How to Design an Efficient Offline Auxiliary Power Supply Workshop

STMicroelectronics & Würth Elektronik

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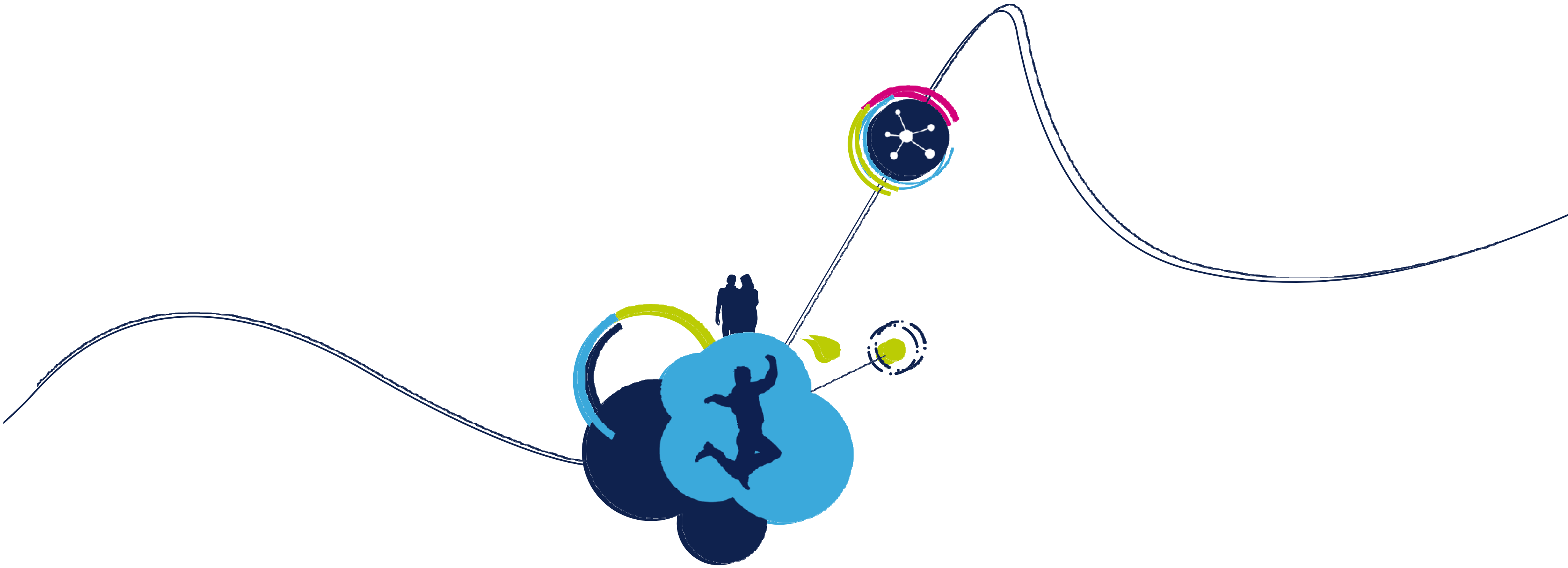
Agenda

- 9:00 – 10:00 Buck and flyback topology for mains applications in auxiliary supplies
- 10:00 – 10:45 Live session: eDesignSuite for easy design
- 11:00 – 11:45 Power inductors for high-voltage buck converters
- 11:45 – 12:30 Design considerations for quasi-resonant flyback converters
- 13:45 – 14:30 Live session: quasi-resonant flyback design with STCH02
- 14:30 – 15:15 Transformers for flyback converters
- 15:30 – 16:15 Live session: Using oscilloscope waveforms to better understand circuit voltages and currents
- 16:15 – 16:30 Conclusions & Summary



Buck and flyback topologies for mains applications in auxiliary supplies

Buck and buck-boost auxiliary SMPS

Theory & critical aspects

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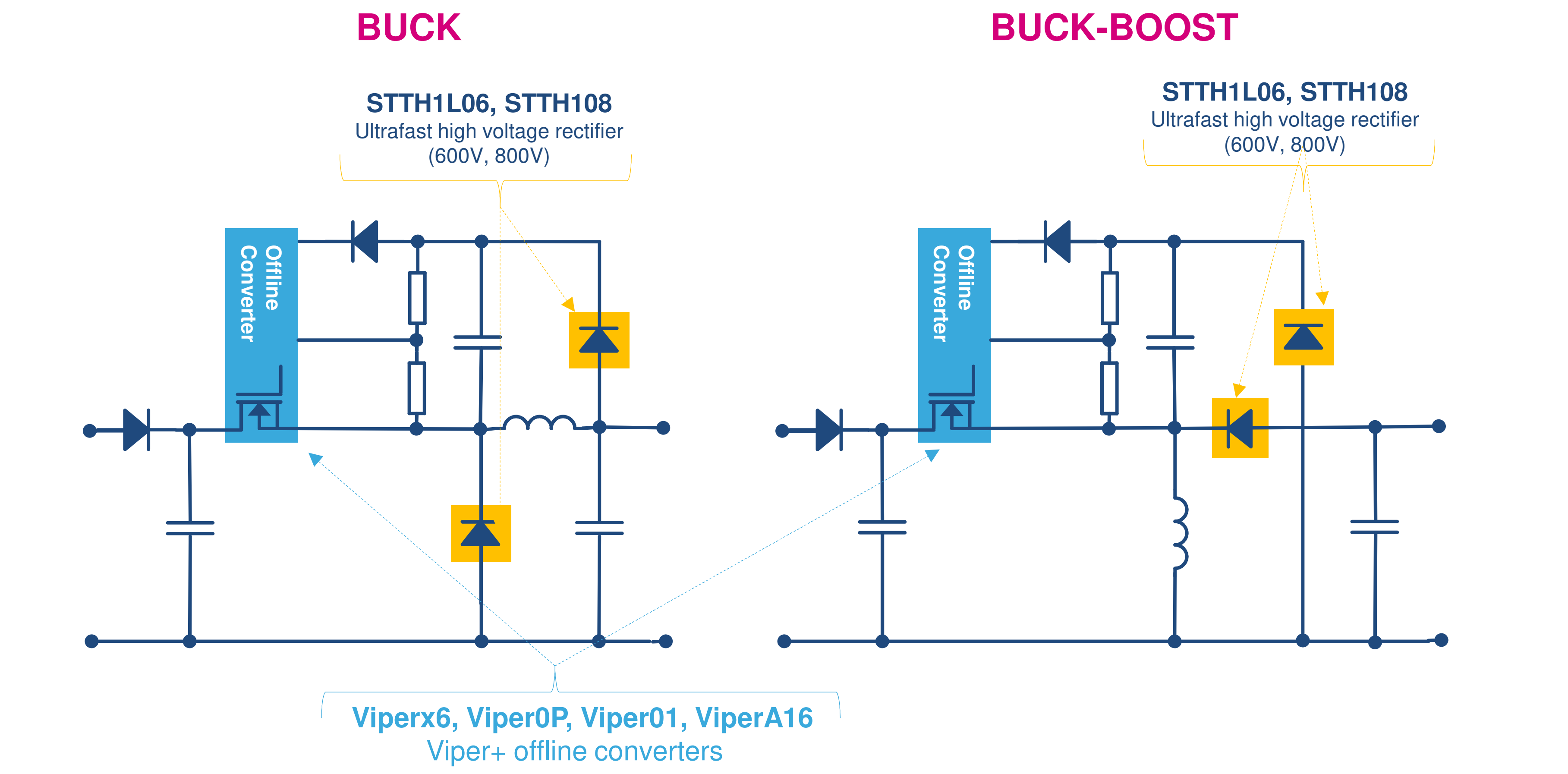
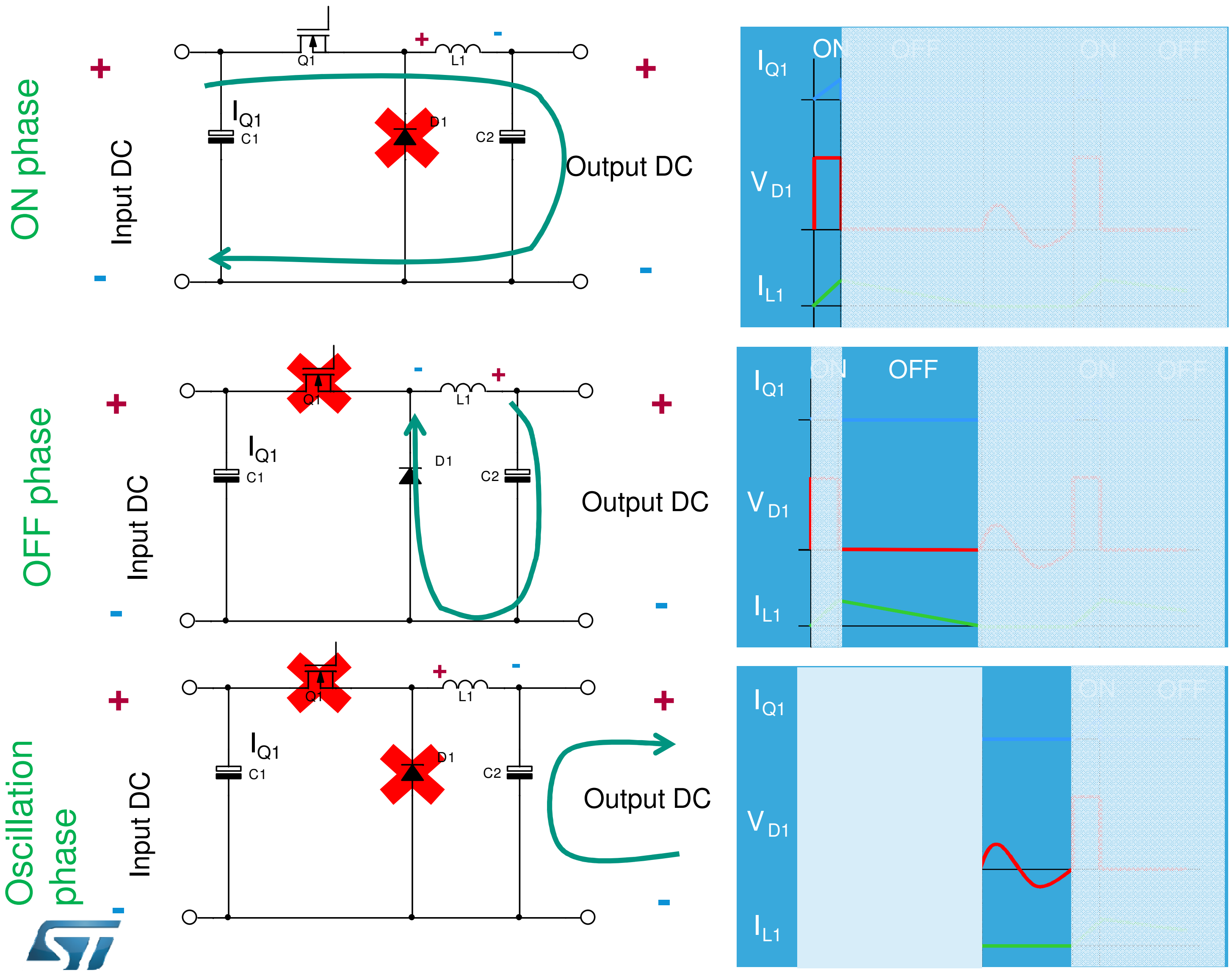
Non-Isolated Auxiliary Power Supply Buck and Buck-boost Converter **Typical schematics & product mapping**

0W < P < 5W – Non -Isolated Auxiliary Supply



Buck – Operational Principle

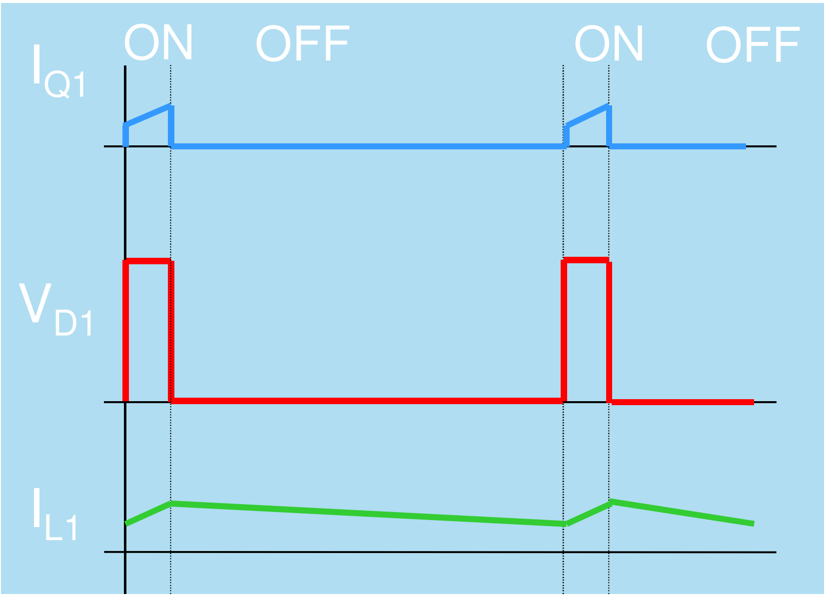


$$\Delta I_{L1} = \frac{t_{ON}\left(V_{in} - V_{out}\right)}{L}$$

$$\Delta I_{L1} = \frac{t_{OFF} V_{out}}{L}$$

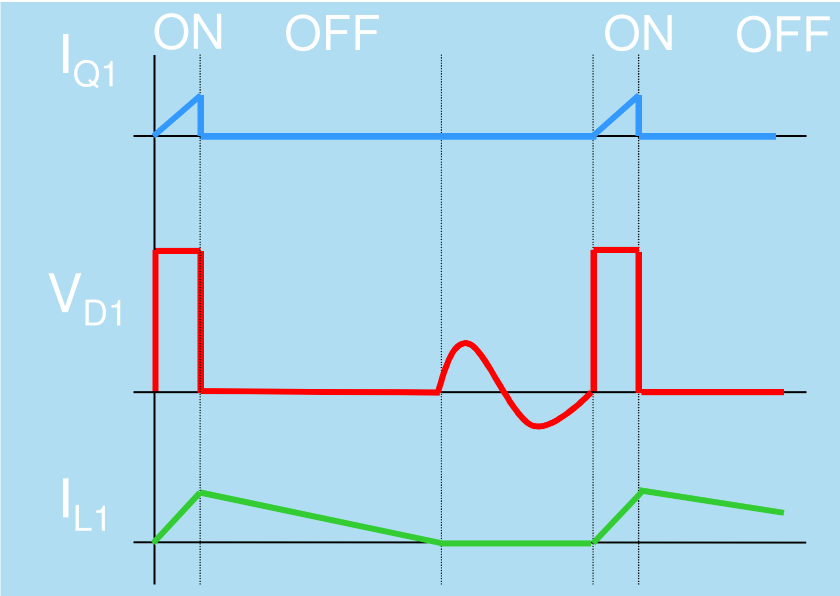
Buck Topology
Continuous Conduction Mode (CCM)
Discontinuous Conduction Mode (DCM)

- CCM
  - + Higher current capability
  - - Recovery effect =>
    - Lower efficiency
    - Worse EMI



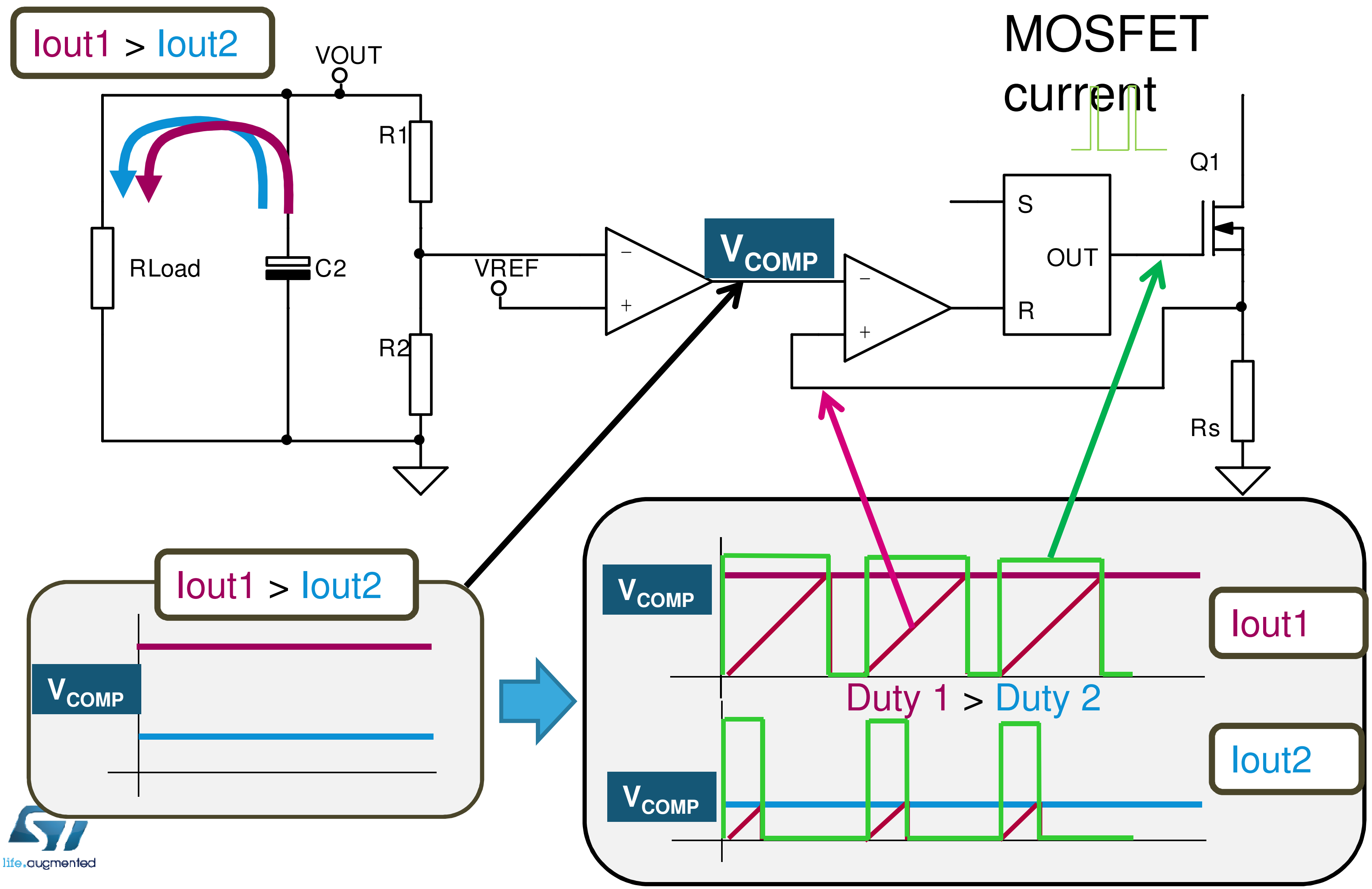
$$I_{OUT} = AVG(I_{L1}) = \frac{I_{L1Max} + I_{L1Min}}{2}$$

- DCM
  - + ZCS turn ON of MOSFET
  - + ZCS turn OFF diode
  - - Delivery less output current

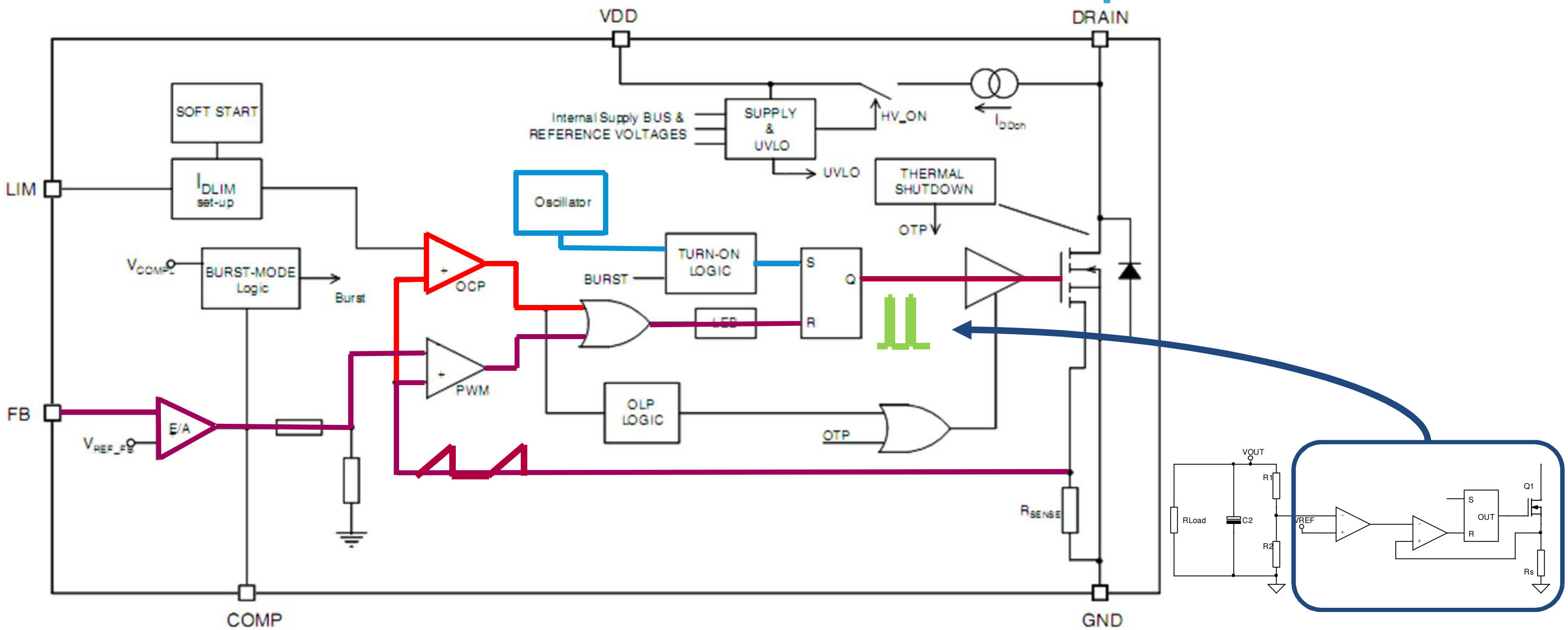


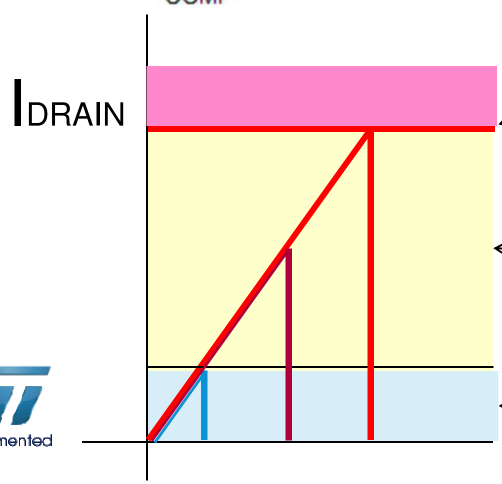
$$I_{OUT} = AVG(I_{L1}) = \frac{1}{2} I_{L1MAX} f(t_{ON} + t_{OFF})$$

Current Mode Control – Principle



Current Control Principle - OCP



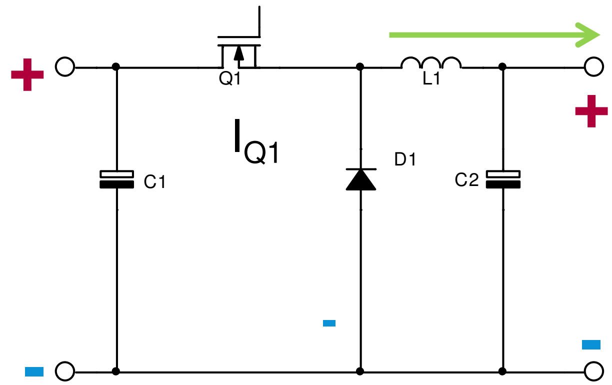


OCP – Viper limits this level independently on the feedback

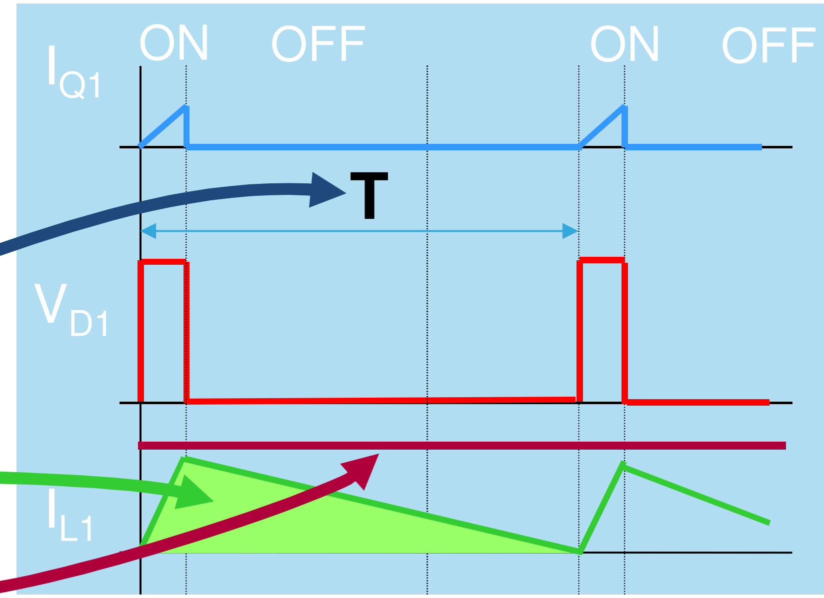
Standard operation – the current is defined by feedback

Stand by – minimum peak current, reduced frequency

Buck – OCP to Maximum Output Current



$$I_{OUT} = \frac{S}{T} \quad S = f(I_{PEAK}) \quad I_{PEAK} < I_{OCP}$$



Maximum output current is limited by OCP

Viper	Typical OCP	~ Iout in CCM
Viper011	120mA	50mA
Viper012	240mA	100mA
Viper06	350mA	150mA
Viper013	360mA	160mA
Viper113	370mA	170mA

Viper	Typical OCP	~ Iout in CCM
Viper16	400mA	200mA
Viper114	480mA	240mA
Viper115	590mA	280mA
Viper26	700mA	350mA

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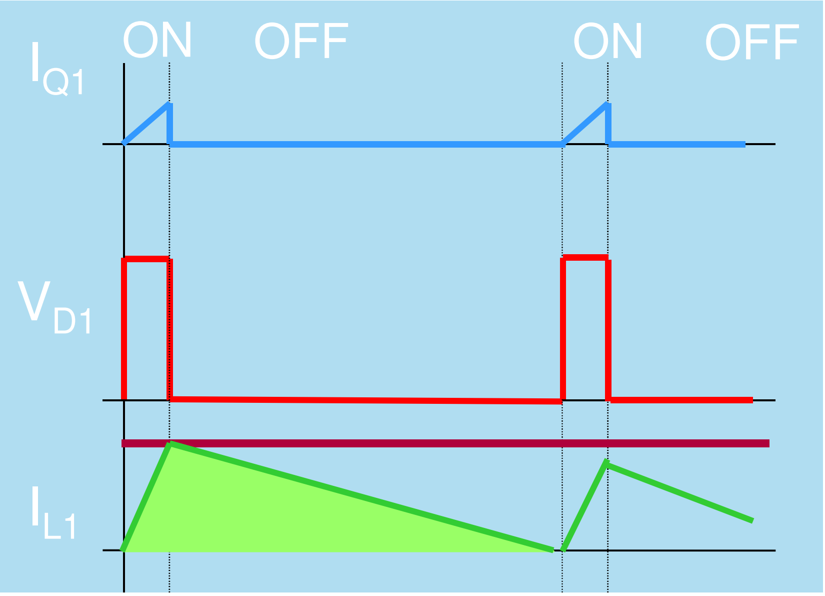
Inductor – Maximum and Minimum Value

Maximum Inductor Value
It is theoretically unlimited but:
- If possible it is recommended to use DCM
- Higher inductance in same package = higher resistance and lower saturation current

$$L_{Boundary} = \frac{V_{OUT}}{2I_{OUT}f}\left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$



Minimum Inductor value
Peak current must not cross the OCP limit during ON time

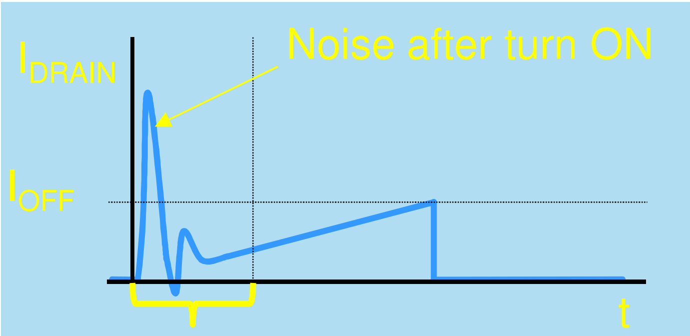
$$L_{min} = \frac{2I_{OUT}V_{OUT}}{fI^2_{pk\max}}\left(1 - \frac{V_{OUT}}{V_{INMAX}}\right)$$

if $$t_{ON} = \frac{L_{min} I_{pk\max}}{V_{INMAX} - V_{OUT}} < T_{ON\_MIN}$$

then $$L_{min} = \frac{(V_{INMAX} - V_{OUT})T_{ON\_MIN}}{I_{pk\max}}$$

Viper	T_{ON_MIN}
Viperx6	450ns
Viperx1x	350ns

Low frequency is good for HV buck … (1)



Minimum ON time T_{ON_MIN}

- It is result of
  - Blanking time (IC must ignores noise after turn ON)
  - Propagation delay of comparators and driver
- It is independent on the operating frequency
- It determinate the minimum operating duty cycle
- Longer period (lower frequency) = lower minimum duty cycle
- Viper06 450ns
- Viper01 350ns

Vin DC (V)	D (%) 5V	t_{ON} (us) for 60kHz 5V	t_{ON} (us) for 30kHz 5V
100 (85VAC)	5.0	0.83	1.67
170V (120VAC)	2.9	0.49	0.97
325V (230VAC)	1.5	0.26	0.50
375V (265VAC)	1.3	0.22	0.33
622V (440VAC)	0.8	0.13	0.26

HV buck works with **very low duty cycle** due to big ratio between input and output voltage

$$D = \frac{V_{OUT}}{V_{IN}}$$

If the required ON time is shorter then minimum ON time SMPS works, but there is small instability and the maximum deliverable output current is reduced.

The 30kHz version is strictly recommended for 5V output.

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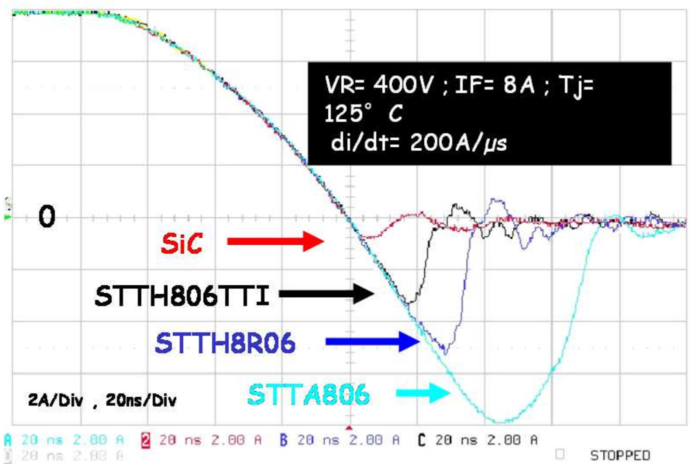
Low frequency is good for HV buck … (2)

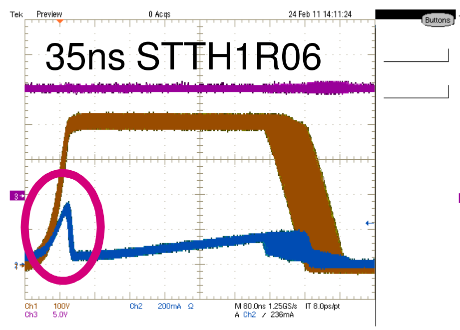


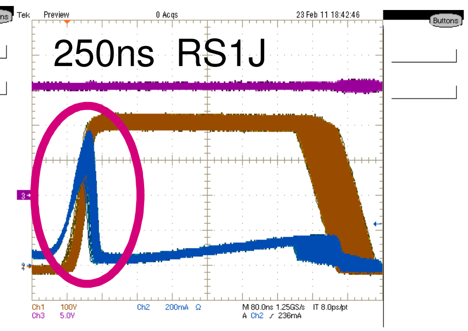
Diode recovery effect

- Si diode need some minimum time to switch OFF
- Two carries type need time to recombinate
- Time and charge amount is defined by
    - Technology
    - Current present in diode at turn OFF
    - Temperature
- From application point of view – diode is conducting short time in reverse way => cross conduction

Diode recovery effect = MOSFET losses

- Important part of energy is burned in MOSFET
- MOSFET losses are proportional
    - Recovery time (diode)
    - Recovery charge (diode)
    - Switching voltage (application)
    - Current present in diode at turn OFF (operating mode)
    - Operating frequency (Viper)





$$P_l \approx f\left(V_{IN}^2 t_{rr} f_{sw} I_{DFW}\right)$$

Recovery effect causes short cross conduction ever turn ON. Effect is much critical in case CCM => **DCM is recommended**. The lost energy is higher at higher power operating frequency => **The 30kHz version is recommended.**

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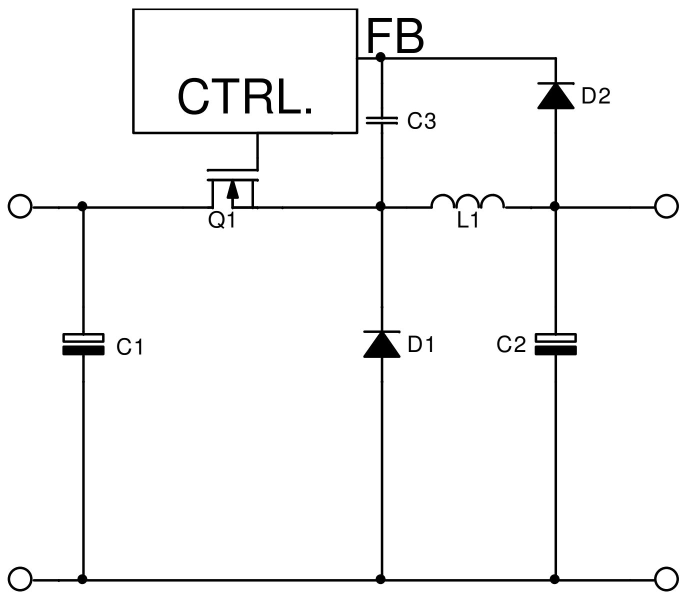
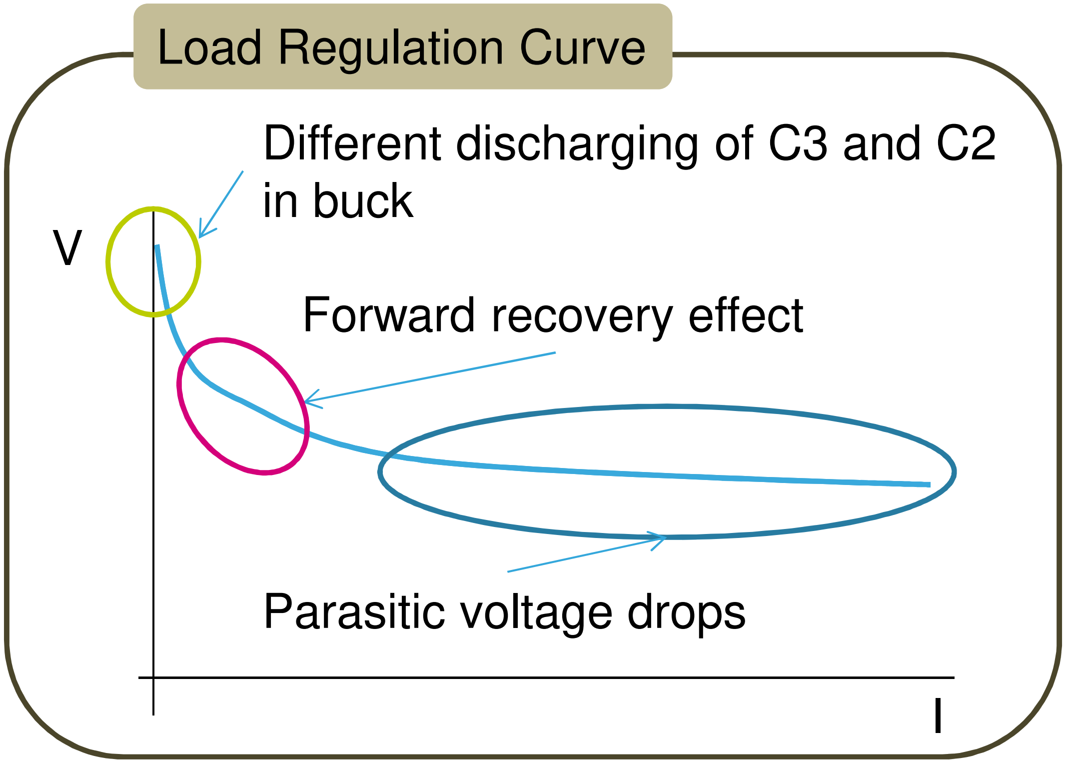
Critical Point 2: Load Regulation in HV Buck



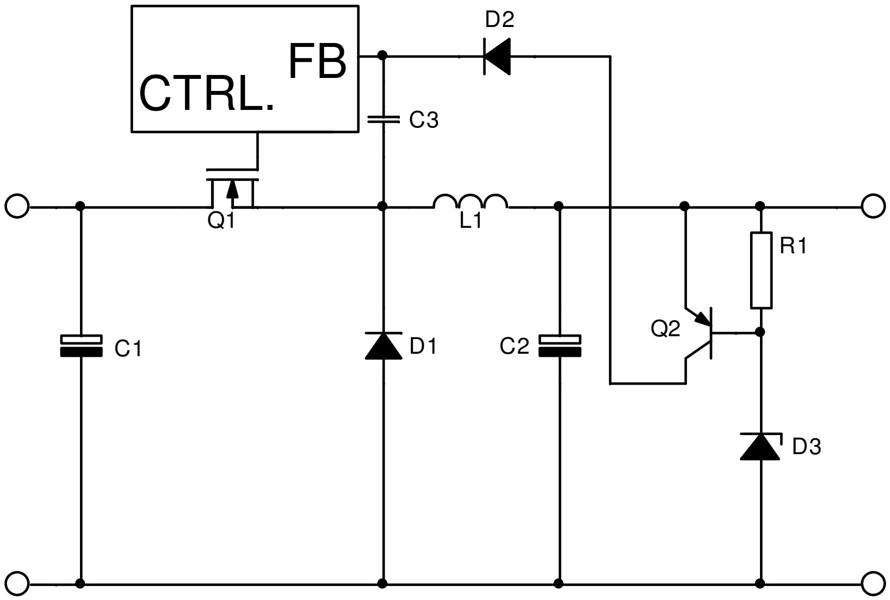


- Standard Feedback C3 is charged from C2 during OFF time
  - Low cost +
  - Not precise –
  - Bleeder mandatory for no load (Buck)

Why the regulation is not FLAT?

- ON time – C2 and L1 is charger through MOSFET
- OFF time
  - C2 is charged from L1 via D1
  - C3 is charged from C2 (respectively L1) via D2 thanks D1 is conducting

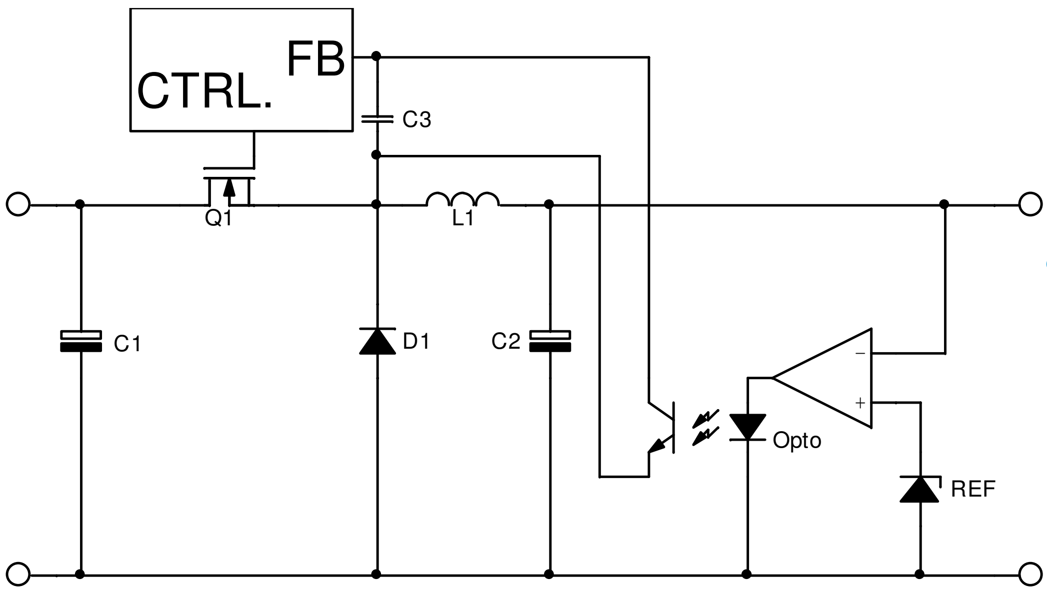
How to Get Better Load Regulation in HV Buck: Solution 1



- Feedback with level shifter C3 is charged from C2 during OFF time through simple EA (Q2)
  - Low cost +
  - Precision 7% – 10%
  - Thermal dependance

- ON time – C2 and L1 is charger through MOSFET
- OFF time
  - C2 is charged from L1 via D1
  - C3 is charged from C2 (respectively L1) via D2 and Q2. The Q2 impedance is changing depending on the output voltage level compare zener voltage diode

How to Get Better Load Regulation in HV Buck: Solution 2



- Feedback with opto like for Flyback
  - High Precision +
  - No thermal dependance +
  - Cost -

- ON time – C2 and L1 is charged through MOSFET
- OFF time
  - C2 is charged from L1 via D1
  - C3 is charged from C2 (respectively L1) via D2 and Q2. The OA control opto like in flyback

Flyback auxiliary SMPS

Theory & critical aspects

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Isolated Auxiliary Power Supply
Typical Schematics & Product Mapping

0W < P < 75W – Isolated Auxiliary Supply

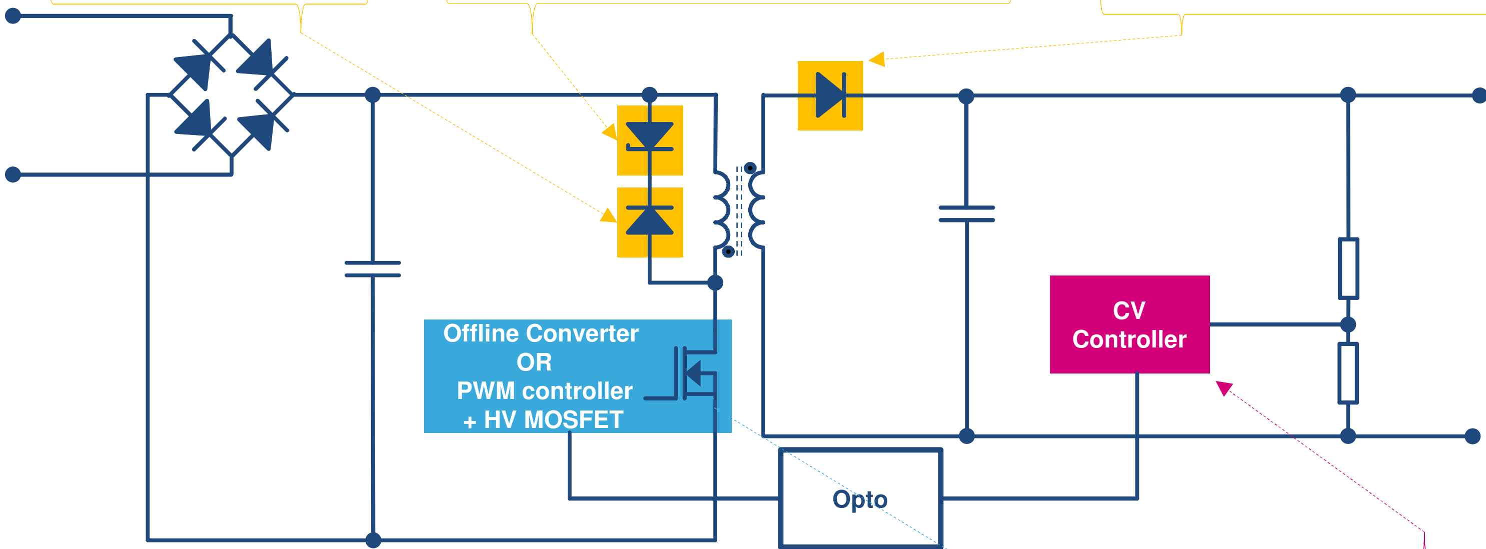
STTH1L06, STTH108
Ultrafast high voltage rectifier
(600V, 800V)

STRVS142 - 280
Voltage suppressor

SMAJ. SMA6J, SMBJ
100A – 188, P6KE
TVS

STPSx40,60,100
Schottky
diodes

FERDx40
Field effect
rectifier diode



Viperx7, Viperx5, Viperx8, Viper06, Viper0P, Viper01
Viper+ offline converters

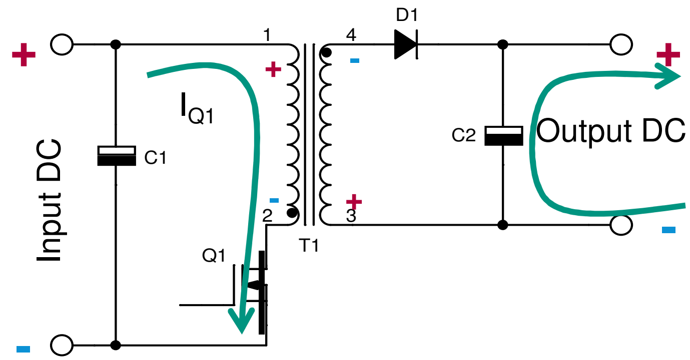
Altair05, 04
CV/CC* offline converters

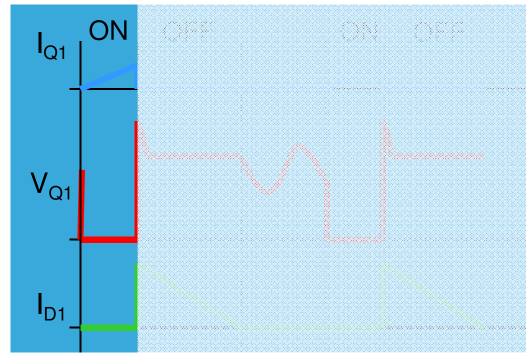
TS43x, TL43x10*
CV controllers
standard family

STCH02, L6566A/B/BH + K5 800V MOSFETs, M2 650V MOSFETs
offline PWM controllers + HV MOSFETs

Flyback – Operational Principle

ON phase

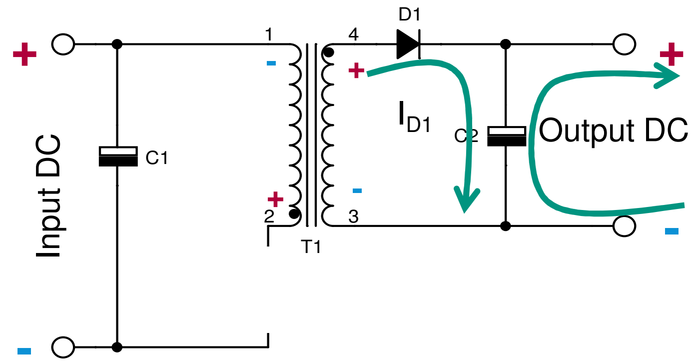


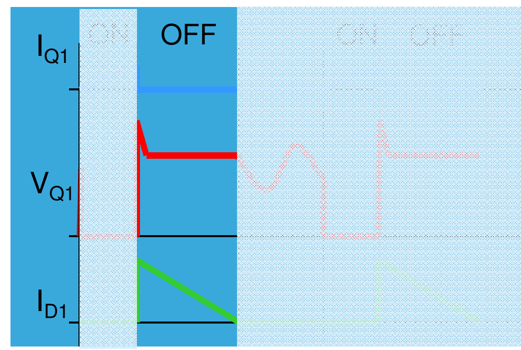


$$E_{T1} = \frac{1}{2} L_P I_{Q1PK}^2$$

$$P_{T1} = \frac{1}{2} L_P I_{Q1PK}^2 f_{SW}$$

OFF phase



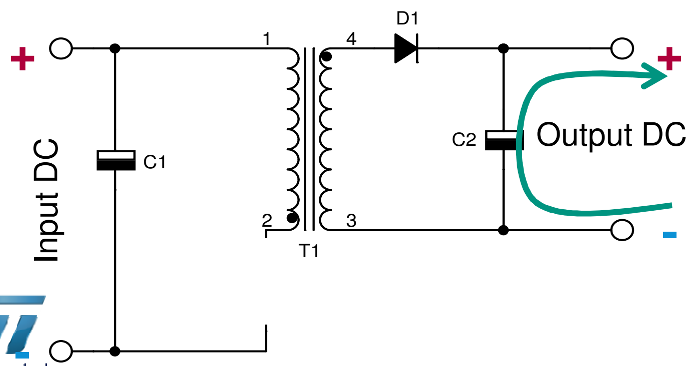


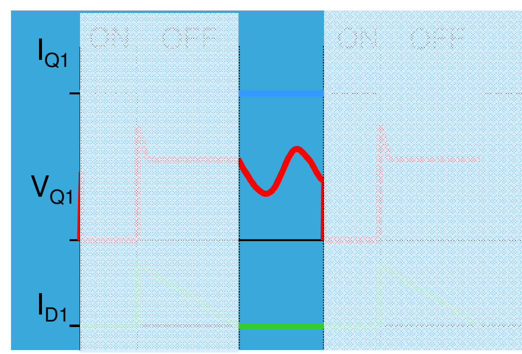
$$I_{D1PK} = \frac{N_P}{N_S} I_{Q1PK} = n_{T1} I_{Q1PK}$$

$$E_{T1} = \frac{1}{2} L_S I_{D1PK}^2$$

$$L_S = \frac{L_P}{n_{T1}^2}$$

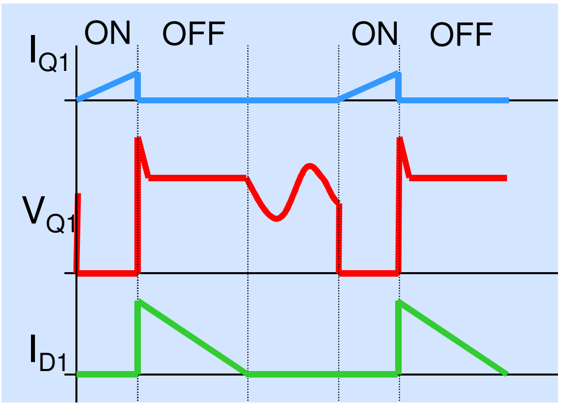
Oscillation phase





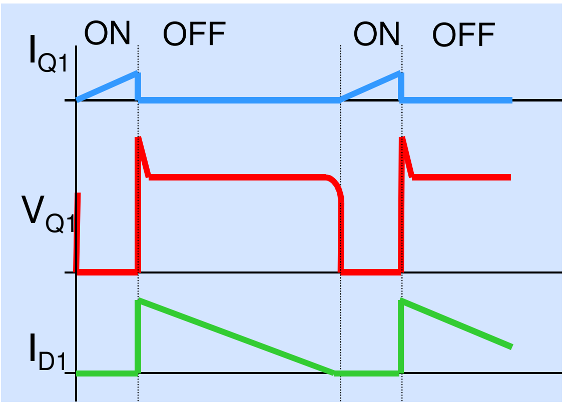
Flyback Modes of Operation

Discontinuous Mode DCM



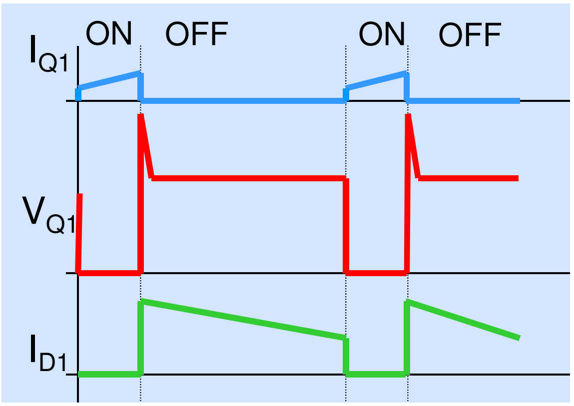
- Benefits
  - ZCS turn ON of MOSFET
  - ZCS turn OFF diode
- Draw backs
  - EMI self-oscillating
  - Unused time slot
- When to use
  - Higher input voltage (typ. 230V)

Quasi Resonant Mode



- Benefits
  - ZCS turn ON of MOSFET
  - ZCS turn OFF diode
  - Reduction turn ON losses
- Draw backs
  - Variable frequency could be problematic
- When to use
  - When efficiency is main parameter

Continuous Mode CCM



- Benefits
  - Higher power capability
- Draw backs
  - Not ZCS – worse EMI and switching power loses
- When to use
  - Need for peak power demands
  - When lower input voltages (110V)

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Key Parameters to Be Considered in Design

Component	Value	Comment	Main impact
MOSFET	V_{BRDS}	Maximum MOSFET stressing voltage	Cost, Efficiency, Reliability
	R_{DSON}	Conductive losses in the MOSFET	Efficiency, Cost
Diode	V_{RRV}	Maximum stressing voltage of diode	Cost, Reliability
	V_{FW}	Conductive losses in the diode	Efficiency, Cost
Controller	I_{PK}	Limitation of primary side peak current	Cost, Size
Transformer	L_{PK}	Primary inductance affects the peak current level	Efficiency, Cost, Size
	n	Transformer turns ration affect most of values above	Efficiency, Cost, Size

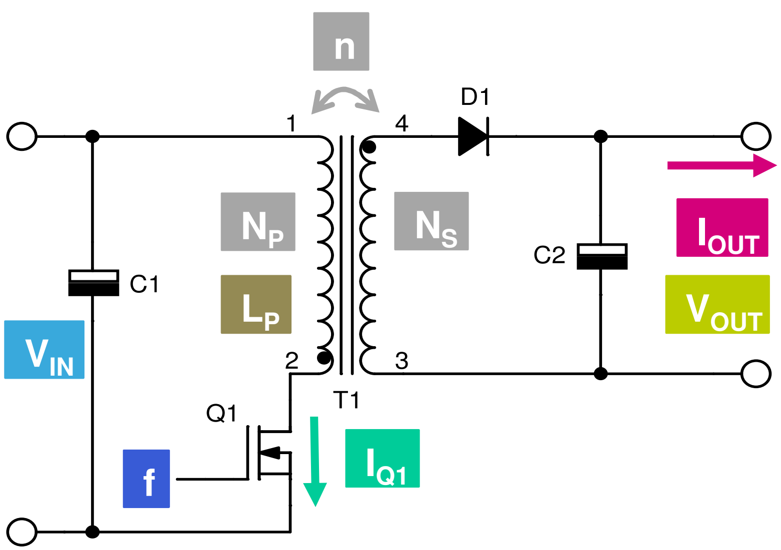
Input data, Basic equitation

Design - Input data:

- V_{IN} – input voltage range
- V_{OUT} – output voltage level
- I_{OUT} – maximum output current

Selected value:

- L_P – primary inductance vs I_{Q1PK}
- n – transformer ratio (N_P/N_S)
- f – operating frequency



$$P_{T1} = \frac{1}{2} L_P I_{Q1PK}^2 f_{SW}$$

$$n = \frac{N_P}{N_S}; L_S = \frac{L_P}{n^2}$$

$$I_{QPK} = \frac{I_{D1PK}}{n}$$

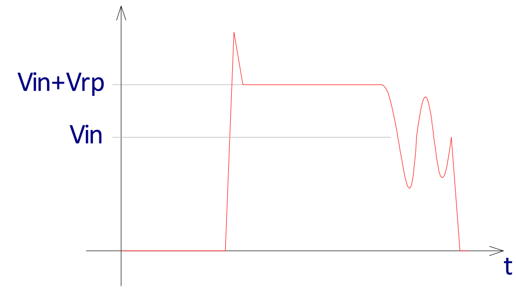
$$V_{DSQ1} = V_{IN} + nV_{OUT} + V_{SPIKE}$$

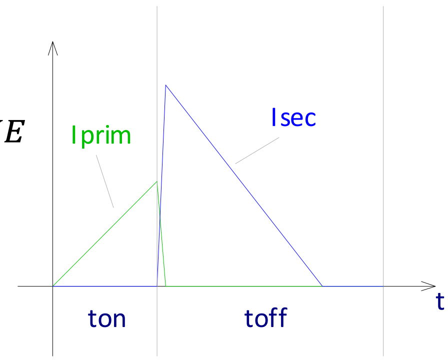
$$V_{DSD1} = V_{OUT} + \frac{V_{IN}}{n}$$

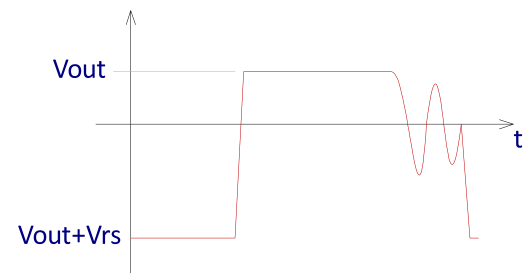
$$V_{KAD1} = V_{OUT} + \frac{V_{IN}}{n}$$

$$I_{Q1RMS} = \sqrt{\frac{L_P f I_{Q1PK}^3}{3V_{IN}}}$$

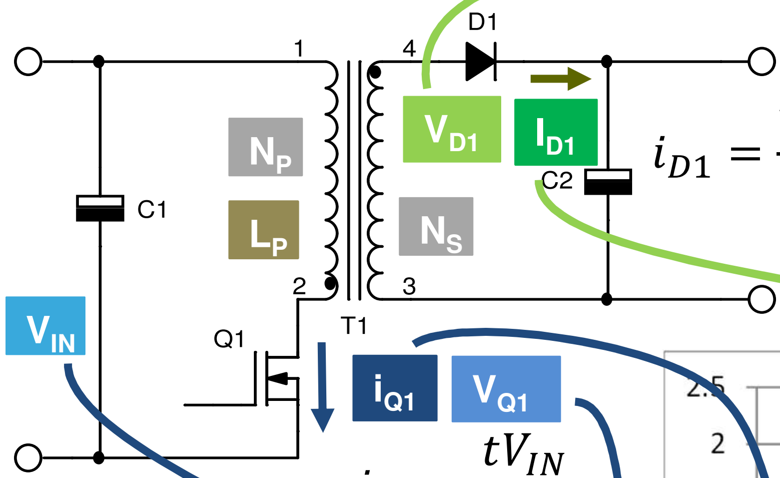
$$I_{D1RMS} = \sqrt{\frac{nL_P f I_{Q1PK}^3}{3V_{OUT}}}$$





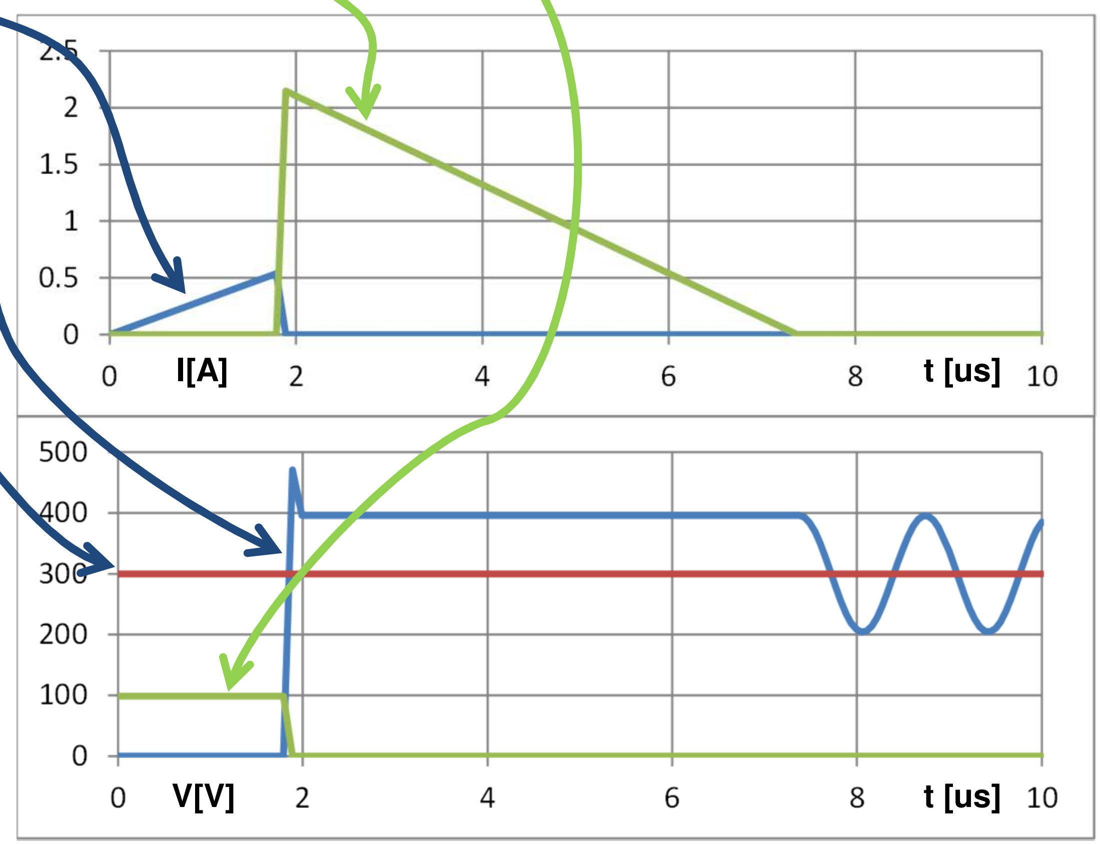


Typical flyback waveforms DCM



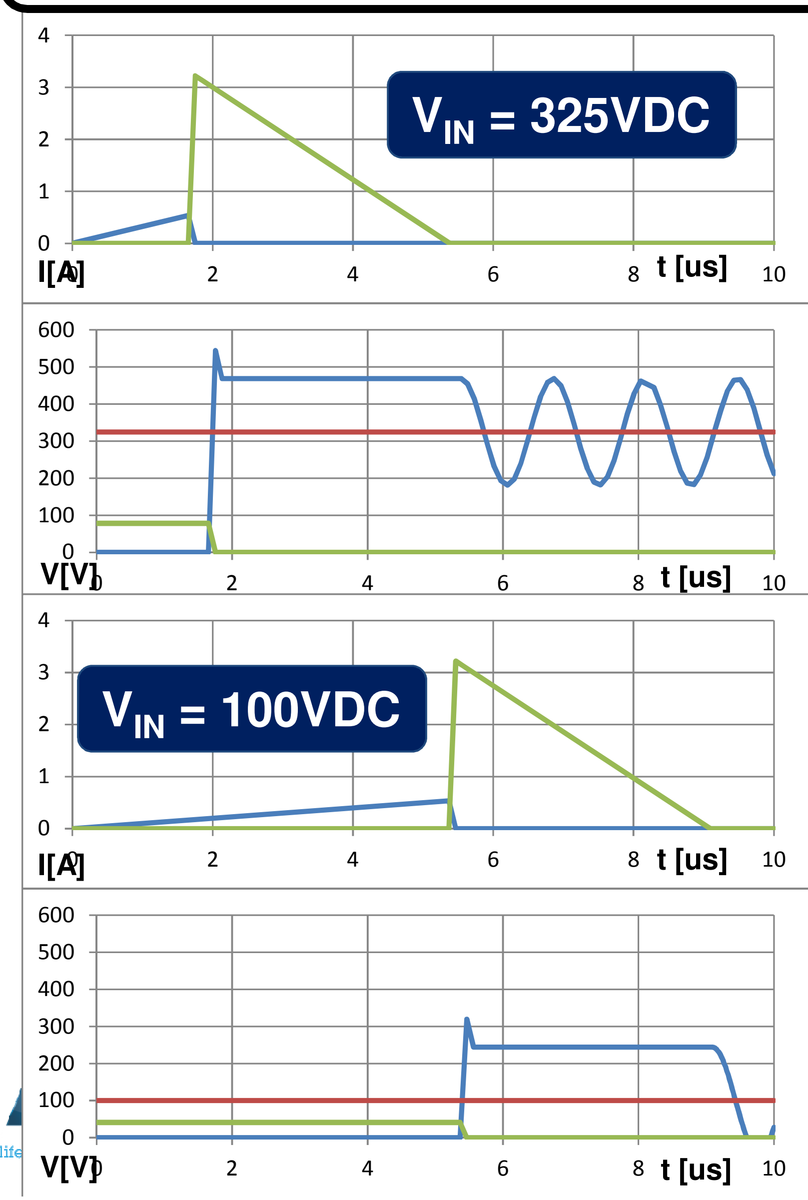
$$i_{D1} = \frac{tn^2 V_{OUT}}{L_P}$$

$$i_{Q1} = \frac{tV_{IN}}{L_P}$$

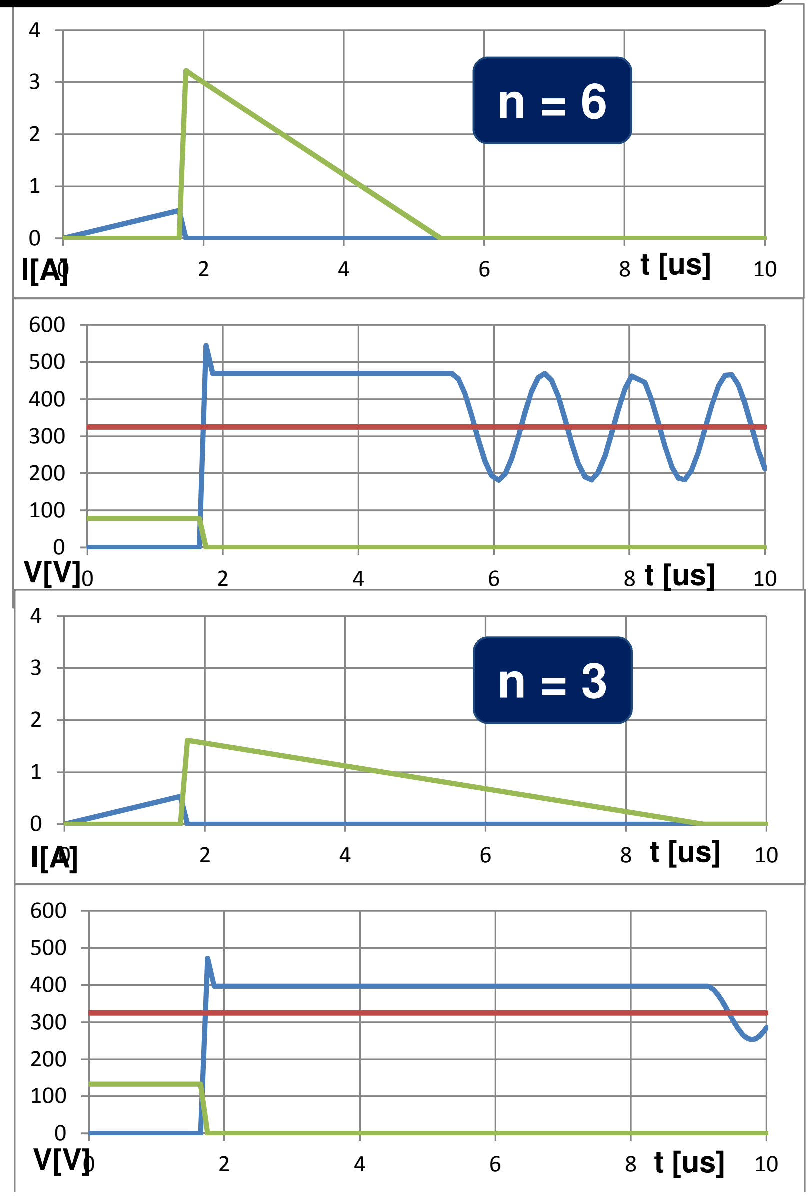


Example of Waveforms for Different Settings (1/2)

V_{OUT} = 24V, I_{OUT} = 0.6A, f = 100kHz
L_P = 1mH, n = 3 – V_{IN} = ?

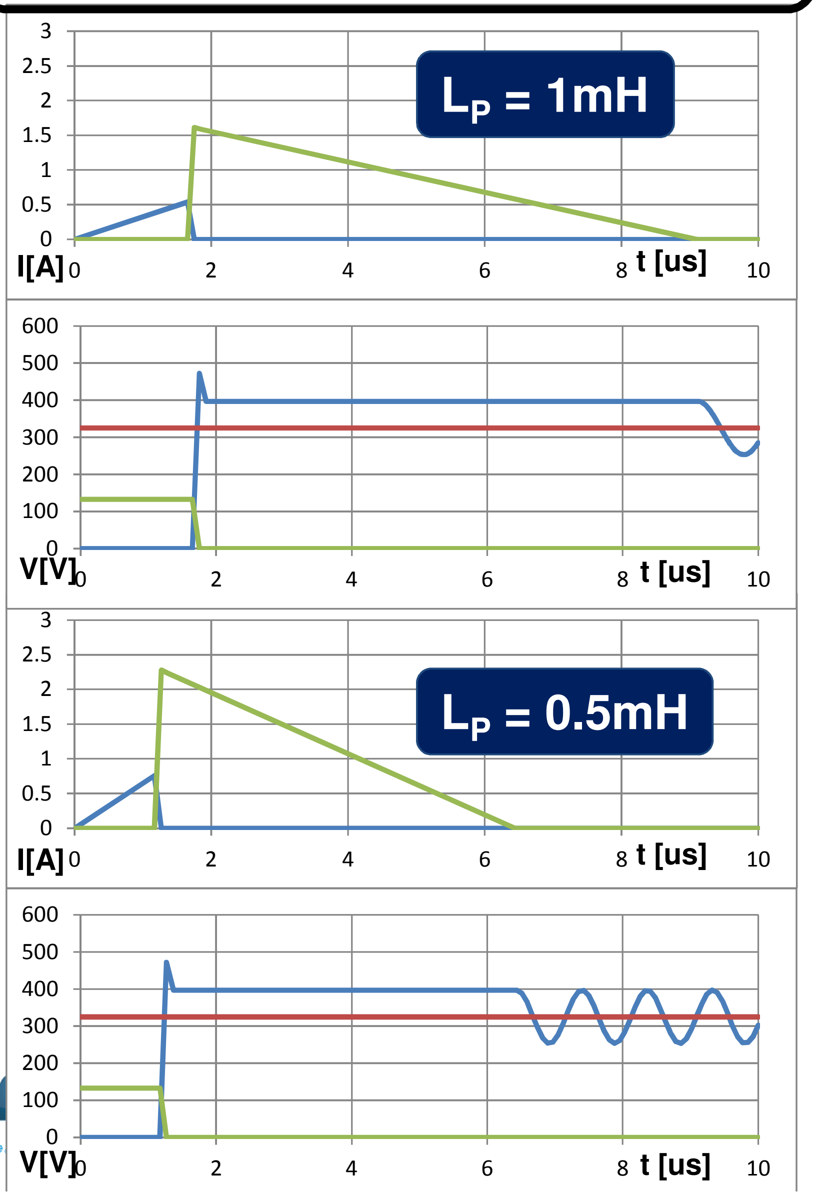


V_{OUT} = 24V, I_{OUT} = 0.6A, f = 100kHz
V_{IN} = 325V, L_P = 1mH – n = ?

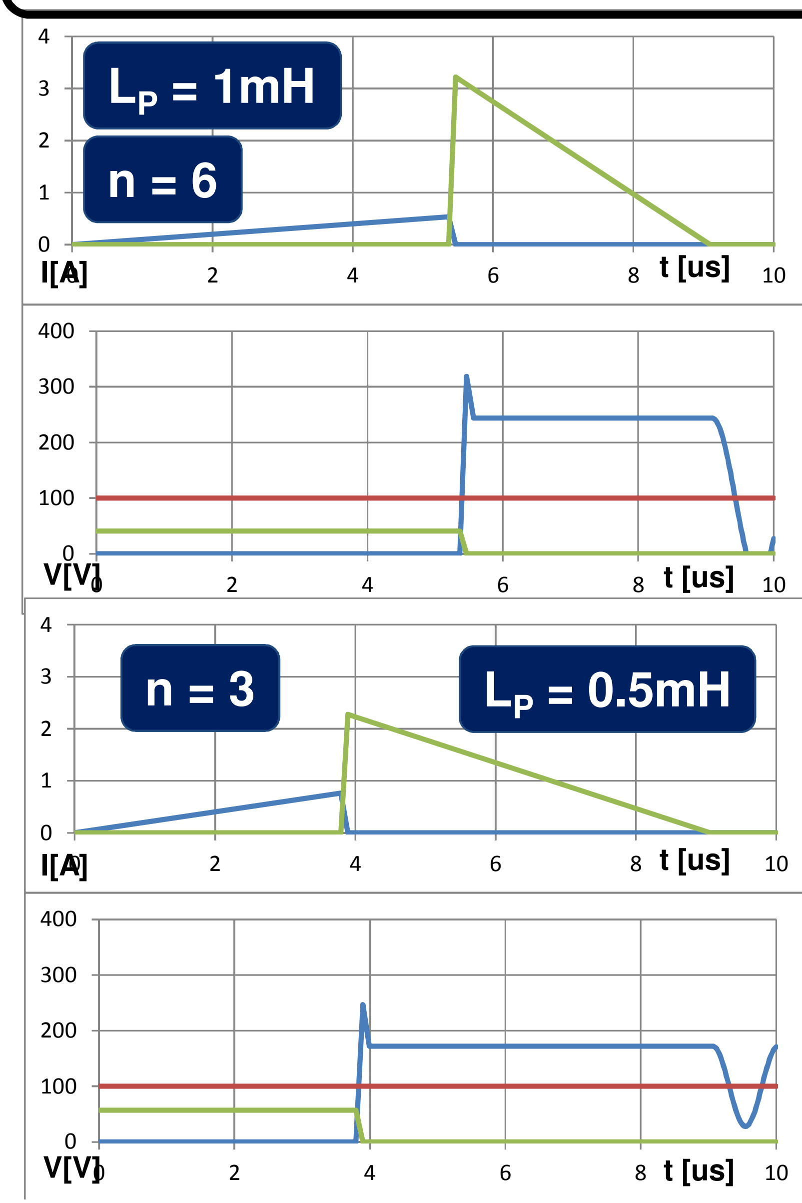


Example of Waveforms for Different Settings (2/2)

V_{OUT} = 24V, I_{OUT} = 0.6A, f = 100kHz
V_{IN} = 325V, n = 3, L_P = ?



V_{OUT} = 24V, I_{OUT} = 0.6A, f = 100kHz
V_{IN} = **100V**, n = ?, L_P = ?



Basic Hints for L_P and *n* Selection

- Try to keep in DCM
- Set the L_P and n for minimum input voltage to use maximum of time slot
- Set L_P to be close (10 – 15%) to peak current limit of driving circuit
- Set *n* to keep enough margin for MOSFET
- Set *n* to keep optimal diode voltage

Viper+ allows to select the max peak current level in fine way

Viper+ includes 800V MOSFET = more freedom for design

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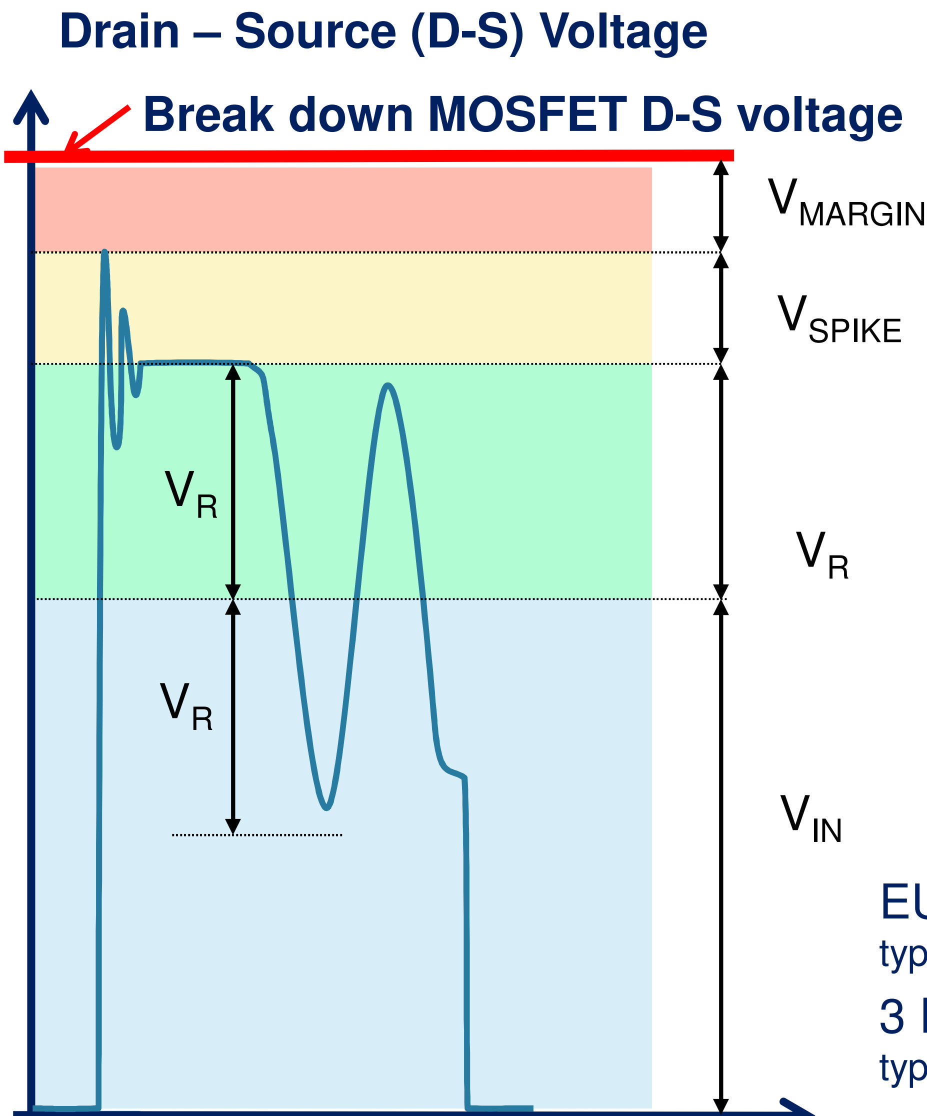
Input voltage range - HV MOSFET



Margin

V_{Margin} = 10 – 30% typically

Leakage inductance spike

Limited by peak calm circuit

V_{SPIKE} = 50 – 200V typically

Reflected Voltage

$$V_R = nV_{OUT}$$

V_R = 50 – 200V typically

Input voltage

V_{INmax} = 265VAC * 1.414 = 380V

	V_{IN}		V_R		V_S		V_M		
EU range typ. values	380V	+	120V	+	100V	+	160V	=	**760V**
3 Phase typ. values	680V	+	150V	+	100V	+	230V	=	**1160V**

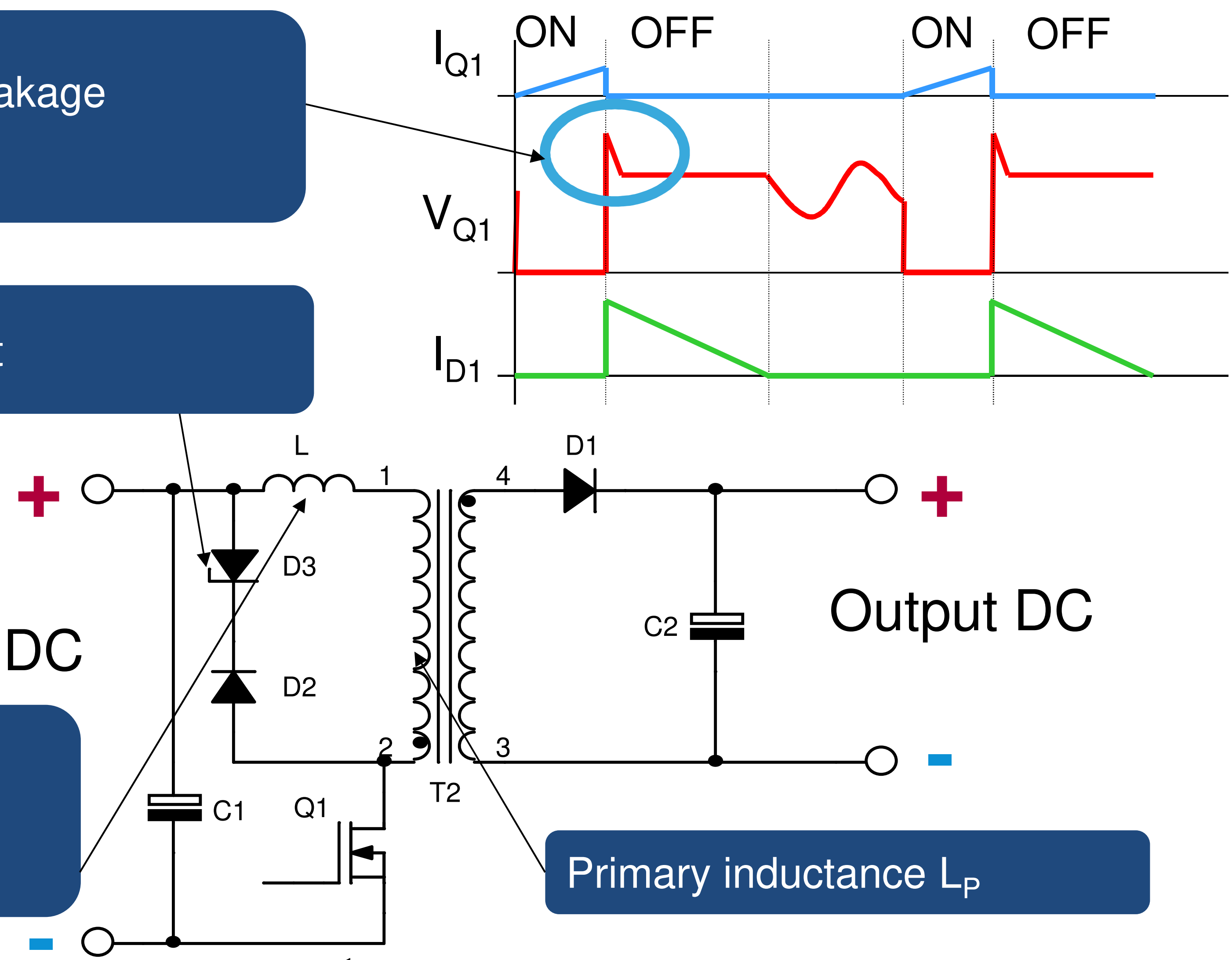
K5 – 800V & Viper+

K5 – 1200V

Flyback Topology – Leakage Inductance

The effect of Leakage inductance L_{LK}

Clamping circuit



Leakage inductance L_{LK}

Primary inductance L_P

$$E_{LP} = \frac{1}{2} L_P I^2_{Q1PK}$$

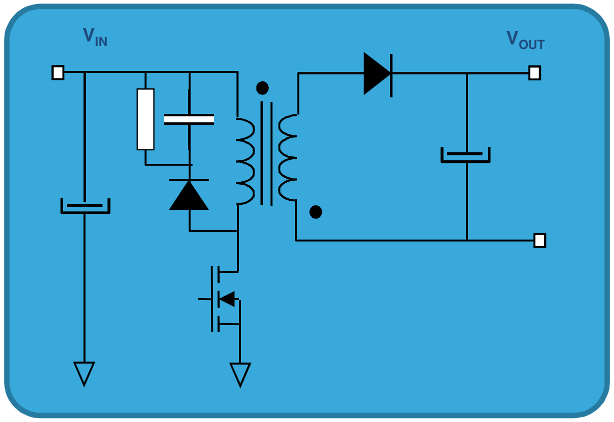
$$E_{LLK} = \frac{1}{2} L_{LK} I^2_{Q1PK}$$

$$n_{LK} = \frac{L_{LK}}{L_P}$$

$$P_{lost} = n_{LK} P_{T1}$$

Flyback Design - Peak Clamp Circuit

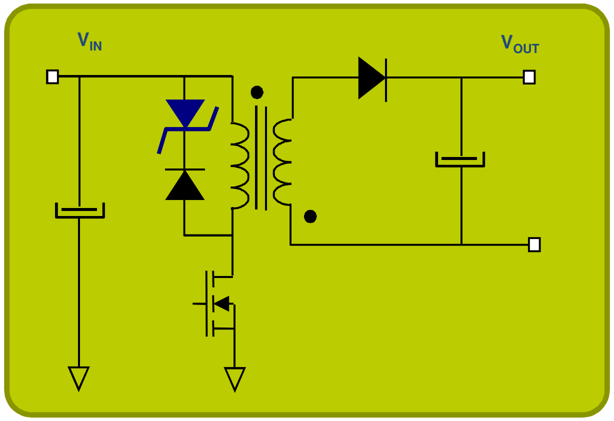
RCD Clamp



Drawbacks

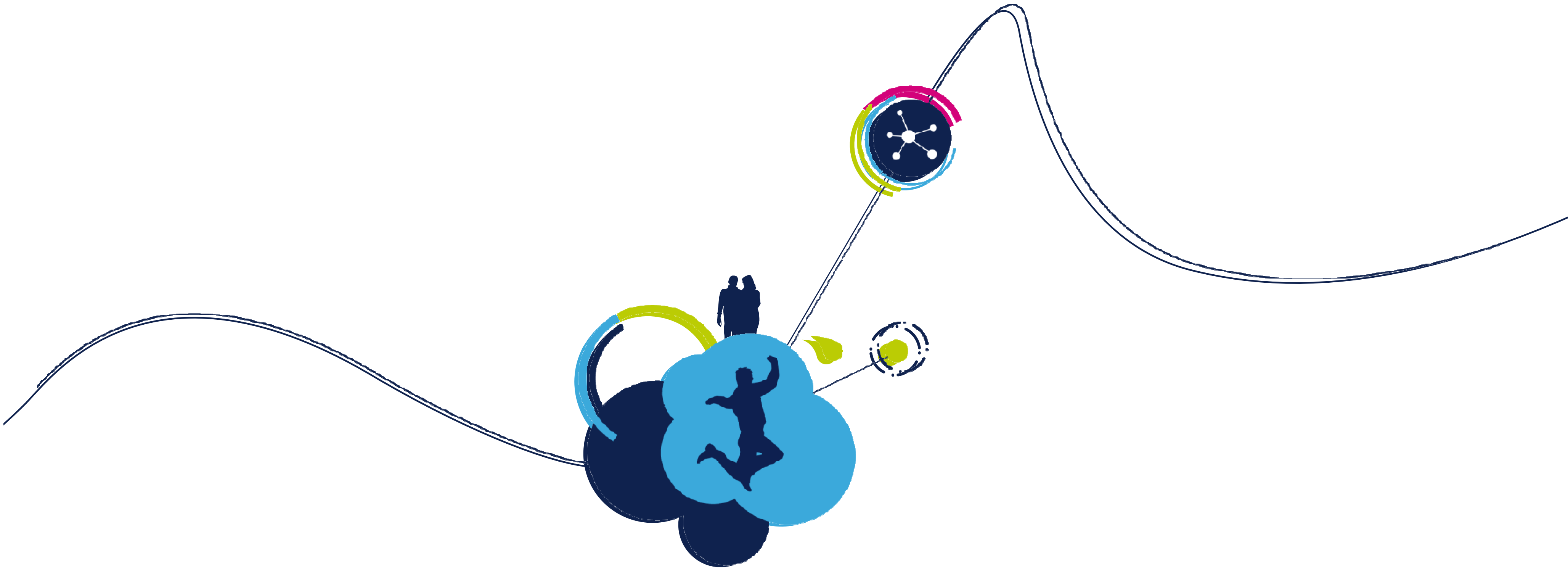
- Additional load burning power even at light/no load
- Peak level depends on the load level

Transil Clamp



Benefits

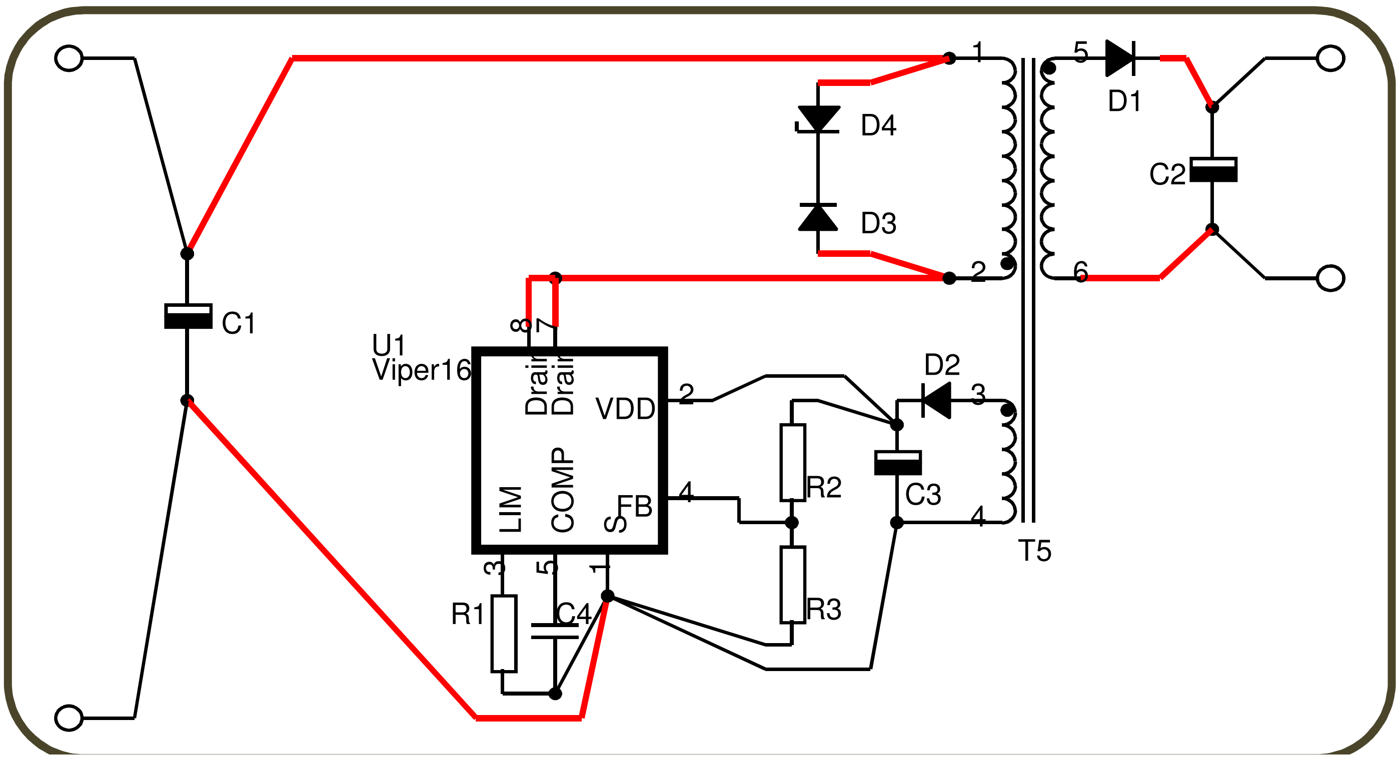
- Best standby
- Best Efficiency
- Precise voltage limitation



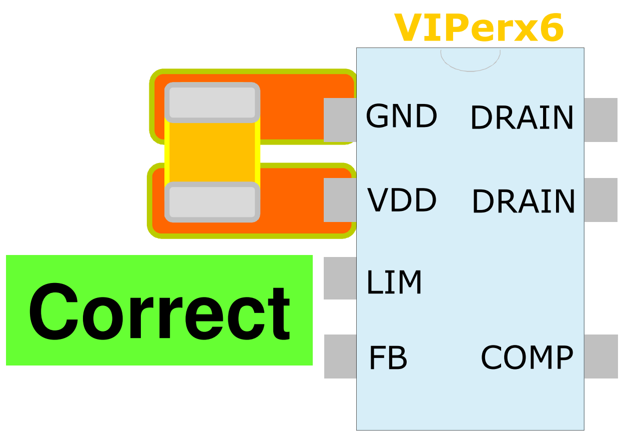
Layout Hints

Tips and Tricks for PCB Layout in Flyback: Connection to GND

- Red lines – HF power tracks – has to be SHORT and WIDE
- Separate power and signal GND
- Connect GND ideally in one point



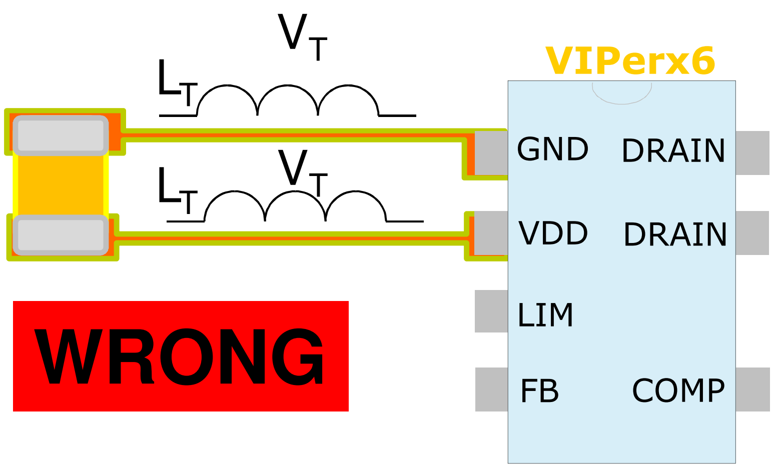
Tips and Tricks for PCB Layout
Vdd Capacitor and Signal Pins



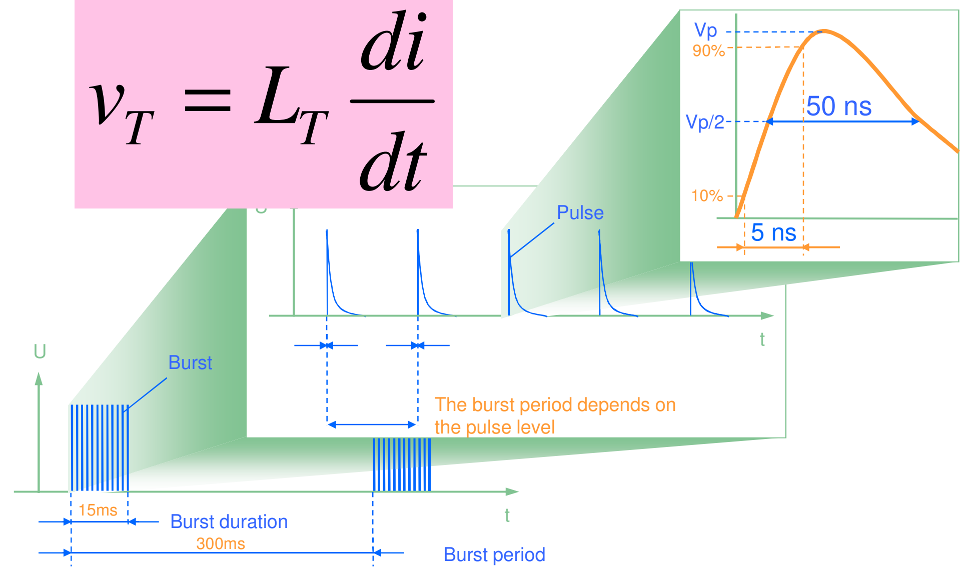
Fast current transients causes voltage drop between Vdd capacitor and Device

MOSFET Turn On/OFF

Electrical Fast Transient (EFT) testing is EN-61000-4-4

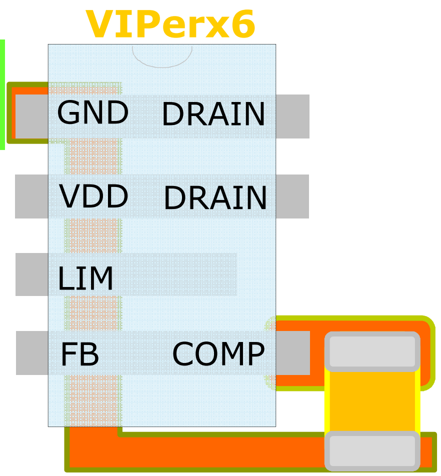


$$v_T = L_T \frac{di}{dt}$$



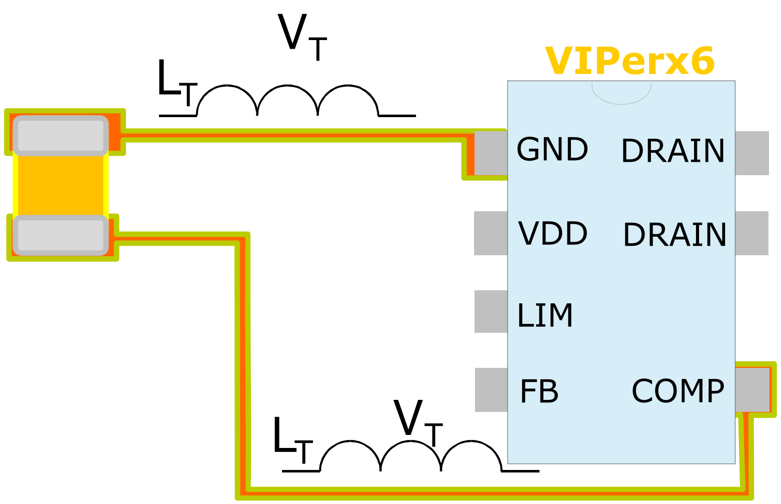
Tips and Tricks for PCB Layout: COMP Pin

Correct



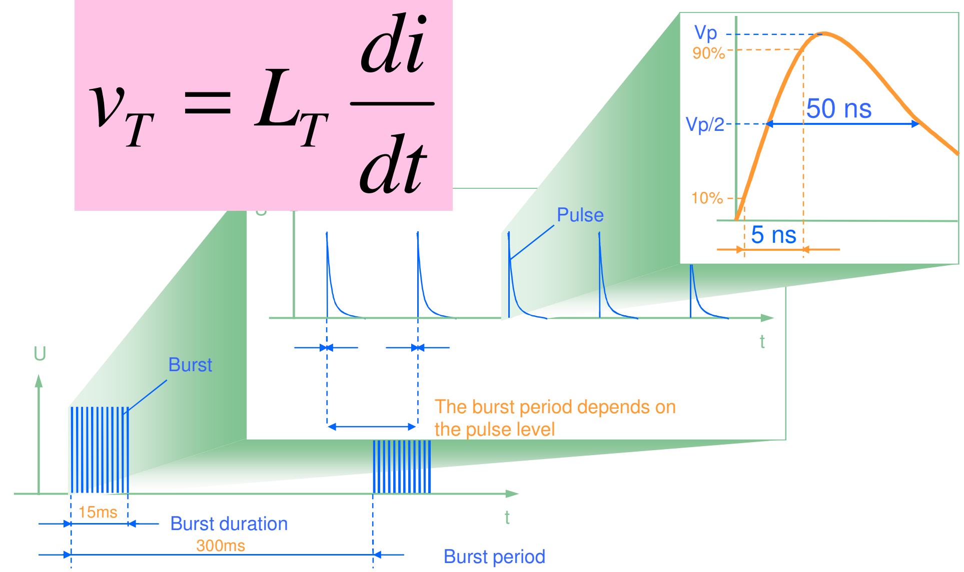
Fast current transients causes voltage drop between Comp pin capacitor and Device – it can cause instability and device reset

Electrical Fast Transient (EFT) testing is EN-61000-4-4

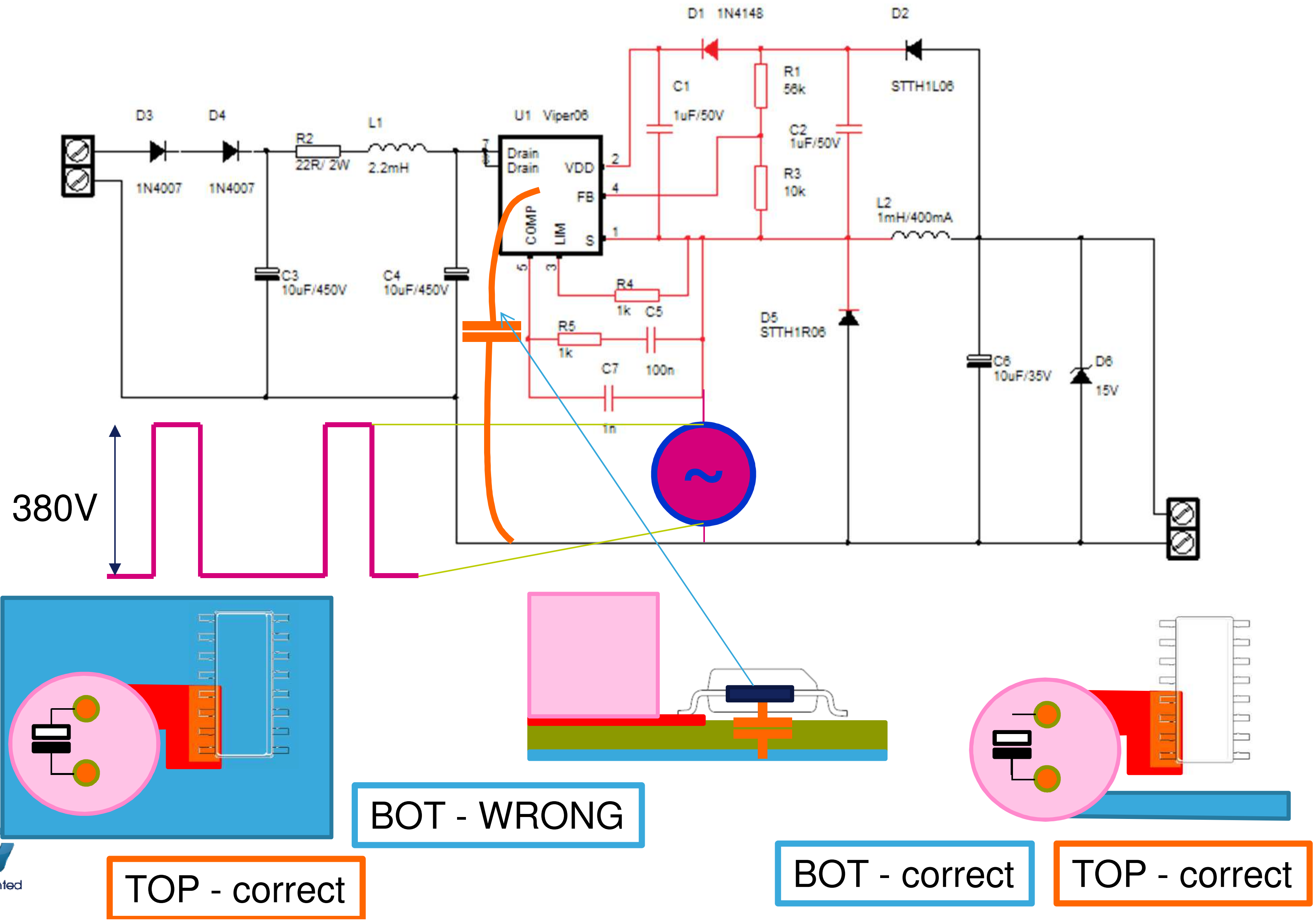


WRONG

$$v_T = L_T \frac{di}{dt}$$



Tips and Tricks for PCB Layout in Buck: Using of Cupper Area in Buck or Buck-Boost



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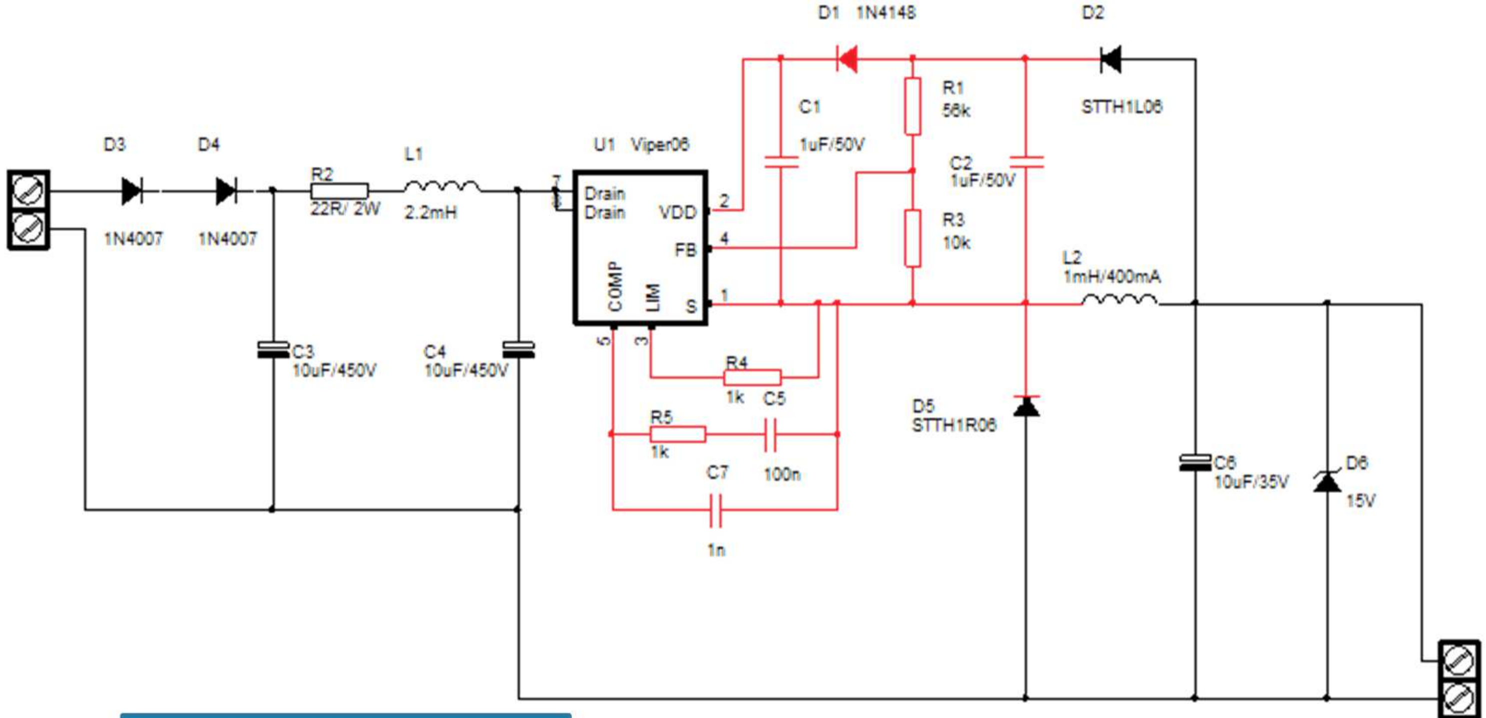
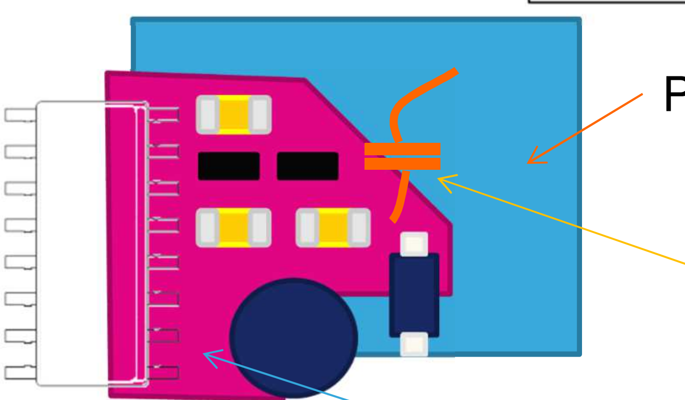
Tips and Tricks for PCB Layout in Buck: EMI - Common Mode Noise – Coupling to PE

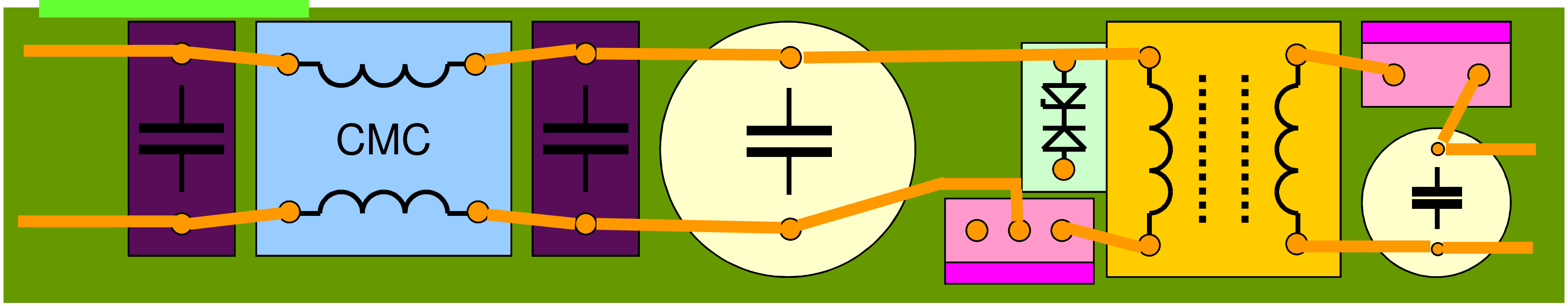


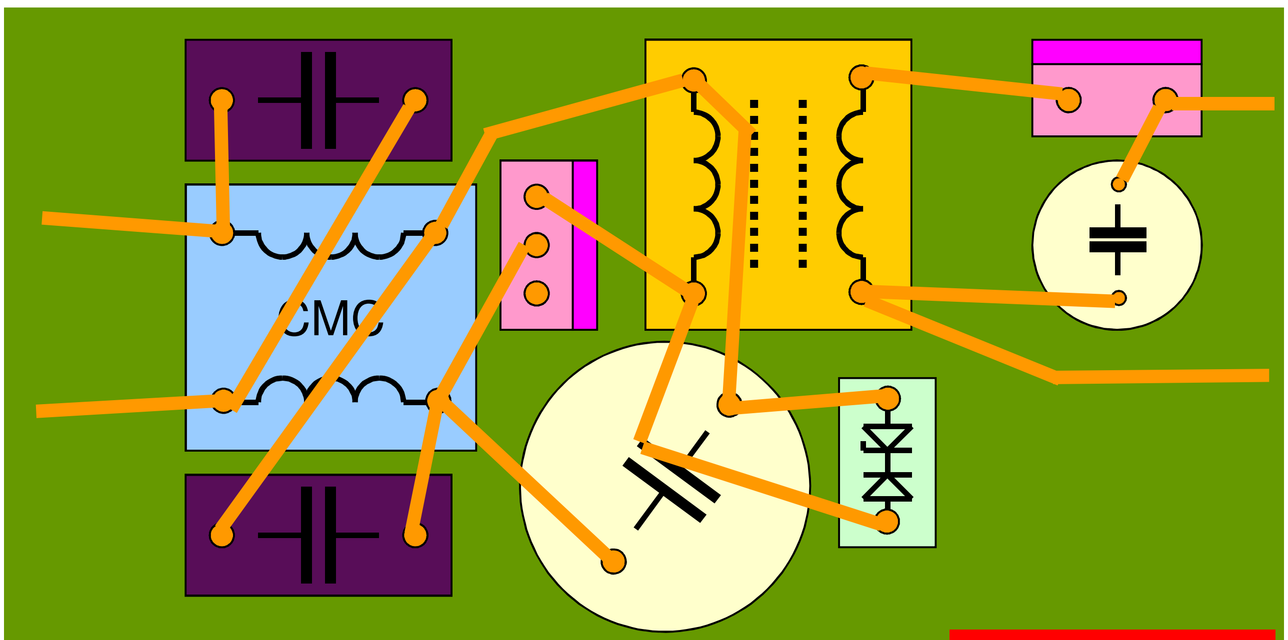


Parasitic capacitance between HOT area and PE causes common mode noise.
Keep the HOT area small as possible.

Tips and Tricks for PCB Layout in Flyback: Design Example

Correct





WORSE

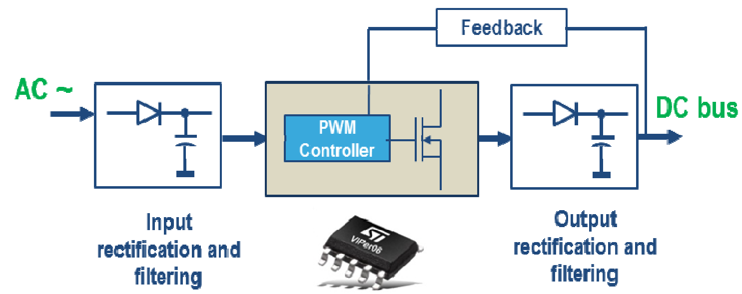
- Reducing parasitic capacitances between hot parts and input of SMPS
  - Transformer core
  - Drain of MOSFET
  - Peak clamp

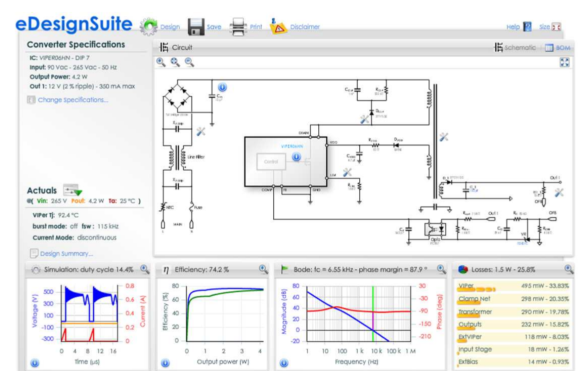
HV Converter for Low Power Auxiliary PS

VIPer+ Family

Smart Switch Mode Power Supply

- Converters for auxiliary Power Supplies up to 15-20W
- Embedded MOSFET > 800V AR for high robustness
- Suitable for buck or buck-boost, flyback with secondary or primary side regulation (SSR & PSR)
- Best-in-class energy saving
- Low EMI & BOM optimization
- Online simulation tool (eDesignSuite) for easy design





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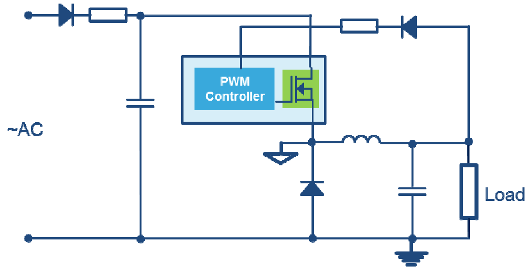
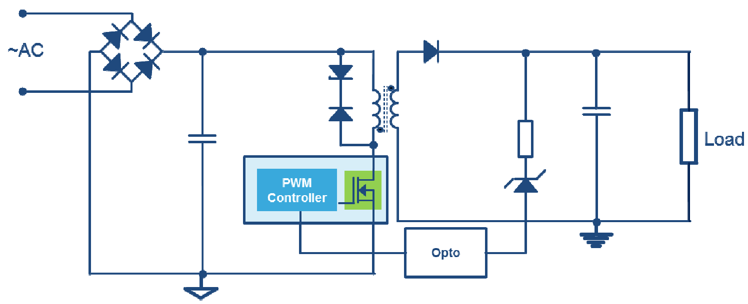
Supported Topologies

Buck & Buck-boost



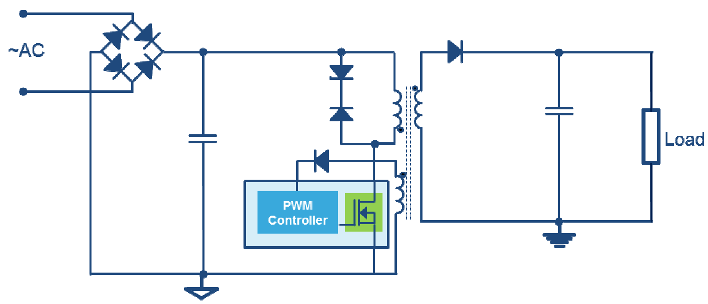
VIPer*6, VIPer*1, VIPer0P

Flyback with secondary side regulation (SSR)



All VIPer families

Flyback with primary side regulation (PSR)



Altair0*, HVLED8**

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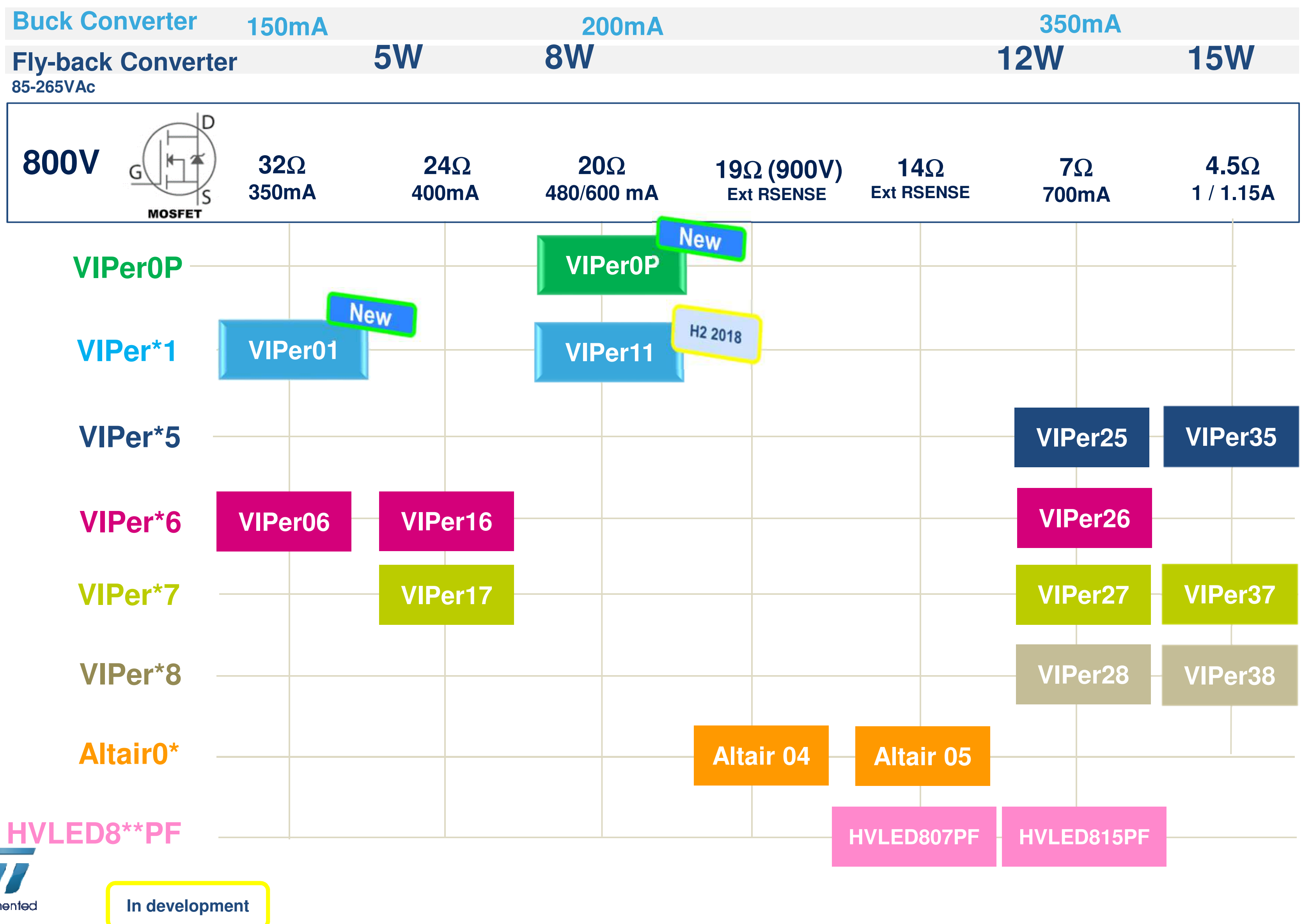
ST Offline Converters Power Overview



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ST Offline Converters Features Overview

Optimized for non-isolated topologies thanks to embedded E/A & self-supply

VIPer0P 800V MOS, Fixed Frequency, Zero-power Mode, Fixed Accurate Current Limitation

VIPer*1 800V MOS, Fixed Frequency, Fixed Accurate Current Limitation with multiple versions

VIPer*6 800V MOS, Fixed Frequency, Settable Current Limitation

Isolated Flyback Only

VIPer*7 800V MOS, Fixed Frequency, Brown-out Protection

VIPer*8 800V MOS, Fixed Frequency, Peak Power Capability

VIPer*5 800V MOS, Quasi Resonant, Brown-out Protection

Quasi-Resonant Isolated Flyback with PSR

Altair0* 800V & 900V MOS version

HVLED8PF** 800V MOS, with also embedded PF correction

EMEA FOCUS

VIPer*6 – VIPer*1 – VIPer0P

Optimized to work also with non-isolated topologies

Simple

VIPer*6 **Embedded E/A, self-supply, settable current limitation**

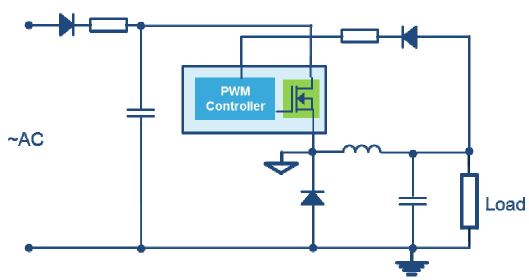
Advanced

VIPer*1 **Embedded E/A, self-supply, accurate current limitation, low stand-by, direct supply 5V**

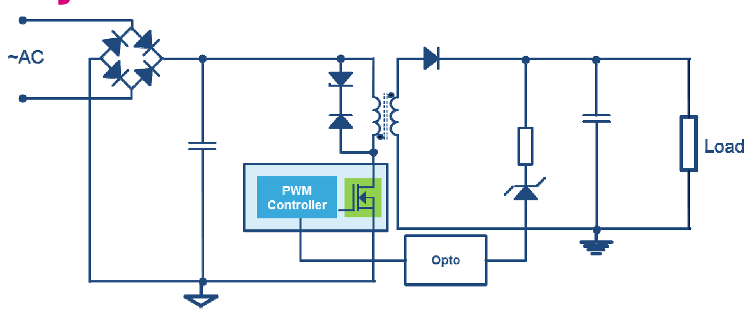
Innovative structure

VIPer0P **Embedded E/A, self-supply, accurate current limitation, Zero Power Mode, easy negative output**

Buck & Buck-boost



Flyback with SSR



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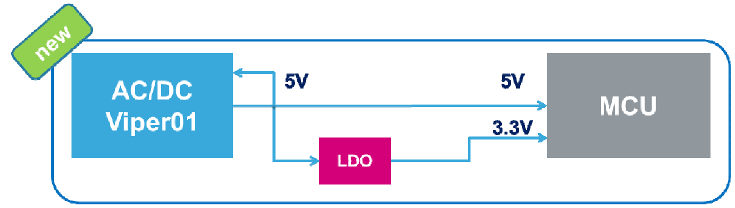
VIPer*6

Parameter	VIPer06	VIPer16	VIPer26
B_{VDSS} [V]	800	800	800
Max R_{DSon} [Ω]	32	24	7
Max I_{Dlim} [mA]	360	400	700
Max P_{OUT} [W] in flyback @ 85-265 VAC	5	6	12
Max I_{OUT} [mA] in buck @ 85-265 VAC	150	200	350
V_{DRAIN_START} [VDC]	45	60	100
F_{OSC} [KHz] Three options	30 / 60 / 120 ± 7% Jittering	60 / 120 ± 7% Jittering	60 / 120 ± 7% Jittering
V_{CC} [V]	11.5 ÷ 23.5	11.5 ÷ 23.5	11.5 ÷ 23.5
Packages	SSO10, DIP7	SO16, DIP7	SO16, DIP7

VIPer01 / VIPer11*

What´s new?

- Wide range of Vdd supply voltages starting from **4.5V** (4.5V – 30V)
  - can be supplied by a 5V output
  - avoid inefficient usage of self supply or additional LDO
- Very low standby consumption: down to **10mW**
- Low input voltage (18V V_{DC})**
  - universal input voltage bus
- Different current versions available
  - no need of external resistor
  - accurate limitation current



Flyback converter, 5V output

V_{IN}	Input power @ no load Supplied from V_{OUT} (diode)	Input power @ no load Self supply
115 V_{AC}	10.3 mW	10.3 mW
230 V_{AC}	11.8 mW	120 mW

10mW stand-by!

Buck converter, 5V output

V_{IN}	Input power @ no load	Efficiency @ Pout 25mW	Efficiency @ Pout 50mW	Efficiency @ Pout 250mW
115 V_{AC}	13.2 mW	54.8 %	61.0 %	72.0 %
230 V_{AC}	19.3 mW	45.5 %	51.0 %	67.5 %

* *Available by H2 2018; I_{DLIM} VIPer11x up to 590mA*

** *in VIPer01 only*

VIPer*1

H2 ´18

Parameter	VIPer01x	VIPer11x
B_{VDSS} [V]	800	800
Max R_{DSon} [Ω]	30	20
I_{Dlim} [mA]	120 / 240 / 360	370 / 480 / 590
Max P_{OUT} [W] in flyback @ 85-265 VAC	5	7
Max I_{OUT} [mA] in buck @ 85-265 VAC	150	250
V_{DRAIN_START} [VDC]	18	30
V_{CC} [V]	4.5 ÷ 30	4.5 ÷ 30
F_{OSC} [KHz] Three options	30 / 60 / 120 ± 7% Jittering	30 / 60 / 120 ± 7% Jittering
Packages	SSP10	SSP10

SSOP10

Order code	I_{DLIM} (OCP)	F_{OSC} ± jitter
VIPer011XS(TR)	120 mA	30 kHz ± 7%
VIPer012XS(TR)	240 mA	
VIPer013XS(TR)	360 mA	
VIPer011LS(TR)	120 mA	60 kHz ± 7%
VIPer012LS(TR)	240 mA	
VIPer013LS(TR)	360 mA	
VIPer012HS(TR)	240 mA	120 kHz ± 7%
VIPer013HS(TR)	360 mA	

Order code	I_{DLIM} (OCP)	F_{OSC} ± jitter
VIPER113XS(TR)	370 mA	30 kHz ± 7%
VIPER114XS(TR)	480 mA	
VIPER115XS(TR)	590 mA	
VIPER113LS(TR)	370 mA	60 kHz ± 7%
VIPER114LS(TR)	480 mA	
VIPER115LS(TR)	590 mA	
VIPER114HS(TR)	480 mA	120 kHz ± 7%
VIPER115HS(TR)	590 mA	

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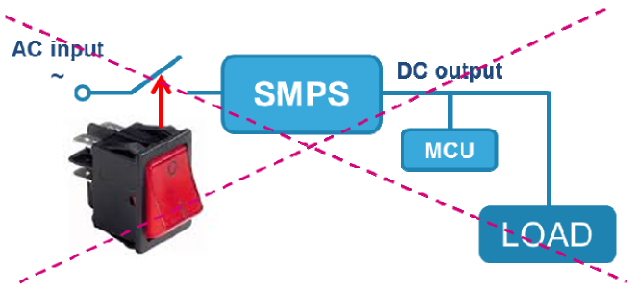
VIPer0P ZPM: Cost-saving Architecture

Zero Input Power State of Art Solution

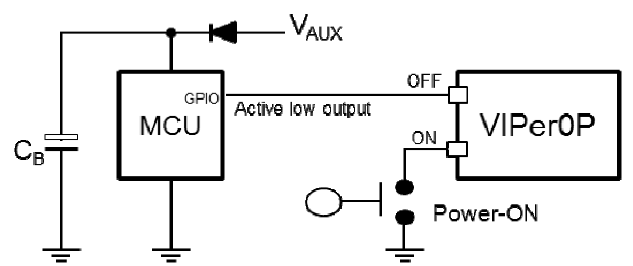


Mechanical switch must be used to have zero input power consumption

Zero Input Power using VIPer0P

4 mW

The zero-power mode (ZPM) feature enables the IC to work in an idle state, where the system is totally shutdown



1. ZPM is entered by MCU (switching stop)
2. ZPM is exited by user through a **tactile switch** (switching restart)

Viper0P: The winning solution

	Zero Power consumption	Stand-by mngmt	Supply voltage range	Max. R_{ON} @ 25°C	MOSFET BV
VIPer0P	**4 mW** (no load)	**Y**	**4.5 – 30 V**	**20**	**800 V**
Closest Competitor	5 mW (load 1mW)	N	6.1 - 9 V	55	700 V

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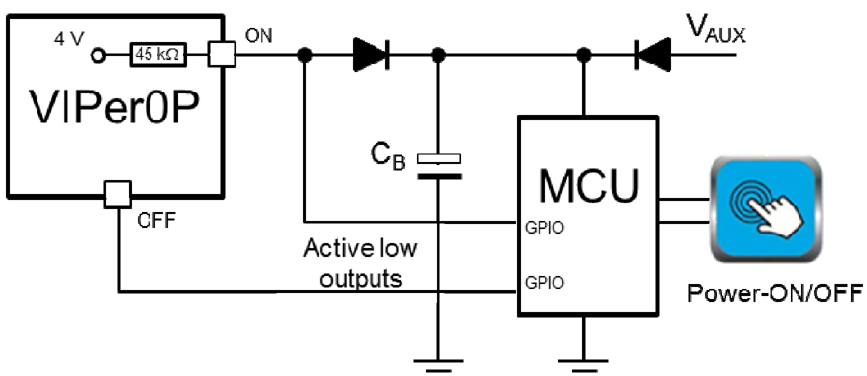
ZPM: Fully Managed by µC

1. In case a µC needs to be always ON, it can be supplied by ON pin.
2. The µC should be 3.3V compatible & low consumption.
3. This approach can be used when capacitive touch interface is used instead of standard button.



STEVAL-ISA192V1

The µC can implement a routine to swicht periodically ON the VIPer so to supply the user interface (capacitive touch sensing)

Average Power Consumption: 30mW
also with load at secondary side (Vout pushed to 0V)

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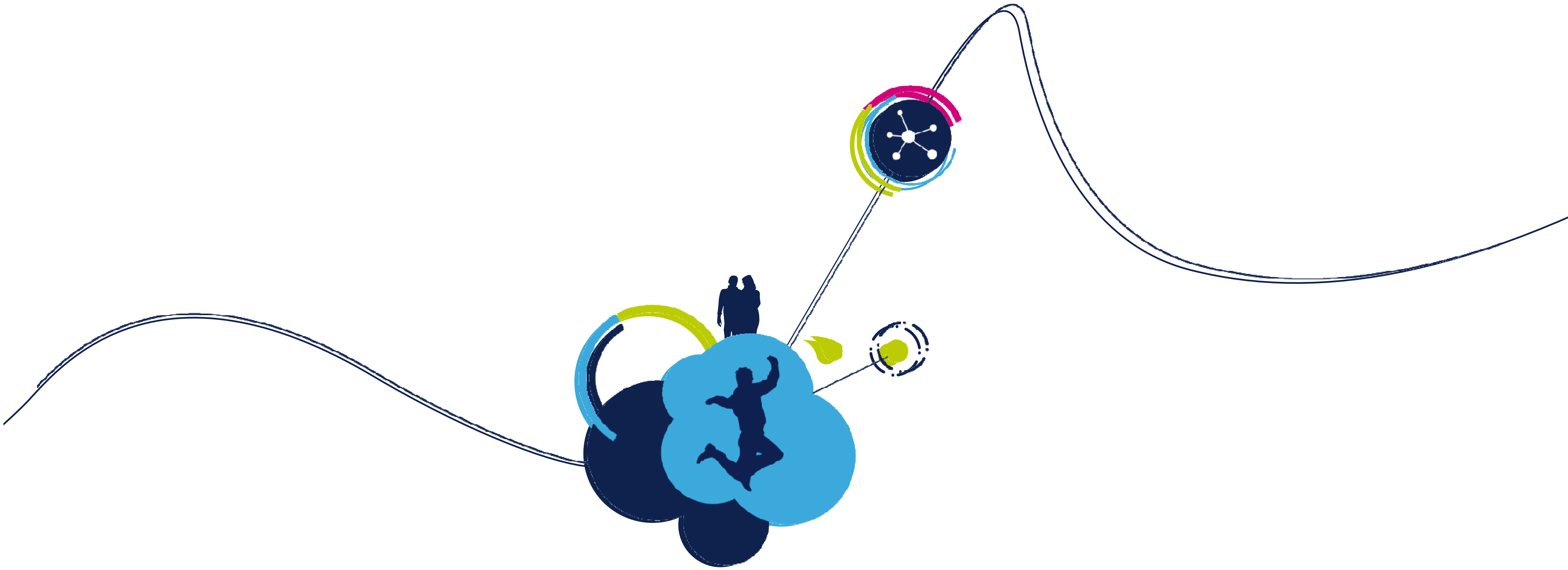

Live session:
eDesignSuite for easy design

eDesignSuite

eDesignSuite is a SW platform that helps to select the right product for power conversion and speeds-up the design-in

AC-DC & DC-DC converters are supported by eDesignSuite

- Go to **www.st.com/edesignsuite**
- Register the first time and log in
- Insert your design specifications
- Get the suitable products
- Choose one, simulate and get
  - Circuit BOM
  - Electrical Waveforms
  - Additional information (stability, efficiency, etc.)

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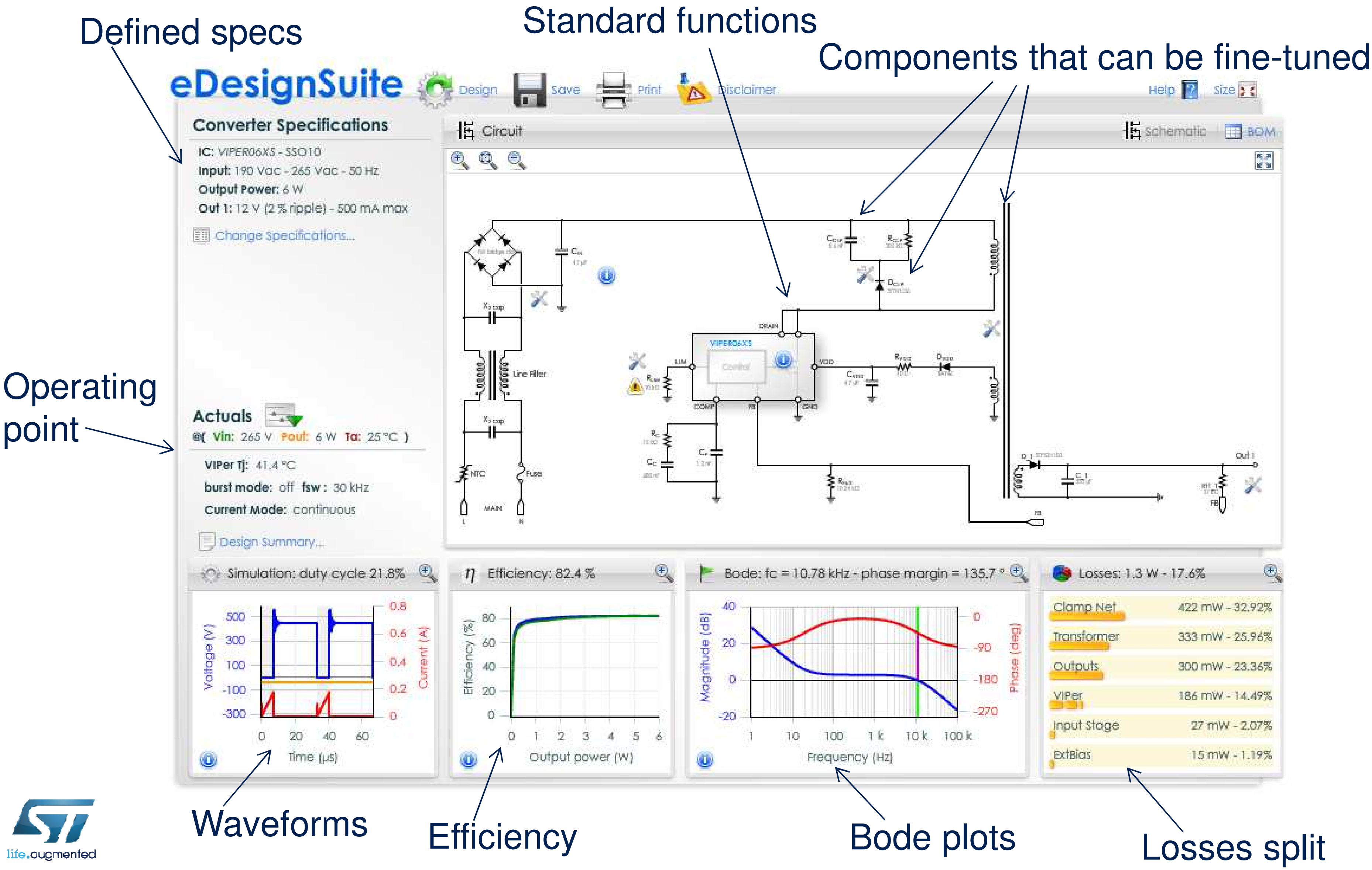
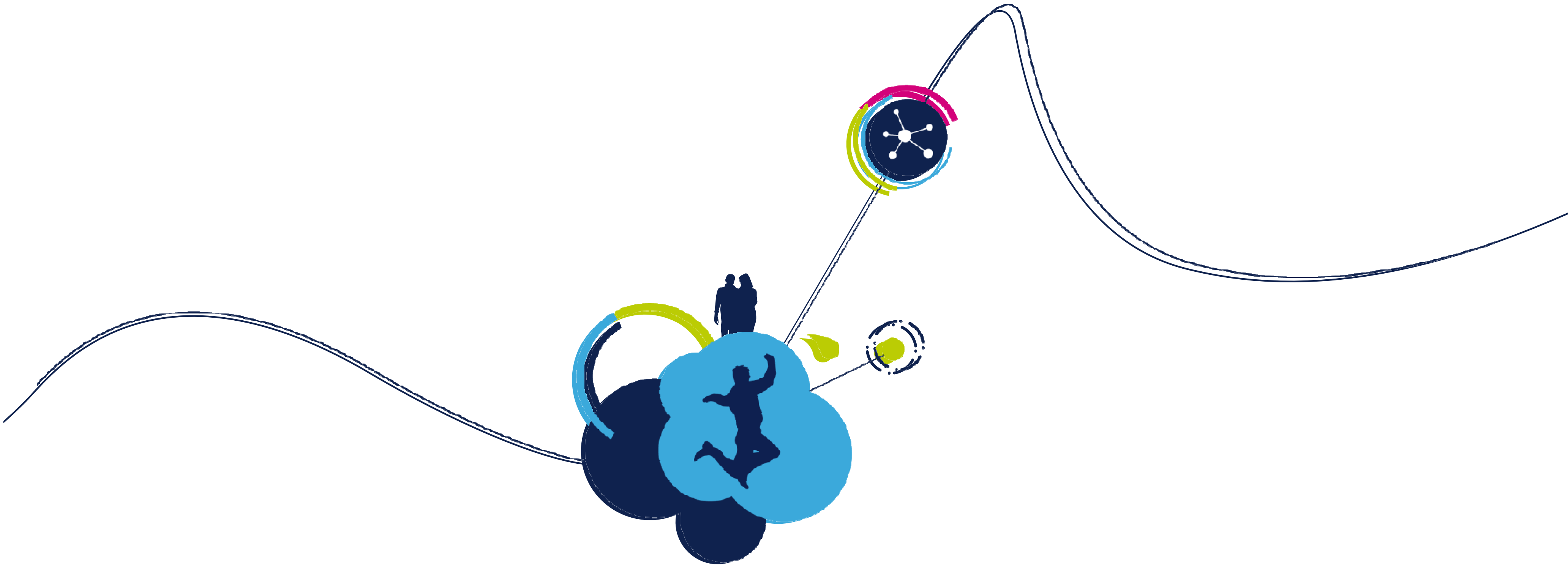
eDesignSuite





Design considerations for quasi-resonant flyback converters

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Quasi-resonant flyback auxiliary SMPS

Theory & critical aspects

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Efficiency and Power Losses

Main areas of energy burn

- Semiconductors
  - MOSFET
    - Conductive loses (RDSON)
    - Switching losses (Parasitic capacitance, switching time)
  - Secondary side rectifier
    - Conductive losses (forward voltage)
    - Switching losses (Parasitic capacitance, Recovery effect)
  - Input bridge (forward voltage)
- Passive
  - Transformer (conductive losses, losses in the core)
  - Output capacitor (conductive losses due to ESR)
  - Input bulk capacitor (conductive losses due to ESR)

MOSFET Power Losses

- Conductive loses
  - Losses are proportional to RDSON and MOSFET RMS current
  - It can be improved by using bigger (in terms of size) MOSFET, but it must be considered the product of MOSFET parasitic capacitance and RDSON is constant for specific MOSFET technology

- Switching losses
  - Capacitive losses – there is saved energy during OFF time into capacitance connected in parallel to MOSFET and this energy is burned in MOSFET during ON time
  - Losses caused by MOSFET resistivity change in dedicated time

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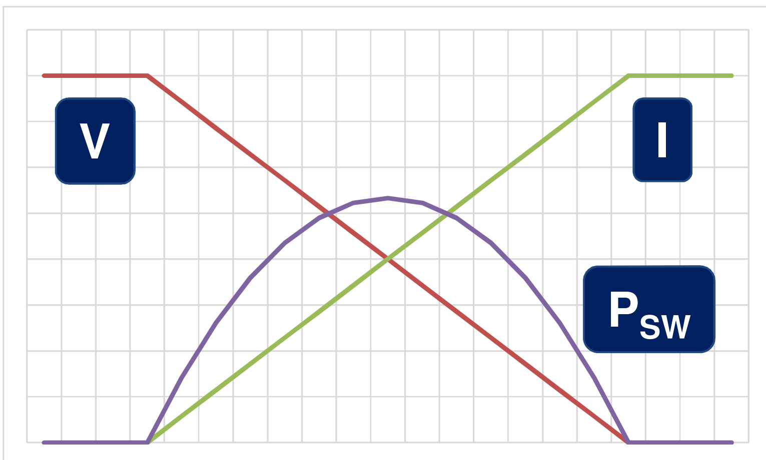
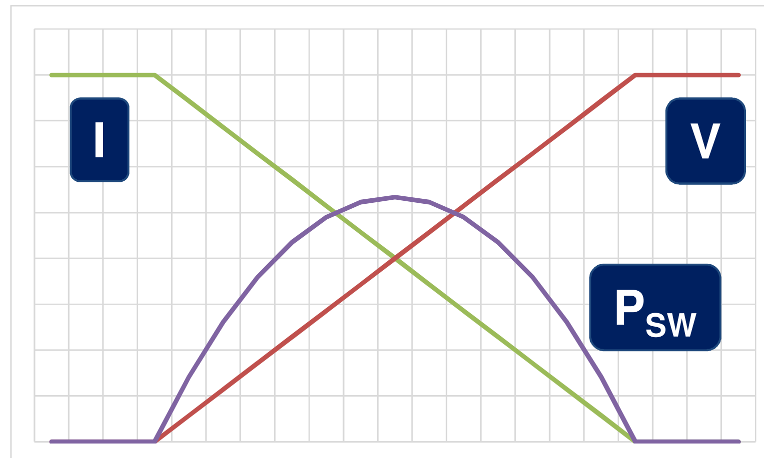
MOSFET Resistivity Swing Switching Losses

TURN ON



TURN OFF

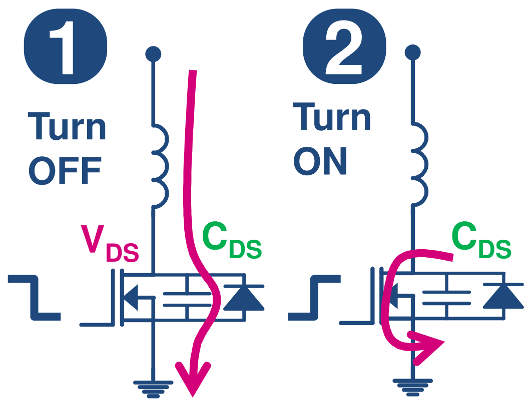


Turn ON/OFF MOSFET duration depends on the driver and gate charge

- TURN ON swing losses can be voided using ZCS (zero current switching) => **DCM or QRM**

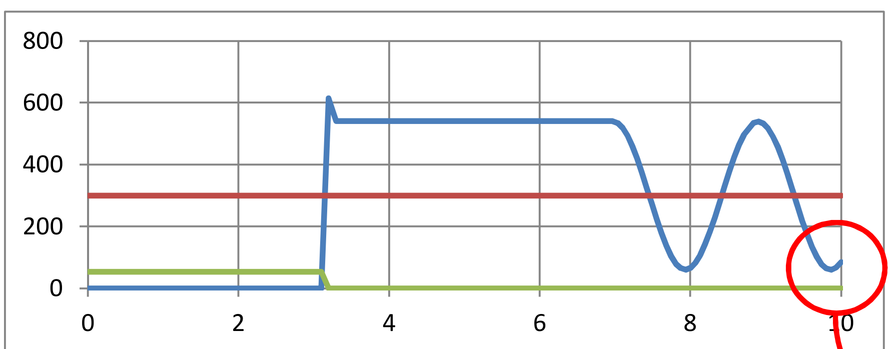
Capacitive Switching Losses

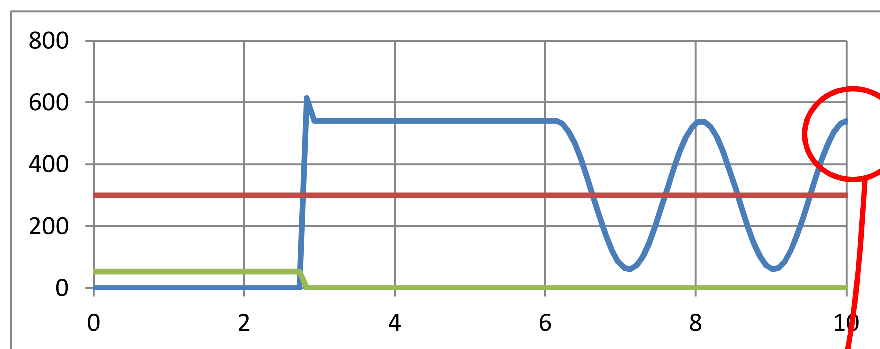
Capacitive losses



1. MOSFET is turned OFF. Parasitic capacitance C_{DS} is charged to V_{DS}
2. MOSFET is turned ON. Energy stored in the C_{DS} is **Burned** in the MOSFET

$$P_{C_{losess}} = \frac{1}{2} V_{TOFF}^{2} C_d f$$

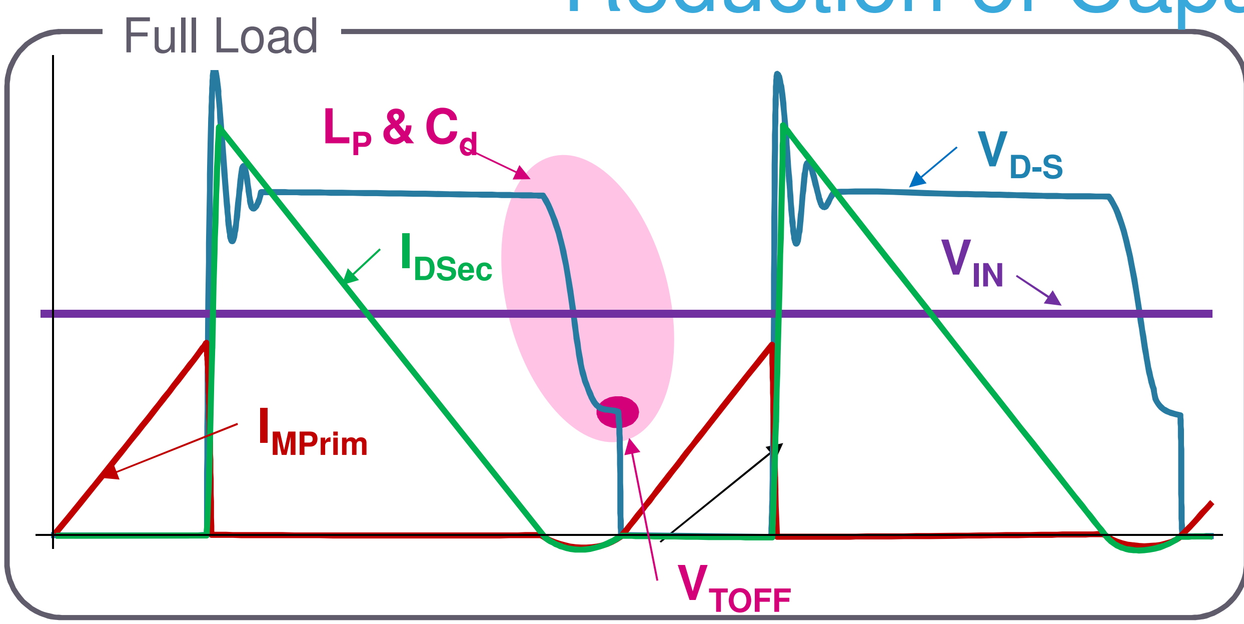




V_{OUT} = 24V, I_{OUT} = 0.9A, C_{PAR}=47pF
P_{CAP_MOS} = **0.0235 W**

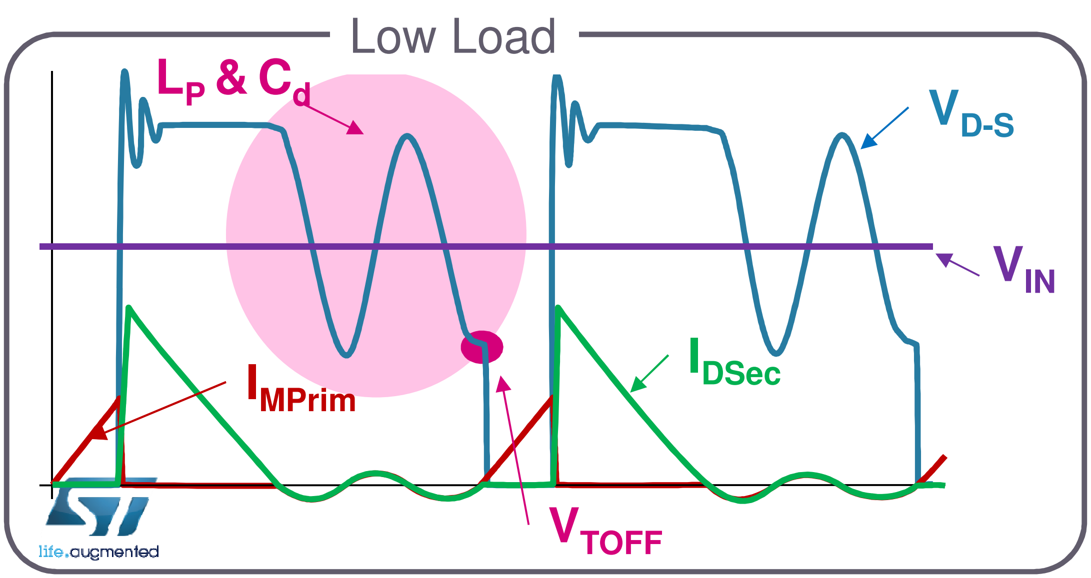
V_{OUT} = 24V, I_{OUT} = 0.7A, C_{PAR}=47pF
P_{CAP_MOS} = **0.711 W**

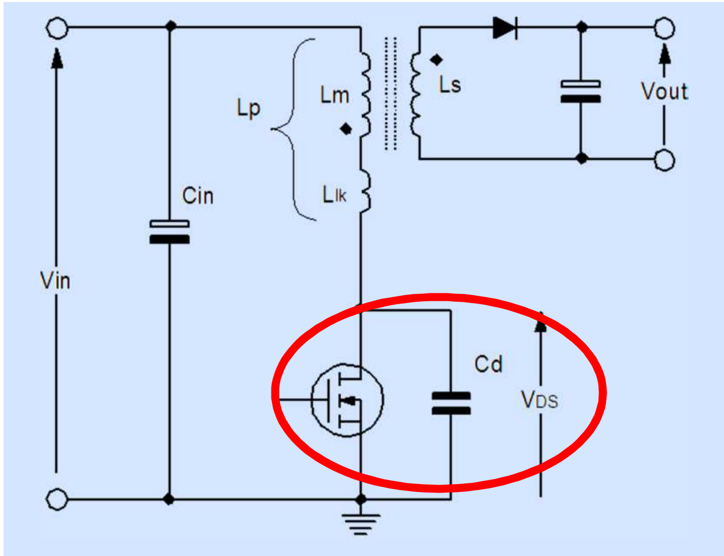
Quasi-resonant Mode of Operation – Reduction of Capacitive Losses



$$P_{C_{losess}} = \frac{1}{2} V_{TOFF}^{2} C_d f$$

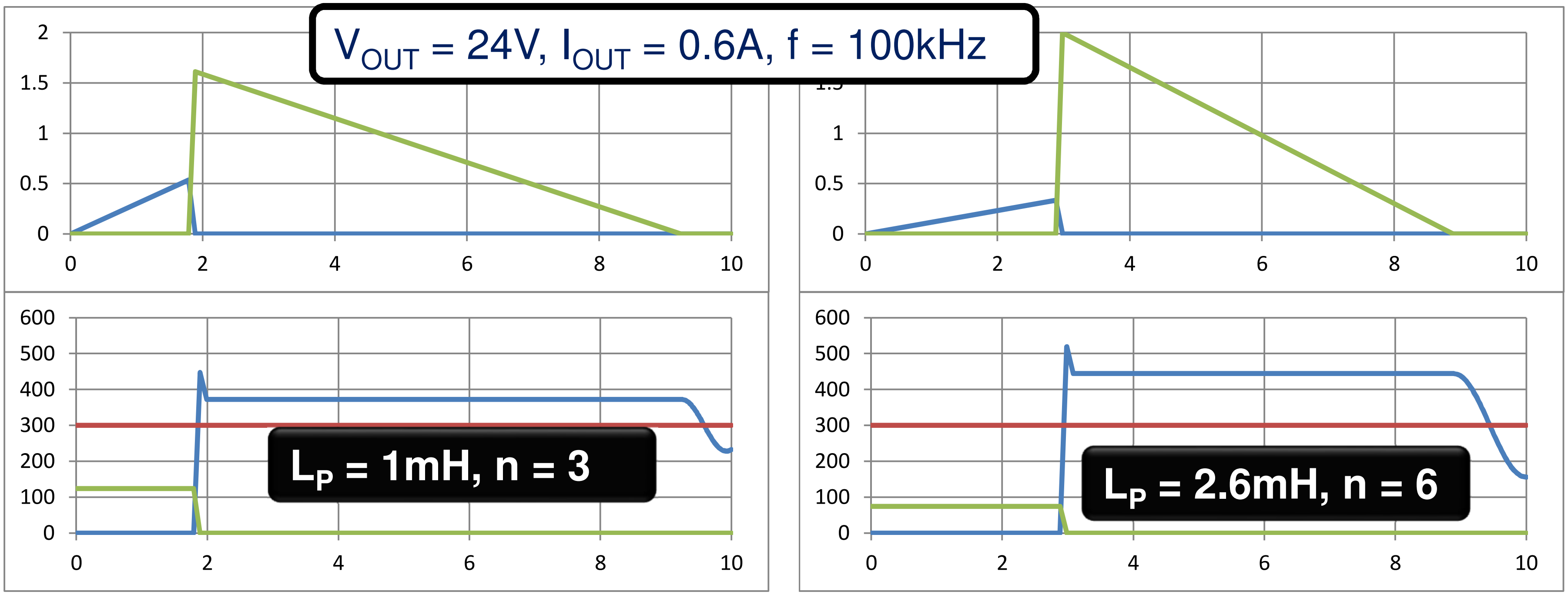
For **Example**:
Cd = 100pF, f = 60kHz
FF: VTOFF = 500V
Pclosses = **0.75W**
QR: VTOFF = 100V
Pclosses = **0.03W**





QR mode – How to Select Basic Parameters of Transformer?

To minimize capacitive losses it makes sense to set **higher reflected voltage** (higher ***n***)



Benefits of higher *n*

- It leads to higher L_P and lower I_{Q1RMS}
- It leads to lower turn ON losses
- It reduces blocking voltage of secondary side rectifier

Drawbacks of higher n

- Higher MOSFET breakdown voltage
- Higher diode RMS current

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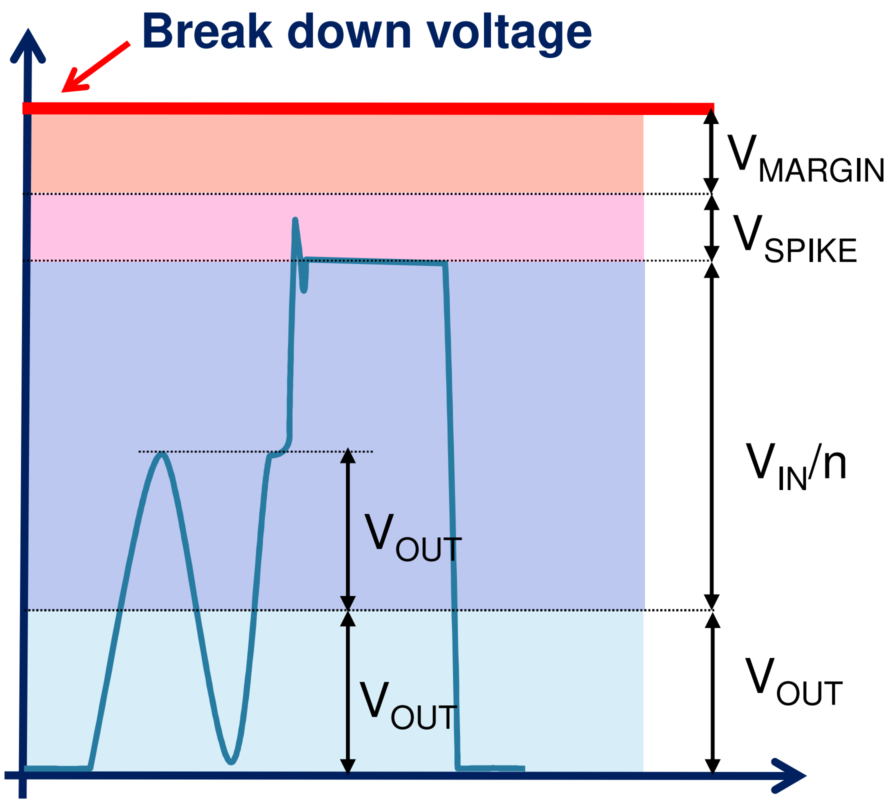
Secondary Rectifier



Margin V_{Margin} = 10 – 30% typically

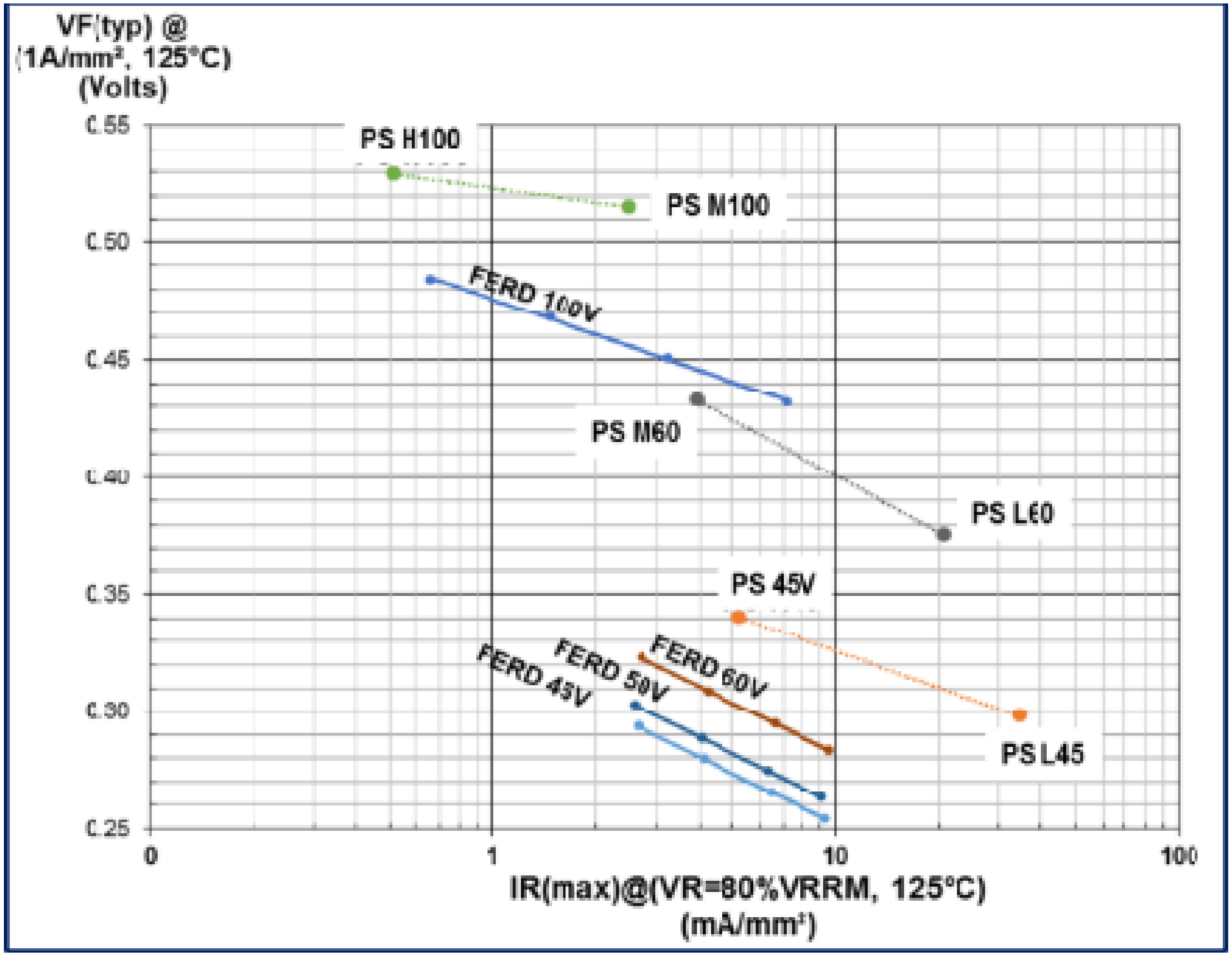
Spike V_{SPIKE} depends on the secondary leakage inductance. It is often 0V.

Forwarded Voltage

$$\frac{V_{IN}}{n} = V_{OUT}\left(1 + \frac{V_{IN}}{V_R}\right)$$

Output voltage

Secondary Rectifier – Blocking Voltage vs. Forward Voltage



Higher secondary side RMS current effect is compensated by using lower forward voltage diode thanks lower blocking voltage.

STCH02

New Flyback Controller

with Low Stand-by

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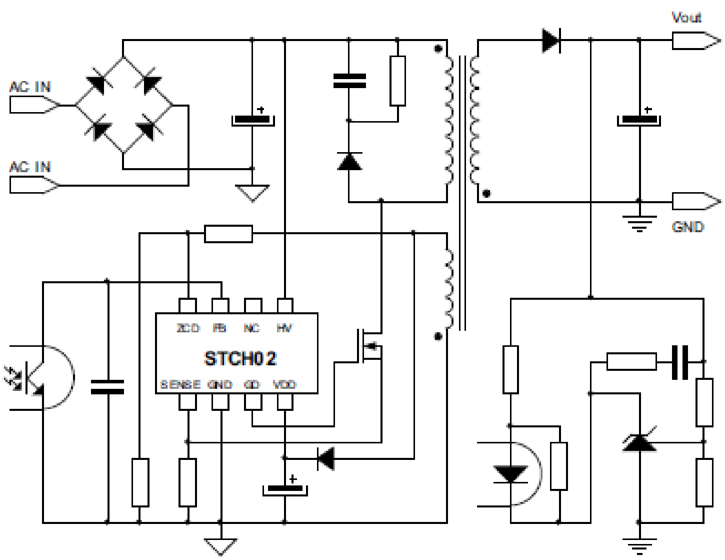
STCH02

Low Stand-by flyback controller for Auxiliary Power Supply & Chargers



- Very Low Stand-by Consumption (< **10mW**)
  - **Exceeding 5 stars**
- Quasi-Resonant (QR) Mode of Operation
  - High efficiency
  - Low EMI
- Embedded 650V high voltage start-up
  - Increased efficiency
  - BOM savings
- Additional Frequency Jittering (9kHz modulating signal) to further reduce EMI
- Also CC/CV supported:
  - Settable max output current in short circuit
  - Fitting also charger applications
- Voltage Feedforward
  - Mains-independent regulation
- SO8 package

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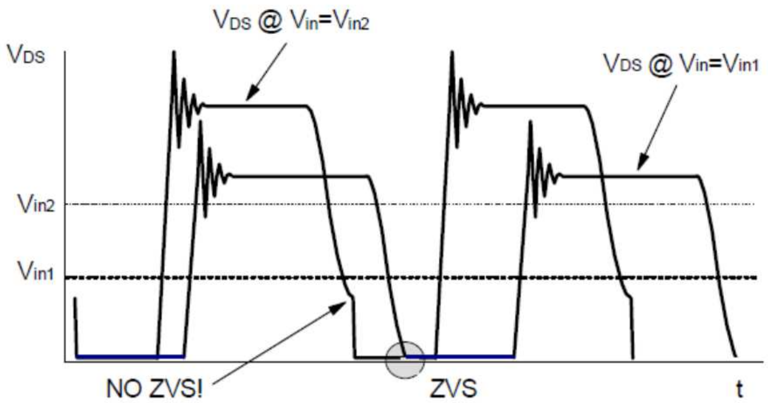
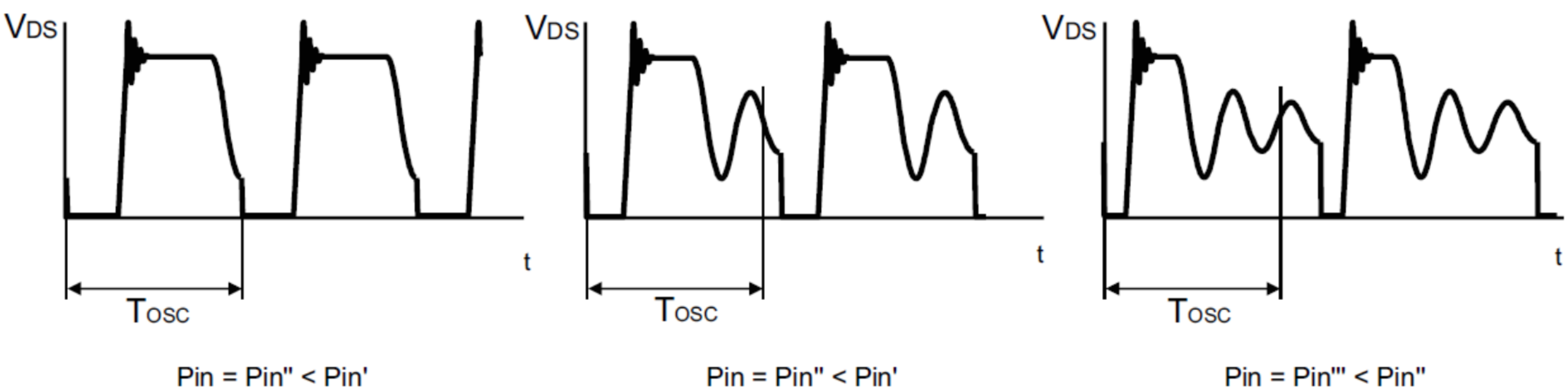
STCH02 QR Mode of Operation

ZVS (Zero Voltage Switching) and Valley Skipping

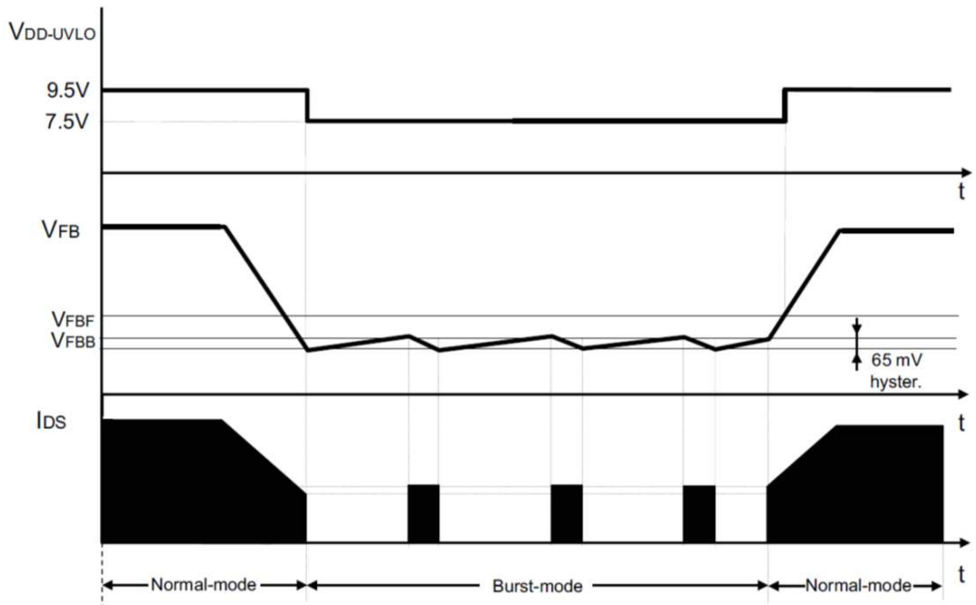


- ZCD (zero current detection) block detects demagnetization of the primary inductance
- At full load and nominal input volatege, this should leas to zero voltage switching (ZVS)
- For higher Vin, this could lead to switch at the minimum drain voltage value
- A maximum frequency is fixed so at light load the next valley is detected (valley skipping)



STCH02 Light Load Management

Burst Mode and Proprietary Adaptive UVLO (Under Voltage Lock-Out)



- At light load, the device enters in burst mode to reduce the consumption
- At no load, the voltage in the auxiliary winding falls considerably, even below normal UVLO
- To avoid intermitted operation, the UVLO is lower in burst mode (adaptive UVLO)
- **< 10 mW** stand-by consumption (Exceeding **5 stars**)

STCH02 Additional Features & Protections

Additional Features

- Additional Frequency Jittering (9kHz modulating signal) for low EMI
- Voltage feedforward for mains independent regulation

Protections

- Short circuit protection through output constant current (CC) operation: settable maximum output current
- Over voltage protection (OVP) with autorestart
- Hiccup mode over current protection (OCP) to prevent against the short-circuit of the secondary rectifier, short-circuit on the secondary winding or a hard-saturated flyback transformer

ST Flyback Controllers Positioning

	L6565	L6566x	HVLED001A	STCH02
Mode of Operation	QR	QR **or FF (with programmable F_{SW})**	QR	QR
PSR (CV)	NO	NO	**YES**	NO
Also CC supported	NO	NO	**YES** (but SSR needed)	**YES**
Power Factor Correction	NO	NO	**YES**	NO
Additional frequency modulation for low EMI	NO	**YES**	NO	**YES**
HV start-up	NO	YES, 700V or 840V	YES, 800V	YES, 650V
Stand-by	depending on ext. HV start-up	~100mW	~250mW	**~10mW**
OCP	pulse-by-pulse and hiccup	pulse-by-pulse + hiccup with counter + 2nd OCP	pulse-by-pulse + hiccup with counter + 2nd OCP	pulse-by-pulse + hiccup with counter + 2nd OCP
Additional short circuit management	shutdown, autorestart with Vcc	shutdown, autorestart with Vcc **or latched**	shutdown, autorestart after 2.5s	output current limitation (CC) down to 0V
Voltage feedforward	YES	YES, **programmable**	NO	YES
Output OVP	NO	YES, autorestart **or latched**	YES, autorestart	YES, autorestart
Input OVP	NO	**Could be obtained by DIS PIN**	**YES**	NO
Brown-out Protection	NO	**YES, programmable**	**YES**	NO
External Components	~ 10	~ 12	~ 8	**~ 6**
Package	SO8, DIP8	SO16N	SSO10	SO8
Highlights	**BASIC**	**HIGH FLEXIBILITY, MANY PROTECTIONS**	**PSR, MANY PROTECTIONS**	**LOW STAND-BY, LOW BOM**

Tools and Materials

- Datasheet
- Demoboard – 5V/3A (15W)
- Excels sheet
- eDesign Suite - under construction – available Q2/2018
- Technical support

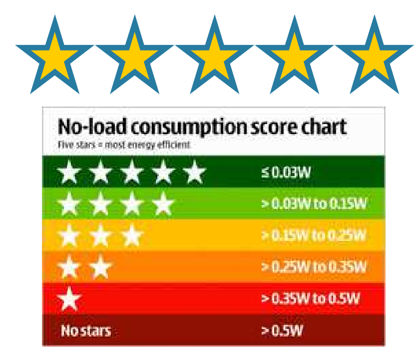
MP: H1 2018

What´s Next? STCH03

Many features more in the same package (SO8)

- More embedded protections for **higher reliability**:
  - OTP
  - Output under-voltage protection for short circuit management
  - OVP possible also in latched mode
- **Improved efficiency at light loads**
- **Optimized BOM** (1 resistor less)

SO8



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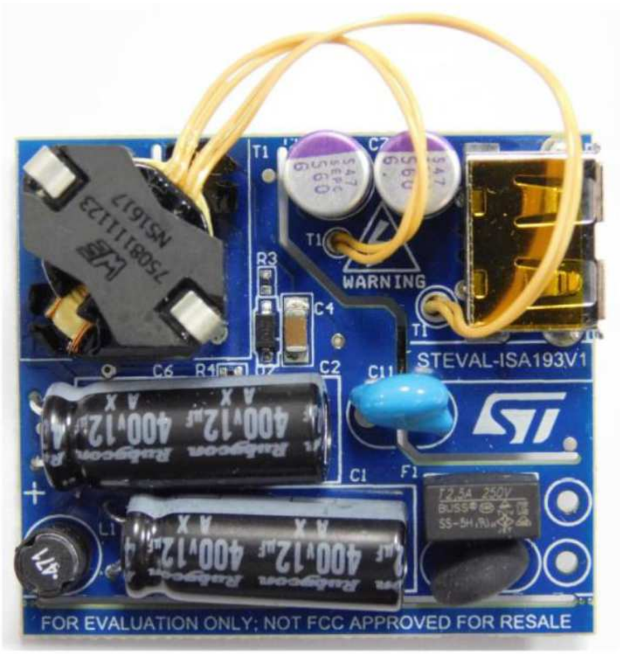
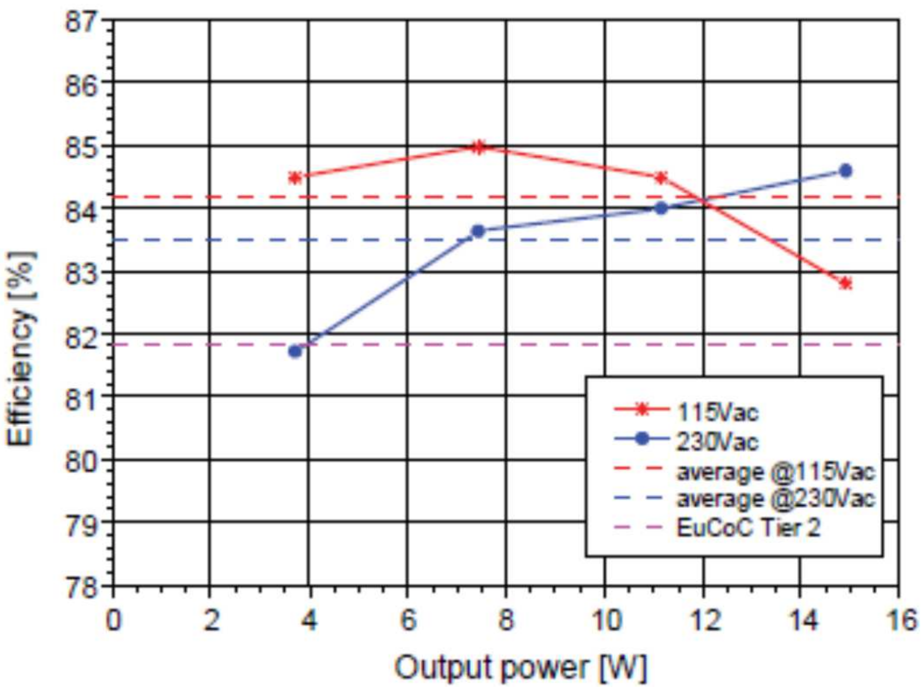
STEVAL-ISA193V1

15W Power Supply based on STCH02

- Vin = 90 – 265 Vac
- OUT = 5V - 3A
- EMI: According to EN55022-Class-B

STEVAL-193V1 performances		
Input voltage	No load consumption	Efficiency @ 10% Pout
115V_{AC}	**7.3 mW**	**80.44 %**
230V_{AC}	**7.5 mW**	**76.51 %**





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