

PCIM 2018 Industry Forum, Hall 6, Booth 155
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Digital Control for Off-Line Power Supplies Using Digital Platform DP2

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Outline

- Introduction
- Minaturized Power Supplies – State of the Art
- Digital Control by Interface UART
- Programmable Digital Control
- Example 1: Wide Range Power Supply
- Example 2: Off-Line LED Driver
- Example 3: Off-Line Supply with Piezo Transformer
- Expectations

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- Introduction

Off-Line Power Supplies: What Customers want

Lowest Costs

Functionality

Depending on
application

Miniaturization

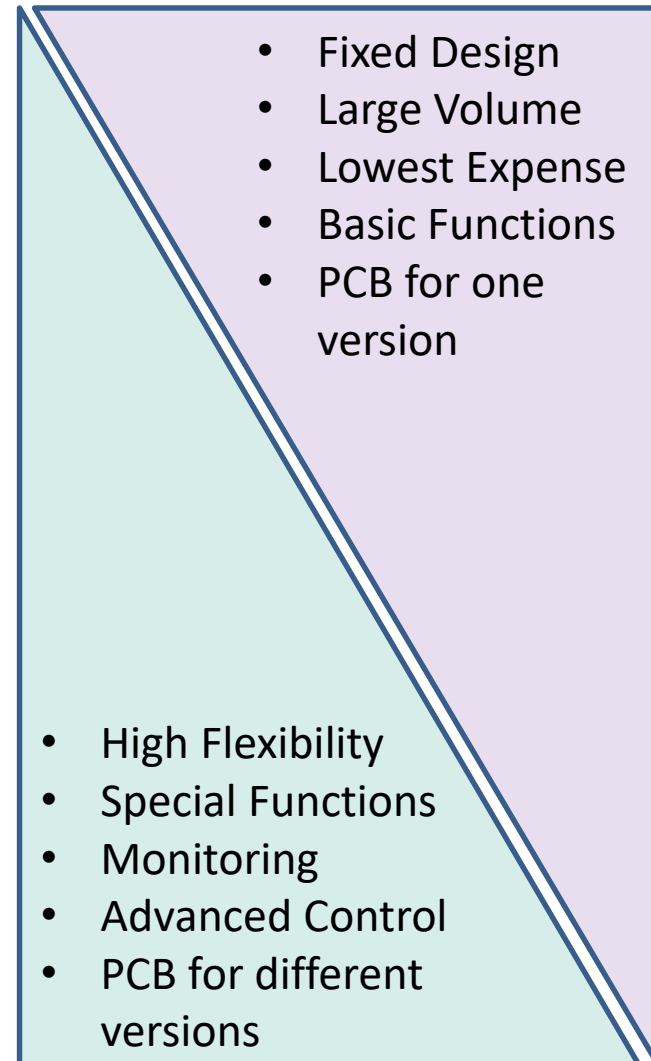
Reliability, Life Time

■ Introduction

Analog Control:
Configuration by
external Components,
Design Parameters

Digital Control:
Configuration by Interface
UART, AD/DA, external
Components

Programmable Digital
Control:
Configuration by Programm
and Interface UART, AD/DA



Outline

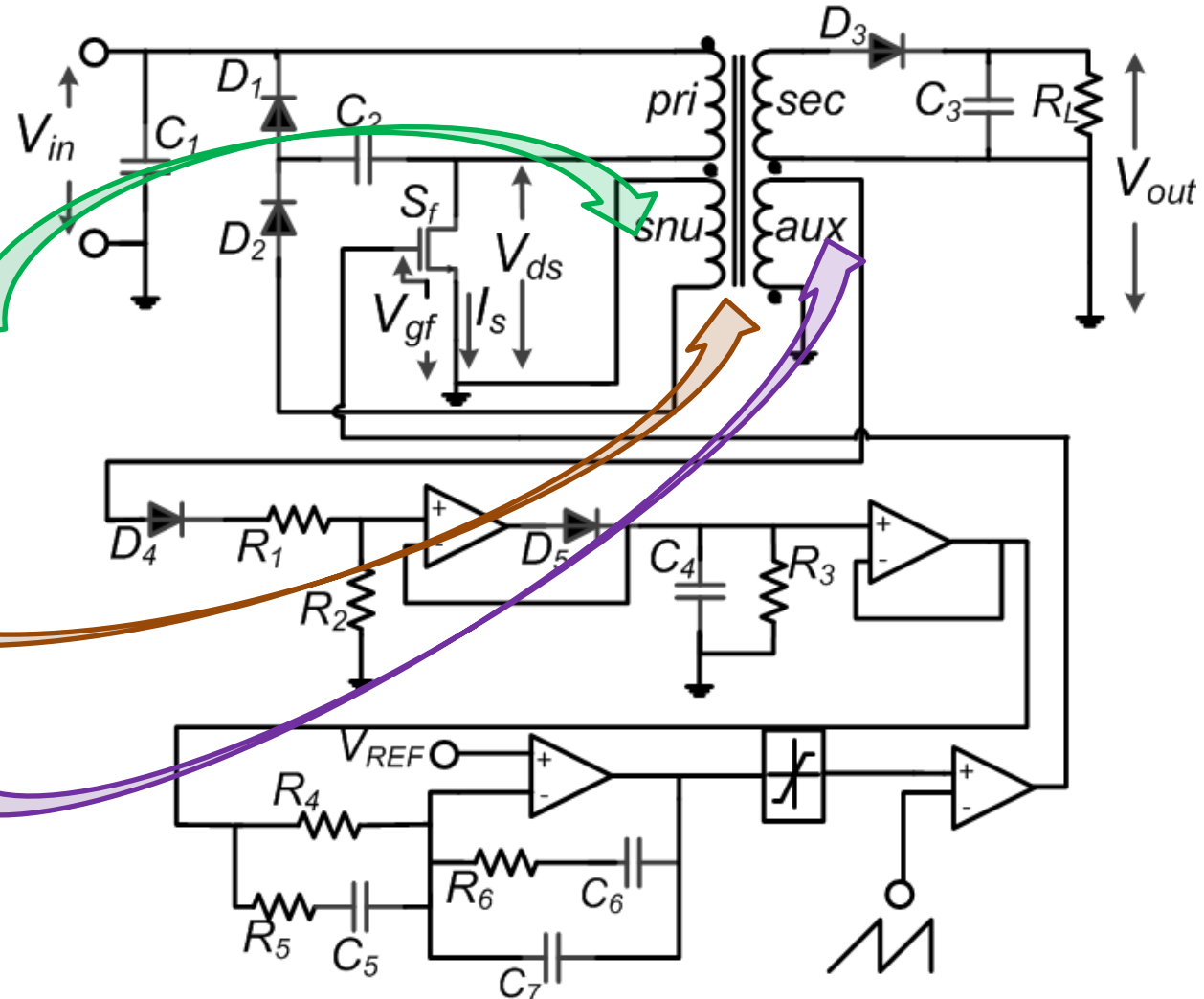
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- Miniaturized Power Supplies – State of the Art

Cheapest solution, but not the smallest

Flyback Converter:

- High efficiency by resonant or regenerative snubber
- Galvanic isolation
- Simple Primary Side Control
- Small number of components



■ Miniaturized Power Supplies – State of the Art

Example: 18 W Off-line Supply - Analog Control at Lowest Expense

FEATURES

Dramatically Simplifies CV/CC Converters

- Eliminates optocoupler and all secondary CV/CC control circuitry
- Eliminates all control loop compensation circuitry

Advanced Performance Features

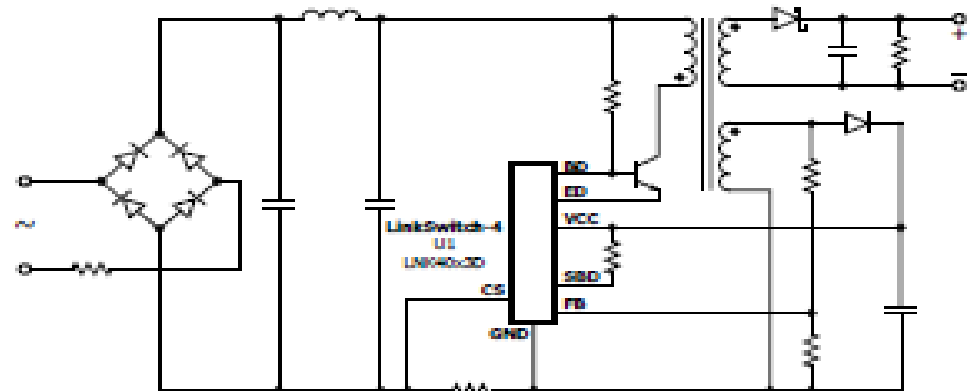
- Dynamic base drive technology provides flexibility in choice of BJT transistor by dynamically optimizing BJT switching characteristics
 - Extends RBSOA of BJT
 - Dramatically reduces sensitivity to BJT gain
- Compensates for input line voltage variations
- Compensates for cable voltage drop
- Compensates for external component temperature variations
- Very accurate IC parameter tolerances using proprietary trimming technology
- Frequency up to 65 kHz to reduce transformer size
- The minimum peak current is fixed to improve transient load response

Enhanced Performance Features

- Easy start for starting into capacitive loads (LNK4114D, LNK4115D)
- Constant power for high current start-up (LNK4214D, LNK4215D)
- 13003 drive improved efficiency with 13003 BJT's (LNK4302S, LNK4322S)

Advanced Protection/Safety Features

- Single fault output overvoltage and short-circuit
- Over-temperature protection
- Active clamp

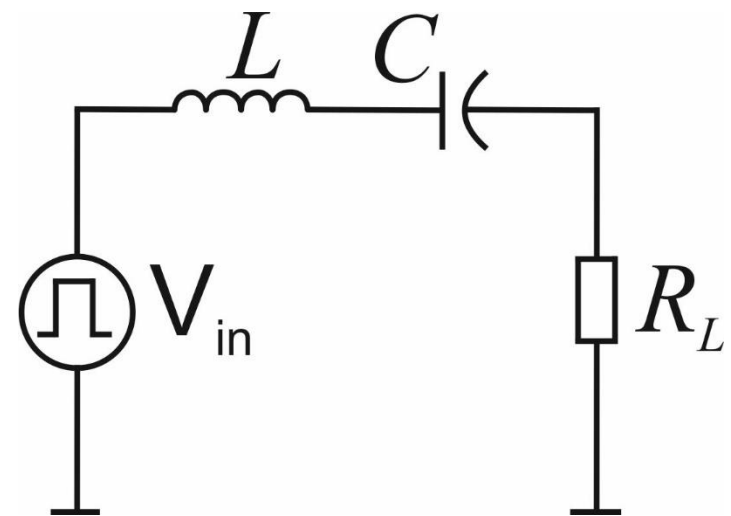
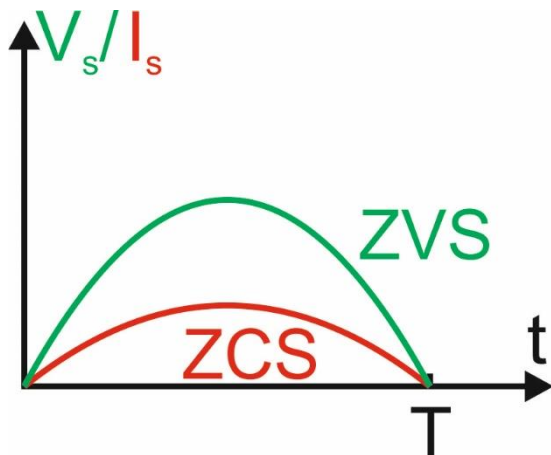


Source: Link Switch-4 Family, Power Integrations

- Miniaturized Power Supplies – State of the Art

Low-Q Topology: allows for extreme size reduction reducing losses in switches and passives

- Loaded factor $Q = \frac{1}{R_L} \sqrt{\frac{L}{C}} \rightarrow 0$ means $L \rightarrow 0, C \rightarrow \infty$
- Resonant Switching with ZVS *and* ZCS at resonance frequency $f_{res} = \frac{1}{2\pi\sqrt{LC}}$



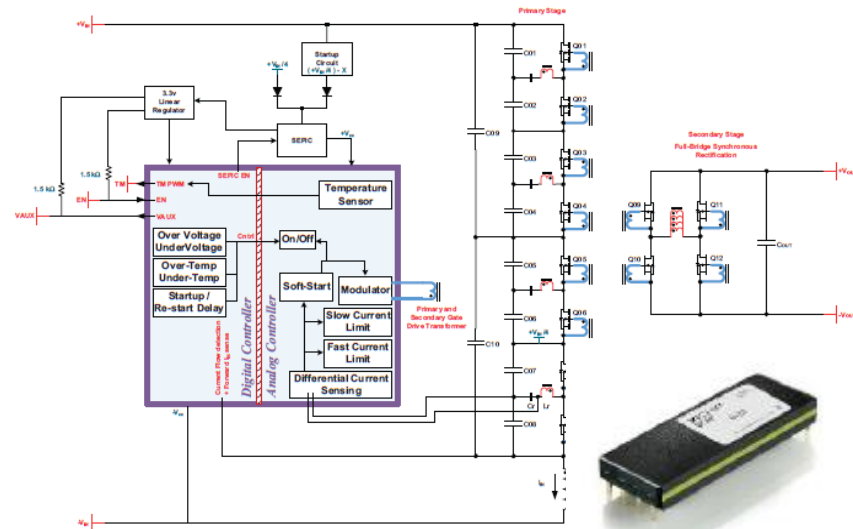
- Miniaturied Power Supplies – State of the Art

Isolation by Magnetic Passive Technology: 114 W/cm^3

- **Integrated magnetic Transformer:** Isolation by **Material**,
 $P_{out} = 1200 \text{ Watt}$, $V = 10,5 \text{ cm}^3$
- **Multilevel-Converter** -> reduced blocking voltage of
 Mosfets: 100 V
- **low Q** -> **unregulated Vout**
- **High frequency (10 MHz)**

- = Miniaturization

Source: VICOR BCM[®] Bus Converter
 BCM380y475x1K2A30



- Miniaturized Power Supplies – State of the Art

Today's highest density for off-line power supply: 114 W/cm^3

$P_{\text{out}} = 1200 \text{ Watt}$: $V = 10,5 \text{ cm}^3$, $\eta = 98\%$, $P_V = 24 \text{ W}$
(output unregulated, without heat sink/cooling)



State of the Art: RECOM RAC-10-SB: $0,303 \text{ W/cm}^3$

$P_{\text{out}} = 10 \text{ Watt}$: $V = 33,0 \text{ cm}^3$, $\eta = 75\%$, $P_V = 3,3 \text{ W}$
(output voltage regulated, no cooling)



Perspective: $P_{\text{out}} = 12 \text{ Watt}$: $V = 0,105 \text{ cm}^3$?

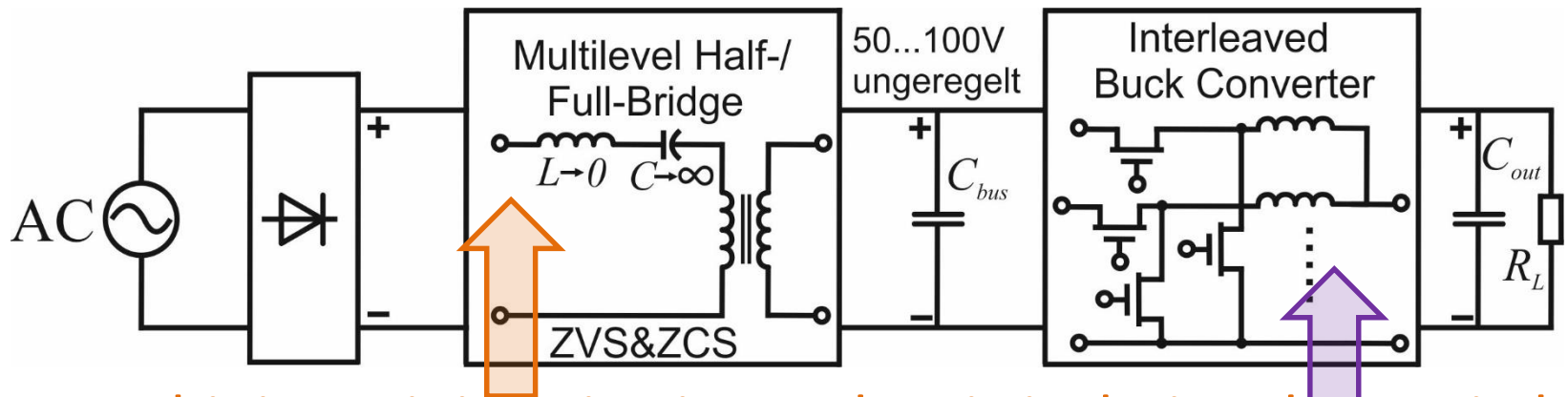
$V = 4,7 \text{ mm} \times 4,7 \text{ mm} \times 4,7 \text{ mm}$



... Extremely small, output voltage regulated - Is this realistic?

- Miniaturized Power Supplies – State of the Art

Multilevel Low-Q and Interleaved Buck: Isolation by passive magnetic technology, control of the output by step-down converter



... combining miniaturization, galvanic isolation, low switching losses of the first stage with output control, output filter reduction in the second stage

Applicable for $P_{out} > 100 \text{ W}$, basic costs at 10 W are too high....

- Miniaturized Power Supplies – State of the Art

	Flyback	Forward	LLC	Low-Q	High-Q
Loaded factor Q	-	-	1,0 – 3,0	0,01 – 0,1	5,0 – 30,0
Maximum Power approx.	50 W	400 W	500 W	2000 W	30 W
Soft Switching	ZVS	ZVS	ZVS	ZVS, ZCS	ZVS
Transformer	Conv. Magnetic	Conv. Magnetic	Planar or Conv.	Planar Integrated	Piezoelectric
Power Density	Low	Low	High	Very High	High
Cost	Very Low	Low	Medium	Very High	High

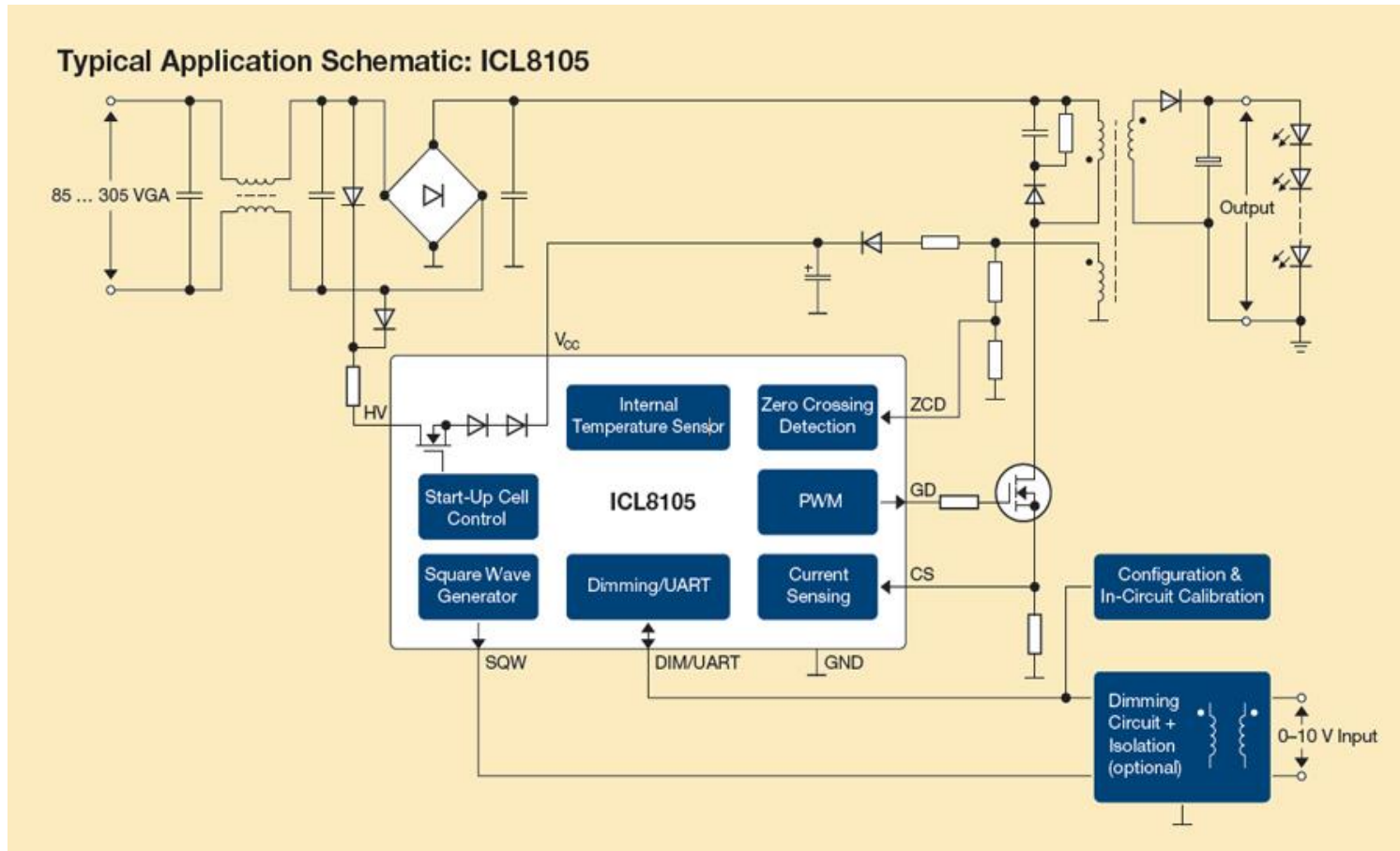
Coparison of Topologies using discrete Components

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■ Digital Control by Interface UART

Example: 10 - 80 W Off-line LED Supply - Digital Control by UART Interface



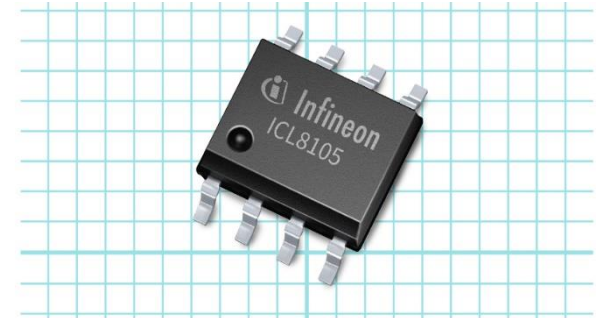
Source: Infineon – .dp Digital Power 2.0™ for Energy Efficient LEDs (ICL8105)
April 1, 2016 by [Future Technology Magazine](#)

■ Digital Control by Interface UART

Example: 10 - 80 W Off-line LED Supply - Digital Control by UART Interface

FEATURES

- Supports AC and DC input
- AC input voltage 90V AC to 305V AC
- Highly accurate primary side control with wide output range
- High output current accuracy
- Efficiency up to 91%
- High power quality, typical power factor up to 0.9 and THD <10%
- Integrated start-up cell
- Digital parameter setting by UART



All relevant error conditions are monitored and protected:

- Under-voltage
- Over-voltage
- Open Load
- Output Shorted

Source: Infineon – .dp Digital Power 2.0™ for Energy Efficient LEDs (ICL8105)

April 1, 2016 by [Future Technology Magazine](#)

- Digital Control by Interface UART

Example: 10 - 80 W Off-line LED Supply – Evaluation Tool



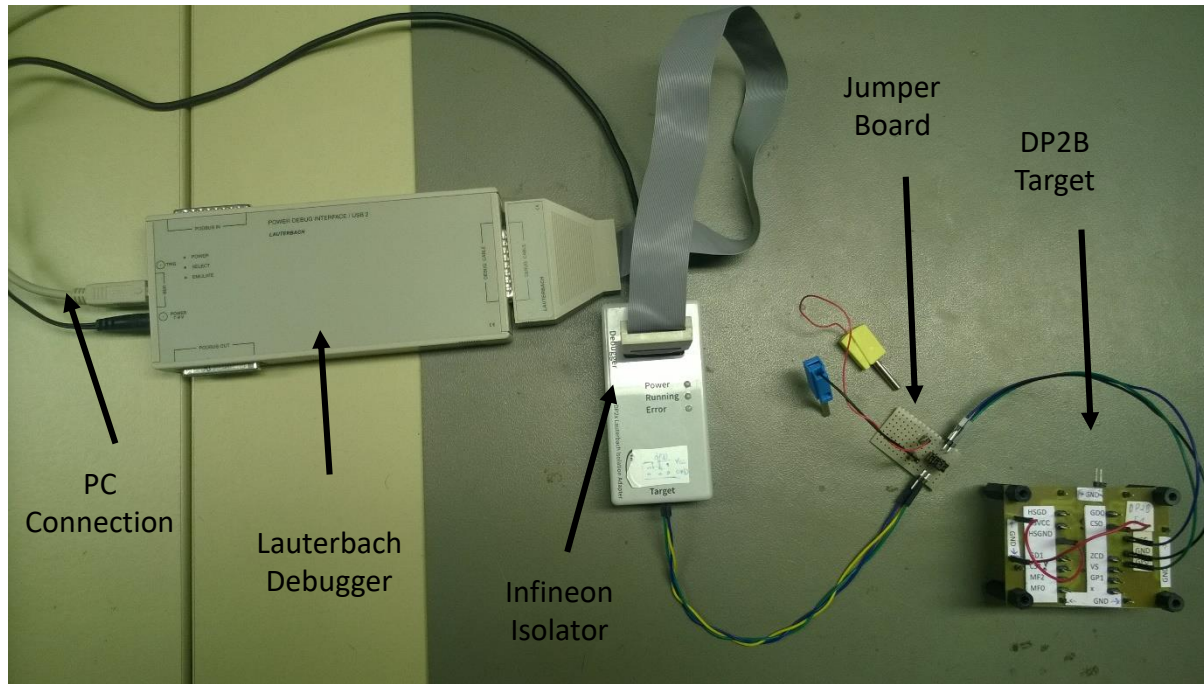
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- Programmable Digital Control

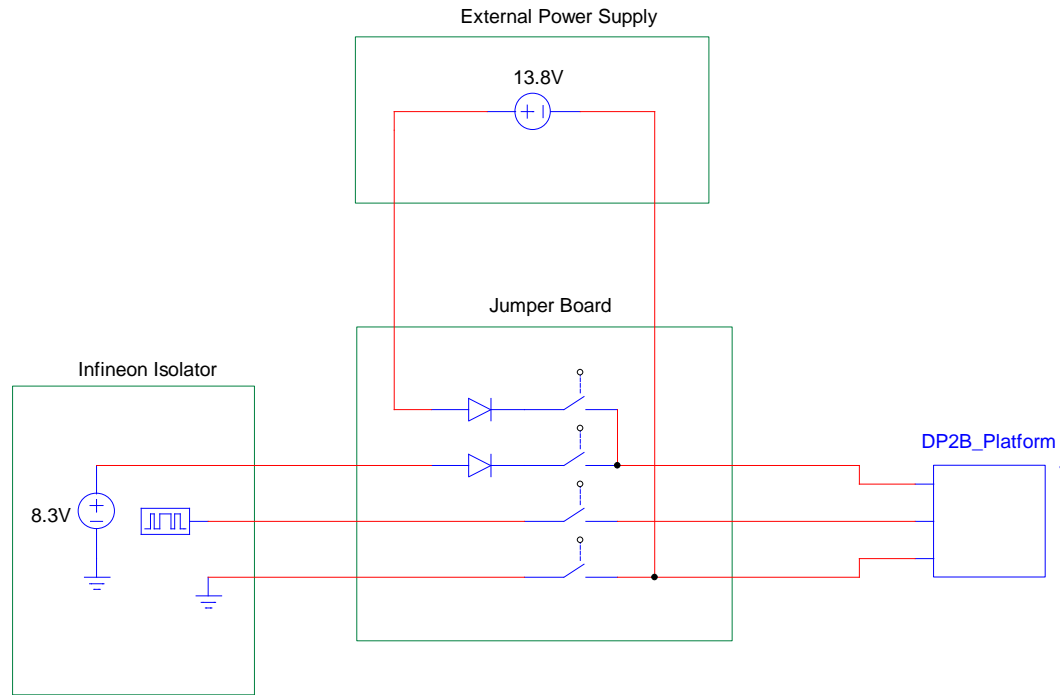
Infineon DP2Bxx Digital Platform for Customer Programming



DP2B Programmer and Debugger Set Up

- Programmable Digital Control

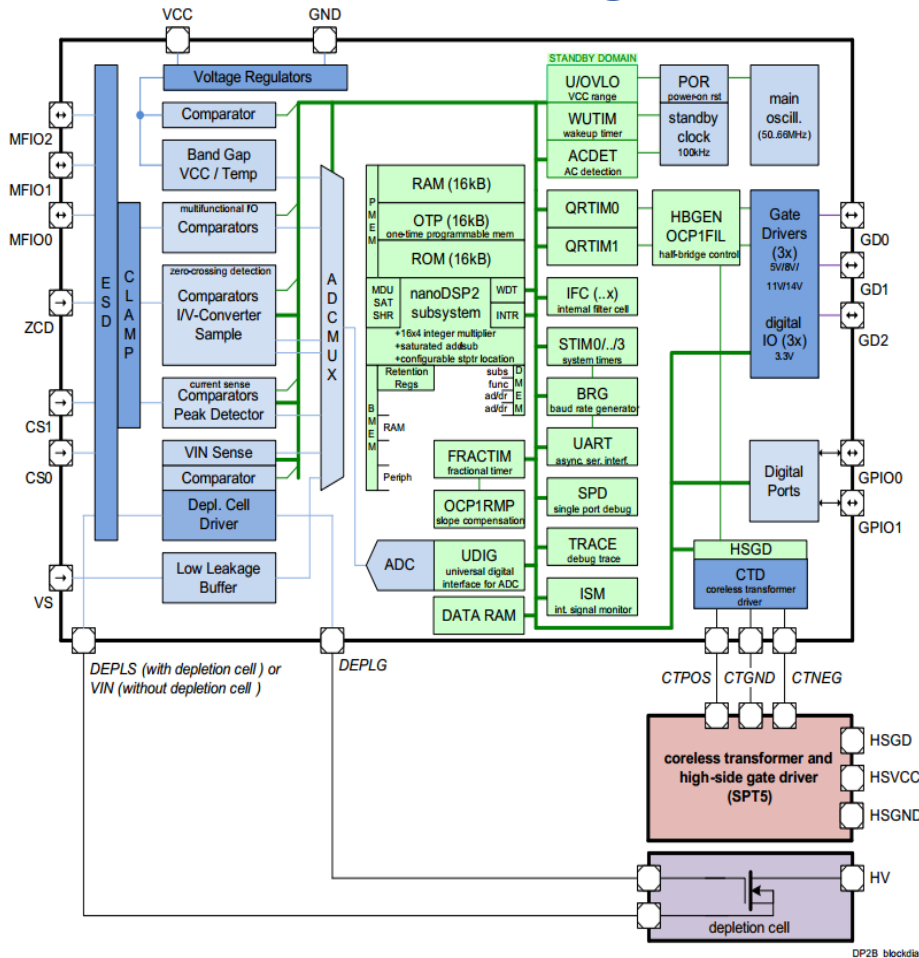
Infineon DP2Bxx Digital Platform for Customer Programming



DP2B programming jumper board

- Programmable Digital Control

Infineon DP2Bxx Digital Platform for Customer Programming



Control Chip: Device Block Diagram [1]

- ❖ 16-bit nano DSP core up to 66MHz
- ❖ 16KB data RAM
- ❖ 16KB program RAM
- ❖ 16KB program ROM
- ❖ 16KB OTP memory
- ❖ Integrated gate drivers
- ❖ 14-channel 8-bit A/D Converter
- ❖ 4 system timers
- ❖ 2 independent QR timers
- ❖ UART interfaces
- ❖ High voltage input for start up and AC detection

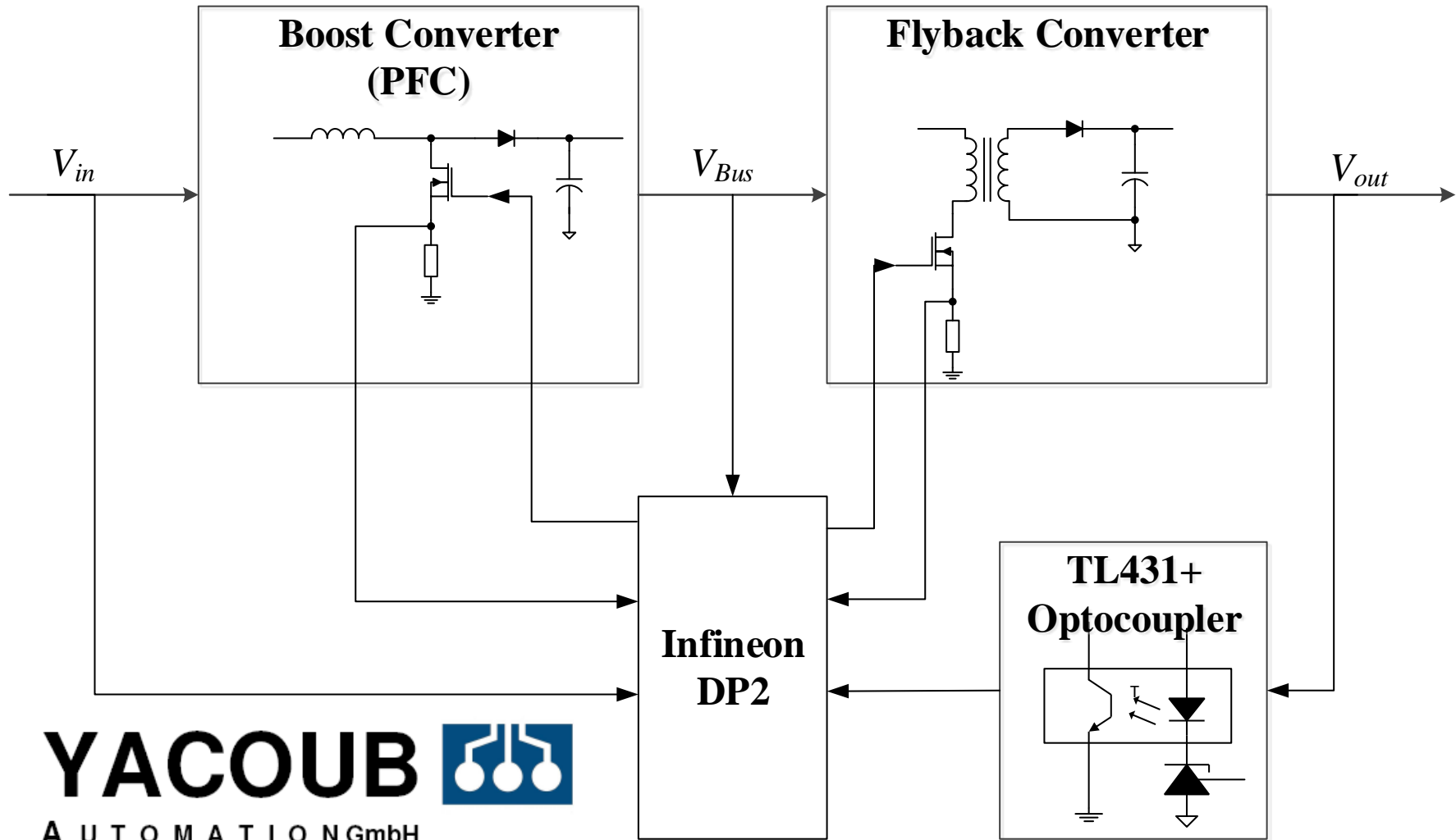
Source [1] : Datasheet of Infineon Technologies AG

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- Example 1: Wide Range Power Supply

System Topology



- Example 1: Wide Range Power Supply

FEATURES

Input Voltage Range:	19VDC ~ 150V DC 70V AC ~ 265V AC (50Hz/60Hz)
Max Output Power:	15W
Output Voltage:	24VDC
Efficiency:	> 80 %
Control Speed:	1ms ~ 5ms
Output ripple:	+/- 10% @ Nominal Power
Inrush current:	≤ 2 A (Peak current)
Extended function:	Interleaving by UART

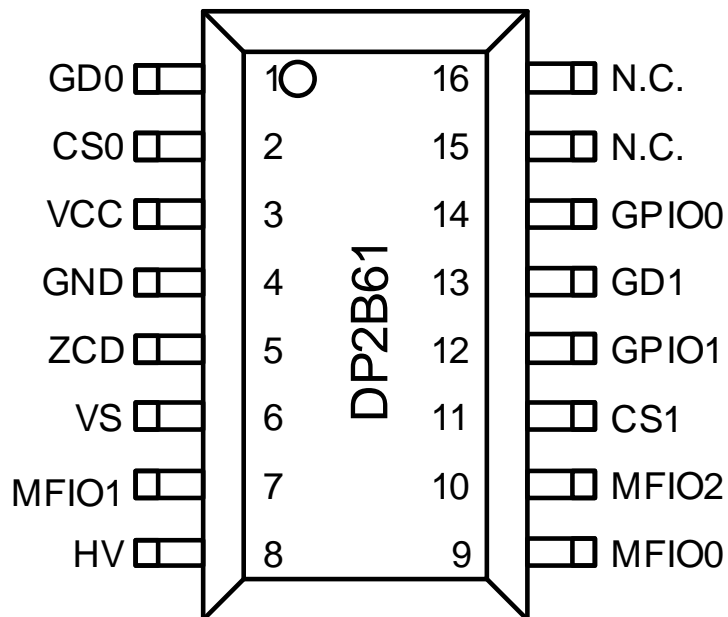
- Example 1: Wide Range Power Supply

Programmed Protection Functions:

1. Over Voltage @ Vbus: deactivates PFC; If Vbus is less than a preset value (less than a reference) PFC is activated
2. Over Current @ Flyback mosfet:
 - a. heavy load → less output volage, constant output power
 - b. very heavy load or short circuit at load, → deactivates first flyback stage, then deactivates PFC (to avoid OV at VBUS)
3. Low Input Voltage : deactivates first PFC, then deactivates Flyback stage

■ Example 1: Wide Range Power Supply

Pin Arrangement DP2B61



Flyback:

GD0: Flyback gate driver

CS0: Flyback MOSFET current sensor (peak current measuring at the falling edge of mosfet gate)

MFIO1: Output voltage of optocoupler

PFC:

GD1: PFC gate driver

CS1: PFC MOSFET current sensor

MFIO2: Rectified input voltage sensor

VS: BUS voltage sensor

Power supply:

VCC: Power supply

GND: Ground

HV: Power Supply for start up

Others:

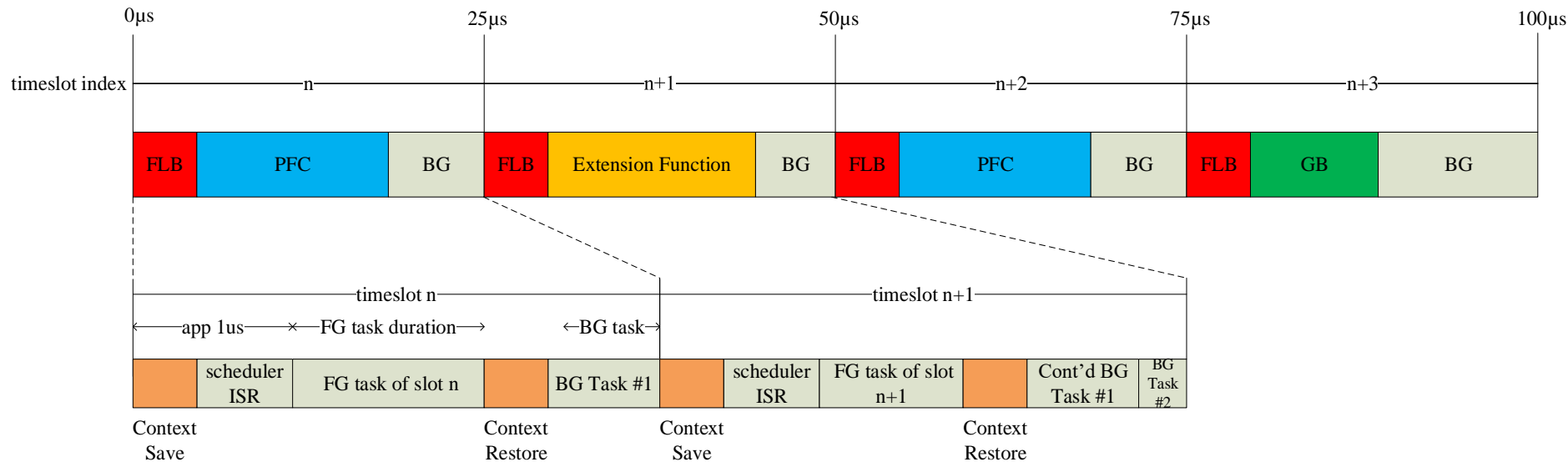
GPIO0: Debugger interface

MFIO0: for extended functions: UART for

Interleaving

- Example 1: Wide Range Power Supply

Scheduler Control Idea



Scheduler (Interrupt Service Routine) triggered by the system timer

A scheduler consists of 4 time slots in cycle (# can be modified)

Each time slot lasts 25μs (duration can be configurable)

Every time slot executes flyback control task

Every 2 schedulers performs PFC control task

Every 4 schedulers runs gearbox task (State machine control the system behavior)



- Example 1: Wide Range Power Supply

Scheduler Control Idea

- The scheduler requires that each foreground task completes within its timeslot, that means: the task **should** not cross the next timeslot boundary. The allocation of tasks and timeslots could be dynamically changed during runtime, but in general it is fixed at compile time.
 - The timebase for the scheduler is usually generated by a system timer
 - The length of each timeslot is configurable at compile time (#SCHEDULER_TIMEBASE_us)
 - Each timeslot allows the execution of zero, one or multiple FG task(s). The allocation of the timeslots is done statically during scheduler initialization. This is done to minimize code size and timing overhead of context handling

- Example 1: Wide Range Power Supply

UART Interface: Interleaving of Modules

- **Flexible output power delivery up to $n \cdot 15\text{W}$ ($n = 10 \rightarrow 150 \text{ Watts}$)**
- **Master–Slave mode: master module controls output voltage, slave mode activated only when master module demands more power (overcurrent occurs at master module)**
- **Communication between the master module and the slave modules over UART interface.**
- **Phase shift on PFC of every activated module to reduce the inrush current**
- **Redundant operation: If the master module fails, next slave module is activated as master \rightarrow High Reliability**

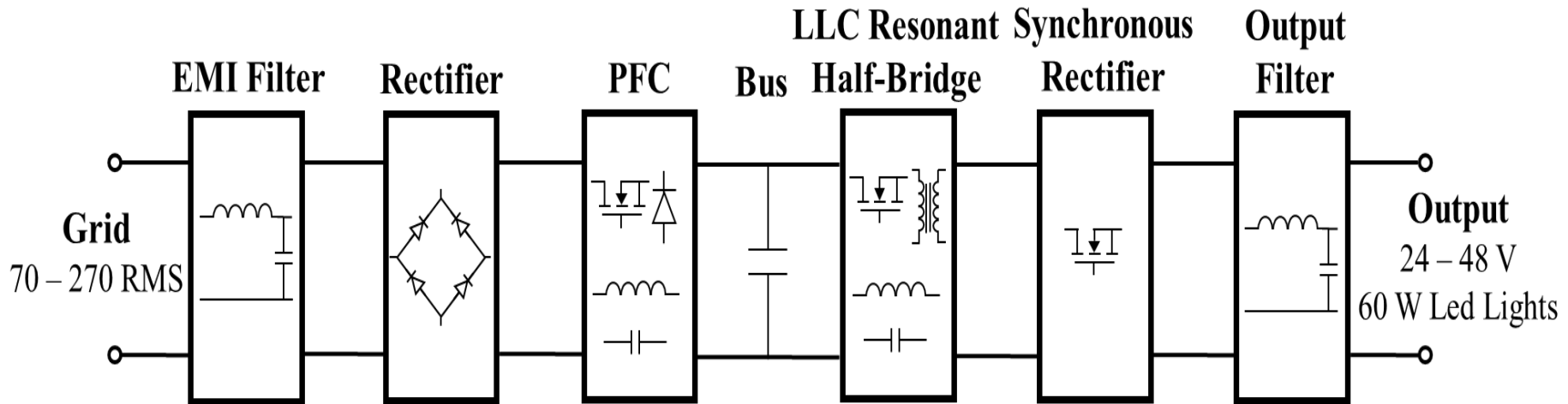
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- Example 2: Off-Line LED Driver

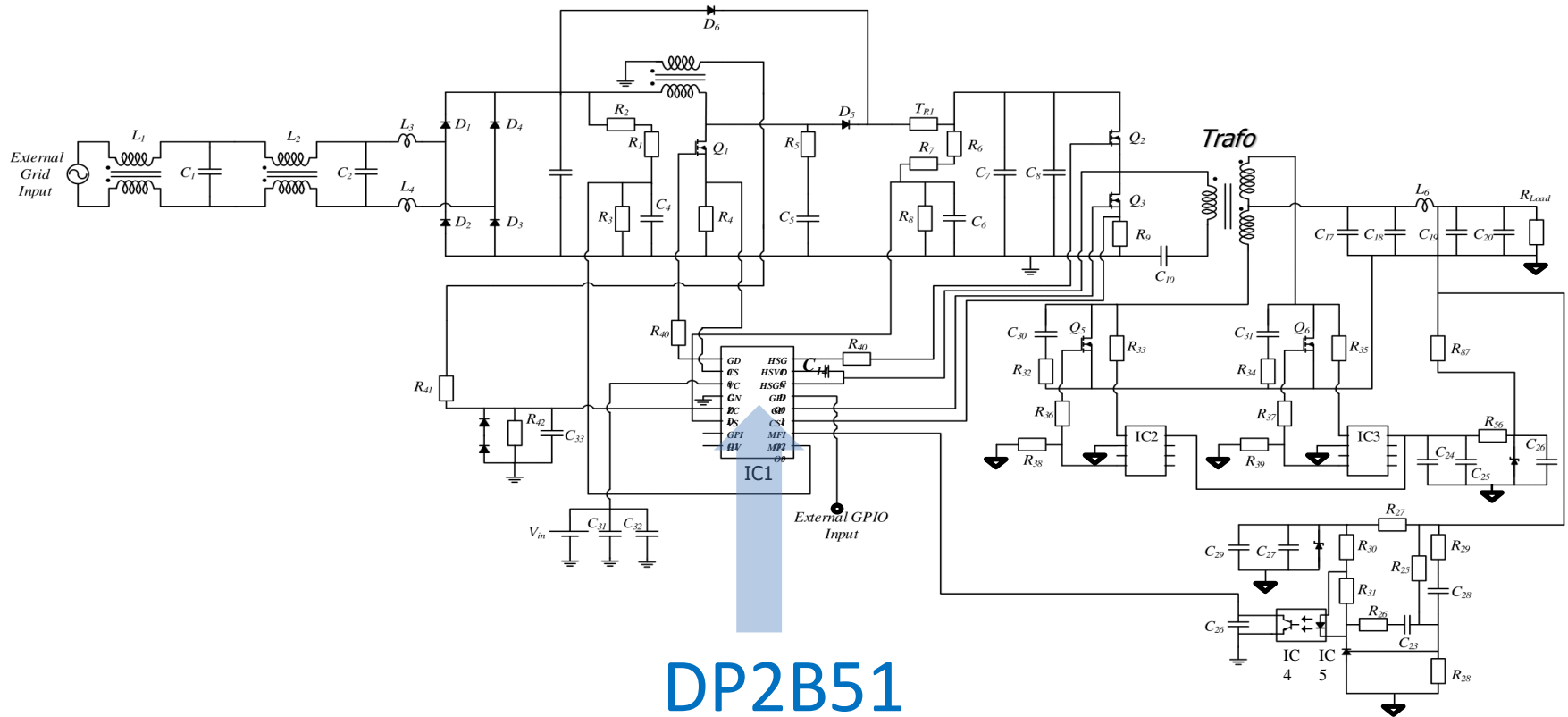
60 Watts Low Profile with PFC and LLC for Constant Output Voltage

Circuit



- Example 2: Off-Line LED Driver

60 Watts Low Profile – Complete Circuit



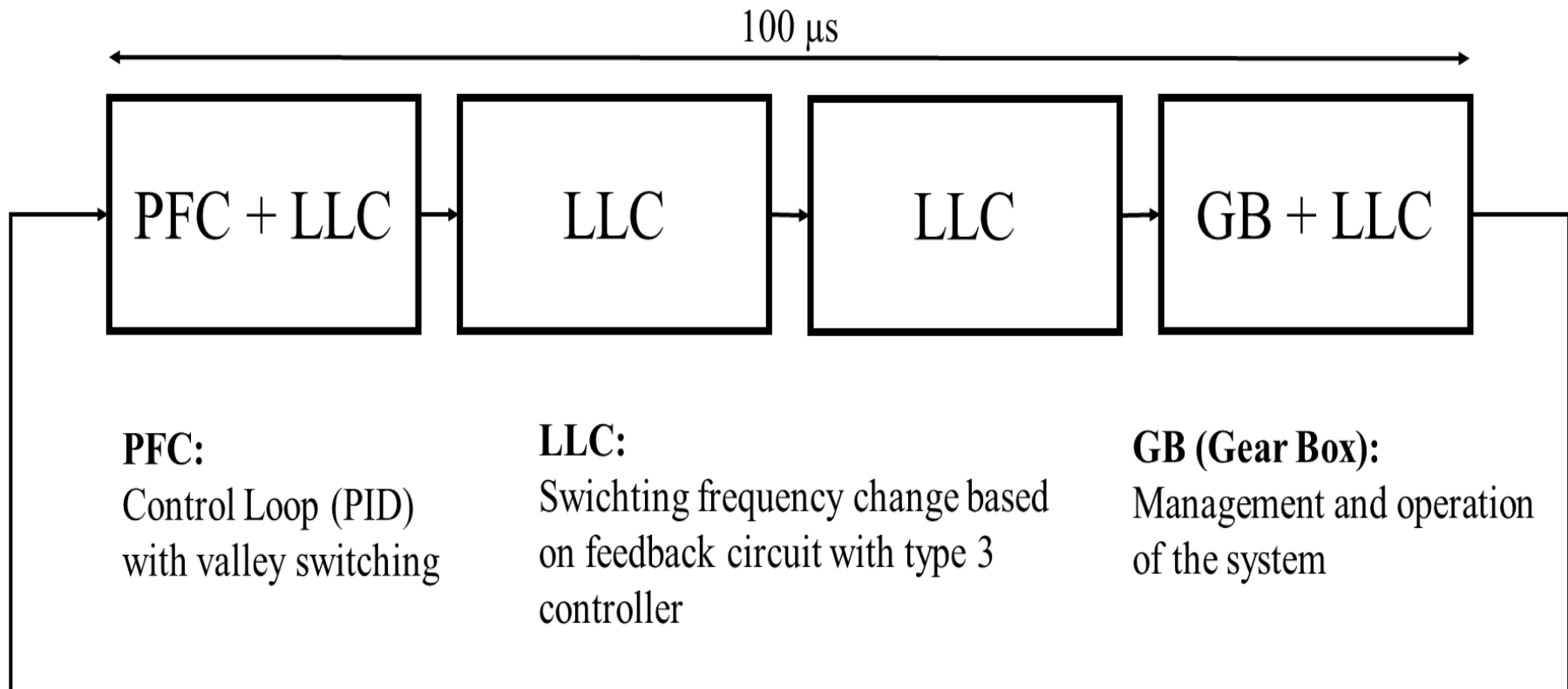
- Example 2: Off-Line LED Driver

FEATURES

- Modularity
- No change in PCB design for different output Voltage (e.g. 24 V, 36 V, 48 V)
- Output and bus voltage programmable at one unique component set up (e.g. for 24 V: V_{out} Range of 20 V – 28 V DC)

- Example 2: Off-Line LED Driver

Program Scheduler



■ Example 2: Off-Line LED Driver

Valley switching

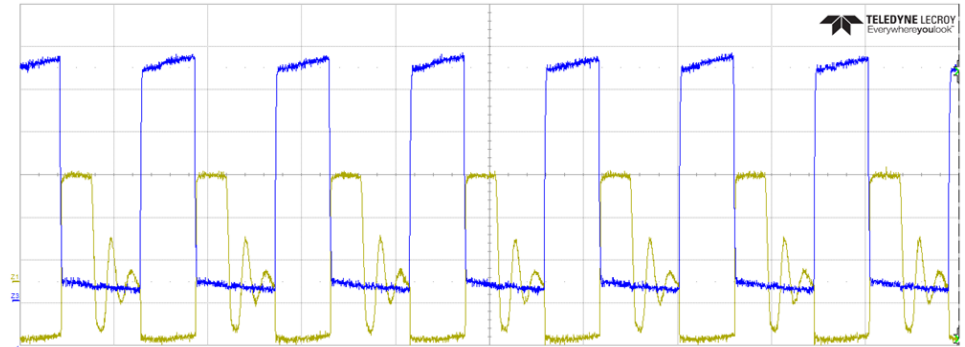
How it works:

The Zero Crossing Detection (ZCD) catches the moment when the boost inductor current goes to zero and the next switching cycle can start.

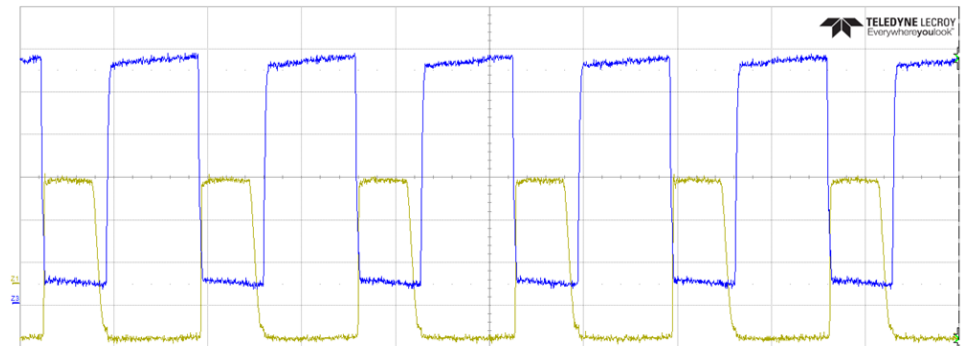
Advantage:

Minimize the switching losses

Examples:



Third valley



First valley

Blue – gate signal

Yellow – Voltage on the inductor

- Example 2: Off-Line LED Driver

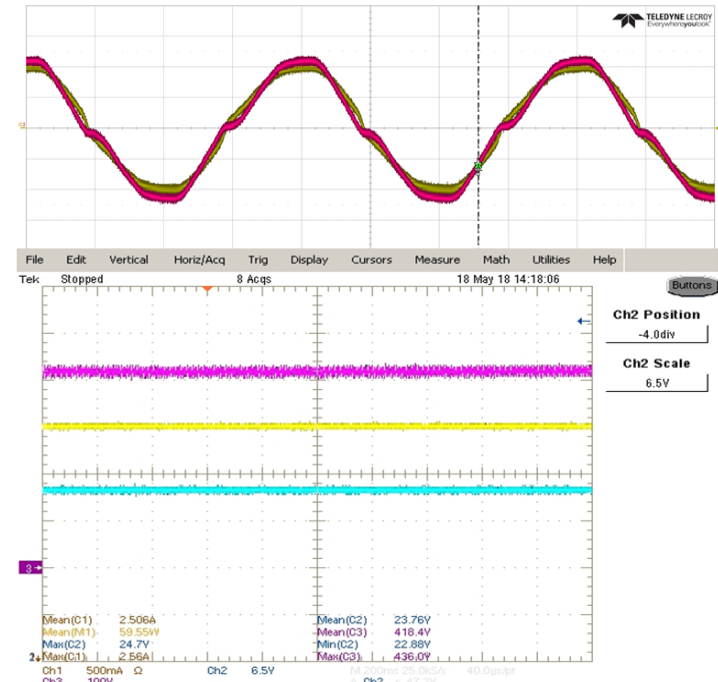
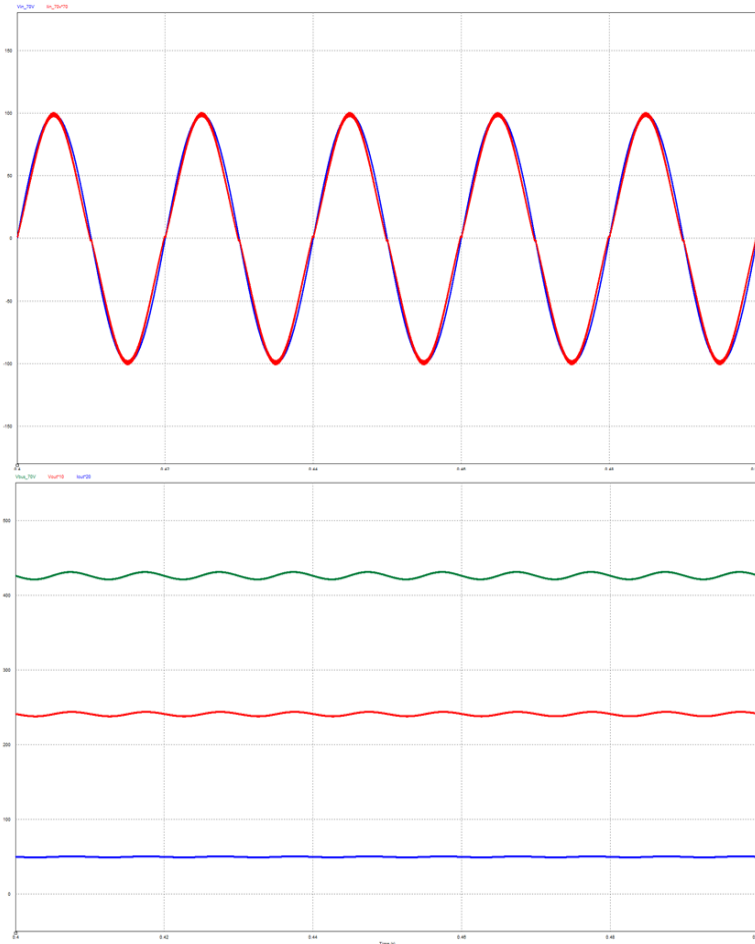
Results 24 V Board

V_{in} (RMS)	Full Load	Half Load	10 % Load	LED Lights
70	0,992/560	0,985/400	0,961/1160	0,992/-
110	0,989/290	0,977/600	0,926/132	0,986/364
120	0,987/640	0,974/440	0,913/372	0,987/348
230	0,955/220	0,900/130	-/100	0,948/236
250	0,944/150	-/84	-/88	0,938/408
270	0,929/130	-/80	-/88	0,918/140

Power Factor/Starting Time (ms)

■ Example 2: Off-Line LED Driver

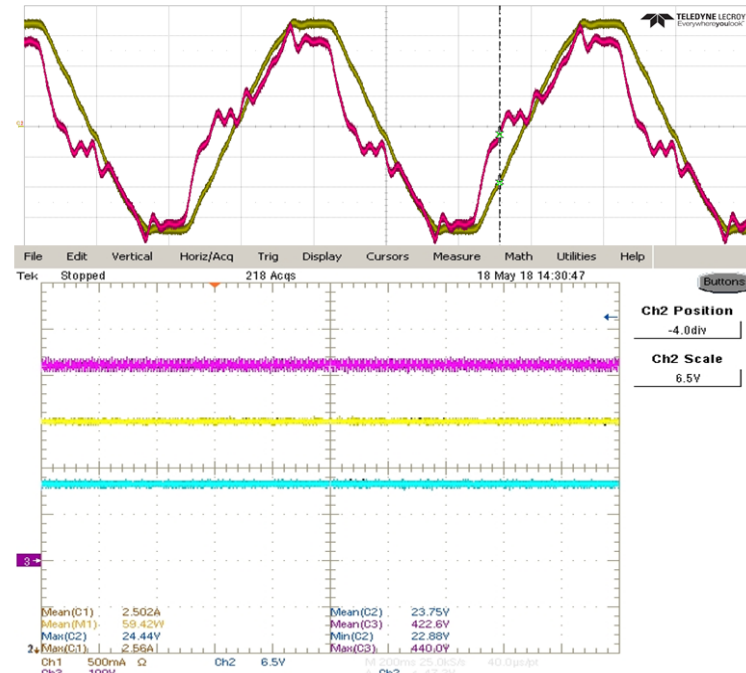
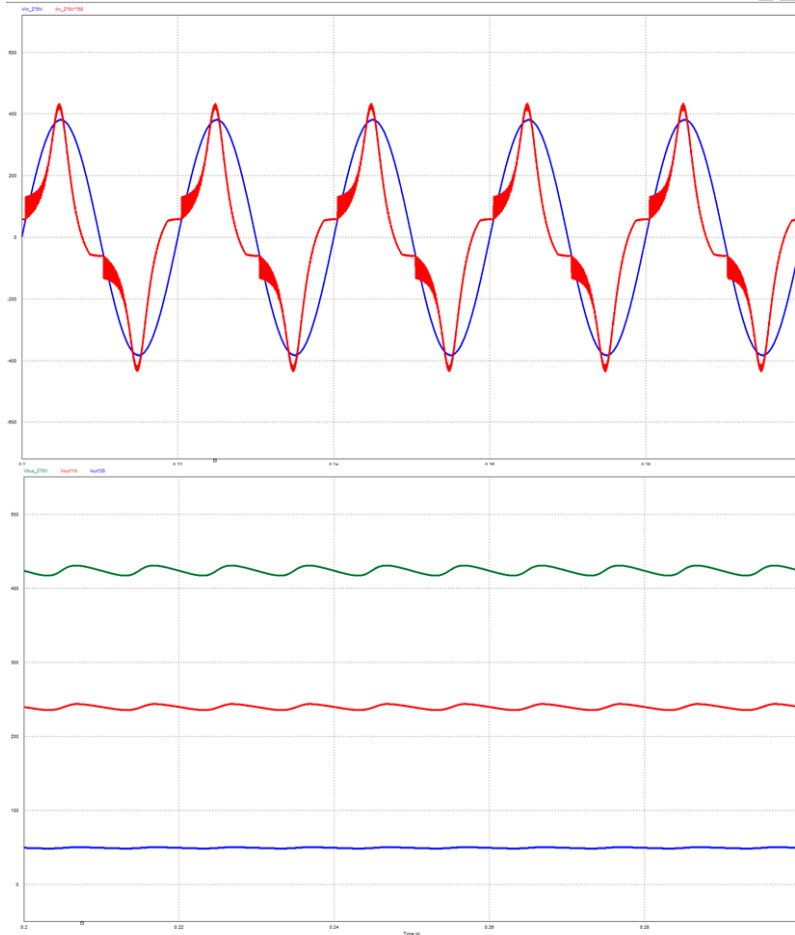
Results 24 V Board 70 V_{RMS}



	Simulated	Tested
Power factor	0,998	0,992
Average bus voltage	426,36	418,40
Average output voltage	24,12	23,75
Average output power	60,64	59,55

- Example 2: Off-Line LED Driver

Results 24 V Board 270 V_{RMS}



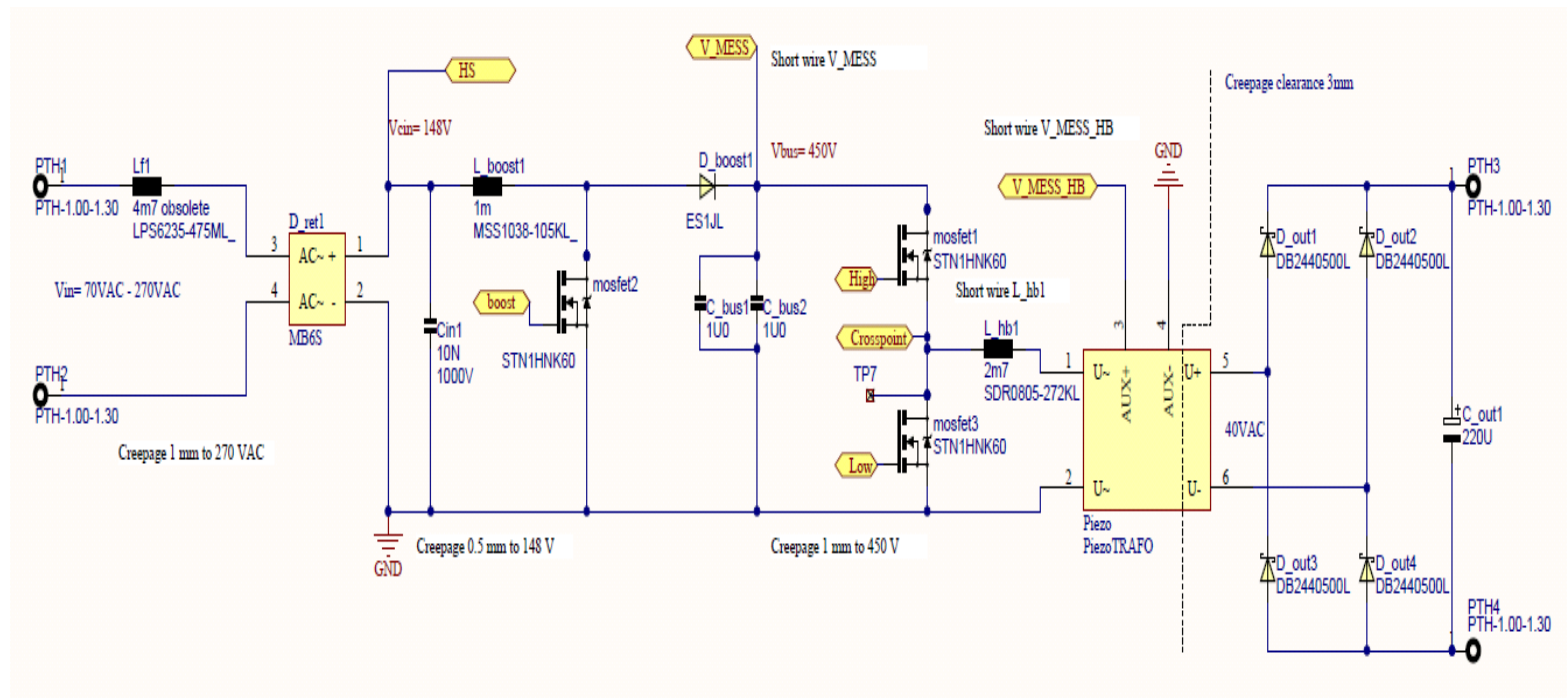
	Simulated	Tested
Power factor	0,867	0,929
Average bus voltage	424,22	422,6
Average output voltage	23,99	23,75
Average output power	59,97	59,42

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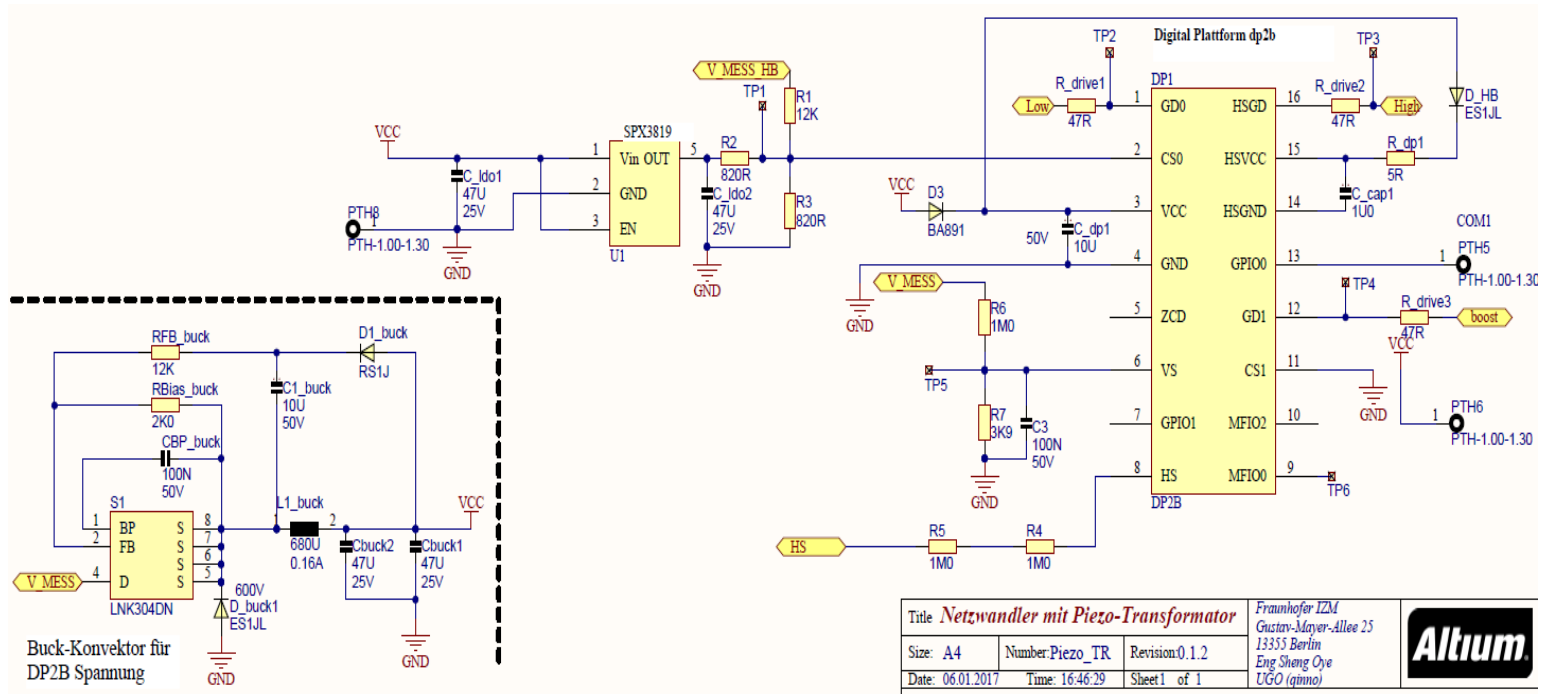
- Example 3: Off-Line Supply with Piezoelectric Transformer

3 Watts Low Profile – Complete Power Circuit



- Example 3: Off-Line Supply with Piezoelectric Transformer

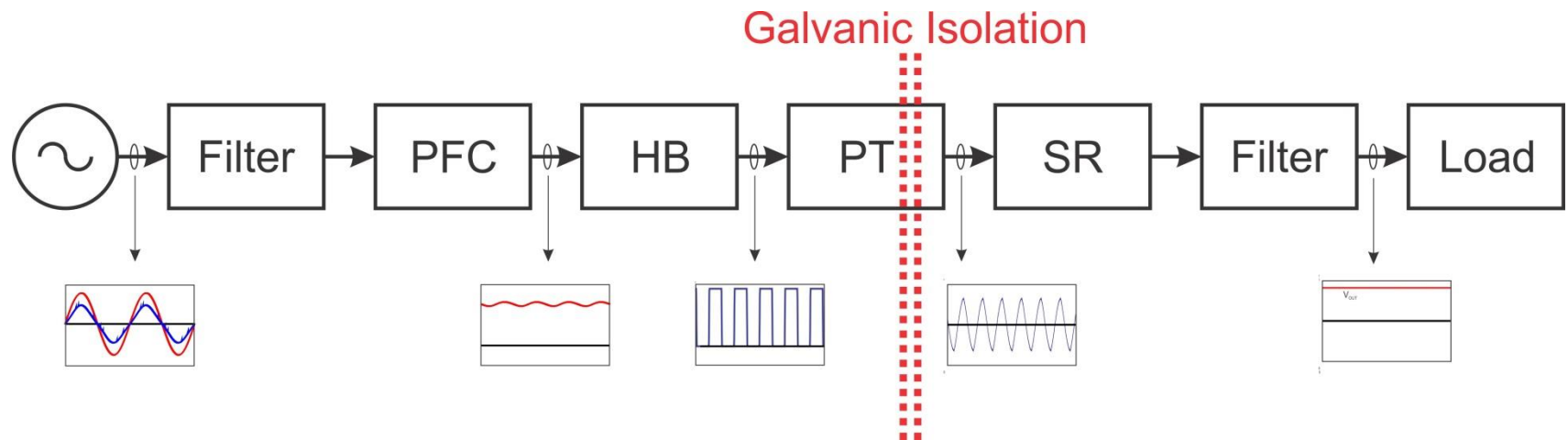
3 Watts Low Profile – Complete Control Circuit



- Example 3: Off-Line Supply with Piezoelectric Transformer

3 Watts Off-Line Power Supply with PT

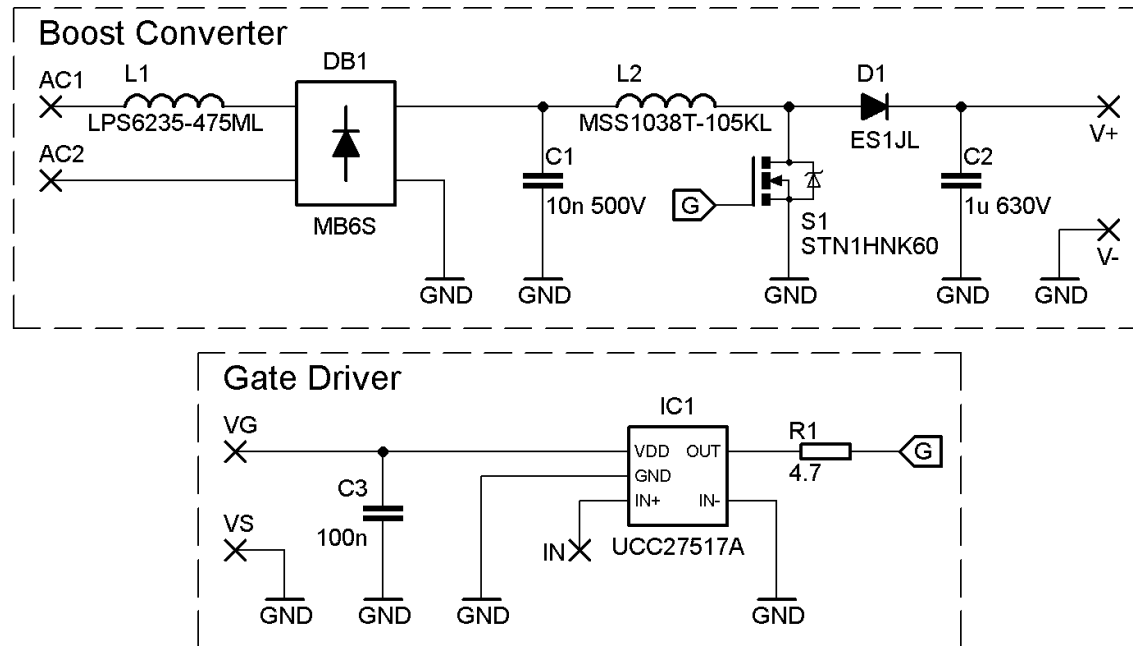
Input Filter + Boost-Converter (PFC) + Serial Inductor Half-Bridge + Piezo-Trafo + Synchronous Rectifier Full-Bridge + Output Filter



- Example 3: Off-Line Supply with Piezoelectric Transformer

3 Watts Off-Line Power Supply with PT

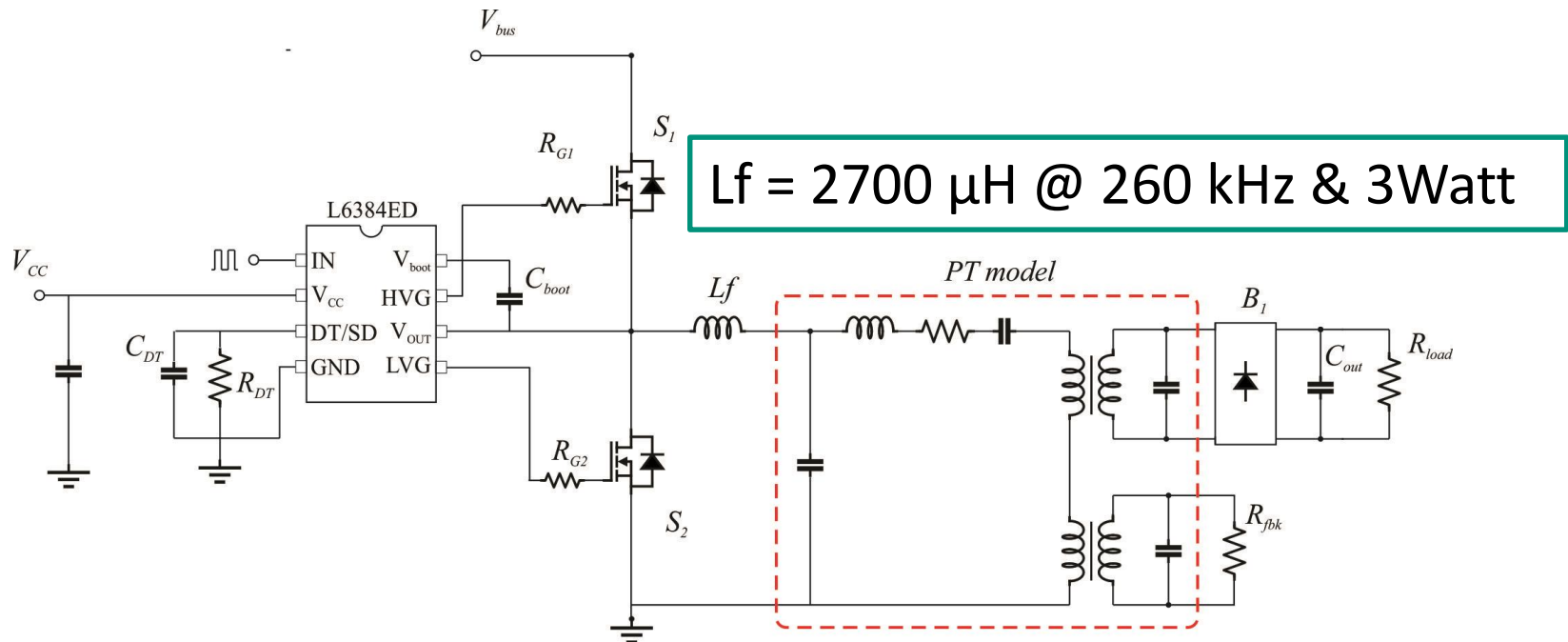
Input Filter + Boost-Converter (PFC)



- Example 3: Off-Line Supply with Piezoelectric Transformer

3 Watts Off-Line Power Supply with PT

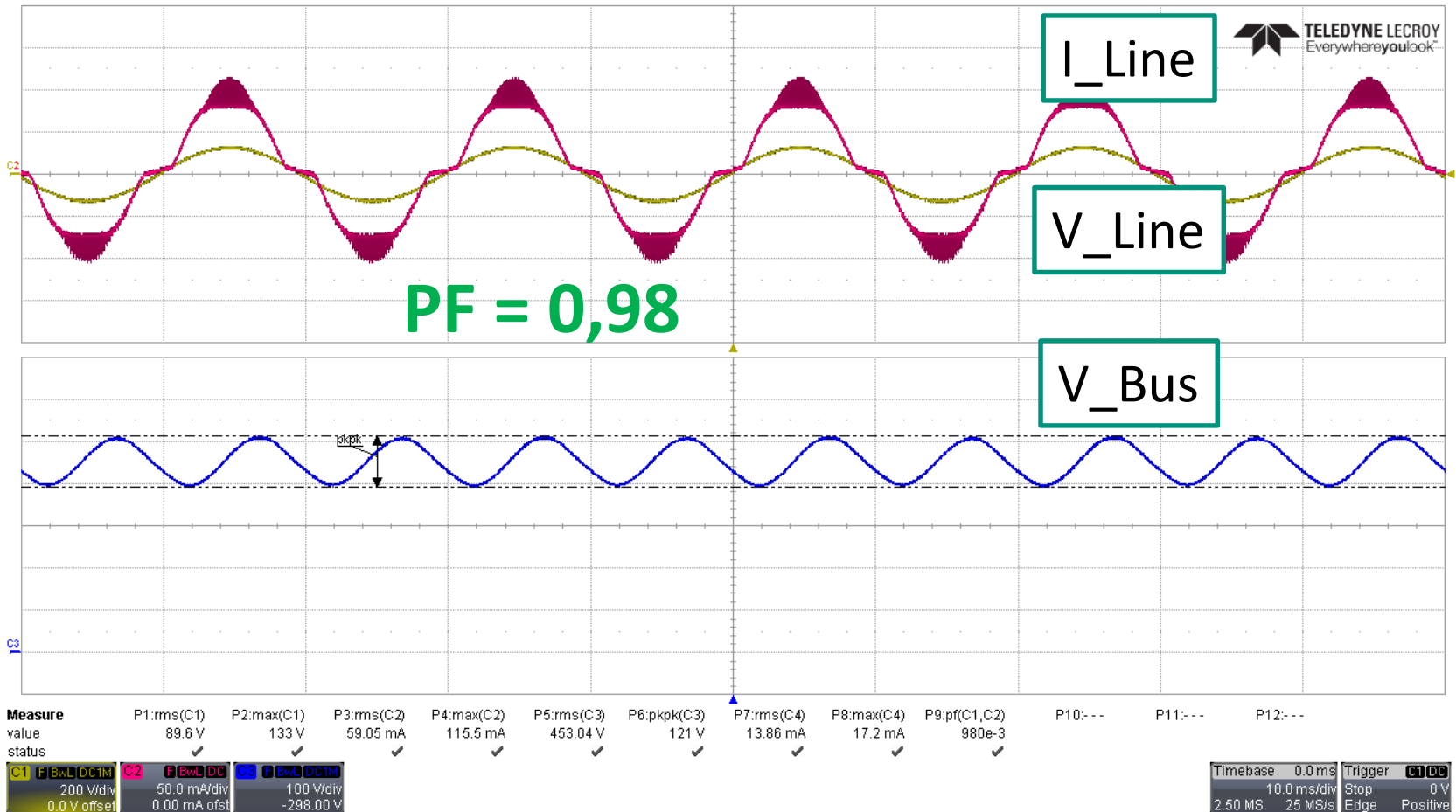
Serial Inductor Half-Bridge + Piezo-Trafo +
Synchronous Rectifier Full-Bridge + Output Filter



- Example 3: Off-Line Supply with Piezoelectric Transformer

Testing Results Pout = 3 Watts

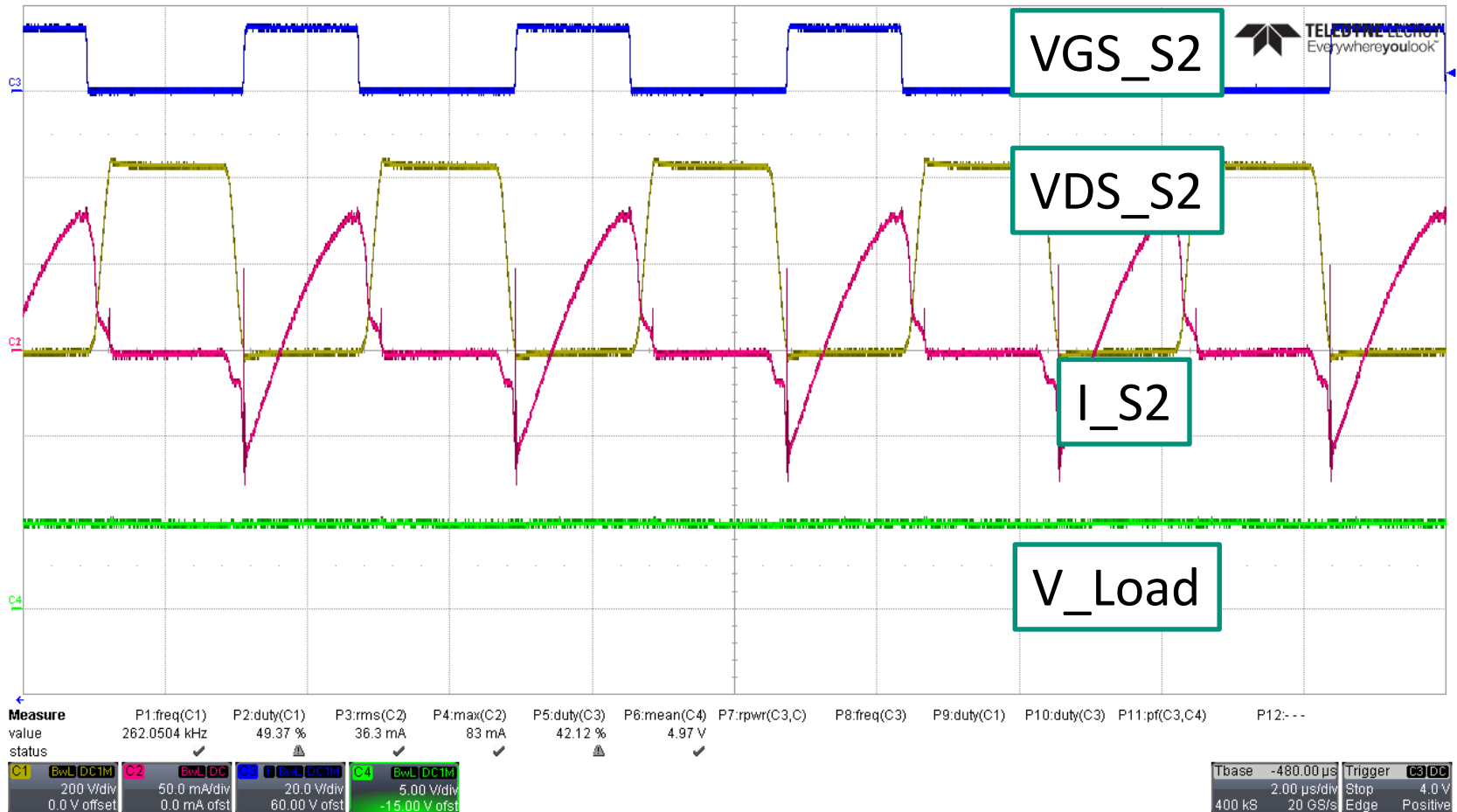
Input Filter + Boost-Converter (PFC) $V_{IN} = 90V_{rms}$



- Example 3: Off-Line Supply with Piezoelectric Transformer

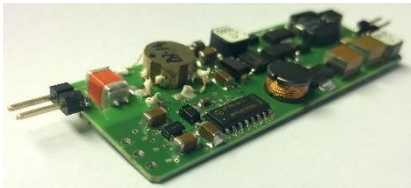
Testing Results $P_{out} = 3 \text{ Watts}$

SIHB + PT + Sync. Rect. + Out. Filter: $V_{BUS} = 450V$



- Example 3: Off-Line Supply with Piezoelectric Transformer

Tested Parameters: $P_{out} = 3\text{ W}$



Parameter	Value
Switching Frequency	261.86 kHz
Output Voltage	4.95 V
Output Power	3.14 W
I_{rms} in Half-Bridge Inductor L_f	55 mA
Ambient Temperature	28 °C
Maximum Temperature of PT	62 °C
Maximum Temperature of L_f	46 °C
Maximum Temperature of Mosfets S1, S2	38 °C

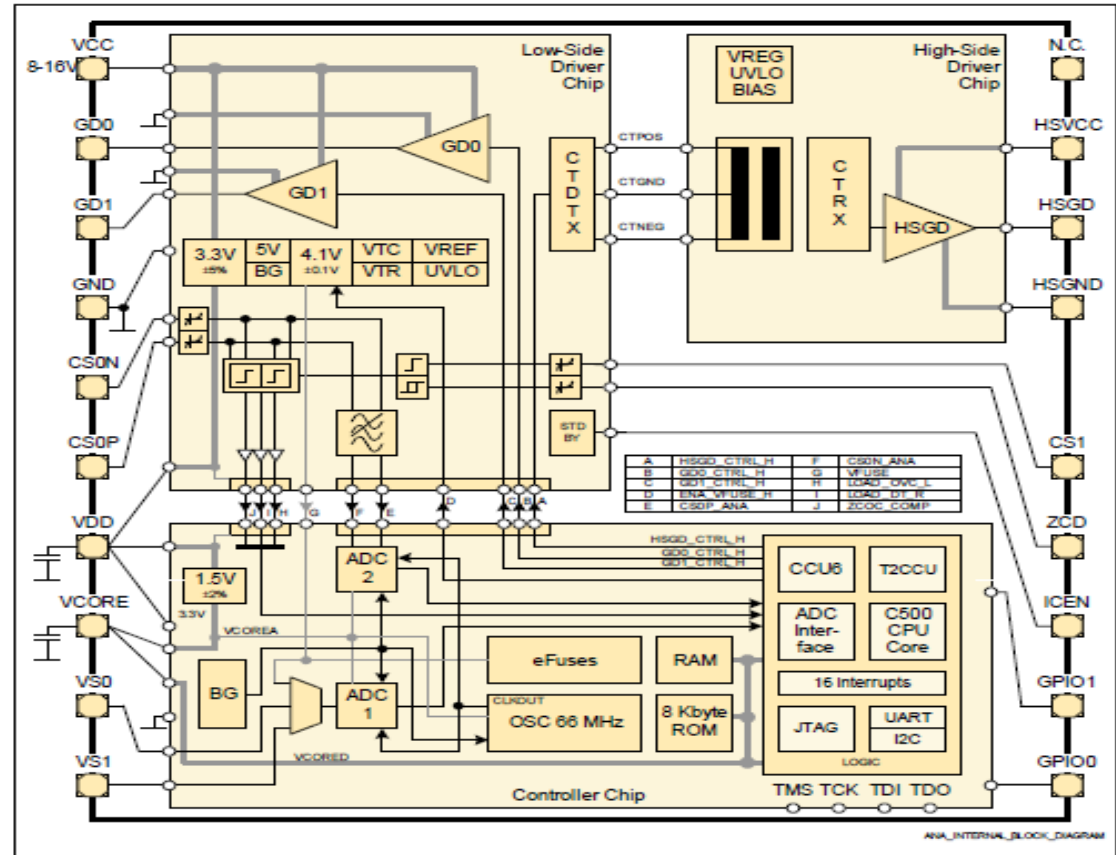
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- Expectations

Digital Plattform for flexible Programming

- Chip by Chip
- Nano-DSP for Low Power Digital Control
- Low-Side Driver
- High-Side driver (DP2B: up to 1 MHz)
- Programmable Pins
- Interleaving through GPIO



Source: DP2B of Infineon Technologies AG

- Expectations

- High Production Volume: Analog power supplies still useful
- Digital Control by UART Interface suitable for one Use-Case
- Digital Programmable Control for Special Use-Cases
- Digital Programming for Special Topologies or Components (as Integrated Piezoelectric transformers) will be applicable in case of request of **magnetic-field-free power conversion** (e.g. in MRT) below 100 Watts

Thank you for your Attention

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