On the Quest for an optimal DC-DC Isolated gate drive supply topology: Formula E and WE-AGDT Transformers

Emil Nierges
Product Manager – Power Isolated

Eleazar Falco
Application Engineer

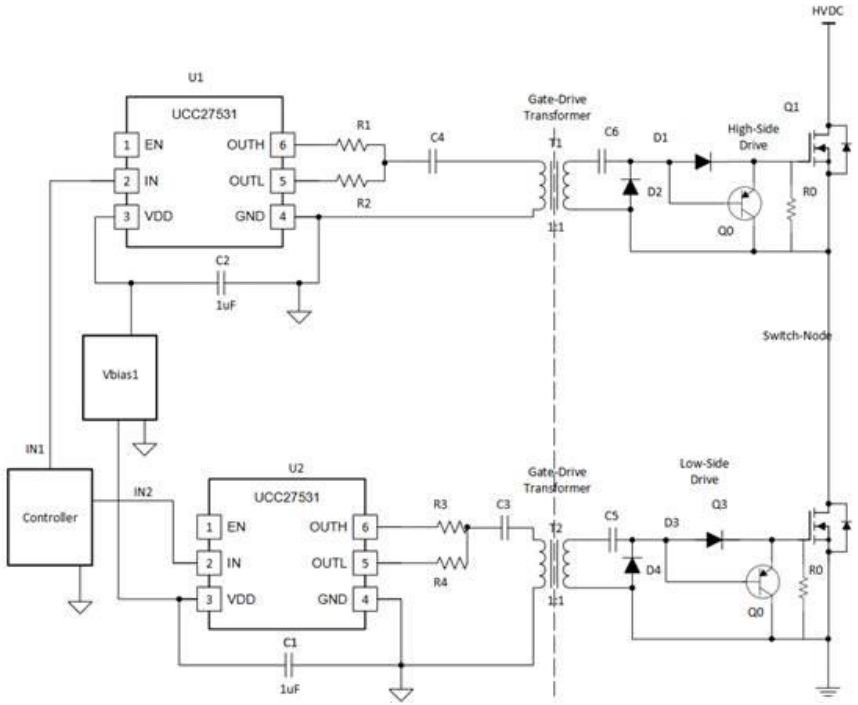
Agenda

- Auxiliary supply in gate driver systems
- DC-DC topologies for gate drive auxiliary supply
- DC-DC Topology Comparison
- WE-AGDT Reference Design and Formula-E

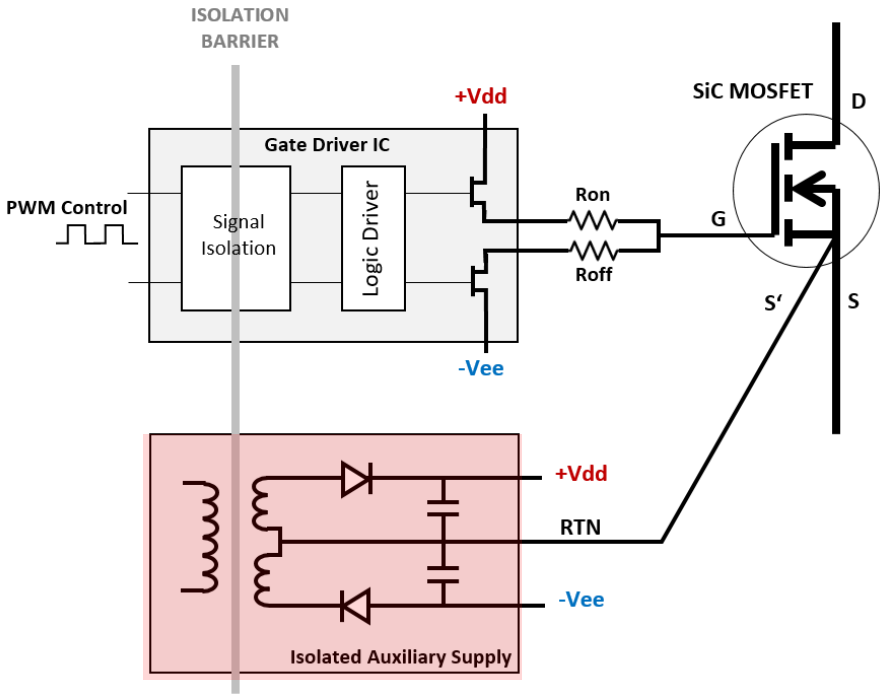
The Auxiliary Supply in SiC-MOSFET and IGBT Gate Driver Systems

Auxiliary Supply in the Gate Drive System

Gate Drive System: Simplified Diagram



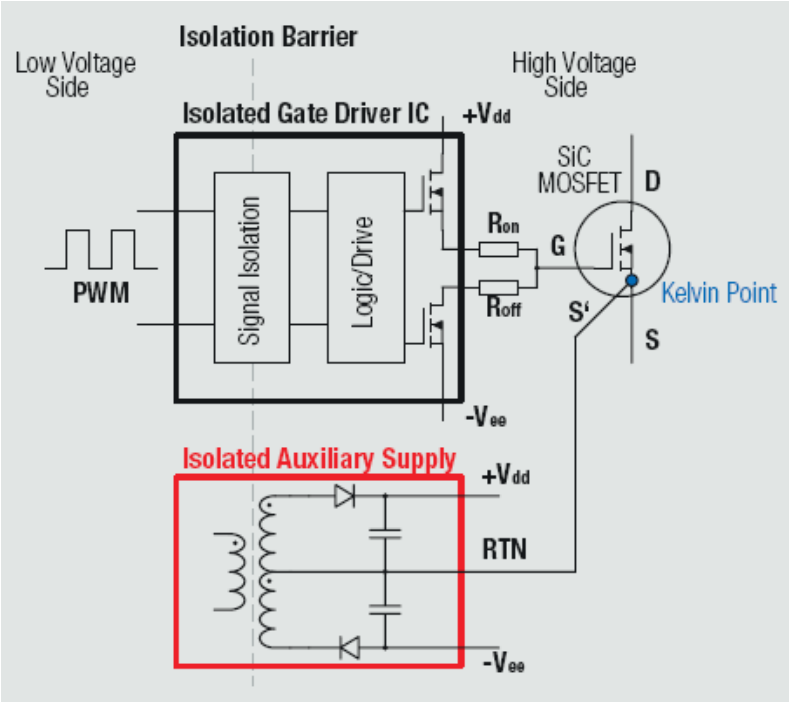
Transformer in Direct drive application

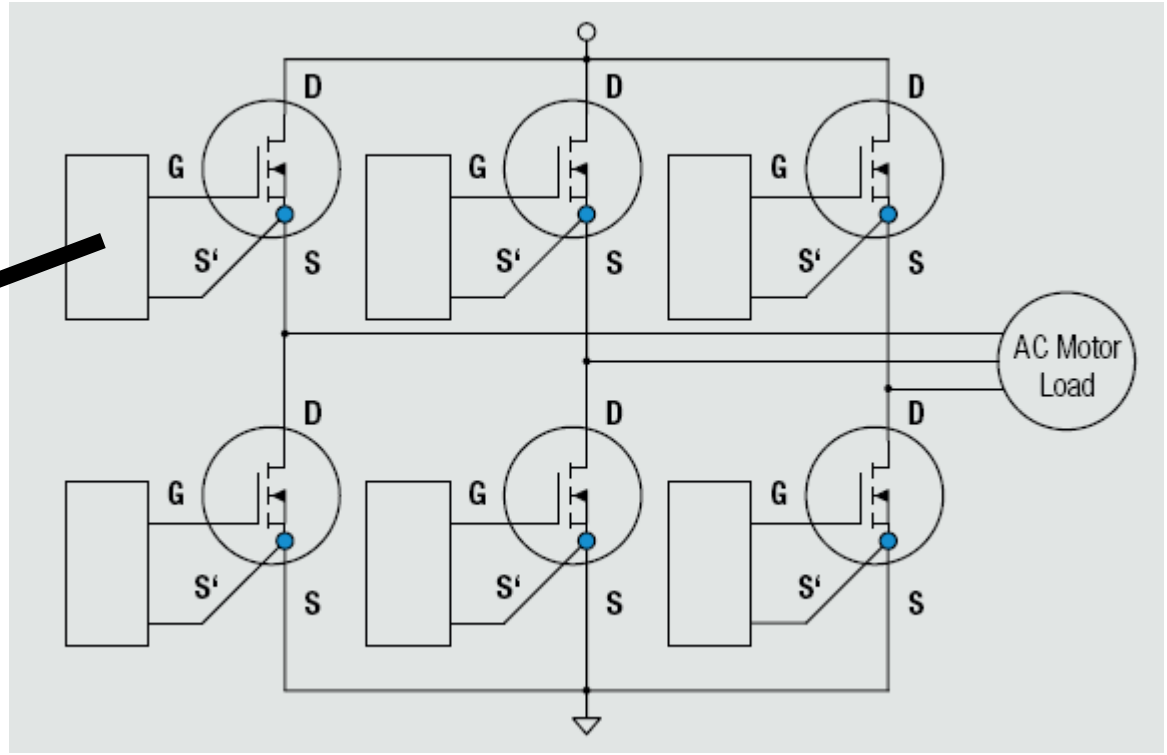


Transformer in DC-DC Auxiliary Supply

Auxiliary Supply in the Gate Drive System

Example Application: Three-phase Motor Inverter





DC-DC topologies for Isolated Gate Drivers

DC-DC topologies for Isolated Gate Drivers

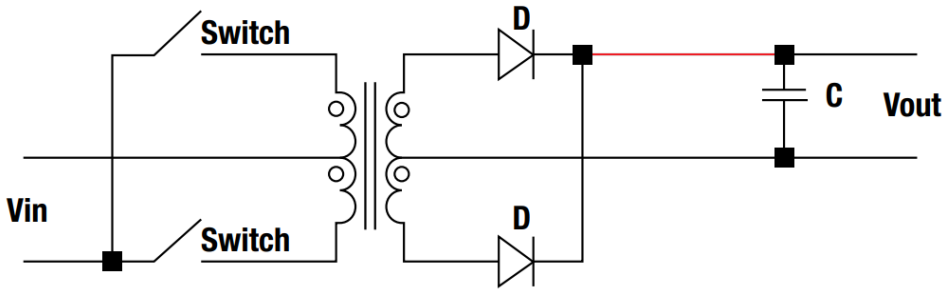
Push-Pull converter

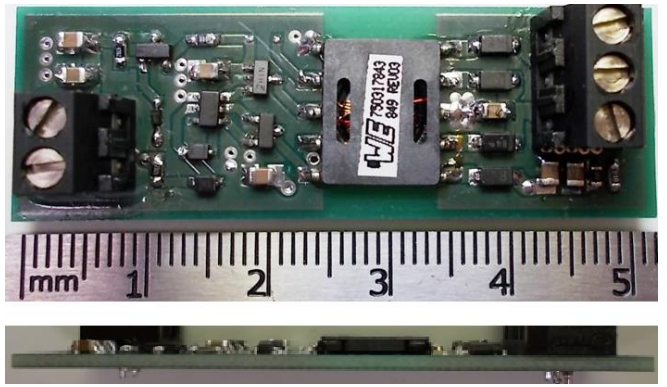
Main Advantages

- ✓ Very simple design
- ✓ Transformer does not store energy (size)
- ✓ Low component count (cost)
- ✓ No need for primary snubber
- ✓ Typical efficiency range around 85-92%

Main Disadvantages

- ❖ Open loop Operation
- ❖ Output Voltage rail(s) are unregulated
- ❖ Tightly regulated input voltage is required





3.5W isolated Push-Pull

Reference Design PMP30555

- Input voltage24V
- Out1 15V /120mA
- Out2 5V / 350mA
- Ultrathin 2mm
- With “cascode” FETs
- No output inductor
- Fixed 50% DC

DC-DC topologies for Isolated Gate Drivers

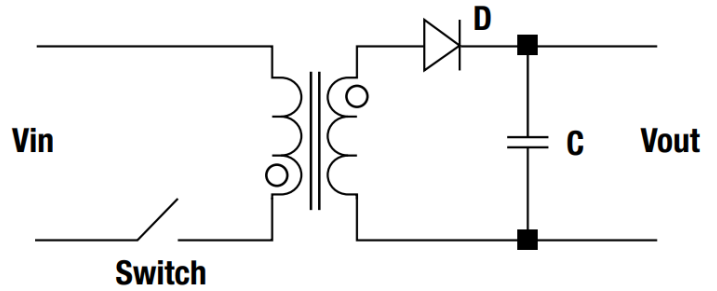
Flyback converter with primary side regulation

Main Advantages

- ✓ Wide input voltage range
- ✓ Well regulated output voltage rail(s) (< 5%)
- ✓ Easy to create multiple outputs
- ✓ Fast transient response
- ✓ Typical efficiency range around 75-86%

Main Disadvantages

- ❖ Transformer stores energy (size)
- ❖ Efficiency vs EMI/immunity (trade-off)
- ❖ Careful design for best performance



Isolated 2.5-W SiC & IGBT Gate-Drive

Reference Design PMP30629

- Input voltage 18V-36V
- Outputs +15V & -4V 130mA
- Primary side regulation
- No auxiliary winding
- No optocoupler
- Configurable single/dual output voltages

DC-DC topologies for Isolated Gate Drivers

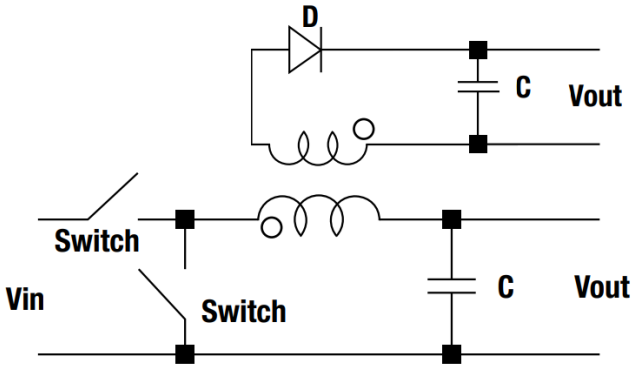
Buck converter with Isolated Outputs (Fly-buck™)*

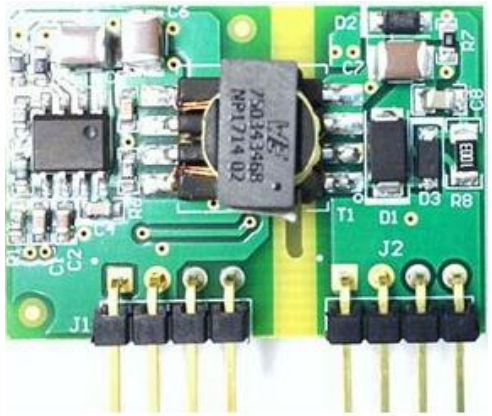
Main Advantages

- ✓ Wide input voltage range
- ✓ Output voltage rail(s) are indirectly regulated
- ✓ Additional non-isolated output voltage rail
- ✓ Fast Transient Response
- ✓ Typical efficiency range around 75-88%

Main Disadvantages

- ❖ Performance very sensitive to Leakage inductance
- ❖ Regulation/Efficiency vs EMI/Immunity (trade-off)
- ❖ Duty cycle practical limitation (~50% max)





Single-Channel, Isolated SiC and IGBT Gate Driver

Reference Design TIDA-01160

- Vin 10-17V
- Vout (isolated) 15V, -8V
- Po = 2W
- Vout non isolated 3.3V
- Small form factor

(*) Fly-buck™ is a trademark of Texas Instruments Inc.

DC-DC topologies for Isolated Gate Drivers

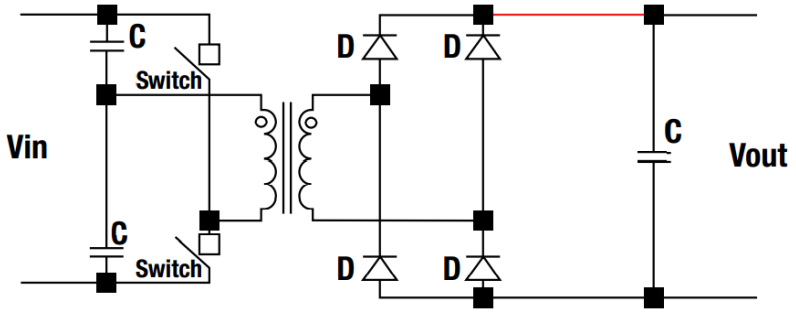
Half-bridge converter

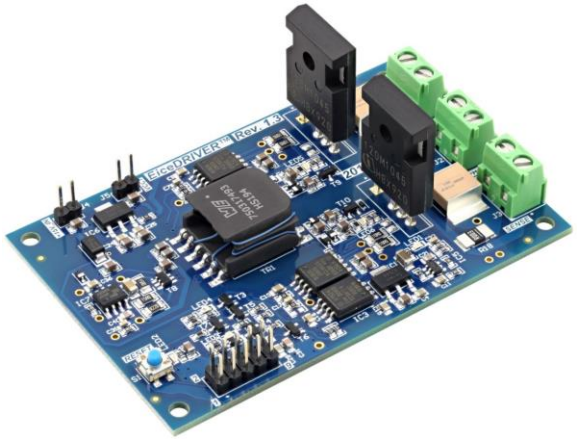
Main Advantages

- ✓ Simple design
- ✓ Transformer does not store energy (size)
- ✓ Low component count (cost)
- ✓ No need for primary snubber
- ✓ Typical Efficiency range around 85-92 %

Main Disadvantages

- ❖ Open loop Operation
- ❖ Output Voltage rail(s) are unregulated
- ❖ Tightly regulated input voltage is required





Infineon-AN2020-05_EVAL-1ED3491Mx12M-ApplicationNotes-v01_00-EN.pdf

Evaluation board 1ED3491Mx12M

- Input voltage 15V
- Two Output sets (+15V, -7.5V)
- Max load currents 133mA
- Meets reinforced isolation
- High creepage & clearance
  - Pri - Pri
  - Sec1 – Sec2

DC-DC topologies for Isolated Gate Drivers

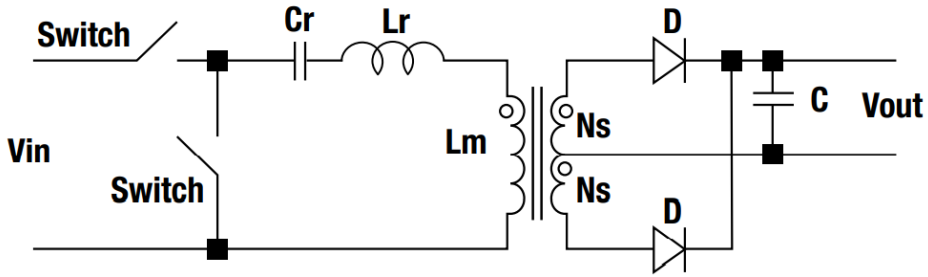
Resonant converter

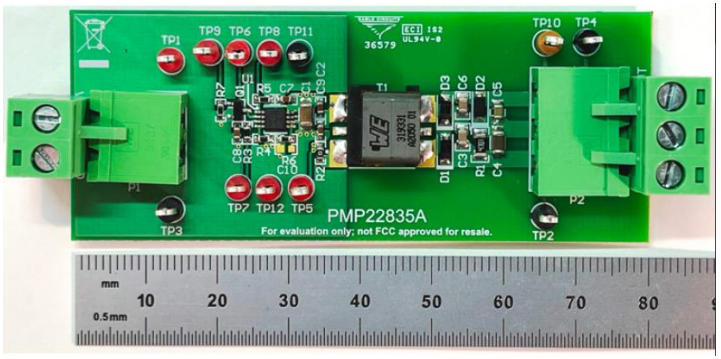
Main Advantages

- ✓ Soft-switching of Transistors
- ✓ Transformer does not store energy (size)
- ✓ Low component count (cost)
- ✓ Very high CMTI
- ✓ Typical Efficiency range around 85-92%

Main Disadvantages

- ❖ Careful design for best performance
- ❖ Output Voltage rail(s) are unregulated
- ❖ Tightly regulated input voltage is required





https://www.ti.com/tool/PMP22835

Reference Design PMP22835

- Vin 24V
- Vout 20V, -4V / 300mA
- Very low parasitic capacitance
- High level of integration IC
- Small form factor

DC-DC Topology Comparison for Gate Driver Systems

DC-DC Gate Drive Supply Topology Comparison

CMTI, Efficiency, Output Voltage Regulation

Topologies	CMTI	Efficiency	Output voltage regulation
Push-Pull	✓✓✓	✓✓✓✓	✓✓✓
PSR Flyback	✓✓✓✓	✓✓✓	✓✓✓✓✓
Isolated Buck	✓✓	✓✓✓	✓✓✓✓
Half Bridge	✓✓✓✓	✓✓✓✓	✓✓✓
Resonant LLC	✓✓✓✓✓	✓✓✓✓✓	✓✓

* With tightly regulated input voltage. Comparison based on a solution of the same area, with the same output voltage and output power specifications.

DC-DC Gate Drive Supply Topology Comparison

Input Voltage range, Output regulation, Energy storage

Topologies	Wide input voltage	Regulated output	Transformer energy storage
Push-Pull	X	X	No
PSR Flyback	✓	✓	Yes
Isolated Buck	✓	✓	Yes
Half Bridge	X	X	No
Resonant LLC	X	X	No

Würth Elektronik WE-AGDT RD001 Reference Design & Formula E

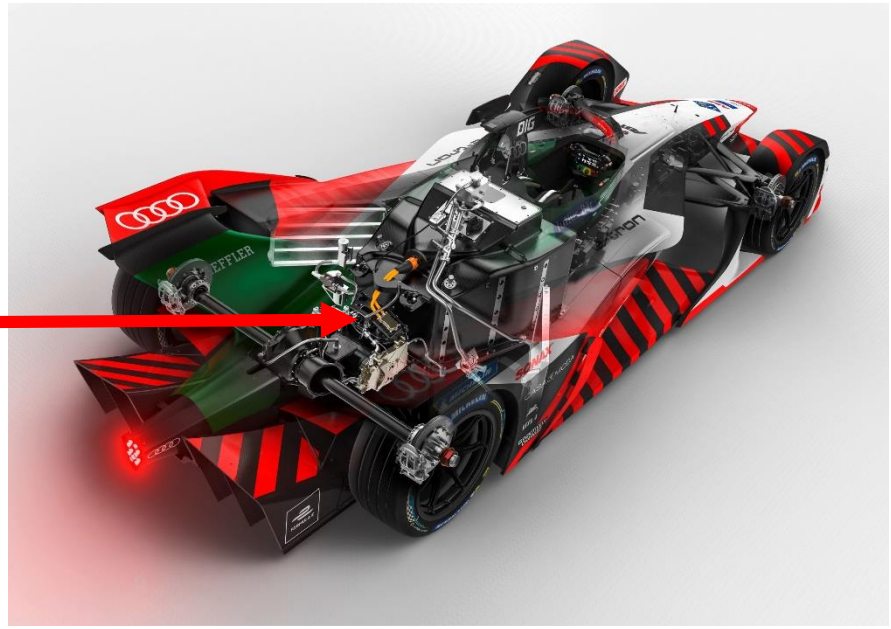
Würth Elektronik and Formula E

Official Technology Partner of Audi Sport ABT Schaeffler Formula E Team

Würth Elektronik and Formula E

WE-AGDT and Reference Design RD001 in the Race !

Würth Elektronik WE-AGDT and Reference Design RD001 are part of the power inverter gate driver system in the innovative Audi MGU05 electric powertrain of the Audi e-tron FE07 Formula-E car.



Isolated PSR Flyback with WE-AGDT Transformer

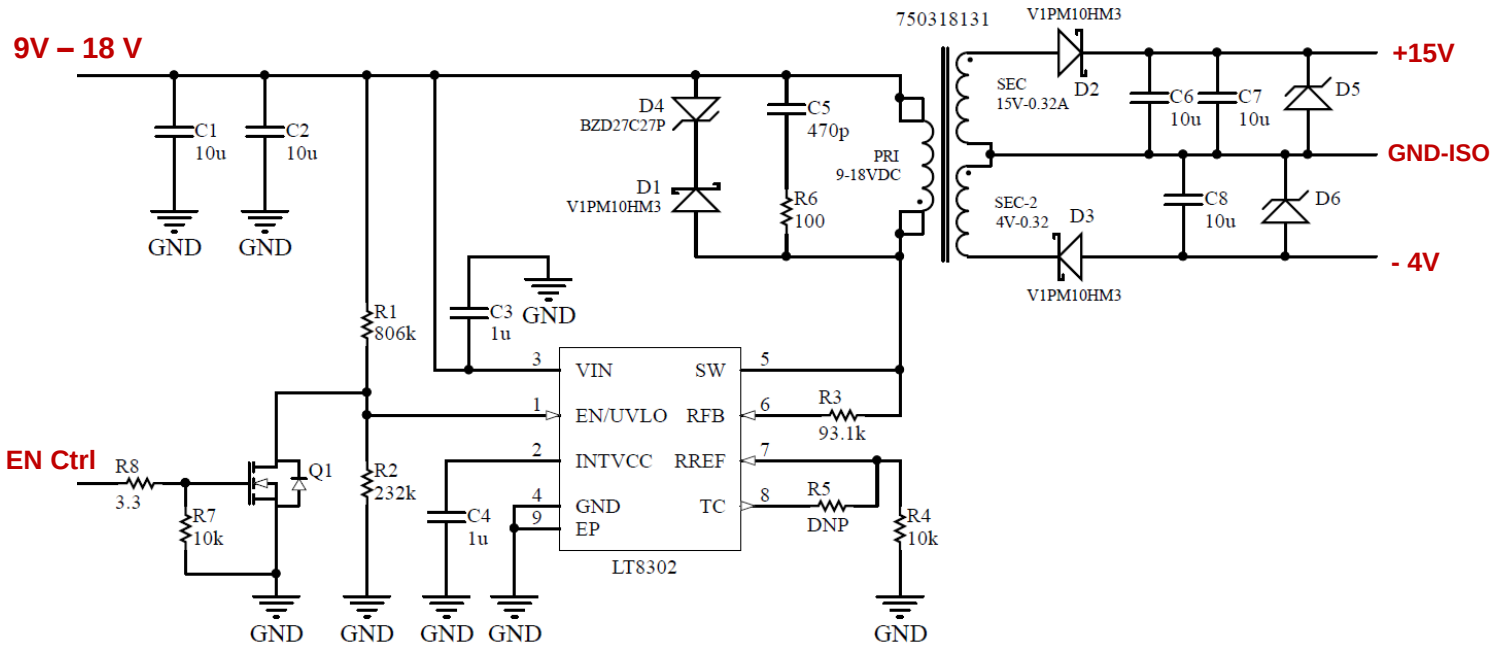
RD001: Basic Specification and Schematic

Basic Electrical Specification (RD001)

- Vin = 9 - 18 V
- Vout = +15 / -4 V
- Pmax = 6 W
- Target Application: SiC-MOSFET and IGBT Gate drivers.

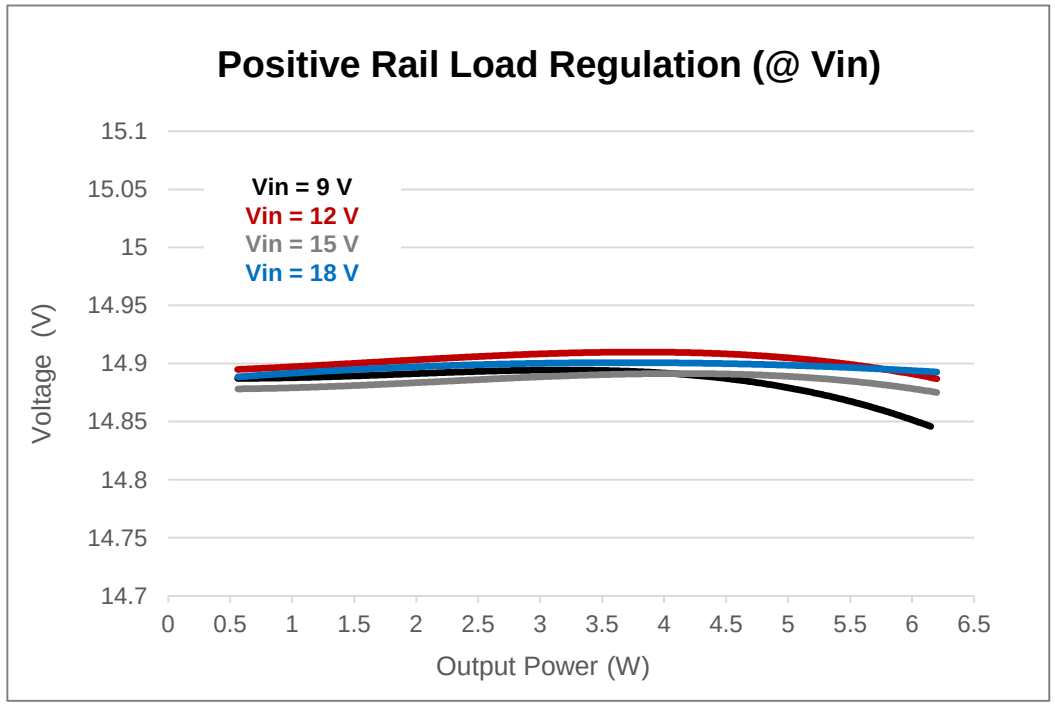
PSR Flyback:

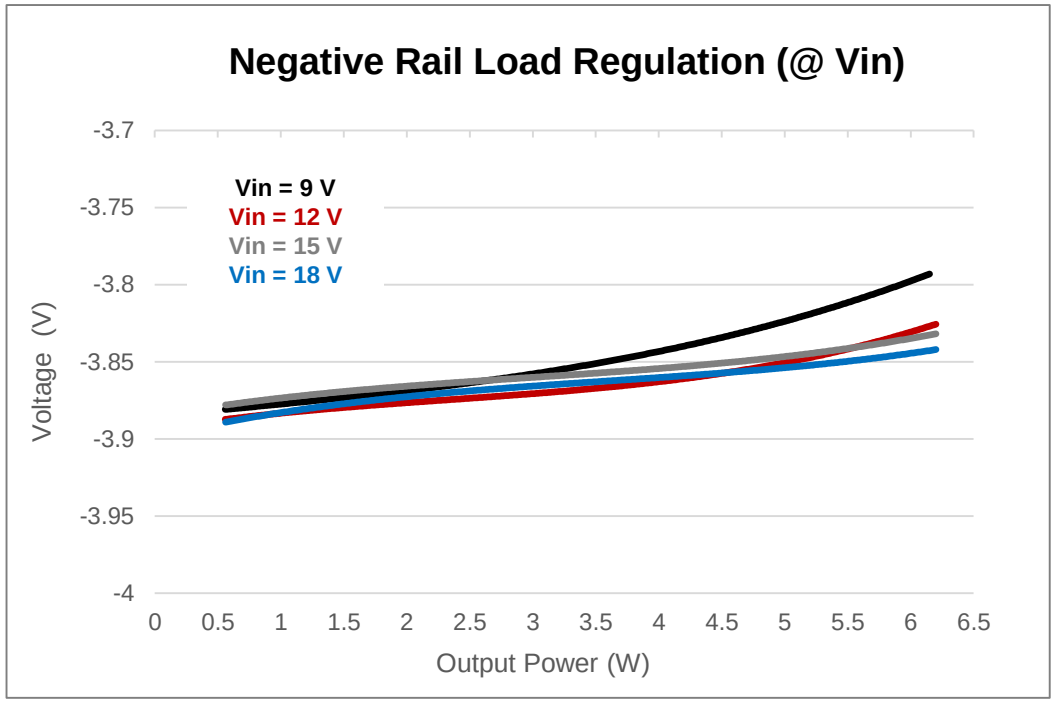
- No need additional input and output regulation stages.
- Very compact size and low overall cost is possible with optimized design.



Isolated PSR Flyback with WE-AGDT Transformer

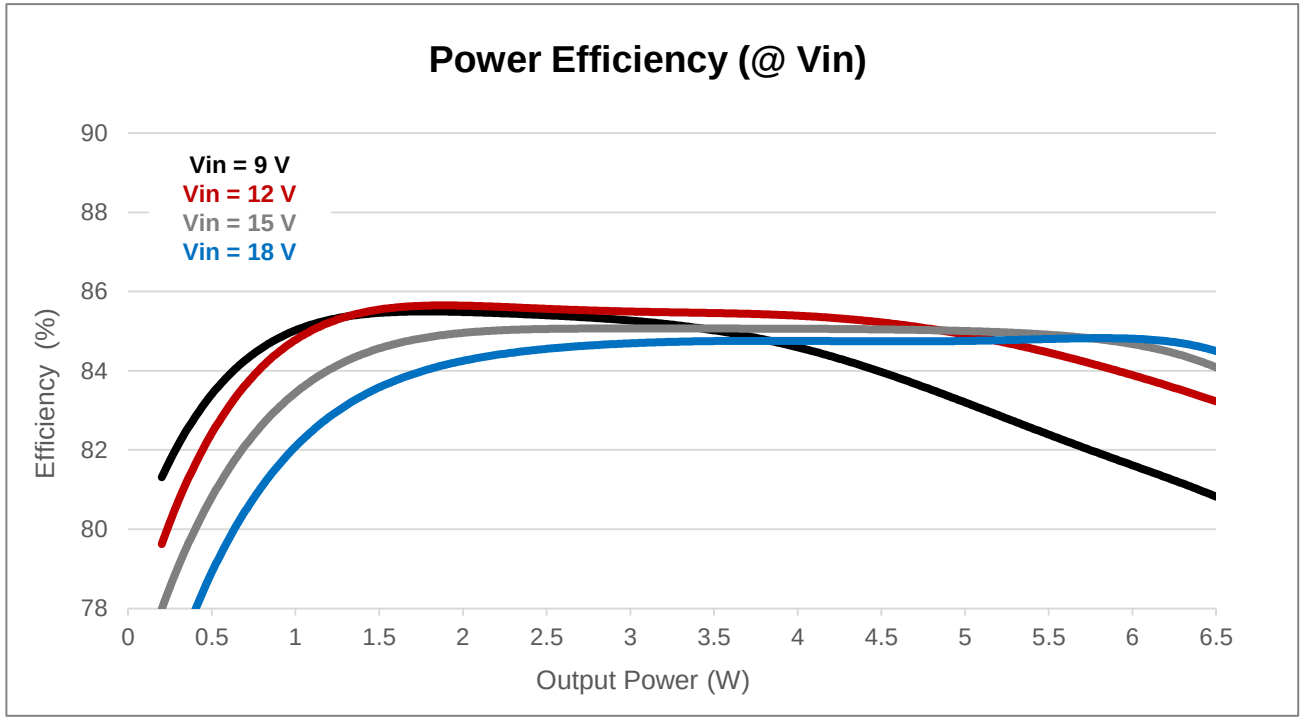
RD001: Output Voltage Regulation





Isolated PSR Flyback with WE-AGDT Transformer

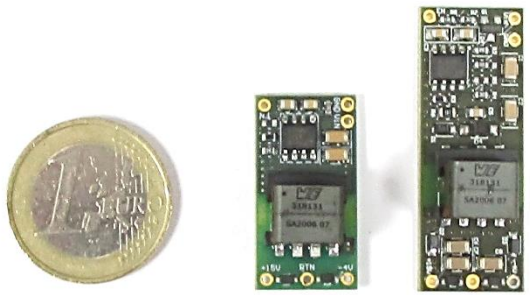
RD001: Power Efficiency



Isolated PSR Flyback with WE-AGDT Transformer

RD001 PCB Layout and Assembly Variants

- Two PCB Layout Variants
  - Single-sided, Two Layer
  - Double-sided, Four Layer
- Two Assembly Variants
  - AEC-Q Components
  - Standard

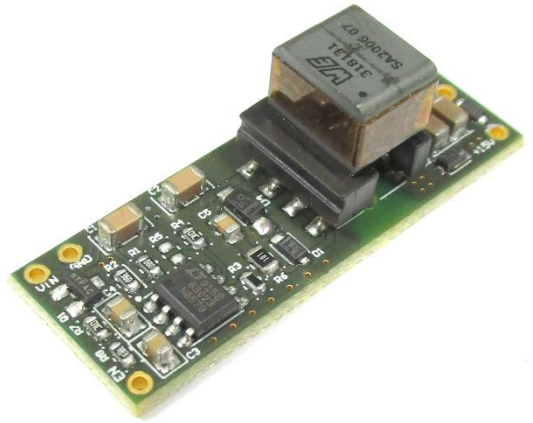


Variant A

(LxWxH) = 27 x 14 x 14 mm

4-layer PCB Design

Components on Top and Bottom



Variant B

(LxWxH) = 40 x 14 x 12 mm

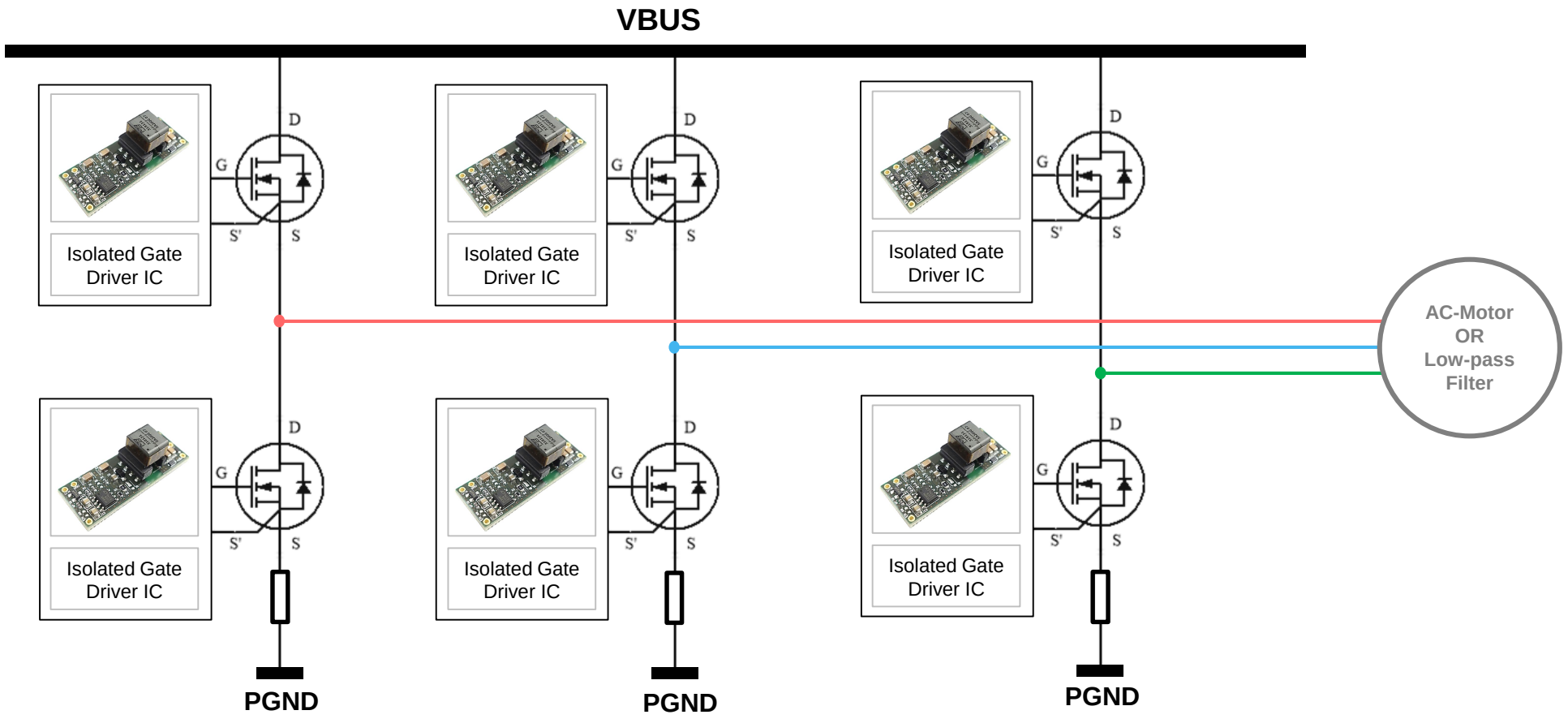
2-layer PCB Design

Components only on Top side

Reference Design Document, PCB Layout and Fabrication files: we-online.com/RD001

Isolated PSR Flyback with WE-AGDT Transformer

RD001: Example 3-phase Inverter or Motor Drive Application (simplified)



Isolated PSR Flyback with WE-AGDT Transformer

RD001: Example Advantages in Inverter Gate Driver Systems

Low Leakage Inductance and DCR

- ✓ Lower Temperature rise
- ✓ Higher ambient temperature

Wide Input Voltage (9 – 18 V)

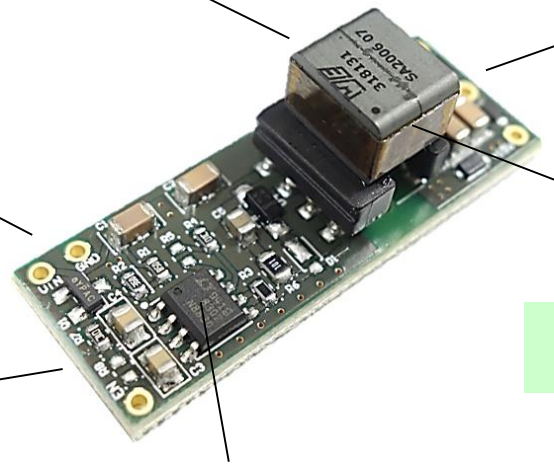
- ✓ Battery Supply (12 V)
- ✓ Loosely regulated input supply

High Output Power upto 6 W

- ✓ Higher SiC-MOSFET switching frequency
- ✓ Higher Inverter Power Density ($R_{DS_{on}} \downarrow \rightarrow Q_g \uparrow$)

$$P = Q_g \cdot F_{sw} \cdot \Delta V_{gs}$$

$$\text{RD001} \rightarrow Q_g \cdot F_{sw} < 0.33\ \text{A}$$



External EN/DIS (3.3V / 5 V)

- ✓ Enable/Disable with control MCU

Low Interwinding Capacitance (7.5 pF typ)

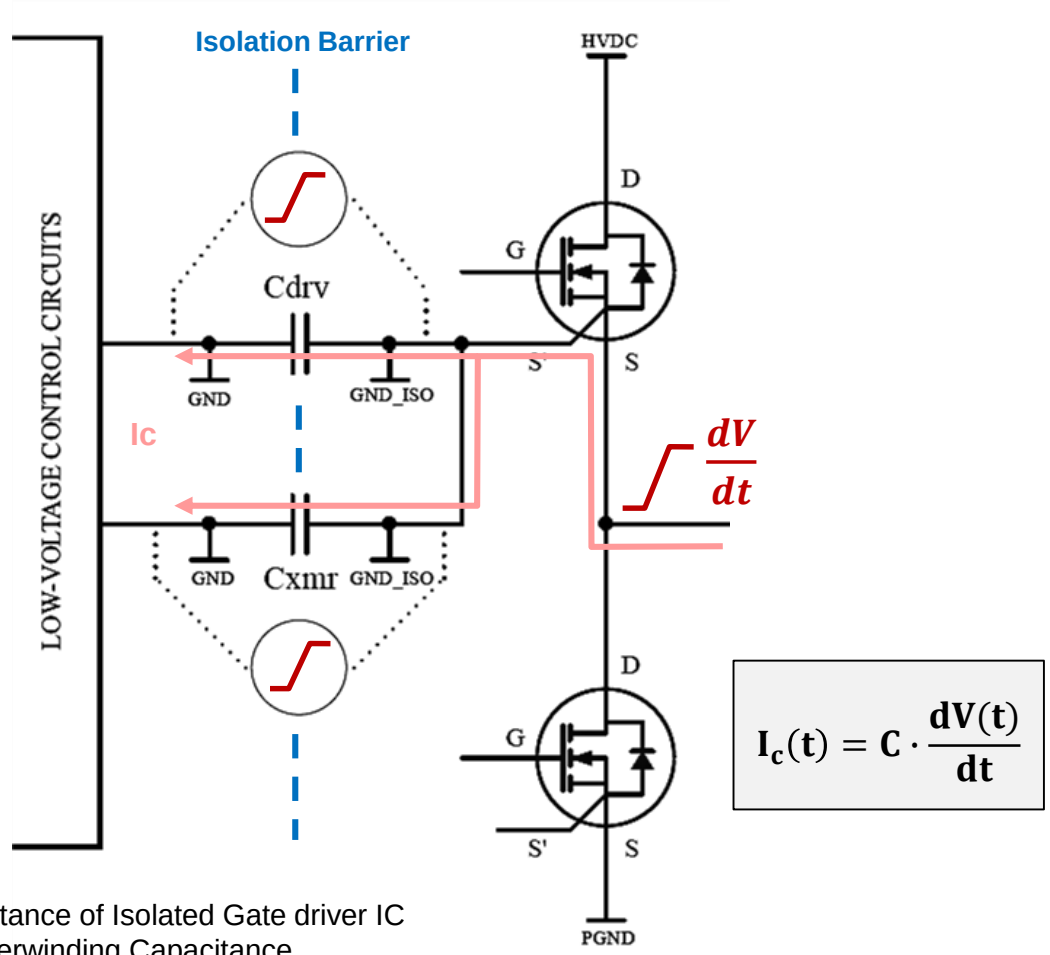
- ✓ High Common-mode Transient Immunity (CMTI)
- ✓ Fast switching speed of Inverter SiC devices
- ✓ Higher Inverter efficiency
- ✓ Less cooling, smaller size, lower cost
- ✓ Better EMI performance

PSR Flyback IC Controller

- ✓ Integrated MOSFET (small size)
- ✓ UVLO, Short-circuit Protection, Thermal Shutdown
- ✓ Regulation without Optocoupler or additional winding

Isolated PSR Flyback with WE-AGDT Transformer

Inverter Half-bridge Leg: CMTI and Isolation Barrier Capacitance



$$I_c(t) = C \cdot \frac{dV(t)}{dt}$$

Cdrv: Parasitic Capacitance of Isolated Gate driver IC
Cxmr: Transformer Interwinding Capacitance

- **Capacitive Coupling (dV/dt)** across isolation barrier
- Common-mode Displacement Currents generated
- Distortion of control signals!
- High Common-mode current stress in the controller!

CMTI: **Common-mode Transient Immunity**

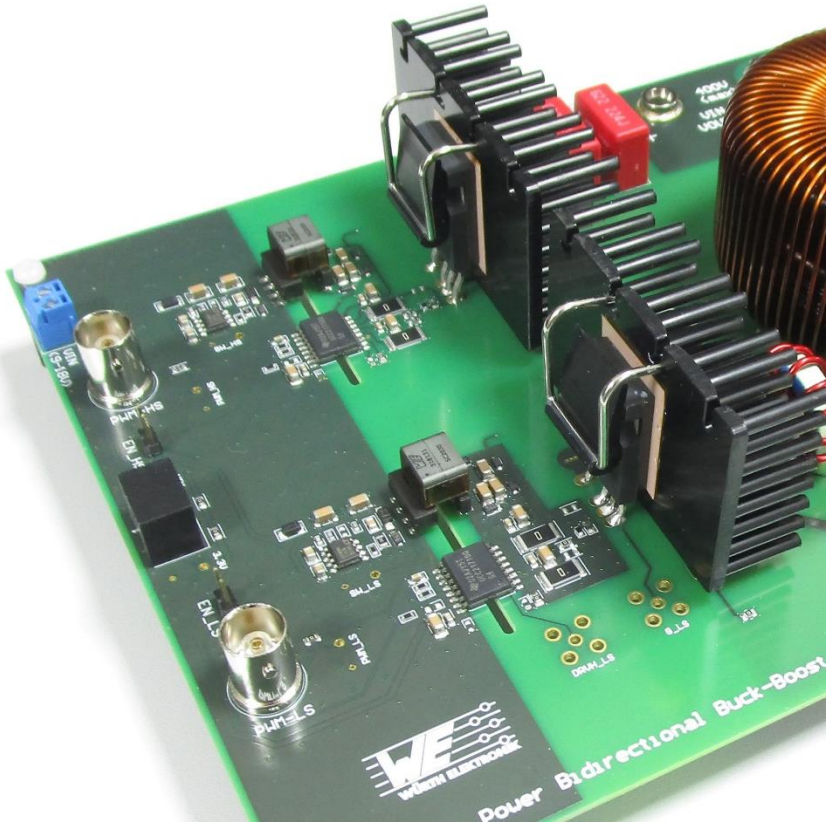
Maximum rate of change of voltage (dV/dt) which can be tolerated across the isolation barrier before malfunction occurs (measured in kV/µs or V/ns)

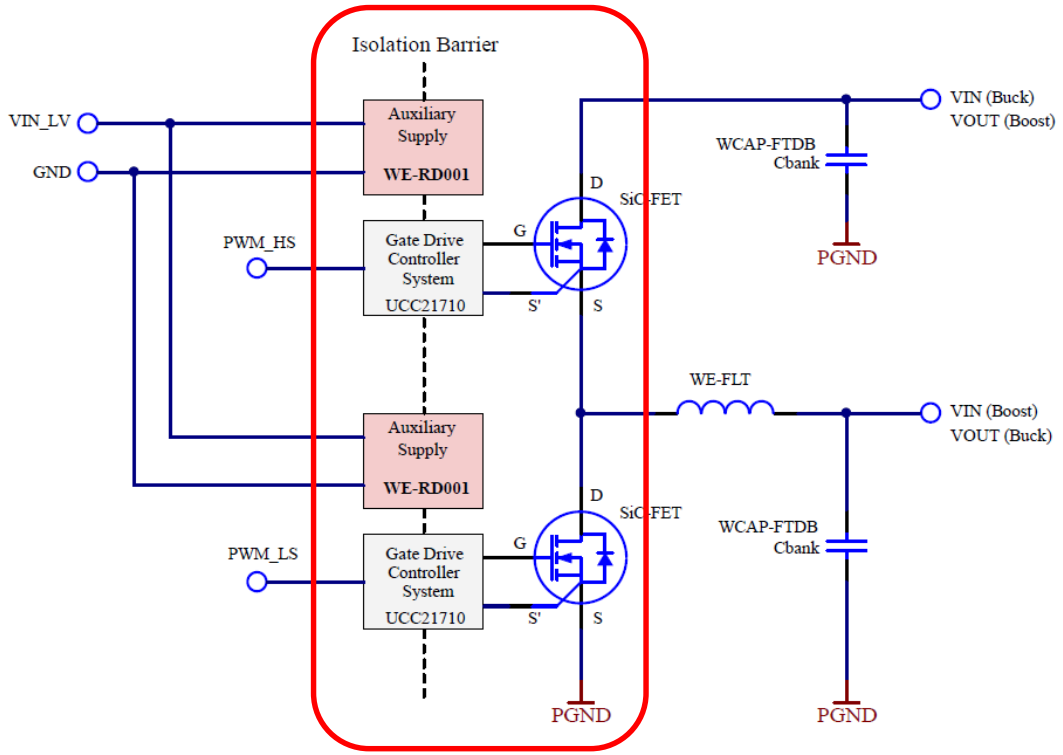
$$(C_{drv} \,\&\, C_{xmr}) \downarrow \text{ then } CMTI \uparrow$$

Minimize Interwinding Capacitance !

Isolated PSR Flyback with WE-AGDT Transformer

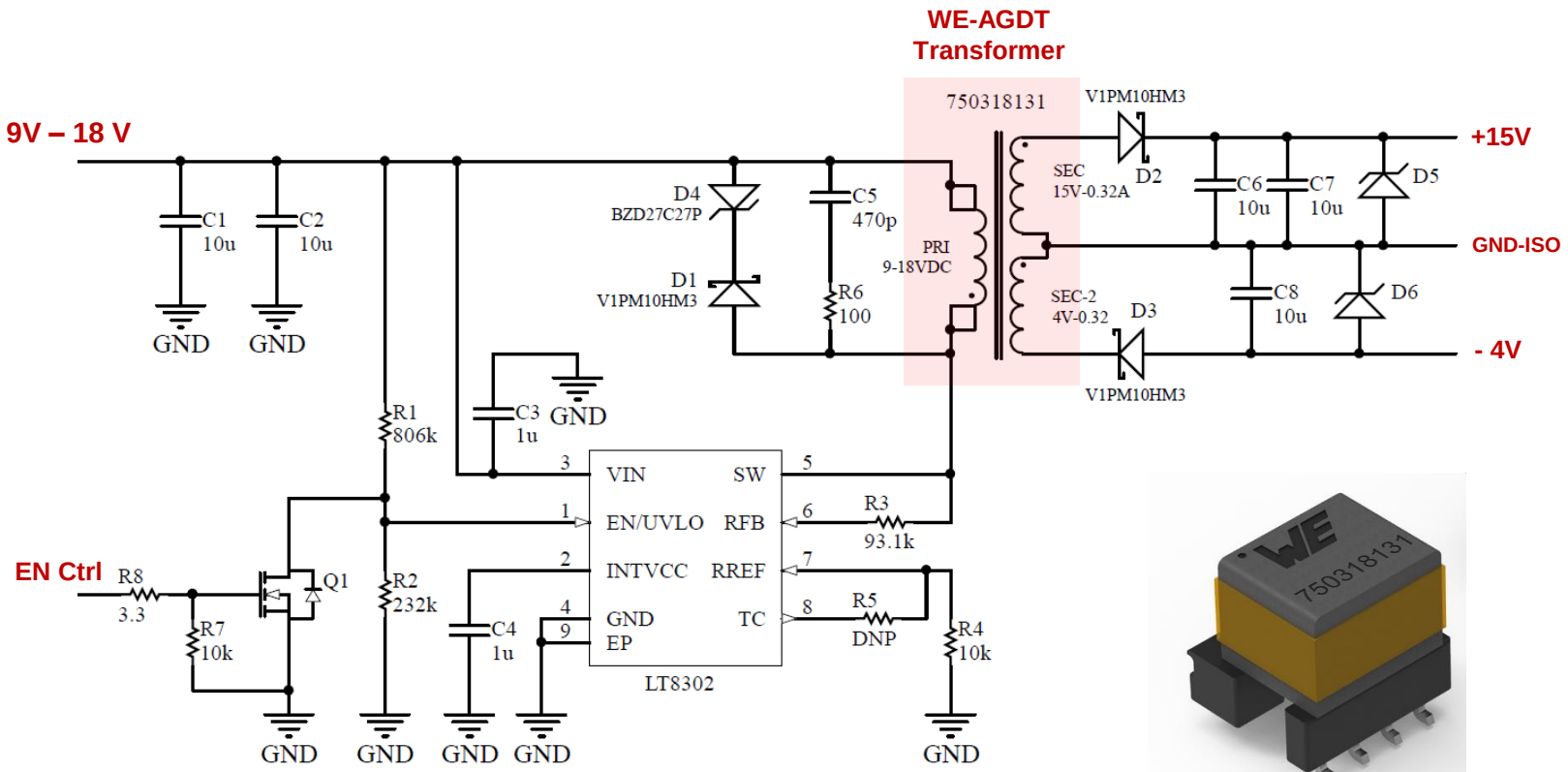
RD001: Example Integration in Gate Driver System (Buck-boost Converter)





Isolated PSR Flyback with WE-AGDT Transformer

RD001: WE-AGDT 750318131 Transformer

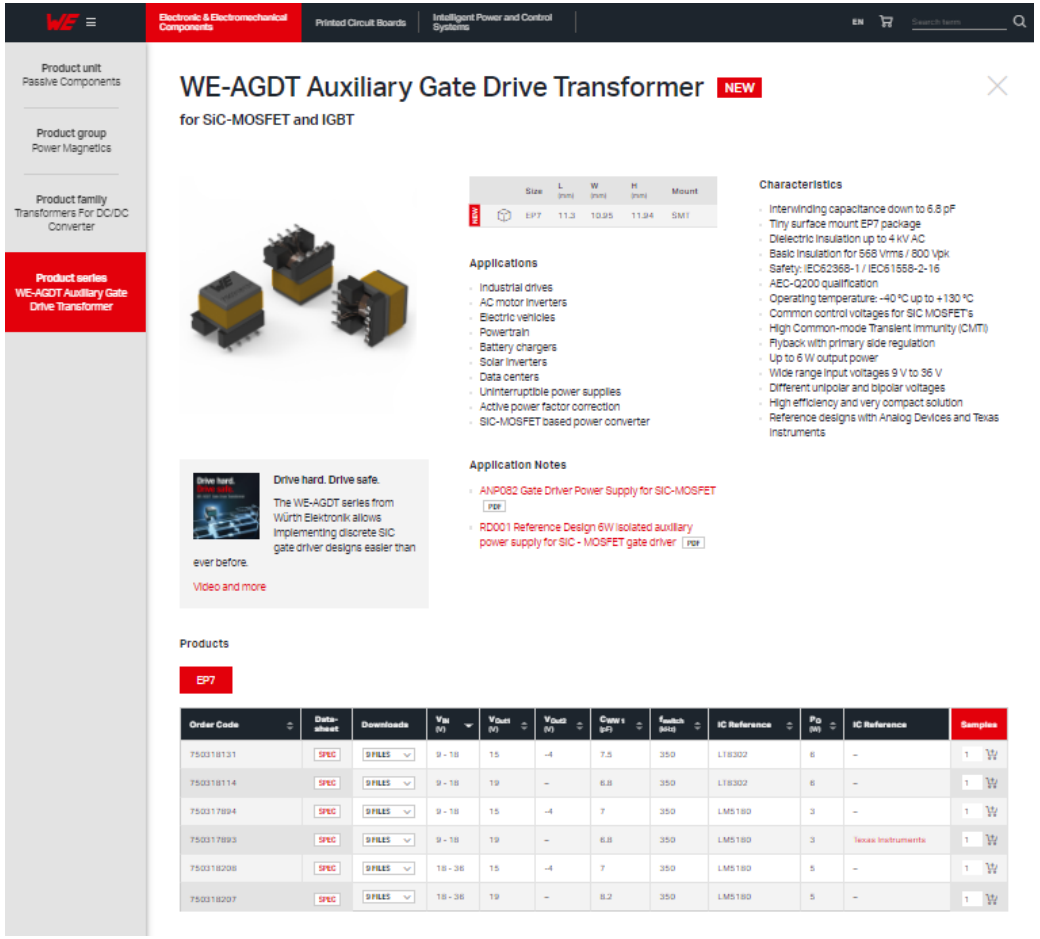


WE-AGDT Transformer

- Tiny EP-7 bobbin package
- SMD Assembly
- Basic Insulation
- 568Vrms/800Vpk
- 4 kV AC Dielectric Insulation
- IEC62368-1 / IEC61558-2-16
- AEC-Q200
- Cp = 7.5 pF (typ.)

Isolated PSR Flyback with WE-AGDT Transformer

WE-AGDT Transformer Series



WE-AGDT Transformers Online Catalog:
we-online.com/WE-AGDT

WE-AGDT Product Video:
we-online.com/gatedriver

Isolated PSR Flyback with WE-AGDT Transformer

WE-AGDT in Automotive Applications (as of April 2021)

- Formula-E as a harsh-environment testing field (e.g. vibration, humidity, etc).
- AEC-Q200 Qualification is already completed.
- Automotive Qualification (PPAP level-3, IATF 16949) is currently **in-progress**.

Automotive Catalog (standard products)

THANK YOU FOR YOUR ATTENTION !!

PLEASE, TYPE IN YOUR QUESTIONS …

… WE ARE HAPPY TO HELP YOU!