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Energy Conversion I

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Desk D216

Layout

- Non isolated choppers
- Switch mode power supplies
- Power components
- **Sinusoidal absorption**

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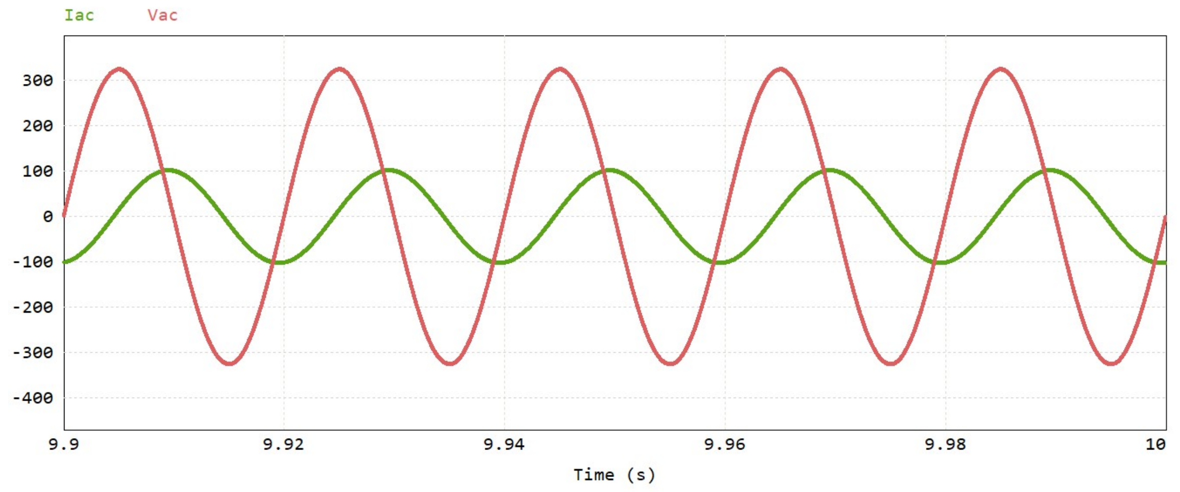
Introduction

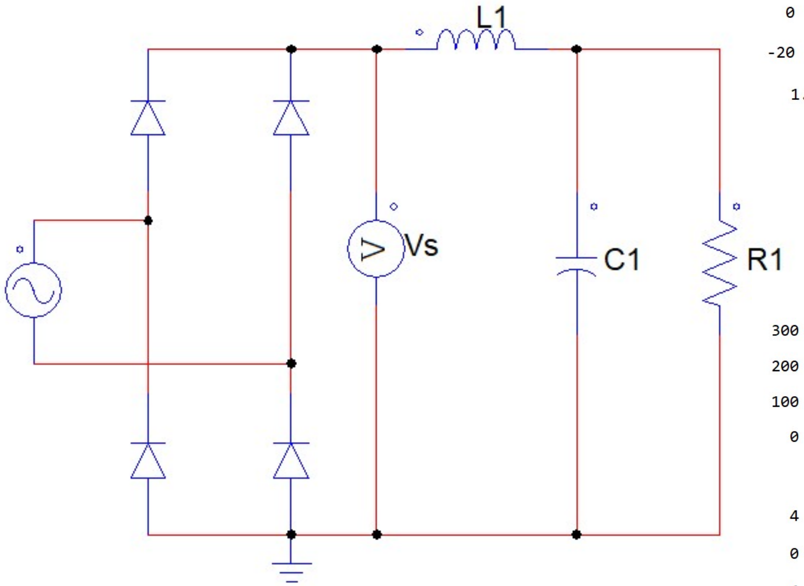
Reminder: Power in AC

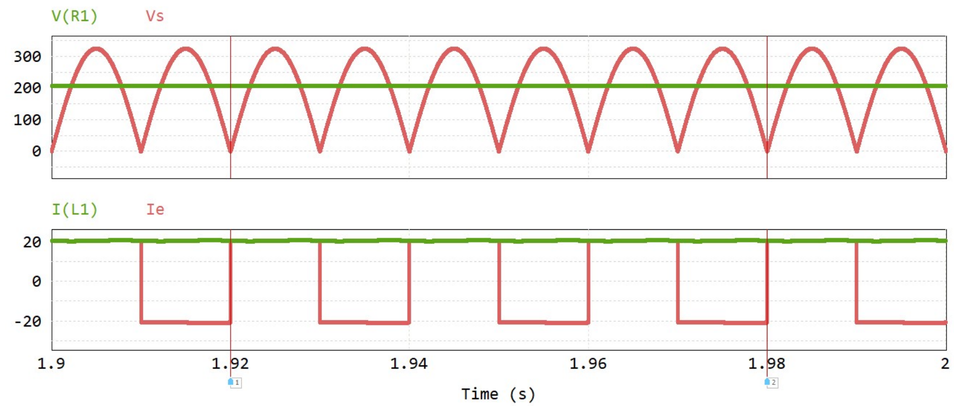
$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt}$$



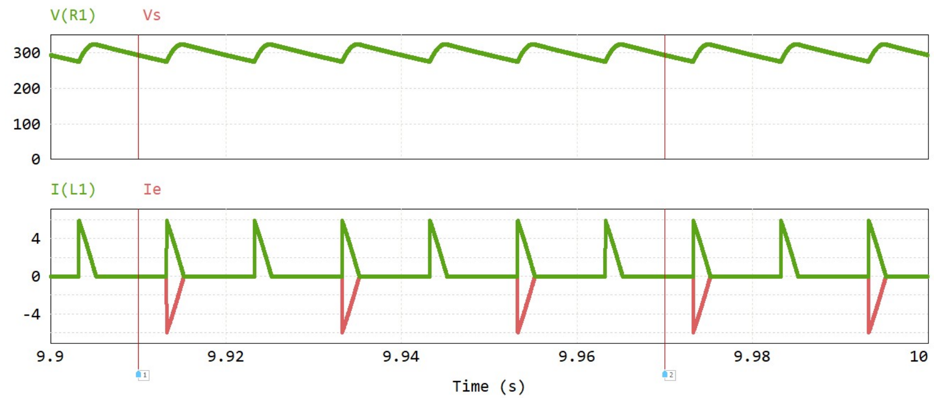
- **Real power:** $P = <p(t)> = <v(t).i(t)> = V_{RMS}.I_{RMS}.\cos(\varphi_1)$
- **Reactive power:** $Q = V_{RMS}.I_{RMS}.sin(\varphi_1)$
- **Apparent power:** $S = V_{RMS}.I_{RMS}$
- **Power factor:** $pf = \frac{P}{S}$
- **Total harmonic distortion:** $THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_{n\,RMS}^2}}{I_{1\,RMS}}$

Reminder: Diode rectifier





$$L = 10H \rightarrow pf = 0,9 \qquad THD = 0,48$$



$$L = 10nH \rightarrow pf = 0,5 \qquad THD = 1,5$$

European standard: 61000-3-2

Limits for harmonics currents emission (class C ≈ lightning)

Tableau 2 – Limites pour les appareils de classe C

Rang harmonique n	Courant harmonique maximal exprimé en pourcentage du courant fondamental d'entrée des luminaires %
2	2
3	30 λ*
5	10
7	7
9	5
11 ≤ n ≤ 39 (harmoniques impairs seulement)	3
* λ est le facteur de puissance du circuit	

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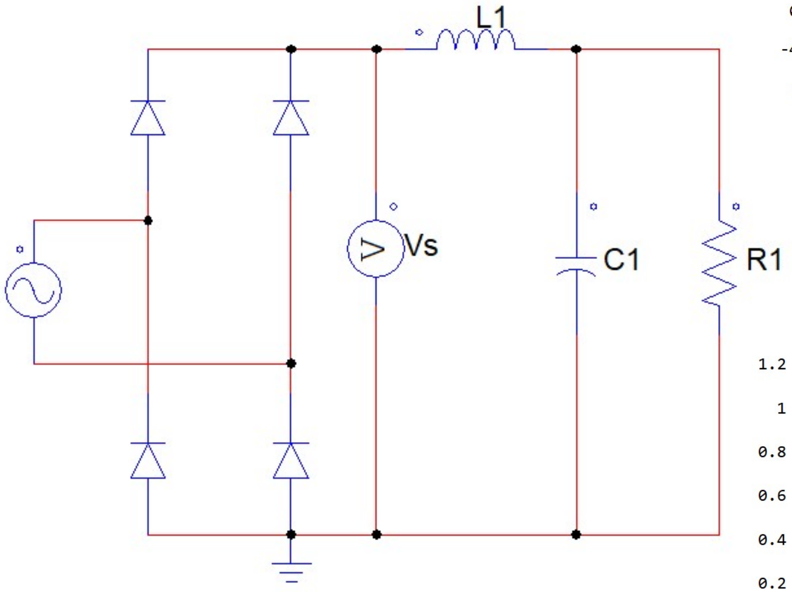
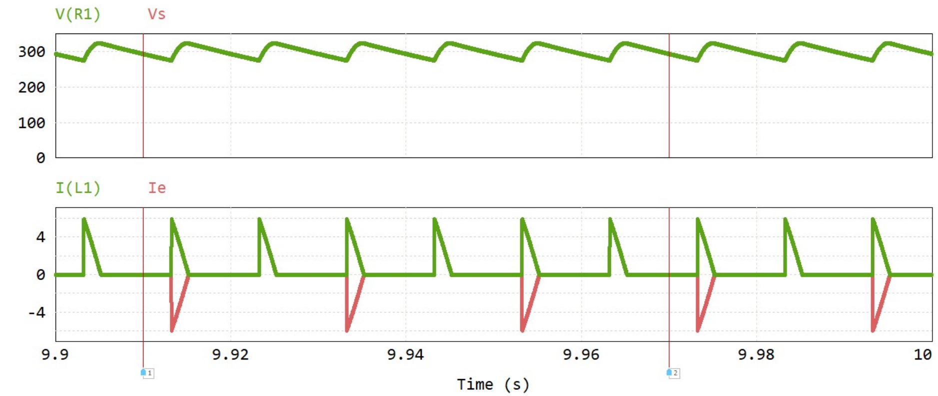
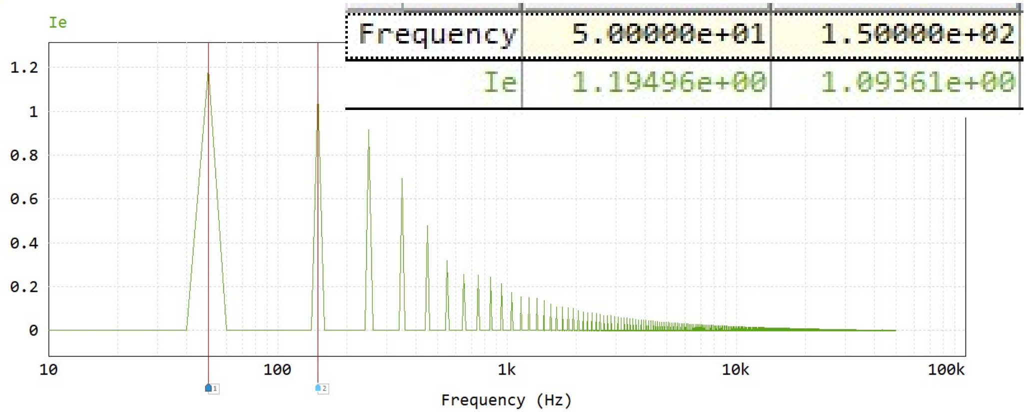
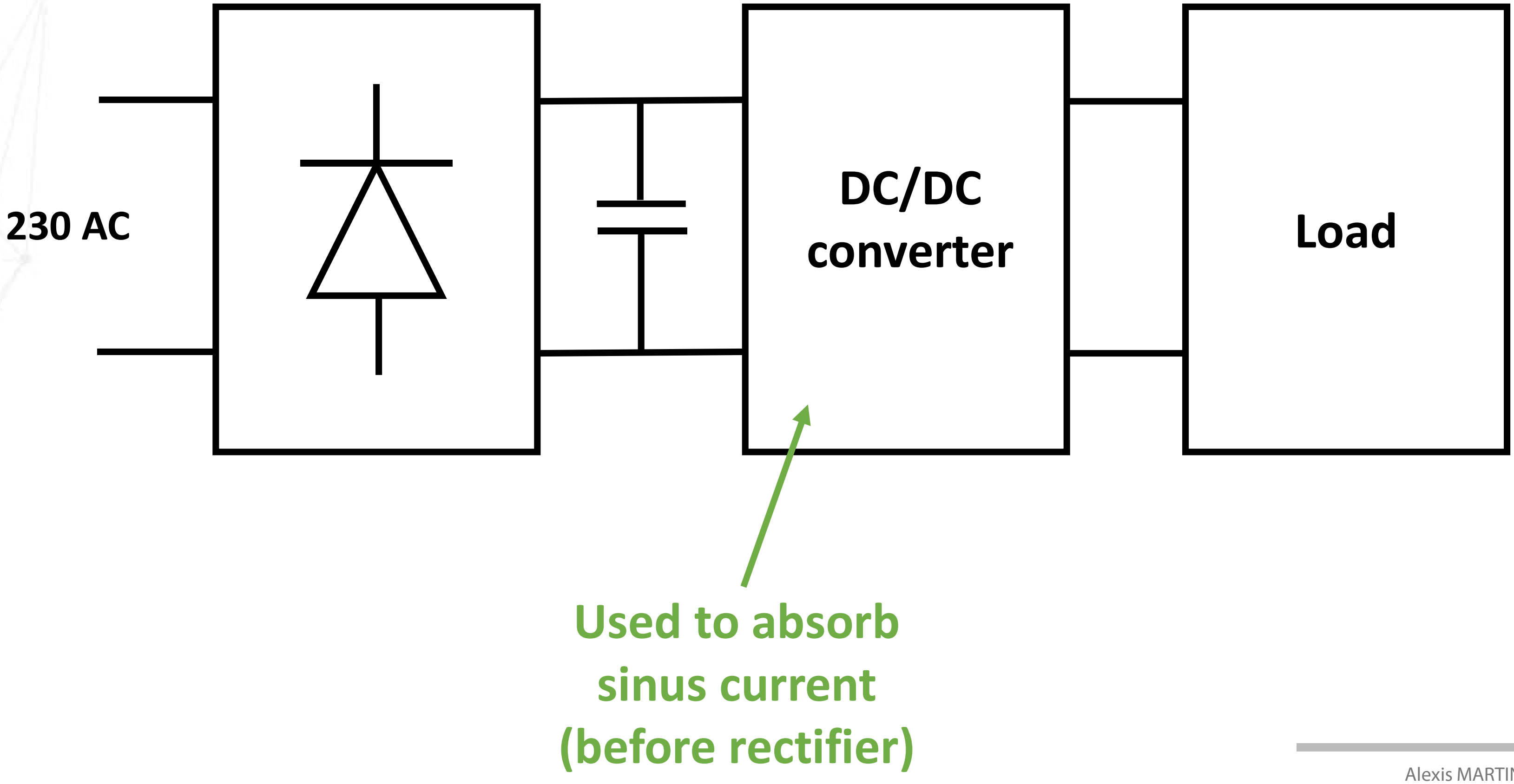
European standard: 61000-3-2







Power factor correction



Boost for PFC

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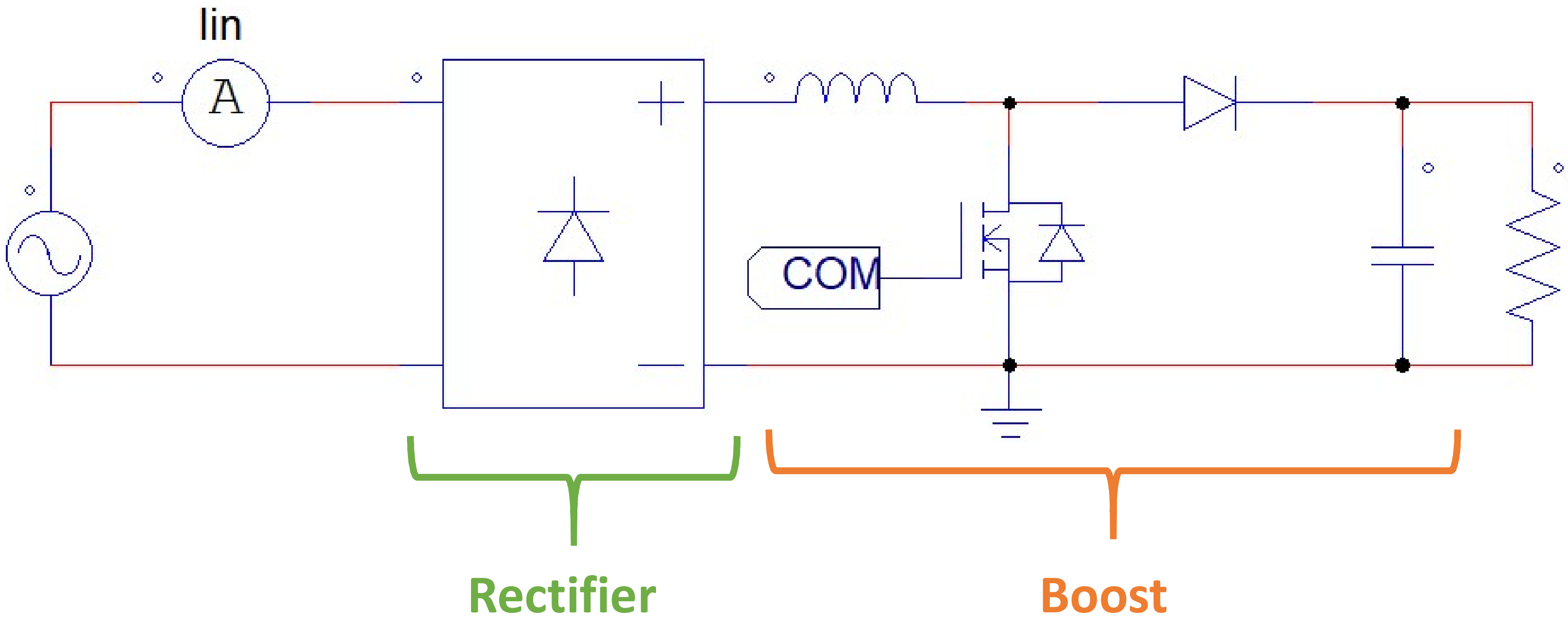
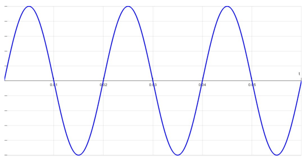
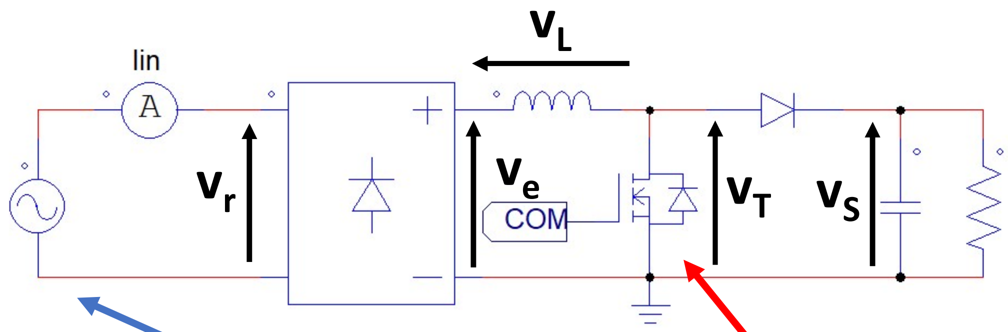
Structure



Structure





$$v_r = V\sqrt{2}\sin(\theta)$$
$$\theta = 2\pi f_{BF} t$$

- 2 frequencies: f_{LF} (50Hz for grid) and f_{HF} (few 10 kHz for switching)

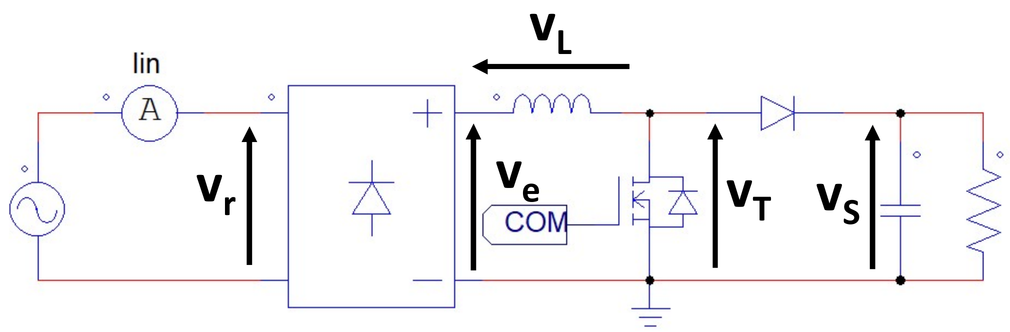
Goal:

- $I_{in} = I.\sqrt{2}\sin(\theta)$

- $v_e = |v_r|$ and $v_e = (1-\alpha)v_S$ $\rightarrow$ $V_S > v_{r\,max}$

- Two control strategies :
  - Fixed switching frequency -> PWM
  - Free switching frequency -> hysteresis control

PWM control

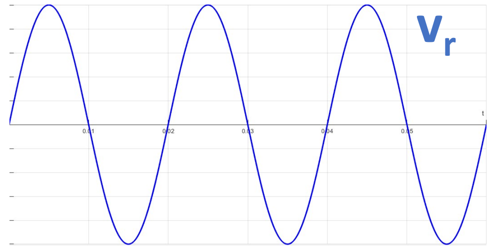


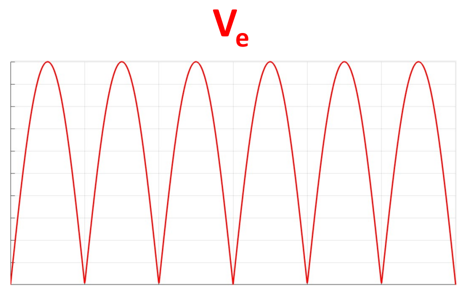
- With PWM control, the switching frequency is fixed, the duty cycle is used to control the current

- For low frequency, the boost is a continuous voltage amplifier controlled with the duty cycle α

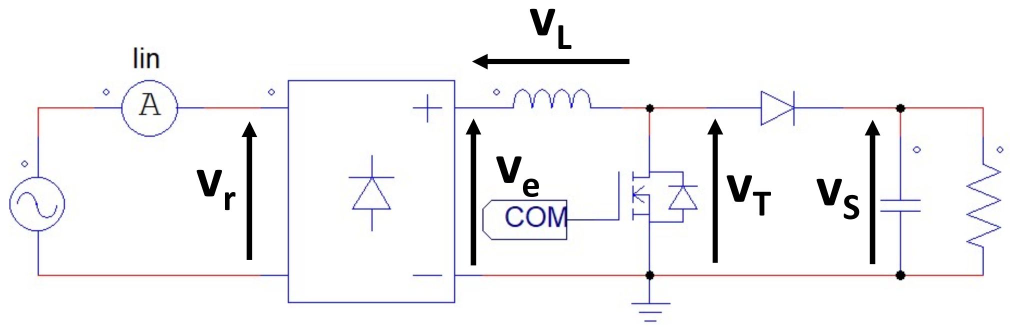
- Continuous conduction of diodes in the rectifier:

$$v_e = |v_r| = V\sqrt{2}.|\sin(\theta)|$$





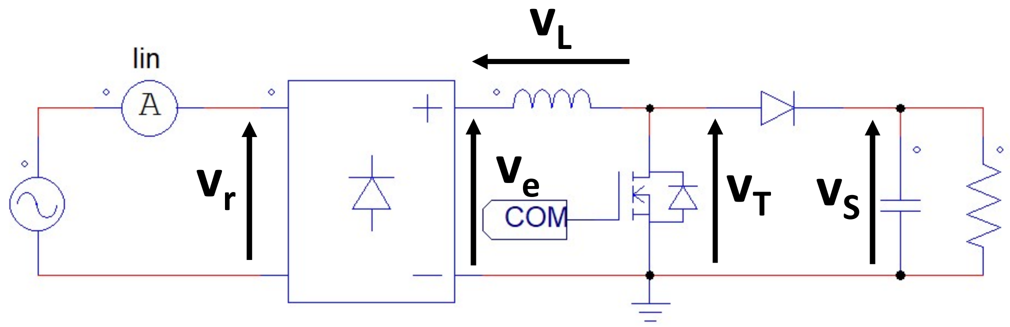
PWM control



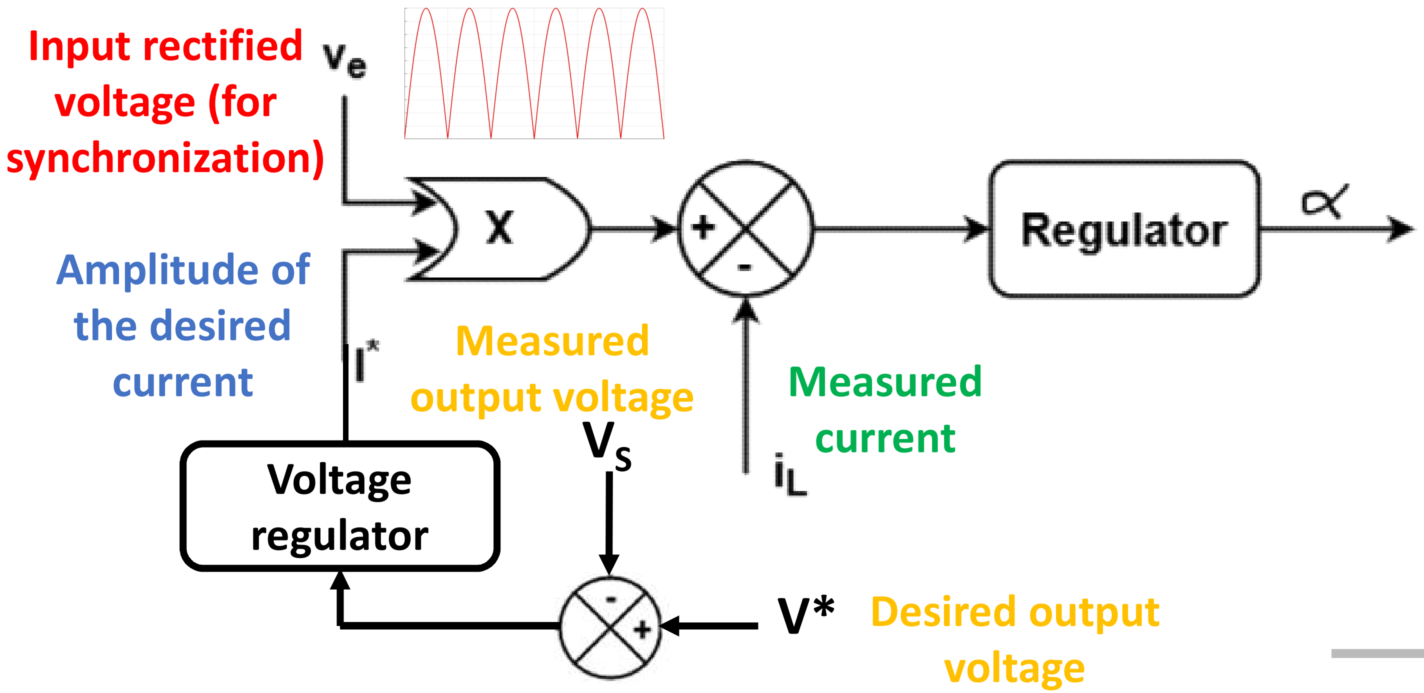
- $v_L = v_e - v_T = V\sqrt{2}.|\sin(\theta)| - (1-\alpha)V_S = L\dfrac{di_L}{dt}$

- We want $I_{in} = I.\sqrt{2}\sin(\theta)$
  - ➢ $i_L = I.\sqrt{2}.|\sin(\theta)|$
- For $0 < \theta < \pi$:
  - ➢ $1 - \alpha = \dfrac{V\sqrt{2}}{V_S}.\sin(\theta) - \dfrac{L.2\pi f_{LF}.\mathrm{I}\sqrt{2}}{V_S}\cos(\theta)$
  - ➢ $\alpha = 1 - \dfrac{V\sqrt{2}}{V_S}.\left(\sin(\theta) - \dfrac{2\pi L f_{LF}.P}{V^2}\cos(\theta)\right)$

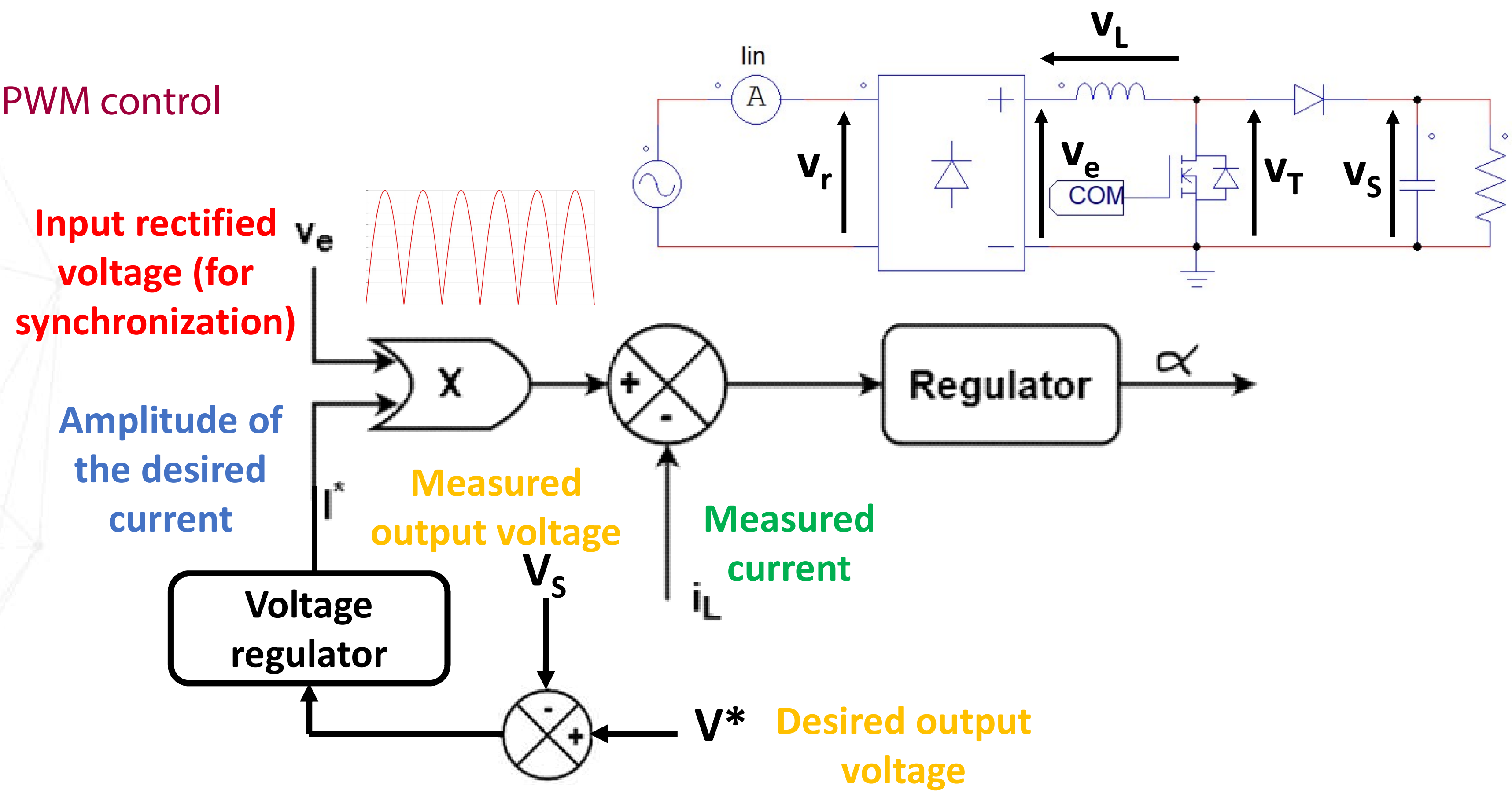
PWM control



$$\alpha = 1 - \frac{V\sqrt{2}}{V_S}.\left(\sin(\theta) - \frac{2\pi L f_{LF}.P}{V^2}\cos(\theta)\right)$$



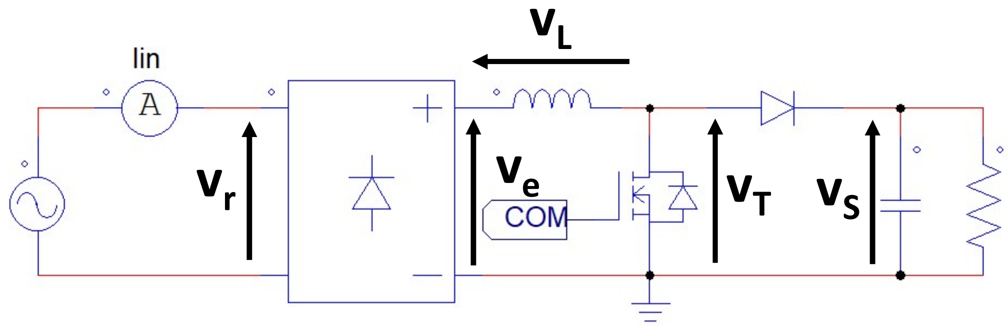
PWM control



Condition: voltage control « slow » (few Hz) to ensure sinusoidal current

Filter the output voltage for measurement (sample at $2f_{BF}$, band-stop filter, high output capacitor)

PWM control: components sizing



- Semi-conductors

$$< i_D > = \frac{P}{V_S} \qquad < i_T > = < i_L > - < i_D > = \frac{P}{V_S}\left(\frac{4}{\pi}\frac{V_S}{V\sqrt{2}} - 1\right)$$

$$I_{T\ RMS} = \frac{P}{V}\sqrt{1 - \frac{8.V\sqrt{2}}{3\pi V_S}} \qquad I_{D\ RMS} = \frac{P}{V}\sqrt{\frac{8.V\sqrt{2}}{3\pi V_S}}$$

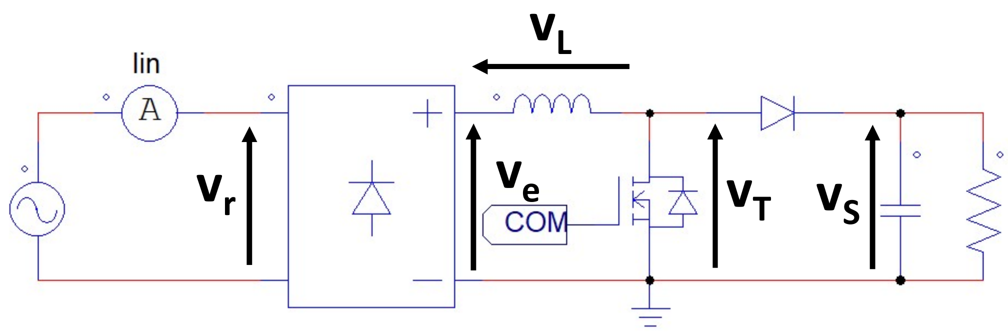
- Output capacitor

$$\Delta V_{S\ BF} = \frac{P}{2\pi f_{BF} C V_S} \qquad I_{C\ RMS} = \frac{P}{V_S}\sqrt{\frac{16.V_S}{3\pi V\sqrt{2}} - 1}$$

- Input inductor: limit the current ripple due to switching BUT small voltage drop

$$\Delta i_{HF} = \frac{V_S}{4 L f_{HF}} \qquad \frac{V}{2\pi I f_{BF}} \gg L > \frac{V_S}{4 f_{HF} \Delta i_{HF}} \qquad I_{L\ RMS} = \frac{P}{V}$$

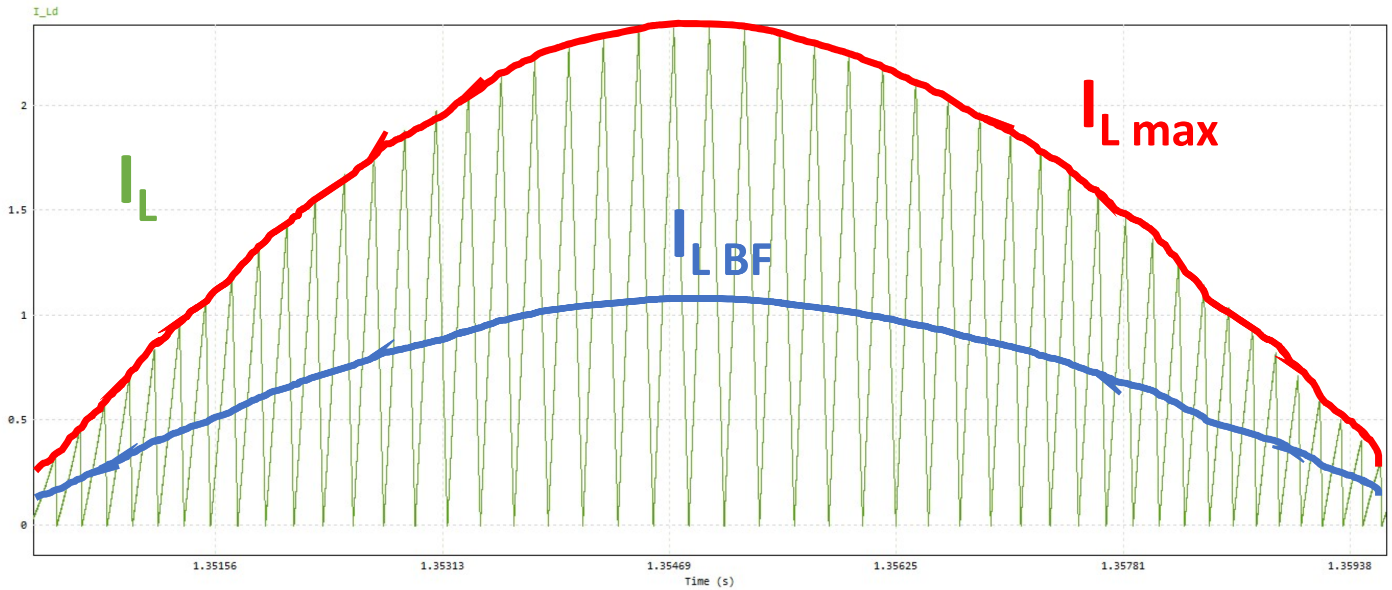
Hysteresis control



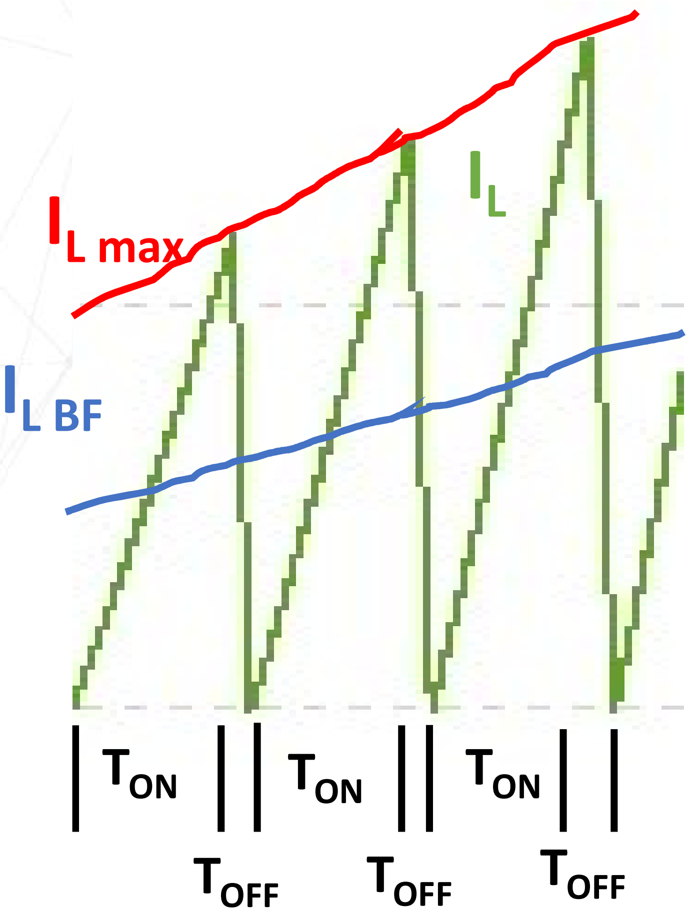
PWM control: need a current regulator to follow a sinus input

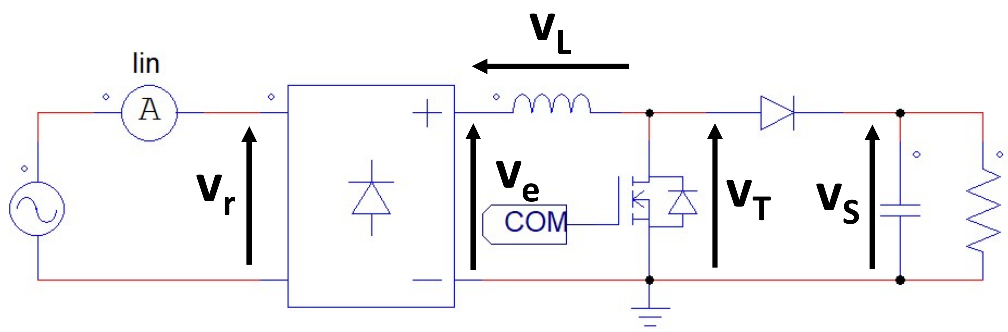
- Complicated to design the regulator

- Hysteresis control



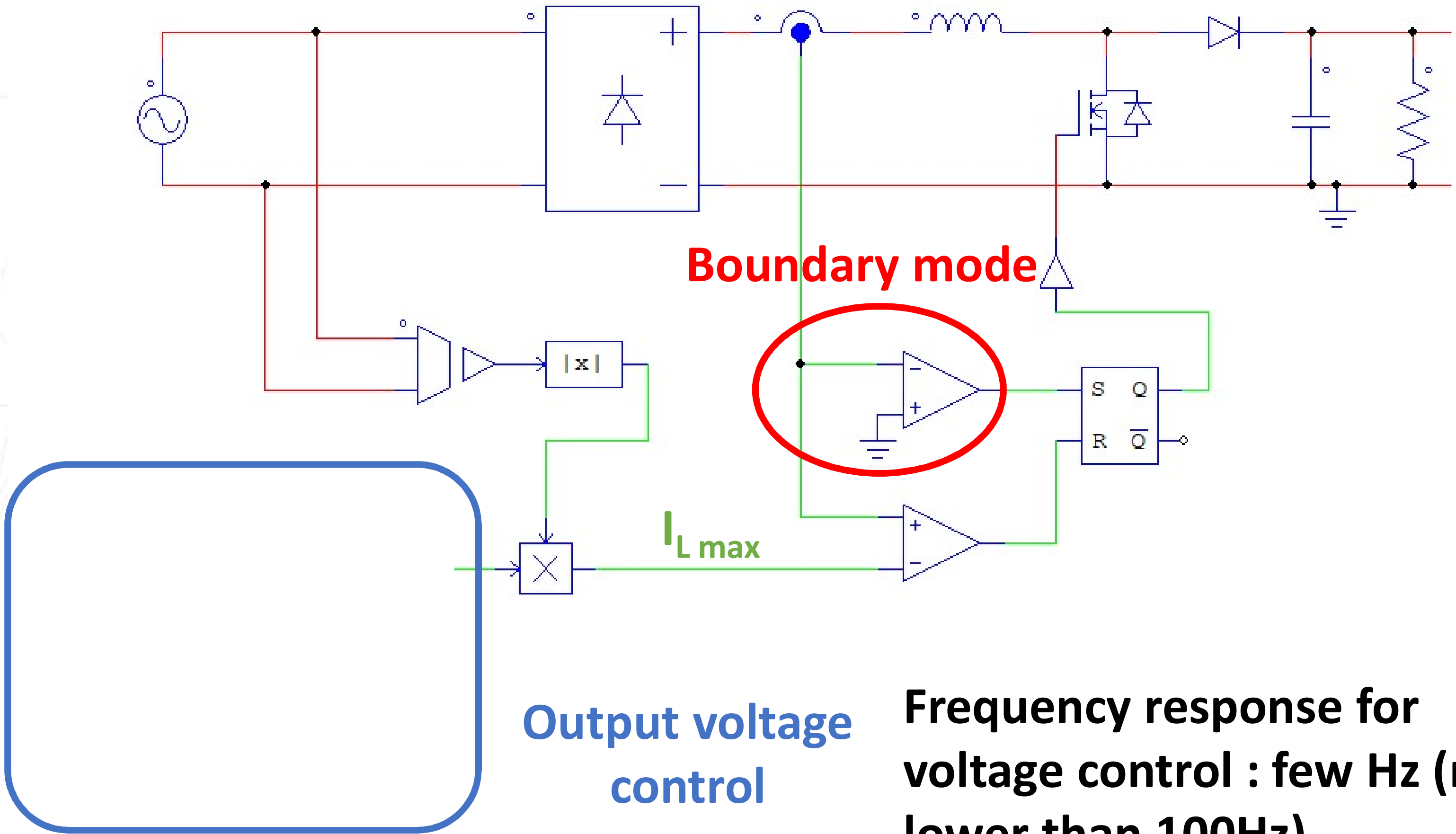
Hysteresis control





- $I_{L\,max} = \frac{V_e}{L} t_{ON} = 2 I_{L\,BF} = 2I\sqrt{2}|\sin(\theta)|$
  - ➢ $t_{ON} = \frac{2LI}{V} = \frac{2LP}{V^2} = cst$
- $t_{OFF} = t_{ON}\frac{1-\alpha}{\alpha} = t_{ON}\frac{V_e}{V_S - V_e}$
  - ➢ $f_{HF} = \frac{1}{t_{ON}+t_{OFF}} = \frac{1}{t_{ON}}\left(1 - \frac{V\sqrt{2}}{V_S}|\sin(\theta)|\right)$
- $f_{HF\,min} = \frac{1}{t_{ON}}$
- $f_{HF\,max} = \frac{1}{t_{ON}}\left(1 - \frac{V\sqrt{2}}{V_S}\right)$

Hysteresis control



Output voltage control

Frequency response for voltage control : few Hz (much lower than 100Hz)

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Example: LED driver

Introduction

Boost

Structure

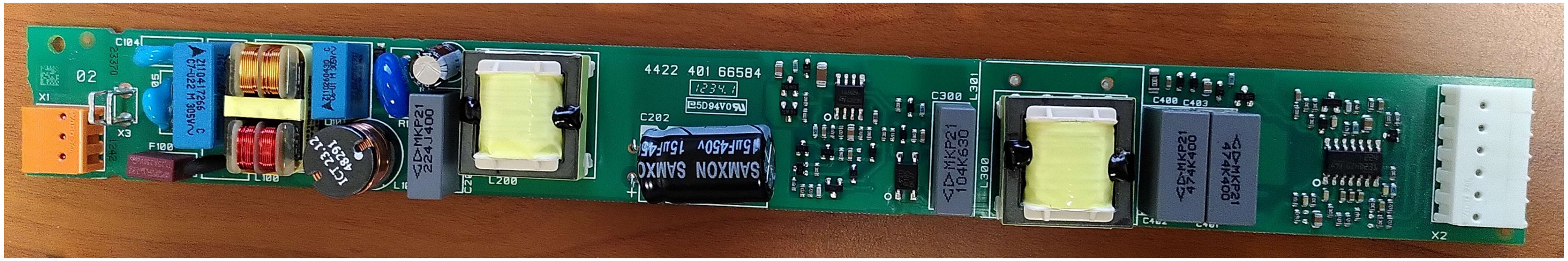
PWM control

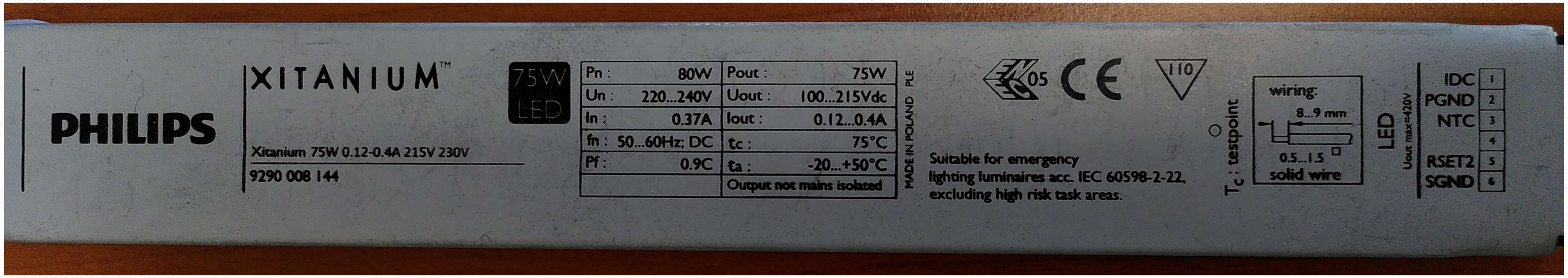
Hysteresis control

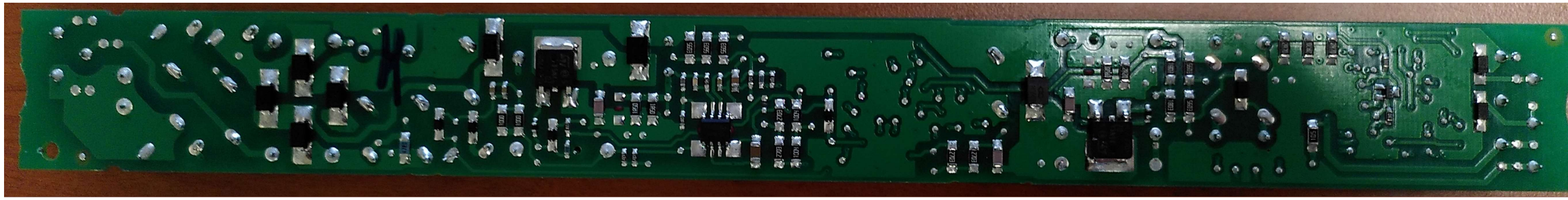
Flyback

Example of converter

Example: LED driver







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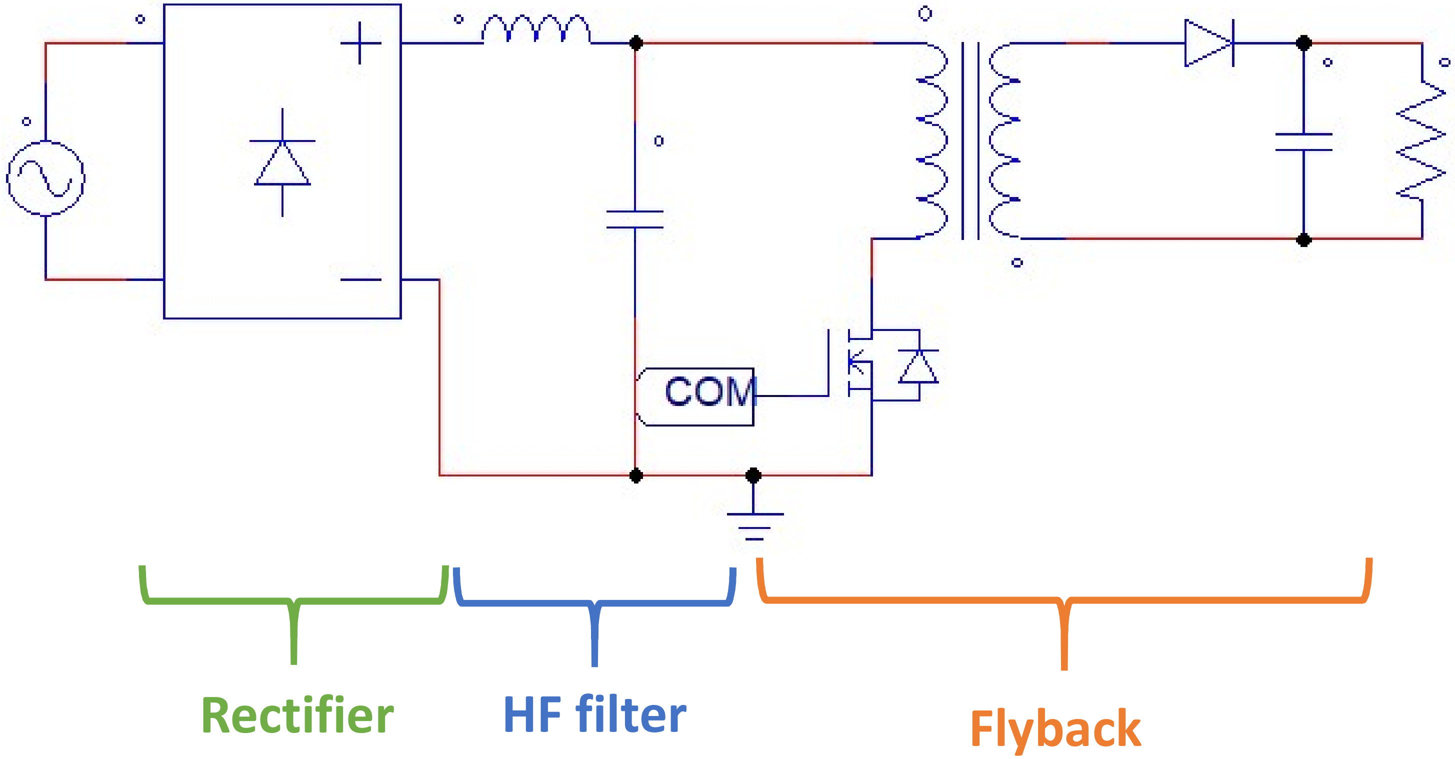
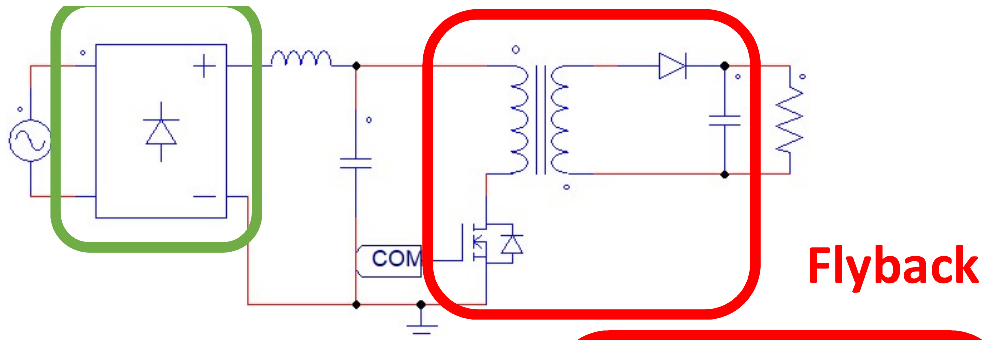
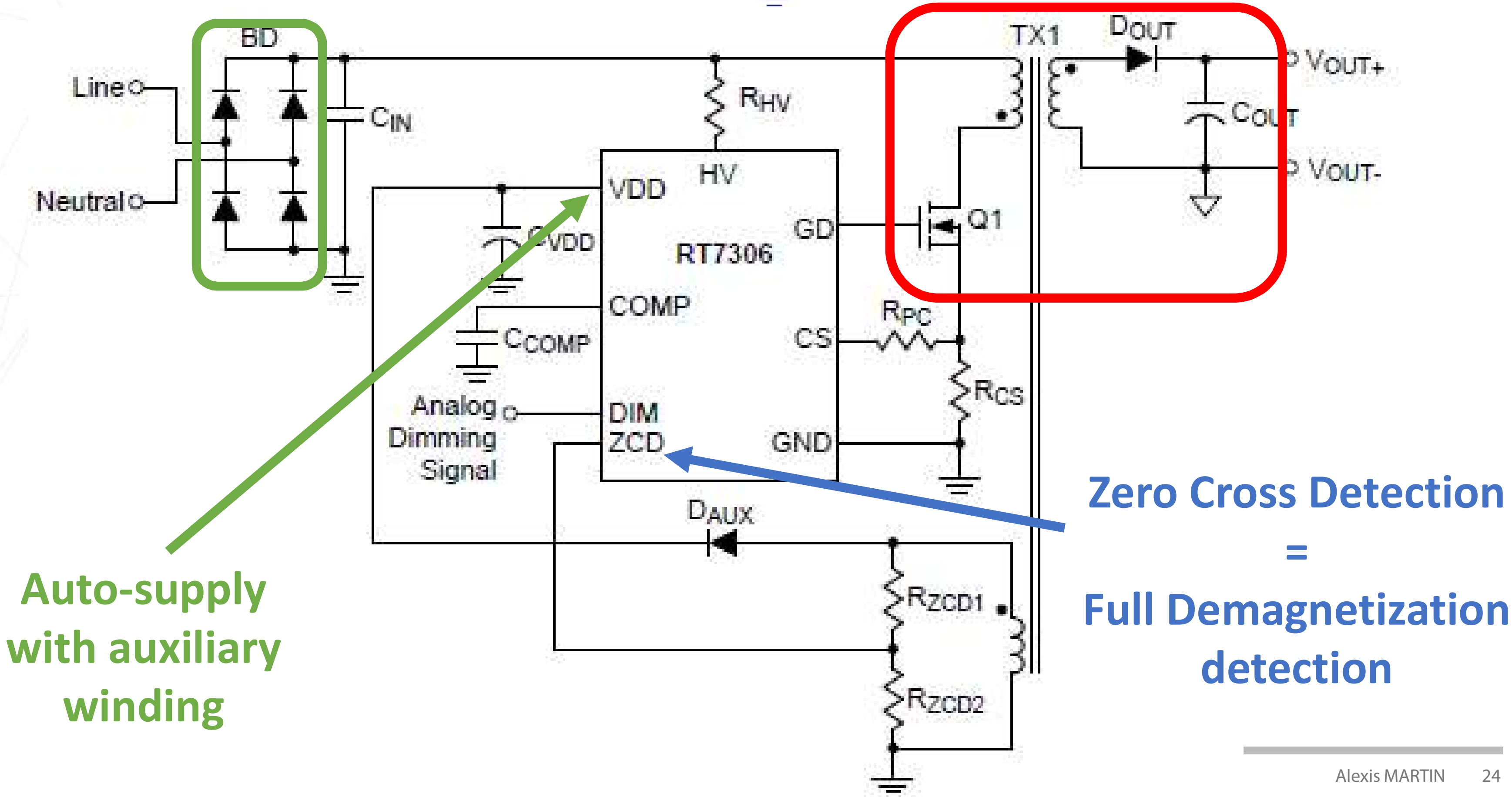
Flyback for PFC

Structure



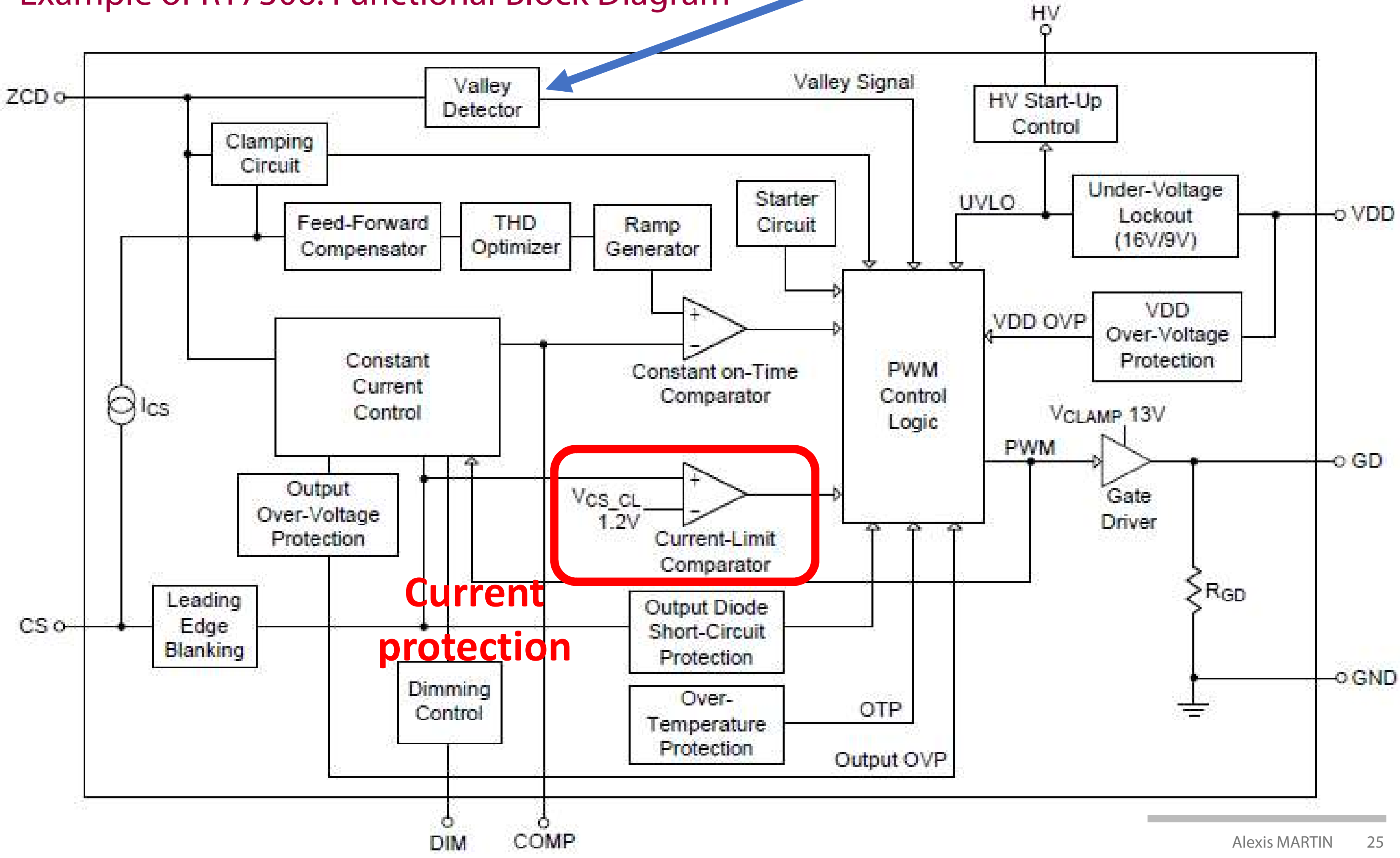
Example of RT7306
(LED driver)



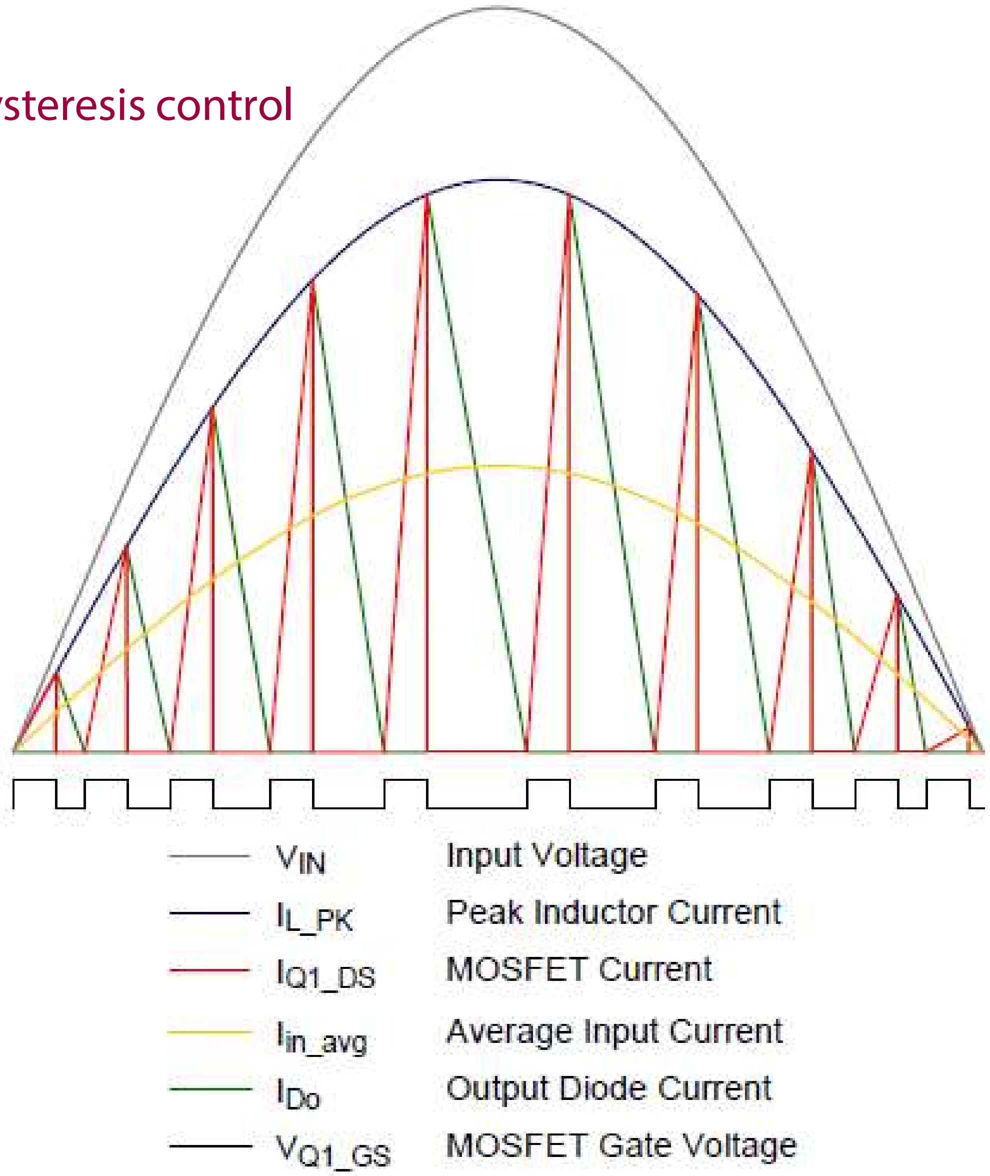


Example of RT7306: Functional Block Diagram

Full demagnetization detection



Hysteresis control



$$I_{L\_PK} = \frac{V_{IN}}{L_m} \times t_{ON}$$

$$I_{L\_PK} = \frac{V_{IN\_PK} \times |\sin(\theta)| \times t_{ON}}{L_m}$$

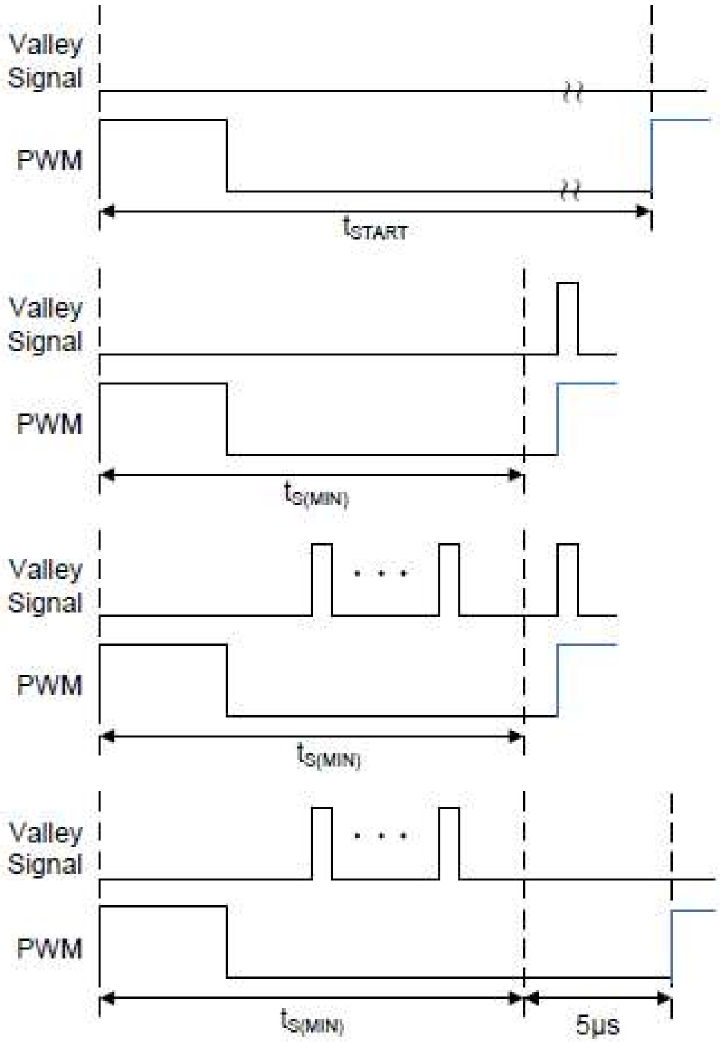
Introduction

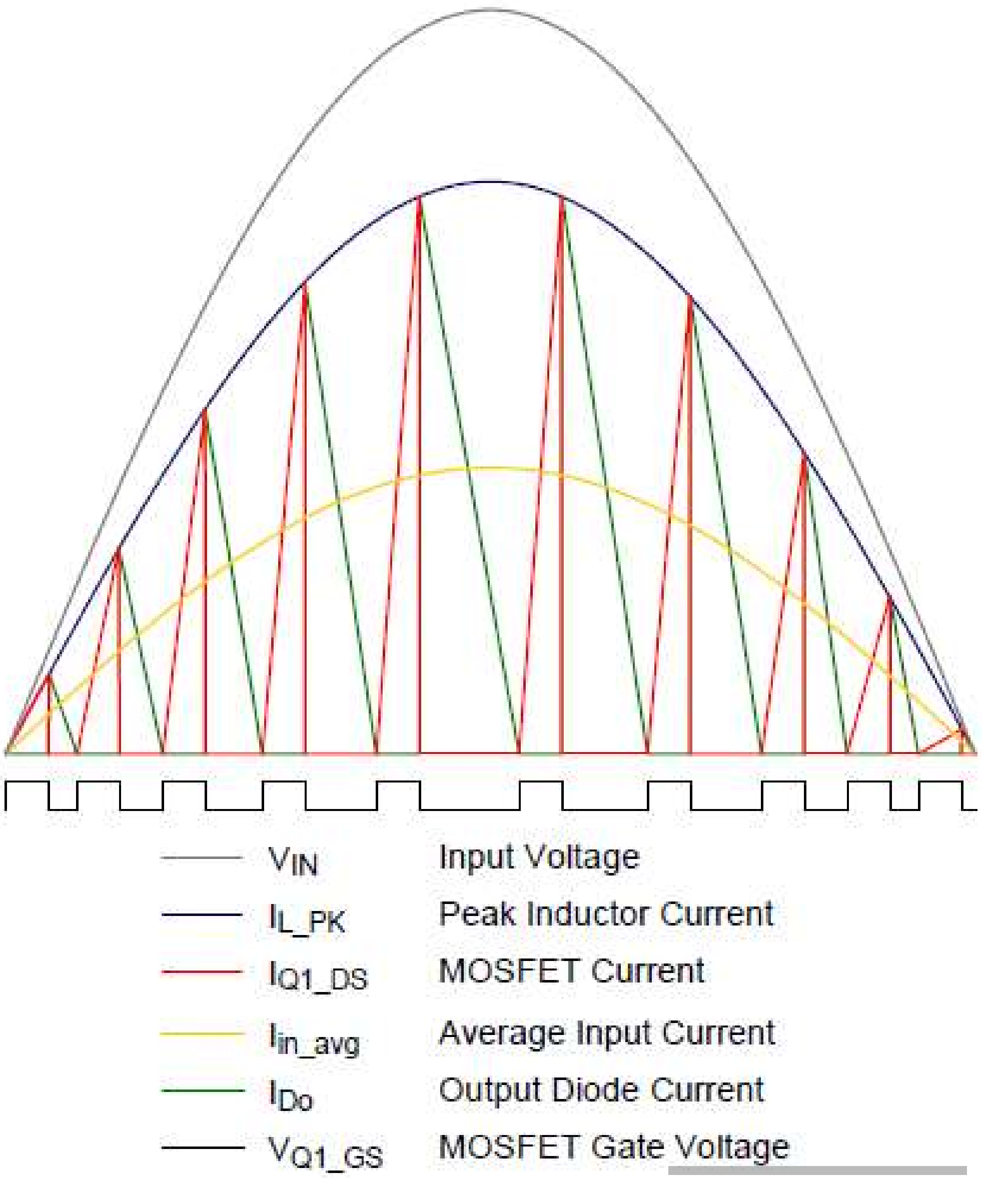
Boost

Flyback
Structure
Example of RT7306
Control

Example of converter

Constant on-time control





Example of a full converter

Example: EVL400W-80PL

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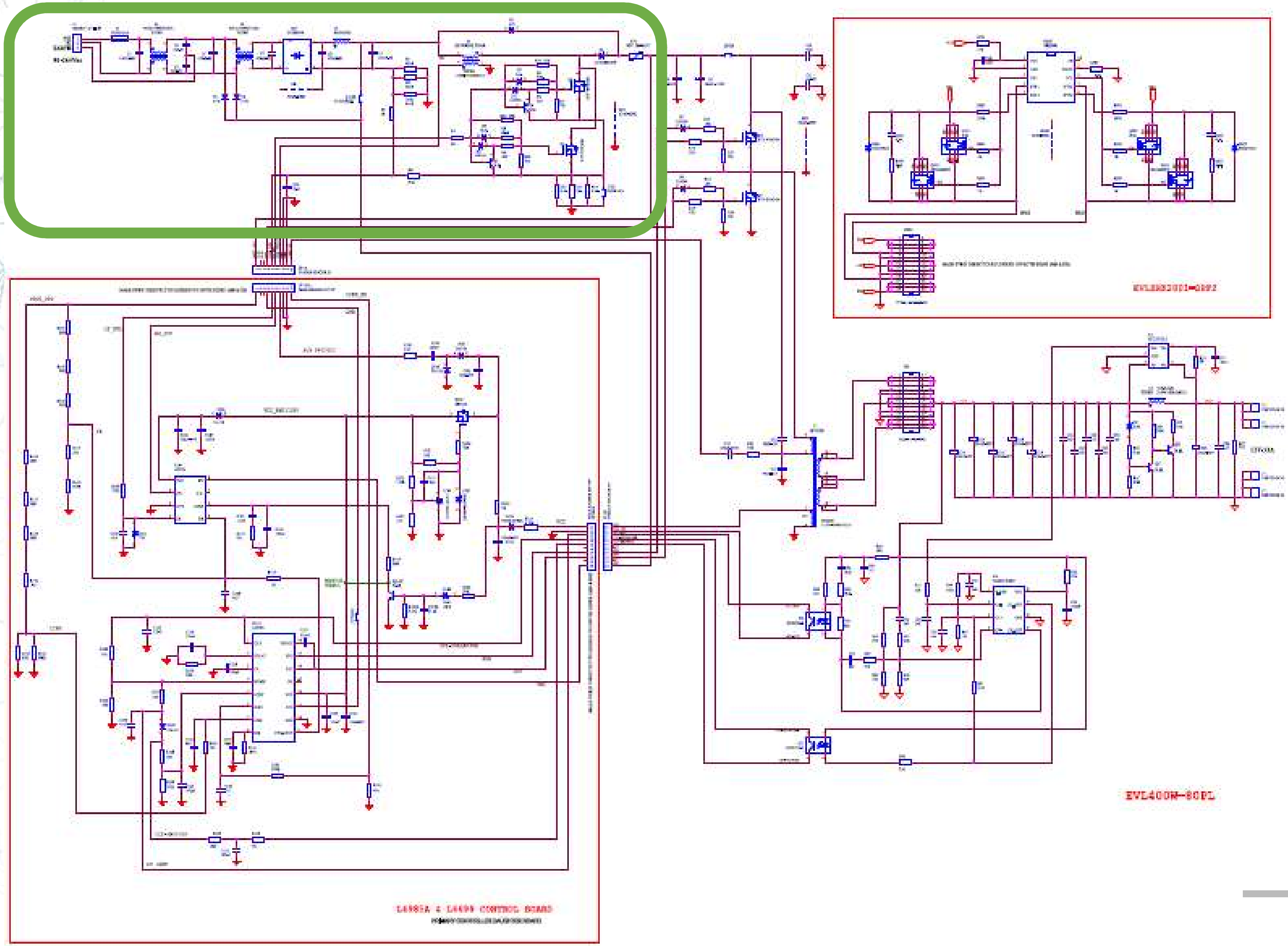
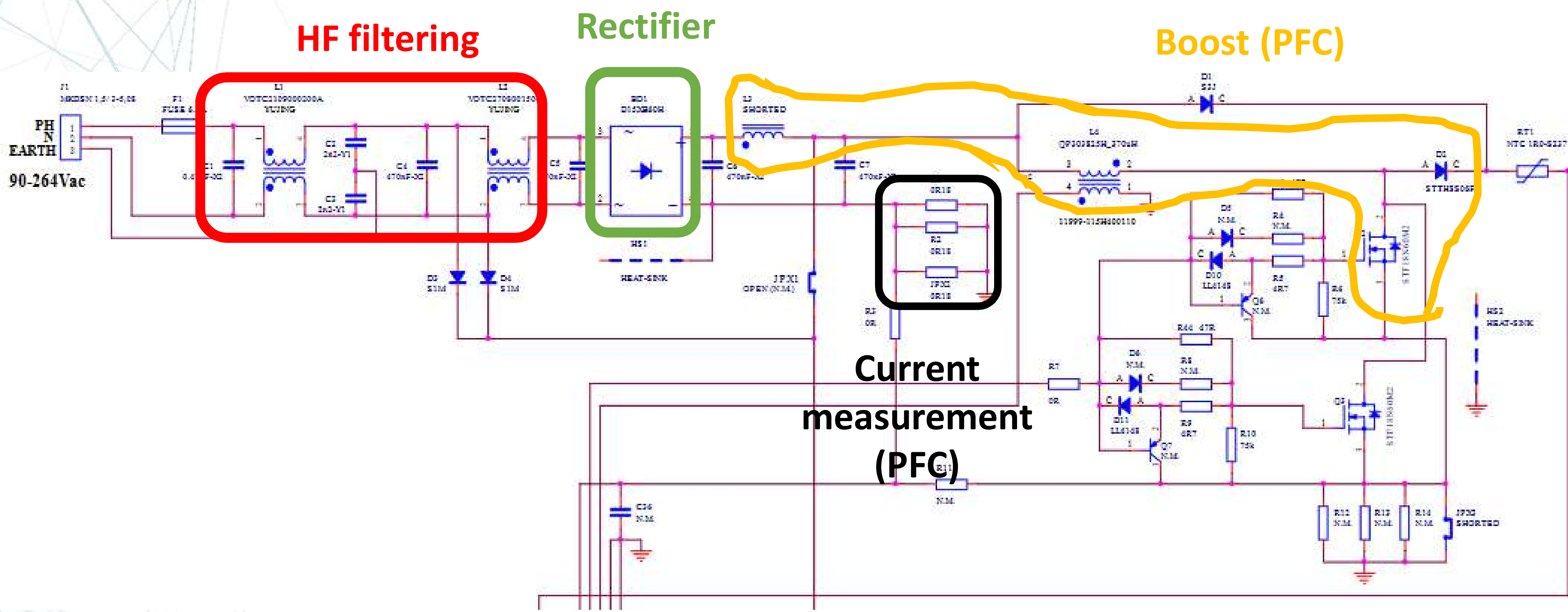
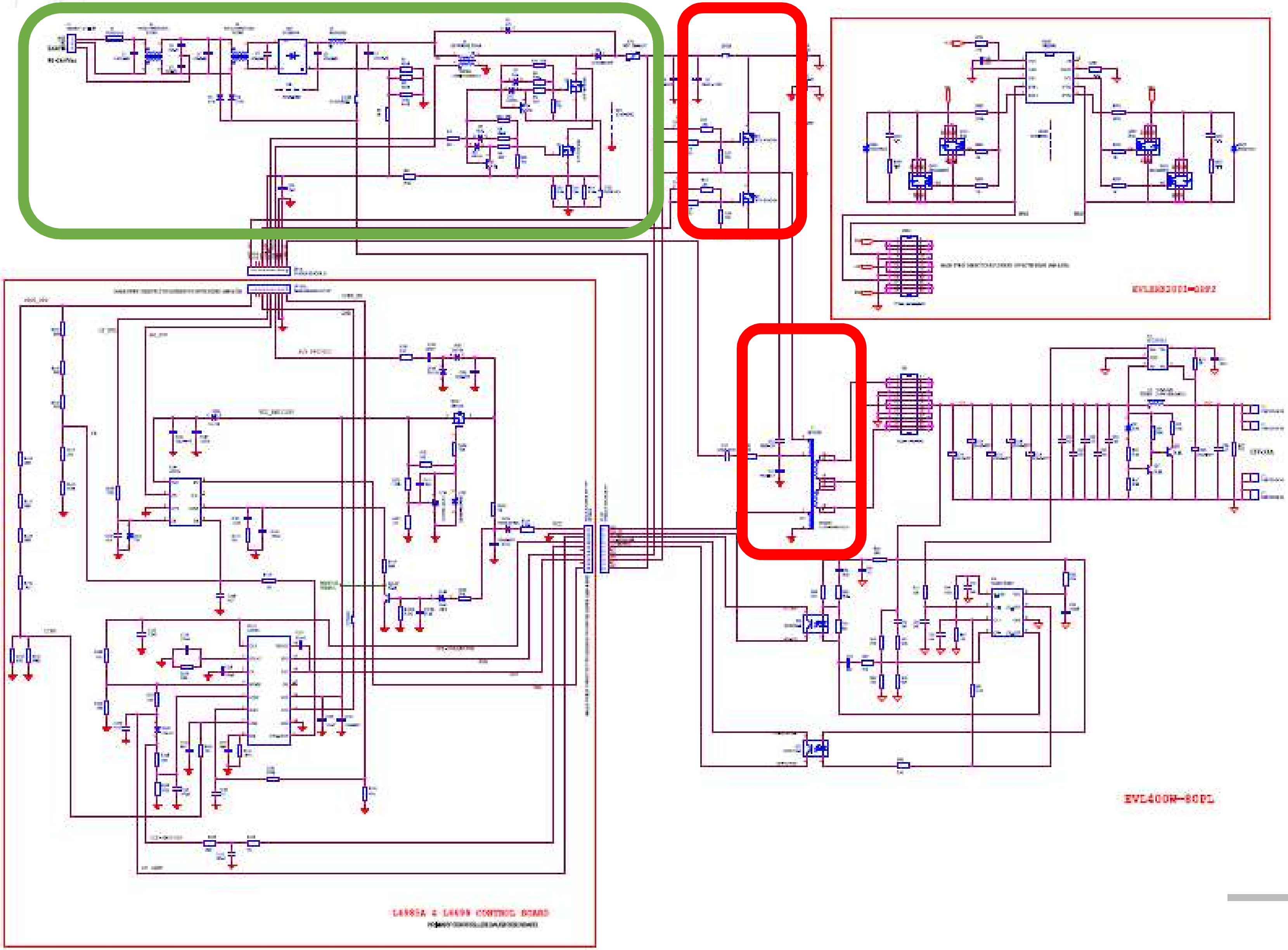
Example: EVL400W-80PL

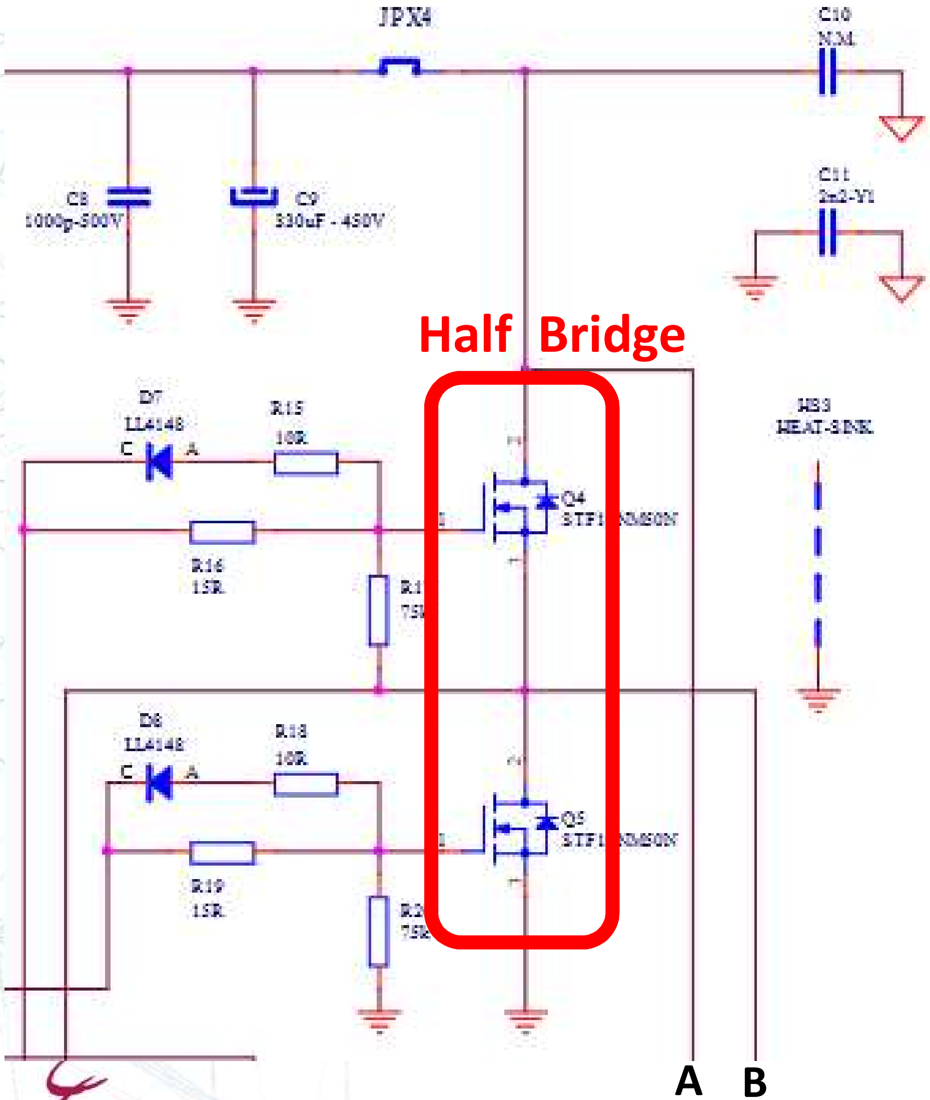
The architecture is based on a two-stage approach: a front-end PFC pre-regulator based on a CCM (Continuous Conduction Mode) boost PFC controller using the L4985A, and a downstream LLC resonant half-bridge converter, designed around the L6699.

- Universal input mains voltage range: from 90 Vac to 264 Vac – frequency from 45 to 65 Hz
- Output voltage: 12 V at 33 A continuous operation
- Overall efficiency at full load: > 89%, according to ENERGY STAR® 6.1 limit for computer and compliant with 80Plus PLATINUM level
- Average efficiency: > 89%, according to European CoC ver. 5 Tier 2 for external power supplies
- Efficiency at 250 mW > 50%, compliant to EuP lot 6 Tier 2 limit for household and office equipment
- No load mains consumption: < 150 mW at 230 Vac, below European CoC ver. 5 Tier 2 limit for external power supplies
- Mains harmonics: meets EN-61000-3-2 Class-D and JEITA-MITI Class-D
- EMI: according to EN55022 Class-B
- Safety: meets EN60950 standards
- RoHS compliant

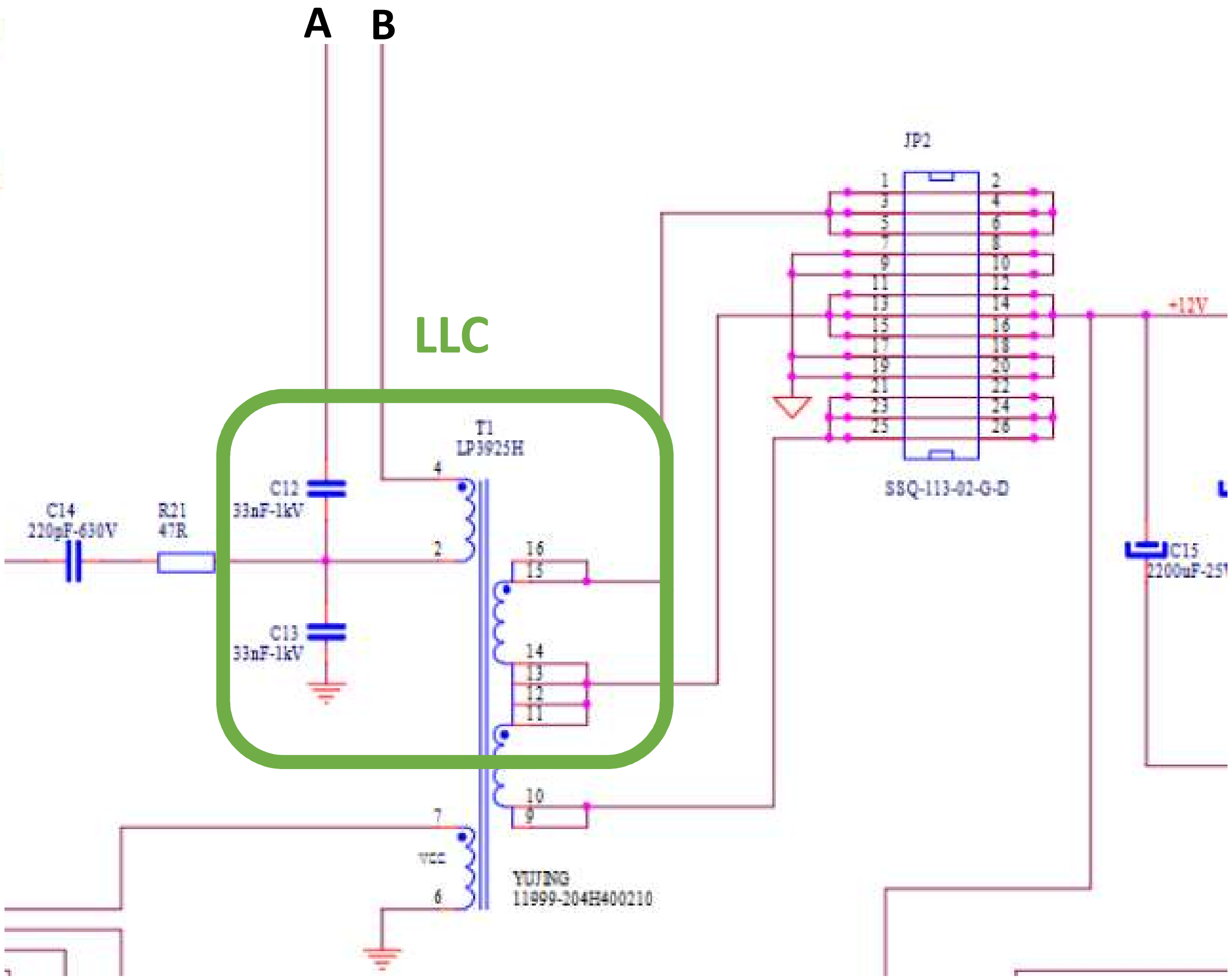

L6591A & L6699 CONTROL BOARD
EVL400W-80PL


HF filtering
Rectifier
Boost (PFC)
Current measurement (PFC)
PH
N
EARTH
90-264Vac
HEAT-SINK
STTH5S06F
HEAT-SINK
SHORTED

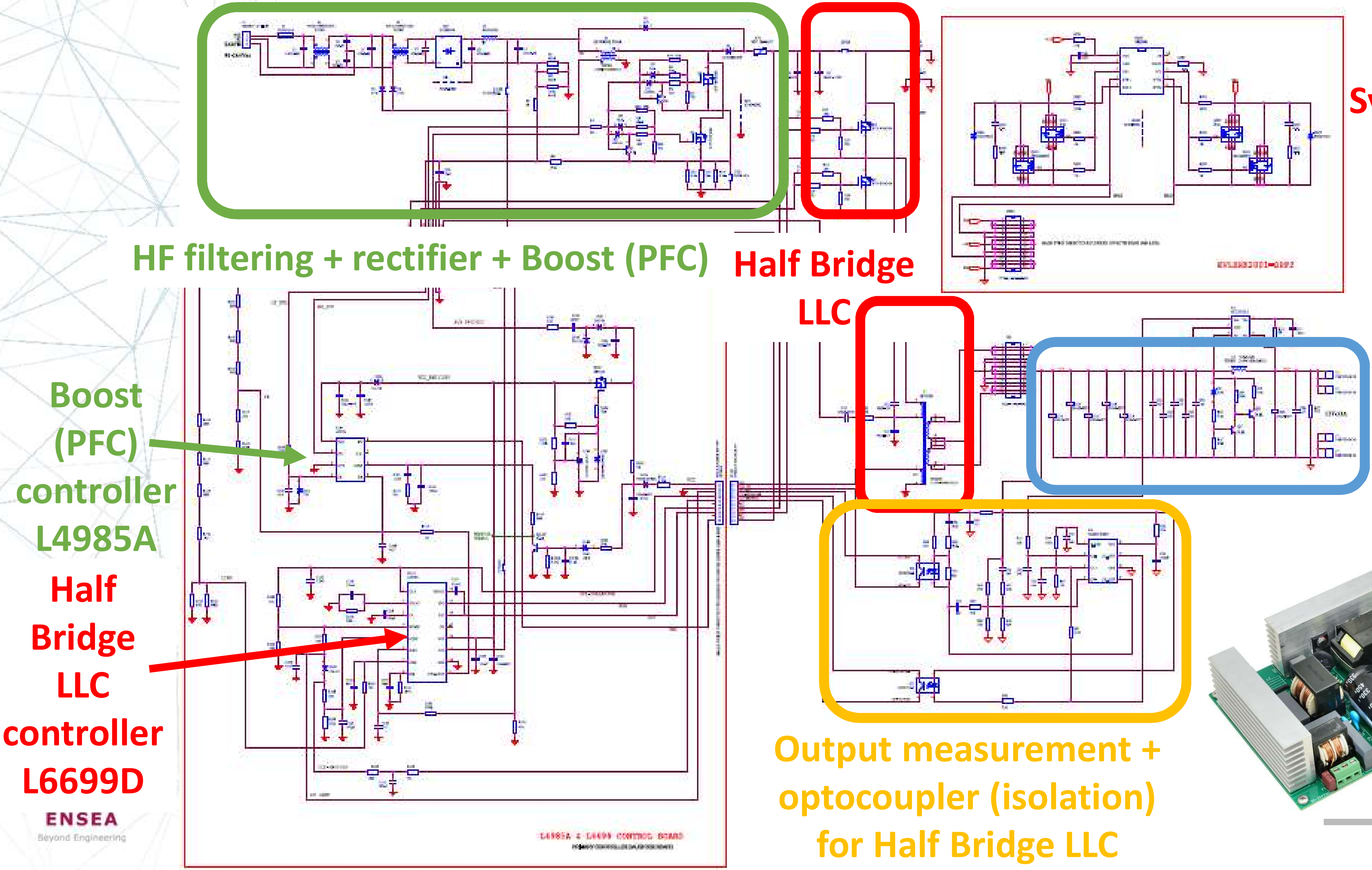

L6599A & L6699 CONTROL BOARD
EVL400W-80DL



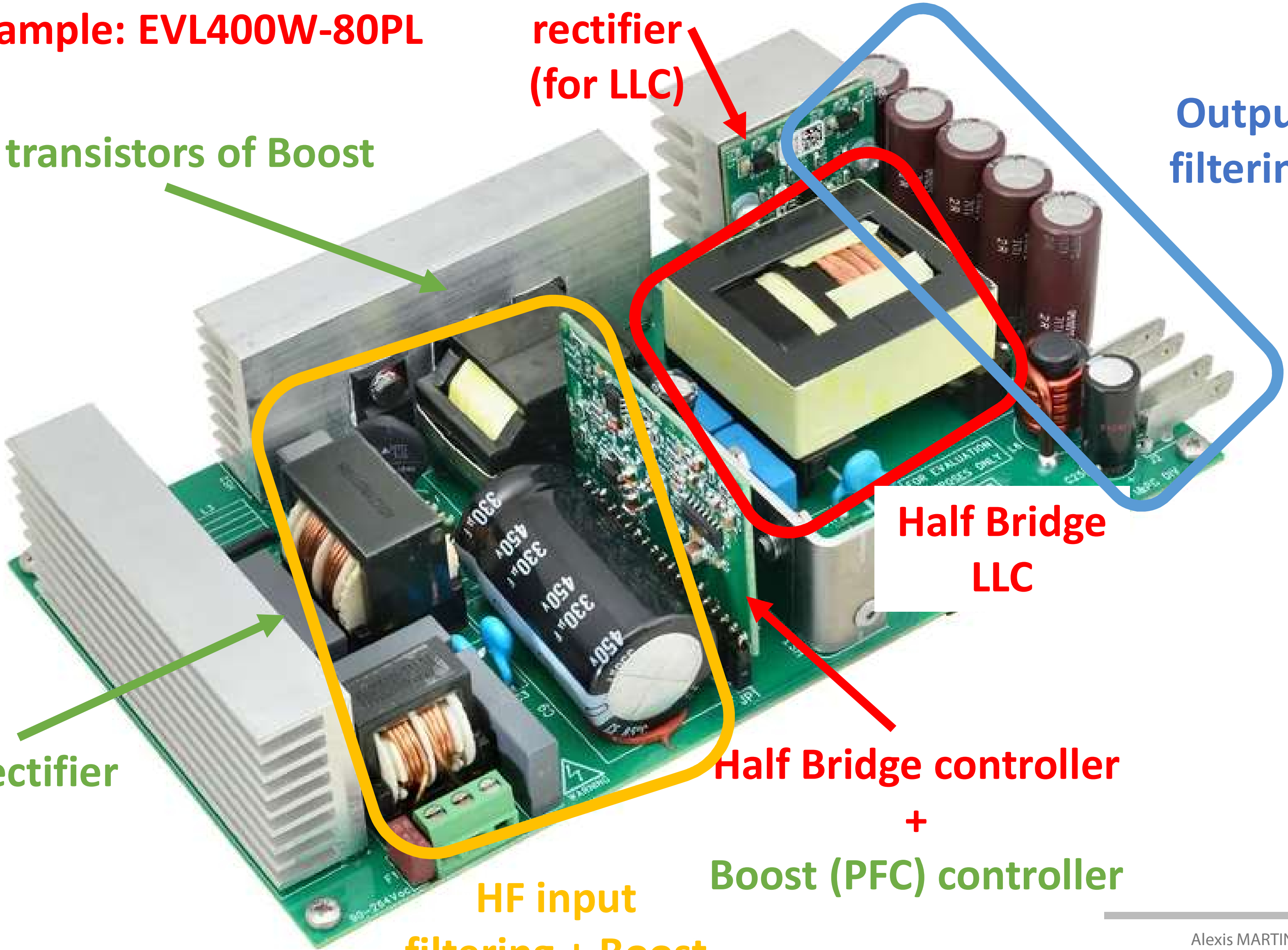
JPX4
C10
N.M.
C8
1000p-500V
C9
330uF - 450V
C11
2n2-Y1
Half Bridge
D7
LL4148
R15
10R
R16
15R
Q4
HS3
HEAT-SINK
D8
LL4148
R18
10R
R19
15R
Q5
A
B



A
B
JP2
LLC
T1
LP3925H
C12
33nF-1kV
C13
33nF-1kV
C14
220pF-630V
R21
47R
SSQ-113-02-G-D
C15
+12V
YUJING
11999-204H400210


HF filtering + rectifier + Boost (PFC)
Half Bridge LLC
Synchronous rectifier (for LLC)
Boost (PFC) controller L4985A
Half Bridge LLC controller L6699D
Output filtering
Output measurement + optocoupler (isolation) for Half Bridge LLC

Example: EVL400W-80PL



Example: EVL400W-80PL