

電動車 OBC 及 DC-DC 轉換器隔離技術及 公共安全閘級驅動 IC 剖析

FAE WEI-HAO CHEN



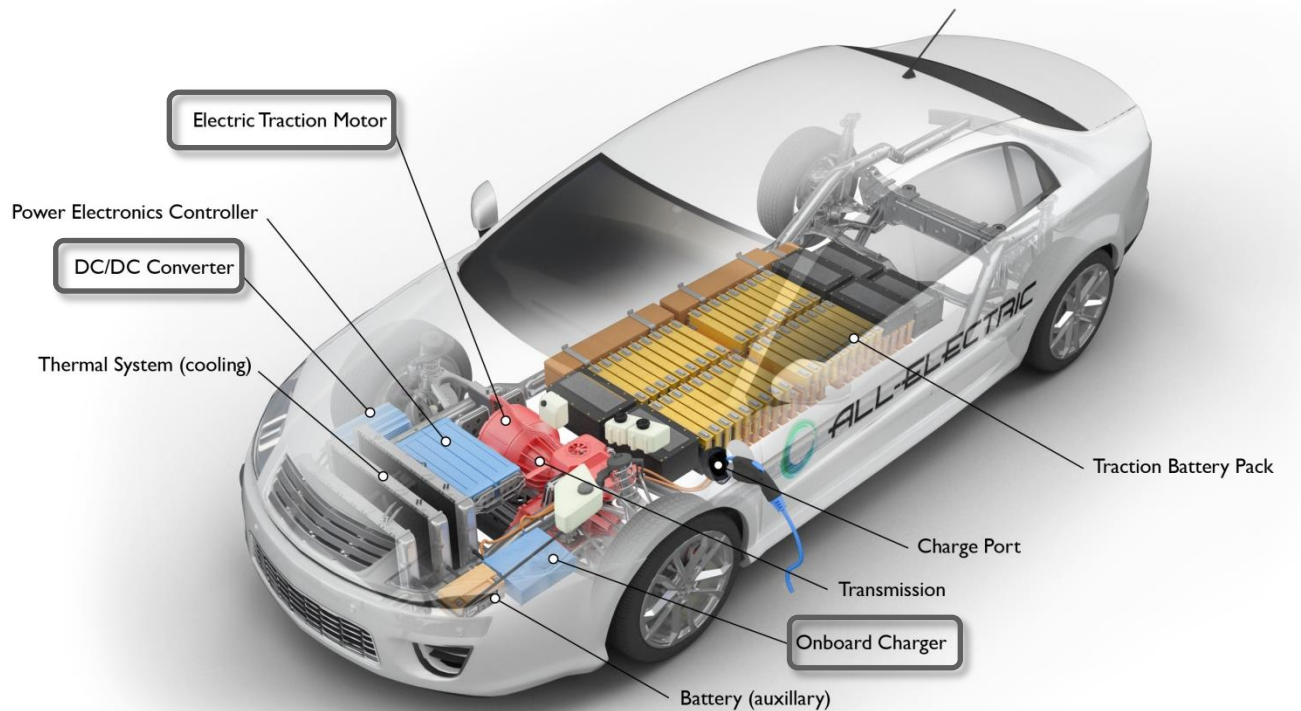
Enabling the
WORLD

to do
MORE

with less
POWER

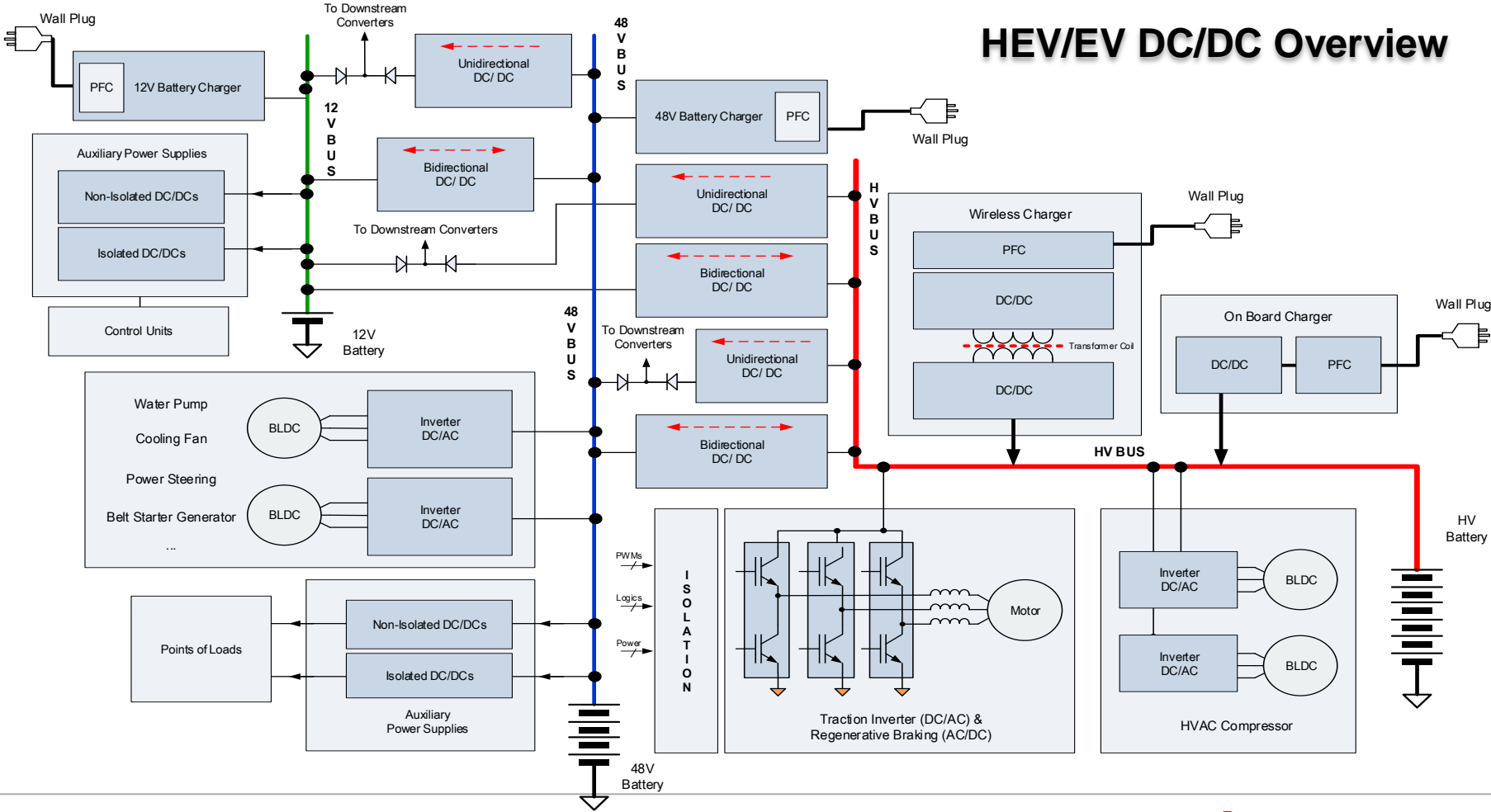
HVP

HEV/EV Powertrain



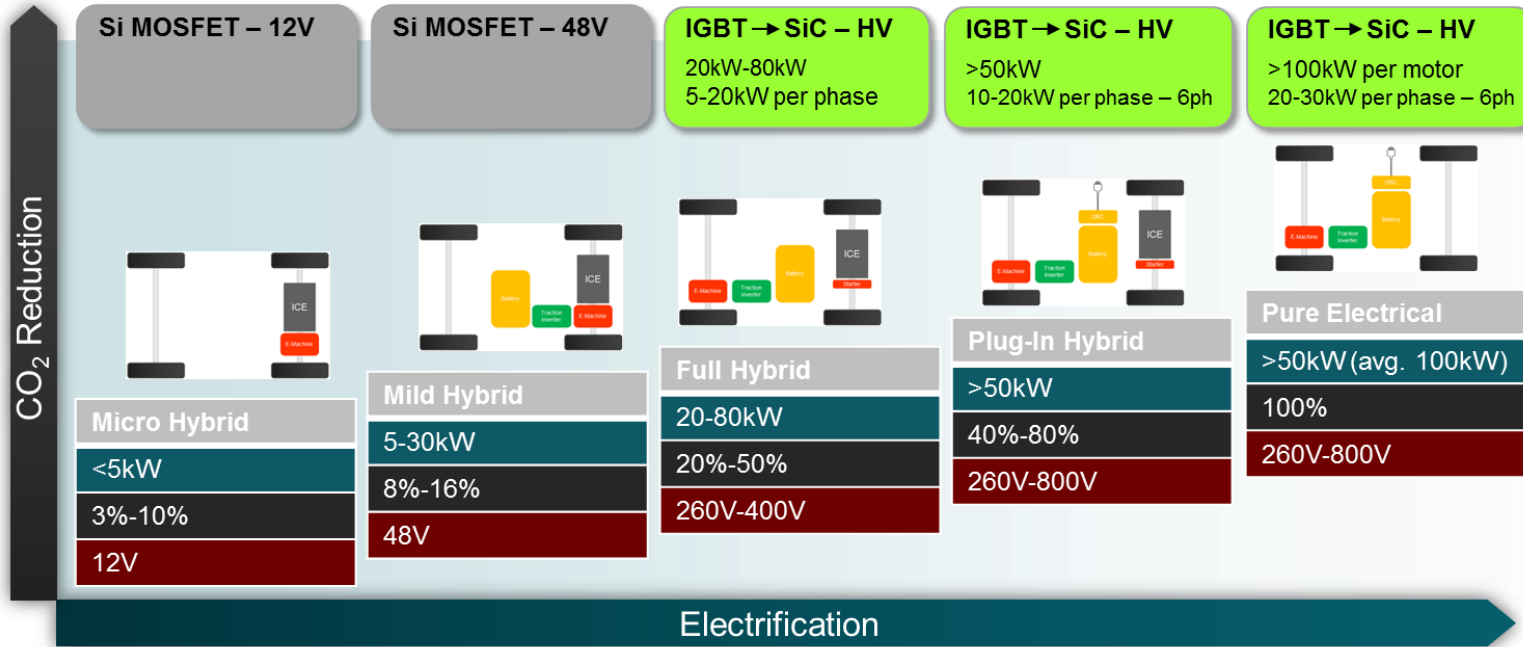
[Source: afdc.energy.gov]

HEV/EV DC/DC Overview



HEV/EV Trends

HEV/EV Landscape



On-board Charger

What is the On-board Charger?

- 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)



What does this EE consist of?

- **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

DC/DC Converter

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.

DC-DC converter for HEV, EV, and FCEV



Efficiently converts main battery's high voltage into a low voltage before supplying it to diverse electric equipment.

What does this EE consist of?

- **Down Conversion**
 - Converts energy from high-voltage (e.g. 48V or 100V ~ 800V) supply to 12V system supply.
 - Switching regulator for efficiency, either a *converter* with integrated switch, or a *controller* with external switch
- **Up Conversion**
 - Converts energy from 12V battery system to higher voltage (e.g. 48V or 100V ~ 800V)
 - Typically a *converter* with integrated switch, or a *controller* with external switch
 - Flyback configuration can be used if isolation is needed between high- and low-voltage supplies
- **Bi-directional**
 - Can direct energy from the low-voltage supply (12V) to the high-voltage side (48V or 100V ~ 800V) or from high-voltage to low-voltage
 - Allows operation of 12V loads from high-voltage generator, and also allows charging of high-voltage battery from 12V power

Why Isolation Technology Matters?

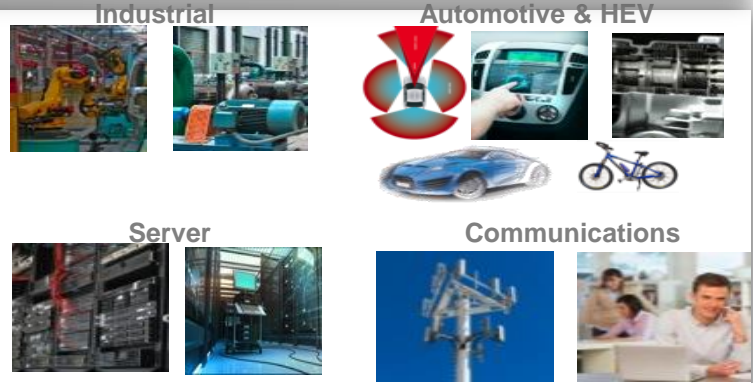
Introduction

What is Isolation?

A means of transporting data & power between a high voltage and a low voltage circuit while preventing hazardous DC or uncontrolled transient current from flowing in between the two

When to isolate?

- To protect from and safely withstand high voltage surges that would damage equipment or harm humans
- To tolerate large ground potential differences and disruptive ground loops in circuits that have high energy or are separated by large distance
- To communicate reliably with high side components in high-voltage motor/inverter drive systems, switches, and metrology applications

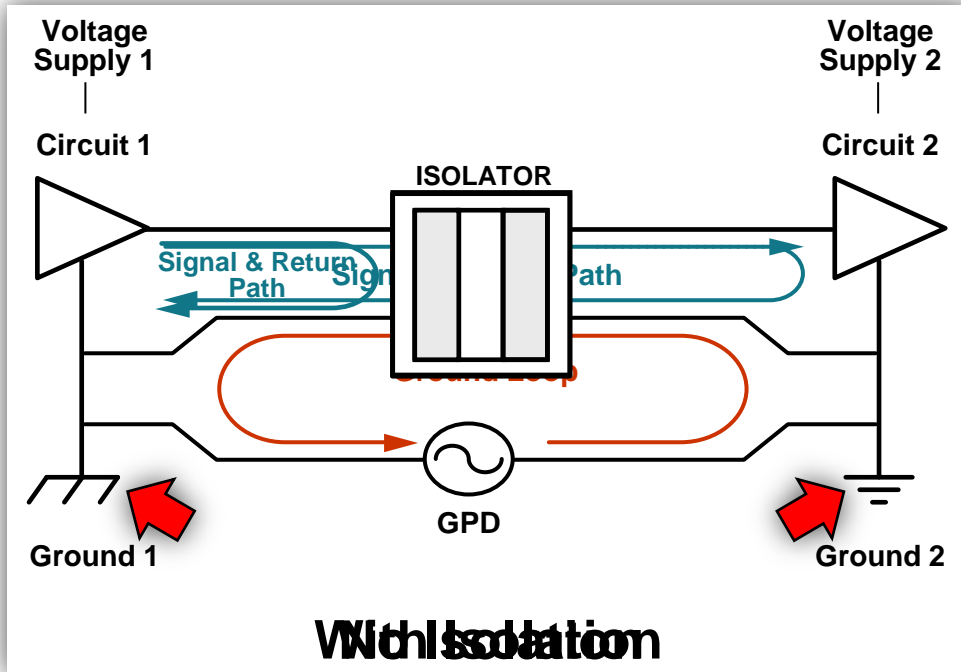


Why Now?

To deliver on

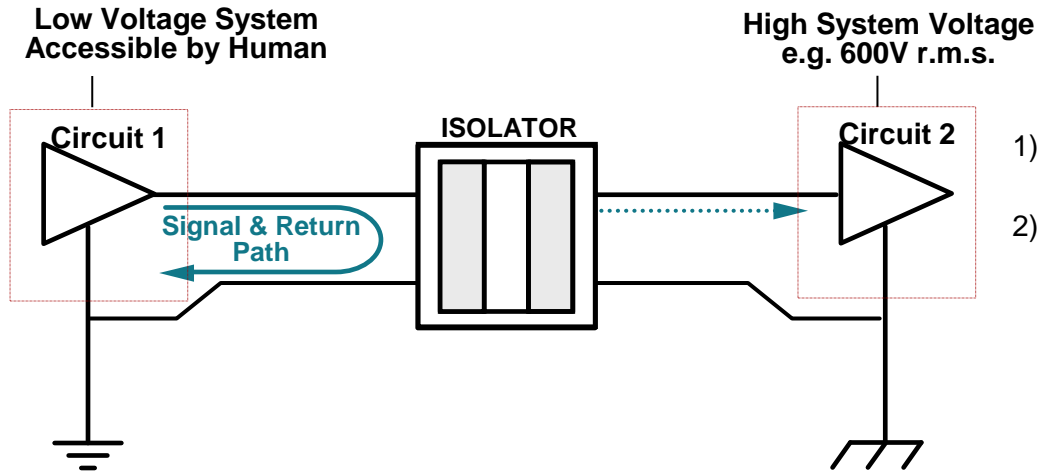
- Industry's move to the **next gen in Industrial Automation** and Control (Reliable links between Controllers/Sensors/Actuators)
- Need for step function **increase in Energy Efficiency** in Motor Drives and Energy Storage/Delivery Systems

Why Isolate? – Breaking the Ground Loop



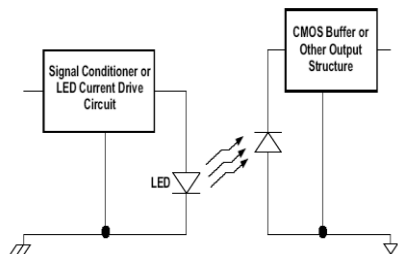
- 1) Electrical Installation can cause large GPDs (ground potential difference) between two remote nodes.
- 2) A direct ground connection between the nodes closes the ground loop.
- 3) Noise sources (i.e. electric motors) injecting large currents into the ground modulate the ground loop current.
- 4) This ground noise then appears in the signal path.
- 5) An isolator breaks the ground loop, thus removing signal path noise.
- 6) The GPD yet still exists and the isolator must be robust enough to withstand the large voltage differences.

Why Isolate? – Protection Against High Voltage

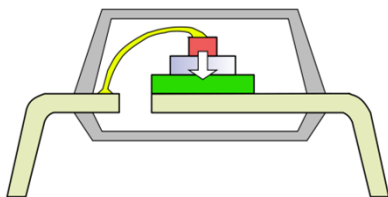


- 1) Industrial equipment running of 100s of volts, temporary overvoltage of 1000s of volts, and 10000v surges.
- 2) Isolation barrier is required to protect low voltage circuitry and human operators

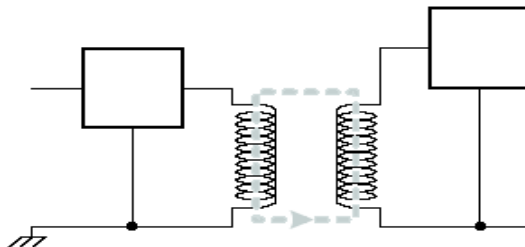
Isolation Technologies



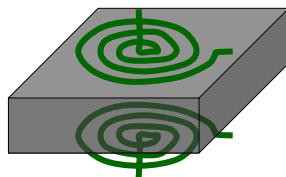
Optical



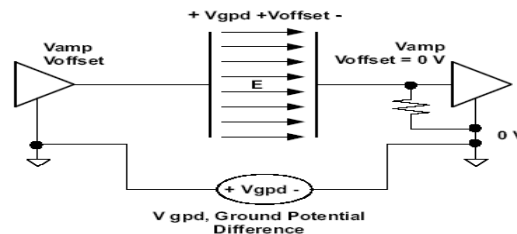
Signal transfer between two isolated circuits using light – LED + phototransistor, 1970s



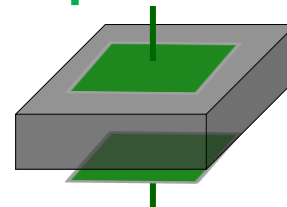
Inductive



Integrated micro-transformer and electronic circuitry, 2001~



Capacitive

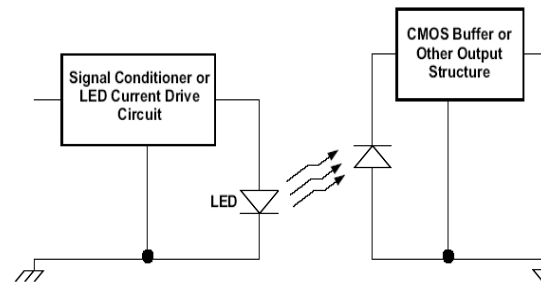


Signal transmission through capacitive isolation with On-Off-Keying (OOK) modulation, 2004

Optical & Magnetic Isolation: Major Drawbacks

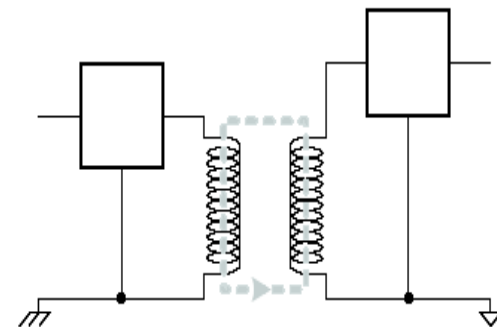
Optical Isolation: Major Drawbacks:

- Low performance
 - Long propagation times
 - Higher quiescent current
- Low robustness and reliability
 - Low noise immunity: Low common mode transient immunity
 - LED Degradation associated with temperature and age



Magnetic Isolation: Major Drawbacks

- Low robustness
 - Lower working voltage → Translates to limited applications
 - Low noise immunity: Low common mode transient immunity
 - High EM emissions – noise issues
- Lower reliability
 - Higher quiescent current
 - Insulator degradation over time



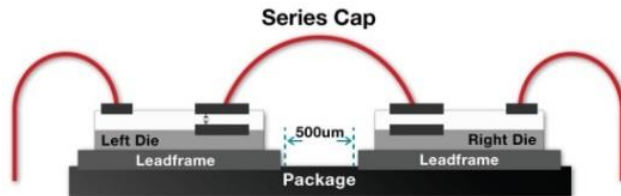
✓ **Capacitive isolation technology does not suffer from the above drawbacks**

TI's Capacitive Signal Isolation Technology

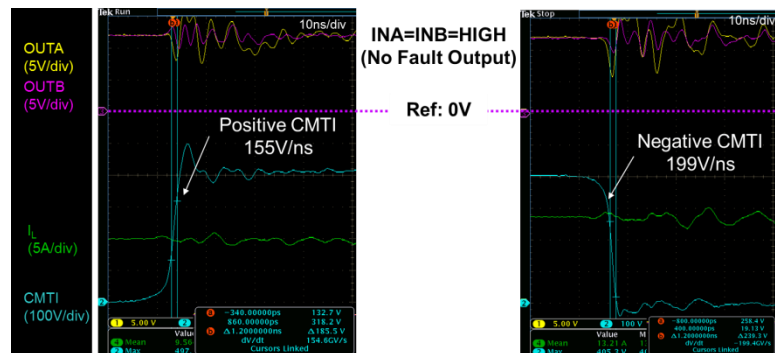
Increased System Robustness over Lifetime

[[Link to ti.com/isolation](https://www.ti.com/isolation)]

- **Industry-leading Integrated Capacitive Isolation**
- SiO_2 is the most stable dielectric over temperature & moisture
- Leverage advantages of TI's customized CMOS process:
 - High precision
 - Tight part-to-part skew
 - No wear out mechanisms
 - Low defect levels
 - Highest lifetime in the industry: $>1.5 \text{ kV}_{\text{RMS}}$ for 40 years
 - Superior transient protection for harsh environments: $>12.8 \text{ kV}$

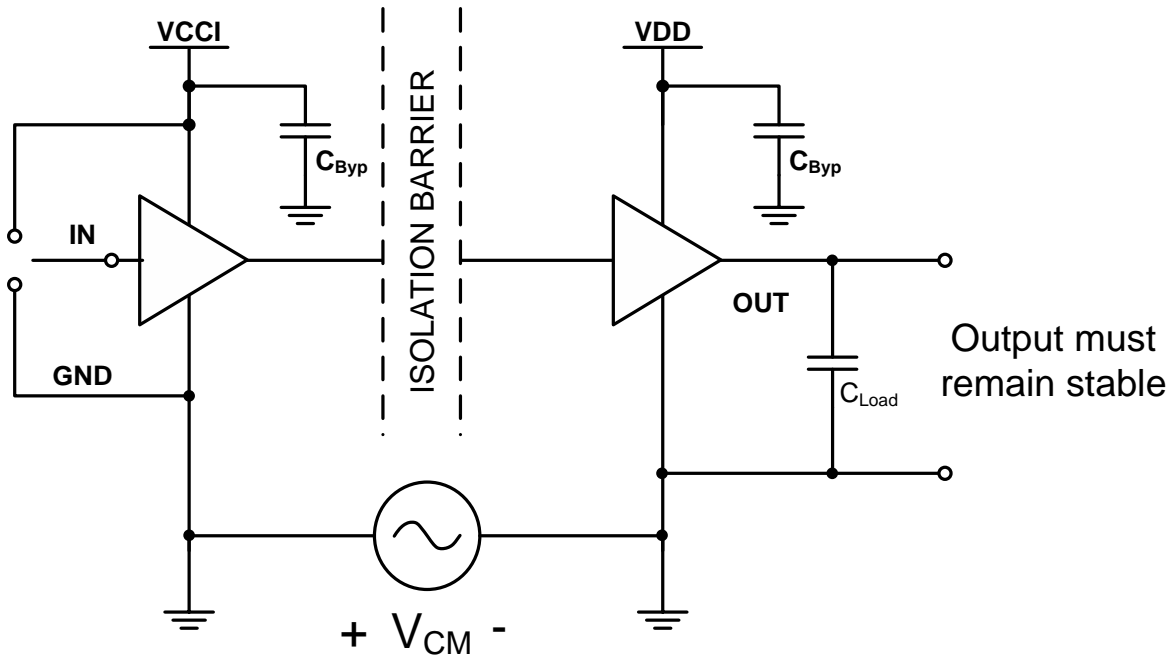


UCC21520 CMTI Results

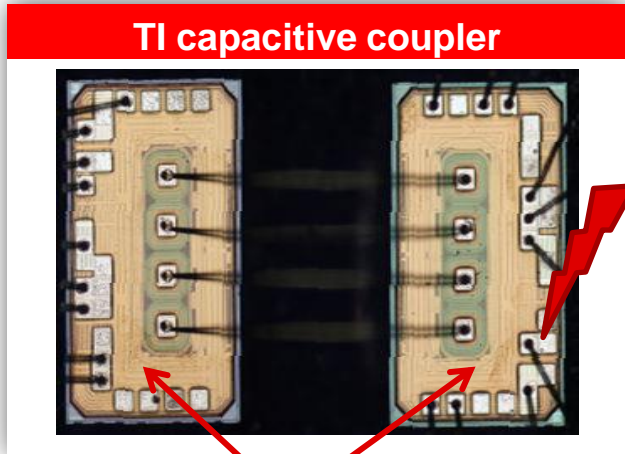


Common Mode Transient Immunity (CMTI)

Evaluate device response while a high voltage transient pulse is applied to ground reference on either side.



“Fail Open” – TI Capacitor vs Opto Coupler

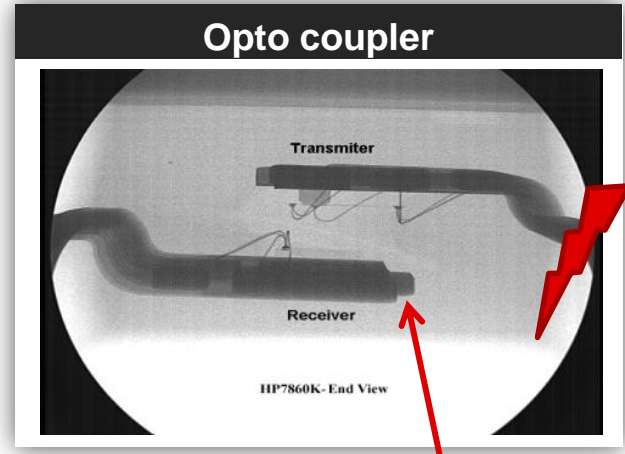


TI capacitive coupler

High Voltage/Current/Power Event on one side of isolator

Isolation build with 2 series SiO₂ Caps

- “Fail Open” due to series Cap
- **Maintain basic isolation** if EOS on either side of isolation barrier



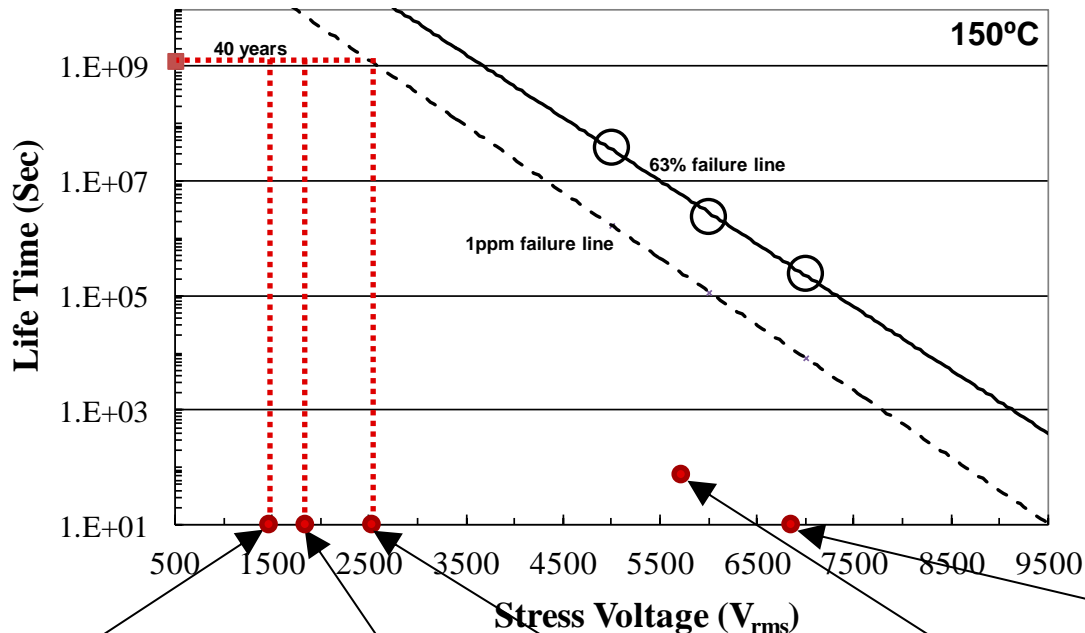
Opto coupler

High Voltage/Current/Power Event on one side of isolator

Isolation build with transparent silicone

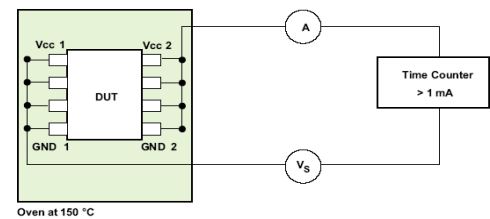
- Easily extend into insulation through heat or electrical overstress
- Isolation performance *degraded*

TDDB-based Lifetime Projection to determine Working Voltage: Capacitive Isolation



[\[Link to White Paper\]](#)

Time Dependent Dielectric Breakdown (TDDB) is widely used to predict lifetime at working voltage



TI Spec:
 $V_{IORM} = 1.5 \text{ kV}_{RMS}$

Required VDE
Safety Margin (1.2x)
 $V_{IORM} = 1.8 \text{ kV}_{RMS}$

Intrinsic Value

$V_{ISO} = 5.7 \text{ kV}_{RMS} @ 60\text{sec}$
Qualification Test

$V_{IOTM} = 6.85 \text{ kV}_{RMS} @ 1\text{sec}$
Production Test

TI's isolation capacitors meet **40 years lifetime** for **1.5kVrms** up to **150°C**

Capacitive Isolation: Measured Benefits

System Level Impact	Industry Specification	Capacitive Isolation	Optical Isolation	Magnetic Isolation
Robustness	Surge rating	12.8+ kVpk	10+ kVpk	10 kVpk
	Working voltage	1.5+ kVrms	1 kVrms	600 Vrms
	Material Group	I	IIIa	II
Noise immunity	EM Emission	Lowest	Lowest	High
	CMTI (Min)	>100V/ns	35V/ns	75V/ns
Performance	Propagation delay	20ns	>100ns	50ns
Reliability	Quiescent current	1mA	>1.5mA	2.0mA

UCC21520-Q1 2-Channel Isolated Gate Driver

Features

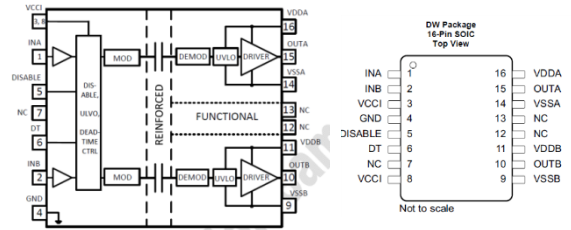
- Pin-for-pin with Si823x and ADuM4223
- 6-A Peak Sink and 4-A Source Output
- 30ns Prop Delay (max), < 5ns Delay Matching, 5ns Max PWM Distortion
- 5.7kVrms Isolation Capability Input-to-Output
- >12.8kV Surge Immunity
- Programmable Overlap and Dead-time Control
- CMTI: 100V/ns (min)
- 3V to 18V Input Supply Voltage
- 6.5 V to 25 V Output Drive Supply Voltage, w/ UVLO
 - UVLO->(blank=8V, A=5V, C=12V)
- Operating range from -40 to 125°C
- Wide Body SOIC-16 (DW) Package
- Single Input and Enable Options (see table)

Applications

- AC/DC & Isolated DC-DC Converters
- High Frequency Inverters, Motor Drives
- Si and SiC MOSFET Gate Drive
- UPS, Solar Power

Benefits

- Drop-in replacement with better performance in key areas
- High(er) drive can eliminate buffer stages and meet the requirements of a wide range of applications
- UL 1577 recognized; VDE certified
- Flexible settings to prevent shoot-through in ½ bridge applications
- Provides high noise immunity for fast/high current designs



Versions:

Part No.	Single or Dual Input	UVLO(V)	Enable or Disable	Status
UCC21520	Dual	8	Disable	Released
UCC21520A	Dual	5	Disable	Released
UCC21521	Dual	8	Enable	Released
UCC21521A	Dual	5	Enable	Released
UCC21521C	Dual	12	Enable	Released
UCC20520	Single	8	Disable	Released

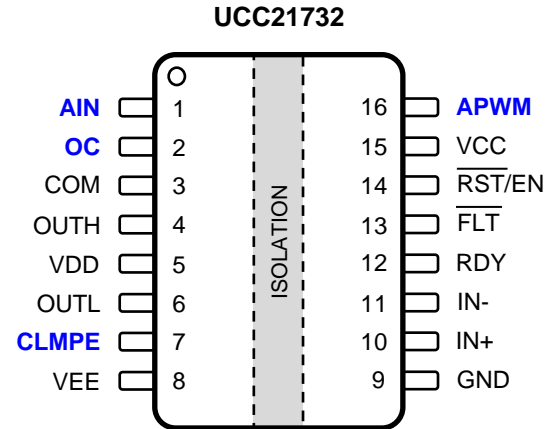
UCC21732: $\pm 10\text{A}$ Single-Channel Isolated SiC/IGBT Driver

Features & Benefits

- Single-channel driver with Reinforced Isolation (5.7kVrms for 60s)
- 33V Max output drive voltage (VDD-VEE)
- Split outputs with up to $\pm 10\text{A}$ peak source/sink currents
- [Logic Output \(5V + VEE\) for External Clamp](#)
- [Fast Over-Current Detection 200ns for 0.7V threshold during short-circuit](#)
- Fault alarm upon Over-current detection, Reset through RST
- [Internal fixed 2-level Turn-Off \(11V, 2.5 \$\mu\text{s}\$ \) + Soft Turn-off \(100mA\) during short-circuit event](#)
- Input and Output Under-Voltage Lockout (UVLO) with Power Good (RDY)
 - Output Positive Supply UVLO: 12V
- Isolated analog-to-digital (PWM) channel (AIN-to-APWM)
 - Switch temperature sensing, system diagnostics, alarm, etc.
- 150V/ns Minimum Common-mode Transient Immunity (CMTI)
- Isolated Fault Feedback Comm (EN/FLT)
- Short Propagation Delay (Input to Isolated Output): 90ns (typ)
- <25ns pulse distortion and part-to-part skew
- 3.0V-5.5V Input Supply Voltage, CMOS Compatible Inputs
- Active Output Pulldown and Default Low Outputs with Low Supply or Floating Inputs
- Rejects input pulses and noise transients shorter than 40ns
- Junction Temperature: -40°C to $+150^{\circ}\text{C}$, Grade 1 Auto
- Max Switching Frequency: 1MHz (for limited operation conditions)

Pinout & Package

 : AEC-Q100



Not to scale

16-pin SOIC DW

10.5mm (L) x 7.5mm (W)

Reinforced Isolation

UCC21732-Q1: Solving YOUR system challenges...

New Features in UCC217XX	Key System Challenge Solved ...		System Benefits
	IGBT	SiC	
±10A peak drive strength (throughout drive voltage range)	>10kW systems use discrete buffers (e.g., NPN+PNP) to increase drive strength: Reliability, drive supply & cost challenges		<ul style="list-style-type: none"> Higher System Reliability + Higher Efficiency Lower System Cost + Smaller PCB Area
>150V/ns CMTI (Min)	(Typically <50V/ns)	SiC switches fast to reduce switching loss	<ul style="list-style-type: none"> Enhanced System Robustness Higher System Efficiency
200ns Over-Current Detection + 650ns Isolated Fault Reporting	Programmable DESAT threshold voltage	SiC has <3μs short-circuit capability	<ul style="list-style-type: none"> Fast System Protection Enhanced System Robustness
2-Level Turn OFF (Option)	Significantly reduced V_{CE} / V_{DS} Overshoot during System Shutdown		<ul style="list-style-type: none"> Safe System Shutdown Enhanced System Robustness Improved Switch Lifetime
Integrated Isolated Accurate Analog-to-PWM Sensor	Eliminate all discrete components used for bus voltage sensing / switch temperature sensing / sec-to-primary feedback / isolated alarm / ...		<ul style="list-style-type: none"> Lower System Cost Smaller PCB Area
VEE UVLO (Option)	Eliminate discrete circuitry for VEE monitoring (voltage sensor + isolator)		<ul style="list-style-type: none"> Lower System Cost Smaller PCB Area
External Miller Clamp (Option)	More effective technique than internal miller clamp for high-power switch modules		<ul style="list-style-type: none"> Enhanced System Robustness Lower System Noise (Ringing + EM)
Standard SOIC-16 DW Package	Small package size, 1 mm pad pitch, pin-to-pin compatibility with better specs		<ul style="list-style-type: none"> Lower System Cost Smaller PCB Area

ISO77xx -Q1: Robust 5kV_{rms} Isolators

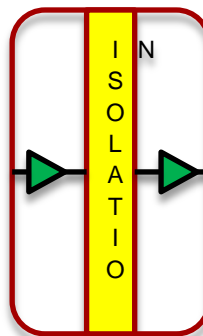
High-Immunity, 100 Mbps, 2.25V Rail support

Features

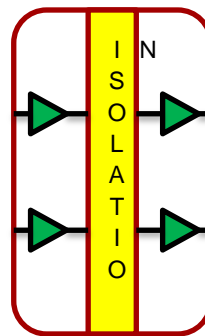
- **Integrated SiO₂ Dielectric Capacitor**
 - 100 Mbps max data rate
 - Typ Prop Delay: **11 ns**
 - Max Ch-Ch Skew: **2.5ns**
 - MAX Part-Part-Skew: **<5ns**
 - Low Power:
 - 1.9mA / channel typical at 1Mbps
 - 1mA/channel in default state
 - 0.5mA/channel in disable state
 - Fast recovery from errors.
 - High and Low Default states available.
- **Immunity and Certifications**
 - Reinforced Isolation (DIN V VDE V 0884-10)
 - **5000 V_{rms}** Isolation Rating (UL 1577)
 - **8000 V_{PEAK} Surge**
 - **1000 V_{rms}** Working Voltage (DIN V VDE V 0884-10)
 - **CMTI: 70kV/μs typical (40kV/μs min)**
- **Power and Package**
 - **2.25V to 5.5V** Wide Supply Range
 - Operating temperature range -55C to 125C
 - SOIC-16W w/ 8 mm creepage / clearance (6, 5, 4, 3, 2 and 1 channels)
 - SOIC-16 narrow package (6,5,4 and 3 channels)
 - Small QSOP-16 package (6,5, 4 and 3 channels)
 - Small SOIC-8 package (2 and 1 channels)

Benefits

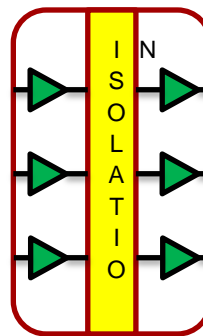
- **Reinforced Isolation Rating**
- **High Immunity and Robustness**
 - System Level EMC for IEC61000-4-x ESD, EFT events, Radiated and Conducted RF immunity.
 - Low EM emissions.
- **Precision timing:**
 - Low propagation delay, low skew and fast recovery from errors
 - beneficial for switching mode synchronous power supplies, and SPI communications
- **Pin to Pin compatible with competitor parts**



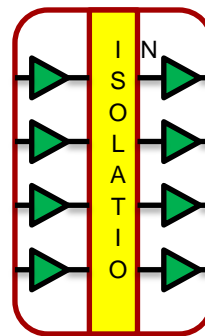
ISO771x



ISO772x



ISO773x



ISO774x

ISOW78xx:

Digital Isolators with Integrated DC-DC Converter

Features

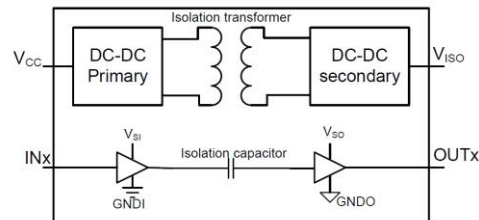
- **Integrated Power with Laminate transformers**
 - 0.65W power, high efficiency
 - Configurable input/output levels
 - 5V to 5V; 5V to 3.3V; => 130mA load current
 - 3.3V to 3.3V => 70mA load current
 - Line regulation: 0.2%
 - Load regulation: 1%
 - **Soft Start**
- **2 or 4 Integrated digital isolation channels**
 - 100Mbps, 13ns prop-delay
- **Immunity and Isolation Certifications**
 - Lowest radiated emissions and highest immunity.
 - Robust EMI for IEC61000-4-x ESD, EFT events
 - ESD: +/-8kV HBM
 - 5000 Vrms Isolation rating (UL 1577)
 - 10000 Vpk Surge VDE Reinforced Isolation
 - 1414 Vpk Working (DIN V VDE V 0884-10)
 - 100kV/us min CMTI
- **Power and Package**
 - Wide input Supply Range: 3V to 5.5V
 - 16-pin Wide SOIC Package (>8.0mm Creepage)
 - Extended Temp: -40 to 125 °C

Applications

- Industrial Automation
- Motor Control
- Grid Infrastructure
- Isolated Power Supplies
- Test and Measurement

Benefits

- **Integrated solution** enables smaller BOM, reduced board space and helps with easier system certification.
- **High drive capability** to power peripheral interfaces
- **Lowest power consumption** reduces device operating temperature enabling higher power delivery, higher channel counts and longer system lifetime than other integrated solutions.
- **Soft start** enables minimal overshoot current, controlled small inrush current.
- **Over 10 db lower radiated emissions** lowers system noise, improves system signal integrity, supports reliable operation of the system in harsh environments.
- Highest level of immunity reduces effect of high-voltage events on the system.
- Pin-to-pin with ADuM6401 and ADuM5401 to allow ease of upgrade



V_{CC} is primary supply voltage referenced to GND1. V_{ISO} is isolated supply voltage referenced to GND2.
 V_{SI}/V_{SO} can be either V_{CC} or V_{ISO} depending on channel direction.
 V_{SI} is input-side supply voltage referenced to GND1 and V_{SO} is output-side supply voltage referenced to GND0.

6.6kW Totem-Pole PFC for High Voltage Battery On Board Charger

Design Features

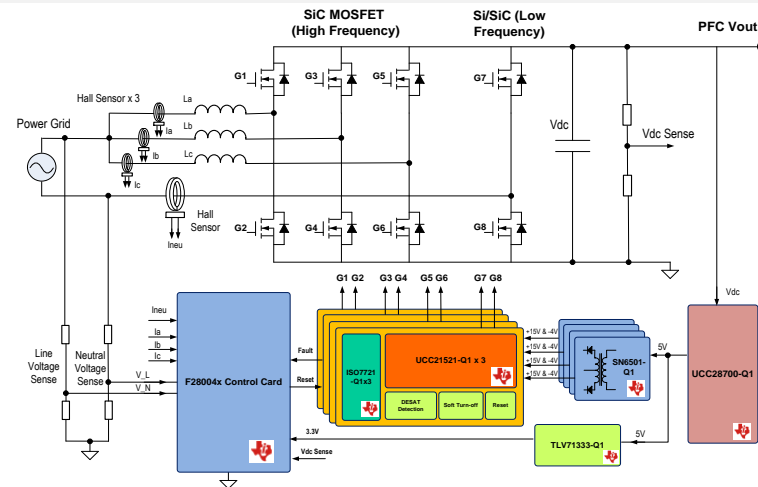
- Using UCC21521 with SiC FETs & C2000 MCU controller
- Power Spec
 - Input: 85-264 Vac , 50/60Hz
 - Output: 400V-600V DC
 - Power: 6.6KW at 240Vrms
 - Efficiency : > 98.5% peak efficiency
- 70-100kHz PWM switching
- Low total harmonic distortion (THD) ~ 1-2% (at low line)
- Soft start for totem pole bridge
- *Short circuit protection with two-level turn off*
- *High Common Mode Transient Immunity (CMTI) of > 100 V/ns*
- Phase shedding to enable higher efficiency
- Variable output voltage for optimizing DC/DC stage efficiency

Tools & Resources

- **TIDA-01605 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** TMS320F28004x, UCC21521-Q1, SN6501-Q1, ISO7721-Q1, UCC28700-Q1

Design Benefits

- High power, high efficiency power design with liquid cooling for powering the systems up to 6.6kW
- Using SiC MOSFETs with TI Drivers offering greater integration for the customers
- Synchronize for multiple phase operation
- High power factor and low total harmonic distortion (THD)
- High performance C2000 controller enables superior control and enables advanced control scheme to be implemented



Automotive Dual-Channel Isolated SiC Gate Driver with Short-Circuit Protection

Design Features

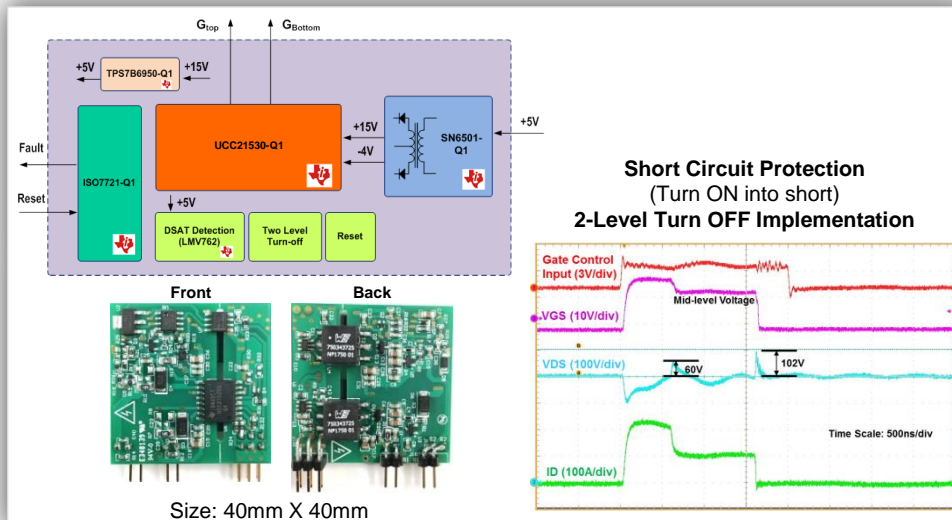
- 6-A peak sink and 4-A source output drive current
- Up to 25V output drive voltage suitable for SiC MOSFETs with operating PWM frequency up to 5MHz
- 18ns prop delay (typ), < 5ns delay matching, <5ns Max PWM Distortion
- 5.7kVrms reinforced isolation capability
- Up to 12.8kV isolation surge Immunity
- Short circuit protection with two-level turn off circuit
- High Common Mode Transient Immunity (CMTI) of >100V/ns (Min)
- Built-in compact push-pull architecture-based isolated bias supplies
- Adjustable negative gate voltage for SiC MOSET turn-off
- Short circuit fault and reset diagnostic function
- Programmable dead-time control & Enable feature

Tools & Resources

- **TIDA-01605 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** [UCC21530-Q1](#), [SN6501-Q1](#), [ISO7721-Q1](#), [TPS7B6950-Q1](#)
(Compatible with UCC21521C & UCC21520-Q1 drivers)

Design Benefits

- Compact/small form factor dual channel gate drive solution (40mm x 40mm)
- Discrete short circuit protection with easily adjustable current limit and delay(blanking) time
- Flexible in optimizing mid-level turn off voltage and delay time
- Easy interface with both digital and analog controllers



Automotive High Voltage & Isolation Leakage Measurement

Features

- >99% Accurate High voltage measurements
- >99% Accurate Isolation leakage current measurements
- Accurate Isolation Voltage measurements
- Accurate Isolation leakage resistance estimation
- Scalable design for multiple battery topologies

Applications

- HEV-EV Powertrain
- Industrial Energy Storage Systems

Tools & Resources

- **TIDA-01513 Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.
- **Device Datasheets:**
 - AMC1301-Q1
 - OPA2348-Q1
 - SN6501-Q1
 - TL4050-Q1
 - TPS76350-Q1

Benefits

- Support the high voltage diagnosis for HEV/EV systems
- Detects the early faults in the Isolation of HEV/EV System
- Support the safety mechanism of the HEV/EV system to avoid any damage to service personnel/operator.

