Using the latest SiC in Level 3 DC Fast Chargers

Power Applications
Rev 0, October 2016
Richardson RFPD

Global Distributor of RF, Wireless, Energy, and Power Solutions

- **Electronic Components & Engineered Solutions**
  - Deep and Broad Selection of Quality Components, Modules and Kits

- **Expert Team of RF Designers and Engineers**
  - ~245 Customer-Facing Team Members: 128 FSEs, 28 FAEs and 89 ISRs

- **Value-Added Services**
  - Design-In Resources, System Integration, Testing and Application Engineering

- **Integrated Supply Chain and Global Logistic Centers**
  - Reno, Nevada; Hong Kong, China; Venlo, Netherlands

- **35 Sales Offices and Locations, 6 Engineering Centers**

- **Richardson RFPD, Inc. - Wholly Owned Subsidiary of Arrow Electronics**
  - Corporate Headquarters in Geneva, IL - USA
1. Introduction to DC Fast Chargers for Electric Vehicles
   - Growing market for level 3 chargers
   - Basic design considerations
   - Current system compared to a SiC based system

2. Why SiC MOSFETs are ideal for this application?
   - New 1kV C3MTM product line
   - Basic guide to driving the C3MTM product line

3. Available support tools
   - SpeedFitTM, free online simulator
   - 20kW LLC Hardware
   - Other Evaluation boards

4. Questions
# BASICS OF EV CHARGING

<table>
<thead>
<tr>
<th></th>
<th>AC</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>1-ph, 120Vac, 16A, 1.92kW</td>
<td>200-450VDC, 80A, 36kW</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Split-phase 240Vac, 80A, 19.2kW</td>
<td>200-450VDC, 200A, 90kW</td>
</tr>
<tr>
<td><strong>Level 3</strong>*</td>
<td>TBD</td>
<td>200-600VDC, 400A, 240kW</td>
</tr>
<tr>
<td><strong>Tesla supercharger</strong></td>
<td>n/a</td>
<td>400V, 350A, 140kW</td>
</tr>
</tbody>
</table>

Source: SAE J1772

* Not yet fully defined

Source: IHS Automotive 2013
EXAMPLE DC FAST CHARGER

- **AC Source**
- **Filter**
- **AC/D C**
- **DC/A C**
- **AC/D C**

- Modular construction using 10 – 15 kW blocks

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>L3 Typical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage (Vac,rms,I-I)</td>
<td>380 – 480, 3-ph</td>
</tr>
<tr>
<td>Output Voltage (VDC)</td>
<td>220 – 550</td>
</tr>
<tr>
<td>Output Power (kW)</td>
<td>25 – 100</td>
</tr>
<tr>
<td>Efficiency</td>
<td>~ 93 %</td>
</tr>
</tbody>
</table>
AC/DC CONVERSION

- Vienna rectifier based topology is very popular with Si SJ Mosfets.
- Uni-directional power flow.

- SiC Mosfets can offer a very compelling solution if V2G connectivity is required.
- 3-ph AFE circuit with SiC MOSFETs can offer very compact and efficient solution.
LEVEL 3 CHARGER TRENDS

- Modular construction will continue
- Need for higher power sub-assemblies, higher power density
- Higher input voltage, reduce connection cable size and heat
- Need for higher efficiency, higher THDi/PF
- Need to be smaller to enable more attractive industrial design
DC/DC CONVERSION

- Higher Efficiency
- ZVS at full load range
- Better EMI
- Larger output ripple / e-caps
- Limited output voltage range

- Wide output voltage range
- Low voltage ripple / no need for e-caps
- Hard switching at light load
- Lower efficiency
- EMI due to hard turn-off
SIMPLIFY WITH SiC

SiC lets you Simplify!

Interleaved 2L Topology

3L LLC Topology

Isolated LLC Resonant DC/DC

2L topology
SI 15KW LLC (20A) VS. SIC 20KW LLC (35A)

600V Si Based 15KW LLC
Output 20A

• 4.1 Kg
• Volume: 180 in^3
• More components

SiC Based 20KW LLC
Output 35A

• 3.2 Kg
• Volume: 68 in^3
• 20% fewer parts

Power Density (W/in^3) 3.5x higher

Less is more!
### LLC SWITCHING DEVICE CONSIDERATIONS

<table>
<thead>
<tr>
<th>Condition</th>
<th>Diagram Description</th>
<th>Voltage Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fs=Fr</td>
<td><img src="image1" alt="Diagram" /></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Fs=200 kHz</td>
<td></td>
</tr>
<tr>
<td>Fs&gt;Fr</td>
<td><img src="image2" alt="Diagram" /></td>
<td>0.933</td>
</tr>
<tr>
<td></td>
<td>Output Voltage Step Down</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fs=260 kHz</td>
<td></td>
</tr>
<tr>
<td>Fs&lt;Fr</td>
<td><img src="image3" alt="Diagram" /></td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Output Voltage Step Up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fs=180 kHz</td>
<td></td>
</tr>
</tbody>
</table>

Diagram Source: Infineon LLC application note
CRITICAL PARAMETERS FOR LLC DEVICES

Primary side Switch

- Parameters that affect conduction losses
  $R_{ds(on)}$ / $V_{cesat}$ at operating temperature

- Parameters that affect voltage blocking
  $V_{ds(max)}$ / $V_{ce(max)}$

- Ease of switching / switching losses
  $C_{iss}$
  $Q_g$
  $C_{oss}$
  $T_{don}$, $T_{doff}$, $T_r$, $T_f$

Secondary side Switch

- Parameters that affect conduction losses
  $V_f$ at operating temperatures

- Parameters that affect recovery losses
  $Q_{rr}$, $T_{rr}$
SiC MOSFETs and enable a better solution
NEW 1000V RATED MOSFETS IN OPTIMIZED PACKAGES

- Low impedance package optimized for SiC
- Kelvin Gate source pin to reduce switching losses and ringing
- Wide creepage for higher voltage capability (>7mm)

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Resistance</th>
<th>Current</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000V, 65mΩ, 36A</td>
<td>C3M0065100J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000V, 120mΩ, 15A</td>
<td>C3M0120100J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000V, 65mΩ, 36A</td>
<td>C3M0065100K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000V, 120mΩ, 15A</td>
<td>C3M0120100K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SWITCHING LOSS COMPARISON @ VDD=600V, RG.EXT=2.5OHM, VGS=-4/+15V

C3M0065100K vs C3M0065090D Switching Loss

Switching Loss (μJ)

Drain to Source Current, $I_{DS}$ (A)
## DEVICE COMPARISON

<table>
<thead>
<tr>
<th>Key Parameters</th>
<th>WS1000V C3M0065100K</th>
<th>CoolMOS™ 900V IPW90R120C3</th>
<th>1200V IGBT /w FRED IKW40N120H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rds(on) @ 25C</td>
<td>65 mΩ</td>
<td>100 mΩ</td>
<td>51.25 mΩ</td>
</tr>
<tr>
<td>Rds(on) @ 150C</td>
<td>90 mΩ</td>
<td>270 mΩ // 3</td>
<td>65 mΩ</td>
</tr>
<tr>
<td>Vds / Vce</td>
<td>1000V</td>
<td>900V</td>
<td>1200V</td>
</tr>
<tr>
<td>Qg</td>
<td>30 nC</td>
<td>270 nC x3</td>
<td>185 nC</td>
</tr>
<tr>
<td>Ciss</td>
<td>660 pF</td>
<td>6800 pF x3</td>
<td>2330 pF</td>
</tr>
<tr>
<td>Coss, 600/0V, 1MHz</td>
<td>60 / 1000 pF</td>
<td>60 / 15,000 pF x3</td>
<td>150 / 1100 pF</td>
</tr>
<tr>
<td>Ton (Tdon+Tf)@25C</td>
<td>28 nS</td>
<td>95 nS</td>
<td>46 nS</td>
</tr>
<tr>
<td>Toff (Tdoff+Tr)@25C</td>
<td>29 nS</td>
<td>420 nS</td>
<td>347 nS</td>
</tr>
<tr>
<td>Package</td>
<td>TO-247-4</td>
<td>TO-247-3</td>
<td>TO-247-3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Parameters</th>
<th>WS C5D50065D</th>
<th>RAPID2 IDW40E65D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vf, 40A, 175C</td>
<td>1.7V</td>
<td>1.65V</td>
</tr>
<tr>
<td>Trr / Qrr</td>
<td>- / 110 nC</td>
<td>60 nS / 1140 nC</td>
</tr>
</tbody>
</table>
SIC MOSFETS ARE EASY TO USE

Mornsun G1209S-2W
Murata MEJ2D1209SC
RECOM R12P209D

+15 / -3V
OR
+15/ 0 V

Si8261ACD-C-IS
Design Support tools
SPEEDFIT ONLINE SIMULATOR

http://www.wolfspeed.com/speedfit/

Input voltage

700 V

Output voltage

500 V

Rated output power $S_o$

20000 W

Switching frequency $F_{sw}$

200 kHz

$C_r$

10 nF

$L_r$

63 $\mu$H

Matching circuits

- Buck converter
- Buck-boost converter
- LLC resonant converter
- Phase shift full bridge converter

SpeedFit is a free online Simulator for SiC devices. LTSPICE & PLECs Model of the devices are also available.
SPEEDFIT OUTPUT

Circuit

System overview

<table>
<thead>
<tr>
<th>Input Voltage</th>
<th>Actual Output Power</th>
<th>Switching Frequency</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>700 V</td>
<td>19.67 kW</td>
<td>200 kHz</td>
<td>98.49 %</td>
</tr>
</tbody>
</table>

Device overview

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Switching Losses</th>
<th>Conduction Losses</th>
<th>Combined Losses</th>
<th>Junction Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSFETs</td>
<td>5.28 W</td>
<td>145.28 W</td>
<td>150.56 W</td>
<td>113 °C</td>
</tr>
<tr>
<td>Diodes</td>
<td>0 W</td>
<td>146.72 W</td>
<td>146.72 W</td>
<td>110 °C</td>
</tr>
<tr>
<td>Converter Losses</td>
<td></td>
<td></td>
<td>297.28 W</td>
<td></td>
</tr>
</tbody>
</table>

General

Source Voltage (Green), Load Voltage (Red) (V)

Input Current (Green), Load Current (Red) (A)

Simulation Status: Analysis completed.
# 20KW LLC REFERENCE DESIGN SPECIFICATION

**P/N CRD-20DD09P-2**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>650 - 750 VDC</td>
<td>VDC</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>400 – 550 VDC</td>
<td>VDC</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>150 - 400 kHz</td>
<td>kHz</td>
</tr>
<tr>
<td>Max. Output Power</td>
<td>20 kW</td>
<td></td>
</tr>
<tr>
<td>Max. Output Current</td>
<td>35** A</td>
<td></td>
</tr>
<tr>
<td>Pk. Efficiency</td>
<td>98.4% n/a</td>
<td></td>
</tr>
<tr>
<td>Power Density</td>
<td>&gt;60 W/in³</td>
<td></td>
</tr>
<tr>
<td>Size***</td>
<td>275 x 220 x 65 mm</td>
<td></td>
</tr>
<tr>
<td>Weight***</td>
<td>3.2 Kg</td>
<td></td>
</tr>
</tbody>
</table>

* Vo upper limit extended to 700V when Iout limited to 20A for single device config.
** Io limited to 20A for single device configuration.
*** PCBA only.

Uses the latest gen C3M0065100K 1000V, 65mohm SiC MOSFET in TO-247-4 package.
BLOCK DIAGRAM

2x C3M0065100K SiC MOSFETs in parallel per switch

Resonant Tank $L_r=16\mu H$, $C_r=35nF$, $L_m=75\mu H$

Constant Current & Constant Voltage feedback loops

Input: 650Vdc-750Vdc

Output: 300Vdc-550Vdc
Max current: 35A
SYSTEM OVERVIEW

- **C3M0065100K SiC MOSFET**
- **Aux power with C2M1000170D**
- **Isolated Main PQ6560 Transformer**
- **SiC MOSFET Driver**
- **PQ3540 resonant inductor**
- **C5D50065D SiC SBD**
- **LLC controller**
- **CC & CV Feedback**
• Need to add an ON/OFF switch
• DC Power source 0-700VDC, 30A
• \(\text{Vin} > 650\text{VDC}\) to start operation.
• \(\text{Vin} > 150\text{V}\) for Aux power supply output.
• 12VDC, 10A per source needed for cooling fans.
• Option for external source to run constant current or voltage mode.
• Add pre-charge circuit or ramp up \(\text{Vin}\) slowly.
• Read user manual before operating.
WAVEFORMS AT FULL LOADING, VIN: 700V, VOUT: 500V, 35A

- ZVS is achieved for turn on and turn off
- It operates at resonant frequency at 200KHZ

Efficiency 98.2% at 200KHZ
It operates below resonant frequency at 180KHZ with output voltage step up.
It operates above resonant frequency at 260KHZ with output voltage step down at full loading 35A output.
DOES NOT COMPROMISE ON EFFICIENCY

Full SiC MOSFET 20kW LLC Converter Efficiency

Note: the efficiency includes aux power losses.
THERMAL PERFORMANCE: 700V INPUT, OUTPUT: 500V 35A

Main transformer

SiC MOSFET

resonant inductor

Output diode
20A OUTPUT LLC RESONANT CONVERTER BLOCK DIAGRAM

- 1pcs C3M0065100K 4L SiC MOSFET in parallel per switch
- 1pcs C4D20120D per switch
- Constant Current & Constant Voltage feedback loops
- Resonant Tank Lr=16uH, Cr=35nF, Lm=75uH
- Input: 650Vdc-750Vdc
- Output: 300Vdc-550dc
- Max current: 20A
- 1pcs C3M0065090D 4L SiC MOSFET in parallel per switch
**EFFICIENCY CURVE WITH 1PCS 65MOHM SIC MOSFET PER SWITCH**

**Note:**
- The efficiency includes aux power losses
- The input voltage is fixed at 700Vdc for all data
- The efficiency curve on the right is fixed output current at 20A with output voltage increasing
- The efficiency curve on the left is fixed output voltage 500V with output power increasing
- Output voltage is ranged from 300V to 700V
## THERMAL PERFORMANCE FOR 10KW VERSION

<table>
<thead>
<tr>
<th>Operating Condition</th>
<th>Xfer</th>
<th>Resonant Inductor</th>
<th>SiC Mosfet Case</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vin=700 VDC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vo= 700VDC</td>
<td>120</td>
<td>57</td>
<td>89</td>
<td>°C</td>
</tr>
<tr>
<td>Io = 20A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vin=700 VDC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vo= 500VDC</td>
<td>94.9</td>
<td>62.8</td>
<td>61.2</td>
<td>°C</td>
</tr>
<tr>
<td>Io = 20A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vin=700 VDC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vo= 300VDC</td>
<td>67.5</td>
<td>88.1</td>
<td>79.1</td>
<td>°C</td>
</tr>
<tr>
<td>Io = 20A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Easily assembly prototype full SiC converters with this half-bridge evaluation board using the latest D2PAK-7L packaged C3M MOSFETs.

**P/N: CRD-5FF0912P**

Foot Print: 3.8” x 4.95” [96.5 x 126 mm]

Height: 2.6” [66 mm]

Weight: 0.6lbs [0.27 kg]
SUMMARY

- SiC MOSFETs can simplify the Full Bridge LLC circuit in a DC fast charger.
- SiC MOSFETs and Diodes significantly improve efficiency and power density of the LLC circuit.
- The new wolfspeed 1000V gen3 devices are ideally suited for this application.
- Design support tools are available:
  - Speedfit Online Simulator
  - Reference design files for the 20kW LLC design
    - BOM
    - Schematic
    - Layout files
    - CAD
  - 20kW Evaluation hardware is available for purchase

www.wolfspeed.com/power
Thank you

Questions?
COMPLETE SURVEY FOR CHANCE TO WIN!

KIT8020-CRD-8FF1217P-1 – 1200V SiC MOSFET Evaluation Kit

CRD-060DD12P – 60W auxiliary supply with 1700V, 1 Ohm MOSFET

CRD-5FF0912P – 900V SiC MOSFET Evaluation Kit

CRD-060DD17P-2 – Auxiliary power supply evaluation board incorporating 1700V SiC MOSFET