Solving Isolated Design Challenges with Isolation Products: Benefits, Applications and Systems Considerations

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www.ti.com/isolation
Agenda

• Brief Introduction to Isolation, Standards and Terminology.

• TI Isolators Physical Construction and Circuit Architectures.

• System Considerations:
  – Electromagnetic Compatibility (EMC)
  – Isolator Failure Modes

• Isolation requirements and usage in end equipment + TI solutions.
  – Motor Control
  – Solar Inverter
  – PLC
  – Automotive
  – Test and Measurement

• TI Designs

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Key Learnings

- An overview of key isolation terminology and concepts.
- Isolation usage in end equipment and TI solutions for the same.
- Applications where TI products are uniquely suited to solve the problem.
- Other systems considerations that apply to isolated systems.
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Introduction

What is Isolation?

Is a means of preventing DC or uncontrolled transient current from flowing between two communicating points.

Why Isolate?

1. Where there is a possibility for high voltage surges that may damage equipment or harm humans.
2. Where interconnections involve large ground potential differences (GPDs) and disruptive ground loops are to be avoided.
3. Communication to high side components in motor drive systems.

*Isolation enables communication between a transmitter and a receiver, referenced to very different ground potentials*

An isolator is an insulator across which signal and power transfer can occur.

Example Isolator in a 16-pin package
Isolation – example applications

### PLC
**I/O & Communication**
Isolate microcontroller from analog inputs/outputs, subject to faults/surges/noise from microcontroller.

### Instrumentation
**Data acquisition & Communication**
Isolate data acquisition channels involving human interfaces from master side that could be supplied from 240V mains.

### Motor Drives
**Gate Drive & Sensing**
Protect microcontroller from High Voltage. Secondary side ground is connected to IGBT emitter: subject to high voltage transitions by construction.

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Other Applications:
- Patient monitoring systems
- Solar Inverters
- HVAC
- Merchant Power
Standards that apply to Isolation

- **Component level Standards:**
  - IEC 60747-5-5 (VDE 0884-5-5) for Opto Isolators.
  - VDE 0884-10 / VDE 0884-11 for Capacitive/Magnetic isolators, reinforced
  - IEC 60747-17
  - UL 1577
  - ---

- **System Level / End Equipment Standards**
  - IEC 61800-5-1, safety requirements for adjustable speed drives
  - IEC 60601-1, Medical equipment standard
  - IEC 61010-1, safety standard for measurement, control and Lab equipment
  - IEC 60950-1, Telecom equipment standard
  - ---

- **EMC and Emissions**
  - IEC 61000-4-x, ESD, EFT, Surge, RF immunity
  - CISPR22 or equivalent, EM emissions

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TI Isolators must pass

Customer boards and systems must pass – TI Isolators should enable
| Parameter          | Definition                                                                                                               | Relevance                                                                 ¶
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Basic Isolation</td>
<td>Isolation that can provide protection against high voltage as long as the barrier is intact.</td>
<td>Basic isolation needs to be coupled with another insulation barrier, if human access is possible.</td>
</tr>
<tr>
<td>Reinforced Isolation</td>
<td>Isolation that is equivalent to two basic isolation barriers in series.</td>
<td>Reinforced isolation by itself is sufficient as a safety barrier against high voltage.</td>
</tr>
<tr>
<td>$V_{IDTM}$</td>
<td>The sinusoidal voltage isolator can tolerate for 60s (defined in pk)</td>
<td>Tolerance to temporary overvoltage on supplies due to load changes, arcing etc.</td>
</tr>
<tr>
<td>$V_{ISO}$</td>
<td>The sinusoidal voltage isolator can tolerate for 60s (defined in rms)</td>
<td>The voltage that the isolator has to handle as part of normal operation (for eg. an isolated gate driver sees a pk voltage equal to the DC bus voltage).</td>
</tr>
<tr>
<td>$V_{IDRM}$</td>
<td>Maximum periodic voltage that the isolator has to handle on a continuous basis throughout its operating life (defined in pk)</td>
<td></td>
</tr>
<tr>
<td>$V_{ICWM}$</td>
<td>Maximum continuous working voltage that the isolator has to on a continuous basis throughout its operating life (defined in pk)</td>
<td></td>
</tr>
<tr>
<td>$V_{SURGE}$</td>
<td>Maximum peak voltage of the 1.2us/50us standard surge waveform that the isolator can handle.</td>
<td>Represents direct and indirect lightening strikes. Min 10kV required for reinforced isolation.</td>
</tr>
<tr>
<td>Creepage</td>
<td>Minimum distance from pins on side 1 to side 2 along the surface of the package</td>
<td>Limits working voltage or continuous voltage due to degradation along package surface (called tracking)</td>
</tr>
<tr>
<td>Clearance</td>
<td>Minimum distance from pins on side 1 to side 2 through the air</td>
<td>Limits peak voltages and surge voltages in system environment due to air breakdown</td>
</tr>
<tr>
<td>CMTI</td>
<td>The maximum rate of change of ground potential difference (GND1-GND2) that the isolator can withstand without bit errors</td>
<td>Indicates robustness of isolator to ground noise. Very important in gate-drive applications</td>
</tr>
</tbody>
</table>

For more details on definitions and terminology, refer: [http://www.ti.com/lit/pdf/slyy063](http://www.ti.com/lit/pdf/slyy063)
Creepage & Clearance

**Creepage distance**

Shortest distance between two conductive leads, across isolation barrier, measured along surface of insulation.

**Clearance distance**

Shortest distance between two conductive leads, across isolation barrier, measured through air.
Data Isolation: Common-Mode Transient Event

CMTI – The change in ground 1 relative ground 2. Measured in kV / μSec.
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How are capacitive Isolators constructed?

Cross Sectional View

High Voltage Capacitor Detail

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<table>
<thead>
<tr>
<th>Bond wire</th>
<th>Mold compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top plate = Al</td>
<td>Bottom plate = Al</td>
</tr>
</tbody>
</table>

- Inter Level Dielectric
  - 800V/um
  - 8-14 μm

Silicon Substrate (doped)
How are capacitive Isolators constructed?

Two Capacitors In Series:
Industry Leading Reinforced Isolation

Isolation build with 2 capacitors
(TI couplers with reinforced isolation)
Circuit Technology

Edge Based Architecture – Best Suited for Low Power

On-Off-Keying Architecture – Best Suited for High Immunity

Spread Spectrum Clock for low emissions

For more details on Circuit Architectures, refer: http://www.ti.com/lit/pdf/slla284
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System Considerations: ESD, EFT and Surge Immunity

- IEC 61000-4-2.
  - Key specifications (level 4):
    - Voltage peak: 8kV.
    - Current peak: 30A
    - Current rise time: 0.7ns to 1ns.
    - Current at 30ns: 16A.
    - Current at 60ns: 8A.

- IEC 61000-4-4.
  - Key specifications (level 4):
    - Voltage peak: 4kV (supply), 2kV(IO).

- IEC 61000-4-5.
  - Key specifications (level 4):
    - Voltage peak: 4kV.
    - Output impedance: 2 Ohms.
System Design: ESD, EFT and Surge Immunity

**Non Isolated Case:**
- On board (and on-chip) ESD structures used to handle enormous energy present in ESD/EFT/Surge strikes.
- Ground movement is of no consequence.

**Isolated Case:**
- Bounce on GND2 is very high, limited only by board parasitic capacitance → high stress and current across the isolation barrier.
- Entire magnitude of the stress suffered by isolation barrier.
- External ESD structures won’t help prevent across barrier stress.
- Isolation Capacitor and associated circuitry must handle ESD/EFT/Surge Voltage and associated currents.

For more details on EMC for Isolators, refer: [http://www.ti.com/lit/pdf/slyy064](http://www.ti.com/lit/pdf/slyy064)
ALL Isolators Fail Short when Stressed Beyond Rated Voltage

Optos

Material: Multi compound packaging process
Silicone + Poly-imide + Mold compound

\[ C_{\text{parasitic}} \]

**intrinsic strength:** 500um * 30V/um = 15kV

---

TI Series Cap

Material: Ultra-low ppm Foundry process
SiO2

\[ 2 \times C_{\text{isolation}} \]

**intrinsic strength:** 26um * 800V/um = 20kV

For more details on failure modes of Isolators, refer: [http://www.ti.com/lit/pdf/slyy081](http://www.ti.com/lit/pdf/slyy081)
TI series cap iso is better than optos when device safety limiting factors are violated and has better aging behavior.

**High-Voltage Fault event Chronology:**
- IEC ESD event or IGBT G-C short occurs
- HV side die is physically compromised (crack)
- Damage extends outward through critical isolation
- Isolation layer is compromised – Extent of damage varies depending on fault energy

**Aging Effect**
- LEDs typically have a half-life of 5-10yrs
- Barrier lifetime numbers are not available

For more details on failure modes of Isolators, refer: [http://www.ti.com/lit/pdf/slyy081](http://www.ti.com/lit/pdf/slyy081)
Series Capacitors Isolation: EOS Damage

Isolation barrier remains intact!

Damage limited to the over-stressed die only.

For more details on failure modes of Isolators, refer: http://www.ti.com/lit/pdf/slyy081
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Isolation in Motor Drives - Architectures

Gate-driver and Voltage/Current sense circuits interface with an earth referenced Control Module.

Gate-driver and Voltage/Current sense circuits interface with a DC bus referenced control module.
Isolation in Motor Drives – Insulation Coordination

Gate-driver and Isolated V/I sense need reinforced isolation

Gate-driver and Isolated V/I sense need basic/functional isolation. Digital isolation link needs reinforced isolation.

For more details on isolation in Motor Drives, refer: [http://www.ti.com/lit/wp/slyy080/slyy080.pdf](http://www.ti.com/lit/wp/slyy080/slyy080.pdf)
Isolation in Motor Drives – Insulation Coordination

Depending on System Voltage (Related to Input Power Supply), insulation requirements change:

1. Temporary Overvoltage (VISO/VIOTM) – upto 6220 Vpk
2. Impulse Voltage (VSURGE) – upto 12 kVpk
3. Creepage and Clearance – upto 14 mm

For more details on isolation in Motor Drives, refer: [http://www.ti.com/lit/wp/slyy080/slyy080.pdf](http://www.ti.com/lit/wp/slyy080/slyy080.pdf)
Isolation in Solar Inverter and Wind Energy Inverter

**CMTI** is a key care about to improve efficiency and reduce cost per unit power.

High working voltage is a key requirement due to increasing bus voltages (1500 V).

High creepage and clearance preferred due to high altitude operation and pollution (dust and moisture).

Insulation Coordination and Isolation requirements are very similar to Motor Drives.

## TI Isolation Products for Motor Control and Renewable Energy

<table>
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<tr>
<th>Products</th>
<th>Description</th>
<th>Key Benefits</th>
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<tbody>
<tr>
<td>ISO78xx DW and DWW</td>
<td>100 Mbps Reinforced Digital Isolators</td>
<td>5.7 kVrms VISO&lt;br&gt;12.8 kV surge&lt;br&gt;Upto 2 kVrms working voltage&lt;br&gt;14.5 mm package&lt;br&gt;100 kV/us min CMTI&lt;br&gt;DESAT and Miller Clamp Safety&lt;br&gt;High data-rates, and low skews&lt;br&gt;CTI &gt; 600 mold compound&lt;br&gt;Fail-Open Behavior</td>
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<td>ISO78xxLLx DW and DWW</td>
<td>150 Mbps Reinforced Isolated LVDS buffers</td>
<td></td>
</tr>
<tr>
<td>ISO585x DW and DWW</td>
<td>Reinforced isolated IGBT/SiC gate-drivers with Safety features</td>
<td></td>
</tr>
<tr>
<td>ISO545x DW</td>
<td>Reinforced isolated Delta Sigma modulators and amplifiers</td>
<td></td>
</tr>
<tr>
<td>AMC130x</td>
<td>Reinforced isolated Delta Sigma modulators and amplifiers</td>
<td></td>
</tr>
<tr>
<td>ISO53xx (Samples available now)</td>
<td>Compact (8-pin) basic isolated IGBT gate-drivers</td>
<td>Compact size, 100 kV/us CMTI, 0.5A to 10A flexible output current drive</td>
</tr>
</tbody>
</table>

Only supplier in the industry to offers this combination.
PLC System Block Diagram - Architecture

1. **ANALOG INPUT**
   - PWR
   - ISO
   - PWR
   - BUS
   - ASIC
   - MCU
   - ISO
   - ADC
   - MUX
   - HART
   - Protection

2. **ANALOG OUTPUT**
   - PWR
   - ISO
   - PWR
   - BUS
   - ASIC
   - MCU
   - ISO
   - DAC
   - Protection

3. **CPU (PLC Controller)**
   - MPU
   - PWR
   - PHY
   - DDR
   - COMM PCIe, GigE
   - ESD
   - BUS
   - ASIC

4. **BUS COUPLER**
   - MINI Master
   - MAXI Slave
   - BUS
   - ASIC
   - MPU
   - PHY
   - ESD

5. **DIGITAL INPUT**
   - PWR
   - ISO
   - PWR
   - BUS
   - ASIC
   - MCU
   - ISO
   - SER
   - Protection

6. **DIGITAL OUTPUT**
   - PWR
   - ISO
   - PWR
   - BUS
   - ASIC
   - MCU
   - ISO
   - SER
   - Protection

7. **POWER SUPPLY**
   - PWR
   - DISPLAY
   - PHY
   - ESD
   - MPU
   - DDR

8. **SPECIAL FUNCTION**
   - PWR
   - ISO
   - PWR
   - BUS
   - ASIC
   - MCU
   - ISO
   - ANALOG FE
   - DRV
   - Protection

- 4-20mA Loop HART 0-10V ±10V
- 4-20mA Loop HART 0-10V ±10V
- 24V On/Off IO-LINK
- 24V On/Off up to 1A/ch
- Protection
- Programmable Logic Controller with local IO (DIN-rail in cabinet)
- Remote IO (DIN-rail)
- Decentralized IO (machine attached)
- HMI

Programmable Logic Controller with local IO (DIN-rail in cabinet)
PLC System – Insulation and Other Requirements

Insulation:

24V powered systems, high voltage is normally not present.

500 Vrms Working Voltage, 2.5 kVrms (1s, VISO), basic isolation is sufficient.

However:

ESD (6kV-8kV) and EFT (4kV) are important!

Especially on the interconnect: ISO-RS485, and ISO-CAN.

Other requirements:

- Low power consumption (to relieve thermal constraints in compact designs).
- EMC – Immunity and Emissions!
- Small packages and multi-channel configurations (6-ch).
- Low propagation delays (for SPI timing closure).
- Lower controller side power supply.
## TI Isolation Products for PLC

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<td>ISO73xx and ISO71xx</td>
<td>25 Mbps and 50 Mbps digital isolators</td>
<td>Lowest emissions, Low Power Consumption, Up-to 6 kV surge protection, 4 kV EFT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compact packages (8D and 16DBQ)</td>
</tr>
<tr>
<td>SN6501 and SN6505</td>
<td>Push-pull transformer drivers for upto 5W isolated power supplies</td>
<td>Flexible output voltages, high efficiency (80%+), low cost, small footprint, flexible output voltages, ultra low emissions, SSC, Soft Start</td>
</tr>
<tr>
<td>ISORS485 and ISOCAN portfolio</td>
<td>ISORS485 and ISOCAN portfolio</td>
<td>Flexible portfolio of interconnect solutions</td>
</tr>
<tr>
<td>ISO77xx (samples now, release to market underway)</td>
<td>100 Mbps Reinforced Digital isolators</td>
<td>2.25V min power supply, &gt; 8kV IEC ESD, EMC hardened, low prop delays, flexible package options (16DW, 8D, 16 DBQ), 6-channel options</td>
</tr>
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Isolation in Automotive - Architectures

Isolation is used in :

1. Battery Management
2. EV motor drive (200V to 800V batteries)
3. On-board charger gate drives.
4. Sensors (eg. temperature, voltage)
5. 12V to 48V or 12V to HV communication interface
Isolation in Automotive – Insulation coordination

Isolation requirement:

1. Mostly basic isolation is required – Even in EV, battery is floating w.r.t. chassis.
3. 2.5 kVrms is usually sufficient, though 3 kVrms is sometimes required.
4. Agricultural high power Diesel->Electric drives may need reinforced isolation (though may not need Q100)
## TI Isolation Products for Automotive applications

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<td>25 Mbps and 50 Mbps digital isolators, 3 kVrms</td>
<td>Lowest emissions, Low Power Consumption, 16DW and 8D packages</td>
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<tr>
<td>SN6501-Q1 and SN6505 (Q100 in 2017 planned)</td>
<td>Push-pull transformer drivers for up-to 5W isolated power supplies</td>
<td>Flexible output voltages, high efficiency (80%+), low cost, small footprint, flexible output voltages, ultra low emissions, SSC, Soft Start</td>
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<td>ISO1540/41-Q1 (Dec’16)</td>
<td>Isolated I2C buffer</td>
<td>Compact two-wire bi-directional communication for isolating sensor ADCs</td>
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<td>ISO77xx-Q1 (RTM starting Jun’16)</td>
<td>100 Mbps Reinforced Digital isolators</td>
<td>2.25V min power supply, &gt; 8kV IEC ESD, EMC hardened, low prop delays, flexible package options (16DW, 8D, 16 DBQ)</td>
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Isolation in Test and Measurement and Smart Metering

Isolation Requirements

1. Reinforced isolation is required.
2. Governed by IEC 61010.
3. Insulation requirements and Creepage and Clearance requirements dictated by voltages being measured.
4. For up to 300V, 4.5 mm creepage/clearance sufficient.
5. For >600V, 11 mm creepage/clearance required.

Isolation is used in:

1. Lab equipment.
3. Automotive test and measurement.
# TI Isolation Products for T&M, Metering

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<td></td>
<td>14.5 mm package</td>
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<tr>
<td></td>
<td></td>
<td>High data-rates, and low skews</td>
</tr>
<tr>
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<td>SN6501 and SN6505</td>
<td>Push-pull transformer drivers for upto 5W isolated power supplies (combined with IEC 61010 xfmrs)</td>
<td>Flexible output voltages, high efficiency (80%+), low cost, small footprint, flexible output voltages, ultra low emissions, SSC, Soft Start</td>
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TI is uniquely positioned for this market!
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• TI Designs

www.ti.com/tidesigns
TIDA-00195
Half-Bridge Isolated IGBT Gate Driver Eval Kit

Features
- Selectable unipolar (+16V) or bipolar (+16V/-9V) isolated power
- 2 isolated IGBT gate drivers in half-bridge configuration
- Functional power supply isolation of 1.5kV DC
- IGBT Gate Drivers with Integrated Capacitive Isolation
  - 50 kV/us CMTI (min)
  - 10000 Vpk Surge VDE Reinforced Isolation
  - 5000 Vrms Isolation rating (UL 1577)
  - 7071 Vpk Transient (DIN EN 60747-5-2)
  - 1414 Vpk Working Voltage
- Driver Safety Features: Active Miller Clamp, Desat Detection, UVLO, Fault Feedback, auto soft-shutdown on short,
- 2.5/5A Peak Source/Sink Split Outputs
- <150 ns (max) Prop Delay
- IEC60747-17 (draft) & VDE0884-10 Approvals
- Enables IEC61800-5-1, IEC60664-1 & IEC62109-1

Benefits
- Scalable for drives as high as 300kW using same power supply
- Open-loop control simplifies power supply design
- Independent power supply per phase simplifies routing and transformer design and allows driving IGBT up to 1200A/4500V
- Single controller can support 3 transformers in parallel to drive 3 phase IGBT Bridge

Applications
- Variable speed AC drives
- Servo drives
- Solar inverters
- UPS

For more details, refer: http://www.ti.com/tool/TIDA-00195
Suited for low voltage drives (400 & 690Vac) up to 55KW

- Designed to drive low power IGBT module with currents <300A
- Built in miller clamp functionality
- Provision for Separate $R_{ON}$ and $R_{OFF}$
- Unipolar gate drive voltage (+15v)
- 8000 $V_{PK}$ Reinforced Isolation
- Very high CMTI of >50 kV/μs
- Generates fault output during short circuit condition and under voltage scenarios

Smallest solution for reinforced-isolated IGBT gate driver power supply

- Precision HF oscillator minimizes magnetics: ultra-small 8mm x 9mm transformer
- Push-pull topology maximizes utilization of transformer currents: ~90% efficiency
- Spread-spectrum clocking reduces EMI
- Individual power supplies allow inverter gate drive layout flexibility
- 25ms soft-start minimizes inrush current
- Shut-down pin allows MCU control of individual power supplies

Variable speed drives
- UPS
- Solar Inverters
- Welding machines

Links to other Key TI Designs

- TIDA-00281: 48V 1kW BLDC Motor Drive

- TIDA-00785: Isolated GaN Driver Reference Design

- TIDA-00794: Thermal Protection Reference Design of IGBT Modules for HEV/EV Traction Inverters
Thank You!

www.ti.com/iso