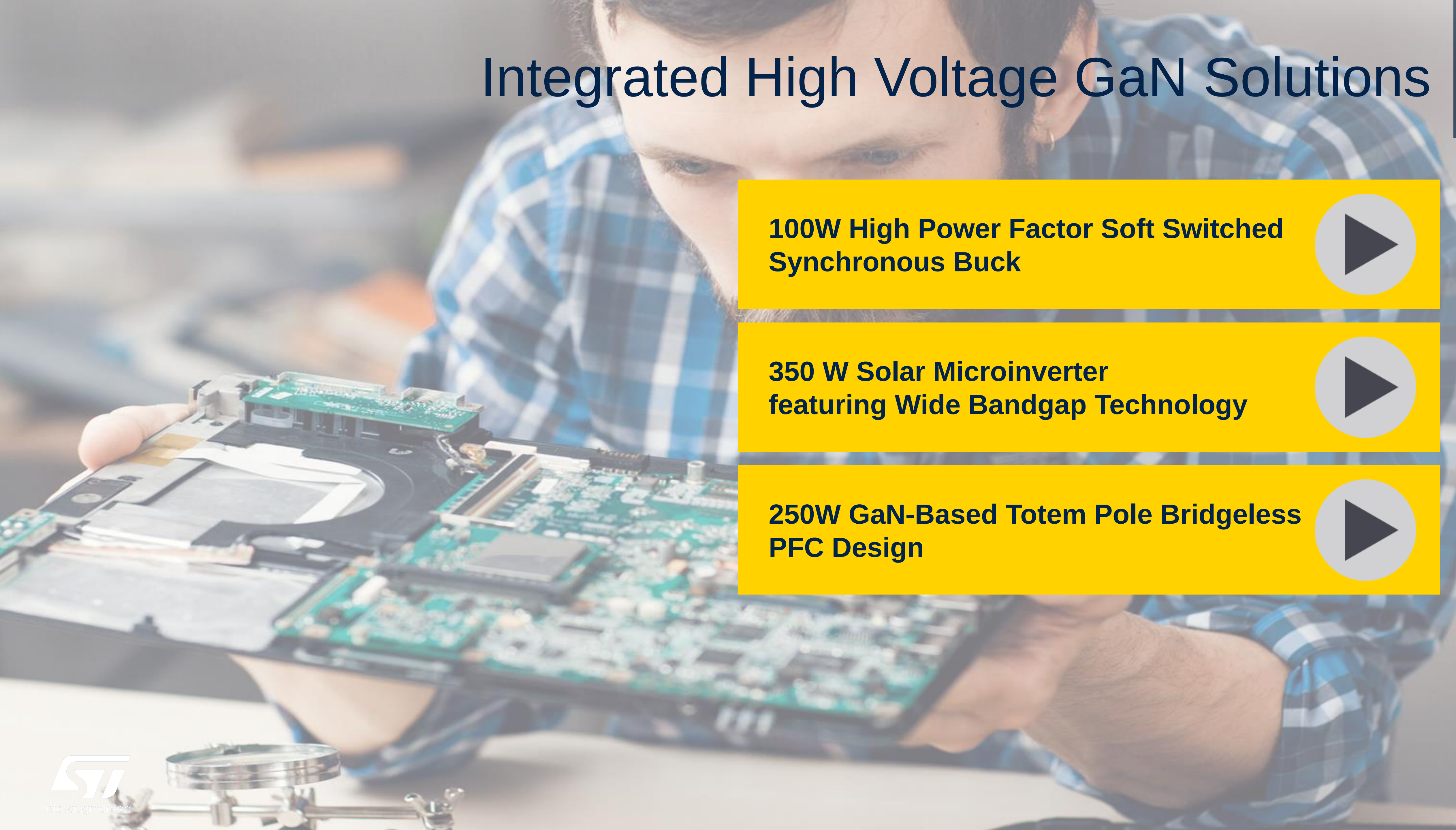
Integrated High Voltage GaN Solutions



100W High Power Factor Soft Switched Synchronous Buck

350 W Solar Microinverter featuring Wide Bandgap Technology

250W GaN-Based Totem Pole Bridgeless PFC Design

100 W High Power Factor Soft Switched Synchronous Buck

Introduction and Proposed Design

GaN SiP Ideal for Resonant Topologies

Advanced flyback controller designed for LED Lighting Applications

Operation, Results, and Additional Designs

Introduction and Proposed Design for a 100 W High PF, SIB solution

Key Design Considerations for LED Lighting Applications

The ease of use of GaN SiP technology allows high efficiency and high switching frequencies in the system while maintaining a small form factor

The THD Optimizer block, integrated in the analog controller, allows low input current harmonic distortion, crucial for LED drivers

The ZVS operation ensures high efficiency and lower radiation footprint

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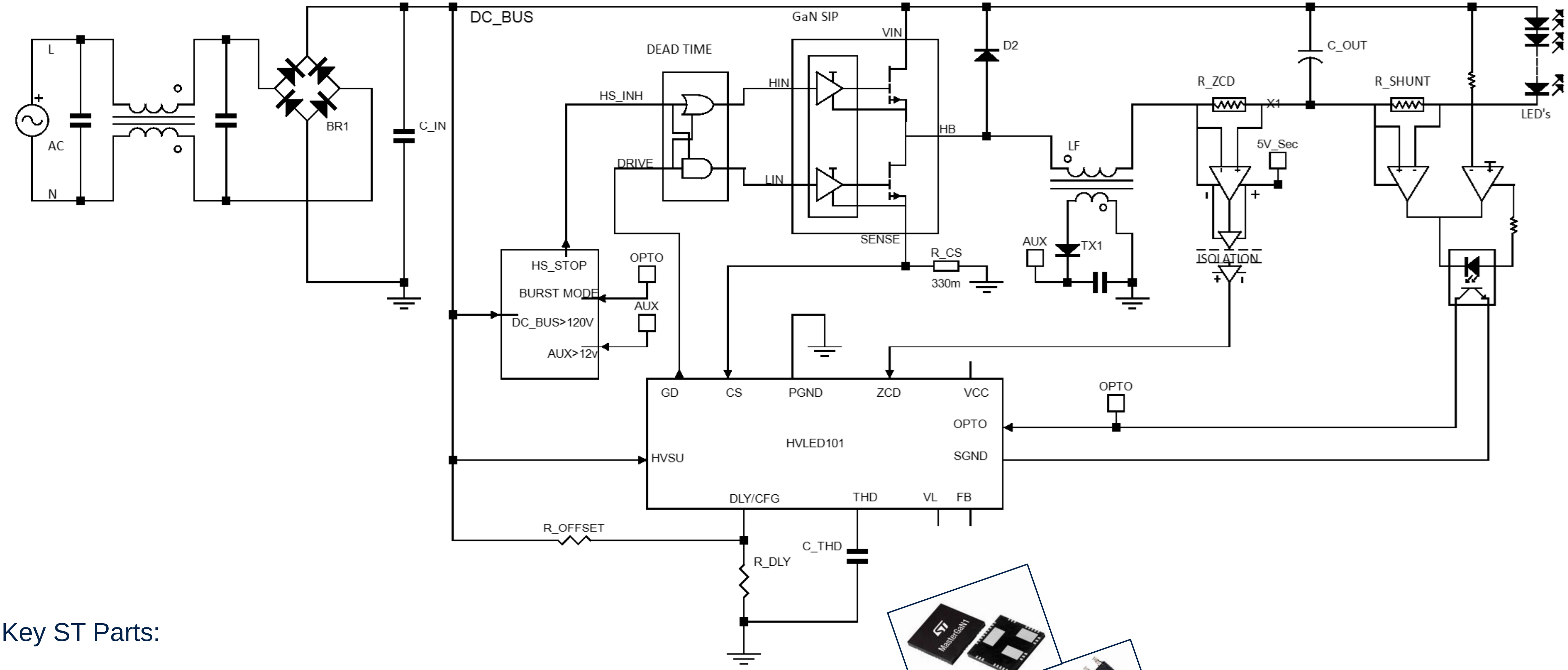
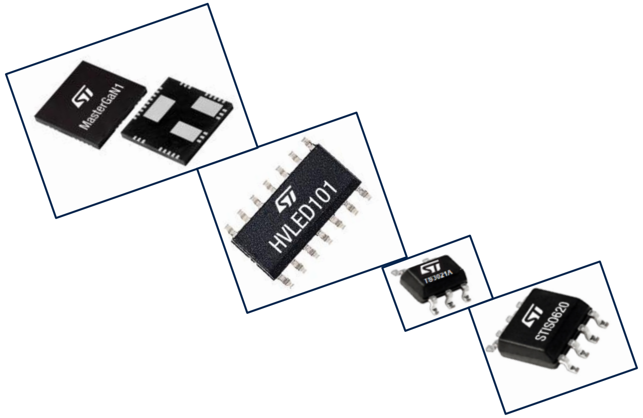
Block Diagram





Key ST Parts:

- ✓ MASTERGAN1
- ✓ HVLED101
- ✓ TS3021A
- ✓ STISO620
- ✓ TSM1052

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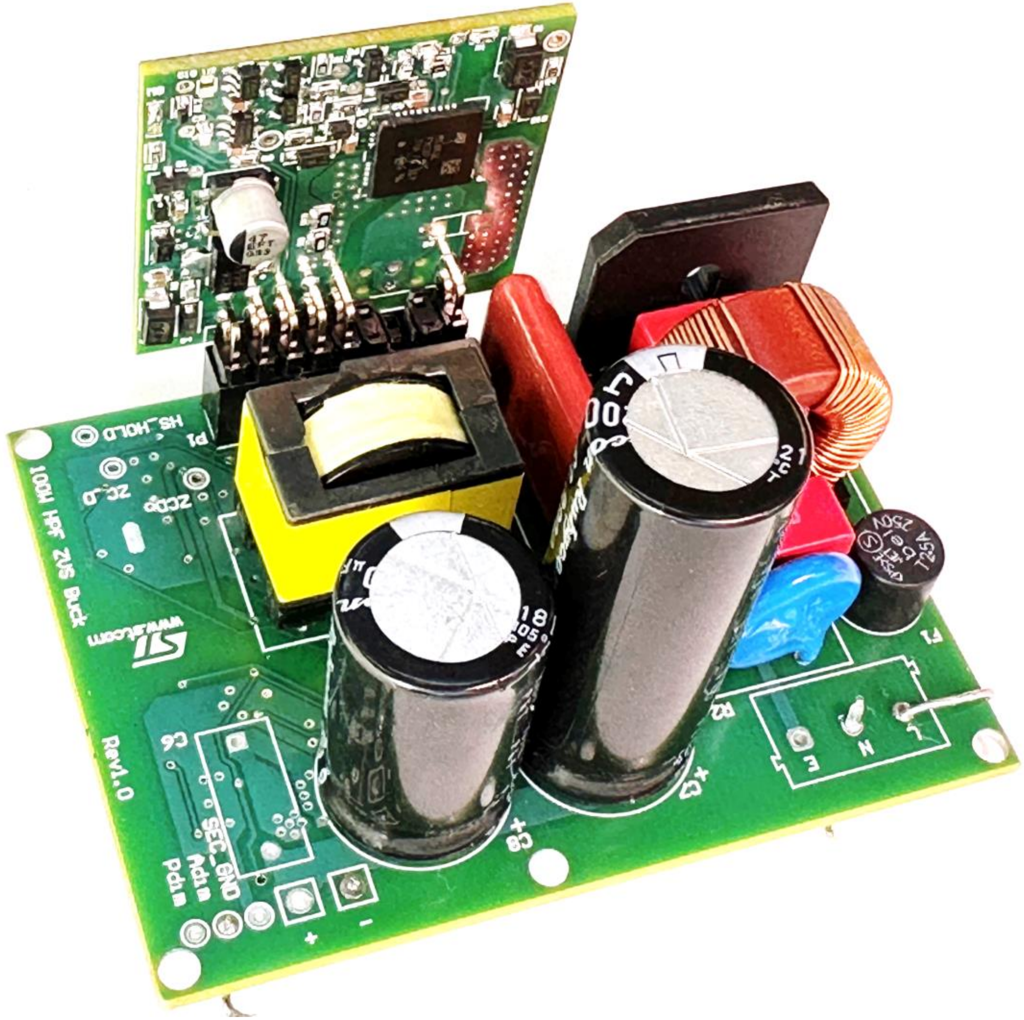
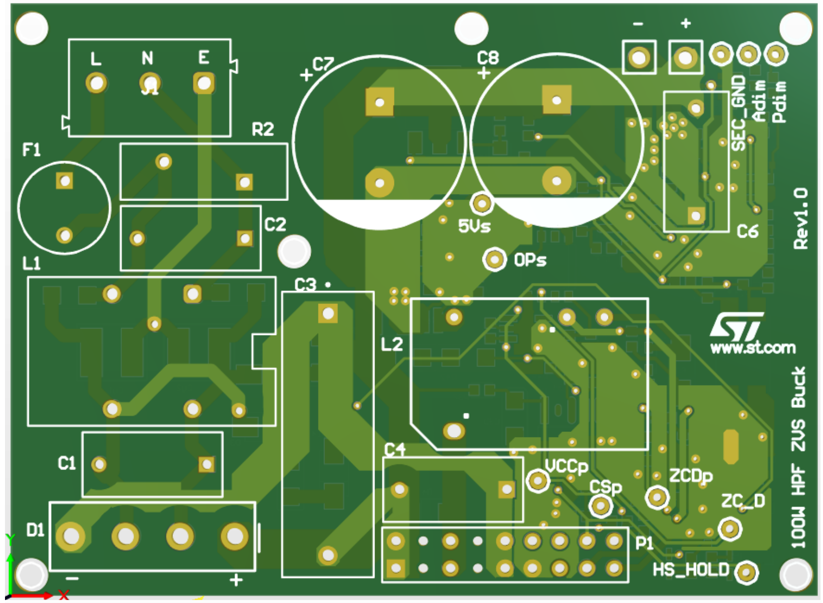
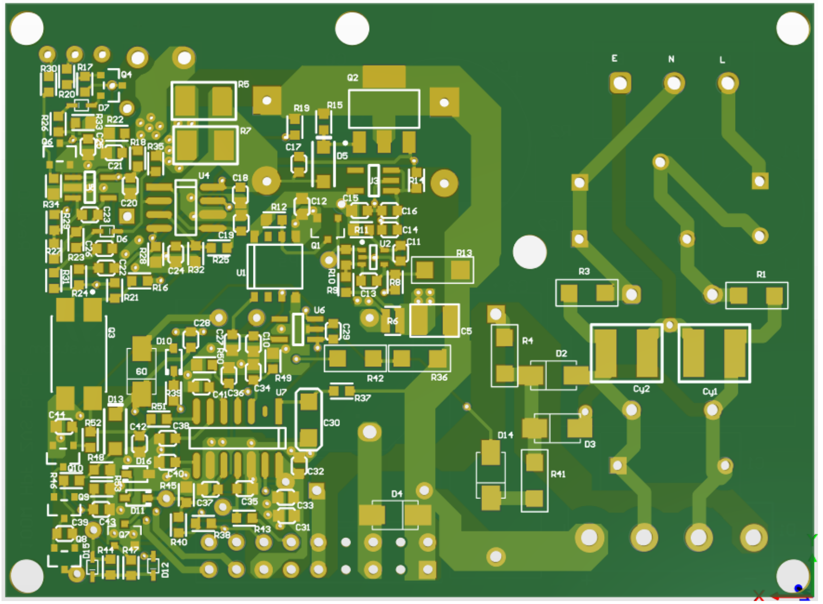
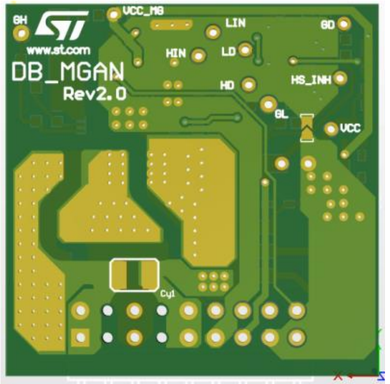
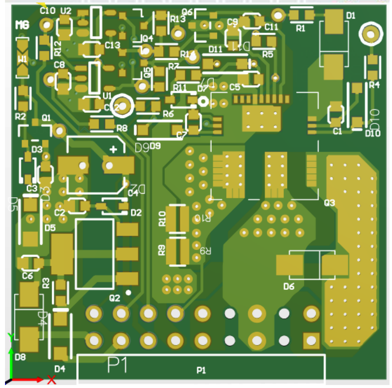
Board Pictures











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GaN SiP reduces the form factor of the design and reduces switching losses vs. Silicon solutions

MasterGaN is an advanced power SiP integrating a gate driver and two e-mode GaN transistors in a half-bridge configuration

The integrated power GaN has an $R_{DS(ON)}$ of 150 mΩ, 650V drain-source blocking voltage

The high side of the embedded gate driver can be easily supplied by the integrated bootstrap diode

The MASTERGAN1L features UVLO protection on VCC, preventing the power switches from operating in low efficiency or dangerous conditions

Why power density matters?

More power in less space

Board area and weight are becoming limiting factors as power demands increase

Reducing size and weight can **cut the total cost of ownership** by making **installation** and **maintenance** both **easier and quicker**

Portability needs high power density

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Smart GaN: Integrating GaN with driver

Benefit	Description
Higher efficiency	Reduced power losses, reduced power consumption, exceeding the most stringent energy requirements
Higher power density	Higher switching speed to reduce systems size and cost
Faster go-to-market	Packaged solution simplifies the design, with a higher level of performance

Product Portfolio by L3 Sub Class: Integrated smart GaNs

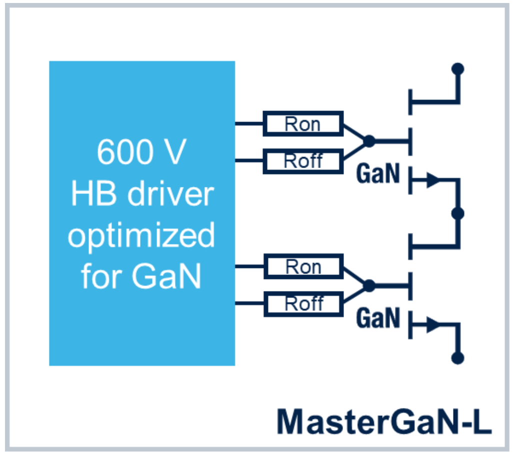
One package
Many Power GaN HEMT for half bridge configuration

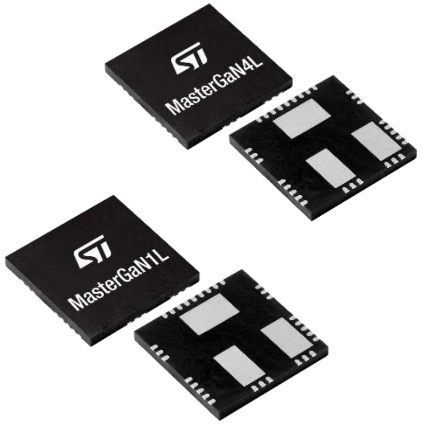
MasterGaN3	MasterGaN2	MasterGaN5	MasterGaN4	MasterGaN4L	MasterGaN1	MasterGaN1L
Up to 45 W	Up to 65 W	Up to 100 W	Up to 200 W	Up to 200 W	Up to 500W	Up to 500W
225 + 450 mΩ	150 + 225 mΩ	450 + 450 mΩ	225 + 225 mΩ	225 + 225 mΩ Low consumption	150 + 150 mΩ	150 + 150 mΩ Low consumption
Mass production	Mass production	Mass production	Mass production	Mass production	Mass production	Mass production

MasterGaN-L

Half-bridge GaN + gate driver optimized for high frequency

Mass production





GQFN 9 x 9 mm^2

Comparison	MasterGaN1	MasterGaN1L
Low power consumption	1mA	0.8mA
Wake-up time	~4us	<1us
Min Ton time	120ns	~50ns

Compact

- 2 power GaNs in symmetric half-bridge configuration
- Embedded gate drivers with integrated bootstrap diode
- **Optimized performance at high switching frequency**
- **Higher efficiency at medium-low load (minimized losses)**

Robust

- **Optimized operation in burst mode (fast wake up)**
- UVLO protection on the lower driving section
- Interlocking function to avoid cross-conduction conditions
- Over temperature protection

Easy Design

- Same GQFN 9x9 mm^2 package of MasterGaN
- Input pins extended range 3.3 to 15 V with hysteresis and pull-down allows easy interfacing with MCU, DSP units or Hall effect sensors
- Dedicated pin for shutdown functionality
- Accurate internal timing match

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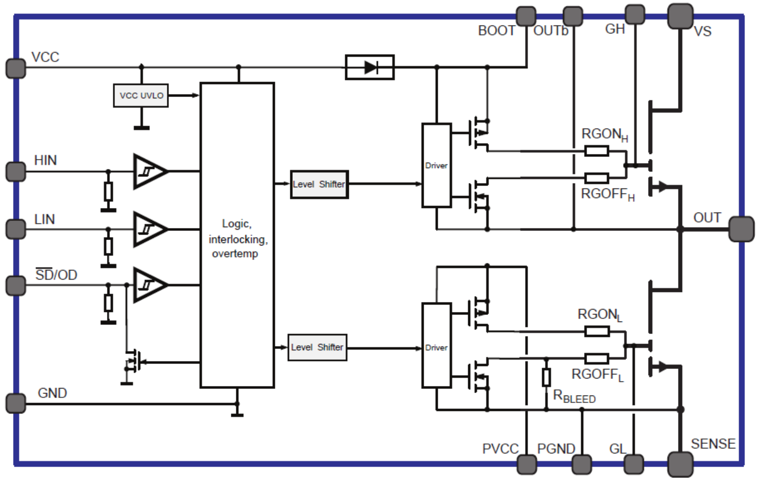
MasterGaN-1L

GaN SiP optimized for resonant topology



	MasterGaN1L
VDS	600V
RDS_{ON}	150 mΩ
IDS_{MAX} (@25C)	10 A

Compact

- Integrated power GaNs
- Embedded gate driver easily supplied by the integrated bootstrap diode
- **Optimized Ton delay to work at higher frequency and higher efficiency with low load in resonant topology**

Robust

- The interlocking function avoids cross-conduction conditions
- Over temperature protection

Easy Design

- Smart solution in GQFN 9x9 mm^2 package
- Input pins extended range 3.3 to 15 V with hysteresis and pull-down- allows easy interfacing with microcontrollers, DSP units or Hall effect sensors
- Dedicated pin for shutdown functionality
- Accurate internal timing match

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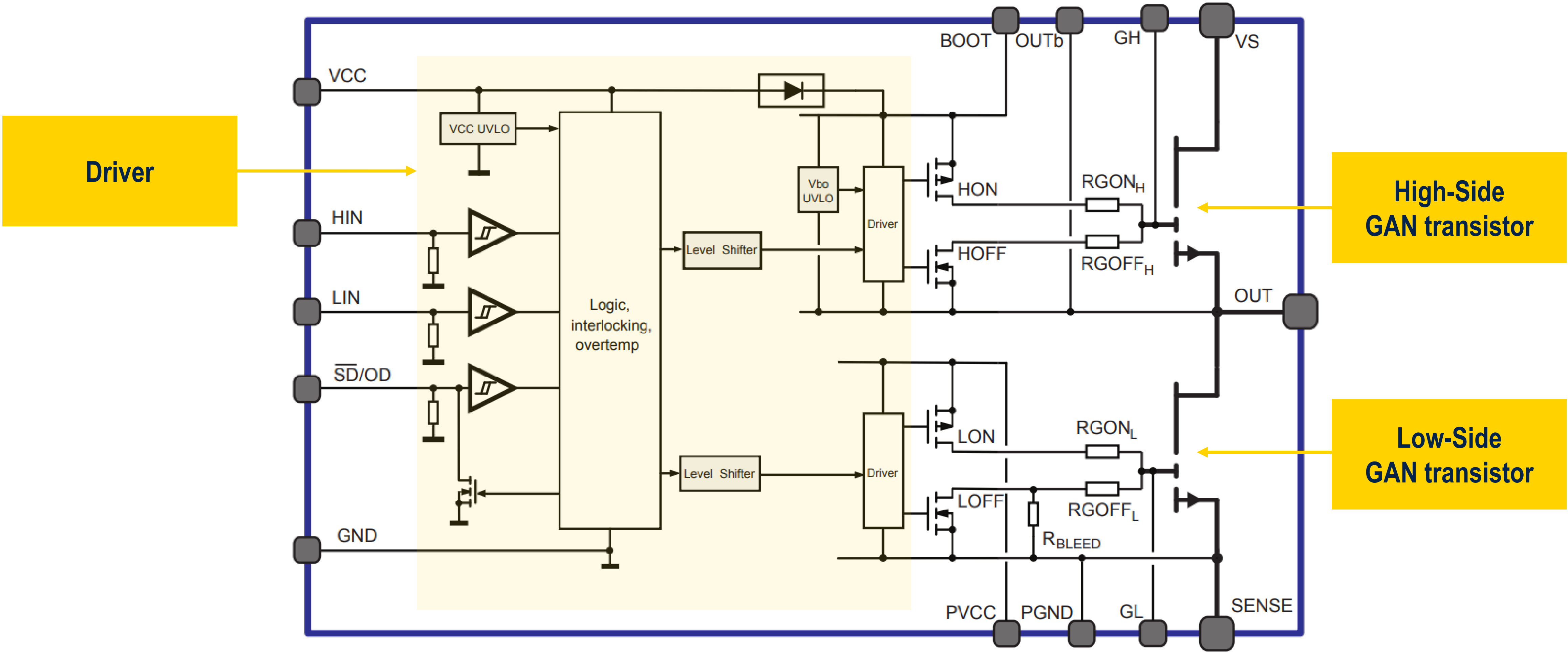
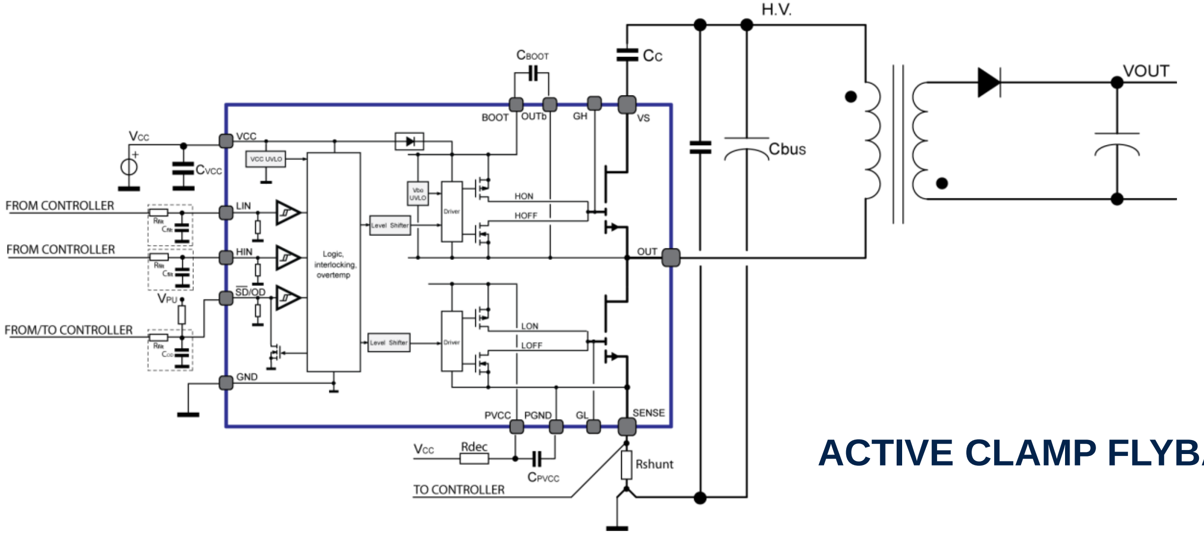
MasterGaN block diagram



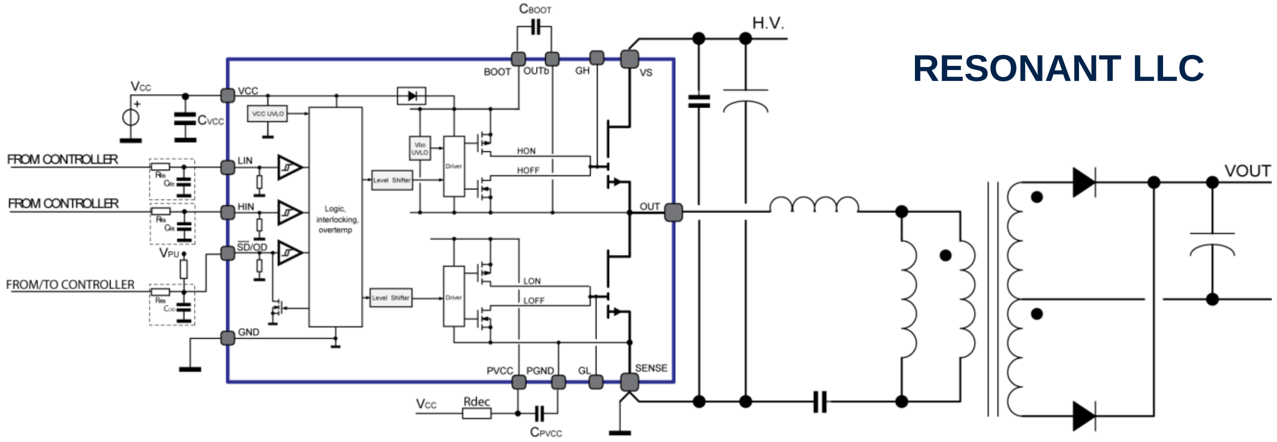
MasterGaN main topologies



ACTIVE CLAMP FLYBACK

Key applications

- Chargers and adapters
- Industrial SMPS



RESONANT LLC

Key applications

- Industrial SMPS
- UPS
- Solar systems
- Servers

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HVLED101

Single stage HPF controller for LED lighting

High efficiency and high power factor QR controller

Noise free operation across output level and dimming

Low distortion in all operating conditions

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HVLED101

HPF QR Flyback controller with Valley Locking and THD Optimizer

Mass production

Key applications

- LED Drivers up to 180W
- High performance Power Supplies

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Valley Locking and Skipping

- Digital engine able to control valley jumping strategy to allow converter running in **noise free mode** and **minimizing power switch losses** for all power levels.

THD Optimizer

- ST proprietary IP embedded to **minimize input current distortion (THD_i)** and **maximize power factor (PF)**

Maximum Power Control - MPC

- This digital engine allow constant output power for whole input voltage range

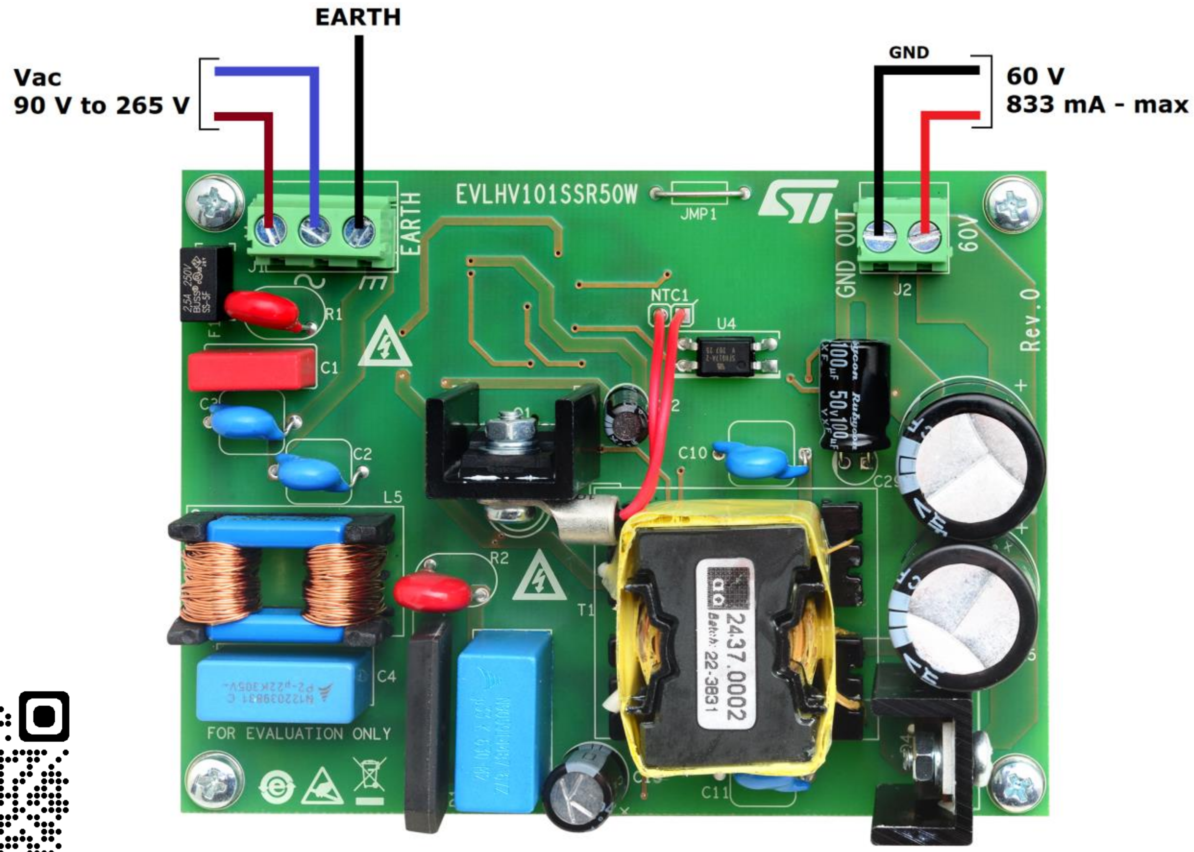
Fast circuit start-up

- High level of integration which embeds 800V start-up structure to allow system start-up in only 250ms

EVLHV101SSR50W

Secondar Side Regulation

- Features
  - Input voltage: 90 – 265 V_{RMS}, f: 45-66Hz
  - Output voltage 60 V / 833 mA
  - High power factor, Low THD
  - Efficiency > 50% in stand-by (P_{OUT} = 240mW)
  - 4 points (25%, 50%, 75%, 100%) > 91%
  - Frequency foldback for noise free operation
  - $T_{AMB-MAX}$ = 60°C
  - Open load voltage limiting (< 65 V)
  - Short-circuit protection with auto restart
  - NTC overtemperature protection for switching MOSFET
  - Safety: Acc. To EN60065
  - EMI: Acc. To EN55022 – conducted emissions



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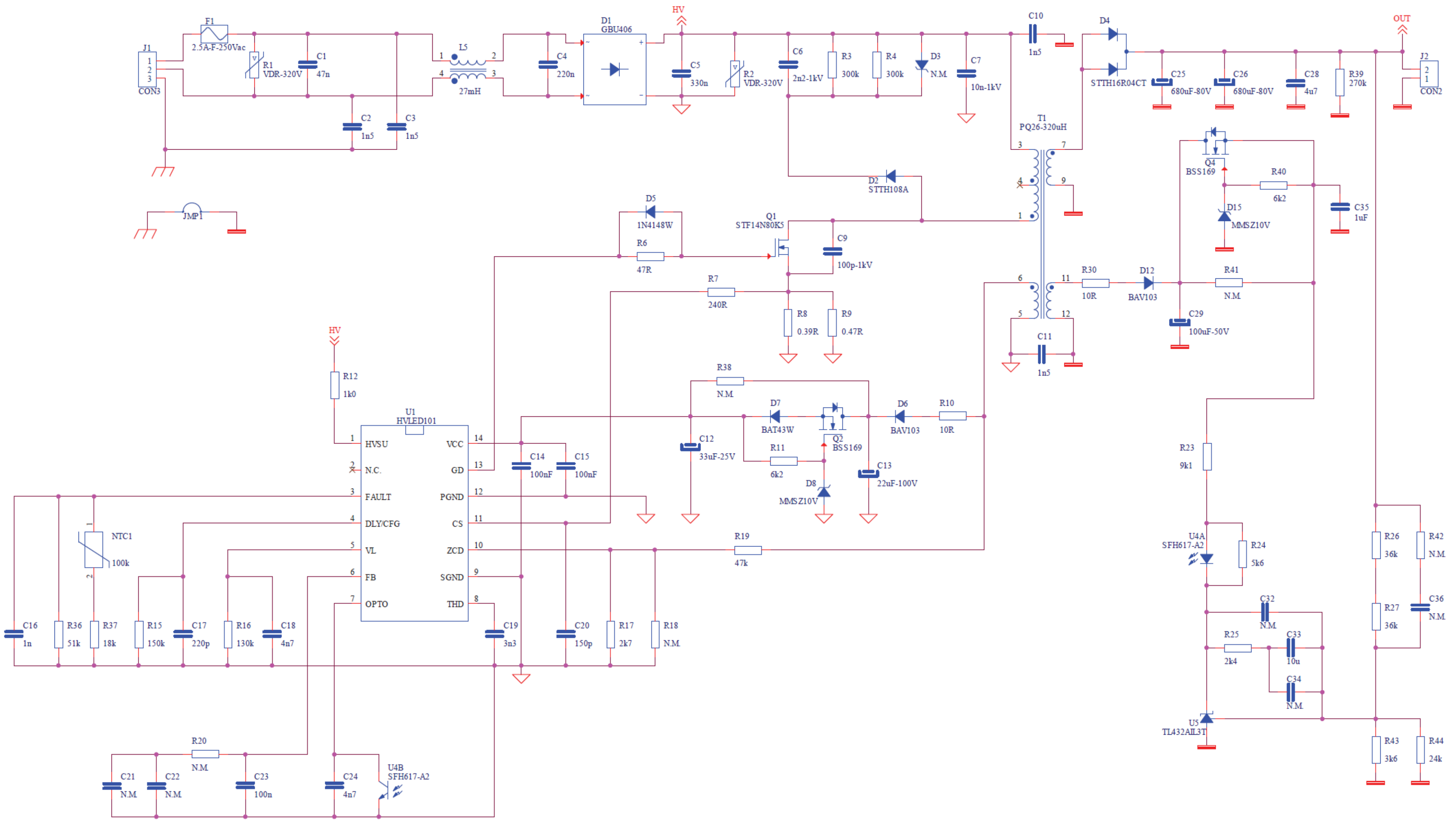
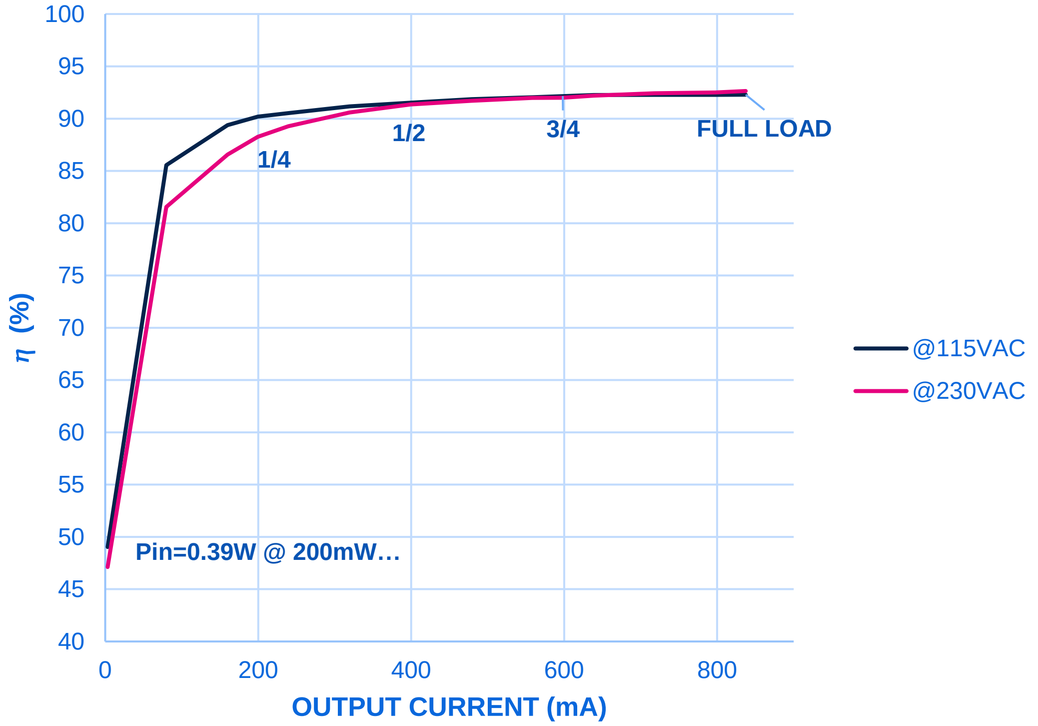
EVLHV101SSR50W Schematic

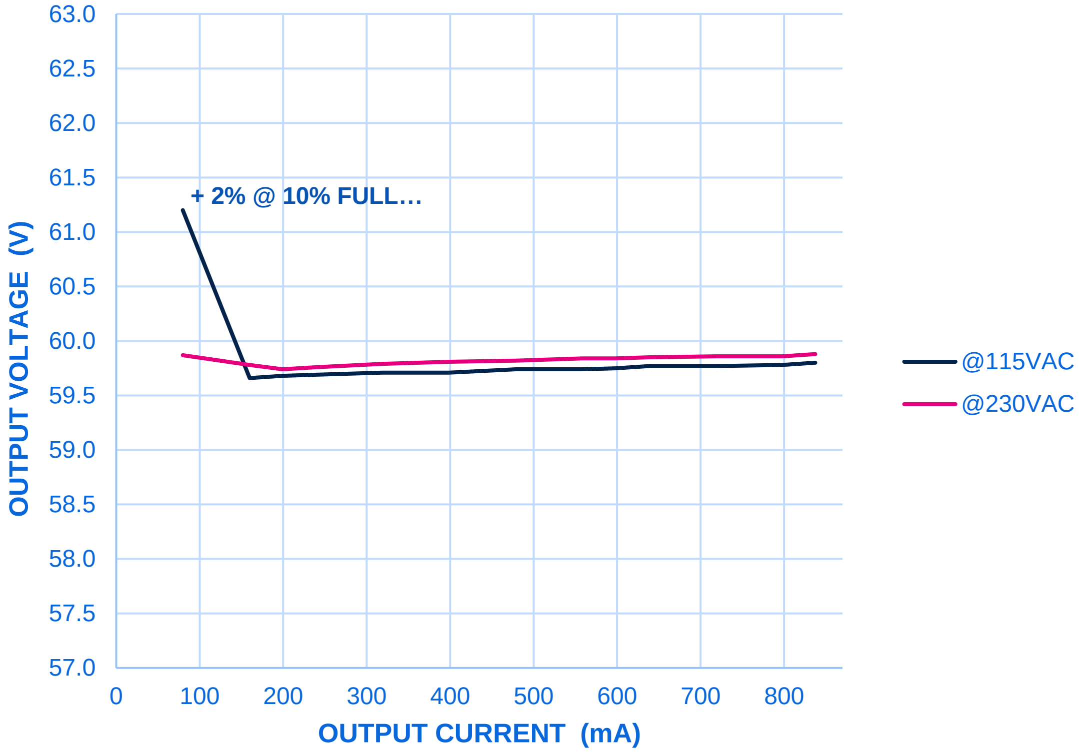


EVLHV101PSR50W

Efficiency

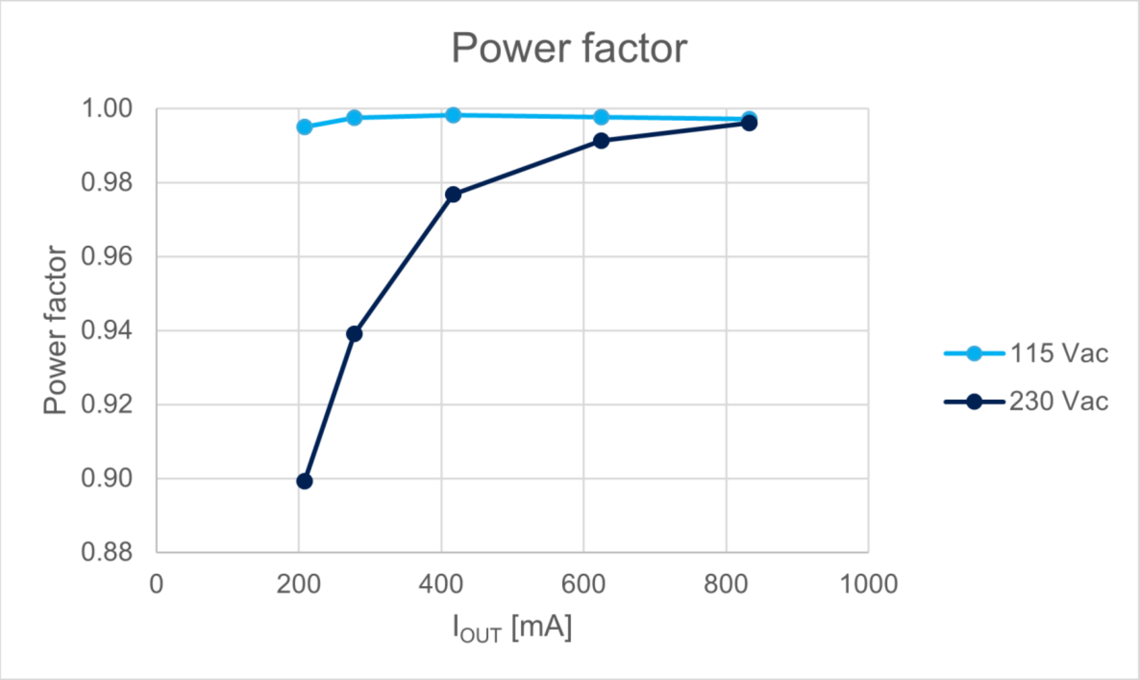


Load Regulation

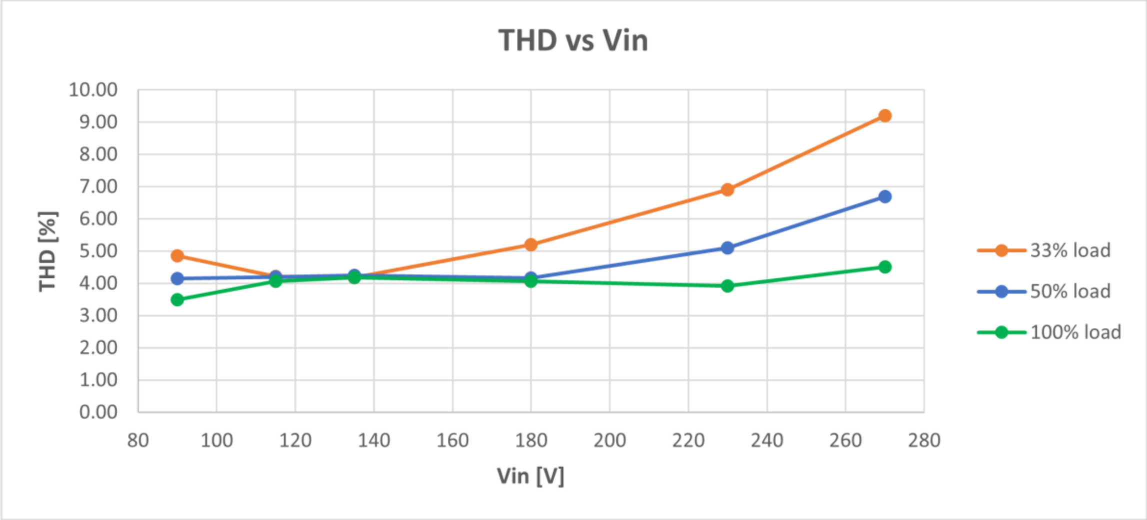


EVLHV101PSR50W – PF and THD

PF

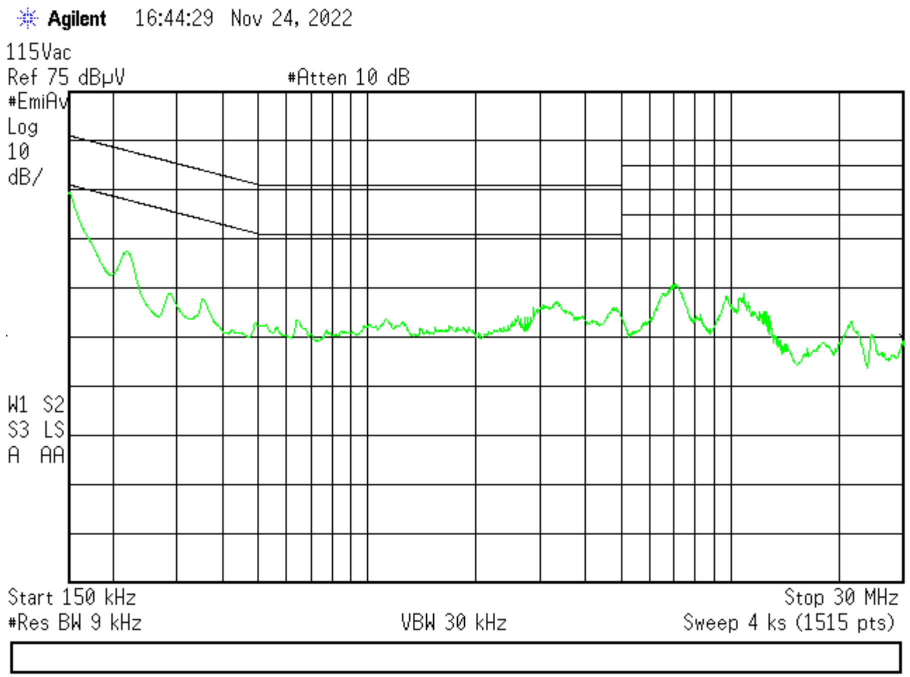


THD

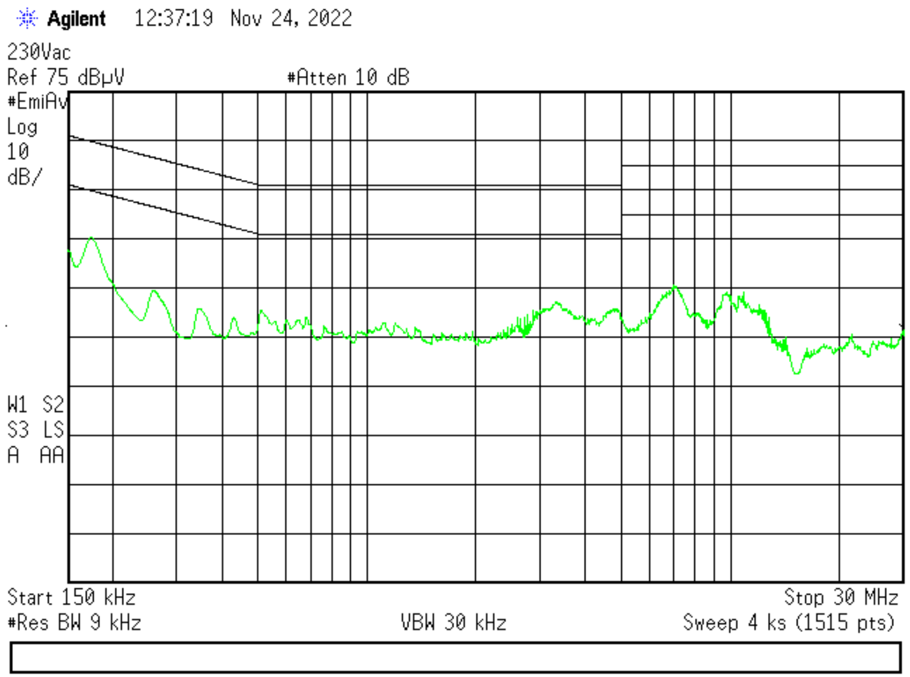


EVLHV101PSR50W – EMI performance

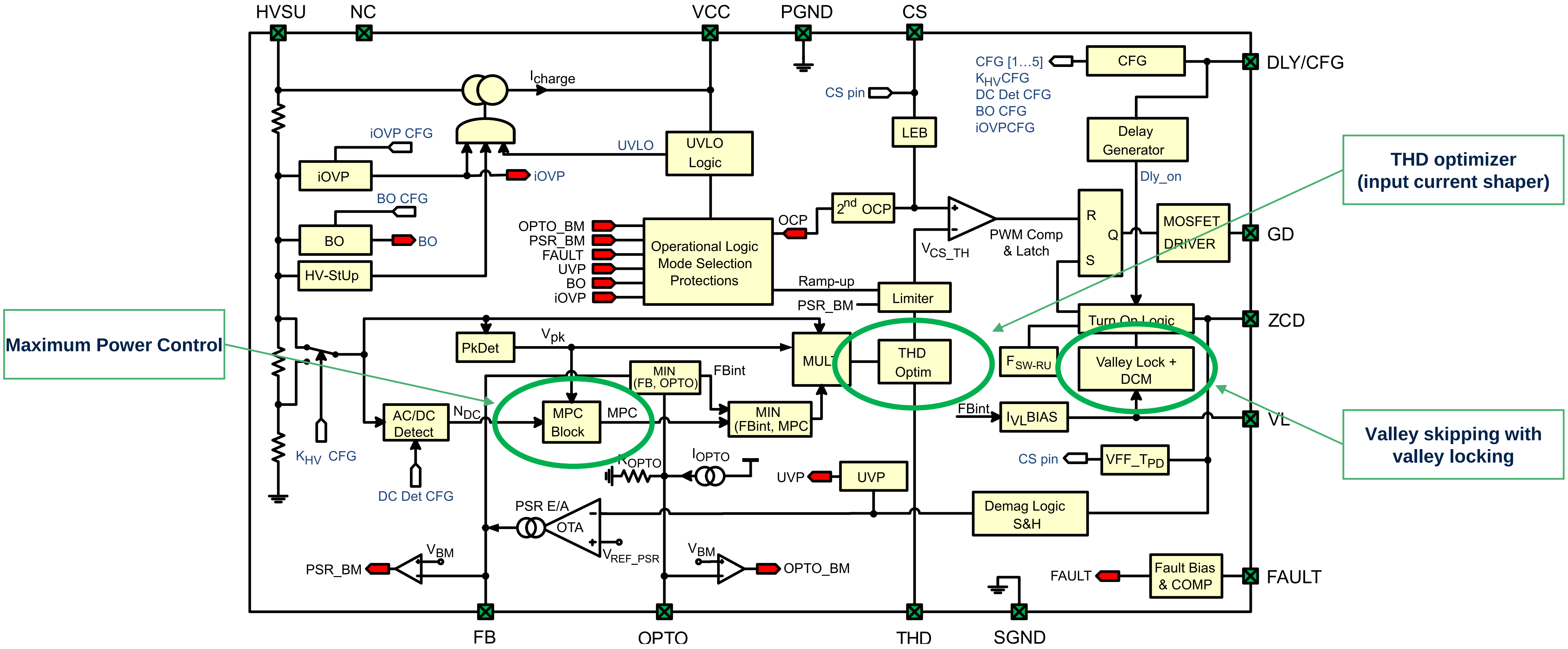
EMI tests 115V~ , Vo=60V & Io=833mA



EMI tests 230V~ , Vo=60V@833mA

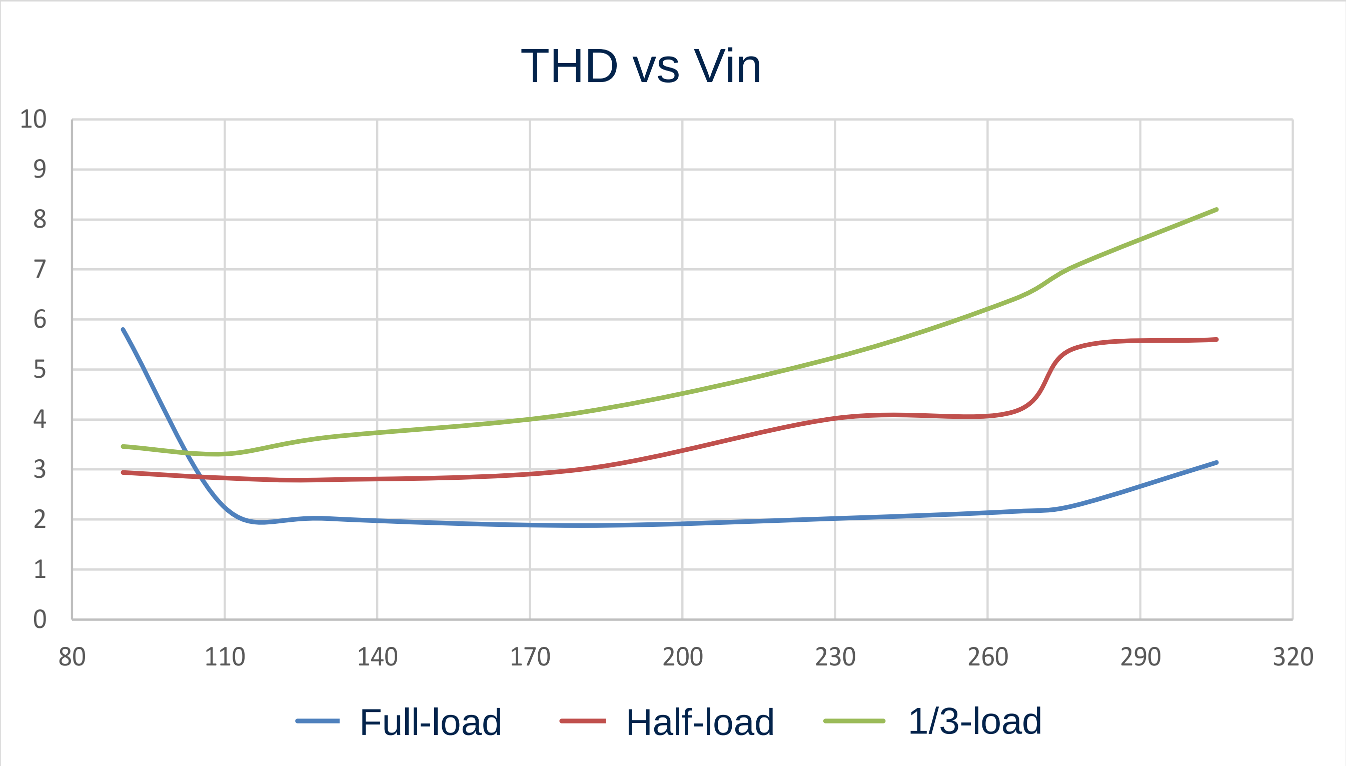


Block diagram



THD Optimizer

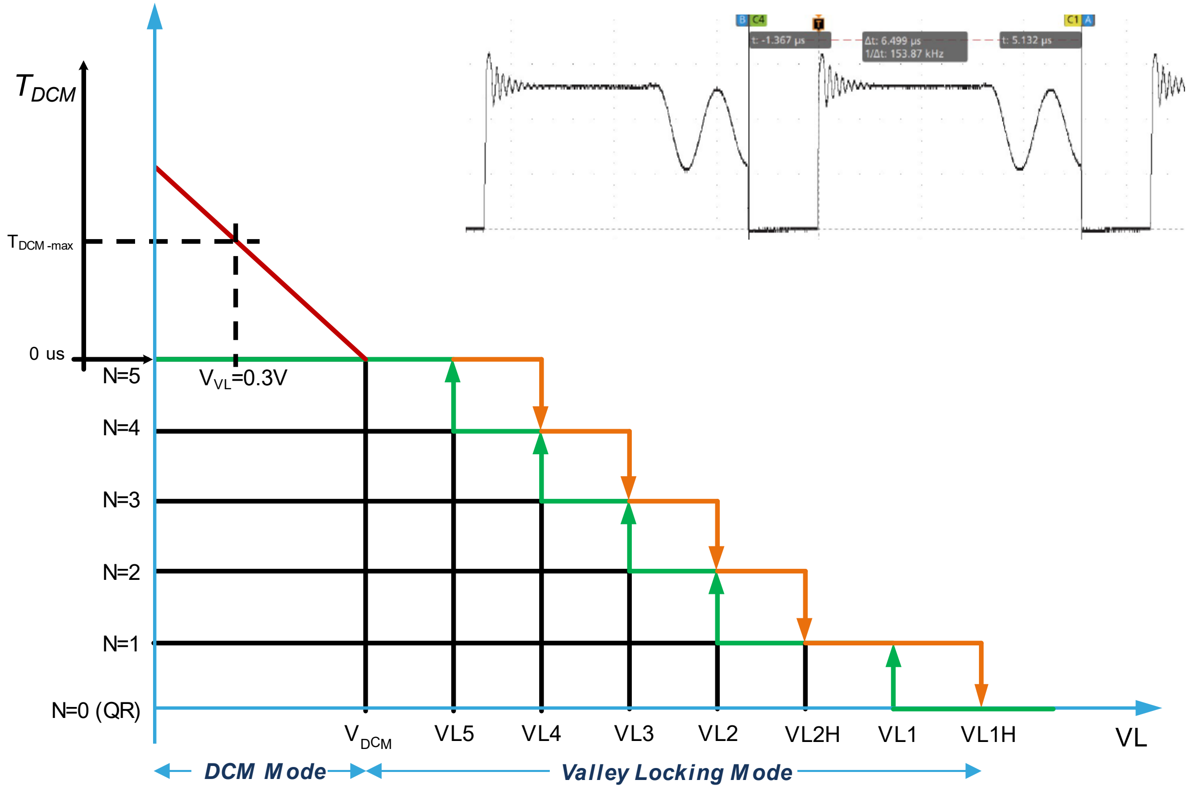
- Our proprietary THD Optimizer[1] minimizes input AC current distortion and maximizes Power Factor, regardless of transformer set-up.
- The distortion method used for THD optimization, along with the Valley locking technique, enables high power factor at full and intermediate loads.
- Valley locking and the THD optimizer circuit ensure even distribution of current at intermediate loads, without any sudden jumps.



(1) US9621029B2

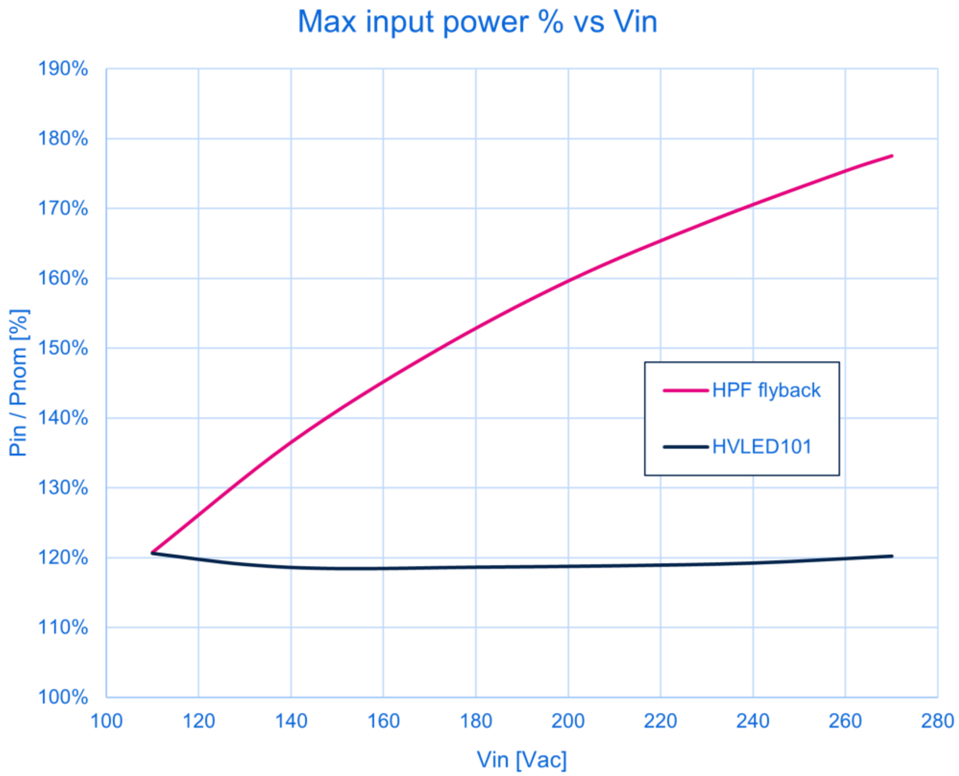
Valley Locking IP

- Reducing the switching frequency at light load can improve the efficiency, power factor, and THD of the QR Flyback.
- In order to avoid random valley jumping, the Valley Locking IP is implemented, and the number of jumping valley remains constant until a significant modification of output power (or input voltage) occurs. As a result:
    - **input THDi is minimized at intermediate load**
    - **audible noise is avoided**
    - **output variable is smoothly regulated**



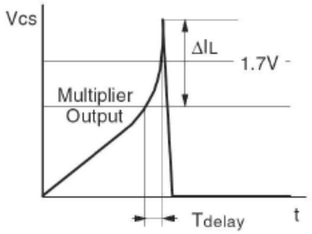
Maximum Power Control - MPC

- The **THD Optimizer** block lets the average value of the OPTO or FB value to be proportional to input power and input voltage.
- An internal **Maximum Power Control** (**MPC**) block generates an internal reference value that is derived from input voltage.
- Such method lets the topology to absorb from input source a **Maximum Power that is independent from input voltage and input shape**.
- At overloading occurrence, the IC does not take any action, but simply limits the delivered power to MPC level.



Protection summary

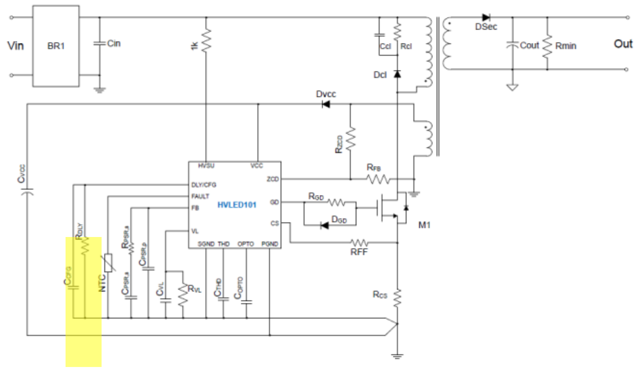
- VCC UVLO (**VCC_low**) with adaptive level to prevent any operation with insufficient driving voltage. Example ensure voltage level for safe gate driving and internal signal processing.
- Maximum Power Control (**MPC**) with +/-10% accuracy of Pout limitation (excluding external component tolerance).
- Secondary side **UVP** with timed shut-down when Vout = 15% of PSR regulation level.
- Over Temperature Protection (**OT**) on a single fault for generic Fault condition.
- Second level **OCP** to prevent damages due:
  - secondary side rectifier short circuit
  - transformer saturation or flux runaway



Inductor saturating hard

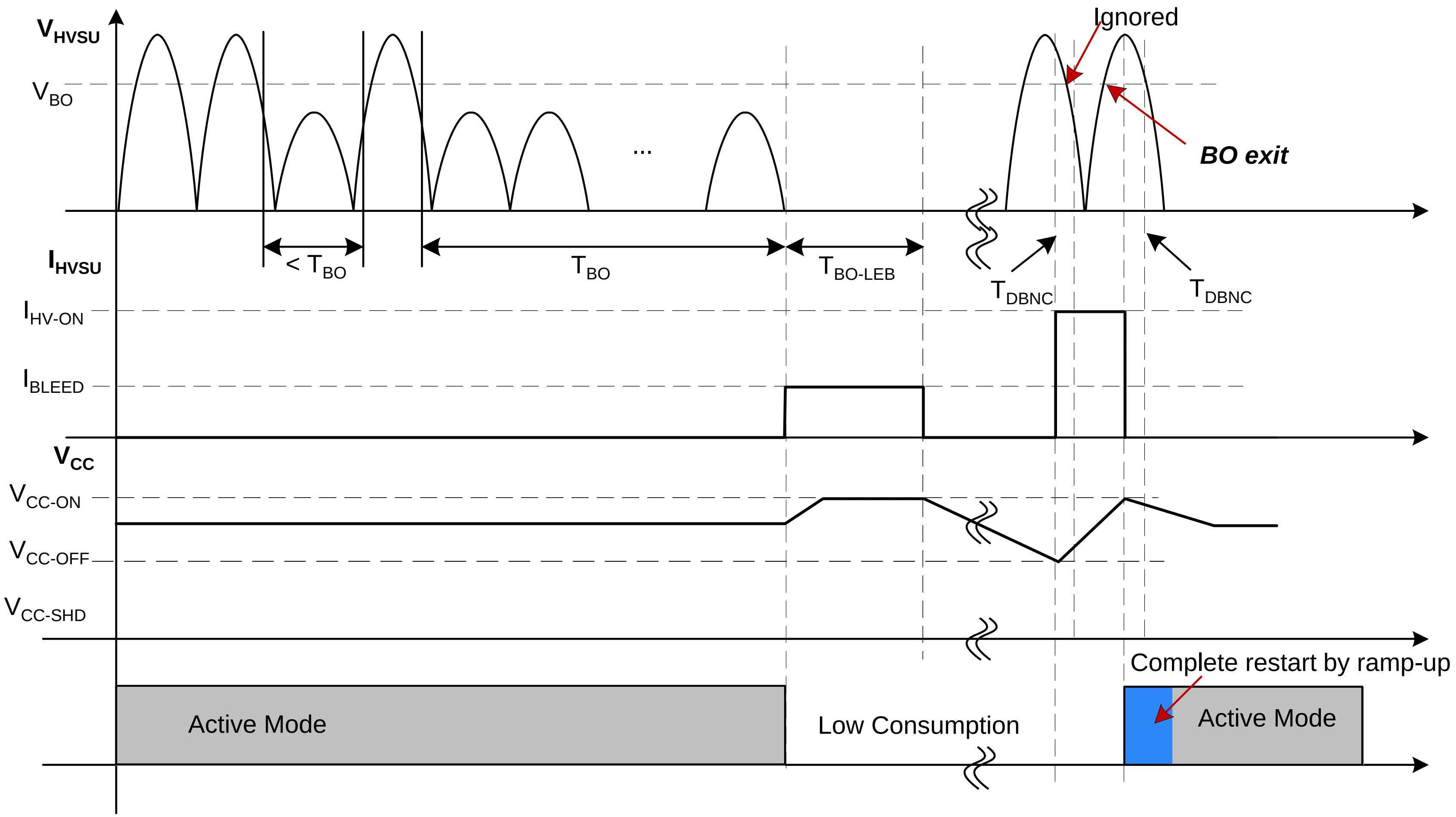
Protection summary

Configurable **input OVP** and **Brown Out** over 5 different presets:



Tau_{CFGn} (µs)	CFG	iOVP	BrOut	K_{HV}	DC Det.	I_{BLEED} @ iOVP	Mains voltage range	Typ. Vin range
30 µs ... 45 µs	CFG1	ON	Low	High	Low	ON	**Universal**	**90 Vac ÷ 305 Vac**
100 µs ... 140 µs	CFG2 (*)	OFF	OFF	Low	Low	N.A.	**Extended**	**> 80 V ÷ 400 Vac**
300 µs ... 410 µs	CFG3	ON	High	High	High	ON	**European**	**180 Vac ÷ 305 Vac**
860 µs ... 1.2 ms	CFG4	OFF	Low	Low	Low	N.A.	**Extended**	**90 Vac ÷ 400 Vac**
> 2.05 ms	CFG5	ON	Low	High	Low	OFF	**Universal**	**90 Vac ÷ 305 Vac**

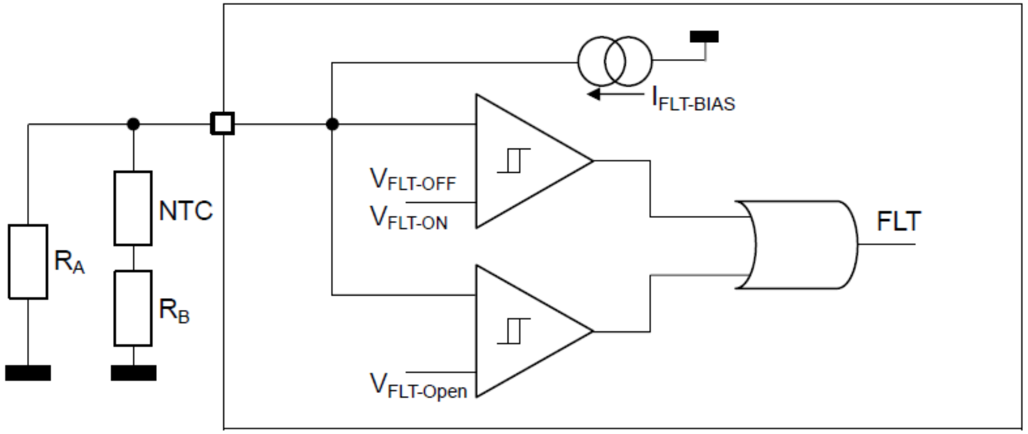
Brownout protection (BOP)



General FAULT pin protection

- If the FAULT pin voltage gets lower than $V_{FLT\text{-}OFF}$ threshold or the pin is left floating, the IC stops operation and enters low consumption mode.
  - A hysteresis is provided that allows operation resuming when the pin voltage is sensed higher than $V_{FLT\text{-}ON}$ ($>V_{FLT\text{-}OFF}$).
  - A precise internal current source $I_{FLT\text{-}BIAS}$ allows managing an overtemperature protection using an external NTC.
  - In case the pin functionality is not used, a 33 kΩ resistor is needed from the pin to ground.

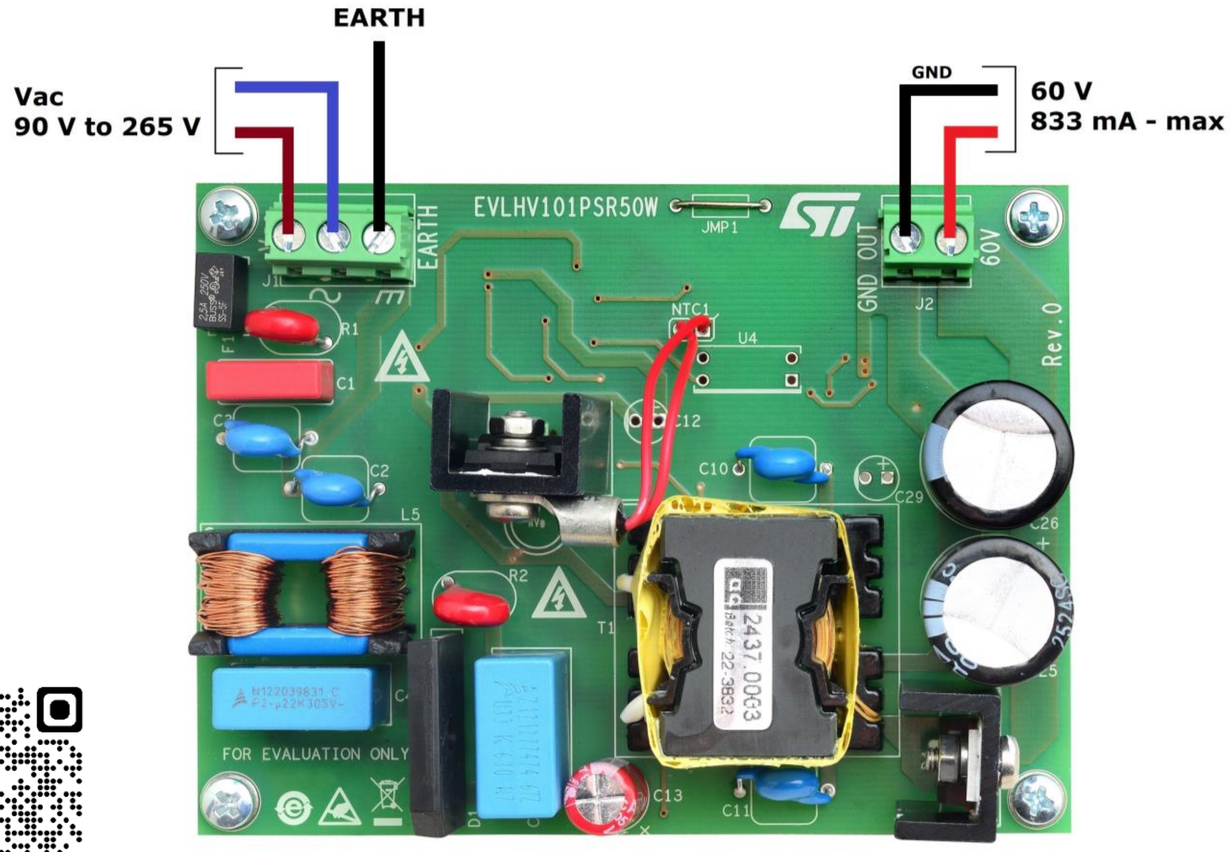
Symbol	Pin/Block	Parameter	Test condition	Min.	Typ.	Max.	Unit
FAULT pin characteristics							
$V_{FLT\text{-}OFF}$	FAULT	FAULT pin disable threshold	Falling edge [trackFLT]	740	800	860	mV
$V_{FLT\text{-}ON}$	FAULT	FAULT pin enable threshold	Rising edge [trackFLT]	790	850	910	mV
$I_{FLT\text{-}BIAS}$	FAULT	FAULT pin biasing current	FAULT = GND	45	50	55	µA
$V_{FLT\text{-}OPEN}$	FAULT	FAULT pin open detection voltage	Active mode	2.6	2.7	2.8	V



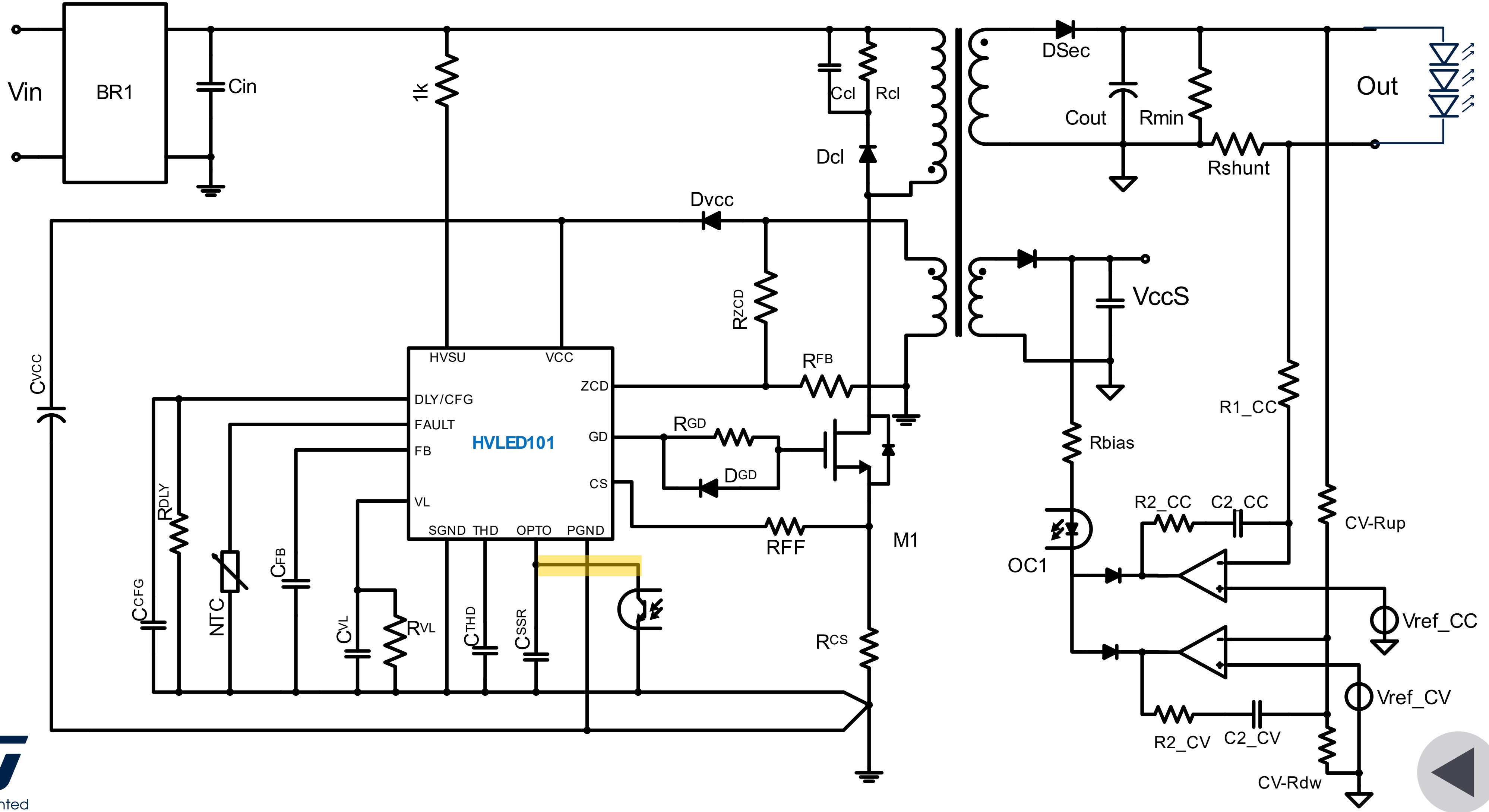
EVLHV101PSR50W

Primary Side Regulation

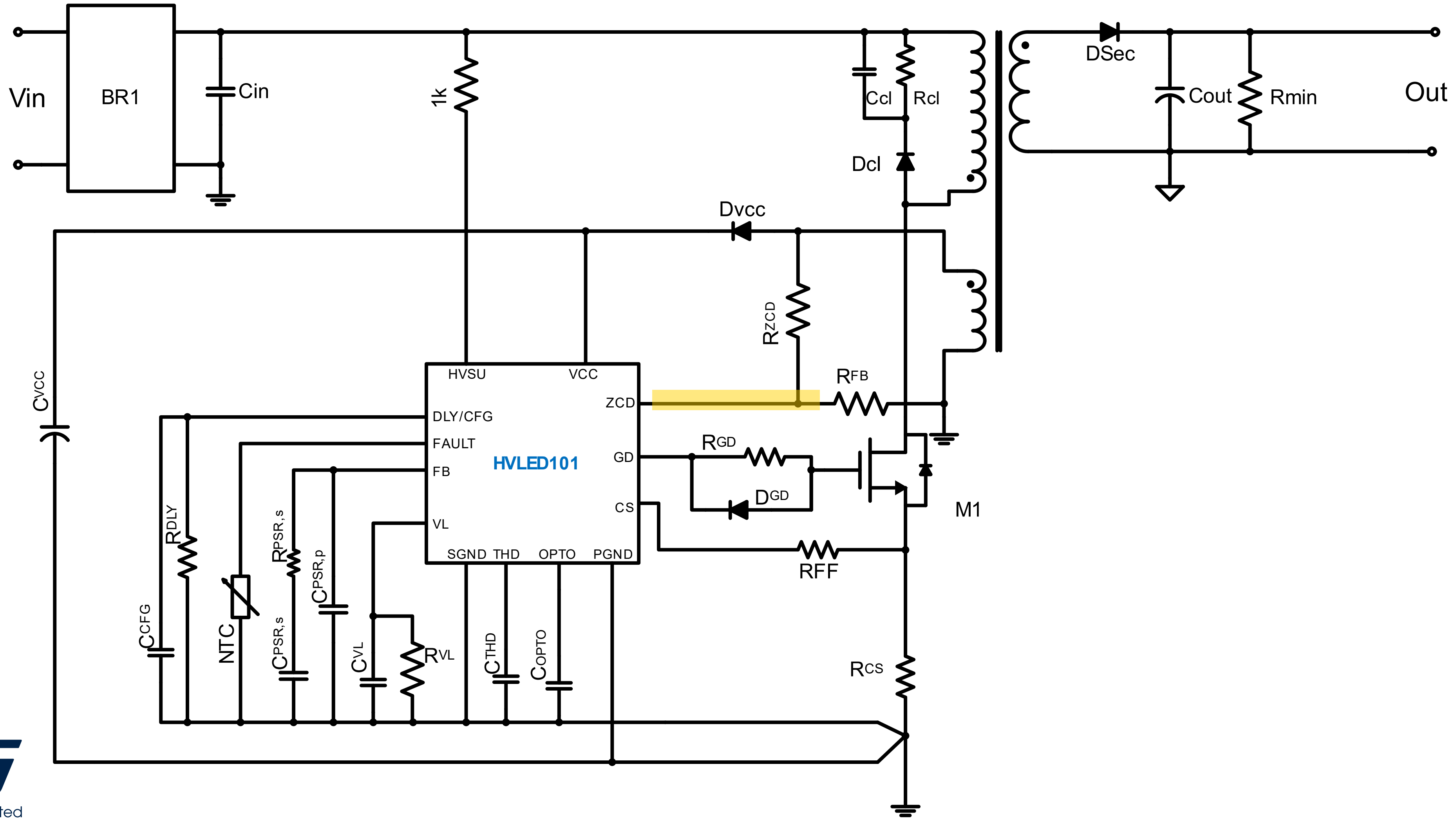
- Features
  - Input voltage: 90 – 265 V_{RMS}, f: 45-66 Hz
  - Output voltage 60 V / 833 mA
  - High power factor, Low THD
  - Efficiency > 50% in stand-by (P_{OUT} = 240mW)
  - 4 points (25%, 50%, 75%, 100%) > 91%
  - Frequency foldback for noise free operation
  - $T_{AMB\text{-}MAX}$ = 60°C
  - Open load voltage limiting (< 65 V)
  - Short-circuit protection with auto restart
  - NTC overtemperature protection for switching MOSFET
  - Safety: Acc. To EN60065
  - EMI: Acc. To EN55022 – conducted emissions



Secondary side regulation configuration



Primary side regulation configuration



The GaN Based SIB converter showed significant performance improvements vs. a similar Si solution

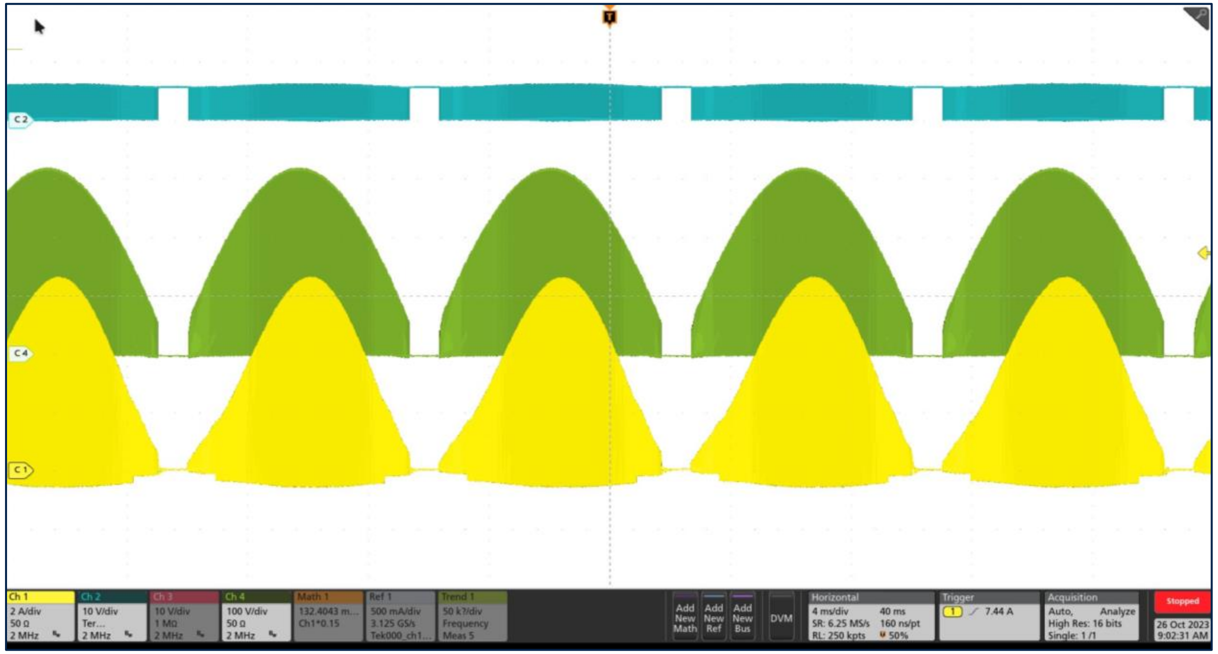
A 100W SIB converter was implemented with constant current and constant voltage feedback to evaluate the performance vs. a similar solution based on HV Si MOSFETs

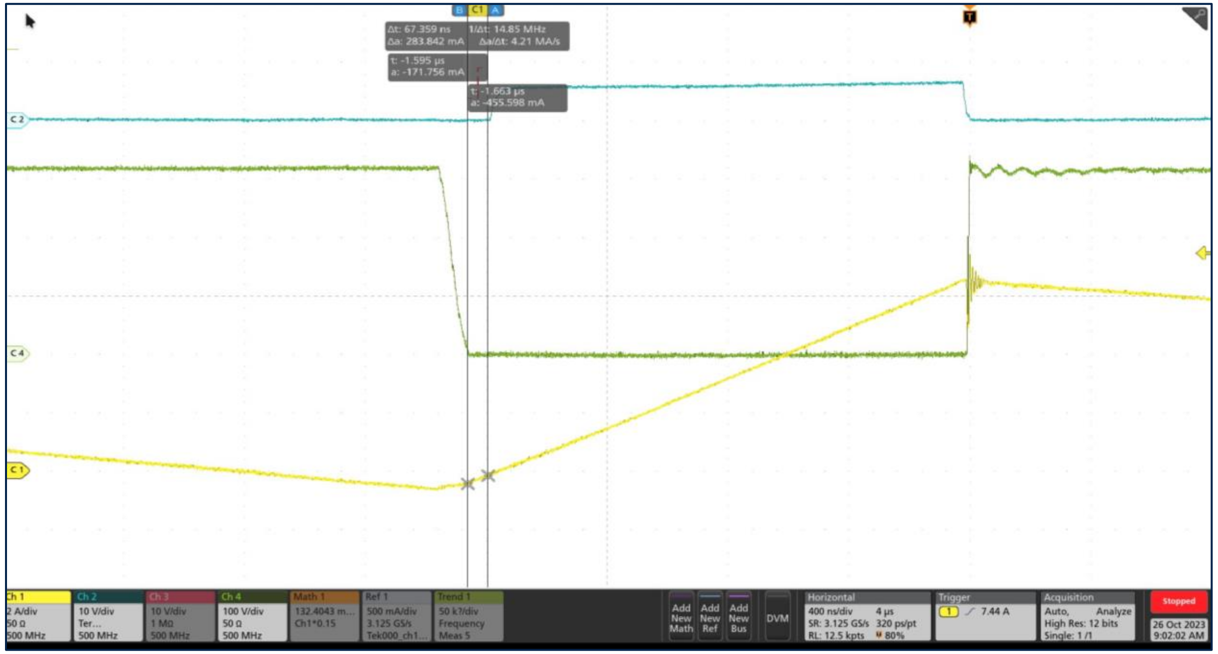
The advanced analog controller simplifies and optimizes ZVS implementation for high efficiency and optimal power quality of input current

SIB topology is suitable for non-isolated LED lighting applications

Experimental results from this prototype demonstrate the effectiveness of GaN technology across the entire operating profile

Some waveforms



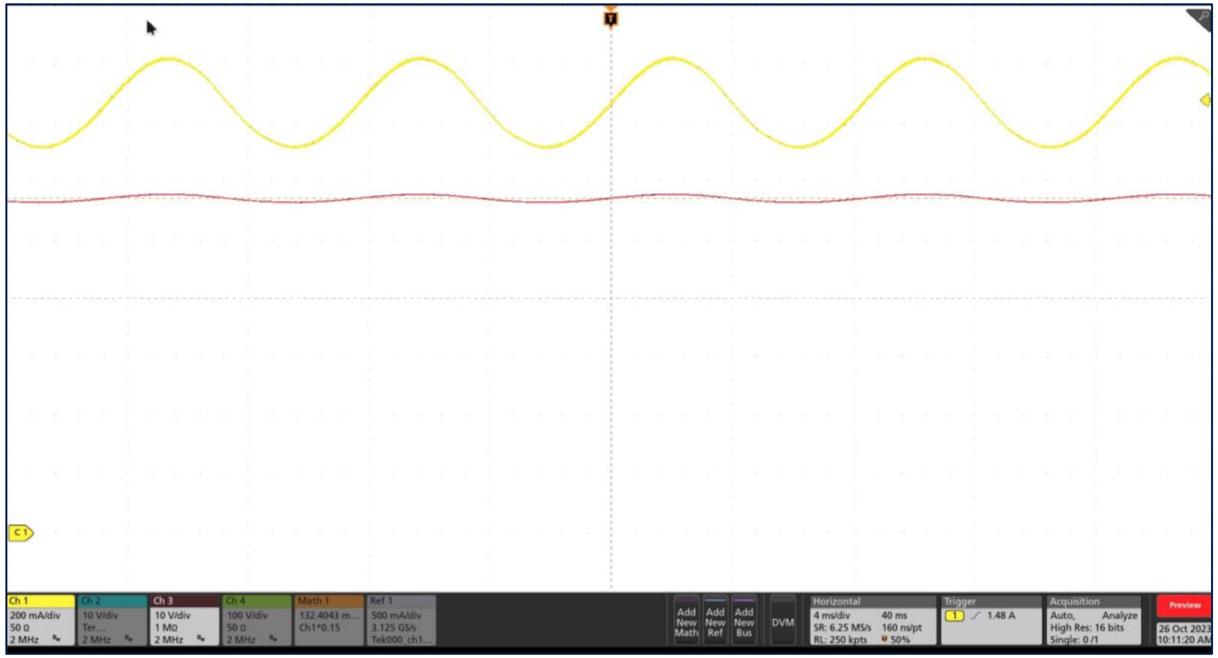


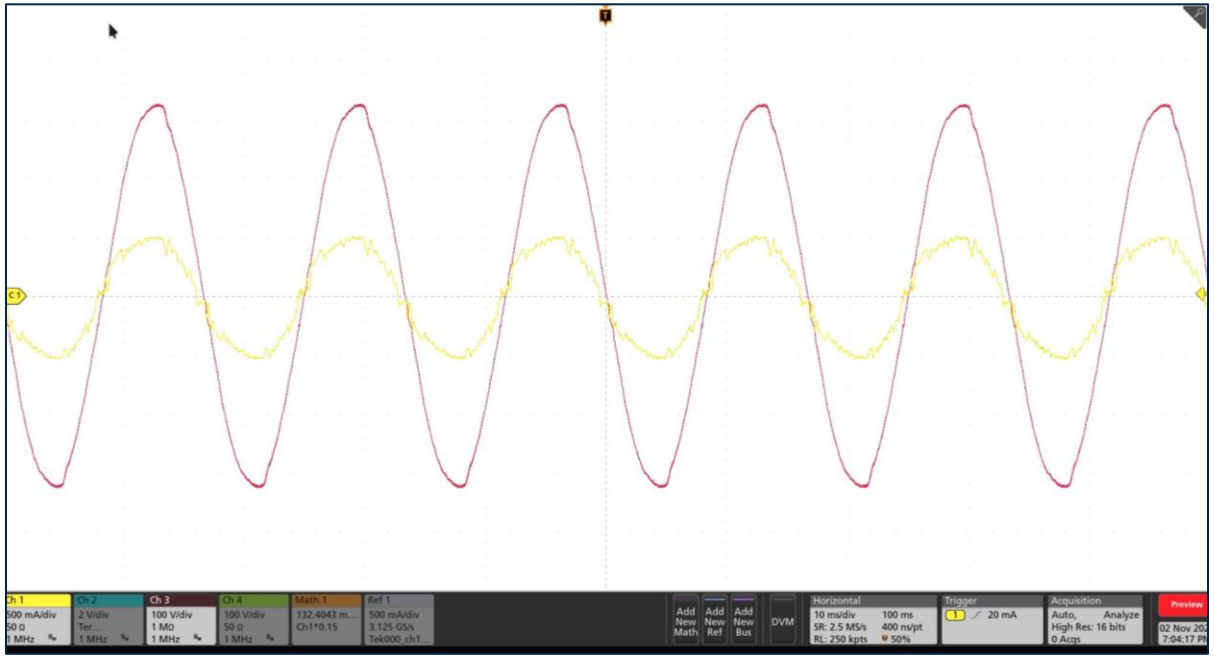
On the left, we see the full envelop of Inductor current.

- the inductor current (yellow trace) together with the gate control signal of the low-side device (cyan trace) and HB node (VHB) of the converter operating with an input of 230V RMS and output of 57V at 1.6A. The effect of the modulated delay time as a function of the input voltage can be appreciated by looking at the negative portion of the inductor current.

- The waveforms on right side shows the ZVS operation of the LS GaN HEMT, where it can be observed that HB node voltage (green trace) falls to zero before the gate control voltage is applied to the LS GaN HEMT. It can also be noticed that the inductor current (yellow trace) has a negative value during this transition.

Some waveforms





- Above waveform shows the output current (yellow trace) containing a low frequency ripple along with the output voltage (pink trace) for the power supply running in the same conditions.

- Waveform above is the input current (yellow trace) shown along the input AC voltage (pink trace) when the converter is operating at 230VAC_RMS.

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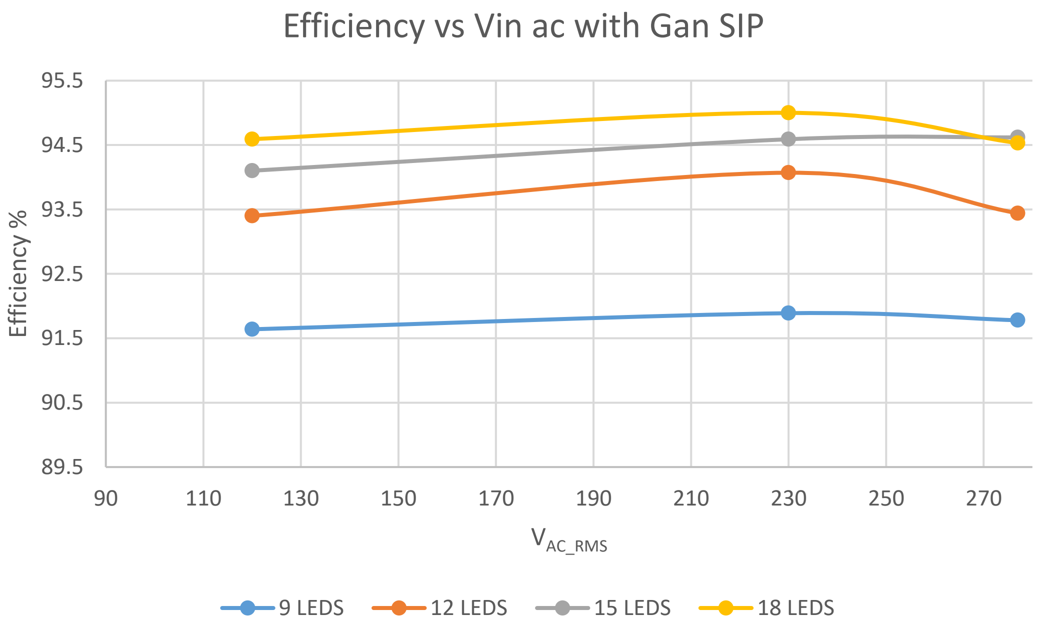
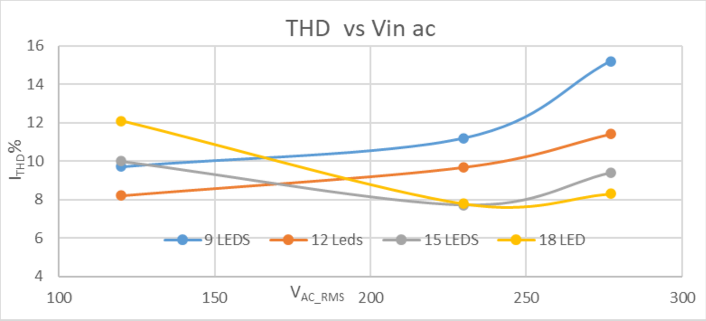
Table of results- 100% Load

S.no	NLED	Vac	V_led	I_led	Pout	Pin	PF	Ithd	Efficiency
1	9	120	28.9	1.62	46.82	51.0936	0.989	9.7	91.64
2		230	28.9	1.63	47.11	51.2688	0.965	11.2	91.89
3		277	28.97	1.65	47.8	52.0824	0.92	15.2	91.78
4	12	120	38.14	38.14	61.41	65.7516	0.99	8.2	93.4
5		230	38.07	1.6	60.91	64.7484	0.974	9.68	94.07
6		277	38.07	1.6	60.91	65.1888	0.965	11.4	93.44
7	15	120	47.37	1.58	74.84	79.5336	0.984	10	94.1
8		230	47.44	1.59	75.43	79.746	0.99	7.7	94.59
9		277	47.52	1.61	76.51	80.8632	0.977	9.4	94.62
4	18	120	55.92	1.38	77.17	81.5808	0.986	12.1	94.59
5		230	56.7	1.61	91.29	96.0948	0.99	7.79	95
6		277	56.67	1.59	90.11	95.3208	0.978	8.3	94.53



Key take aways:

- THD
    - THD < 15% @230V
    - THD stays <20 though the load voltage variations
- Efficiency
    - Average Efficiency 93.6%
    - Average Efficiency @230V is 93.9%
- PF>0.95 throughout full input output range.



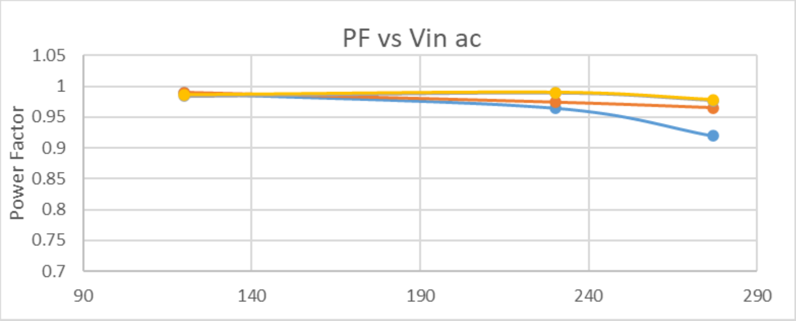


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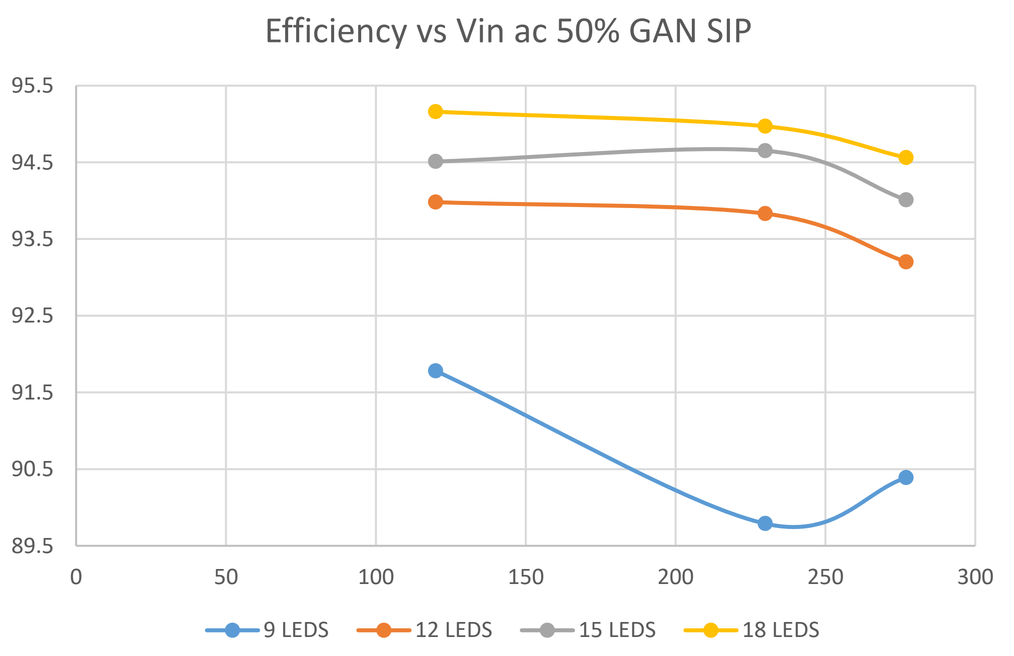
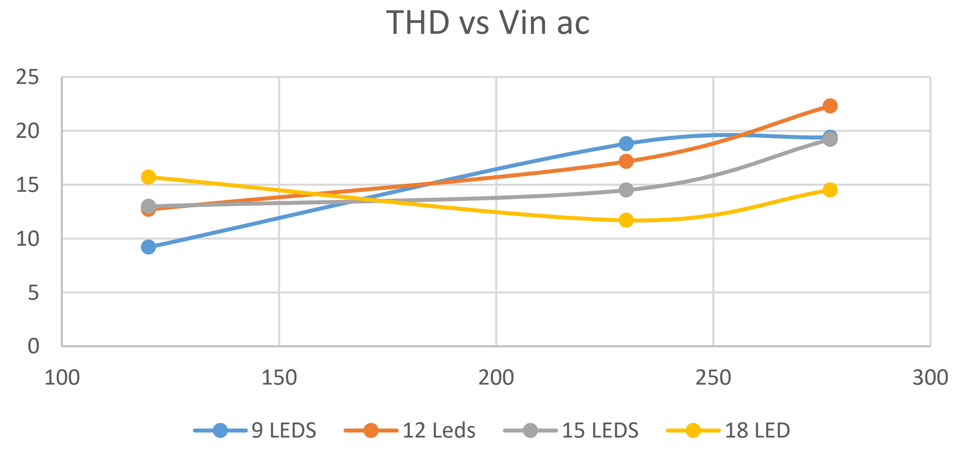
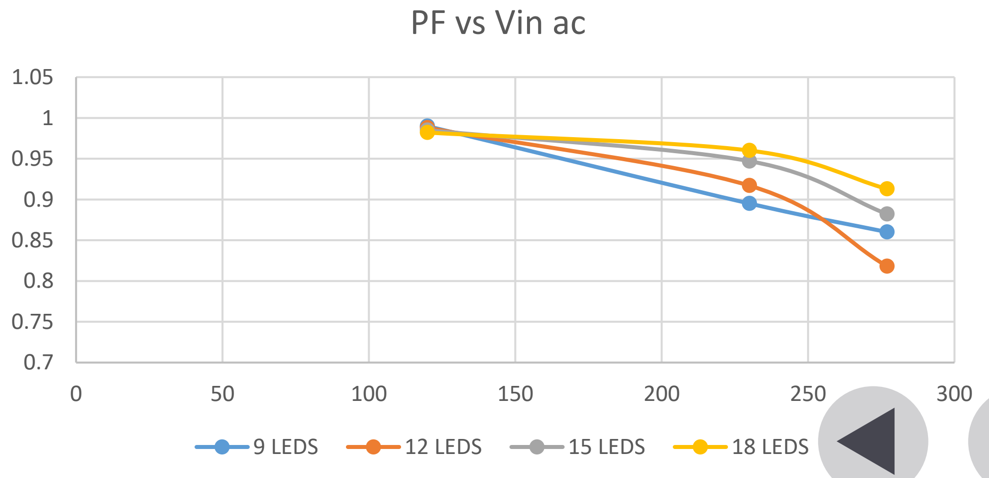
Table of results- 100% Load

S.no	NLED	Vac	V_led	I_led	Pout	Pin	PF	Ithd	Efficiency
1		120	27.15	0.8	21.72	23.664	0.99	9.2	91.78
2	9	230	27.69	1	27.69	30.84	0.895	18.8	89.79
3		277	28.2	1.24	34.97	38.6892	0.86	19.4	90.39
4		120	35.94	0.808	29.04	30.9012	0.988	12.7	93.98
5	12	230	35.95	0.802	28.83	30.726	0.917	17.15	93.83
6		277	36.03	0.82	29.54	31.6968	0.818	22.3	93.2
7		120	45.08	0.812	36.6	38.7264	0.985	12.99	94.51
8	15	230	45.09	0.812	36.61	38.6808	0.947	14.5	94.65
9		277	45.04	0.802	36.12	38.4204	0.882	19.2	94.01
4		120	53.71	0.808	43.4	45.606	0.982	15.7	95.16
5	18	230	53.68	0.806	43.27	45.564	0.96	11.7	94.97
6		277	53.64	0.797	42.75	45.2112	0.913	14.5	94.56







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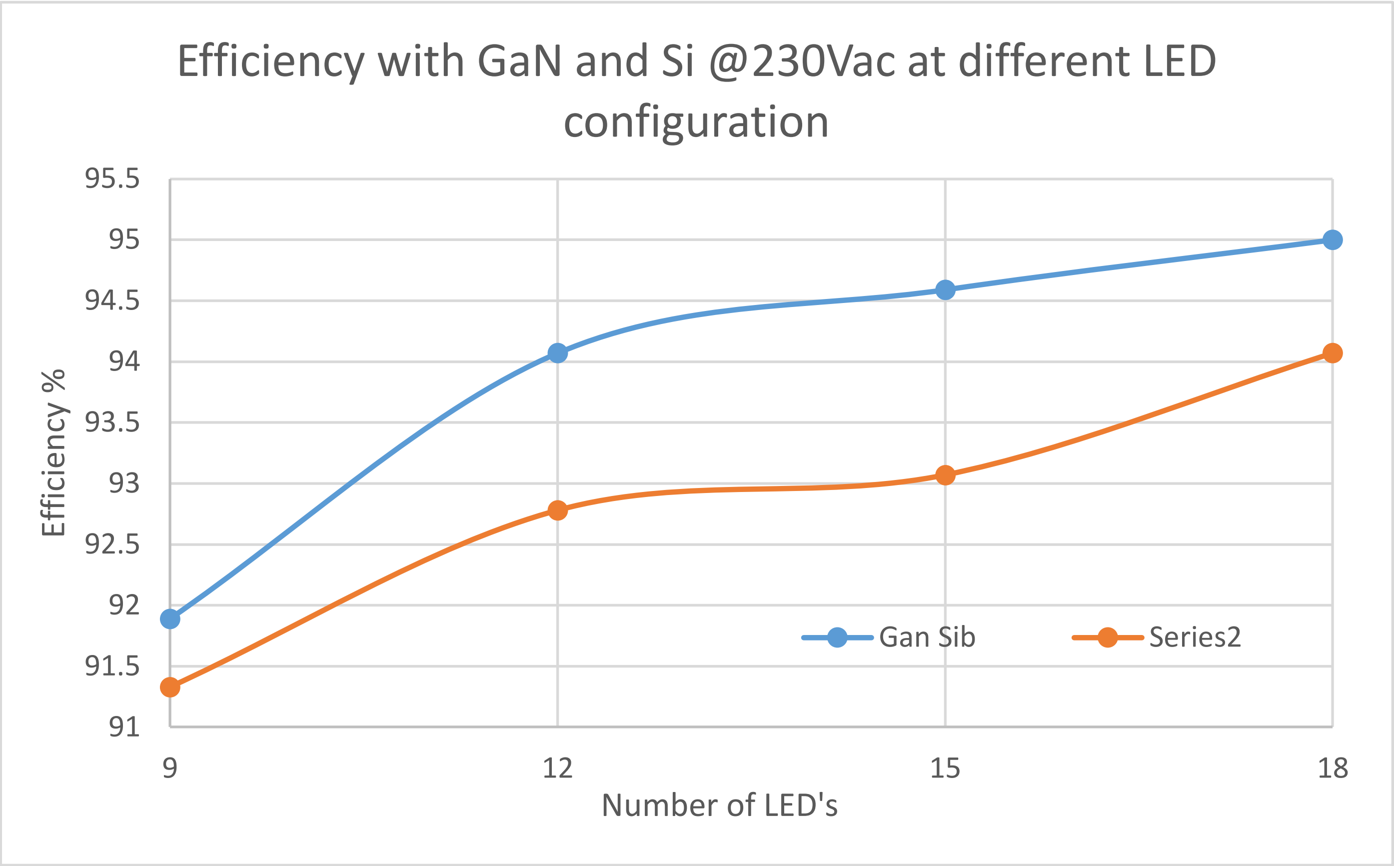
GaN vs Si MOSFET performance

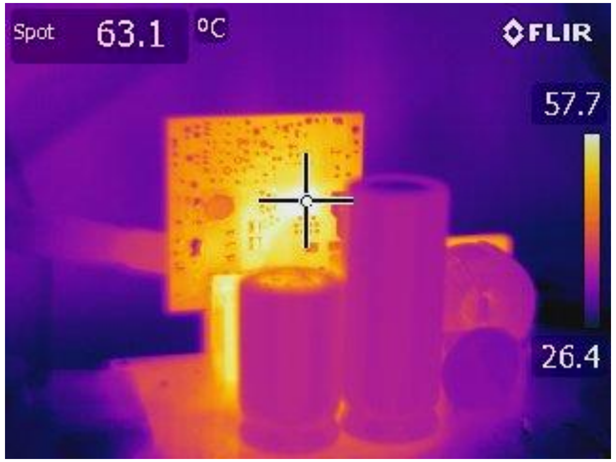
- The peak efficiency of the GaN-based converter is 95.1% while the silicon-based one reaches 94%. The efficiency gain is present across the entire operating profile (Fig. 18) resulting in lower operating junction temperatures for the GaN-based solution. The reduced output capacitance of the GaN transistors and the slightly lower on-state resistance enable higher efficiency.

- The efficiency difference could be further increased by optimizing the operating current of peripheral circuits and the magnetic components.



Summary

- The solution presented here is the design and implementation of a 100W Synchronous Inverse Buck (SIB) converter for LED drivers, with a wide input voltage range, High Power Factor (HPF) and high efficiency.
- The proposed converter is based on a High Voltage GaN HEMT SiP and a novel advanced Quasi-Resonant (QR) analog controller with Power Factor Correction (PFC) control.
- The SIB is controlled to achieve Zero Voltage Switching (ZVS) for both the power switches.
- The analog controller includes a "THD Optimizer" block, which ensures low I_{THD}, a crucial factor for offline LED drivers.
- In the SIB, the High-Side (HS) switch always switches under ZVS, but the Low-Side (LS) switch operates in hard switching. The solution here exploits the zero current detection and power device turn-on delay feature of the dedicated analog controller to add ZVS for the LS GaN transistor. The GaN SiP technology enables high-efficiency and high switching frequencies, while maintaining a small form factor.
- The thermal characterization was performed by loading the converter at 100W with 230V_{AC_RMS} input, with an open frame and ambient temperature of 25° C. The maximum temperature on the GaN SiP was recorded at 78.5°C without any cooling fan or heat sink. Image on the right shows the case temperature of the GaN SiP with a small heat sink placed on the bottom side of the PCB.



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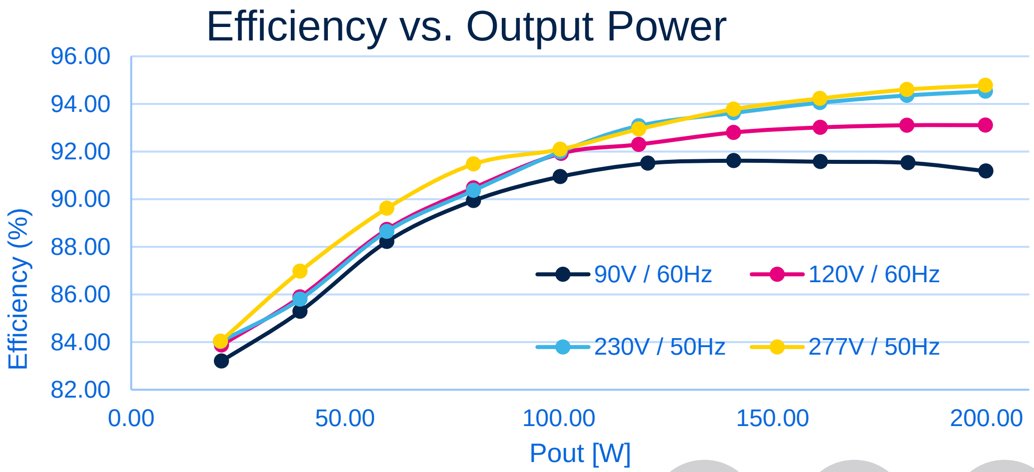
EVL012LED: High voltage 200 W LED driver

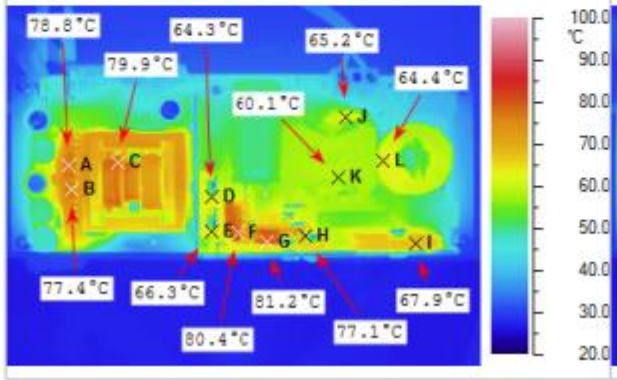
Parameter	Value
Input mains range	90V~277Vac, frequency 45~65Hz 120~430Vdc
Output Voltage range	36~56Vdc
Full load efficiency	94.5% @ 230Vac
Maximum output power	200W
No load mains consumption	< 500mW
3 in 1 dimming function	1 ~ 10V, 10V PWM signal or resistance
Dimensions	200 x 55 x 15 mm (L x W x H)
PCB	Double layer, 35um, F4R



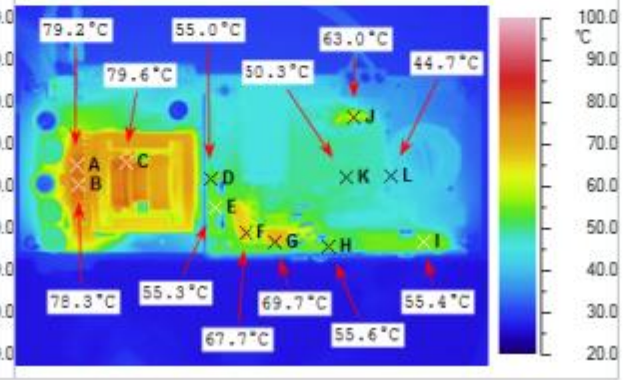
EVL011A150ADP: High voltage 150 W LED driver

Parameter	Value
Input mains range	90V~264Vac
Output Voltage range	12Vdc (±5%)
Full load efficiency	>90% @ 115/230Vac
Maximum output power	150W
No load mains consumption	< 75mW
Hold-up time	> 10ms
Dimensions	175 x 65 x 35 mm
PCB	Double side, 70 µm, CEM-1, mixed PTH/SMT

Thermal Map at Full Load

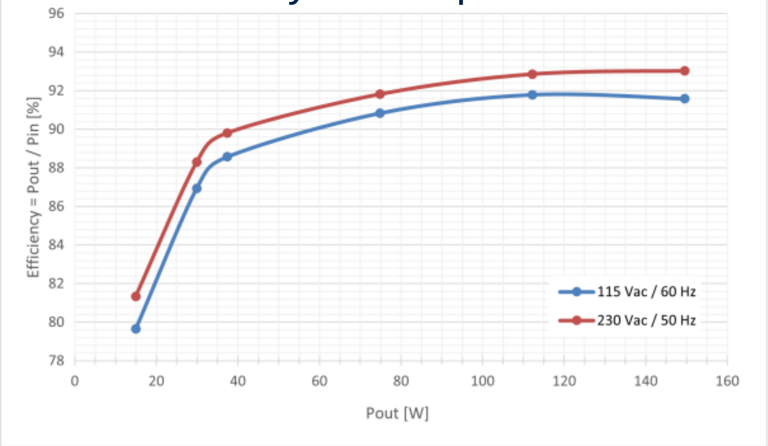


115 Vac, 60Hz



230 Vac, 50Hz

Efficiency vs. Output Power



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350 W Solar Microinverter
featuring Wide Bandgap Technology
Benefits of Wide Bandgap Technology
Introduction and Proposed Design
System Output and Efficiency
Other GaN Designs to fit your application
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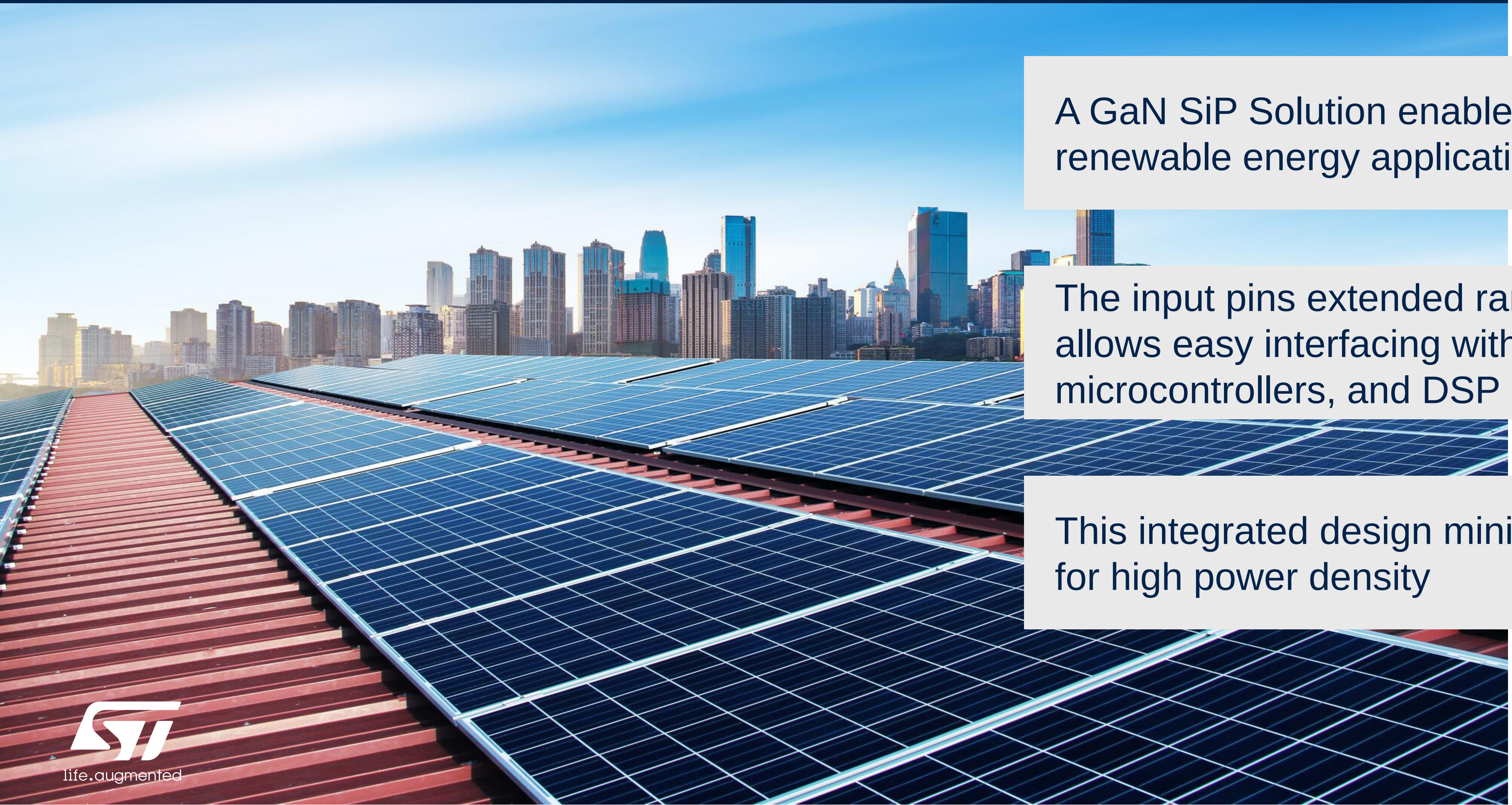
Wide Bandgap Technology offers many benefits vs. Si

The realized benefits of GaN technology is key for renewable energy customers and users



A GaN SiP Solution enables high efficiency crucial for renewable energy applications

The input pins extended range on the GaN SiP allows easy interfacing with analog controllers, microcontrollers, and DSP units

This integrated design minimized board space ideal for high power density

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Why power density matters?

More power in less space

Board area and weight are becoming limiting factors as power demands increase

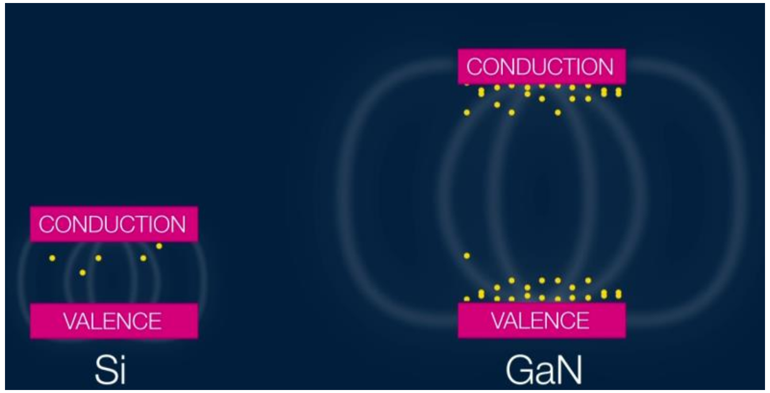
Reducing size and weight can **cut the total cost of ownership** by making **installation** and **maintenance** both **easier and quicker**

Smaller and lighter boards leads to less materials, lower shipping weights, and smaller carbon footprint

The benefits of GaN

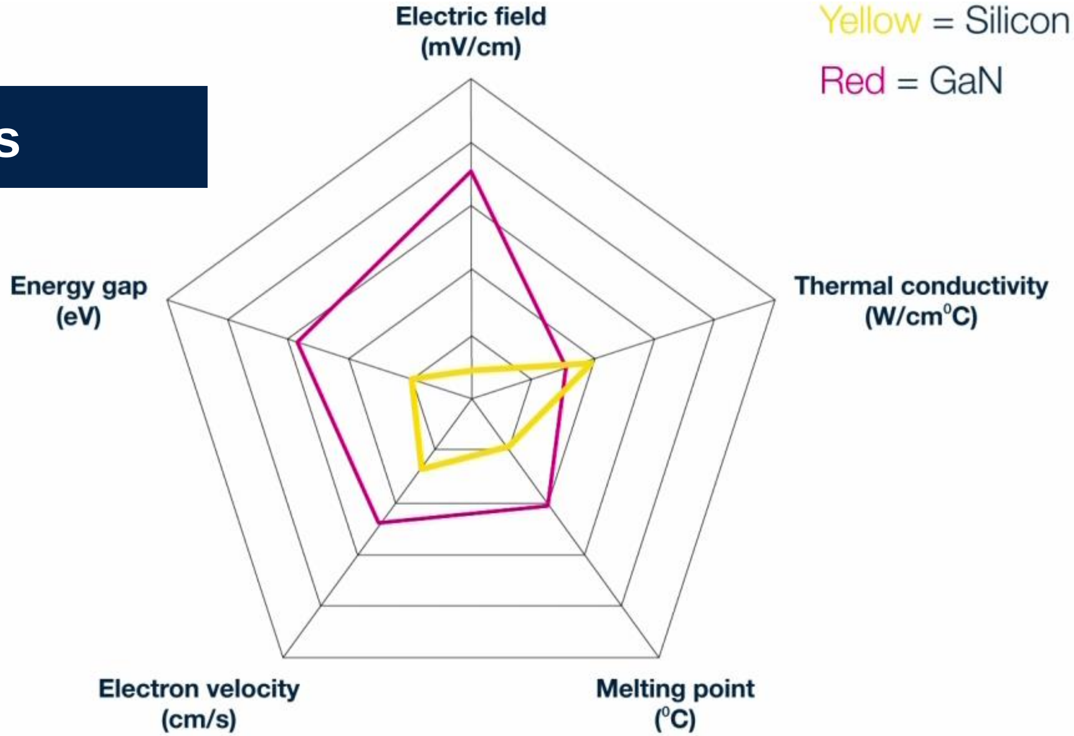
Wider bandgap is the key!

- Higher breakdown voltage
- Higher current density
- Higher switching speeds
- Lower on-resistance



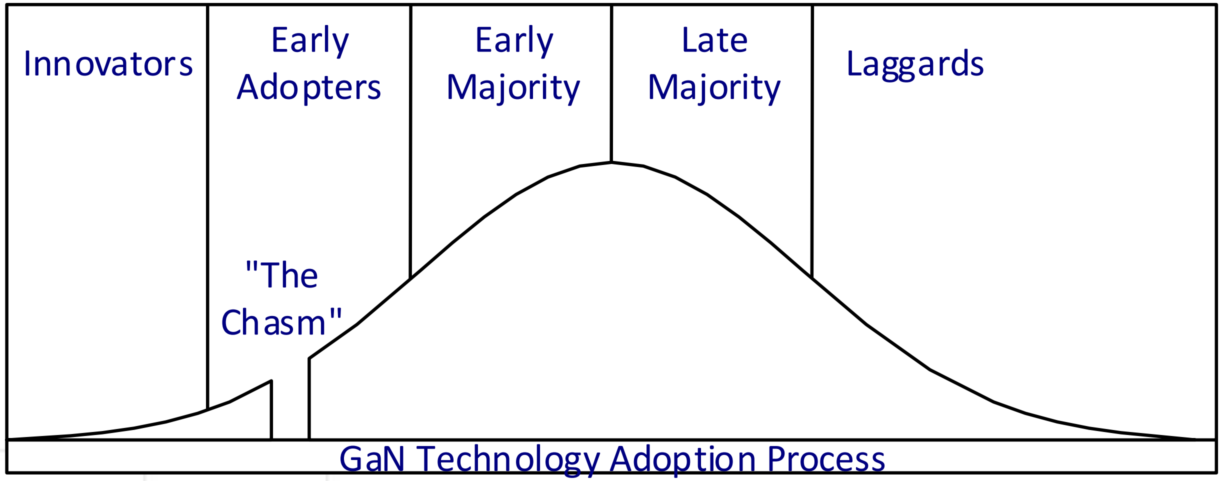
Benefits of GaN for power electronics

- Higher switching frequencies
- Higher efficiency
- Higher power density
- System downsizing
- Higher integration



Wide bandgap trends vs technology adoption

- In Consumer, GaN crossed the Chasm in 2020-2021 on the push of fast chargers rapid growth and now started to be deployed to other AC/DC.
- System in Package with embedded drivers/controllers (MASTERGAN, VIPerGaN) will contribute to adoption due to simplicity of integration.



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GaN value proposition

Higher efficiency

Reduced power losses, reduced power consumption, exceeding the most stringent energy requirements

Greener World

Higher power density

Higher switching speed to reduce systems size and cost

Smaller Products

Reinventing power

Intrinsic properties of GaN will push for new system design opportunities

Smarter Design

Smart GaN: integrating GaN with driver

Higher efficiency

Reduced power losses, reduced power consumption, exceeding the most stringent energy requirements

Higher power density

Higher switching speed to reduce systems size and cost

Faster go-to-market

Packaged solution simplifies the design, with a higher level of performance

Product Portfolio by L3 Sub Class: Integrated smart GaNs

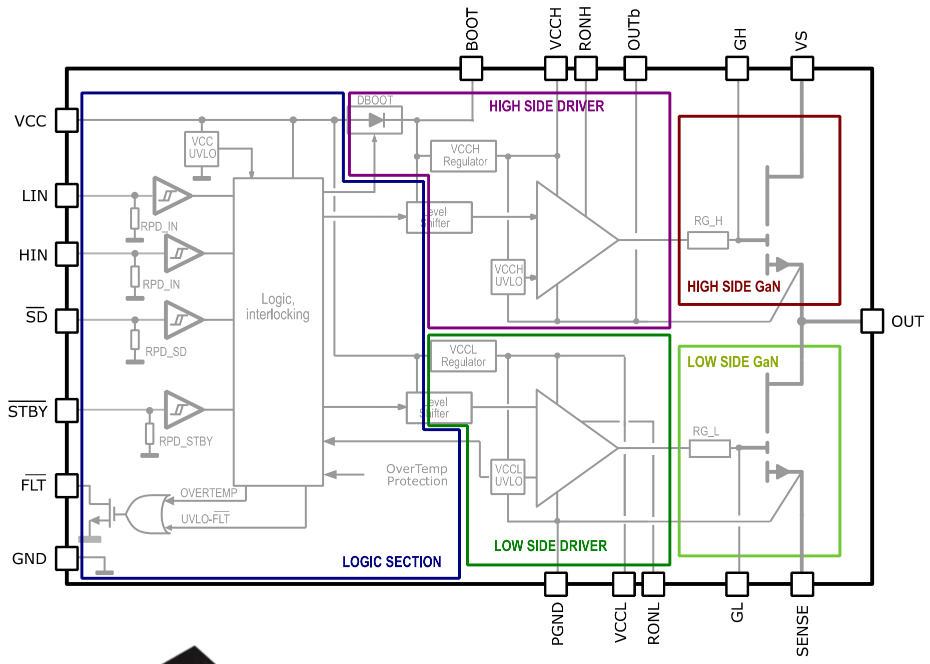
One package
Many Power GaN HEMT for half bridge configuration

MasterGaN3	MasterGaN2	MasterGaN5	MasterGaN4	MasterGaN4L	MasterGaN1	MasterGaN1L
Up to 45 W	Up to 65 W	Up to 100 W	Up to 200 W	Up to 200 W	Up to 500W	Up to 500W
225 + 450 mΩ	150 + 225 mΩ	450 + 450 mΩ	225 + 225 mΩ	225 + 225 mΩ Low consumption	150 + 150 mΩ	150 + 150 mΩ Low consumption
Mass production	Mass production	Mass production	Mass production	Mass production	Mass production	Mass production

MasterGaN6/MasterGaN7 – MasterGaN evolution

Advanced power solution integrating a gate driver and two enhancement mode GaN transistors in half-bridge configuration

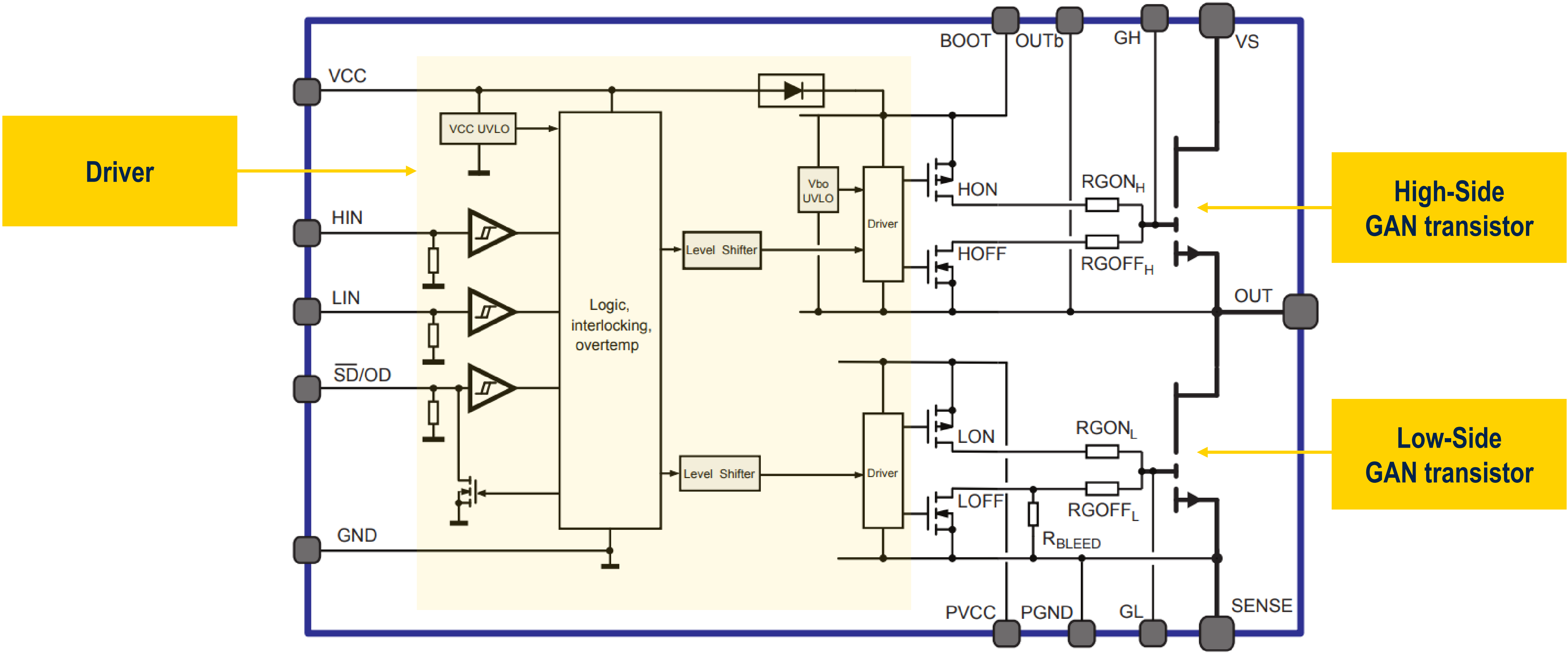
ES available



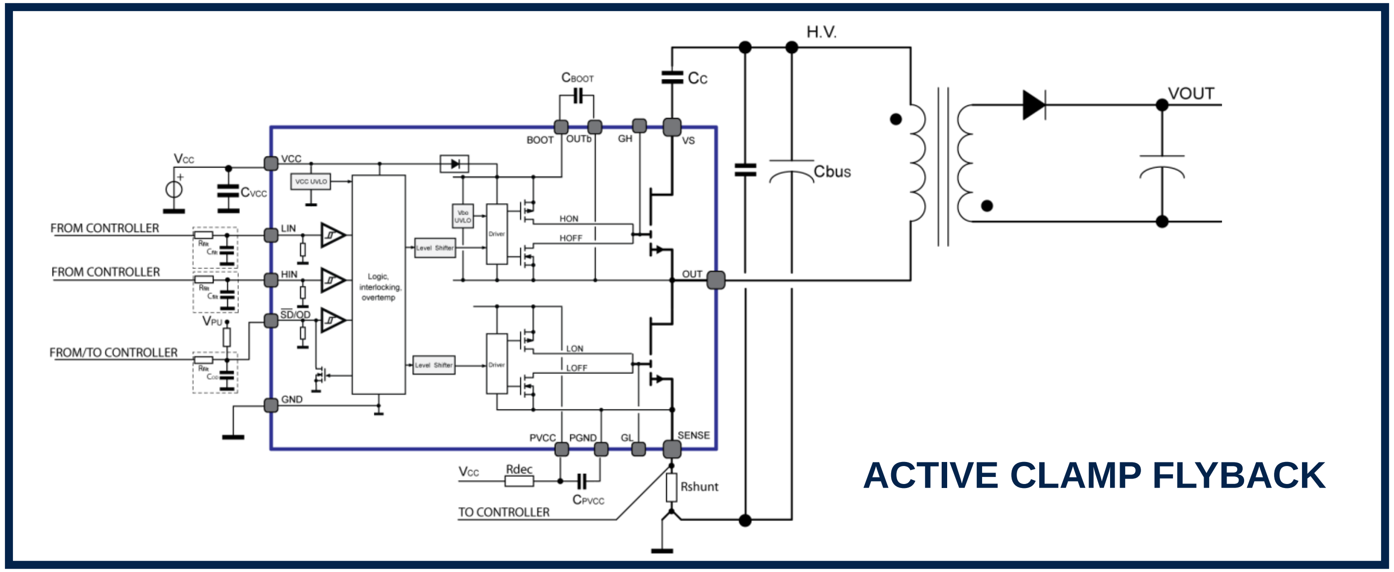
	MastergaN6	MasterGaN7
VDS	600V	
RDS_{ON}	150 mΩ	270 mΩ
IDS_{MAX} (@25C)	10 A	6 A

Compact	• Integrated power GaN • **Integrated Linear regulators** to supply low side and high side output stages
Robust	• **Support to Hard Switching Topology** • UVLO protection on both the lower and upper driving sections, preventing the power switches from operating in low efficiency or dangerous conditions, and the interlocking function avoids cross-conduction conditions • Over temperature protection
Easy Design	• Smart solution in GQFN 9x9 mm^2 package • Input pins extended range 3.3 to 15 V with hysteresis and pull-down- allows easy interfacing with microcontrollers, DSP units or Hall effect sensors • Dedicated pin for shutdown functionality • Accurate internal timing match

MasterGaN block diagram

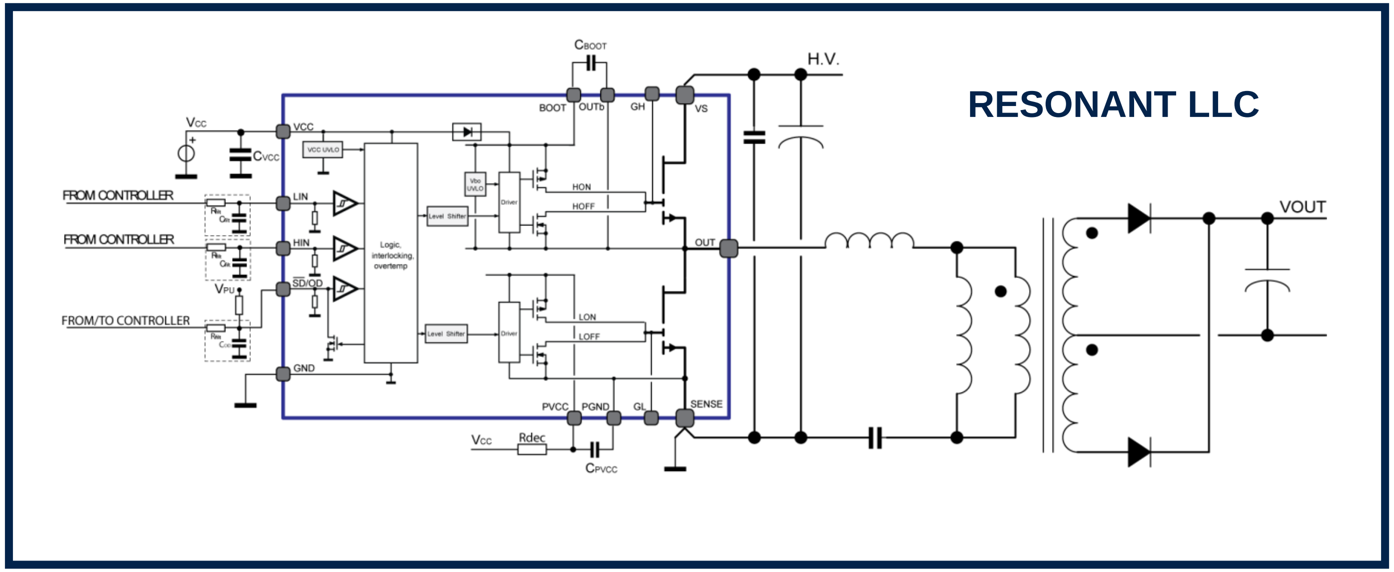


MasterGaN main topologies



Key applications

- Chargers and adapters
- Industrial SMPS



Key applications

- Industrial SMPS
- UPS
- Solar systems
- Servers

Introduction and Proposed design of a GaN based Solar microinverter

Microinverters are often used as an alternative to string inverters to perform the DC to AC power conversion at solar panel level in residential PV panel systems

A solar microinverter helps maximize energy yield and mitigate problems related to partial shading, dirt, or single PV panel failures

A microinverter is composed of a DC-DC converter implementing MPPT and DC-AC inverter to shape current and voltage for injection into the AC grid

The demo design is based on two power stages: an interleaved isolated boost DC-DC converter and a DC-AC converter with a GaN SiP as the power stage

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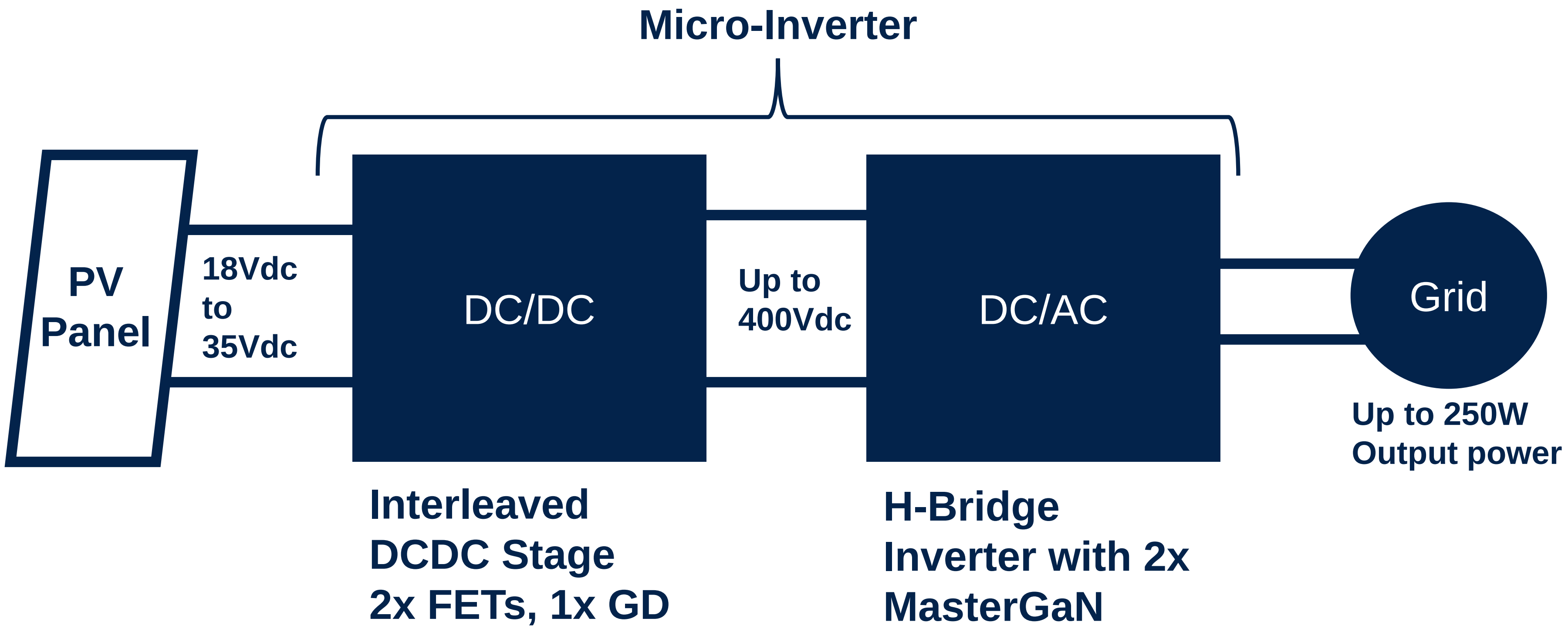
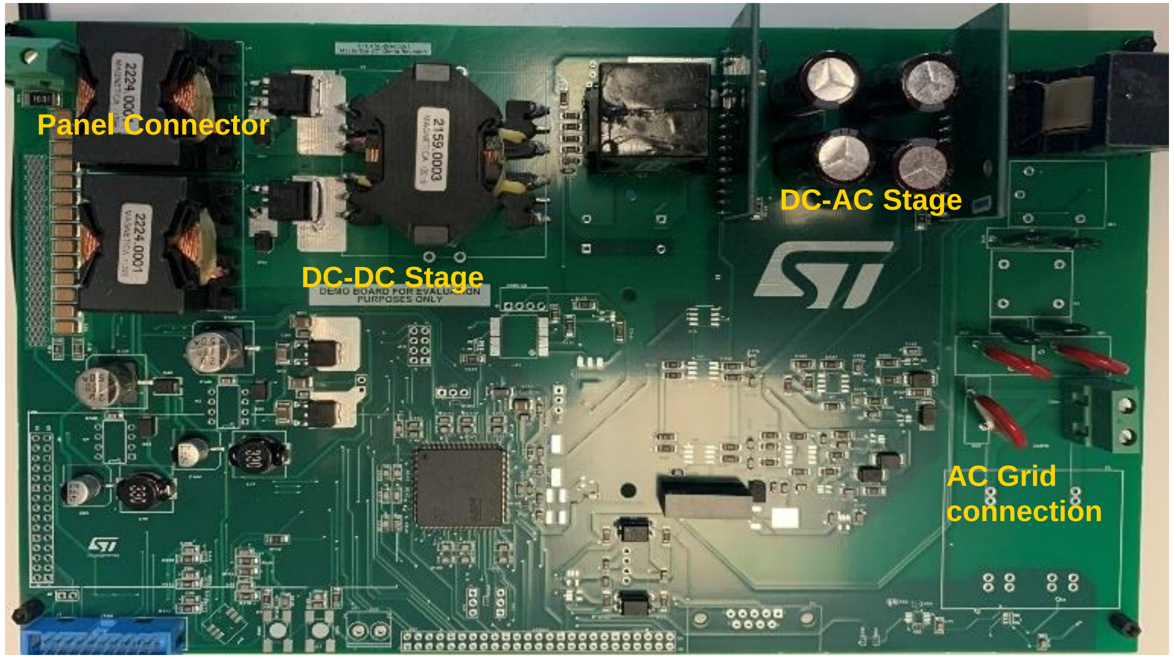
Micro-inverter block diagram



Micro-inverter Reference Design

Key Features

- DC-AC 2-stage micro-inverter for 250W PV application
- MasterGaN6/7 daughter card integration
- First stage – DC-DC; Second stage – DC-AC
- First stage based on Interleaved boost topology
- Second stage based on 2 MasterGaN6 daughter cards
- Bi-polar modulation scheme based on Advanced Timer for inverter stage
- Higher switching frequency (Tested up to 150kHz for secondary side)
- Measured efficiency of MasterGaN6 DC-AC stage – 97.3%
- Design files available in Altium

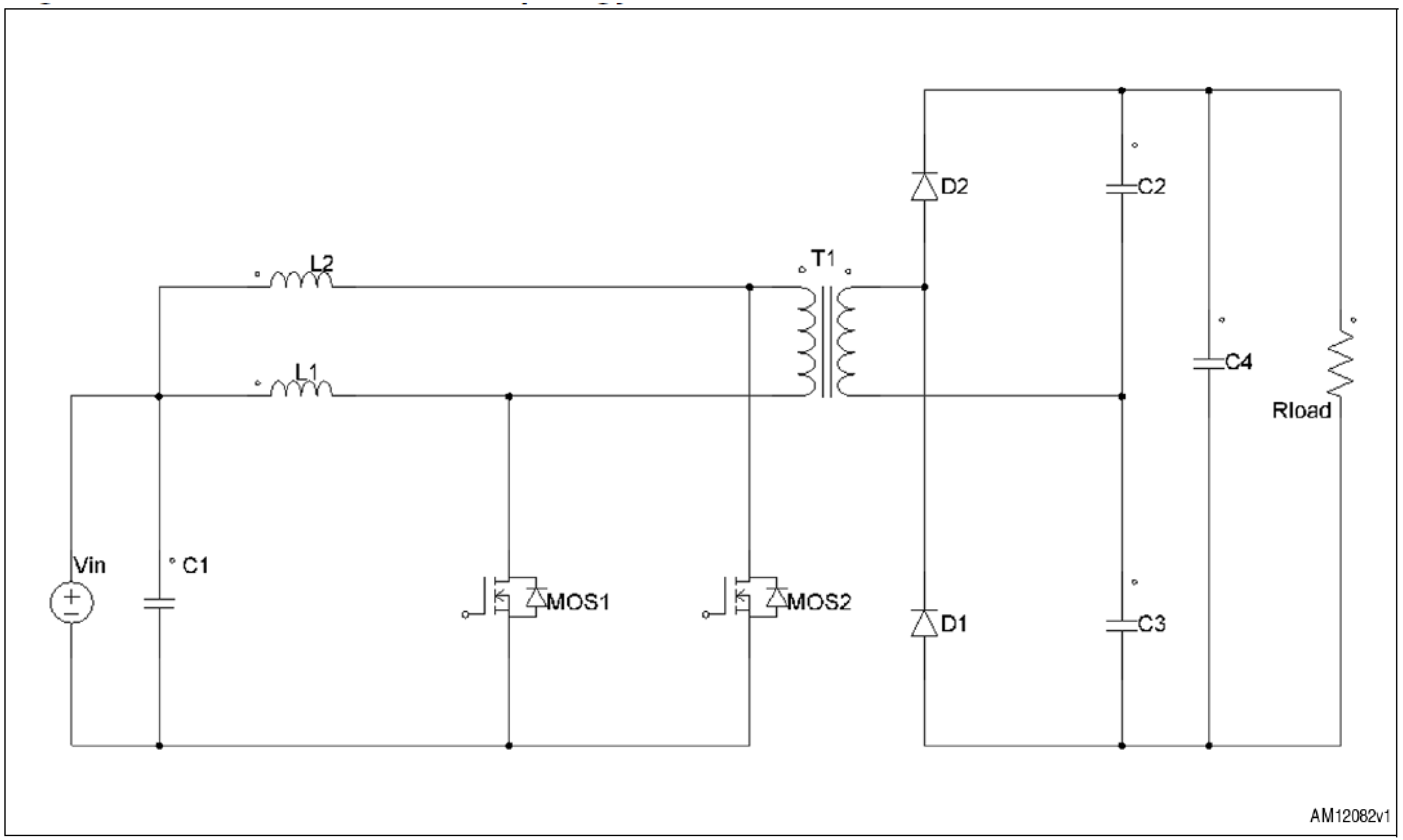


Main Products

- Integrated System-in-Package - MasterGaN6/7
- Gate Drivers – PM8834
- Power Discrete - STH310N10F7-2, STPSC12065G-TR
- DCDC Buck Regulators – L4971
- LDO - ST732
- Controller - STM32F103
- Analog Op-amps – TSV911, TS3011
- Isolation – STISO620

Schematic and layout – Available in Altium Designer

Interleaved DC-DC Stage



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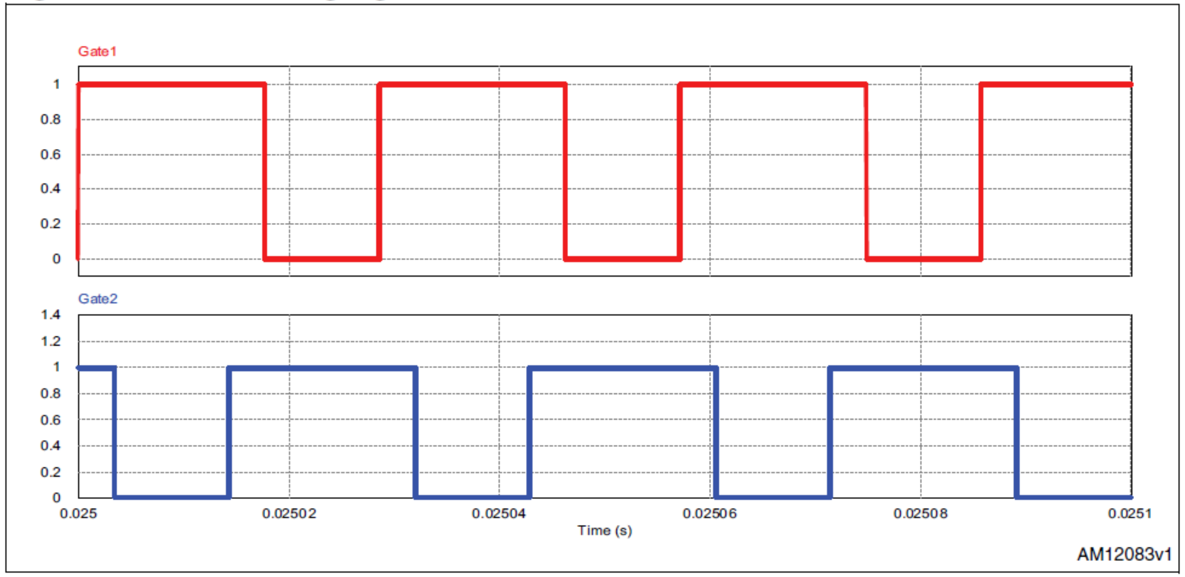
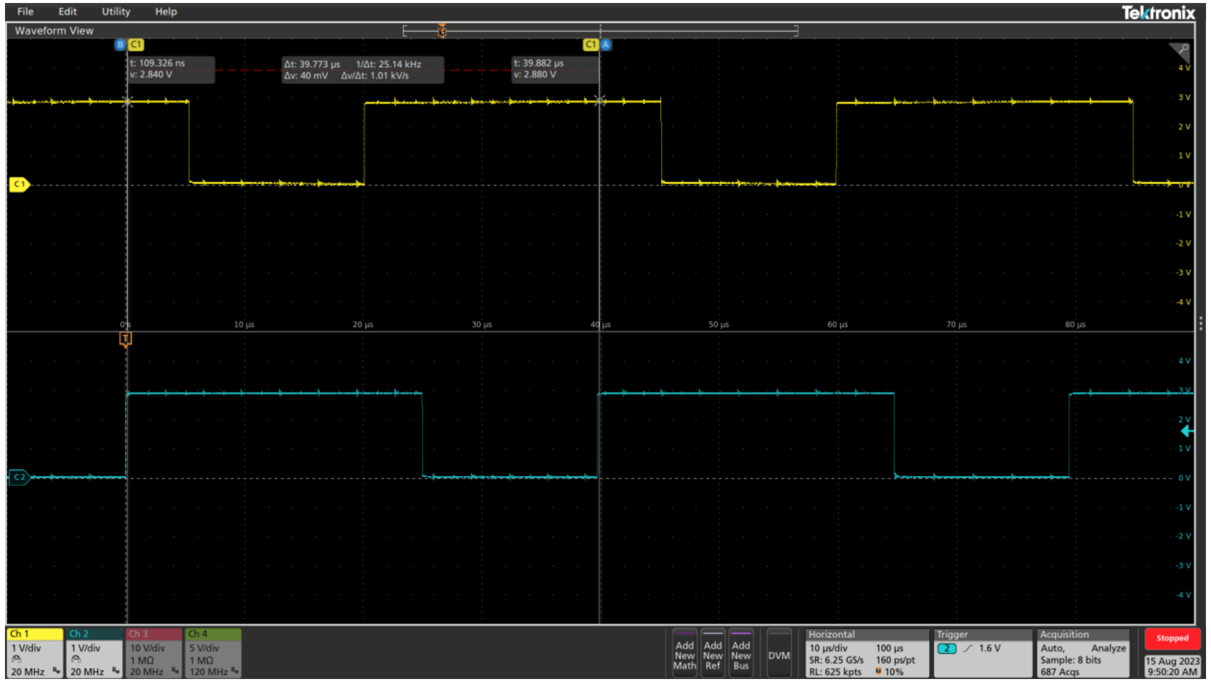
Interleaved DC-DC Stage
Gate driving signals

Figure 4. Gate driving signals of the DC-DC converter

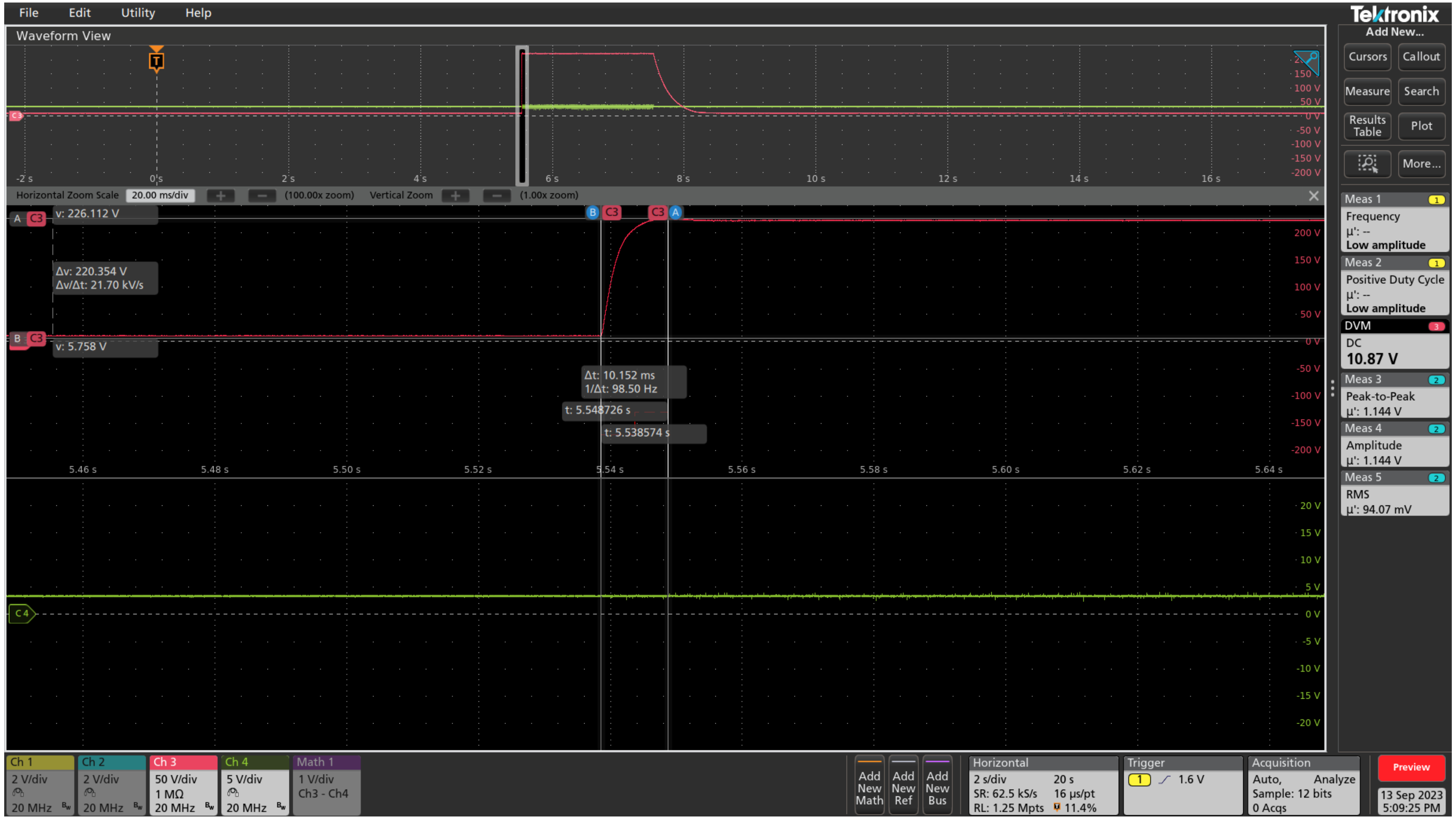




FW generated using CubeMx

$\delta_{min} = 50\%, \delta_{max} = 70\%$

DC-DC Startup waveform at 55% duty cycle



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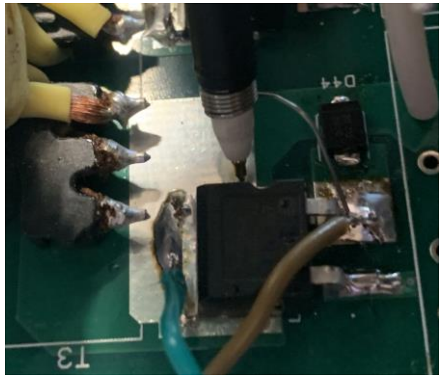
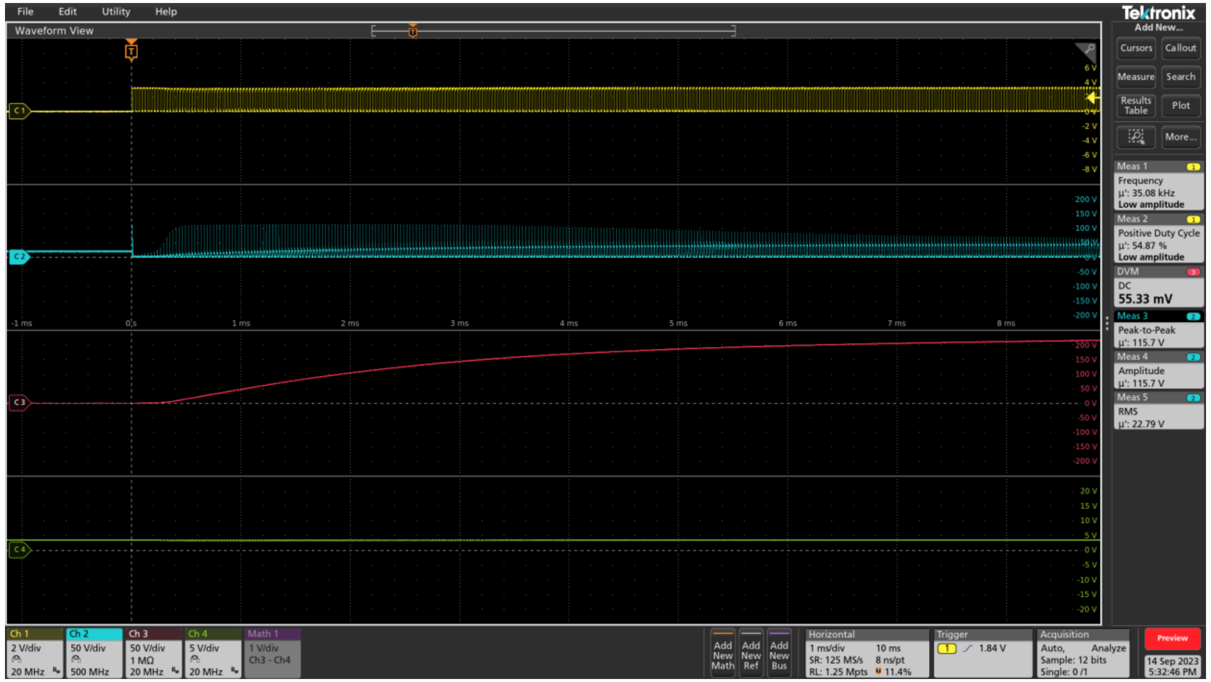
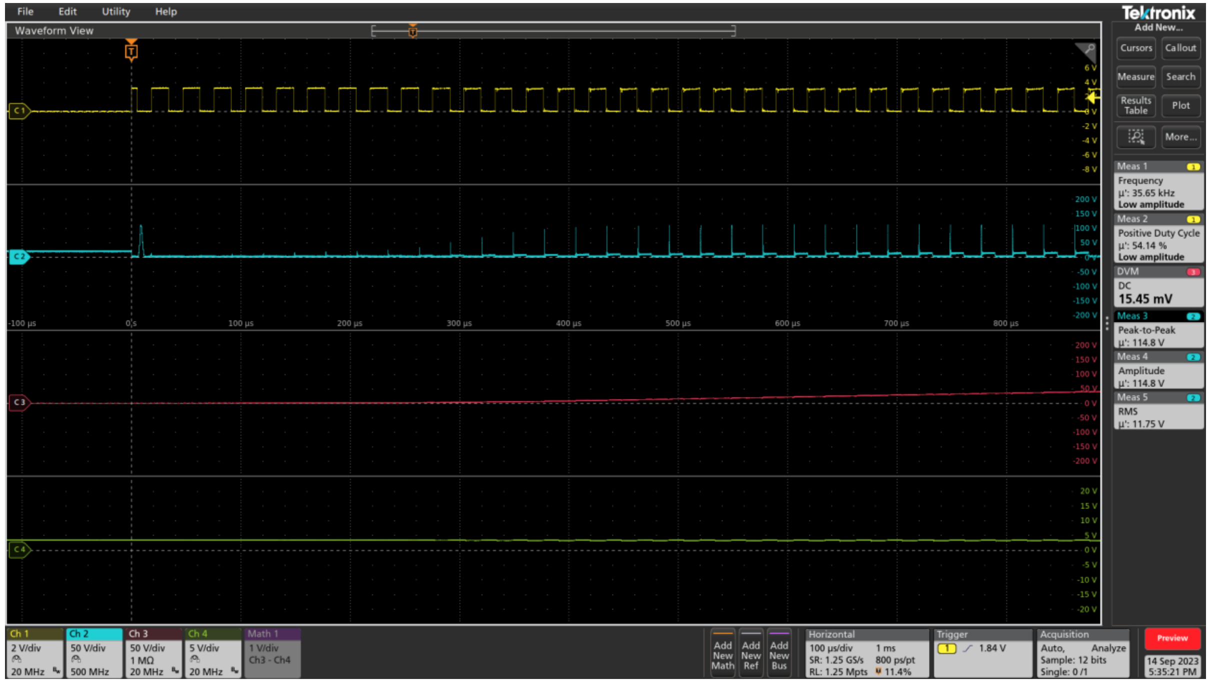
Interleaved DC-DC Stage
Vds during startup







Vpeak is less than 115V for < 10ms
@18Vdc
25degC ambient
2.5kohm resistance at output

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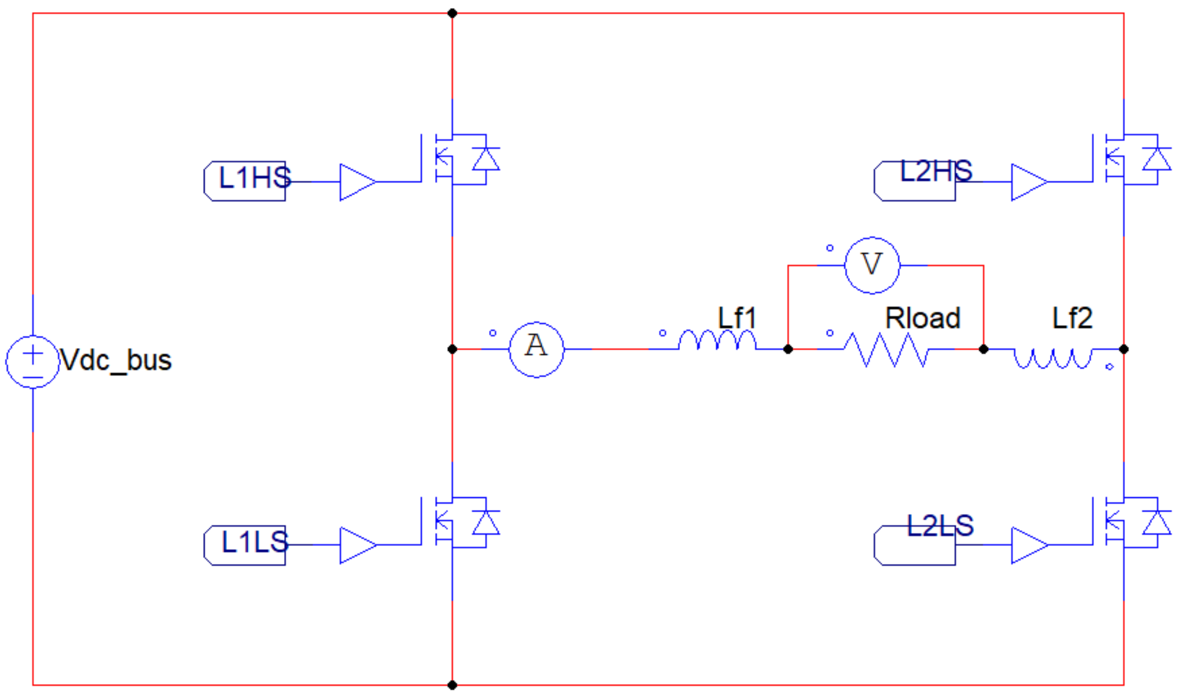
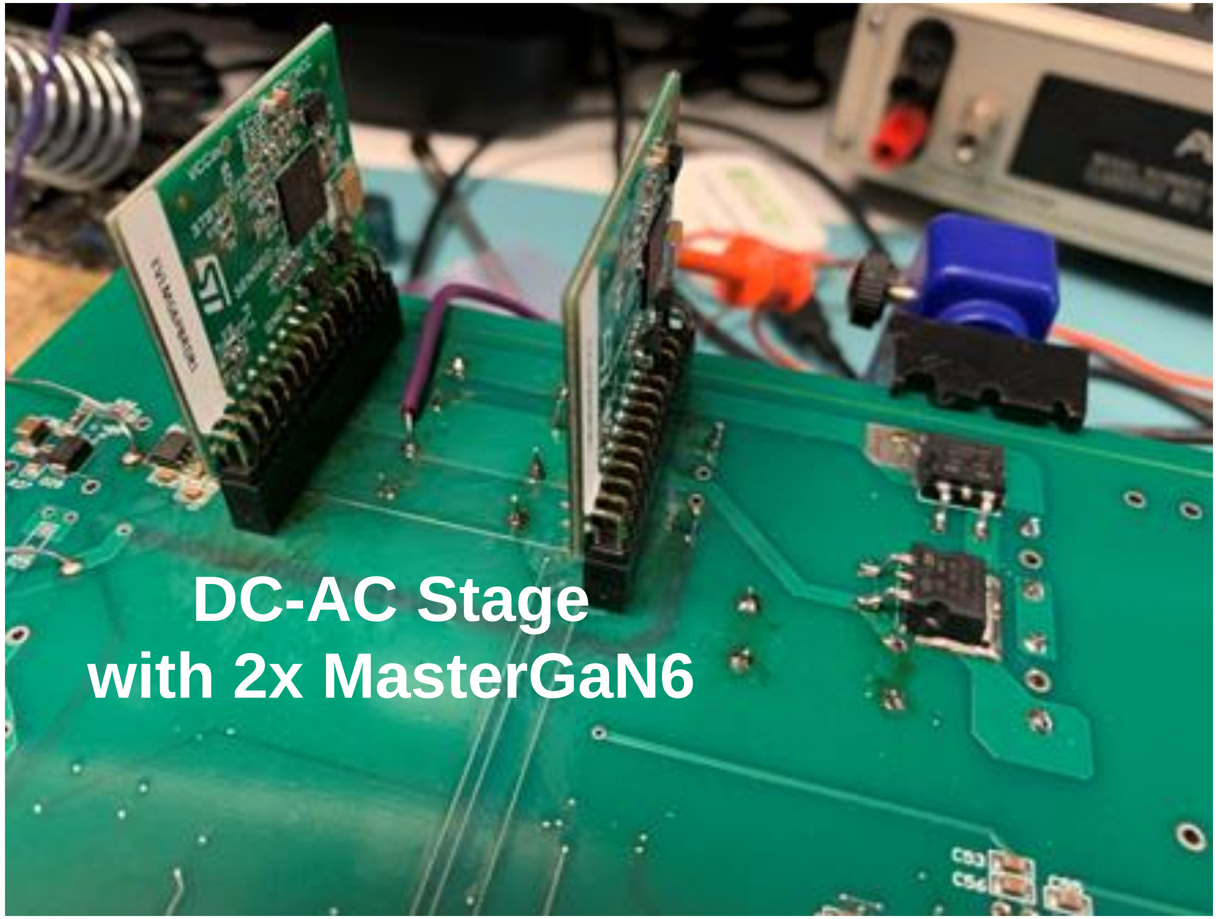
DC-AC power stage with MGaN6 Daughter cards





- Bipolar PWM driven by STM32F103ZET6
- L1HS and L2LS – Driven together
- L2HS and L1LS – Driven together
- Frequency, Dead time and Modulation Index – Configurable via firmware

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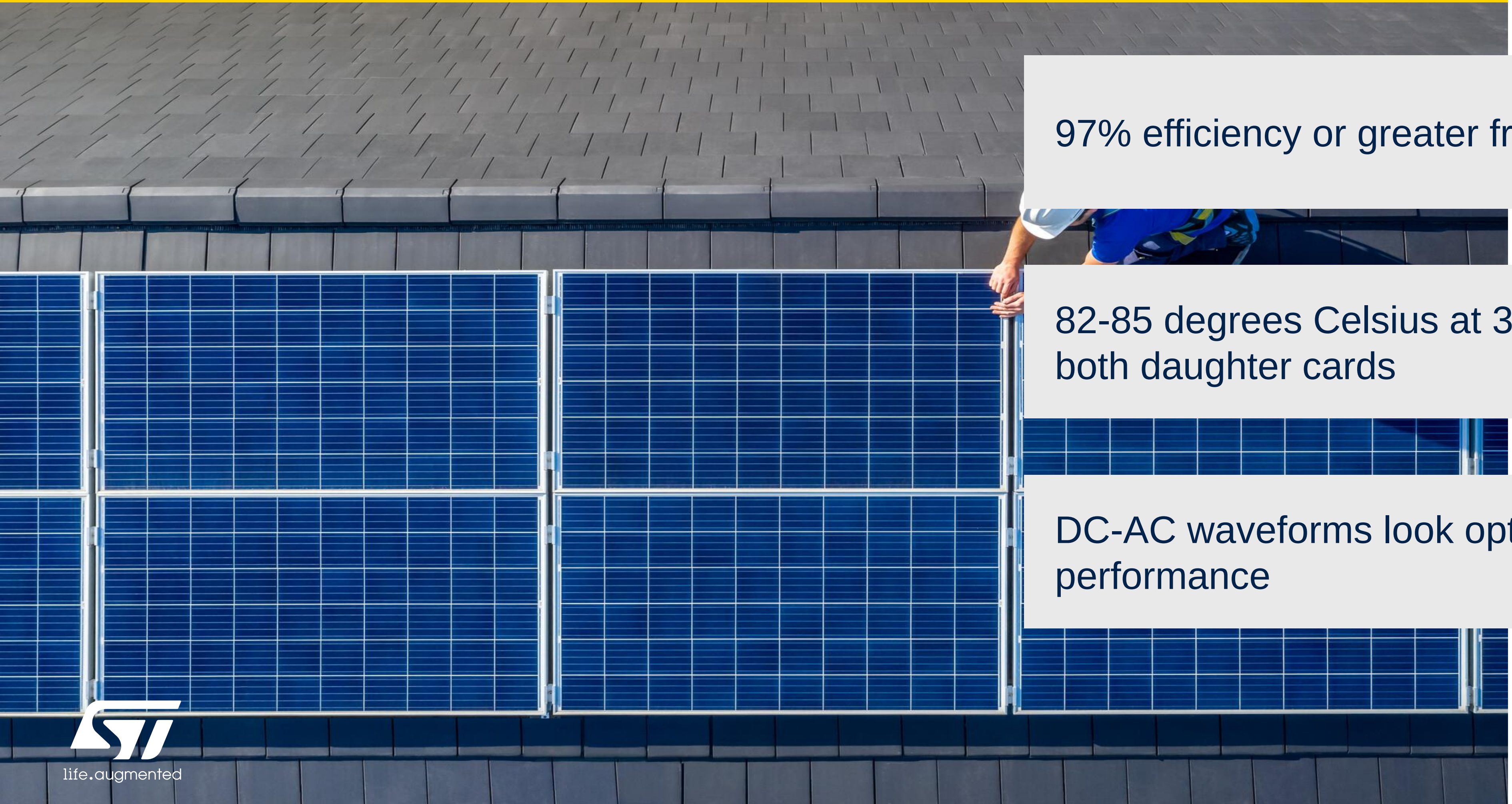
The System showed strong performance, greater than 97% efficiency

The results show strong system efficiency and thermal performance

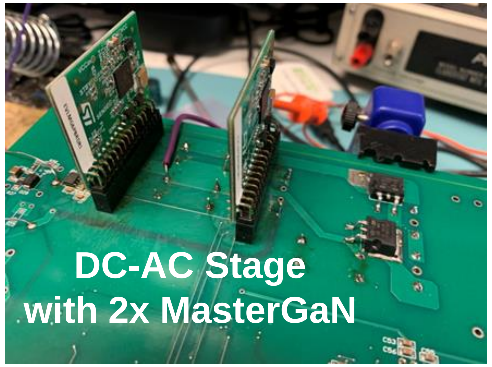


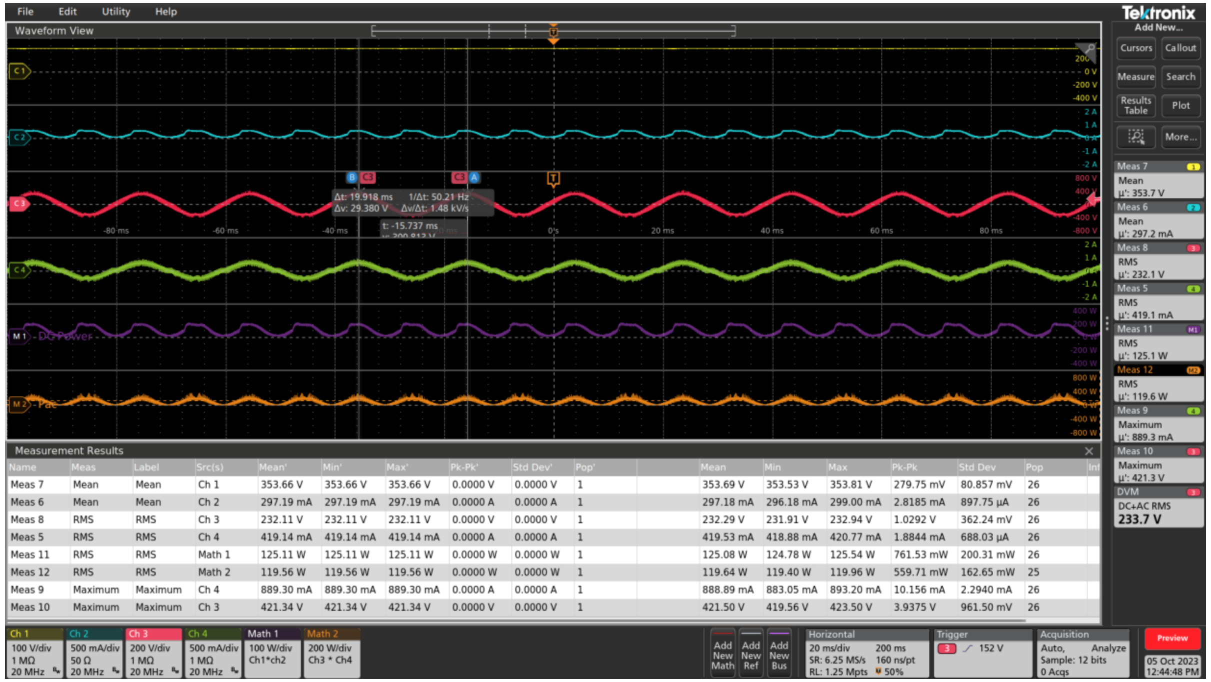
97% efficiency or greater from 150 W to 350 W

82-85 degrees Celsius at 350 W with heatsink on both daughter cards

DC-AC waveforms look optimal for microinverter performance

DC-AC waveforms





$$f_{AC} = 60Hz$$
$$f_{sw} = 100kHz$$

$$f_{AC} = 50Hz$$
$$f_{sw} = 100kHz$$

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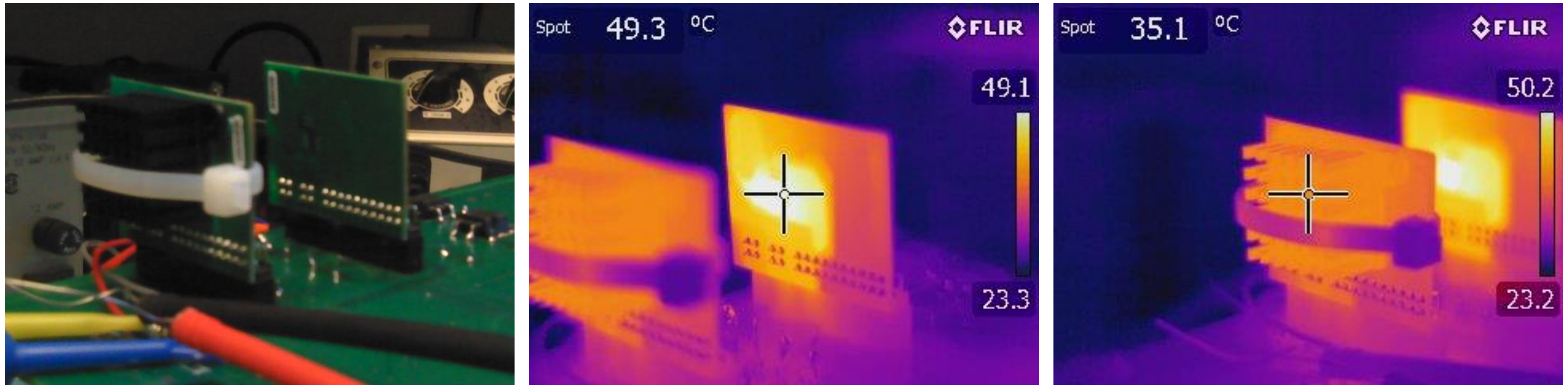
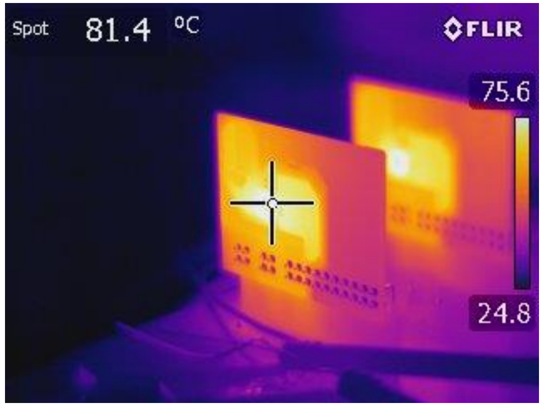
DC-AC thermal measurements

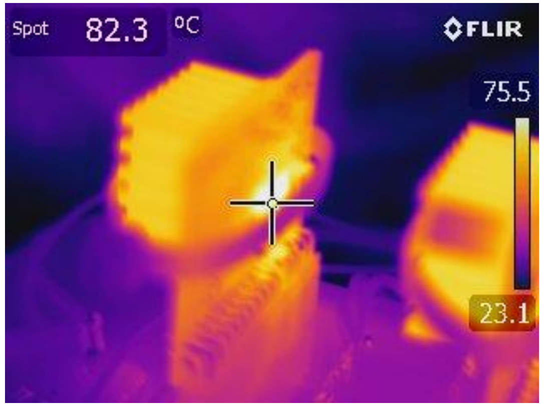
- > 90 deg C at 250 W without heatsink
- 82-85 deg C at 350 W with heatsink on both daughter cards
- ~12-15 deg C deltaT with/without heatsink at similar operating conditions
- Temperatures cross 90 deg C at 150 kHz, 250 ns at 100 W



With/without heatsink @ Pin = 25W



Without heatsink @ Pin = 200W



With heatsink @ Pin = 350W

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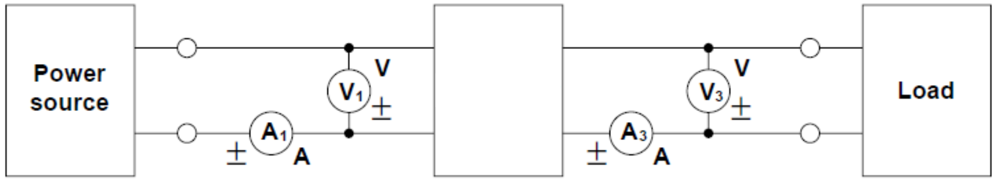
DC-AC efficiency measurements

Wiring Systems and Equations

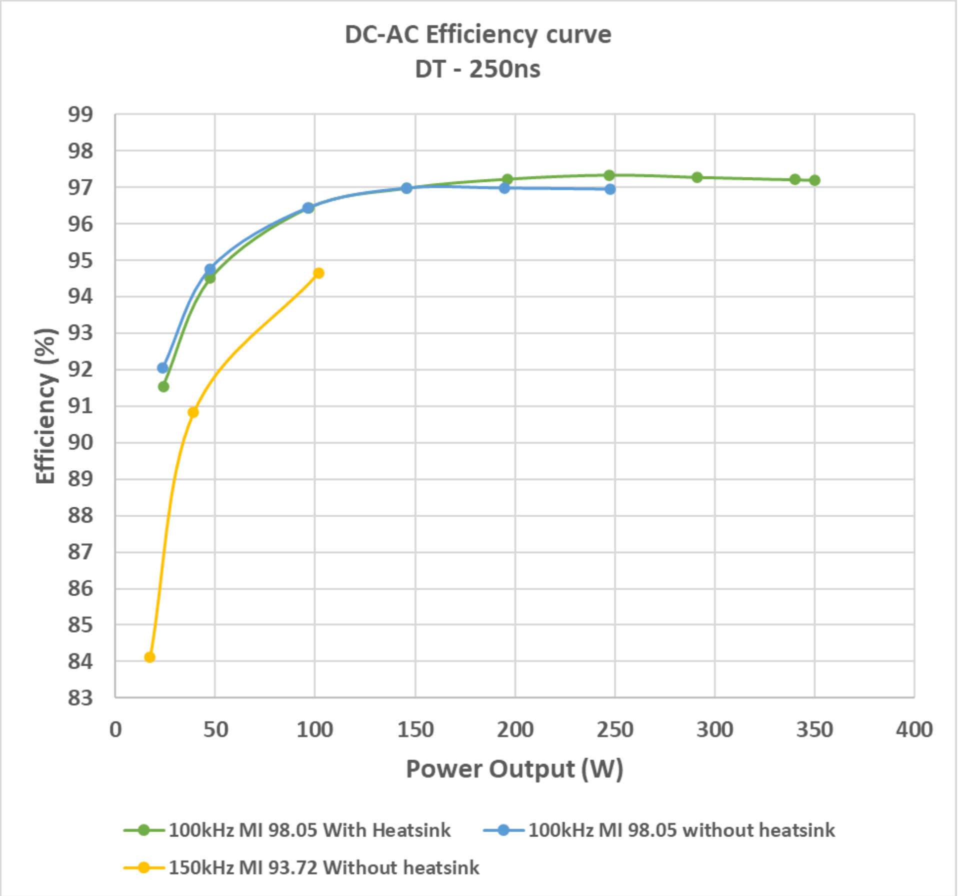
Two-wire system for both input and output:

Select 1Φ2W, 1Φ3W (for 253620 only) or 3Φ3W (for 253620 only).



$$\text{Equation: } \eta = \frac{W3}{W1} \infty 100(\%)$$

WT1030M – Digital Power Meter



Peak efficiency = 97.3%
After line filter inductors on AC side
Filter inductor design > 10 years old. Needs optimization

250 W GaN-Based Totem Pole Bridgeless PFC Design

Introduction and Proposed Design

Benefits of GaN Technology and Totem Pole Bridgeless PFC Topology

Results and Conclusions

Similar Designs and References

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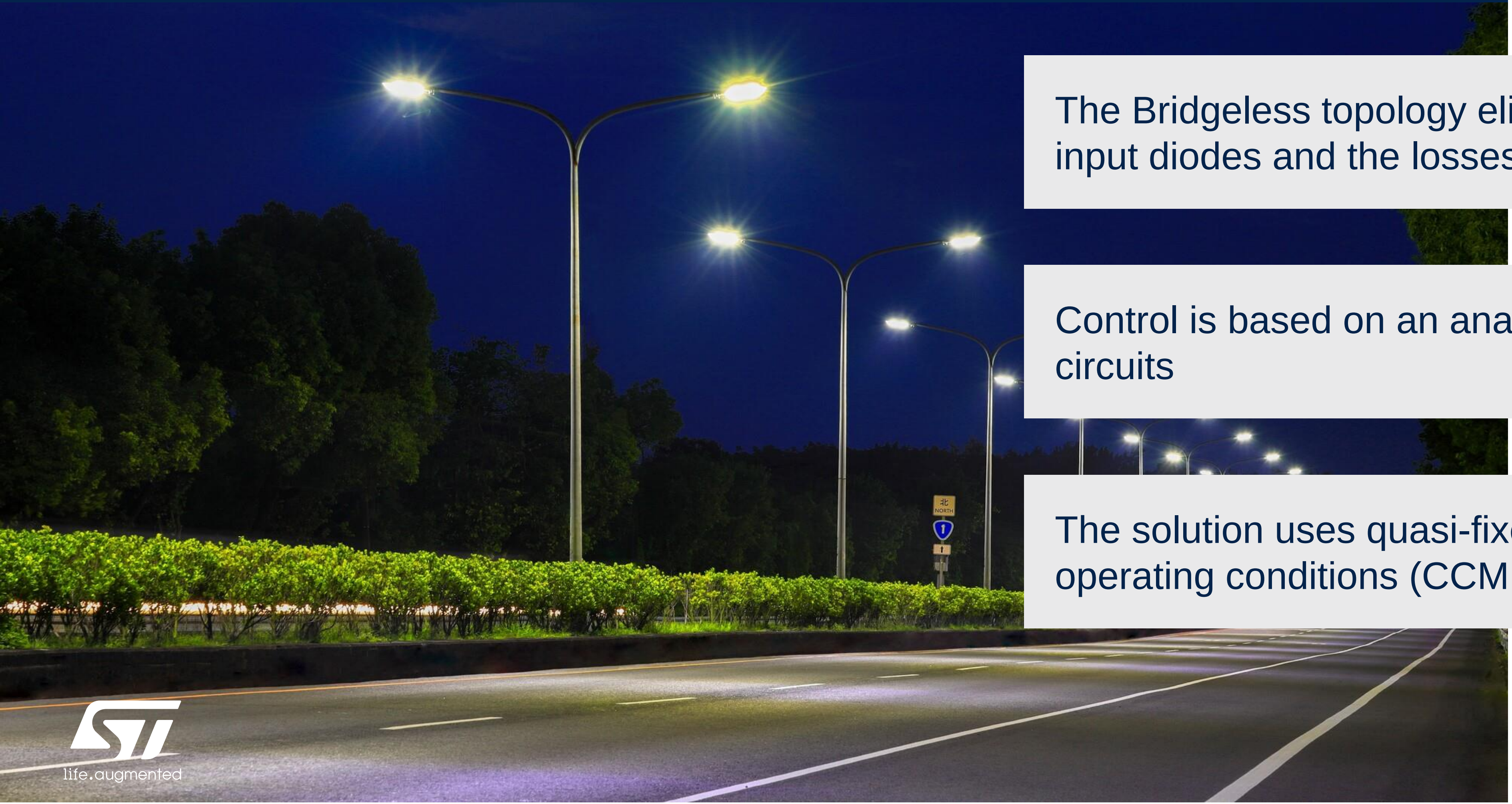
Topology

Introduction and Proposed Design



The Bridgeless topology eliminates the use of the input diodes and the losses associated with them

Control is based on an analog controller and external circuits

The solution uses quasi-fixed frequency in all operating conditions (CCM, DCM)

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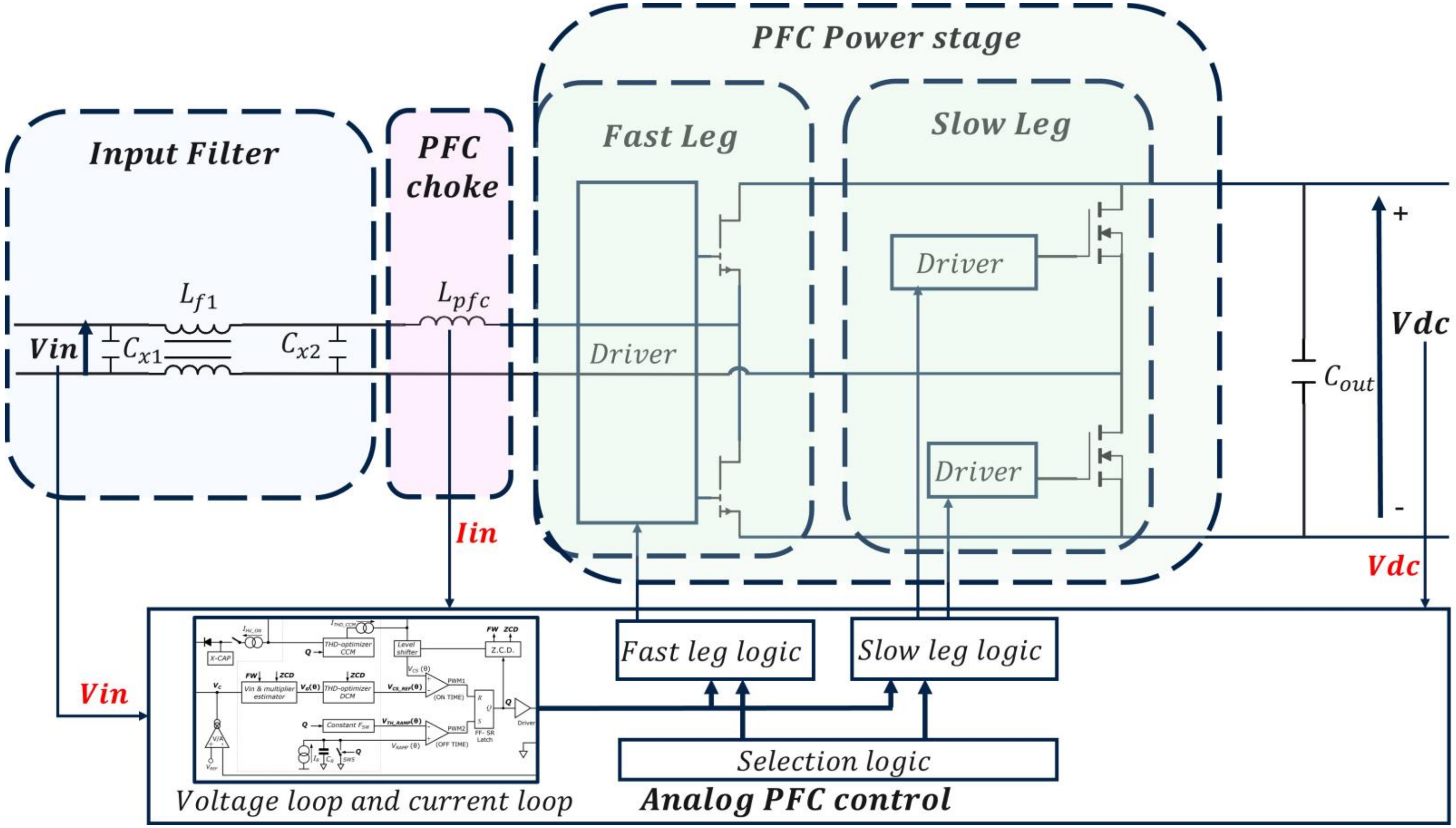
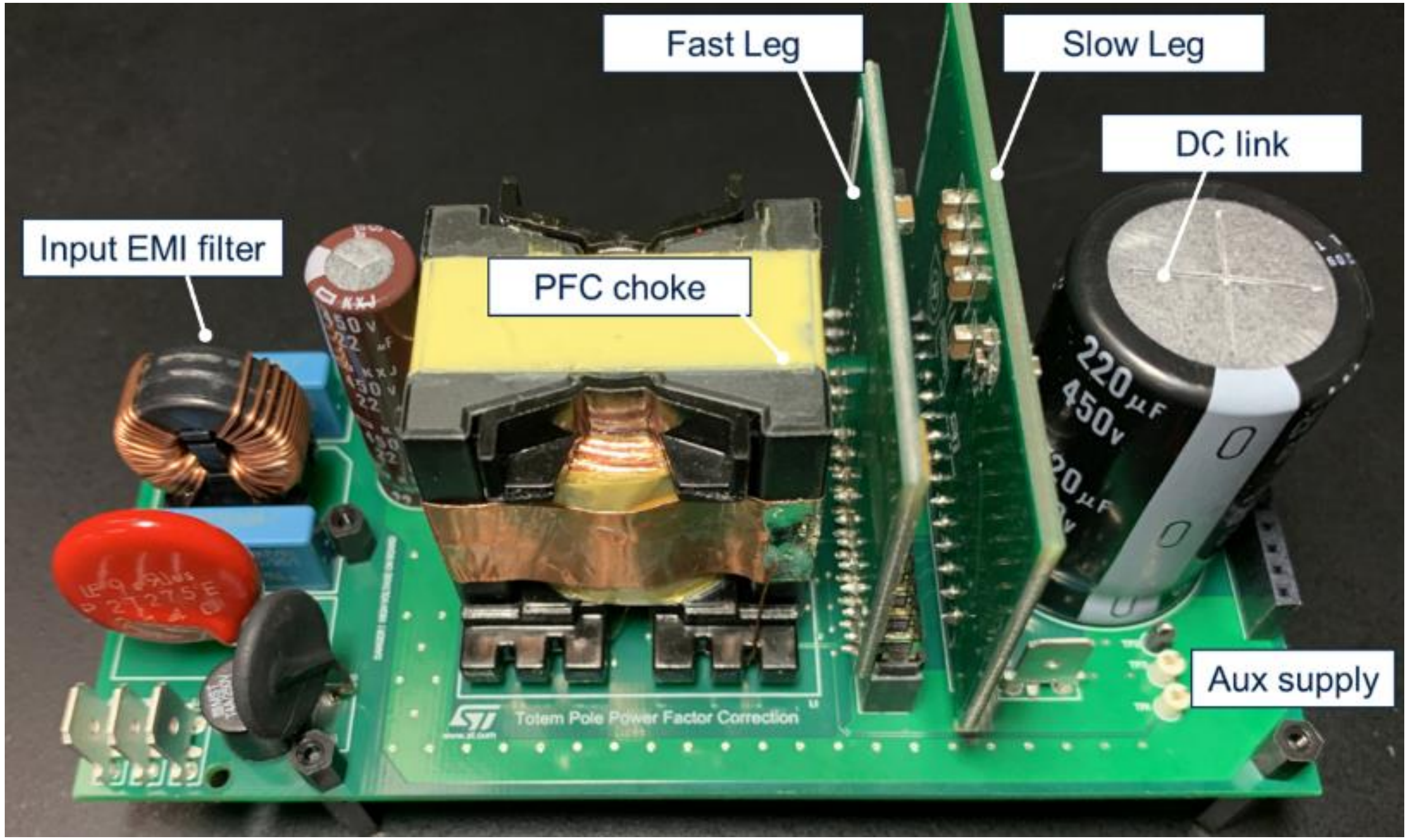
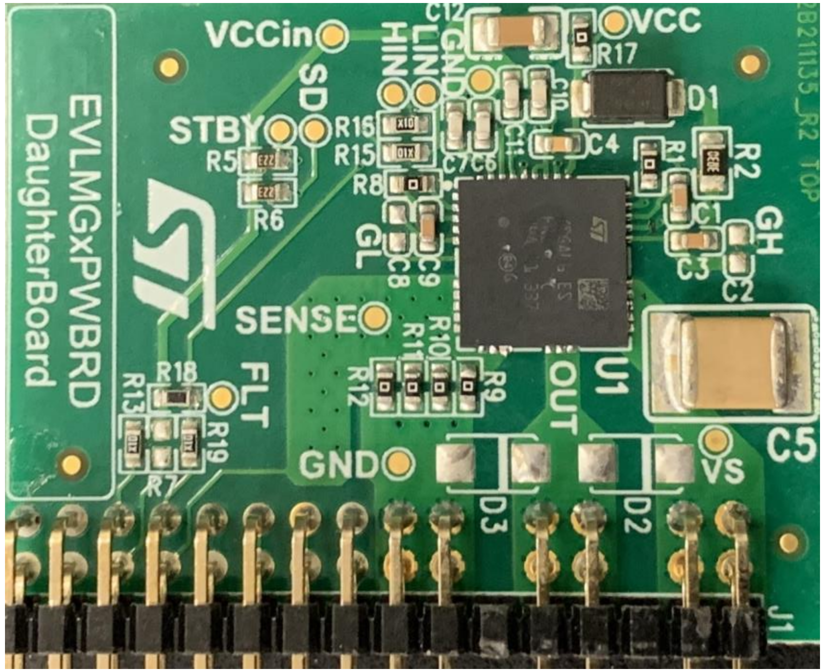
Block Diagram

- Slow Leg
  - Switched at line frequency
  - Uses high voltage Silicon FETs
- Fast Leg
  - Uses an integrated SiP with two 650V GaN FETs in a Half Bridge configuration, including the gate drivers
  - Switched at higher frequency than the slow leg based on the modulation generated by the PFC controller to regulate the line current
- The PFC controller naturally limits the harmonic content of the current drawn from the grid



Board Layout





Fast Leg board with GaN SiP

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Benefits of Wide Bandgap Technology and Totem Pole Bridgeless PFC Technology

The Bridgeless Topology with GaN offers many key benefits

Bridgeless topologies simplify the design compared to traditional PFC circuits

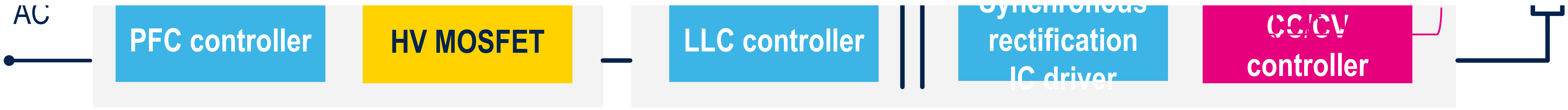
The use of GaN creates lower on-resistance, small parasitic capacitance, decreasing system losses

Analog control can be a good option for cost sensitive applications

AC-DC Conversion Portfolio by Function

Power factor correctors, a variety of controllers and supervisors / housekeeping ICs

Solutions meeting all switch mode power supply design needs and over performing the most demanding energy saving regulations



L6562, L6563, L6564, L4981, L4984
L4985/6
PFC controller families

L6599A/AT, L6699
Resonant controller

SRK2000/A
Synchronous rectification

SEA05, TSM10*, SEA01
CC/CV controllers

PFC Analog Control

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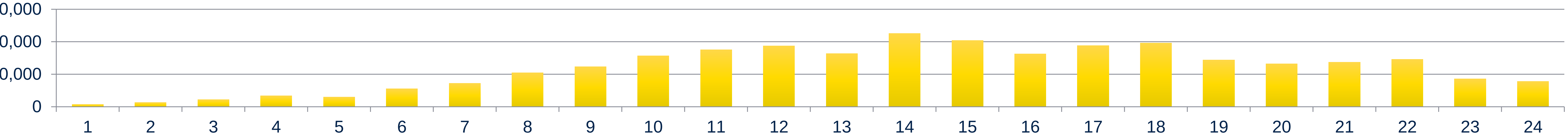
PFC – Topologies & ICs Portfolio

The L4985A was used in this design, ideal for CCM operation

PFC shipped



TM Transition Mode		CCM Continuous Conduction Mode	
L6562A, L6562AT	DIP8, SO8	**L4981A/B**	SO20
L6563H	SO16	**L4984D**	SSOP10
L6563S	SO14	**L4985A/B**	SO8
L6564D	SSOP10	**L4986A/B**	SSOP10
L6564H	SO14		
L6564T	SSOP10		

25W 75W 600W 3KW **POWER**

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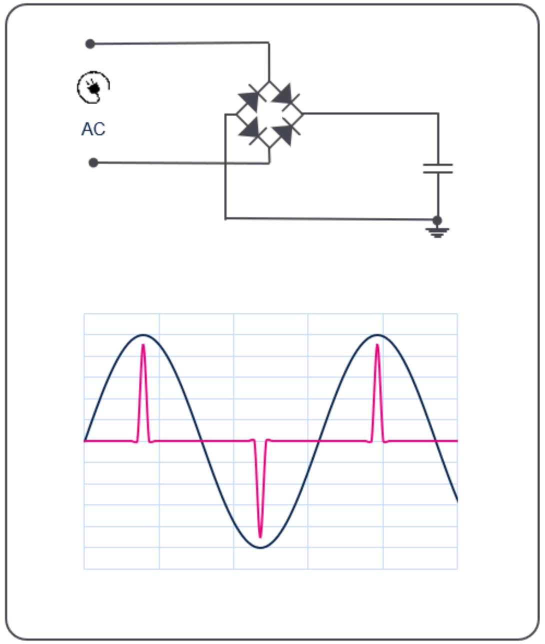
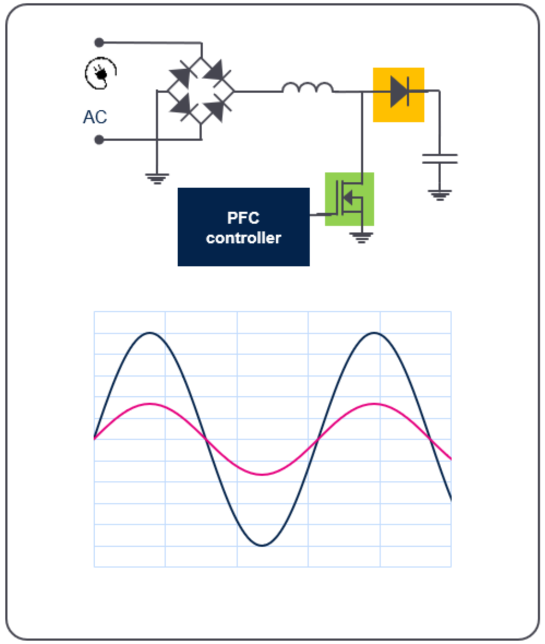
Motivation to adopt PFC





Input voltage **Input current**

Assuming same load power

Higher RMS current
Higher losses on mains

Lower RMS current
Lower losses on mains

Depending on power level and application, standard IEC 61000-3-2 is mandatory

Ecosystem

To support Design in and shorten time to market

400V 350W, single stage

Boost converter:
- V_{IN} = 90 ~ 265 V_{AC}
- V_{OUT} = 400 V_{DC}
- P_{OUT} = 350 W
- THD < 10 %
- Efficiency = 97.5 %
- F_{SW} = 65 kHz

Order code:**EVL4985-350W**

Prototypes available

400V 350W, single stage

Boost converter:
- V_{IN} = 90 ~ 265 V_{AC}
- V_{OUT} = 400 V_{DC}
- P_{OUT} = 350 W
- THD < 10 %
- Efficiency = 97.5 %
- F_{SW} = 65 kHz
- With Pgood_in/out

Order code:**EVL4986-350W**

Prototypes available

400V 1000W, single stage, BARBI

Boost converter:
- V_{IN} = 90 ~ 265 V_{AC}
- V_{OUT} = 400 V_{DC}
- P_{OUT} = 1000 W

Order code:**EVL4986-BL1KW**

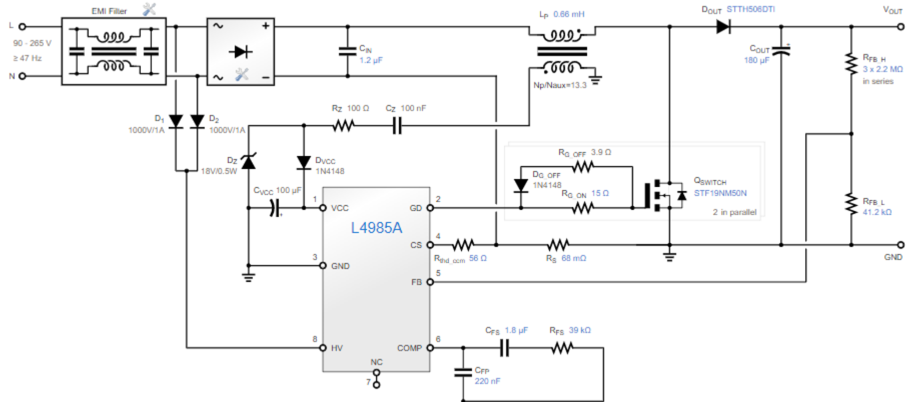
Prototypes available

12V 400W, L4985+L6699+SRK2001

80+ Platinum:
- V_{IN} = 90 ~ 265 V_{AC}
- V_{OUT} = 12 V at 33 A
- P_{OUT} = 400 W

Order code:**EVL400W-80PL**

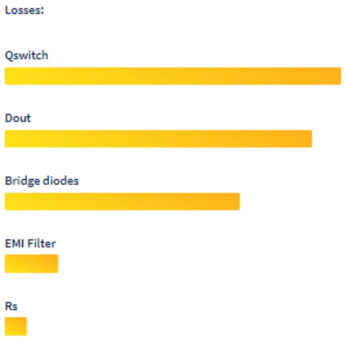
Under development



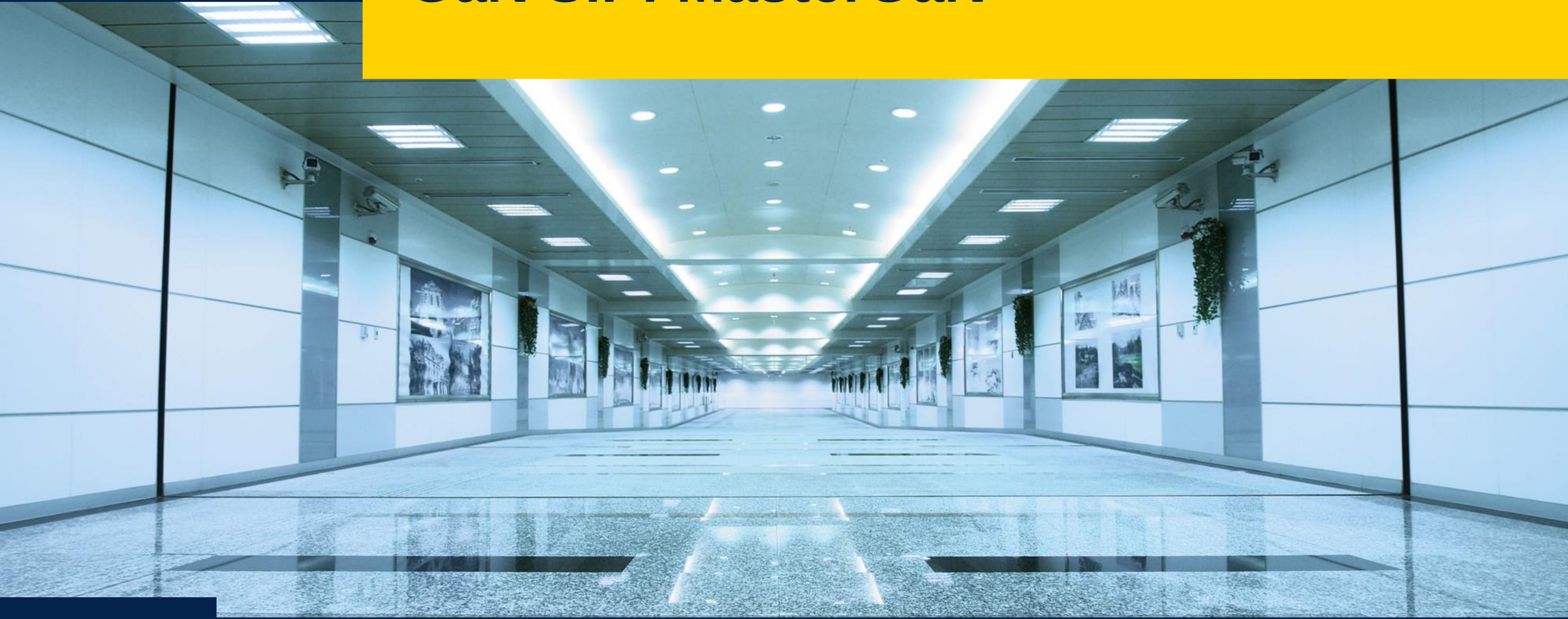
eDesignSuite ready !

Circuit - BOM

Type	Ref	Value	Description
IC	IC	L4985A	L4985A - SO 8 - STMic…
Capacitor	Cin	1.2 µF	Film capacitor
Bridge Rectifier	BR_diode	Rdyn: 25 mΩ - Vth: 0.7 V	Bridge Rectifier
Capacitor	Cout	180 µF	PFC Aluminium elect…
Inductor	Lp	0.66 mH	PFC Inductor
Resistor	Rthd_ccm	56 Ω	56 Ω
Resistor	Rs	68 mΩ	2 W metal film resistor
Qswitch	Qswitch	STF19NM50N	2 in parallel N-chann…
Resistor	Rg_on	15 Ω	One for each Qswitch…
Diode	Dg_off	1N4148	100mA, 100V, one for …
Resistor	Rg_off	3.9 Ω	One for each Qswitch…
Diode	Dout	STTH506DTI	Ultrafast diode
Resistance	Rfb_h	3 x 2.2 MΩ	High voltage standar…
Resistor	Rfb_l	41.2 kΩ	Standard film resistor
Capacitor	Cfp	220 nF	General purpose cera…
Capacitor	Cfs	1.8 µF	General purpose cera…
Resistor	Rfs	39 kΩ	Standard film resistor



GaN SiP: MasterGaN



Why power density matters?

More power in less space

Board area and weight are becoming limiting factors as power demands increase

Reducing size and weight can **cut the total cost of ownership** by making **installation** and **maintenance** both **easier and quicker**

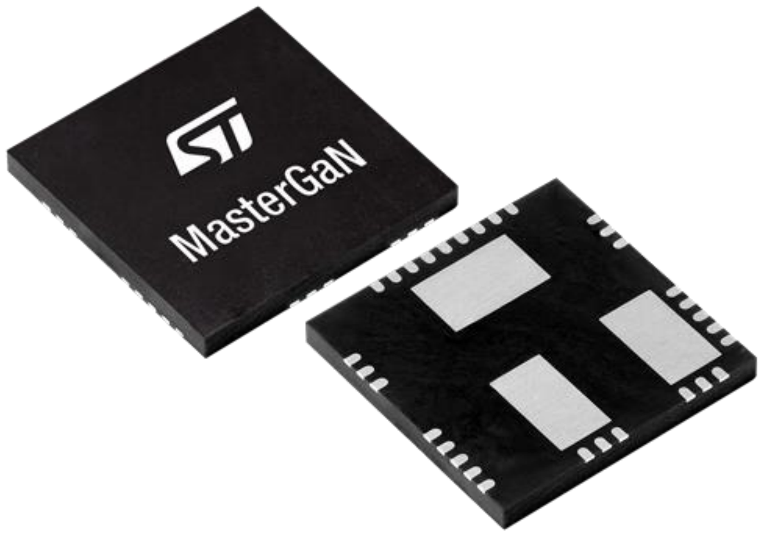
Portability needs high power density

Smart GaN: Integrating GaN with driver

Higher efficiency	Reduced power losses, reduced power consumption, exceeding the most stringent energy requirements
Higher power density	Higher switching speed to reduce systems size and cost
Faster go-to-market	Packaged solution simplifies the design, with a higher level of performance

MasterGaN – Riding the new wave of GaN Power

The world first solution combining 600 V half-bridge driver with GaN HEMT



One driver – Many scalable power size, pin to pin compatible for half bridge configuration

Compact	**High power density** 4x smaller vs Si solution High efficiency
Robust	**Offline driver optimized for GaN HEMT** for fast, effective and safe driving and layout simplification
Easy Design	**Smart solution** in GQFN 9 x 9 mm^2 package Scalable power, pin to pin compatible

Product Portfolio by L3 Sub Class: Integrated smart GaNs

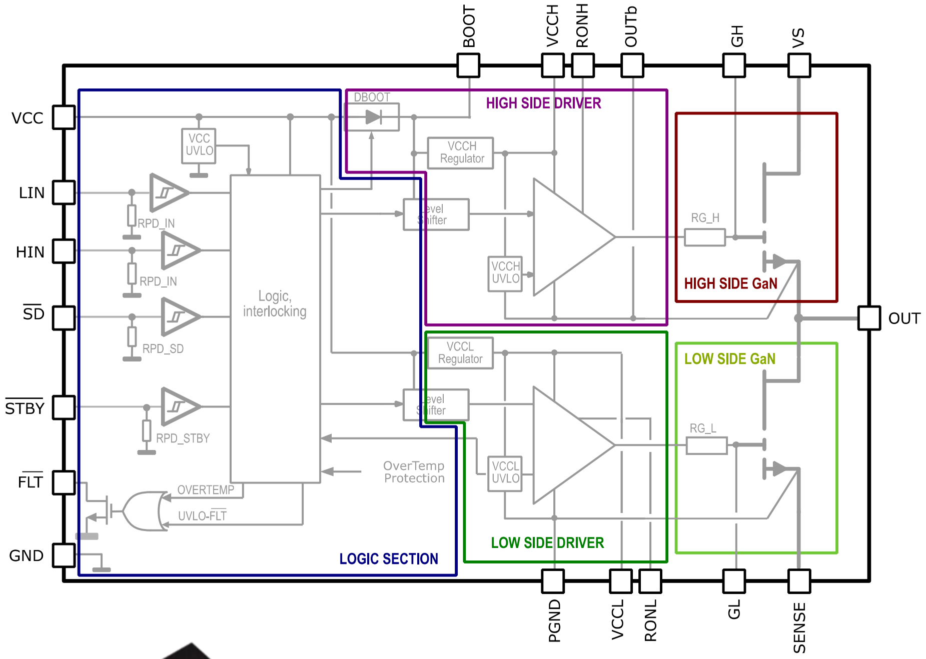
One package
Many Power GaN HEMT for half bridge configuration

MasterGaN3	MasterGaN2	MasterGaN5	MasterGaN4	MasterGaN4L	MasterGaN1	MasterGaN1L
Up to 45 W	Up to 65 W	Up to 100 W	Up to 200 W	Up to 200 W	Up to 500W	Up to 500W
225 + 450 mΩ	150 + 225 mΩ	450 + 450 mΩ	225 + 225 mΩ	225 + 225 mΩ Low consumption	150 + 150 mΩ	150 + 150 mΩ Low consumption
Mass production	Mass production	Mass production	Mass production	Mass production	Mass production	Mass production

MasterGaN6/MasterGaN7 – MasterGaN evolution

Advanced power solution integrating a gate driver and two enhancement mode GaN transistors in half-bridge configuration

ES available



	MastergaN6	MasterGaN7
VDS	600V	
RDS_{ON}	150 mΩ	270 mΩ
IDS_{MAX} (@25C)	10 A	6 A

Compact

- Integrated power GaN
- **Integrated Linear regulators** to supply low side and high side output stages

Robust

- **Support to Hard Switching Topology**
- UVLO protection on both the lower and upper driving sections, preventing the power switches from operating in low efficiency or dangerous conditions, and the interlocking function avoids cross-conduction conditions
- Over temperature protection

Easy Design

- Smart solution in GQFN 9x9 mm^2 package
- Input pins extended range 3.3 to 15 V with hysteresis and pull-down- allows easy interfacing with microcontrollers, DSP units or Hall effect sensors
- Dedicated pin for shutdown functionality
- Accurate internal timing match

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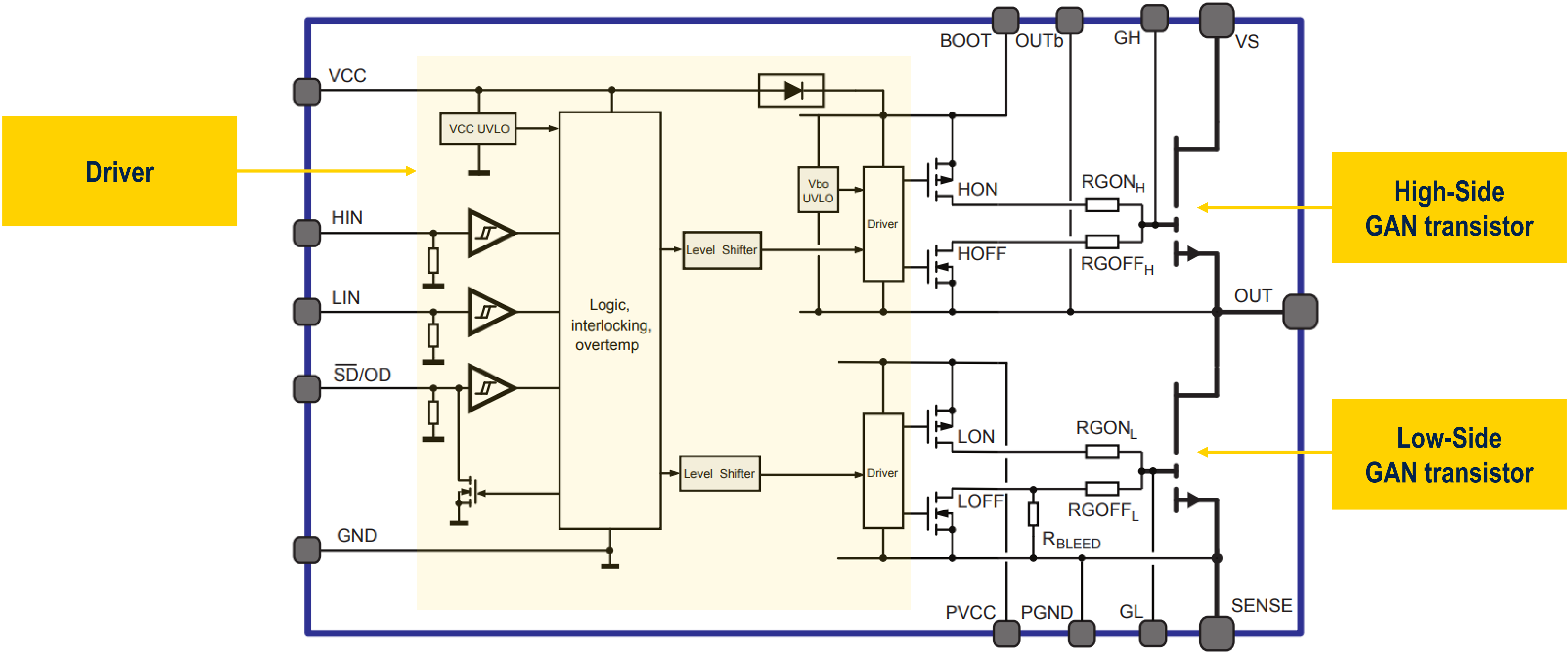
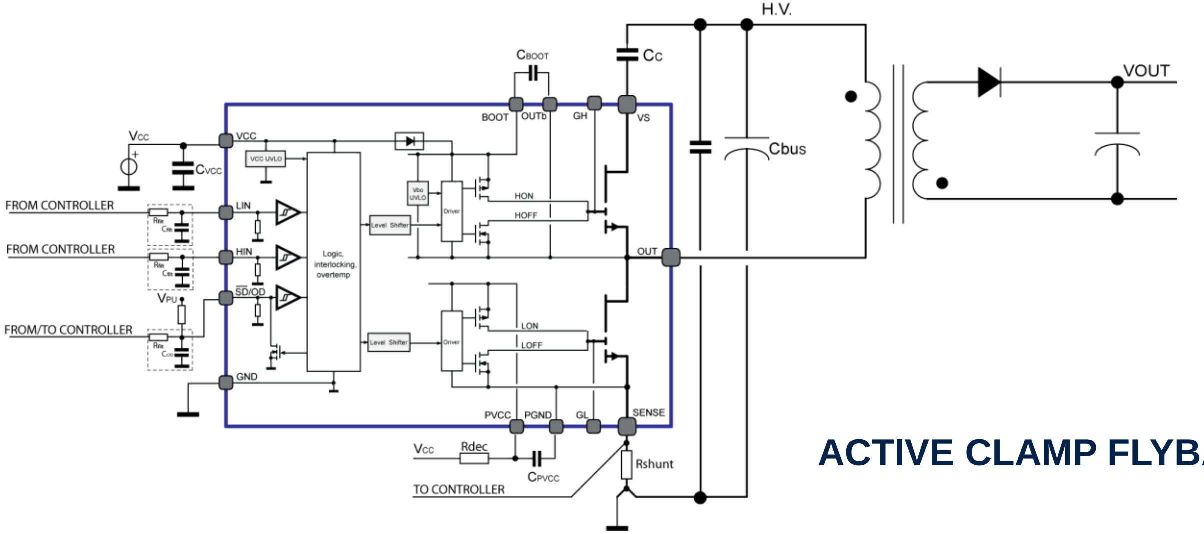
MasterGaN block diagram



MasterGaN main topologies

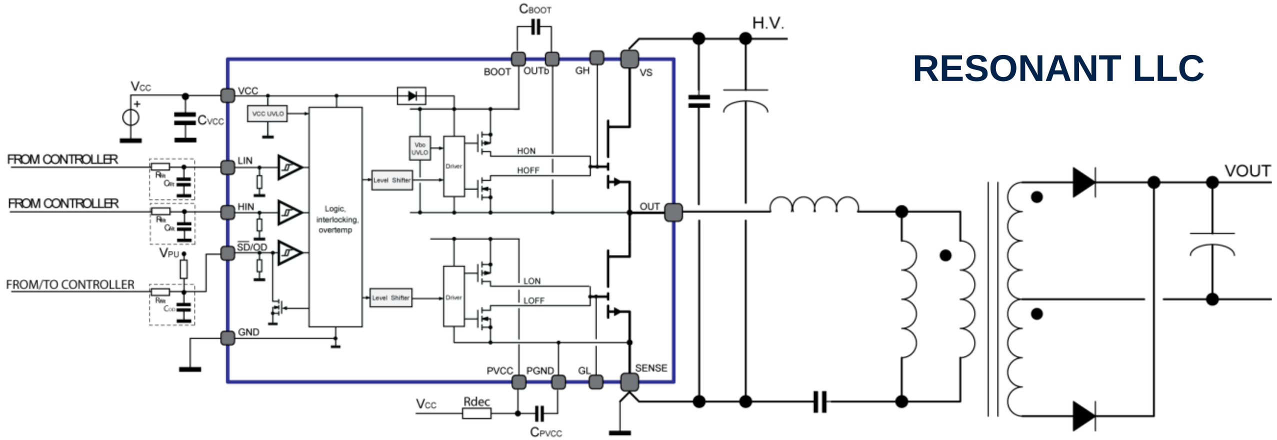


ACTIVE CLAMP FLYBACK

Key applications

- Chargers and adapters
- Industrial SMPS

RESONANT LLC



Key applications

- Industrial SMPS
- UPS
- Solar systems
- Servers

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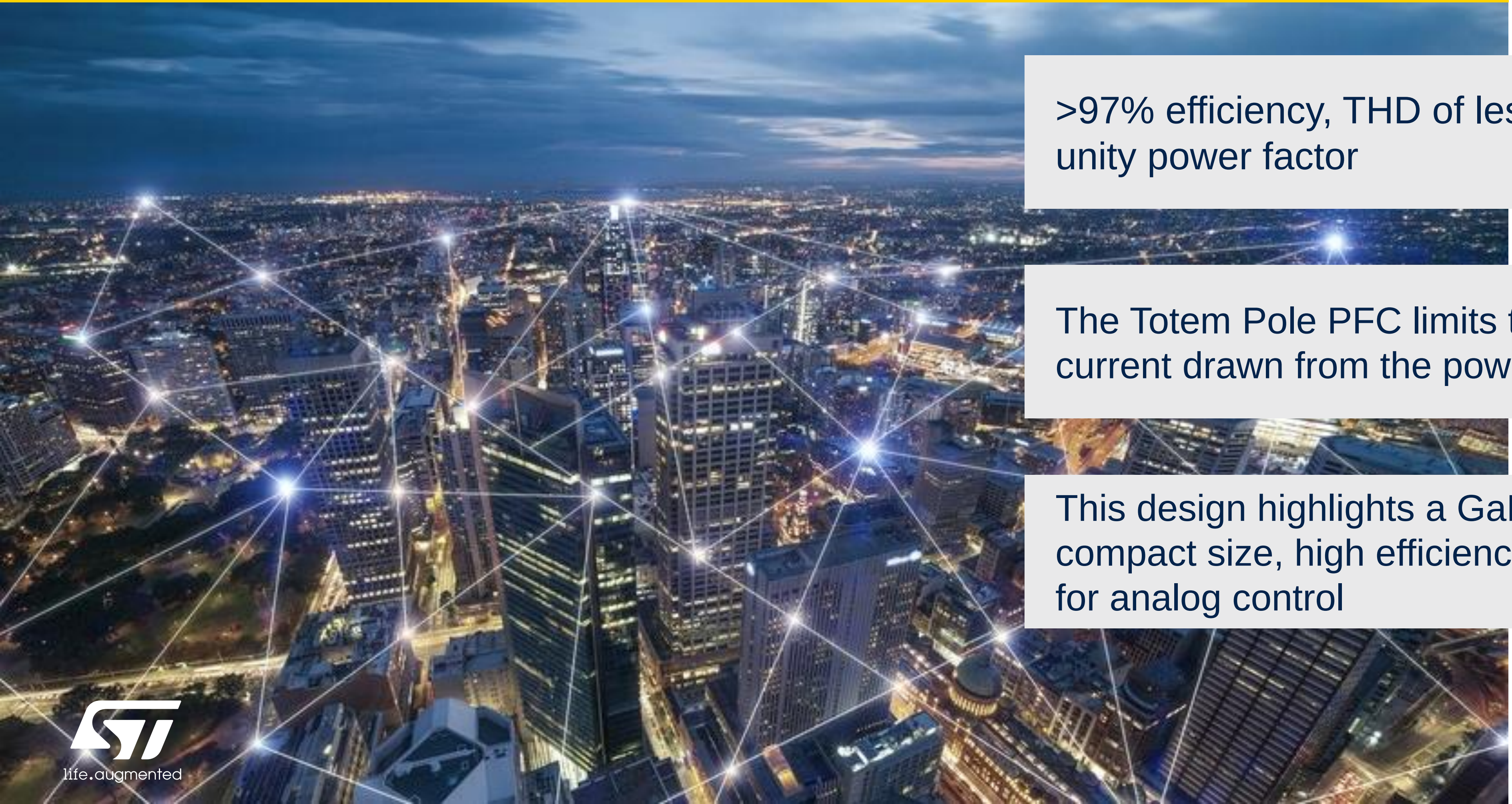
Results and Conclusions

The Gan based Totem Pole PFC design showed strong system efficiency and favorable THD

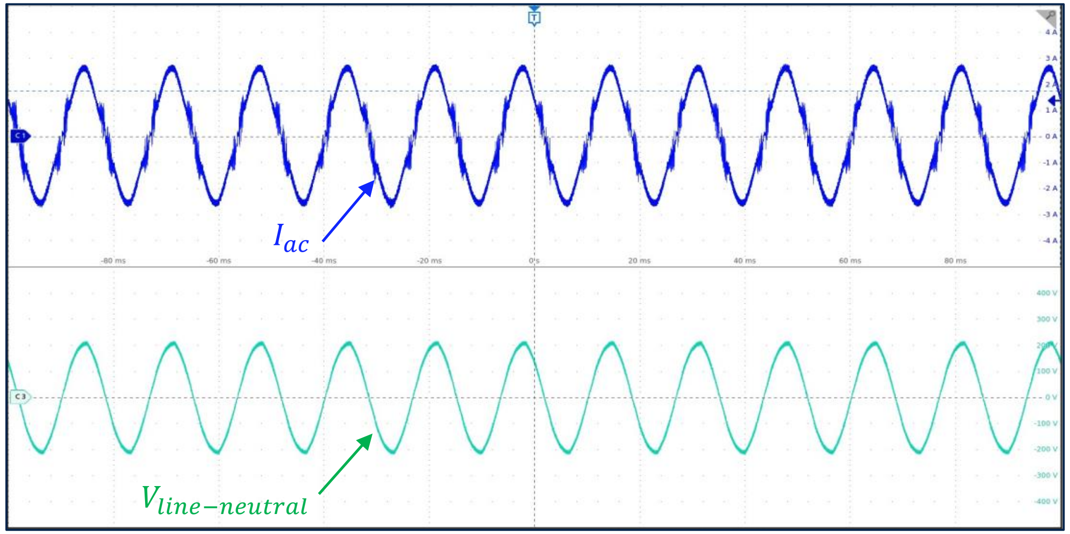


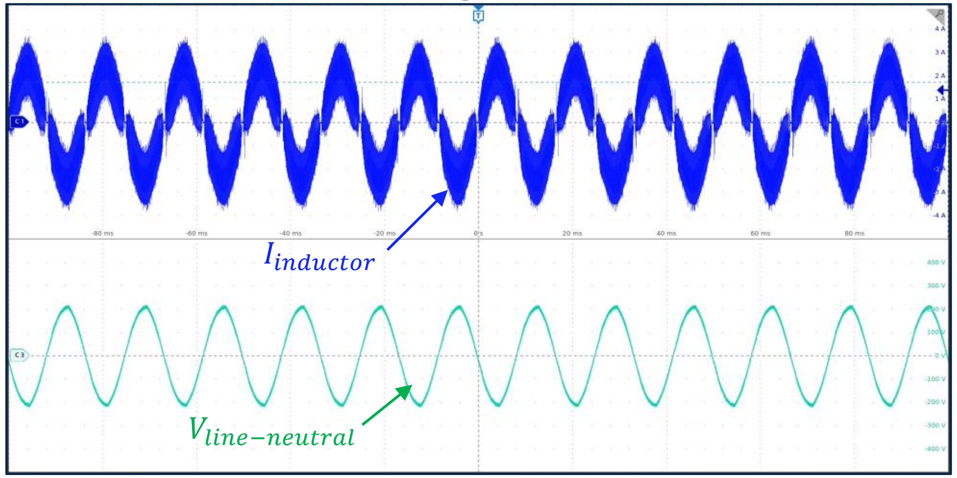
>97% efficiency, THD of less than 15% and close to unity power factor

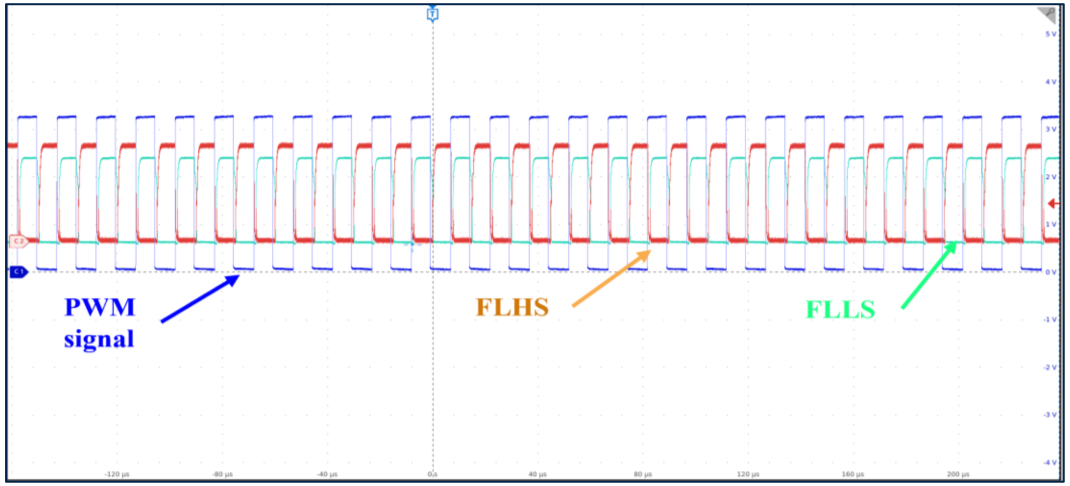
The Totem Pole PFC limits the harmonic content of the current drawn from the power grid

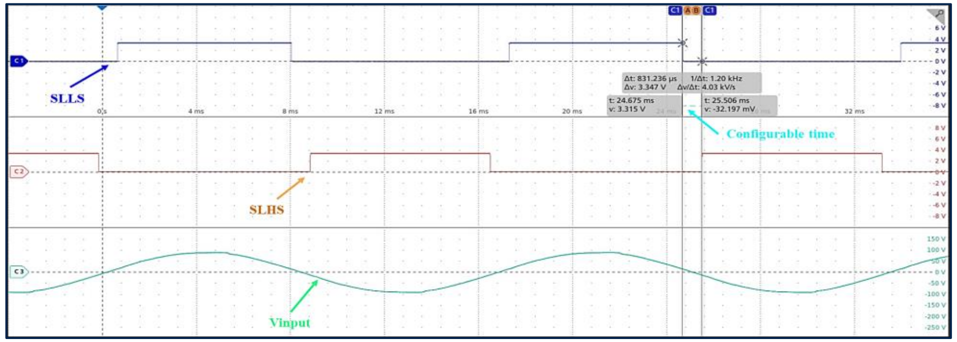
This design highlights a GaN-based converter with compact size, high efficiency and optimal performance for analog control

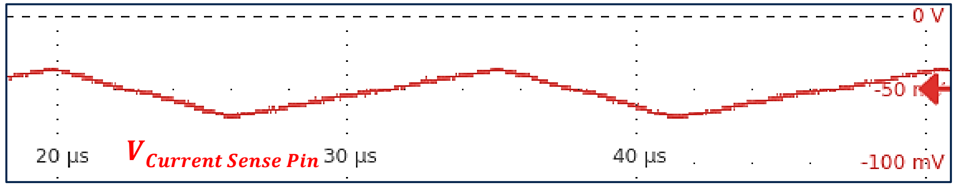
System Waveforms







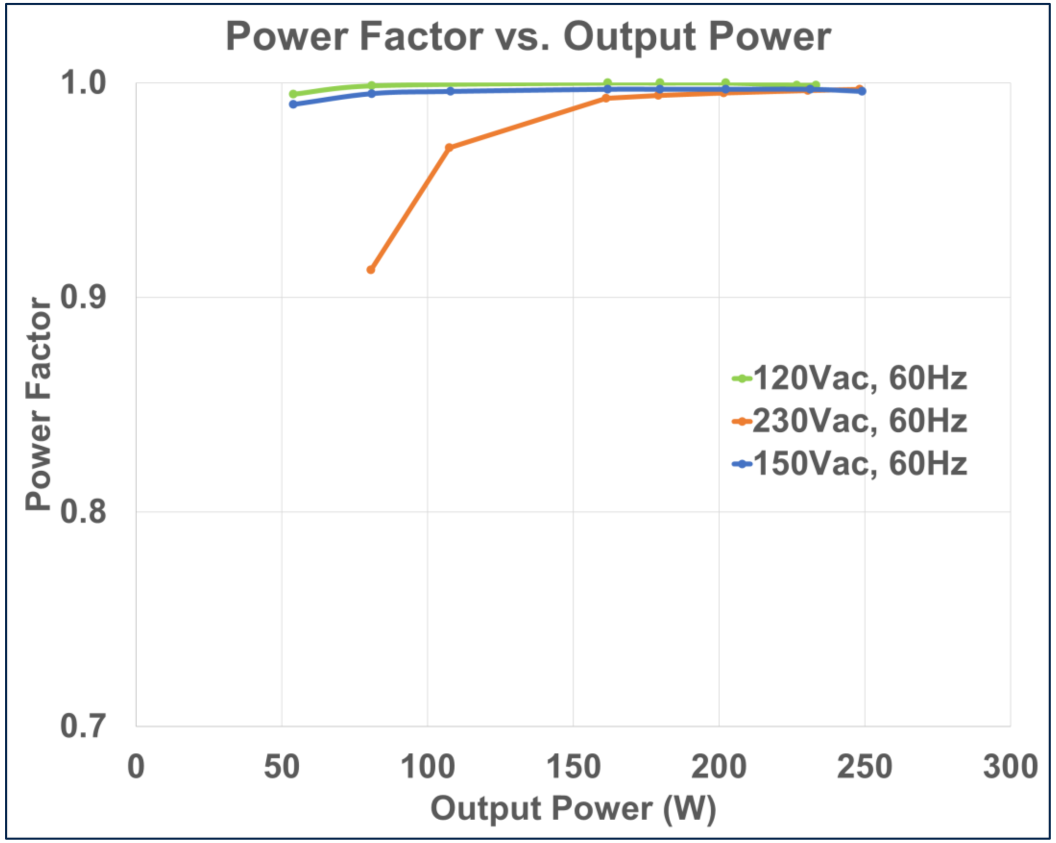


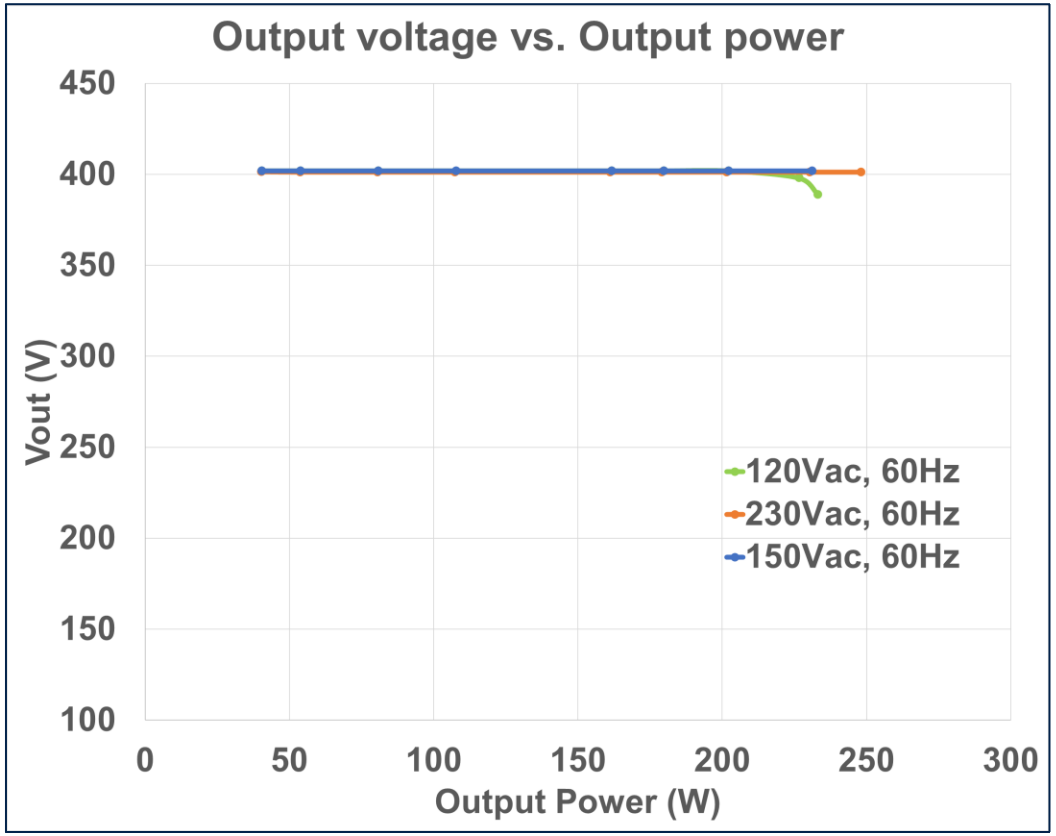


PWM signal generated by the analog controller is split into **Fast Leg High Side** and **Fast Leg Low Side** driving signals

Current was sensed using a shunt-resistor followed by a precision, isolated amplifier which was then rectified.

Power Factor and Output Voltage vs. Output Power





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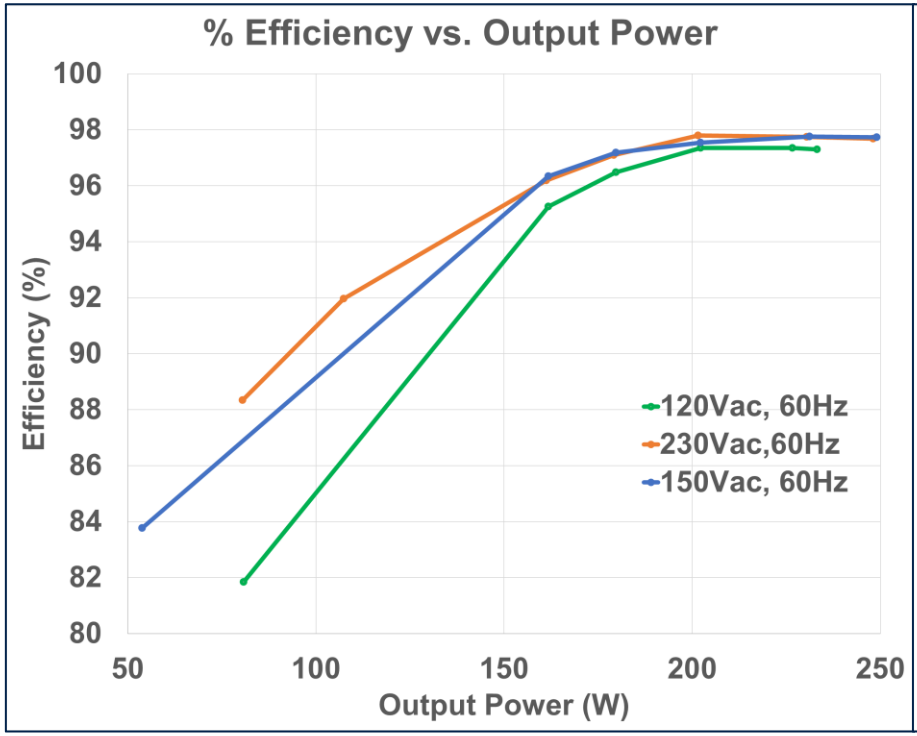
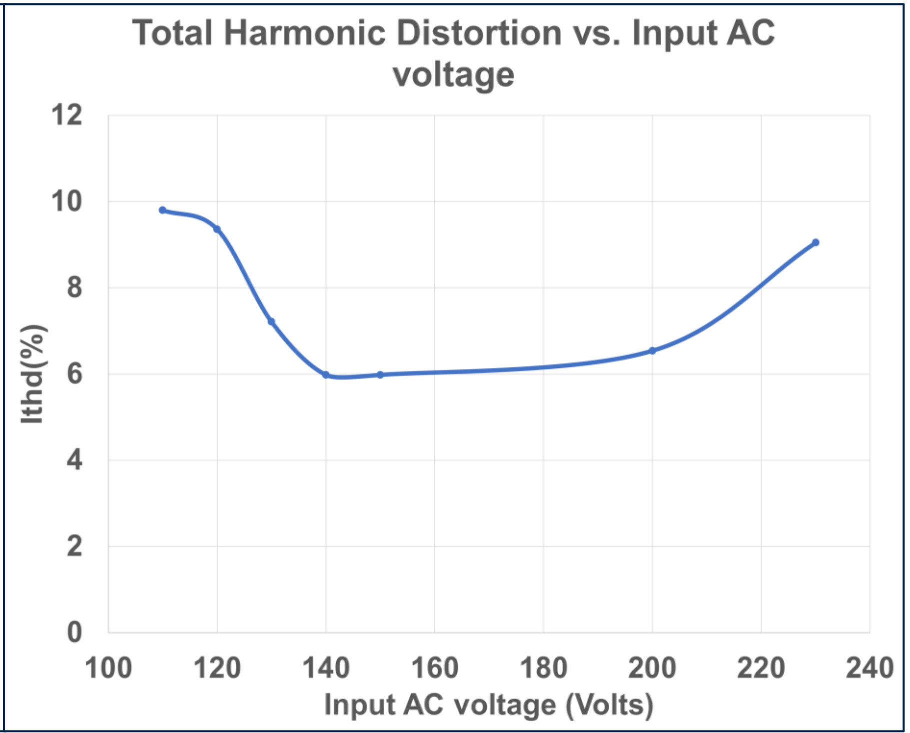
System Efficiency and Total Harmonic Distortion (THD)

- The converter showed efficiency >97%
- THD of less than 15% and close to unity power factor





Additional GaN SiP Power Supply Solutions

Versatile and Efficient Designs to fit your power supply needs

250W Resonant Power Supply with GaN for Industrial Power supply applications

350W Inverse Buck for offline LED lighting applications

Simplified boards to evaluate driving GaN SiPs

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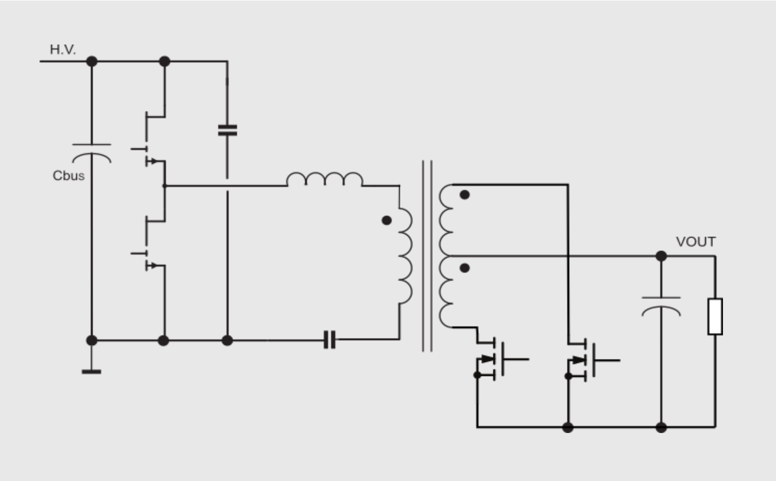
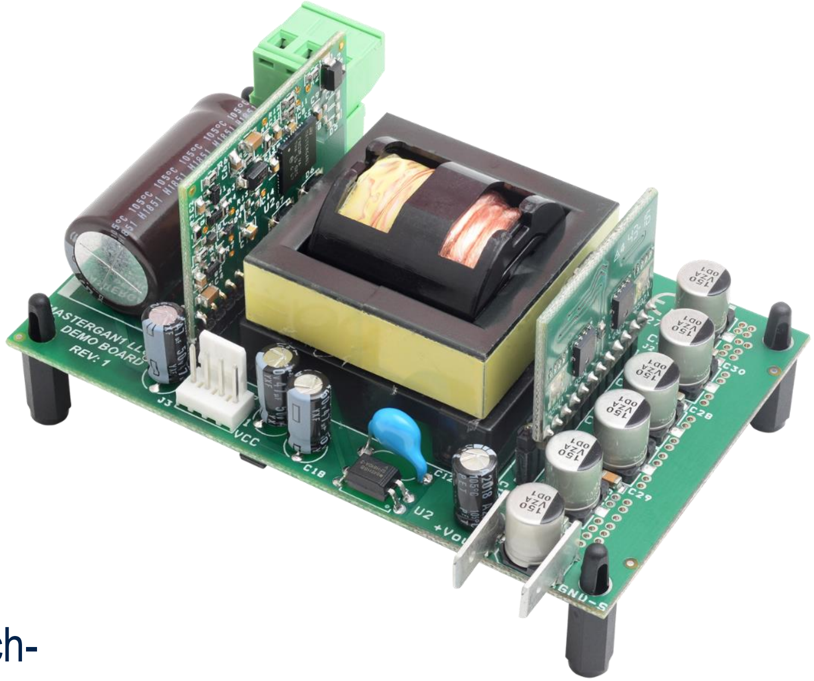
250 W Resonant demo board

EVLMG1-250WLLC
250 W resonant demo board based on MasterGAN1





Databrief available on the web

KEY APPLICATIONS
Ultra-fast and ultra-compact switch-mode power for applications such as:
- Industrial DC-DC applications
- Adapters
- Consumer SMPS

250W Resonant Demo Board
- L6599A + **MasterGaN1** + SRK2001
- Vout=24V **Iout=10A**
- Freq switching **~250 kHz**
- Dimension: 105 x 65 x 35 (H) mm

Benefits:
- **Higher switching frequency** compared to Si MOSFETs => **smaller transformer**
- Higher efficiency (~95%)
- **No heatsink required** for MasterGaN1 heat dissipation

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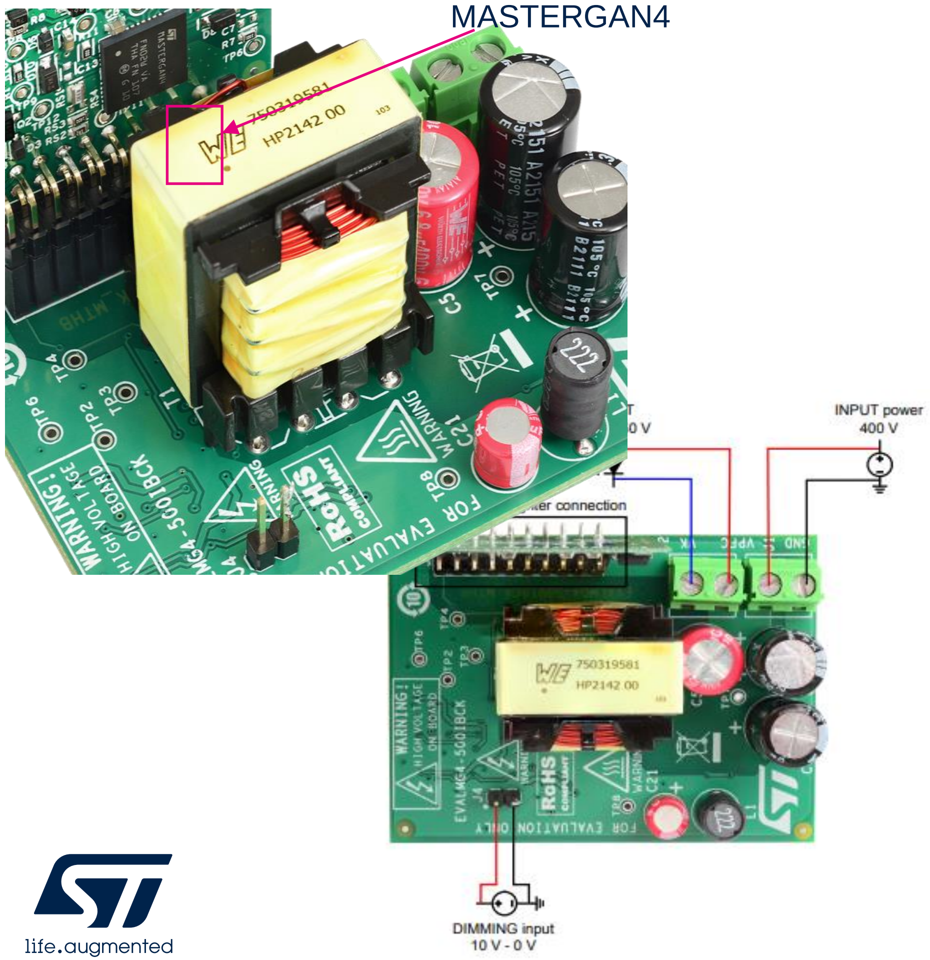
High efficiency and small size for HV lighting

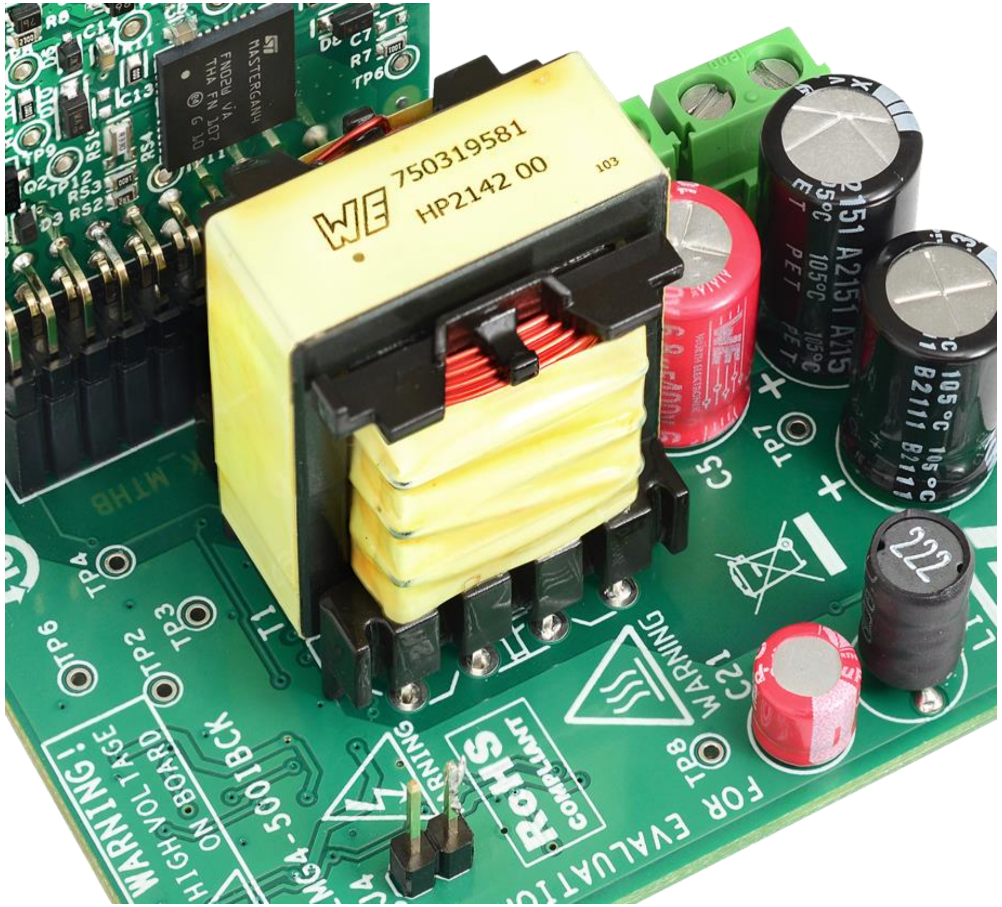
EVLMG4-500WIBCK: MASTERGAN4 350 W Inverse Buck demo board



Benefits	• Higher switching frequency compared to Si MOSFETs => **smaller inductor** • **Higher efficiency** • **No heatsink** required for MASTERGAN4 heat dissipation => **lighter and more compact solution**

Features	• HVLED002 + **MASTERGAN4 +** VIPER06
	• Input Voltage = 400V to 420V
	• Output Voltage = 150V to 350V
	• Output Current = 700mA, 1Amp or 1.2Amp
	    • HW selectable by shunt resistor
	• Operating frequency < 150kHz to facilitate EMI compliancy
	    • Heatsink free solution to have small volume occupation
	• Multiple mode dimming using 0-10V: PWM and analog dimming

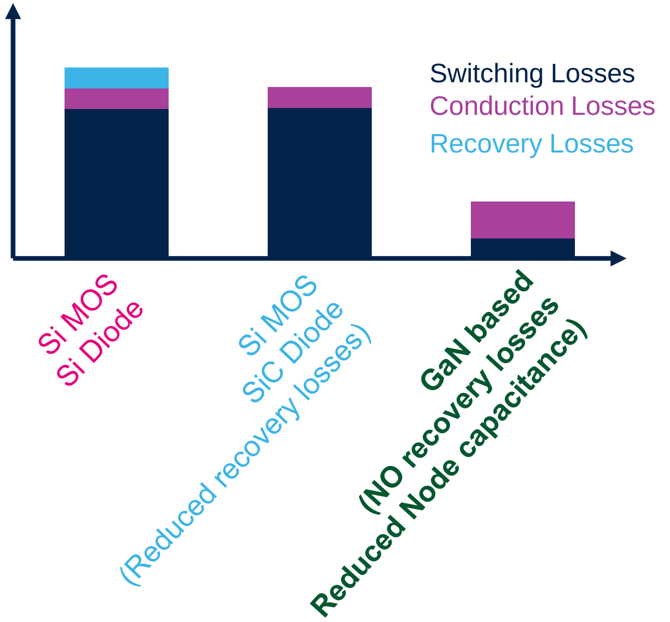
Lower power losses eliminates need for heatsink



EVLMG4-500WIBCK

Three configuration has been considered and compared on 350W demo board connected to its lamp (high bay lamp):

- Silicon switch and Si Diode as rectifier
- Silicon switch and SiC diode as rectifier
- MASTERGAN4 synchronous rectified

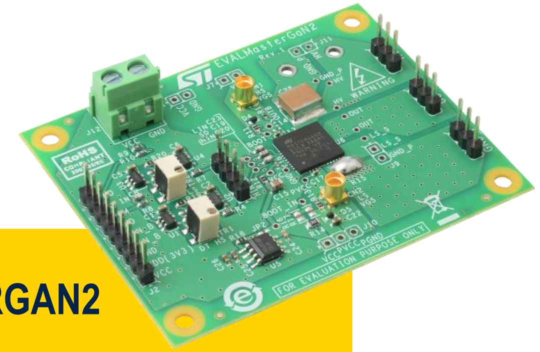


MasterGaN - Ecosystem

Evaluation board & ecosystem available at

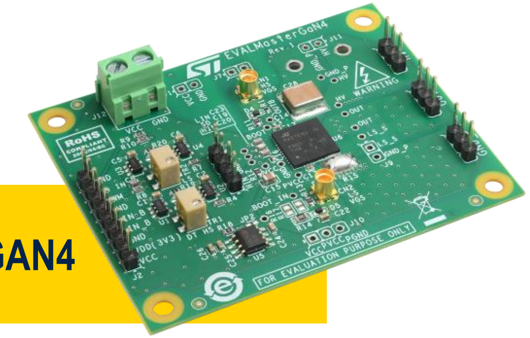
EVALMASTERGAN1

- Switch-mode power supplies
- Chargers and adapters
- High-voltage PFC
- DC-DC & DC-AC converters
- UPS systems
- Solar power



EVALMASTERGAN2

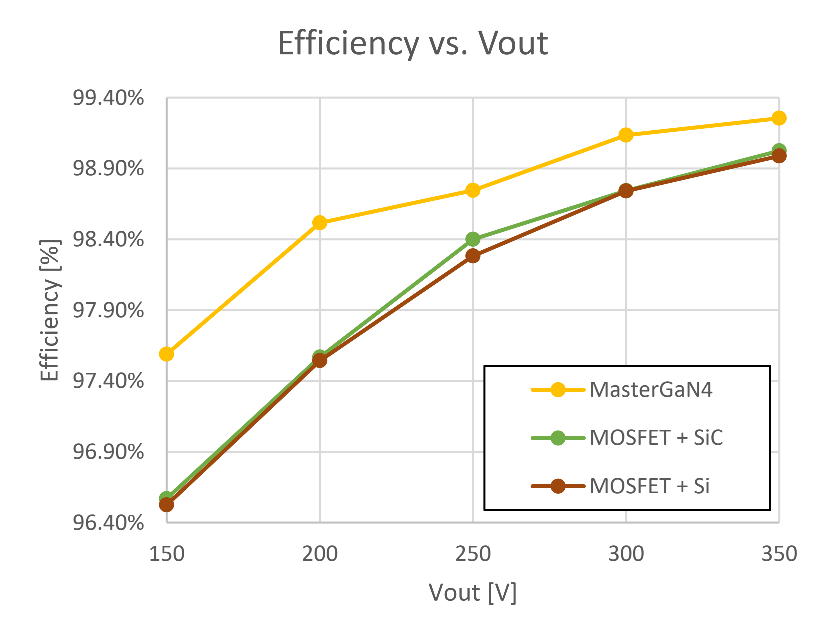
- Switch-mode power supplies
- Chargers and adapters
- High-voltage PFC
- DC-DC converters

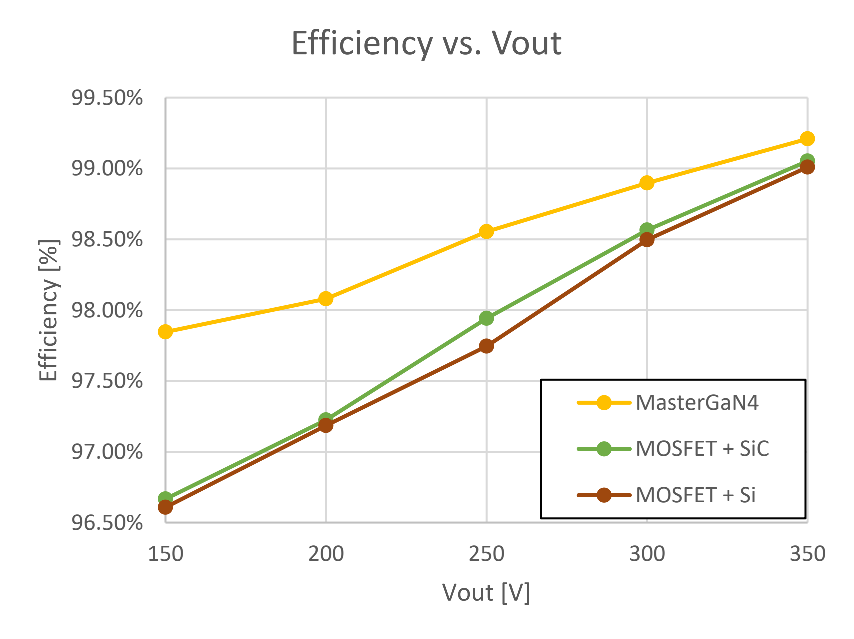


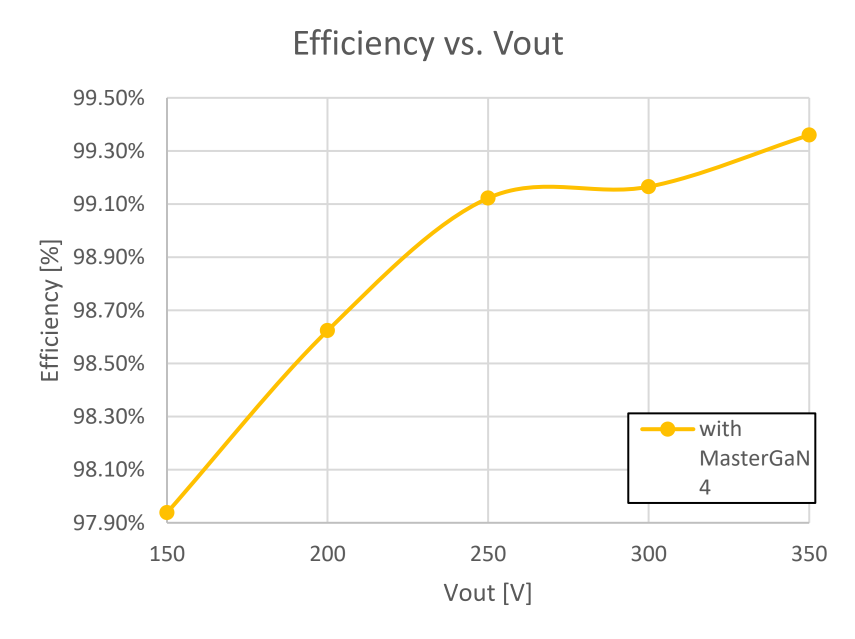
EVALMASTERGAN4

- Switch-mode power supplies
- Chargers and adapters
- High-voltage PFC
- DC-DC & DC-AC converters

MASTERGAN vs Si solutions: efficiency comparison







Iout = 0.7 A

- MASTERGAN4: ΔI = 3.10 %
- MOSFET + SiC: ΔI = 5.8 %
- MOSFET + Si: ΔI = 5.8 %

Iout = 1.0 A

- MASTERGAN4: ΔI = 3.10 %
- MOSFET + SiC: ΔI = 4.56 %
- MOSFET + Si: ΔI = 4,89%

Iout = 1.2 A

- MASTERGAN4: ΔI = 4%

No comparison with MOSFET, Because MOS temp. becomes too high without heatsink

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Additional GaN SiP Power Design

Versatile and Efficient Designs to fit your power conversion needs

250W Resonant Power Supply with GaN for Industrial Power Supply Applications

350W Inverse Buck for LED Lighting Applications, 170W LCC Converter for Li-Ion battery chargers

Simplified evaluation boards to test GaN SiP half-bridge performance

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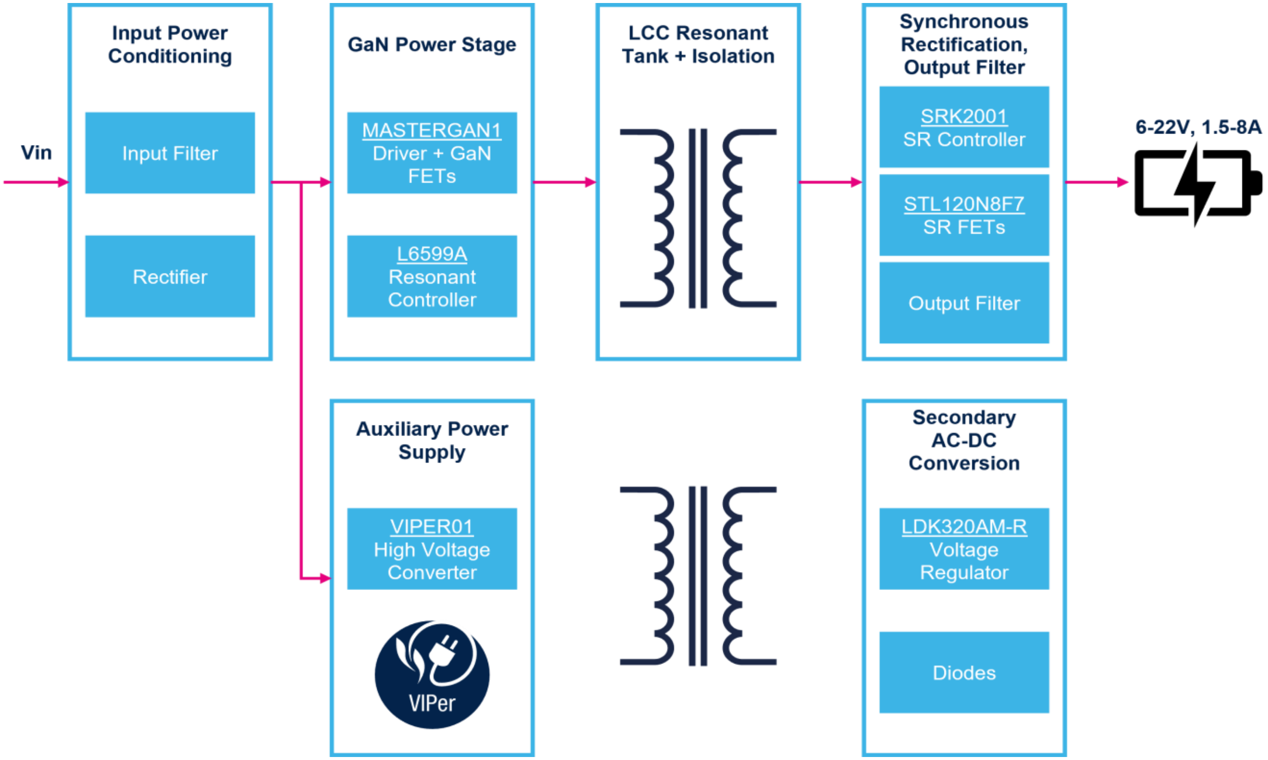
170W LCC Converter Ideal for Li-Ion Battery Chargers

Introduction of GaN FETs Improves Reliability and System Efficiency



LCC Converter is designed properly to shape the gain curve appropriately to maintain highest possible efficiency

The design does not need the use of heatsinks and fans, allowing for a fully sealed charger and increased system reliability

GaN based solution shows significant efficiency and overall performance increases vs. Silicon solution

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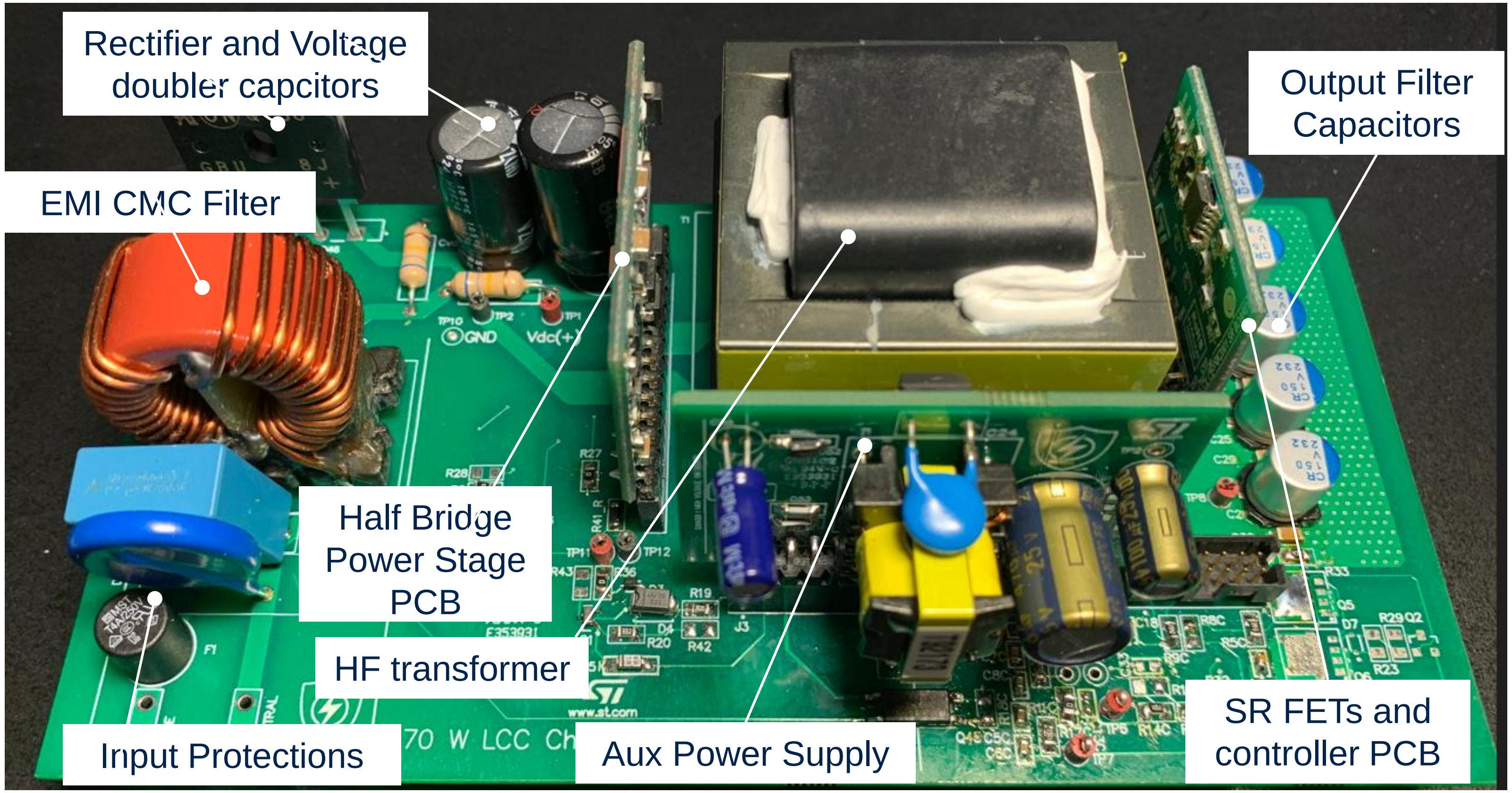
Prototype Design

The 170 W Prototype Design is very compact and does not require heatsinks when using GaN Power Stage

- The resonant controller is placed on the bottom of the PCB and is used to perform CC/CV control, can operate up to 700 kHz
- The two HB power stages (Si and GaN) are interchangeable on the board, allowing easy and reliable testing of both technologies



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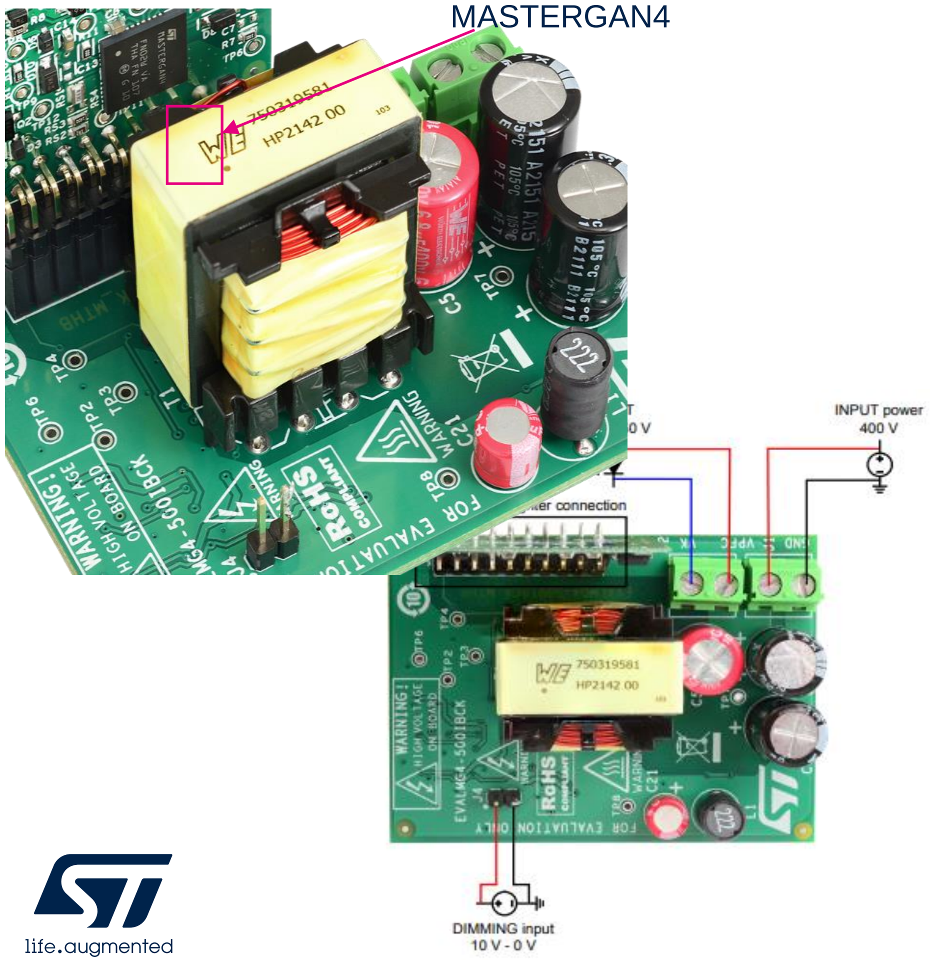
High efficiency and small size for HV lighting

EVLMG4-500WIBCK: MASTERGAN4 350 W Inverse Buck demo board



Benefits

- Higher switching frequency compared to Si MOSFETs => **smaller inductor**
- **Higher efficiency**
- **No heatsink** required for MASTERGAN4 heat dissipation => **lighter and more compact solution**

Features

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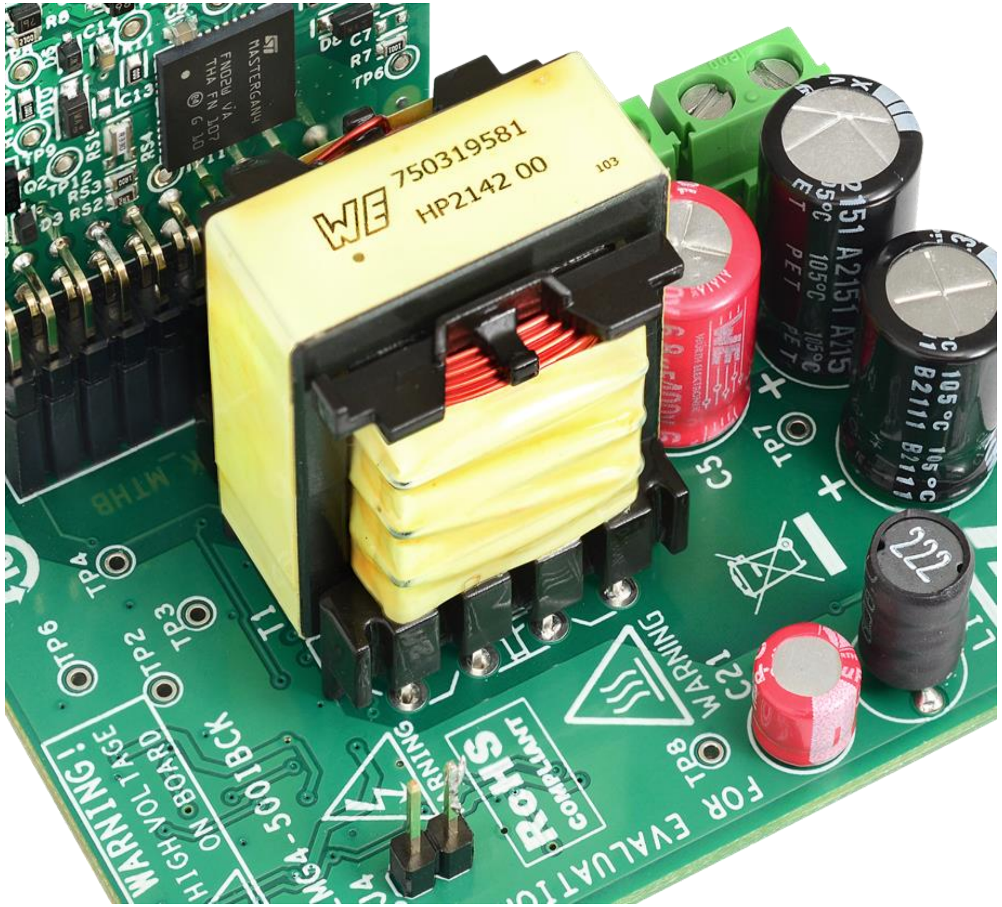
- Input Voltage = 400 V to 420 V
- Output Voltage = 150 V to 350 V
- Output Current = 700 mA, 1 Amp or 1.2 Amp
  - HW selectable by shunt resistor
- Operating frequency < 150 kHz to facilitate EMI compliancy
  - Heatsink free solution to have small volume occupation
- Multiple mode dimming using 0-10 V: PWM and analog dimming

Lower power losses eliminates need for heatsink



EVLMG4-500WIBCK

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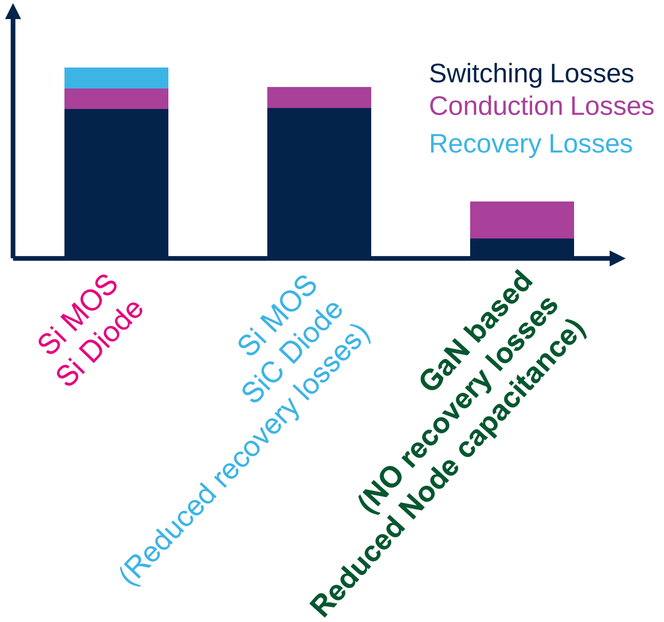
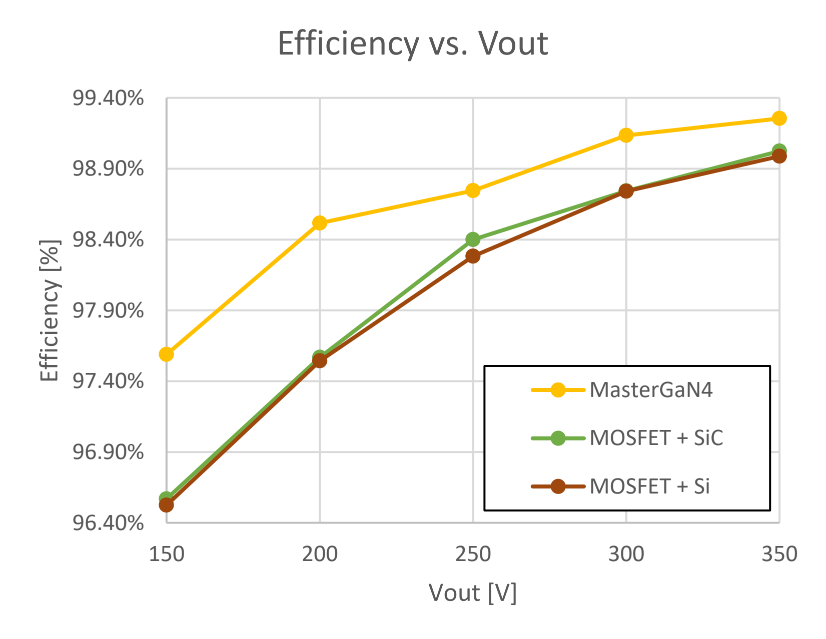
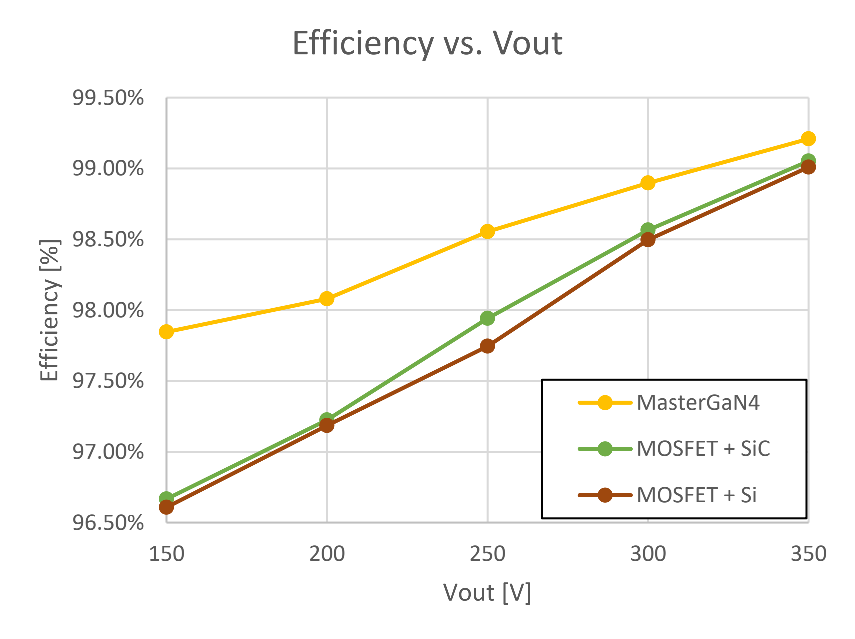
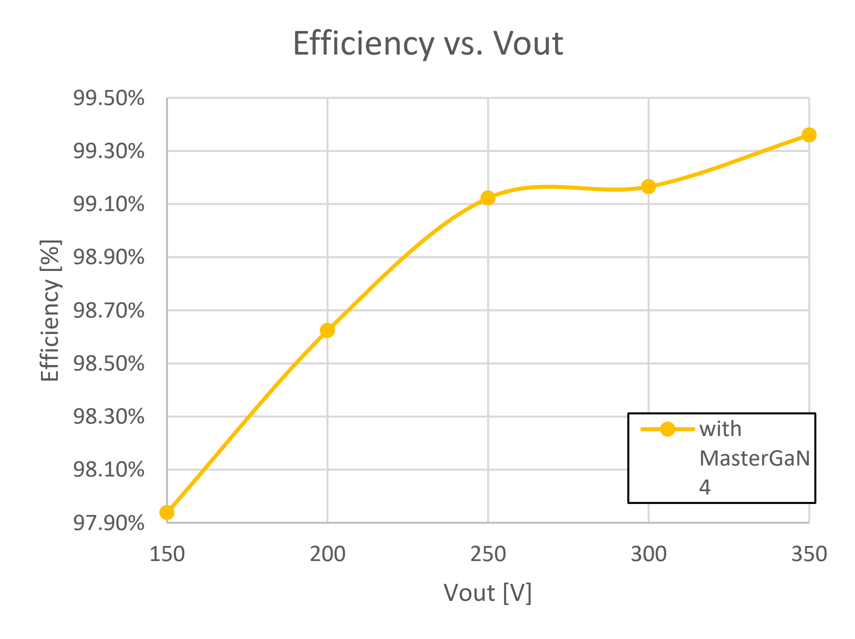
- MASTERGAN4 synchronous rectified



MASTERGAN vs Si solutions: efficiency comparison







Iout = 0.7 A

- MASTERGAN4: ΔI = 3.10 %
- MOSFET + SiC: ΔI = 5.8 %
- MOSFET + Si: ΔI = 5.8 %

Iout = 1.0 A

- MASTERGAN4: ΔI = 3.10 %
- MOSFET + SiC: ΔI = 4.56 %
- MOSFET + Si: ΔI = 4,89%

Iout = 1.2 A

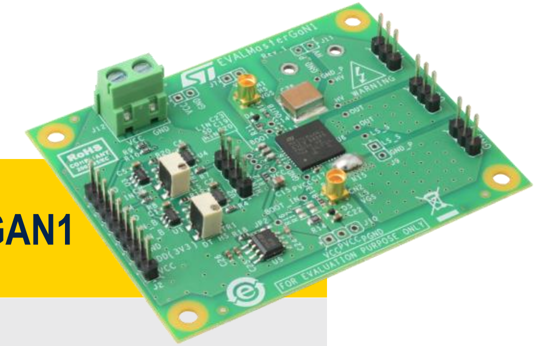
- MASTERGAN4: ΔI = 4%

No comparison with MOSFET, Because MOS temp. becomes too high without heatsink

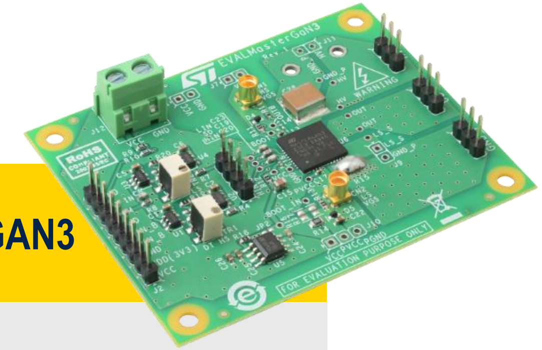
MasterGaN – ecosystem

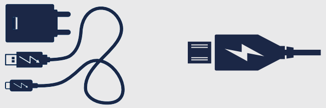
Evaluation board & ecosystem available at www.st.com/mastergan

EVALMASTERGAN1

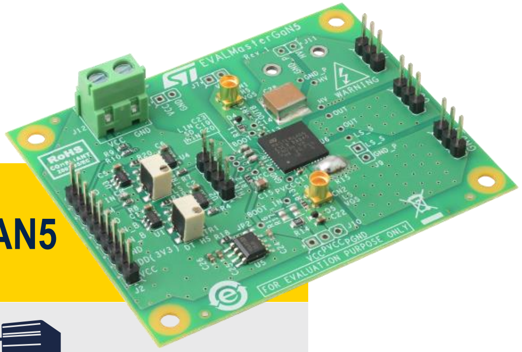


EVALMASTERGAN3

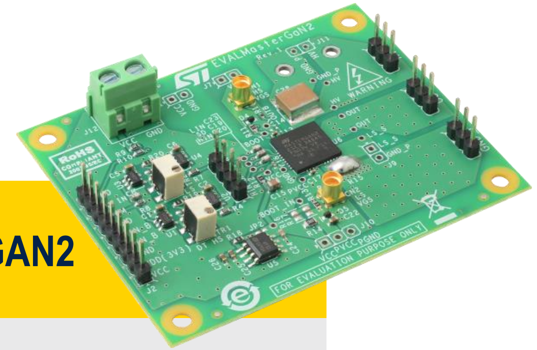




EVALMASTERGAN5



EVALMASTERGAN2



EVALMASTERGAN4