Designing Low Power SMPS with VIPerPlus Family of Products

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Santa Clara, CA

Agenda

- Flyback Topology
- Buck Topology
- eDesignSuite Examples

Introduction

Applications

Auxiliary Power Supply

Major Appliances

Air conditioning

Industrials

Lighting

Electrical Vehicle

Main Power Supply

Smart Meters

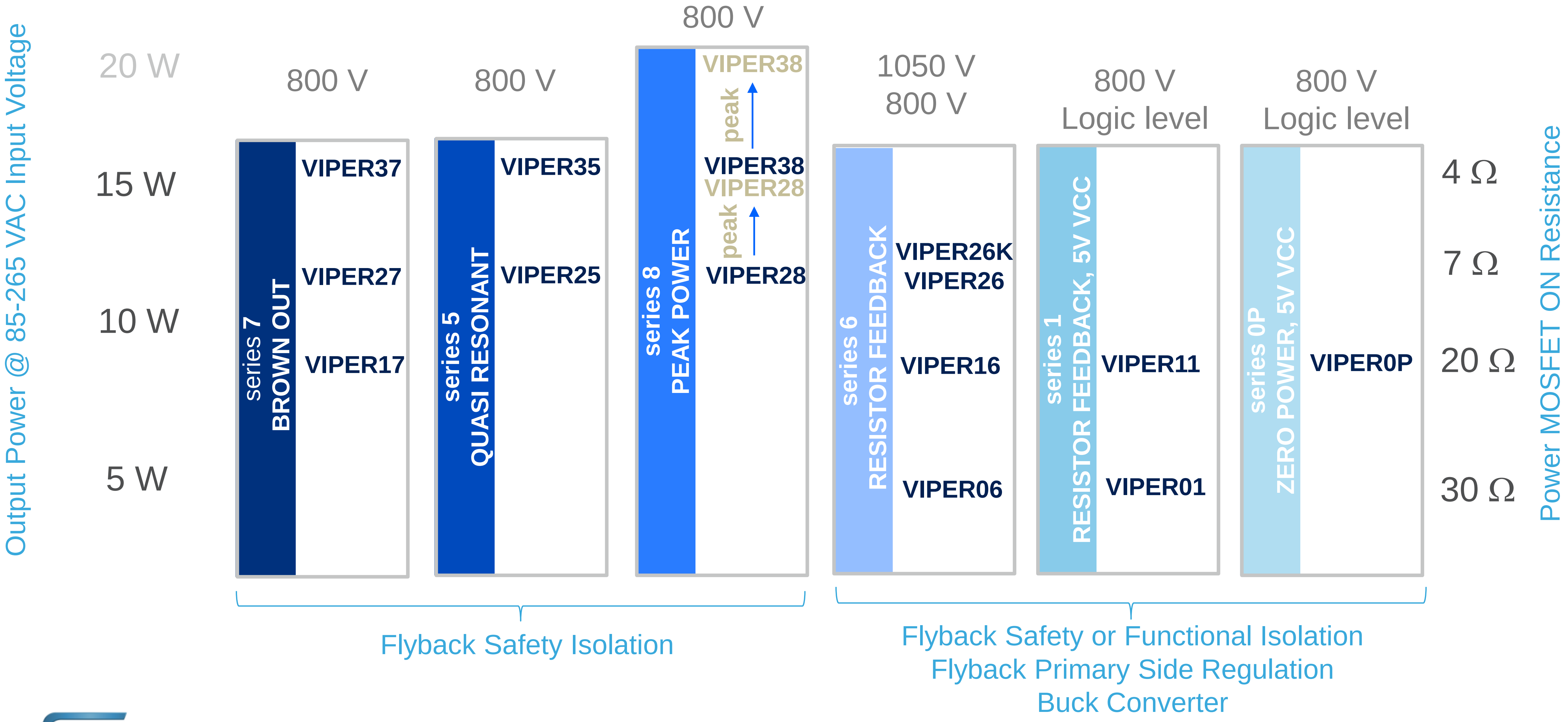
Smart Buildings

Small Industrials

Small Appliances

Adapters

Products



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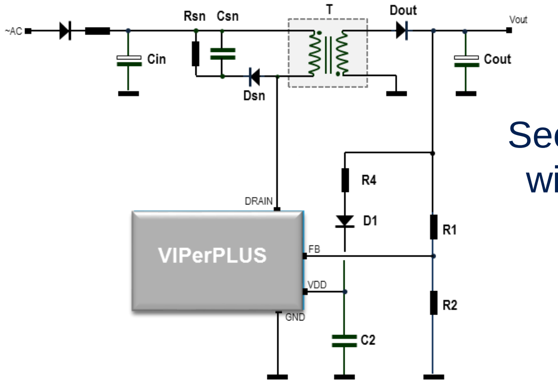
Which Topology?

Functional Isolation (Not Isolated Galvanically)

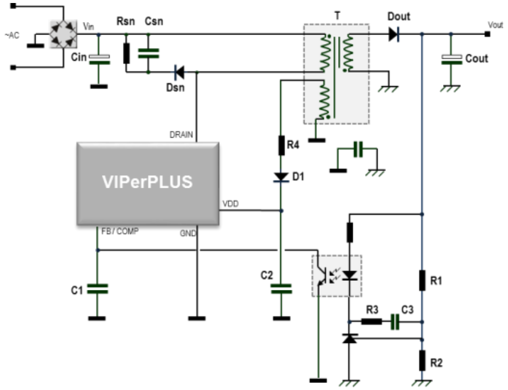


Secondary Regulation
with Resistor Divider

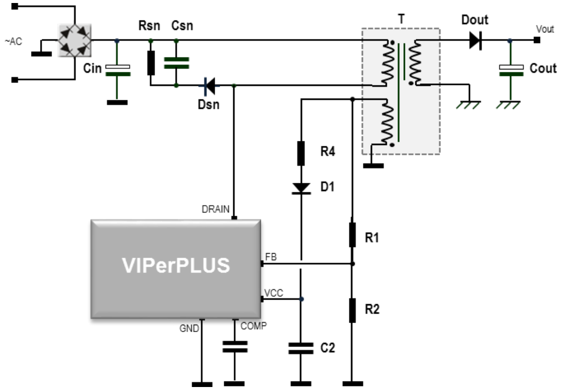
Flyback Converter

Galvanic Isolation For Touchable Outputs

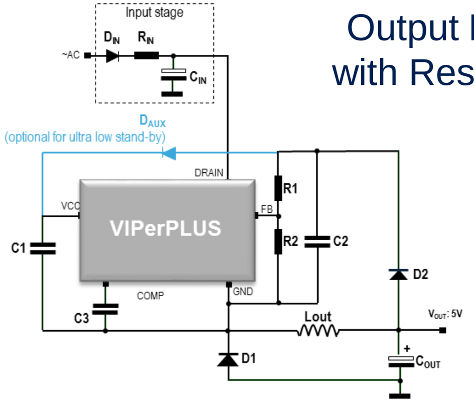
Secondary-Side Regulation
With Opto-Coupler For Tight Regulation



Primary-Side Regulation
Without Opto-Coupler



Buck Non-Isolated



Output Regulation
with Resistor Divider

Buck Converter
Small Inductor
Compact PCB

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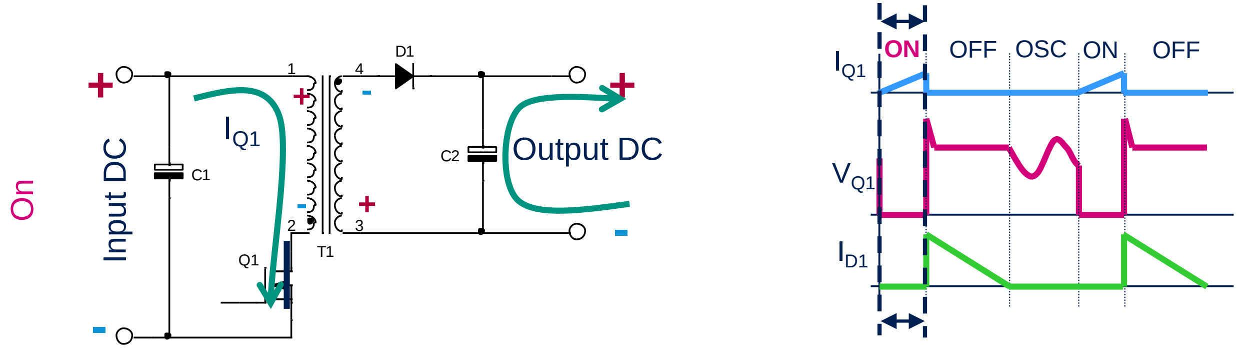
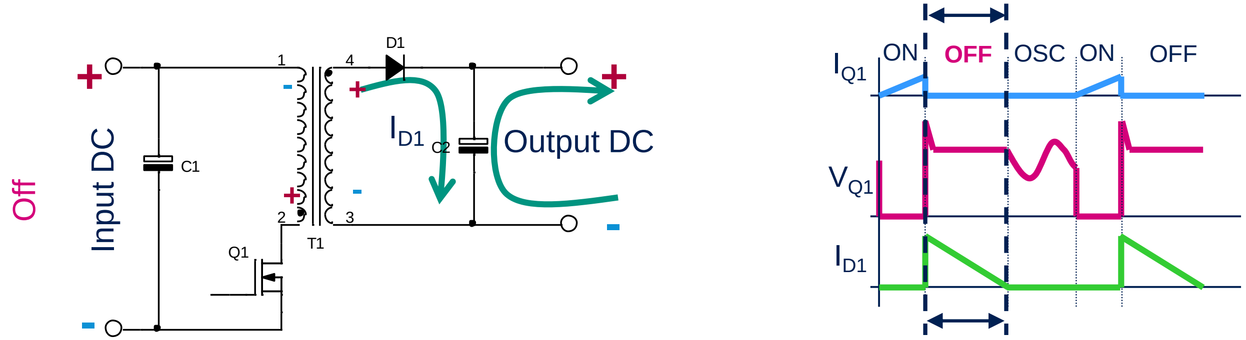
Flyback Topology Optimization

Flyback Operation



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

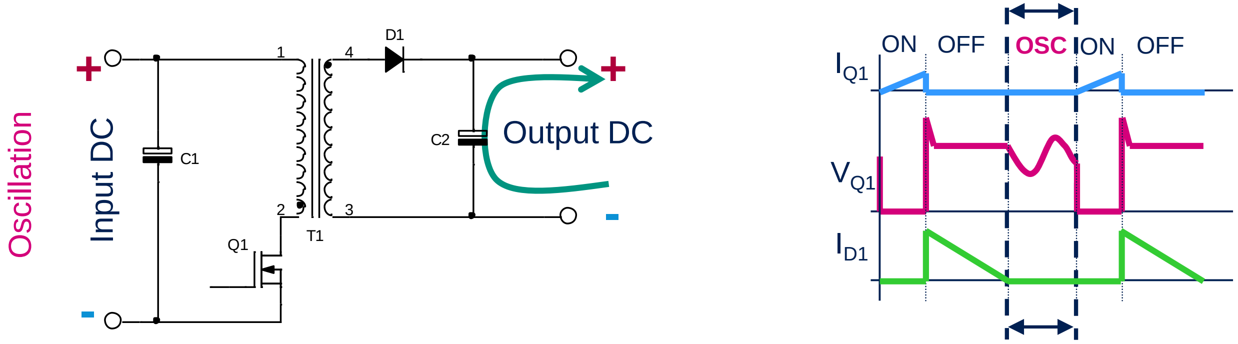
$$P_{T1} = \frac{1}{2} L_P I_{Q1PK}^2 f_{SW}$$



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

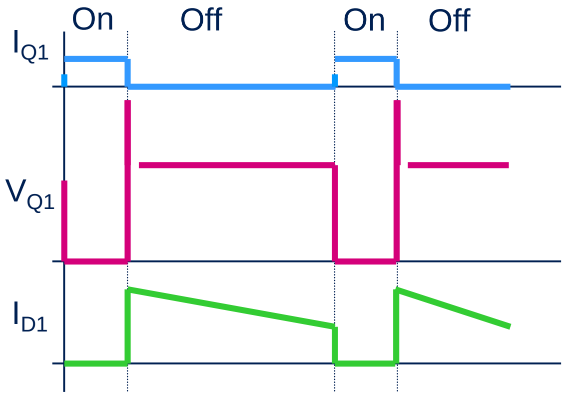
$$E_{T1} = \frac{1}{2} L_S I_{D1PK}^2$$

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



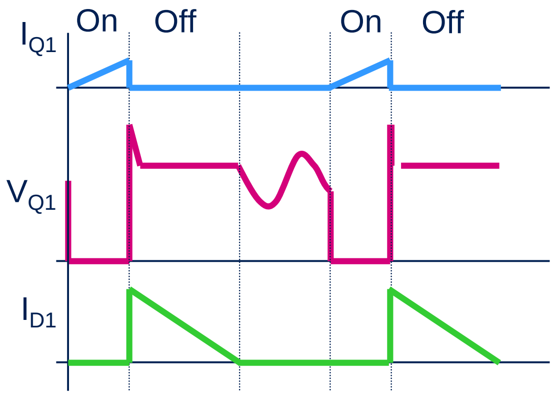
Operation Modes

Continuous Mode (CCM)



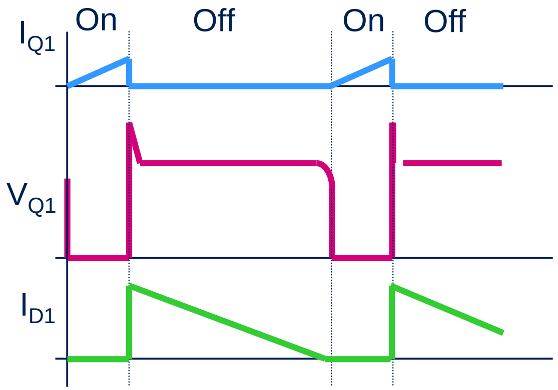
- Benefit
  - Higher power capability
  - Smaller transformer
  - Smaller output caps
- Drawback
  - Not ZCS – worse EMI and switching Losses
  - Control instability possible
- Where to Use
  - Higher peak power demands
  - Lower input voltages, e.g.,110V

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

- Three fixed frequencies: 30±3kHz , 60±4kHz and 115±8kHz
- 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

- 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

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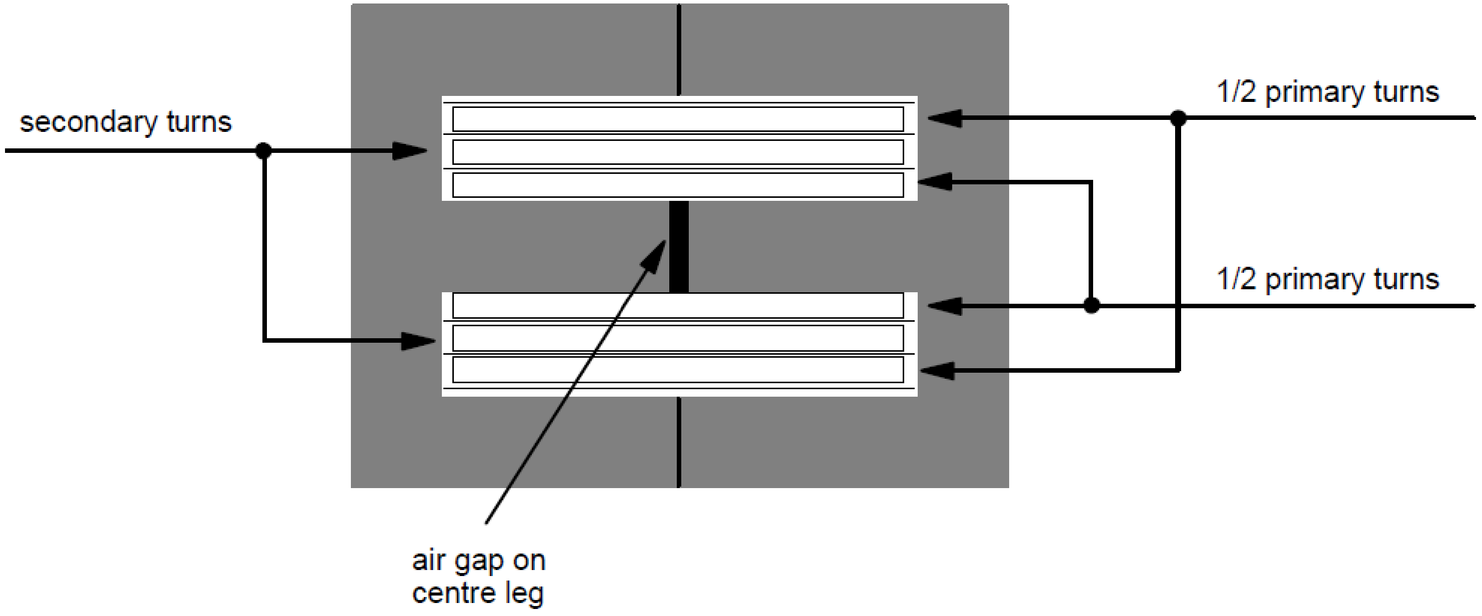
Minimizing Lleakage by Interleaving

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

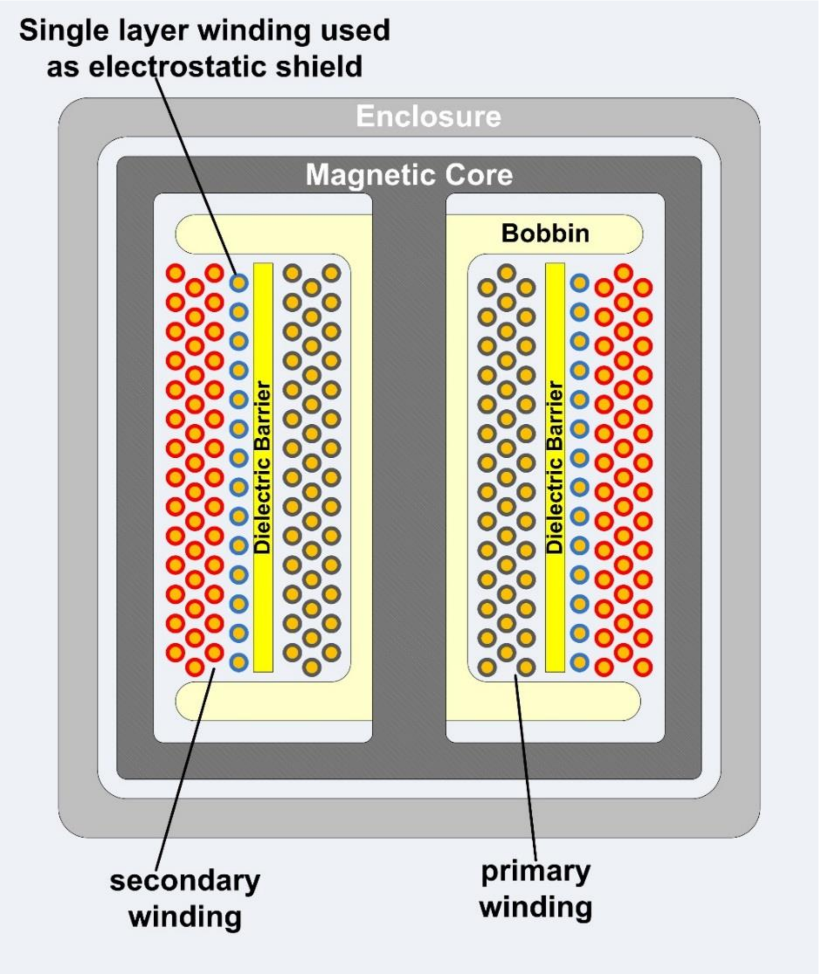


Reflected Voltage Selection

- 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 Vds 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

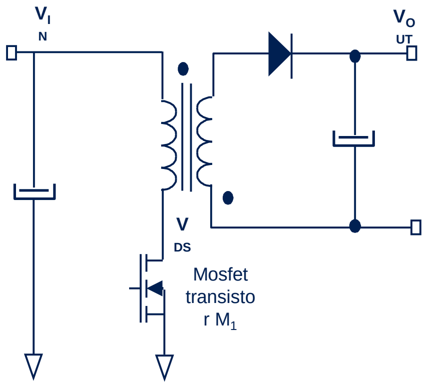
Shielded or Non-Shielded

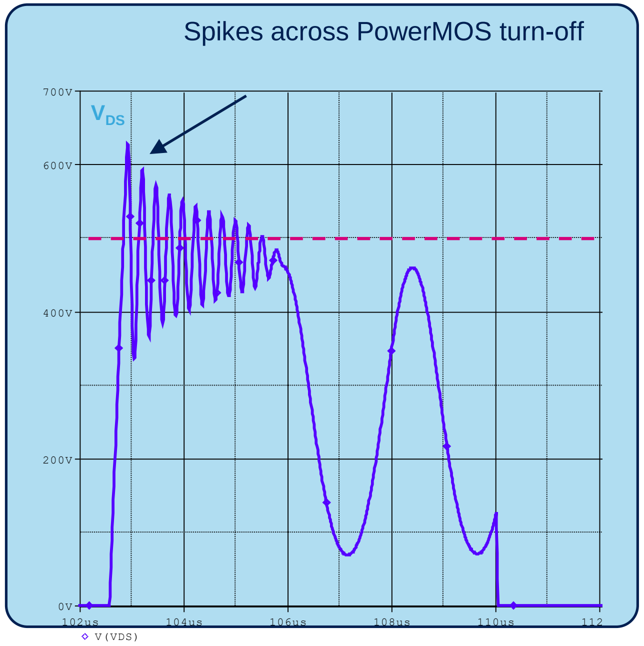
- Shielded transformer has better EMI but larger leakage inductance
- Non-shielded transformer has worse EMI but smaller leakage inductance

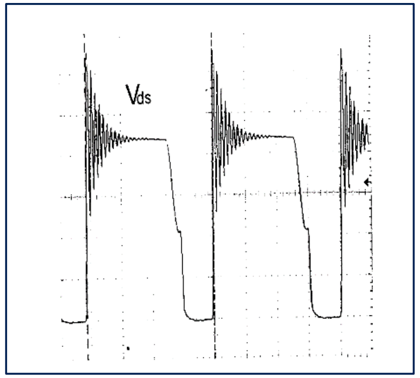


Clamp Circuit

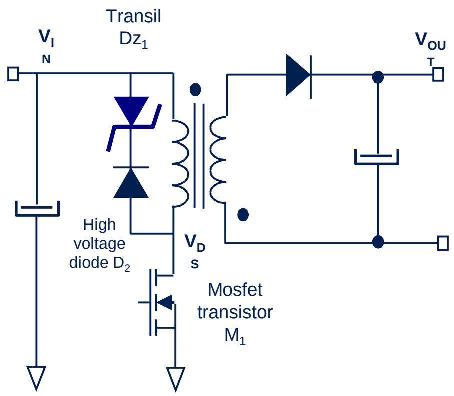
Without Clamp Circuit

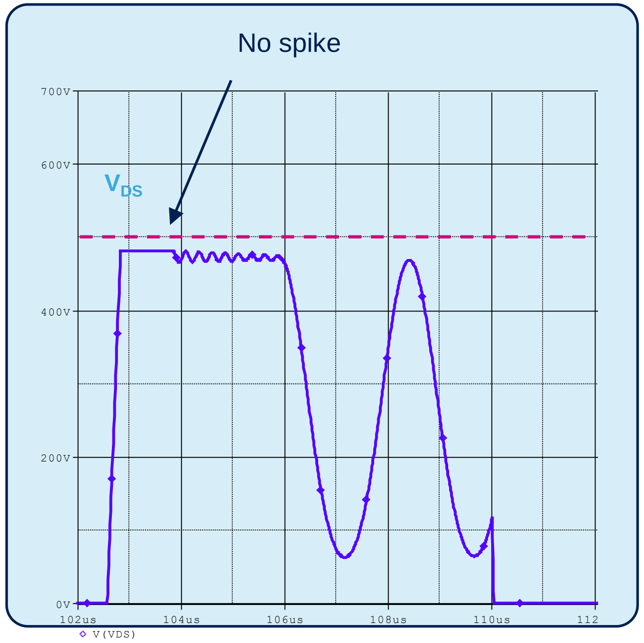




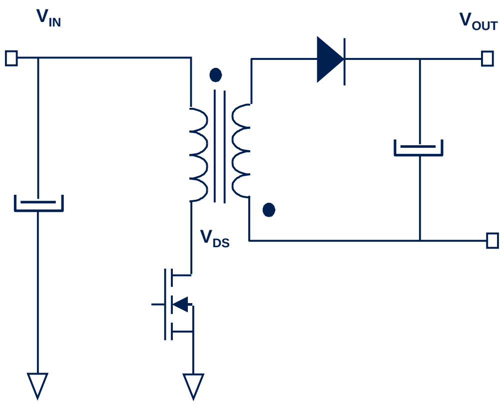


With Clamp Circuit

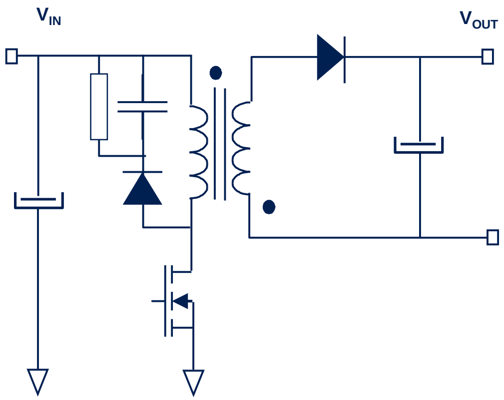




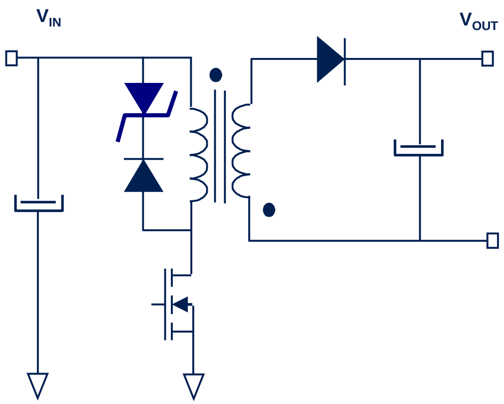
Clamp Implementations



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

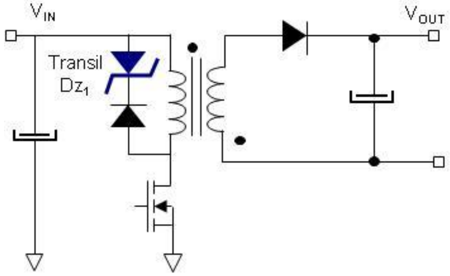


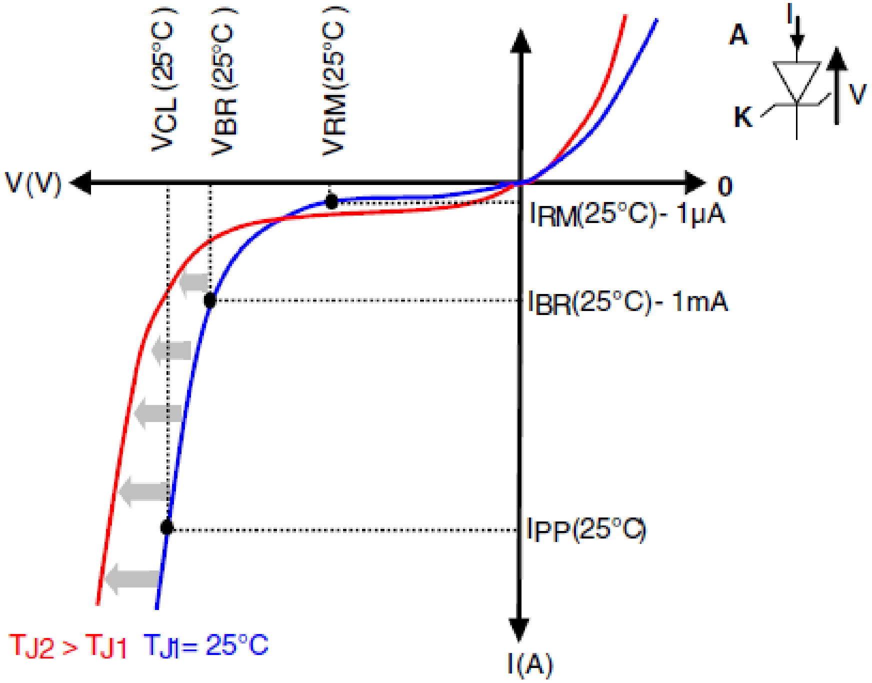
- RC to limit dV/dt, then to limit overvoltage
- Slope may vary depending on components
- Margin on V_{DS} is depending on components
- Test to be done for validation



- 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



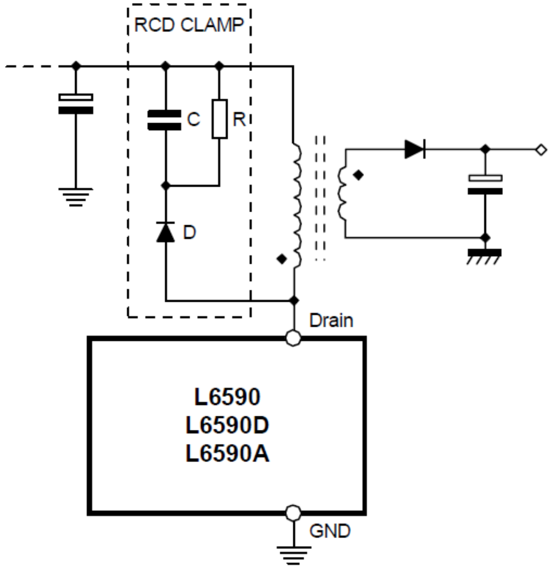


- VRM is stand-off voltage and must be selected to allow the FET to switch: VRM > VR
- VCL is the clamping voltage and is critical to choose as close as possible to the application requirement
- Extensive data published on STRVS datasheet makes the selection for the right part easy and robust

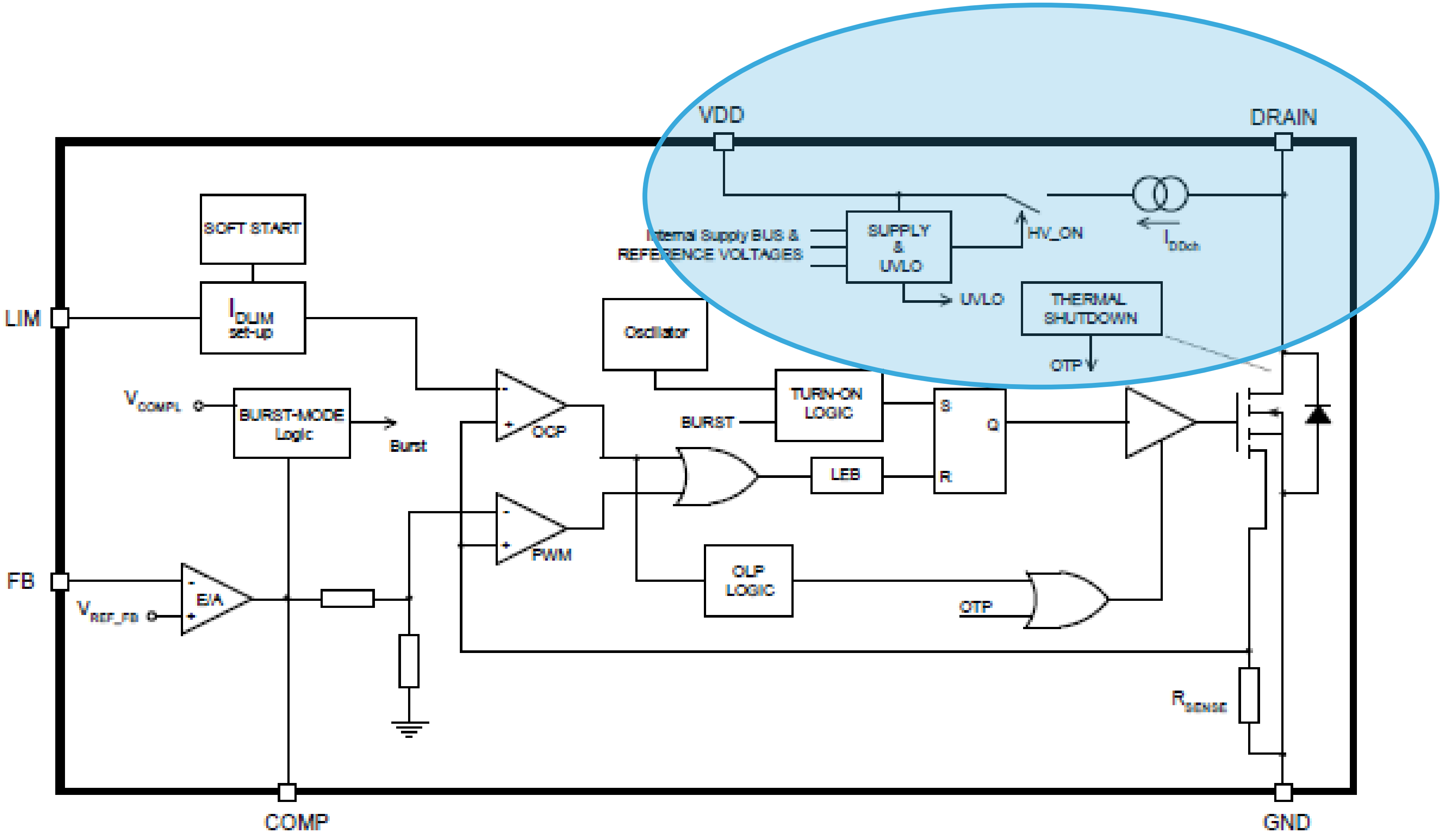
RCD Snubber

- 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

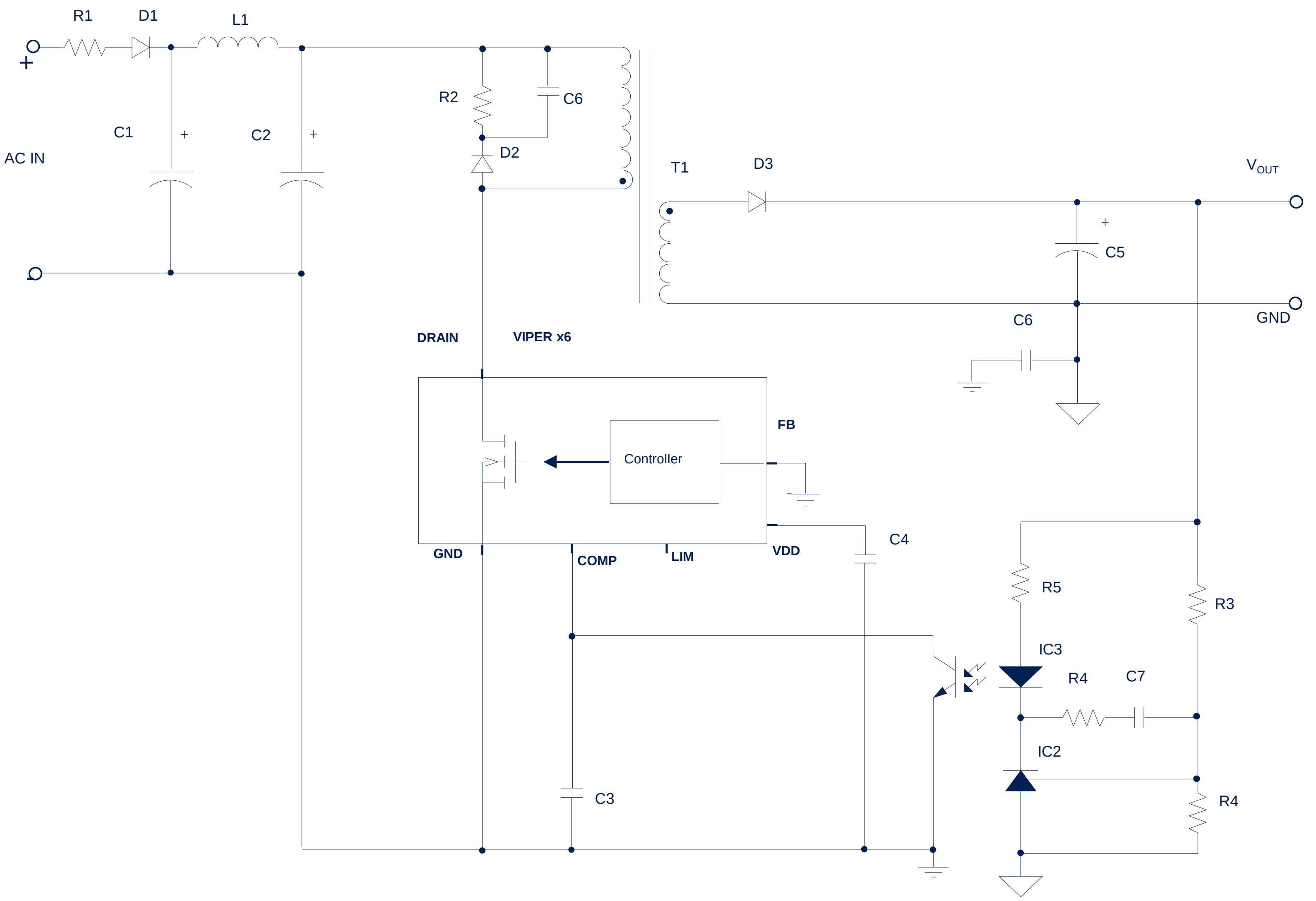
R	C	V_{CL}	$V_{DS}(PK)$	EMI	$P_{DISS}(R)$	Cost
↓	↑	↓	↓	↓	↑	↑
↑	↓	↑	↑	↑	↓	↓



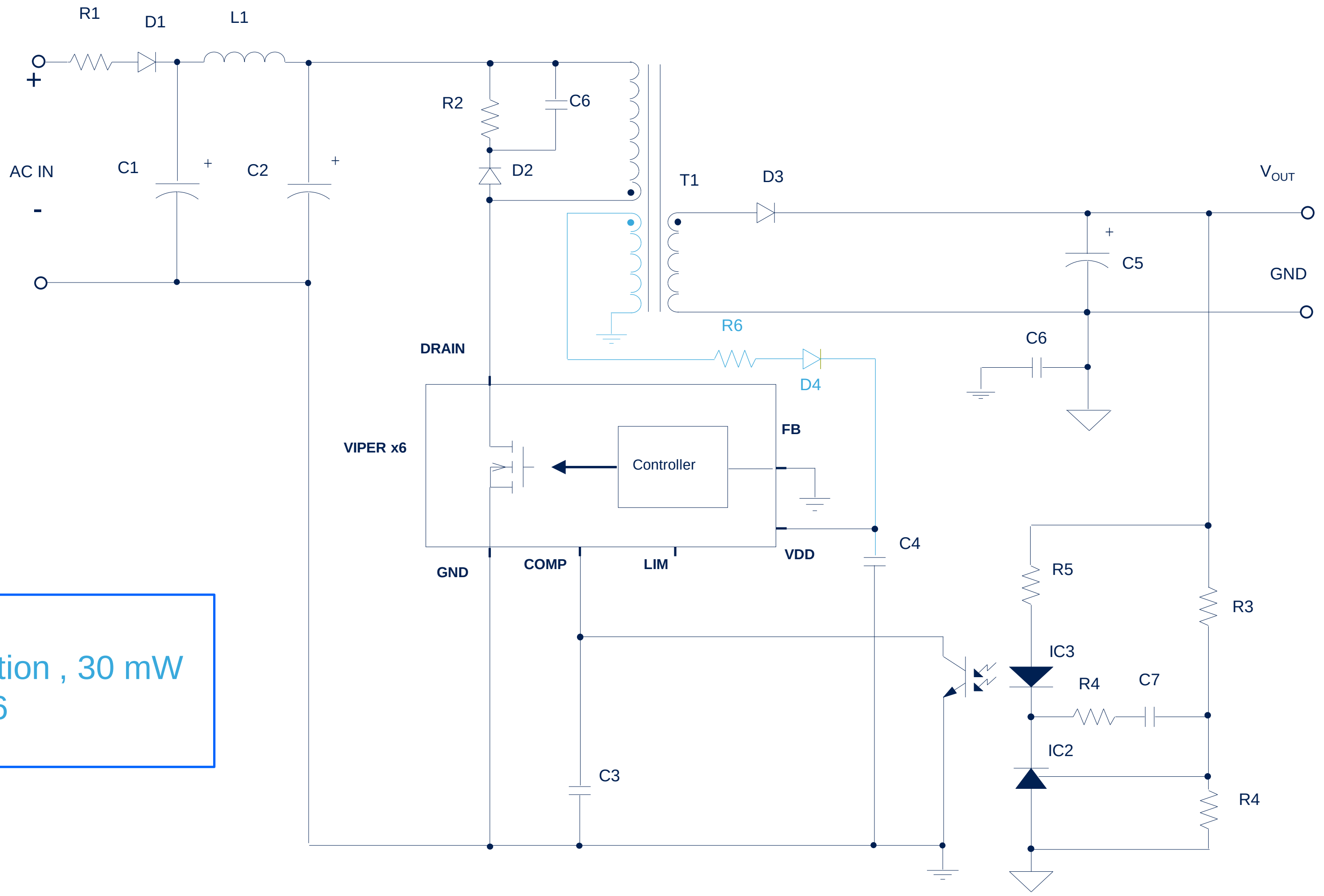
Stand-By Consumption: HV Start-Up



Stand-By Consumption

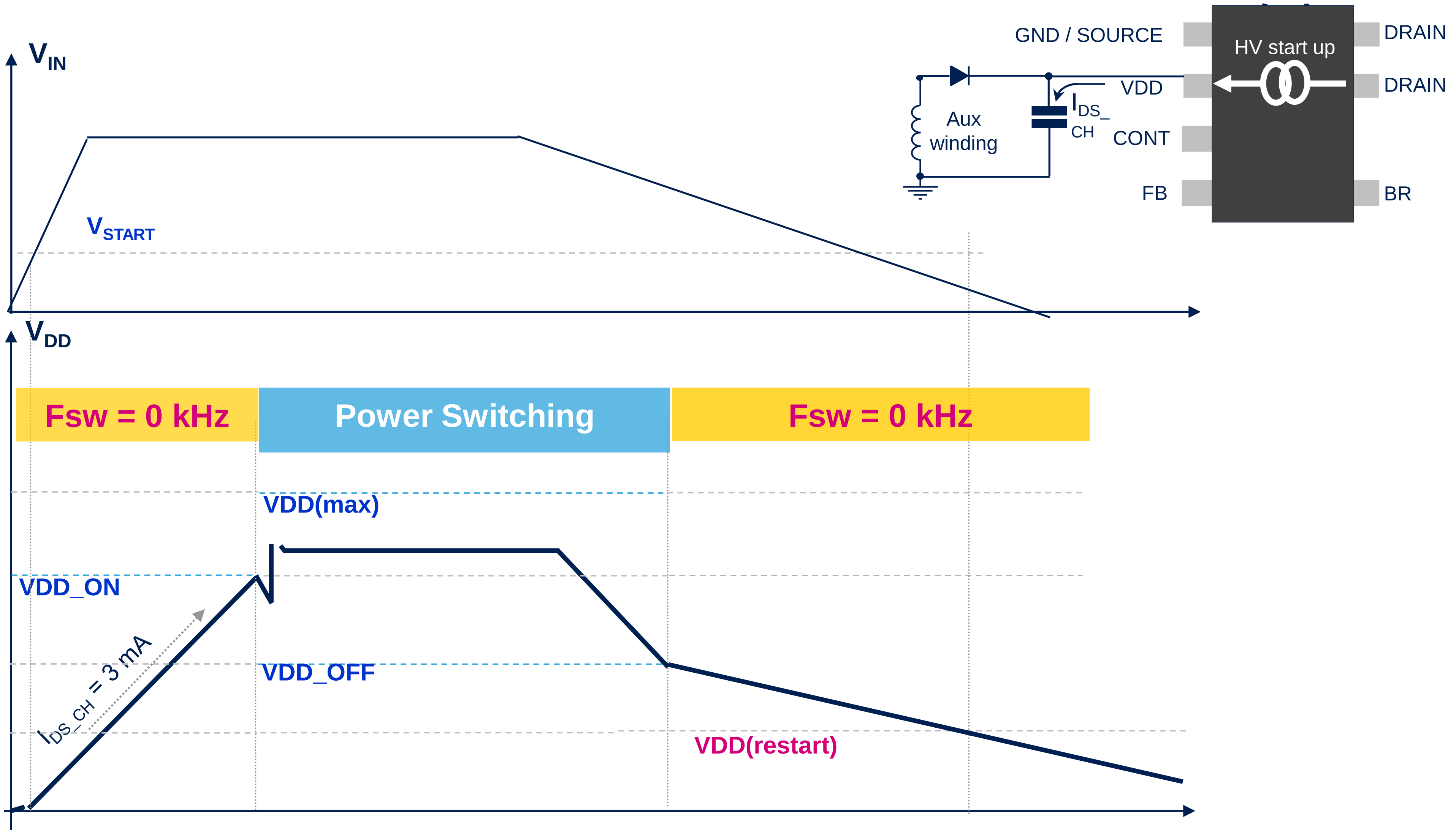


Stand-By Consumption



Stand-by optimization , 30 mW
D4, R6

Stand-By Consumption: HV Start-Up



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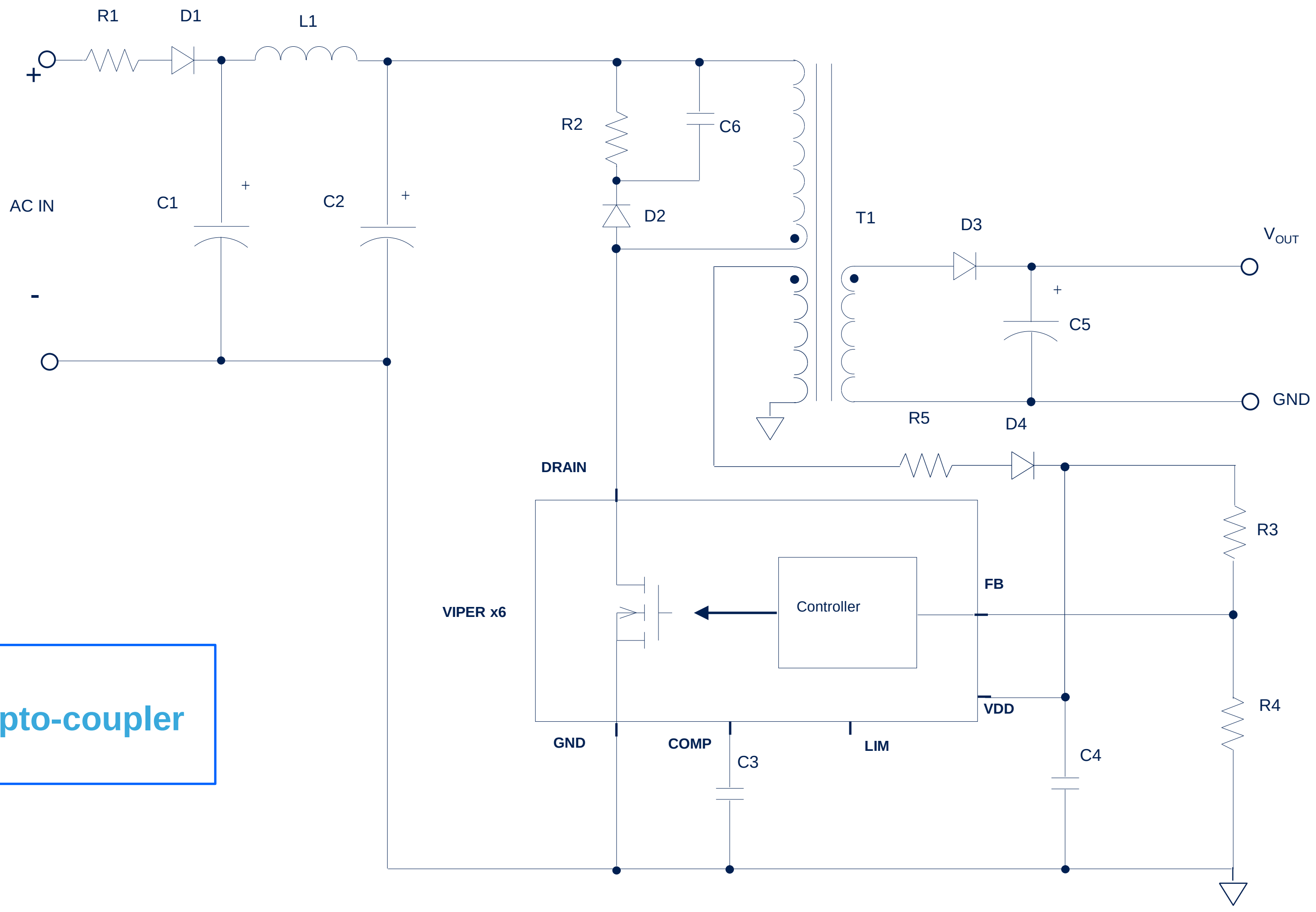
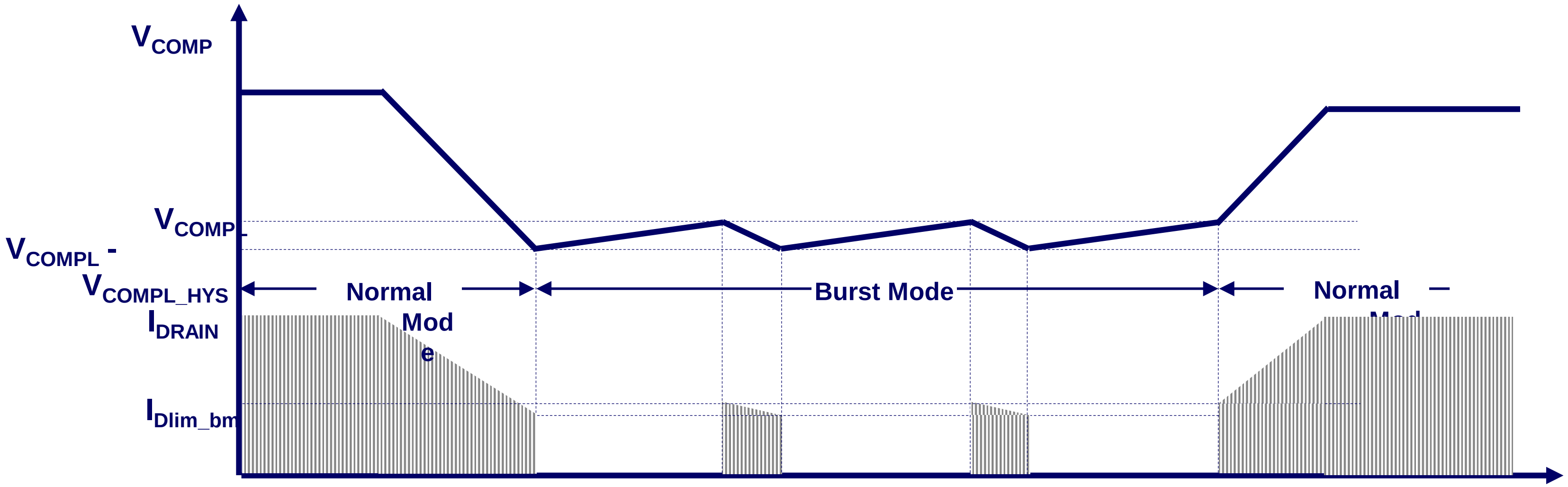
Stand-By Consumption



No need of the opto-coupler

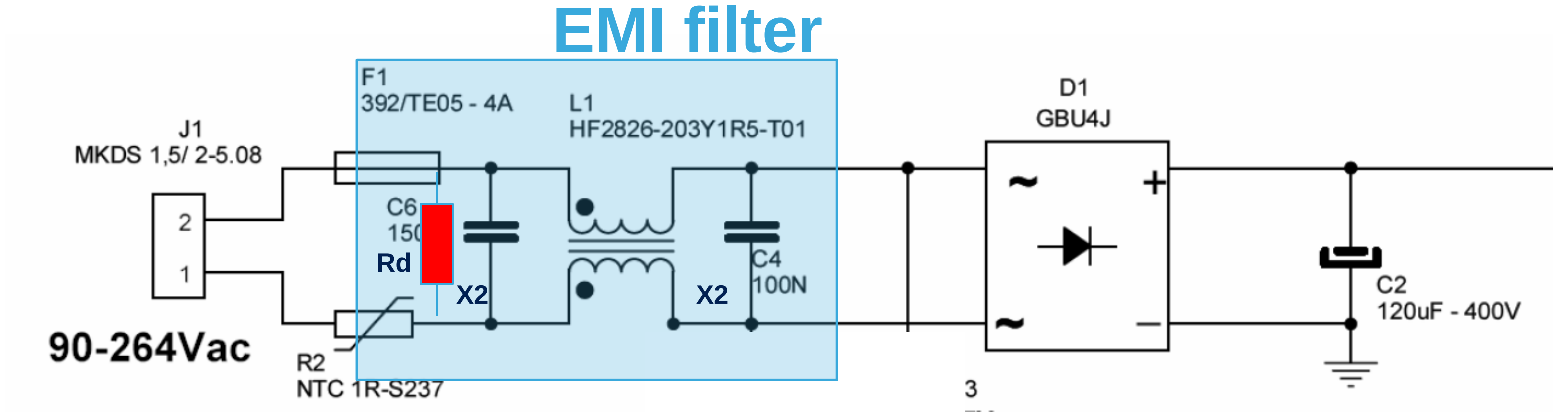
Stand-By Consumption: Burst Mode



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

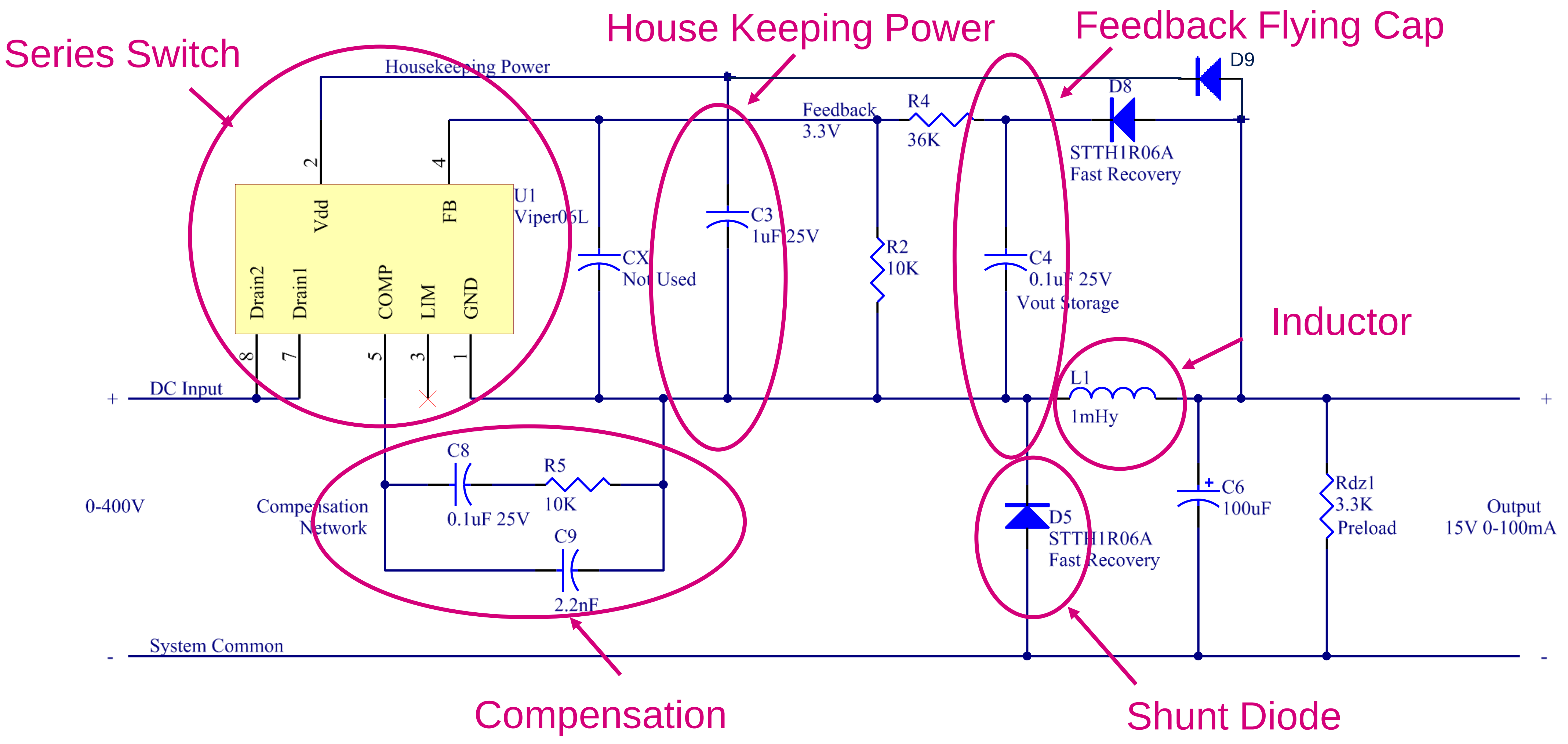
X-Cap Discharge

- 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

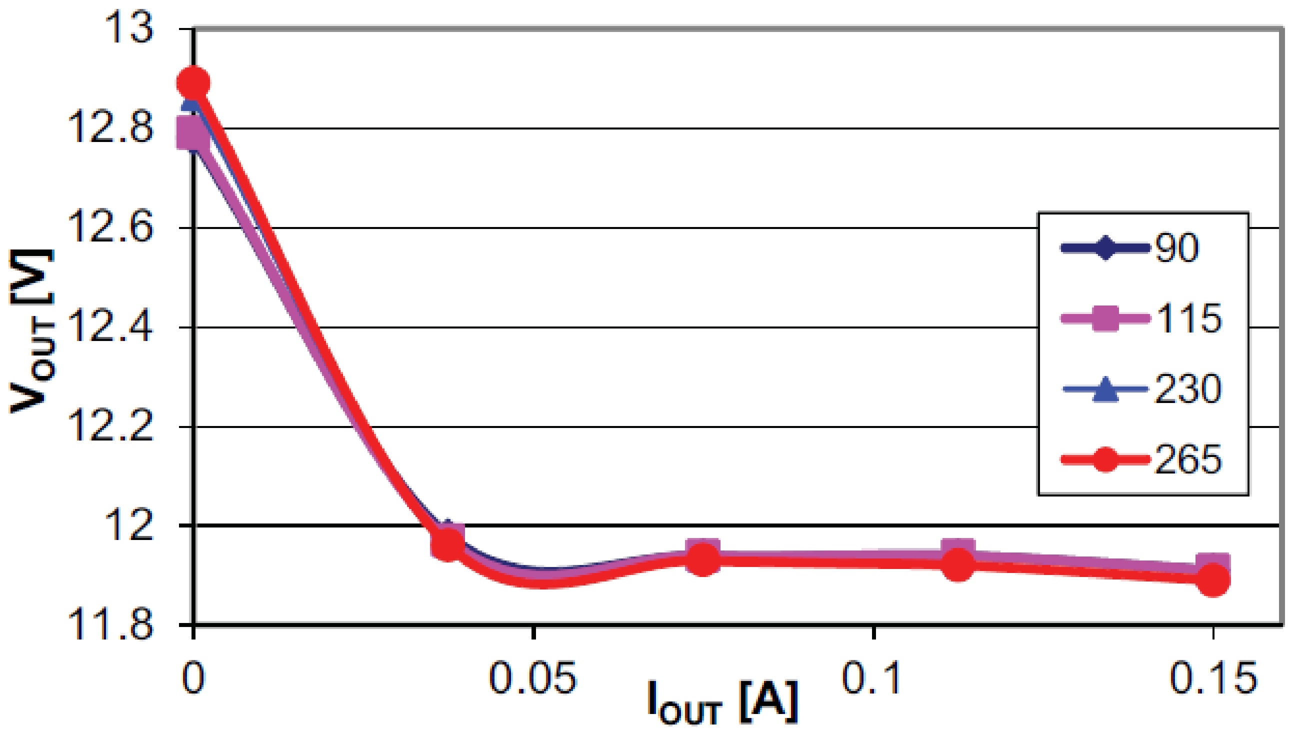


“Flying Capacitor” Feedback Scheme

- 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 ensure diode turn-on
- C4 must hold output voltage information when Viper is in burst mode

“Flying Capacitor” Feedback Scheme (Cont.)

- Low cost solution
- Minimum load required



Select Switching Frequency

SELECT FREQUENCY FOR 5 V OUTPUT BUCK

Vin 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

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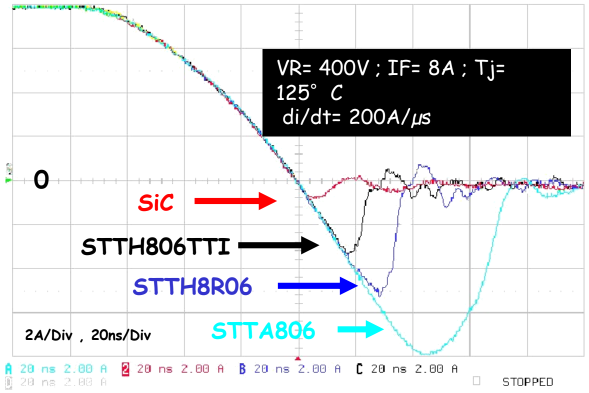
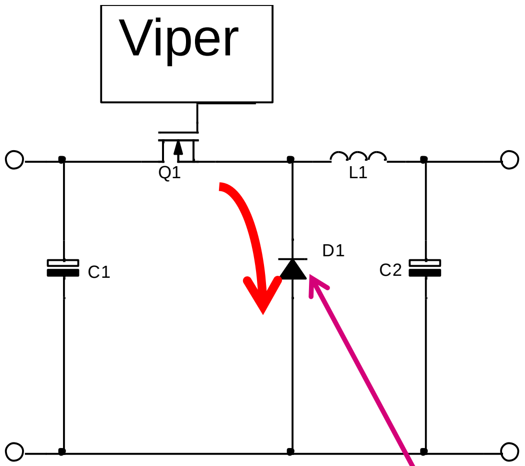
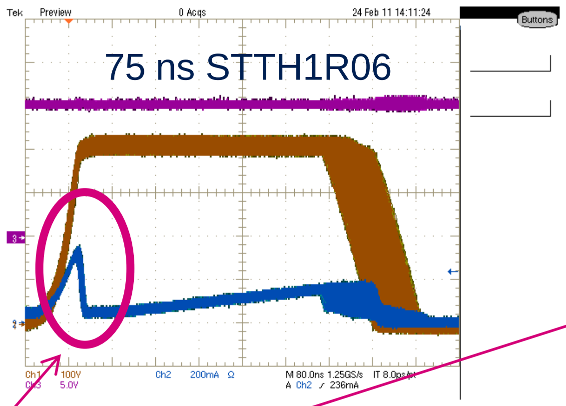
Minimum on Time

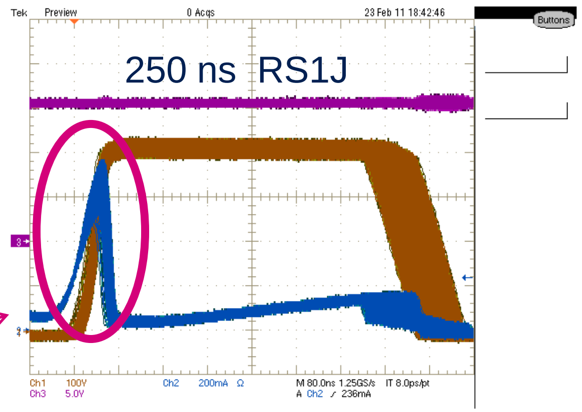
- Duty cycle of Viper Buck converter is limited by minimum on time
  - Viper06 450 ns
  - Viper01 350 ns
- If the required ON time is shorter then minimum ON time, Buck still works, but there is small instability and the maximum deliverable output current is reduced.
- The 30kHz version is strictly recommended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

Diode Recovery Effect









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

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Layout Optimization

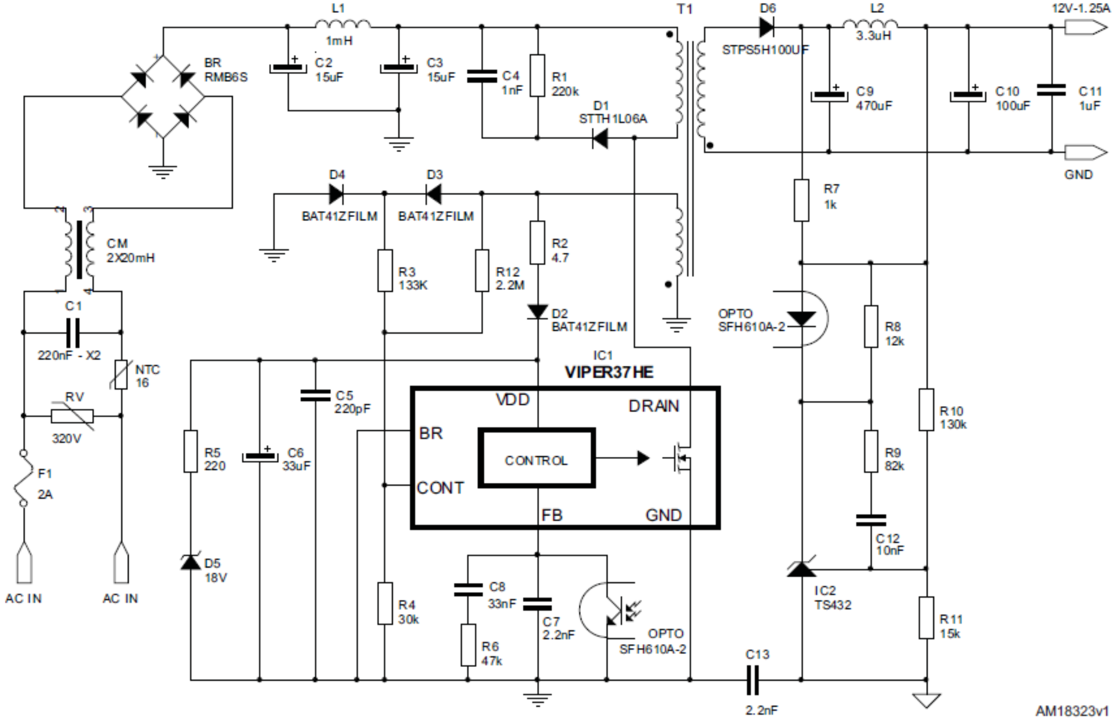
- Minimize interconnection lengths of following components:
  - Input filter caps, input-side transformer (or inductor), power MOSFET, sensing resistors and active-clamp or snubber circuits
  - Output-side transformer (or inductor), rectifier diodes and output filter caps
- Keep power and signal circuitries 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

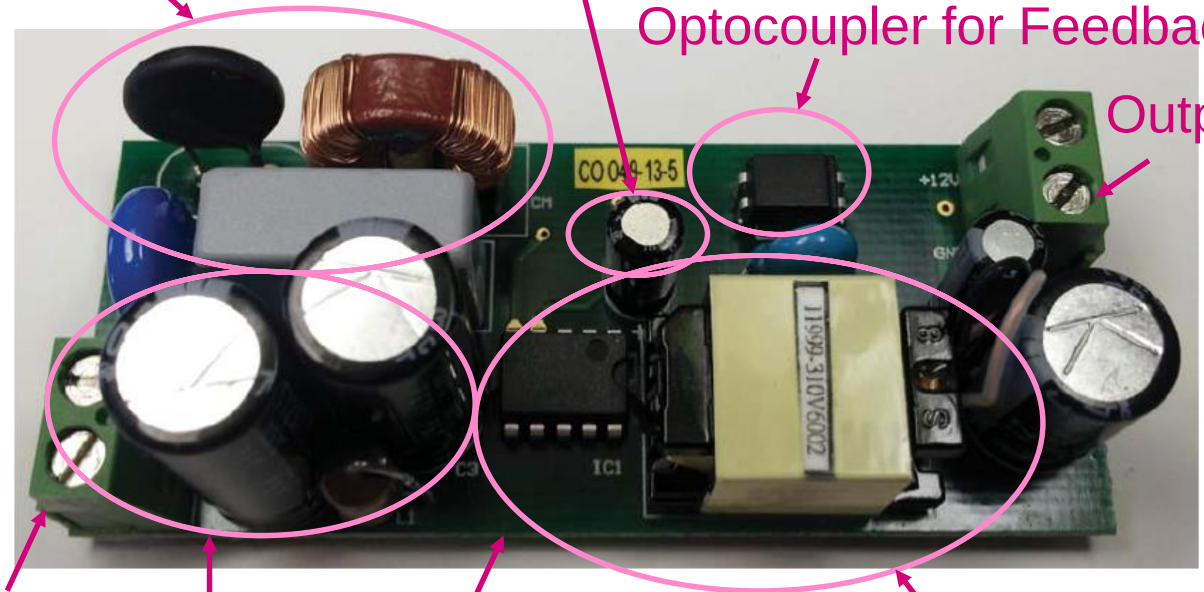
- EN 55022 is an European EMC standard applicable to information technology equipment with a rated supply voltage not exceeding 600 V
- Properly size EMI filter: differential mode filter for power < 5 W; X-, Y-caps, and common mode choke for power > 15 W
- Designers often use snubbers and soft switching 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

Design Example

Electrical Schematic



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



Evaluation Board (30 x 72 mm) Max

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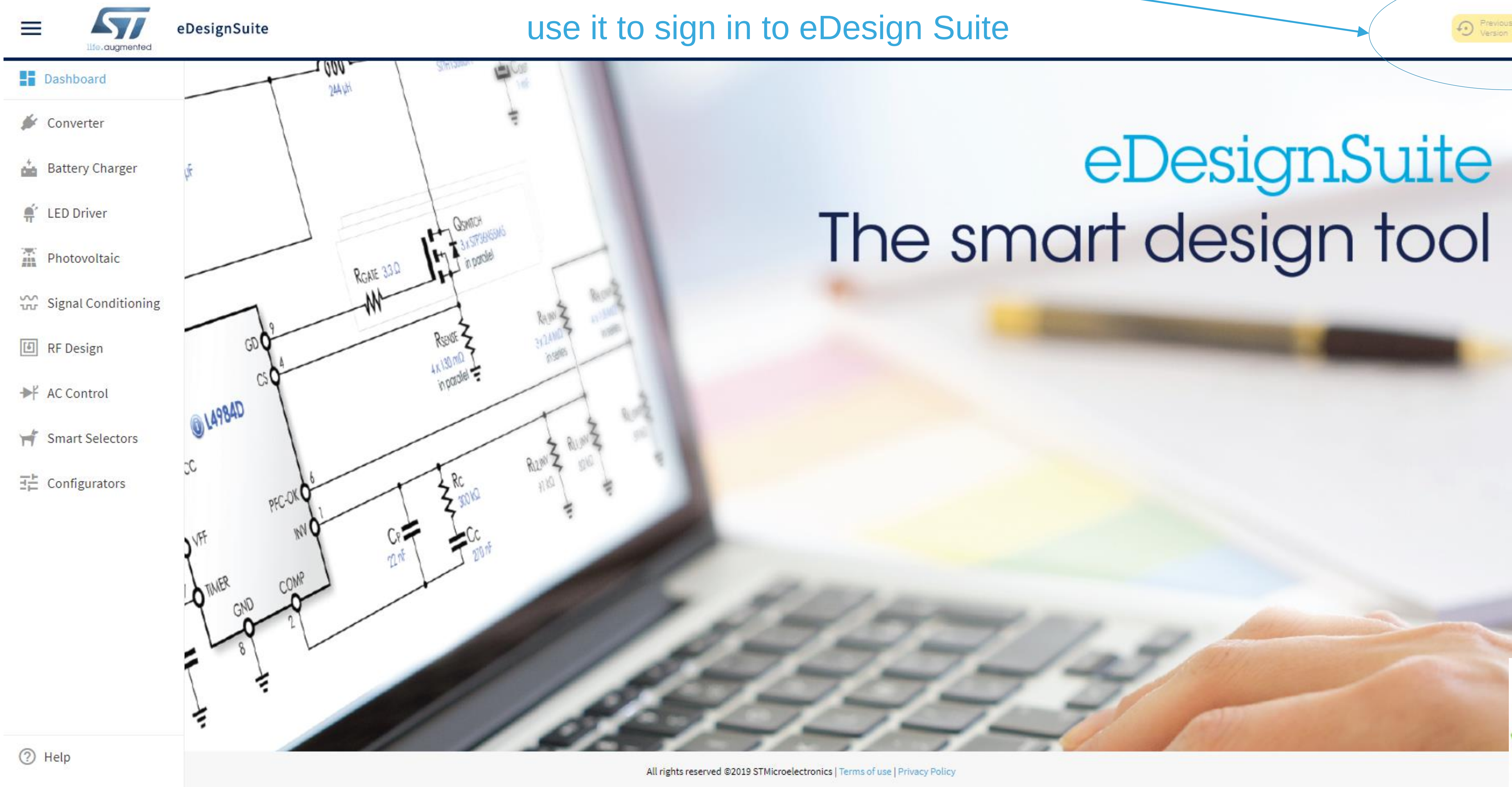
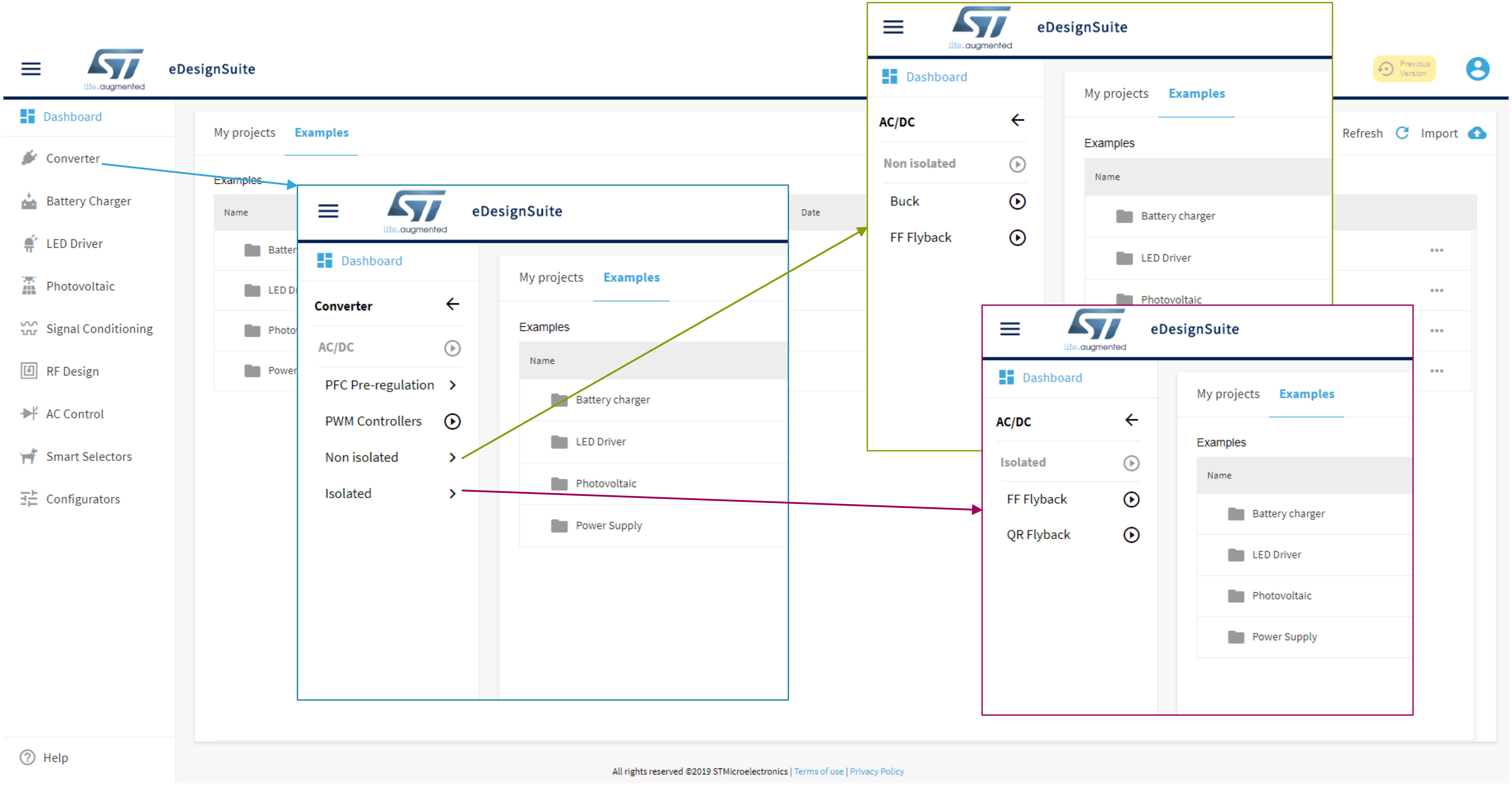
EDesignSuite Examples

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




eDesignSuite
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Dashboard
Converter
Battery Charger
LED Driver
Photovoltaic
Signal Conditioning
RF Design
AC Control
Smart Selectors
Configurators
Help
My projects
Examples
Refresh
Import
Name
Date
Converter
AC/DC
PFC Pre-regulation
PWM Controllers
Non isolated
Isolated
Battery charger
LED Driver
Photovoltaic
Power Supply
Buck
FF Flyback
QR Flyback
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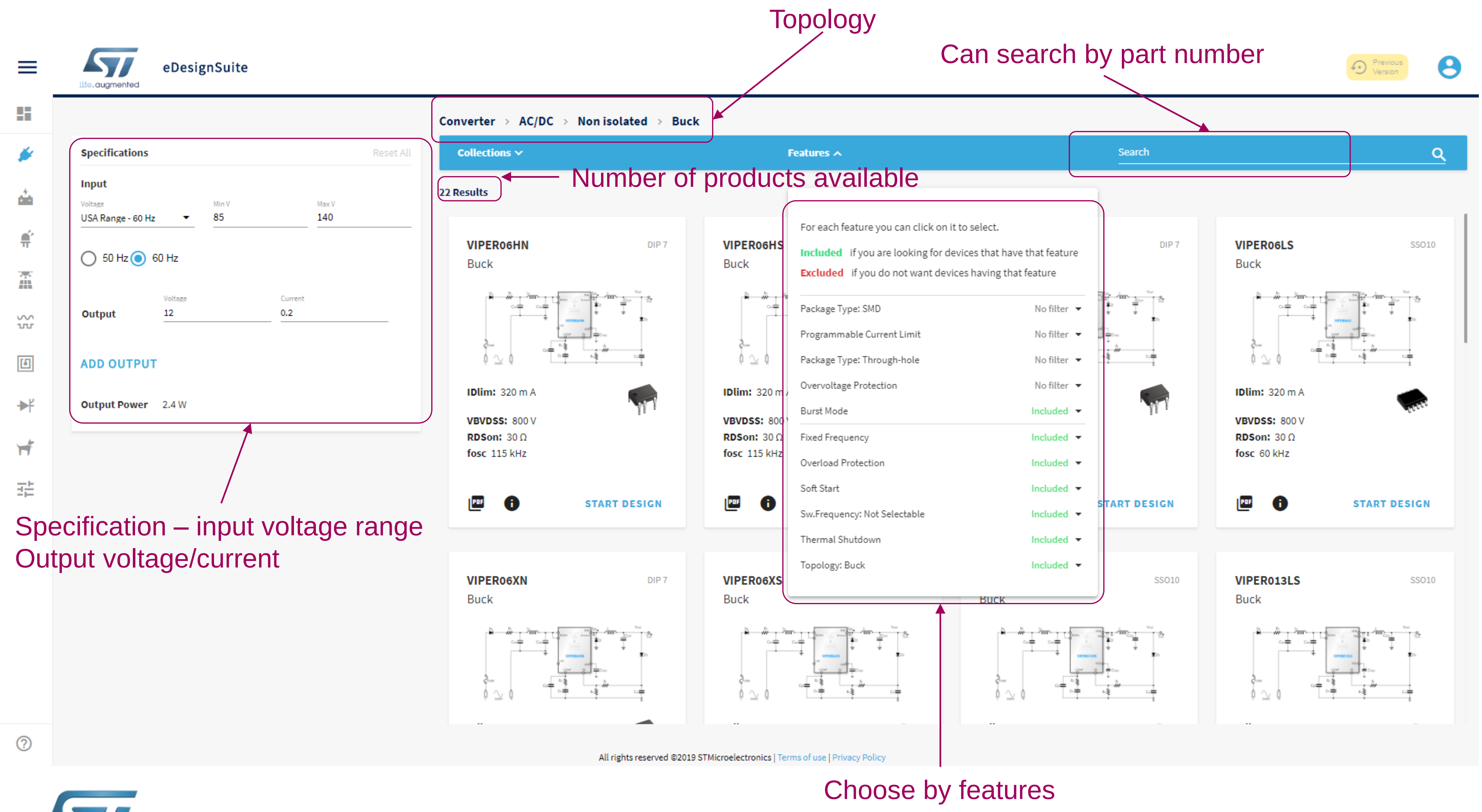
Topology
Can search by part number
eDesignSuite
Converter > AC/DC > Non isolated > Buck
Collections
Features
Search
Number of products available
22 Results
Specifications
Reset All
Input
Voltage
USA Range - 60 Hz
Min V
85
Max V
140
50 Hz
60 Hz
Output
Voltage
12
Current
0.2
ADD OUTPUT
Output Power 2.4 W
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
VIPER06HN
DIP 7
Buck
IDlim: 320 m A
VBVDSS: 800 V
RDSon: 30 Ω
fosc 115 kHz
START DESIGN
VIPER06HS
Buck
VIPER06LS
SSO10
Buck
IDlim: 320 m A
VBVDSS: 800 V
RDSon: 30 Ω
fosc 60 kHz
VIPER06XN
DIP 7
VIPER06XS
VIPER013LS
SSO10
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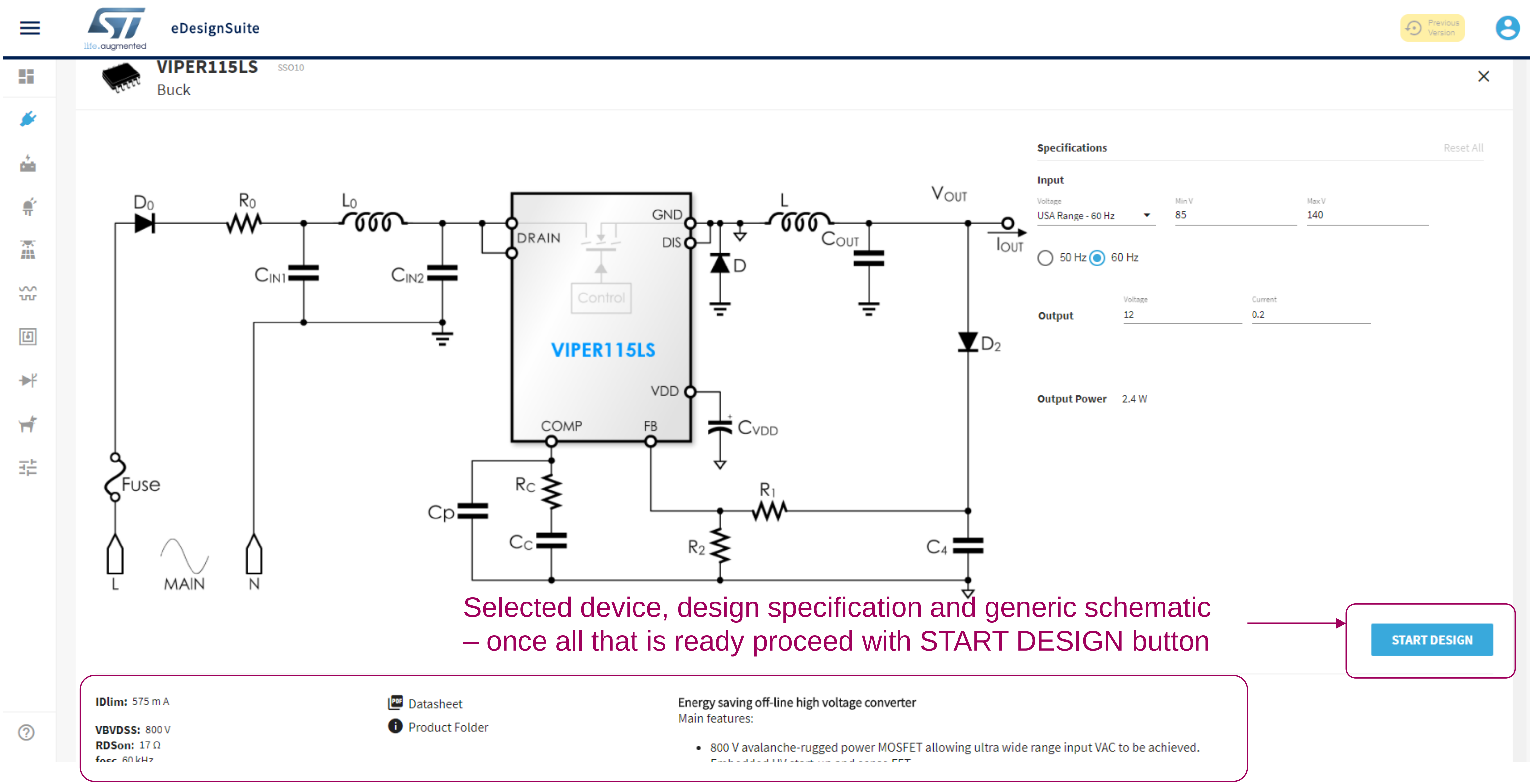
Specification – input voltage range
Output voltage/current
Choose by features



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

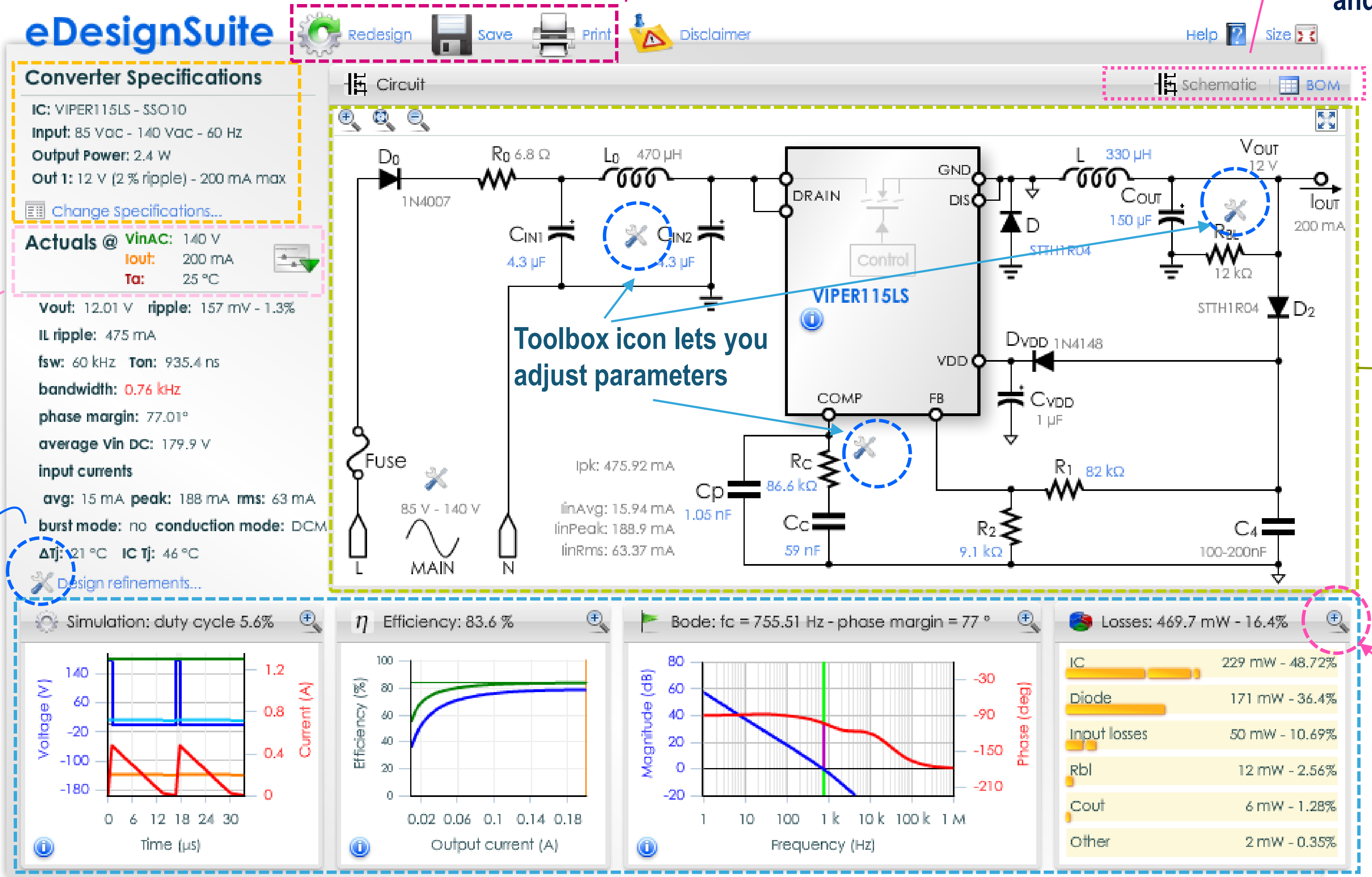
More details on the selected device (e.g. Viper115LS) – datasheet link, main electrical parameters, features

Design commands

Bill of materials and schematic

Specification

Operating conditions can be varied



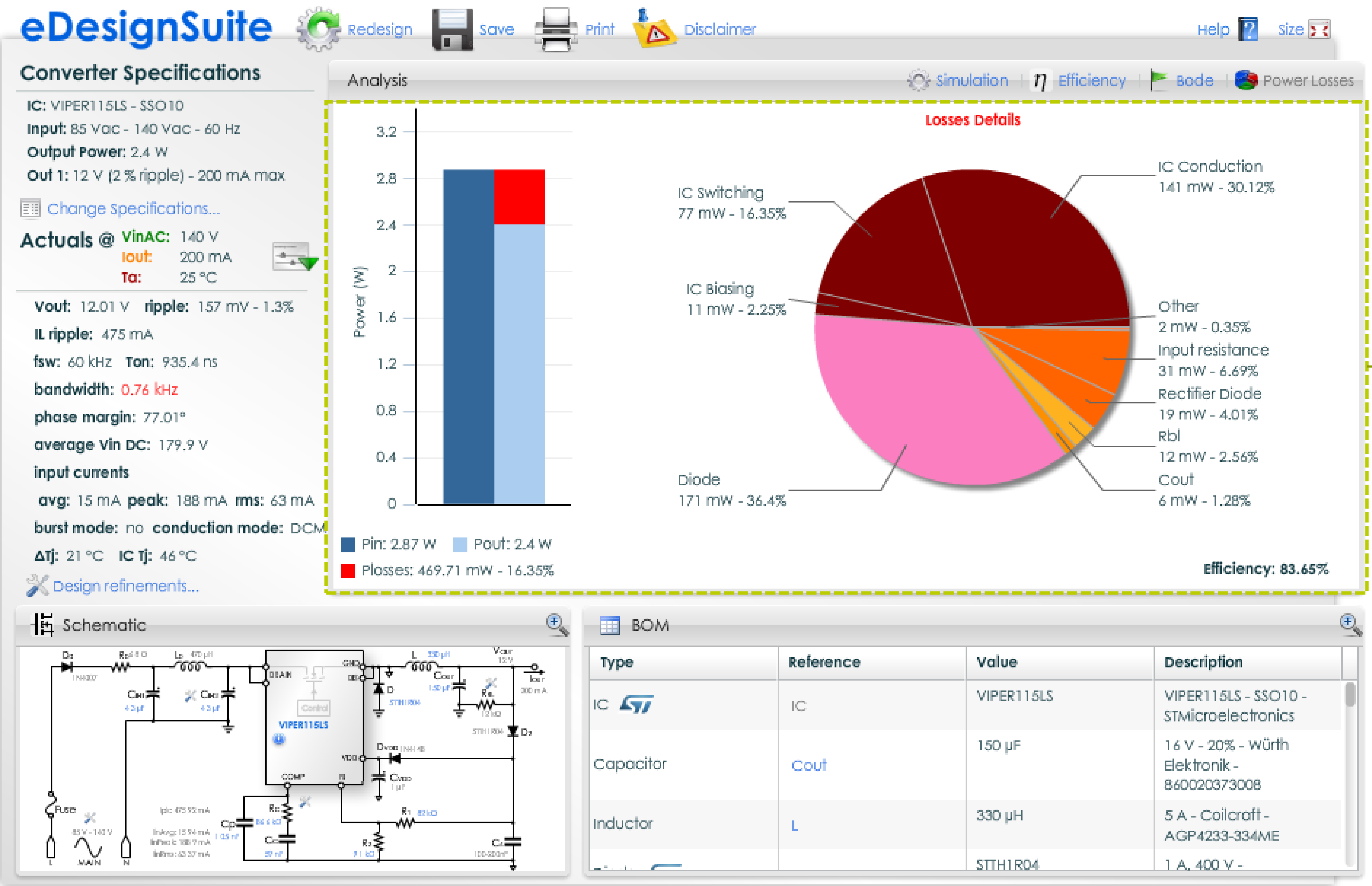
Toolbox icon lets you adjust parameters

Annotated and interactive schematic

The user can customize some of the characteristics

A set of qualitative metrics

Click to maximize



Very useful losses distribution chart

Thank You!