MPS 先进 PFC+LLC解决方案

March 2024

Agenda

- PFC+LLC Topology Inductions
- MPS Solutions for PFC and LLC
- MPS Solutions for SR

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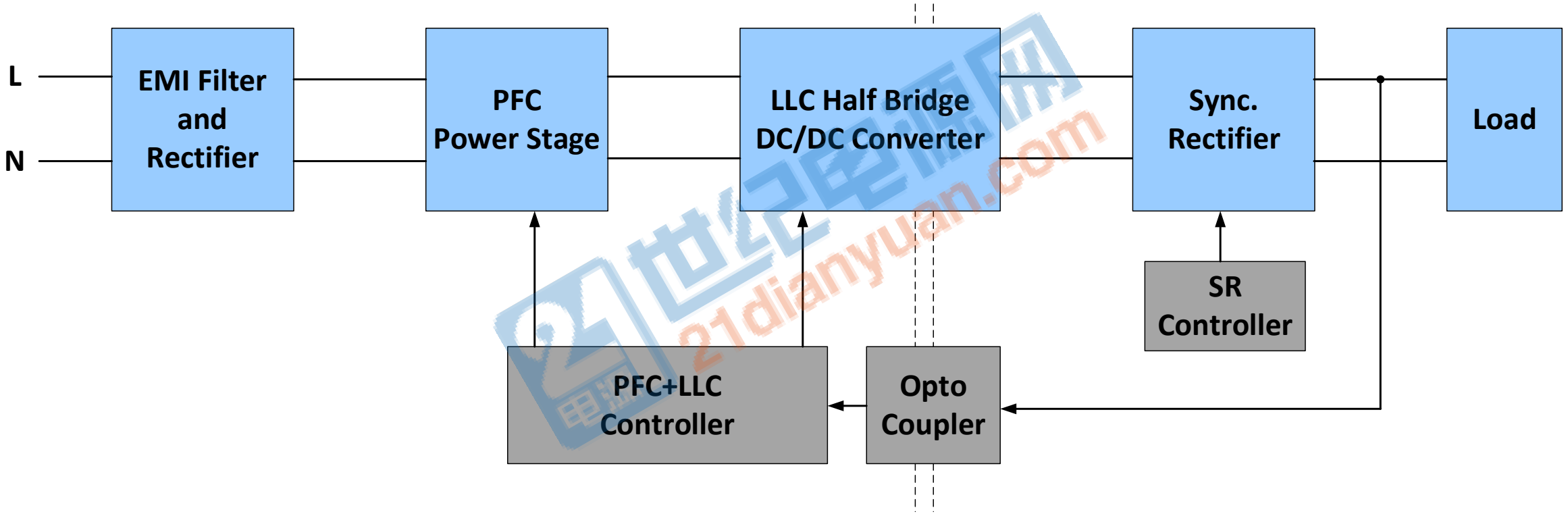
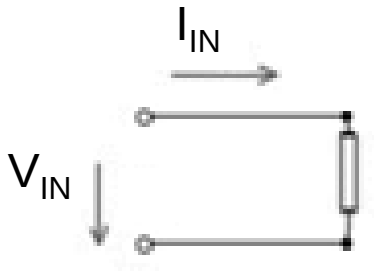
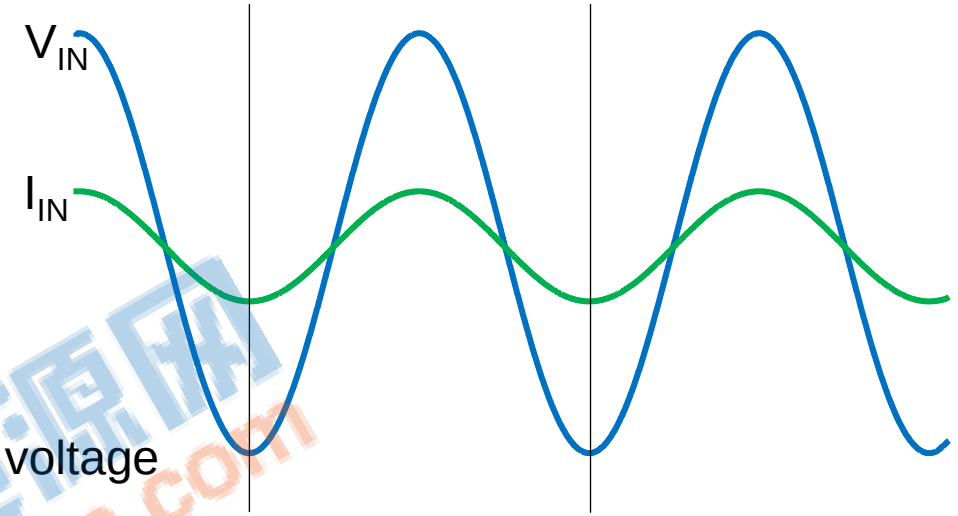
Block Diagram



What Is PFC?

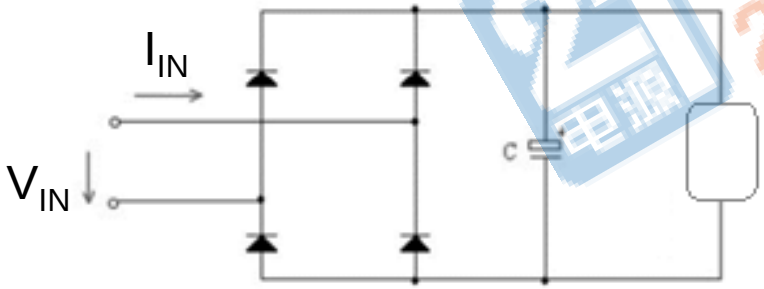
- A PF of 1 corresponds to the resistor case:

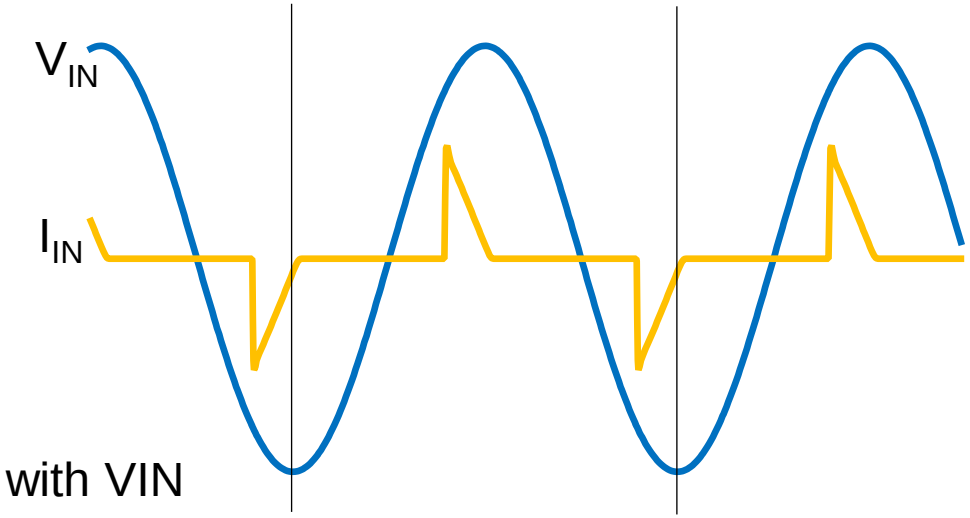




  - The current is sinusoidal and in phase with the input voltage

- A usual power supply has a PF lower than 1:

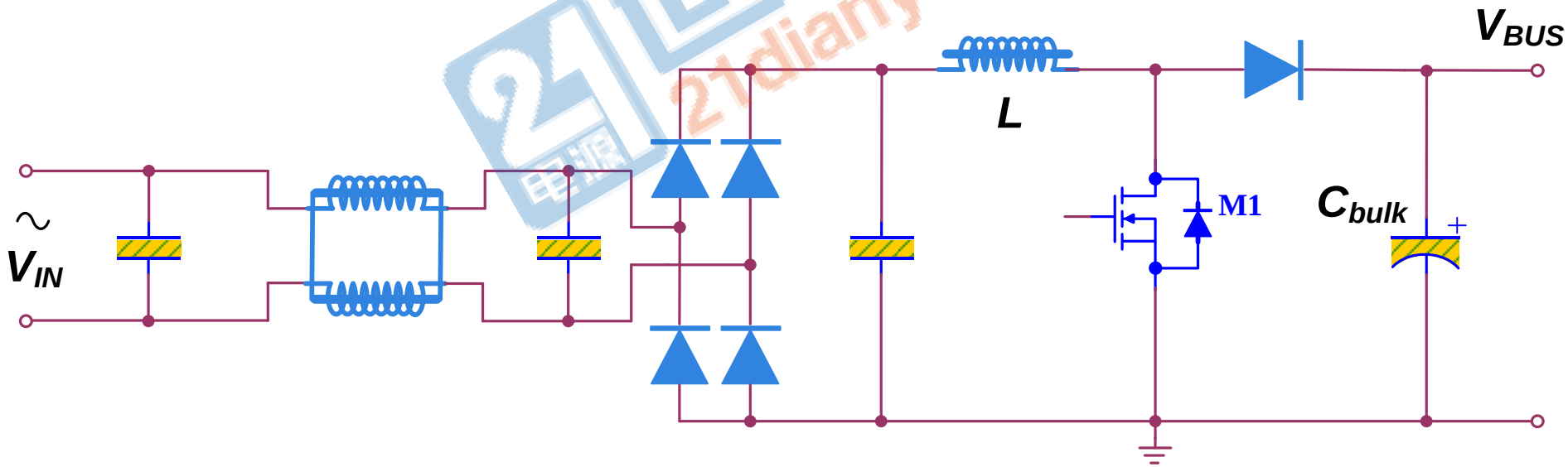




  - The current is not sinusoidal, and may be out of phase with VIN
  - Larger RMS current circulates in input (higher reactive power)

Boost PFC Topology

- Popular Because
  - Sinusoidal AC Line current
  - Power Factor is high
- Output Voltage is higher than input
  - Typically 380V to 400V
  - Can provide hold-up time in the event of loss of AC line cycle

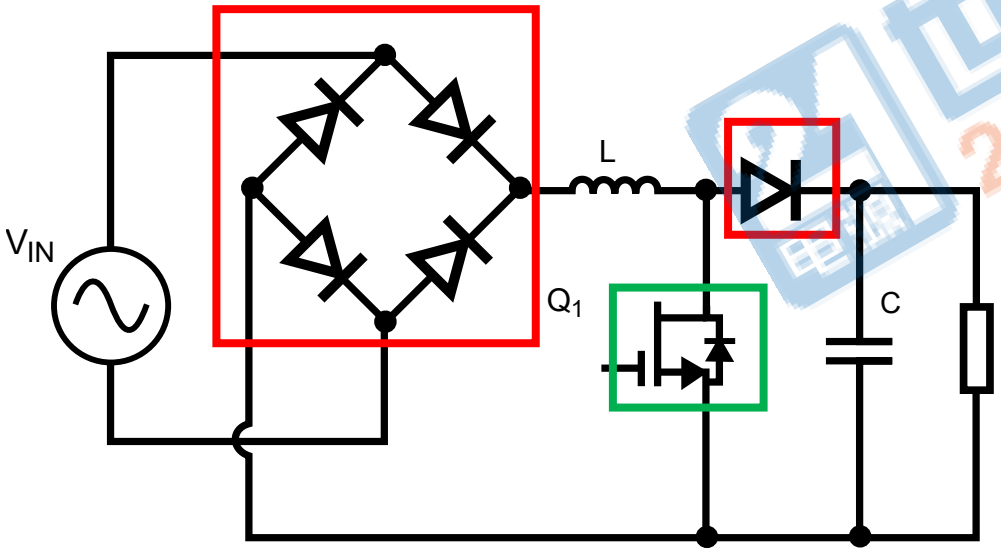


Boost PFC Topology

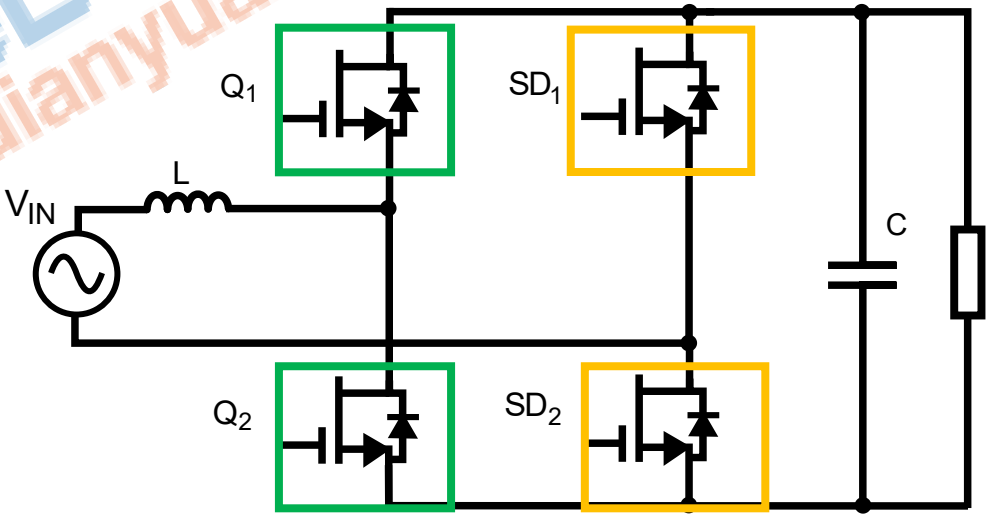
There are many more active PFC structure, most of them based on the boost topology.

For example: interleaved boost, bridgeless boost, Vienna rectifier, Totem-Pole, etc.

Full-bridge rectifier + Boost



Totem-pole bridgeless PFC



Fast Switching

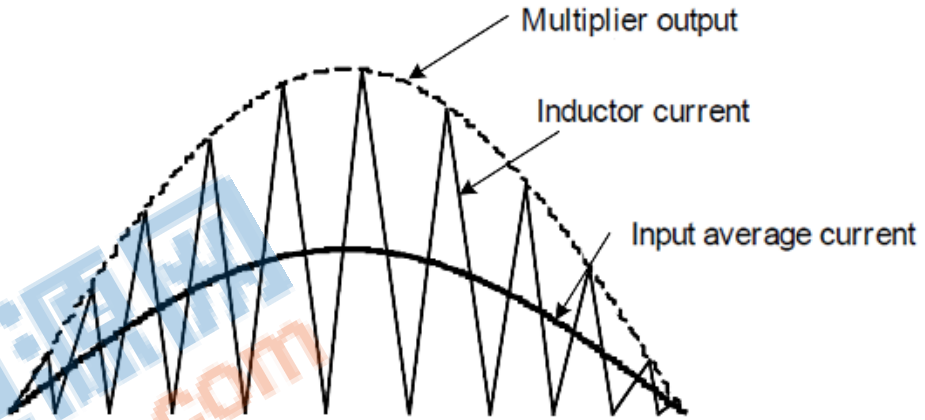
f_{SW} = 100kHz

Slow Switching

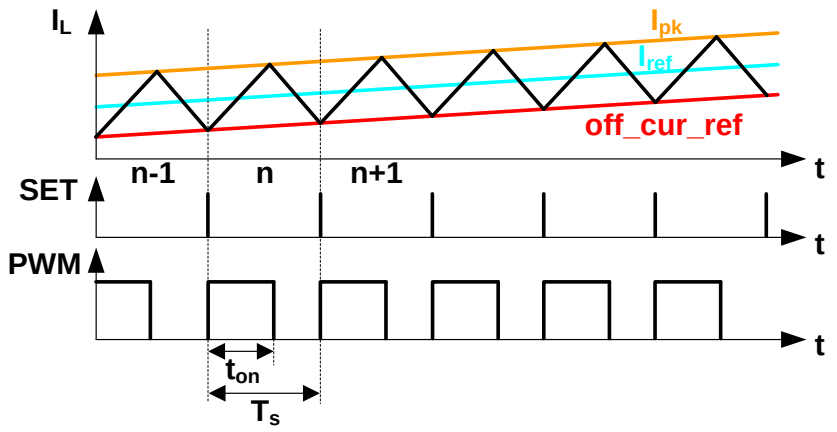
$f_{SW} = f_{GRID}$

Boost PFC Topology

- CrM: Critical conduction mode
  - Variable Frequency
  - High Peak Current
  - Low cost Diode

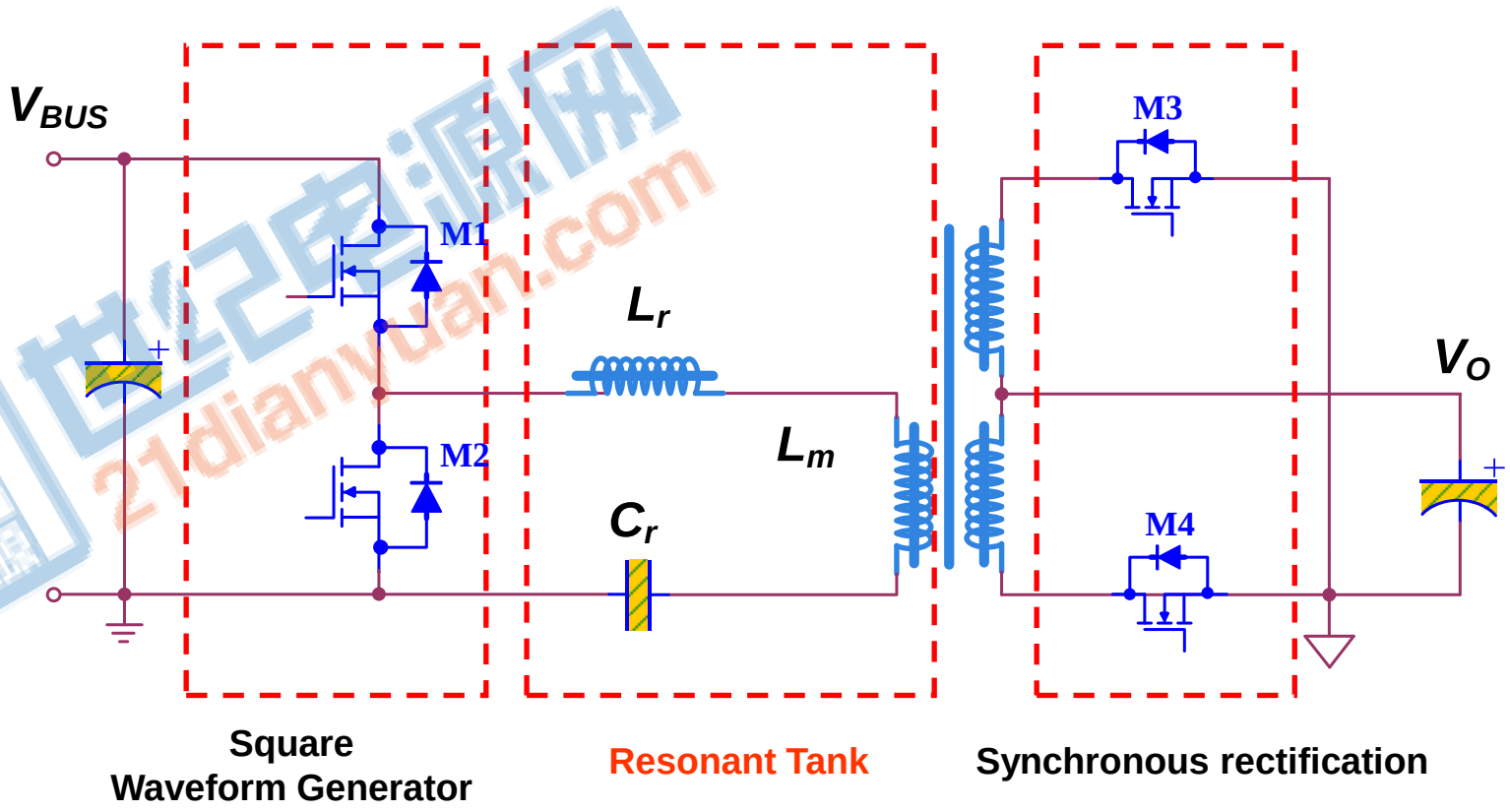


- CCM: Continous Conduction Mode
  - Fixed Switching Frequency
  - Lower Peak Current
  - Diode reverse recovery



LLC Topology

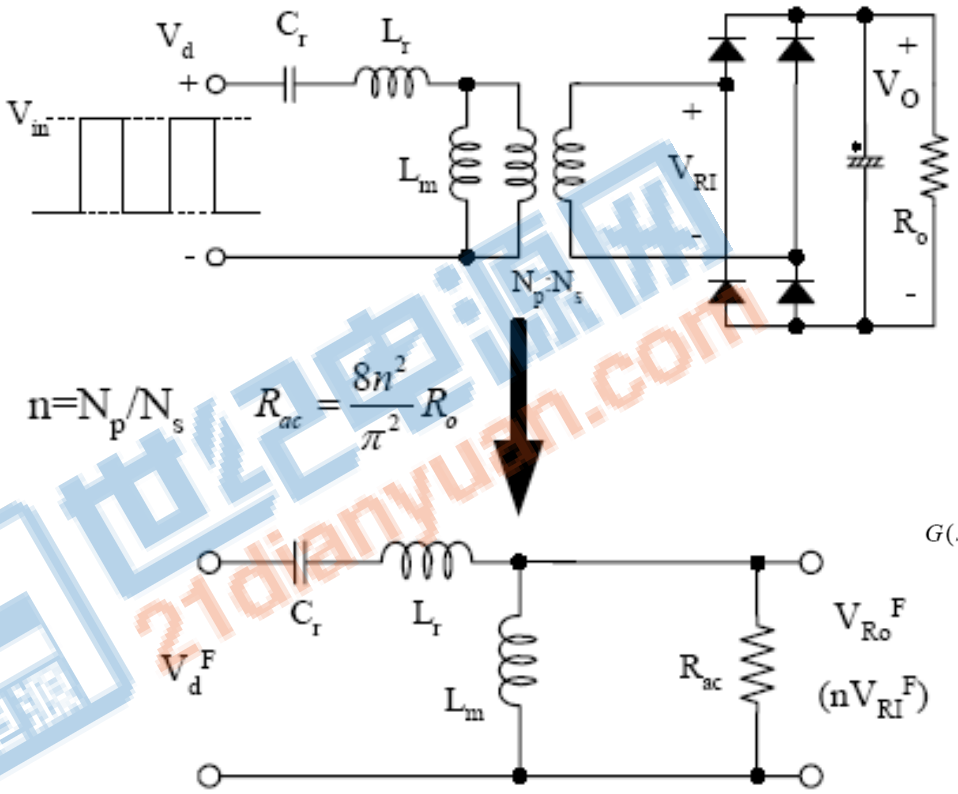
- The LLC Topology is popular because
  - Simple structure, small size
  - High efficiency, ZVS
  - Low EMI



LLC Topology

Fundamental assumptions of fundamental wave analysis：

- The input voltage is a square-wave pulse train.
- Q>0.5 and $f_0 \approx fs$, use fundamental waves instead of square waves.

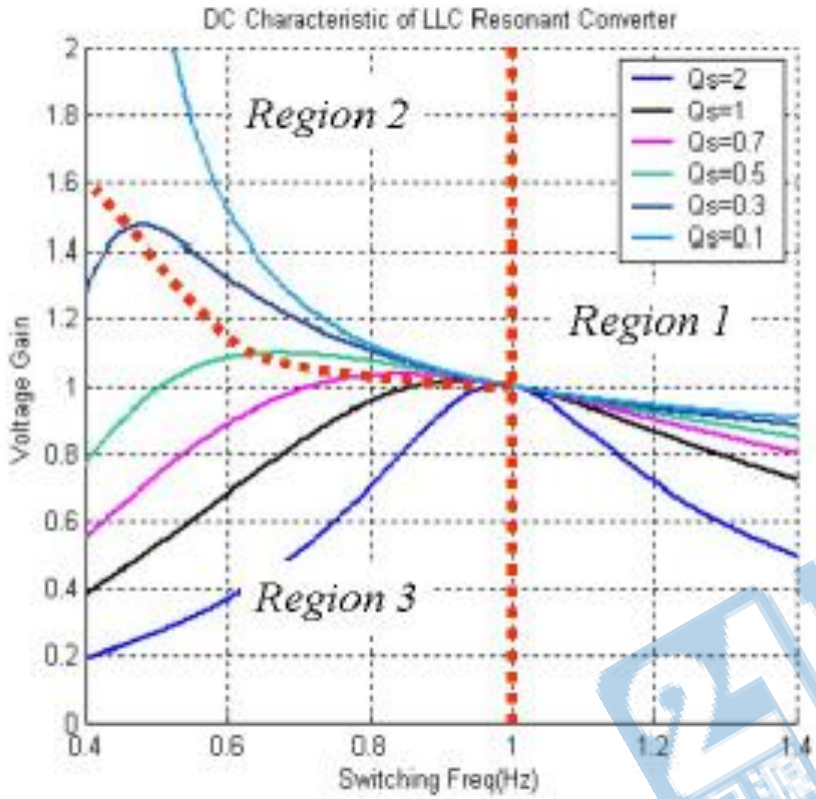


AC Equivalent Circuit of LLC Resonant Converter

$$\omega_r = \frac{1}{2\pi\sqrt{L_r \bullet C_r}} \qquad Q = \frac{\omega_r \bullet L_r}{R_{ac}} \qquad K = \frac{L_m}{L_r}$$

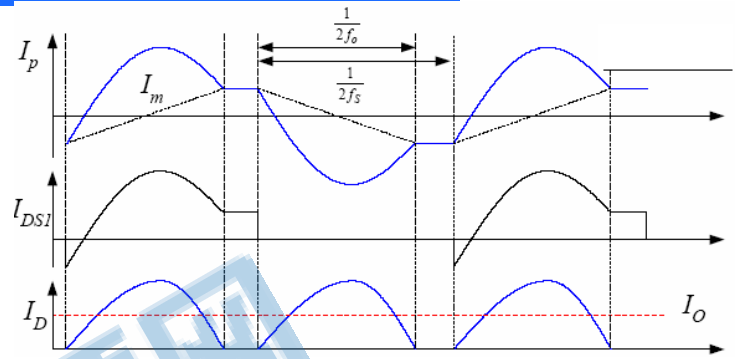
$$G(s) = \frac{K \bullet \left(\frac{s}{\omega_r}\right)^2}{Q \bullet K \bullet \left(\frac{s}{\omega_r}\right)^3 + (1+K) \bullet \left(\frac{s}{\omega_r}\right)^2 + Q \bullet K \bullet \left(\frac{s}{\omega_r}\right) + 1}$$

LLC Topology

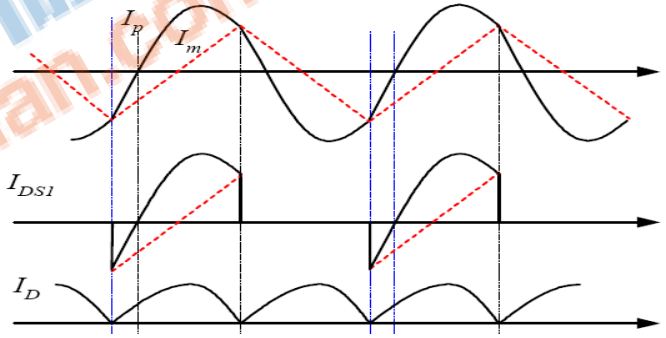


DC Characteristic of LLC Resonant Converter

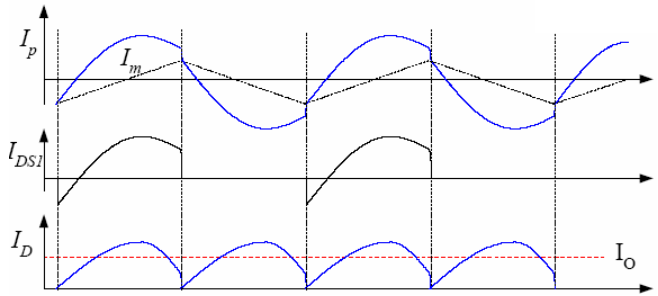
- In normal operation, LLC works at the vicinity of the resonant frequency.
- During hold-up period, LLC works at the Fs<Fr to achieve high gain.
- In light load, LLC may work at the Fs>Fr to achieve high efficiency.



(1) Fs<Fr Region2



(2) Fs=Fr At resonant frequency



(3) Fs>Fr, Region 1

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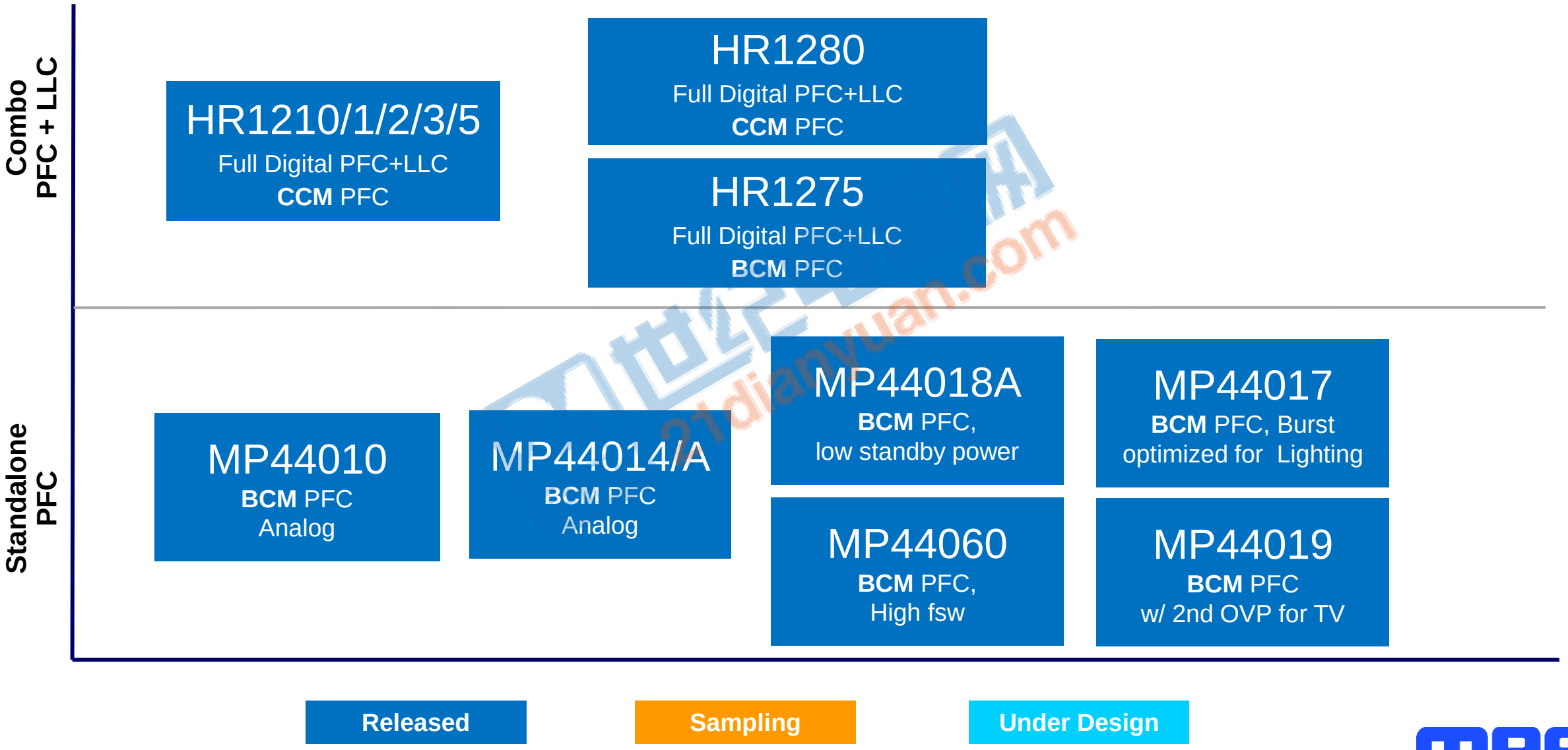
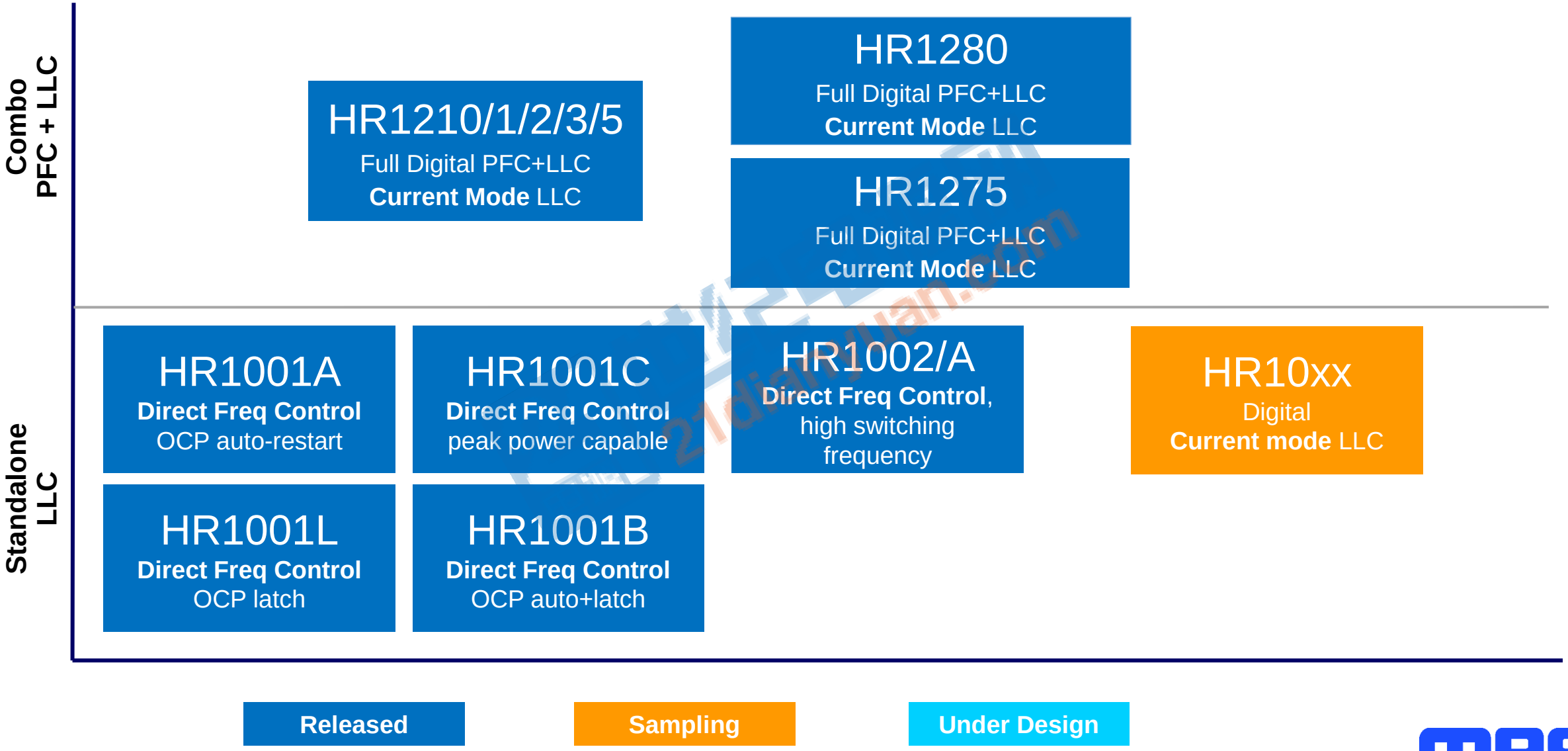
MPS PFC Roadmap



MPS LLC Controllers Roadmap

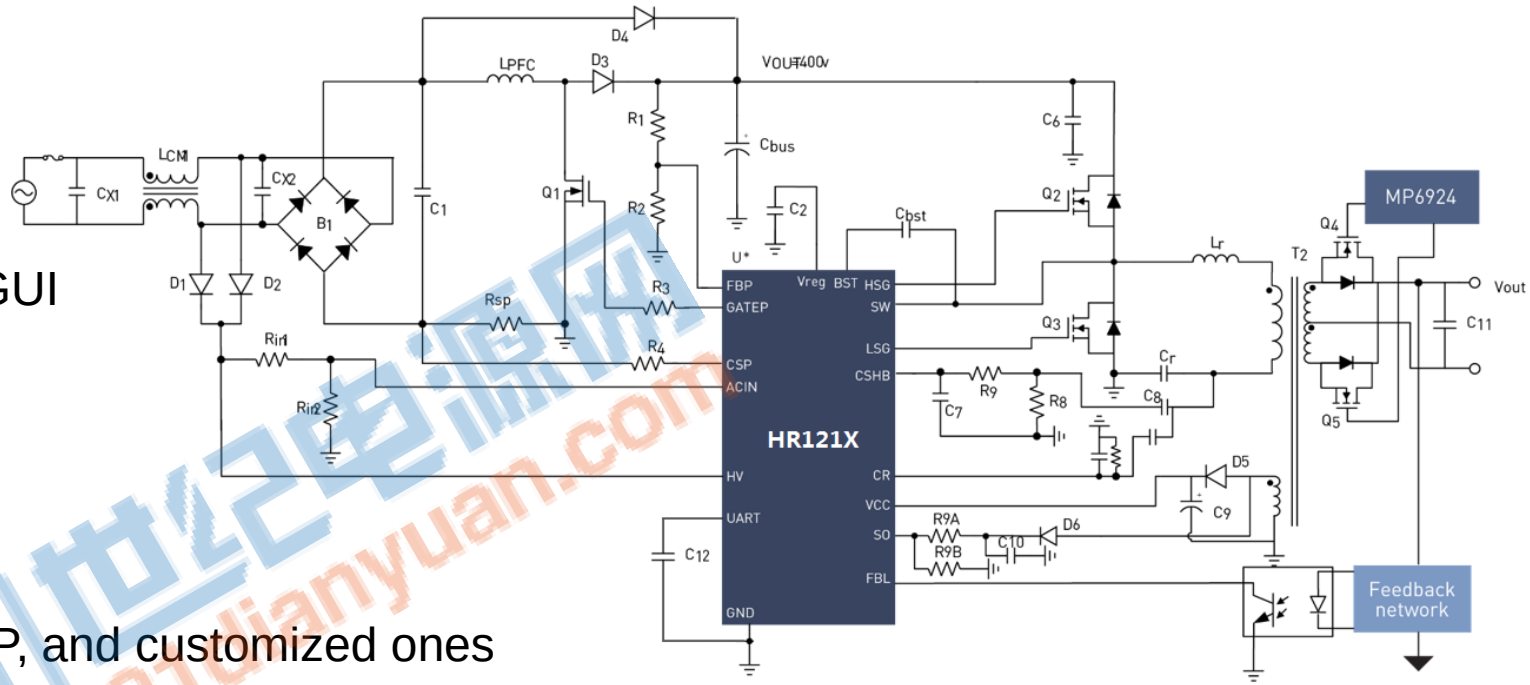


HR121x – Digital PFC+ LLC Combo Controller

Key Features

System Overall

- Digital control programmable through GUI
- <100mW no load power loss
- High efficiency at light load
  - > 80%@ 5W, > 65%@0.5W
- Comprehensive protections.
  - Brown-in/out, OVP, OCP, OLP, OTP, and customized ones



PFC Section

- Built-in HV start-up and X-cap discharger.
- CCM&DCM multimode control
- PF compensation, easy to get >0.9 PF at 10% load
- Two stage digital loop compensation

LLC Section

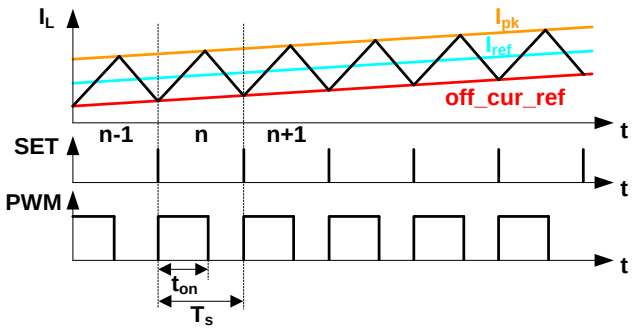
- 600V integrated HB driver and BST diode
- Current mode control
- Proprietary burst and skip operation modes
- Adaptive dead time and capacitive mode protection

HR121x – Digital PFC+ LLC Combo Controller

- Multi-mode PFC

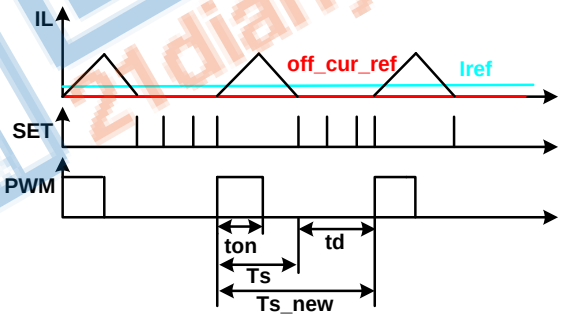
A set signal determines the CCM valley current point and DCM point.

CCM



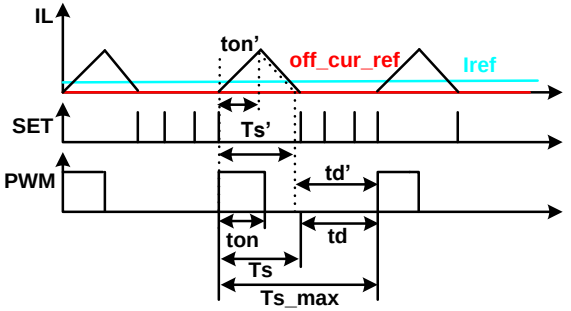
CF-DCM

Constant frequency



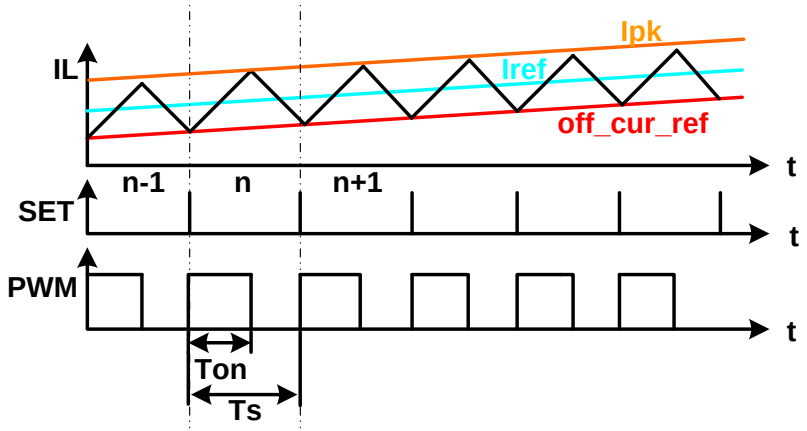
VF-DCM

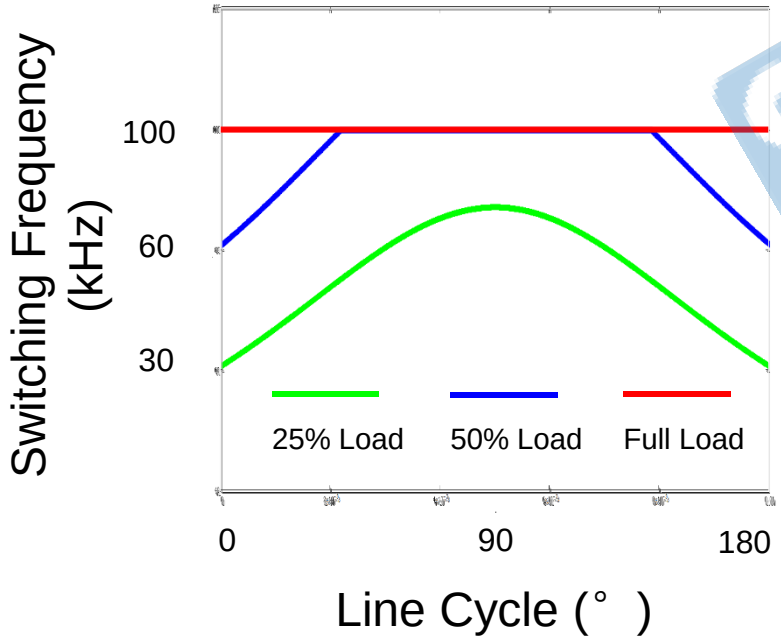
Variable frequency

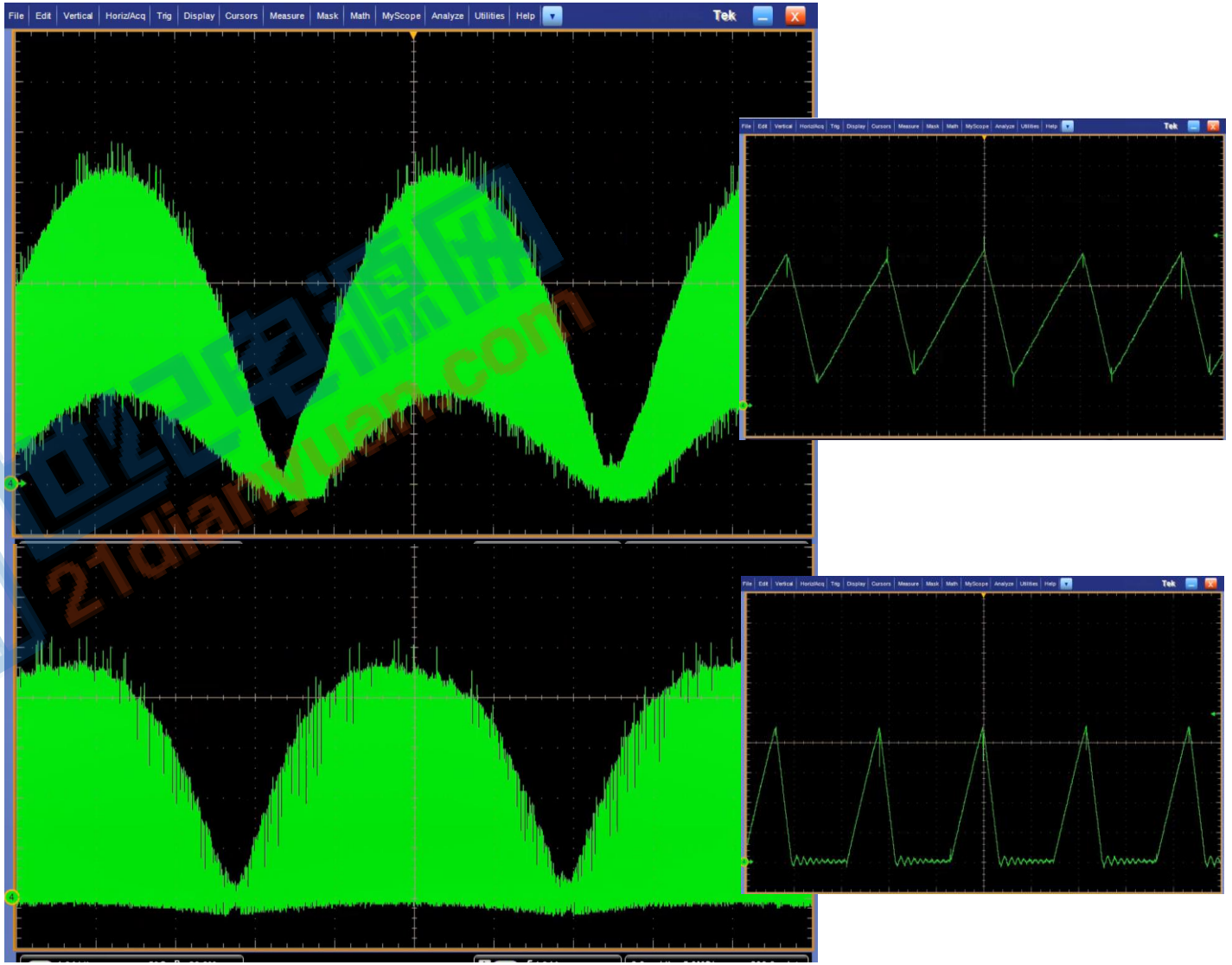


HR121x – Digital PFC+ LLC Combo Controller

CCM&DCM PFC Control

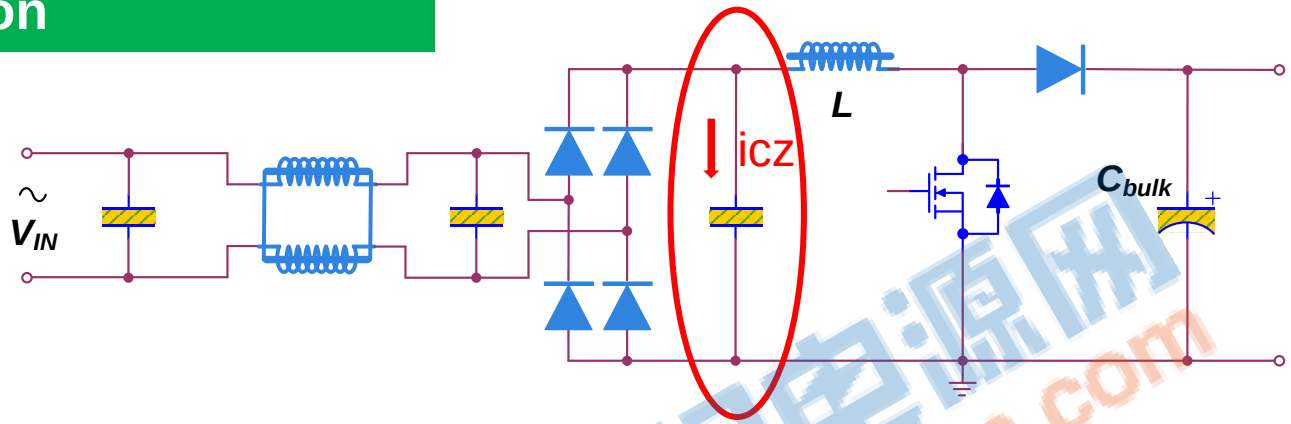


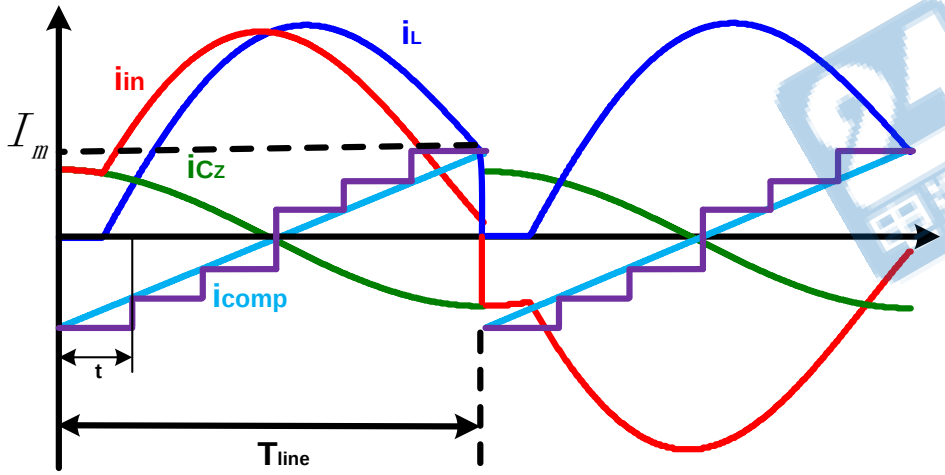


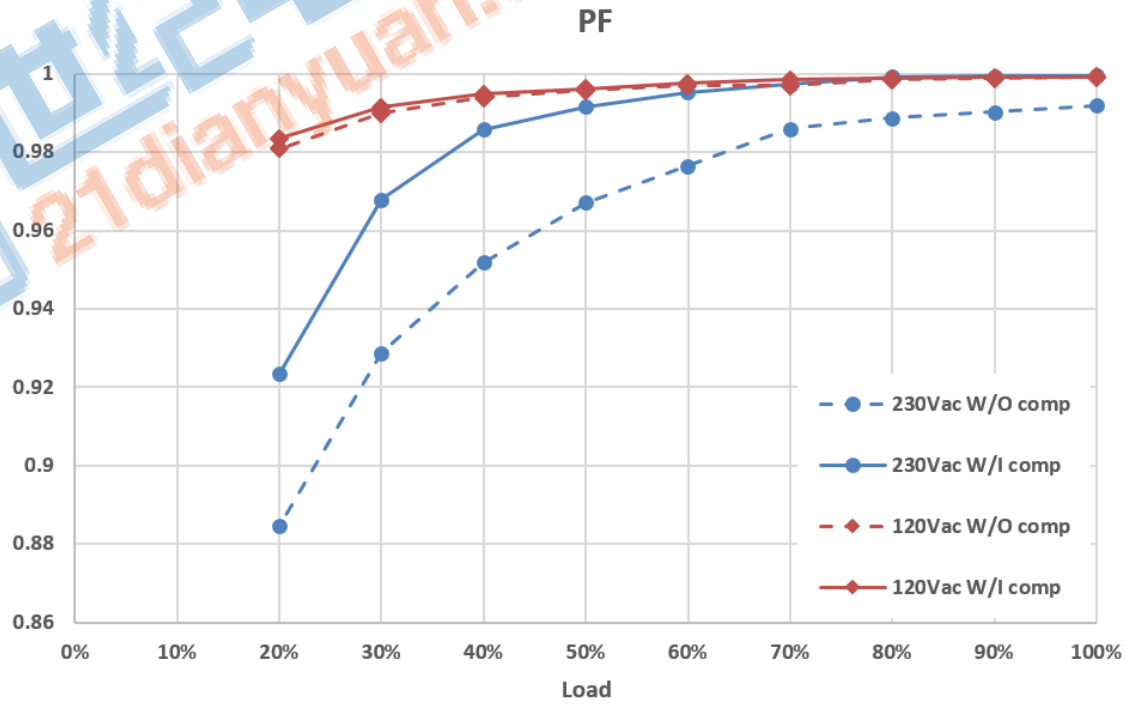


HR121x – Digital PFC+ LLC Combo Controller

PF Compensation

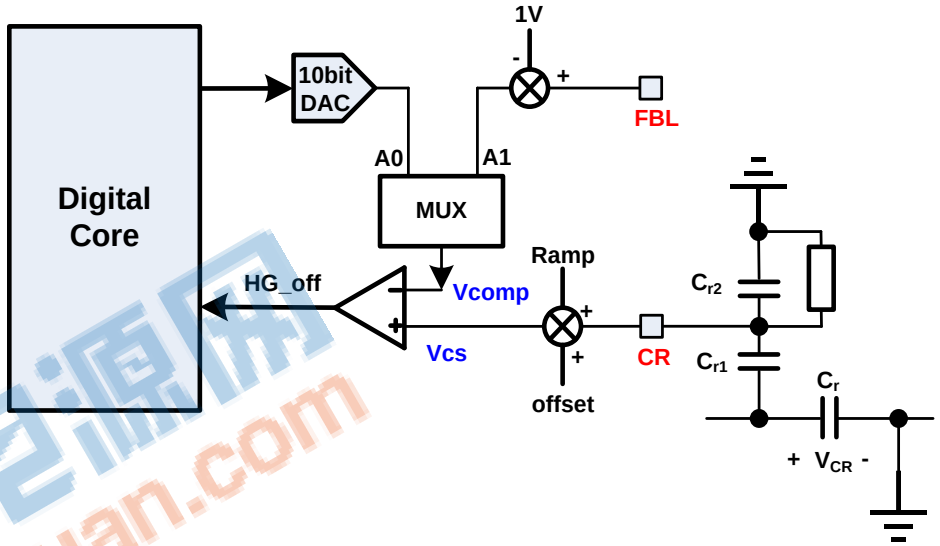




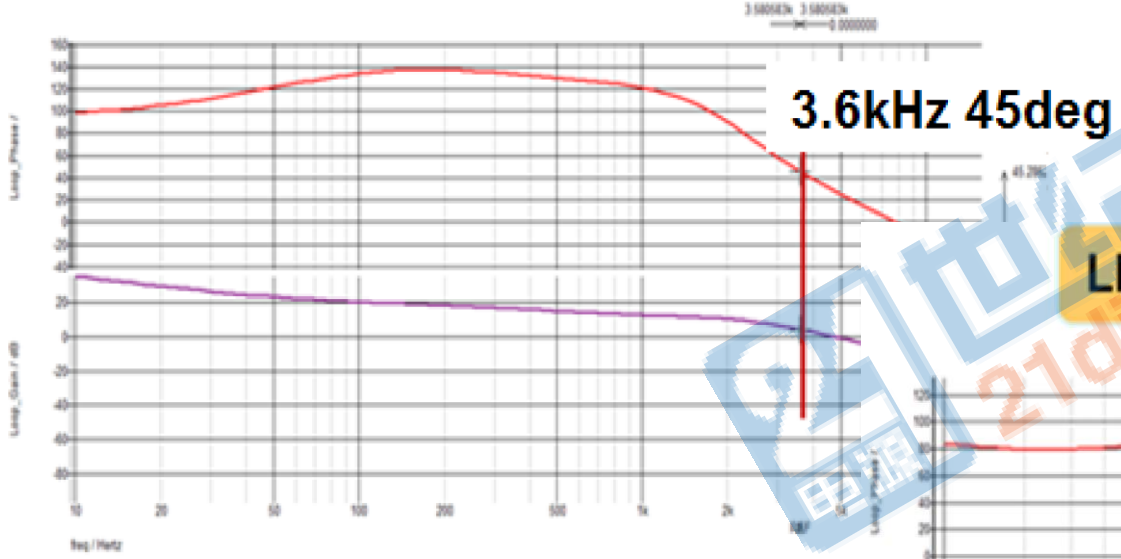


HR121x – Digital PFC+ LLC Combo Controller

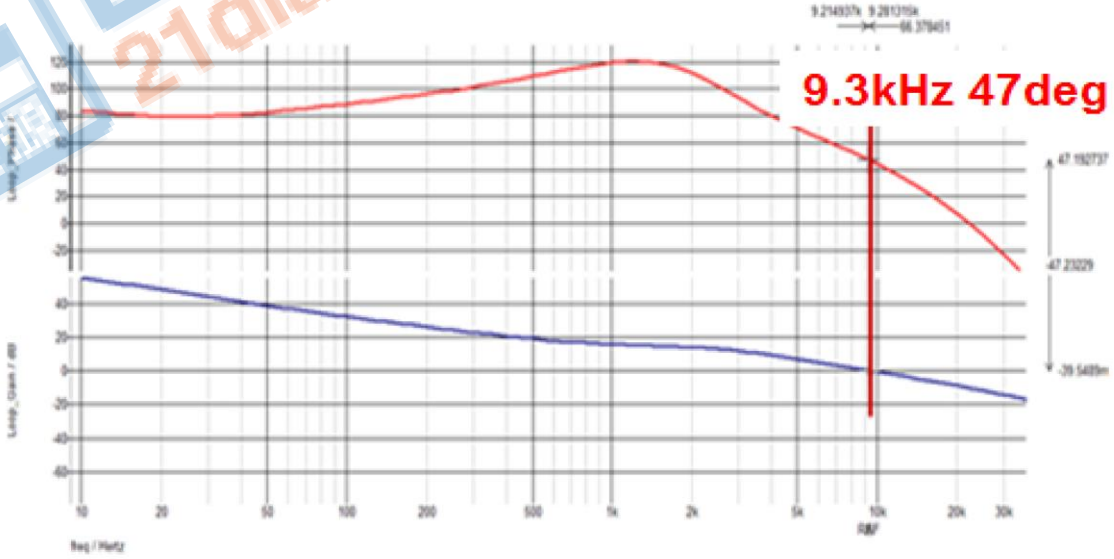
Current Mode LLC Control



LLC_Voltage Mode Control

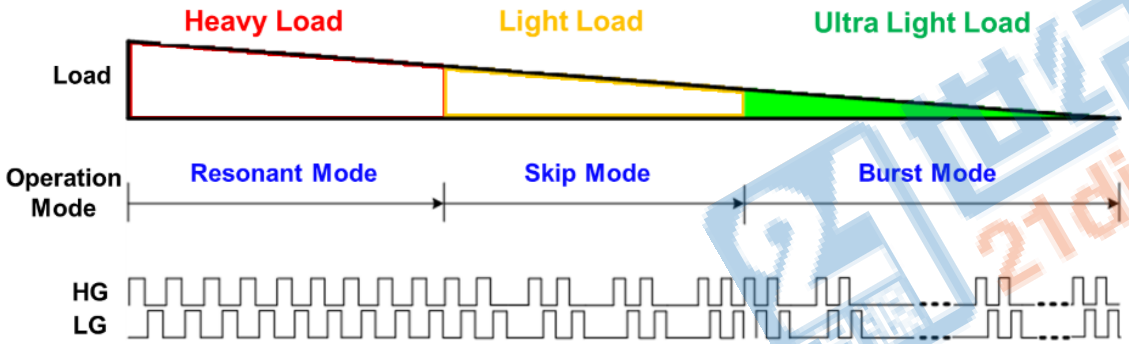


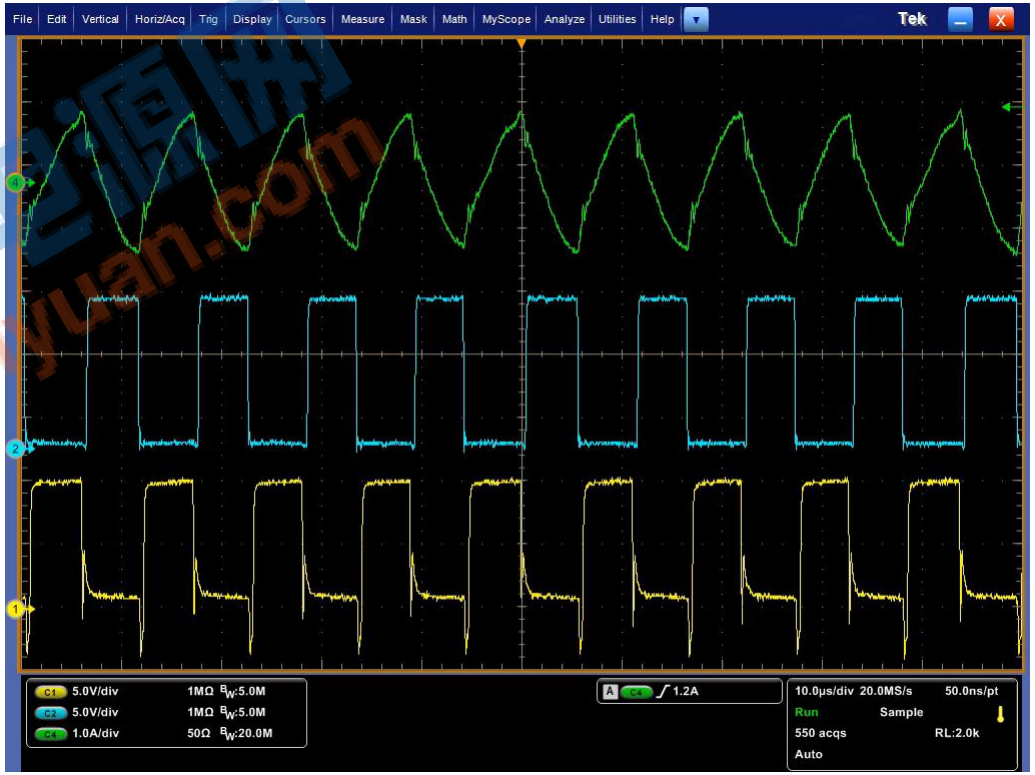
LLC_Current Mode Control



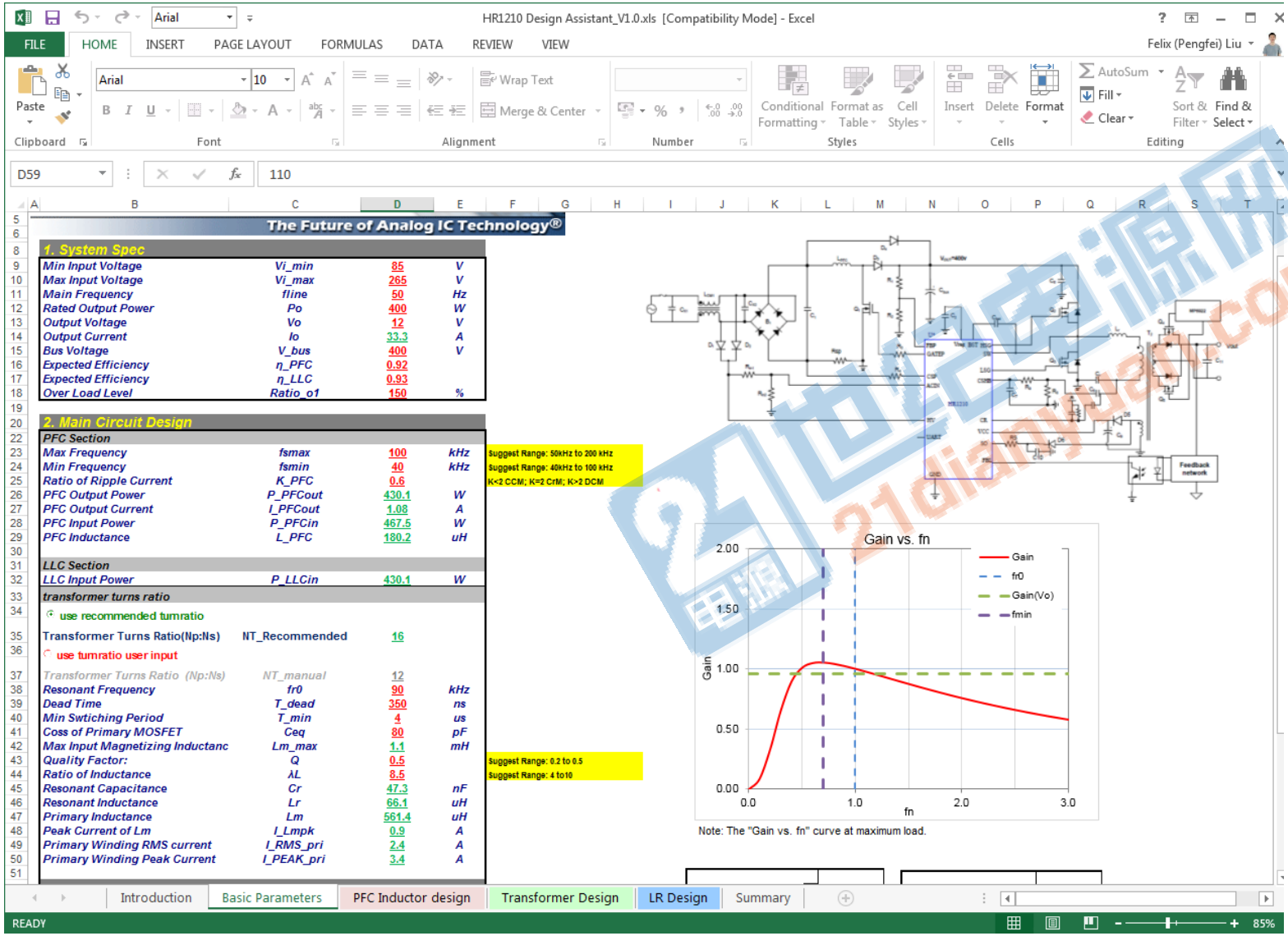
HR121x – Digital PFC+ LLC Combo Controller

Skip and Burst Modes for Light Load





Design Tool



Vin	90-264 VAC
Vout	12 V
Iout	50 A
PFC fs	70 kHz
LLC fs	100 kHz

HR1210
Spreadsheet

HR1275– Digital PFC+ LLC Combo Controller

Key features

General System Features

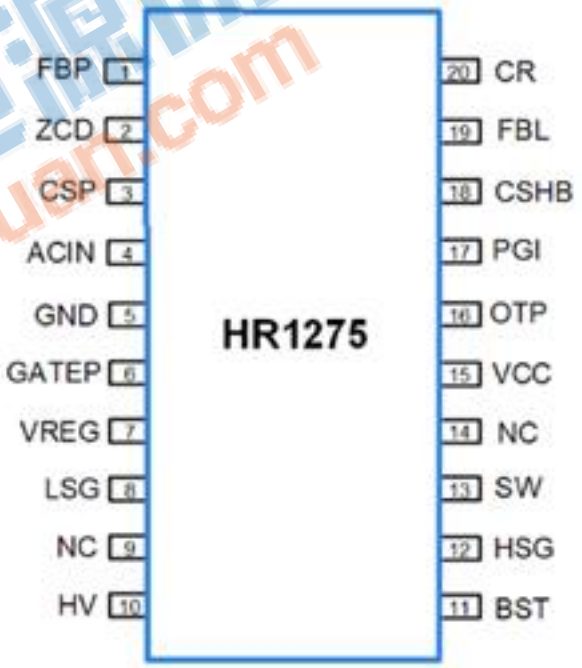
- Total <75mW No Load Power Loss
- HV Current Source for Start Up
- Smart X-cap Discharge
- Power Good Function
- External Over Temperature Protection (OTP)
- UART Interface for Parameters Program
- User-Friendly GUI for Digital PFC & LLC

PFC Controller

- CrM/DCM Multi Mode PFC Control with High Efficiency from Light Load to Full Load
- PFC Intelligent Valley Switching for Low Audible Noise
- PFC Input Cap Current Compensation and THD Compensation
- PFC Programmable Soft Burst-On for Higher Light Load Efficiency with Low Audible Noise
- OCL,OLP, OVP Protection

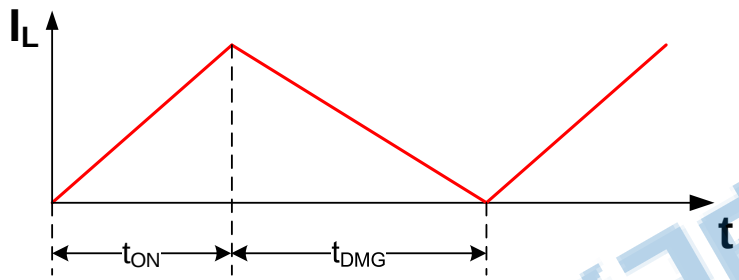
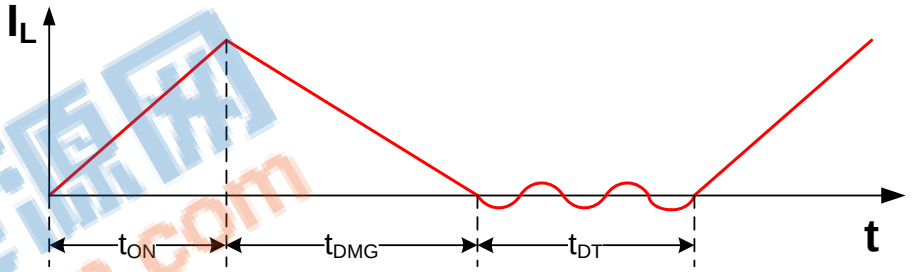
LLC Controller

- LLC Current Mode Control
- LLC Precise Entry/Exit Skip/Burst Mode Control
- Peak Power Mode
- LLC Adaptive Dead Time Adjustment
- LLC Capacitive Mode Protection
- OCP, OPP,CMP Protection



HR1275– Digital PFC+ LLC Combo Controller

PFC Control

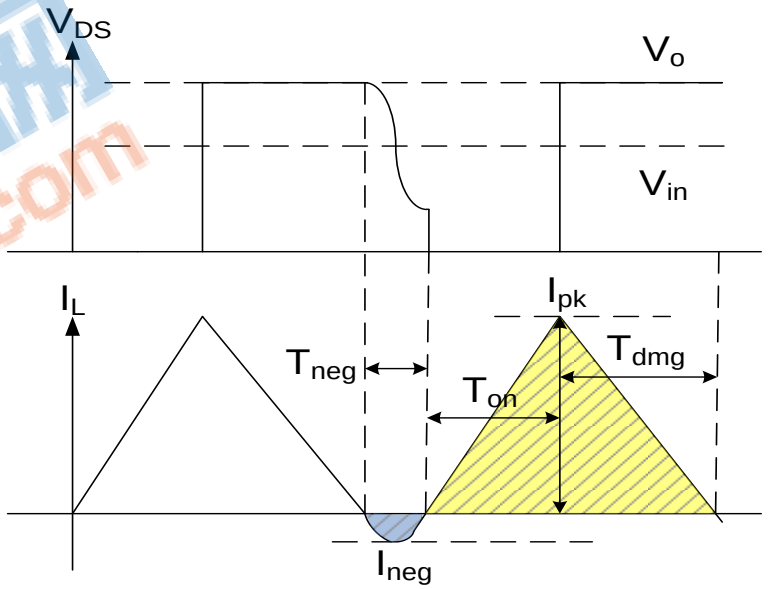
	CrM (Critical conduction mode)	DCM (Discontinuous conduction mode)
Operation Mode		
Input Current	$I_{IN1}(\theta)=\frac{\lvert V_{AC}(\theta)\rvert}{2\times L}\times t_{ON}(\theta)=\frac{\lvert V_{AC}(\theta)\rvert}{R_{EQ1}}$	$I_{IN2}(\theta)=\frac{\lvert V_{AC}(\theta)\rvert}{2\times L}\times t_{ON}(\theta)\times D_C(\theta)=\frac{\lvert V_{AC}(\theta)\rvert}{R_{EQ2}}$ $D_C(\theta)=\frac{t_{ON}(\theta)+t_{DMG}(\theta)}{t_{ON}(\theta)+t_{DMG}(\theta)+t_{DT}}$
Input Equivalent Impedance	$R_{EQ1}=\frac{2\times L}{t_{ON}(\theta)}$	$R_{EQ2}=\frac{2\times L}{t_{ON}(\theta)\times D_C(\theta)}$
Condition for PF=1	$t_{ON}(\theta)=\varepsilon(\text{constant})$	$t_{ON}(\theta)\times D_C(\theta)=\varepsilon(\text{constant})$

HR1275– Digital PFC+ LLC Combo Controller

THD Compensation

The actual PFC inductor current consists of two parts, one is positive peak current (Ipk) depend by the PFC switch on-time (Ton), the other is negative current (Ineg) lead by the CrM/DCM ringing:

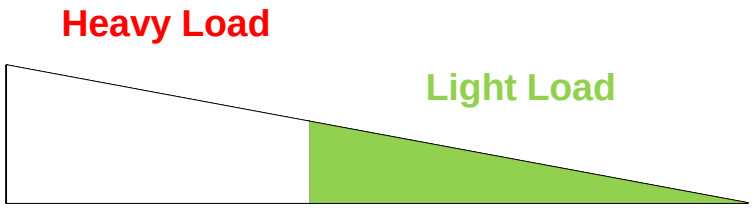
$$I_{in} = \frac{(T_{on}+T_{dmg})\cdot\frac{I_{pk}}{2} - \int_0^{T_{neg}} I_{neg}(t)dt}{T_{on}+T_{dmg}+T_{neg}}$$

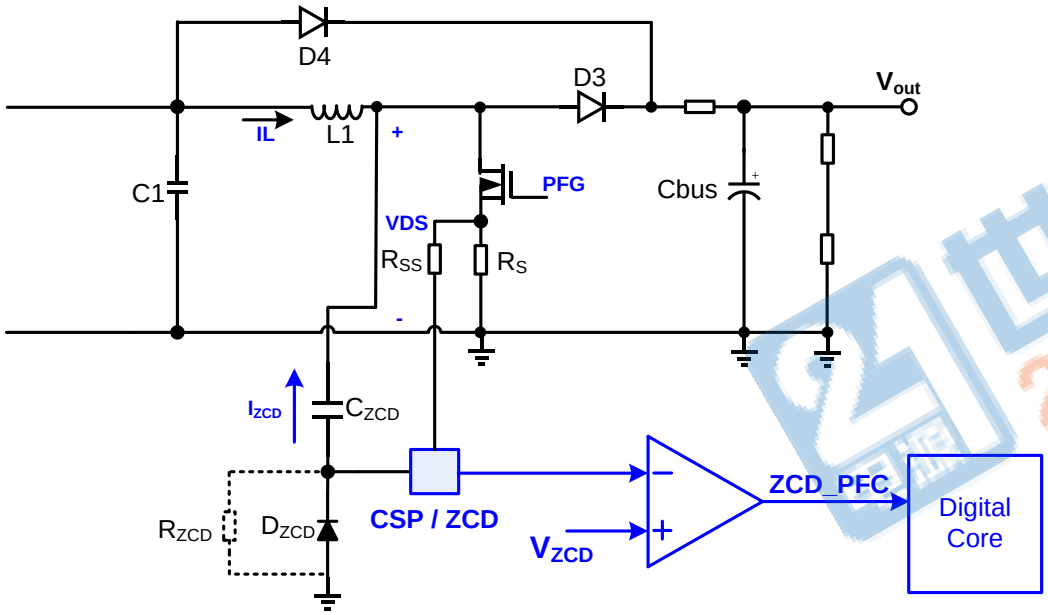


PFC Inductor Current in CrM/DCM

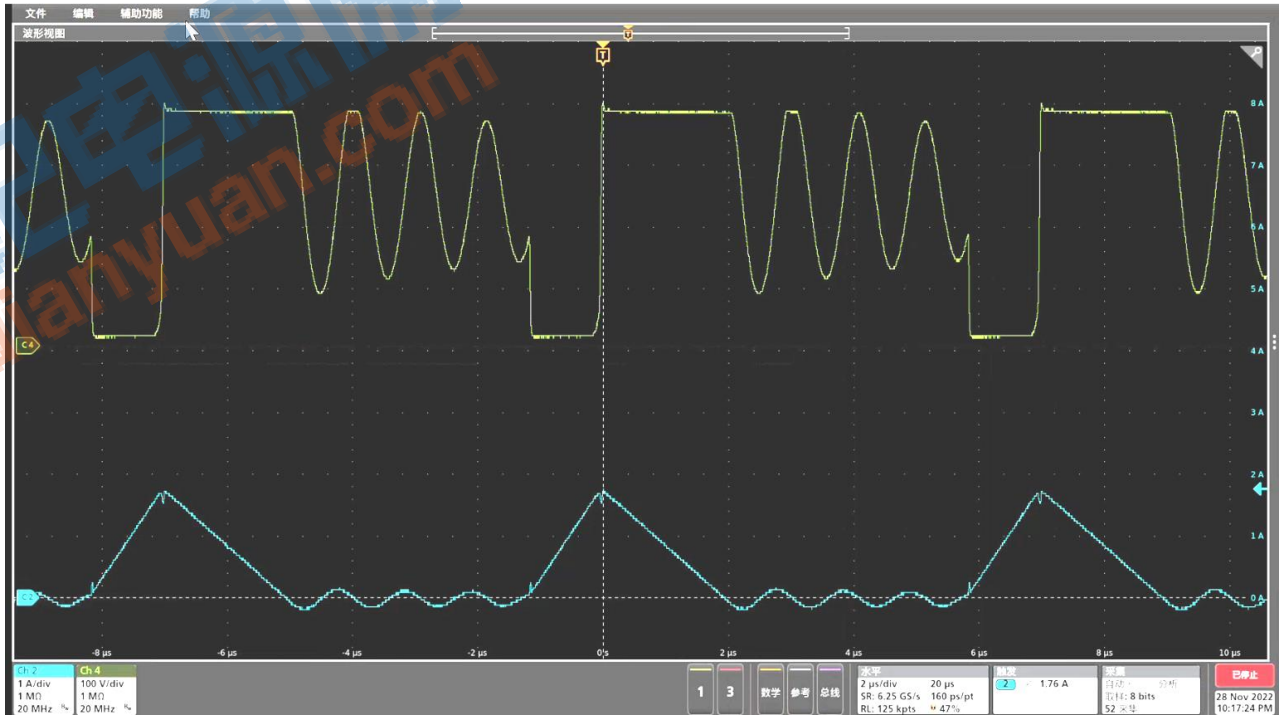
HR1275– Digital PFC+ LLC Combo Controller

PFC Valley Switching





CH2 I_{PFC} CH4 V_{ds}

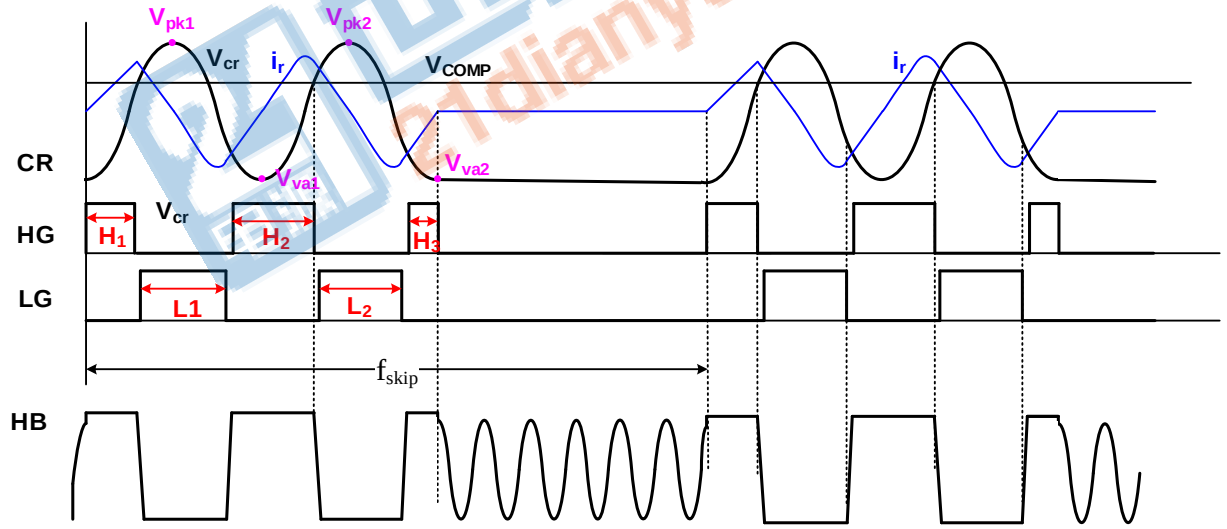


HR1275– Digital PFC+ LLC Combo Controller

LLC Light load efficiency optimization

Convectional frequency control leads to higher switching frequency at light load, which increase the switching loss. And because the **magnetizing current** takes a major part in the primary current, it leads to condition loss.

HR1275 incorporates a skip mode to increase light load efficiency by **inserting idle time** between certain number of switch cycles. So that the overall switching cycle and magnetizing current are reduced.

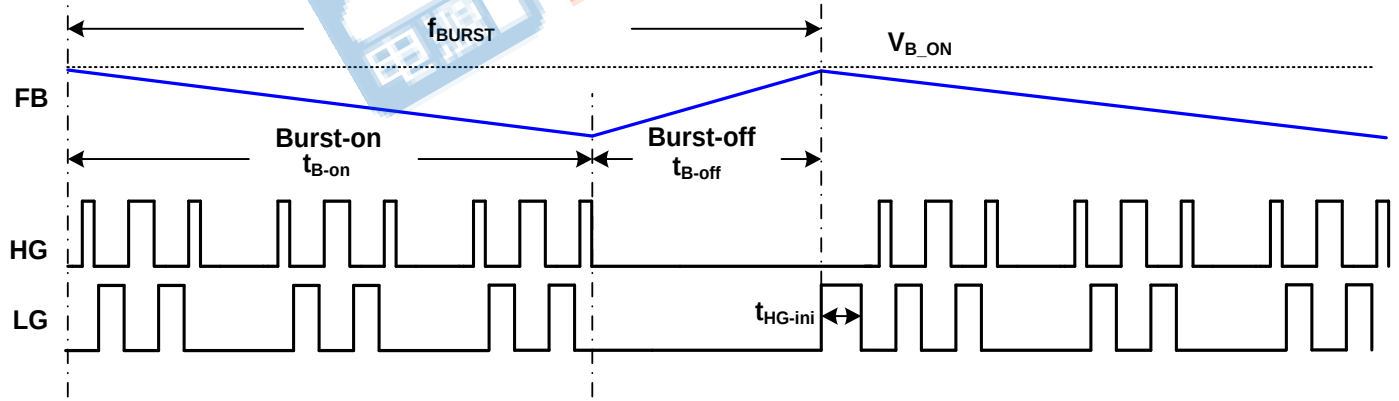


HR1275– Digital PFC+ LLC Combo Controller

LLC Light load efficiency optimization

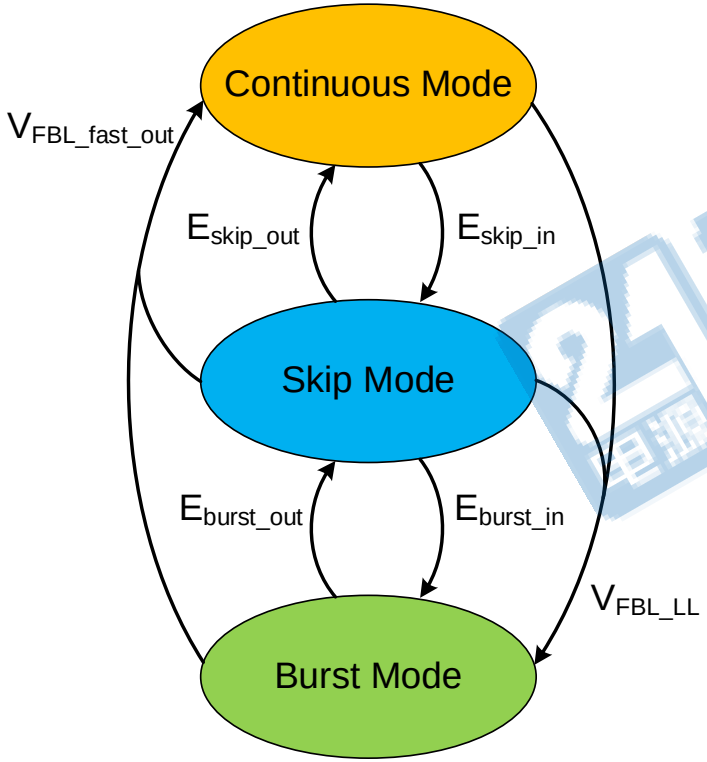
As the load gets even lighter, to further limit the average switching frequency, **a longer switch idle time** will be inserted into the skip mode to **improve Light load efficiency**.

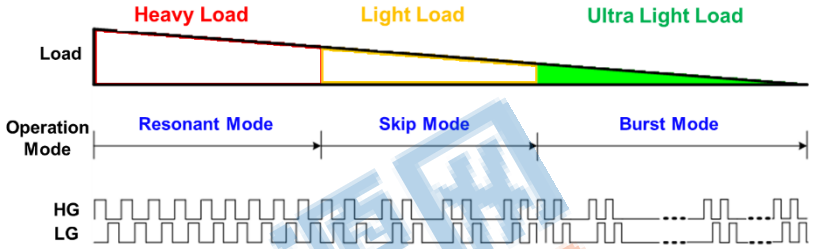
- Programmable fixed V_{COMP}
- Programmable T_{H1} and T_{L1}
- Programmable skip frequency
- PWM on/off based on FBL voltage
- Burst frequency control
- FBL pull-up resistor control for power saving



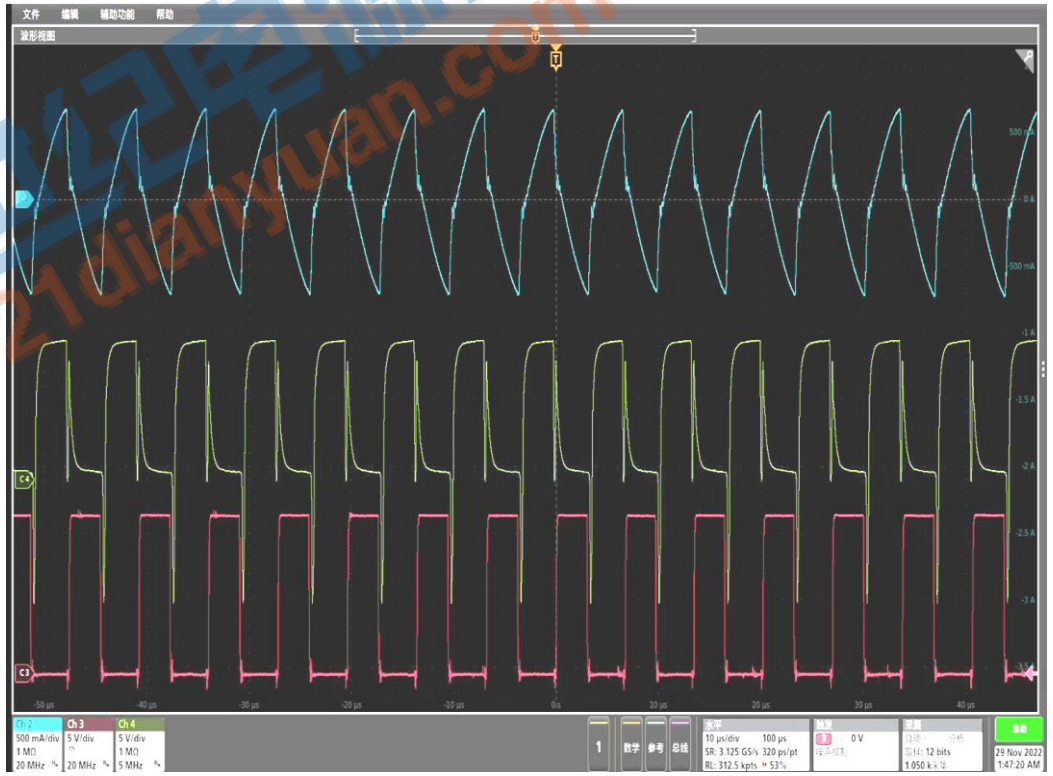
HR1275– Digital PFC+ LLC Combo Controller

Efficient multi-mode LLC control





CH2 I_{LLC}
CH3 LSG
CH4 HSG



HR1275– Digital PFC+ LLC Combo Controller

Friendly GUI

LLC Skip Mode Debug

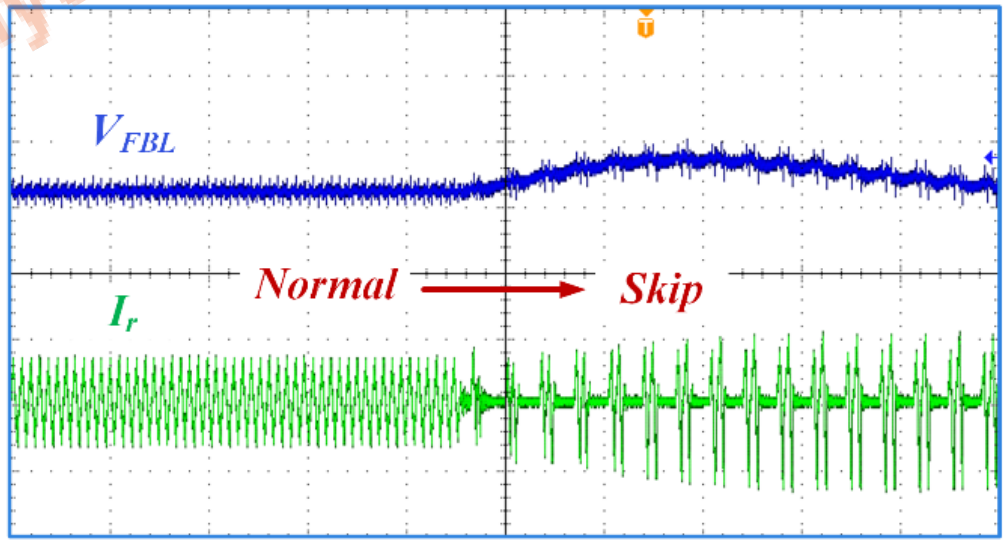
Step 1	Step 2	Step 3	Step 4	Step 5
Measure key parameters in Normal Mode	Debug Vcomp@max skip load	Debug Vcomp@min skip load	Debug SKIP IN/OUT Energy	SKIP Debug Done

Adjust the ***SKIP IN Energy OFFSET*** to get the desired ***SKIP IN Load***.

SKIP IN Load 1.2 A

SKIP IN Energy OFFSET -45 - + %

1 78 1023



Agenda

- PFC+LLC Topology Inductions
- MPS Solutions for PFC and LLC
- MPS Solutions for SR

MPS LLC SR Controllers Roadmap

Gen 1

- SOIC8
- CCM/DCM Operation
- Max 300kHz

MP6903

- Fast turn-off delay (<20ns)
- Max 180V VDS rating
- 300uA sleep mode current

- SOIC8 & SOIC14
- CCM/DCM Operation
- Max 300kHz

MP6922/22A

- Fast turn-off delay (<20ns)
- Max 180V VDS rating
- Dual Channel SR driver
- <600uA sleep mode current

Gen 2

- SOIC14
- CCM/DCM Operation
- Max 300kHz

MP6923

- Fast turn-off delay (<20ns)
- Max 180V VDS rating
- <600uA sleep mode current
- Anti-bounce logic

- SOIC8
- CCM/DCM Operation
- Max 300kHz

MP6924/25

- Fast turn-off delay (<20ns)
- Max 180V VDS rating
- 150uA sleep mode current
- 4.2V~35V wide range VDD
- Enhanced driver ability

Released

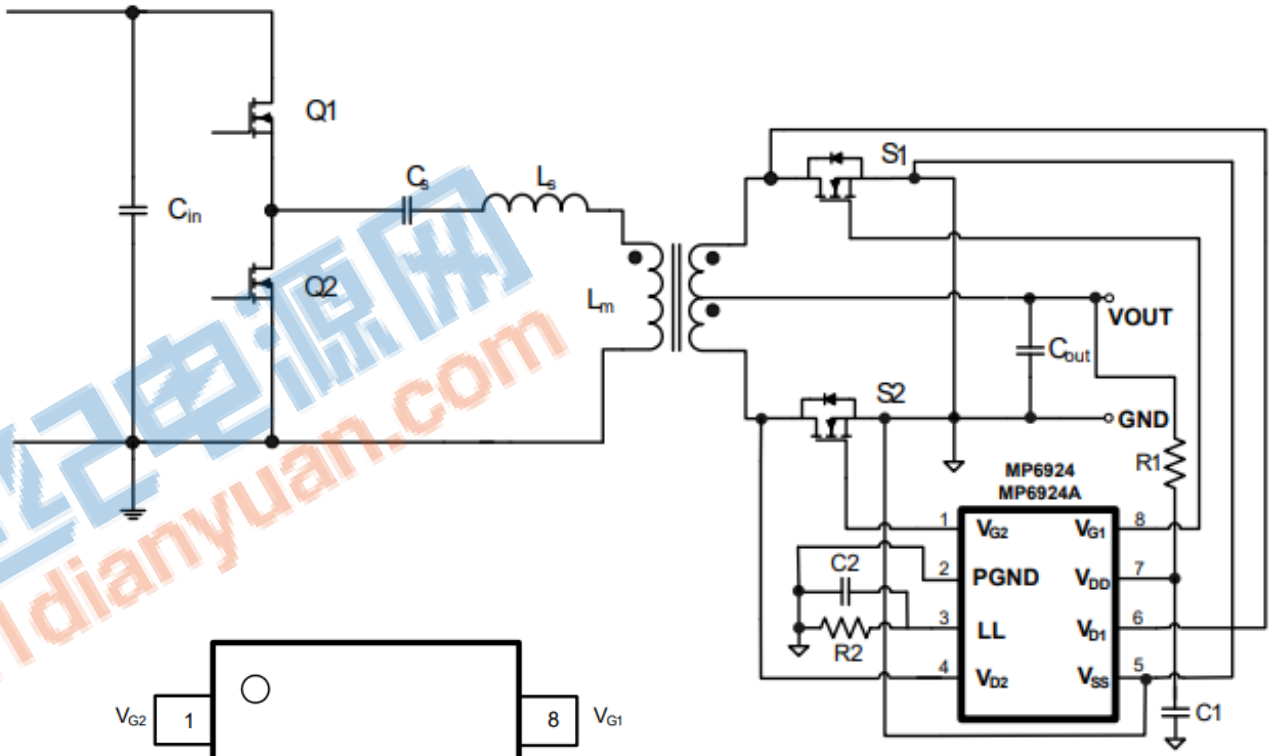
In development

Plan

MP6924A Key Features

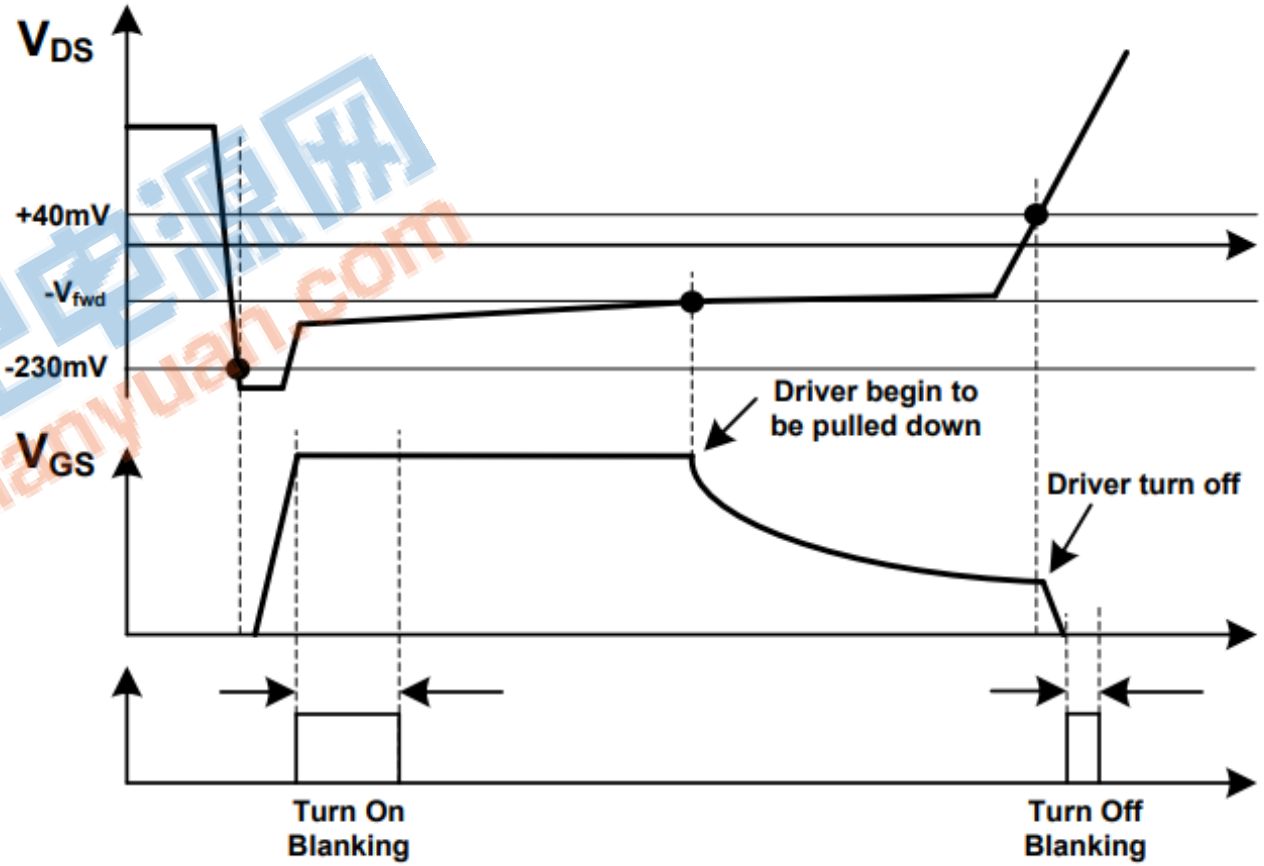
- Works with Standard and Logic Level MOSFETs
- Fast Turn-Off Total Delay of 35ns
- 4.2 V to 35 V Wide VDD Operating Range
- 175μA Low Quiescent Current in Light-Load Mode
- Supports CCM, CrCM, and DCM Operation

  Supports High-Side and Low-Side.



MP6924A Adaptive Forward Voltage

- When VDS rises above the forward voltage drop (-Vfwd), the MP6924A pulls down the gate voltage level to make the on resistance of the MOSFET larger to ease the rise of VDS.
- VDS adjusted to be around –Vfwd. This function puts the driver voltage at a very low level when the synchronous MOSFET is turning off, which boosts the turn-off speed.



Thank you!

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