Digital Capacitive Isolators: Operation, Benefits, and Applications

Bruce Liu
Analog FAE
bruce_liu@ti.com
Agenda

• Introduction:
  – What is Isolation?
  – Why Isolate?

• Standards that apply to Isolation

• Isolation Terminology and Key Parameters

• Different Isolation technologies
  – TI’s isolation technology
  – Comparison of key parameters

• Application examples and Portfolio

• Electro Magnetic Compatibility (EMC) for Isolated Systems

• Q & A

• Feedback on TI devices: what do you want to see us do?
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 the potential for 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*
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.
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.
1) Communication to high side device requires isolation as part of the construction of the motor drive system.

2) The Emitters of high side IGBTs switch between 0 to HV DC rail – this is the same as the secondary side GND for the isolated Gate Driver.
Why Isolate?? - Other reasons

- Other reasons

Noise isolation
Ground loop isolation
Iso 7441
Data
SN 65HVD233
120 Ω
120 V
Motor 480V
Fan
LVC2G06
Amp
ISO 7421
DSP
TMS 320 F2810
DSP with CAN Controller
ISO 7421
Noise isolation
SN 65HVD233
ISO 7220M
SN 75477
Amp
Amp
ADS 1255
24-Bit
OPA 333
Sensor
TMP 101
120 V
120 Ω
ISO 721
ISO 7441
ISO 7421
Block High Voltage
ISO 721
ADC 1255
24-Bit
OPA 333
Sensor
120 V
120 Ω
Questions

• Where do you isolate?
• Why do you isolate?
• What voltages do you see?
Standards that apply to Isolation

- **Component level Standards:**
  - IEC 60747-5-2 (VDE 0884-5-2) for Opto Isolators, basic
  - IEC 60747-5-5 (VDE 0884-5-5) for Opto Isolators, reinforced
  - VDE 0884-10 Ed 2.0 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, Medical equipment standard
  - IEC 61010, safety standard for measurement, control and Lab equipment
  - IEC 60950, Telecom equipment standard
  - ---

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

• Essentially Isolation Requirements and Performance.

• How well can the isolator handle:
  – Steady high voltage over lifetime
  – Occasional Overvoltage
  – Surges

• What isolation ratings are required for a given system voltage

• How “reliable” is the isolation:
  – Basic or Reinforced?
Isolation Terminology (1)

- **Creepage Distance** – The shortest path between two conductive parts across the isolation barrier measured along the surface of the insulation. The shortest distance path is found around the end of the package body.

- **Clearance** – The shortest path between conductive input and output leads measured through air.

- **Isolation Capacitance (C_{Io})** – Total capacitance between the terminals on a first side connected together and the terminals on a second side of the isolation barrier connected together forming a 2-terminal device. Typical value is 1 or 2 pF.

- **Isolation Resistance (R_{Io})** – Resistance between the terminals on a first side connected together and the terminals on a second side of the isolation barrier connected together forming a 2-terminal device. Typical value is $>10^{12}$ Ohms.
Isolation Terminology (2)

- **Comparative Tracking Index (CTI)** – Measure of how easily the packaging material or mold compound will erode under electric discharge. Higher CTI values of the insulating material requires smaller minimum Creepage distance.

- **Material Group (per CTI)** - Materials are separated into four groups according to their CTI (Comparative Tracking Index) values. For isolators, this is based on the mold compound properties of packages.
  - **Material group I:** $600V < CTI$
  - **Material group II:** $400V < CTI < 600V$
  - **Material group IIIa:** $175V < CTI < 400V$
  - **Material group IIIb:** $100V < CTI < 175V$

- **Common Mode Transient Immunity (CMTI)** – Refers to the ability of a circuit to maintain signal integrity during quick changes in reference potential between the primary and secondary sides. It is specified as the $dV/dt$ up to which no false toggling of the output will occur (e.g. 25 kV/us).

- **Repetitive Voltage (V_{IORM})** – *Definition: Voltage input to output repetitive maximum.* A repetitive peak value of withstand voltage that may be applied across the Isolation barrier through its lifetime. It includes all repetitive transient voltages but excludes all non-repetitive transient voltages; e.g., 560 $V_{PK}$, 891 $V_{PK}$, or 1414 $V_{PK}$.

- **Transient Overvoltage (V_{IOTM})** – *Definition: Voltage input to output transient maximum.* Voltage that may occur temporarily across the barrier (tested per VDE for 1 minute during certification and 1 sec during production), e.g., 4 $kV_{PK}$ or 6 $kV_{PK}$.
Isolation Terminology (3)

- **Isolation or Withstand Voltage** ($V_{ISO}$) - Voltage that may occur temporarily across the barrier (tested per UL for 1 minute during certification and 1 sec during production at 120% of the rated voltage), mostly $2.5 \text{kV}_{\text{RMS}}$ or $5 \text{kV}_{\text{RMS}}$.

  Transient, Isolation, Withstand, Dielectric voltage or rating is sometimes used interchangeably.

- **Surge Voltage** ($V_{IOSM}$) – The highest instantaneous value of an isolation voltage pulse with short time duration and of specified waveshape. Surge testing replicates lightning strikes. Each device is subjected to 50 discharges in each polarity. For reinforced insulation, VDE requires a minimum of 10 kV$_{PK}$ rating

  ![Diagram](https://via.placeholder.com/150)

- **Partial Discharge** – Partial discharge is localized electrical discharge which occurs in the insulation between all terminals of the first side and all terminals of the second side of the coupler. Vpd is partial discharge voltage at which less than 5 pico columbs of electrons are detected across insulation barrier. It is tested at $1.875 \times V_{IORM}$ for 1 second during production.
Isolation Terminology (4)

• **Insulation:**
  - **Functional insulation** – Insulation needed for the correct operation of the equipment.
  - **Basic insulation** – Insulation that provides basic protection against electric shock.
  - **Supplementary insulation** – Independent insulation applied in addition to Basic insulation in order to ensure protection against electric shock in the event of a failure of the Basic insulation.
  - **Double insulation** – Insulation comprising both Basic and Supplementary insulation.
  - **Reinforced insulation** – A single insulation system which provides a degree of protection against electric shock equivalent to Double insulation under the conditions specified by the standard.

• **Pollution Degree:**
  - **Pollution Degree 1** – No pollution, or only dry, non-conductive pollution occurs. The pollution has no influence, e.g. a circuit in a hermetically sealed box such as IC chip.
  - **Pollution Degree 2** – Normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation must be expected, e.g. a circuit used in an office environment such as circuitry inside a computer.
  - **Pollution Degree 3** – Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation which is expected, e.g. a circuit that is exposed to outside air but not in direct contact with precipitation such as circuitry inside a garage door opener.
  - **Pollution Degree 4** – The pollution generates persistent conductivity caused by conductive dust or by rain or snow, e.g. an exposed outdoor control box for a water pump.
Data Isolation: Common-Mode Transient Event

CMTI – The change in ground 1 relative ground 2. Measured in kV / μSec.
Questions?

- What standards do you need to certify to?
- What standards are giving you grief?
Different Isolation Techniques

Galvanic Isolation
• Isolated circuits exchange signals without DC current flow between the isolated domains.

Transformer Isolation
• A form of Galvanic isolation using transformers to provide an AC coupled data path with coil separation providing the isolation.
• The same topology can also be used to transfer power.

Capacitive Isolation
• Great fabrication tolerances with Silicon dioxide based dielectric.
• High breakdown processes around 800V/um.

Optical Isolation
• Uses Mold compound for dielectric
• Very cost effective, but high variation from part to part.

Wireless Technology
• Dielectric thickness is variable and Frequency dependencies must be specified per application.
Isolation Techniques

<table>
<thead>
<tr>
<th></th>
<th>Capacitive ISO72X</th>
<th>Inductive ADuM1xx</th>
<th>GMR IL7x</th>
<th>Optical HCPL-07xx</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{io}$</td>
<td>1 pF</td>
<td>1 pF</td>
<td>1.1 pF</td>
<td>0.6 pF</td>
</tr>
<tr>
<td>Isolation Dielectric</td>
<td>SiO2</td>
<td>Polyimide</td>
<td>Polyimide</td>
<td>Mold compound</td>
</tr>
</tbody>
</table>
How are capacitive Isolators constructed?

Cross Sectional View

- **Transmit Chip**
- **Receive Chip**

- **LF-Channel**
- **HF-Channel**

**High Voltage Capacitor Detail**

- **Top plate = Al**
- **Inter Level Dielectric** (Tons of SiO₂)
- **Bottom Plate = Silicon Substrate (doped)**
- **Bond wire**
- **Mold compound**

- **Dimensions**: 8-14 μm
How do our capacitive Isolators work?

DC-Path

Signal

OSC

PWM

DC

Transient

Pulse

90%  10%

Signal

AC-Path

Signal

Duty Cycle

90%  10%

AC

DC

signal

Pulse

90%  10%

AC

signal

Tempor}

TXAS INSTRUMENTS
Which technology is better (1)

- Working Voltage (VIORM):
  - Magnetic isolators limited to <500V r.m.s.
  - Opto and Capacitive can do 1kV r.m.s. and beyond.

- Transient Overvoltage (VIOTM)
  - Comparable, 5kV r.m.s. and beyond.

- Surge Voltage:
  - Traditionally Opto and Magnetic better (>10kV)
  - Capacitor based fast catching up.

- CMTI:
  - Magnetic and Capacitive at 25kV/us minimum.
  - Optical worse at 15kV/us minimum.
  - We are looking to push this up.
Which technology is better (2)

- Timing parameters (Propagation delay and skew):
  - Capacitive the best (10ns prop delay), Opto and Magnetic worse (>25ns)

- Parameter stability with time:
  - Capacitive and Magnetic very stable
  - Opto performance known to degrade with time as LED ages.

- Power Consumption at Low Data rate:
  - Magnetic the best (at the expense of high emissions, and power at high data rates).
  - Opto the worst (LED power itself very high)
  - Capacitor in between.

- Power at high data rates:
  - Capacitive the best, followed by Opto, magnetic the worst.
## Specs and Reliability Comparison

<table>
<thead>
<tr>
<th>Specification</th>
<th>Opto (Avago)</th>
<th>Magnetic (ADI)</th>
<th>Capacitive (Si Labs)</th>
<th>Capacitive (TI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Data Rate (Mbps)</td>
<td>50</td>
<td>150</td>
<td>150</td>
<td>150</td>
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<tr>
<td>Typ Power Consumed/Ch @ 25Mbps &amp; 3.3V (mA)</td>
<td>16</td>
<td>3.4</td>
<td>2.7</td>
<td>2</td>
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<tr>
<td>Max Propagation Delay Time (ns)</td>
<td>22</td>
<td>32</td>
<td>13</td>
<td>12</td>
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<tr>
<td>Pulse Width Distortion (ns)</td>
<td>2</td>
<td>2</td>
<td>4.5</td>
<td>1.5</td>
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<tr>
<td>Channel-to-Channel skew (ns)</td>
<td>16</td>
<td>2.0</td>
<td>2.5</td>
<td>1.6</td>
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<tr>
<td>Part-to-Part Skew (ns)</td>
<td>20</td>
<td>10</td>
<td>4.5</td>
<td>2</td>
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<td>ESD on all Pins (kV)</td>
<td>± 2</td>
<td>± 2</td>
<td>± 4</td>
<td>± 4</td>
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<tr>
<td>Minimum CM Transient Immunity (kV/us)</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>25</td>
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<tr>
<td>Temperature Range (°C)</td>
<td>-45..125</td>
<td>-40..125</td>
<td>-40..125</td>
<td>-40..125</td>
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<tr>
<td>MTBF @ 125°C, 90% Confidence (Hrs)</td>
<td>6.92E+04</td>
<td>3.17E+07</td>
<td>-</td>
<td>1.65E+09</td>
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<td>FIT@ 125°C, 90% Confidence (per 1E+09 hrs)</td>
<td>14391</td>
<td>31.55</td>
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<td>0.6</td>
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<td>Radiated Electromagnetic-Field Immunity</td>
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<td>IEC61000-4-3 (80MHz-1000MHz)</td>
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<td>Fails*</td>
<td>Fails*</td>
<td>Complies</td>
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<tr>
<td>MIL-STD 461E RS103 (30MHz-1000MHz)</td>
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<td>Fails*</td>
<td>Fails*</td>
<td>Complies</td>
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<tr>
<td>High-Voltage Lifetime Expectancy (yrs)</td>
<td>-</td>
<td>&lt; 10</td>
<td>&gt; 60*</td>
<td>&gt; 28</td>
</tr>
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</table>

* Devices passed the minimum criteria set by some standards. See details later in the presentation.
Competitive Analysis: Dielectric Material

• **SiO2**: ISO72x Typical BV is 800 Vpeak/μm
  – DTI of 16μm => 12.8kV isolation
  – DTI of 32μm => 25.6kV isolation

• **Polyimide**: Transformer core Typical BV is 250 Vpeak/μm
  – DTI of 16μm => 4kV isolation
  – DTI of 32μm => 8kV isolation
  – DTI of 80μm needed to achieve 20kV isolation

• **Epoxy**: Opto-couplers: Typical BV is 50 Vpeak/μm
  – DTI of 16μm => 0.8kV isolation
  – DTI of 32μm => 1.6kV isolation
  – DTI of 400μm needed to achieve 20kV isolation.

• Epoxy based dielectric needs to be 16 x larger than SiO2 based dielectric to be as strong!
Competitive Analysis – \( \frac{(I_{CC1} + I_{CC2})}{\text{# of Channels}} \)

Capacitive Isolators have slightly higher channel currents only in the lower 5% of the bandwidth spectrum.
Questions

• Which isolation technology would you use?
# Digital Isolators Portfolio & Roadmap

<table>
<thead>
<tr>
<th>CHANNEL COUNT</th>
<th>ISO7130 (F)</th>
<th>ISO7131 (F)</th>
<th>ISO7132 (F)</th>
<th>ISO7133 (F)</th>
<th>ISO7134 (F)</th>
<th>ISO7135 (F)</th>
<th>ISO7136 (F)</th>
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<td>ISO775</td>
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*Failsafe low coming 2015
## Isolated Functions

<table>
<thead>
<tr>
<th>5kV RMS</th>
<th>2.5kV RMS</th>
<th>Full Duplex</th>
<th>Half Duplex</th>
<th>Half Duplex</th>
<th>CAN</th>
<th>I2C</th>
<th>GATE DRIVERS</th>
<th>Others</th>
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<td>ISO3086T w/ Xfmr Driver</td>
<td>ISO3080</td>
<td>ISO3086</td>
<td>ISO3088</td>
<td>ISO1176T w/ Xfmr Driver</td>
<td>ISO1050DUB</td>
<td>ISO1541</td>
<td>SOIC-16W</td>
<td>SOIC-8N</td>
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<td>BUS VCC = 5V</td>
<td>BUS VCC = 5V</td>
<td>BUS VCC = 5V</td>
<td>BUS VCC = 5V</td>
<td>BUS VCC = 5V</td>
<td>BUS VCC = 5V</td>
<td>Bi-directional Data</td>
<td>1 Mbps</td>
<td>40 Mbps</td>
</tr>
<tr>
<td>20 Mbps, SOIC-16W</td>
<td>200 Kbps, SOIC-16W</td>
<td>20 Mbps</td>
<td>20 Mbps</td>
<td>40 Mbps</td>
<td>1 Mbps, SOIC-16W</td>
<td>Uni-directional Clk</td>
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<td>200 Kbps, 5V, SOIC-16W</td>
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<td>ISO35T w/ Xfmr Driver</td>
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<td>BUS VCC = 3.3V</td>
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<td>BUS VCC = 5V</td>
<td>BUS VCC = 5V</td>
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<td>Transformer Driver</td>
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<tr>
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<td>1 Mbps, SOIC-16W</td>
<td>1 Mbps, SOIC-16W</td>
<td>1 Mbps, SOIC-16W</td>
<td>1 Mbps, 1MHz</td>
<td>3.3V or 5V supply</td>
<td>3.3V or 5V supply</td>
<td>VDE Reinforced</td>
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<td>2.5V, 5V supply</td>
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<td>Bi-directional Data</td>
<td>1 Mbps, 1MHz</td>
<td>1.5kV Isolation</td>
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<td>1 Mbps</td>
<td>2.5A, VCC2= 15-30V</td>
<td>2.5A, VCC2= 15-30V</td>
<td>2.5V, 5V supply</td>
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<td>SOIC-16W</td>
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<td>2.5V, 5V supply</td>
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<td>2.5V, 5V supply</td>
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</tbody>
</table>

**Notes:**
- **TI Information – NDA Restrictions**
- **Existing**
- **New**
- **Preview**

**Texas Instruments**
Isolated RS-485 Bus Design

Node 1
- Vcc1
- GND1
- MCU
- 530Ω (361Ω)
- 135Ω (143Ω)
- 530Ω (361Ω)
- GND1_ISO
- Vcc1_ISO

Termination Plug with Failsafe Biasing

Node 2
- Vcc2
- GND2
- MCU
- 530Ω (361Ω)

Node 3
- Vcc3
- GND3
- MCU
- 120Ω

Termination Plug

Texas Instruments
Isolated RS-485 Node Design

PSU

L1
N
PE

+ 3.3V
- 0V

PSU

Short thick Earth wire or Chassis

Protective Earth Ground, Equipment Safety Ground

Non-isolated Ground

Floating RS-485 Common

Texas Instruments
Isolating the I²C Bus

SDA channel design and voltage levels at SDA1

SDA channel timing in receive and transmit directions
Isolated I²C DACQ System

T1 = 1:2.0, 11Vμs from Wuerth-Electronics / Midcom
Order No: 760390015
Isolated Power Supply Design

Push-pull transformer driver, can drive one to two transformers, with and without linear regulators.
Isolated CAN with ISO1050
Isolated Digital Input Module

SN6501

1:1.7 MBR0520L

5VISO

1μF

1μF

0.1μF

optional

RIN 0:7

Vcc

10V..34V

0V

Vcc1

Vcc2

MBR0520L

ISO7242

SN65HVS885

RE0

RE1

RE2

RE3

RE4

RE5

RE6

RE7

SIP

LD

CLK

SOP

HOT

IP0

IP1

IP2

IP3

IP4

IP5

IP6

IP7

IP8

IP9

IP10

IP11

IP12

IP13

IP14

IP15

IP16

IP17

IP18

IP19

IP20

IP21

IP22

IP23

IP24

IP25

IP26

IP27

IP28

GND

DVcc

XOUT

MSP430

UCB0CLK

F2132

UCB0SOMI

DVss

P3.0

P3.1

EN1

INA

INB

OUTA

OUTB

OUTC

OUTD

GND1

GND2

Vcc

3.3V

Vin

10k

0.1μF

1μF

Vcc

10k

0.1μF

0.1μF

10k

1μF

GND

DVss

DVcc

optional

RIN 0:7

44.8k

TXAS INSTRUMENTS
Isolated Gate Driver for Motor Control
**ESD**
- 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.

**EFT**
- IEC 61000-4-4.
- Key specifications (level 4):
  - Voltage peak: 4kV (supply), 2kV(IO).
  - Output impedance: 50 Ohms.

**SURGE**
- IEC 61000-4-5.
- Key specifications (level 4):
  - Voltage peak: 4kV.
  - Output impedance: 2 Ohms.
ESD/EFT/Surge – non-isolation case

- ESD/EFT/Surge protection involves on-board and on-chip protection circuitry and overvoltage suppressors.
- These convey ESD/EFT/Surge currents safely to GND and protect circuitry.
- AC path to Protection Earth (PE) prevents bounce on GND.
  - GND bounce is not a reliability concern for IC.
Case 1:

- \( C_{HV} \) provides an AC path to PE for ESD current.
- Bounce on GND2 is limited \( \Rightarrow \) less stress across the isolation barrier.

Case 2:

- GND on strike side is floating.
- Bounce on GND2 is very high, limited only by board parasitic capacitance \( \Rightarrow \) high stress and current across the isolation barrier.
- Entire magnitude of the stress suffered by isolation barrier
- External ESD structures won’t help
Questions?

• What applications do you see in your systems?
• What EMC problems have you faced?
Thank You!

http://e2e.ti.com/
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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
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