Evolution of EV charging and solutions for future needs

by Harald Parzhuber

Agenda

1. Overview on EV charging

2. Solutions & Implementations
   I. AC charging stations
   II. DC charging stations

3. Future Trends
   I. Vehicle to Grid (V2G) and needs for bidirectional chargers/equipment

Overview of EV charging

1. Overview on EV charging

2. Solutions & Implementations
   - AC charging stations
   - DC charging stations

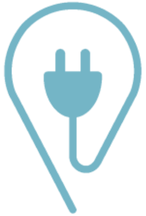
3. Future Trends
   - Vehicle to Grid (V2G) and needs for bidirectional chargers/equipment

Overview of EV charging

AC Level 1 Chargers (Private)

<3.7kW Charging cable

Home (Over night) charging



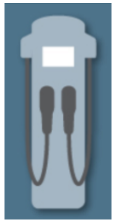
+ Works with existing power line infrastructure at home/office
+ Lowest cost option to trickle charger your car

- Slow charger (best for overnight charging)

AC Level 2 Charger (Public)

<22kW Charging station

Public slow charging



+ Faster charging than L1
+ Intermediary option both from cost and charging capabilities

- Needs Infrastructure power line upgrade

DC Portable Charger (Private)

3-11kW Charging station

Charger for OBC less cars

+ Portable DC chargers can potentially help make EVs more affordable
+ Power level can be easily scaled to customer needs
+ Bidirectional charging for customers that can use it

- Complex to design as it has to met strict form factor requirements (thermal)

DC Fast Charger (Public)

50-150kW+ Charging station

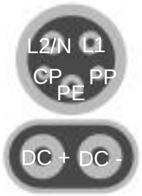
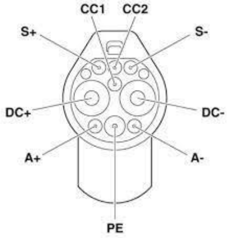
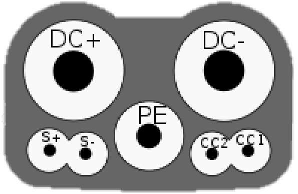
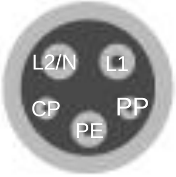
Parking+ Highway Charging

+ Offers filling gas like experience for EVs
+ Modular architecture - made up of 6/12racks with 60/30kW AC:DC & DC:DC power modules

- Cost
- Needs infrastructure power line upgrade

Charging standards – A worldwide view

From 2022

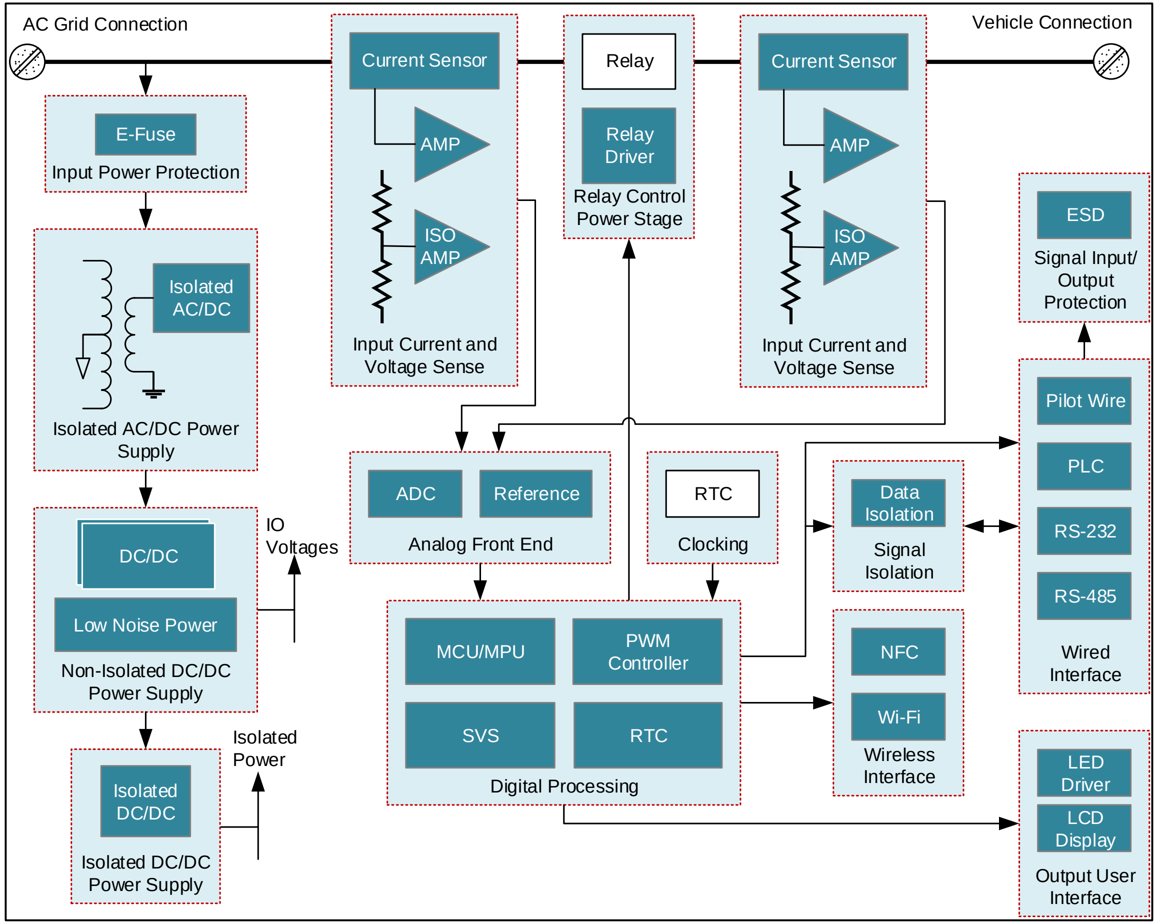
Country	Japan	N. America	Europe	Except EU	China	China – Jap
DC	**CHAdeMO**	**CCS1**	**CCS2**	**Tesla**	**GB/T**	**CHAoJI**
Inlet						
Max Power	1000Vx400A = 400kW	1000Vx400A = 400kW		410Vx330A=135kW	950x250A=237.5kW	1500Vx600A=900kW
Communication	CAN (ISO 11898)	Pilot Wire & PLC (ISO 15118)		CAN (SAE J2411)	CAN (SAE J1939)	CAN (SAE J1939)
V2G	Yes	under development		No	und. development	planned
AC	**J1772**	**J1772**	**Mennekes**	**Tesla**	**GB/T**	**CHAoJI**
Inlet		 Same as CCS1	 Same as CCS2			Combinations of CHAoJi + AC Inlets
# Phases	Single Phase	Single Phase	Single/3 Phase	Single Phase	Single/3 Phase	Single/3 Phase

Charging solutions – AC charging

Level 1 & 2 EV charging station

TIDA-00637
Gen-1
J1772 compliant L1/2 EVSE

TIDA-010071
Gen-2
J1772 compliant L1/2 EVSE



TIDC-EVSE-WIFI
WiFi® enabled L1/2 EVSE

TIDC-EVSE-NFC
NFC enabled L1/2 EVSE

Level 1 and 2 SAE J1772 compliant EV Service Equipment (EVSE) – Reference design TIDA-010071

Features

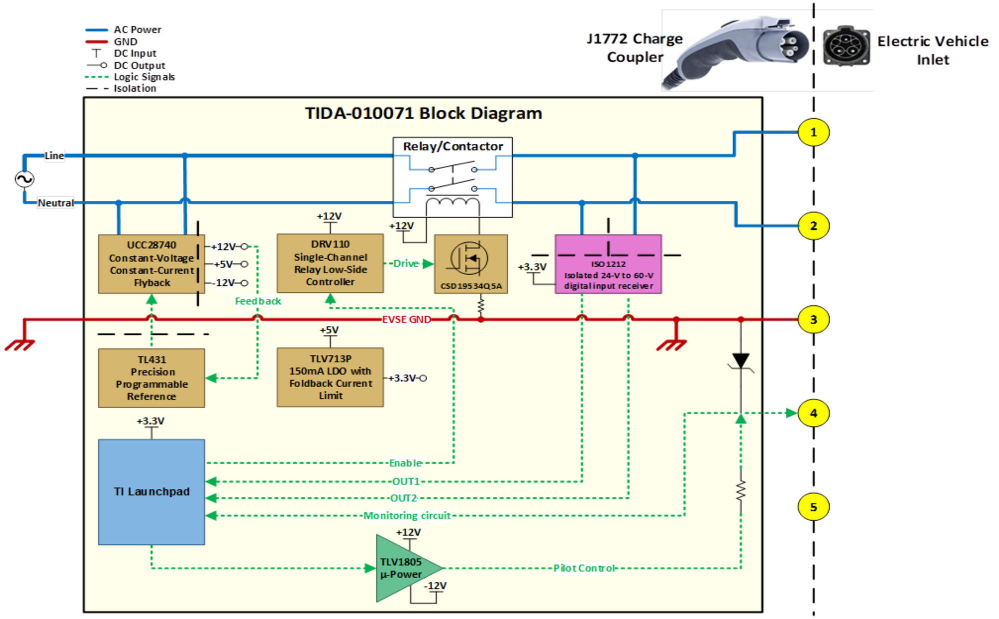
- SAE J1772 compliant pilot signal output and return
- High efficiency, tight output voltage regulated, low standby isolated AC-DC fly back power stage based on UCC28740 and TL431
- DRV110 current controller used for driving high current relays or contactors
- Isolated line voltage sensing using ISO1212 digital-input receiver for welded relay/contactor detection
- Onboard Launchpad connectors to interface with any MCU family

Benefits

- Output voltage regulation (<±5%) of AC-DC flyback stage and high slew of TL1805 enables to meet SAE J1772 certification for control pilot interface
- Low standby of UCC28740 based AC-DC stage enables to achieve energy star ratings for EV charging stations
- Current controlled relay/contactor driver to avoid thermal problems and reduce power dissipation
- Isolated line voltage sensing to detect fusing of contacts due to arcing

Applications

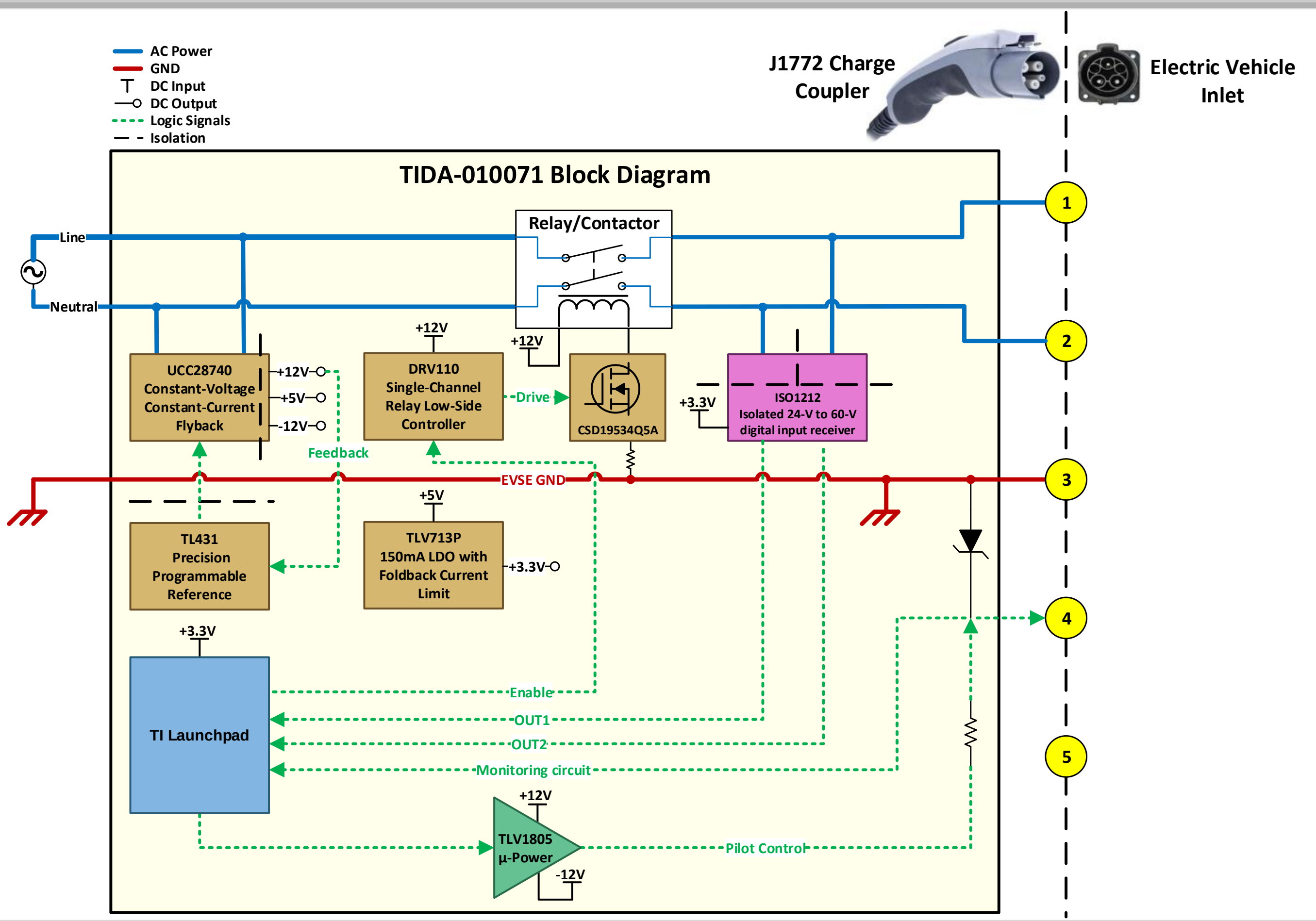
- AC charging (pile) station
- DC charging (pile) station



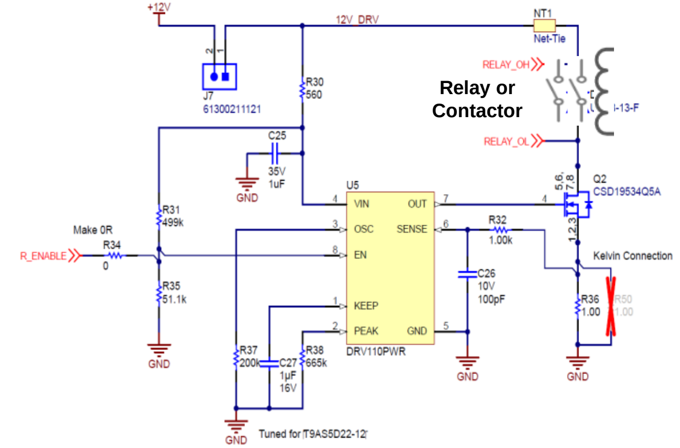
Tools & Resources

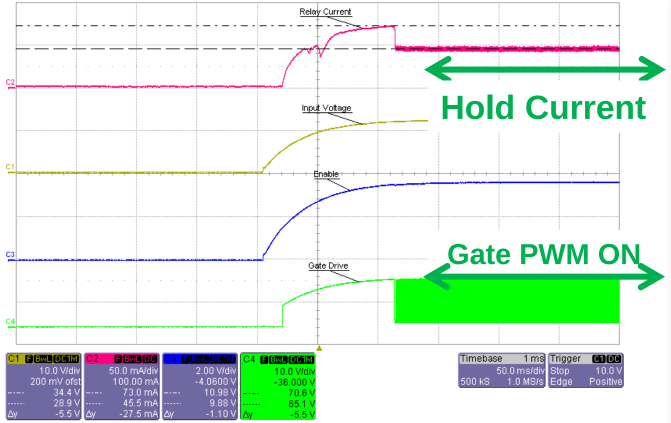
- **TIDA-010071**
- **Design Files:** Schematics, BOM and BOM Analysis, CAD Files
- **Key TI Devices:** UCC28740, TL431 DRV110, ISO1212, TLV1805, CSD19538Q5A

System block diagram



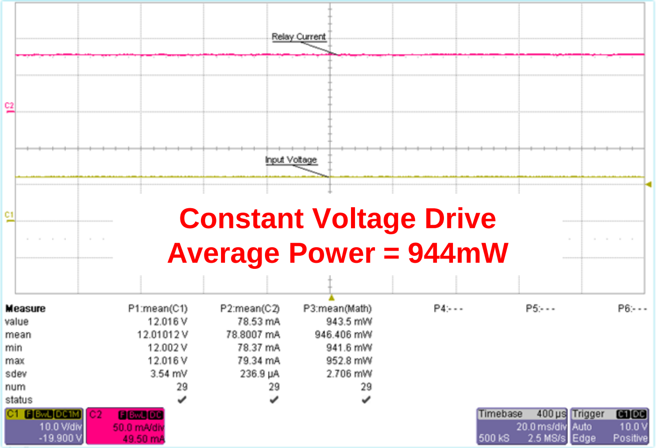
40% reduction in power dissipation using DRV110

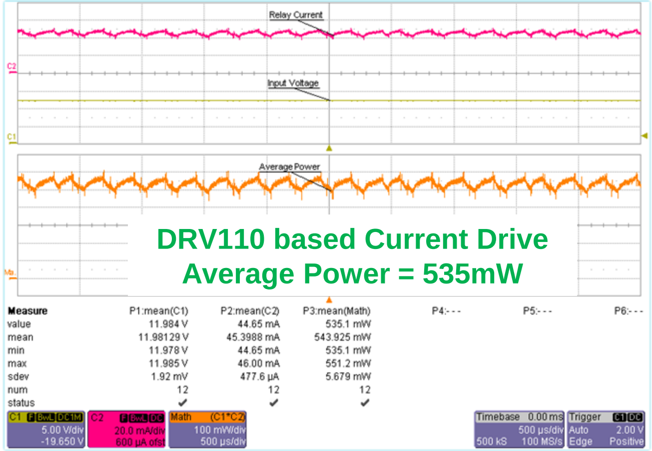




Features:

- DRV110 capable of driving any solenoid with extended period of actuation of solenoids, relays, contactors, etc
- Reliable ON/OFF through current control
- Peak/hold current architecture
- Internal Zener and external FET support high-voltage VIN:
  - 120V and 230V AC supply through rectifier and RS resistor
  - 24V, 48V, and higher DC supply through RS resistor

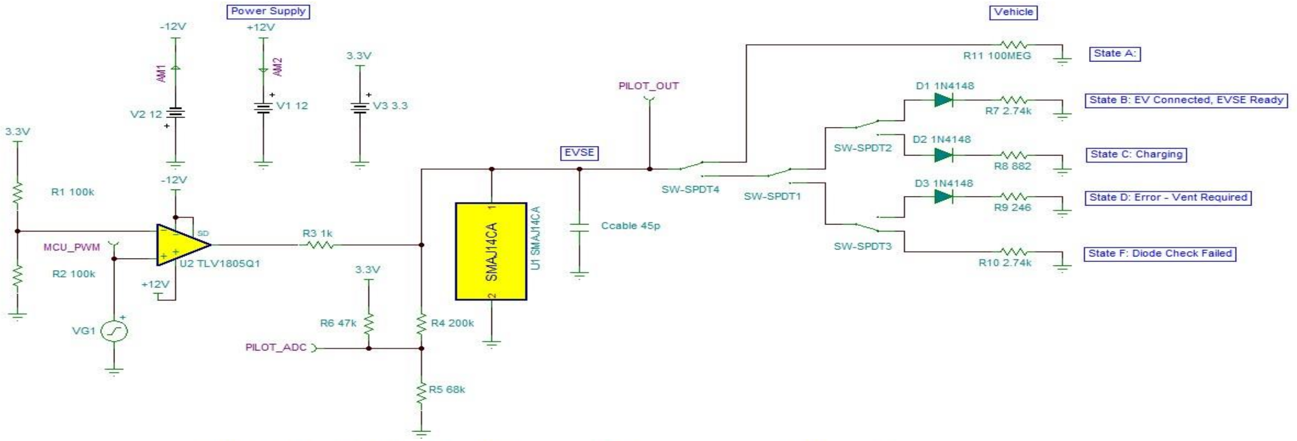


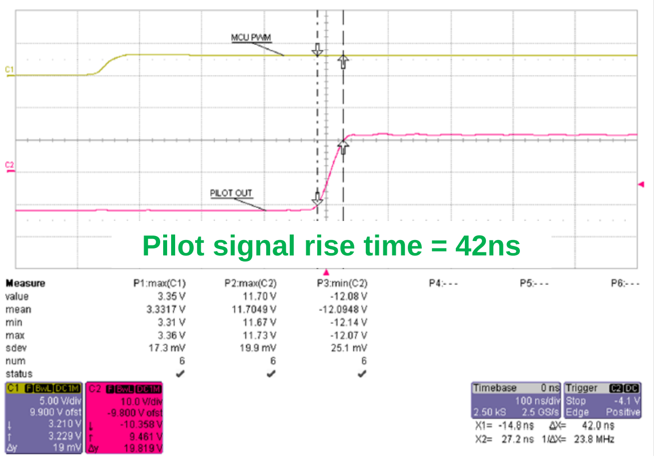


Benefits:

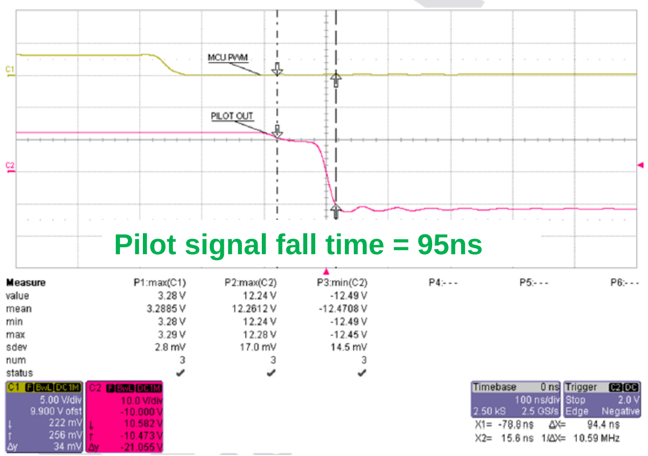
- Reliable current control ensures relays stay energized regardless of temperature
- Peak/hold current architecture reduces power consumption (**Half as compared to constant voltage drive**) and thermal dissipation resulting in higher performance efficiency over time
- Integrated Zener can accommodate a wide range of voltages, external FET can be sized for suitable current

SAE J1772 compliant control pilot signal interface





Pilot signal rise time = 42ns



Pilot signal fall time = 95ns

Table 1. Control Pilot Signal Generator Parameters per SAE J1772

PARAMETER(1)	MIN	NOM	MAX	UNITS
Voltage high, open circuit	11.40	12.00	12.60	V
Voltage low, open circuit	–11.40	–12.00	–12.60	V
Frequency		1000		Hz
Pulse width(2)		5		µs
Rise time(3)		2		µs
Fall time(3)		2		µs
Settling time(4)		3		µs

(1) Tolerances to be maintained over the environmental conditions and useful life as specified by the manufacturer

(2) Measured at 50% points of complete negative-to-positive or positive-to-negative transitions

(3) 10% to 90% of complete negative-to-positive transition or 90% to 10% of complete positive-to-negative transition measured between the pulse generator output and R1. Note that the term generator is referring to the EVSE circuitry prior to and driving the 1-kΩ source resistor with a ±12-V square wave. This circuitry shall have rise/fall times faster than 2 µs. Rise and fall times slower than this will begin to add noticeably to the output rise and fall times dictated by the 1-kΩ resistor and all capacitance on the pilot line.

(4) To 95% of steady-state value, measured from the start of transition

TEXAS INSTRUMENTS

Isolated line sensing for contact weld detection

Input Configuration				
VAC	Vin_max	Rthr R41+R42 R45+R46	Rshunt R47 R49	Rsense R43 R48
110	148	33k	24k	560
240	300	60k	15k	560

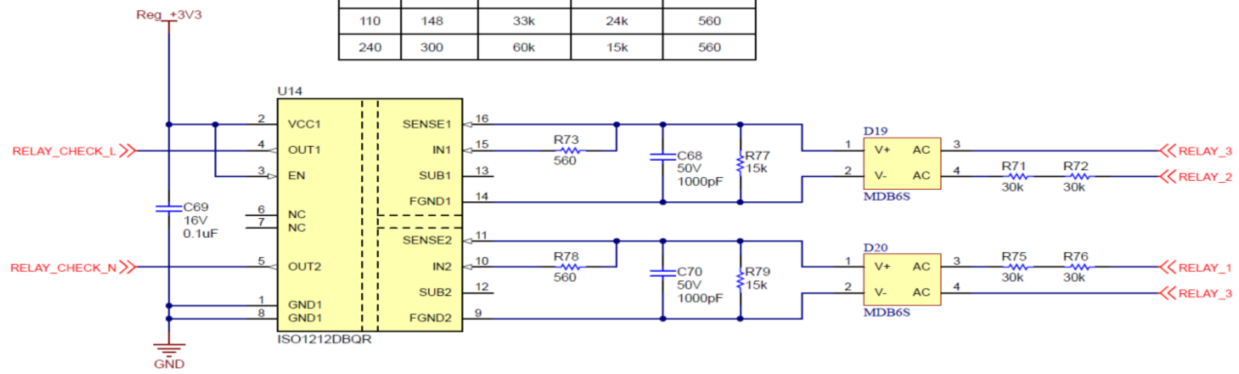


Figure 43. ISO1212 Digital Outputs and Input Line Voltage When Relay is Closed

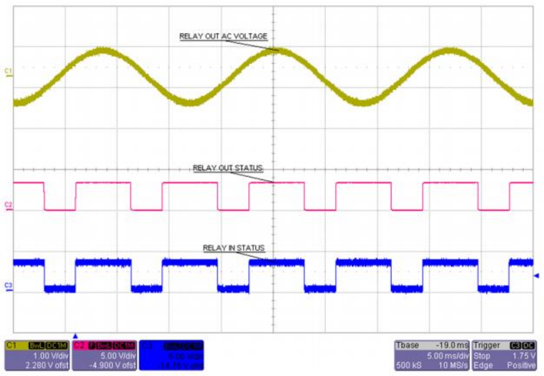
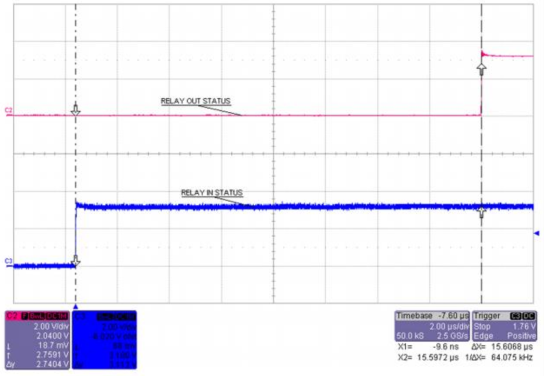


Figure 44. Delay Between Digital Outputs of ISO1212



- For safety reasons, detecting the output voltage of the primary relay is critical
- The contacts can experience arcing and become fused together, providing power to the plug even when the system is not powering it
- Checking that the operation completed correctly is important and should be done every time the relay is opened
- To implement this check, the ISO1212 fully-integrated, isolated digital-input receiver is used to sense line voltage
- The outputs (OUT1 and OUT2) from the ISO1212 device are GPIO-level DC signals that are high when voltage is present and are fed directly into the MCU for fault detection

DC charging stations

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3. Future Trends
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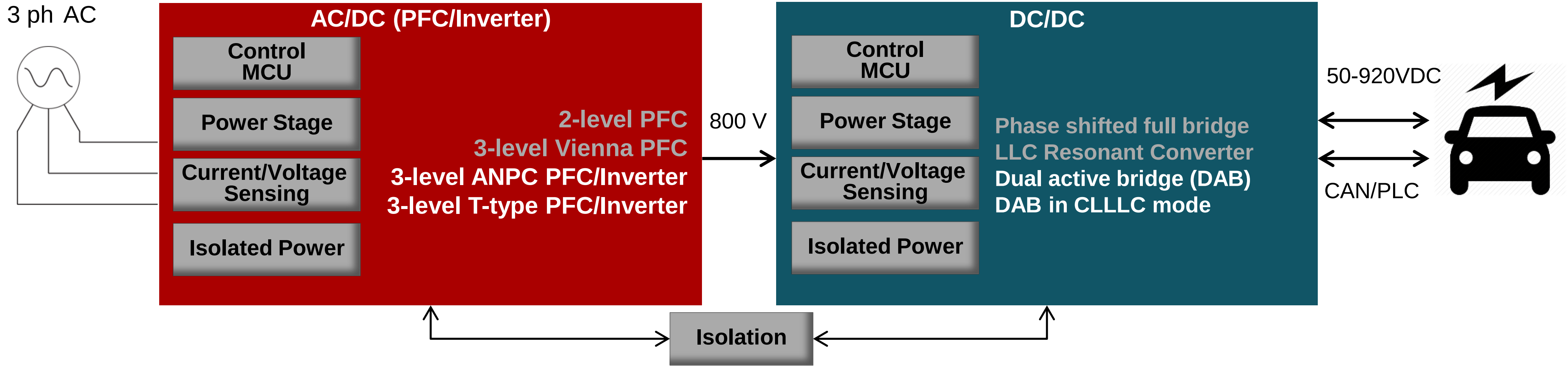
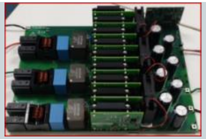
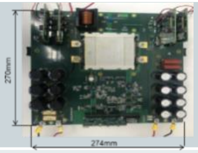
EV charging station power module

For power topology selection please refer to App note



	TIDA-01606 3-L T-type PFC/Inverter	TIDA-010210 3-L ANPC PFC/Inverter	TIDA-010054 Dual Active Bridge DC/DC	TIDM-02002 Dual Active Bridge in CLLLC DC/DC
				
Power level	10kW	10kW	10kW	6.6kW
Switching frequency	50kHz	100kHz	100kHz	500kHz (nom.)
Topology used for	10kW-25kW	10kW-40kW	8-25kW	8-25kW

10kW 3-phase 3-level bidirectional inverter/converter – Reference design TIDA-01606

Features

- 10kW 3-Phase 3-Level inverter/rectfier using SiC MOSFETs
- System Specifications:
  - Input/Output : 800V/1000V
  - Output/Input : 400VAC 50/60 Hz
  - Power : 10KW/10KVA
  - Efficiency : > 99% peak efficiency
  - PWM frequency : 50kHz
- Uses ISO5852, UCC5320 gate driver & C2000 MCU controller
- Uses Littelfuse LSIC1MO120E0080 1200V 80mOhms SiC MOSFETS
- Reduces output filter size by switching inverter at 50KHz
- Isolated current sensing using AMC1306 for load current monitoring
- Differential voltage sensing using OPA4350 for load voltage monitoring
- Targets less than 2% output current THD at full load

Applications

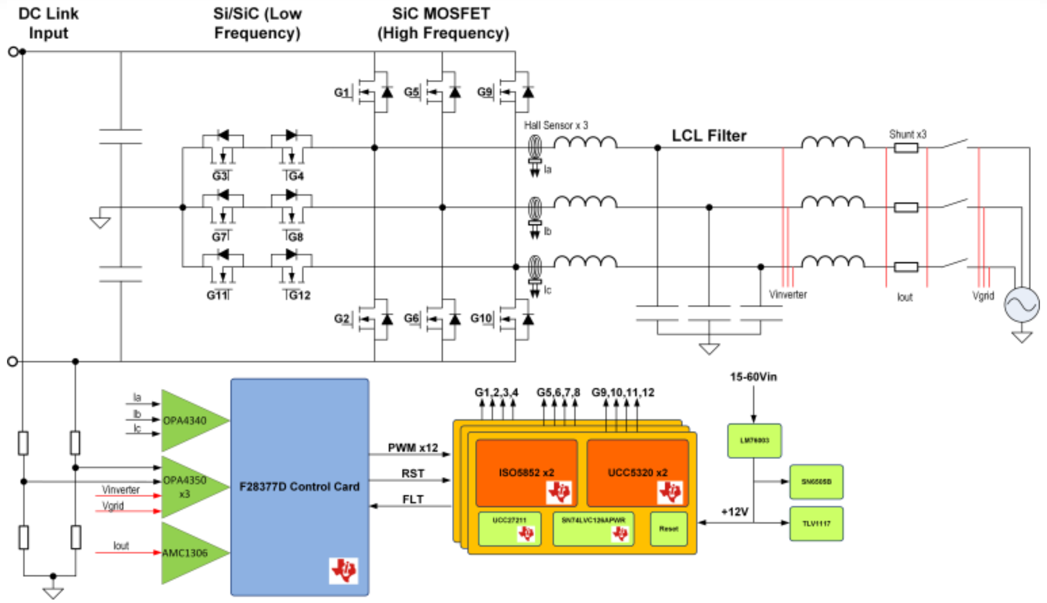
- DC EV Charging (Pile) Stations / Portable DC charging stations
- Energy Storage Systems (Storage Ready Solar Inverters)

Tools & Resources

- TIDA-01606 Tools Folder
- **C2000 Digital Power SDK**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** UCC5320, ISO5852, AMC1306, SN6505, TMS320F28379D, OPA4350, OPA350, LM76003, PTH08080WAZT, UCC27211

Benefits

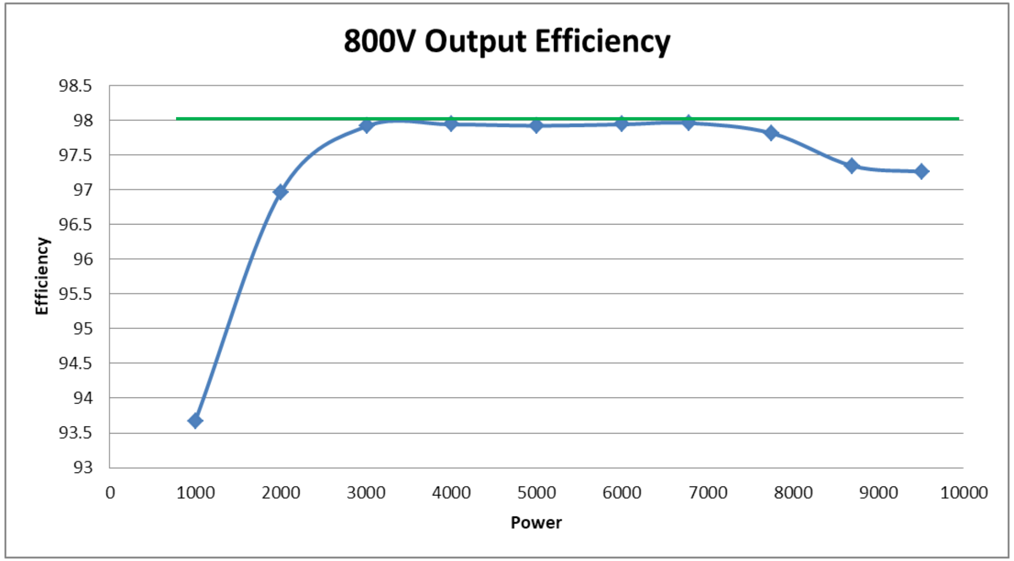
- 3-Level T-type inverter topology for reduced ground current in transformer-less grid-tie inverter applications
- Reduced size at higher efficiency using low Rdson SiC MosFET and higher switching frequency (50kHz) at higher power (10kW)
- Platform for testing both 2-level and 3-level inverter by enabling or disabling middle devices through digital control



Test results of TIDA-01606

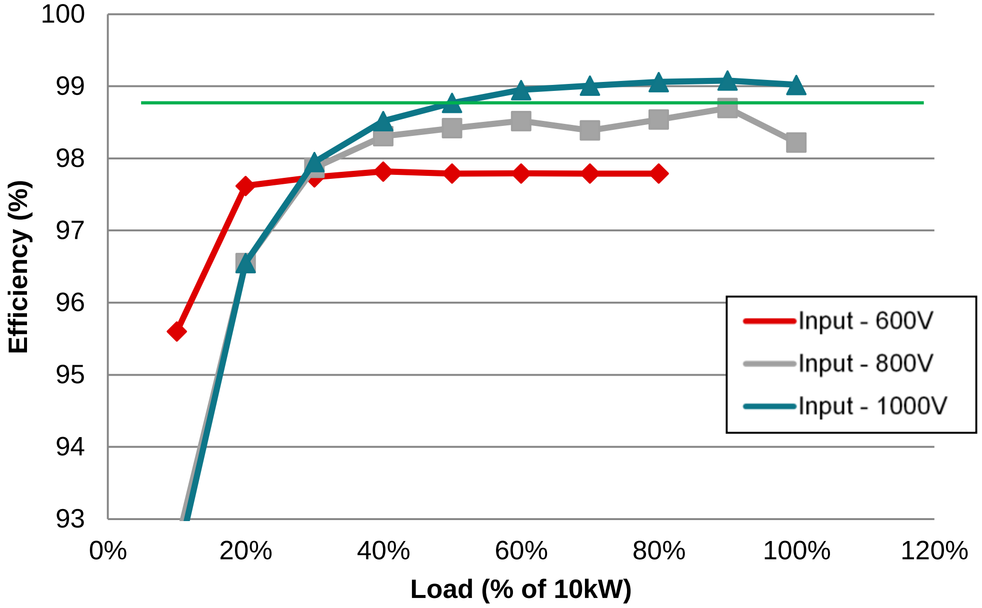
Rectifier efficiency (vs.) load

97.9% peak efficiency



Inverter efficiency (vs) load

99.07% Peak efficiency



Summary results for TIDA-01606

Measured Results for Rectifier

System Parameter	Value
Input voltage	400 VAC
Output voltage	800 VDC
Maximum power	10 kW
PWM frequency	50 kHz
Efficiency (peak)	**97.9% @ 7 kW**
Efficiency (full load)	**97.2% @ 10 kW**
Size	**350 mm x 200 mm x 100 mm**

Measured Results for Inverter

SYSTEM PARAMETER	VALUE
Input Voltage	600-1000Vdc
Output Voltage	400VAC 50/60Hz
Maximum Power	10kW
PWM Frequency	50kHz
Efficiency (Peak)	**99.07% @ 8kW**
Efficiency (Full Load)	**99.02% @ 10kW**
Size	**350mm x 200mm x 100mm**

6.6kW, 3-phase, bidirectional ANPC 3-level inverter/ PFC power stage – Reference design TIDA-010210

Features

- 3 phase, 3 level Inverters/PFCs using SiC or GaN
    - Input/Output up to 800VDC
    - Input/Output 400VAC 50/60Hz
    - Switching frequency 100kHz
- Uses 650V rated switches in 800V system (due to 3-levels)
- Novel on-board protection implemented using CLB of C2000
- Iso-dual channel driver supports high freq. operation (100KHz)
- Shunt based current sense (high accuracy & linearity over temp.)
- Power module with up to 10A current (on AC side) capable

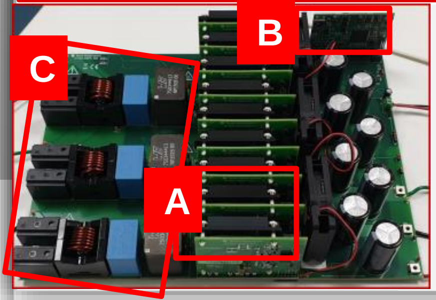
Benefits

- High power density due to high switching freq. (100kHz) and high efficiency (>98% at full load)
- Bidirectional operation with <1ms direction changeover
- Low component stress helps to improve system reliability
- Optimized control scheme needs 6 PWMs vs. 9 PWMs
- Reduced cost - four high freq. switches (vs. 6) per arm
- Real-time safety operation with no-extra cost

Applications

- DC EV Charging (Pile) Stations / Portable DC charging stations
- Energy Storage Systems (Storage Ready Solar Inverters)

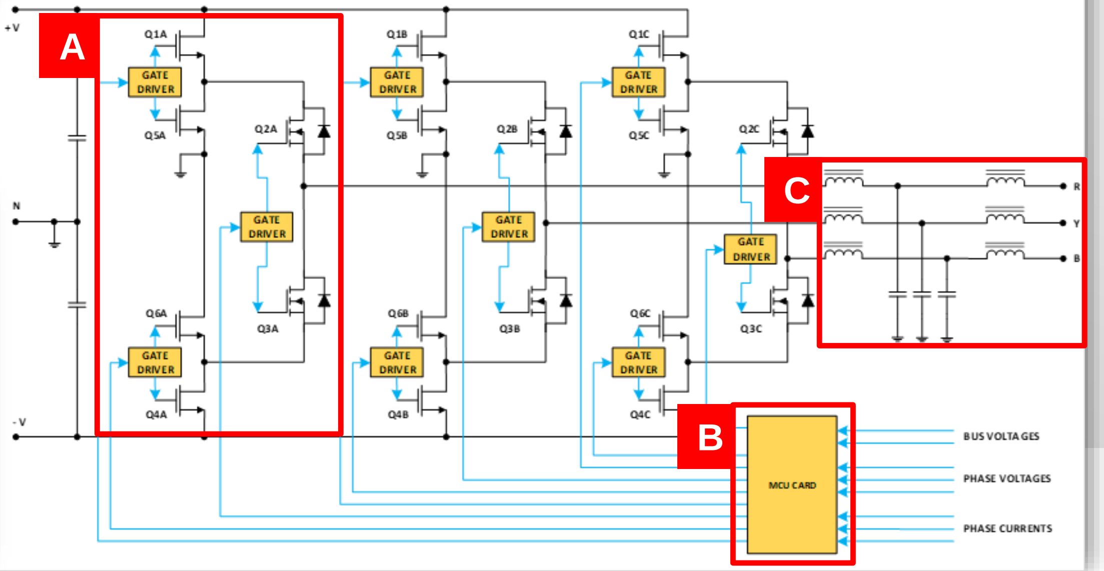
Tools & Resources



TIDA-010210 Tools Folder

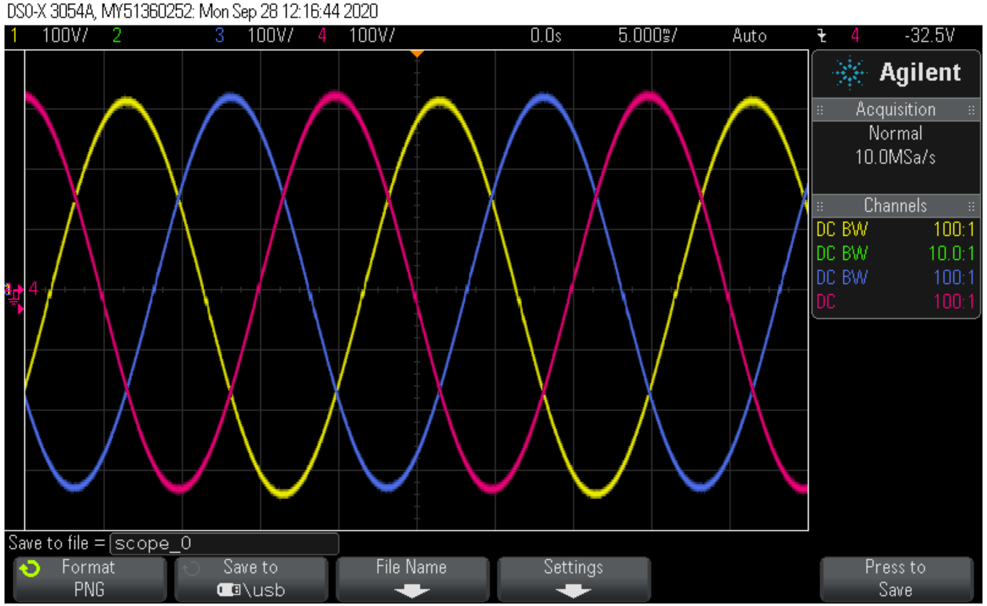
Design Files: Schematics, BOM and BOM Analysis, Design Files

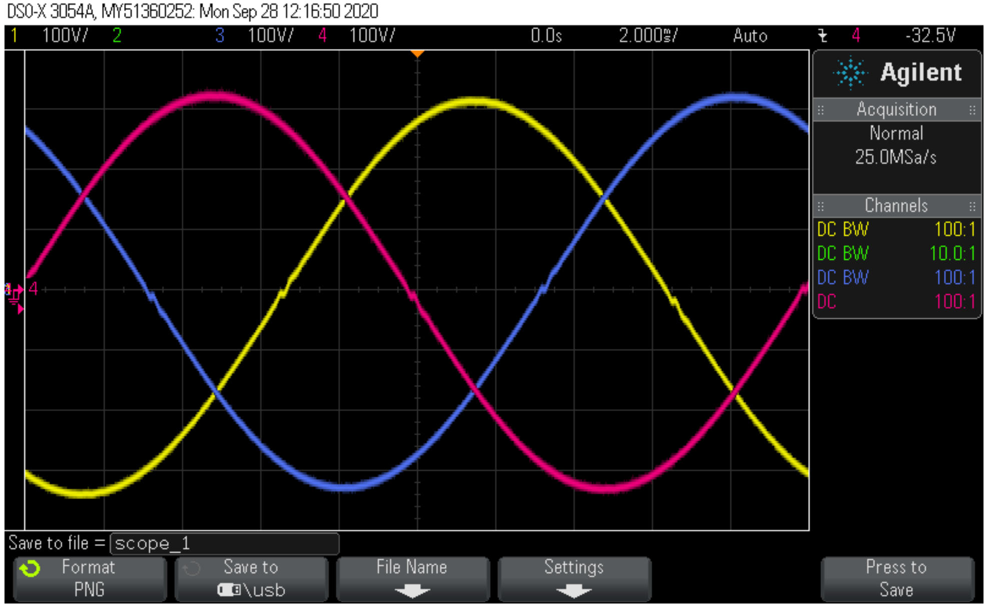
Key TI Devices: LMG3410R050, UCC21530, AMC3302, UCC21541, LMT87, TLV9004, TPS563200, LP5907, SN6501, OPA4376, TMS320F28004x



Test results of TIDA-010210

Open loop test – Output voltage waveforms

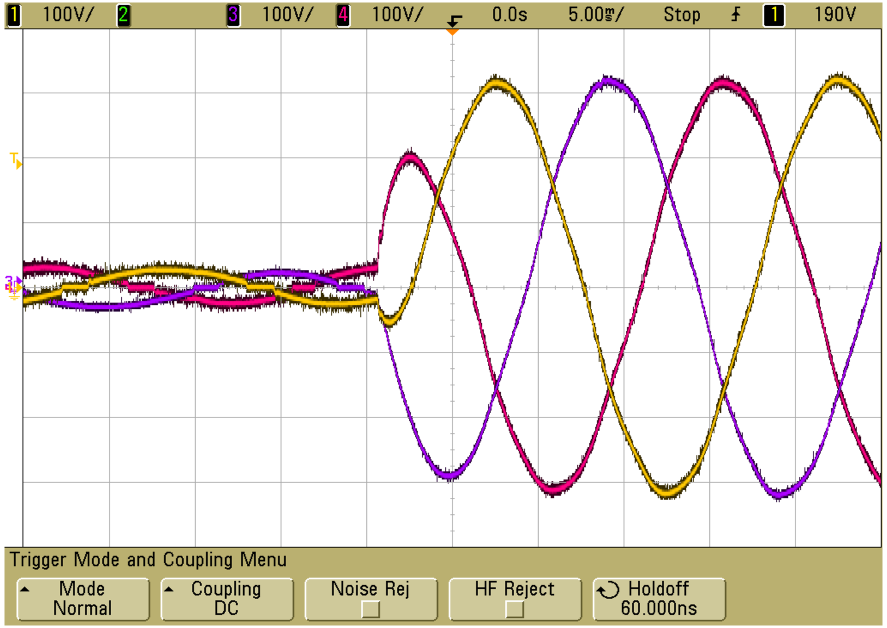


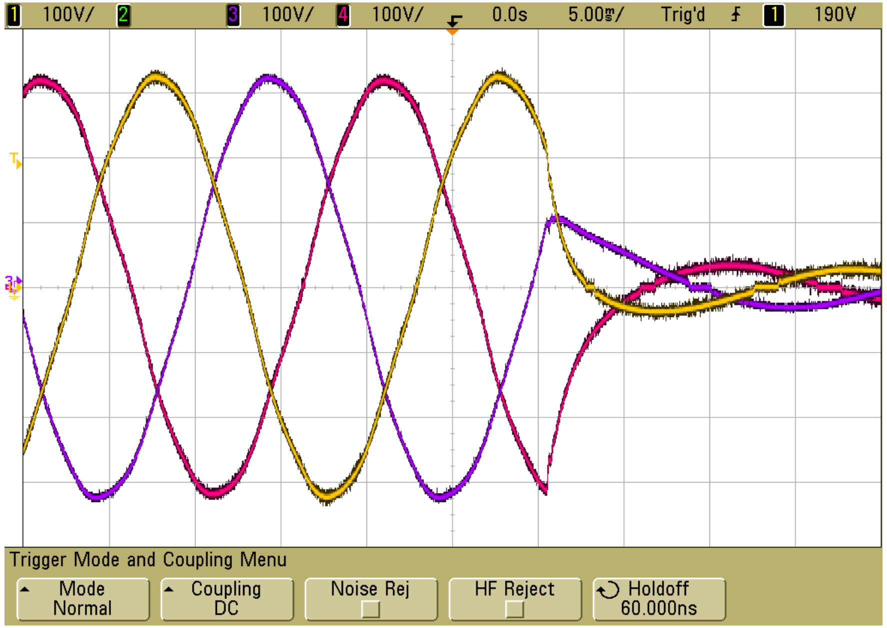


- Clean sinusoidal waveforms with the new PWM scheme
- Low distortion with configurable logic block based protection active

Test results of TIDA-010210

Transient response

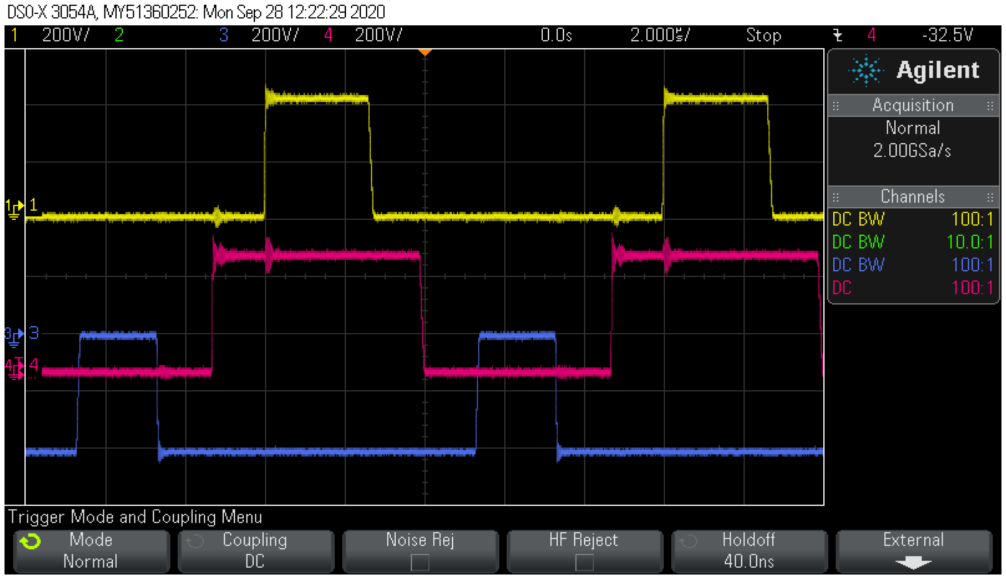


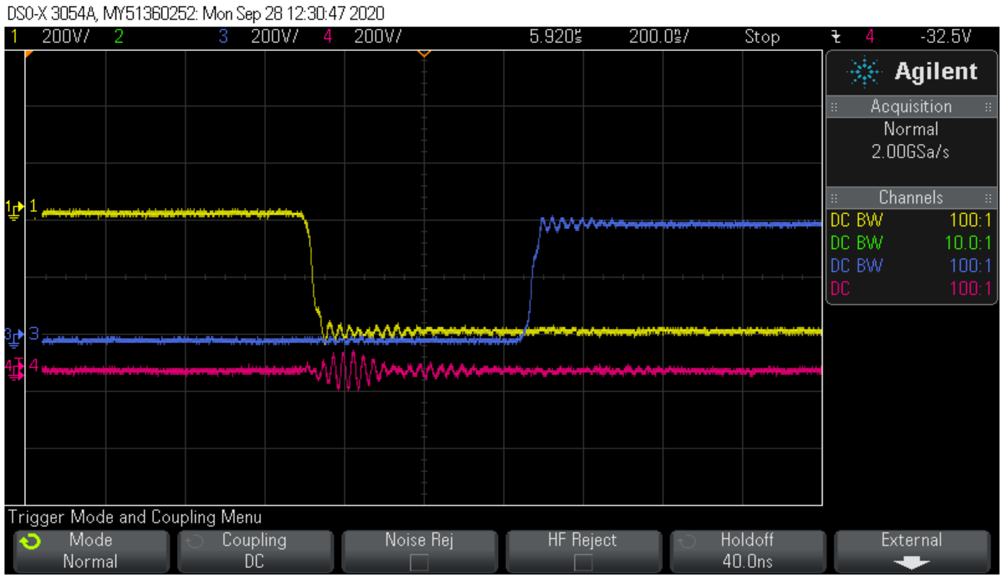


- Voltage waveform with current switching from 1A - 6A and 6A – 1A shows stable loop
- Settling time of ~ 5ms for both transitions

Test results of TIDA-010210

Switch voltage stress



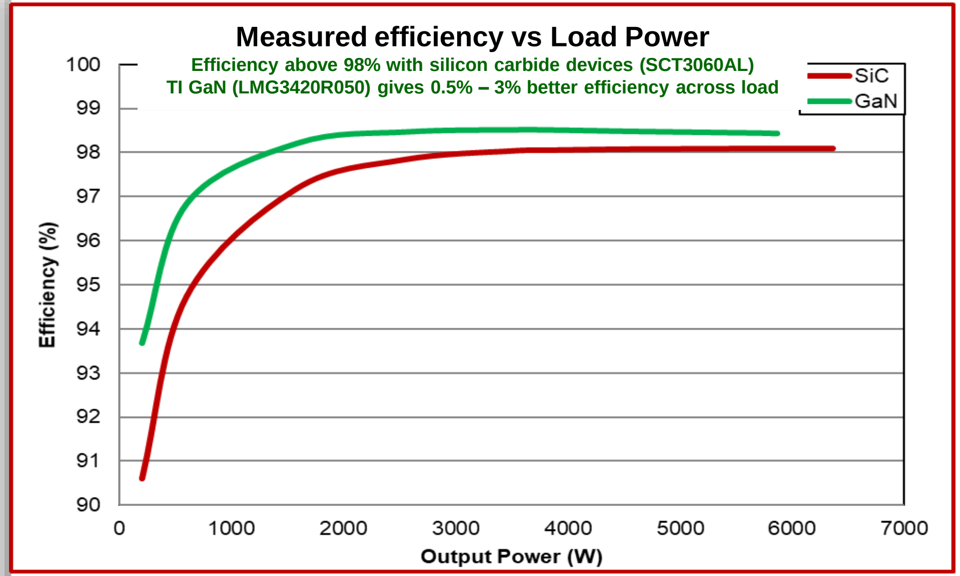


- 460V drain to source voltage at input voltage of 796V
- Hard turn-on with dv/dt of 16V/ns
- Soft turn-off at 4V/ns

Test results of TIDA-010210

Measured results summary

System Parameter		Value
Nominal Output voltage	V_{IN} = 799V, 6kW load	229V
Output voltage balance	V_{IN} = 799V, 6kW load	±2.0V
DC offset on output	V_{IN} = 799V, 6kW load	±0.5V
Efficiency	V_{IN} = 799V, 4kW load V_{IN} = 799V, 6kW load	98.5% 98.4%
I_{THD}	V_{IN} = 799V, 6kW load	1.9%
Voltage stress on switching device	V_{IN} = 799V, 6kW load	470V
Transient settling time	Load step 6A to 1A & back	5ms
Switching Frequency		100kHz



Bidirectional Dual Active Bridge (DAB) DC/DC – Reference design TIDA-010054

Features

- Input Voltage: 700-800-V DC (HV-Bus voltage/Vienna output)
- Output Voltage: 350-500 V
- Output power level: 10kW (@400 – 500V) , 7.5KW (@350V)
- Single phase DAB capable of bidirectional operation
- Soft switching operation of switches over a wide range
- Achieves peak efficiency – 98.2%, full load efficiency – 97.5%
- Less than 3% ripple target for output voltage
- Dual channel reinforced isolated gate driver
- Single phase shift modulation
- Switching frequency -100 kHz
- Power density – 2.25 KW/L

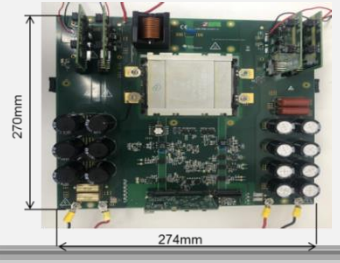
Benefits

- Single phase shift modulation provides easy control loop implementation. Can be extended to dual phase shift modulation for better range of ZVS and efficiency
- SiC devices offer best in class power density and efficiency
- Dual channel reinforced gate driver UCC21530 reduces the total component count for driving SiC MOSFETS
- Provides modularity and ease of bidirectional operation

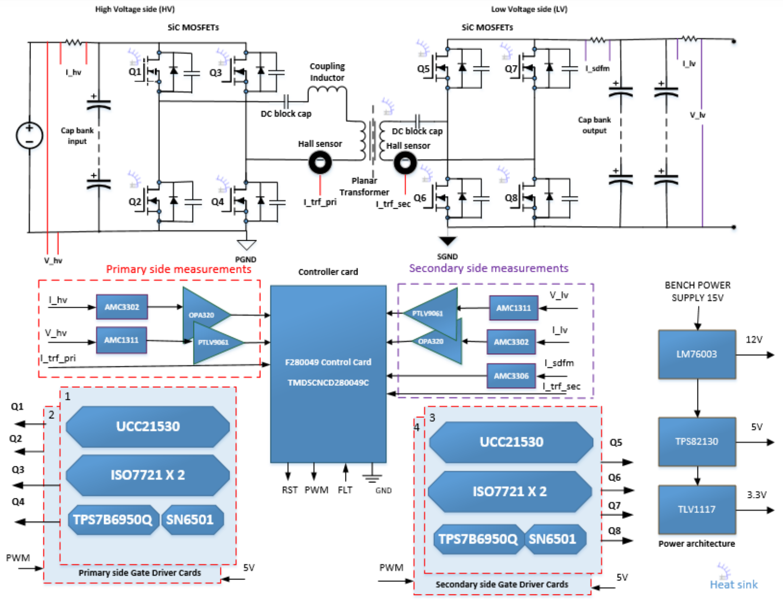
Applications

- DC Charging (Pile) Station / Portable DC Charging Station
- On board chargers (OBC)
- Power conversion systems (PCS) in energy storage

Tools & Resources

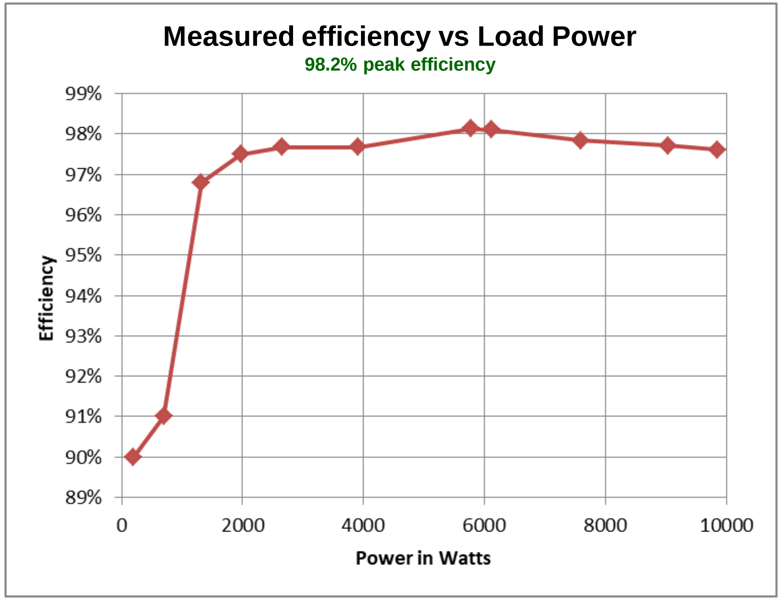


- TIDA-010054 Tools Folder
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** TMS320F280049, AMC1311, AMC3302, AMC3306 UCC21530, ISO7721, TPS82130, SN6501, SN6505, OPA320



Test results of TIDA-010054

Measured results summary	
System Parameter	**Value**
Input voltage	700-800 Vdc
Output voltage	380-500 Vdc
Maximum power	10 kW
PWM frequency	100 kHz
Efficiency (peak)	**98.2% @ 5.8kW**
Efficiency (full load)	**97.61% @ 10kW**
Size	**274mm x 270mm x 60mm**



Bidirectional CLLLC resonant Dual Active Bridge (DAB) – Reference design TIDM-02002

Features

- V1: 400-600V DC (HV-Bus voltage/ PFC output)
- V2: 280-450V (battery)
- Power Level: 6.6kW
- CLLC symmetric tank capable of bidirectional operation
- Soft switching, across load, close to resonance operation achieves high efficiency, 98% Efficiency
- Snubber less design enables higher density
- Switching Frequency 500kHz nominal, 300-700kHz range
- Active synchronous rectification scheme implemented using Rogowski coil based current sensor
- Power Density of 40W/inch^3

Applications

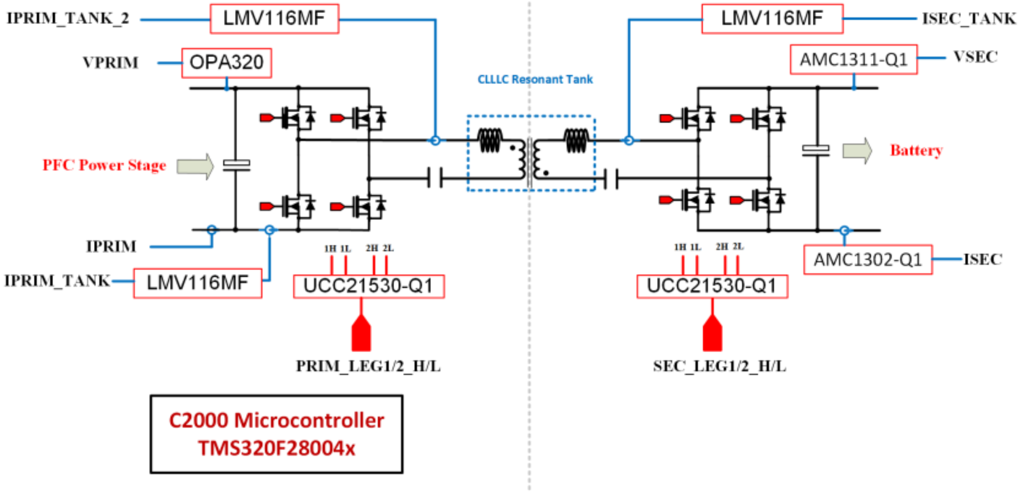
- On Board Chargers (OBC)
- DC Charing (Pile) Station / Portable DC Chargers
- Power conversion systems (PCS) in energy storage

Tools & Resources

- TIDM-02002 Tools Folder
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** TMS320F280049C, UCC21530-Q1, ISO7721-Q1,AMC1311-Q1, AMC1302-Q1, OPA320, LMV116MF, SN6505BDBVR, TPS7B6950QDCYRQ1

Benefits

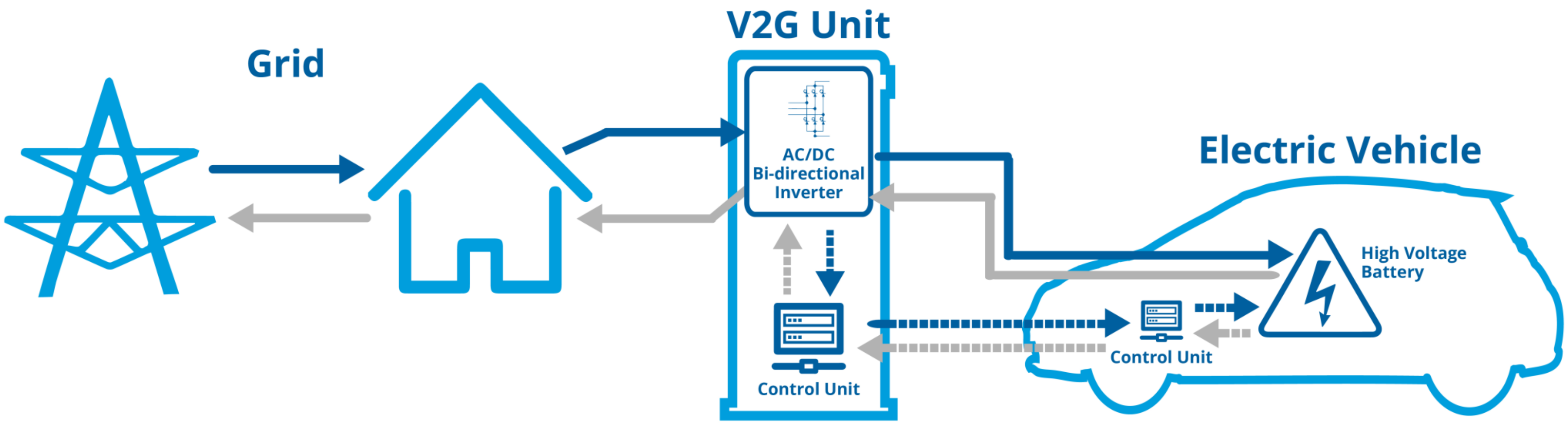
- Type 4 PWM with Hi-Resolution on C2000 MCU enable high frequency resonant converters control
- CMPSS, X-Bar and PWM enable active synchronous rectification for better efficiency
- CLA enables integrated OBC with AC-DC and DC-DC controlled using one MCU
- SFRA enables quick verification of control design on resonant converters where mathematical model is not known



Future trends

1. Overview on EV charging
2. Solutions & Implementations
   - AC charging stations
   - DC charging stations
3. **Future Trends**
   - **Vehicle to Grid (V2G) and needs for bidirectional chargers/equipment**

The future V2G?



- Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles, such as electric cars (BEV) and plug-in hybrids (PHEV), communicate with the power grid to sell demand response services by either returning electricity to the grid or by throttling their charging rate
- Since at any given time 95 percent of cars are parked, the batteries in electric vehicles could be used to let electricity flow from the car to the electric distribution network and back. This represents an estimated value to the utilities of up to $4,000 per year per car

Multilevel topologies enable vehicle to gird (V2G)

Multilevel topologies

- Smaller passives offer up to **50% reduction in size** for a 3-level inverter vs. a 2-level inverter.
- Multilevel topology enables **FETs with significantly lower switching and conduction losses** which improves efficiency by using FETs with half the blocking voltage for the same DC bus voltage
- Three level topologies keep the switching voltage to half of a 2-level inverter which **improves overall EMI and makes EVs with 800V battery technology easier to support**

Bidirectional topologies

- **GaN and SiC improve overall efficiency** and absorbs losses in the additional switches required in a bidirectional topology
- Real-time micro controller with **high-frequency PWMs and high-bandwidth current and voltage sensing** enables that higher switching frequency offered by GaN and SiC
- Bidirectional charging benefits customers with time-of-use plans and help **make the grid more resilient**

Technology trends in EV charging

DC Chargers

50-150kW DC Charging station

- Public charging stations
- 15kW-30kW per power module
- Silicon and IGBT
- 2-level topologies
- Uni directional charging
- 400V battery (500VDC bus)
- 30-50min 20%-80% recharge

Faster highway charging

300-900kW Fast DC Charging station

- Public charging stations
- 30-60kW per power module
- **SiC FETs/modules**
- **Multilevel topologies**
- Uni-directional charging
- 800V battery (950VDC bus)
- 10-15min 20%-80% recharge

AC Chargers

11kW AC Charging station

<3.7kW Level 1 AC charger*

- Public & Home charging stations
- Every PEV/EV comes with AC Level 1
- Uni directional charging
- 8-17h recharge

Faster home/public charging

3-22kW Portable DC charger

- Private charging stations
- **GaN**
- 2-level or **multilevel topologies**
- **Bidirectional charging**
- 800V battery (950VDC bus)
- 4-8h to full charge

22kW AC Charging station

- Private / public charging stations
- Split and poly phase connection
- ISO15118 support
- 4-8h to full charge

Semiconductor needs

Real-time Microcontrollers

- TMS320F2838x, 37x
- TMS320F28004x
- TMS320F28002x

Precision signal chain and sensing

- AMC13xx
- AMC33xx
- OPAx350

High power electronics

- LMG3425
- LMG341x
- UCC217xx
- UCC53xx
- UCC2351x
- UCC2153x/54x

Texas Instruments

Thank you