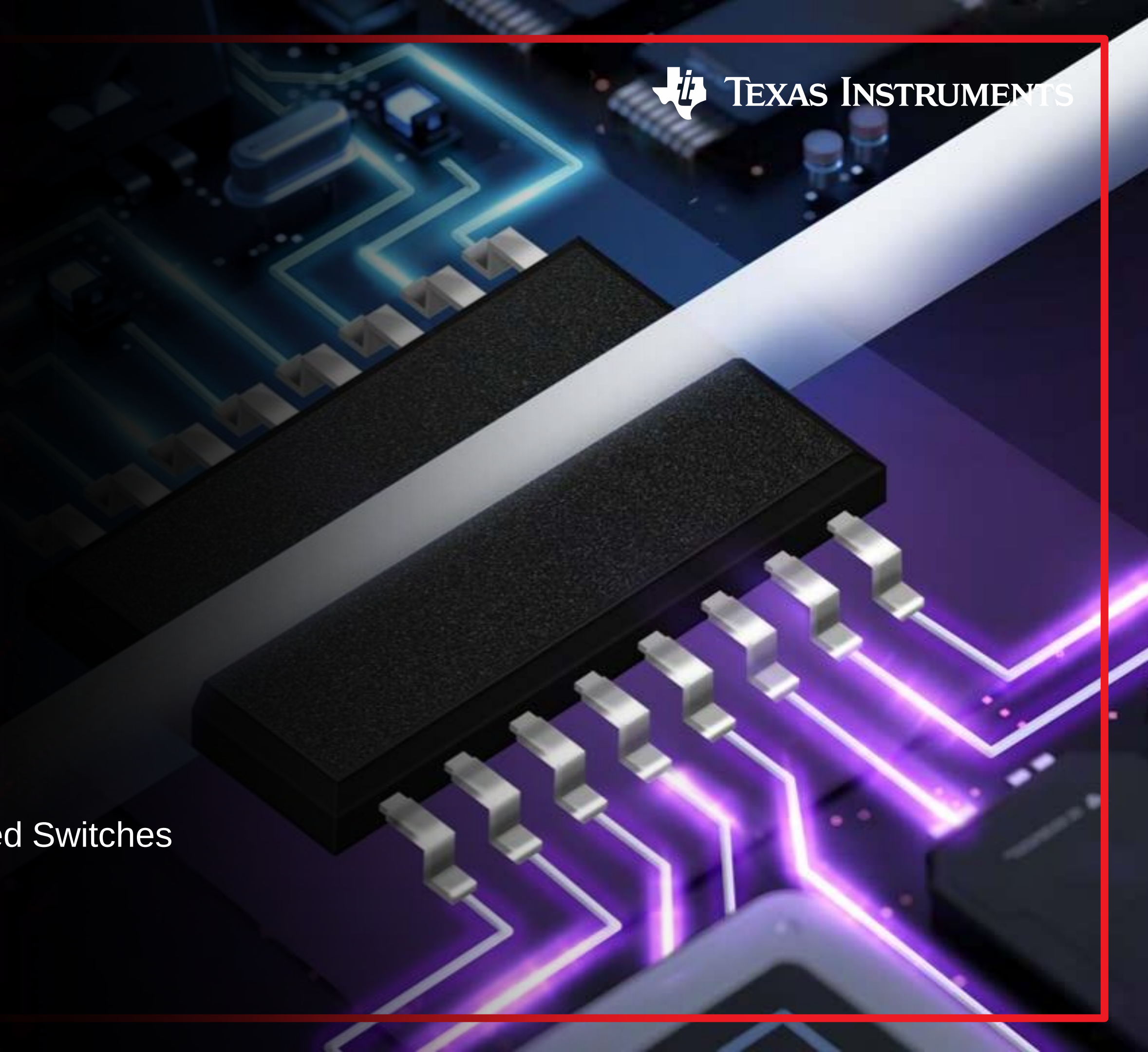


TI High-voltage Seminar

Replacing optical and electro-mechanical switches with TI's latest isolation technologies

Neel Seshan

Systems and Marketing Manager, Isolated Switches

Manasa Gadiyar

Systems Engineer, Isolation

Agenda

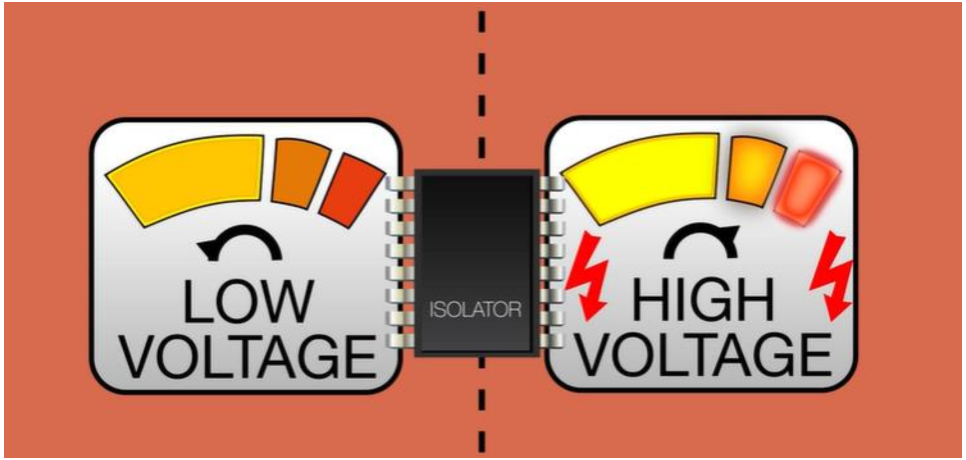
- Introduction to isolated switching
- TI’s isolation technology
- Overview and use cases of TI’s portfolios of opto-emulator switches & solid-state relays

Isolated switches

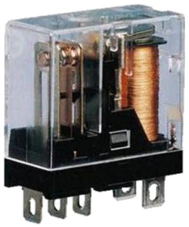
Control high voltage load with a low voltage signal

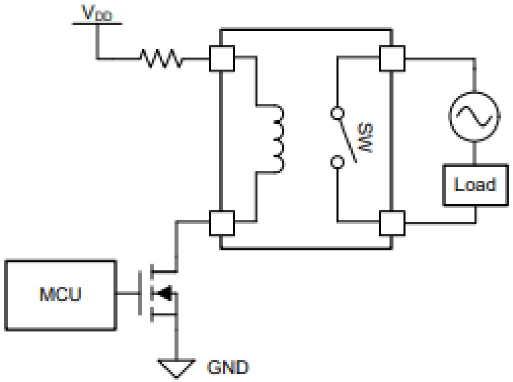
Handle ground potential differences between communicating subsystems

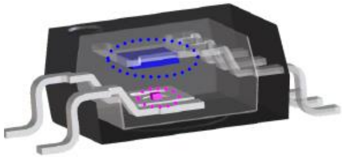
Protect low-voltage circuitry from high voltages

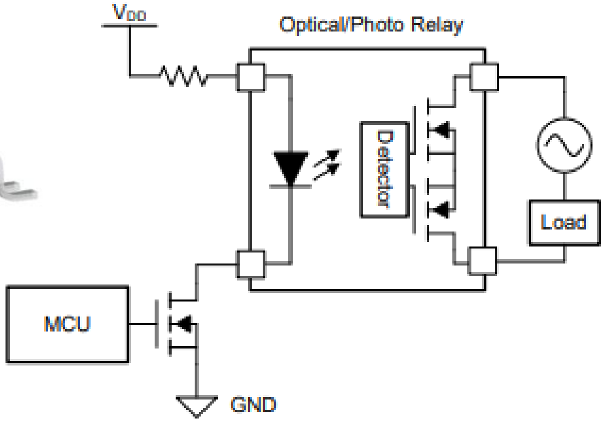

LOW VOLTAGE
ISOLATOR
HIGH VOLTAGE

Traditional isolated switches




VDD
SW
Load
MCU
GND




VDD
Optical/Photo Relay
Detector
Load
MCU
GND

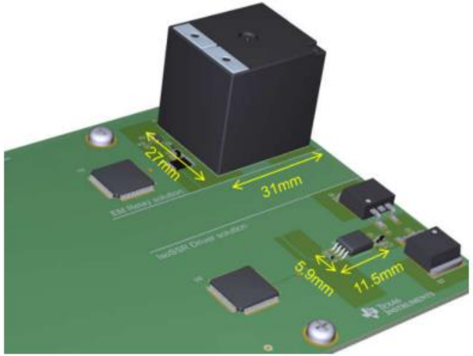
Electro-mechanical relays (EMR)

Solenoid based action for mechanical switching

Optical relays (solid-state relays)

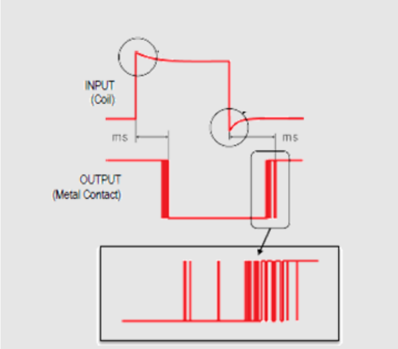
Optical coupling with solid-state switching

Electro-mechanical relays



- **Electrical isolation:**
  - Electro-mechanical relays use metal contacts instead of integrated or external MOSFETs. This eliminates leakage current within the device due to the ability to implement a pure mechanical disconnect, thereby providing excellent electrical isolation
- **Cost-effective:**
  - Simpler construction of devices leads electro-mechanical relays to be relatively cheaper then solid-state relays
- **Noise immunity:**
  - Less susceptible to electromagnetic interference thereby suitable for noisy environments
- **Bulky:**
  - Electro-mechanical relays usually have larger size (including height) because the package needs to accommodate space for all of the parts within the device, such as the metal contacts, coil, and spring

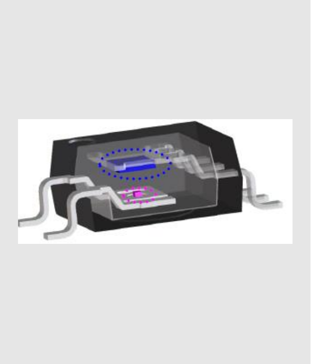
Electro-mechanical relays (EMRs)

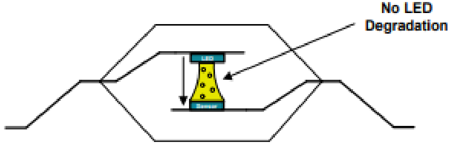


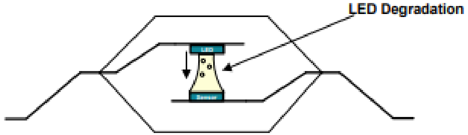
Chatter in mechanical relays

- **Slower switching speed:**
  - Current flowing through the metal contacts must reach a certain condition before switching to an open/closed state (ex. not oscillating when closed), thereby requiring a longer settling time
- **Power hungry:**
  - Current required to magnetize the coils in the electro-mechanical relay may be large thereby increasing the power consumption of the system
- **Noisy:**
  - Variations on the voltage or current supply can cause opening and closing of the contacts know as relay chatter, that reduces the life-span of the device
- **Reliability concern:**
  - Metal contacts experience wear and tear, such as welding shut. This limits the number of switching cycles before experiencing complete failure, thus limiting overall reliability

Optical relays and photo relays

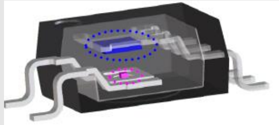


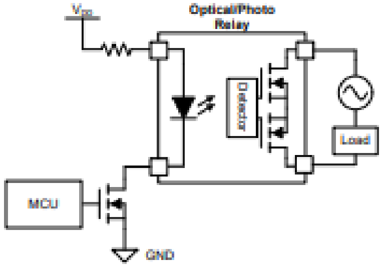




- **Small size:**
  - Simpler construction of photo-relays leads to smaller package foot-prints
- **Fast switching:**
  - Opto-relays switch faster than mechanical relays with minimal chatter/noise on the output switching FETs
- **Low EMI:**
  - Since light is used to transfer data from LED to the sensor, the emissions and immunity performance is better than other solid-state relays
- **LED degradation:**
  - LED's are subject to light decay, which is the reduction of light output capacity due to extreme conditions, such as over-temperature or over-current. As a result, the LED within a photo relay does not have enough luminosity to drive a gate voltage, which limits the switch functionality of the device

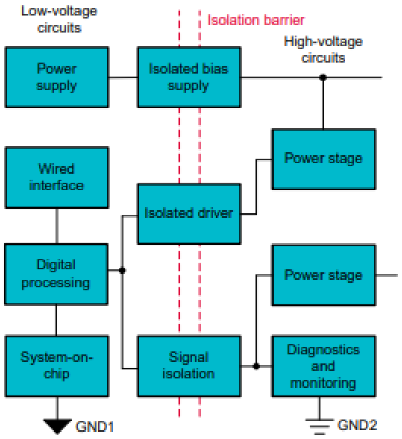
Optical relays and photo relays

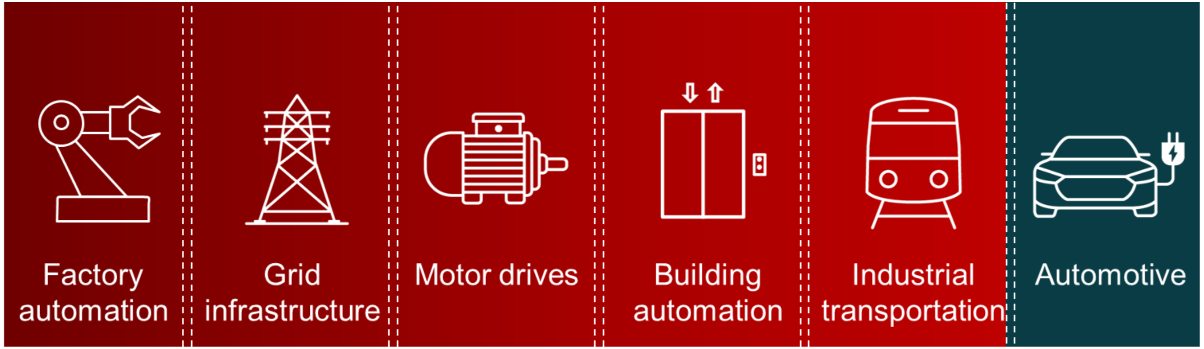




- **Limited temperature range:**
  - Typical opto-relays have limited temperature range to ensure high performance (ex. timing). To achieve higher temperature ranges, most photo relays have to use more expensive materials, which is not practical in most applications
- **External circuit:**
  - Photo relays need an external current-limiting resistor and often use additional FETs to manage the LED’s on or off state

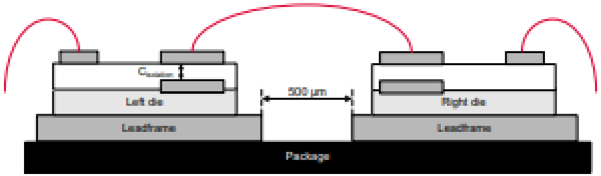
Isolated switches are everywhere

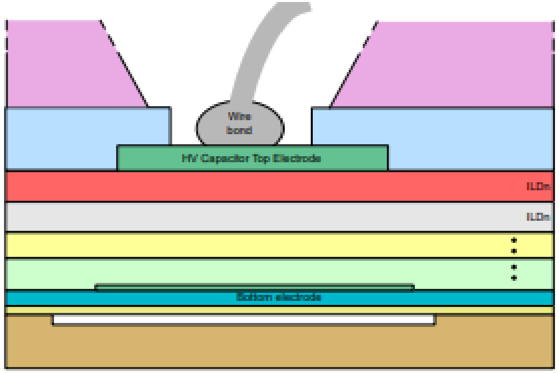

Low-voltage circuits
Isolation barrier
High-voltage circuits
Power supply
Isolated bias supply
Wired interface
Power stage
Isolated driver
Digital processing
Power stage
System-on-chip
Signal isolation
Diagnostics and monitoring
GND1
GND2


Factory automation
Grid infrastructure
Motor drives
Building automation
Industrial transportation
Automotive

TI’s isolation technologies | Capacitive

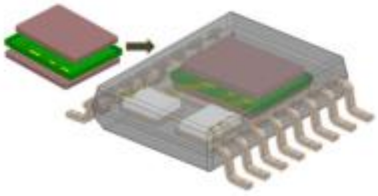
- Capacitive isolation technology based on AC signal transfer across a dielectric
- TI’s capacitive isolators are constructed using an SiO_2 dielectric, which provides very high dielectric strength
- SiO_2 is an inorganic material → extremely stable over moisture and temperature
- Proprietary methodology for multilayered capacitor and multilayer passivation improves isolator quality and reliability by reducing the dependence of high-voltage performance on any single layer
- Supports working voltages (V_{IOWM}) of 2 kV_{RMS}, withstands isolation voltages (V_{ISO}) of 7.5 kV_{RMS} and has a surge voltage capability of 12.8 kV_{PK}

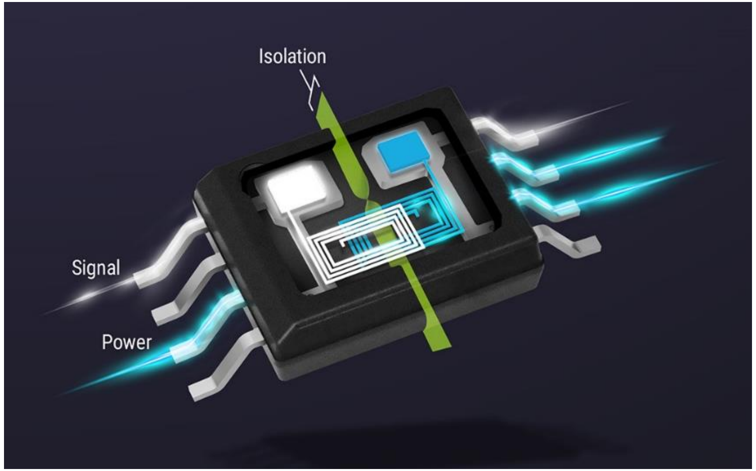

$C_{isolation}$
500 µm
Left die
Right die
Leadframe
Leadframe
Package


Wire bond
HV Capacitor Top Electrode
ILDn
ILDn
Bottom electrode

TI’s isolation technologies | Inductive

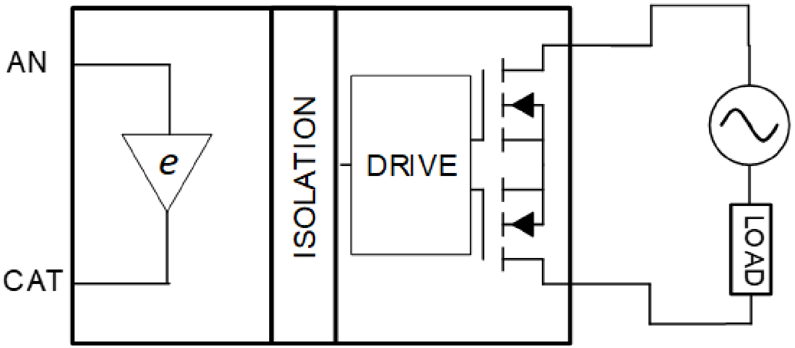
- Magnetic isolation is typically used in applications that require high-frequency DC/DC power conversion
- TI uses a proprietary multichip module approach for magnetic isolation, which co-packages a high-performance planar transformer with an isolated power stage and dedicated controller die
- Transformers with either a high-performance ferrite core to improve coupling and transformer efficiency, or an air-core to save cost and complexity when the application requires only modest power transfer
- By combining both signals and power transfer over the same integrated transformer coil, both solution cost and size are minimized





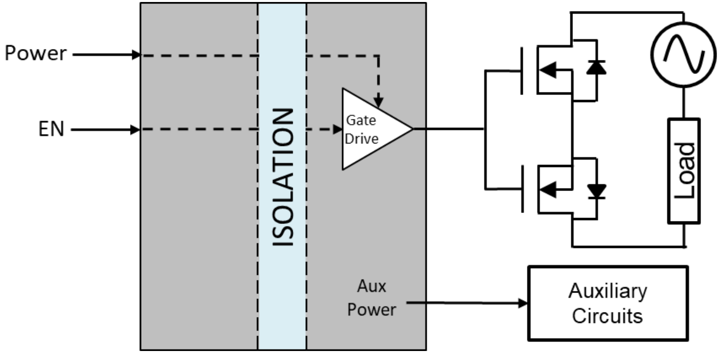
TI’s opto-emulator switches & solid state relays (SSRs)

Opto-emulator switches

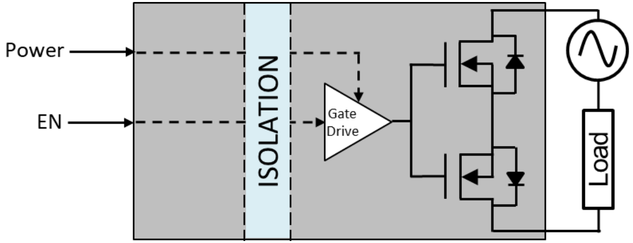

AN
CAT
e
ISOLATION
DRIVE
LOAD

Isolated switches and drivers

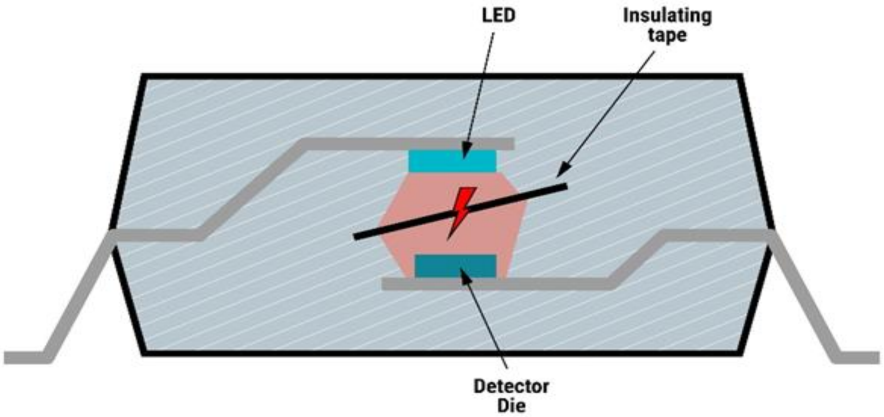
External FET Driver

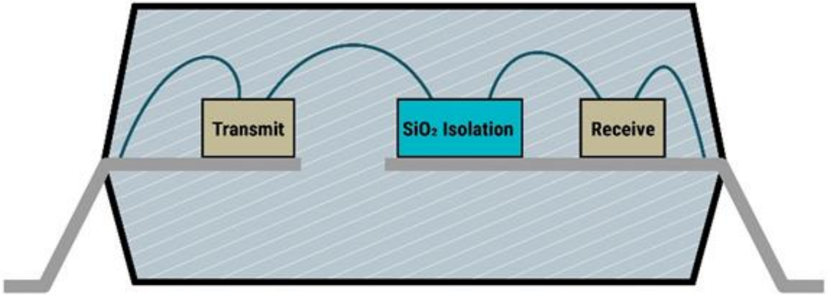

Power
EN
ISOLATION
Gate Drive
Aux Power
Auxiliary Circuits
Load

Internal FET Switch


Power
EN
ISOLATION
Gate Drive
Load

Introduction to opto-emulators | ISOM86xx

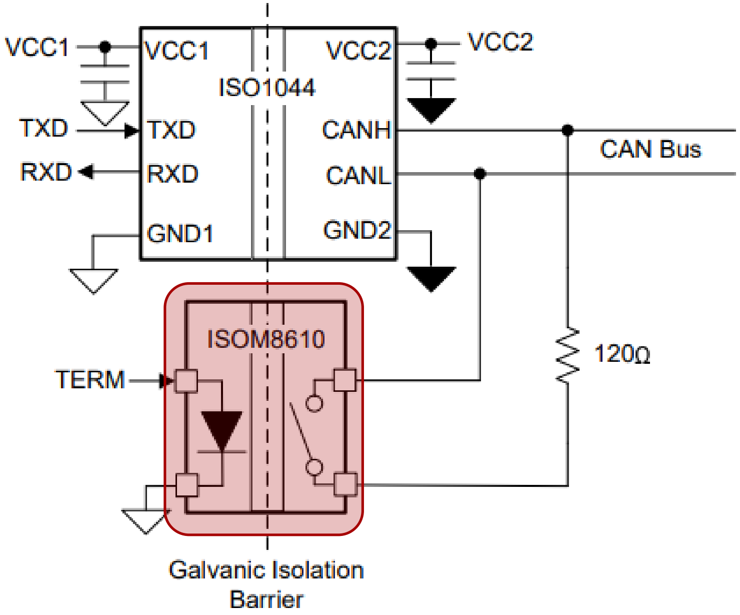

LED
Insulating tape
Detector Die


Transmit
SiO₂ Isolation
Receive

- Epoxy dielectric for isolation
- LED signal transmission, affected by aging
- GaAs LED bias current increases with temperature and lifetime operation, requires compensation
- Slower switching speeds

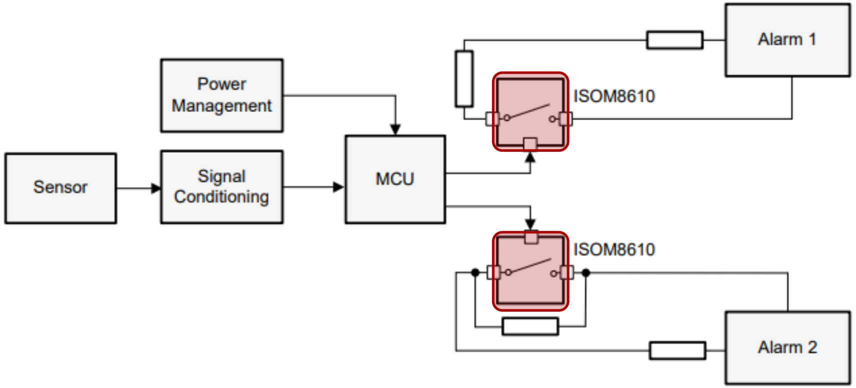
- SiO_2 dielectric for robust isolation
- Diode emulated, no physical GaAs LED
- 'LED emulator' input eliminates over-compensation on bias current across temperature and lifetime operation
- Faster switching speeds

Switchable termination on CAN/RS485


VCC1
VCC1
ISO1044
VCC2
VCC2
TXD
TXD
CANH
CAN Bus
RXD
RXD
CANL
GND1
GND2
ISOM8610
TERM
120Ω
Galvanic Isolation
Barrier

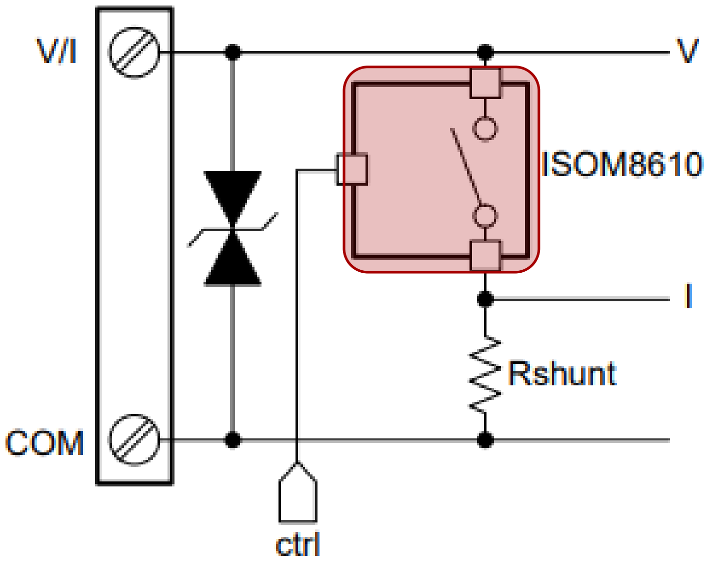
- Software configurable termination on the CAN/RS485 bus.
- Enable/disable termination for multi-node configs on the CAN/RS485 lines
- Enable half/full duplex designs with isolated switches
- TERM = High enables the termination; TERM = Low disables termination
- High common mode blocking voltage of ±70V, low off-state leakage <1uA

Low power switching in intrusion alarms


Power Management
Sensor
Signal Conditioning
MCU
ISOM8610
Alarm 1
ISOM8610
Alarm 2

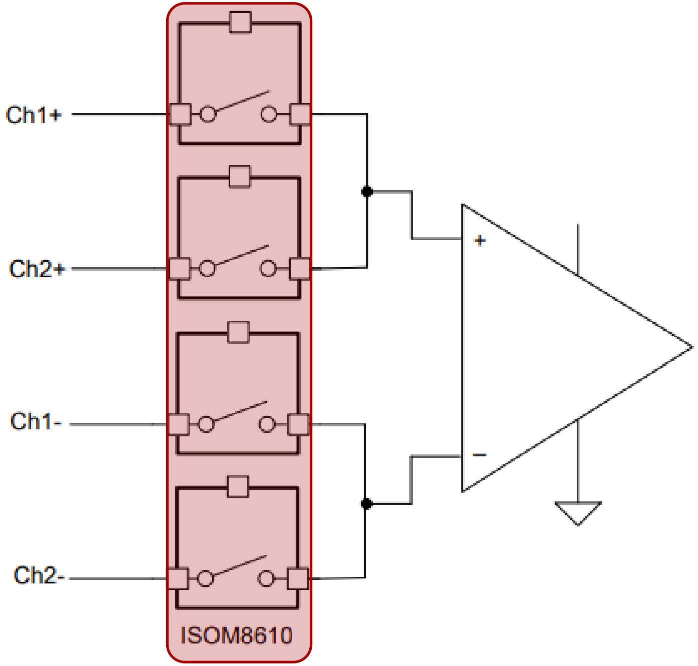
- Detect any disturbance from sensors placed in spaces of interest
- Based on architecture, normally closed outputs may be needed
- ISOM86xx does not need to be compensated for 3x-4x LED current deration over lifetime operation
- Ultra low-IF (0.8mA) very useful when sensors directly interface with the ISOM86xx

Switch burden resistor in universal input module



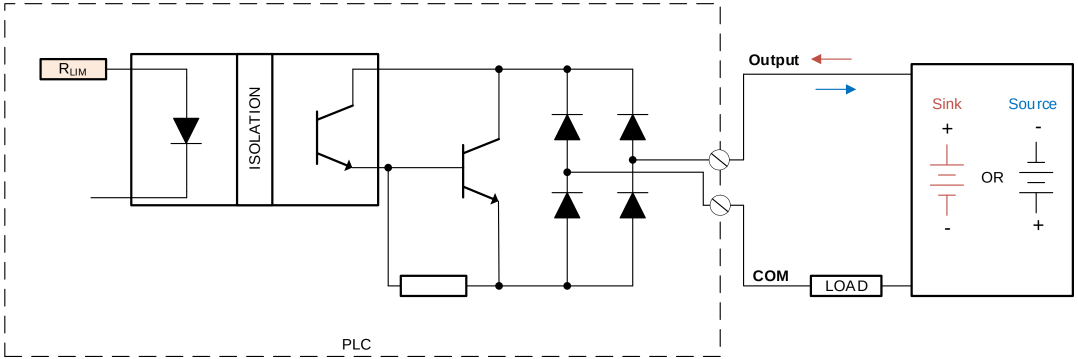
- Enable/disable precision burden resistors on Analog input module
- Rshunt is set for current input, disabled for voltage input
- When ctrl = High, Rshunt set for 4-20mA current input mode
- When ctrl = Low, Rshunt set for ±10V voltage input mode
- Blocks high voltage common mode up-to 70V with <1uA leakage
- Does not require high voltage supply on switch side

Channel-to-channel isolated input modules



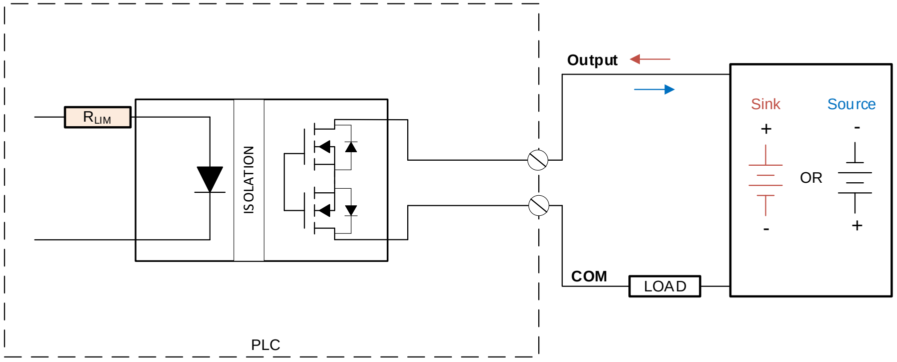
- Each differential pair multiplexed using ISOM86xx
- High voltage blocking in Channel-to-channel isolated input modules
- Up to 70V blocking with no secondary side high voltage supply
- ISOM86xx offers best-in-class switching time <200μs
- Blocks high voltage common mode up to 70V with <1uA leakage

Compact isolated digital output modules


RLIM
ISOLATION
Output
COM
LOAD
Sink
+
-
Source
-
+
OR
PLC

- Source/sink capable digital output modules use multiple discrete elements for high capacity
- Generally use photo-coupler with additional transistor for higher capacity, bridge stage for bidirectional capability and sometimes Zener diodes for high voltage blocking
- ISOM86xx can displace all these components with symmetrical 70V blocking and 150mA current capacity

Compact isolated digital output modules

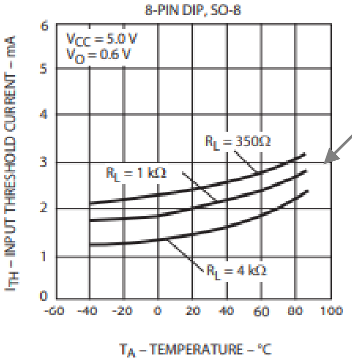

Output
RLIM
ISOLATION
Sink
Source
+
-
OR
-
+
COM
LOAD
PLC

- Source/sink capable digital output modules use multiple discrete elements for high capacity
- Generally use photo-coupler with additional transistor for higher capacity, bridge stage for bidirectional capability and sometimes Zener diodes for high voltage blocking
- ISOM86xx can displace all these components with symmetrical 70V blocking and 150mA current capacity

ISOM86xx benefits over optocoupler switches

Robust performance across temp

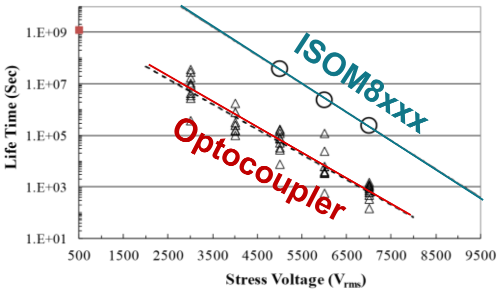
Opto performance varies widely across temperature. Customers are forced to design for worst case (driving harder) leading to increased power consumption and decreased lifetime. **Opto-emulators can enable simpler design with lower device variance.**



80% Typical Input threshold variation across temp

Reliable isolation

Part to part variation and skew is known to be high in optocouplers. Opto-emulators have FIT (failure in time) rates that are order of magnitudes stronger than optocouplers.



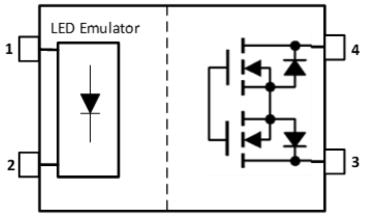
Optocoupler failure variation versus TI's consistent performance w/ SiO_2 dielectric

Lower power budgets

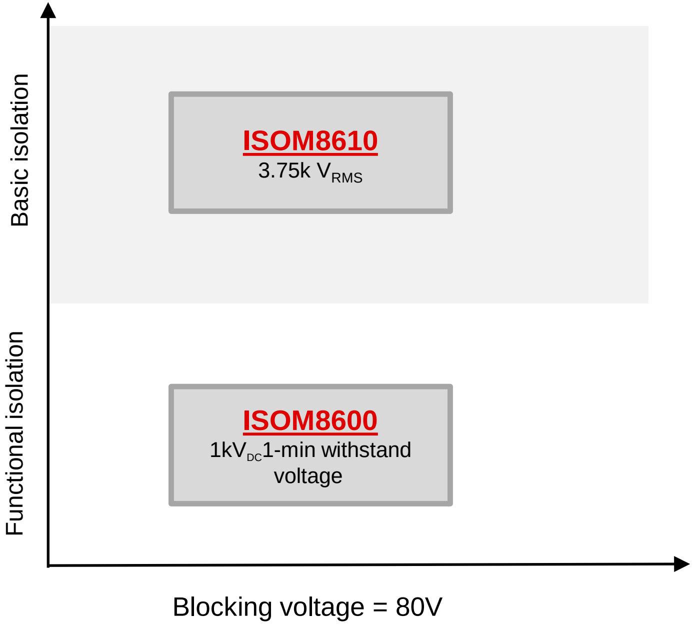
Opto-couplers consume as much as 10mA per channel due to deration of the LED over lifetime operation.

Engineers need to overdesign for lifetime operation, and this factor can be as high as 3x to 4x of rated currents.

The deration factors are not readily available on the datasheet, making it extremely challenging for the system design to work for lifetime operation.



Getting started with opto-emulator switches



Basic isolation

ISOM8610
3.75k V_{RMS}

Functional isolation

ISOM8600
1kV_{DC} 1-min withstand voltage

Blocking voltage = 80V

Opto-emulator switch

Technical Collateral

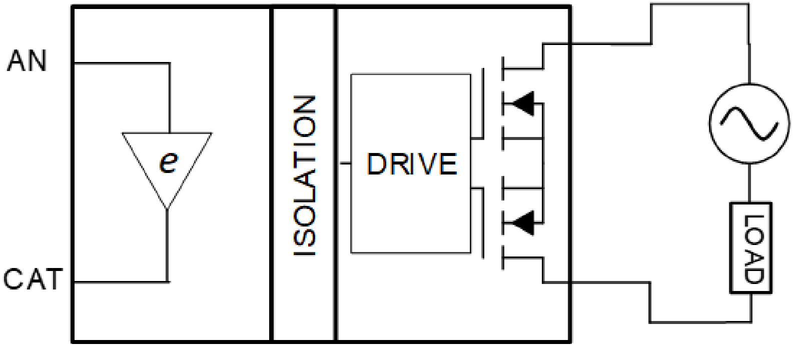
- Upgrading Relays With Opto-Emulator Switch
- Upgrading your designs with TI’s Pin-to-Pin Opto-emulator switch: ISOM8610
- Demystifying Isolation Certification Standards: Optocouplers vs Opto-emulators
- Opto-emulators explained: Why you should upgrade your optocoupler technology
- Introduction to Opto-Emulators
- FAQ Forum : Opto-emulators

Evaluation boards

ISOM8610DFGEVM — ISOM8610DFG, Single Channel Opto-emulator switch with integrated FET Evaluation Module

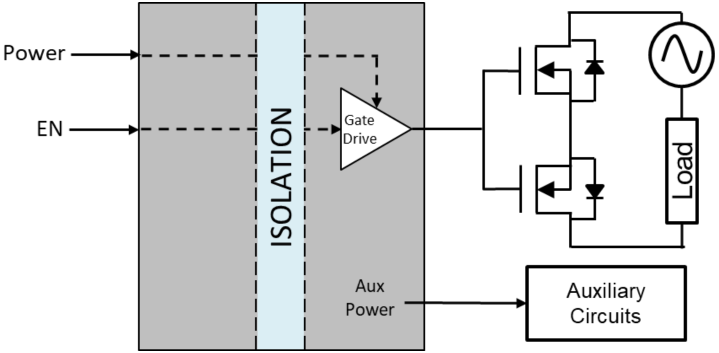
TI’s opto-emulator switches & solid state relays

Opto-emulator switches

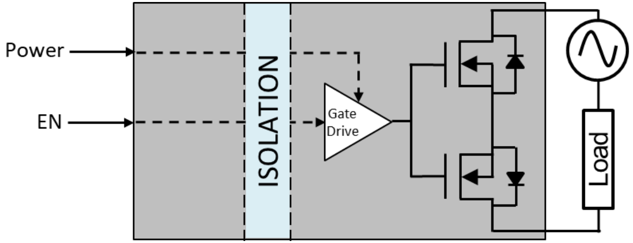

AN
CAT
e
ISOLATION
DRIVE
LOAD

Isolated switches and drivers

External FET Driver

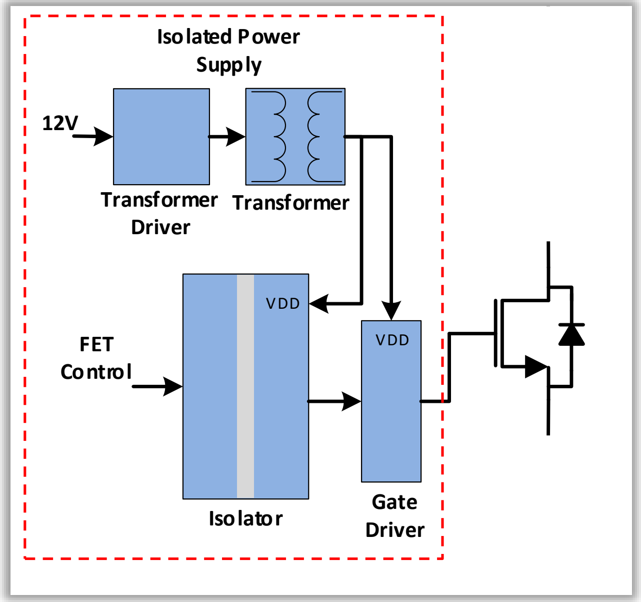

Power
EN
ISOLATION
Gate Drive
Aux Power
Auxiliary Circuits
Load

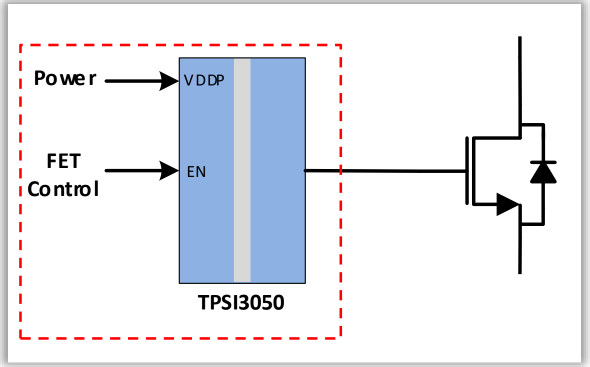
Internal FET Switch

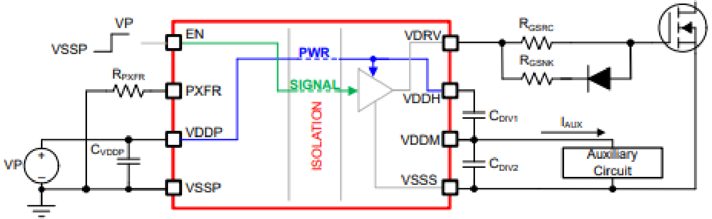

Power
EN
ISOLATION
Gate Drive
Load

Isolated switch driver integration | TPSI305x/-Q1

TPSI305x/-Q1 is an isolated switch driver with integrated power supply that provides a single chip solution for FET driving.

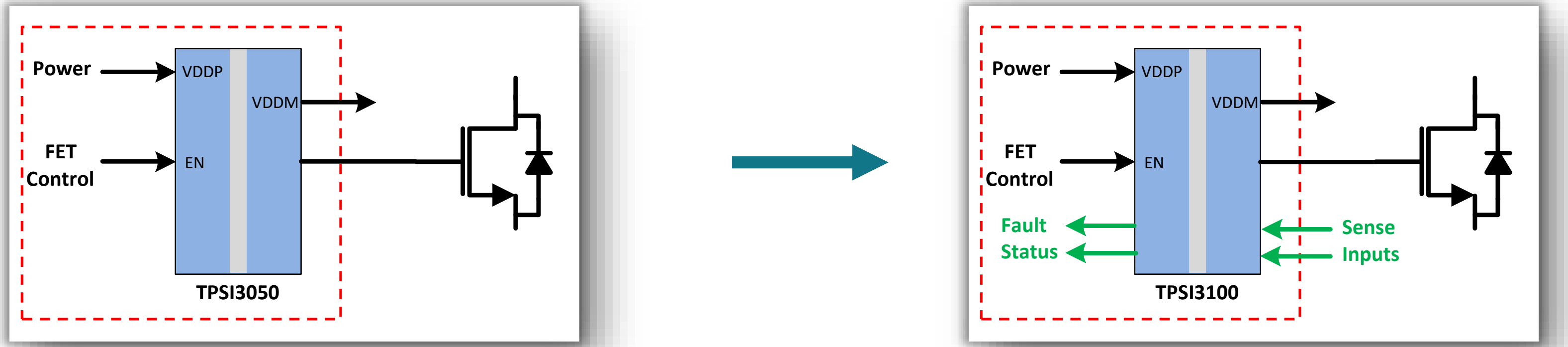

Isolated Power Supply
12V
Transformer Driver
Transformer
VDD
FET Control
VDD
Isolator
Gate Driver


Power
VDDP
FET Control
EN
TPSI3050


VP
VSSP
EN
R_{PXFR}
PXFR
VDDP
C_{VDDP}
VP
VSSP
PWR
SIGNAL
ISOLATION
VDRV
VDDH
VDDM
VSSS
R_{GSRC}
R_{GSNK}
C_{DIV1}
C_{DIV2}
I_{AUX}
Auxiliary Circuit

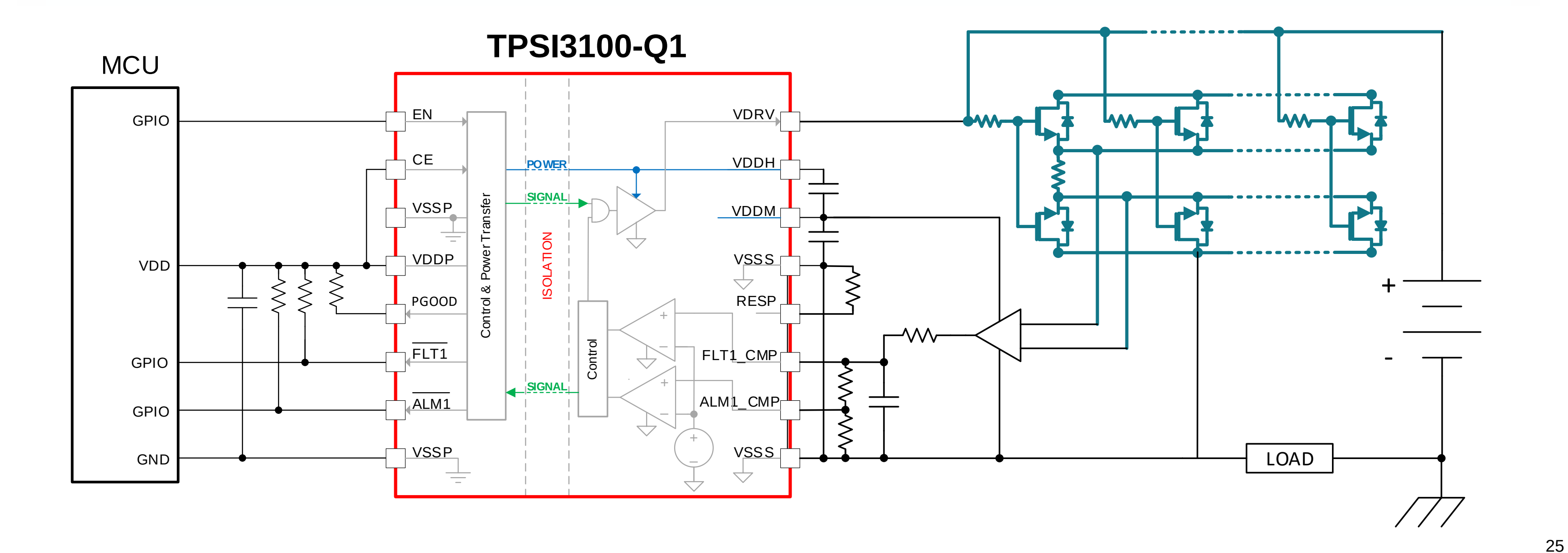
Isolated switch driver integration with feedback | TPSI310x/-Q1

- Back-channel communication offers diagnostic information to LV MCU
- No need for digital isolator


Power
VDDP
VDDM
FET Control
EN
TPSI3050
Power
VDDP
VDDM
FET Control
EN
Fault
Status
Sense
Inputs
TPSI3100

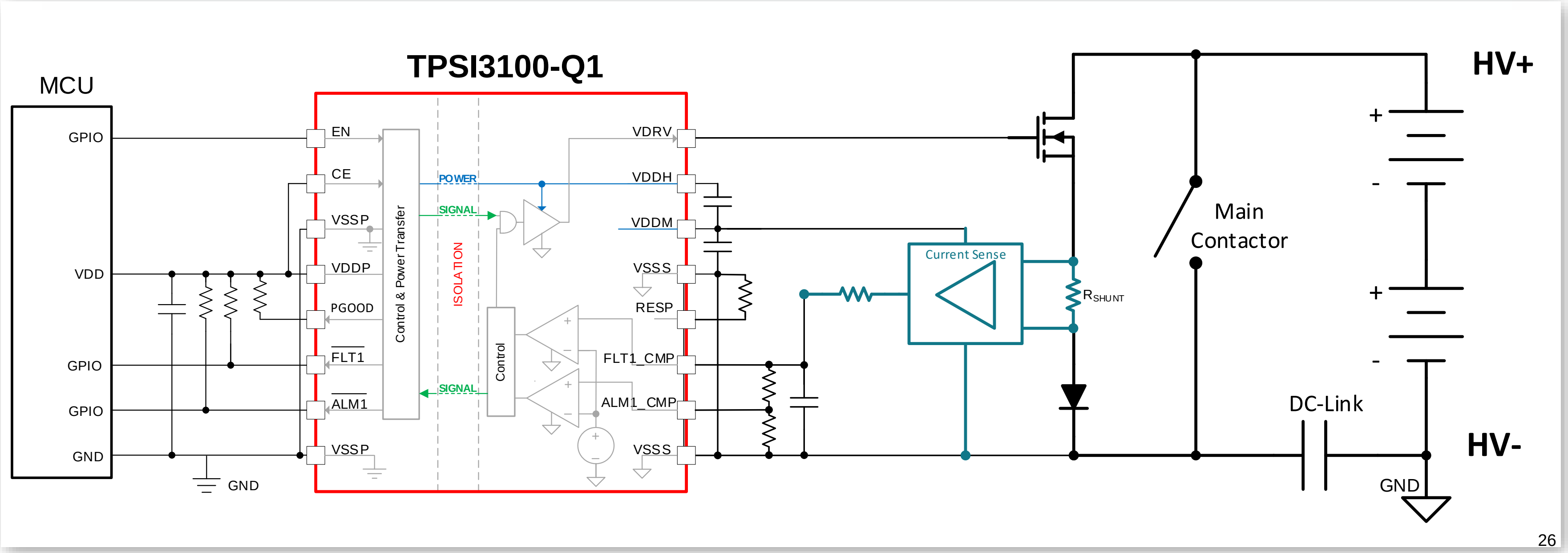
Isolated switch driver in power distribution unit

With 1.5A/3A peak (source/sink) drive capability can switch multiple FETs as in a PDU.


TPSI3100-Q1
MCU
GPIO
VDD
GPIO
GPIO
GND
EN
CE
VSSP
VDDP
PGOOD
FLT1
ALM1
VSSP
Control & Power Transfer
POWER
SIGNAL
ISOLATION
SIGNAL
Control
VDRV
VDDH
VDDM
VSSS
RESP
FLT1_CMP
ALM1_CMP
VSSS
+
-
LOAD

Passive pre-charge with overcurrent protection

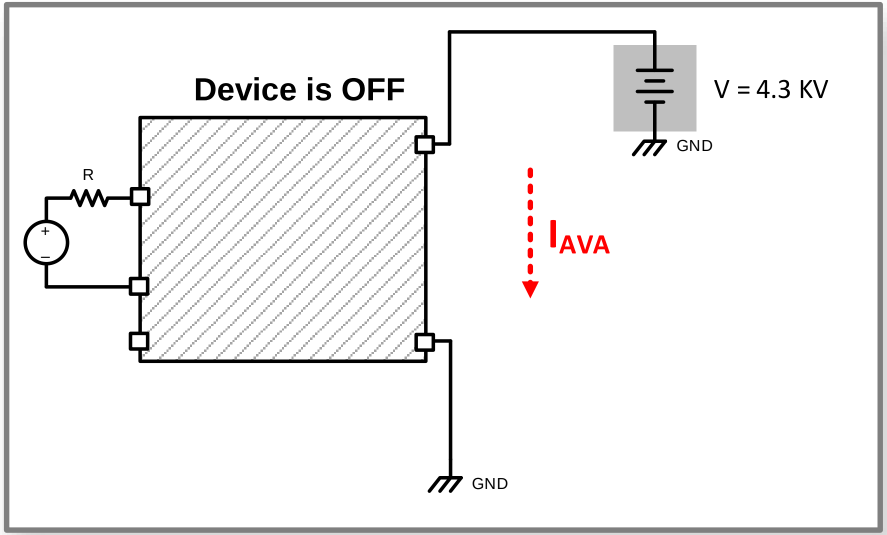
Passive pre-charge with TPSI3100-Q1 offers a low complexity and high reliability solution.



TPSI3100-Q1
MCU
GPIO
VDD
GPIO
GPIO
GND
GND
EN
CE
VSSP
VDDP
PGOOD
FLT1
ALM1
VSSP
Control & Power Transfer
POWER
SIGNAL
ISOLATION
SIGNAL
Control
VDRV
VDDH
VDDM
VSSS
RESP
FLT1_CMP
ALM1_CMP
VSSS
Current Sense
R_{SHUNT}
Main Contactor
DC-Link
HV+
HV-
GND
+
-
+
-

Insulation monitoring: High-voltage testing

Insulation monitoring devices must pass a high voltage test up to 4.3 kV in the OFF state

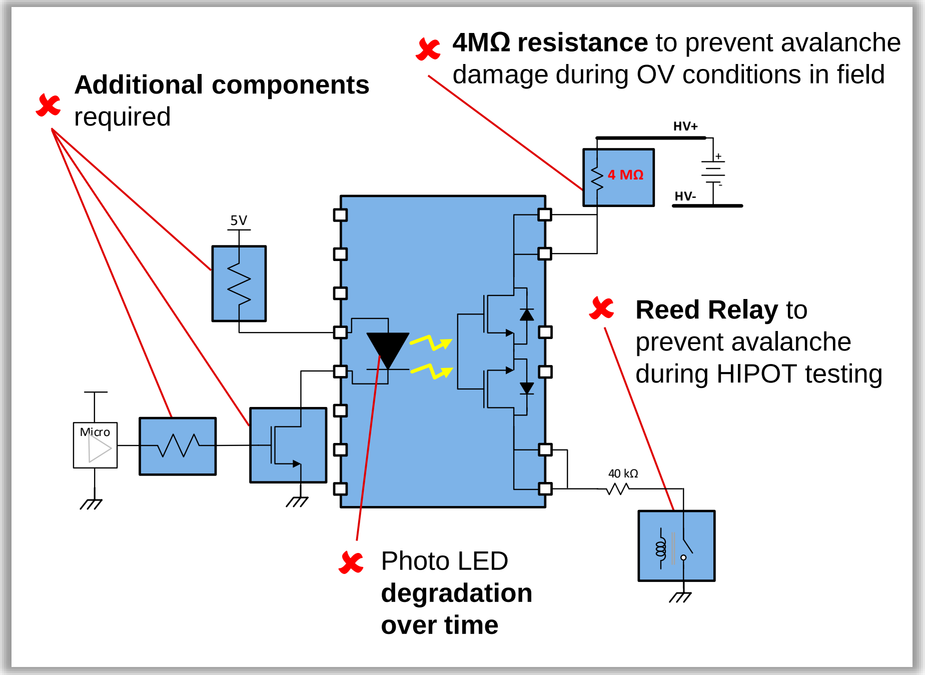


To verify reliability, a high voltage is applied to the device while OFF. This test is called a *Withstand Voltage Test* or a *High Potential Test*.

These high voltages can cause **avalanche current (I_{AVA})** to flow through, even though the device is OFF.

Isolated switch: Optimized insulation monitoring

The TPSI2140-Q1 is a solid state relay that delivers cost savings and improved measurement accuracy with its 1mA-2mA avalanche rating and robust capacitive isolation barrier.

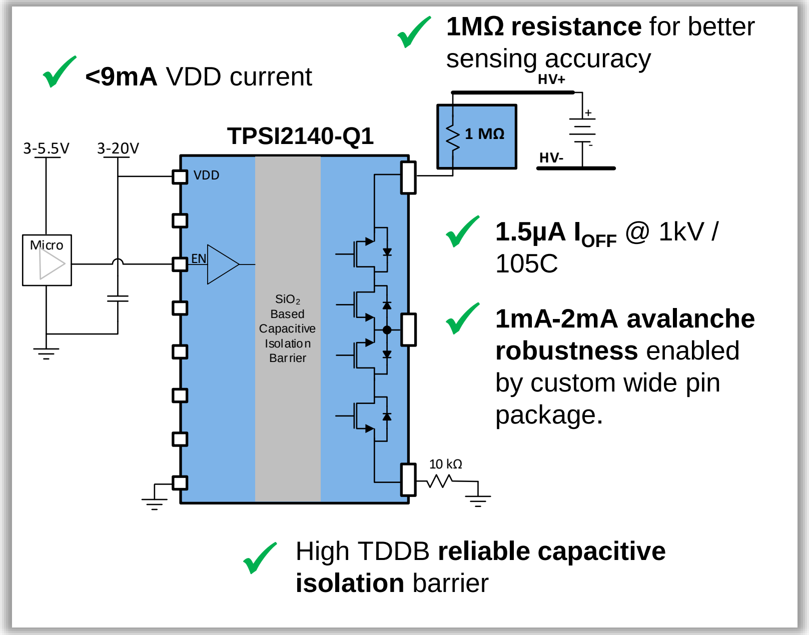

HV+
4 MΩ
+
-
HV-
5V
Micro
40 kΩ

✗ **Additional components** required

✗ **4MΩ resistance** to prevent avalanche damage during OV conditions in field

✗ **Reed Relay** to prevent avalanche during HIPOT testing

✗ Photo LED **degradation over time**


3-5.5V
3-20V
TPSI2140-Q1
VDD
EN
Micro
SiO₂ Based Capacitive Isolation Barrier
HV+
1 MΩ
+
-
HV-
10 kΩ

✓ **<9mA** VDD current

✓ **1MΩ resistance** for better sensing accuracy

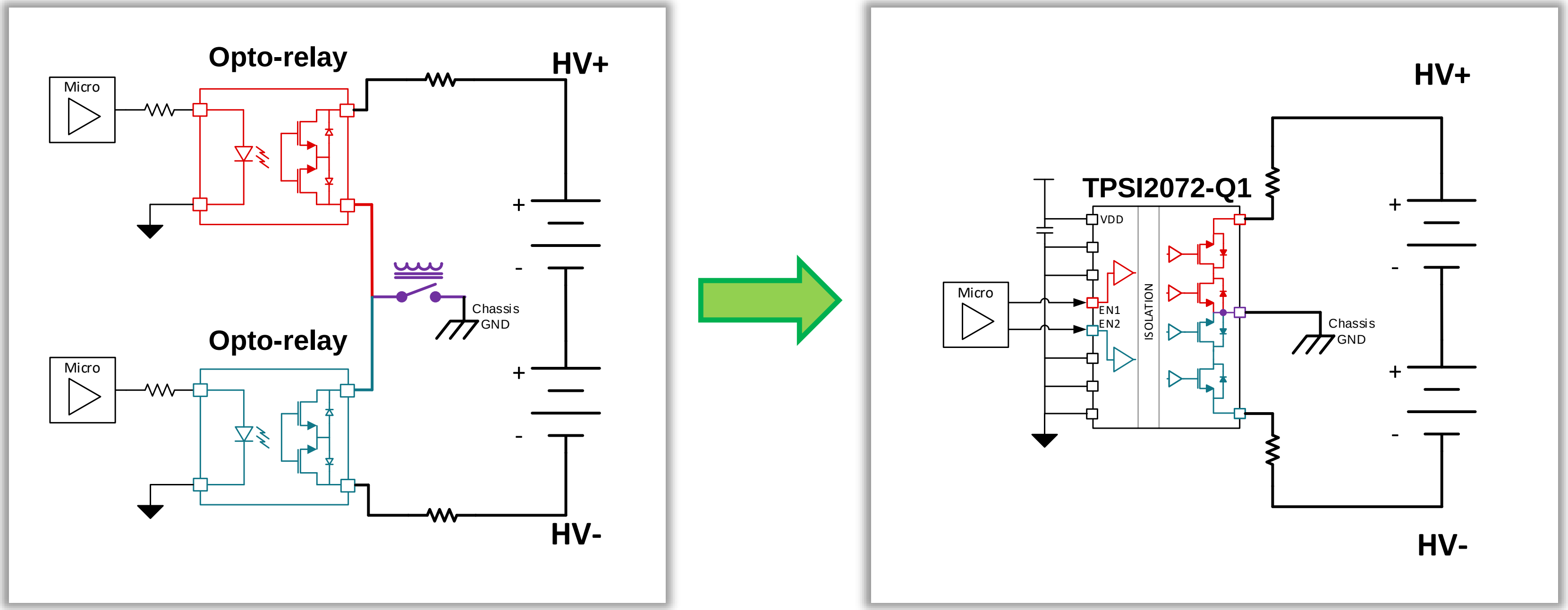
✓ **1.5µA I_{OFF}** @ 1kV / 105C

✓ **1mA-2mA avalanche robustness** enabled by custom wide pin package.

✓ High TDDB **reliable capacitive isolation** barrier

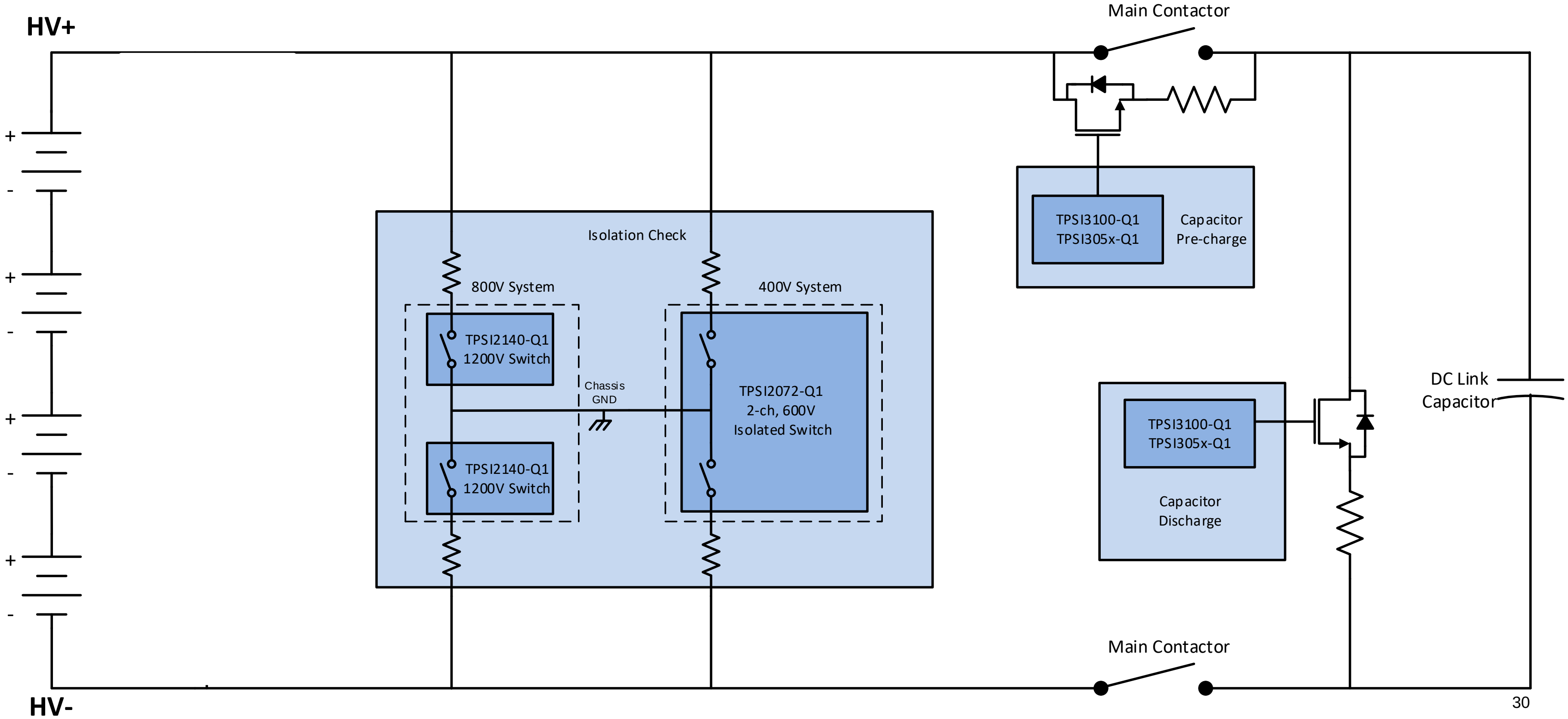
Multi-relay replacement in 400V BMS systems

- TPSI2072-Q1 integrates the function of two 600V opto-relays into a single package.
- Additionally, it can withstand up to 2mA of avalanche current, replacing external mechanical switches.



Opto-relay
Micro
HV+
+
-
Chassis GND
Opto-relay
Micro
+
-
HV-
HV+
TPSI2072-Q1
VDD
Micro
EN1
EN2
ISOLATION
Chassis GND
+
-
+
-
HV-

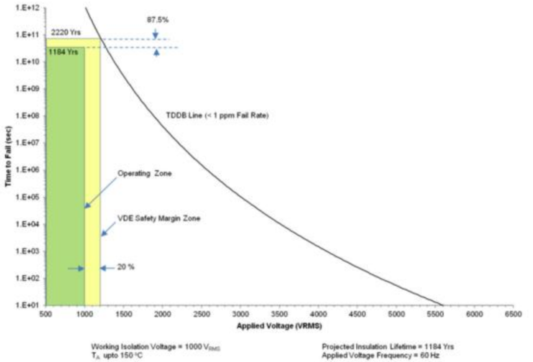
Isolated switches and switch drivers in BMS applications


Main Contactor
HV+
+
-
+
-
+
-
+
-
Capacitor Pre-charge
TPSI3100-Q1
TPSI305x-Q1
Isolation Check
800V System
400V System
TPSI2140-Q1
1200V Switch
Chassis GND
TPSI2072-Q1
2-ch, 600V
Isolated Switch
TPSI2140-Q1
1200V Switch
DC Link
Capacitor
TPSI3100-Q1
TPSI305x-Q1
Capacitor Discharge
Main Contactor
HV-

TI's SSR benefits over EMRs and photo relays

Higher system reliability & best-in-class isolation

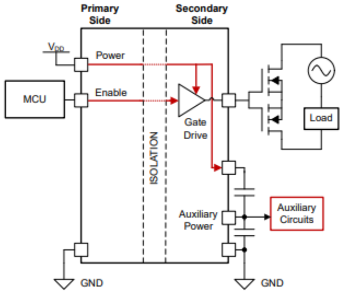
- Improves system lifetime with basic isolation up to 3.75 kV_{RMS} and reinforced isolation up to 5 kV_{RMS} by eliminating wear & tear of EMRs and LED degradation of photo relays.



TPSI3050-Q1 Insulation Lifetime Projection Data

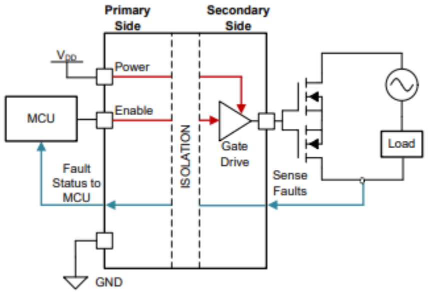
Integrated power & signal isolation

- Reduces solution size and cost by integrating the power and signal transfer over an isolation barrier in a single chip.
- Ability to provide an auxiliary power source on the secondary side allows for low-voltage systems, such as current sense amplifiers, to be powered without requiring any external power source on the secondary side of the device.


Primary Side
Secondary Side
V_{DD}
Power
MCU
Enable
Gate Drive
ISOLATION
Load
Auxiliary Power
Auxiliary Circuits
GND
GND

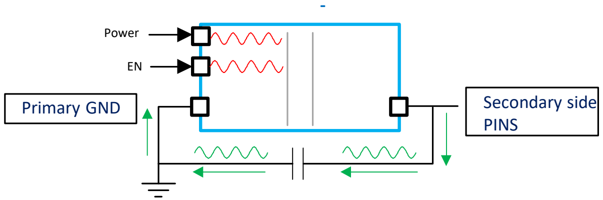
Smarter switches with back channel communication

- Ability to send signal and power from primary to secondary side, as well as send diagnostics like fault and alarm signals from secondary to primary side.
- These diagnostic features can be used to detect system faults like over current or monitor system conditions like in-rush currents.

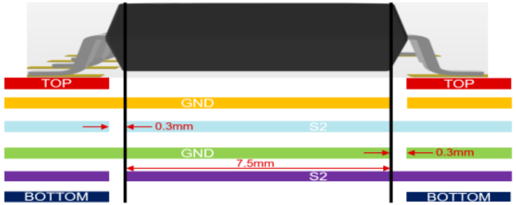

Primary Side
Secondary Side
V_{DD}
Power
MCU
Enable
ISOLATION
Gate Drive
Load
Fault Status to MCU
Sense Faults
GND

EMI optimization

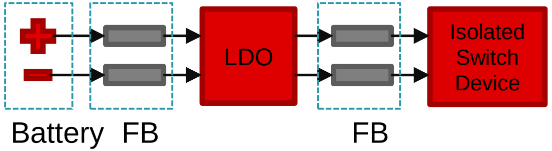
- Transferring power over a capacitive or inductive isolation barrier results in higher EMI than optical relays and EMRs
- Newer devices are designed to help minimize conducted and radiated emissions with spread spectrum techniques, symmetric drive, optimized switching frequency etc.
- Additional system level techniques (Y-cap, stitching cap, ferrite beads) can be used to improve EMI performance further to meet automotive standards (CISPR 25 Class 5) or industrial standards (CISPR 32)


Power
EN
Primary GND
Secondary side PINS

Surface mounted Y-capacitor

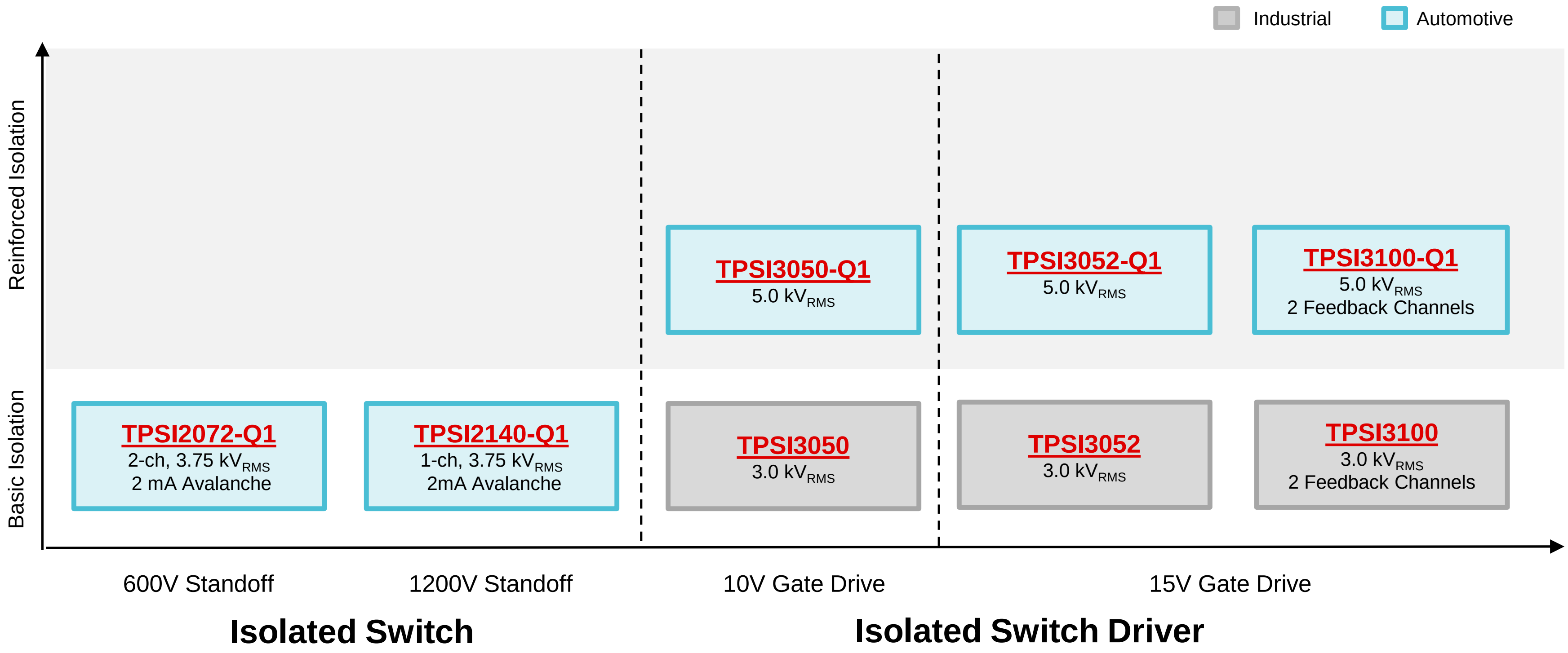

TOP
TOP
GND
0.3mm
S2
GND
0.3mm
7.5mm
S2
BOTTOM
BOTTOM

Integrated PCB stitching capacitor


LDO
Isolated Switch Device
Battery
FB
FB

Ferrite beads

Getting started with isolated switches and drivers



▨ Industrial 🟦 Automotive

Reinforced Isolation

TPSI3050-Q1
5.0 kV_{RMS}

TPSI3052-Q1
5.0 kV_{RMS}

TPSI3100-Q1
5.0 kV_{RMS}
2 Feedback Channels

Basic Isolation

TPSI2072-Q1
2-ch, 3.75 kV_{RMS}
2 mA Avalanche

TPSI2140-Q1
1-ch, 3.75 kV_{RMS}
2mA Avalanche

TPSI3050
3.0 kV_{RMS}

TPSI3052
3.0 kV_{RMS}

TPSI3100
3.0 kV_{RMS}
2 Feedback Channels

600V Standoff

1200V Standoff

10V Gate Drive

15V Gate Drive

Isolated Switch

Isolated Switch Driver

Getting started with isolated switches and drivers

Technical Collateral

- Basics of Solid-State Relays
- How solid-state relays simplify insulation monitoring designs in high-voltage applications
- How to Achieve Higher-reliability Isolation and a Smaller Solution Size with Solid-state Relays
- Why Pre-Charge Circuits are Necessary in High-Voltage Systems
- How to Design High-voltage Systems with Higher Reliability While Reducing Solution Size and Cost
- Designing Safer, Smarter and More Connected Battery Management Systems
- When to use SSR or Isolated Gate Driver

Reference Designs

- TIDA-050063: High-voltage solid-state relay active precharge reference design
- TIDA-050059: Overcurrent and overtemperature protection for solid-state relays reference design
- TIDA-050058: Zero-cross switching for solid-state relays reference design
- TIDA-010232: AFE for insulation monitoring in high-voltage EV charging and solar energy reference design
- TIDA-01513:Automotive High-Voltage and Isolation Leakage Measurements Reference Design

Evaluation boards

- TPSI3050Q1EVM — TPSI3050-Q1 evaluation module for automotive load switch driver with reinforced isolation
- TPSI3052Q1EVM — TPSI3052-Q1 evaluation module with reinforced isolation and 15-V gate drive
- TPSI31XXQ1EVM — TPSI31xx-Q1 evaluation module
- TPSI2140Q1EVM — TPSI2140-Q1 evaluation module for 1200-V 50-mA isolated switch with 2-mA avalanche rating
- TPSI2072Q1EVM — TPSI2072-Q1 evaluation module for two-channel 600-V isolated switch

Calculation Tools

- ACTIVE-PRECHARGE-CALC — Active precharge reference design (TIDA-050063) calculator tool
- SLVRBI9 — TPSI3050-Q1, TPSI3052-Q1, TPSI3050, TPSI3052 Design Calculator

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