High Voltage Solutions in HEV/EV Part II: - DC/DC Converters and Traction Inverters

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What will I get out of this session?

- Purpose:
  To provide an overview of complete high voltage power solutions in DC-DC Conversions and Traction Inverters
  - Introduction
  - Devices
  - Reference Designs

- Part numbers mentioned:
  - UCC28951-Q1, LM25037-Q1, UCC280x-Q1, UCC28C4x-Q1, LM5021-Q1
  - UCC27201A-Q1, UCC21520-Q1

- Reference designs mentioned:
  - TIDA-00281, TIDA-01505, TIDA-00366
  - PMP7797, PMP8657

- Relevant End Equipment:
  - DC-DC Converters
    - Car Trunk Audio Amplifier
    - Car Heater
    - Auxiliary Power for Traction Inverter
  - Traction Inverters
**What is the DC/DC Converter?**

- The DC/DC converter provides transfer of energy between the higher voltage battery system and the lower voltage (typically 12V) systems.

- The higher voltage supplies large loads such as traction motor, air-conditioning, and starters. Lower-power components such as infotainment and safety systems will remain on 12V supplies.

**What does this EE do?**

- **Down Conversion**
  - Converts energy from HV 48V or 100V ~ 800V to 12V
  - Switching regulator for efficiency, a *converter* with integrated switch, or a *controller* with external switch

- **Up Conversion**
  - Converts energy from 12V battery system to HV (48 or 100 to 800V)
  - A *converter* with integrated switch, or a *controller* with external switch
  - Flyback configuration if isolation needed between HV and LV

- **Bi-directional**
  - 48V or 100 to 800V ↔ 12V
**Customer Challenges:**

- High performance with integrated strong sink/source gate driver
- Higher duty cycle and longer Soft Start
- Customer liked Automotive TI Design PMP7797
- Higher duty cycle, strong gate drivers and programmable soft start,

**End Equipment:**

- * High-eff Boost for trunk amplifier
- * Car Heater
- * Car Audio Amplifier

**PMP7797** is a wide-input SEPIC converter designed for automotive applications. This design uses the LM25037Q push-pull controller as an interleaved boost, which incorporates two gate drivers for controlling two sets of MOSFET switches.
Question #1: What type of dc-dc converter or inverter are you using/designing?

- A) Push-pull, phase-shifted full bridge, LLC, or what, using which devices?
- B) Three-phase inverter for synchronous AC motor (permanent magnet?) or asynchronous AC motor (squirrel cage, or what type)?
- C) What is control algorithm for the inverter and for the motor?
- D) Other (for those that answered “other”, would someone to share?)
What is the (Traction) Inverter?

- EV/HEV Traction inverter converts energy stored in a battery to instantaneous multiphase AC power for a traction drive.

Mandatory Sub Systems

- **Front-End**
  - Battery
  - Input power protection
  - Signal Isolation

- **Power Stage**
  - Isolated DC/DC power supply
  - Non-isolated DC/DC power supply
  - Current & Voltage Sense
  - Digital Processing

- **Self-Diagnostics / Monitoring**
  - Signal Isolation
Motor:
• Max. power 60 kW
• Max. torque 240Nm
• Max. rpm 13,000 min–1
• Peak current 410Arms
• Nominal voltage 200 VAC
• Motor length 250 mm
• Motor diameter 246 mm minimum
• Motor weight 49 kg
• Max. efficiency 95 %

Inverter:
• Operating voltage range 270 – 420 V DC
• Ambient temperature operating range – 40 °C to + 85 °C
• AC peak current 10 s 430 Arms
• AC continuous current 185 Arms
• Degree of protection IP6K9K
• Weight < 7 kg
EV/HEV Traction inverter converts energy stored in a battery to instantaneous multiphase AC power for a traction drive.

**HV Battery**
48 V for low voltage or several hundred volts for high voltage systems.

**HV Relay (contactor)**
Allows to disconnect the battery from the system.

**Traction Motor**
Synchronous (PMAC) or Asynchronous (induction) motor.

**IGBT Modules**
Usually half-bridge configuration per module. Three modules are needed to get 3-phase full bridge.
A Driver for every FET

**MOSFET**
- UCC21520-Q1
- UCC27201A-Q1
- LM5109B-Q1
- UCC27517A-Q1
- UCC27524A-Q1

**IGBT**
- UCC21520-Q1
- UCC27531-Q1

**SiC FET**
- UCC21520-Q1
- UCC27531-Q1

**GaN FET**
- LM5113-Q1
- LMG5200
- LMG3410

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**AC/DC (PFC)**
- DC/DC
- EV and HEV
- Automotive

**<650V Motor Drive**
- Solar Micro Inverters

**>650V Motor Drive**
- Solar String Inverters
- Air Conditioner
- Induction Heating

**High Voltage Motor Drive**
- EV Power Train Inverters
- Solar Inverter
- UPS

**48V:POL**
- AC/DC (PFC)
- DC/DC

**Motor Drive**
- Audio Amps
- Inverters
The TIDA-00366 reference design provides a reference solution for 3-Phase inverter rated up to 10kW designed using:

- reinforced isolated dual gate driver **UCC21520-Q1**,
- reinforced isolated amplifier **AMC1301-Q1**, and
- **TMS320F28027**.
What is the UCC21520-Q1?

- Industry’s fastest 5.7kVrms isolated dual channel gate driver
- The first of a new gate-driver family in TI’s isolation portfolio
- Integrated components, advanced protection features and optimized switching performance – allows for faster time to market
- Can be used as a low-side, high-side, high-side/low-side or half-bridge driver.
Key Features to Help

**LM5021-Q1** with low start up quiescent current, low current sense threshold, and slope compensation

Leveraging the reference design of the **PMP8657**, and the FAE design support on design calculations / transformer design helped lock down this design win.
UCC27201A-Q1
120V high- / low-side gate driver for 48V applications

Differentiated Features & Benefits

- Increased drive current, shorter propagation delays over competition ➔ Allows best-in-class efficiency in high-frequency converters, inverters
- Negative voltage capability at switch-node (HS pin) ➔ Best-in-class robustness
- Max Boot voltage (HB pin) of 120V, integrated 120V Bootstrap diode, Max VDD of 20V ➔ Offers highest level of flexibility in automotive power electronics
- Wider temperatures range: -40°C to 140°C ➔ Best-in-class reliability and robustness

Target Applications

- Half bridge and Full bridge for 48V loads to drive auxiliary inverters – Heat pumps, air-conditioning, power steering, pre-tensioners for seat belts etc
- 48V-12V Bi-directional DC/DC for high-power (several-kW) battery charging/balancing

Applications / Subsystem

- Half bridge and Full bridge for 48V loads to drive auxiliary inverters
- 48V-12V Bi-directional DC/DC for high-power battery charging/balancing

[Diagram showing UCC27201A-Q1 usage in different applications]
Design Features

- CISPR 25 EMI test results available
- BLDC motor drive designed to operate on 48V automotive systems
- Isolated CAN interface connects to automotive networks on 12V battery systems
- Automotive (AEC-Q100) qualified components
- **Target Applications**: turbocharger, water pump, oil pump

Design Benefits

- Operates over a wide range of voltages from 48V battery systems
- Simplifies firmware development and reduced BOM count
- Designed to communicate over industry standard automotive CAN bus

Tools & Resources

- **TIDA-00281 Tools Folder**
- **Test Data/Design Guide**
- **Design Files**: Schematics, BOM and BOM Analysis, Design Files
Design Features

• Wide-Vin isolated Flyback DC/DC converter over the Ultra wide input voltage range of 40V to 1000V DC, up to 1200V transient.
• Regulated output voltage 15V (<5% regulation) and output current up to 4A.
• SiC MOSFET solution with high voltage rating, low gate charge, and fast switching transients.
• SiC gate Driver adaption from an integrated MOSFET gate driver utilizing center-tapped transformer.
• Constant switching frequency with duty cycle range from 15% to 80%.
• Current mode control with cycle-to-cycle over current limitation.
• Automotive Grade 1 qualified Transformer with Reinforced isolation (tested at 5.7kV High-Pot).

Design Benefits

• Designed for isolated unidirectional power supplies in HEV/EV Traction Inverter systems.
• Support regenerative breaking with the minimum start-up voltage of 40V.
• Extendable to higher voltage and higher power range.
• Automotive Grade 1 qualified Transformer with Reinforced isolation.

Tools & Resources

• TIDA-01505 Tools Folder
• Test Data/Design Guide
• Design Files: Schematics, BOM and BOM Analysis, Design Files

TIDA-01505 Automotive 40V-1000Vin, 15Vout, 60W Flyback Reference Design for 800V Battery System
Question #2: What is the most needed among them?

• A) Reliability
• B) Cost
• C) One stop shopping
• D) Other (for those that answered “other”, would someone to share?)
Summary

- TI is a one stop high voltage solution provider for automotive applications.
- Solutions and Successful Stories are reviewed for DC-DC Converters and Traction Inverters
- Introduced TI Driver Solutions