High Voltage Solutions in HEV/EV Part I:
- On Board Chargers and Charging Stations

Hong Huang
What will I get out of this session?

• **Purpose:**
  
  To provide an overview of complete high voltage power solutions in on board chargers and charging stations

  - Introduction
  - Devices
  - Reference Designs

• **Part numbers mentioned:**
  
  - UCC28070-Q1, UCC28951-Q1, LM25037-Q1
  - UCC28700-Q1, UCC28730-Q1, UCC280x-Q1, UCC28C4x-Q1, LM5021-Q1
  - UCC27201A-Q1, UCC21520-Q1

• **Reference designs mentioned:**
  
  - TIDA-00558
  - TIDA-01159
  - TIDM-1007

• **Relevant End Equipments:**
  
  - On Board Chargers
  - Charging Stations
# On Board Charger / Charging Station

## Product Spectrum

### On Board Charger

<table>
<thead>
<tr>
<th>PFC</th>
<th>DC-DC Conversion</th>
<th>Drivers (MOSFET, IGBT, SiC, GaN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-isolated DC/DC Power Supply including power stage, incl. LDO</td>
<td>Isolated power supply between DC potentials including power stage, incl. LDO</td>
<td>Isolated 115/230V AC/DC Power Supply including power stage, incl. LDO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comments</th>
<th>Most preferred solution</th>
<th>Based on system architecture</th>
<th>Based on system architecture</th>
<th>Based on system architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>TI P/N</td>
<td>LM5118-Q1</td>
<td>LM5137-Q1</td>
<td>TLC2870-Q1</td>
<td>UCC2870-Q1</td>
</tr>
<tr>
<td>LM5185-Q1</td>
<td>UCC28730-Q1</td>
<td>UCC280x-Q1</td>
<td>AMC1301-Q1</td>
<td>UCC27210-Q1</td>
</tr>
<tr>
<td>TPS54540-Q1</td>
<td>SN6501-Q1</td>
<td>UCC284x-Q1</td>
<td>INA18-Q1</td>
<td>ISO1605-Q1</td>
</tr>
<tr>
<td>TPS586733-Q1</td>
<td>SN6505-Q1</td>
<td>LM5021-Q1</td>
<td>OPA376-Q1</td>
<td>ISO3452-Q1</td>
</tr>
<tr>
<td></td>
<td>UCC28570-Q1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UCC28951-Q1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| # Sockets Expected | 2 | 2 | 1 | 1 | 4 | 7 | 2 | 1 | 1 | 1 | 1 |

<table>
<thead>
<tr>
<th>TI Design</th>
<th>High VOLT Interactive</th>
<th>DC-DC Conversion PFC Drivers (MOSFET, IGBT, SiC, GaN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DC-DC Conversion PFC Drivers (MOSFET, IGBT, SiC, GaN)</td>
</tr>
</tbody>
</table>
Key End Equipment in Powertrain Systems

Powertrain

- Transmission Management: TCU
- Transmission Management: Sensors
- Transmission Management: Actuators
- Electronic Power Steering
- Electrical Power Generation/Storage
- Inverter
- Bi-directional Power Transfer
- On-board Charger (Charging Station)
- Battery Management System

Engine Management:
- ECU
- Sensors
- Actuators

Engine Fuel and Management:
- (Gas and Gas Station)

TI HVP
(High Voltage Power)
What is the On-board Charger & the Charging station?

- An On Board Charger is used in an electric vehicle (EV) or hybrid electric vehicle (HEV) to charge the traction battery (48V or HV usually ~400V)
- This includes:
  - Converts the grid 50/60Hz into DC
  - Adjusts the DC level to the levels required by the battery and provides the galvanic isolation
  - Usually includes a Power Factor correction (PFC)
  - PFC Controller and Rectification
    - High Efficiency rectification with lowest harmonic impact to the grid
  - Controller
    - Analog or Digital Control (<2kW to >100kW)
    - Adjusts the DC level to the levels required by the battery
  - Galvanic Isolation
    - Galvanic Isolation Grid to Battery
    - Bias Supply
  - Diagnostics
    - Temperature Sensing
    - Current & Voltage Sensing
    - Iso Barrier
- A charging station is to provide a battery charger equipment at home or on the road, like a gas station.
## On Board Charger Classification

<table>
<thead>
<tr>
<th>Power source Infrastructure</th>
<th>Category</th>
<th>OBC Power</th>
<th>Connector</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>~110V AC ~230V AC</td>
<td>Level 1</td>
<td>12A to 20A</td>
<td>Convenient cable as per</td>
<td>Based on battery, charging times &gt;6hours</td>
</tr>
<tr>
<td></td>
<td>Single phase</td>
<td>&lt;4 kW</td>
<td>OEM/Region</td>
<td></td>
</tr>
<tr>
<td>~230V AC ~400V AC</td>
<td>Level 2</td>
<td>17A to 80A</td>
<td>Dedicated EVSE</td>
<td>Based on battery, charging times &lt;3hours</td>
</tr>
<tr>
<td></td>
<td>1 to 3 phase</td>
<td>&lt;20 kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Fast Charging</td>
<td>Level 3</td>
<td>&gt;50 kW</td>
<td>Dedicated EVSE</td>
<td>Based on battery, charging times are targeted for &lt;1hour</td>
</tr>
<tr>
<td></td>
<td>3 Phase Grid Power/ Relevant</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Standards for On Board Chargers
- SAE J1772, IEC 62196
- CHAdeMO
- CCS (GB/T 20234)
- Tesla/OEM specific etc.
**AC/DC (PFC) Controller**
- Less losses
- Regulatory requirement
- Different topologies for power levels

<table>
<thead>
<tr>
<th>Topology</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCM Flyback</td>
<td>&lt; 100 W</td>
</tr>
<tr>
<td>TM Boost</td>
<td>To ~350 W</td>
</tr>
<tr>
<td>CCM Boost</td>
<td>&gt; 300 W</td>
</tr>
<tr>
<td>Interleaved TM Boost</td>
<td>To 1000 W</td>
</tr>
<tr>
<td>Interleaved CCM Boost</td>
<td>&gt; 1000 W</td>
</tr>
</tbody>
</table>

**Isolated DC/DC Controller**
- 400 V → 48 / 12 V
- 48/54/24 → 48/12V Buck
- 12V/5V → 48V/54V Boost Topology

<table>
<thead>
<tr>
<th>Topology</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Clamp Forward</td>
<td>To 300 W</td>
</tr>
<tr>
<td>Push-Pull Flyback power level</td>
<td>To 500 W</td>
</tr>
<tr>
<td></td>
<td>To 100W</td>
</tr>
<tr>
<td>Half-Bridge</td>
<td>100 – 300 W</td>
</tr>
<tr>
<td>(Phase shifted) Full Bridge</td>
<td>&gt; 500 W</td>
</tr>
<tr>
<td>LLC</td>
<td>&lt; 1 kW</td>
</tr>
</tbody>
</table>
Question #1: What power levels, topologies, devices challenges, ref designs have you used or are you using?

- A) TI products like UCC28070-Q1, UCC28951-Q1, LM25037-Q1, UCC28C4x-Q1, UCC28730-Q1, UCC280x-Q1, UCC27201A-Q1, UCC21520-Q1, and?
- B) 500W, 3kW, 20kW, or higher?
- C) Any reference designs, and what are they?
- D) Other (for those that answered “other”, would someone share?)
### Portfolio of Automotive Solutions Selections

#### ~500W

**Applications:**
- Premium Audio

**TI Solutions:**
- UCC280x/A/
- LM5030, LM5033
- TL494/TL594

**Solution Benefits:**
- High efficiency
- High-speed
- Low power
- Minimal external parts count

#### < 3.3kW

**Applications:**
- On-Board Charger
- Charging Piles
- Electric Vehicle Inverters

**TI Solutions:**
- UCC28951-Q1
- UCC28070-Q1

**Solution Benefits:**
- Best in class efficiency
- Automotive qualification
- Active control of the SR
- Enhanced ZVS
- Best in class interleaving solution
- Current synthesis and quantized voltage feed-forward

#### > 20kW

**Applications:**
- Fast/Charging Piles
- Charging Stations

**TI Solutions:**
- C2000 with Digital Controller
  - UCC28070-Q1 (1ph? 3ph?)
  - UCC28951-Q1

**Solution Benefits:**
- High efficiency
- Best in class interleaving solution
- Current synthesis and quantized voltage feed-forward
Solutions for Flyback

- UCC28C4x-Q1
- UCC280x-Q1
- UCC28730-Q1
- UCC28700-Q1
- LM5021-Q1
- Operating Temperature -40°C to 125°C
- Packages: SOIC, SOT, VSSOP

Benefits

- Low Power dissipation.
- High frequency operation with low startup, operating currents lowers startup loss and power consumption for improved efficiency.
- Feedback accuracy and fast response to transients
- Safety and protection features integrated

Applications

- Switch Mode Power Supplies (SMPS)
- DC to DC Converters
- Industrial Power conversion
- Automotive Power Train
Features

- Primary Side Regulation (PSR) eliminates ALL secondary-side feedback components
- <52µA IC current consumption in standby mode
- 5% output voltage regulation accuracy
- Internal 700-V startup switch
- Load short circuit protection
- 83-KHz max switching frequency enables compact power supply designs
- DCM valley switching control scheme
- Wide VDD range allows small bias capacitor
- Protection Functions: Over Voltage, Low Line & Over Current
- Programmable cable compensation
- AEC-Q100, Temperature Grade 1 (-40 to 125 C)
- SOIC-7 Package

Benefits

- Primary-side regulation ➔ Eliminates 9 feedback components (TL431, opto, etc.) and issues with opto long term reliability and temperature shifts
- Zero* standby (52µA) current consumption ➔ Ultra low power drain from battery in standby mode
- Load short circuit protection ➔ Robust solution with integrated protection
- MOSFET valley switching ➔ High efficiency

Applications

- Automotive AC/DC and DC/DC power
- Auxiliary power supply for Automotive power train in HEV
- Flyback and Buck power converters
Application Need/ Care About

Customer Problems:

- Charger has to meet automotive standards and standard rules: EN61000-3-2 Harmonics Standard, CISPR25 – Conducted and Radiated Emissions (automotive), ISO 11452 - Conducted and Radiated Immunity (automotive), EN61000-6-3 - Conducted and Radiated Emissions for component connected to HVAC power lines
- For better efficiency and lower EMC disturbance a two stage interleaved PFC has been used in this solution

- Programmable switching frequency (30k – 300kHz ) allow the customer to optimize the efficiency
- Output voltage sensing to improve reliability since it allows to:
  - Improved transient response
  - Output over voltage protection with fail-safe pin
  - Open loop protection
- Interleaved allow the customer to have lower rms current with fewer/cheaper caps → higher reliability → lower cost
- Frequency dithering to reduce EMI peak signatures, allowing smaller filter design. Reduced ripple allows smaller EMI filter design. → higher power density
Question #2: What is your PFC solution?

- A) Single Phase, Three-Phase?
- B) UCC28070-Q1
- C) C-2000/UCD3138
- D) Other (for those that answered “other”, would someone to share?)
Onboard Charger – Power supply < 3.3 kW

### Isolated AC/DC Power Supply
- **Description**: Isolated 115/230V AC/DC Power Supply incl. power stage, LDO

<table>
<thead>
<tr>
<th>TI P/N</th>
<th>Interleaved CCM PFC Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No optocoupler needed ⇒ cheaper end solution comparing to competition</td>
</tr>
</tbody>
</table>

### Isolated DC/DC Power Supply
- **Description**: Isolated power supply between DC potentials incl. power stage, LDO

<table>
<thead>
<tr>
<th>TI P/N</th>
<th>PSFB; Drivers: Isolated Dr, SR Dr,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UCC28951-Q1 best in class efficiency, reducing BOM</td>
</tr>
</tbody>
</table>
To address ever tightening fuel economy demands the automotive industry is adopting two battery power systems to facilitate Stop-Start operation in which the internal combustion engine shuts down when stopped or coasting, and automatically restarts when power is applied.

Typically a 12V lead acid battery will be used to power many of the car’s traditional systems, but a 48V Lithium battery will be used to operate the starter. That same 48V battery will provide a storage reservoir to capture regenerative braking or coast down energy. This creates a need to move power bi-directionally between the two batteries depending on overall system needs.

This design addresses deploying the SM72295 (Full Bridge Driver) in a 48:12 bidirectional charger.
The TIDA-01159 design provides a reference solution for half-bridge isolated gated drivers used in driving power stages of UPS, inverters, server and telecom applications.

This TI Design is based on the UCC21520 reinforced insulated gate driver from TI, and is capable of driving MOSFETs and SiC-FETs. The reference design contains a built-in isolated push-pull auxiliary power supply for powering the output of the isolated gate driver.

By bringing together the isolated gate driver and isolated power supply (SN6505B) in a compact board with a form factor (30 mm × 35 mm), this reference design provides a fully tested robust half-bridge driver solution, capable of withstanding >100 kV/μs common-mode transient immunity (CMTI).
Features

- GaN based Totem Pole 1PH PFC with three interleaved phases using LMG3410 & controlled using C2000 MCU
- Power Spec
  - Input: 85-265 Vac, 50/60Hz
  - Output: 400V DC
  - Power: 3.3KW at 220Vrms & 1.6KW at 110Vrms
  - Efficiency: > 99% peak efficiency
- Low total harmonic distortion (THDi) < 2%
- 100 kHz PWM switching
- Soft starting for totem pole bridge
- Phase shedding to enable higher efficiency
- Non Linear control loop to reduce voltage spikes

Benefits

- High power density design, with form factor matching OEM specifications
- Using latest TI-GaN with integrated gate drivers offering greater integration for the customers.
- High performance C2000 controller enables superior control and enables advanced control scheme to be implemented

Applications

- On-board chargers for EV
- Telecom Rectifiers
- Other industrial applications

Key TI Devices: TMS320F28075, LMG3410, UCC27714D, UCC28740, UCC24636
Available through TI.com Homepage as seen above

Also Available through every individual device product page with WEBENCH models available as seen below

- Products available on WEBENCH today
- Automotive versions available
Summary

- TI is a one stop high voltage solution provider for automotive applications.
- Solutions and Successful Stories are reviewed for OBC and Charging Stations.
- Introduced TI Solutions of PFC, DC-DC, and Bias for Automotive Applications.