Nordic Power Converters

Powering a brighter future™

Towards Integration of Offline Multi-MHz Power Supplies

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10TH INTERNATIONAL WORKSHOP ON POWER SUPPLY ON CHIP (PWRSOC)

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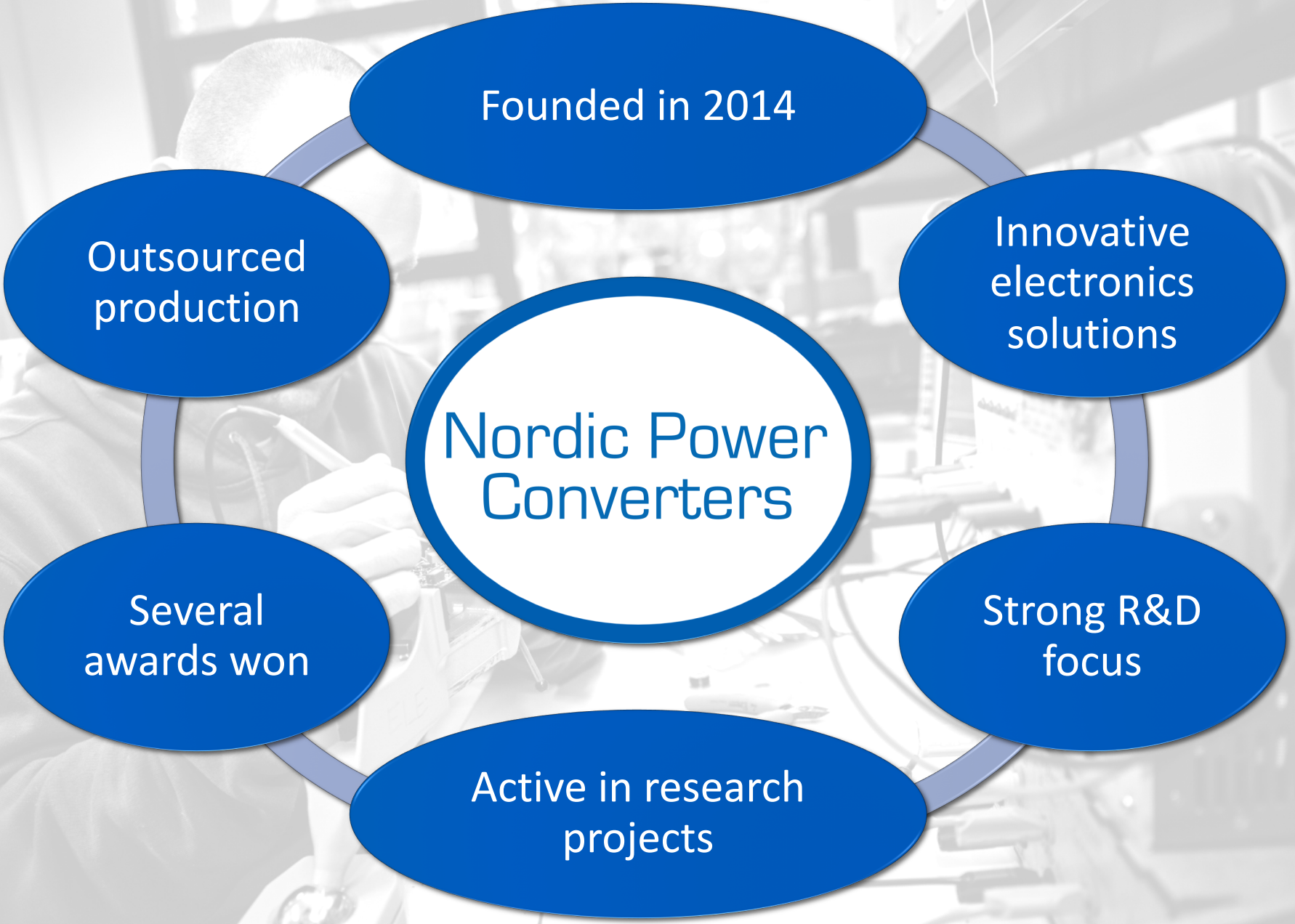
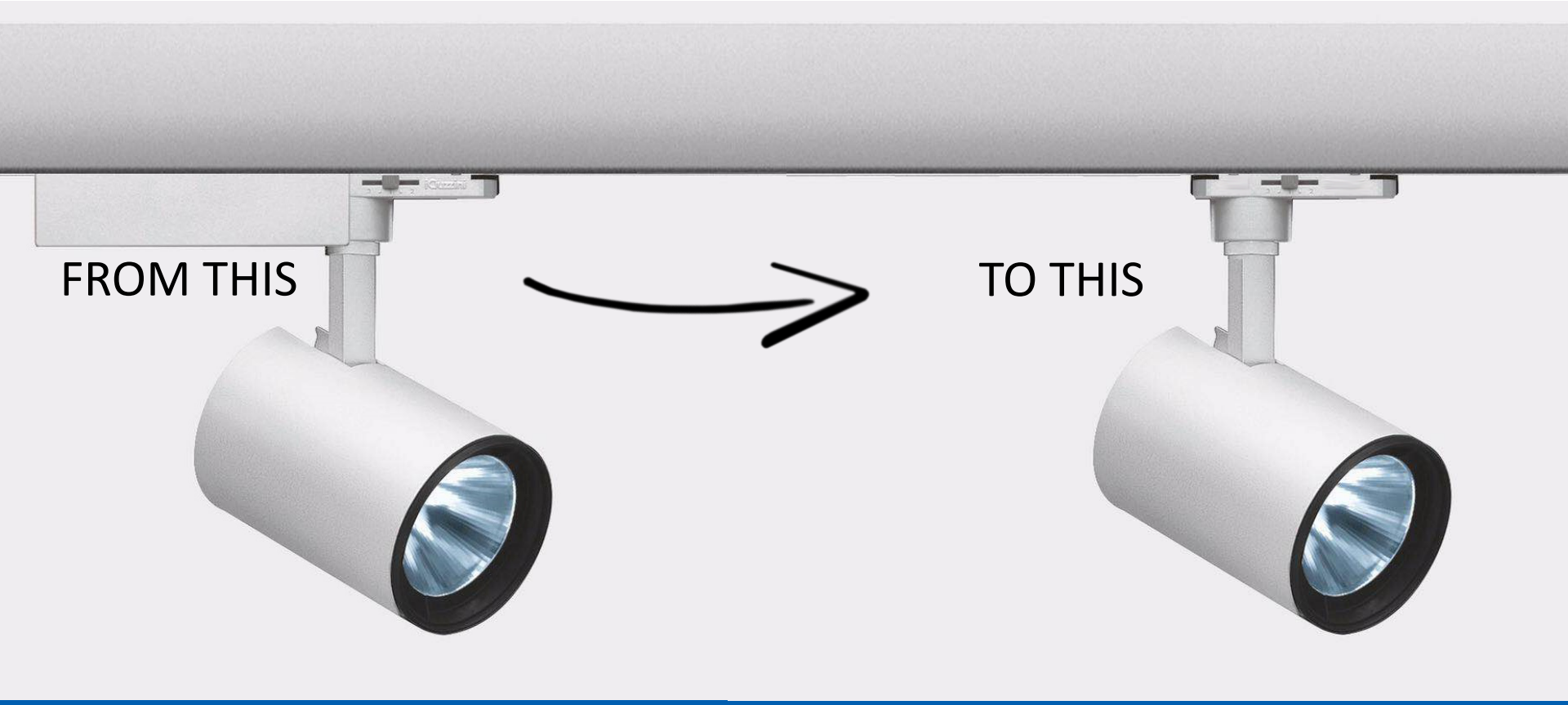
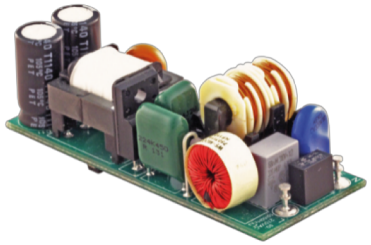

Nordic Power Converters
Founded in 2014
Innovative electronics solutions
Strong R&D focus
Active in research projects
Several awards won
Outsourced production

Our vision

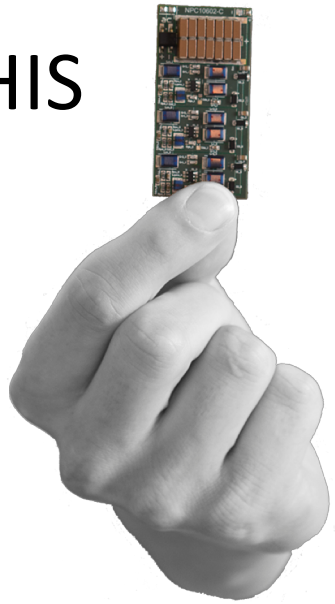


In other words…



FROM THIS…TO THIS

Utilizing patented breakthrough technology for power supplies



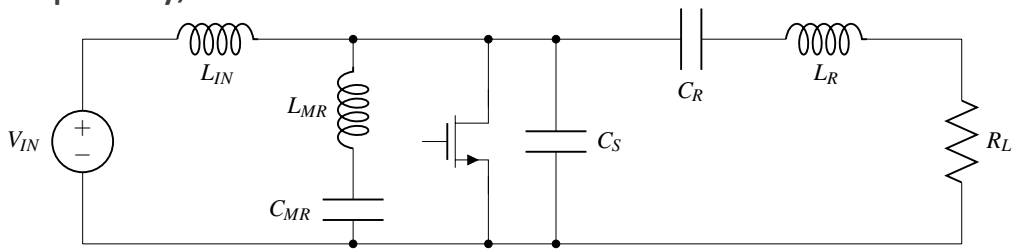
- Operating at much higher switching frequencies
- Resonant converter topologies with ZVS

Outline

- Converter topologies
- Resonant gate drive
- LED driver examples
- Towards integration

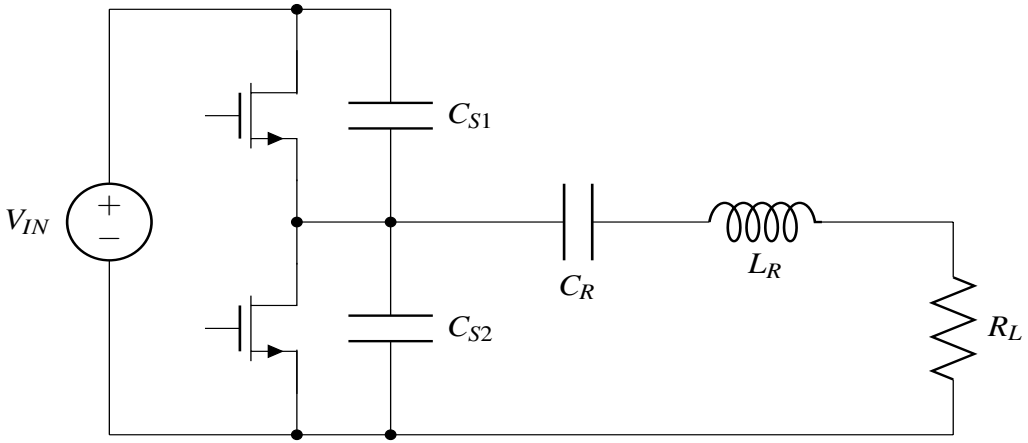
Single switch topologies

- Class E
  - Utilizes MOSFET parasitic output capacitor as part of circuit topology
  - Single low side switch
  - Huge MOSFET voltage stress (>3.6 times VIN)
  - Large input choke (large volume, slowing down response)
- Class EF2/φ2
  - Additional LC branch (LMR, CMR) tuned to 3rd harmonic
  - Reduced MOSFET voltage stress (≈ 2.5 times VIN)
  - Introduces another resonant current branch, which is lossy
  - Increased complexity, size and cost



Half bridge topology

- Class DE (half bridge)
  - Utilizes MOSFET parasitic output capacitor as part of circuit topology
  - Low MOSFET voltage stress (= 1 times V_{IN})
  - Also suitable for higher input voltage levels (>50 V)
  - Lower peak voltage results in lower resonant currents for higher efficiency
  - Reduced number of inductors for high power density and low cost
  - High side gate driver is required



Class φ_2 vs Class DE

Class φ_2	Component count	Class DE (half bridge)
1	MOSFETs	2
3	Inductors	1
2	Capacitors (excl. parasitics)	1
	MOSFET stress	
≈ 2.5 x V_{IN}	Voltage stress	V_{IN}
½ C_{OSS} $(2.5 \times V_{IN})^2$	Peak C_{OSS} energy	½ C_{OSS} V_{IN}^2

Fundamental drawbacks

- 6.25 times more energy in C_{OSS}
- More resonant currents due to 3rd harmonic branch
- >V_{IN} voltage stress
- 3 times as many inductors

- Requires high side gate driver
- Two MOSFETs (lower voltage rating)

Outline

- Converter topologies
- Resonant gate drive
- LED driver examples
- Towards integration

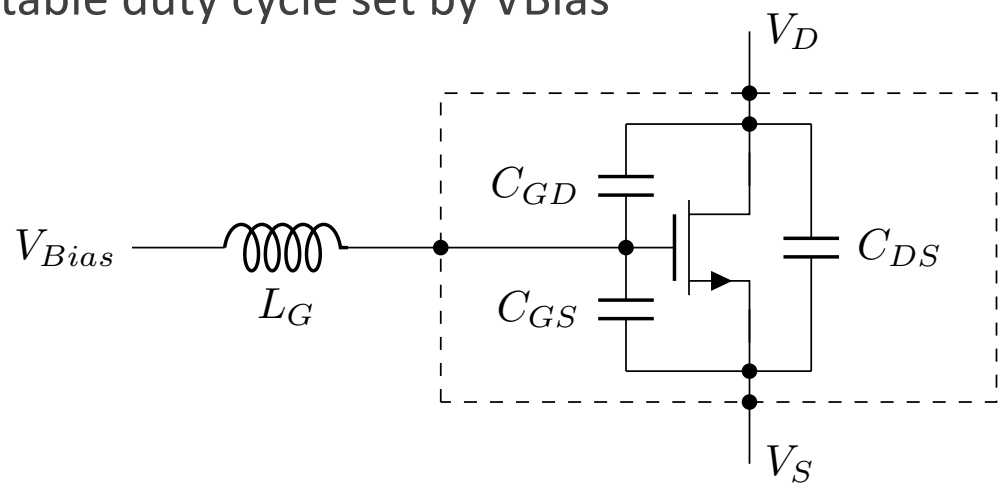
Gate drivers

- Conventional approach:
  - Gate driver IC
  - Hard-switched gating losses increase significantly with frequency
- Our approach:
  - Innovative resonant gate drive enables high-frequency operation
  - Resonant gating recycles turn on/off energy
  - Self-oscillating gate drive for low losses and low complexity
- Further potential of resonant gate drive
  - Can be used to drive silicon devices at MHz frequencies
  - Can be used for high side switches
  - Can be used for synchronous rectification

Self-oscillating gate driver

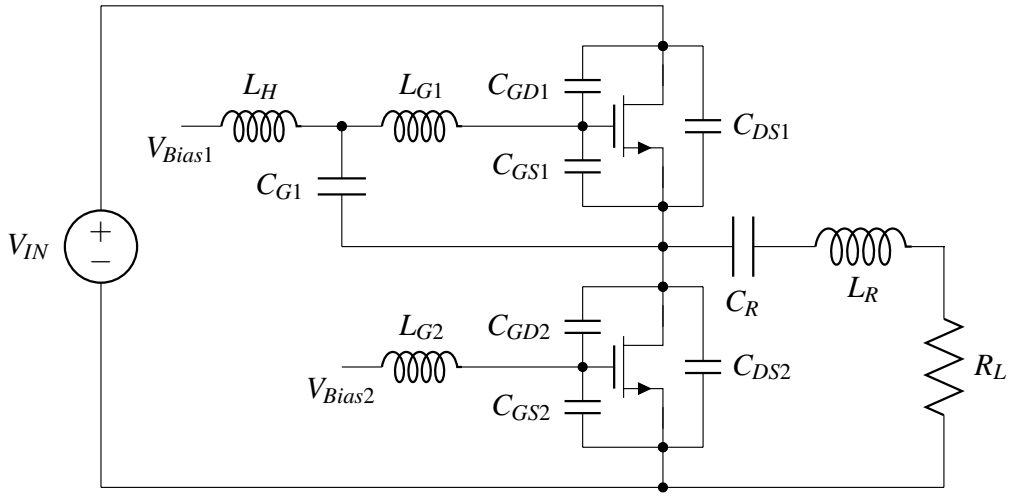
(WO2014067915A2)

- Simple, low cost self-oscillating gate drive
  - Utilization of MOSFET parasitic capacitors
- High pass filter from drain to gate
  - Designed to have sufficient gain and close to 180° phase shift at fsw
  - Sinusoidal waveform drives the MOSFET gate
- Adjustable duty cycle set by VBias



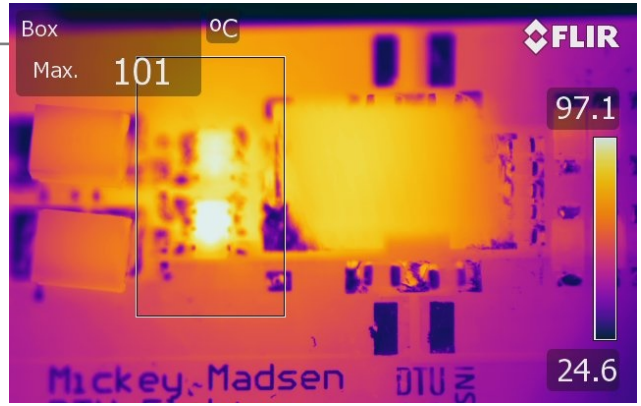
High side gate drive

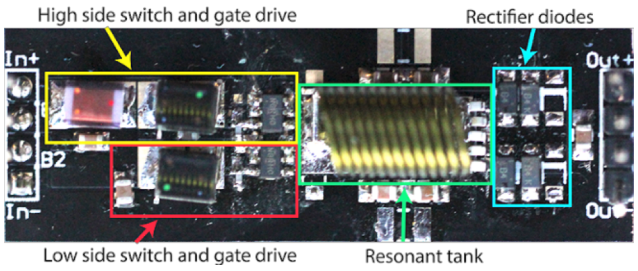
- Similar concept for high side MOSFET drive
- Only two additional components are needed
  - CG1 ensures high side voltage reference
  - LH provides dc path for average bias voltage control



First VHF half bridge

- The worlds first VHF half bridge converter
- Specifications:
  - Peak efficiency: 85%
  - Input voltage: 150 V
  - Output voltage: 40 V
  - Output power: 16 W
  - Switching frequency: 29 MHz
  - Power density of 1.5 W/cm3
    - Box volume of 50 x 17 x 12 mm





- Since then (2014), the core technology has been drastically improved
  - Up to 95% efficiency for similar specifications today

[1] M. P. Madsen, A. Knott and M. A. E. Andersen, *"Very high frequency half bridge DC/DC converter,"* 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014

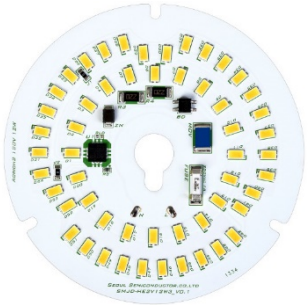
Outline

- Converter topologies
- Resonant gate drive
- LED driver examples
- Towards integration

LED driver application

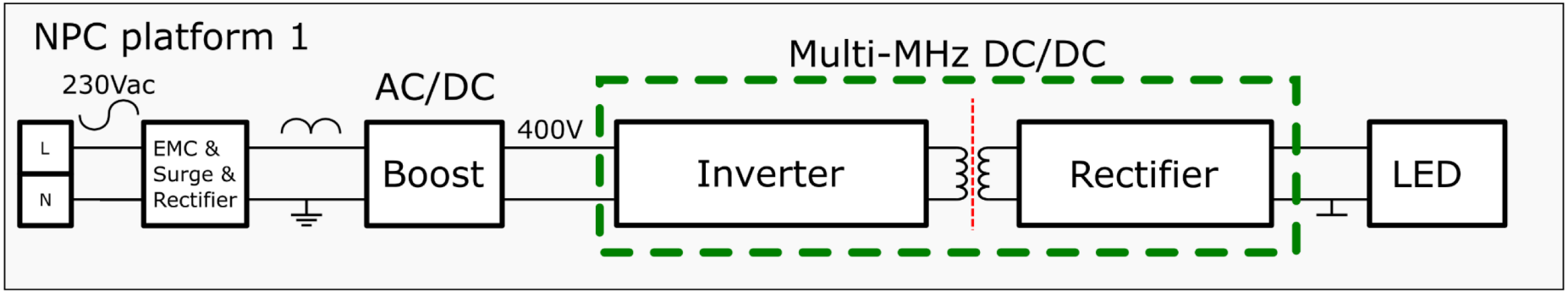
- High performance LED drivers are mainly governed by three blocks

- Typically three ways to miniaturize the driver
  - Reduced bulk cap
  - Single stage solutions
  - AC/driverless LEDs



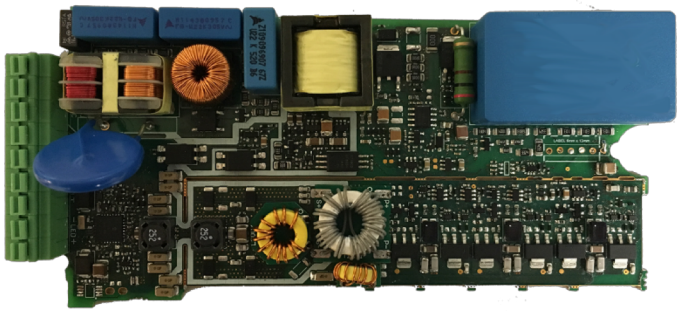
- But performance, especially flicker, is compromised!
  - Multi-MHz converters can shrink size without penalizing performance

Converter platform 1



- Conventional AC/DC boost converter
- Multi-MHz resonant DC/DC converter
  - Including isolation transformer
- Regulation and control interfaces (not shown)

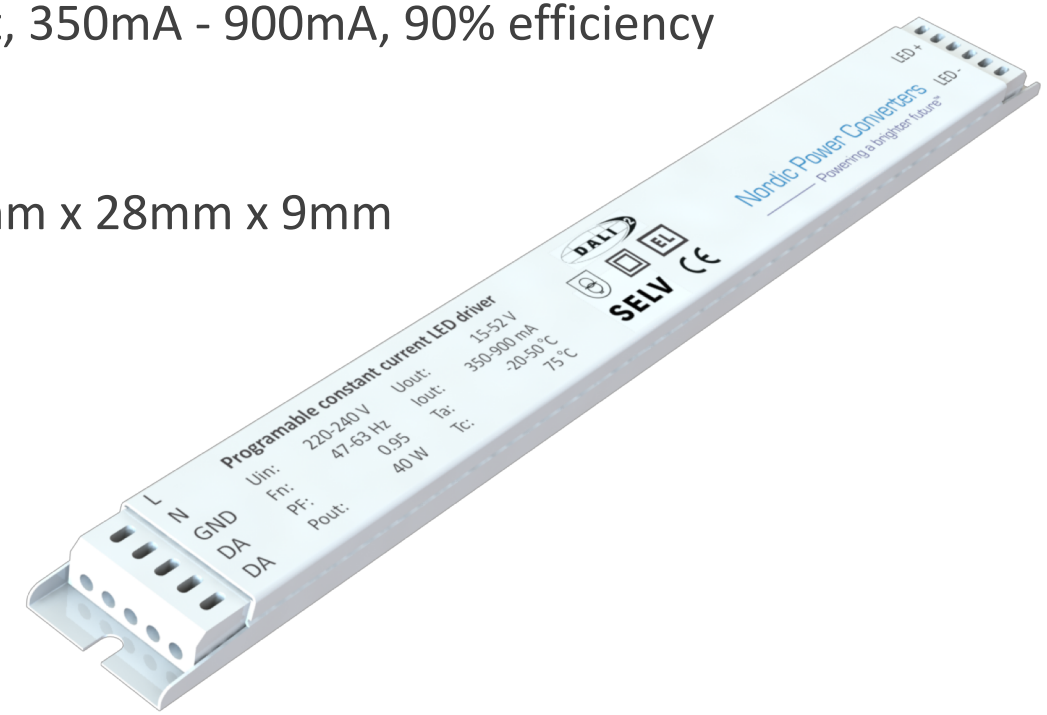
Platform 1:
60 W outdoor driver product



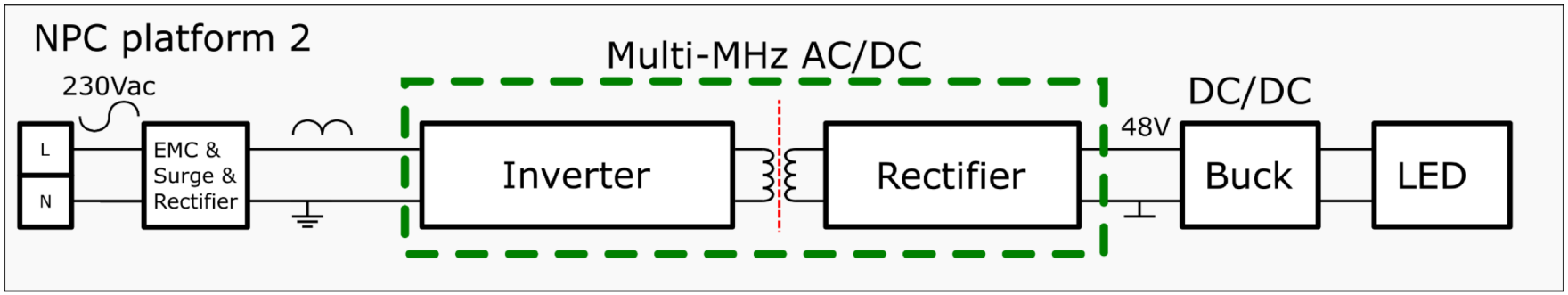
- Constant current / constant voltage LED driver
  - Conventional boost PFC
  - Resonant class DE running at 6MHz
  - MCU for regulation and external DALI control
- 88% efficiency (V_{IN}: 230Vac; V_{OUT} = 48V)
- **Half the size** of comparable drivers
- No electrolytics and 120.000 hrs lifetime
- Highest surge protection on the market (DM: 10 kV/5 kA and CM: 8 kV/4 kA)
- DALI, 1-10 V, CLO, 24hrs control, BlackBox, etc.
- CE certified
  - Pilot installations in July 2017 in Denmark

Platform 1: Next generation

- Indoor application: linear LED driver
- 230Vac, 15-52V output, 350mA - 900mA, 90% efficiency
- DALI control
- Ultra-flat design: 250mm x 28mm x 9mm
  - Excl. casing



Converter platform 2

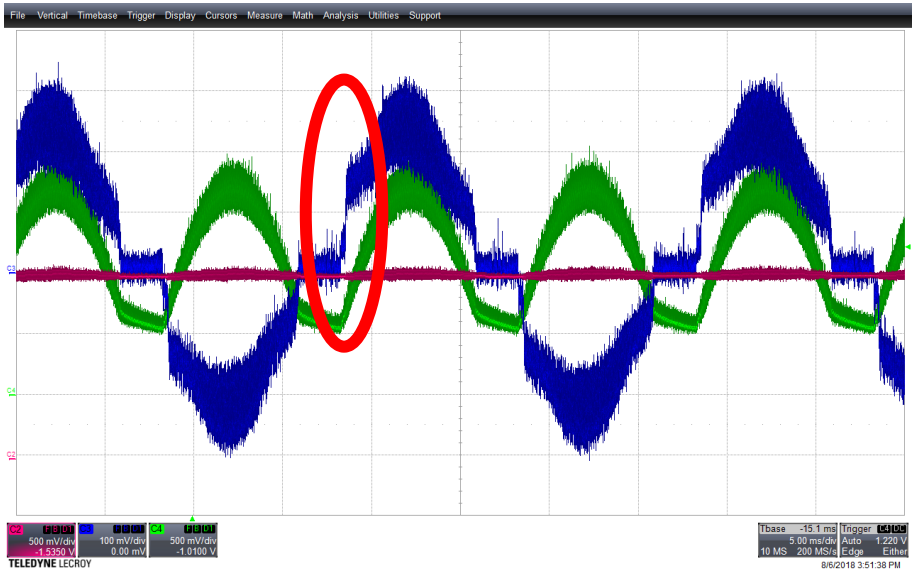


- Multi-MHz resonant AC/DC converter
  - Including isolation transformer
- Buck DC/DC converter
- Regulation and control interfaces (not shown)

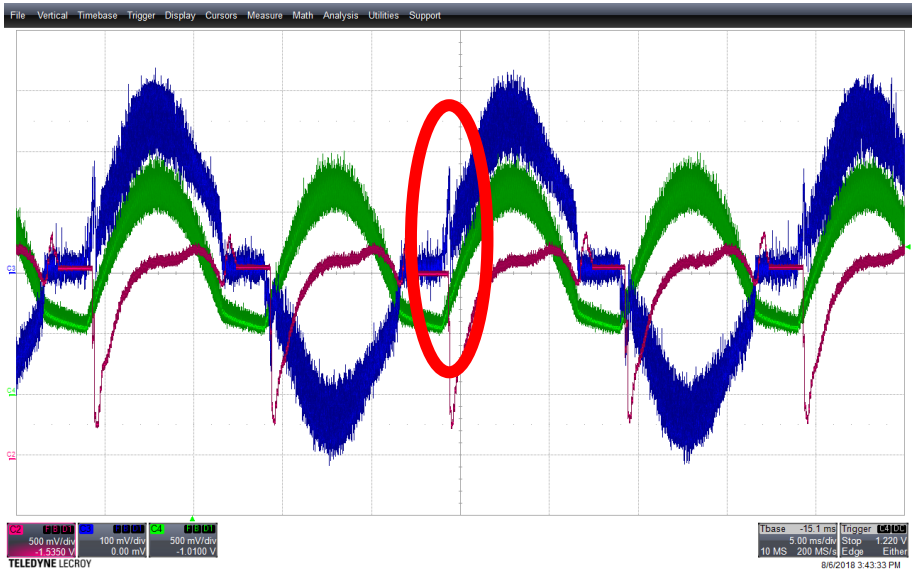
Power factor correction (PFC)

- Essentially buck type PFC -> challenging to meet harmonic limits
- PFC to meet requirements (IEC 61000-3-2 class C)

Without PFC -> harmonic **fail**



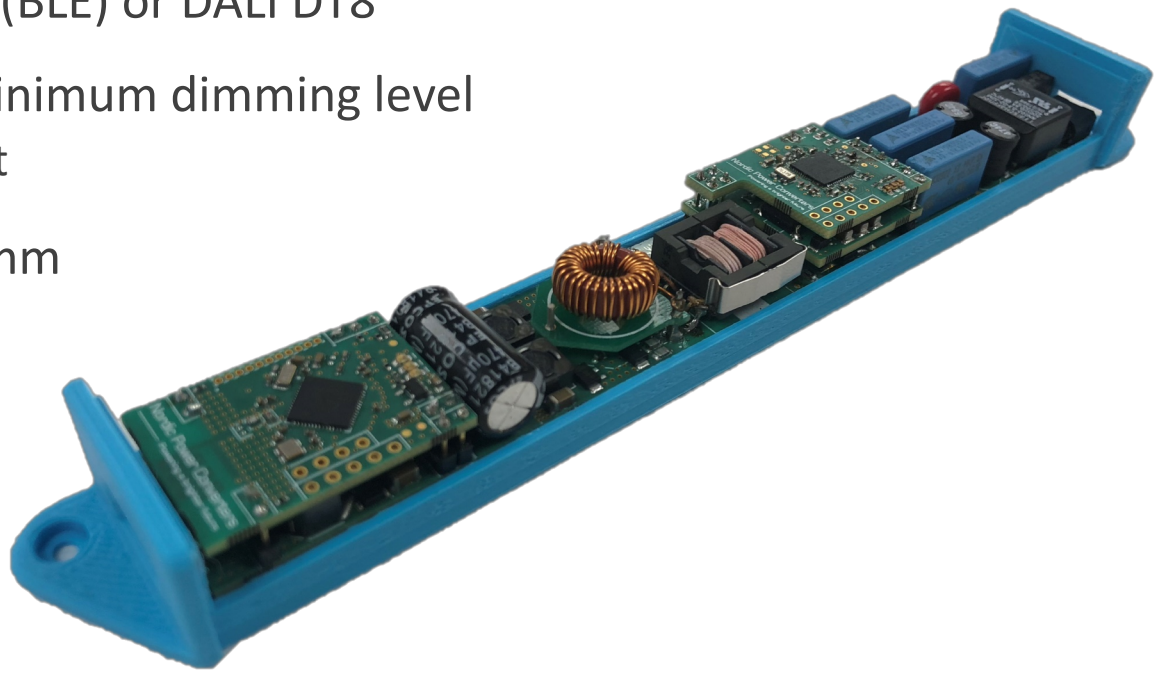
With PFC-> harmonic **pass**



Green: Vac_rec (sensed) Blue: Iin Pink: Control PWM

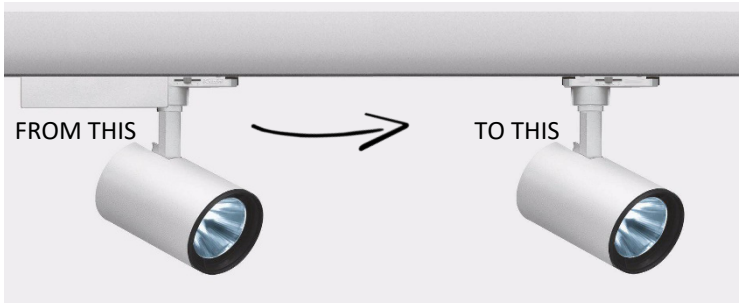
Platform 2: First Implementation

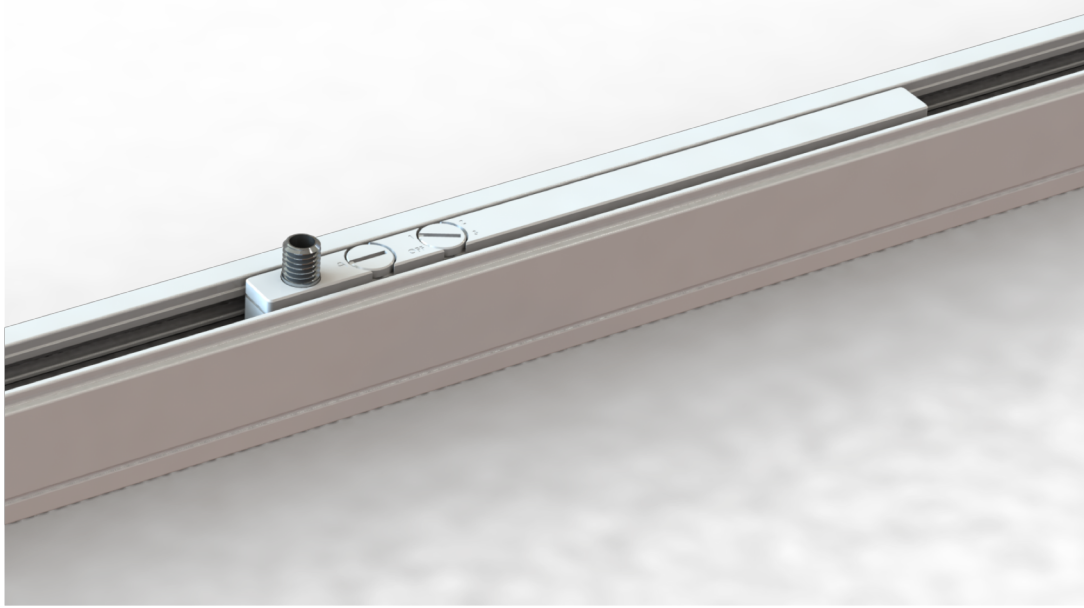
- Dual channel output for tunable white application
- 230Vac, 10-40V output, 900mA, 85% efficiency
- Bluetooth low energy (BLE) or DALI DT8
- Low flicker and low minimum dimming level
  - For high quality of light
- 170mm x 23mm x 12mm
  - Excl. casing



Platform 2: Next generation

- Fully in-track LED driver
- Towards our main vision





Outline

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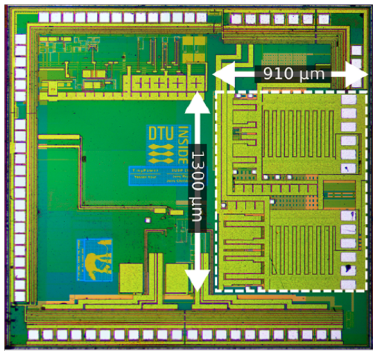
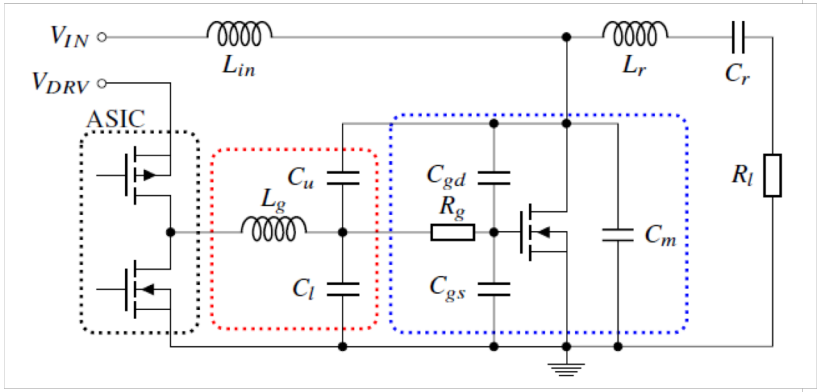
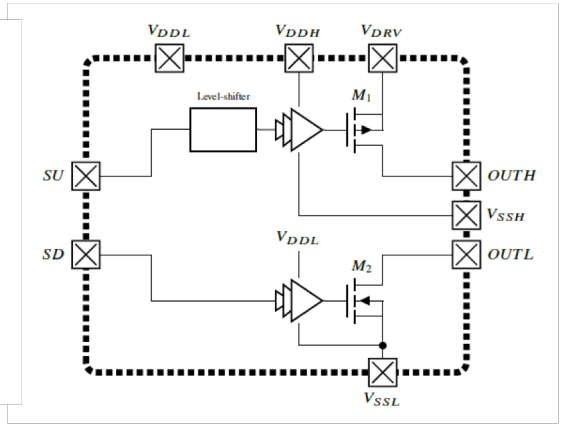
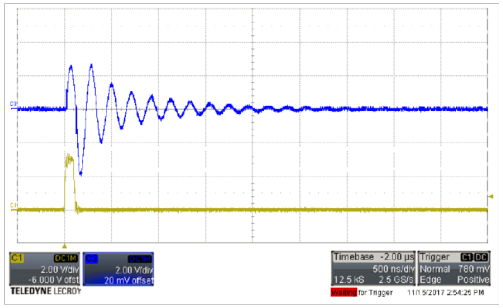
Gate driver integration

- Current implementation uses discrete components
  - Takes up significant PCB area
- Dedicated gate driver ASIC[2]
  - Designed for up to 30MHz operation
  - Precise ON and OFF signal generation





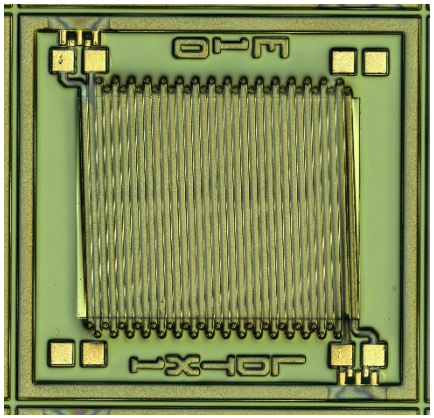


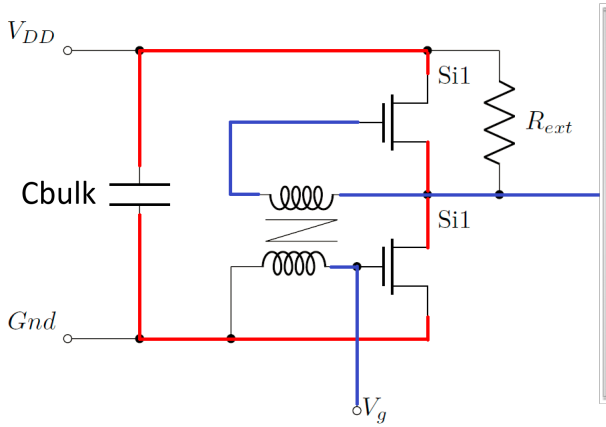


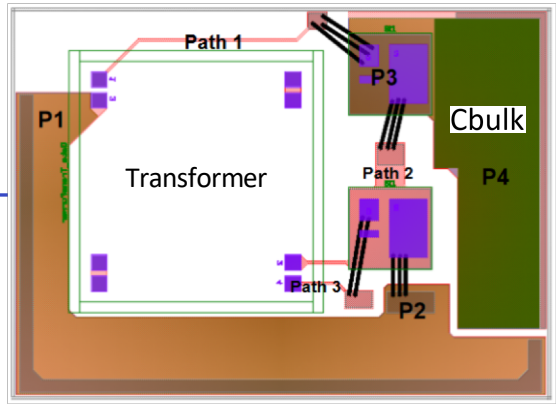
[2] Jacob E. F. Overgaard, Jens Christian Hertel, Jens Pejtersen and Arnold Knott, " Application Specific Integrated Gate-Drive Circuit for Driving Self-Oscillating Gallium Nitride & Logic-Level Power Transistors," to be published at NORCAS 2018

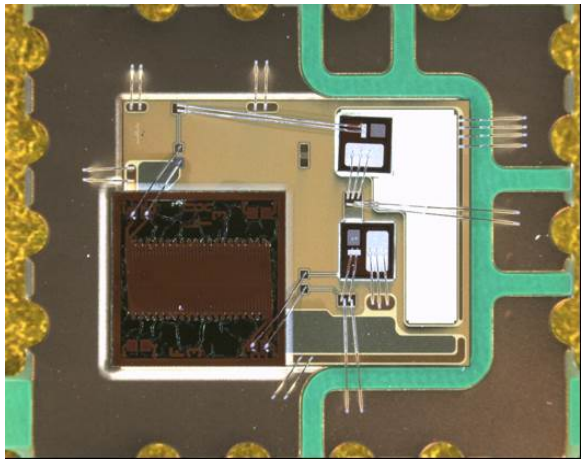
SIP integration

- Part of LEDLUM Horizon 2020 project
- Silicon interposer integration
  - Half-bridge mosfets (bare die)
  - Gate transformer (Tyndall)
  - Integrated 600V Cbulk capacitor (Murata)
- Recently manufactured -> currently under test



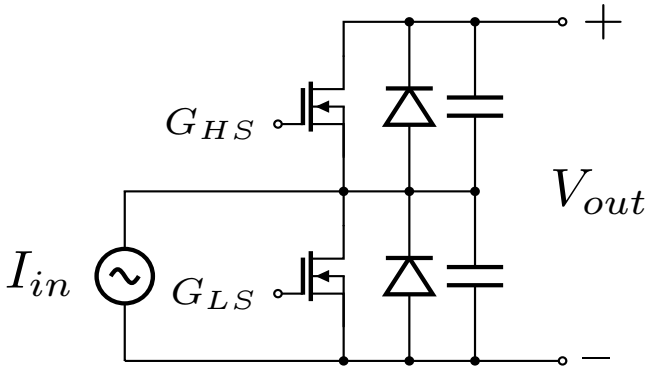


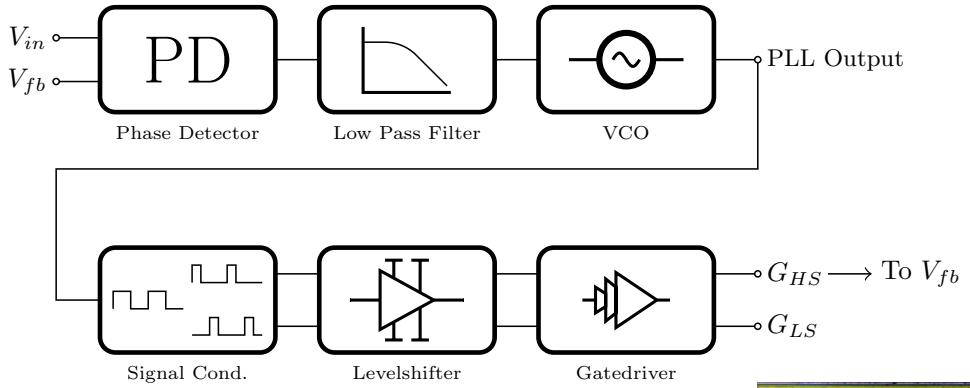




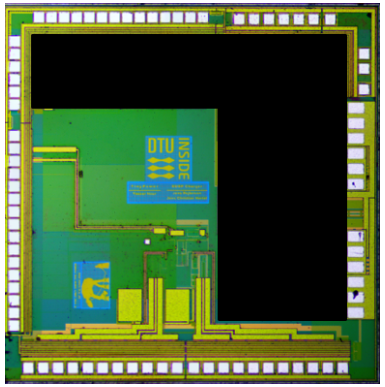
Synchronous rectification

- Design by Jens Christian Hertel -> Check out his Eposter!
- Synchronous rectification at multi-MHz switching frequencies
  - PLL based



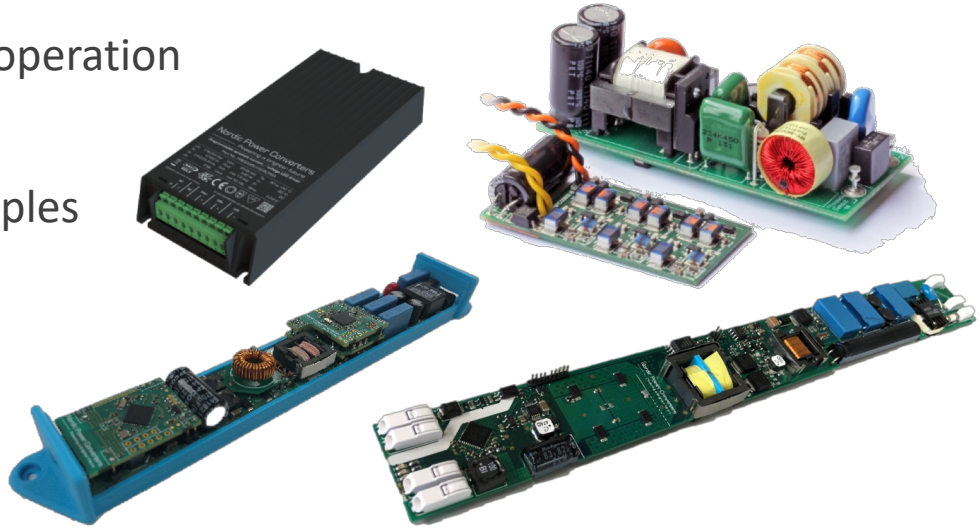


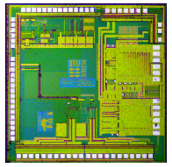
- First test in full converter prototype
  - 1%-point efficiency improvement (82.5% -> 83.5%)
    - 230 Vac, 9 Vout, 2.25 Aout
  - Half bridge rectifier -> 2x improvement for full bridge rectifier

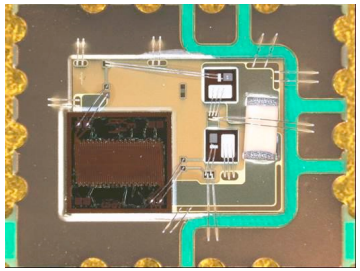


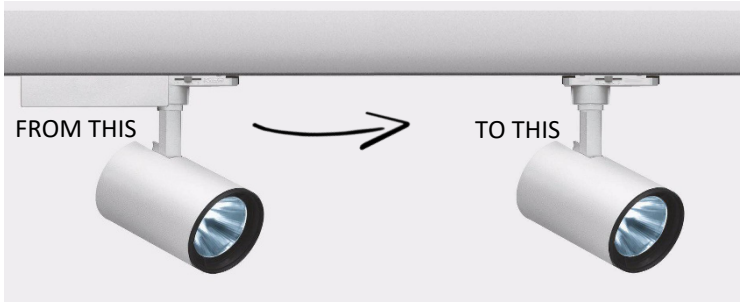
Summary

- Topologies suited for VHF converters (class E, class φ2, half bridge, SEPIC)
- Resonant gate drive for Multi-MHz operation
  - High side resonant gate driver
- Several LED driver application examples
  - Bringing the technology to the market
  - First product
  - Next generation demonstrators
- Steps taken towards integration
  - Gate driver integration
  - SIP power stage integration
  - Synchronous rectification









Nordic Power Converters

Powering a brighter future™

Thank you for your attention!

QUESTIONS?

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No 731466."

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