



Designing Low Power SMPS with VIPerPlus Family of Products

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Applications Engineer



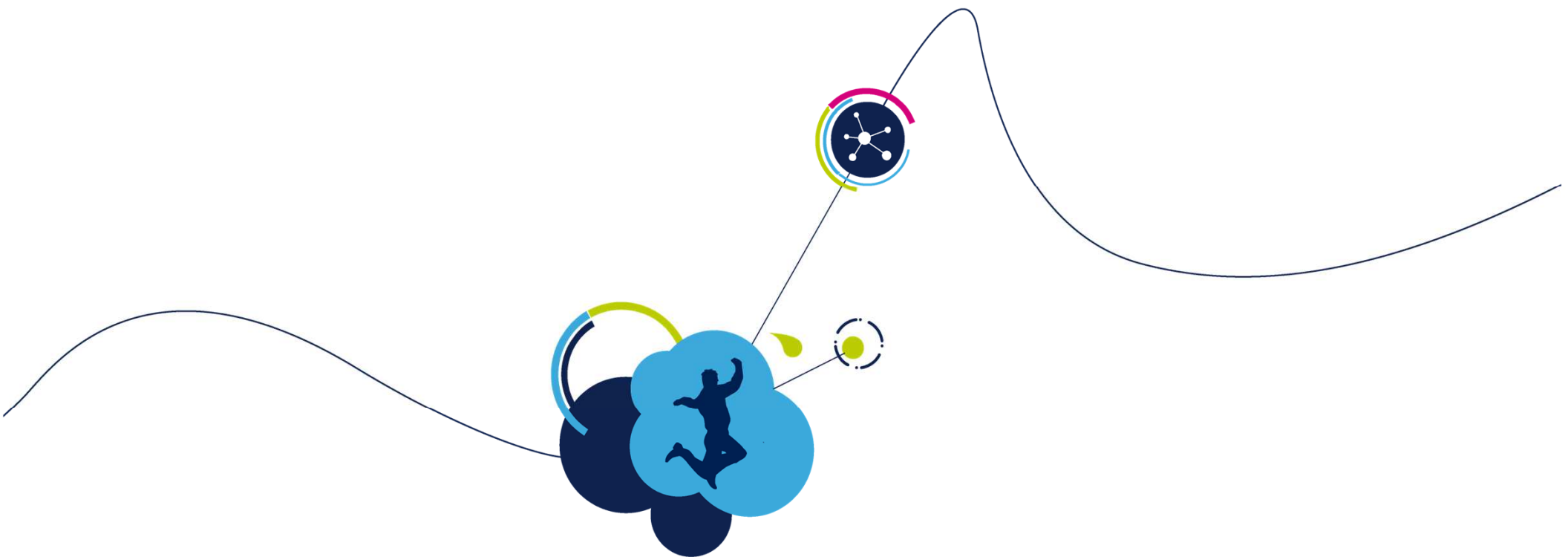
Technology Tour 2019

Anaheim, CA | March 26



Agenda 2

- Flyback Topology
- Buck Topology
- eDesignSuite Examples



Introduction

Auxiliary Power Supply

Major Appliances



Air conditioning



Industrials



Lighting



Electrical Vehicle



Main Power Supply

Smart Meters



Smart Buildings



Small Industrials



Small Appliances

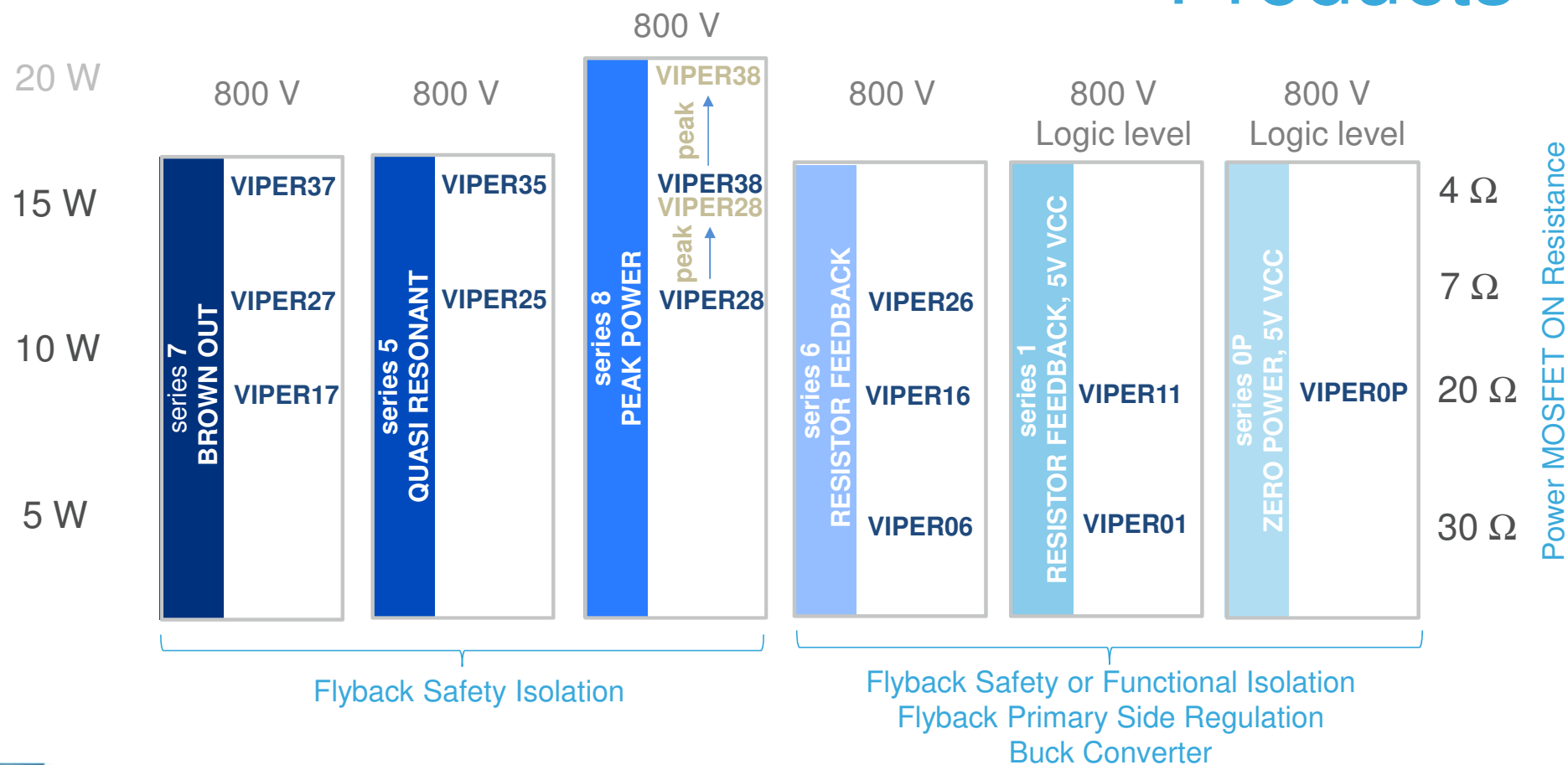


Adapters



Products

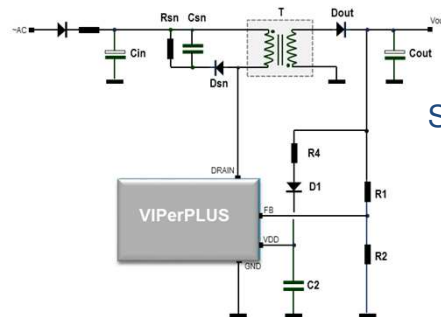
5



Which Topology?

6

Functional Isolation (Not Isolated Galvanically)



Secondary Regulation with Resistor Divider

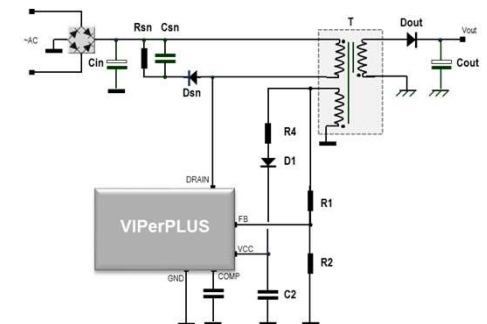
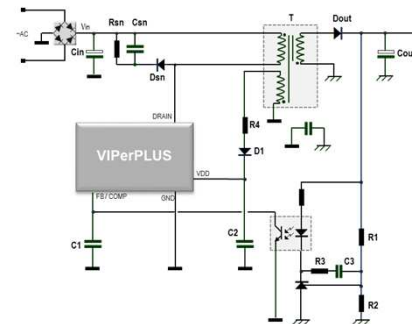
Flyback Converter



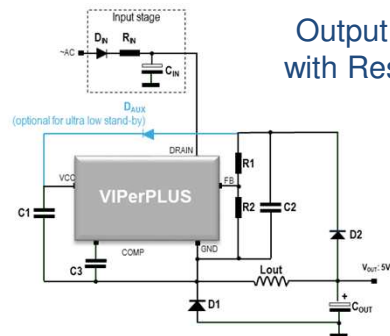
Galvanic Isolation For Touchable Outputs

Secondary-Side Regulation With Opto-Coupler For Tight Regulation

Primary-Side Regulation Without Opto-Coupler



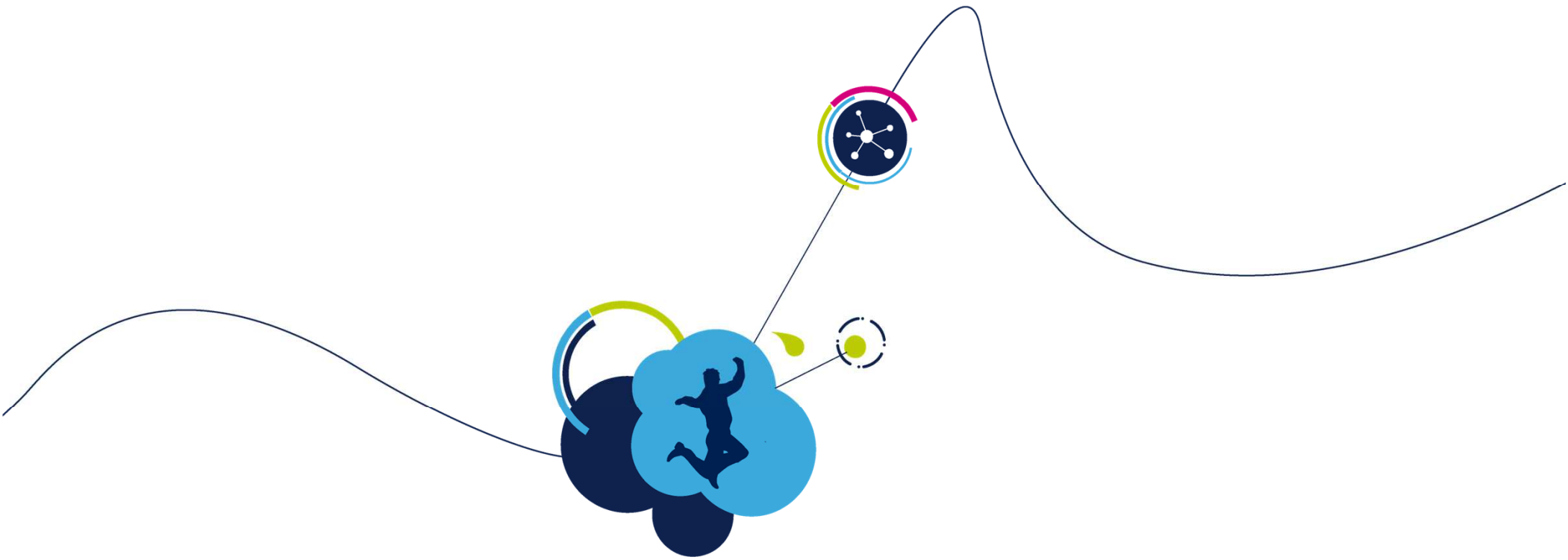
Buck Non-Isolated



Output Regulation with Resistor Divider

Buck Converter
Small Inductor
Compact PCB

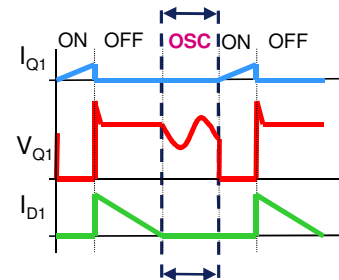
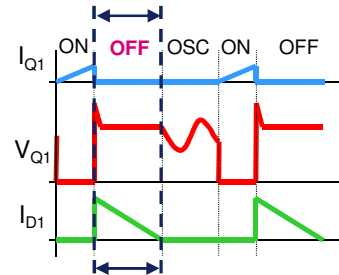
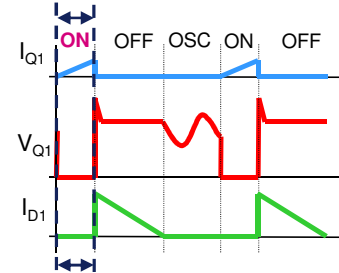
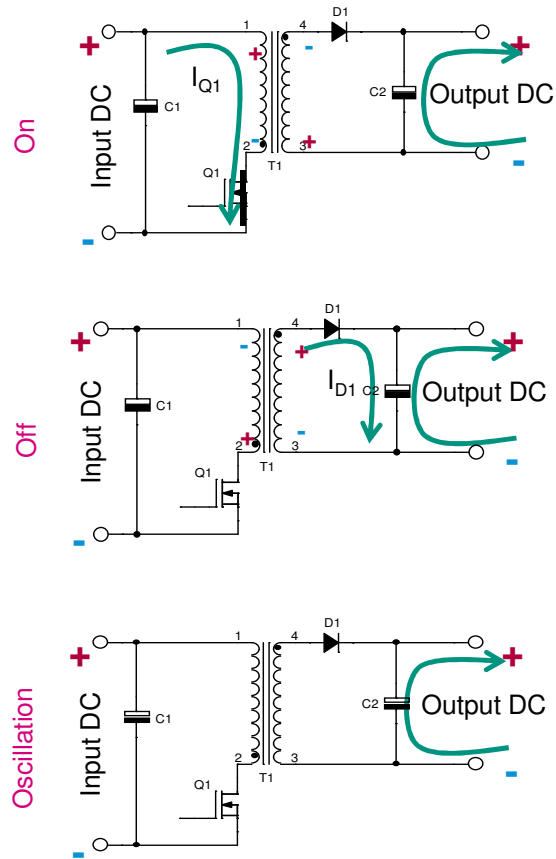




Flyback Topology Optimization

Flyback Operation

8



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

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

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

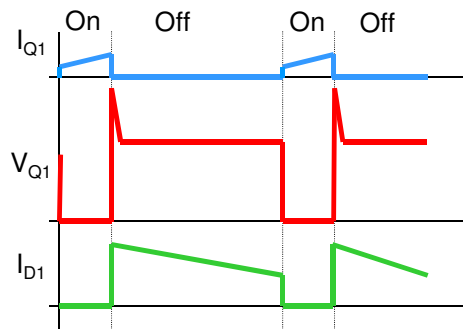
$$E_{T1} = \frac{1}{2} L_S I_{D1PK}^2$$

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

Operation Modes

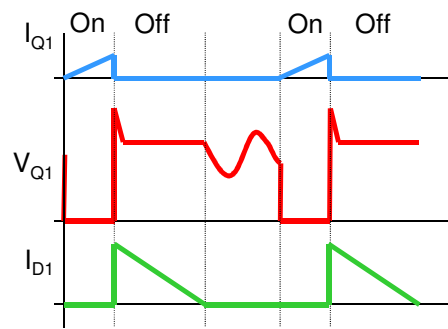
9

Continuous Mode (CCM)



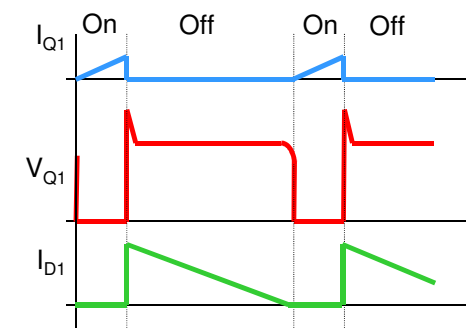
- **Benefit**
 - Higher power capability
 - Smaller transformer
 - Smaller output caps
- **Drawback**
 - Not ZCS – worse EMI and switching Losses
 - Control instability possible
- **Where to Use**
 - Higher peak power demands
 - Lower input voltages, e.g., 110V

Discontinuous Mode (DCM)



- **Benefits**
 - ZCS turn-on of MOSFET
 - ZCS turn-off of diode
 - Simple Feedback loop
 - Low noise
 - Lower switching cap loss
- **Drawbacks**
 - EMI due to self-oscillating
 - Unused Time slot
- **Where to Use**
 - Higher input voltage, e.g., 230V

Transition Mode (TM)



- **Benefits**
 - ZVS turn-on of MOSFET
 - ZCS turn-off of Diode
 - Simple feedback loop
 - Low noise
- **Drawback**
 - Variable frequency could be problematic for EMI
- **Where to Use**
 - When efficiency is a concern

Select Switching Frequency

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- Three fixed frequencies: $30 \pm 3 \text{ kHz}$, $60 \pm 4 \text{ kHz}$ and $115 \pm 8 \text{ kHz}$
- Priority on transformer size?
 - Higher frequency allows to reduces L_p using less turns and smaller core size
- Priority on power efficiency?
 - Lower frequency allows to improve the efficiency

TYPICAL CORE SIZE VERSUS OPERATING FREQUENCY

Frequency	E10	E13	E16	E20	E25
30 kHz	1.5 W	2 W	4 W	7 W	
60 kHz	3 W	4 W	6 W	13 W	25 W
115/120 kHz	5 W	6 W	8 W	18 W	32 W

Transformer Design

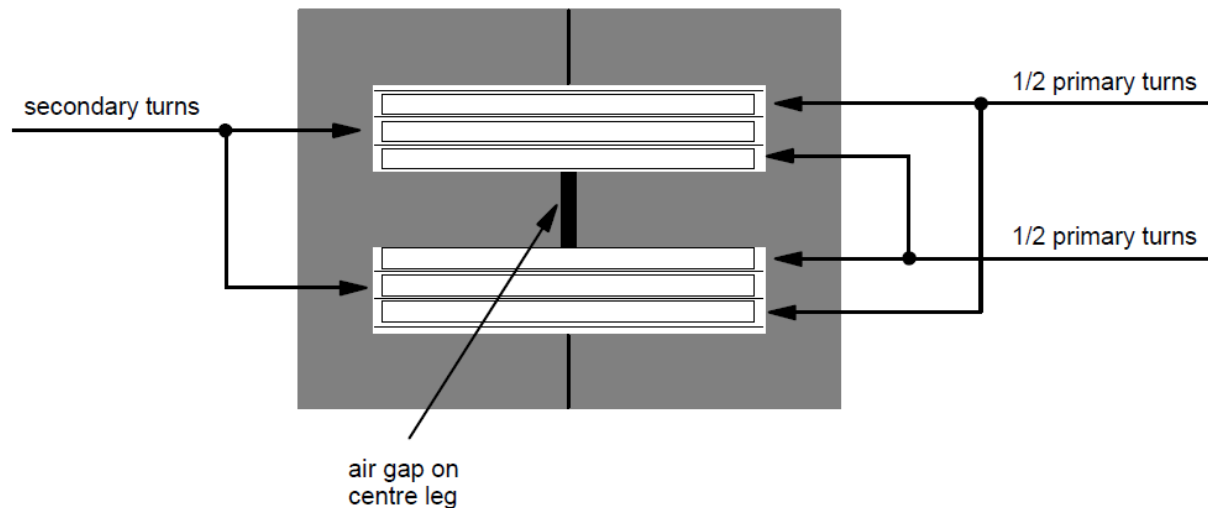
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- Basic specification of transformer include
 - Size, isolation barrier, reflected voltage, peak (or saturation) current, frequency, input voltage range, output voltage and output current range
- Leakage inductance influence power loss, snubber and EMI
 - Typical leakage inductance is 1~3% of primary inductance depending on the transformer structure
 - $P_{Leakage} = \frac{1}{2} L_{Leakage} I_P^2 \times f_s$
- Reflected Voltage V_R is the voltage reflected from secondary output to the primary of transformer

Minimizing L_{leakage} by Interleaving

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- Leakage inductance can be reduced by splitting primary winding in 2 halves and sandwiching secondary winding in between



Reflected Voltage Selection

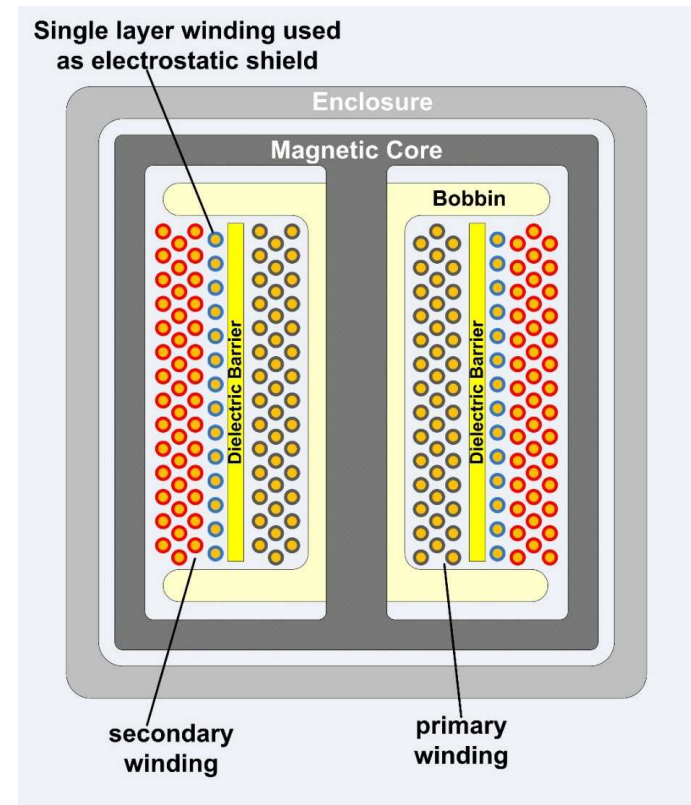
13

- Optimize reflected voltage to set maximum duty cycle. As a rule of thumb, make it equal to minimum DC input voltage
- High reflected voltage means high V_{ds} stress and higher snubber losses
- Lower reflected voltage means higher off time, higher RMS losses and higher primary peak current
- A positive side effect of lower reflected voltage is that it leads to better magnetic coupling between windings, which, in turn, helps to reduce leakage inductance

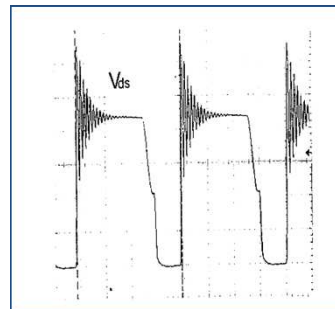
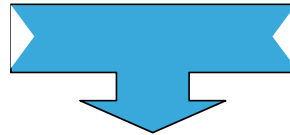
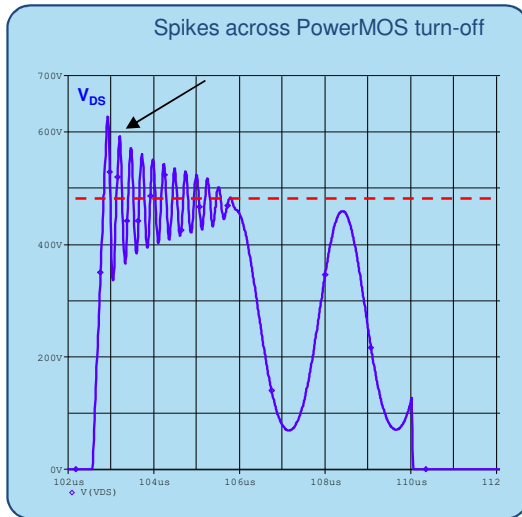
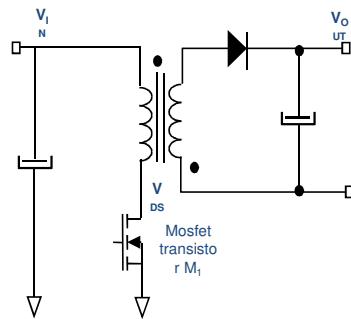
Shielded or Non-Shielded

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- Shielded transformer has better EMI but **larger leakage inductance**
- Non-shielded transformer has worse EMI but smaller leakage inductance



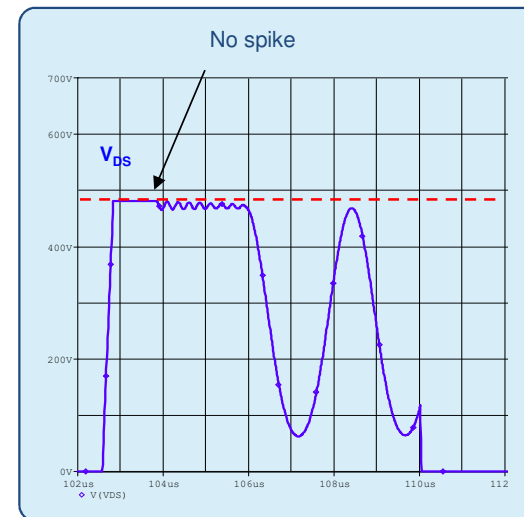
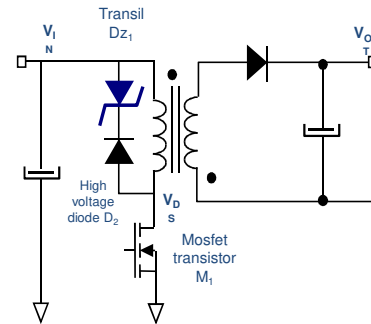
Without
Clamp
Circuit



Clamp Circuit

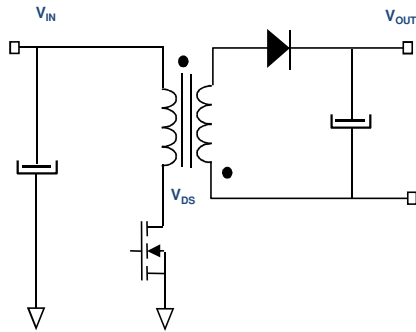
15

With Clamp
Circuit

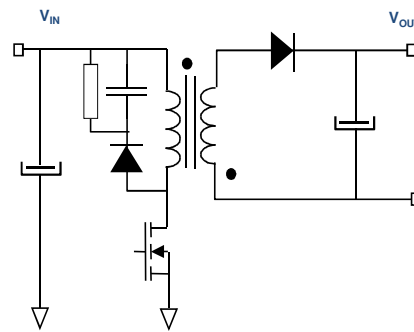


Clamp Implementations

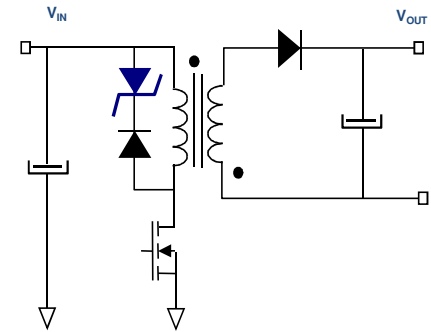
16



- No protection
- Test to be performed to know max V_{DS}
- MOS / IGBT to be oversized in voltage (more expensive, efficiency drop)



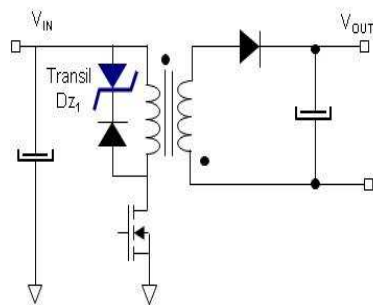
- RC to limit dV/dt , then to limit overvoltage
- Slope may vary depending on components
- Margin on V_{DS} is depending on components
- Test to be done for validation



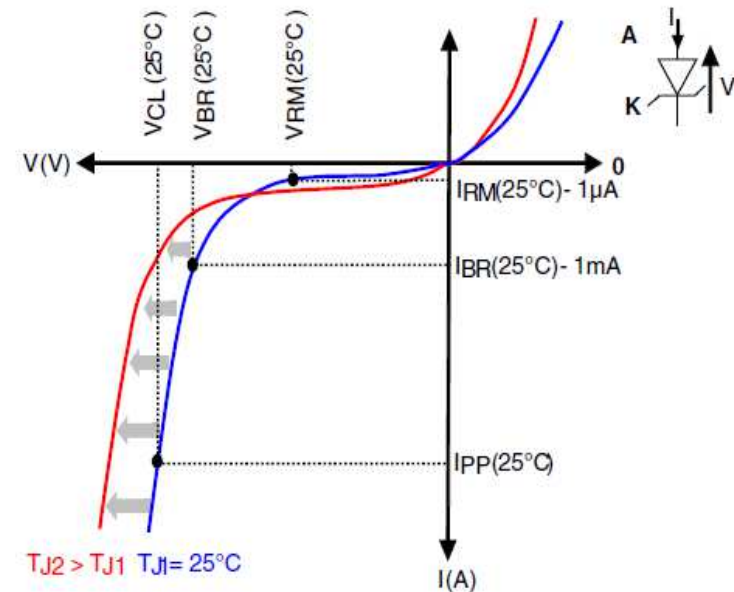
- Maximum clamping voltage only depends on STRVS
- Datasheet/product adapted to repetitive surges
- Margin on V_{DS} can be easily calculated
- Validate with minimal test

New Clamping Technology: STRVS

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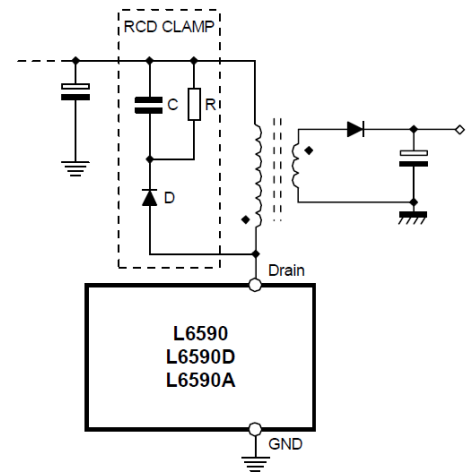
- VRM is stand-off voltage and must be selected to allow the FET to switch: $VRM > VR$
- VCL is the clamping voltage and is critical to choose as close as possible to the application requirement
- Extensive data published on STRVS datasheet makes the selection for the right part easy and robust



RCD Snubber

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- RCD sizes and values need to be carefully selected. There is a tradeoff between RC values, power dissipation, EMI and clamping effect
- RCD clamp dissipates power even under no-load conditions: there is always the reflected voltage across the clamp resistor R



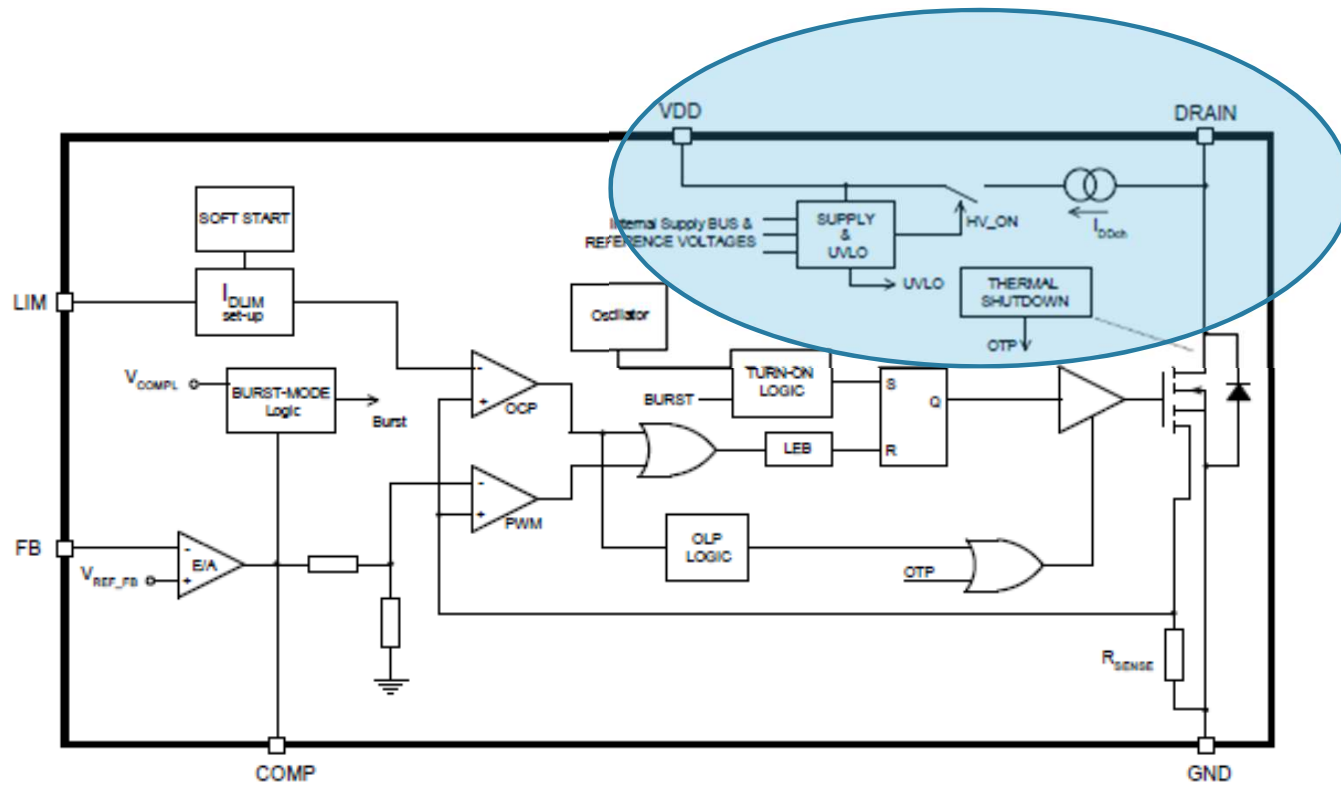
R	C	V_{CL}	$V_{DS(PK)}$	EMI	$P_{DISS(R)}$	Cost
↓	↑	↓	↓	↓	↑	↑
↑	↓	↑	↑	↑	↓	↓

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Stand-By Consumption: HV Start-Up

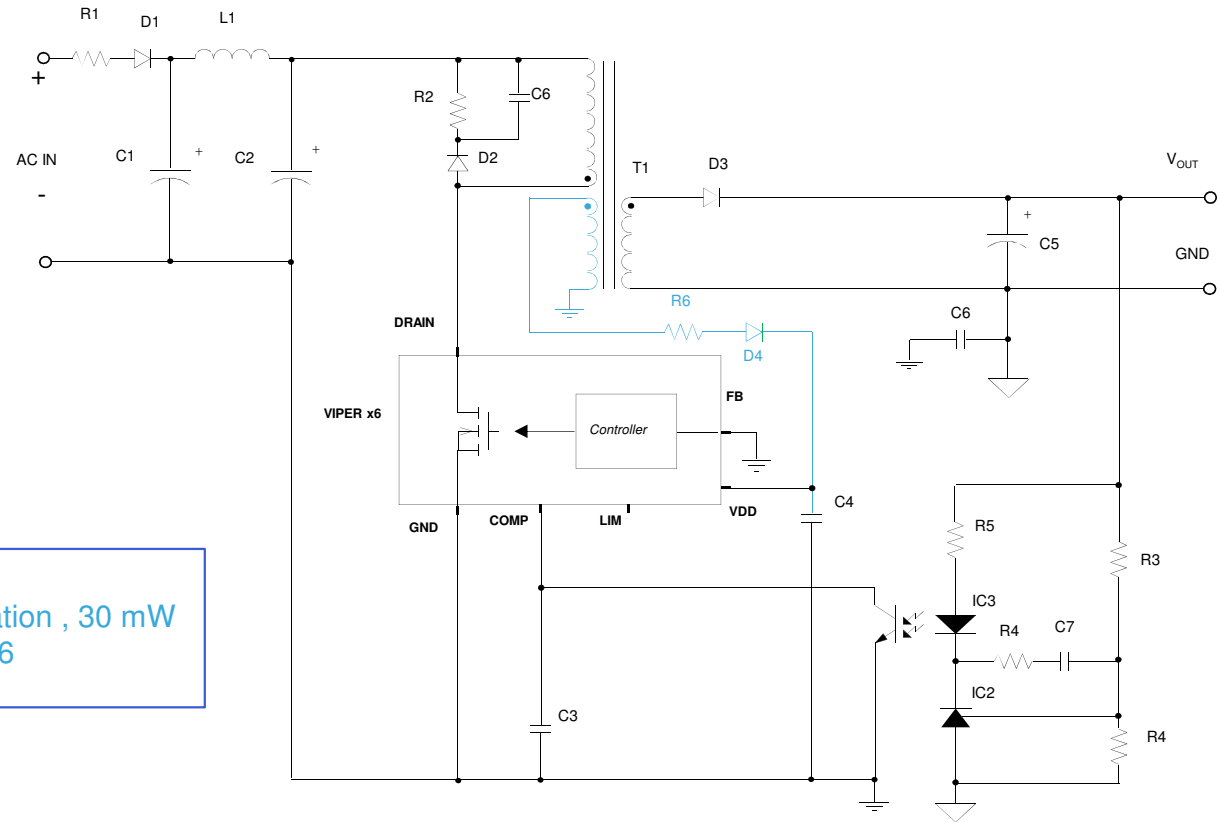
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Stand-By Consumption

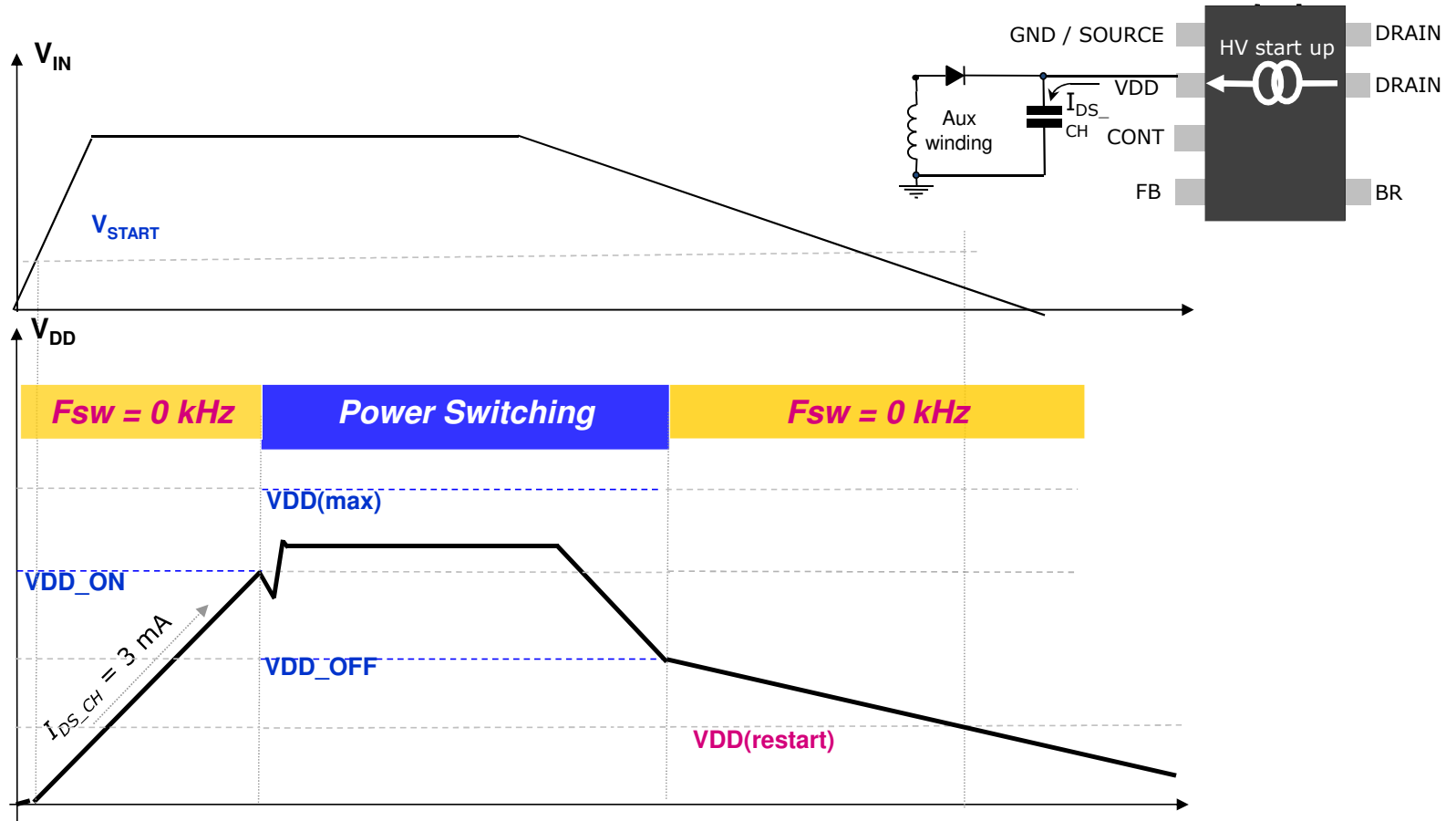
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Stand-by optimization , 30 mW
D4, R6



Stand-By Consumption: HV Start-Up

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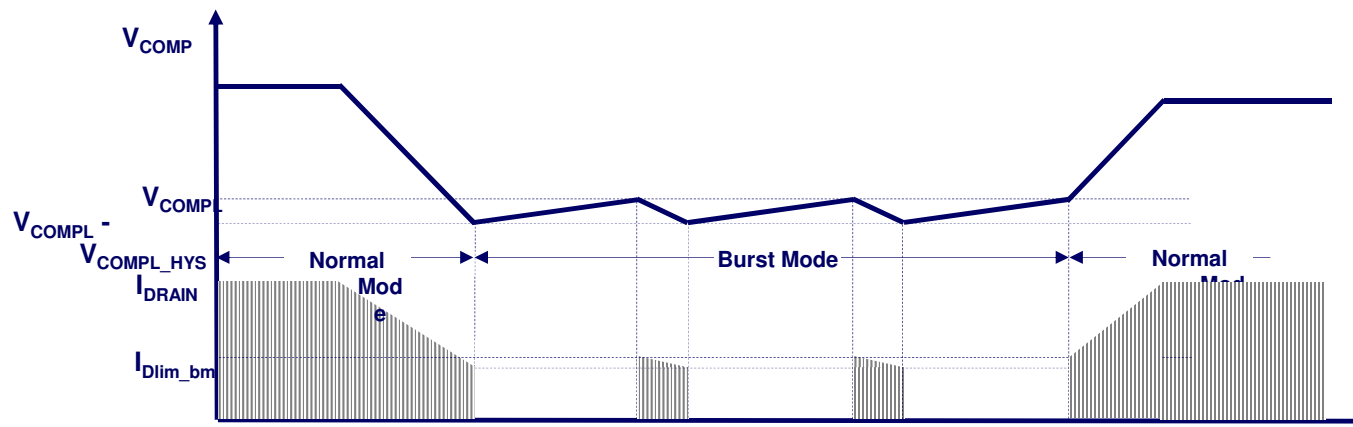


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Stand-By Consumption: Burst Mode

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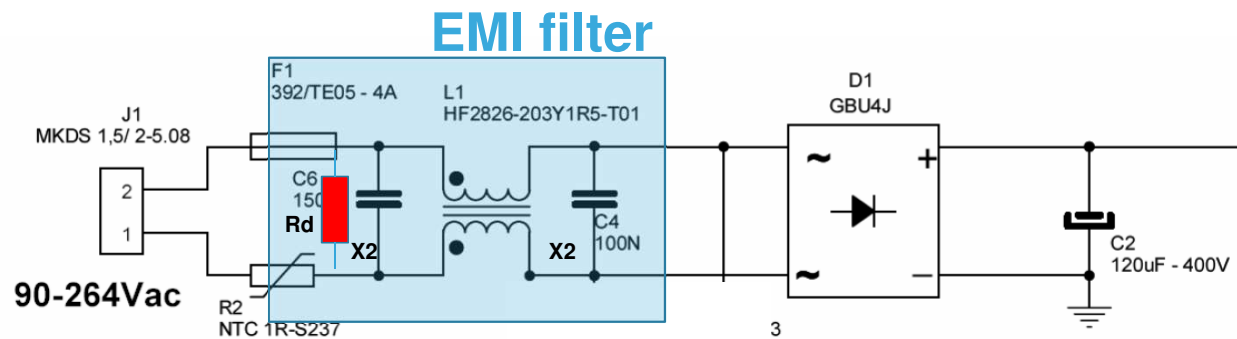


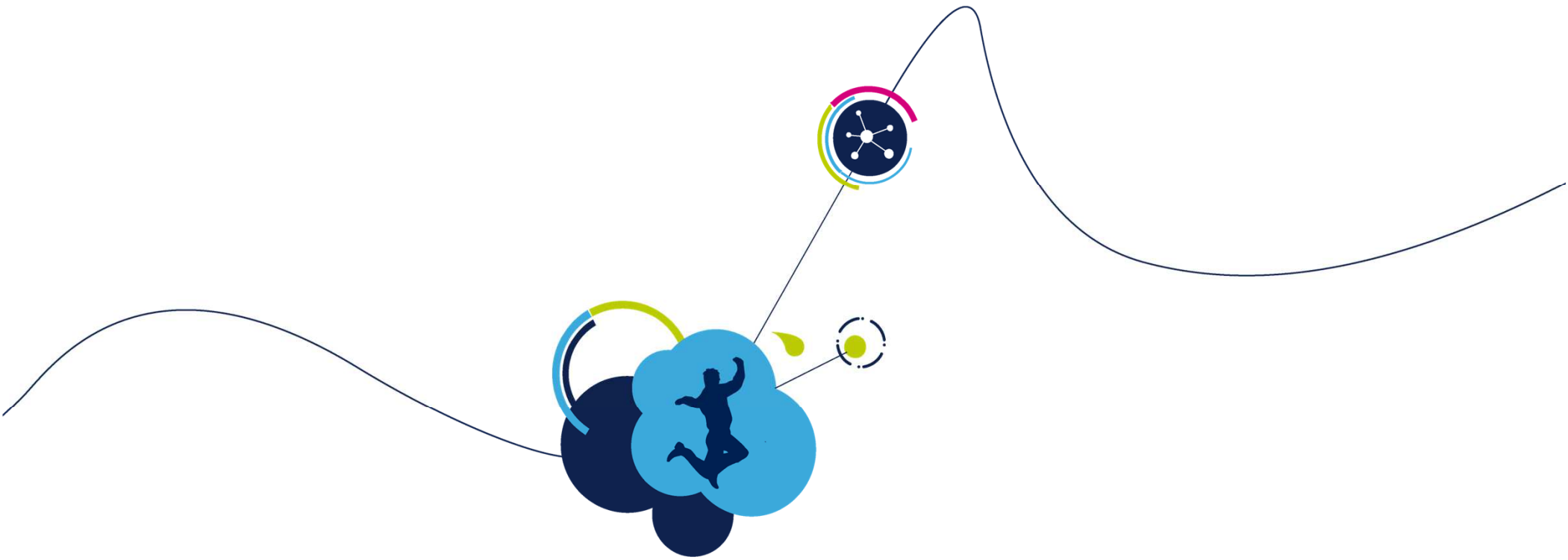
$V_{COMP} < V_{COMPL}$ starts burst mode

X-Cap Discharge

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- The EMI filter in the input of the power converter typically consists of capacitors across the AC mains and CM choke
- According to safety regulations, e.g. UL 1950 and IEC61010-1, capacitors on the mains must be discharged within a given time after the appliances is suddenly disconnected
- A discharge resistor is typically connected in parallel, resulting in additional power losses, as long as the appliance is plugged
- A new function has been recently introduced in order to actively discharge the X capacitor through the HV start-up circuit

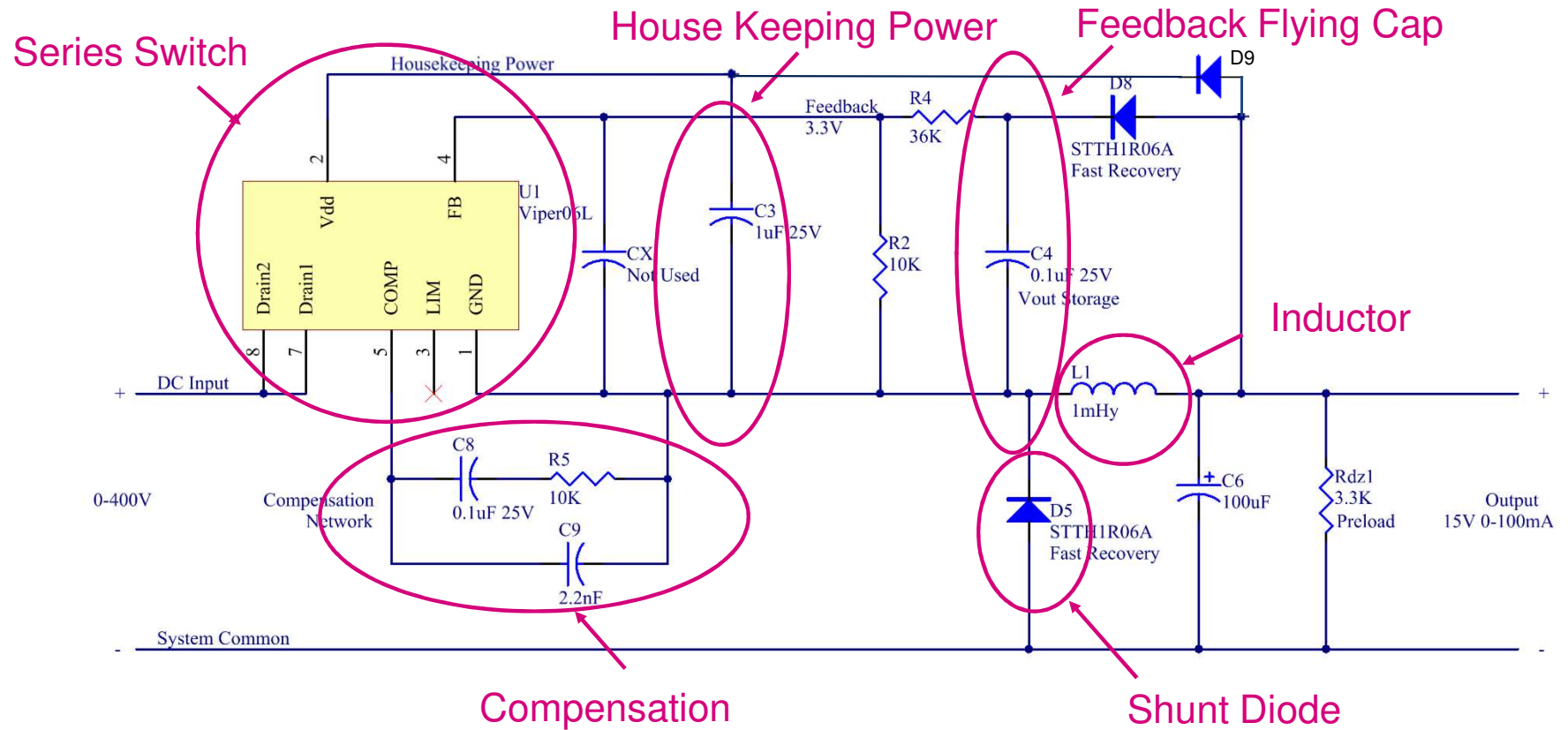




Buck Topology Optimization

Buck Schematic

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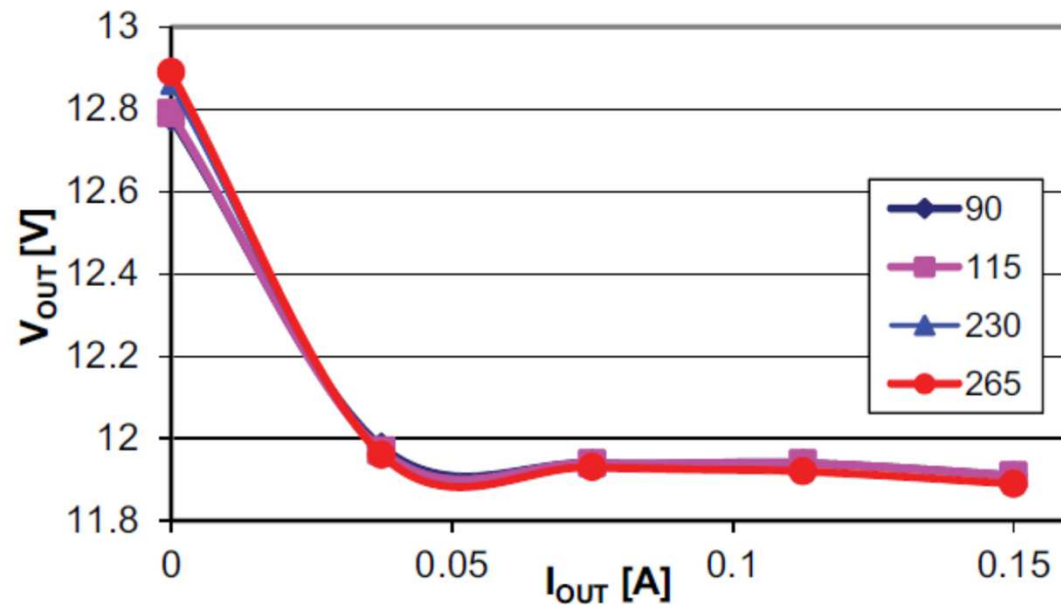
“Flying Capacitor” Feedback Scheme

- C4 stores output voltage, transfers level into Viper feedback loop
- R4 – R2 discharge C4 slowly
- Load current is required to turn on D5 and D8 to charge C4
- A light load MUST be present to insure diode turn-on
- C4 must hold output voltage information when Viper is in burst mode

“Flying Capacitor” Feedback Scheme (Cont.)

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- Low cost solution
- Minimum load required



Select Switching Frequency

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SELECT FREQUENCY FOR 5 V OUTPUT BUCK

V _{in} DC (V)	D (%) 5 V	t _{ON} (μs) for 60 kHz 5 V	t _{ON} (μs) for 30 kHz 5 V	VIPer01 Minimum ON time
100 (85 VAC)	5.0	0.83	1.67	0.35 μs
170V (120 VAC)	2.9	0.49	0.97	
325V (230 VAC)	1.5	0.26	0.50	
375V (265 VAC)	1.3	0.22	0.33	
622V (440 VAC)	0.8	0.13	0.26	

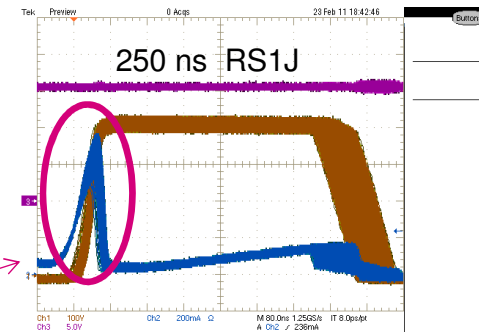
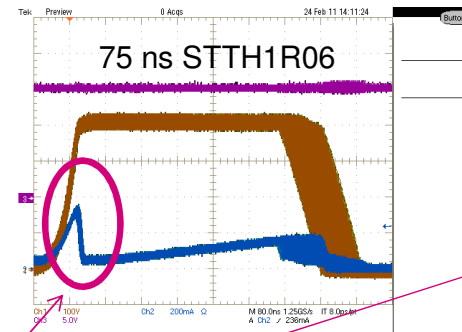
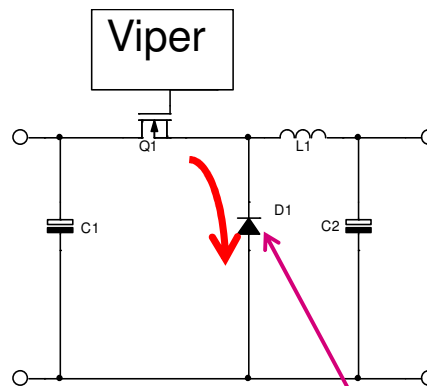
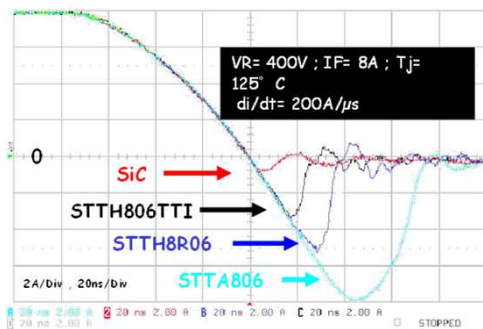
Lower frequency allows to handle the regulation even in the case of a very high ratio between input and output voltages

Minimum ON Time 31

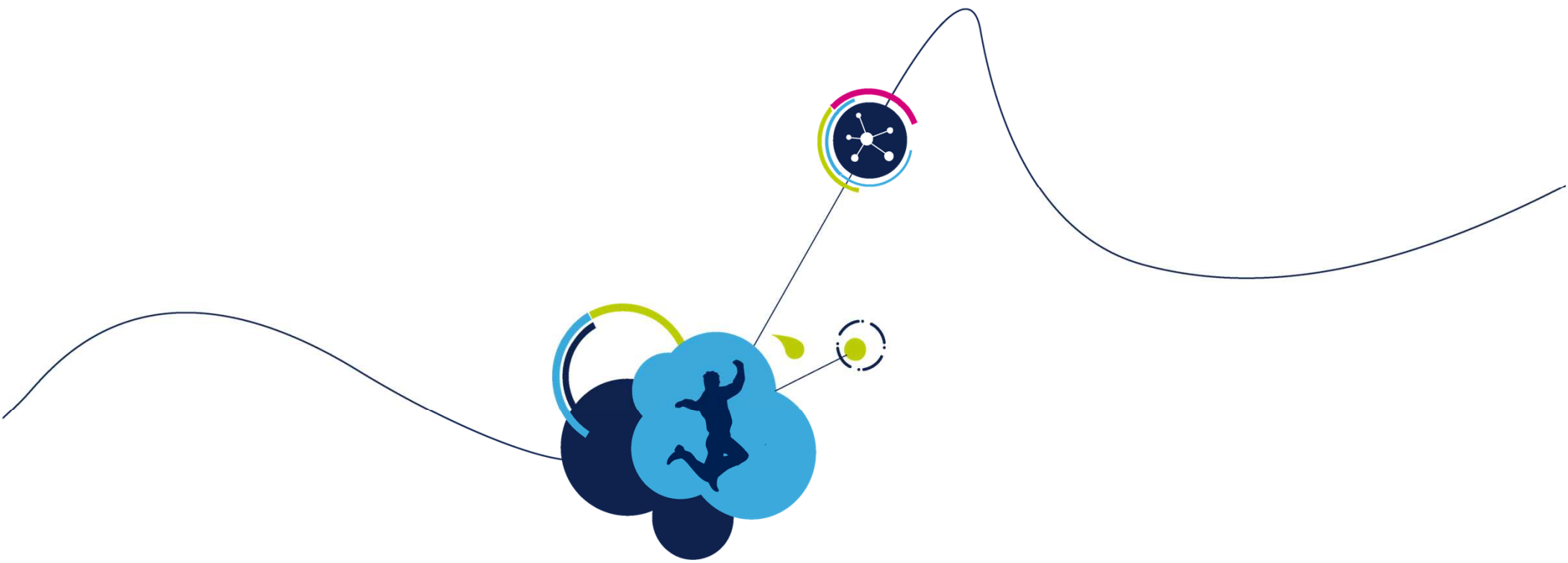
- Duty cycle of Viper Buck converter is limited by minimum on time
 - Viper06 450 ns
 - Viper01 350 ns
- If the required ON time is shorter than minimum ON time, Buck still works, but there is small instability and the maximum deliverable output current is reduced.
- The 30kHz version is strictly recommended for 5V output

Diode Recovery Effect

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Recovery effect causes short cross conduction every 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**.



Layout and EMI Optimization

Layout Optimization

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- Minimize **interconnection lengths** of following components:
 - Input **filter caps**, input-side transformer (or inductor), **power MOSFET**, sensing resistors and active-clamp or **snubber circuits**
 - Output-side transformer (or inductor), rectifier diodes and **output filter caps**
- Keep **power and signal circuitries separated** and be careful of connection between the signal and power grounds
- Assure component isolation and **spacing by safety standards**
- **Prioritize ground** over all routes
- **Large copper areas** for thermal and EMI
- Add **sufficient VIAs** for better thermal performance
- Keep the **feedback path** as far as possible from power components and noise traces
- External **compensation components** should be **close to IC**
- Copper **traces for power** should be **thick and short** and **sharp angles** should be avoided

EMI Optimization

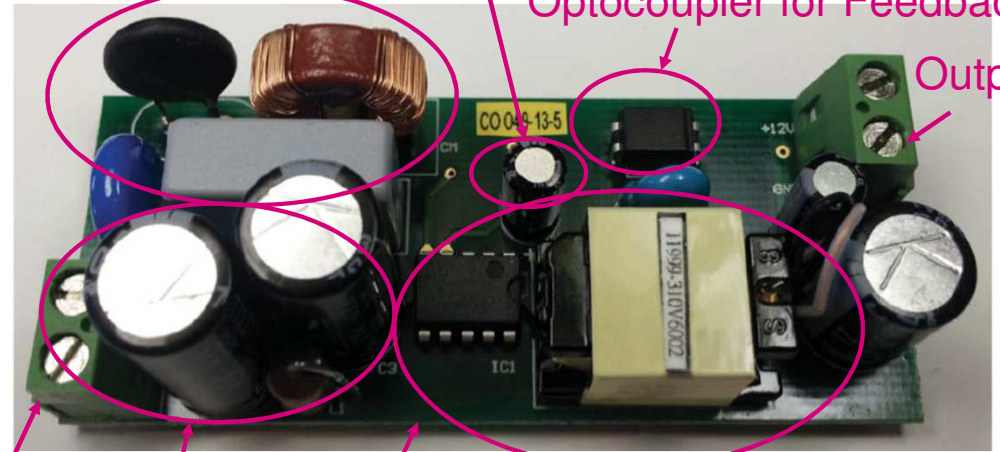
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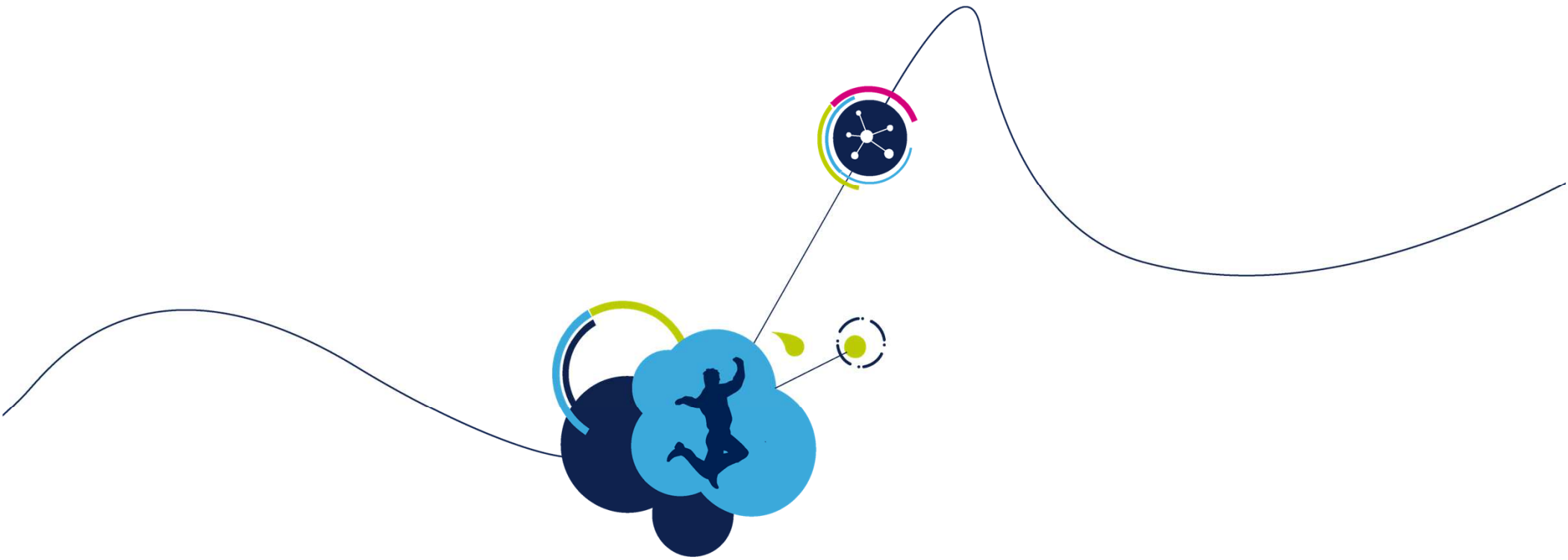
- EN 55022 is an European EMC standard applicable to information technology equipment with a rated supply voltage not exceeding 600 V
- Properly size EMI filter: **differential mode filter** for power < 5 W; X-, Y-caps, and **common mode choke** for power > 15 W
- Designers often use **snubbers and soft switching techniques** to minimize the EMI
- **Shielded transformer has better EMI** but also has larger leakage inductance
- Connect heatsinks to ground
- Focus on coupling paths from EMI sources to EMI sensitive components
- Strategic orientation and placement of components can reduce EMI generation significantly
- Eliminate **environmental interference on EMI test**
- Use an **accurate EMI analyzer** to carry **quasi-peak, and average** measurement to meet standards
- ST offers **PWM operation with frequency jittering** for low EMI

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VIPER37HE 100~265 VAC IN, 12 VDC 15 W OUT

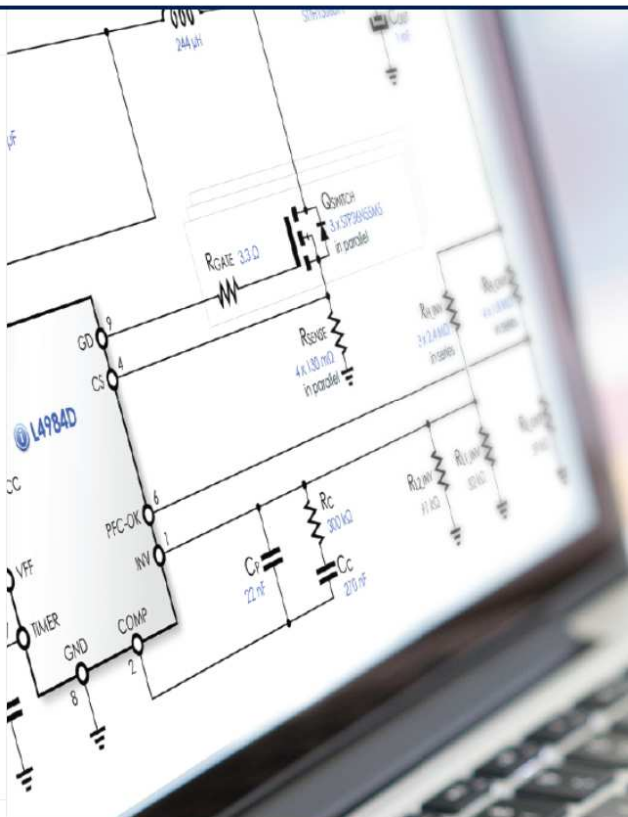




eDesignSuite Examples

<https://my.st.com/analogsimulator/>
Create an ST.com account and
use it to sign in to eDesign Suite

- Dashboard
- Converter
- Battery Charger
- LED Driver
- Photovoltaic
- Signal Conditioning
- RF Design
- AC Control
- Smart Selectors
- Configurators
- Help



eDesignSuite

The smart design tool



STMicroelectronics eDesignSuite

Dashboard

My projects Examples

Converter

Battery Charger

LED Driver

Photovoltaic

Signal Conditioning

RF Design

AC Control

Smart Selectors

Configurators

Examples

Name

Battery

LED D

Photo

Power

Dashboard

My projects Examples

Converter

AC/DC

PFC Pre-regulation

PWM Controllers

Non isolated

Isolated

Examples

Name

Battery charger

LED Driver

Photovoltaic

Power Supply

Dashboard

My projects Examples

AC/DC

Non isolated

Buck

FF Flyback

Examples

Name

Battery charger

LED Driver

Photovoltaic

Refresh

Import

Help

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ST eDesignSuite

Converter > AC/DC > Non isolated > Buck

Can search by part number

Search

22 Results

Number of products available

Topology

Specifications

Input

Voltage: USA Range - 60 Hz

Min V: 85

Max V: 140

50 Hz 60 Hz

Output

Voltage: 12

Current: 0.2

ADD OUTPUT

Output Power: 2.4 W

Specification – input voltage range
Output voltage/current

For each feature you can click on it to select.

Included if you are looking for devices that have that feature
Excluded if you do not want devices having that feature

Package Type: SMD No filter

Programmable Current Limit No filter

Package Type: Through-hole No filter

Overvoltage Protection No filter

Burst Mode Included

Fixed Frequency Included

Overload Protection Included

Soft Start Included

Sw.Frequency: Not Selectable Included

Thermal Shutdown Included

Topology: Buck Included

BUCK

Choose by features

VIPER06HN Buck DIP 7

IDlim: 320 mA

VBVDSS: 800 V

RDSon: 30 Ω

fosc: 115 kHz

START DESIGN

VIPER06HS Buck DIP 7

IDlim: 320 mA

VBVDSS: 800 V

RDSon: 30 Ω

fosc: 115 kHz

START DESIGN

VIPER06LS Buck SS010

IDlim: 320 mA

VBVDSS: 800 V

RDSon: 30 Ω

fosc: 60 kHz

START DESIGN

VIPER06XN Buck DIP 7

VIPER06XS Buck SS010

VIPER013LS Buck SS010

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eDesignSuite



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VIPER115LS

SS010

Buck



Specifications

Reset All

Input

Voltage
USA Range - 60 Hz

Min V

85

Max V

140

50 Hz 60 Hz

Output

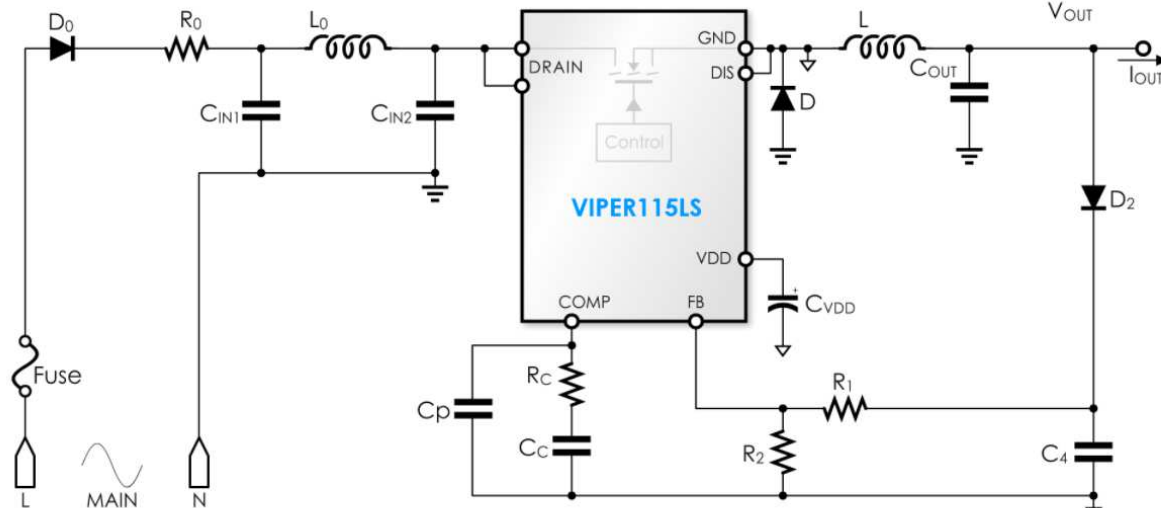
Voltage

12

Current

0.2

Output Power 2.4 W



Selected device, design specification and generic schematic – once all that is ready proceed with **START DESIGN** button

START DESIGN

IDlim: 575 mA

VBVDSS: 800 V

RDSon: 17 Ω

fsw: 60 kHz

Datasheet

Product Folder

Energy saving off-line high voltage converter

Main features:

- 800 V avalanche-rugged power MOSFET allowing ultra wide range input VAC to be achieved.



More details on the selected device (e.g. Viper115LS) – datasheet link, main electrical parameters, features

eDesignSuite

Design of commands

Specification

Operating conditions can be varied

The user can customize some of the characteristics

A set of qualitative metrics

Bill of materials and schematic

Annotated and interactive schematic

Click to maximize

Toolbox icon lets you adjust parameters

Converter Specifications

IC: VIPER115LS - S5010
 Input: 85 Vac - 140 Vac - 60 Hz
 Output Power: 2.4 W
 Out 1: 12 V (2 % ripple) - 200 mA max

Actuals @ VinAC: 140 V
 Iout: 200 mA
 Ta: 25 °C

Vout: 12.01 V ripple: 157 mV - 1.3%
 IL ripple: 475 mA
 fsw: 60 kHz Ton: 935.4 ns
 bandwidth: 0.76 kHz
 phase margin: 77.01°
 average Vin DC: 179.9 V
 input currents
 avg: 15 mA peak: 188 mA rms: 63 mA
 burst mode: no conduction mode: DCM
 ΔTj: 21 °C IC Tj: 46 °C

Simulation: duty cycle 5.6%

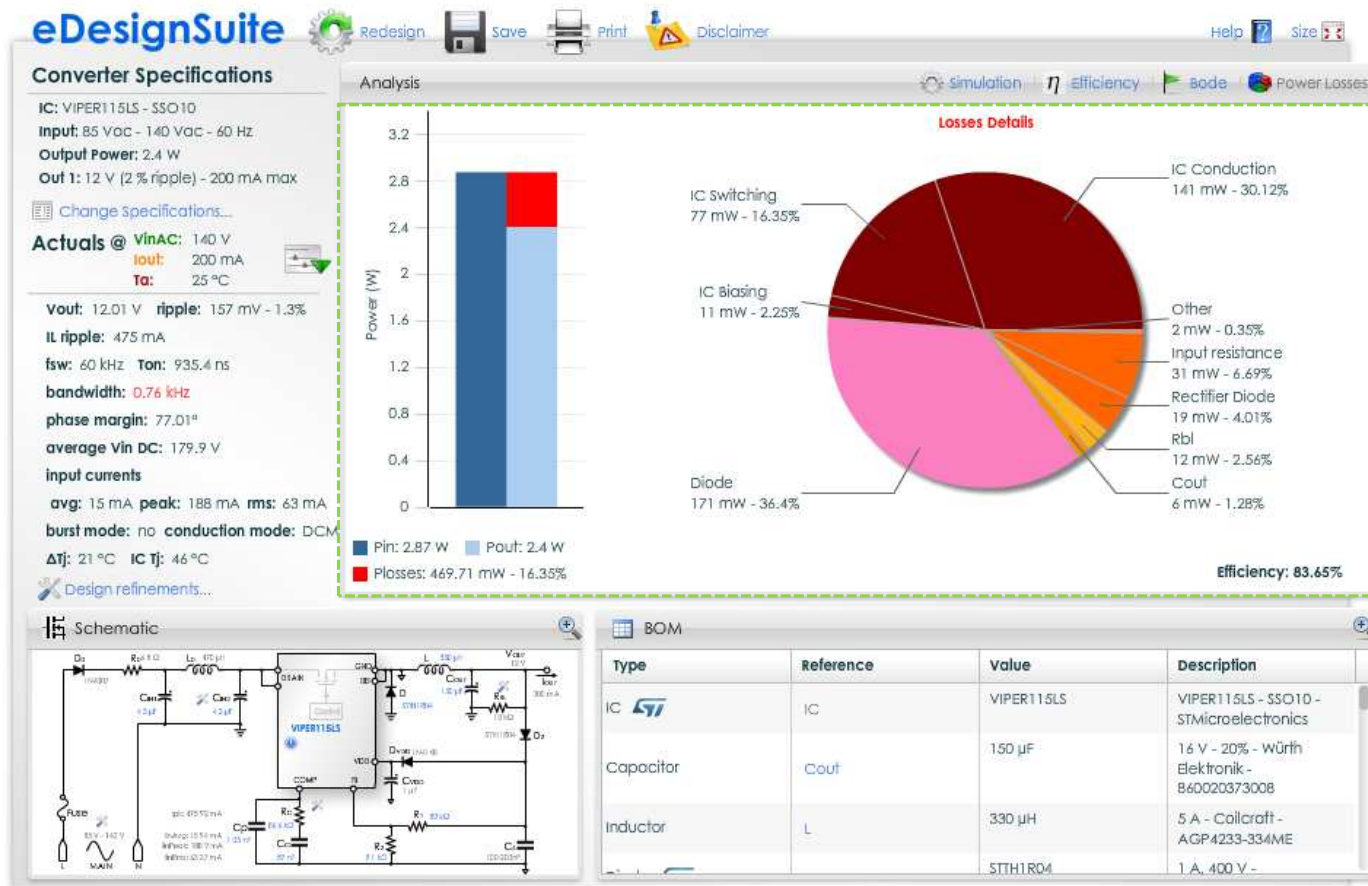
η Efficiency: 83.6%

Bode: fc = 755.51 Hz - phase margin = 77 °

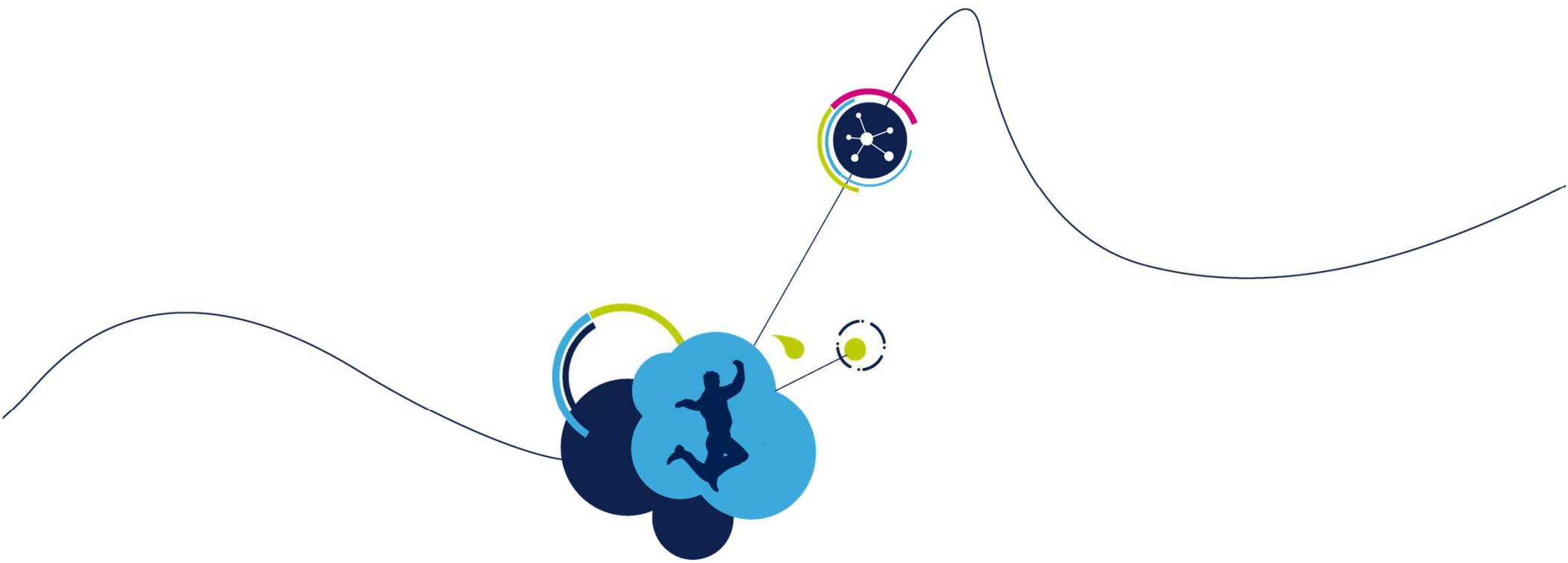
Losses: 469.7 mW - 16.4%

IC 229 mW - 48.72%
Diode 171 mW - 36.4%
Input losses 50 mW - 10.69%
rb1 12 mW - 2.56%
Cout 6 mW - 1.28%
Other 2 mW - 0.35%

Circuit Schematic: The schematic shows a VIPER115LS IC in a flyback topology. Key components include a MOSFET (D0), a diode (D2), a transformer (Lp), and various passive components (resistors R0, R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15, R16, R17, R18, R19, R20, R21, R22, R23, R24, R25, R26, R27, R28, R29, R30, R31, R32, R33, R34, R35, R36, R37, R38, R39, R40, R41, R42, R43, R44, R45, R46, R47, R48, R49, R50, R51, R52, R53, R54, R55, R56, R57, R58, R59, R60, R61, R62, R63, R64, R65, R66, R67, R68, R69, R70, R71, R72, R73, R74, R75, R76, R77, R78, R79, R80, R81, R82, R83, R84, R85, R86, R87, R88, R89, R90, R91, R92, R93, R94, R95, R96, R97, R98, R99, R100, R101, R102, R103, R104, R105, R106, R107, R108, R109, R110, R111, R112, R113, R114, R115, R116, R117, R118, R119, R120, R121, R122, R123, R124, R125, R126, R127, R128, R129, R130, R131, R132, R133, R134, R135, R136, R137, R138, R139, R140, R141, R142, R143, R144, R145, R146, R147, R148, R149, R150, R151, R152, R153, R154, R155, R156, R157, R158, R159, R160, R161, R162, R163, R164, R165, 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Very useful losses distribution chart



Thank you!