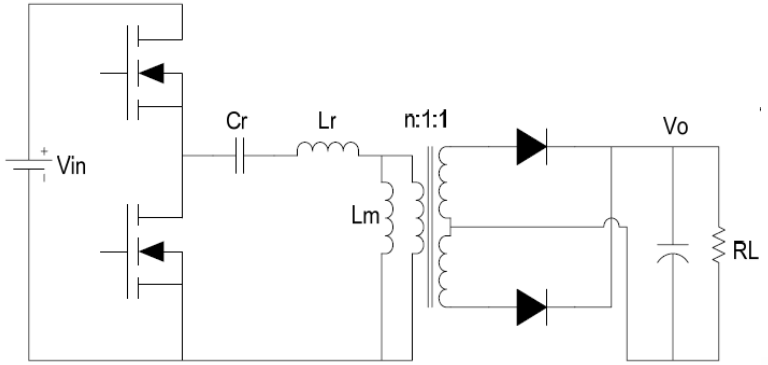
Question #2: What is most important for LLC?

- A)Low standby power and good light load efficiency
- B)Fast transient response
- C)Zero current switching prevention
- D)Low total system cost

TI has addressed all of them with our new LLC controller UCC25630x!

LLC Introduction

- LLC stands for inductor-inductor-capacitor DC/DC converter
  - Resonant inductor L_r
  - Magnetizing inductor L_m
  - Resonant capacitor C_r
- It is a resonant topology
- The LLC Topology is Popular Because
  - Zero voltage switching (High efficiency)
  - Low EMI
  - Low Component Stresses



Resonant frequency

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$$

UCC25630x: Hybrid Hysteretic Control (HHC)

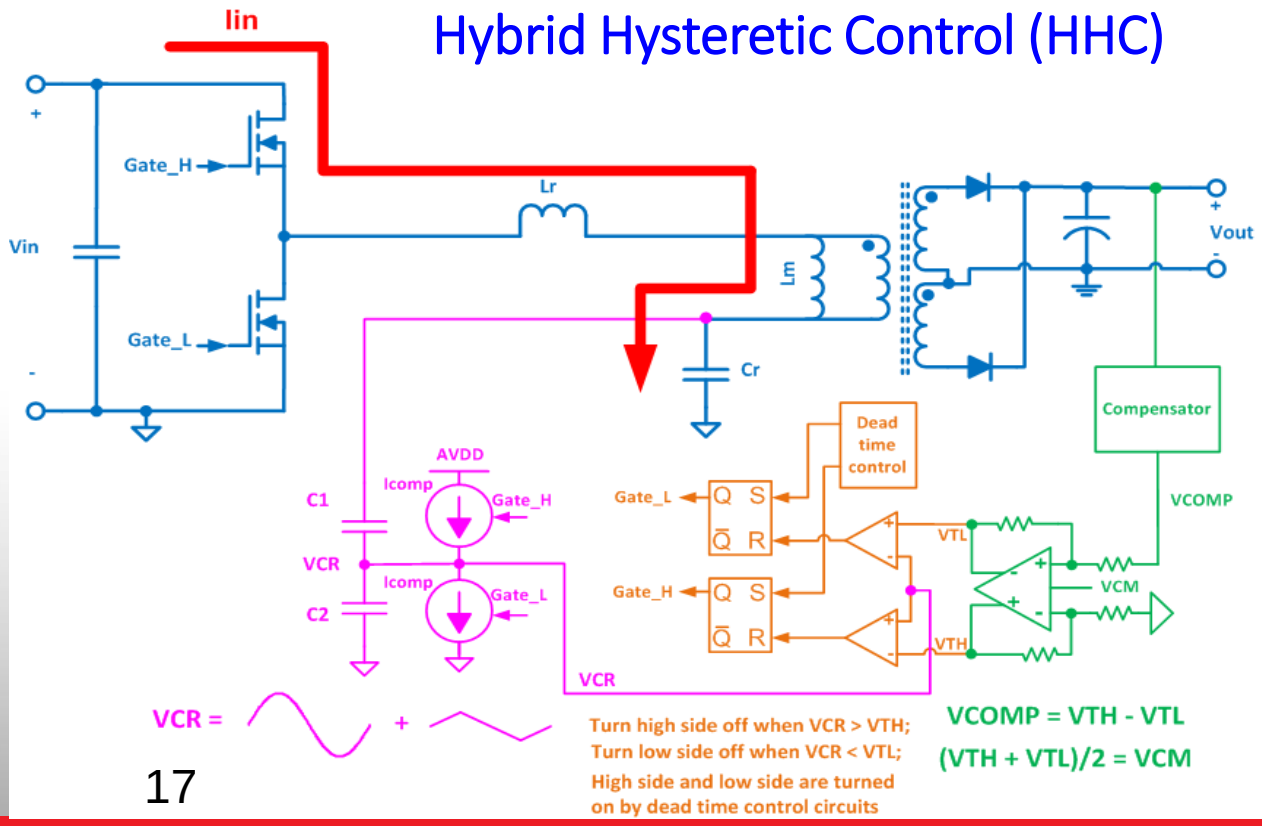
Traditional LLC control method: Direct frequency control (DFC) - switching frequency is determined by control Loop output

- exhibit second order behavior
- Bode plot changes with Vin and load
- Limited loop bandwidth
- Low phase margin

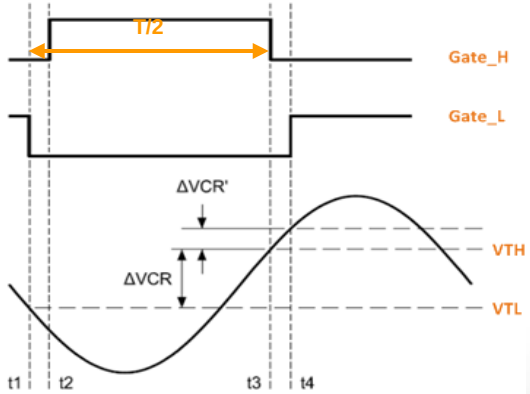
UCC25630x novel control method: Hybrid hysteretic control (HHC) (Patent pending) - switching frequency is determined by comparing VCR voltage with thresholds, control loop adjusts thresholds

- First order system
- Easy to compensate
- High loop bandwidth

Hybrid Hysteretic Control (HHC)



Gate Drive Waveform Generation



$$VCOMP \approx \frac{C1}{(C1+C2)C_r} \times Iin_{avg} \times T + Icomp \times \frac{T}{2}\frac{1}{C1+C2}$$

Charge control element

Frequency control element

Adjust the balance of **charge control** and **frequency control** to make $VCOMP$ linearly relate to Iin_{avg}

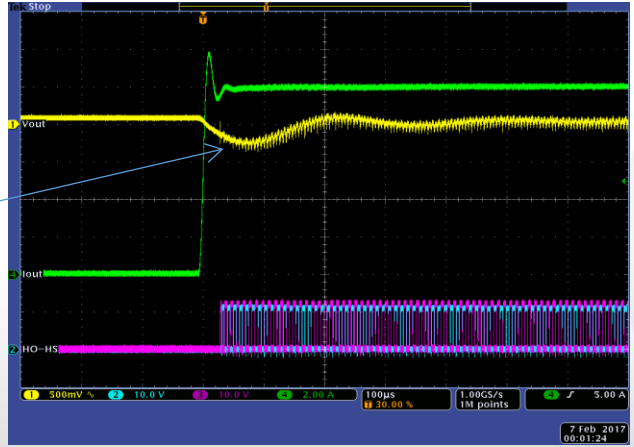
$$VCOMP \propto Iin_{avg}$$

UCC25630x HHC – Load transient test results

HHC

No load to full load transient

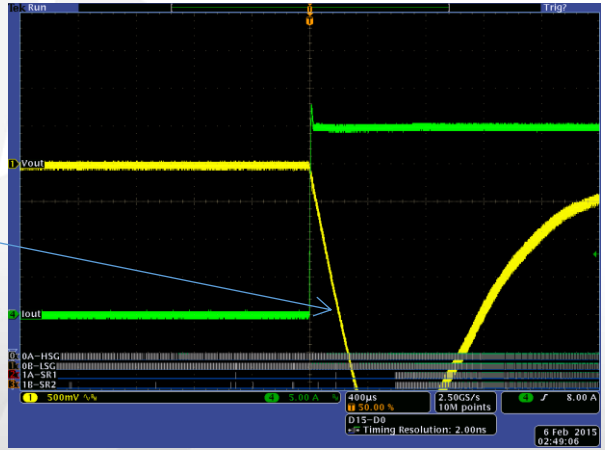
Vout diviation 1.25%



DFC

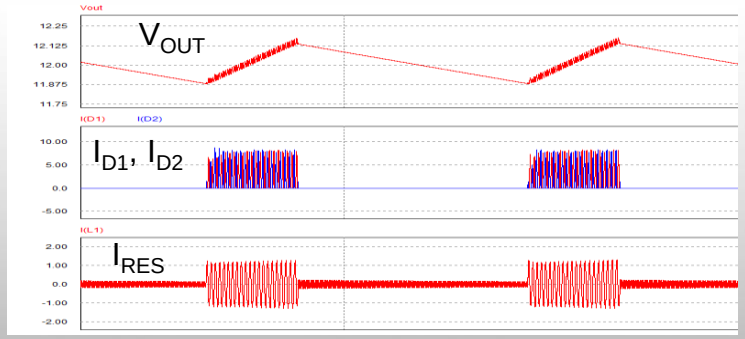
No load to full load transient

Vout diviation >20%

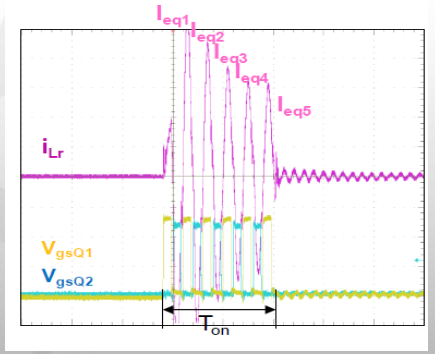


UCC25630x:Burst Mode to improve light load efficiency

- UCC25630x enters burst mode at light load
  - The burst mode load threshold is programmable
  - Fixed burst pattern on each burst cycle
- The burst mode threshold adaptively changes with input voltage
  - consistent burst threshold load can be achieved across Vin range



UCC25630x burst

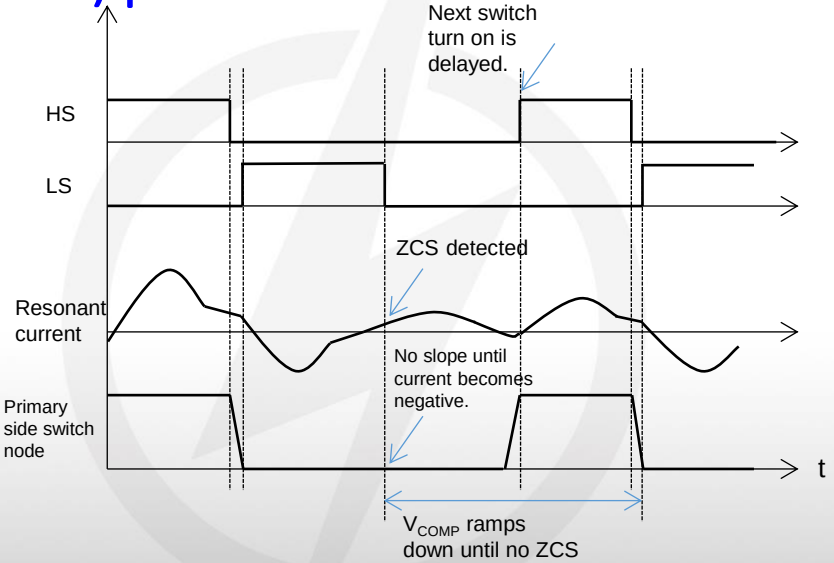


Conventional burst

UCC25630x: Zero current switch (ZCS) prevention

If LLC operating in capacitive region:

- Loss ZVS
- Potential shoot through
- High EMI
- Feedback loop changes to positive

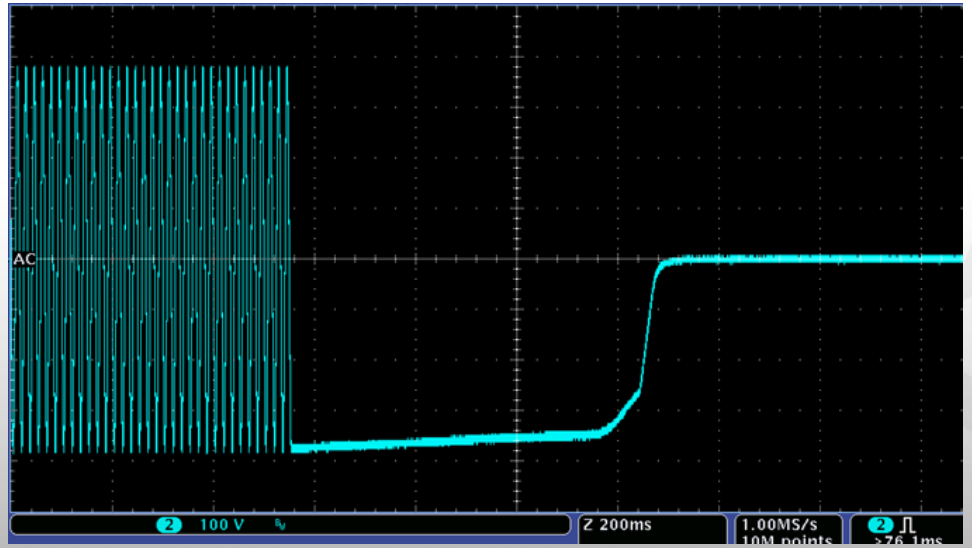


UCC25630x can prevent LLC enters capacitive region:

1. Polarity of the inductor current is sensed
2. ZCS is detected if at HS or LS turn off edge, the direction of the resonant current (Ipolarity) is not correct
3. HS or LS switch will not be turned on until the next slew is detected on primary side switch node.
4. Vcomp will be rapidly ramped down until there a complete switching cycle without a near ZCS event is detected.

UCC25630x: X-cap Discharge Function

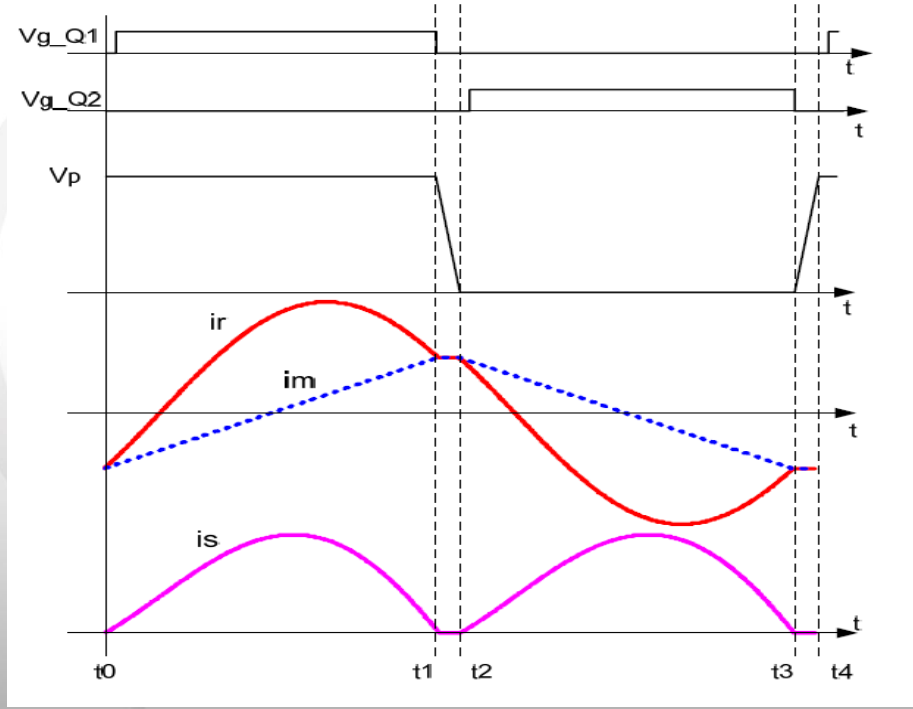
- X-capacitors used in EMI filters on the AC side of the diode bridge rectifier must be discharged to a safe voltage within certain time.
- This function is integrated in UCC25630x, Eliminating external x-cap discharge IC



Test condition: Vac = 264Vrms, disconnect AC randomly, discharge time from AC 264V to below 30V: 700ms

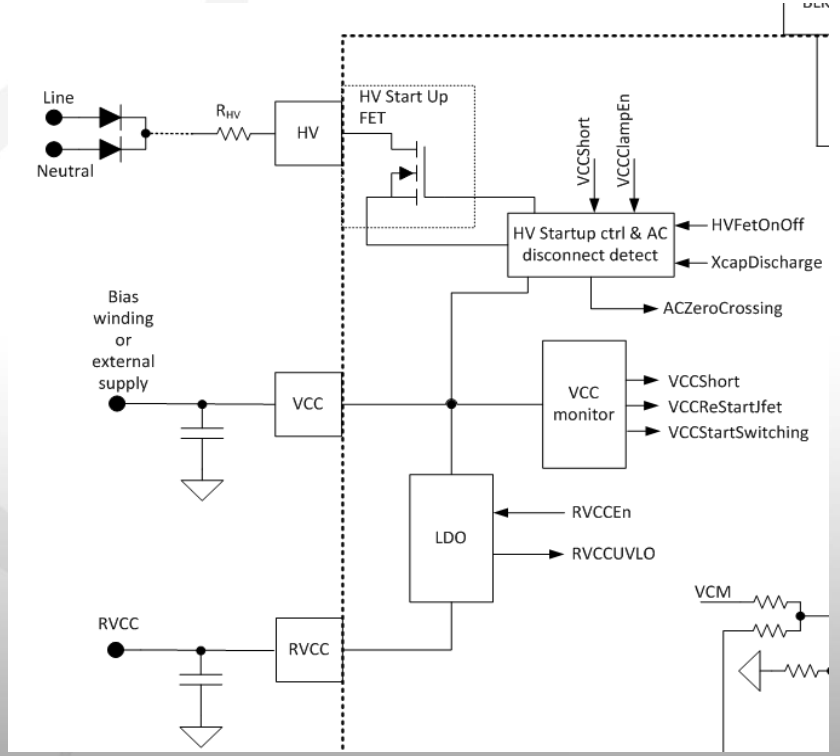
UCC25630x: Adaptive Dead Time

- Dead Time – Q1 and Q2 are both off
- Adaptive Dead Time
  - ❖ Allows LLC to achieve ZVS (reduce switching loss)
- UCC25630x monitors the half-bridge switched node to determine the required dead-time
- The dead-time is automatically adjusted to provide optimum efficiency and security of operation



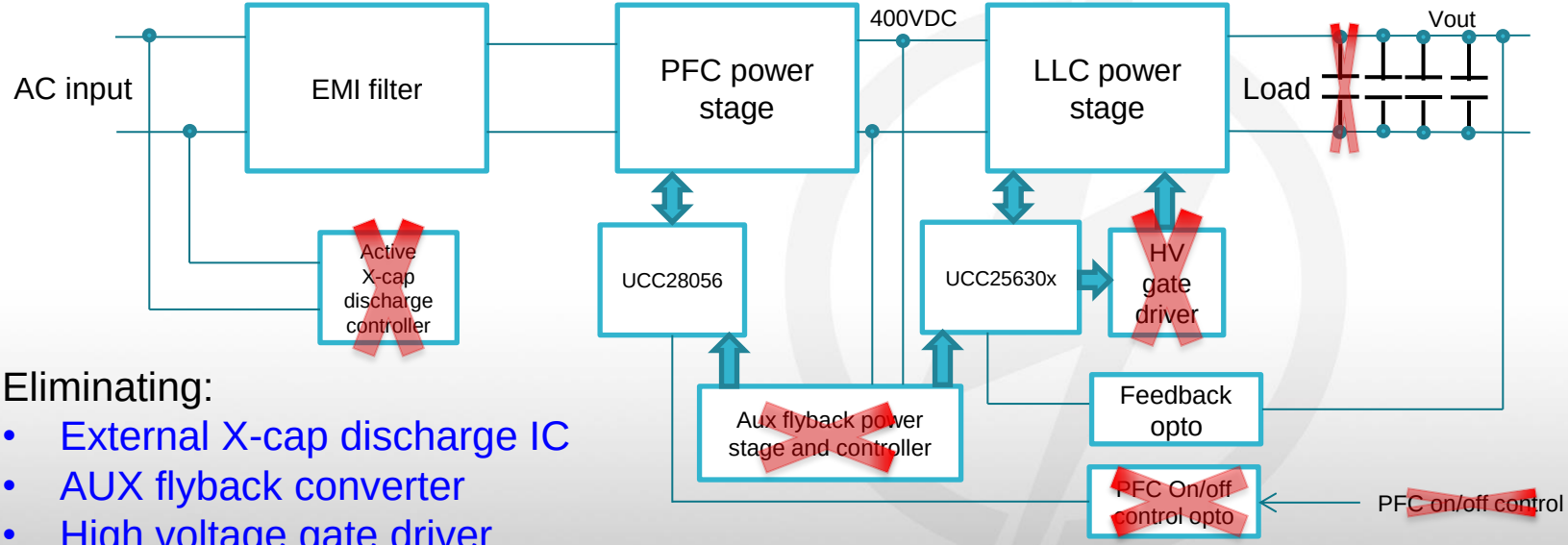
UCC25630x: High Voltage Start-up

- UCC25630x uses self bias start up. Eliminating the separate auxiliary flyback converter.
- Start up sequence:
  1. When AC is first plugged in, JFET is turned on and starts to charge the VCC capacitor.
  2. Once the VCC pin voltage exceeds its threshold, the JFET will be turned off and RVCC will be enabled to turn on the PFC.
  3. When PFC output voltage reaches a certain level, LLC is turned on.
  4. When LLC is operating, the bias winding will supply current for both the PFC and the LLC controller ICs.



Summary

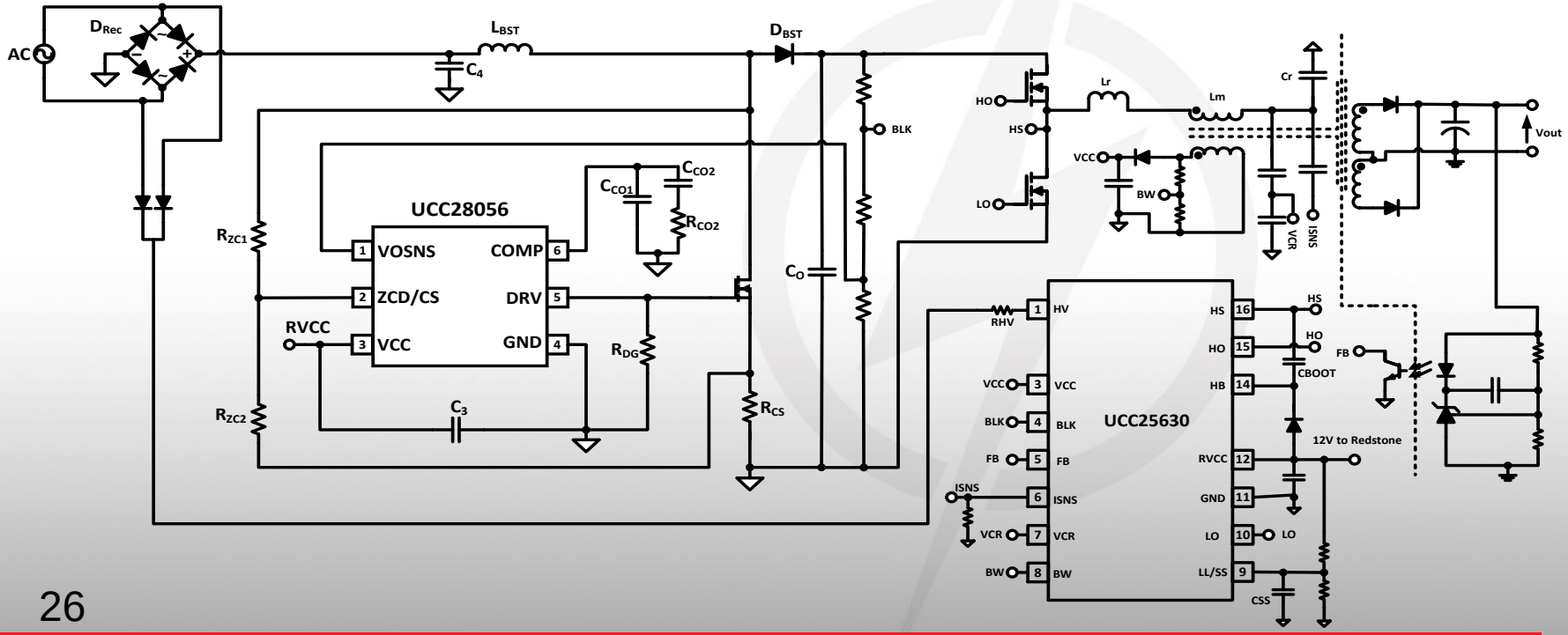
Next-Generation AC/DC Solution for Medium Power Application



Eliminating:

- External X-cap discharge IC
- AUX flyback converter
- High voltage gate driver
- PFC on/off control circuit
- Less output capacitance

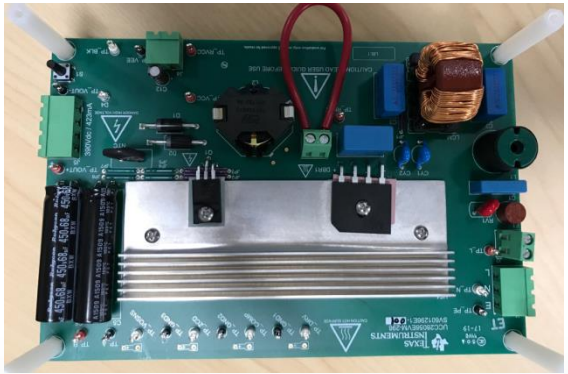
Detailed System Block Diagram



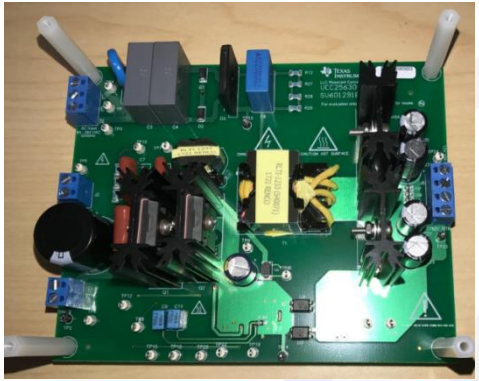
UCC28056 + UCC25630x Key Market Differentiators:

- A high efficient AC/DC system solution for digital TV, adaptor, appliances, lighting, power tools, etc. with superior light load efficiency
- The total system standby power consumption (with both PFC and LLC on) is around 75mW.
- Integrated high voltage start-up circuit
- Best in class load and line transient response with very simple compensation design
- Excellent THD and PF across the entire operation range
- Integrated X-capacitor discharge
- Internal 640V high-side gate driver
- Reduced BOM count

EVM, Reference design:



UCC28056 EVM



UCC256301 EVM

UCC256301 reference design PMP20795

More reference design are coming:

1. PMP20946 – LCC design for lighting. (Targeting finish testing by the end of August)
2. PMP20947 – LLC design for lighting. (Targeting finish testing by the end of August)
3. PMP21000 – Single stage AC-DC LLC design. (Targeting finish testing by the end of September)
4. PMP20769 – 1kW full bridge LLC

Thank you!