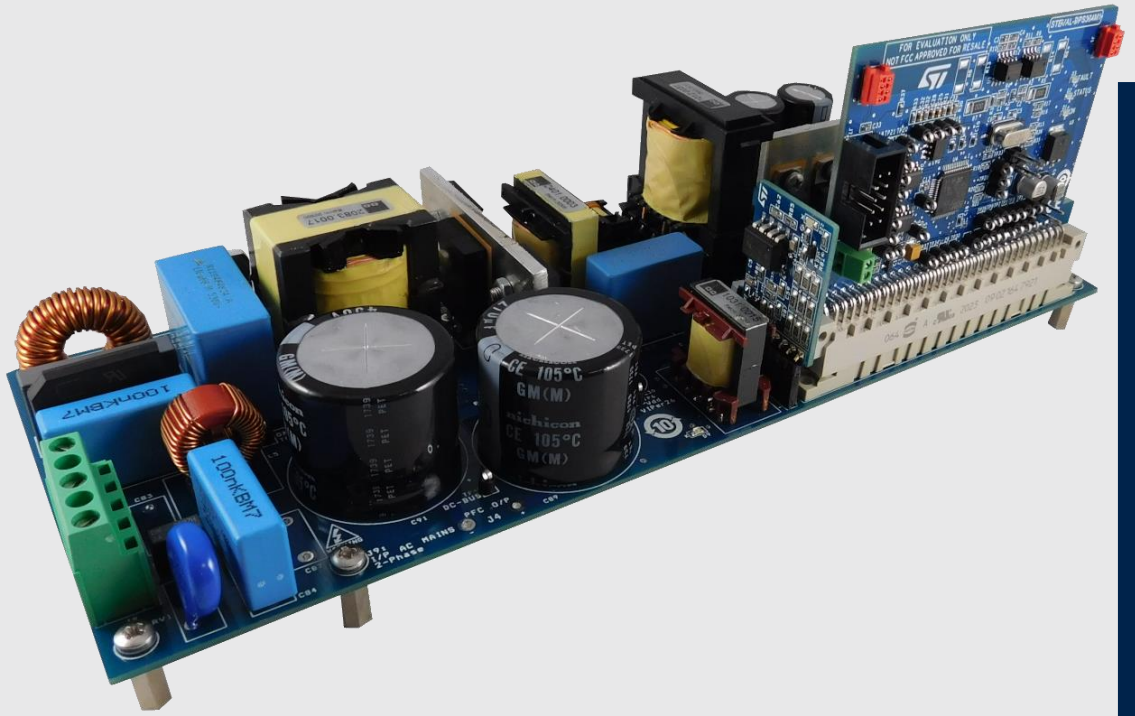

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STEVAL-LLL009V1

300 W very high AC input voltage LED driver with digital power control

System Research and Application

Agenda

1. Introduction
2. Specification and outline
3. Architecture & key products
4. Key products overview
5. LCC topology fundamentals and synchronous rectification
6. Efficiency, operative performance
7. FW architecture
8. Schematics & layout

Introduction

Introduction

A digitally-controlled 300 W power supply

Configuration: PFC + DC-DC conversion + synchronous rectification

- PFC working in Transition Mode
- DC-DC conversion based on Half Bridge LCC resonant converter, controlled by MCU
- Synchronous rectification based on Full Bridge topology, controlled by MCU

The evaluation board can either work in **Constant Voltage (CV)** mode
or **Constant Current (CC)** mode

Design challenges

- Very high input voltage range: 270 V – 480 V AC
- THD @ Full load (270 V – 480 V AC): <10%
- Peak efficiency @ maximum load: >93.5%

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Specification and outline

STEVAL-LLL009V1 evaluation kit Specification and features

- **Configuration**: PFC + HB-LCC + FB-Sync. Rectification

- **Input voltage range**: 270 V – 480 V AC
- **PFC output voltage**: 725 ± 2.5%
- **PFC operating mode**: Transition Mode

- **Power factor @ Full load (270 V–480 V AC):** > 0.95
- **Power factor over input voltage span 270 V–480 V AC:** > 0.9 for Load > 33% of Maximum Load

- **THD @ Full load (270 V – 480 V AC):** <10%
- **THD over input voltage span 270 V – 480 V AC:** < 20% for Load > 25% of maximum load

- **Peak efficiency @ maximum load:** >93.5%

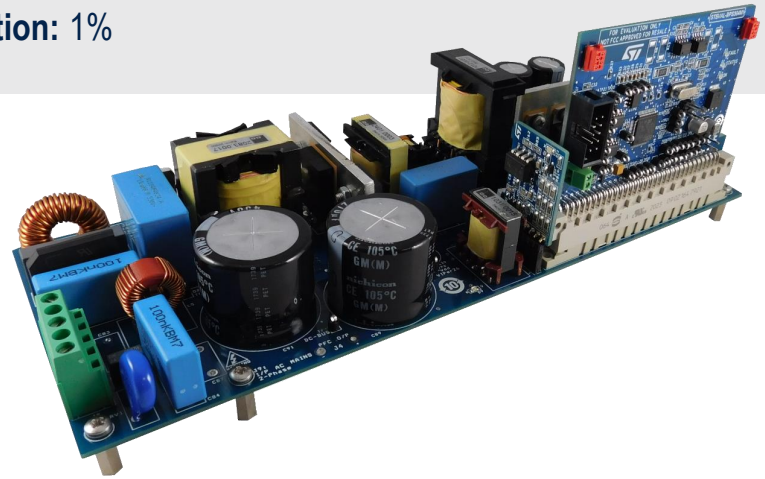
- **Maximum output power:** 300 W
- **Output configuration:** Constant Voltage (CV) or Constant Current (CC)
- **Output:** Constant Voltage (CV) Mode: 48.5 V ± 1% with maximum of 6.25 A
- **Output:** Constant Current (CC) Mode: 6.25 A ± 2.5% with output voltage ranging from 36 V to 48 V

- **DC-DC converter topology:** Half bridge LCC resonant converter
- **Half bridge LCC resonant converter:** Closed loop switching frequency: 90 kHz to 275 kHz
- **Half bridge LCC resonant converter:** Start-up switching frequency: 280 kHz

- **Synchronous rectification topology:** Full bridge

- **HF transformer isolation:** 3 kV
- **Cooling:** Natural air

- **Dimming approach:** Analog dimming
- **Dimming control:** 0 - 10 V
- **Default brightness level:** 100%
- **Dimming resolution:** 1%



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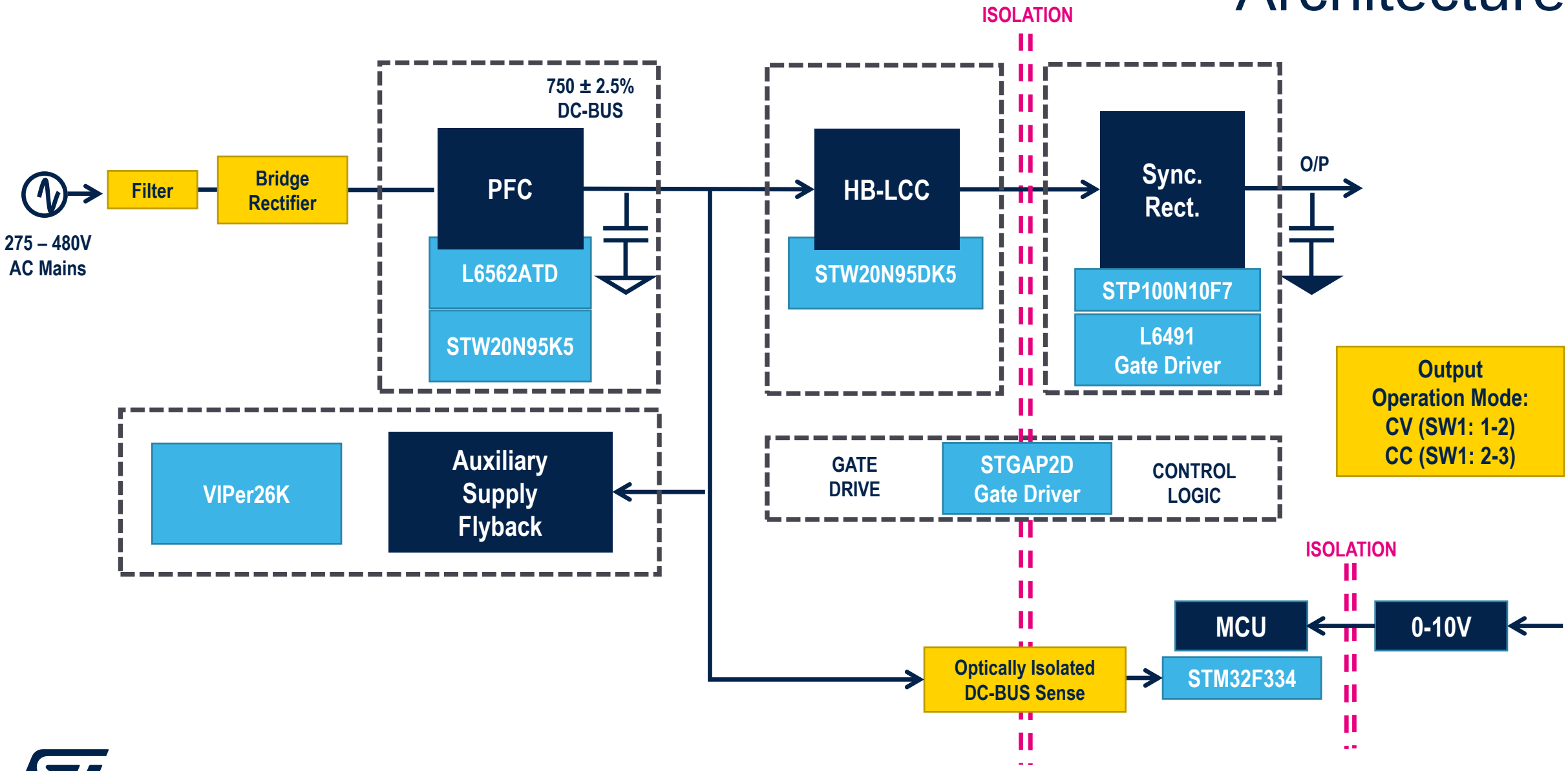
Architecture & key products

Architecture



STEVAL-LLL009V1 evaluation kit
Key products

STW20N95DK5 (MDmesh™ DK5 N-channel Power MOSFET)
STW20N95K5 (MDmesh™ K5 N-channel Power MOSFET)
STP100N10F7 (STripFET™ F7 N-channel Power MOSFET)

STM32F334R8 (Cortex-M4 32-bit CPU with FPU core)

STGAP2D (Isolated Half-Bridge Gate Driver)
L6491 (High Voltage High and Low-Side Gate Driver)
PM8841 (Low-Side Gate Driver)

VIPER267K (Auxiliary Supply: High Voltage Converter)

KF50BD-TR (Low Drop Voltage Regulators)

TSZ121 (Operational Amplifier)

STTH512 (Ultrafast Diode)
STTH112 (Ultrafast Diode)
STTH1L06 (Low Drop Ultrafast Diode)
STPS3L60 (Power Schottky Diode)

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Key products overview

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Control unit & gate driving

STM32F334
32-bit Microcontroller

- Cortex-M4 at 72MHz (90DMIPS)
- HRTIMER 10ch - 217ps (4.6GHz eq)
- High-speed ADCs and Built-in analog
- T° -40/105°C

LQFP32
LQFP48
LQFP64
UFQFPN32
WLCSP49

STGAP2D
Isolated half-bridge gate driver

- Functional Isolation 1700V
- 4 A Sink/Source current capability
- 3V3 / 5 V logic inputs
- Up to 26 V supply voltage

SO16

L6491
4 A half-bridge gate driver

- 600V Half Bridge
- Up to 4A gate driving current capability
- On Chip OpAmp
- Integrated Bootstrap Diode

PQFN 8x8
SO16

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F3 series STM32F334 – 64kB

Cortex-M4 at 72MHz (90DMIPS)

LQFP 32/48/64, T° -40..105°C

HRTIM timer is made of Hi-Resolution + Waveform Builder & Event Handler

- 217ps (4.6GHz eq.) high resolution guaranteed on all channels vs voltage, temperature or manufacturing deviation. 10-channels timer made of 6 timings units that can be cross-coupled or work independently
- Advanced PWM waveforms generation with SW minimized
  - Smart functions, such as a HW burst mode controller
  - One DMA channel per timer
  - One parameter modification can change multiple events (timer chaining)
- Complex event management: 10 external events inputs and 5 Fault inputs
- Numerous interconnect

High-speed ADCs for precise and accurate control

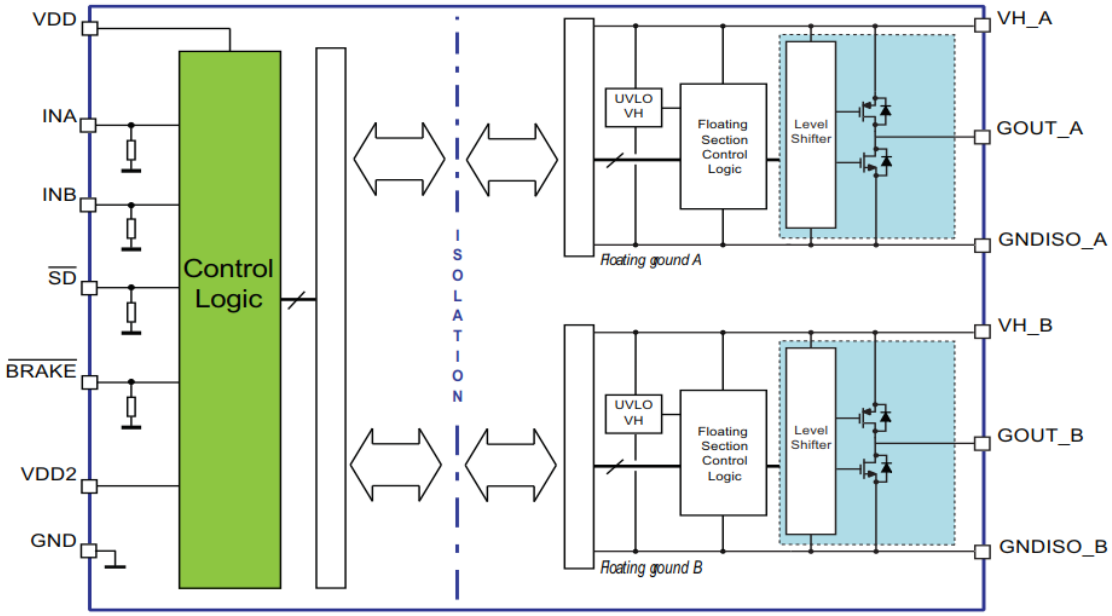
- 12-bit SAR – 5MSps, single-ended and diff. inputs
- Down to 21ns sampling time
- Multiple triggers for PWM

Built-in analog for protection and signal conditioning

- Ultra Fast comparators (26ns)
- Op-Amp with built in Gain (PGA)

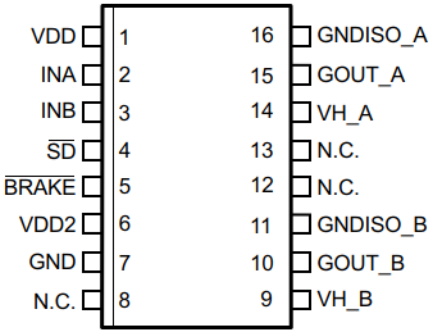
STGAP2D isolated half-bridge gate driver

Functional Isolation 1700 V, 4 A half-bridge gate



- 3V3 / 5 V logic inputs (logic thresholds 1/3, 2/3 of VDD)
- **Up to 26 V supply voltage**
- **4 A Sink/Source current capability**
- Short propagation delay: 80 ns
- UVLO Function
- Stand-by function
- 100 V/ns CMTI
- Functional Isolation up to 1700 V
- Temperature shut-down protection

- Single input pin, in phase with output
- Shut-Down SD pin, with integrated pull-down
- BRAKE pin
- Interlocking
- Negative gate drive ability
- SO16 Package



Key applications

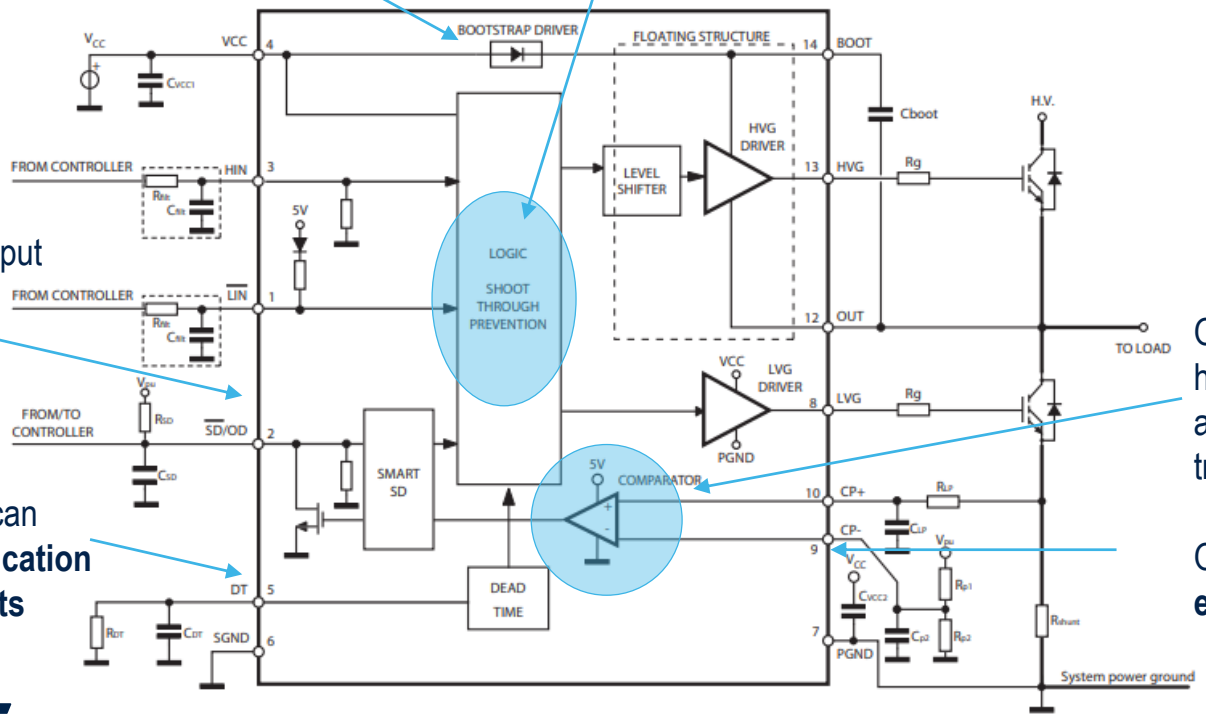
- Motor control
- Factory automation
- Industrial drives and fans
- DC-DC converters
- Induction heating
- Welding

L6491 half-bridge gate driver

4 A half-bridge gate drivers

Embedded diode **reduces BOM**

Embedded features optimized for **F**ield **O**riented **C**ontrol **(F.O.C.)** applications



Shutdown input or **OCP indicator**

Dead Time can **match application requirements**

Overcurrent Protection has a **fast response** and information is transferred to controller

OCP Threshold is **externally settable**

- **600 V Half Bridge**
- **Up to 4A** gate driving current capability
- On-chip **OpAmp**
- Embedded **Comparator**
- Integrated **Bootstrap Diode**
- **Adjustable Dead Time**
- **Interlocking function**
- SO-14 Package

Key applications

- Home appliances
- Factory automation
- HID ballast
- DC-DC converters
- Induction heating
- UPS

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LCC power MOSFETs & auxiliary power supply

STW20N95DK5
N-channel power MOSFET

- Fast-recovery body diode
- V(BR)DSS = 950 V
- RDS(on) max. = 0.330 Ohm
- ID = 18 A

STPOWER

TO-247

Viper267K
High voltage converter

- 1050 V Avalanche Rugged Primary MOSFET
- Embedded HV Start Up (800 V)
- PWM Current Mode Controller
- IDLIM = 700 mA

VIPerPlus

SO16

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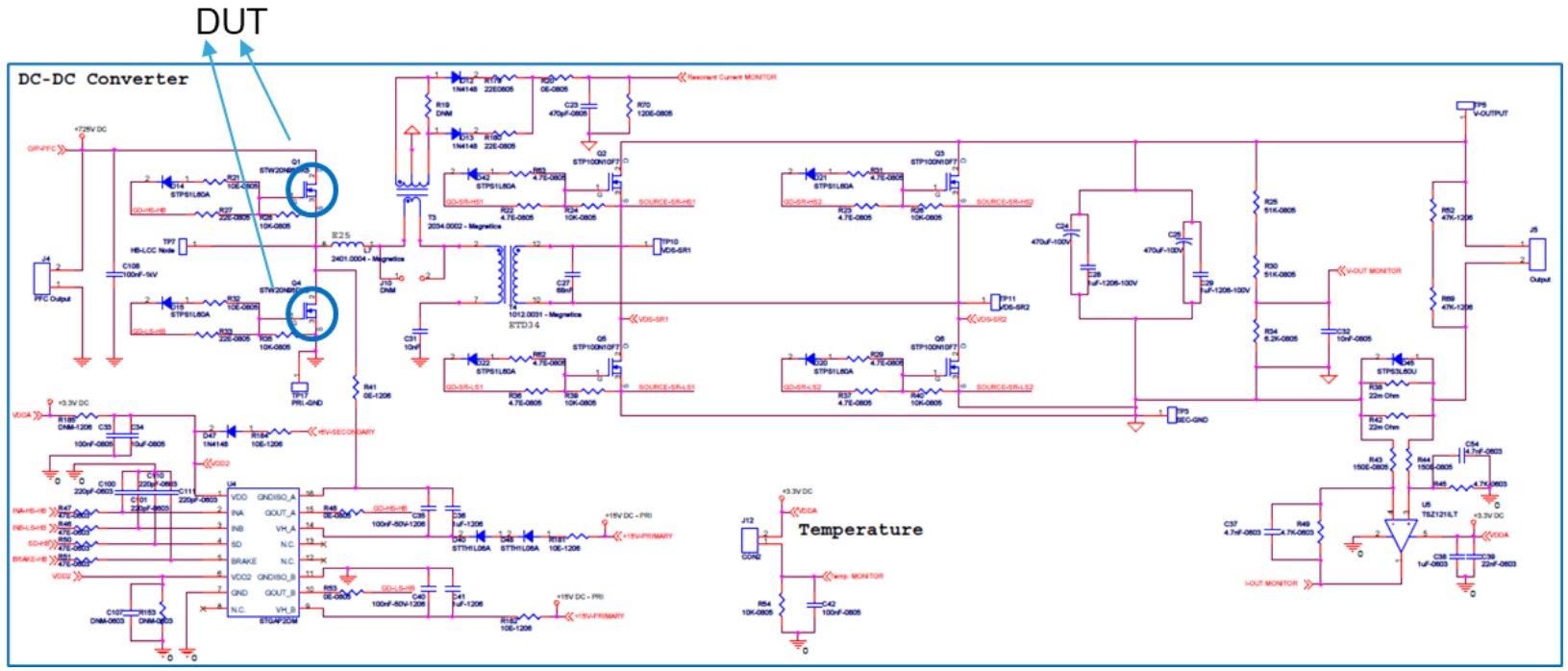
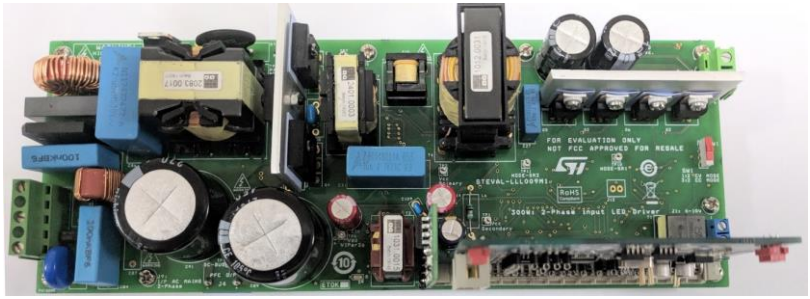
MDMesh DK5 STW20N95DK5
950 V, 330 mΩ, 18 A

STEVAL-LLL009V1: LCC Stage Electrical Schematic



- BVDSS 950V VHV Blocking Voltage
- Fast Recovery Body Diode
- Ideal for Bridge-based topology
- Extremely good Coss / Ciss profiles



Key applications

- Atmosphere Lighting
- Industrial Lighting
- Green House Lighting
- Hi-Bay Lighting
- Welding

NEW

VIPer26k

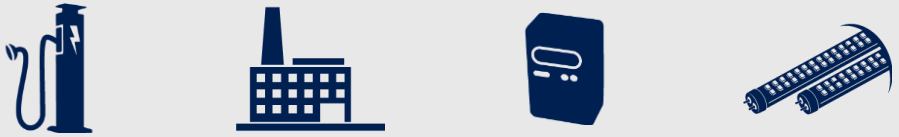
Make a robust SMPS for super wide range input

Key features

- 1050 V Avalanche Rugged integrated primary MOSFET
- Embedded HV start up (800V)
- PWM current mode controller
- Fixed frequency 60 with jittering
- Embedded E/A (3.3V reference voltage) for direct feedback using a resistor divider

	BV	Max R_{DSON}	ILIM	Fly Back
VIPER26K	1050V	8 W	500-700 mA	10W

Isolated and non-isolated auxiliary power supply



Versatile for key SMPS topologies

- Buck converter / inductor-based topology
- Fly-back in **primary side** w/o opto-coupler
- Fly-back isolated with opto-coupler

Benefits in applications

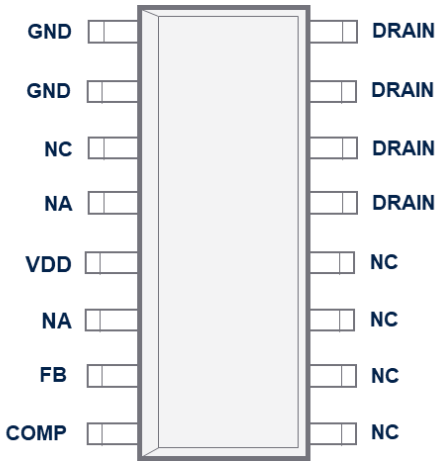
- **Easy compliance with IEC 61000-4-2/4/5 immunity test** (8kV Burst/ 2kV Surge, 20kV Air Elect. discharge, 10kV Contact discharge) Low Stand-by : 30mW @ 230VAC
- **Low Stand-by** : 30mW @ 230VAC
- **High efficiency at light load**
- **Reduced EMI filter** thanks to the jittering
- **Protections** : Short circuit, Open loop, Thermal shutdown
- **Current Limit options (500 and 700mA)** to limit the max power and optimize the inductor/transformer size.

Ecosystem

- eDesignSuite (Design, BoM , transformer design, Simulation)
- Spice Models
- Evaluation boards: Buck converter boards, Fly-back PSR isolated, Fly-back SSR Isolated

VIPer26k parameter table

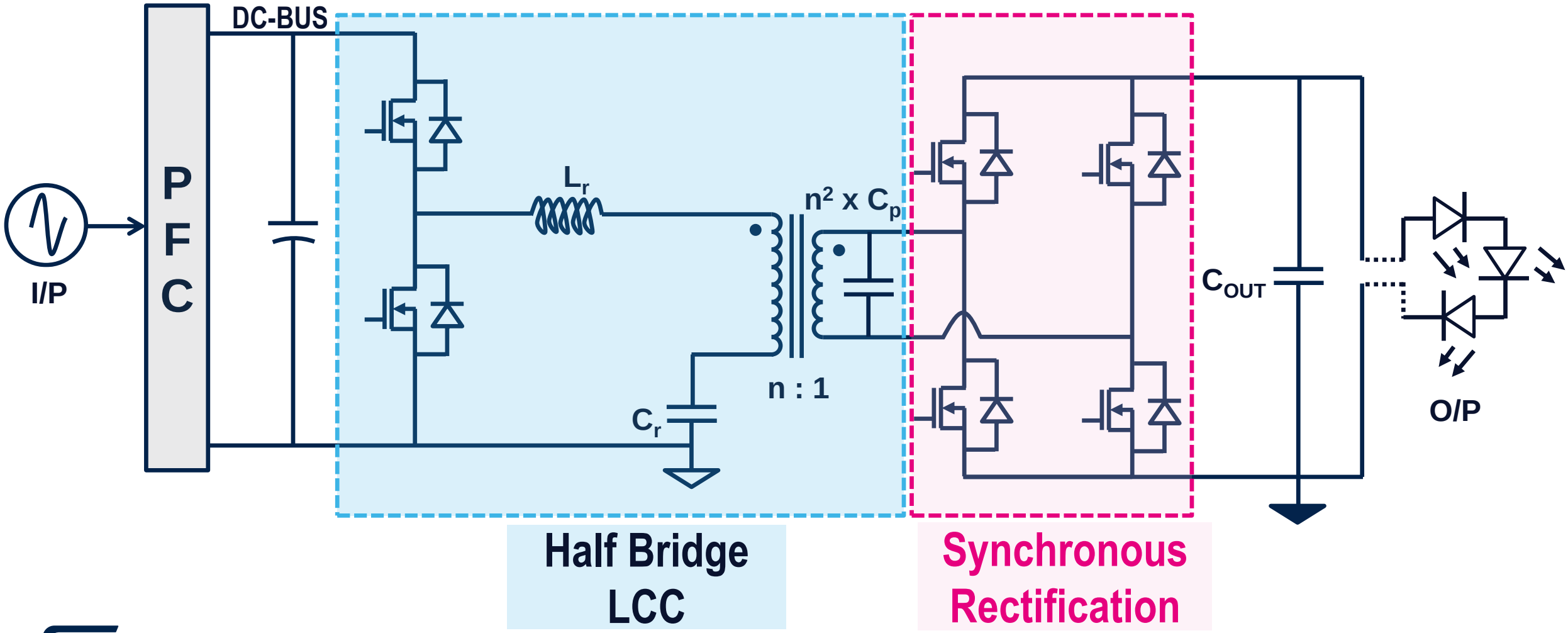
Pin	Short description
GND	Controller ground and MOSFET source
N.C.	Not internally connected
N.A.	Not available for user (recommended to connect to GND)
VCC	Controller supply
FB	3.3V reference voltage / EA input for direct voltage feedback
COMP	EA output for compensation network in non isolated flyback Optocoupler connection in isolated flyback
DRAIN	1050 V FET drain



	VIPer26xK
P_{OUT} @85-265V_{AC} Flyback converter 50C amb temp	10W
I_{OUT} Buck converter	250 mA (VIPER265K) 350 mA (VIPER267K)
BV_{DSS}	1050 V
R_{DSon}	8 Ω max
I_{DLIM} [mA]	500 mA (VIPER265K) 700 mA (VIPER267K)
F_{OSC} [kHz] ± Jittering	60 kHz ±7%
V_{CC}	11.5V to 23.5V
$V_{DRAIN\ START}$	60V DC max
Package	SO16N

LCC topology fundamentals and synchronous rectification

LCC resonant converter block diagram



LCC resonant converter gain vs normalized frequency

Resonant Frequency $f_r = \frac{1}{2\pi\sqrt{L_r C_r}}$

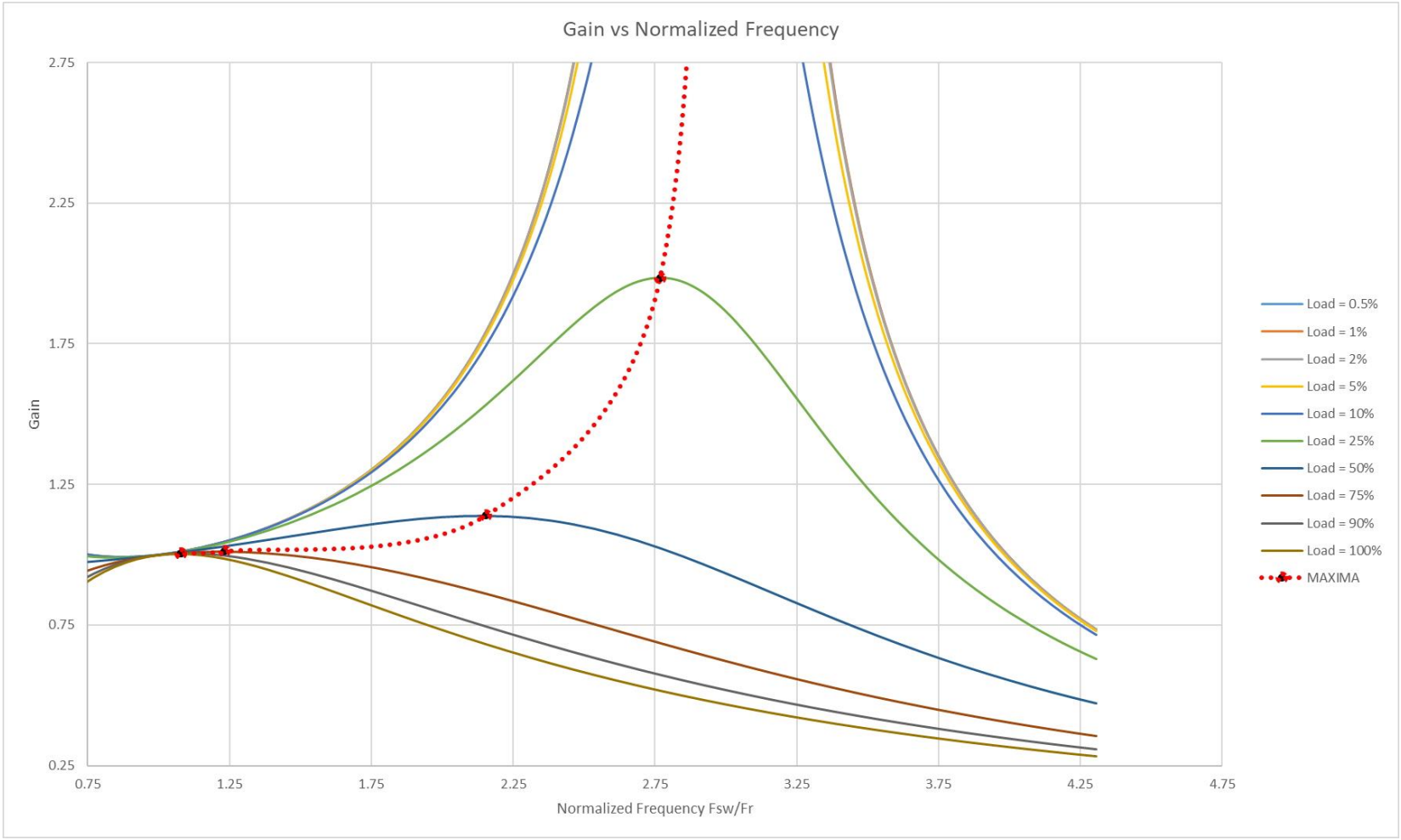
$$\lambda = \frac{L_m}{L_r}$$

$$\mathrm{A} = \frac{C_r}{C_p}$$

Characteristic Impedance $Z_0 = \sqrt{\frac{L_r}{C_r}}$

Quality Factor $\mathrm{Q} = \frac{1}{R_{ac}}\sqrt{\frac{L_r}{C_r}}$

Normalized Frequency $f_n = \frac{f_{sw}}{f_r}$



$$\mathbf{Mg\,(fn, Q, \lambda, A)} = \left|\frac{\mathbf{V_o}'}{\mathbf{V_{in}}'}\right| = \frac{1}{\sqrt{\left[1 + \frac{1}{\lambda}\left(1 - \frac{1}{\mathbf{f_n}^2}\right) + \frac{1}{\mathbf{A}}\left(1 - \mathbf{f_n}^2\right)\right]^2 + \mathbf{Q}^2\left(\mathbf{f_n} - \frac{1}{\mathbf{f_n}}\right)^2}}$$

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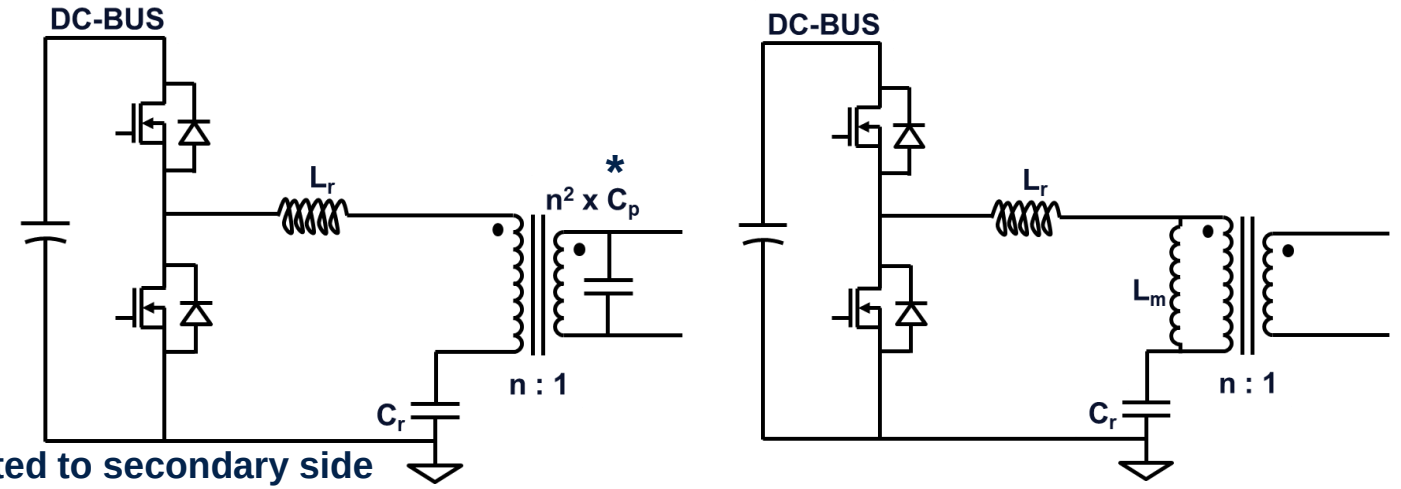
LCC vs LLC resonant converter operating frequency

Frequency	LCC Converter	LLC Converter
f_{r1}	$\frac{1}{2\pi\sqrt{L_r\left(\frac{C_rC_p}{C_r+C_p}\right)}}$	$\frac{1}{2\pi\sqrt{(L_r+L_m)C_r}}$
f_{r2}	$\frac{1}{2\pi\sqrt{L_rC_r}}$	$\frac{1}{2\pi\sqrt{L_rC_r}}$
Desired Operating Region $f_{operation}$	$f_{operation} > f_{r2}$	$fr1 < f_{operation} < f_{r2}$

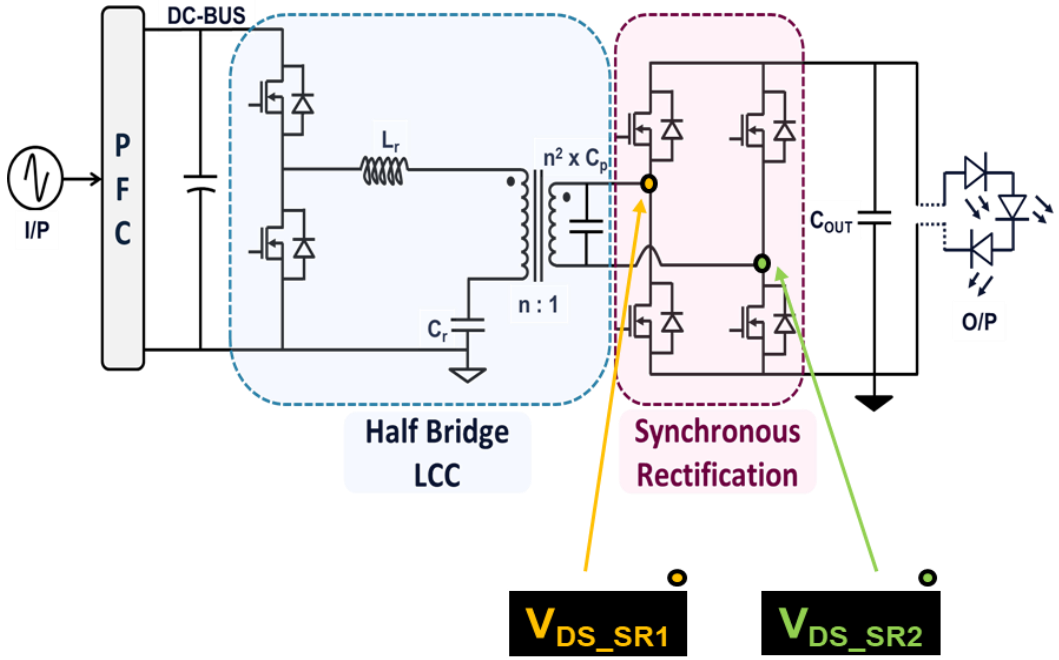


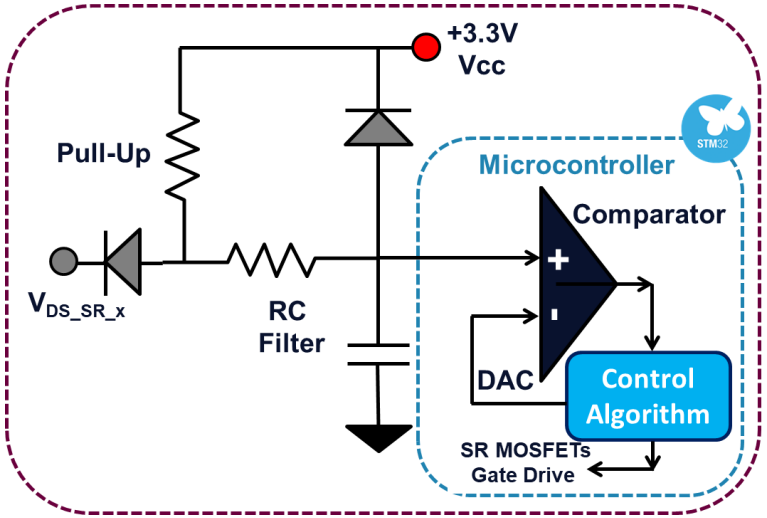
* C_p reflected to secondary side

Synchronous rectification VDS sensing technique

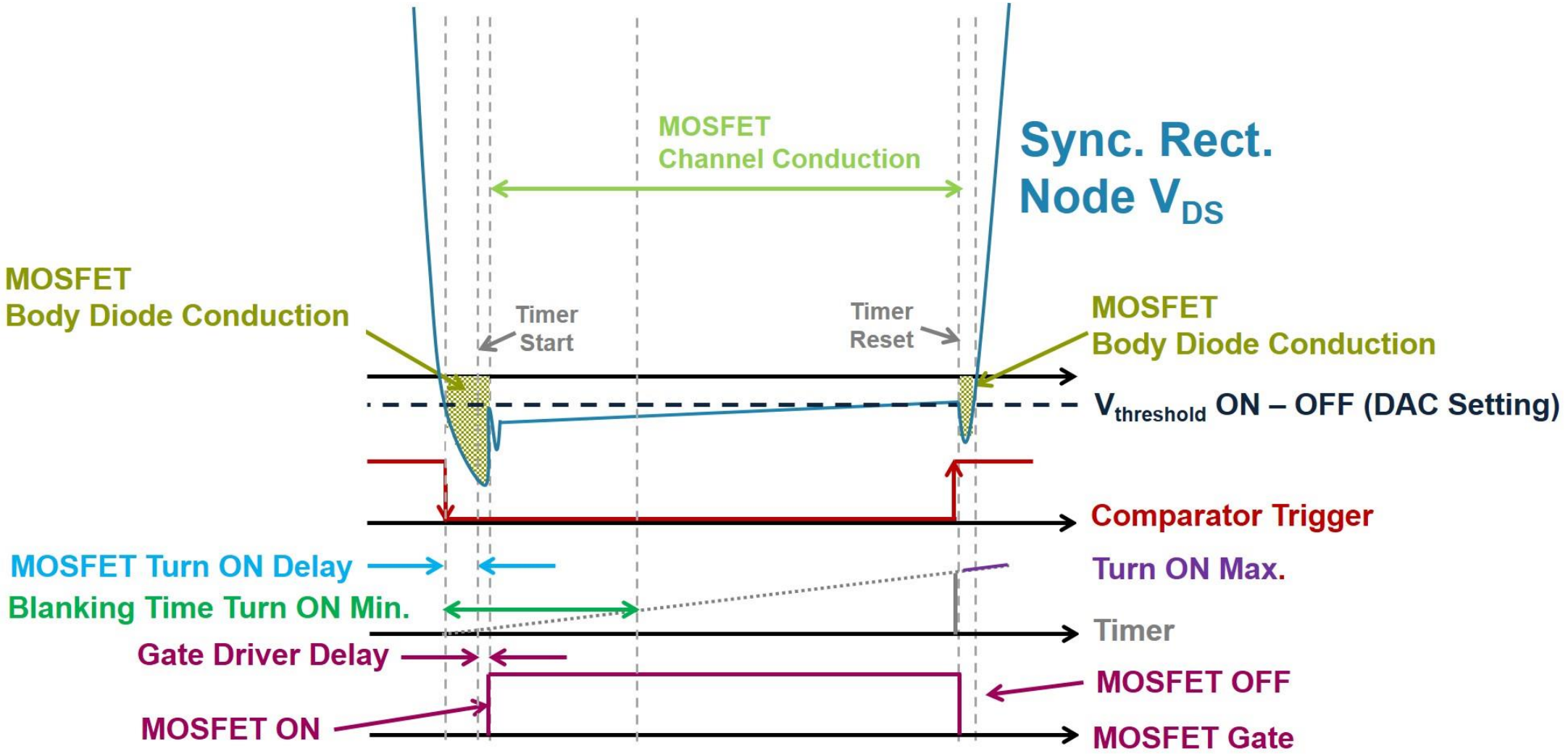
Synchronous rectification (SR) stage node voltages (V_{DS_SR1} and V_{DS_SR2}) are sensed to drive SR stage MOSFETs.

- The sensing network is composed of a fast diode and a pull-up resistor connected to the microcontroller (MCU) supply voltage.
- When the SR MOSFET drain voltage is above the MCU Vcc, the diode is reverse biased and the sensed voltage is pulled up to Vcc.
- When drain voltage is below Vcc, the diode is forward biased and the sensed voltage is equal to this voltage plus the voltage drop of the diode that gives a positive shift.
- The current during positive biasing is limited by the pull-up resistor.





Synchronous rectification digital control scheme



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Efficiency, operative performance

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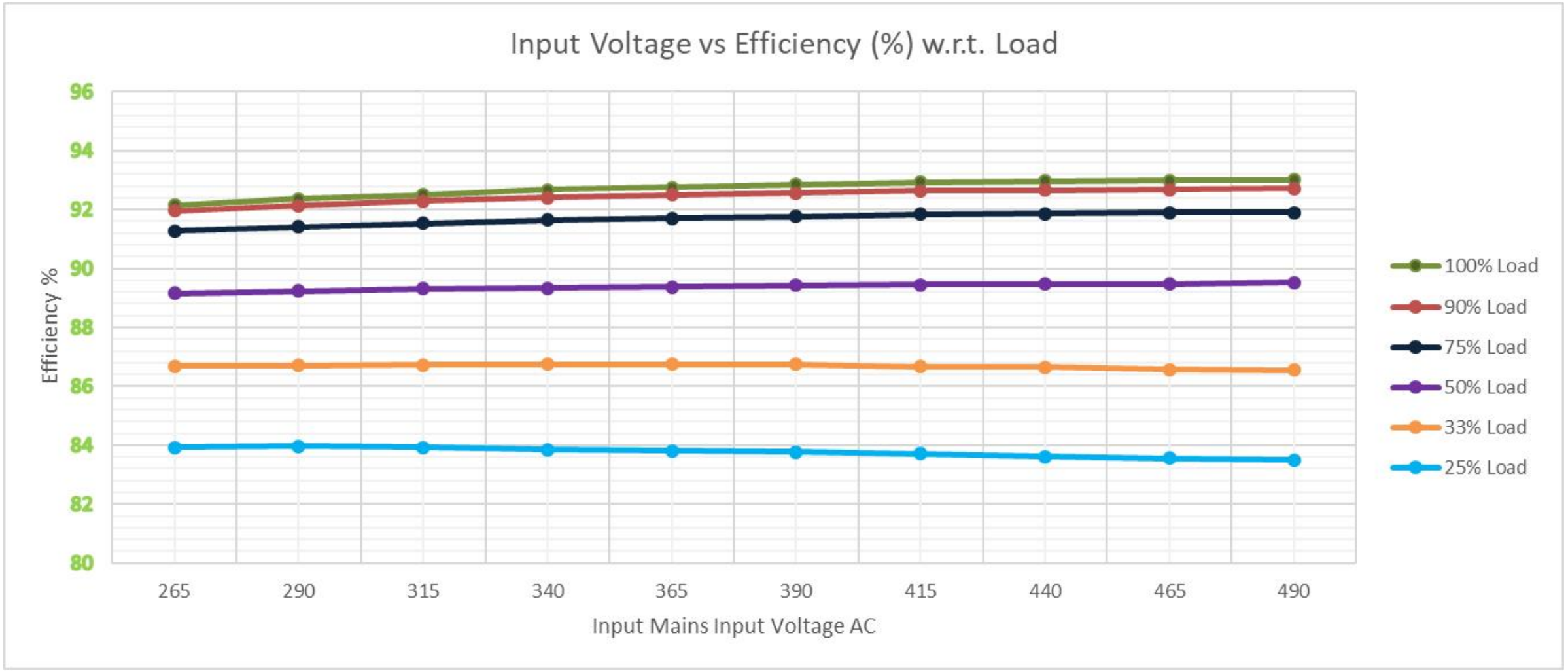
Input voltage vs efficiency w.r.t. Load CV configuration



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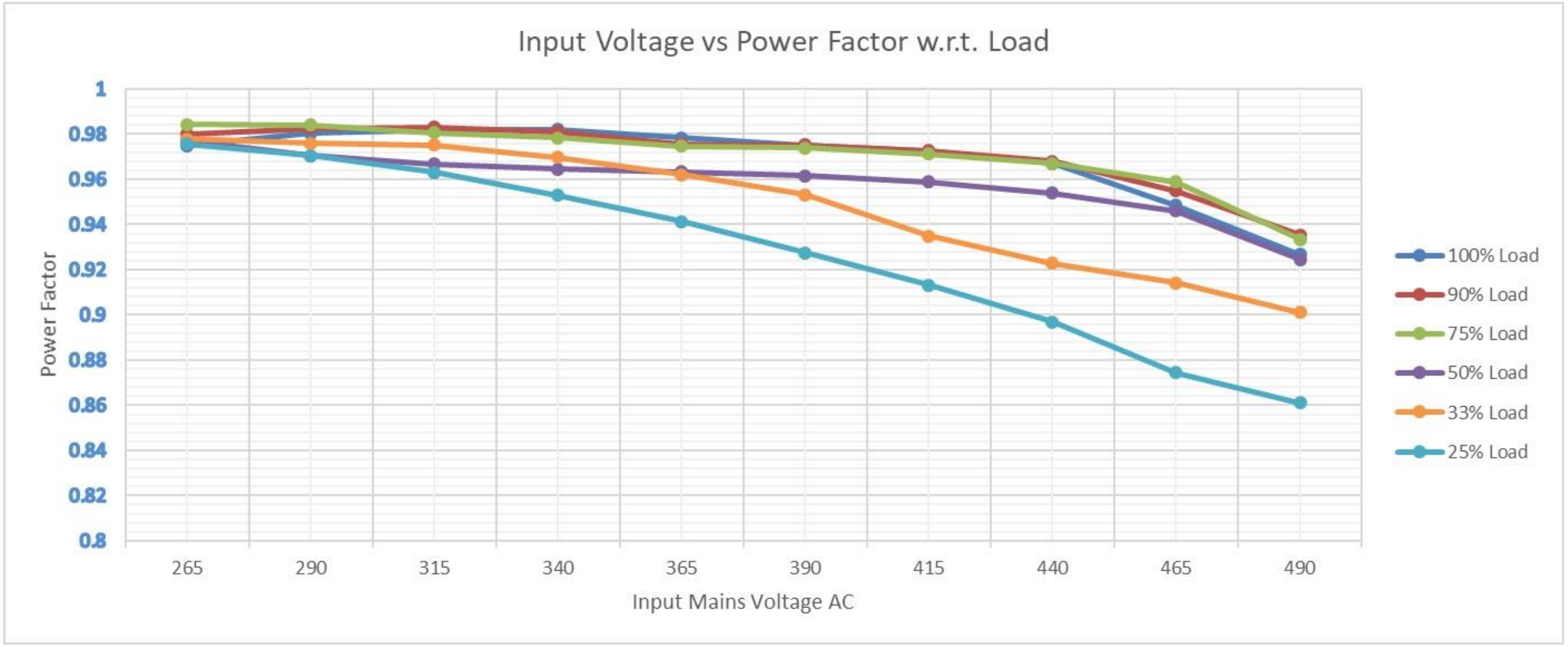
Input voltage vs power factor w.r.t. Load CV configuration



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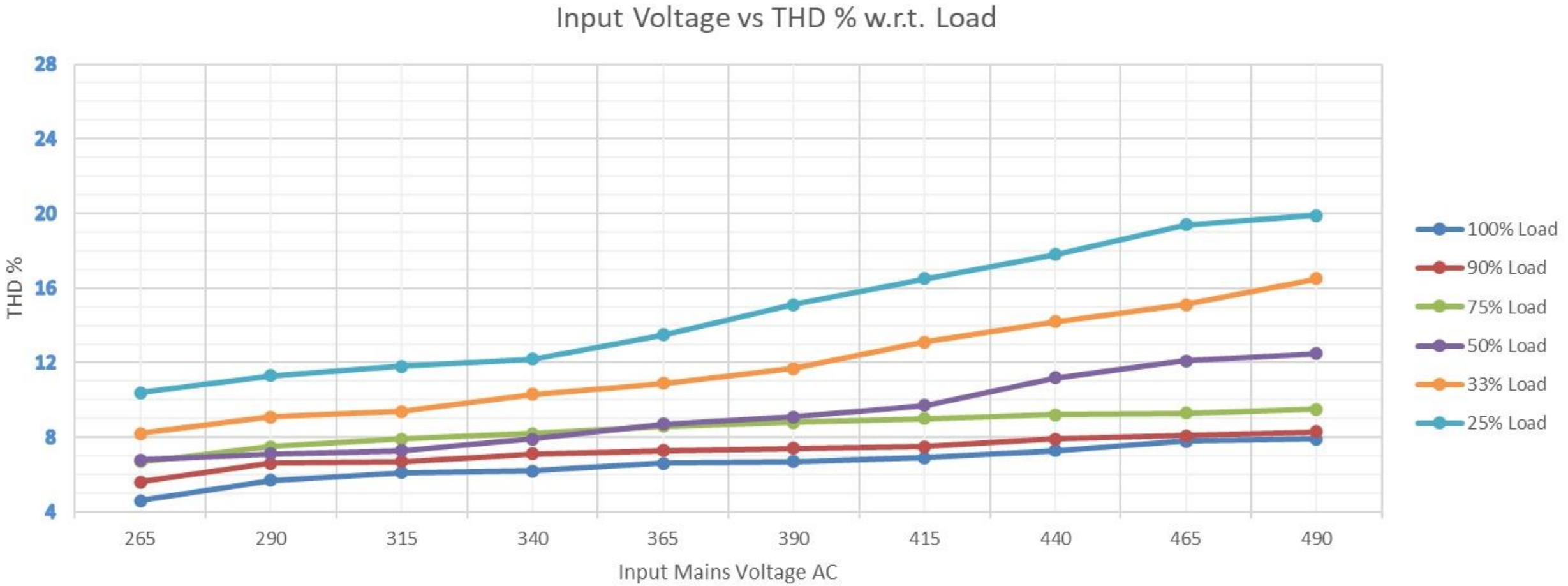
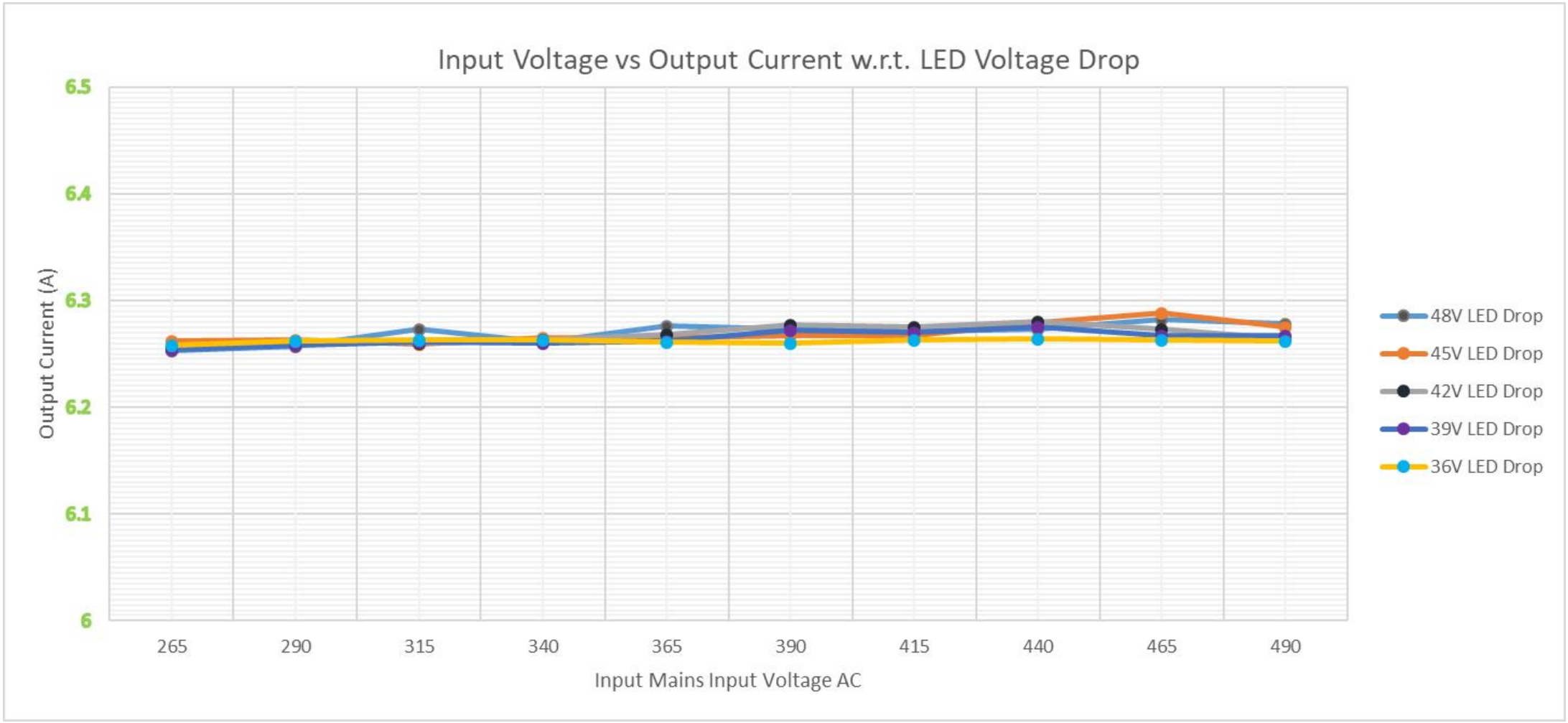
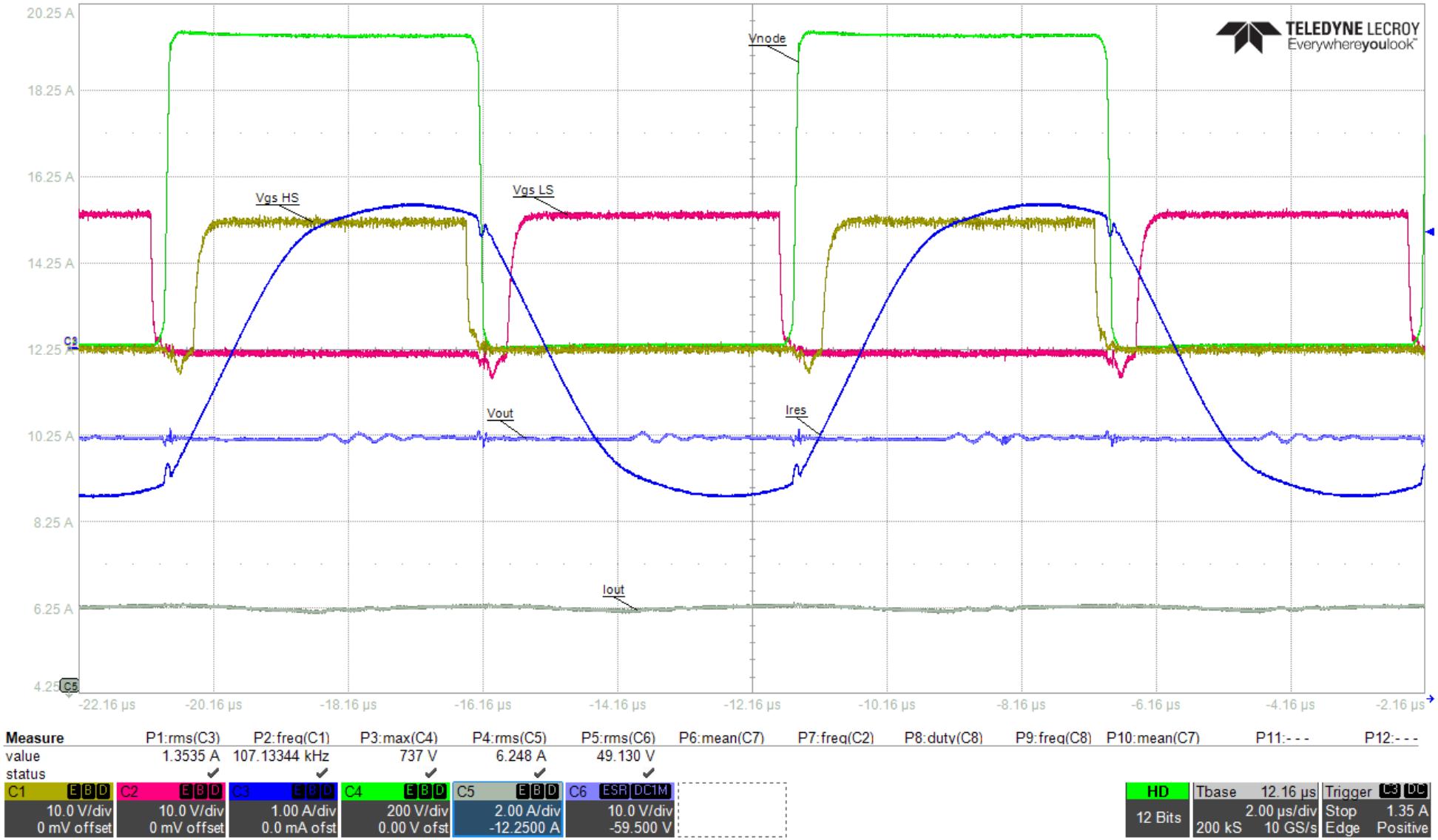
Input voltage vs THD w.r.t. Load CV configuration



Input voltage vs output current w.r.t LED drop CC configuration



HB-LCC stage - 100% load CV configuration



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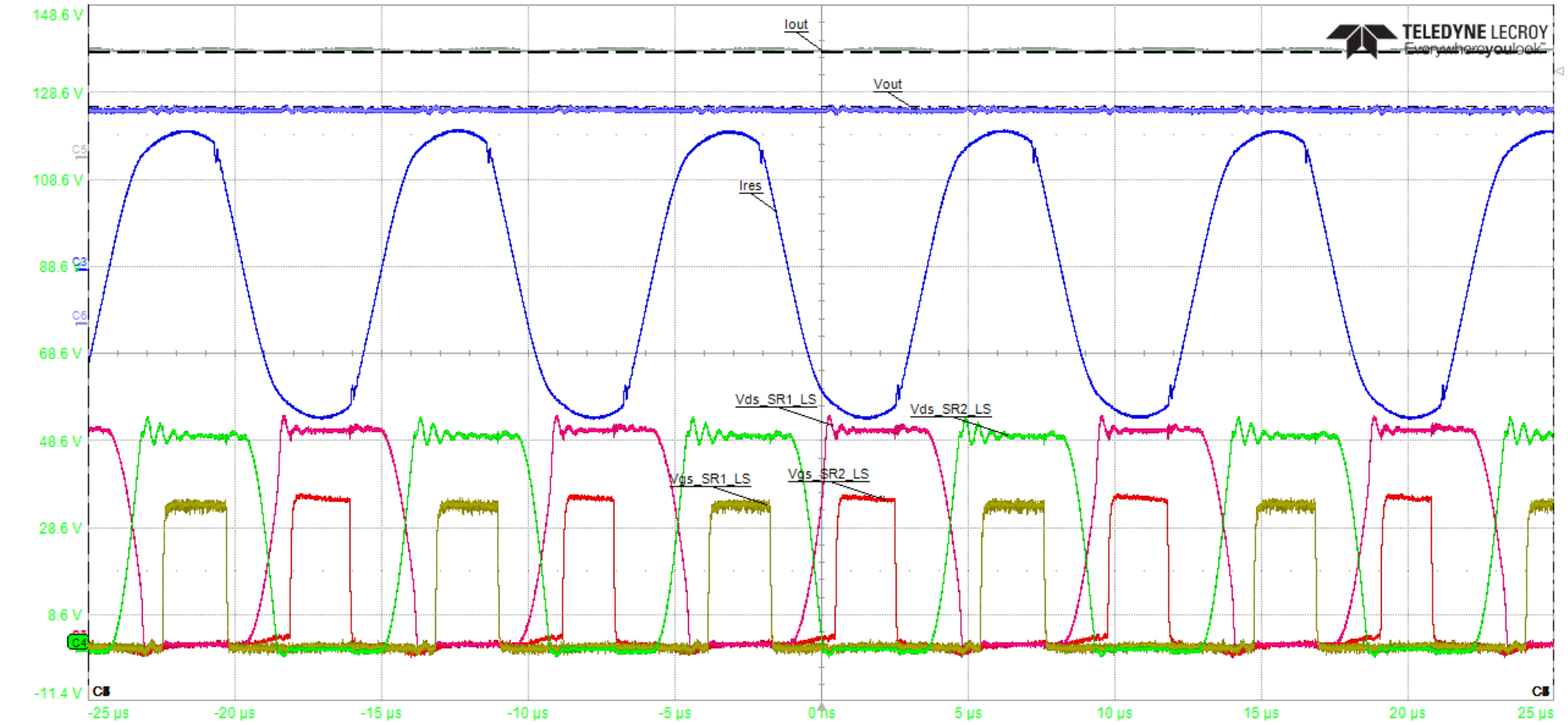
Synchronous rectification with 48V output CC configuration



Measure	P1:rms(C3)	P2:freq(C1)	P3:max(C4)	P4:rms(C5)	P5:rms(C6)	P6:mean(C7)	P7:freq(C2)	P8:duty(C8)	P9:freq(C8)	P10:mean(C7)	P11:- - -	P12:- - -
value	1.2914 A	107.75701 kHz	54.0 V	6.154 A	48.97 V							
status	✔	⚠	✔	✔	✔							

C1	C2	C3	C4	C5	C6	C7
10.0 V/div	20.0 V/div	1.00 A/div	20.0 V/div	5.00 A/div	20.0 V/div	10.0 V/div
-33.920 V	-66.728 V	950.0 mA	-68.588 V	11.250 A	6.800 V	-33.200 V
62.2 V	123.3 V	1.88 A	125.2 V	2.90 A	49.8 V	61.5 V
68.4 V	135.7 V	2.50 A	137.6 V	6.00 A	62.2 V	67.7 V
Δy 6.2 V	Δy 12.4 V	Δy 620 mA	Δy 12.4 V	Δy 3.10 A	Δy 12.4 V	Δy 6.2 V

HD	Timebase 0.0 µs	Trigger C5 DC
12 Bits	5.00 µs/div	Stop 5.00 A
	500 kS 10 GS/s	Edge Positive

X1= 24.9999 µs ΔX= -49.9999 µs
X2= -25.0000 µs 1/ΔX= -20.00004 kHz

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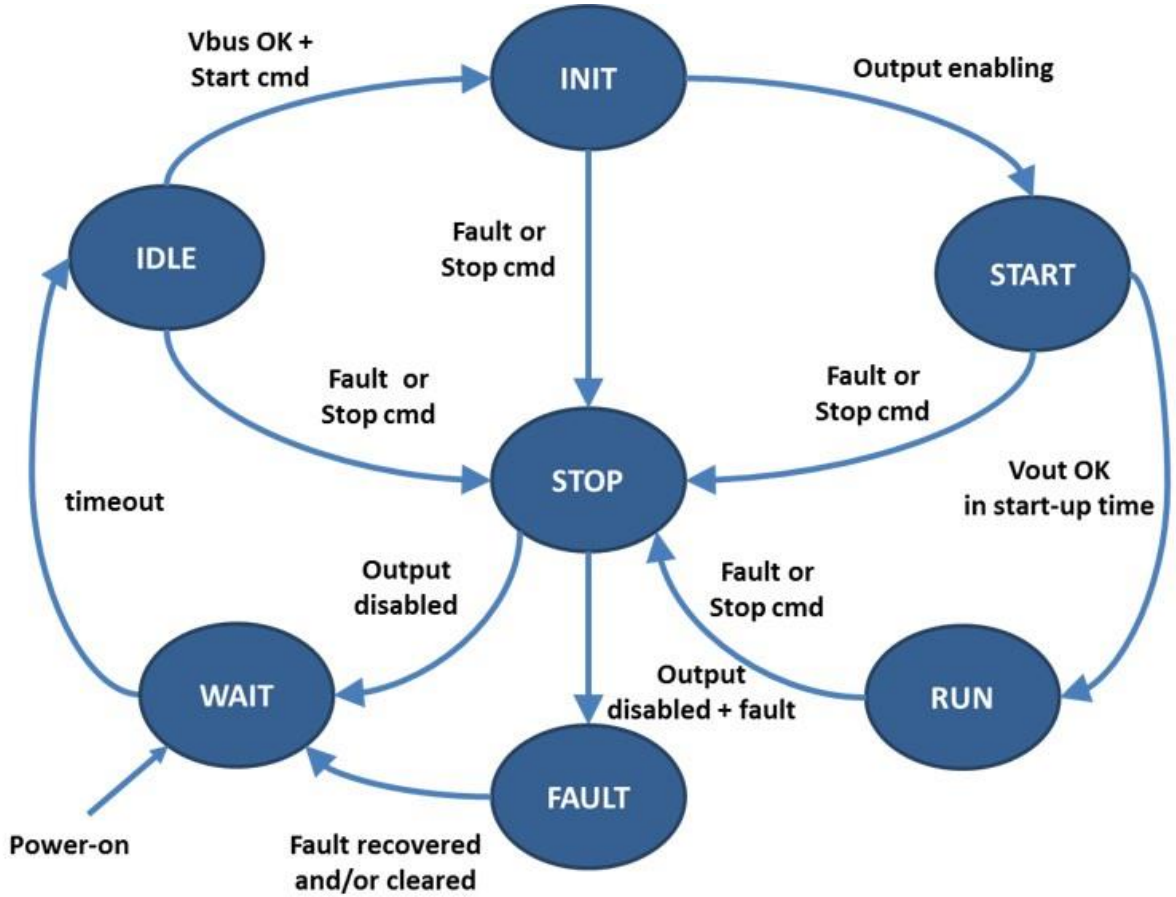
FW architecture

FW architecture

Control Features

- 50 kHz PI voltage control loop.
- PWMs generation with 217 ps resolution (HRTIM).
- Startup with linear frequency decreasing to avoid current spikes.
- Start-up protection on mismatch of output voltage.
- SR based on embedded comparators and voltage sensing.
- Automatic SR activation depending on output load.
- Fast overcurrent protection with internal comparator.
- Analog watchdog on output voltage for overvoltage protection.



STEVAL-DPS334C1
MCU control board and adapter board

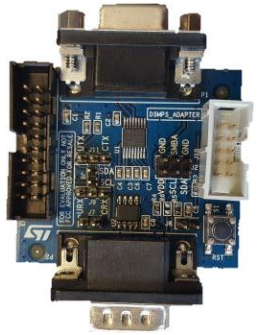
Digital Power Supply Control Board based on STM32F334

STEVAL-DPS334M1

Features

- STM32F334R8 microcontroller
- 64 pin connector for control signals
- Opto-coupled serial communication (board-to-board communication)
- RC filters for analog inputs
- Diode arrays for analog signal protection (DA108S1)
- CAN, RS232, and SMBus communication channels
- External power Supply voltage: 5V
- Embedded 5V/3.3V voltage regulator
- Dedicated test points for debugging
- LEDs for power-on, faults and general purpose

Adapter board



STEVAL-DPSADP01

Features

- Enabling Debug (SWD connection)

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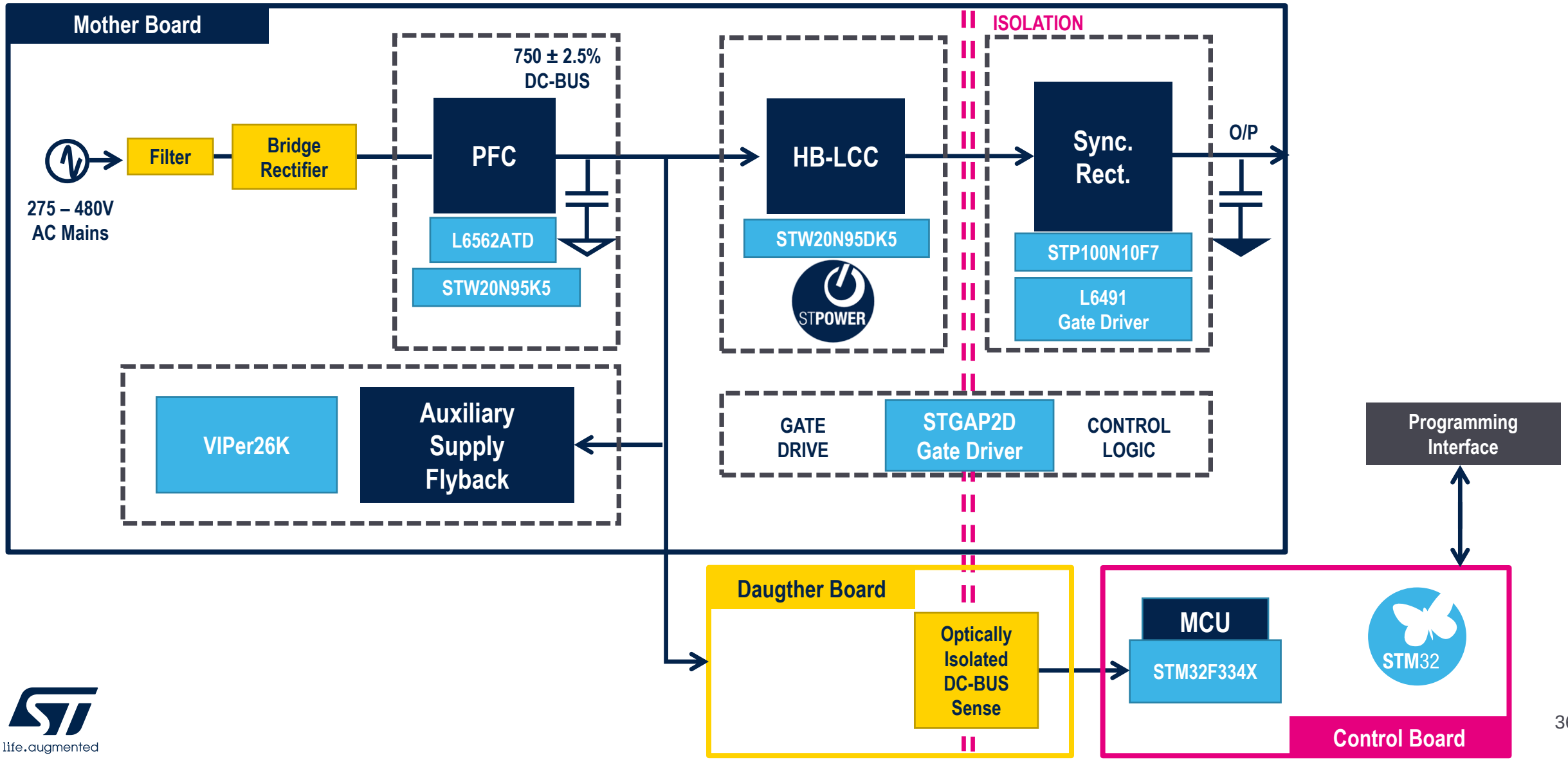
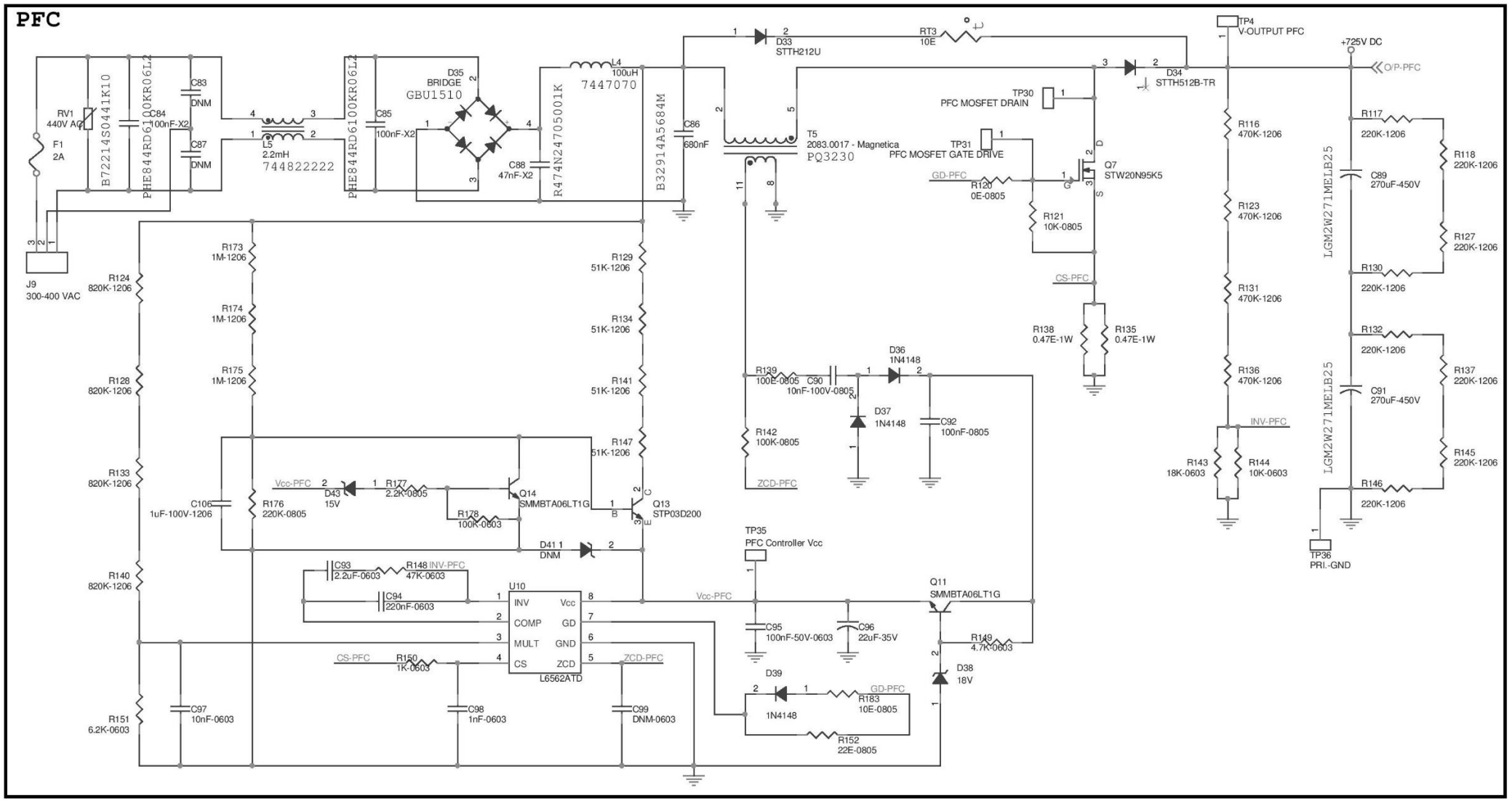
Schematics & layout

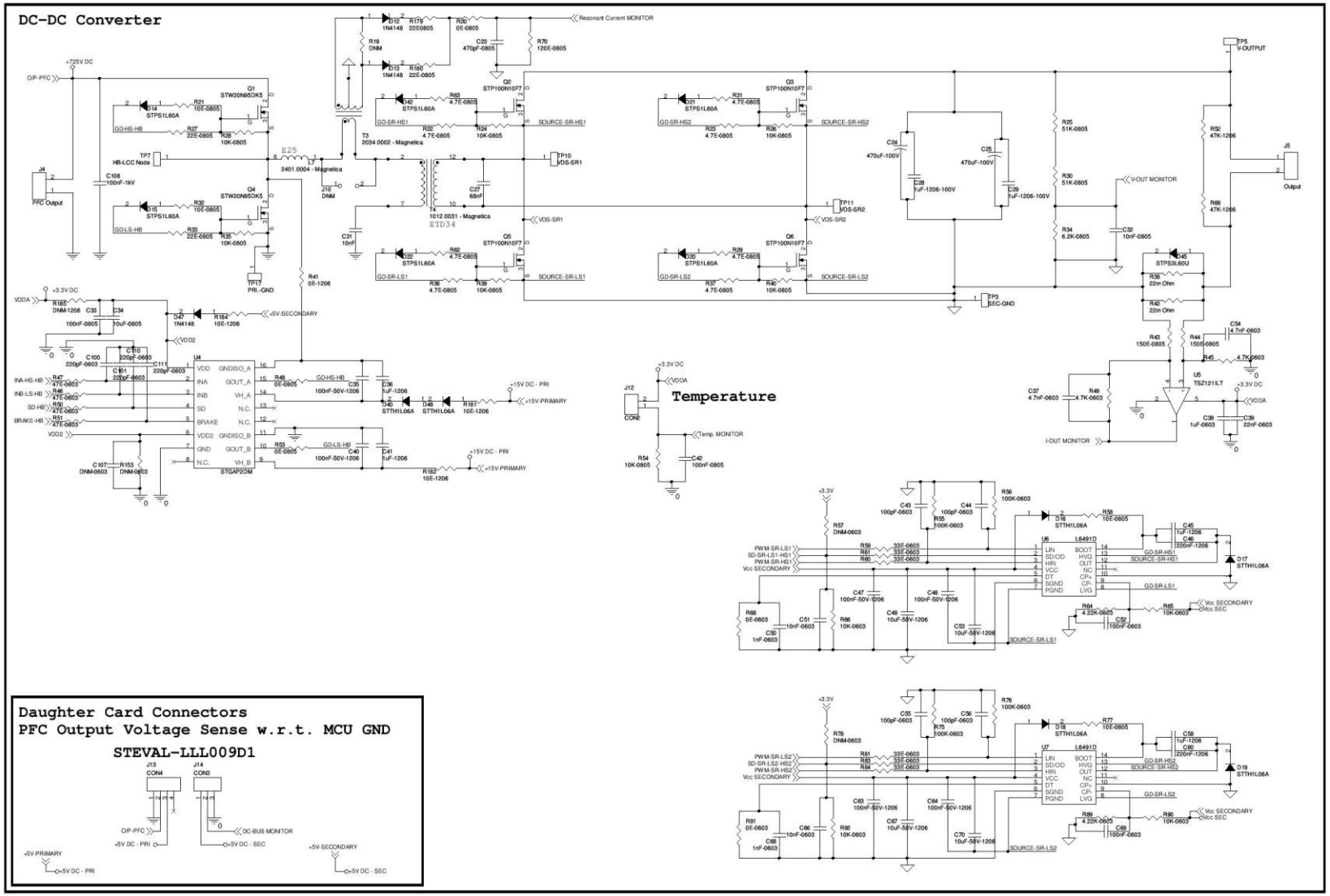
STEVAL-LLL009V1 - Evaluation boards involved



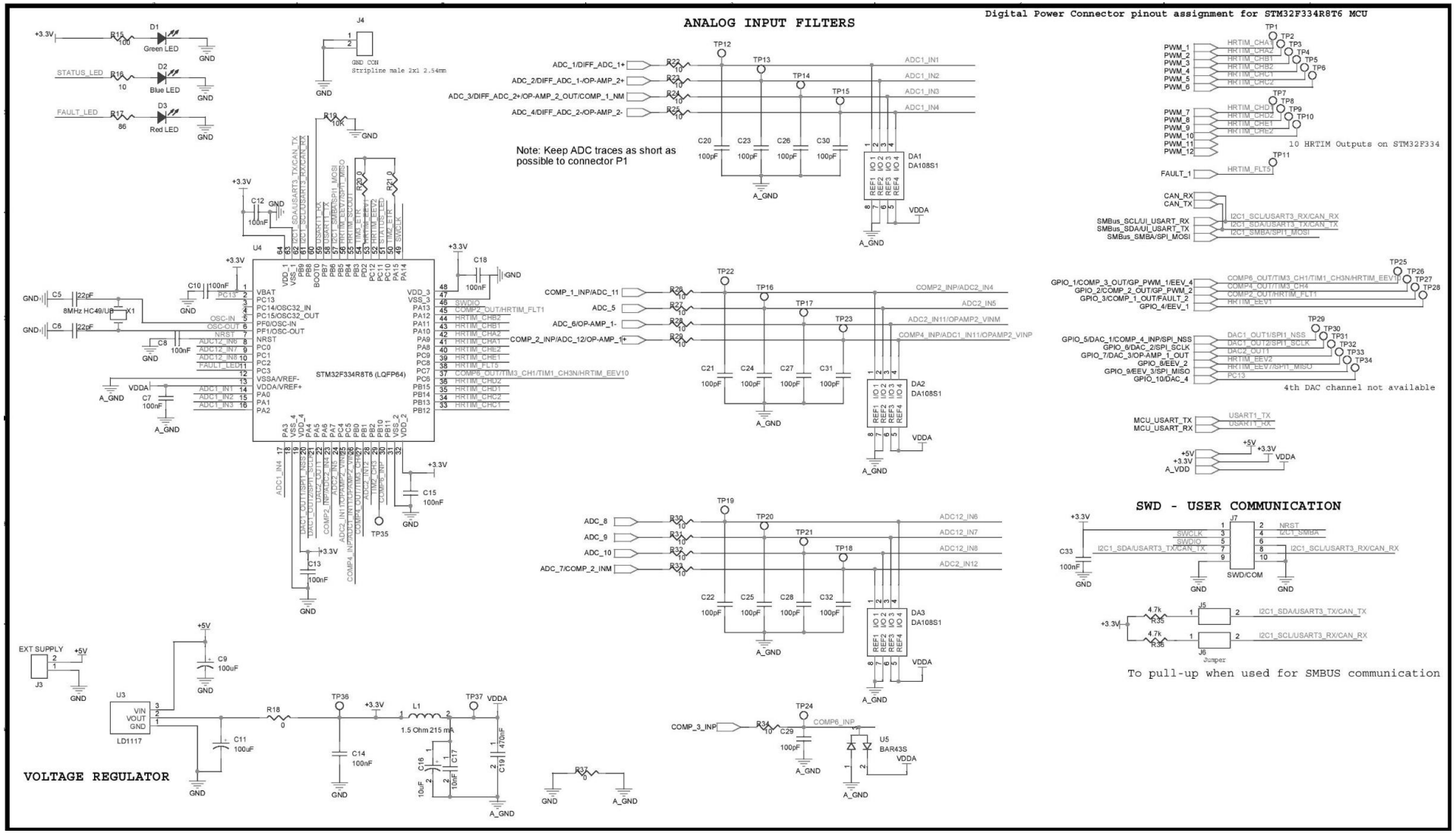
Mother board schematic: PFC section



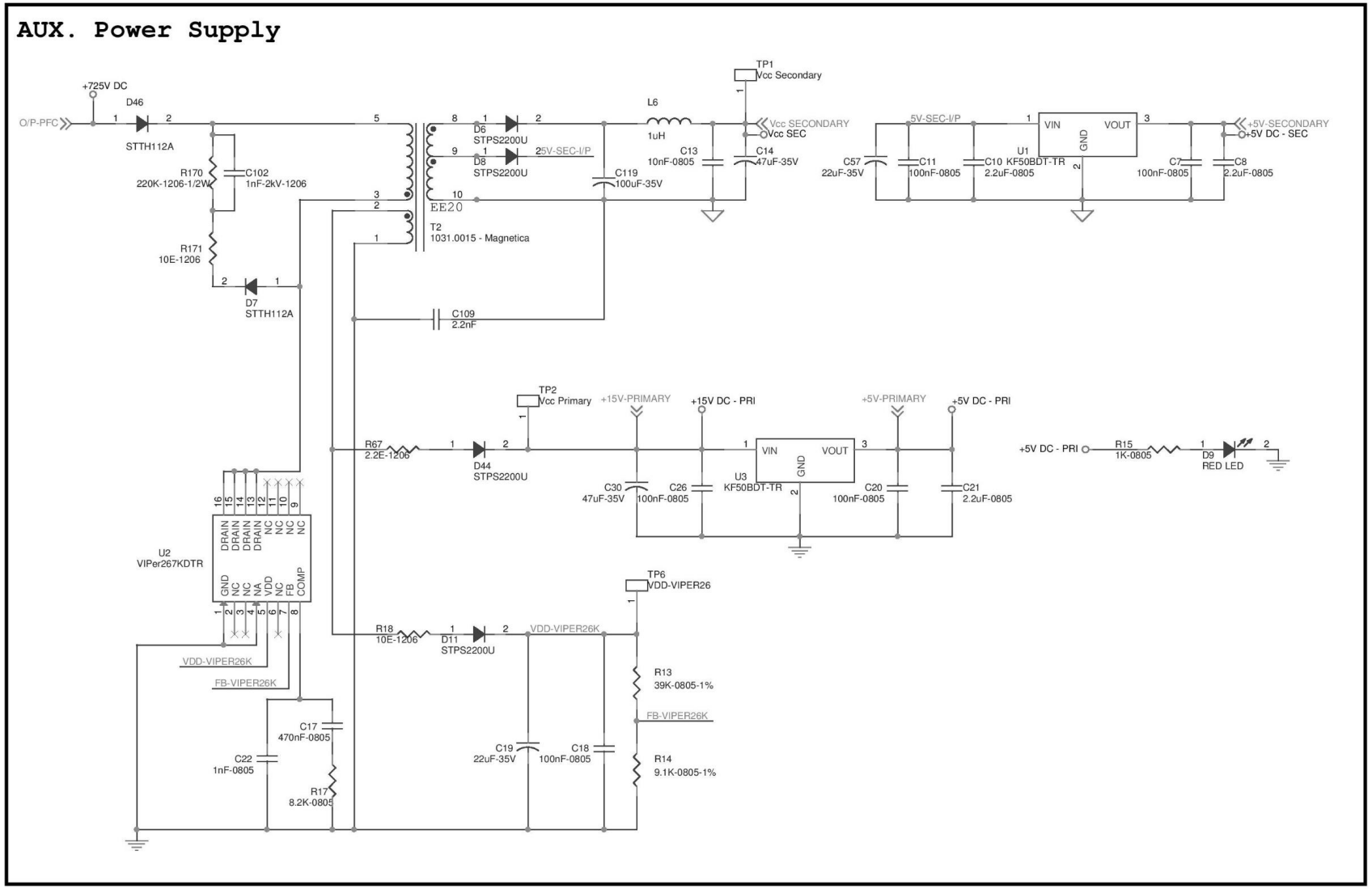
Mother board schematic: DC-DC section



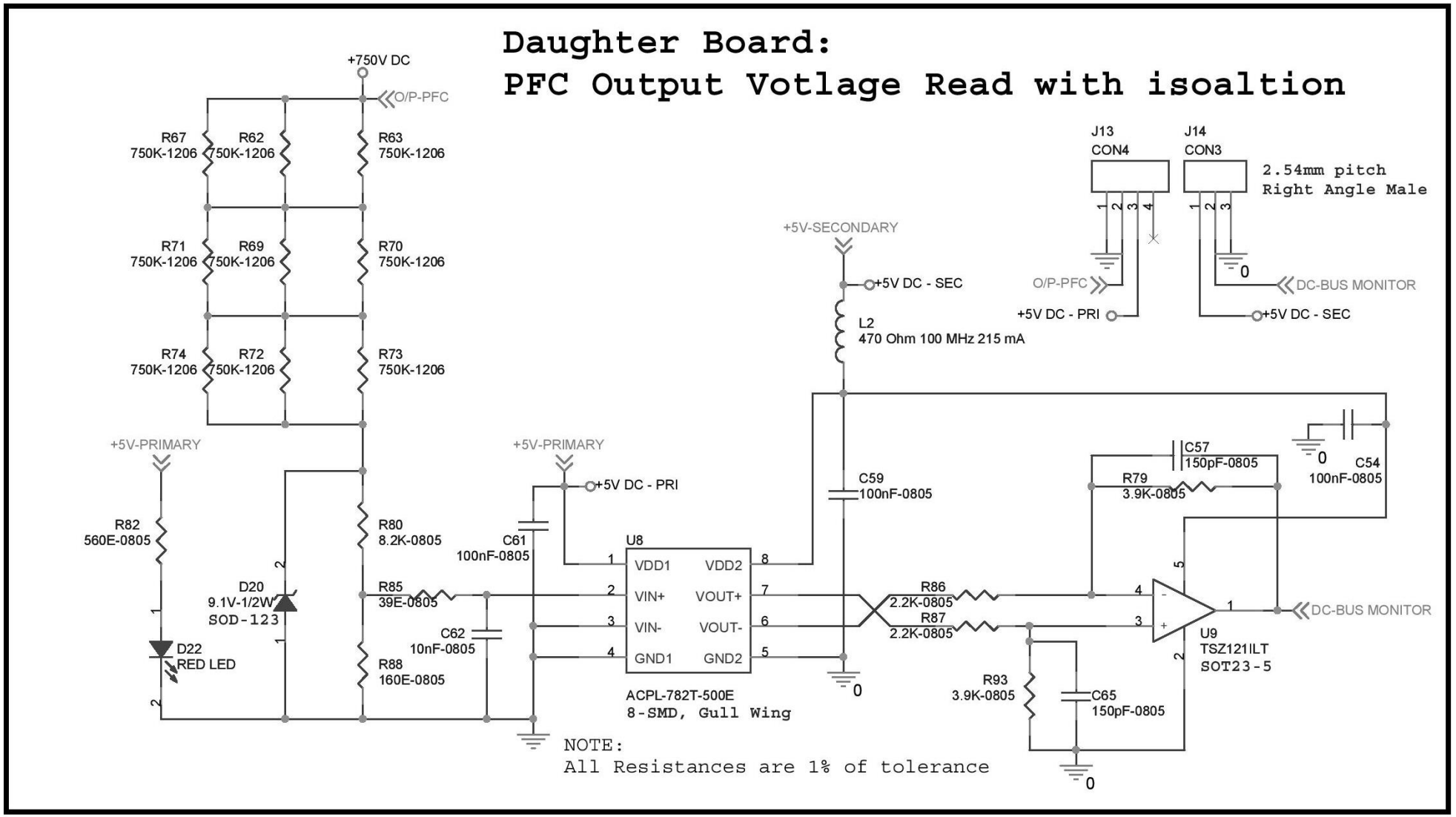
Control board schematic: MCU section



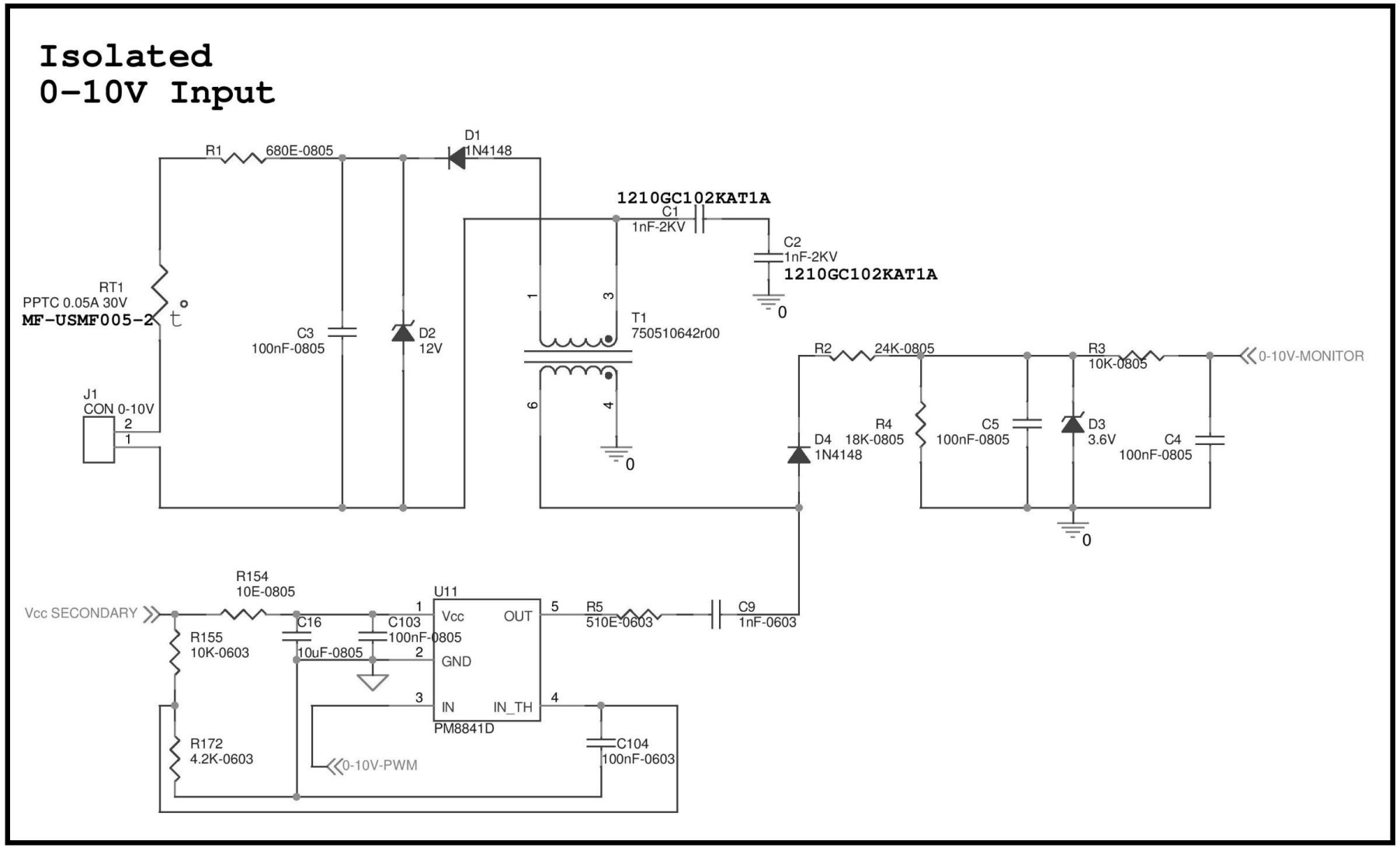
Mother board schematic: Aux. supply section



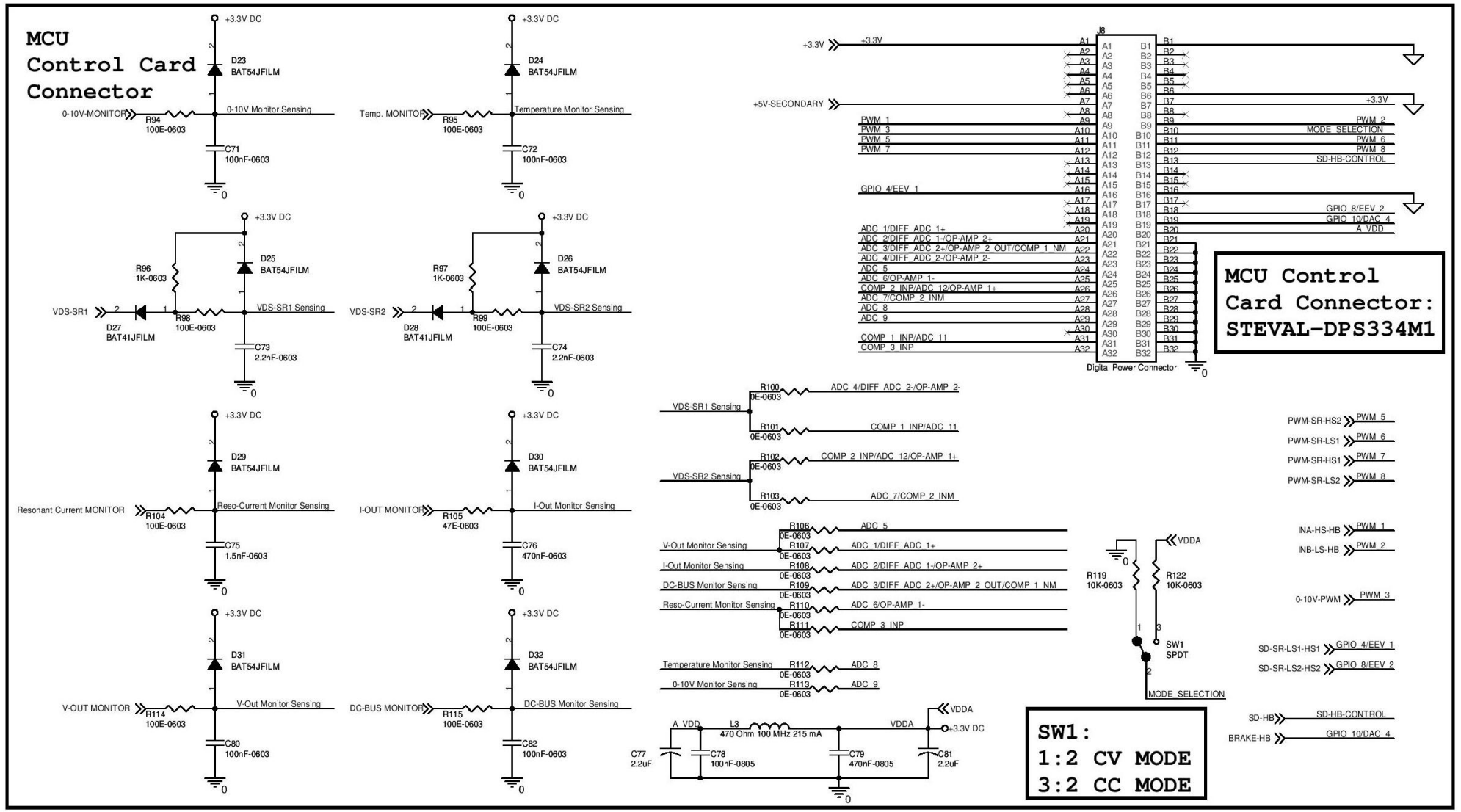
Daugther board schematic: PFC output sensing



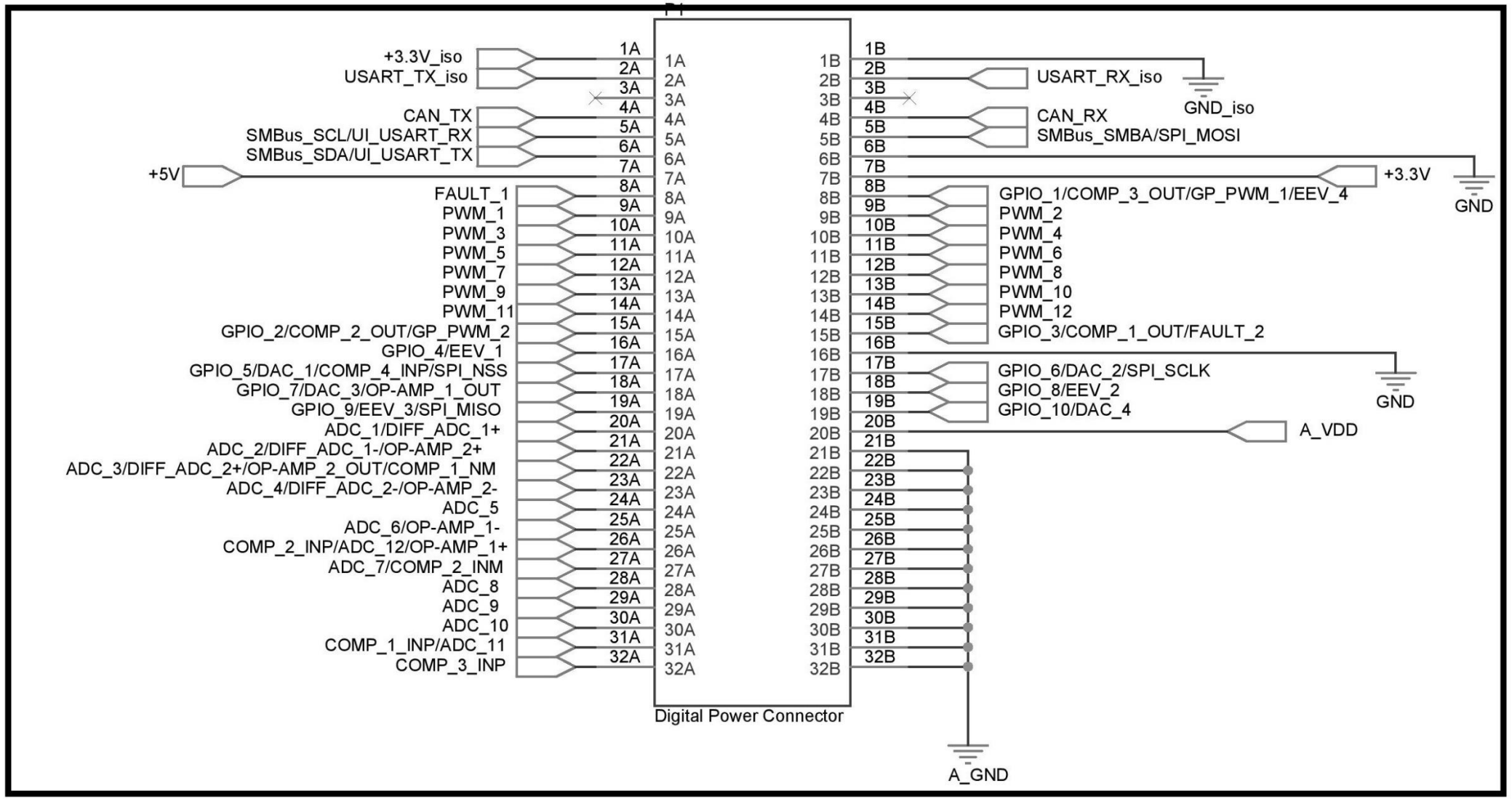
Mother board schematic: 0 – 10 V input



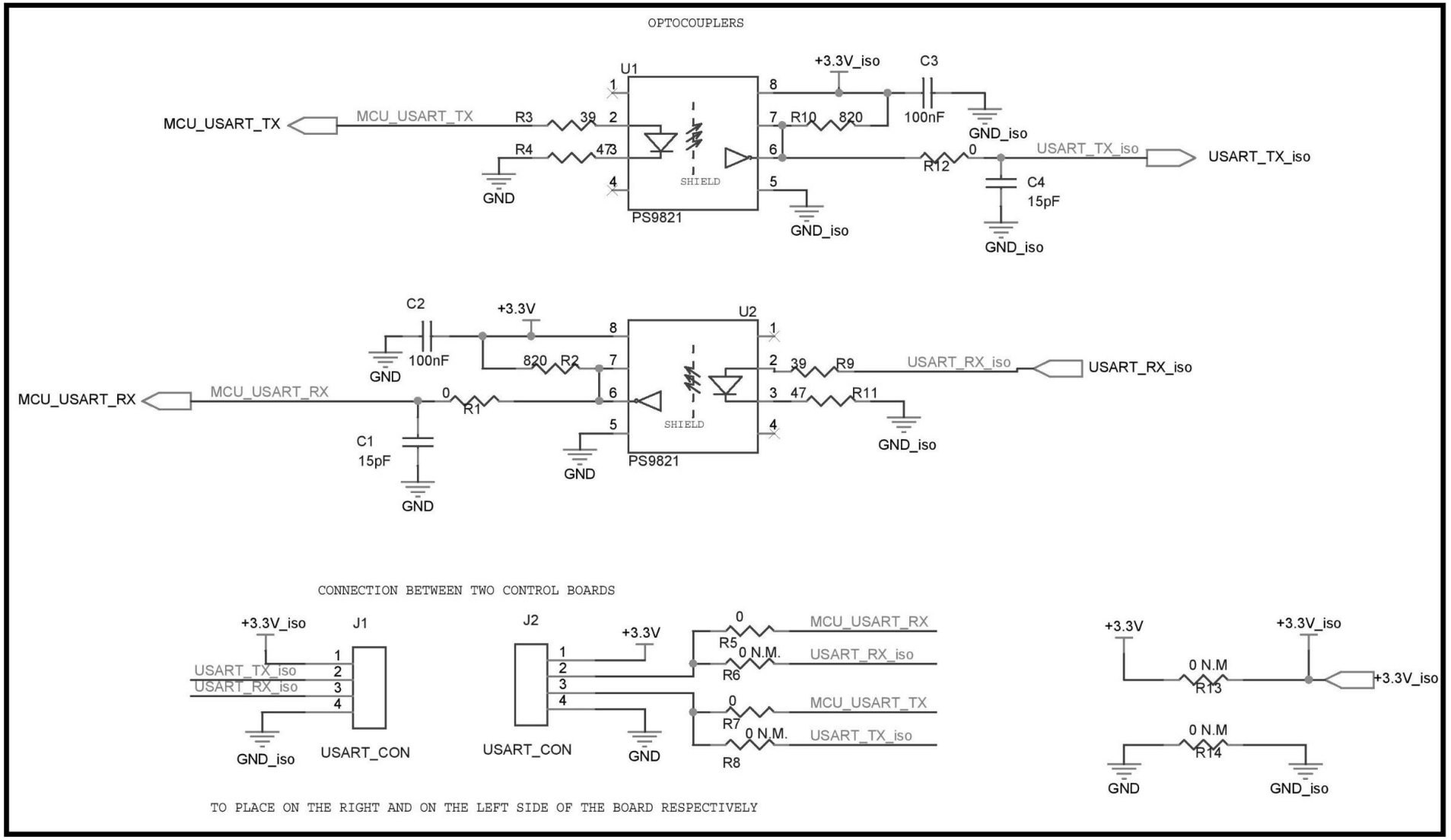
Mother board schematic: MCU card connector



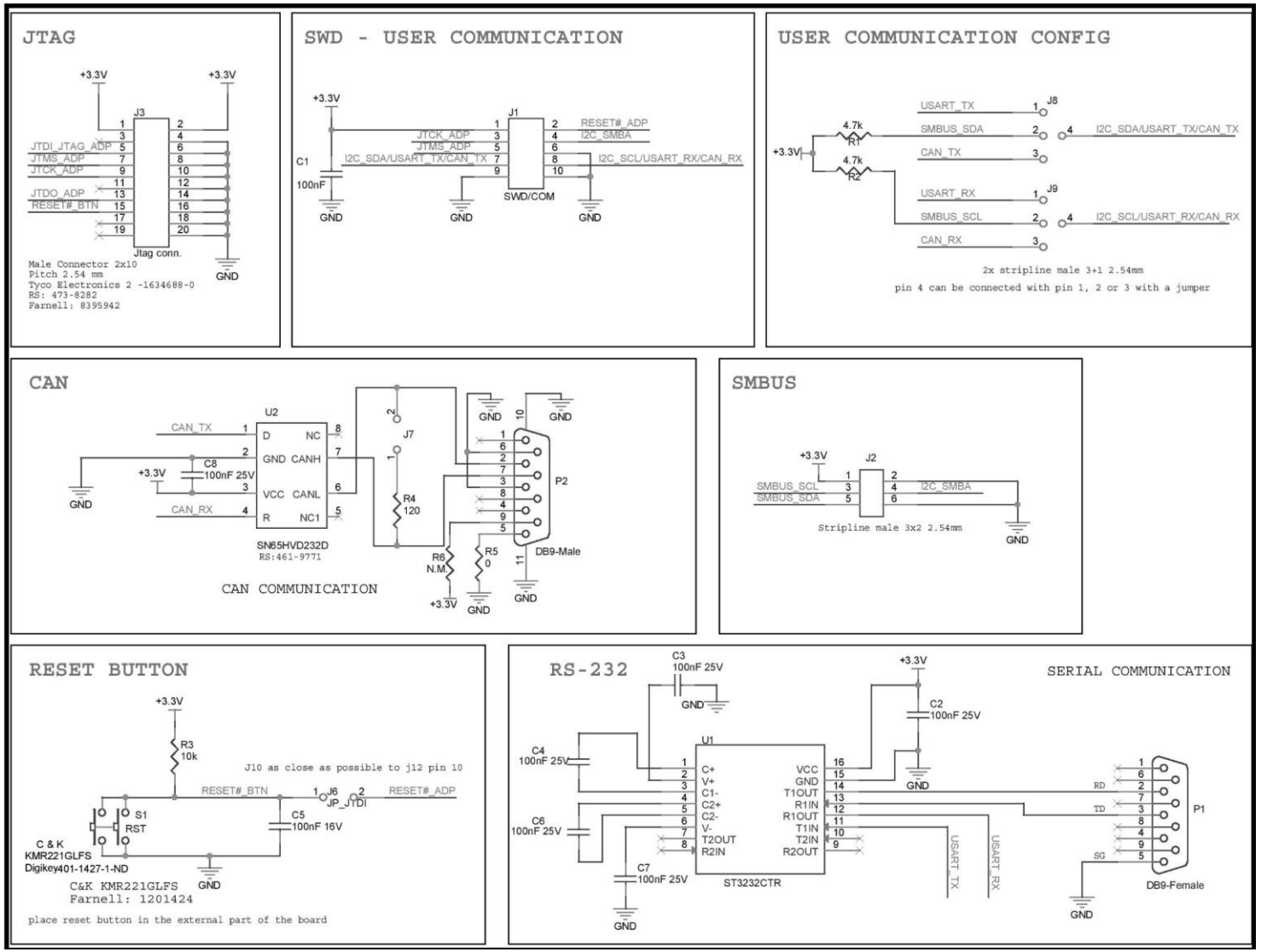
Control board schematic: MCU card connector



Mother board schematic: USART connections



Adapter board schematic: Programming connector



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