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

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Agenda

- Charging Infrastructure
- Bias Power Supply and its Challenge
- MPS Solution of Isolated Bias Power Supply
- LLC & Flyback comparison
  for Bias Power Supply Application
- Bias Power Supply Module Solution

Charging Infrastructure

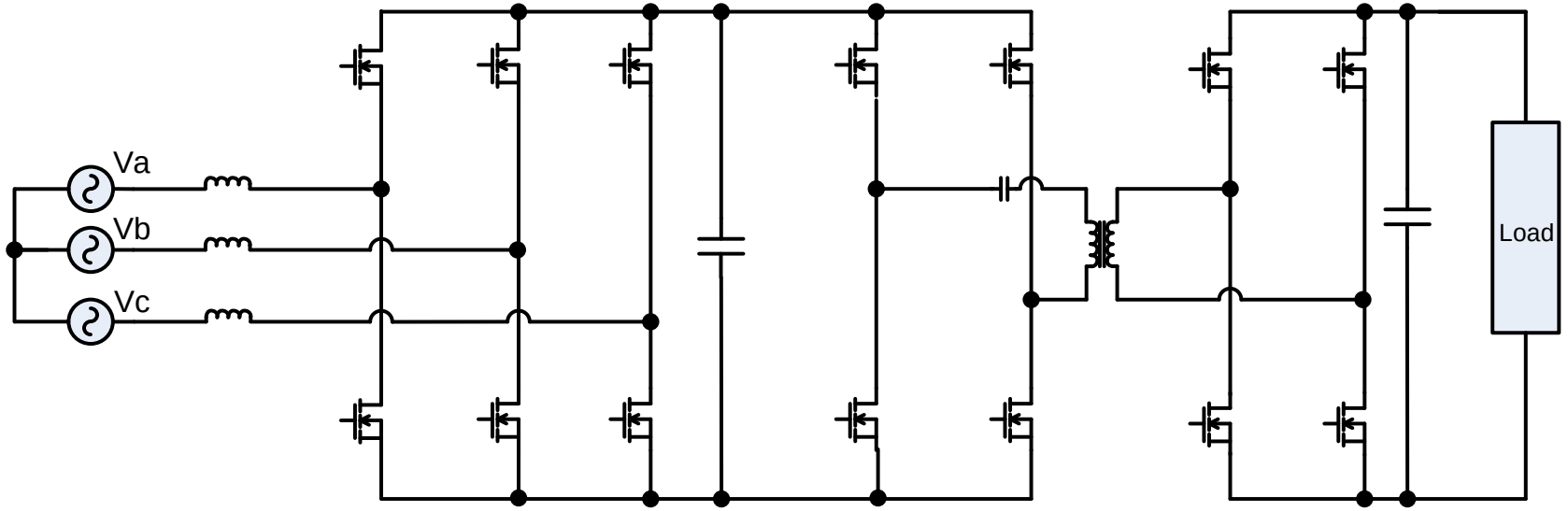
Overview of EV Charging Infrastructure

- 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

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

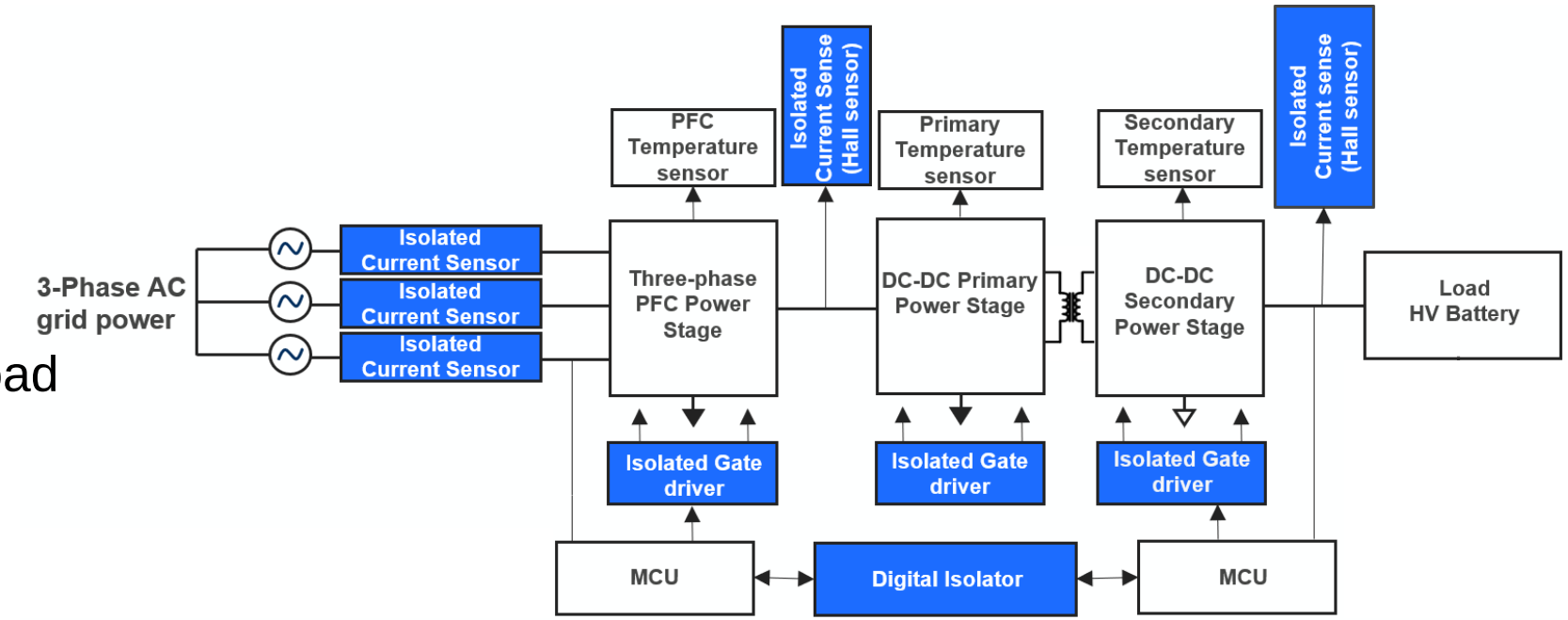


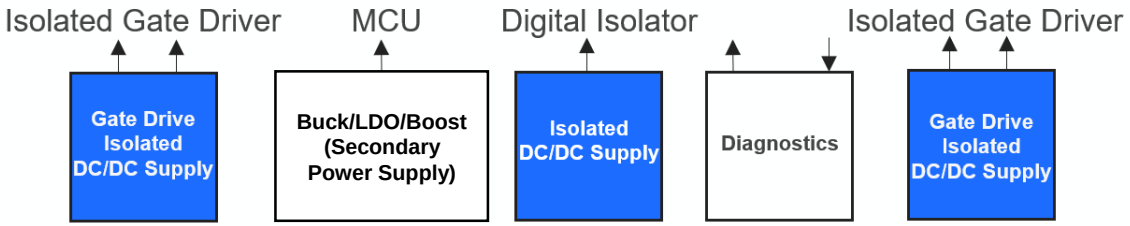
DC Fast-Charging System

Need Isolation Part To：
1. Protect personnel from physical and electrical injuries

2. Protection of downstream load devices and systems

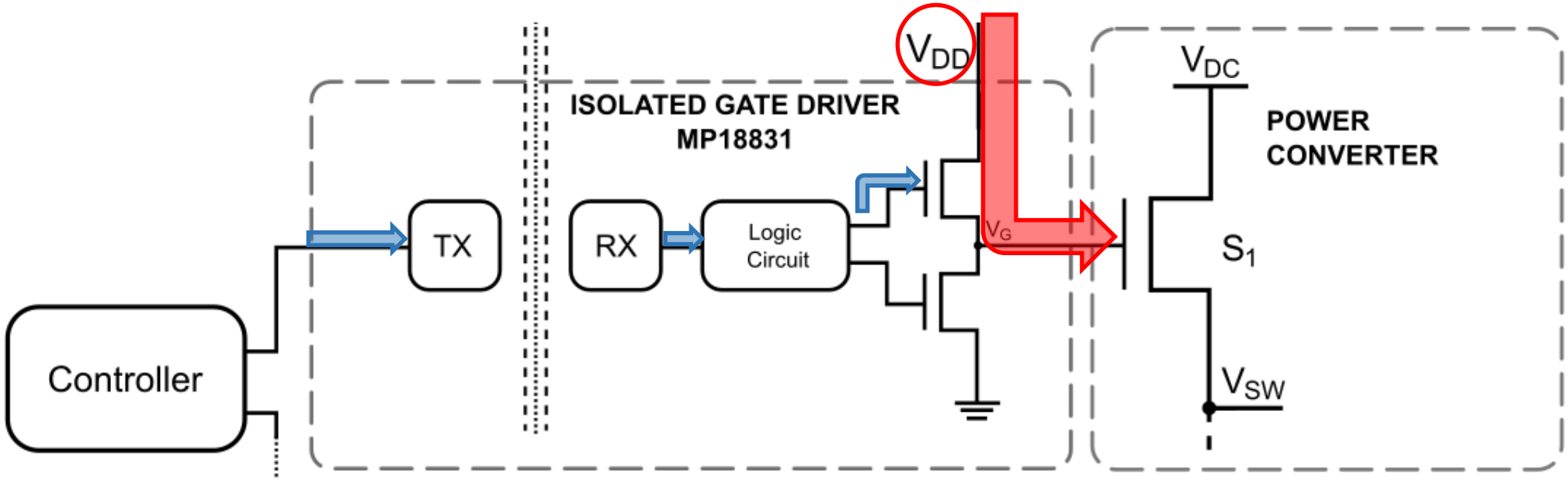
3. Improve common mode interference suppression performance and anti-interference ability



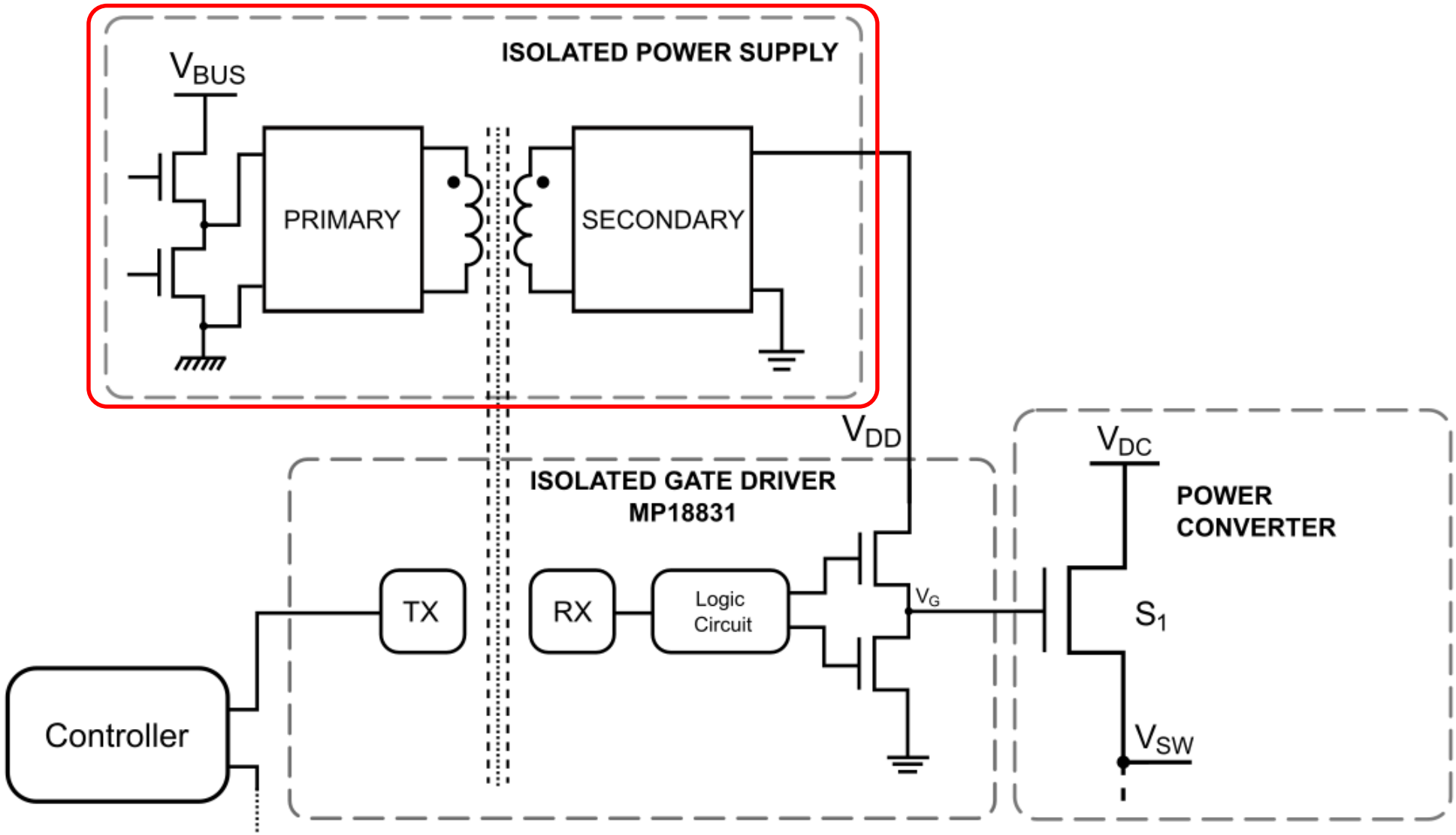


Bias Power Supply and its Challenge

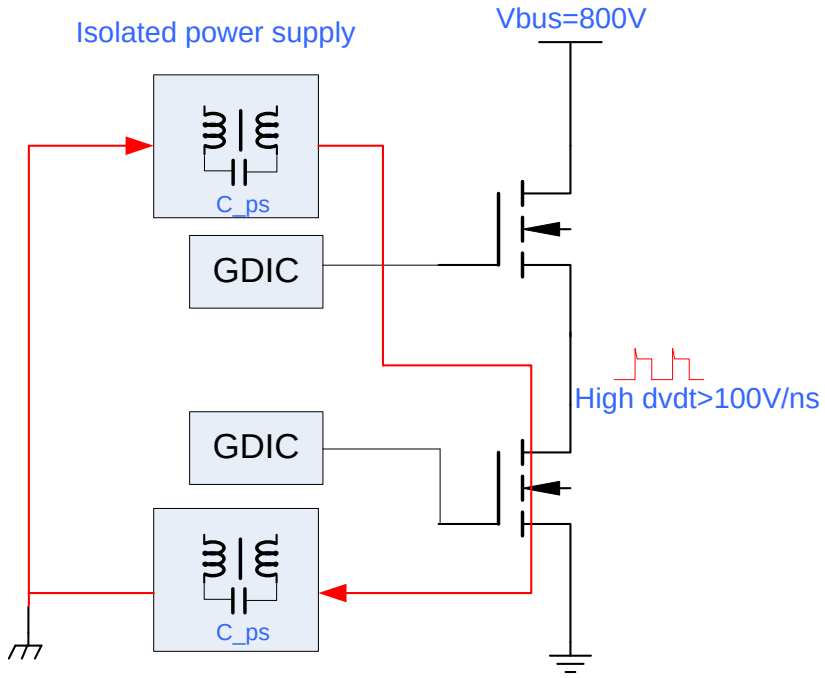
Isolated Power Supplies for Gate Drivers



Isolated Power Supplies for Gate Drivers (contd.)



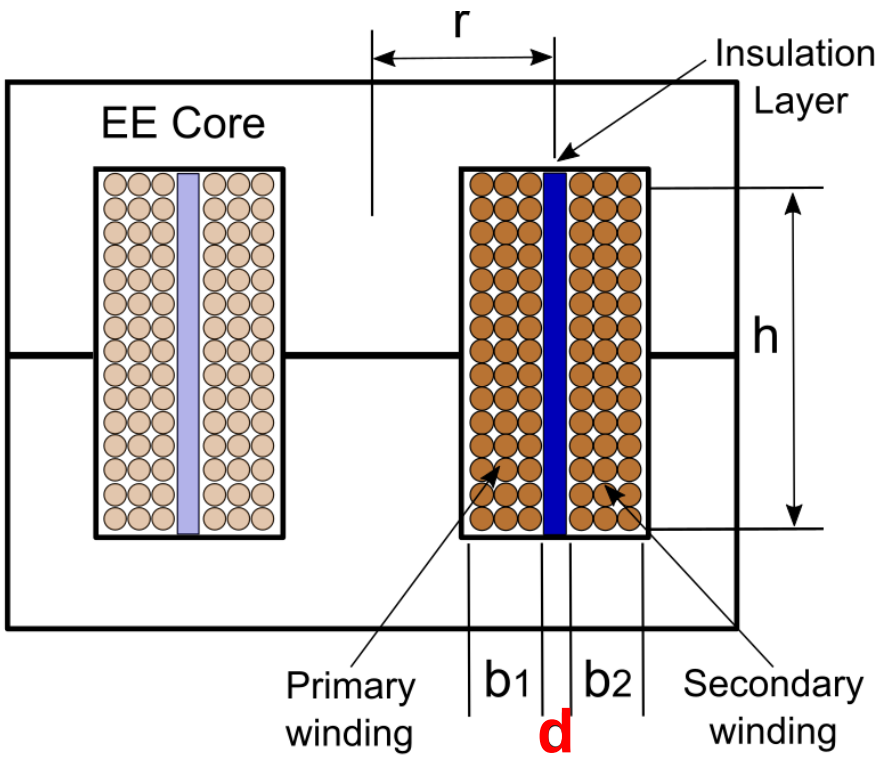
Transformer Requirements for Gate Drive Power Supply



Trends on High-power Systems:

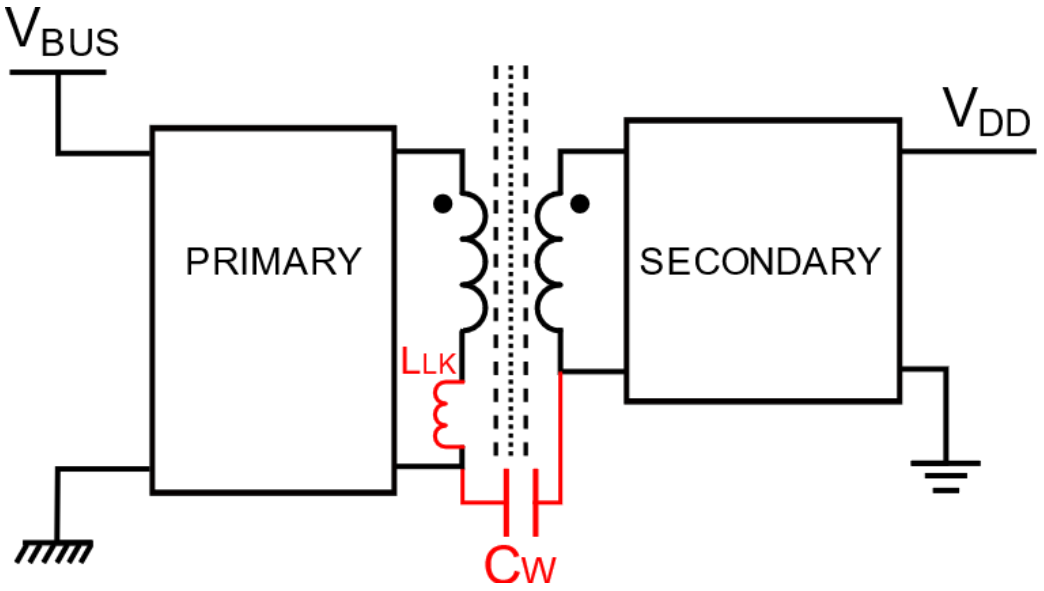
- Bus Voltage Increase → Higher Isolation Voltage Needed for Transformers
- Higher dV/dt → Requires Lower Interwinding Capacitance
  - Assuming 20pF Capacitor
  - I_{CM} = 100V/ns x 20pF / 2 = 1A
  - I_{CM} is disruptive to the MCU, GDIC, and GDPS

Low-Capacitance Transformer Design

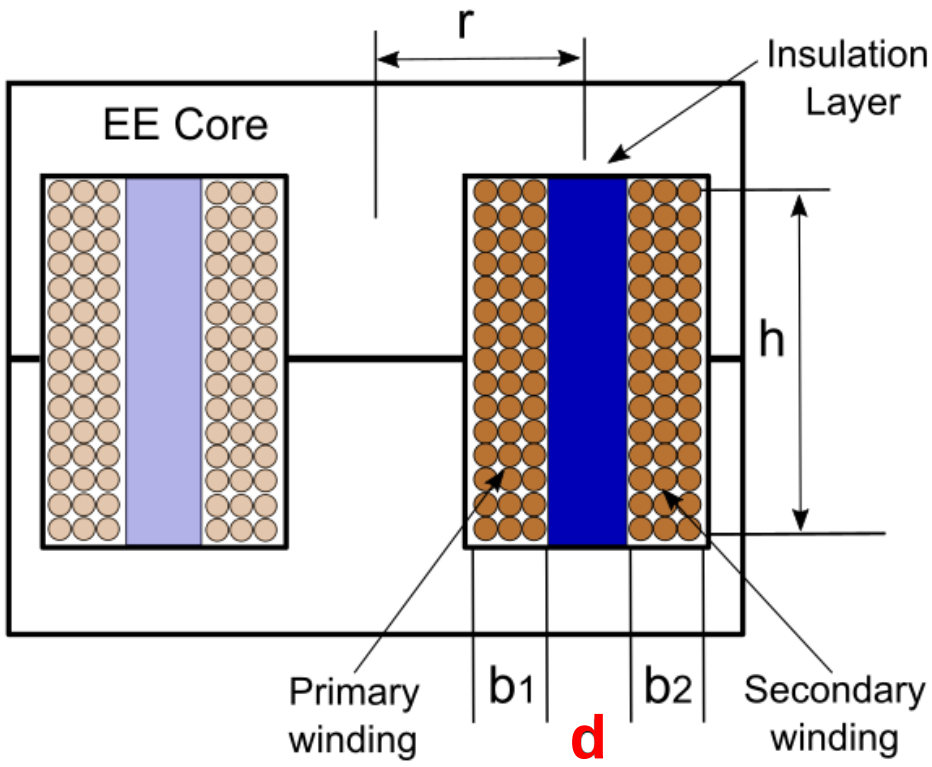


$$C_W = \frac{\epsilon_0 \epsilon_r A}{d}$$

To decrease C_W → Increase the distance between windings



Low-Capacitance Transformer Design

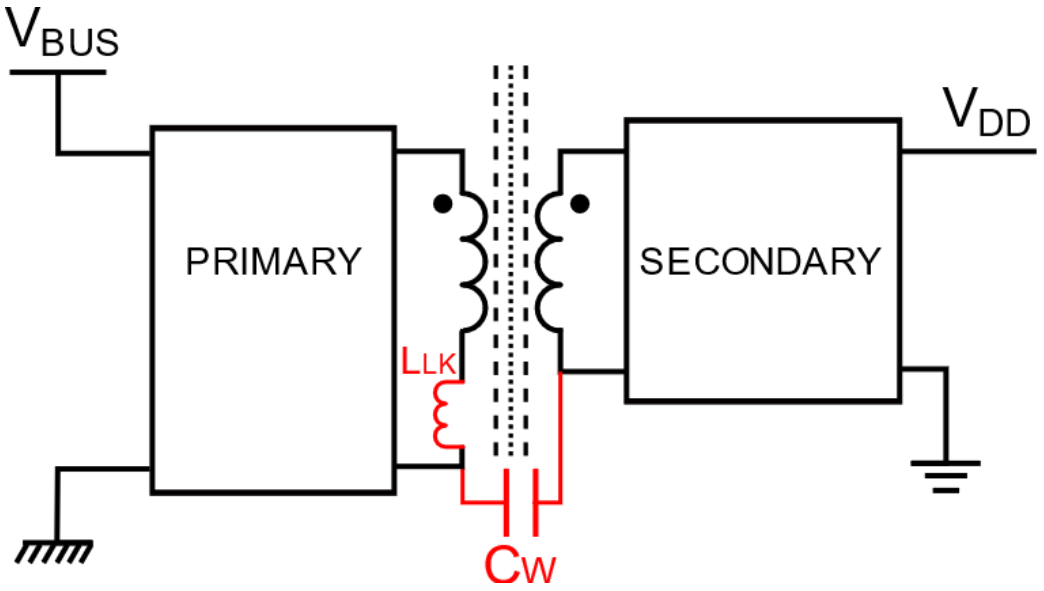


$$C_W = \frac{\epsilon_0 \epsilon_r A}{\boldsymbol{d}}$$

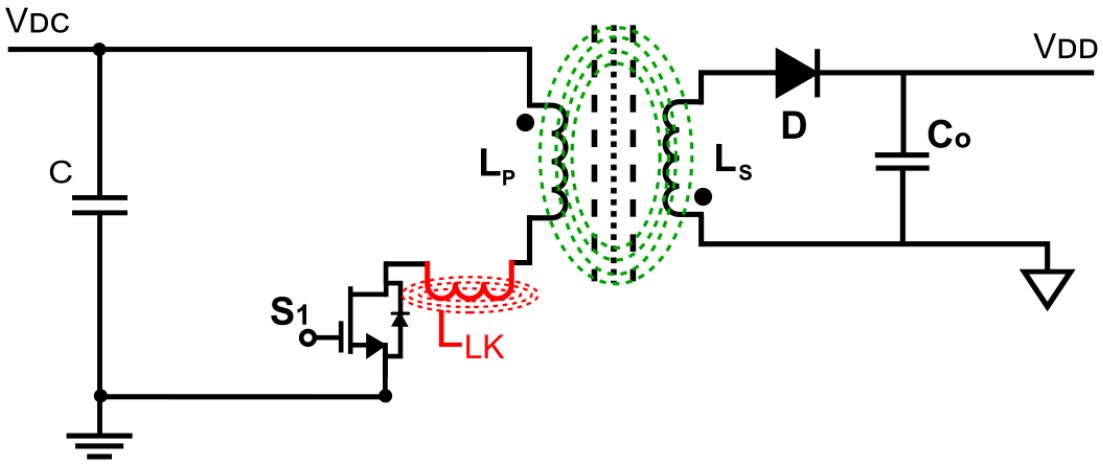
To decrease C_W → Increase the distance between windings

Increase the distance between windings → Increase L_{LK}

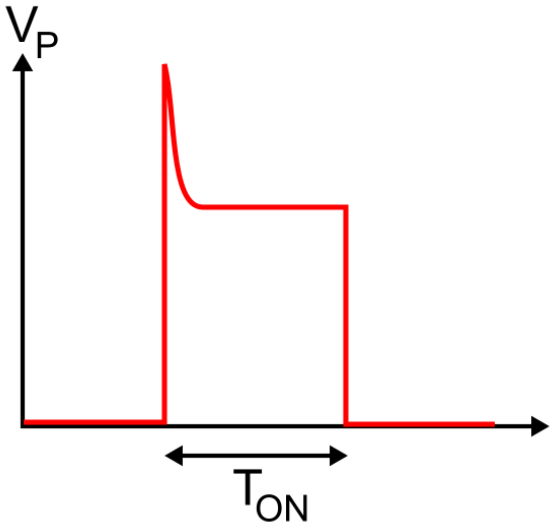
$$L_{LK} = \frac{8\pi^2 \times r \times N_P^2}{h}\left(\boldsymbol{d} + \frac{b_1 + b_2}{3}\right)$$



Flyback Converter Operation with L_{LK}

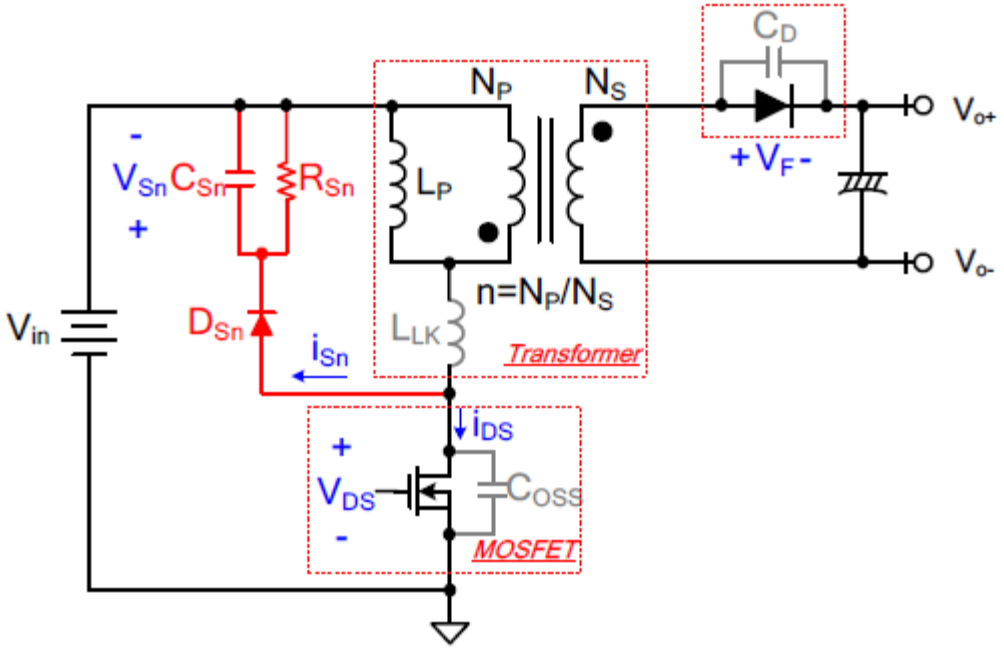


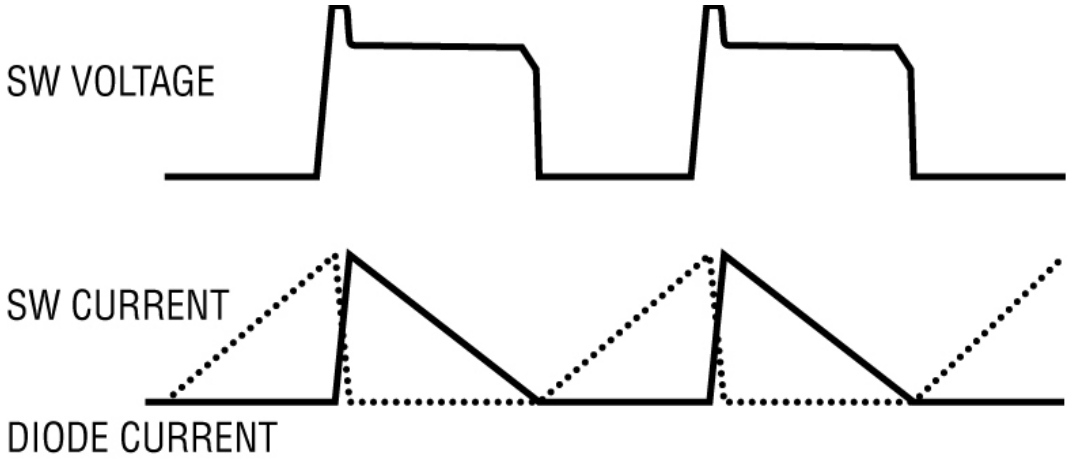
Flyback Converter



Voltage across Primary

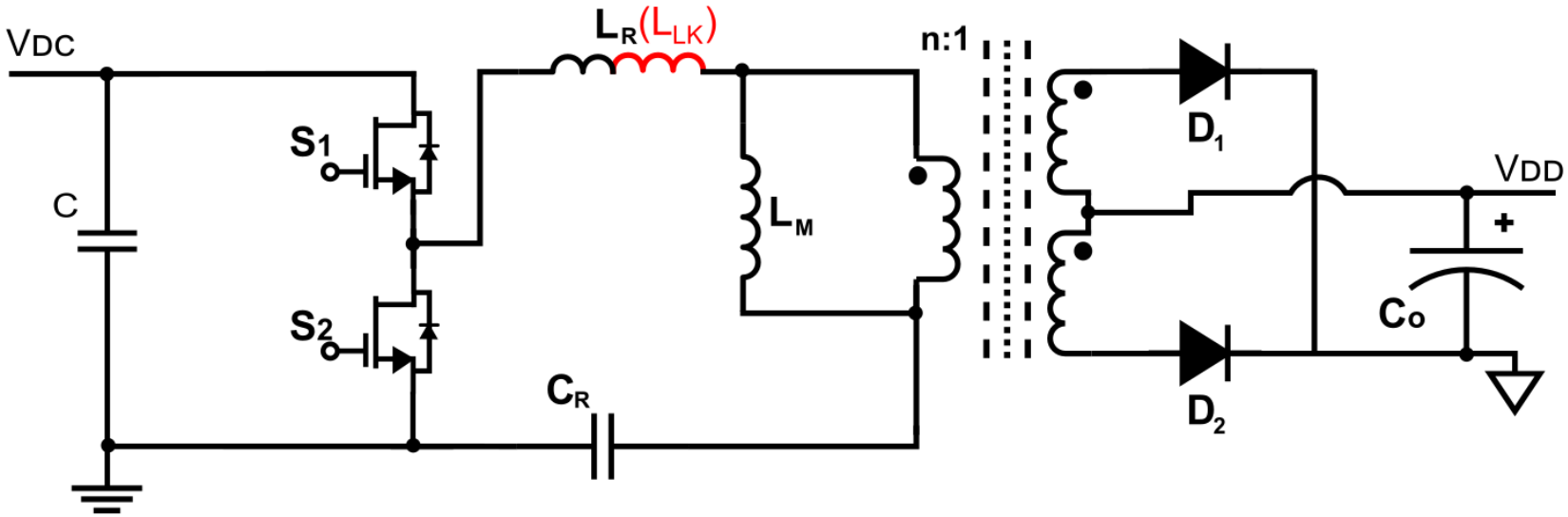
Flyback Converter with Clamping Circuits





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

MPS Solution of Isolated Bias Power Supply

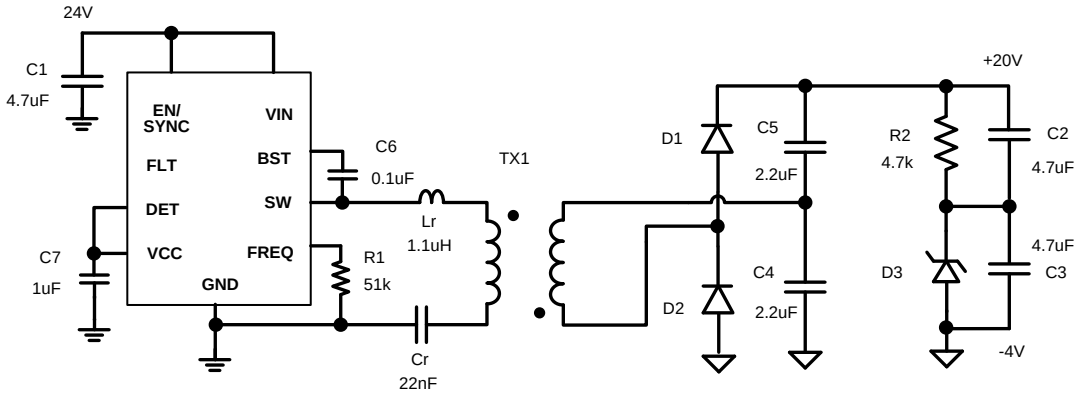
MPQ18913 – 30V, 0.5A LLC Transformer Driver for Isolated Bias Supplies

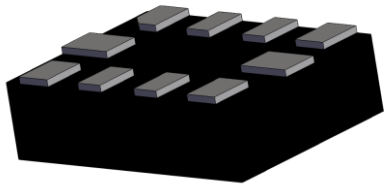
FEATURES

- 5V to 30V Input Voltage Range
- Half-Bridge Transformer Driver for Isolated LLC Resonant Converters
- Configurable Frequency: up to 5MHz (913)
- Configurable Frequency: up 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 6W
- Available in a QFN-10 (2mmx2.5mm) Package with Wettable Flanks

Applications

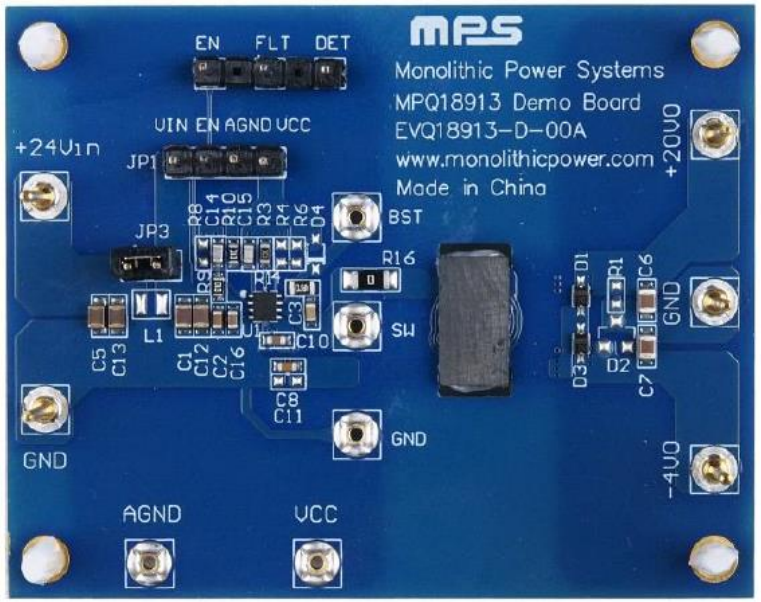
- IGBT/SiC Gate Driver Bias
- EV DC Fast-Charging Stations
- EV Traction Inverters/Onboard Chargers



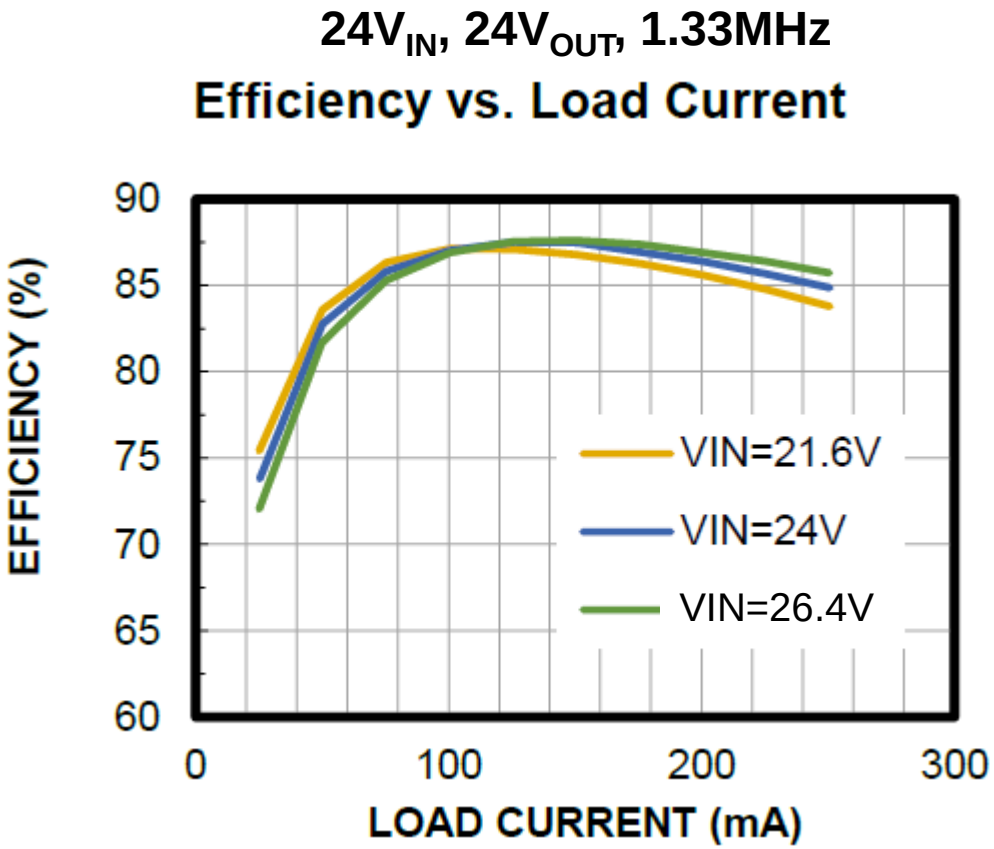


Available in a QFN-10 (2mmx2.5mm) Package

MPQ18913 Evaluation Board



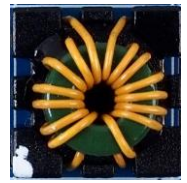
EVQ18913-D-00A Evaluation Board



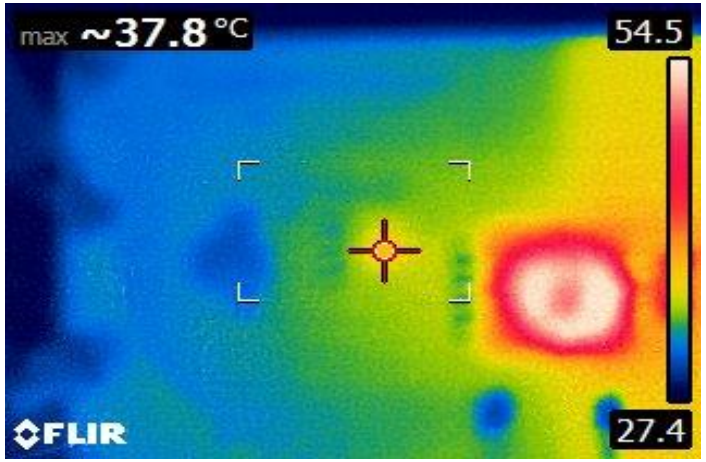
MPQ18913 Evaluation Board

EVQ18913-D-01A

- 5kV Isolation Solution
- 0.5MHz Frequency
- 6W Max Pout
- 89% Peak Eff



5kV Isolation with Ciw≈4pF



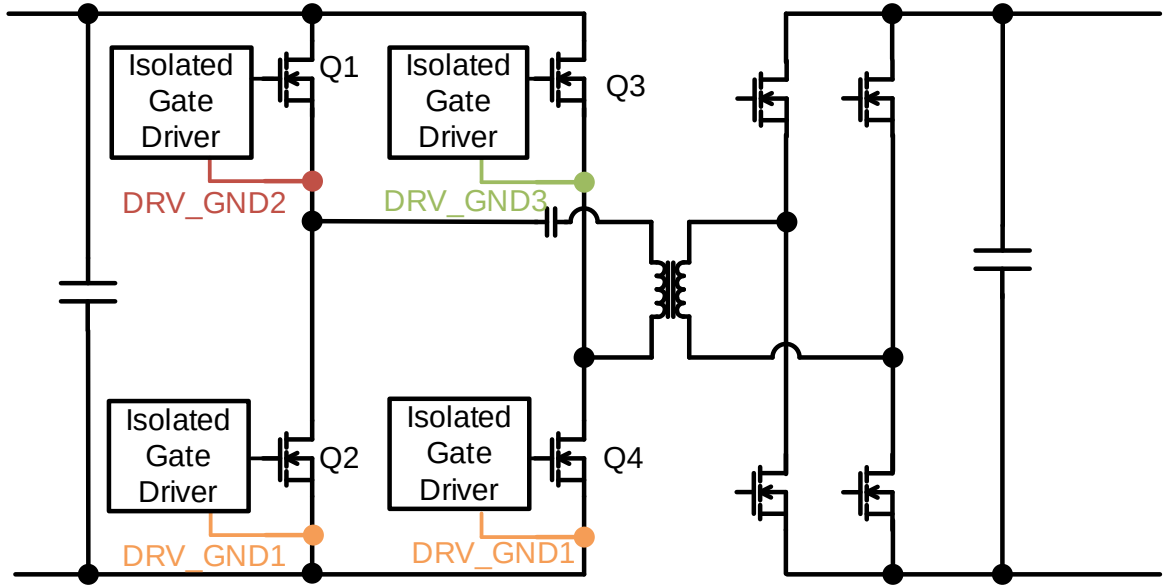
High Eff and Low thermal resistance

Bias Power Supply for Full Bridge

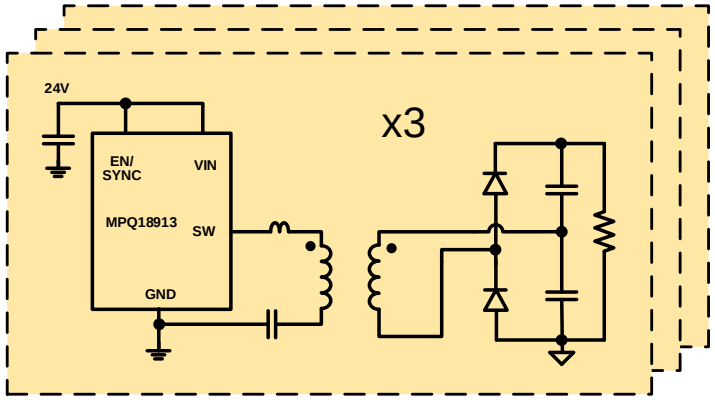
Power State:
Q1~Q4 Power FET of Primary side

Drive reference ground(of full bridge):
Q2&Q4: **DRV_GND1**
Q1: **DRV_GND2**
Q3: **DRV_GND3**

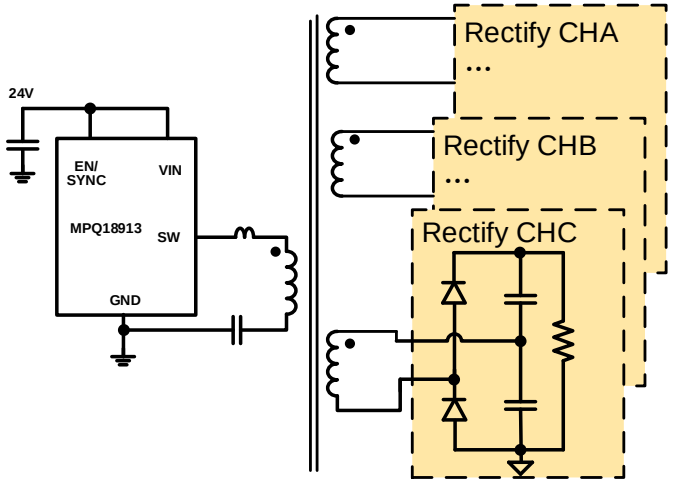
Need at least 3 channel isolated output



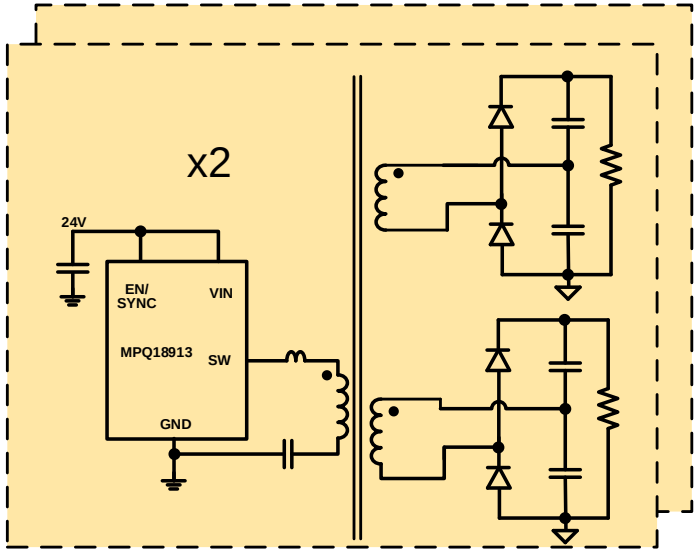
Bias Power Supply for Full Bridge



3x MPQ18913 3x 1P1S Trans



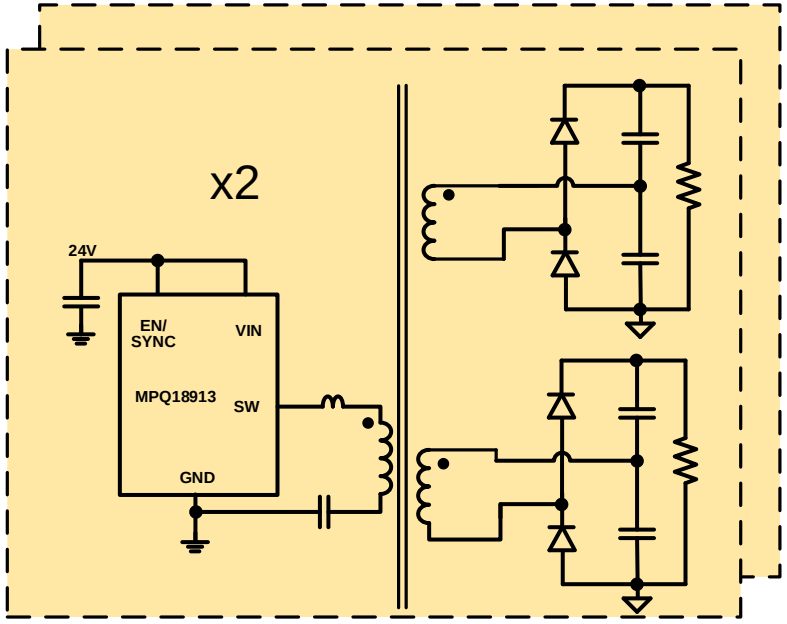
1x MPQ18913 1x 1P3S Trans



2x MPQ18913 2x 1P1S Trans

Bias Power Supply for Full Bridge

Solution	3x MPQ18913 3x 1P1S Trans	1x MPQ18913 1x 1P3S Trans	2x MPQ18913 2x 1P2S Trans
Total Max Output Power	3*6W	About 6W	2*6W
Cost	Highest	Medium	Less high
Layout Convenience	Medium	Less	Most
Load Regulation (Without LDO)	Good	Poor	Good

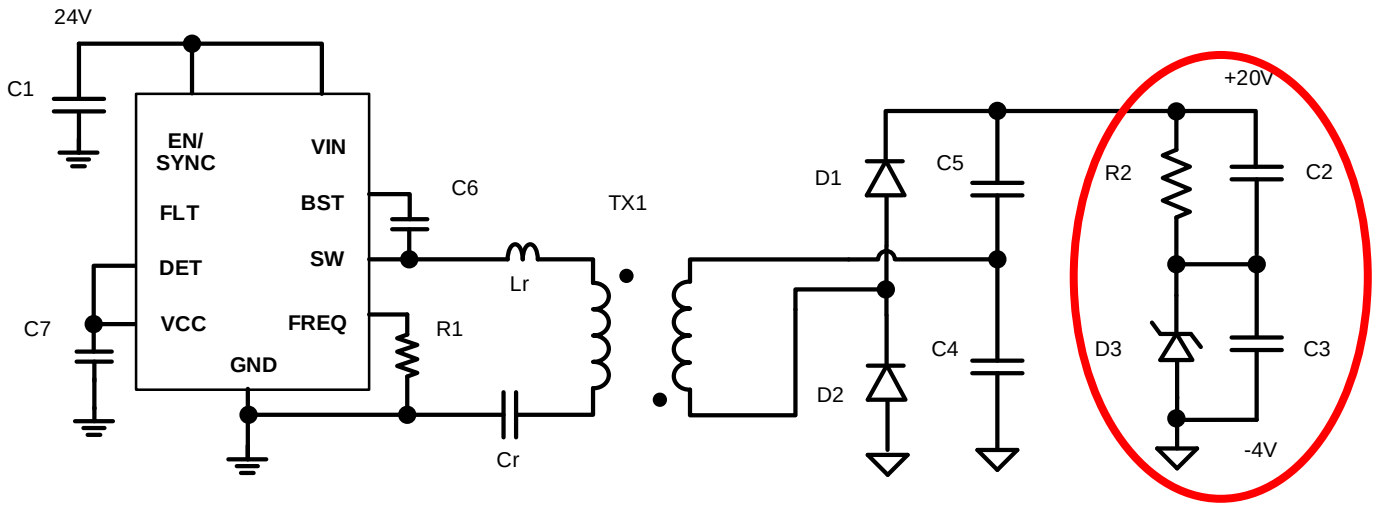


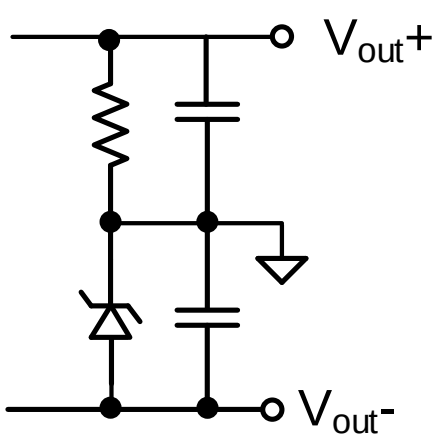
2x MPQ18913 2x 1P2S Trans

- Power DRV the same
  Qg of HS and LS the same
- Transformer symmetry
  S-P-S structure

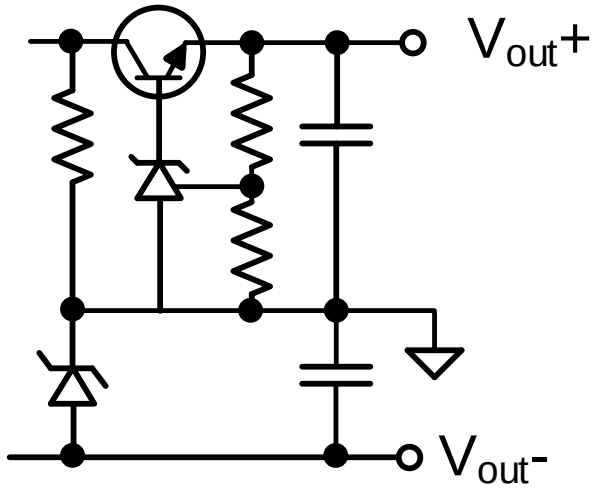
- Good Load Regulation
- Reduce transformers types for the system

Positive/Negative Voltage for Bias Power Supply





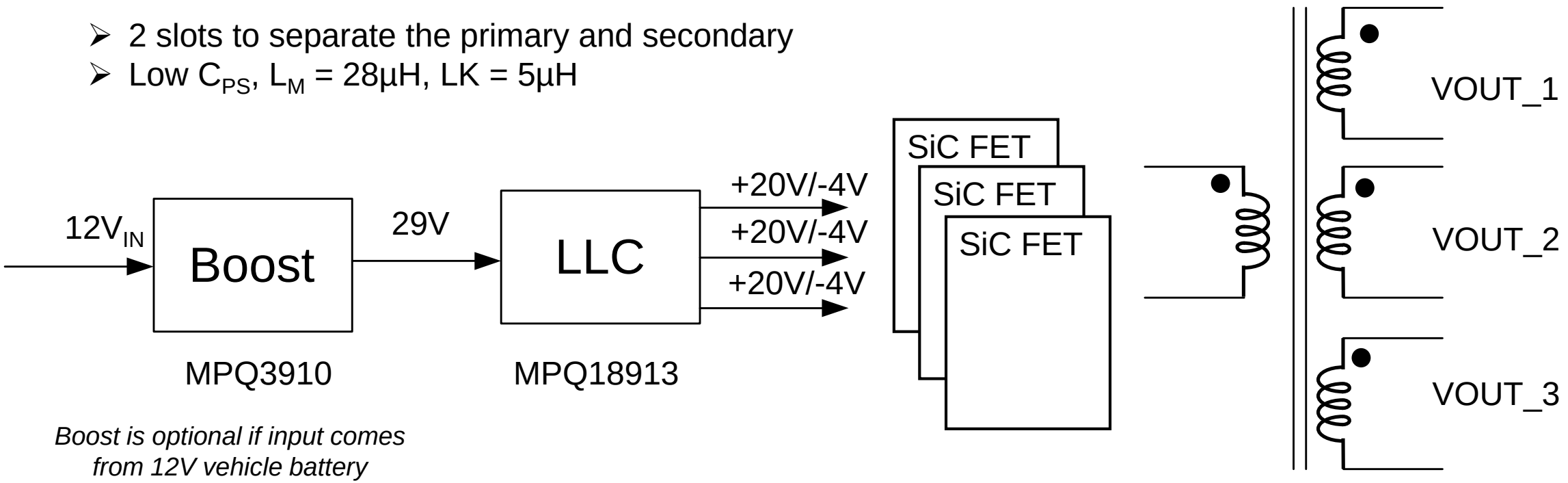
- Low Cost
- Positive Rail no Regulate



- High Cost
- Both Rail Regulated

Multi-Output with the MPQ18913

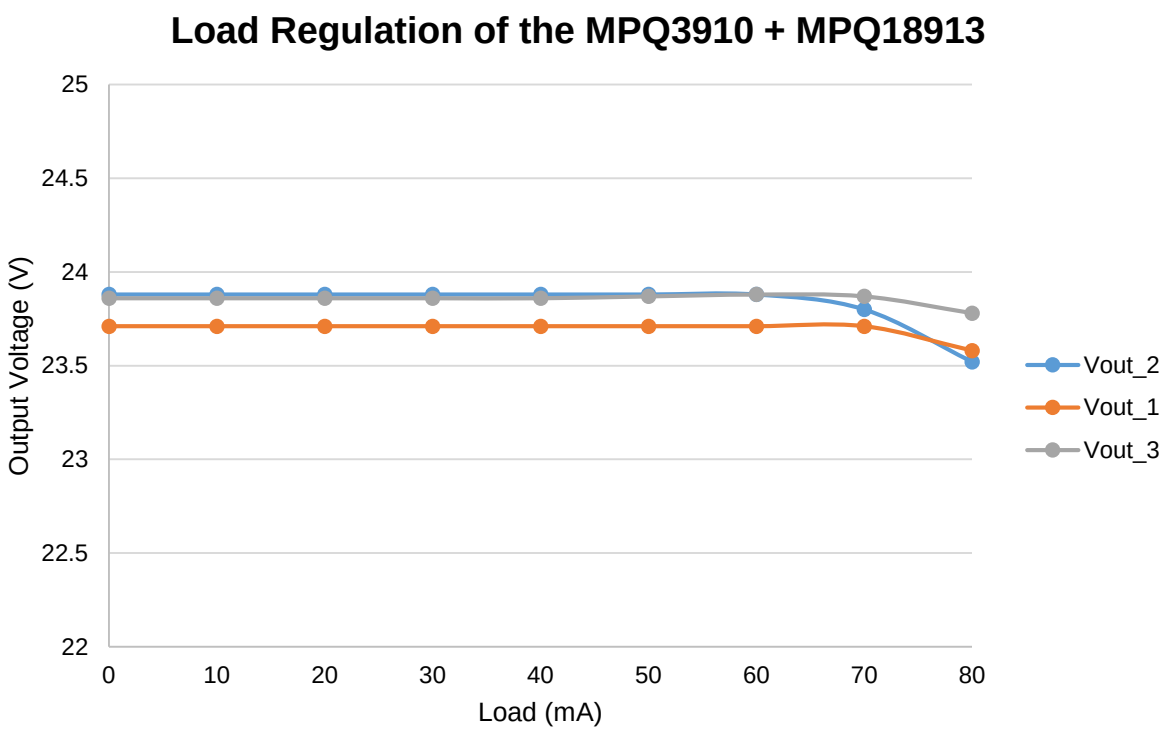
- 2 slots to separate the primary and secondary
- Low C_{PS}, L_M = 28µH, LK = 5µH

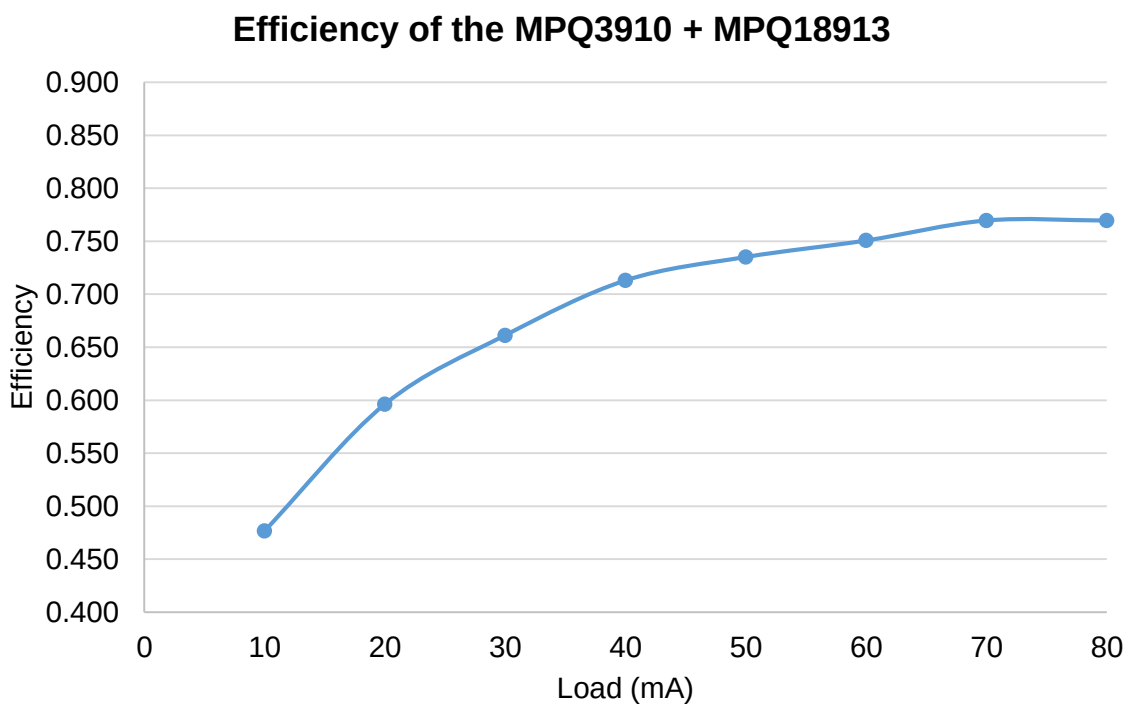


MPQ3910: $5V_{IN}$ to $35V_{IN}$ Boost Controller
Frequency 30kHz to 400kHz
1A MOSFET Gate Driver
Pulse-Skip Mode at Light Loads
Protection Features: OVP, SCP, OTP
MSOP-10 Package, AEC-Q100 Qualified

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

Performance with the MPQ3910 + MPQ18913





Spreadsheet for Design

Power Solution Experts

Version 1.0
Date: 2022 May. 25th
Legal Notice

This spreadsheet is used for LLC Resonant converter design based on MPQ18913.
which needs further bench verification.

01_Circuit Design

1. Circuit Design includes **01_Basic Parameters;**
2. Input required specs in blue font, like ***Vin_dc_min*** 12 ***V***
3. Step by step, get recommended results , like ***Po_total*** 6.00 ***W*** based on input;
4. take the note besides **Suggest Range: 4 to 30** as reference to check the data validity;

Next Step

02_Magnetic Design

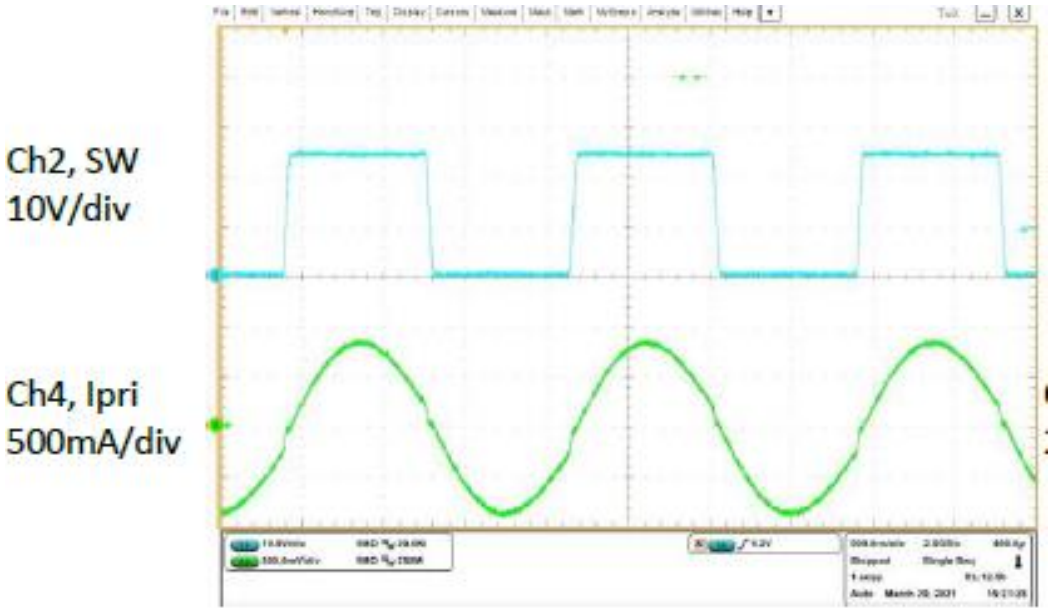
1. Magnetic Design includes **02_Transformer Design ;**
2. Input the parameters like flux density Bm and then get required AP;
3. Click **Use Standard Core** to select core from built-in core database, with selected core shape like **EER** , winding turns are calculated accordingly , Click **Create Custom Core** if user need manually input core data Ae and Aw , winding turns are calculated based on manually input;
4. Adjust the coil diameter in **36#** and check the calculated fill factor validation;

end of design

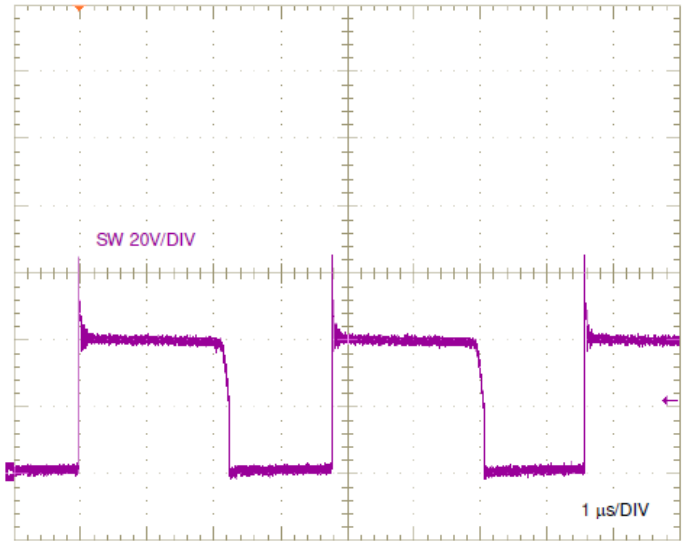
- You can contact MPS FAE for this.

LLC & Flyback comparison for Bias Power Supply Application

MPQ18913/4 vs. Flyback Topology



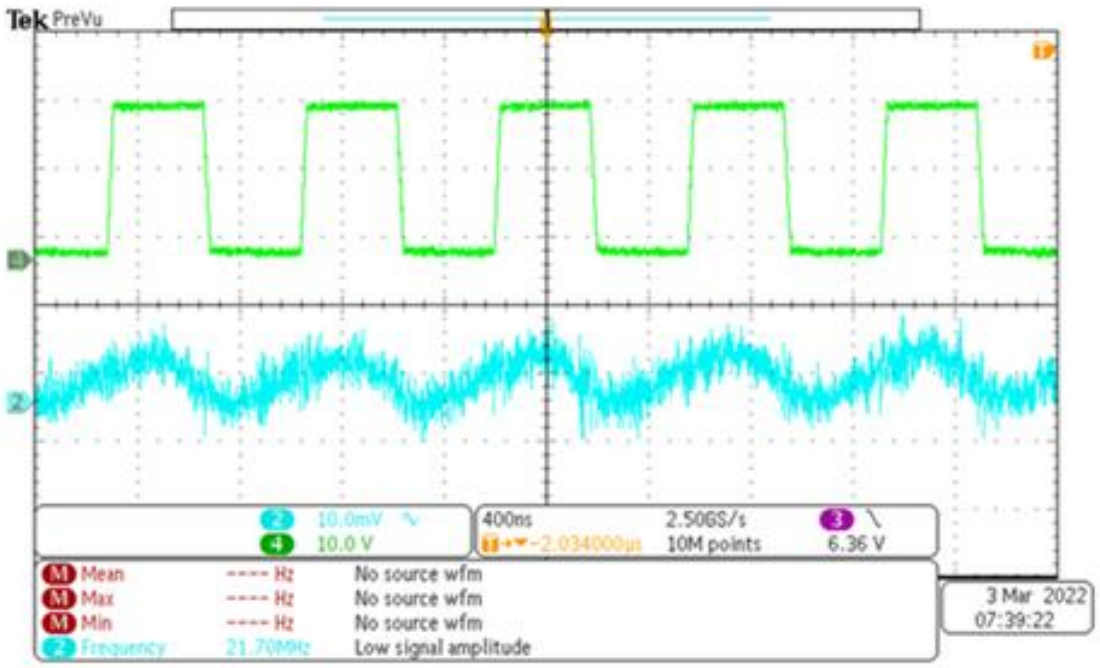
MPQ18913 SW Waveform (Top)



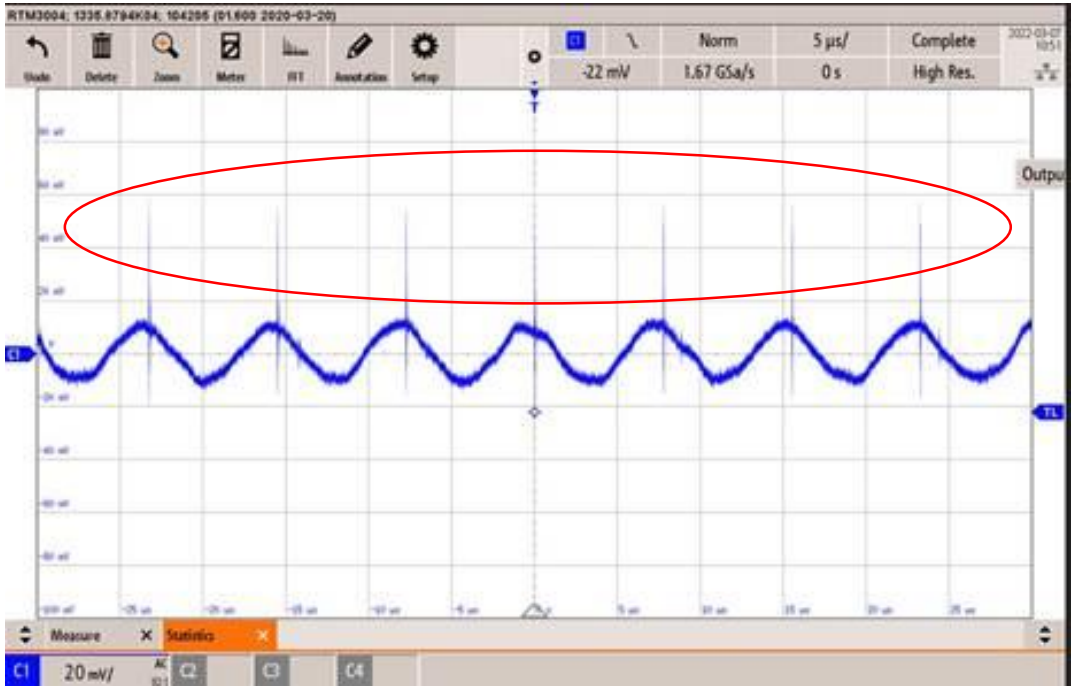
Competitor Flyback SW Waveform

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)

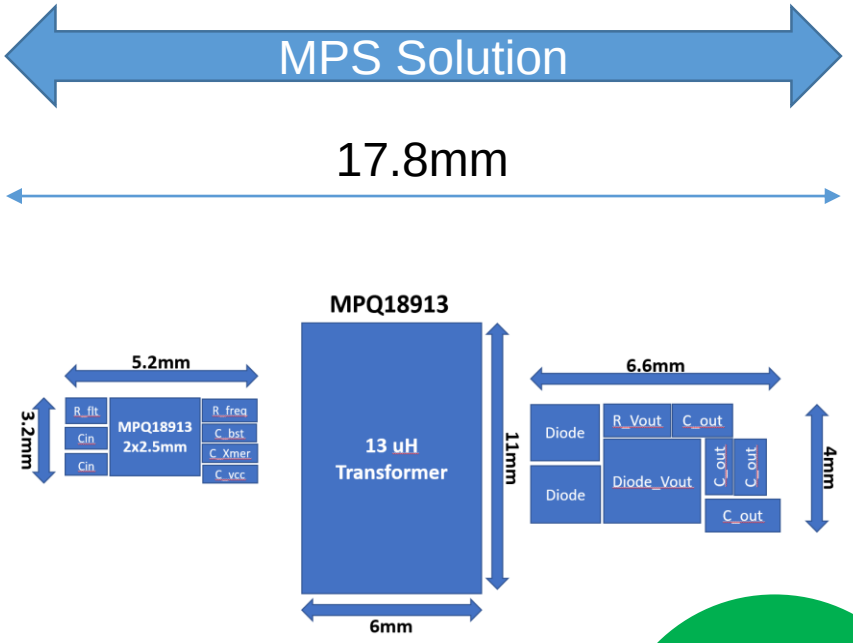


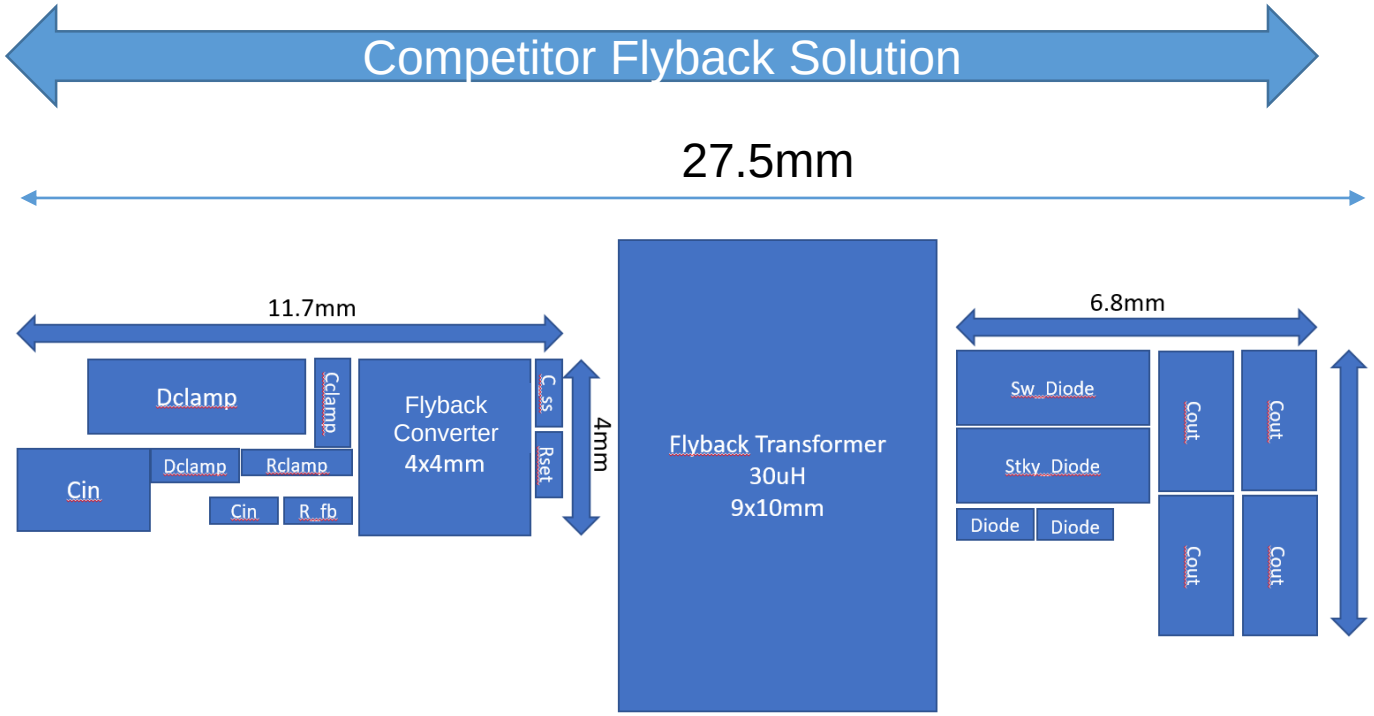
MPQ18913 Input Voltage Waveform (Bottom)



Competitor Flyback Input Voltage Waveform

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 Topology

	MPQ18913/4 LLC Resonant Topology	Competitor 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

Bias Power Supply Module Solution

MID6W2424A- 24V to 24V Isolated Module

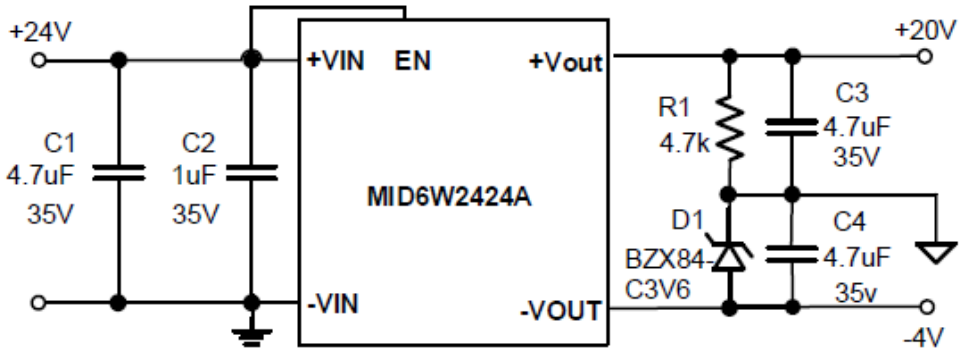
Key Features:

- 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
- LGA 10x10mm package
- Operating Temperature -40C to 105C

Applications

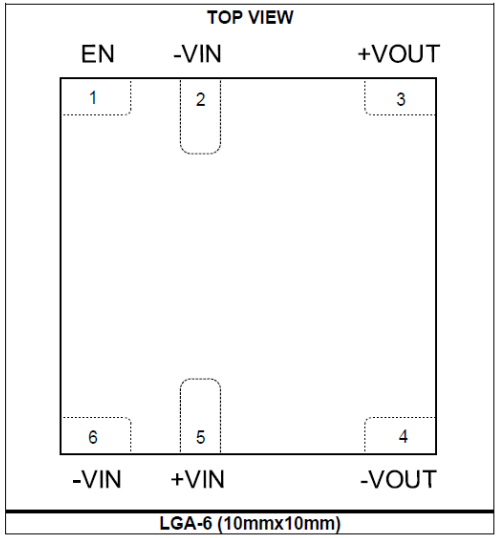
- SiC/IGBT Gate Drive Power Supply
- Industrial Automation, PLC I/O modules,
- Grid protection relays

Typical Circuit



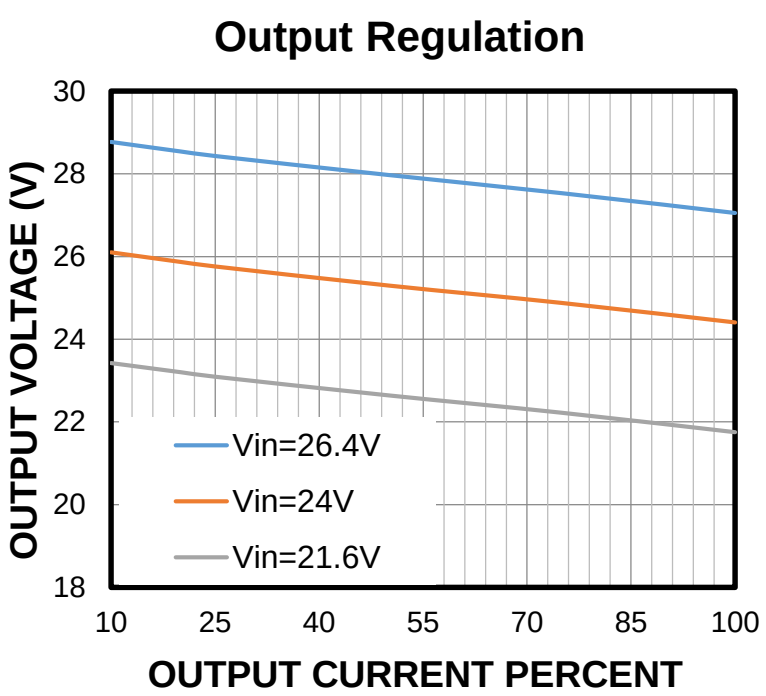
SiC Gate Drive Power Supply

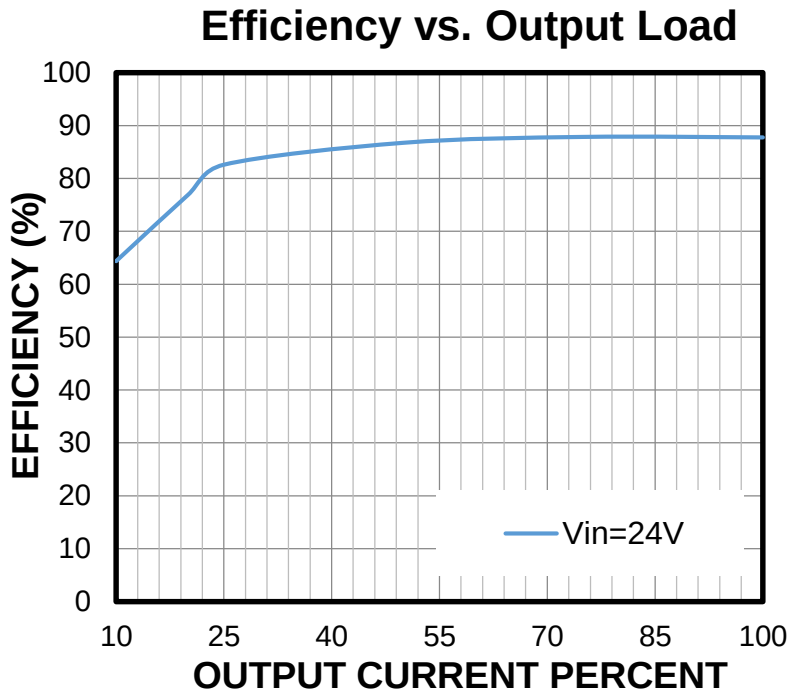
PACKAGE REFERENCE



MID6W2424A performance

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

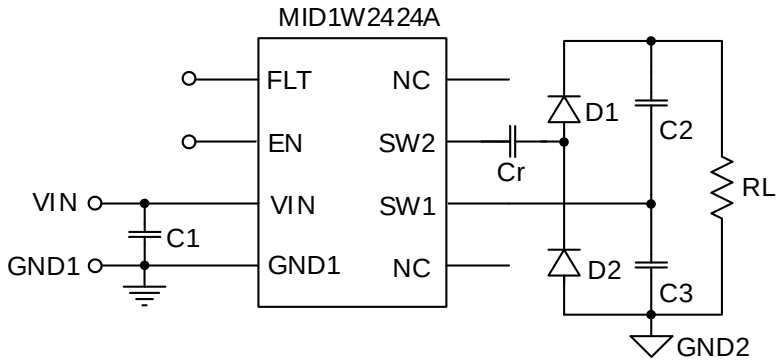


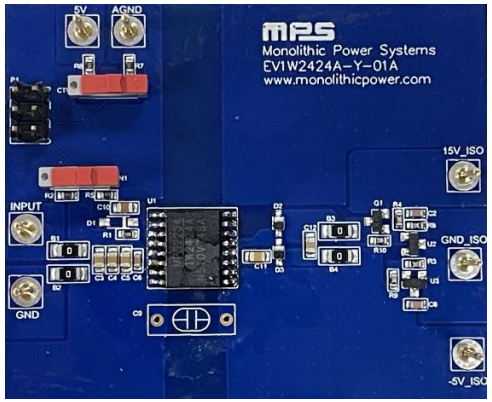


MID1W2424A – 1.5W 24V Isolated Module

FEATURES

- 5V to 30V Input Voltage Operation Range
- 3kVrms, 5kVrms Isolation Voltage Options
- 1.5W Output Power Options
- Integrated Transformer
- 60% Efficiency with Full Load
- 100 kV/µs CMTI
- 8 pF Isolation Capacitance
- Soft start, OCP, input OVP, OTP, and FLT Indicator
- **AEC-Q100 Option**
- Available in SOICW-16 Package





Applications

- IGBT/SiC Gate Driver Bias
- EV DC Fast Charging Stations
- EV Traction Inverter/On-Board Charger

Summarize

- Charger station with higher power rating:
  - ➢Higher BUS voltage
  - ➢Higher switching frequency/speed with SiC

- 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.
  - ➢Smaller Ciw\Higher isolate rating
  - ➢Better thermal performance
  - ➢Smaller solution size

Thank You