Maximizing the Power Density of DC Fast-Charging Systems with an LLC Power Supply

February 2023

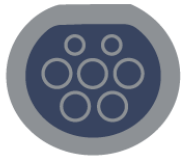
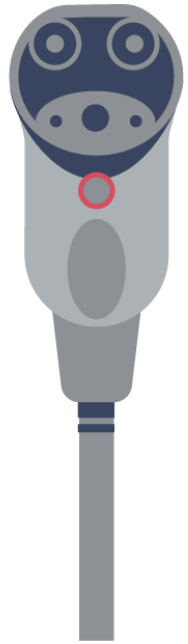
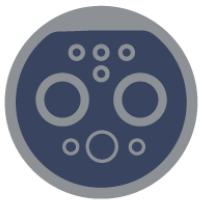
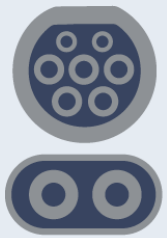
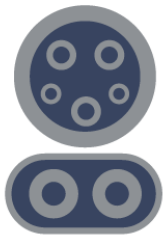
Agenda

- Overview of Charging Infrastructure
- DC Fast-Charging Station Block Diagram
- MPS Solutions for Charging Infrastructure
- Designing a Resonant LLC Power Supply
- Conclusion

Overview of EV Charging Infrastructure

- L1 Charger:
  - L1 chargers charge at 3kW or less
  - Uses OBC inside a vehicle to charge the battery
- L2 Charger:
  - L2 chargers charge at 3kW to 22kW
  - Uses OBC inside a vehicle to charge the battery
- DC Fast Chargers (DCFC):
  - DCFC charge at 50kW to 400kW, and can charge 10% to 90% of an EV battery in as fast as 18 minutes

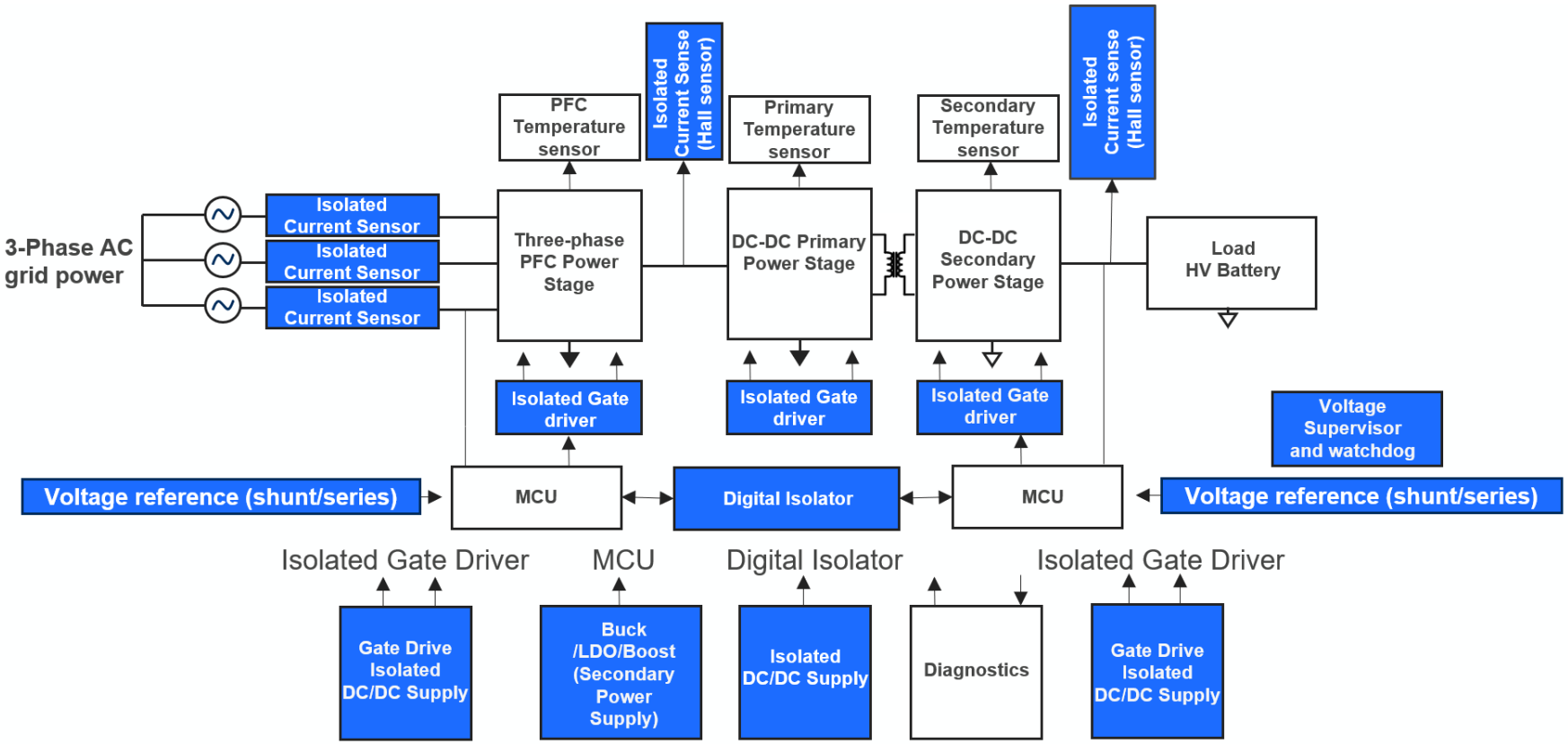
Charging Plug Standards Globally

	China	EU and rest of markets	North America South Korea	Japan	All Markets Tesla in EU uses CCS2
AC L1 (120V) Power:1kW-3kW L2 (208V-240V) Power:3kW-19kW	 GB/T	 Mennekes (Type 2)	 J1772 (Type 1)	 J1772 (Type 1)	 Tesla
DC L3/DC Fast Charger 400V-800V Power: 50kW-400kW	 GB/T	 CCS2	 CCS1	 CHAdeMO	

DC Fast-Charging System

DC Fast-Charging Station

- Converts a 3-phase AC voltage into a 250V to 800V DC voltage
- Contains several of the subunits on the right to get to a 350kW+ output
- Power factor correction (PFC) stage converts an AC voltage into an intermediate DC voltage
  - 3-phase, 3-level rectifier/inverter topology is typically used for the PFC stage
- Second stage converts the intermediate DC voltage into the target battery charging voltage



MPS Electrification – *We Know What Drives You*

Electrification

Si Carbide
Compatible solutions

Integration
Low component count
Lower solution cost

800V Solutions
Enable high-voltage charging solutions

Technology

Power | Analog

800+ SKUs
Broad portfolio with flexible, scalable solutions

MPSafe™
Functional safety ready

Experience

12 Years
Automotive industry

1.8 Billion
Automotive units shipped

Quality

10x
Finer quality record vs. industry standard

0.06 DPPM
Quality record

Run Cooler

Design Faster

Push Higher Performance

Achieve EMC Resilience

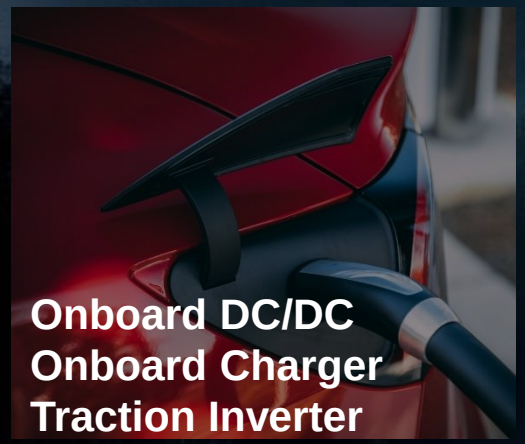
Capacitive Isolation

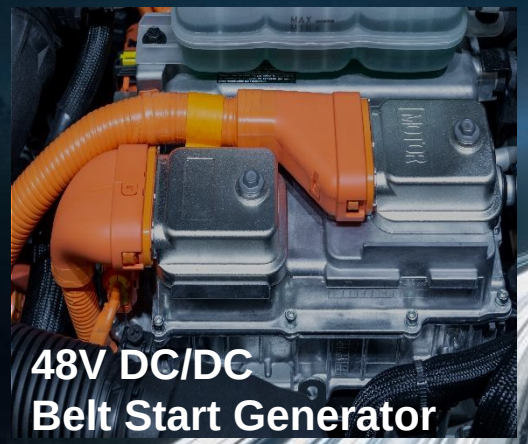
Integrated Solutions

Improve Quality

Extend Battery Runtime

Automotive EV/MHEV Applications





- Supports various isolation requirements to maximize system safety level
- Industry-leading performance
- Switching frequency up to 10MHz to minimize solution size

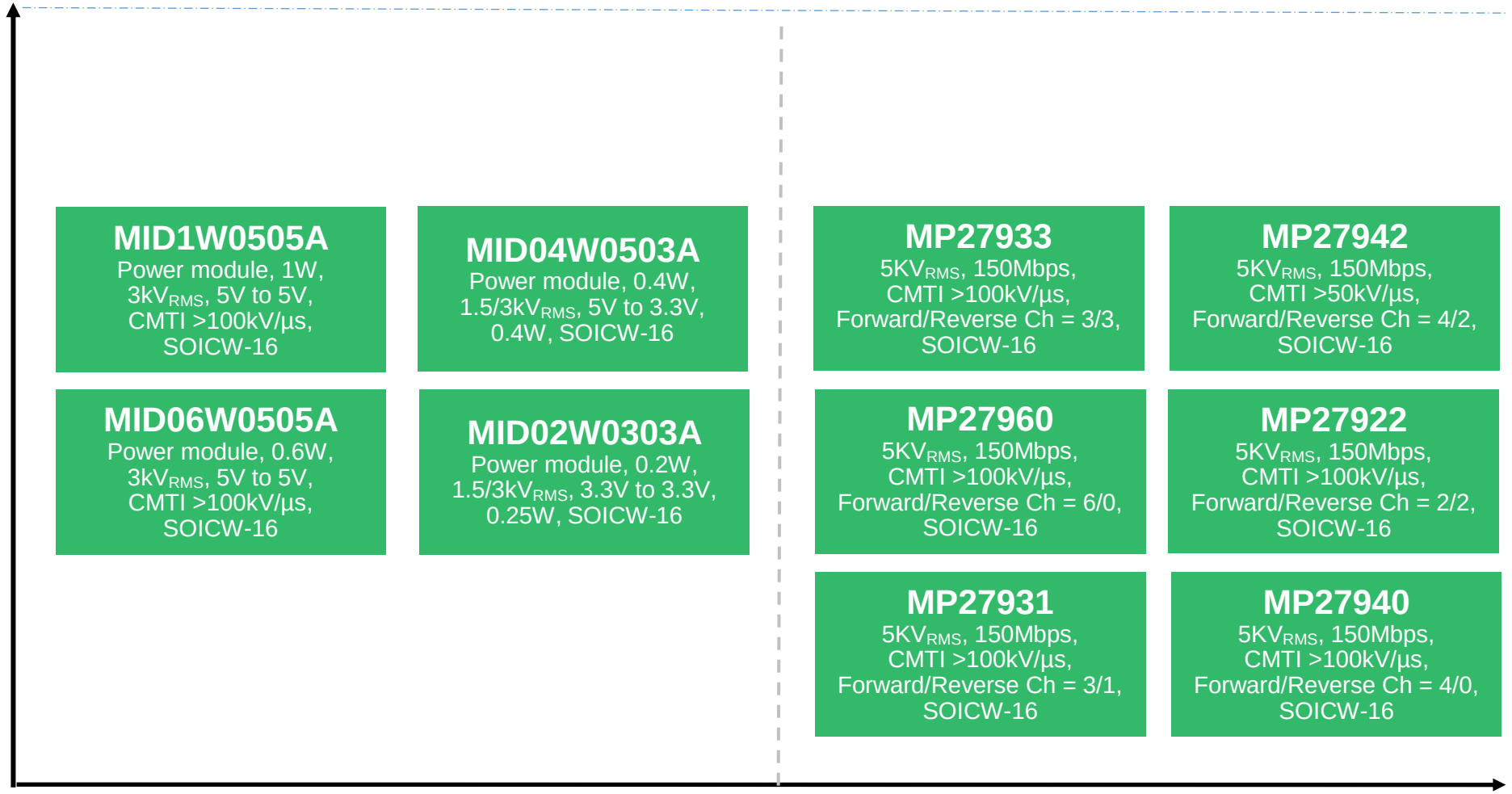
Isolated products compliant with different safety specifications:

- UL1577 – E322138
- VDE V 0884-11

AEC-Q100 Qualified Products

- Isolated Gate Drive
- Digital Signal Isolator
- Isolated Power
- Isolated Amplifier
- Half-Bridge GaN Driver

Digital Isolator/Power Supply Roadmap



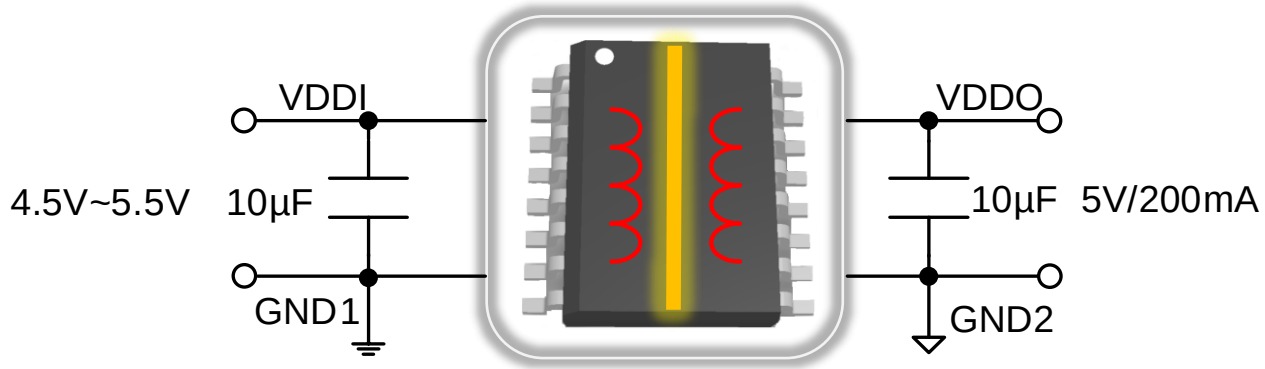
Newly Released Sampling

MID1W0505A- 5V to 5V Isolated Module

Key Features:

- Input Range: 3V to 3.6V or 4.5V to 5.5V
- 3.3V/5V Output Voltage
- Excellent Load Transient Performance
- 0.5% Load Regulation, 1.5% Line Regulation
- Strong Magnetic Field Immunity
- 0.25W, 0.4W, 0.6W, 1W Output Rating Option
  - MID1: 1W, MID06: 0.6W
  - MID04: 0.4W, MID02: 0.2W
- SCP, OCP, and OTP
- 3kV$_{RMS}$ Isolation
- 54% Efficiency
- Low Emission: Meets CISPR 32 Class B
- Small SOICW-16 Package

Typical Circuit



Applications

Industrial automation, PLC I/O modules
Grid protection relays
Isolated sensor power
Isolated bias for RS-485/CAN

MP(Q)279xx – 4~6 Channel digital isolator

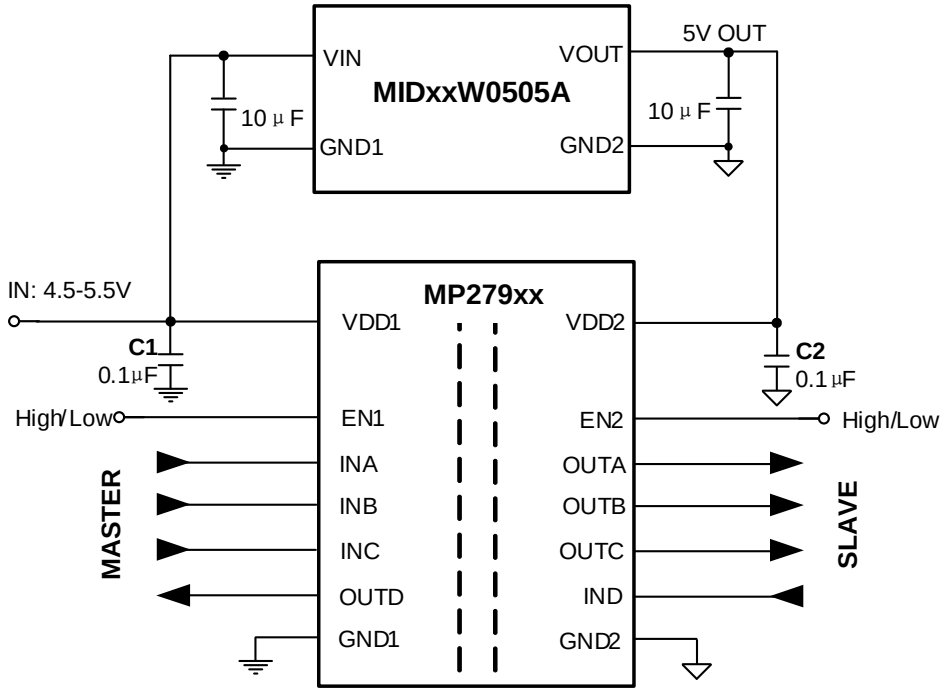
Key Features

- Wide Input Range: 2.5V to 5.5V
- Up to 150Mbps Data Rate, 20Mbps Option
- MP279xx family (forward channels/reverse channels)
  - 4 channel 31 (3/1), 40 (4/1), 22(2/2)
  - 6 channel 33 (3/3), 42(4/2), 60(6/0)
- Ultra-Low Power Supply Current
- High Electromagnetic Immunity
- >±100kV/μs Common-Mode Transient Immunity
- 13ns Propagation Delay for 5V Operation
- $5kV_{RMS}$ Isolation, $2.5kV_{RMS}$ Option
- Selectable Channel Direction
- Selectable Output Default Value
- Available in SOICW-16

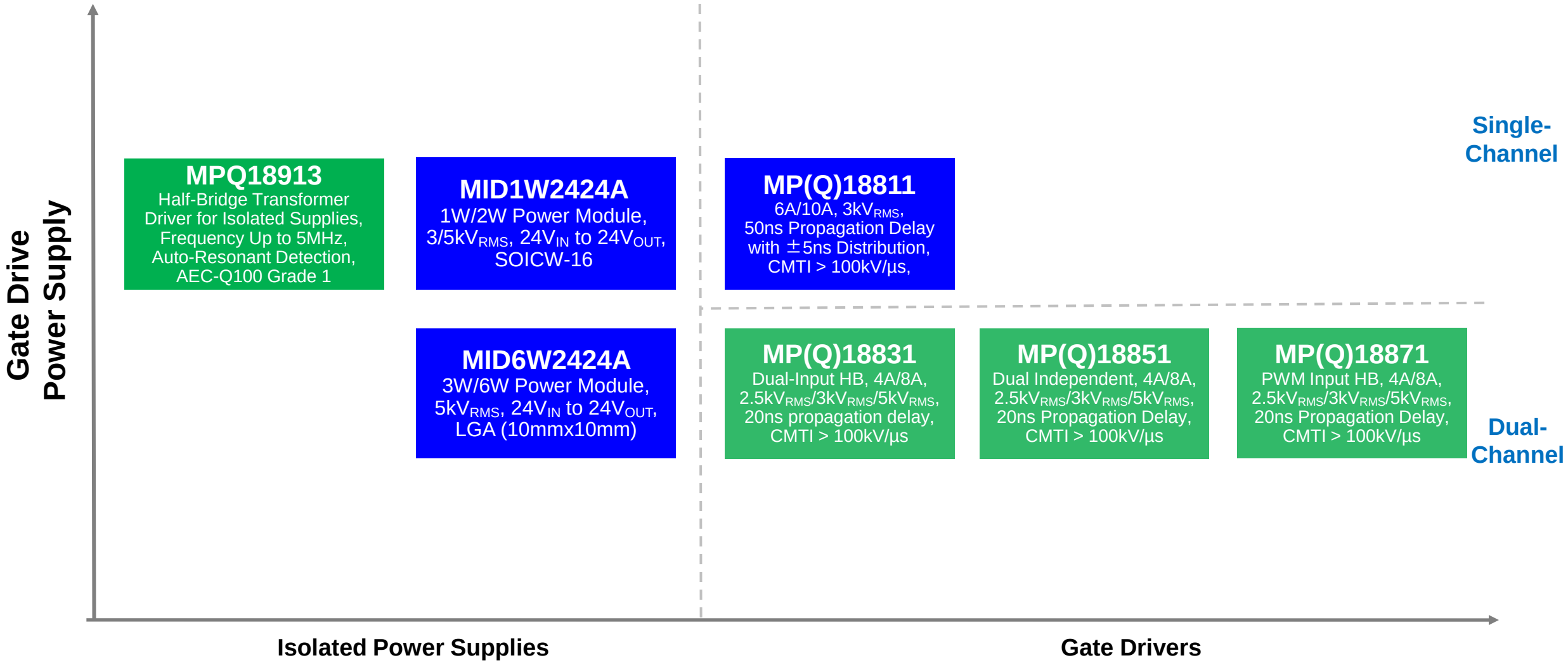
Applications

- E-Meters, Isolated ADCs/DACs, Motor Control, Industrial Automation, SPI Isolation

Typical Circuit



Isolated Gate Driver/Power Supply Roadmap

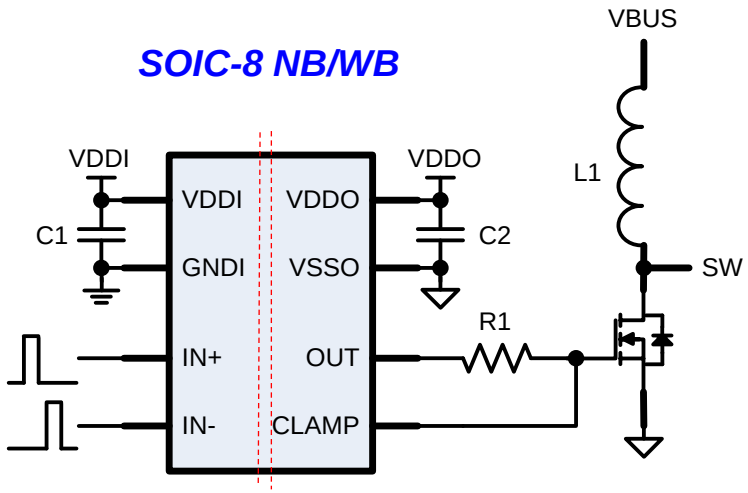


MP(Q)18811 – Isolated Single-Channel Gate Driver

FEATURES

- 5kV for SOIC-8 WB, 3kV$_{RMS}$ Input to Output Isolation for SOIC-8 NB
- CMTI >100kV/μs
- TTL and CMOS Compatible Inputs
- Differential-Input Control
- Up to 30V Output Drive Supply with UVLO Options (5V/8V/10V/12V/15V)
- Output Configurations: Single-Output with Miller Clamp or Split Outputs
- 6A Source/10A Sink Peak Current Output
- 50ns Typical Propagation Delay
  - Tight ±5ns Distribution from Part to Part
- Active Miller Clamp
- Operating Junction Temperature Range –40℃ to +150℃
- Packages: SOIC-8 NB, SOIC-8 WB
- AEC-Q100 Qualified (MPQ18811)

SOIC-8 NB/WB



Applications

- SiC/IGBT Gate Drive Power Supply
- Industrial Automation, PLC I/O modules
- DC Fast Charger
- Grid protection relays

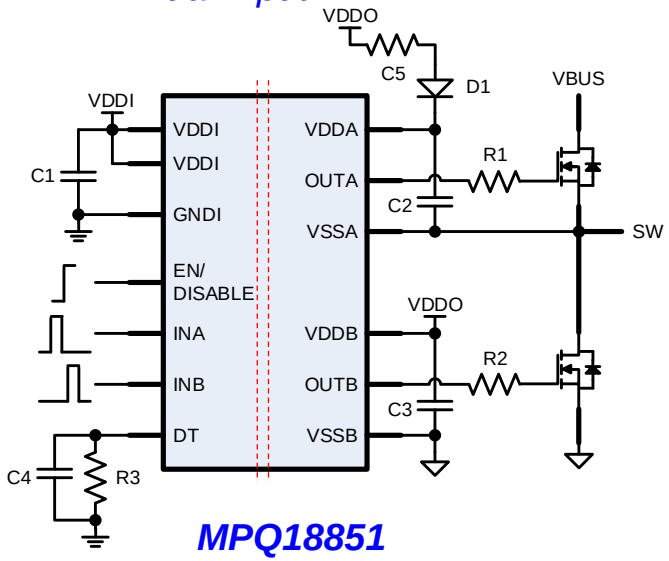
MP(Q)1883/5/71 - Isolated Dual-Channel Gate Driver

FEATURES

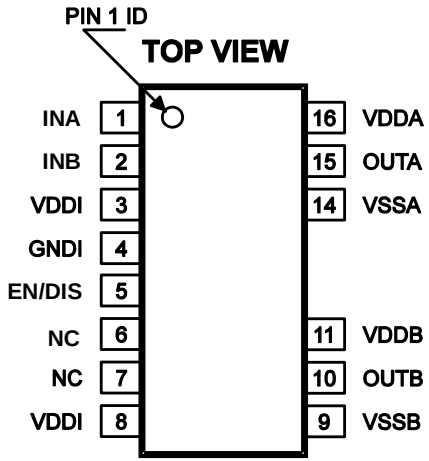
- Flexible Configuration: Rich Family, Independent Dual-Channel Driver, Dual-/PWM-Input Half-Bridge Driver
- Up to $5kV_{RMS}$ Isolation
- CMTI >100kV/µs
- TTL and CMOS Compatible Inputs
- 30V Output Drive Supply with UVLO Options (5V/8V/10V/12V/15V)
- 4A Source/ 8A Sink Peak Current Output
- 50ns Typical Propagation Delay
  - Tight ±10ns Distribution from Part to Part
- Standard Packages: Narrow Body SOIC-16; Wide Body SOIC-16, 5mm x 5mm LGA-13, Wide Body SOIC-14 Packages (3.3mm creepage)
- AEC-Q100 Qualified
- Operating Junction Temperature Range –40°C to +150°C

MPQ18831

Dual Input HB

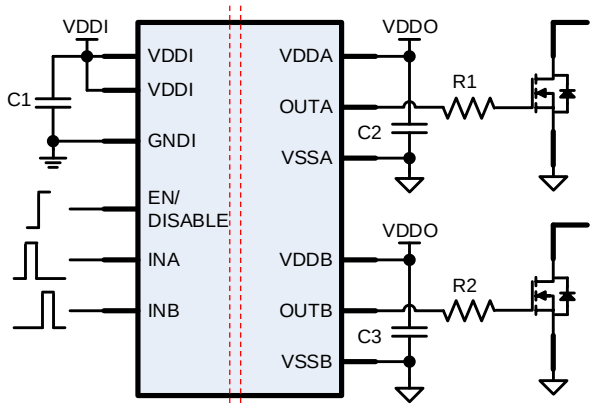


3.3mm creepage



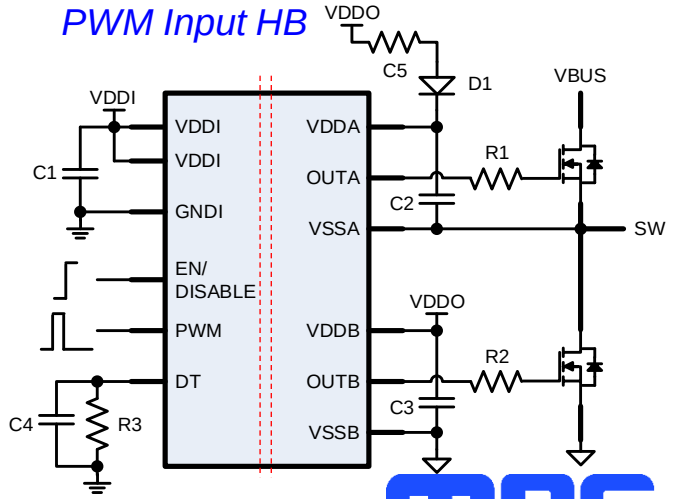
MPQ18851

Dual Independent Drivers



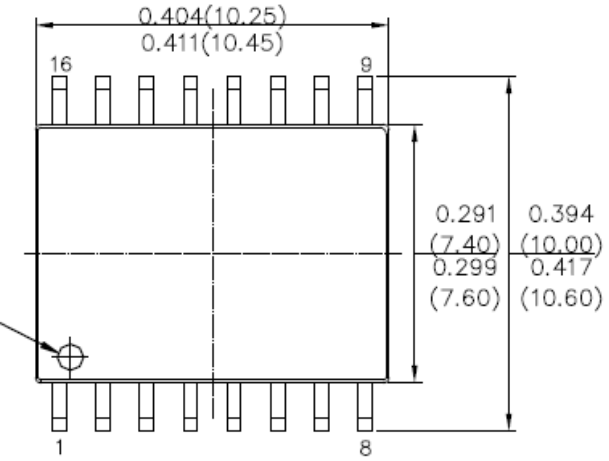
MPQ18871

PWM Input HB

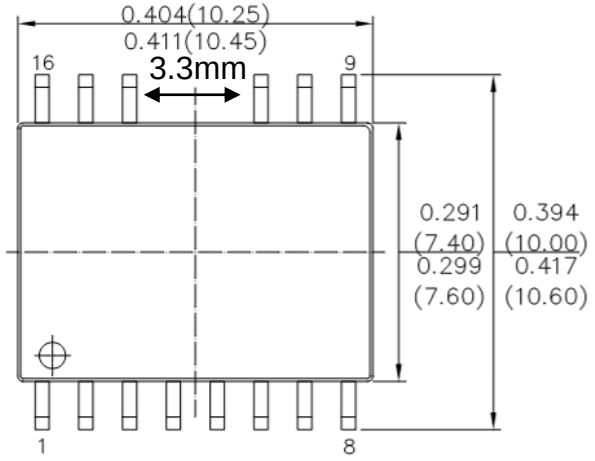


Isolation Voltage Rating with Different Packages

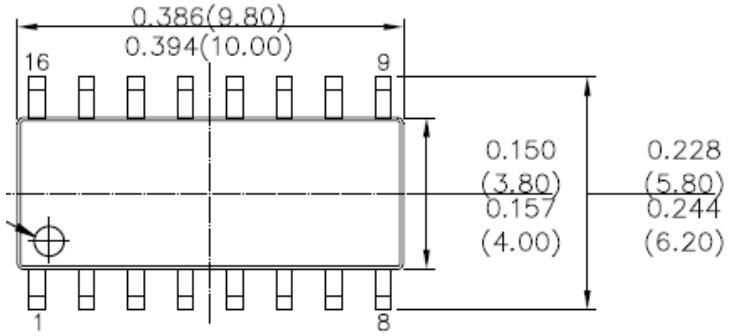
SOIC-16 WB



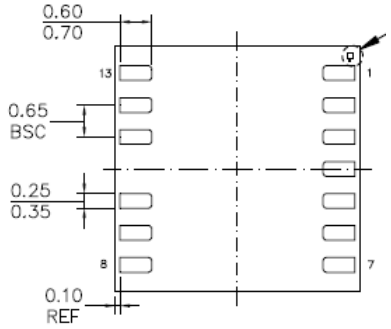
SOIC-14 WB



SOIC-16 NB



LGA-13



Package	Isolation Rating
SOIC-16 WB/SOIC-14 WB	$5kV_{RMS}$
SOIC-16 NB	$3kV_{RMS}$
LGA-13	$2.5kV_{RMS}$

MID6W2424A- 24V to 24V Isolated Module

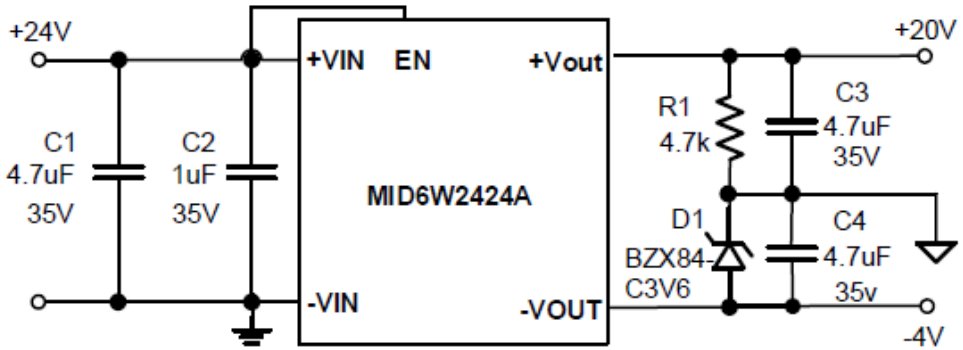
Key Features:

- Input Range: 5V-30V (Typical: 24V ± 10%)
- Power level 3W/6W, **87% peak efficiency**
- Transformer Turns ratio
  - MID6W1224/MID3W1224 1:2 turns ratio
  - MID6W1524/MID3W1524 1:1.6 turns ratio
  - MID6W2424/MID3W2424 1:1 turns ratio
- Strong Magnetic Field Immunity
- SCP, OCP, OTP Protection
- 5kVrms Isolation
- LGA 10x10mm package
- Operating Temperature -40C to 105C

Applications

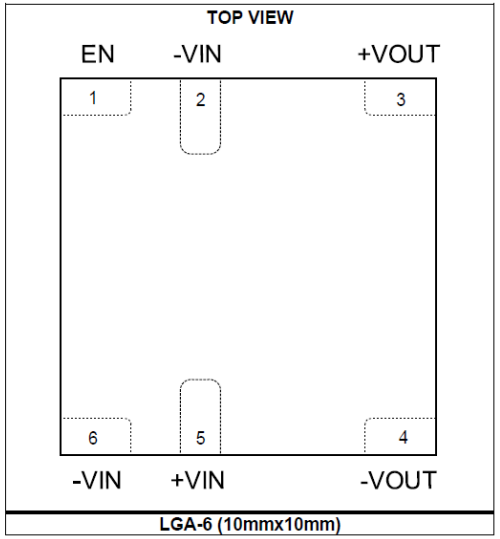
- SiC/IGBT Gate Drive Power Supply
- Industrial Automation, PLC I/O modules,
- Grid protection relays

Typical Circuit



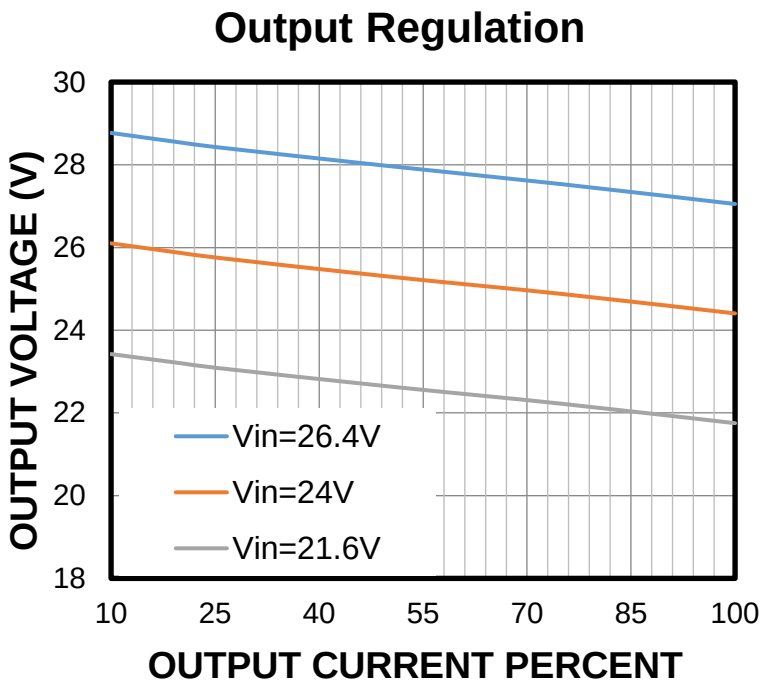
SiC Gate Drive Power Supply

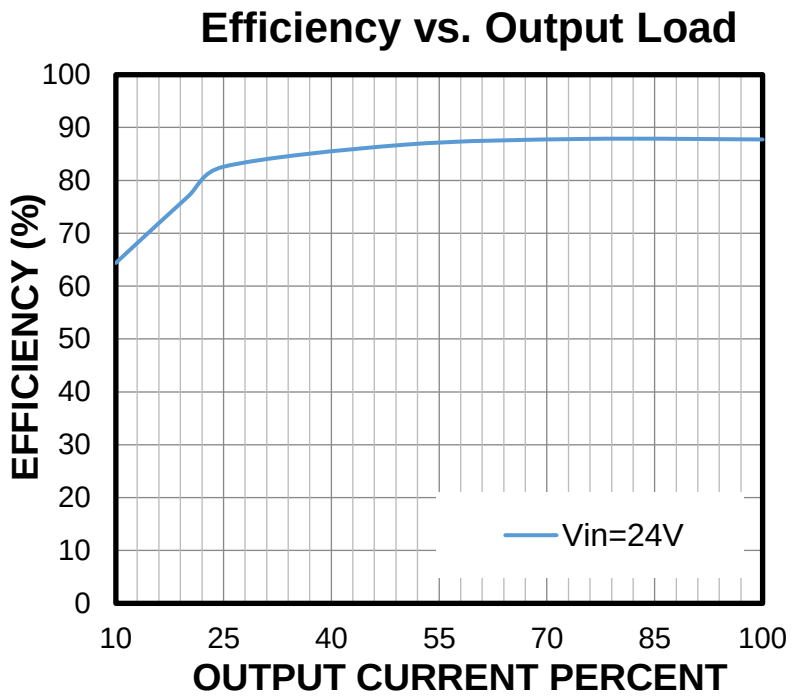
PACKAGE REFERENCE



MID6W2424A performance

V_{IN} = 24V, I_{out} = 0.25A (Full Load), T_A = +25°C.





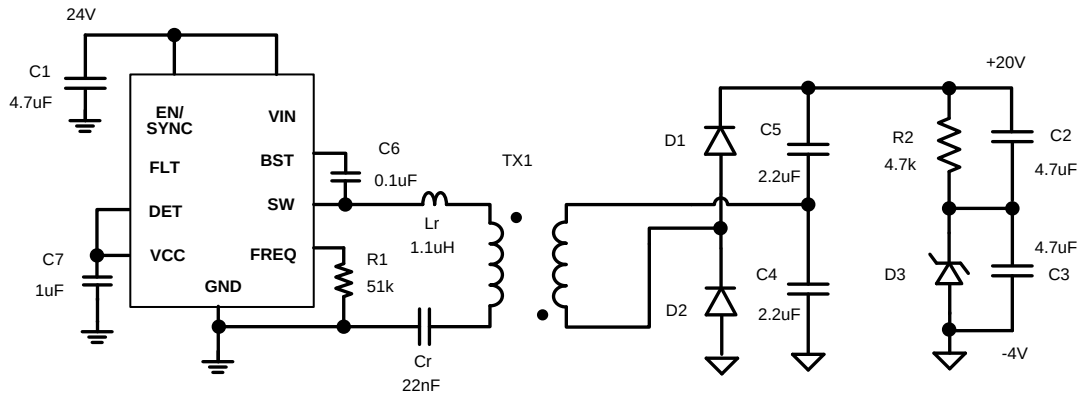
MPQ18913 – 30V, 0.5A LLC Transformer Driver for Isolated Bias Supplies

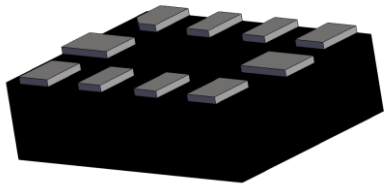
FEATURES

- 5V to 30V Input Voltage Range (50V Surge)
- Half-Bridge Transformer Driver for Isolated LLC Resonant Converters
- Configurable Frequency: 750kHz to 5MHz (913)
- Configurable Frequency: 750kHz to 10MHz (914)
- External Clock Input for Switching Synchronization
- Automatic Resonant Frequency Detection
- Optional Spread Spectrum for EMI Reduction
- Internal Soft Start
- OCP, SCP, OVP, OTP and FLT Reporting
- Supports Up to 5W
- Available in a QFN-10 (2mmx2.5mm) Package with Wettable Flanks

Applications

- IGBT/SiC Gate Driver Bias
- EV DC Fast-Charging Stations
- EV Traction Inverters/Onboard Chargers

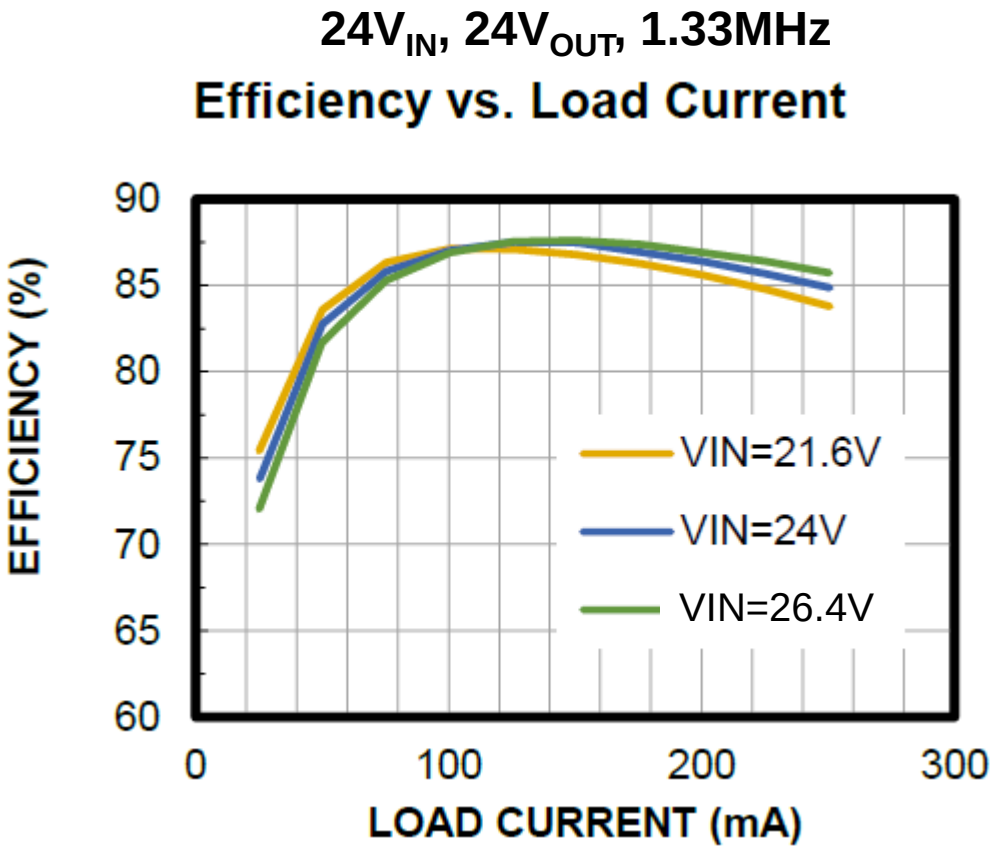




Available in a QFN-10 (2mmx2.5mm) Package

MPQ18913 Evaluation Board

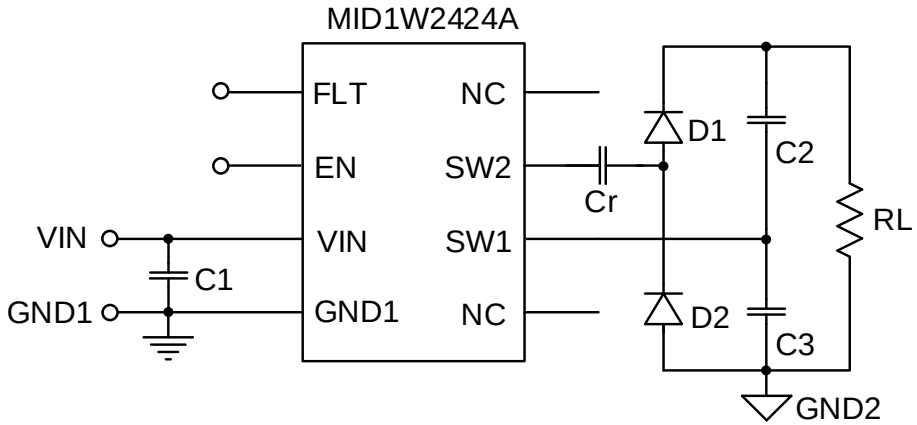
EVQ18913-D-00A Evaluation Board



MID1W2424A – 1W/2W, 24V Isolated Module

FEATURES

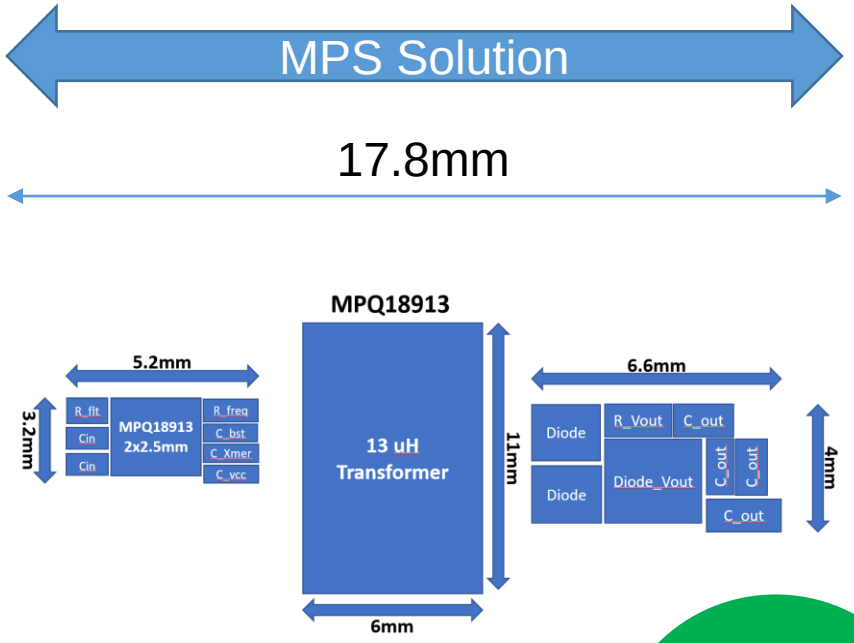
- 5V to 30V Input Voltage Operation Range
- $3kV_{RMS}$, $5kV_{RMS}$ Isolation Voltage Options
- 1W, 2W Output Power Options
  - Integrated 1:1 Transformer
- 60% Efficiency with Full Load
- 100kV/µs CMTI
- 8pF Isolation Capacitance
- Soft Start, OCP, Input OVP, OTP, and FLT Indicator
- **AEC-Q100 Option**
- Operating Temperature -40°C to 125°C
- Available in an SOICW-16 Package

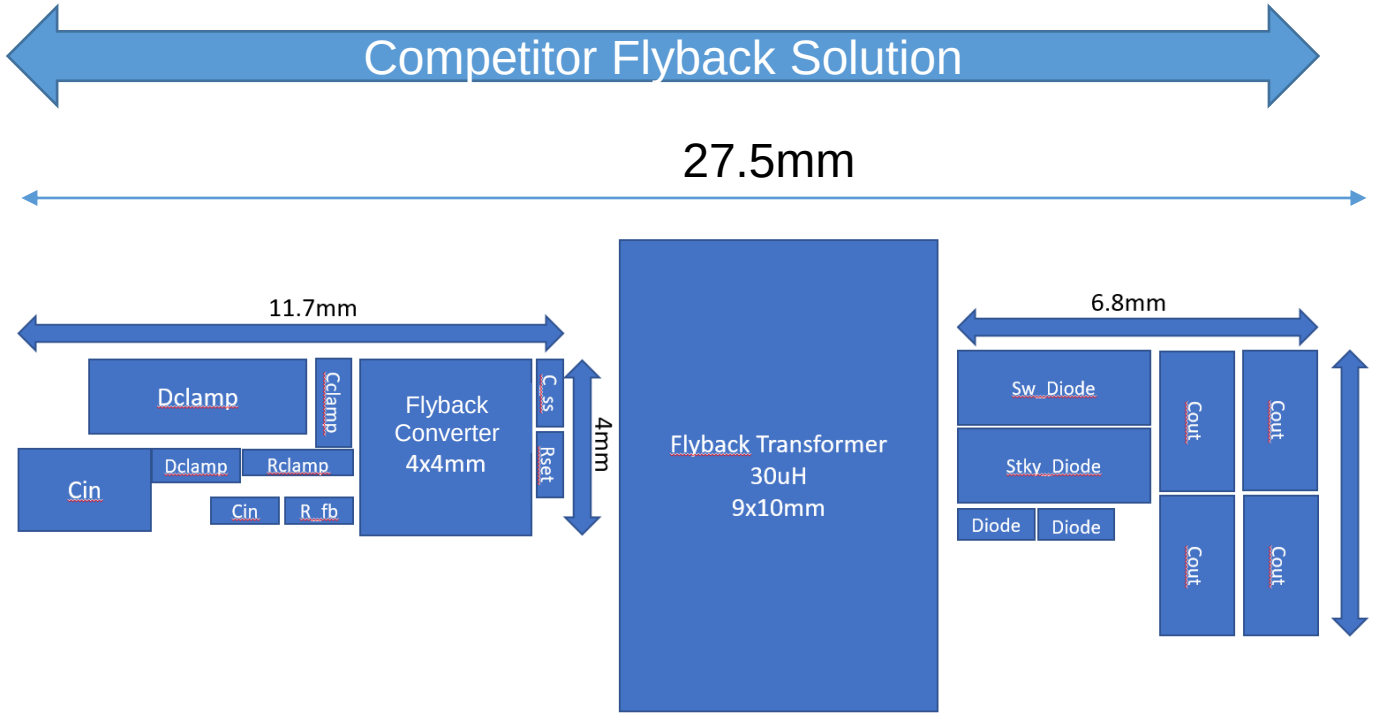


Applications

- IGBT/SiC Gate Driver Bias
- EV DC Fast-Charging Stations
- EV Traction Inverters/Onboard Chargers

PCB Footprint Analysis – Isolated Bias Supply





40% Smaller Solution Size!

Solution Size: 109mm²
Total Area: 196mm²
Components: 21

Solution Size: 180mm²
Total Area: 275mm²
Components: 26

MPQ18913 vs. Flyback BOM Cost Analysis

	MPQ18913 LLC Resonant Topology	PSR Flyback Converter Topology
HV Capacitor	11.6µF (= $0.12)	4.7µF + 0.1µF (= $0.05)
LV Capacitor	2µF (= $0.01)	64µF + 47nF (= $0.32)
Schottky Diode	2 (= $0.08)	1 (= $0.04)
Zener Diode	0	3 (= $0.12)
Switching Diode	0	1 (= $0.04)
Resistors	2 (= $0.02)	3 (= $0.03)
Transformer	13uH, 11x6mm ($0.36)	30µH, 9mmx10mm ($0.50)
IC	X	X
BOM Cost	**= $0.59 + X**	**= $1.10 + X**

46% Lower BOM Cost!

LV capacitor assumed to be $0.05/10µF
HV capacitor assumed to be $0.10/10µF

MPQ18913 vs. MID1W2424 BOM Size Comparison

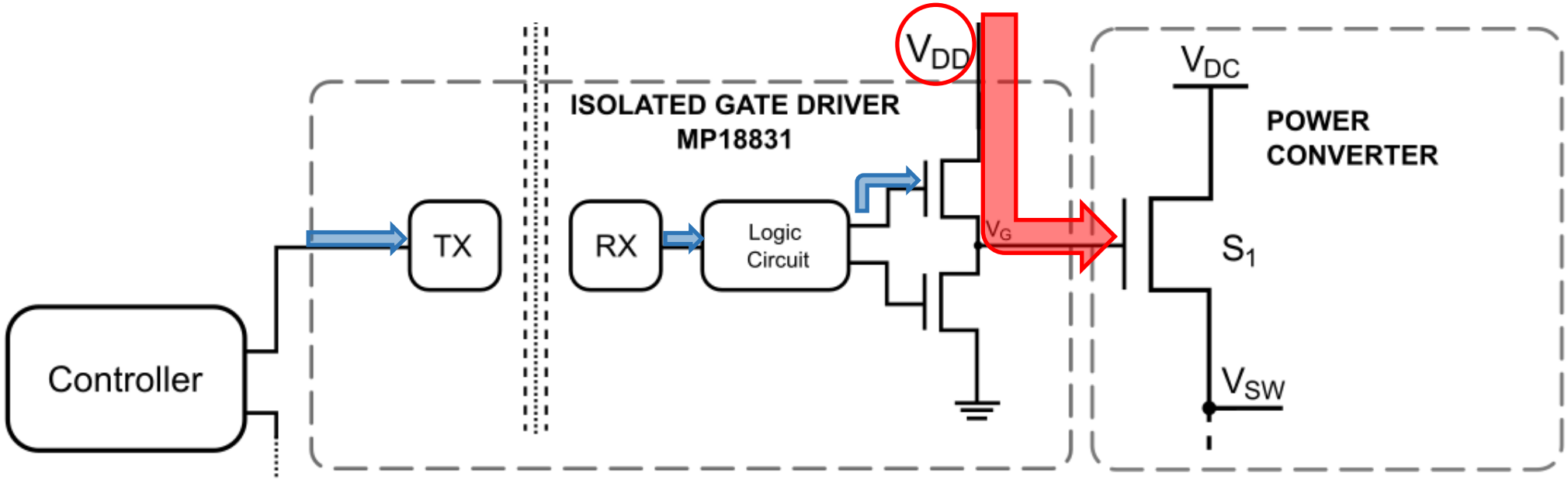
	Discrete Solution MPQ18913	Module Solution MID1W2424
PCB Area for LV Size	25mm^2	120mm^2
Transformer Size	7 x 9 = 63mm^2	N/A
PCB Area for HV Size	30mm^2	30mm^2
Total Area	120mm^2	150mm^2
Max Height	9mm	2.65mm

- Transformer height is estimated by the creepage requirement of 7.1mm
- Discrete solution is smaller due to a small 63mm^2 transformer
- **The main advantage of module solutions are in the total height requirement from integrating the transformer**

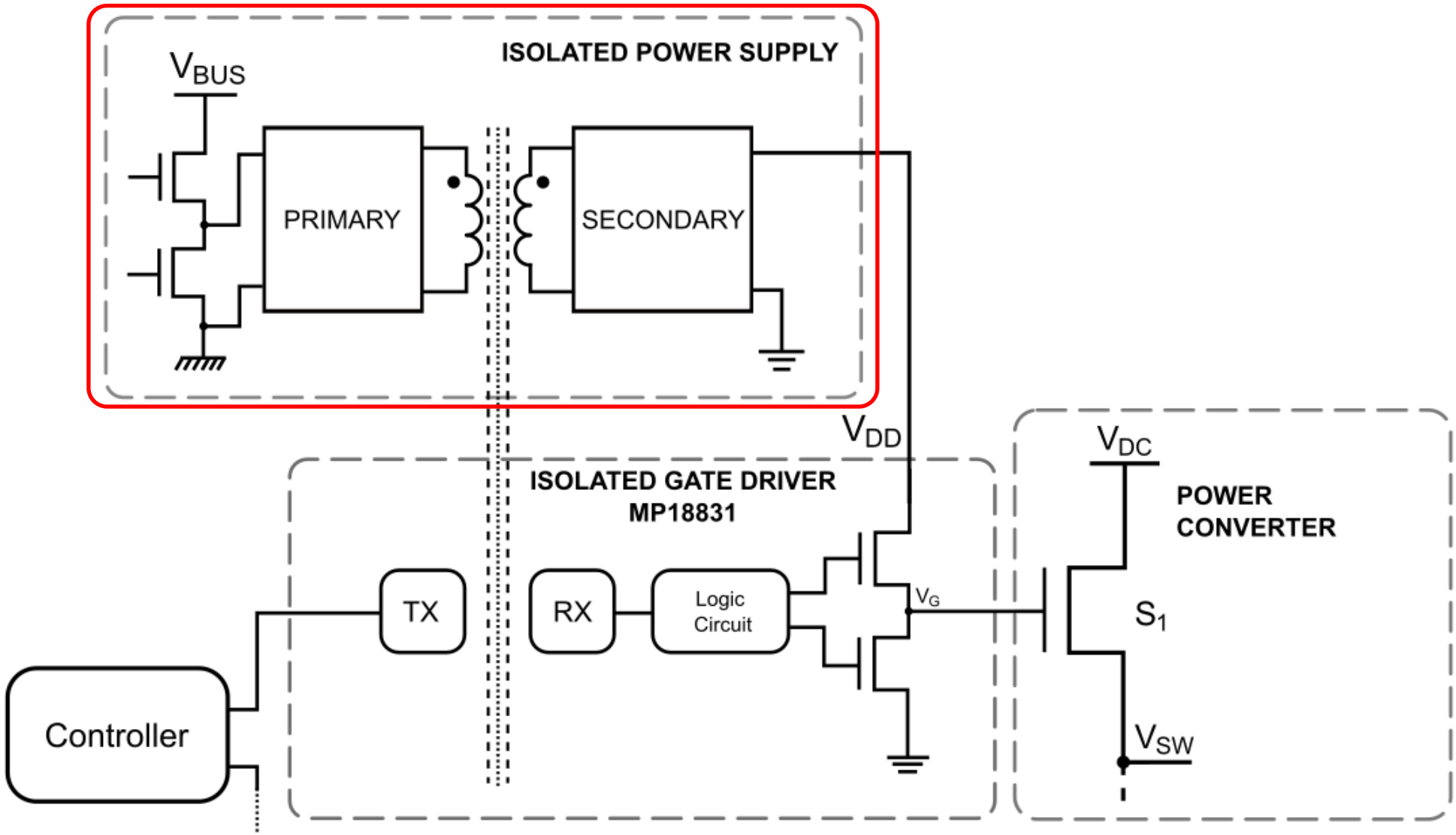
MPQ18913 vs. Flyback Topology

	MPQ18913/4 LLC Resonant Topology	Competitor PSR Flyback Topology
Switching Frequency	High (Up to 10MHz)	Low (<400kHz)
Transformer Size	13µH (11mmx6mm)	30µH (10mmx10mm)
Leakage Inductance	Utilize leakage inductance as part of resonant tank	Leakage inductance induce voltage spike and extra loss
Isolation Voltage	High (up to 5kV)	Low (1.5kV)
Isolation Capacitance	Low (6pF)	High (13pF to 25pF)
EMI Emissions	Better	Worse
Package Size	2mmx2.5mm	4mmx4mm
Diodes (including Zener)	3	6
Solution Size	109mm^2	180mm^2
BOM Components	21 components	26 components

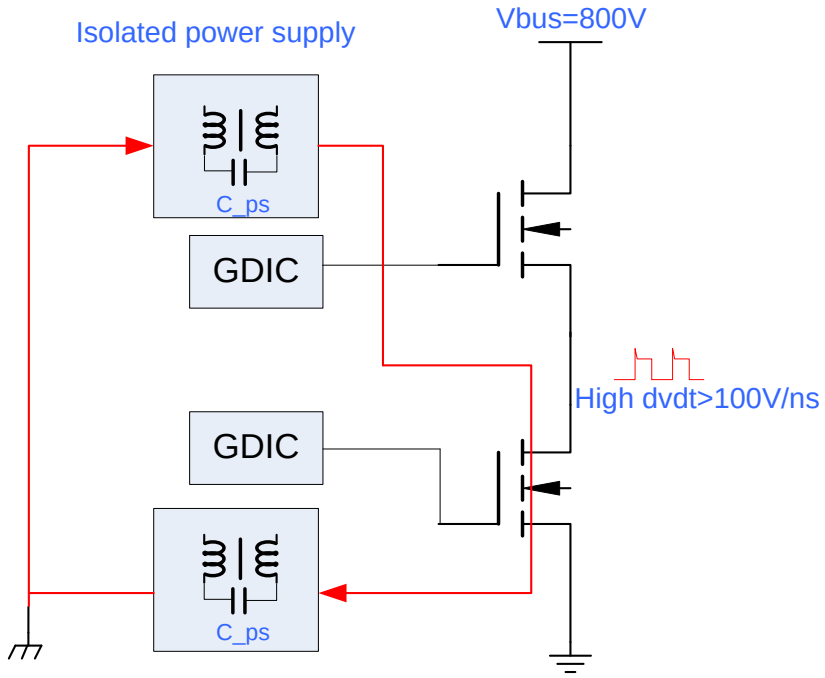
Isolated Power Supplies for Gate Drivers



Isolated Power Supplies for Gate Drivers (contd.)



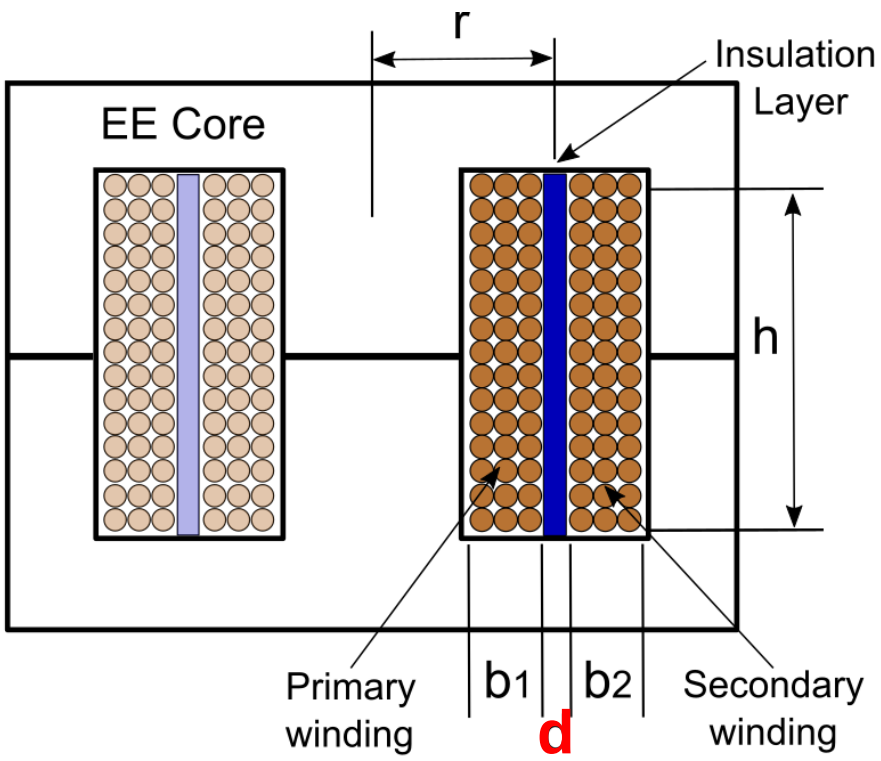
Transformer Requirements for Gate Drive Power Supply



Trends on High-power Systems:

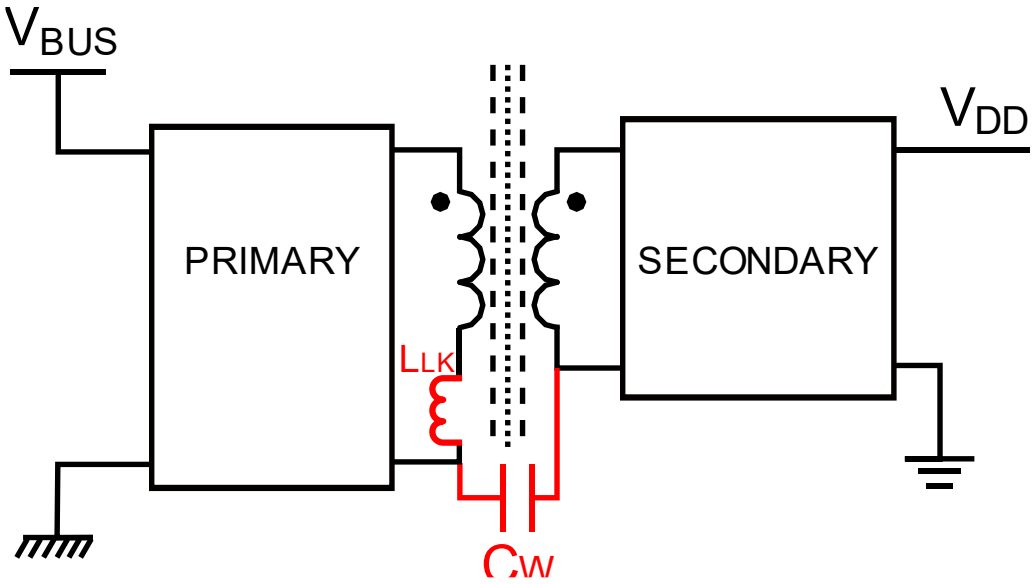
- Bus Voltage Increase → Higher Isolation Voltage Needed for Transformers
- Higher dV/dt → Requires Lower Interwinding Capacitance
  - Assuming 20pF Capacitor
  - I_{CM} = 100V/ns x 20pF / 2 = 1A
  - I_{CM} is disruptive to the MCU, GDIC, and GDPS

Low-Capacitance Transformer Design

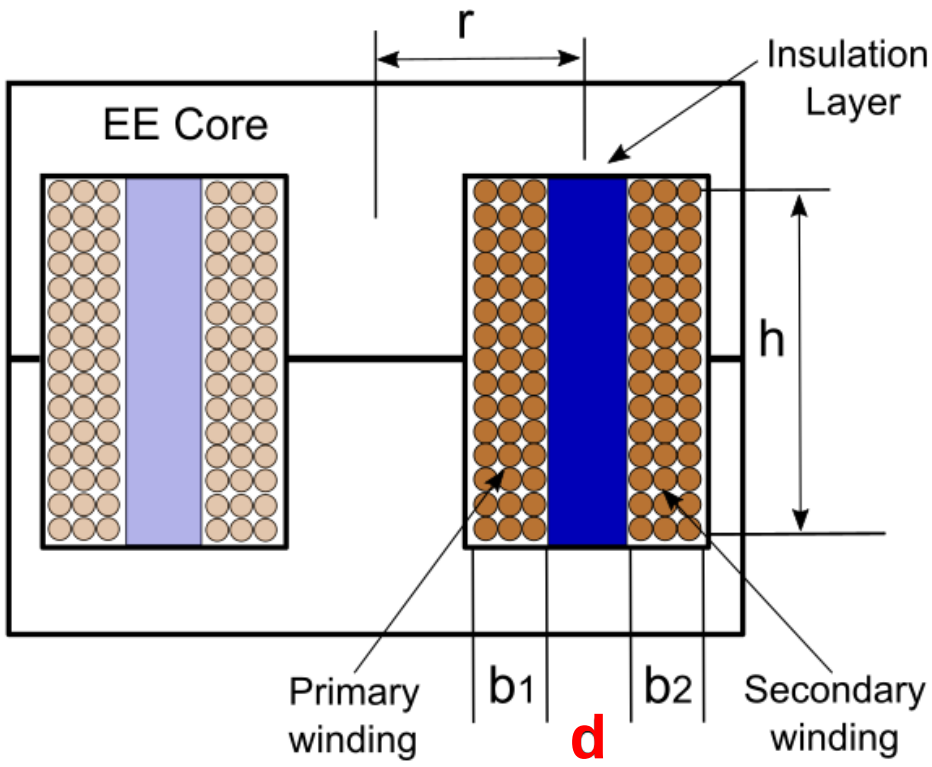


$$C_W = \frac{\epsilon_0 \epsilon_r A}{d}$$

To decrease C_W → Increase the distance between windings



Low-Capacitance Transformer Design

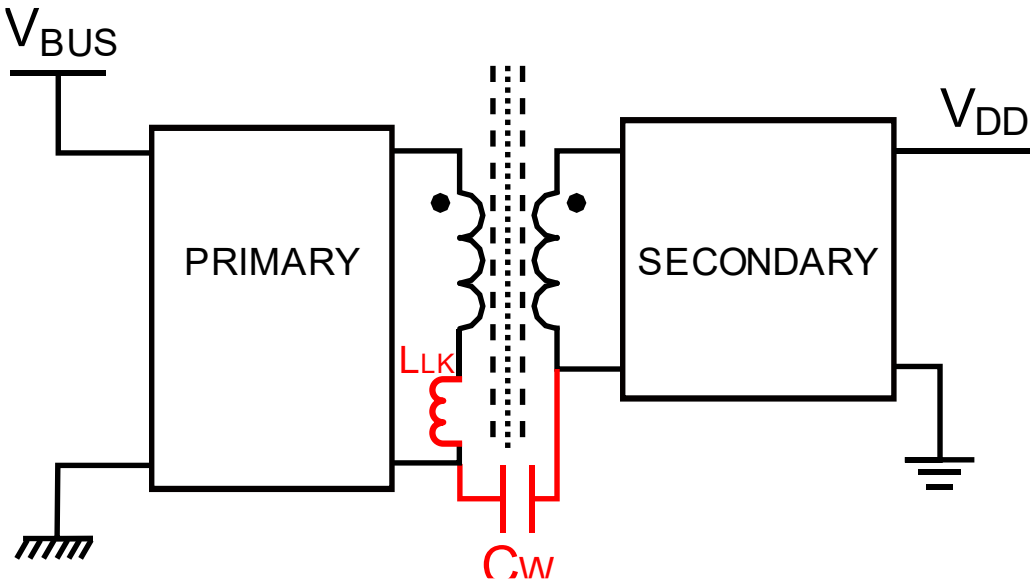


$$C_W = \frac{\epsilon_0 \epsilon_r A}{\boldsymbol{d}}$$

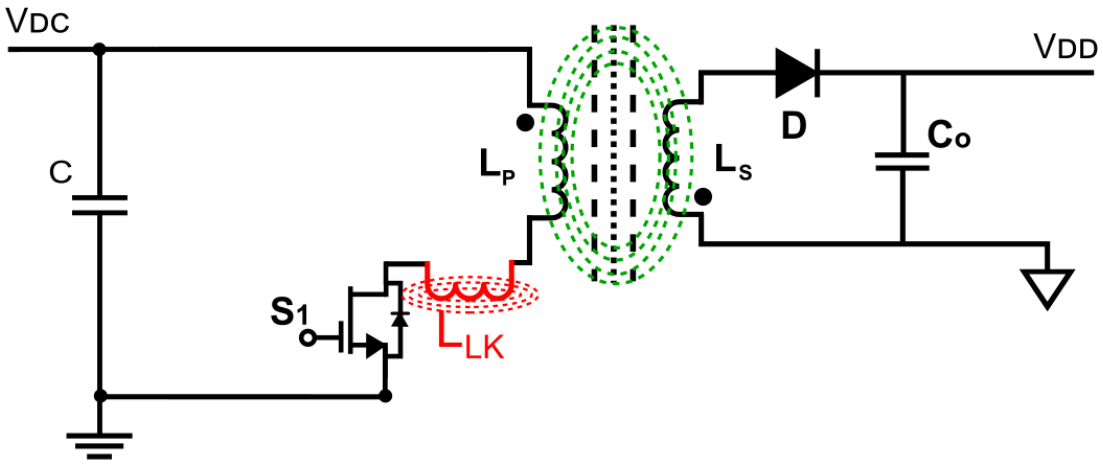
To decrease C_W → Increase the distance between windings

Increase the distance between windings → Increase L_{LK}

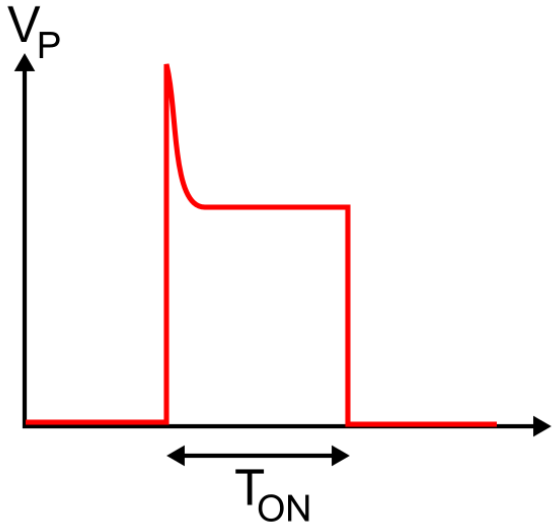
$$L_{LK} = \frac{8\pi^2 \times r \times N_P^2}{h}\left(\boldsymbol{d} + \frac{b_1 + b_2}{3}\right)$$



Flyback Converter Operation with L_{LK}

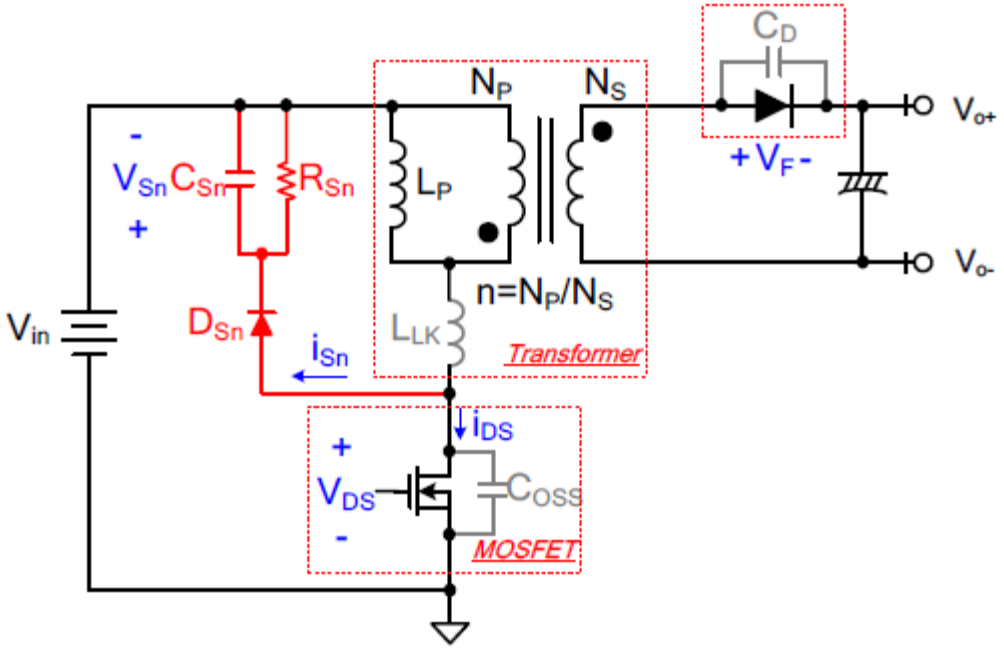


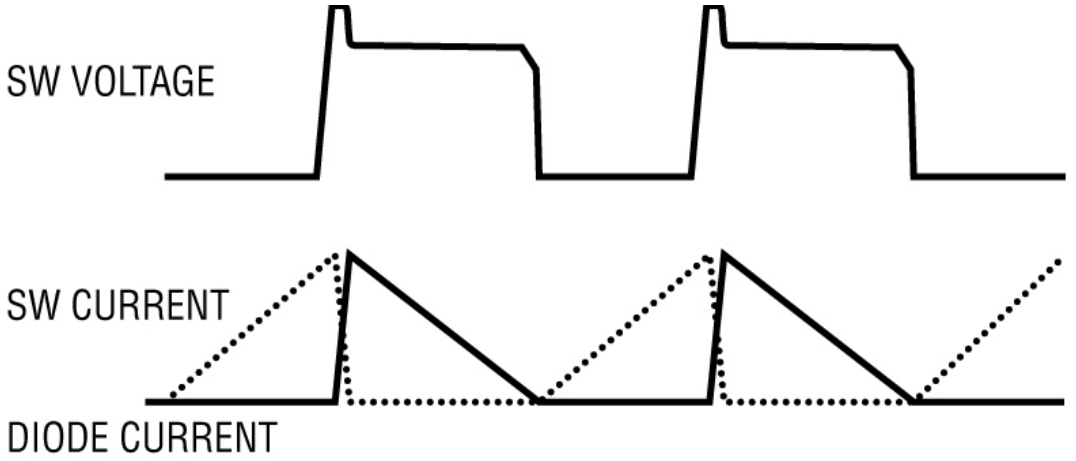
Flyback Converter



Voltage across Primary

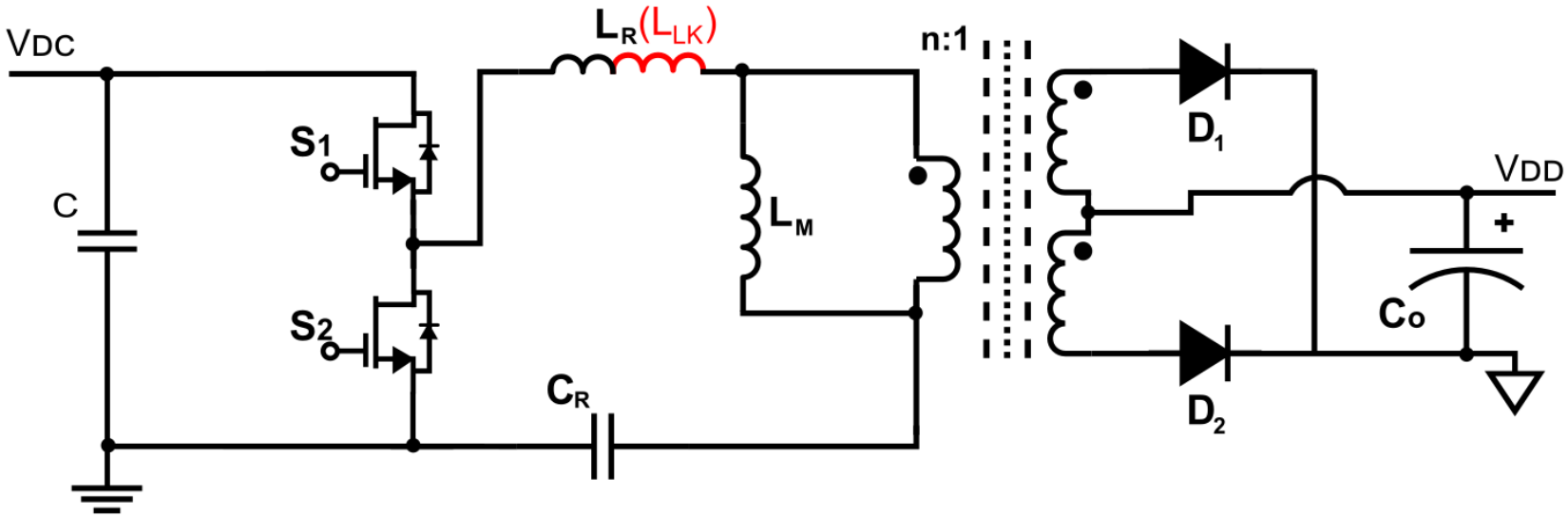
Flyback Converter with Clamping Circuits





SW voltage spikes increase the device rating, complicate snubber design, generate loss and noise, and limit the max operating frequency.
The larger the leakage, the worse the performance of the flyback

LLC Converter Operation with L_{LK}

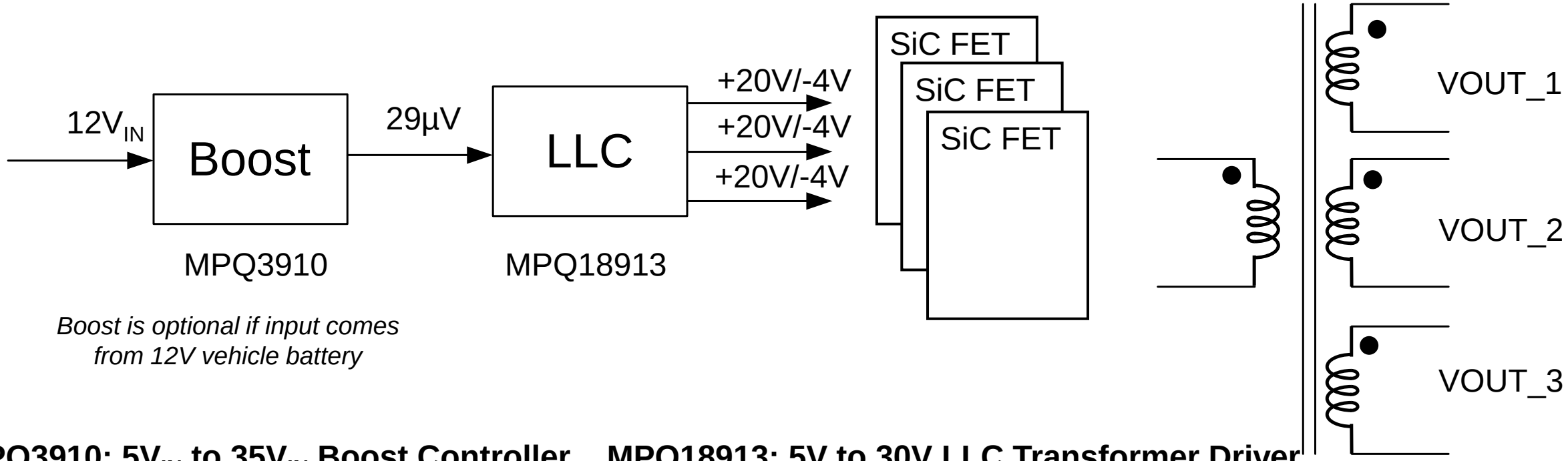


Soft Switching - ZVS → High Switching Frequency Achievable with LLC

Sample Design for Biasing SiC FETs

Multi-Output with the MPQ18913

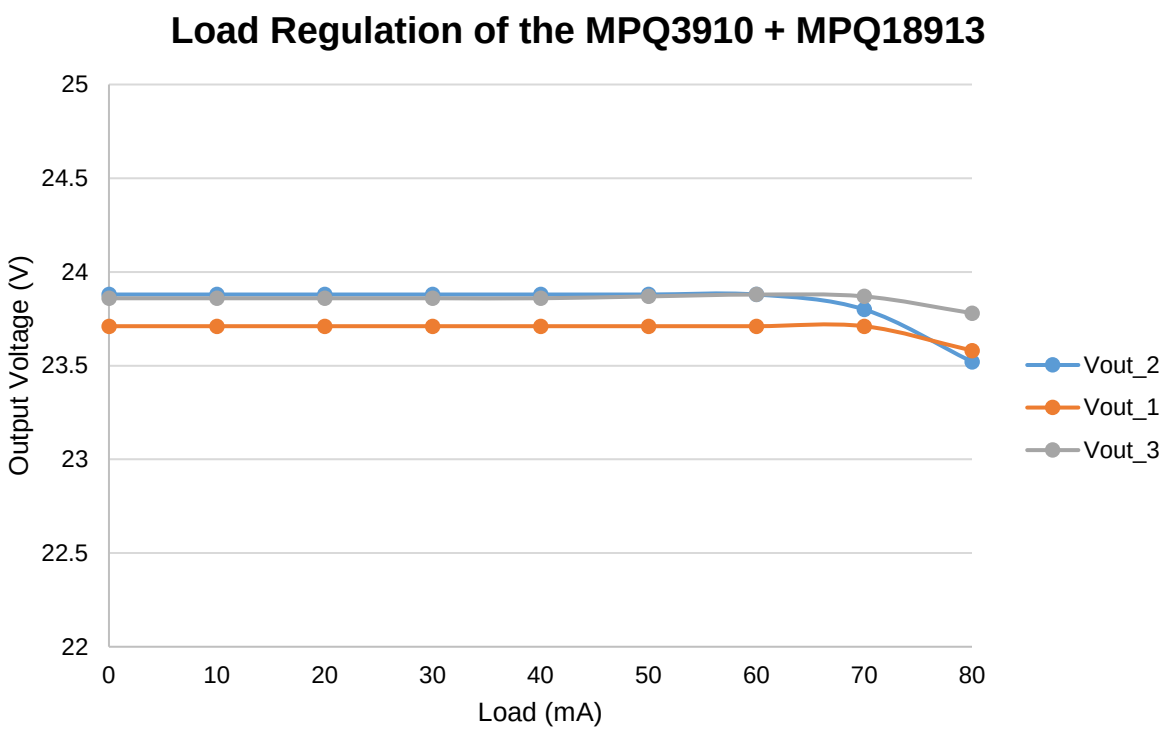
- 2 slots to separate the primary and secondary
- C_{PS} < 1pF, L_M = 28µH, LK = 5µH

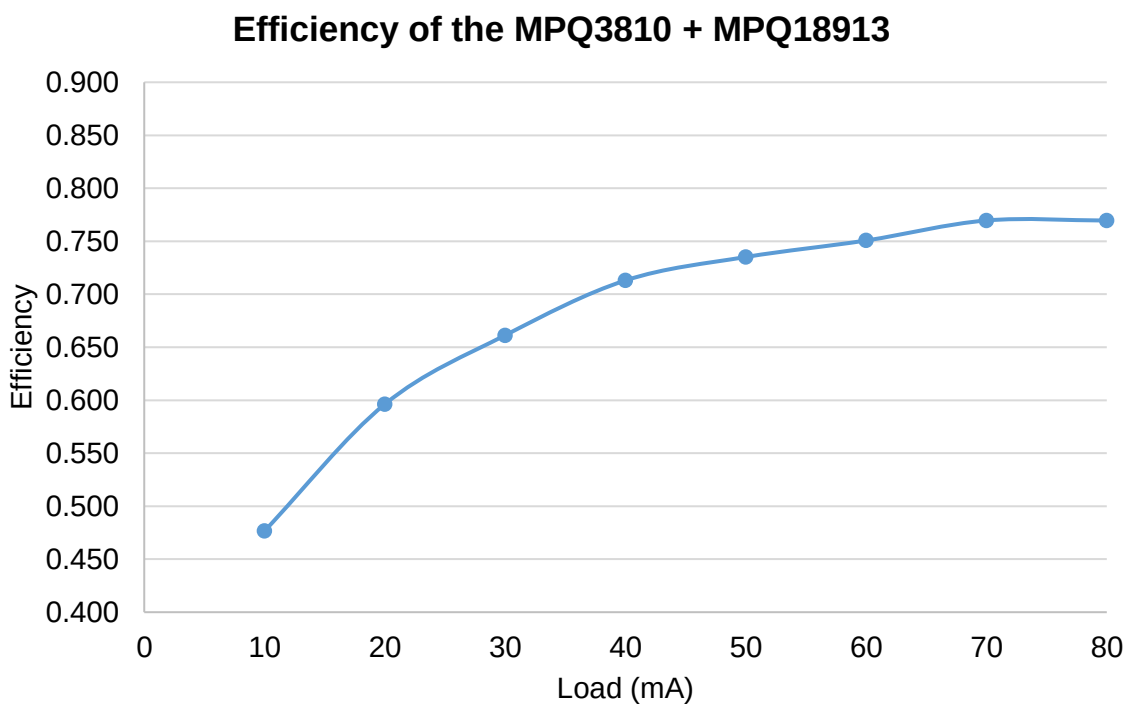


MPQ3910: $5V_{IN}$ to $35V_{IN}$ Boost Controller
Frequency 30kHz to 400kHz
1A MOSFET Gate Driver
Pulse-Skip Mode at Light Loads
Protection Features: OVP, SCP, OTP
MSOP-10 Package, AEC-Q100 Qualified

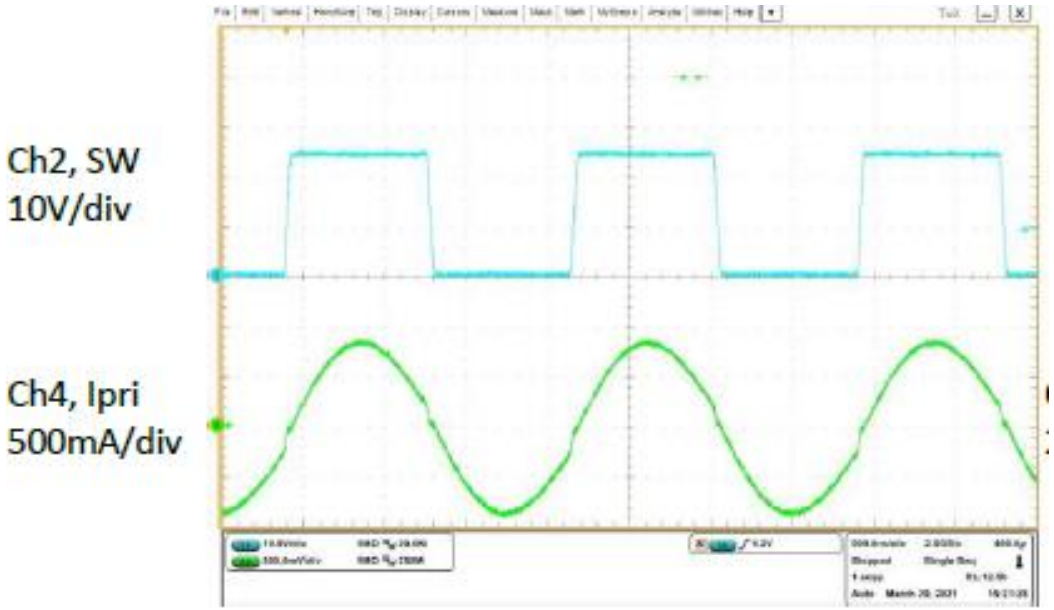
MPQ18913: 5V to 30V LLC Transformer Driver
Frequency 750kHz to 5MHz
Automatic Resonant Frequency Detection
Spread Spectrum
Supports Up to 6W
QFN-10 (2mmx2.5mm), AEC-Q100 Qualified

Performance with the MPQ3910 + MPQ18913

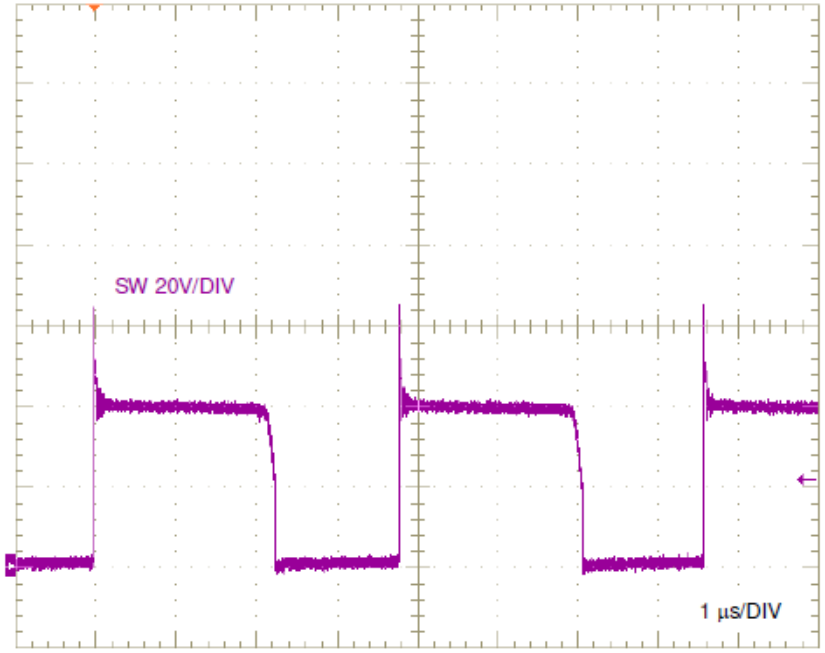




MPQ18913/4 vs. Flyback Topology



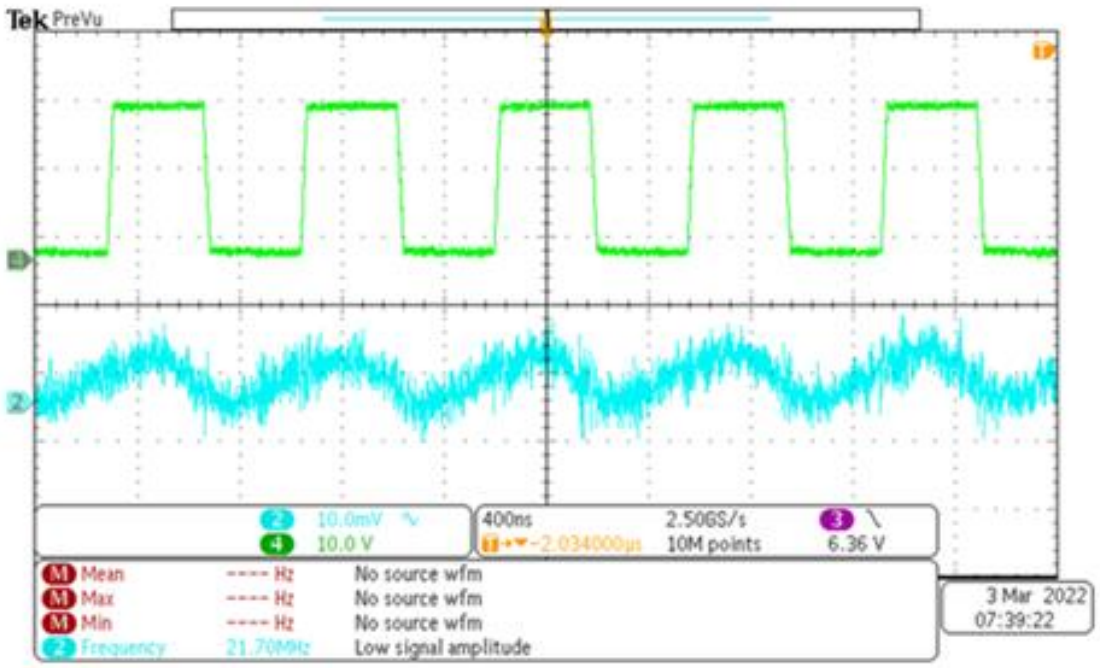
MPQ18913 SW Waveform (Top)



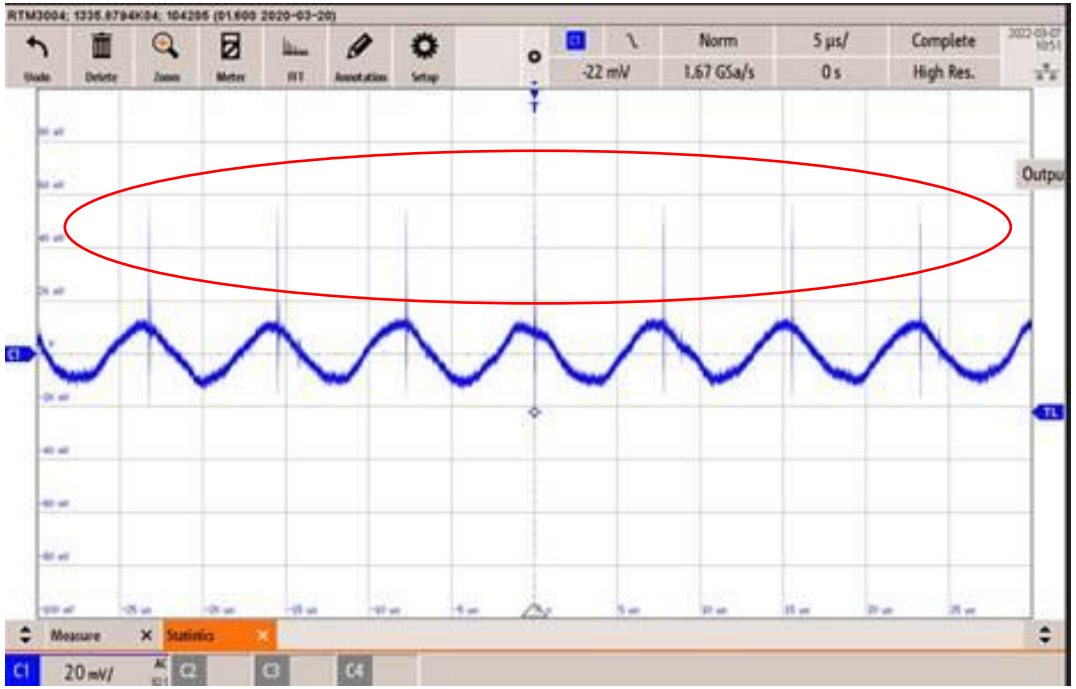
Competitor Flyback SW Waveform

MPQ18913/4 vs. Flyback Topology

The MPQ18913 uses a soft switching topology, resulting in better EMI performance compared to hard switching in a flyback that can couple switching noise to the input rail (circled in red)



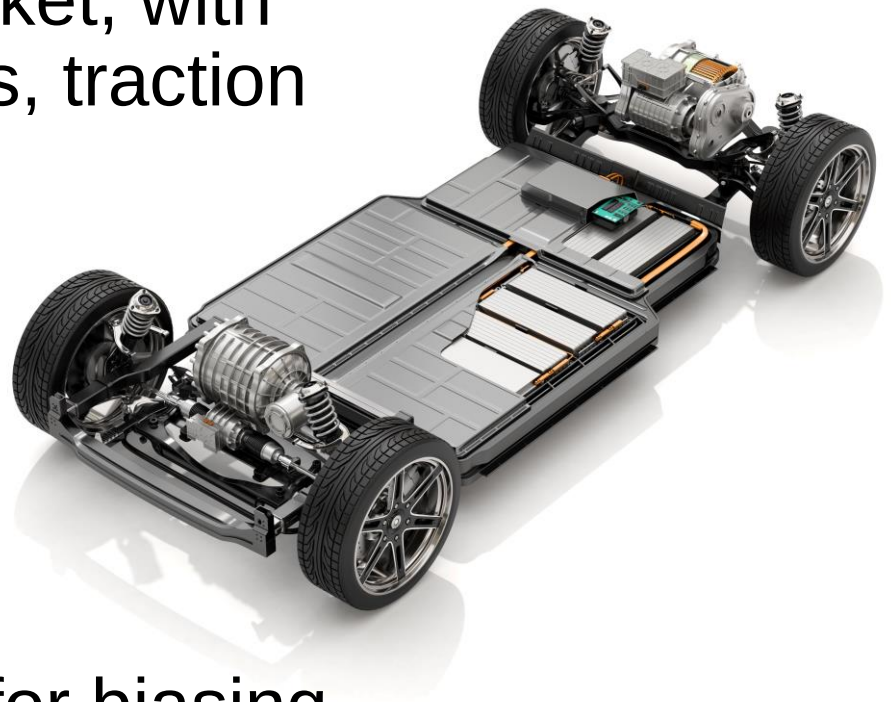
MPQ18913 Input Voltage Waveform (Bottom)



Competitor Flyback Input Voltage Waveform

Takeaways

- MPS is invested in the electrification market, with innovative solutions for onboard chargers, traction inverters, and charging stations
  - Digital Isolators
  - Low-Voltage Power Modules
  - Isolated Gate Drivers
  - LLC Gate Driver Power Supplies



- Resonant LLC supplies are a great way for biasing either IGBTs or SiC FETs to help increase power density in next-generation designs over a traditional flyback

Thank You