Valley Switching Boost Power Factor Correction (PFC) Reference Design

C2000 Systems Solution: Digital Power

TIDM-1022: http://www.ti.com/tool/TIDM-1022

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Detailed agenda

- Background:
    - Reference design feature
    - Valley switching application
    - Type-4 PWM-based valley switching control
- System configuration
    - Hardware modification
    - Peripheral usages
    - Control diagram
    - Software structure
- Technical challenges
- Waveforms and test results

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TIDM-1022:Valley switching boost PFC

TIDesigns

Features

- Interleaved, 750W, two-phase boost PFC stage
- Full range parameter: 95~260 Vrms, 47~63Hz, 750W
- 200kHz switching frequency under normal condition (load > 10%)
- 150~330kHz variable Pulse Width Modulation (PWM) switching under light load (<10%)
- Programmable output voltage, 380-V DC output nominal
- Low Total Harmonic Distortion (THD): Close to 5% at 5% load
- High efficiency > 92% at 5% load
- powerSUITE™ support for easy adaptation of design for user requirement
- Software Frequency Response Analyzer (SFRA) for quick measurement of open loop gain
- Full digital control using TI's Piccolo F280049 controller
- Protects for output overcurrent and overvoltage conditions
- Programmable valley switching and valley skipping

Applications

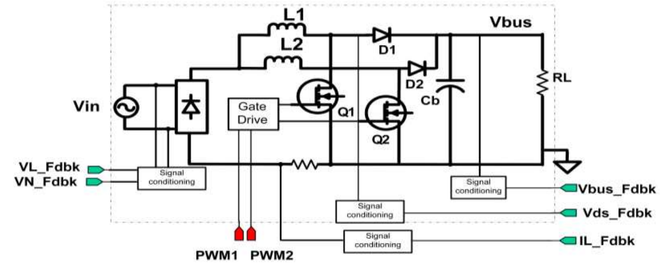
- Onboard chargers for Electronic Vehicles (EVs)
- Server and network power supplies
- Telecom rectifiers
- Industrial power supplies

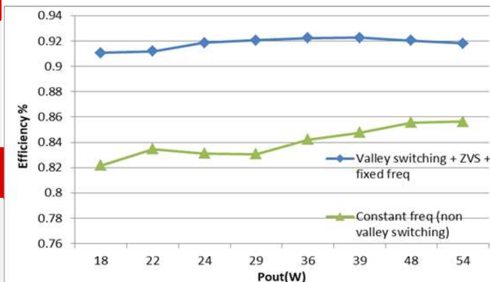
Tools & Resources

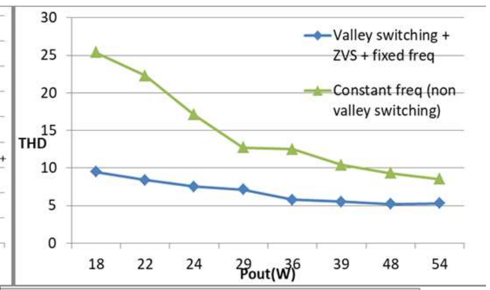
- Key TI devices: TMS320F280049, OPA365, SN74LVC1G3157 , TPS795 , UCC27524

Benefits

- High efficiency and low THD enabled under light load condition.
- Using latest type-4 PWM offers flexibility to implement valley switching and valley skipping.
- High-performance C2000 controller enables superior control and enables advanced control scheme to be implemented.
- powerSUITE support enables easy adaptation of software.
- CLA support enables better integration options.



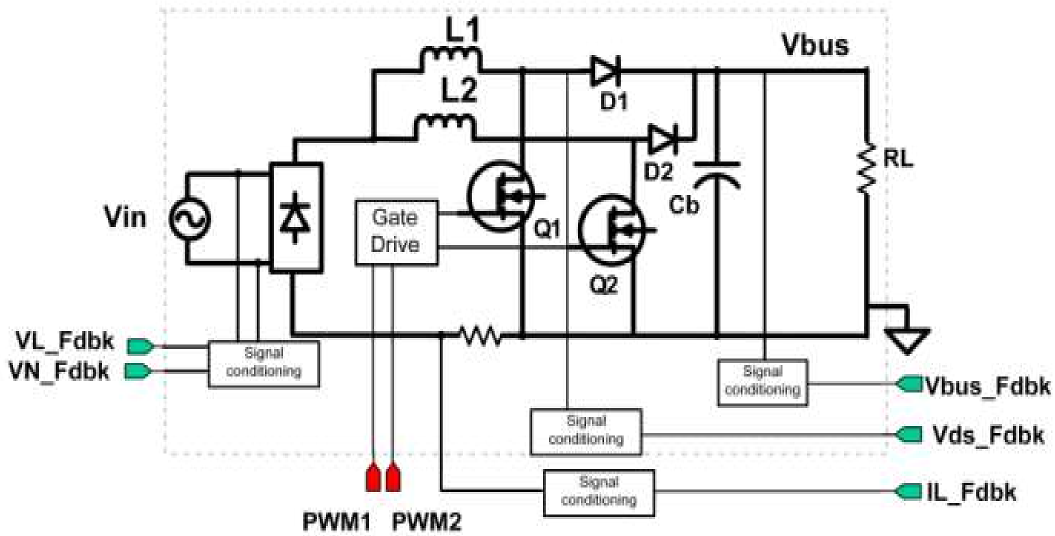




Project background

2-phase Interleaved Power Factor Correction (ILPFC) converter:

- The function of a PFC stage is to convert the AC voltage to a regulated DC bus voltage while drawing a sine wave input current in-phase with the AC input voltage.
- This is implemented using a bridge rectifier followed by a boost PFC stage.



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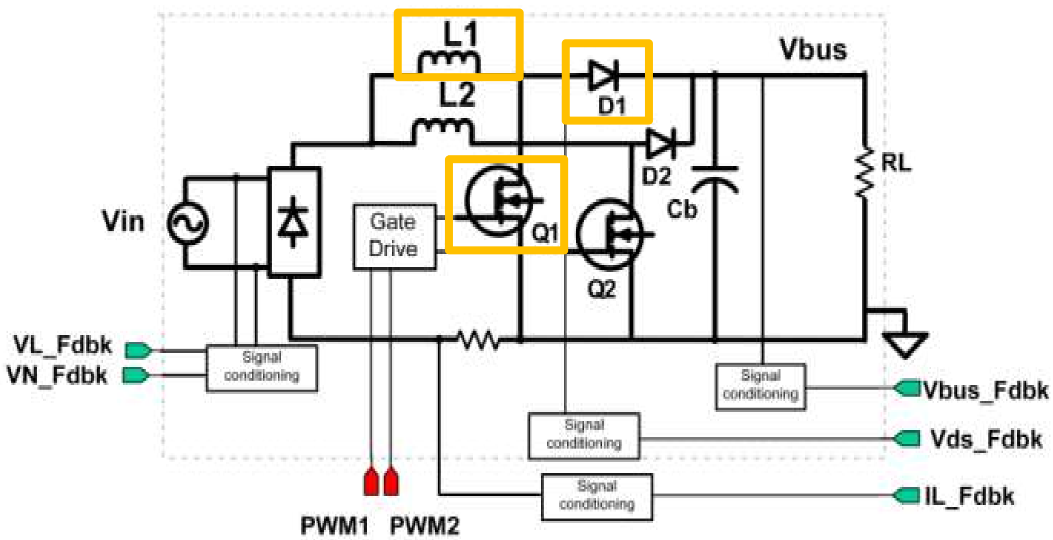

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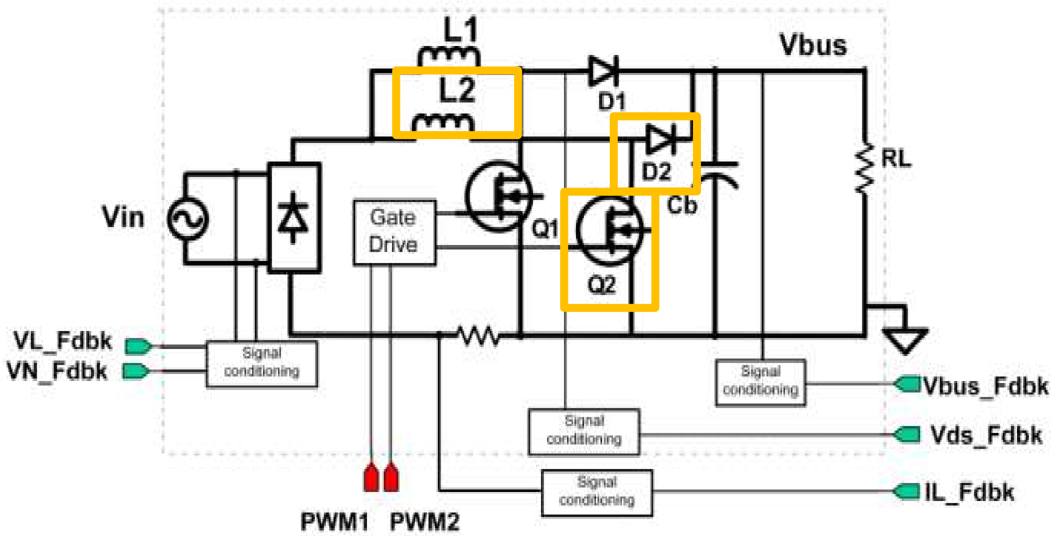
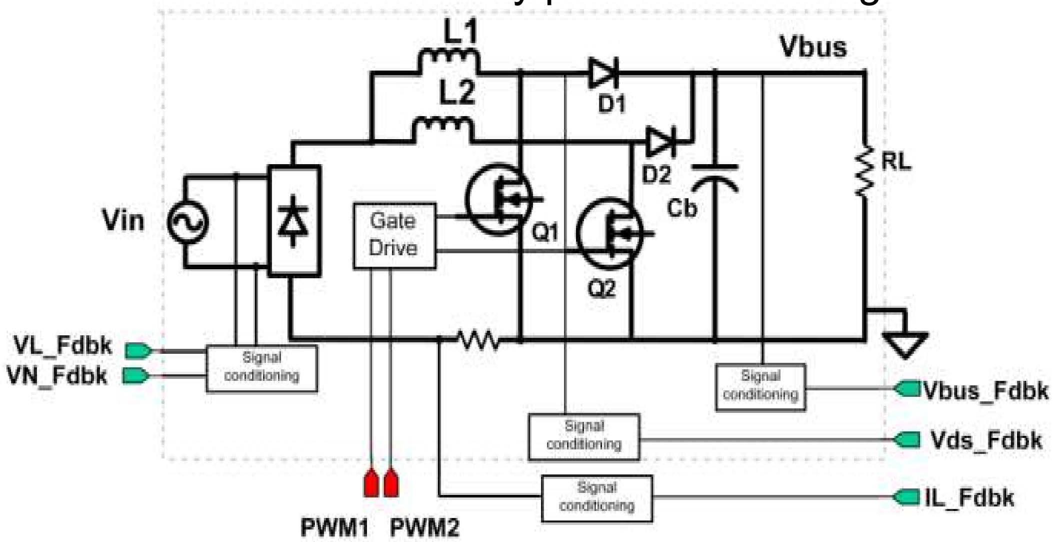


Project background

Valley switching

- Valley switching is a soft-switching technique, also called quasi-resonant switching.
- D1 reverse-biased, energy resonates between L1 and parasitic capacitor of Q1.
- Switch should be turned ON at the valley point of the voltage across it.



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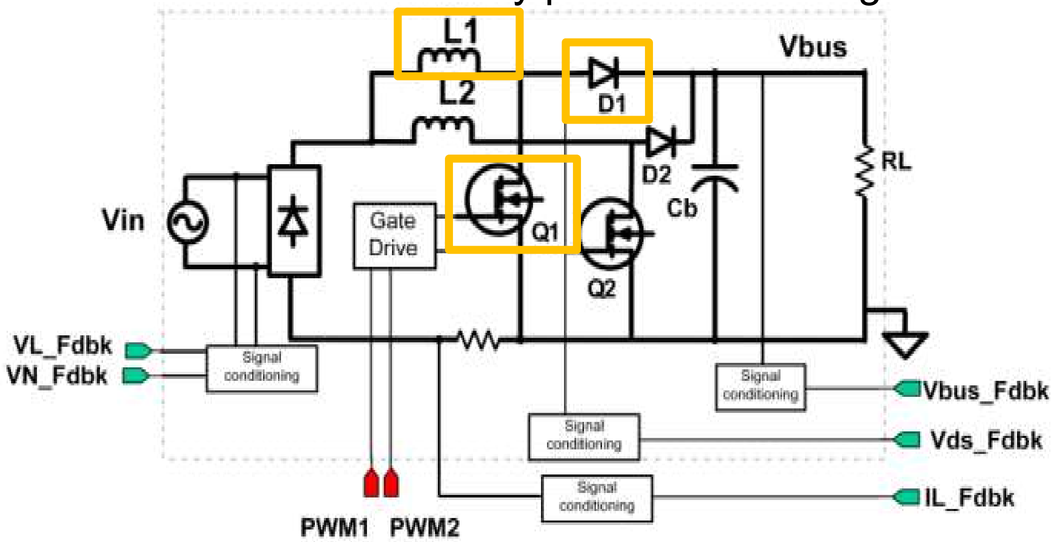

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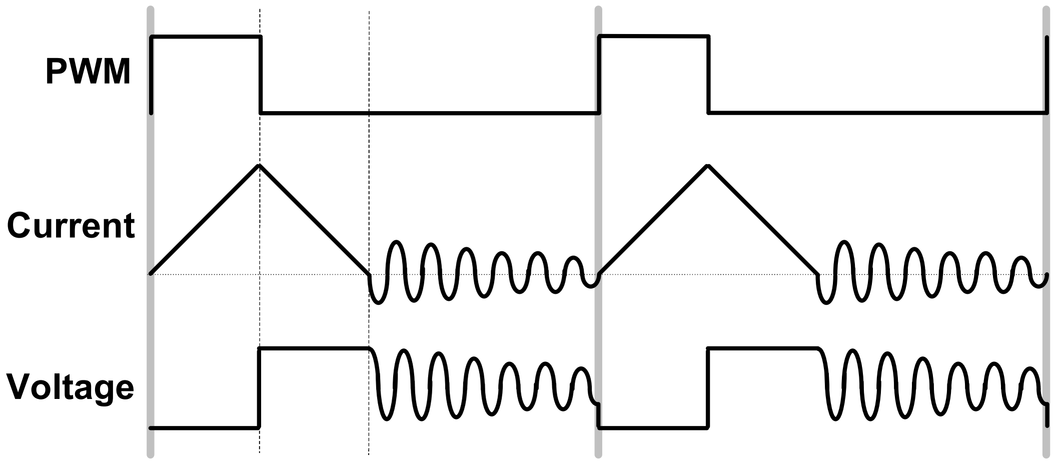
Valley-switching with Type-4 PWM allows the following:

- Capture of the oscillation frequency/period
- Accurate delay of the PWM switching instant
- Programmable number of edges before the delay takes effect



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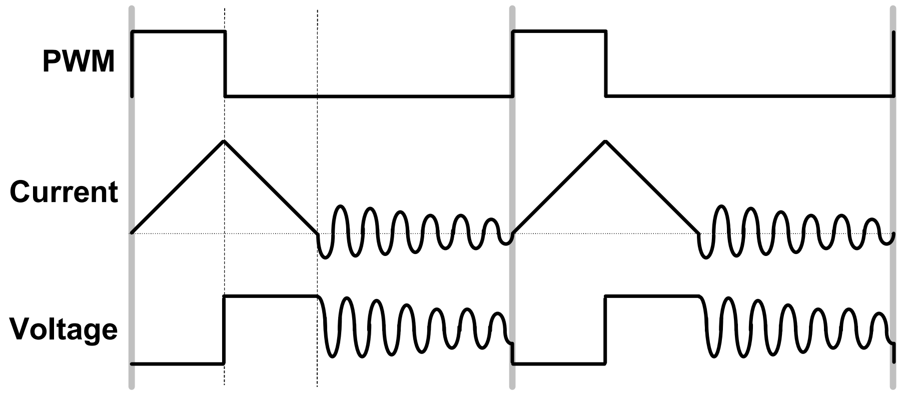

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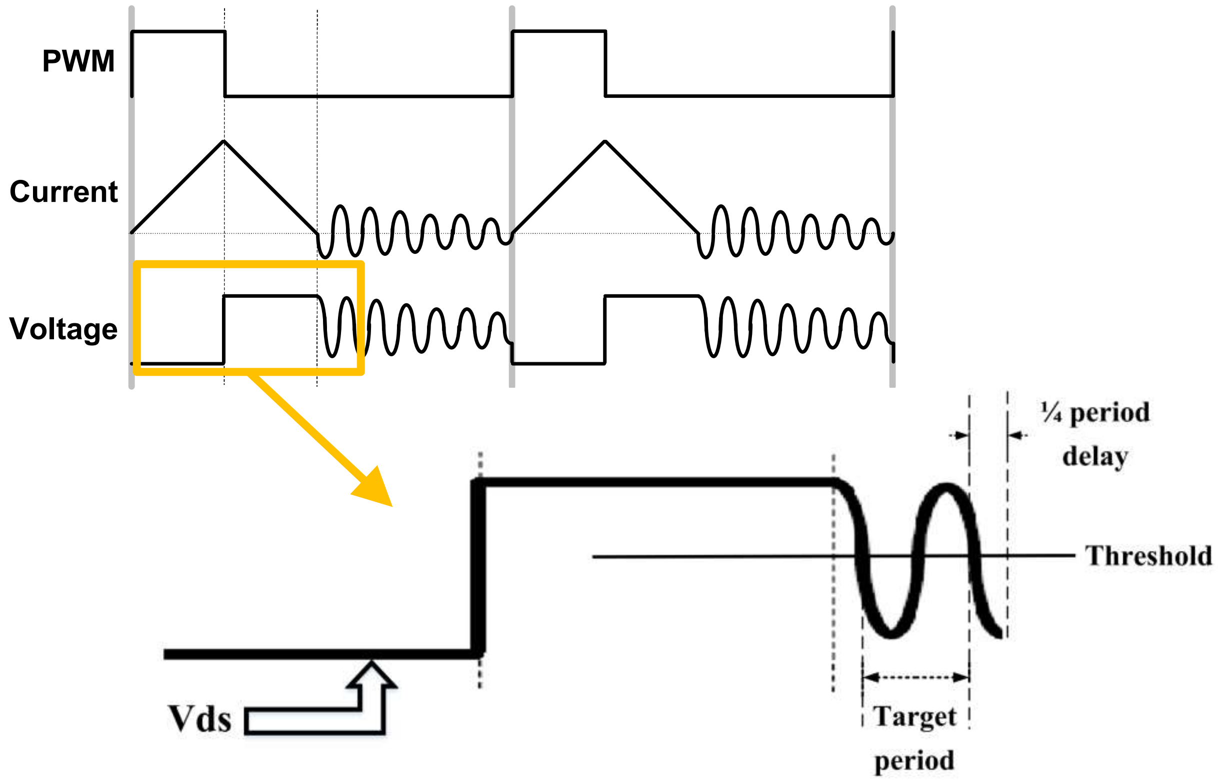

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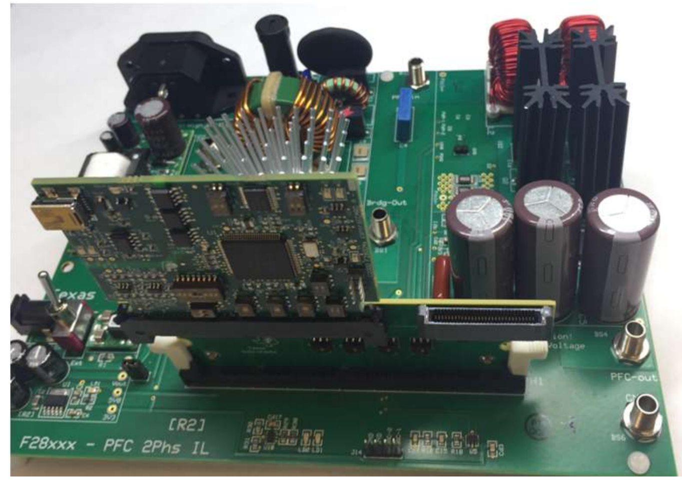
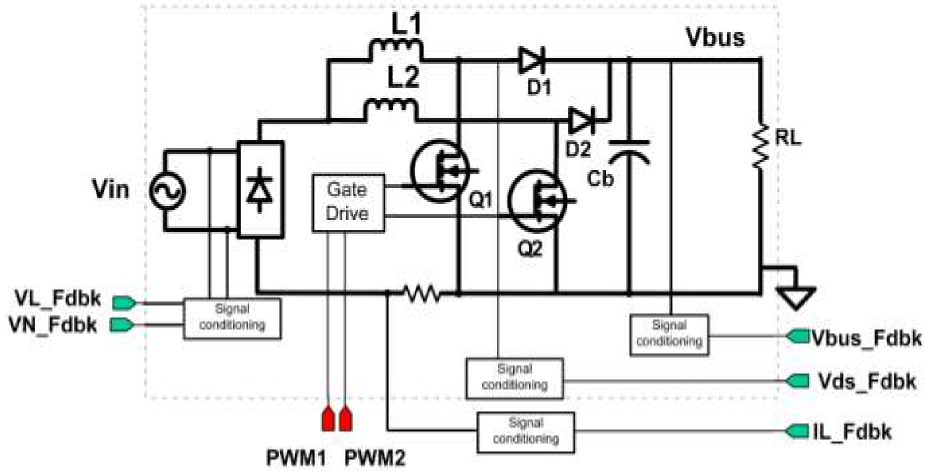
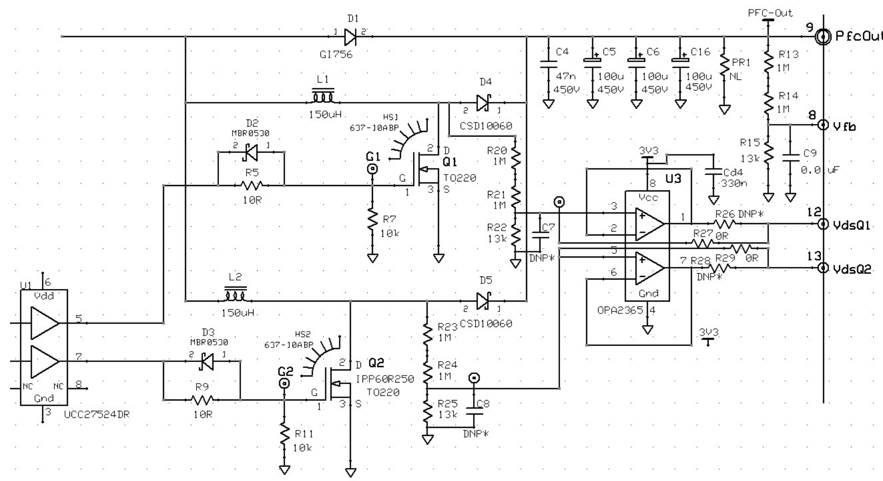
System configuration

- Valley switching is based on a modified ILPFC board with an extra Vds sensing circuit
- Valley switching is enabled under light load condition with single phase.



Note: Base board modifications can be found in Reference Design User Guide: http://www.ti.com/lit/tidueg3





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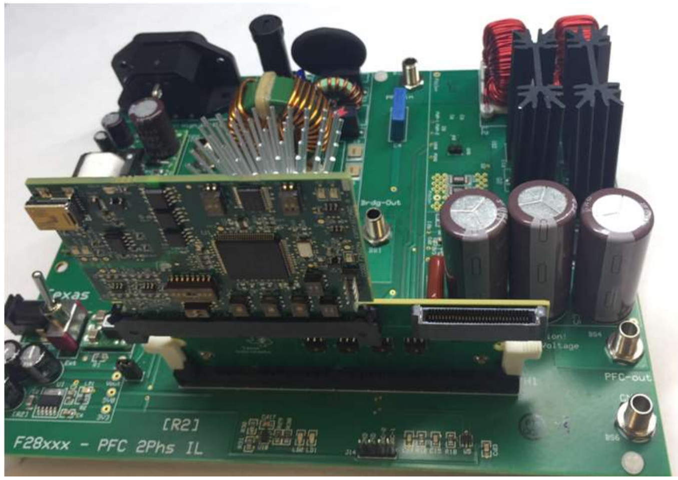

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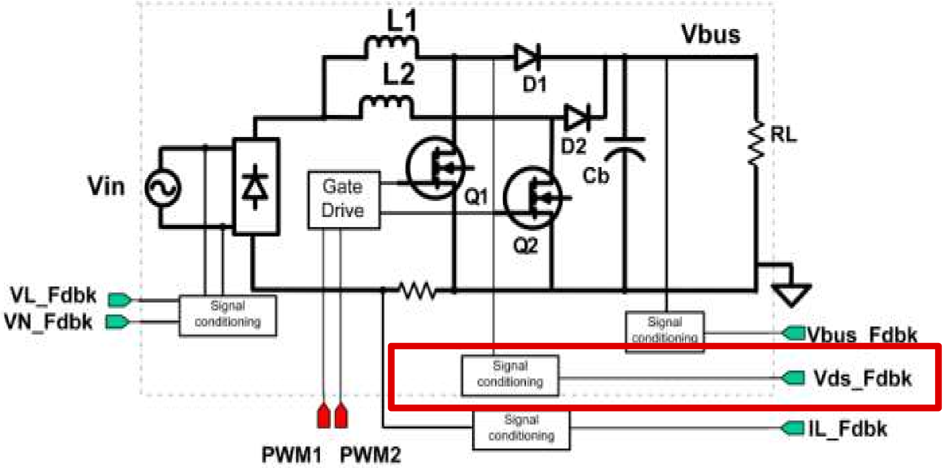

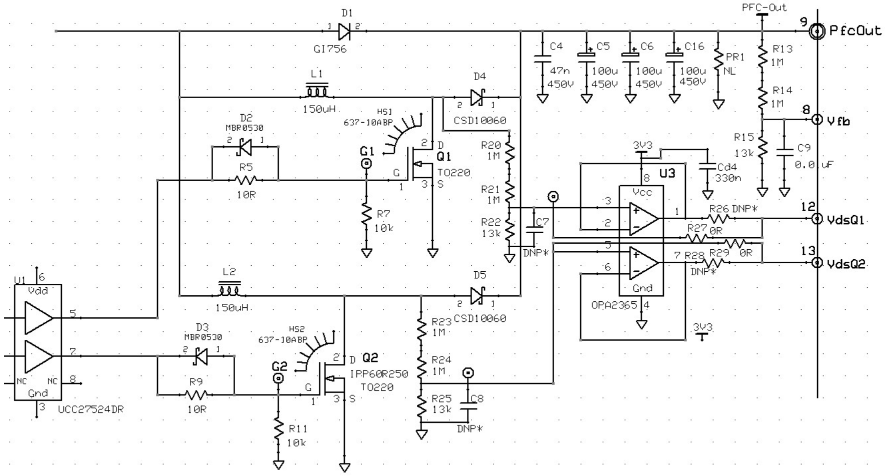

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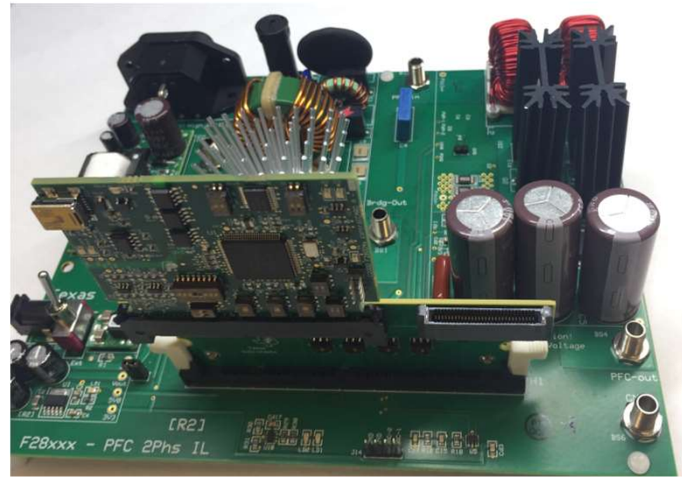

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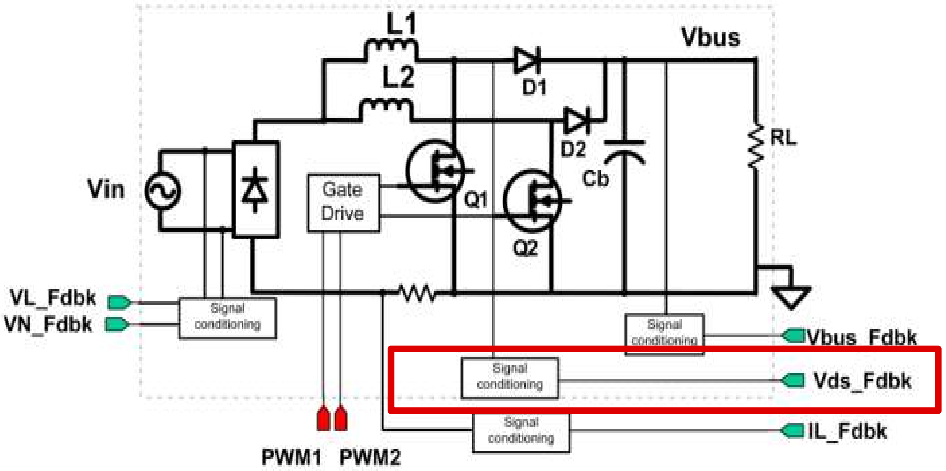
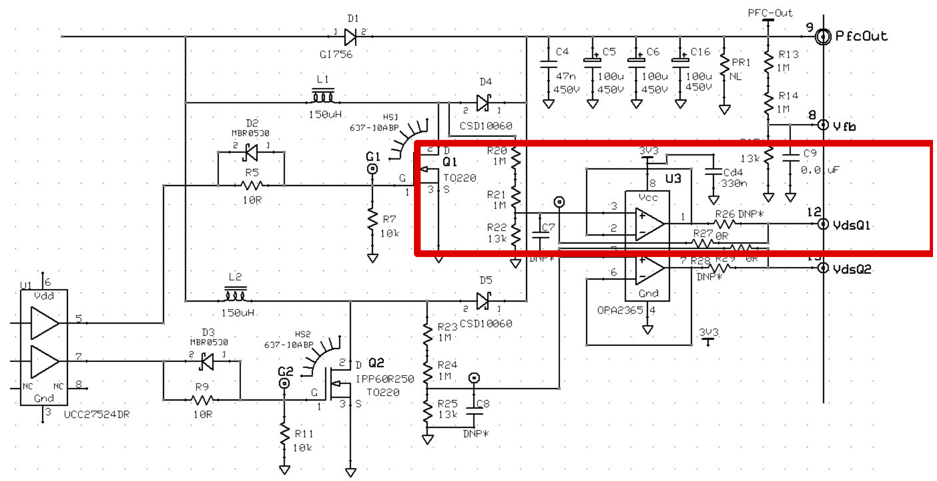
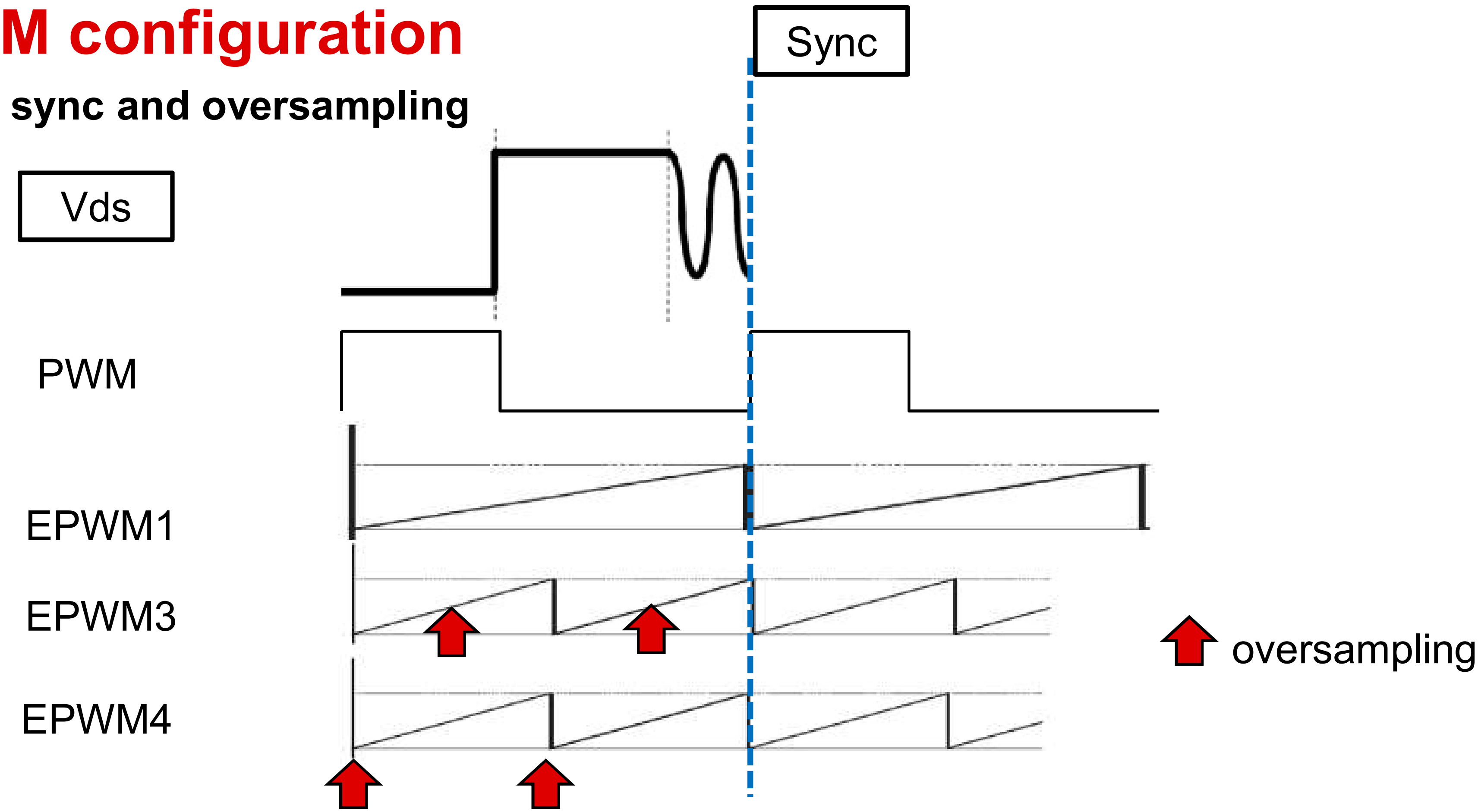




Peripheral usages

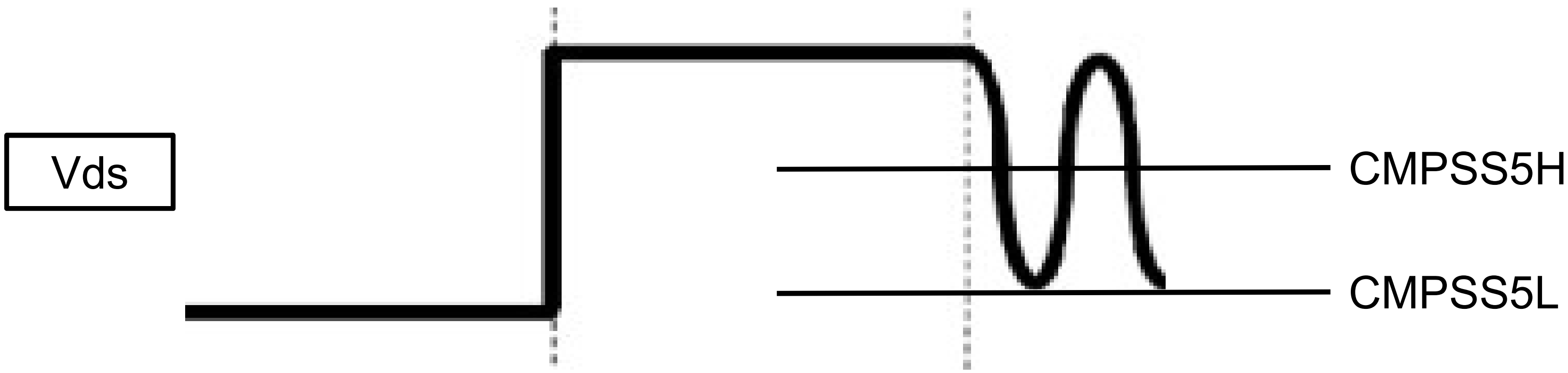
PWM configuration

PWM sync and oversampling

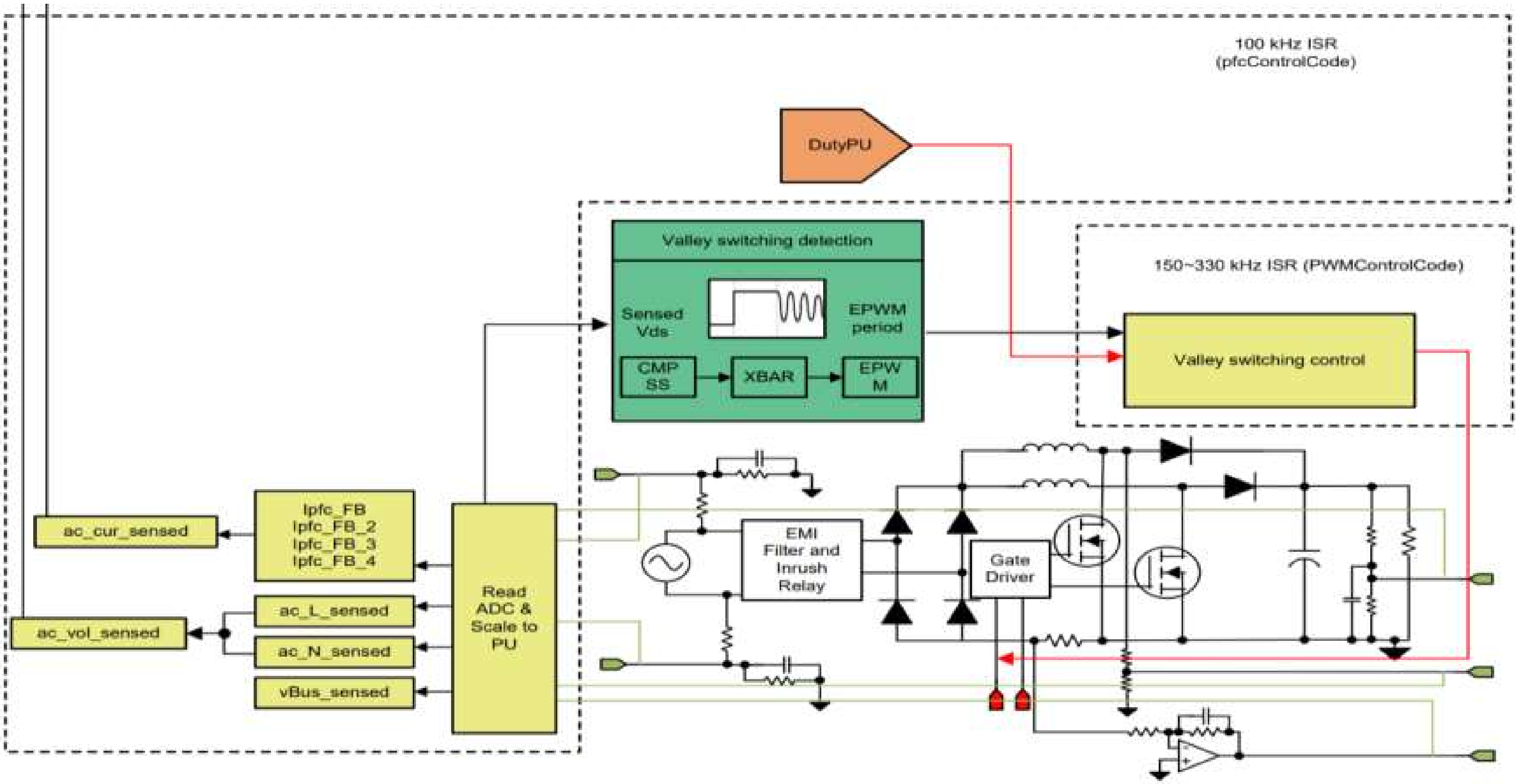


CMPSS configuration

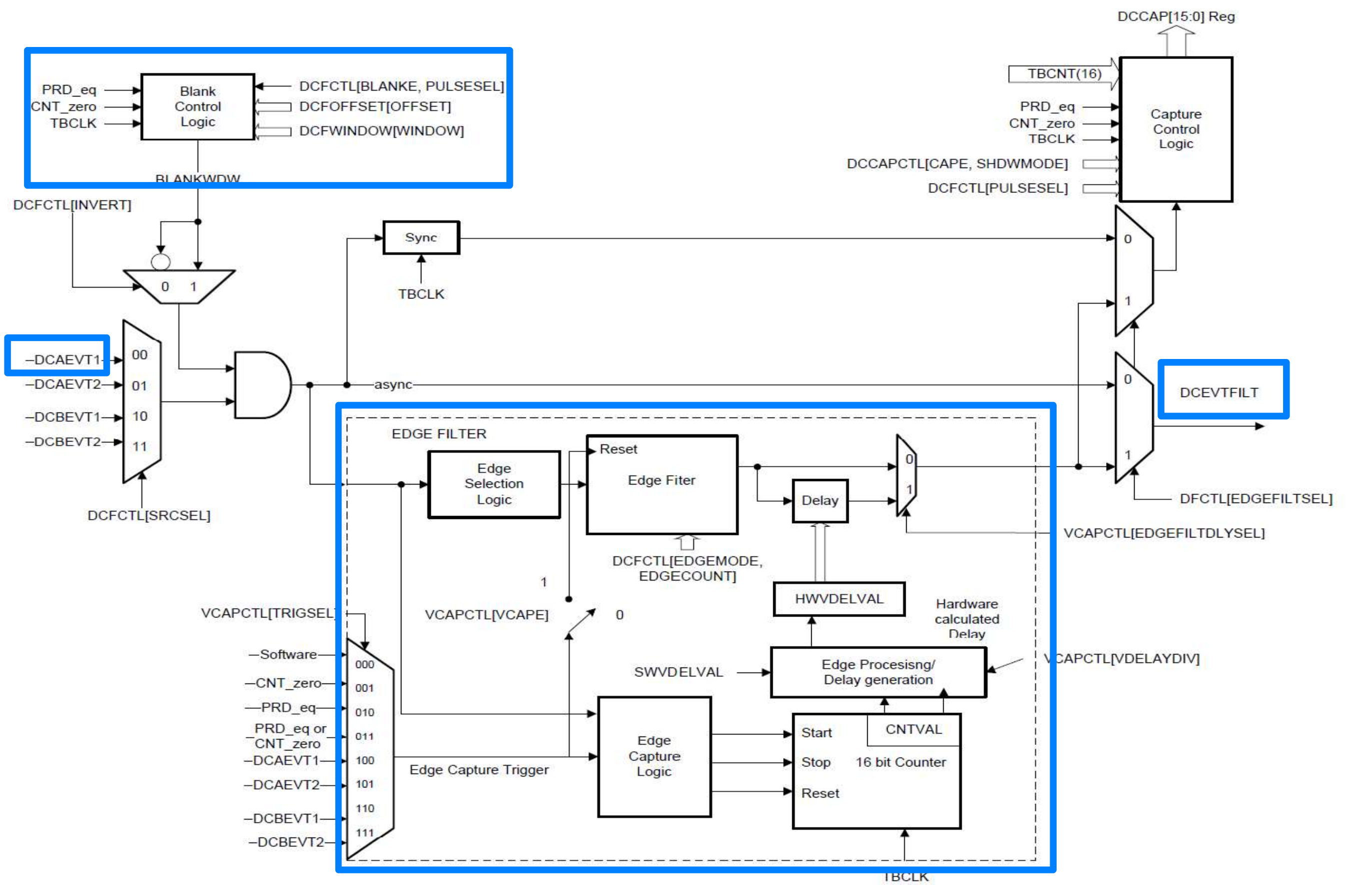
- CMPSS2H for current protection
- CMPSS5H for valley capture
- CMPSS5L ZVS or valley switching mode selection



Valley switching control diagram



Valley switching block in EPWM module



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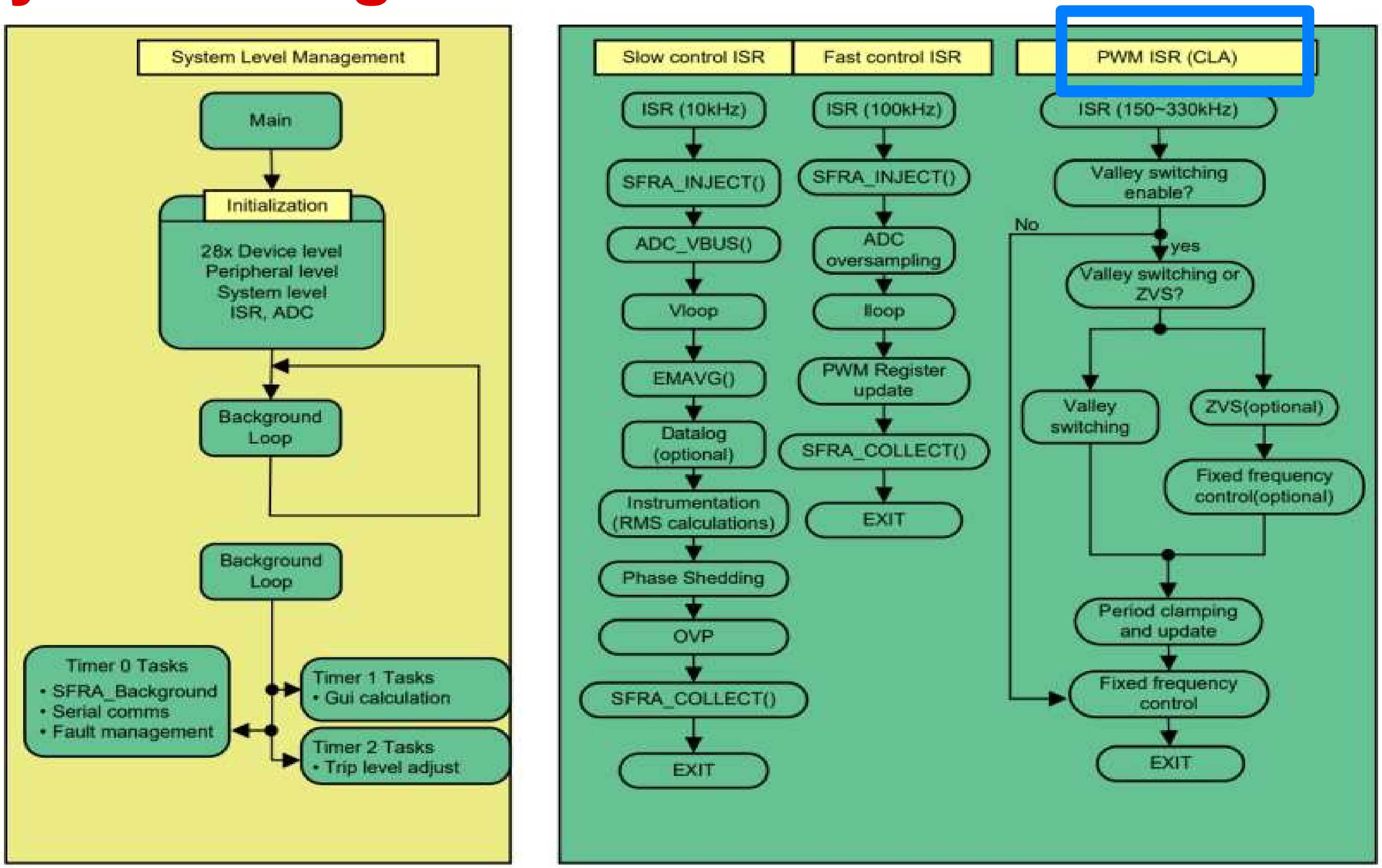
Valley switching software structure



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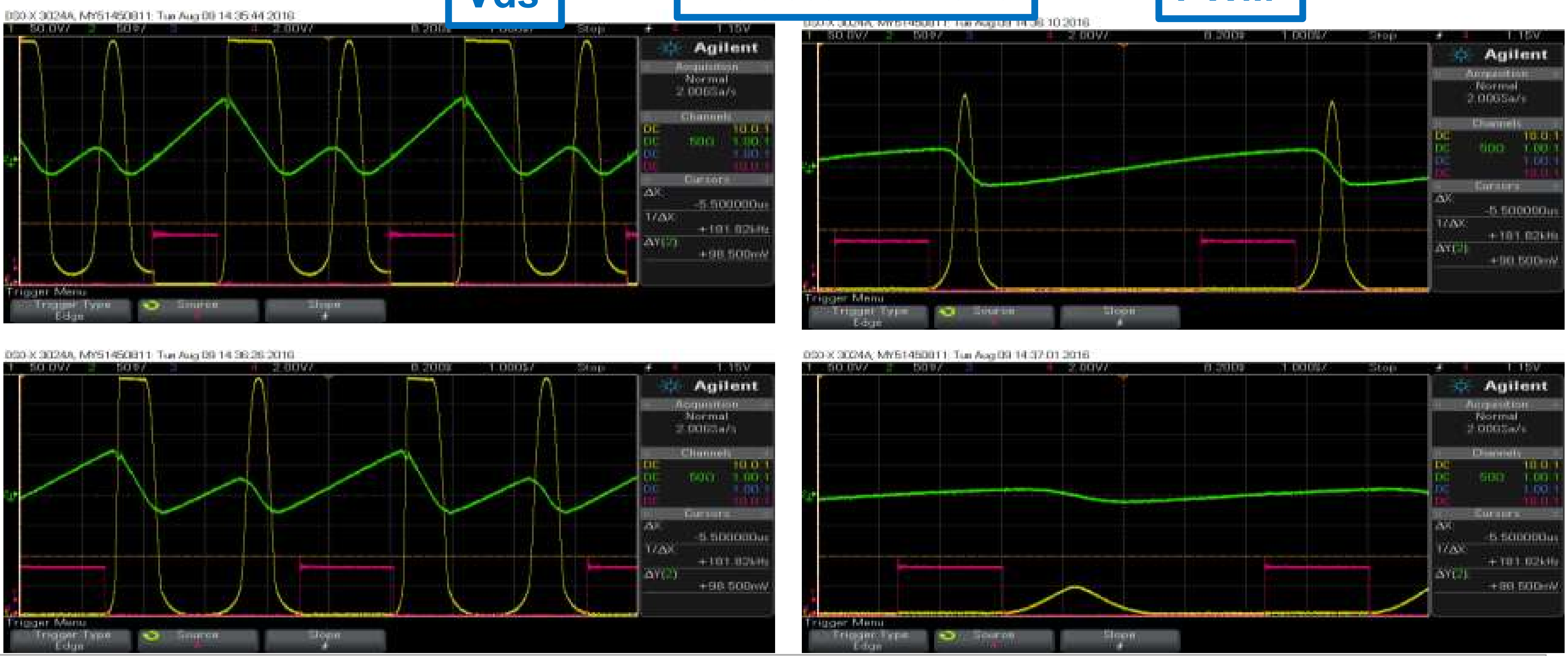
PFC with valley switching (AC input)

The Vds waveform is decided by several factors: instantaneous input voltage, load, bus voltage, etc.

Vds

Inductor current

PWM



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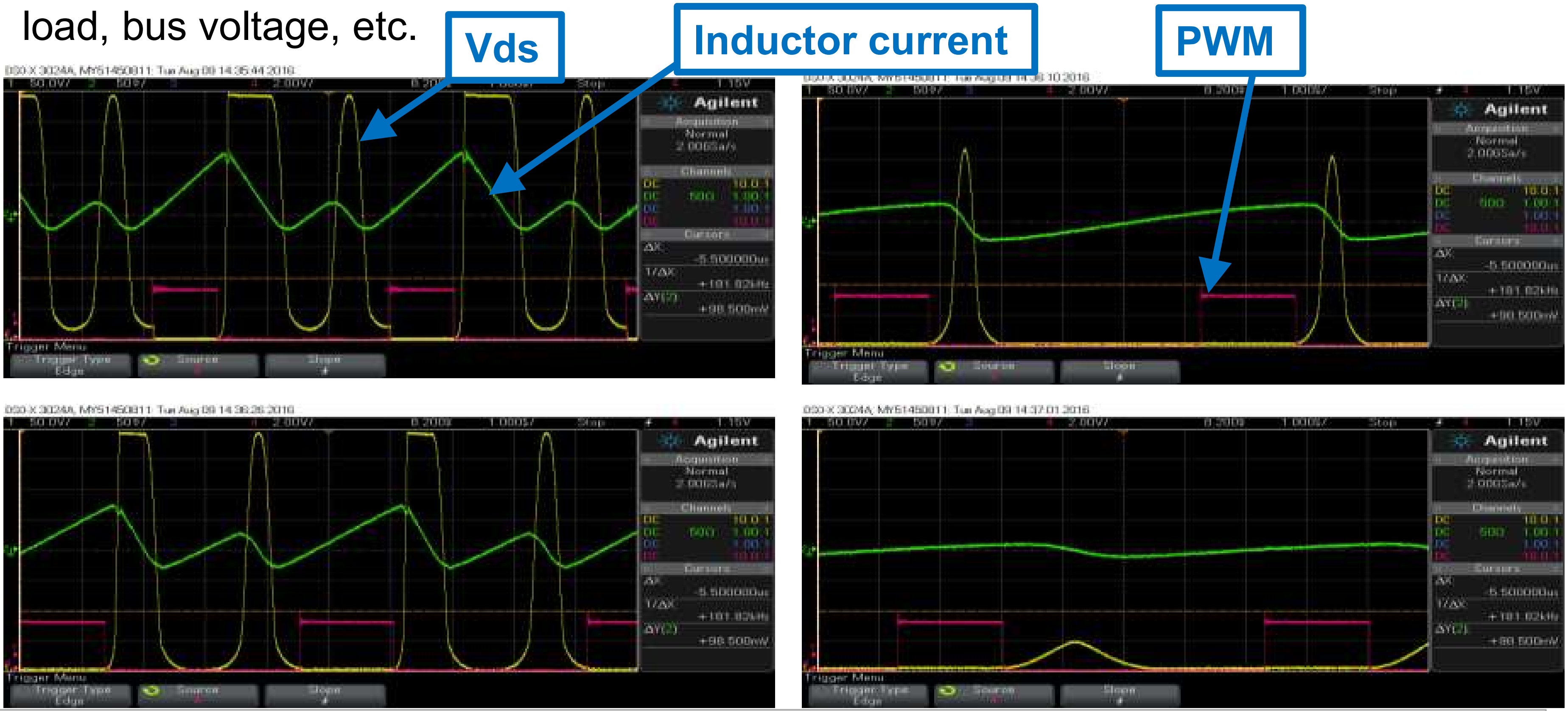
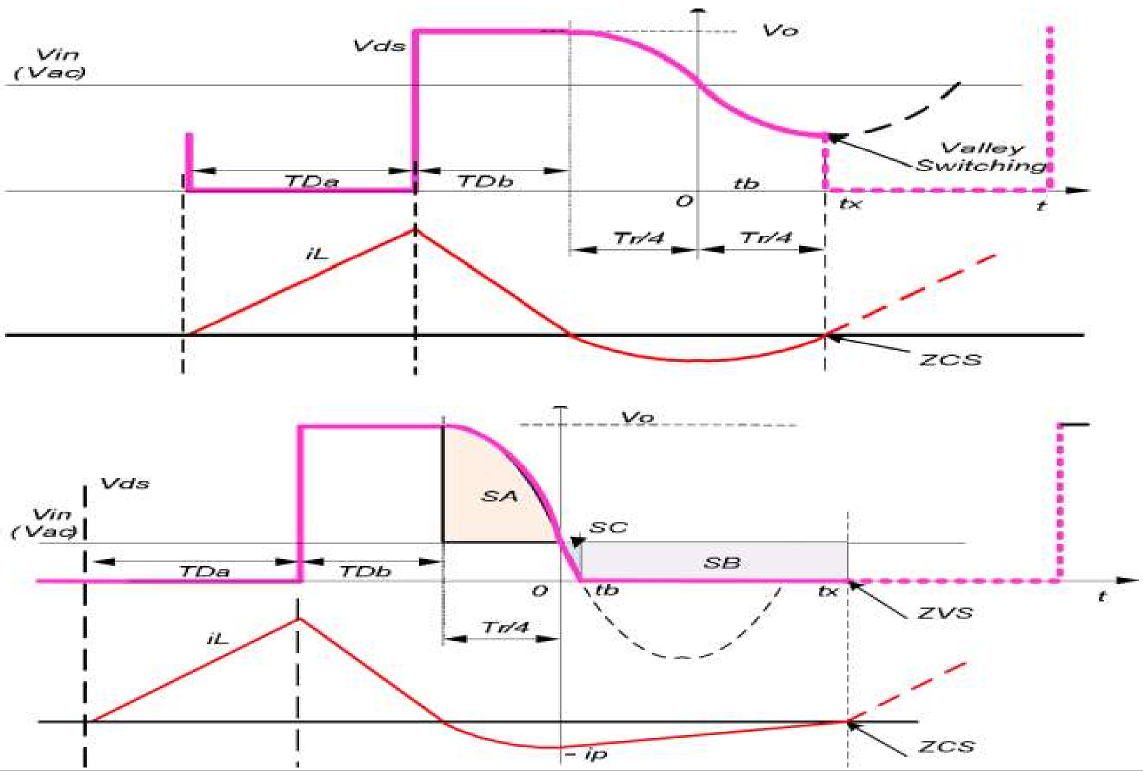


PFC with valley switching (AC input)

Valley switching and ZVS

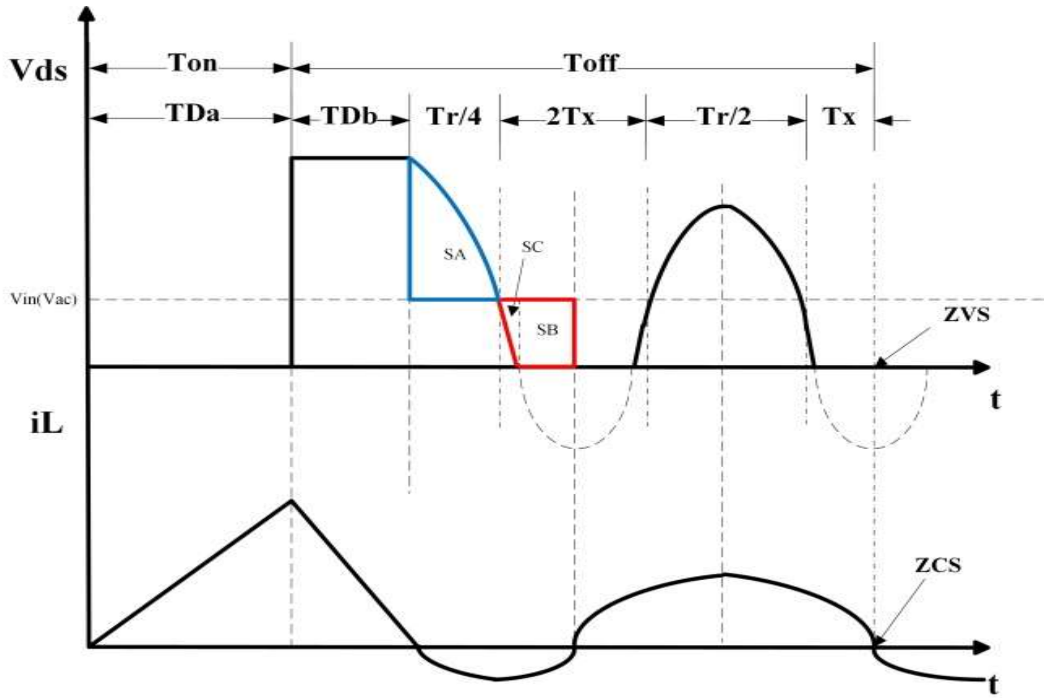


$$Vin > \frac{1}{2} \cdot Vbus$$

$$Vin < \frac{1}{2} \cdot Vbus$$

PFC with valley switching (AC input)

- **ZVS – Calculation-based control**
- **Details are available in the application note: http://www.ti.com/lit/sprach7**

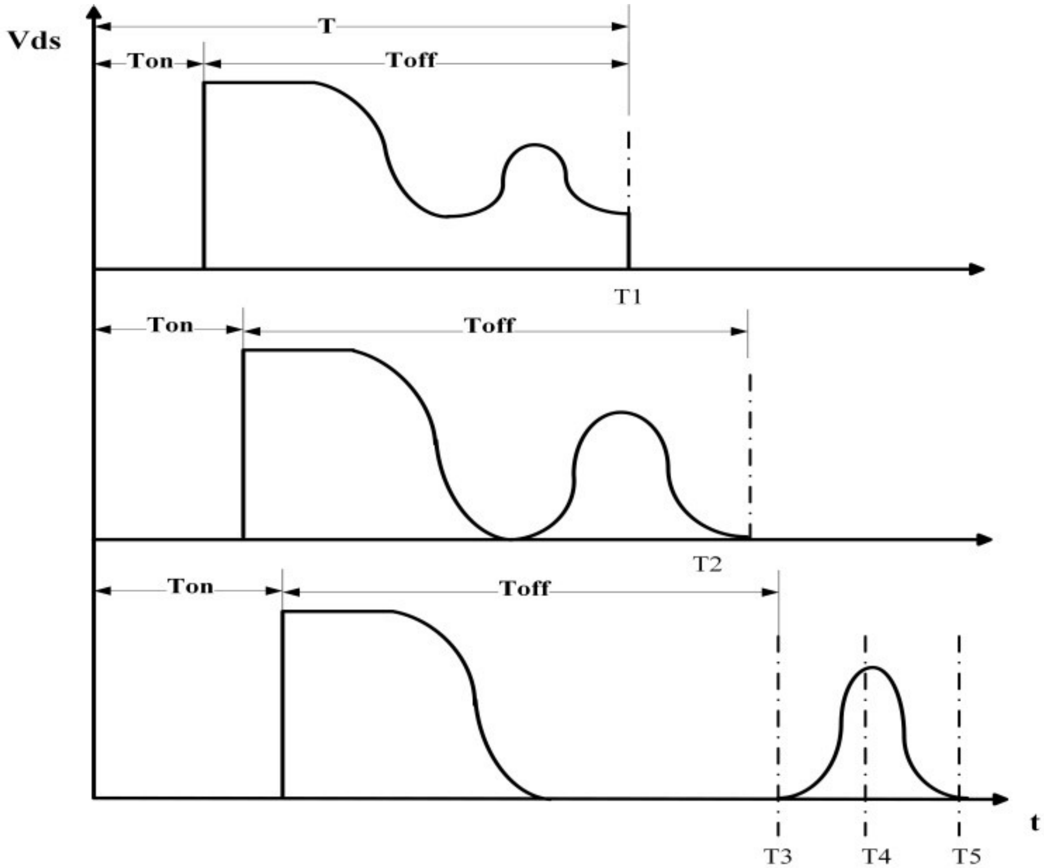


a. $TDb = TDa \cdot V_{in}/(V_o - V_{in})$

b. $T_x = V_o \cdot T_r/(8 \cdot V_{in})$

c. $T_s = TDa + TDb + (T_r/4 + T_x) \cdot 3$

Technical challenges



Valley switching

ZVS/Valley switching threshold

Fixed frequency

Technical challenges

Difficult to reduce the current distortion:

- Target: Seamless transition between valley switching, ZVS, fixed frequency operating modes
- Methods: Clamp freq during valley switching, ZVS coefficients, blanking window, CMPSS threshold, hysterisis control, etc.

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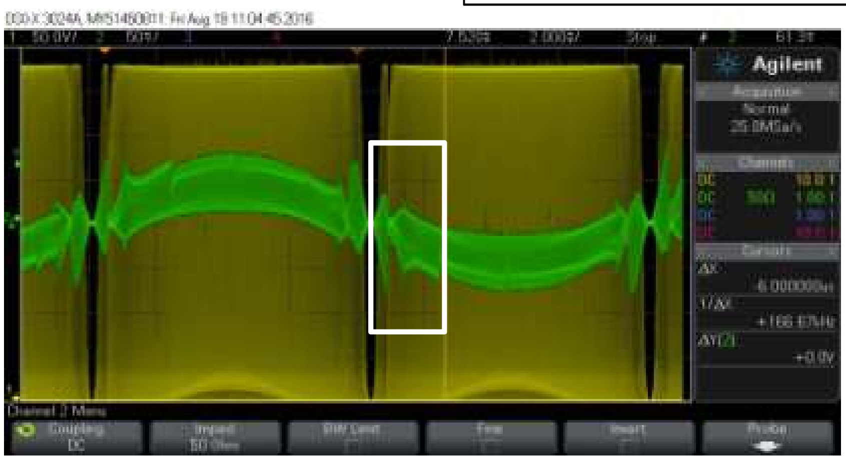
Input current distortion before implementing multi-mode control



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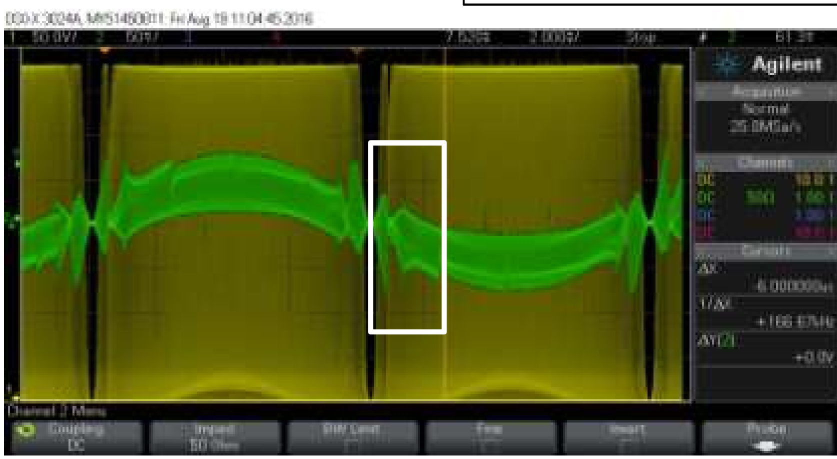
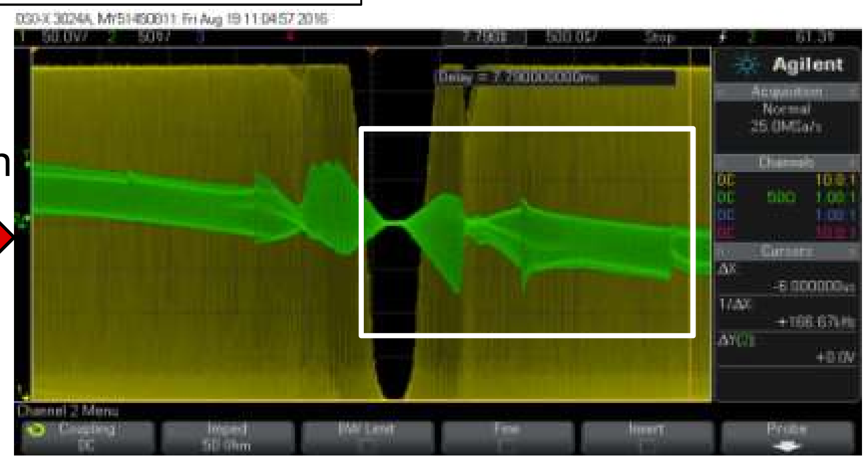
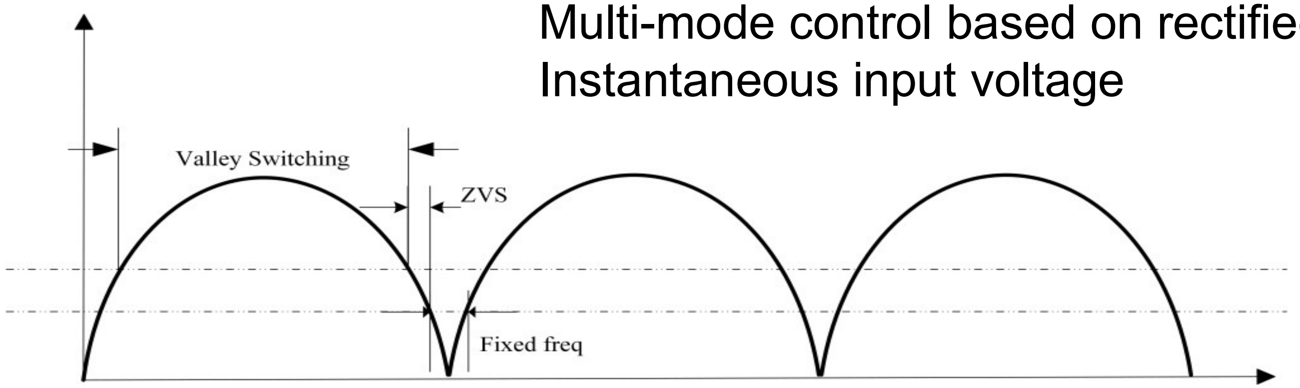


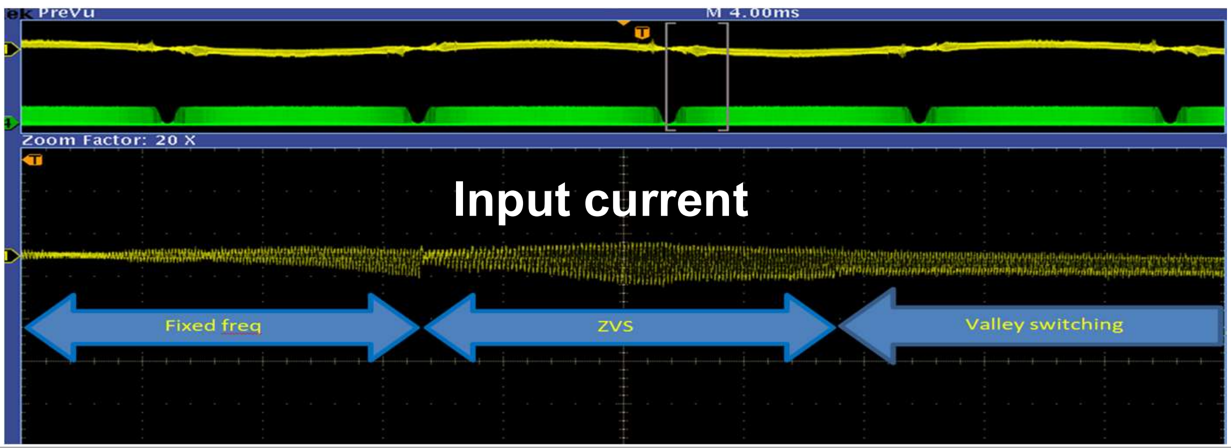
Zoom in



Technical challenges

Multi-mode control based on rectified Instantaneous input voltage

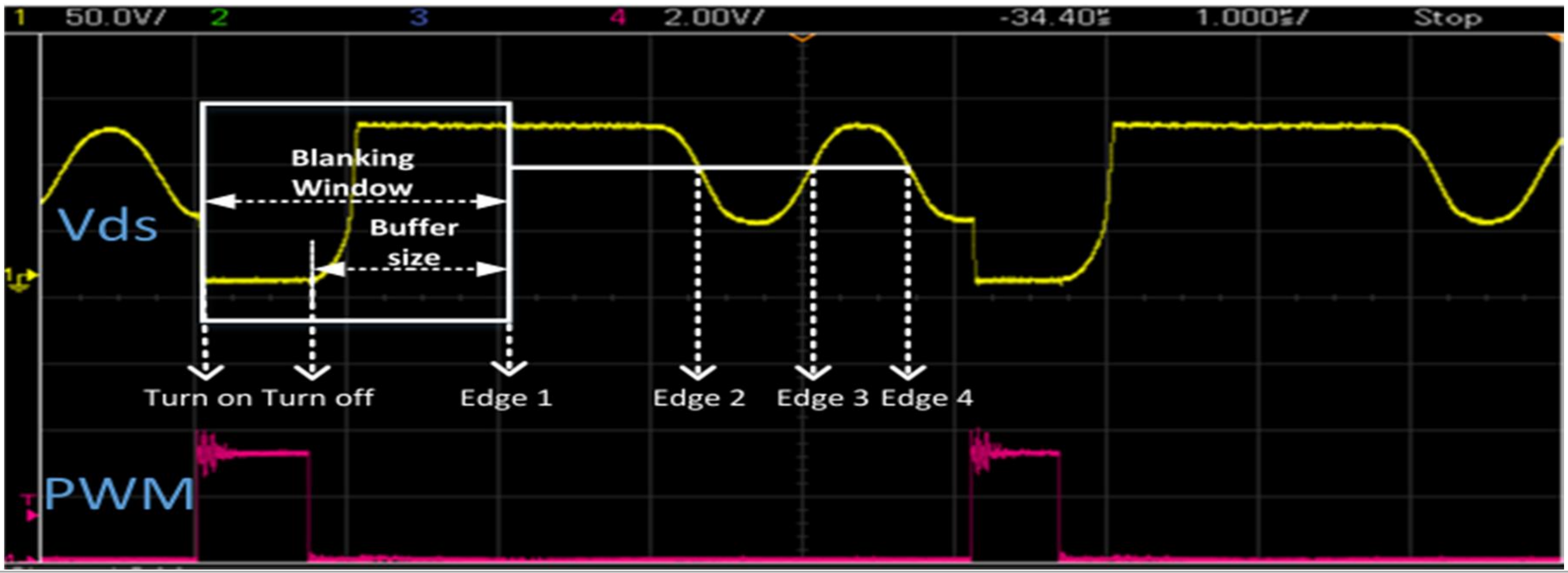




Vds waveforms under multi-mode control

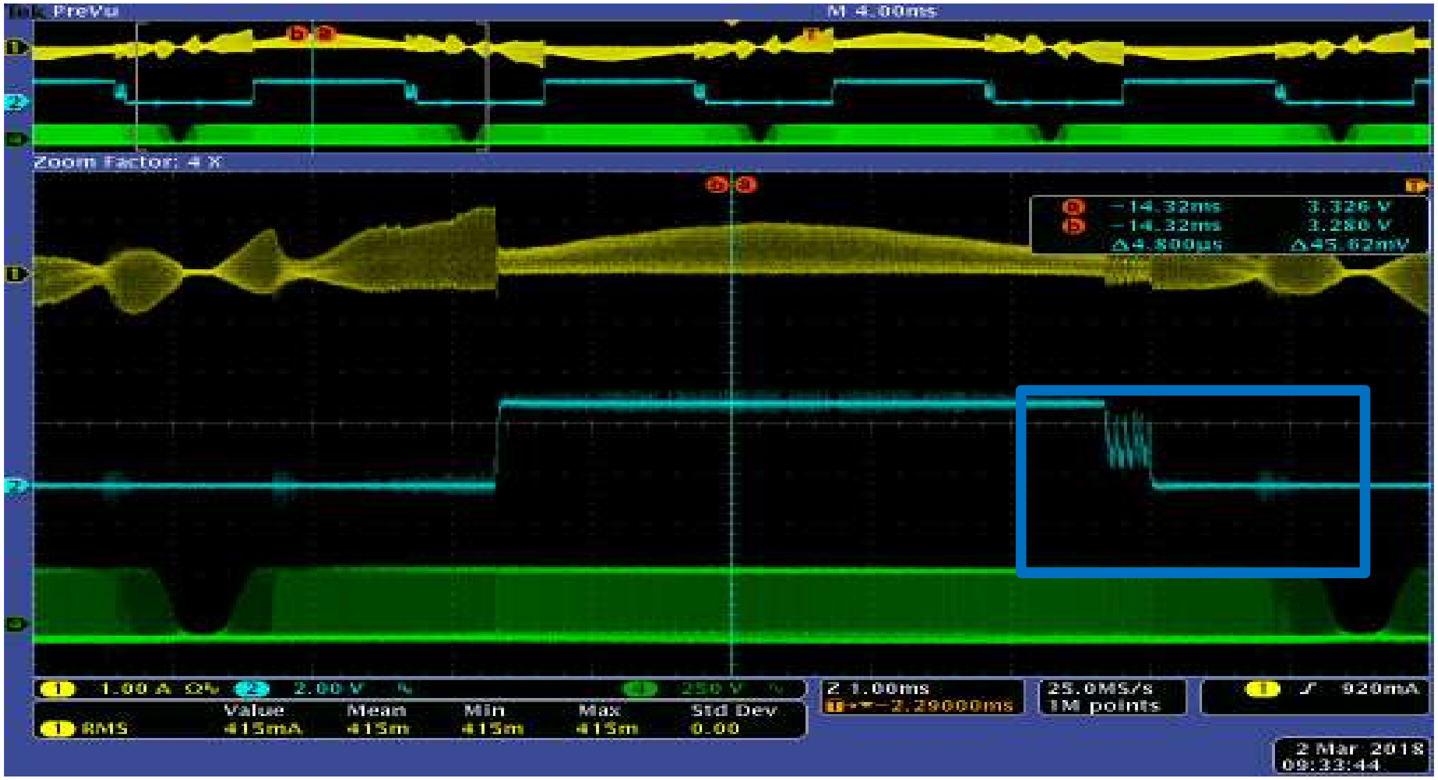
Blanking window

- Reasons for using blanking window:
  - Limit the max freq
  - Filter the noise
- Blanking window length = Duty cycle *period + Buffer size
- The high to low edge of blanking window itself will be counted as the first edge.



Hysteresis control

ZVS/valley switching transition



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- Current waveform improved with optimized valley switching control
- Low line test condition:

  5% load 120V input, 380V output

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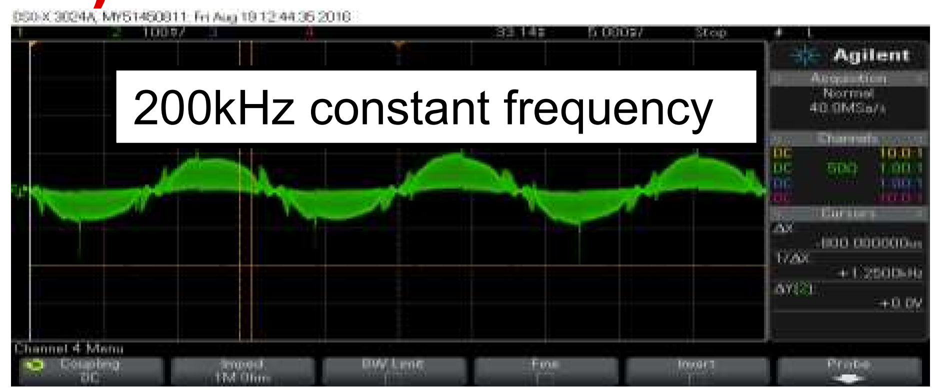

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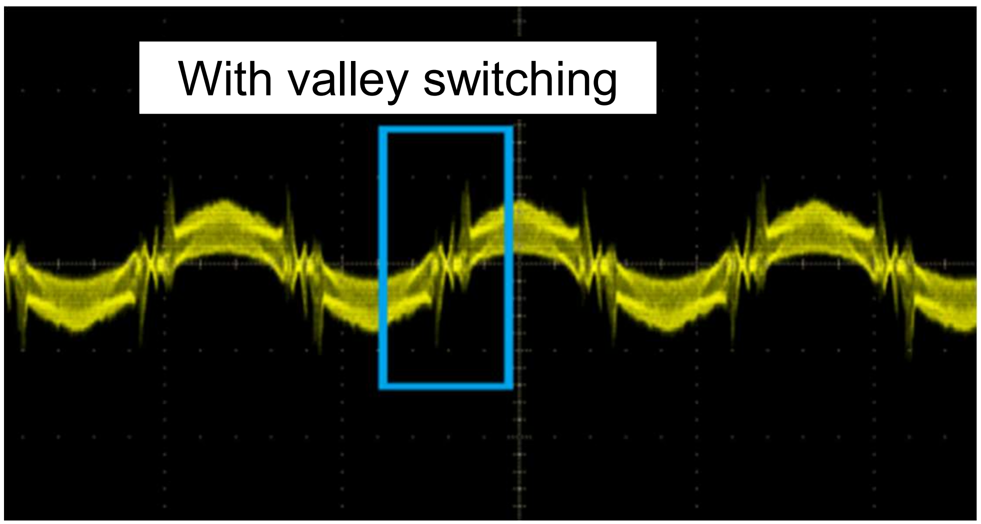

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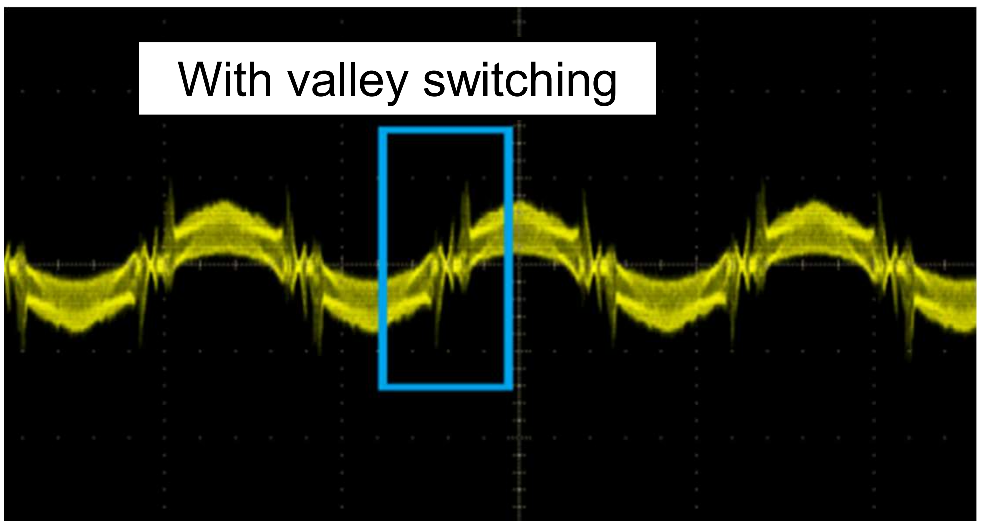
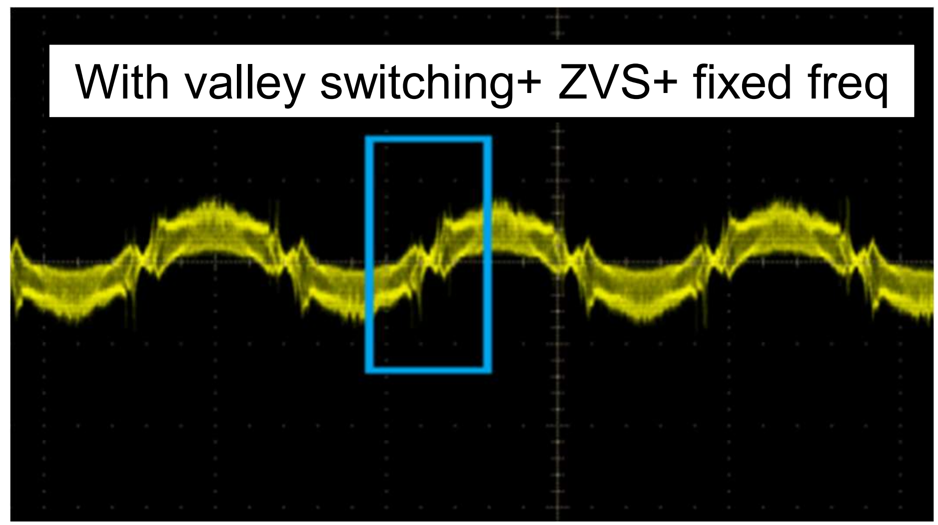
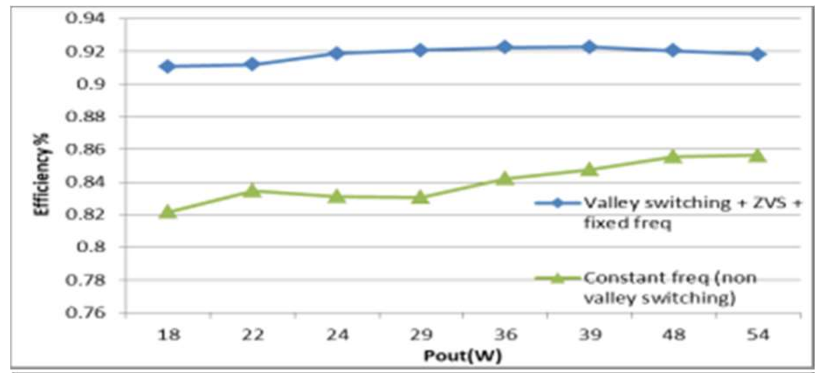


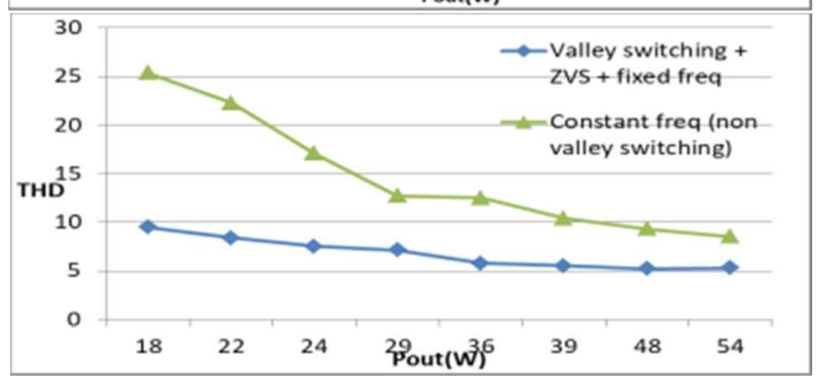


Performance comparison

Constant freq control compared to multi-mode control

System Characteristics		
5% load Single phase	Low line (Vin = 120V)	High line (Vin = 220V)
Efficiency	84% → 92%	89% → 92%
THD	10% → 6%	22% → 7%

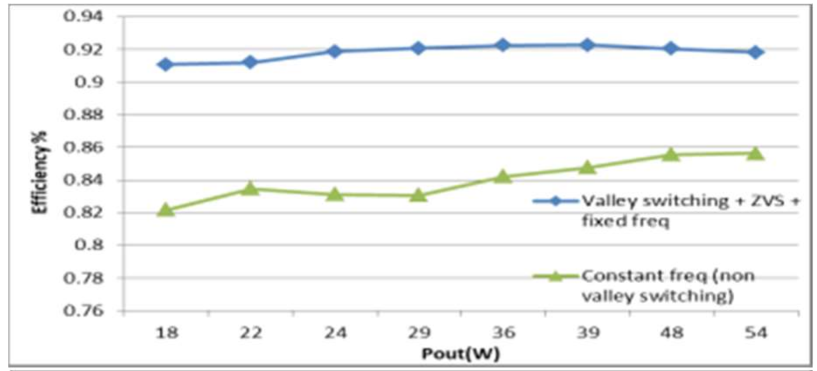


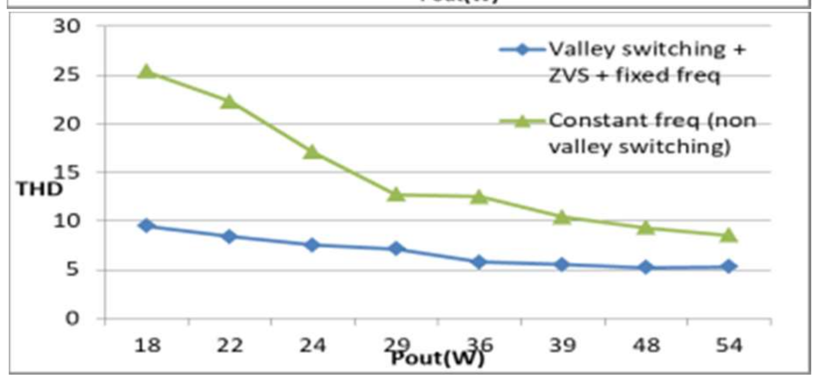


TIDM-1022 THD compared to spec

THD meets the requirement of the spec (Server customer)

System Characteristics		
7% load Single phase	Low line (Vin = 120V)	High line (Vin = 220V)
THD	5.3%	6.2%
Required THD based on the spec (5-10% load)		8%





For more information

- Download the valley switching Boost Power Factor Correction (PFC) reference design: http://www.ti.com/tool/TIDM-1022
- Learn more about the Piccolo 32-bit MCU (TMS320F280049): http://www.ti.com/product/TMS320F280049
- Control Law Accelerator (CLA) Usage in TIDM-1022: http://training.ti.com/tidm1022-cla-usage
- For questions about this training, refer to the E2E Community Forums for C2000 Processors at http://e2e.ti.com