Comparing Digital Signal Isolation Techniques

Tim Lafferty

Thanks to Ashish Gokhale. For help in putting this together.

Texas Instruments

Topics

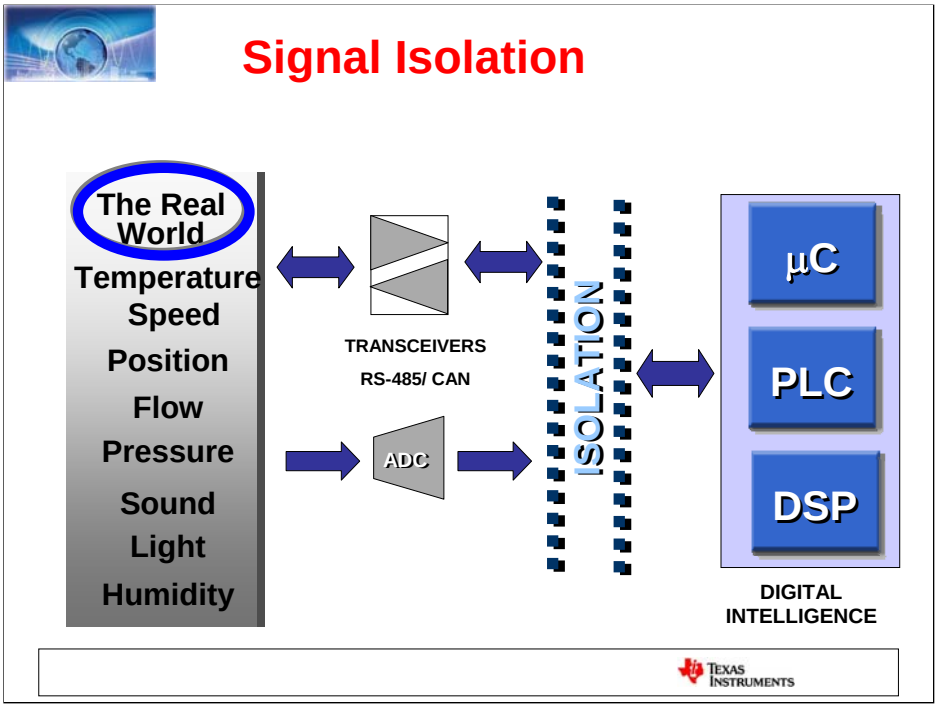
What is Isolation – General information

Some Applications Using Isolation

Digital Isolation Techniques and Comparison

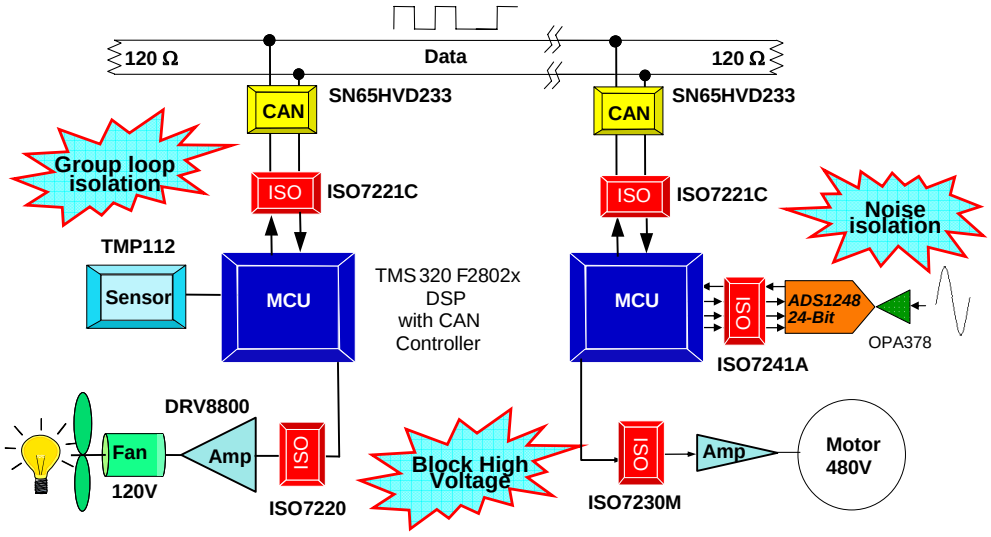
Isolation Terminology & Standards

TI Isolation Products Roadmap (for reference)



In most applications, Isolation separates the “Real World” from sensitive controllers, may it be Microcontrollers, Programmable Logic Controllers, or Digital Signal Processors.

Why Isolate??


120 Ω
Data
120 Ω
CAN
SN65HVD233
CAN
SN65HVD233
Group loop isolation
ISO
ISO7221C
ISO
ISO7221C
Noise isolation
TMP112
Sensor
MCU
TMS 320 F2802x
DSP
with CAN
Controller
MCU
ISO
ADS1248
24-Bit
OPA378
ISO7241A
DRV8800
Fan
120V
Amp
ISO
ISO7220
Block High Voltage
ISO
Amp
Motor
480V
ISO7230M

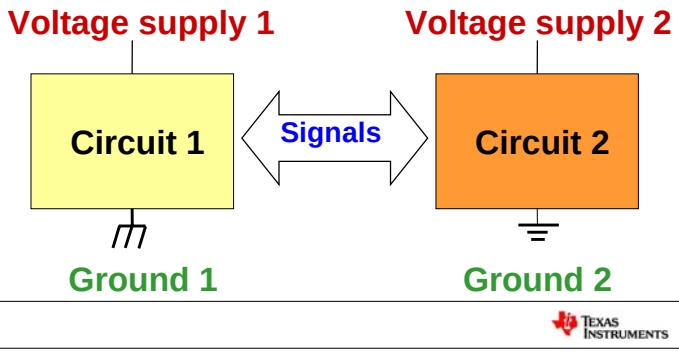
Why Isolation is required

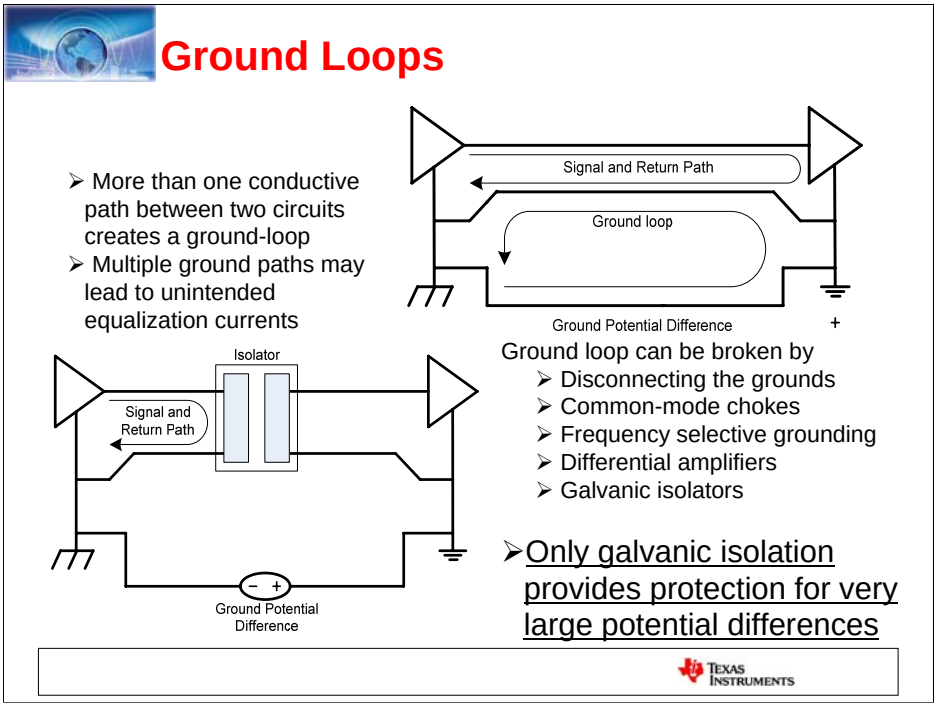
Galvanic isolation:

Although Circuit 1 and Circuit 2 exchange signals, no current (electrons) pass from Circuit 1 to Circuit 2.

Why is isolation required in electrical systems:

- Break ground loops
- Reduce common mode noise
- Safety from high voltages





For low speed interfaces, often it is attempted to provide a single point ground. As the transmission rate increases so does the impedance of the return line, creating a frequency dependent ground potential difference. In order to lower the impedance multiple grounds are used. This however creates ground loops. There are multitudinous options to break these loops:

Disconnecting the grounds, which however forces equalizing currents onto the signal lines or requires isolated power-supplies

Common-mode chokes

Frequency selective grounding (AC-coupling)

Differential amplifiers with wide common mode voltage range

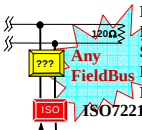
Galvanic isolators

Except for galvanic isolation, all solutions are only suitable up to a couple of volts potential difference.

Isolation is used to:

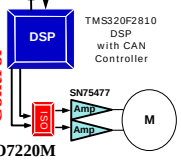
BLOCK high Voltage
ISOLATE Grounds
CONTROL Noise

Home Automation



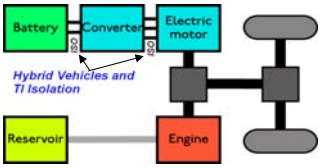
Fieldbus – Modbus, Profibus, Device Net Data Buses, CAN, Smart Distributed Systems, RS485, CC-Link, CANopen DeviceNet, RS232, RS422, etc

ISO7221C



ISO7220M

And Battery backups



- Industrial Controls
  Servo, Sensors, etc…
- Medical
- Motor Control

High Performance Analog
Data Acquisition
Audio

gramable Logic Controlers

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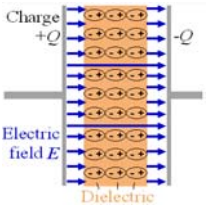
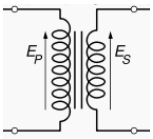
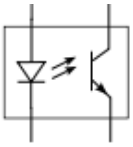
Key methods of Isolation



Ewald Georg von Kleist invented the first recorded capacitor 1745



Michael Faraday demonstrated the transformer principle in 1831



Zarlink Invented the opto-coupler (1968)

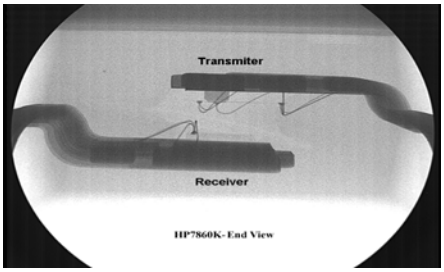
Others…

Sound, RF, light, Mechanical, etc

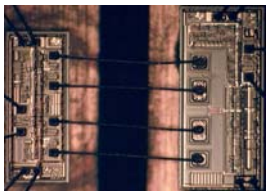
Dielectric Materials Used for Isolation

- SiO2: ISO72x Typical BV is 1000 Vpeak/um
  - Inorganic
  - Highly Stable (over temperature, moisture, time), high quality
  - Used extensively and for long time as dielectric in semiconductor (low defect rates)
  - Deposited in a controlled semiconductor process
- Polyimide: ADI Transformer core Typical BV is 250 Vpeak/um
  - Organic
  - Retains moisture – affects lifetime especially at high voltages
  - Used in semiconductor mainly for stress relief & now as isolation barrier
- Epoxy: Opto-couplers: Typical BV is 50 Vpeak/um
  - Uses filler materials
  - Leaky (higher partial discharge)
  - Applied at packaging as mold compound
  - Voids and anomalies are common

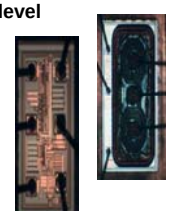
Internal Construction



Optical: Isolation functionality added at package level

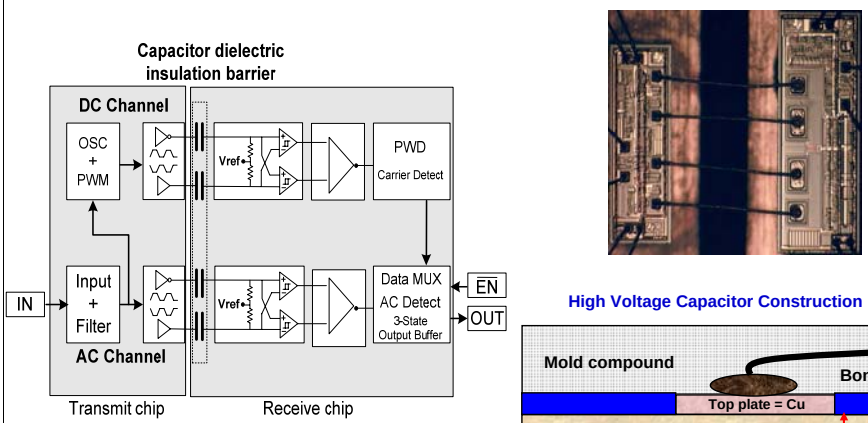


ISO72x: Integrated at process level

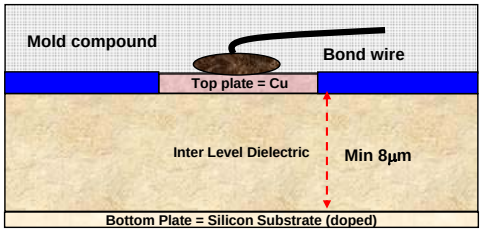


ADuM1100: Integrated at process level

Integrated Capacitor Technology



High Voltage Capacitor Construction



This slide demonstrates the process technology advantage of TI's on-chip capacitive technology.

Shows block diagram of the basic circuit and a photo of the actual product. The cross-section of the capacitor is shown to show how we implement capacitive technology. Oxide is used extensively in semiconductor products and has proven reliability and manufacturability. Since oxide is a standard semiconductor process, adding high-voltage capacitors requires only a slight change to the baseline process.

If asked, the process node is 0.8 micron BiCMOS. The technology is patent pending.

Talk about the inherent advantages of capacitors. (see below for comparison)

By placing them on-chip and using a semiconductor-grade silicon oxide dielectric, it's all part of the manufacturing flow, which increases reliability.

Comparing Isolation solutions:

ISO72x: Capacitive

- **High immunity to electro-magnetic noise**
- **High reliability & lifetime: Dielectric is standard semiconductor grade silicon dioxide**
- **High performance: data rate, prop delays, PWD**
- **Lower power over opto**

Optical

- **High immunity to electro-magnetic noise**
- **Drive current performance degradation over lifetime (CTR)**
- **No High Speed switching, economical solution for low speed**
- **Power hungry, low volt operation with degraded performance**

Inductive/Transformer/GMR

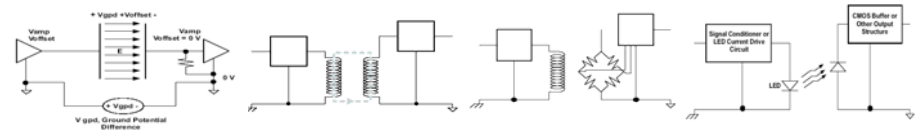
- **Magnetic coupling – inherently susceptible to magnetic fields**
- **High performance available, no ESD protection (ADuM1100)**
- **Data integrity issues (IL7xx; HCPL09xx)**
- **Low power over opto**

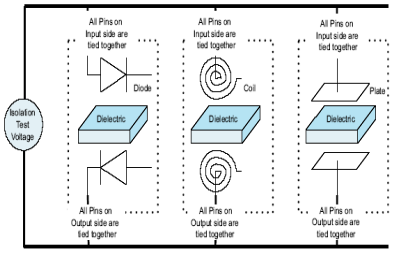
Isolation Techniques (It's all capacitive)

Source: TI App note SLLA198 www.ti.com/iso721

(Click on above link for web info)

Capacitive Inductive GMR Optical



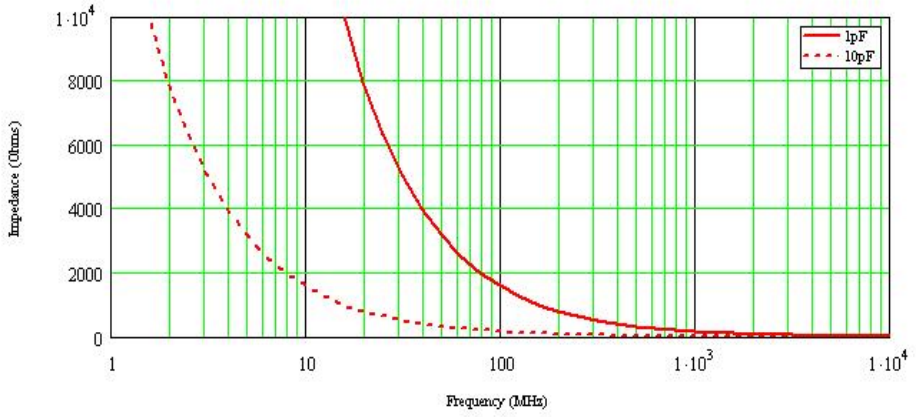


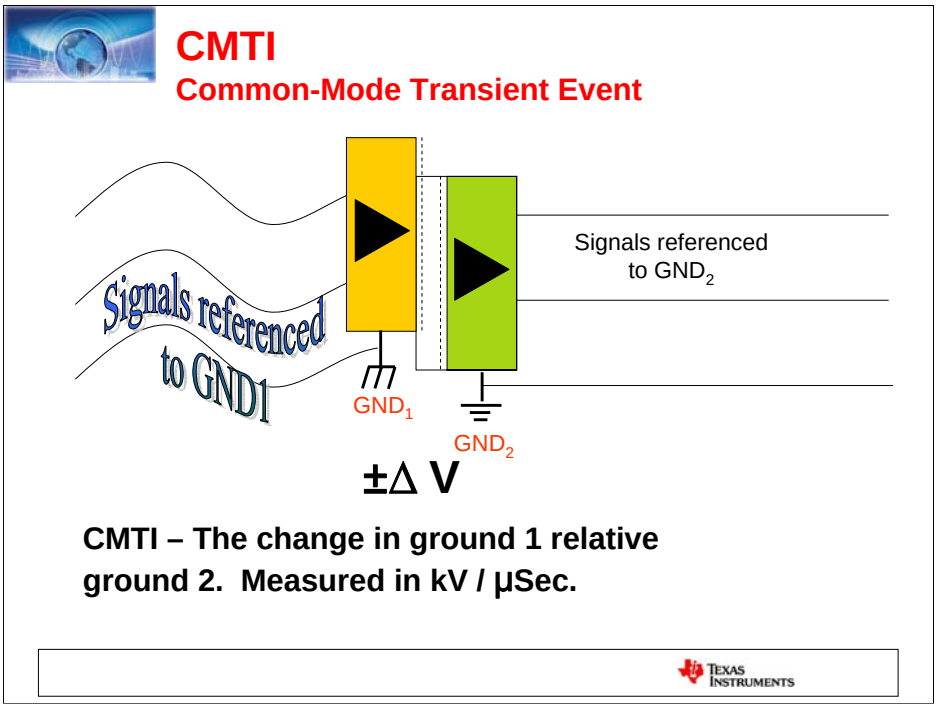
	Capacitive ISO72X	Inductive ADuM1xx	GMR IL7x	Optical HCPL-07xx
C_{IO}	1 pF	1 pF	1.1 pF	0.6 pF
Isolation Dielectric	SiO	Polyimide	Polyimide	Mold compound

- All isolated couplers are capacitive coupled (active or parasitic)
- C_{IO} for any type is comparable

Capacitance across the barrier

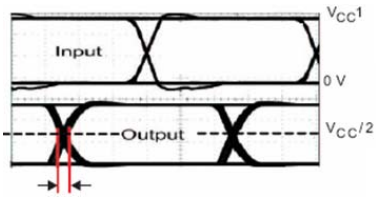
$n := 0, 1 .. 40$ $f(n) := 10^{10}$ $\omega(n) := 2 \cdot \pi \cdot f(n)$ Frequency Data Points for Plotting



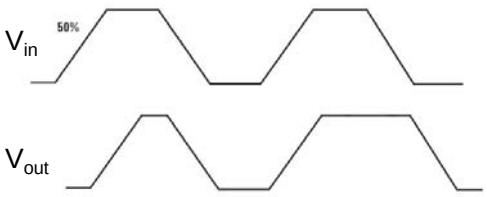


This slide is a pictorial of the benefits of isolation. The supply rails of Vcc1 float with respect to those of Vcc2. The offset would impact the transmission, if the receiver is unable to reject the common mode noise/frequency. Galvanic isolation makes the input, which is referenced to GND1, independent from GND2, which significantly enhances the common mode rejection.

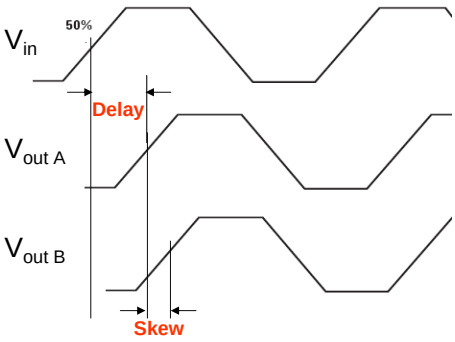
Specs to Know

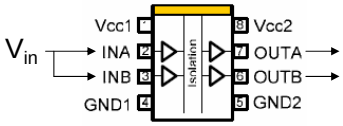


Jitter



Pulse Width Distortion





Spec Compare

- *Low Pulse Distortion, Skew - 1ns*
- *Low Skew 1ns*
- *25Mbps @ -40to125°C*
- *Highest ESD - 4kV ESD*
- *1E6 Better Noise Immunity*
- *Long LIFE SPAN >25 Years*

Vendor	Part Number	Data Rate	Pulse Width Distortion	Skew Chan to Chan	Skew Part to Part	Prop Delay	CMTI	ESD on All Pins	Over Volt @ time	Max Working	Temperature
TI	ISO722xM	150Mbps	1ns	1ns	3ns	16ns	25	±4kV	4kV@60sec	560V	-40to125C
Magnetic		90Mbps	2ns	2ns	10ns	32ns	25	??	4kV@10sec	560V	-40to105C
Hi end opto		25Mbps	6ns	20ns	20ns	40ns	10	??	4kV@60sec	560V	-40to85C
Mid opto		??Mbps	35ns	40ns	40ns	100ns	5	??	4kV@1sec	260V	-40to100C
Features Benefits		Speed	Accuracy	Accuracy	Accuracy	Accuracy	Reliability	Reliability	Reliability	Operating Range	Operating Range

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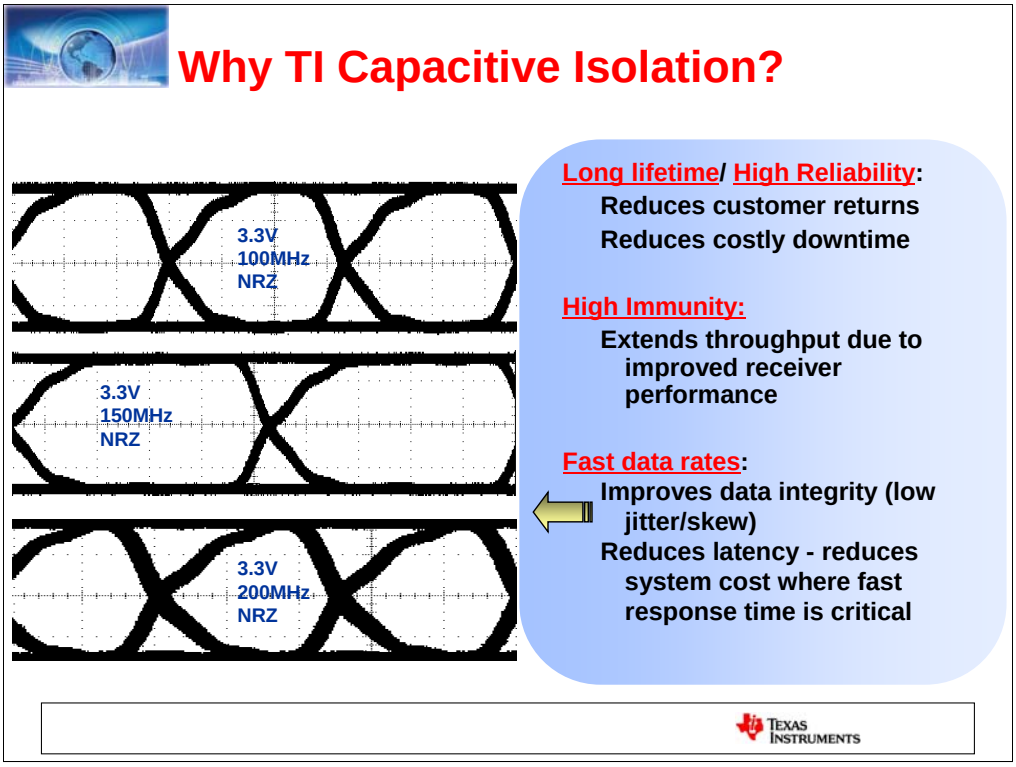


Emphasize sub-bullets, which are the benefits (underlined).

Eye diagram shows the clean eye pattern obtained using ISO721 at fast data rate of 100 Mbps.

Example of end user benefit: end customer may be able to buy a lower-current motor because of the fast response time.

ISO721 enables fast response time, which is important even for applications that don't require the high data rate

Voltage transient immunity provides immunity to high voltage spikes, protecting data from corruption.

"Extends throughput" means that data is transmitted faster and without noise – receiver always sees true data

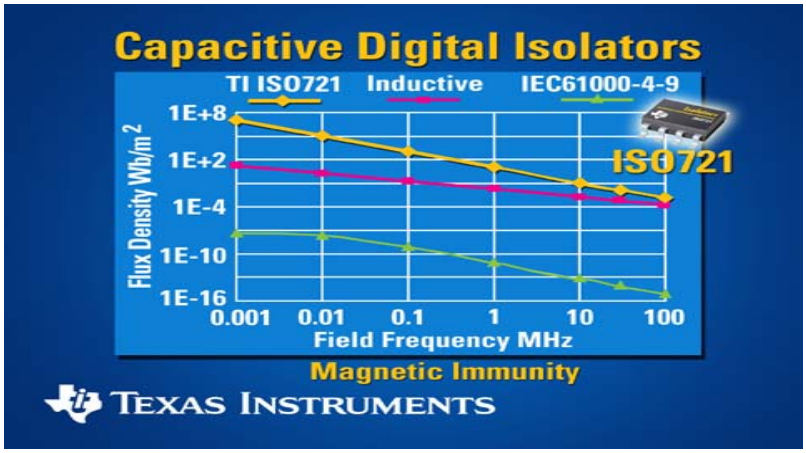
Competitive Comparison: Magnetic Immunity

IEC 61000-4-8

- 1KHz Field Frequency
- 10^6 x higher Immunity than ADI

Source: TI App note SLLA181A **www.ti.com/iso721**

(Click on above link for web info)

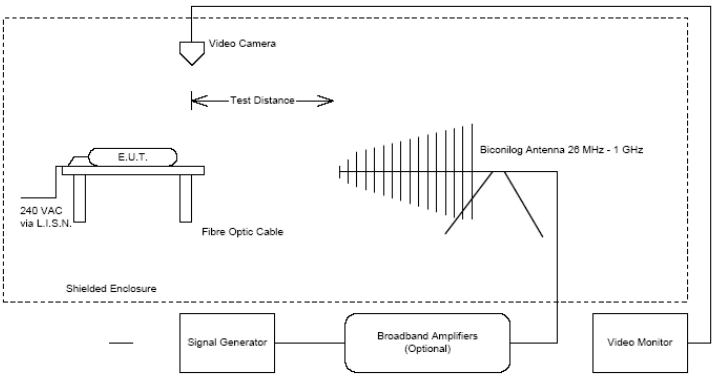


E-field immunity Test Report

Nemko

EN55024
REPORT NO.8289EEU1Rev1
EQUIPMENT: 7221C, 1201CRZ

Test Configuration - Radiated Electromagnetic Immunity (Shielded Room)



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E-field immunity Test Report

Nemko

EN55024
REPORT NO.8289EEU1Rev1
EQUIPMENT: 7221C, 1201CRZ

Abstract: Immunities: **ISO7221C**
EUT X7221C

Name of Test	Basic Standard	Test Specification	Results
Radiated Electro-magnetic Field	IEC61000-4-3: 1995	80MHz to 1000 MHz 80% AM @ 1 kHz Level X 100 V/M	Complies
Radiated Electro-magnetic Field RS103	MIL-STD 461E RS103	2MHz to 30 MHz 50% AM @ 1 kHz 200 V/M	Complies
Radiated Electro-magnetic Field RS103	MIL-STD 461E RS103	30MHz to 1000 MHz 50% AM @ 1 kHz 100 V/M	Complies

Abstract: Immunities: **Magnetic**
EUT 1201CRZ

Name of Test	Basic Standard	Test Specification	Results
Radiated Electro-magnetic Field	IEC61000-4-3: 1995	80MHz to 1000 MHz 80% AM @ 1 kHz Level X 100 V/M	Fails
Radiated Electro-magnetic Field RS103	MIL-STD 461E RS103	2MHz to 30 MHz 50% AM @ 1 kHz 200 V/M	Complies
Radiated Electro-magnetic Field RS103	MIL-STD 461E RS103	30MHz to 1000 MHz 50% AM @ 1 kHz 100 V/M	Fails

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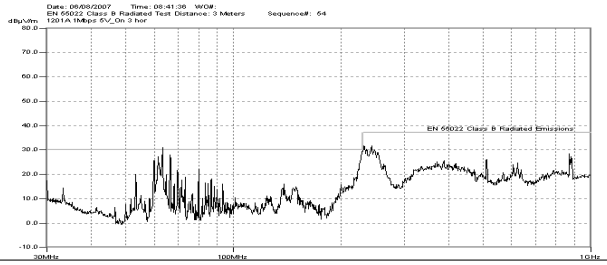
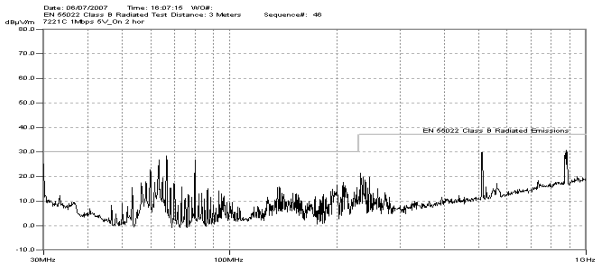
EN55022 Class B Radiations Testing

1Mbps: Comparison of Radiated Noise Spectrum – Antenna Horizontal

Magnetic: 1Mbps operation @ 5V Vcc



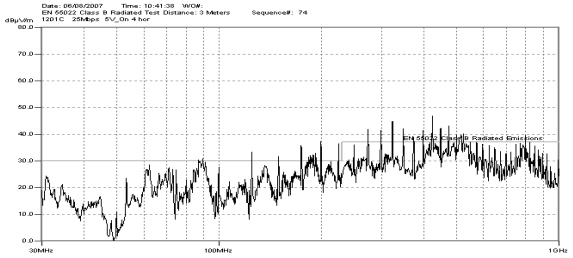
ISO7221: 1Mbps operation @ 5V Vcc



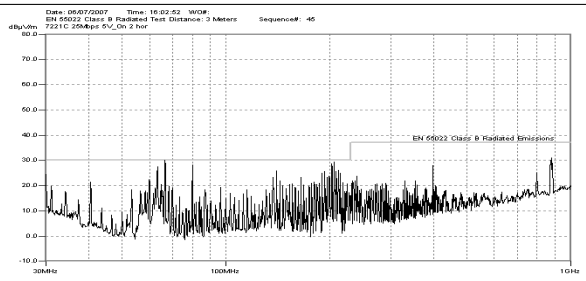
EN55022 Class B Radiations Testing

25Mbps: Comparison of Radiated Noise Spectrum – Antenna Horizontal

Magnetic: 25Mbps operation @ 5V Vcc



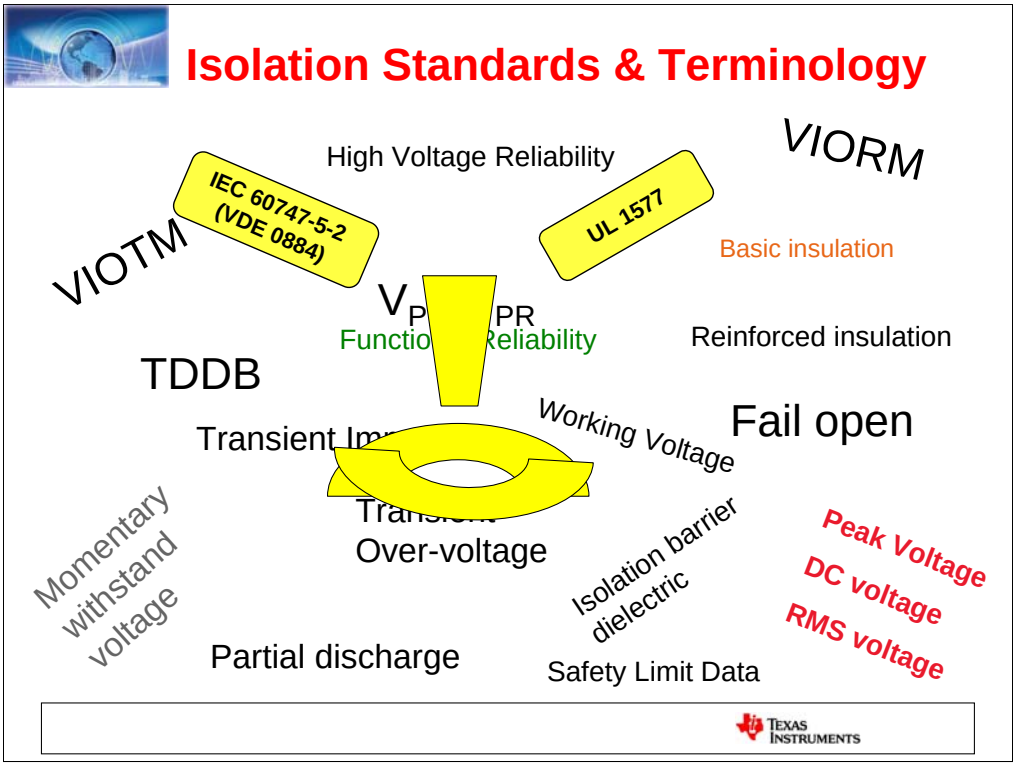
ISO7221: 25Mbps operation @ 5V Vcc



OptoCoupler warning from Data Sheet

- **Degradation -** In general, the emission of the LED used in photocouplers will degrade over time.
- In the case of long term operation, please take the general LED degradation (50% degradation over 5 years) into the design consideration.
- Please decide the input current which become 2 times of MAX. IFHL.

Isolation Standards & Terminology



Isolation Standards - Most common

- IEC60747-5-2 aka VDE0884
- UL1577
- CSA Component Acceptance 5A
- ISO72xx certified with all three

Fail open

- UL defines fail open as a condition where device functionality may be compromised but the isolation is intact. Limited to functional fails only.
- By definition, dielectric does not fail open
- Optos fail functional before dielectric degradation, however, when isolation ratings exceeded, optos fail short, so does any other coupler or insulator

Creepage and 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 (line of sight).

Package/ designation	Creepage mm	Clearance mm
Narrow body SOIC/ D	4.3	4.8
Gull wing / DUB	6.8	6.1
Wide body SOIC/ DW	8.1	8.34

TI Package Specs

Pollution Degree

(Environmental Conditions)

- **Pollution degree 1.** No pollution or only dry, nonconductive pollution occurs. The pollution has no influence (example: sealed or potted products).
- **Pollution degree 2.** Normally only nonconductive pollution occurs. Occasionally a temporary conductivity caused by condensation must be expected (example: product used in typical office environment).
- **Pollution degree 3.** Conductive pollution occurs, or dry, nonconductive pollution occurs that becomes conductive due to expected condensation (example: products used in heavy industrial environments that are typically exposed to pollution such as dust).
- **Pollution degree 4.** Pollution generates persistent conductivity caused, for instance, by conductive dust or by rain or snow.

Isolation Standards - Most common

- All standards perform isolation testing
- Electrical testing only with regard to effect on isolation ratings
  - Input safety current
  - Thermal ratings
- Some variation of environmental testing, creepage & clearance measurements, material classifications for pollution degree etc
  - Temperature cycle/shock
  - Autoclave
  - High temperature bake
- Followed by isolation testing
  - IEC/VDE: 4000V for 60 sec, 1050V partial discharge
  - UL: 3500V for 60 sec
  - CSA: 4200V for 60 sec

TI Reliability Tests – for reference

Test	Failure Modes Checked
SSLT/ HTOL	Potentially finds failures related to mobile ions, EM, GOI, particles, design or mask errors. **MTTF, FIT's are based on SSLT**
HAST (Biased)	Primarily identifies failures related to electrolytic corrosion.
Autoclave	Package related: Primarily identifies failures related to galvanic corrosion or leakage.
Thermal Shock	Primarily identifies failures related to mechanical stress from different Thermal Characteristics of materials. Common failure modes include ball bond and stitch bond lifts or fractures, die surface shear stress damage, die cracks and BOAC-related stress failures. BCB delamination, cracks
Temperature Cycle	Same as above
High Temperature Storage	Primarily identifies failures related to bond inter-metallic growth, stress voiding and data retention.
Moisture sensitivity Level	Evaluates package reliability after high-temp reflow at board assembly. Primary failure modes similar to temp cycle and thermal shock, plus delamination.
TDDB/ High Voltage Lifetime	Dielectric degradation due to temperature, electric field

ISO72x Reliability Results

Test Type	Conditions/Duration		Sample Size/ Fail Results Lot#1	Lot#2	Lot#3
**Life Test,	150C	1000 Hours	116/0	116/0	112/0
**HAST	130C/85%RH,	96 Hours	77/0	77/0	77/0
**Autoclave,	121C/15 PSIG	240 Hours	77/0	77/0	76/0
**Thermal Shock,	-65/150C	1000 Cycles	77/0	77/0	77/0
**Temp Cycle,	-65/+150C	1000 Cycles	75/0	77/0	77/0
**High-Temp Storage, 170C		420 hours	77/0	77/0	77/0

**** Preconditioning sequence:**
Parametric test per datasheet
High Voltage Test: >/= 3000Vrms/1sec plus 1500Vrms Partial discharge (5pC) for 1 sec
Parametric test per datasheet
Moisture Sensitivity Level 1-260C Hybrid Interval Reflow

Post Test:
Parametric test per datasheet
R_{IO}: 500Vrms (>1E9 ohms)
Parametric test per datasheet

Voltage ratings

VIORM (per VDE)

- Working voltage
- Continuous rating
- Tested with 1.875*Rated Voltage: 100% production

VIOTM (per VDE)

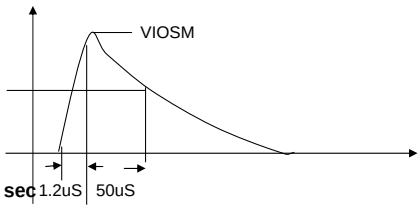
- Max voltage, short duration
- Tested with rated voltage: 100% production

VIOSM (per VDE)

- Max surge rating per IEC60664-1

UL ratings

- Rated at 60 sec duration (no fail)
- 100% production tested at 120% of UL rating for 1 sec



Basic insulation (per UL)

- 2500Vrms rating - 4242V high voltage production test

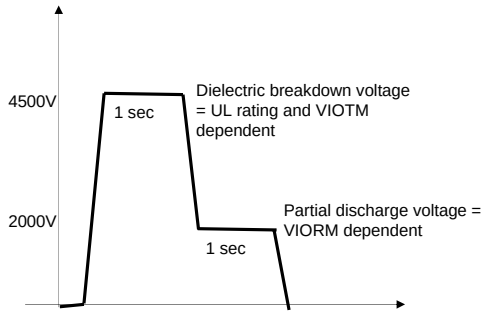
Reinforced insulation (per UL)

- 3750Vrms rating – 6363V high voltage production test

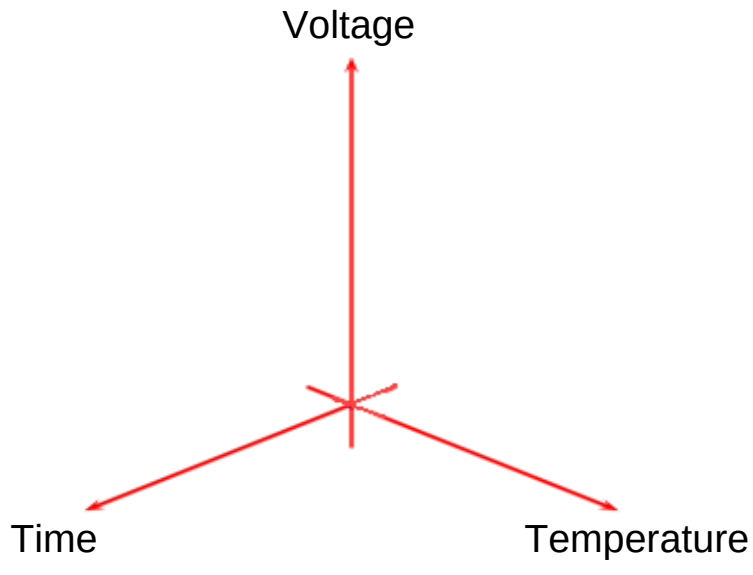
Production testing – ISO72xx

High Voltage test: Breakdown test, at least 4242V needed for 1 sec per UL and 4000V for 1 sec per VDE

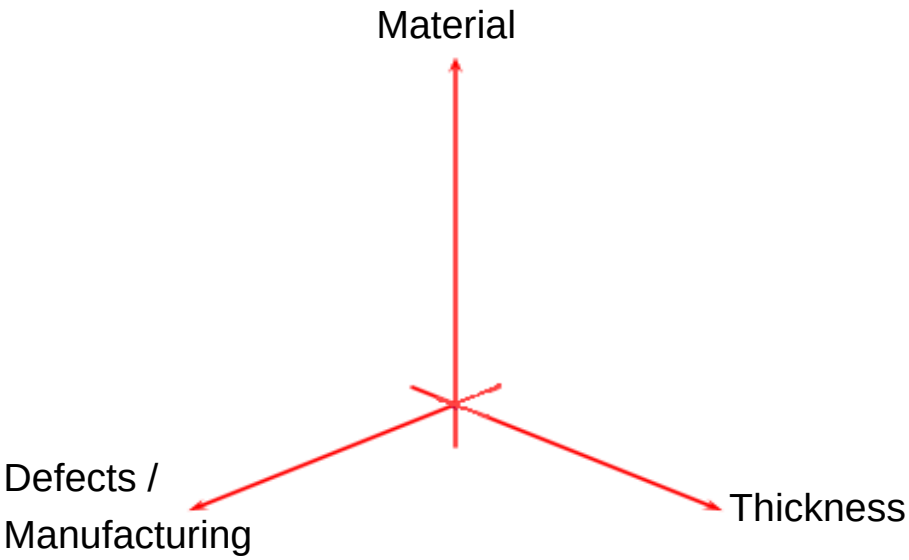
PD test: 5pC limit, VIORM*1.875 = 1050V minimum, per IEC/VDE



Life of an Insulator



Life of an Insulator



Dielectric Materials Used for Isolation

- SiO2: ISO72x Typical BV is 1000 Vpeak/um
  - Inorganic
  - Highly Stable (over temperature, moisture, time), high quality
  - Used extensively and for long time as dielectric in semiconductor (low defect rates)
  - Deposited in a controlled semiconductor process
- Polyimide: ADI Transformer core Typical BV is 250 Vpeak/um
  - Organic
  - Retains moisture – affects lifetime especially at high voltages
  - Used in semiconductor mainly for stress relief & now as isolation barrier
- Epoxy: Opto-couplers: Typical BV is 50 Vpeak/um
  - Uses filler materials
  - Leaky (higher partial discharge)
  - Applied at packaging as mold compound
  - Voids and anomalies are common

Partial discharge

- PD – Is a localized ionization that occurs around *anomalies* in an insulator. Such as a voids in solid insulation (epoxy, polymer).
- If a PD test passes it is a Non-destructive test.
- Predictive test used for indicating dielectric quality and a predictor of future performance.
- Used by IEC/VDE
- PD is measured in pC (5 pC is limit). (5×10^{-12} Coulombs)
- 100% production test required per VDE/IEC

High Voltage
100% Production Test

- Test platform: HT9464
- Pass/fail test only, fail bins:
  - Leakage fail, also called high voltage (HV) fails
    - Fail mode is particles/defects/trace contamination
  - Partial discharge (PD) fails
    - Indicates systematic or bulk dielectric problem
    - Used for predicting future/field performance of dielectric

HT9464 production setup sample picture

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High Voltage Lifetime – TDDB (time dependent dielectric breakdown)

$\ln(TF) \propto \frac{\Delta H_o}{k_b T} - \gamma Eox$

$\ln(TF) \propto -MVs$

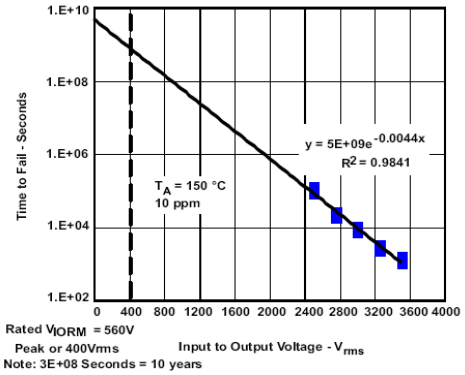
γ is the field acceleration parameter.

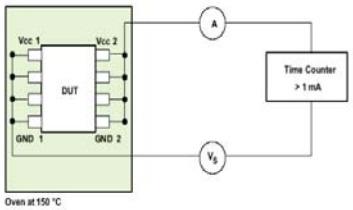
M (voltage acceleration parameter)

k_b is Boltzmann's constant

ΔH_o is the enthalpy for oxide breakdown (referred to as activation energy)

V_{IORM}, Vpeak	Lifetime per TDDB E-Model (in Years)
200	85
400	46
560	28
700	18
800	13

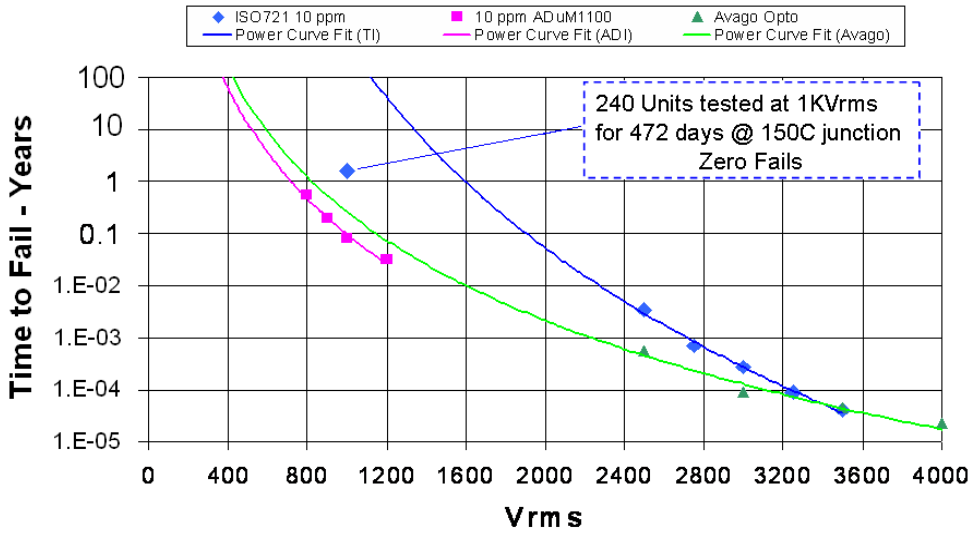




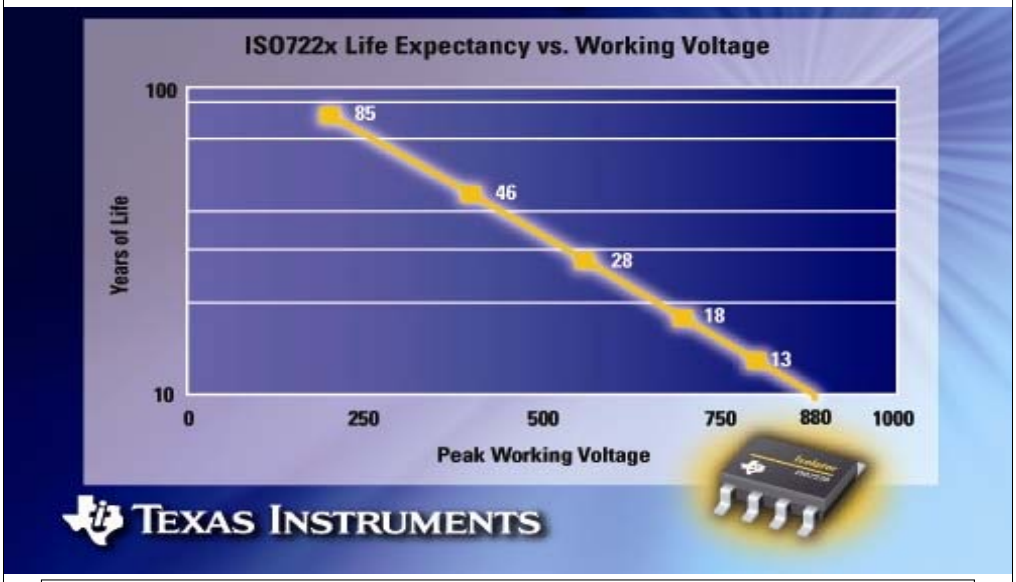
Test began 12/15/05 on 240 Units at 1kVrms over 15k hours logged with 0 fails

Source:App Note SLLA197, Ashish Gokhale, Gaddi Haase

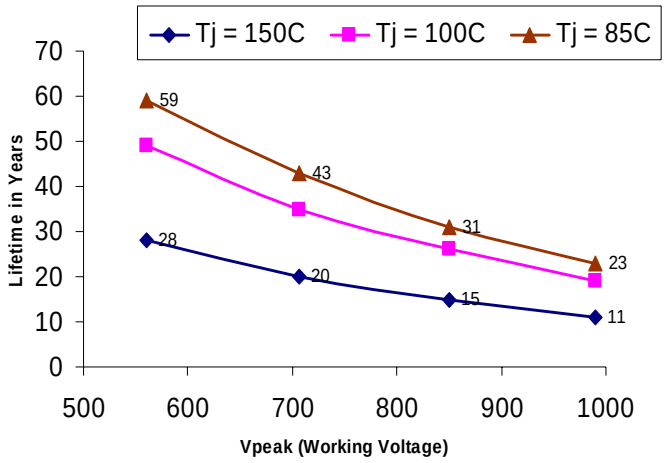
Competitive Comparison
High Voltage Lifetime



ISO722x - Life Expectancy



High Voltage Lifetime: Temperature and Voltage Effect



TI – Highest Performance, Longest Life

TI

- SIO_2 - Glass Inorganic
  - Stable Time / Temp / Humidity
  - 1000v/µm break down
  - Built in TI fabs
- Differential Signal
  - Higher Noise Immunity
    - Mag, E-field, CMTI
- Dual Channel
  - Fast AC and Encoded
    - Best of both

ADI

- Polyimide - Plastic Organic
  - Absorbs moisture
  - 250v/µm break down
  - 3rd party manufacture
- Single Ended Signal
- Single Encoded channel
  - High jitter, distortion,

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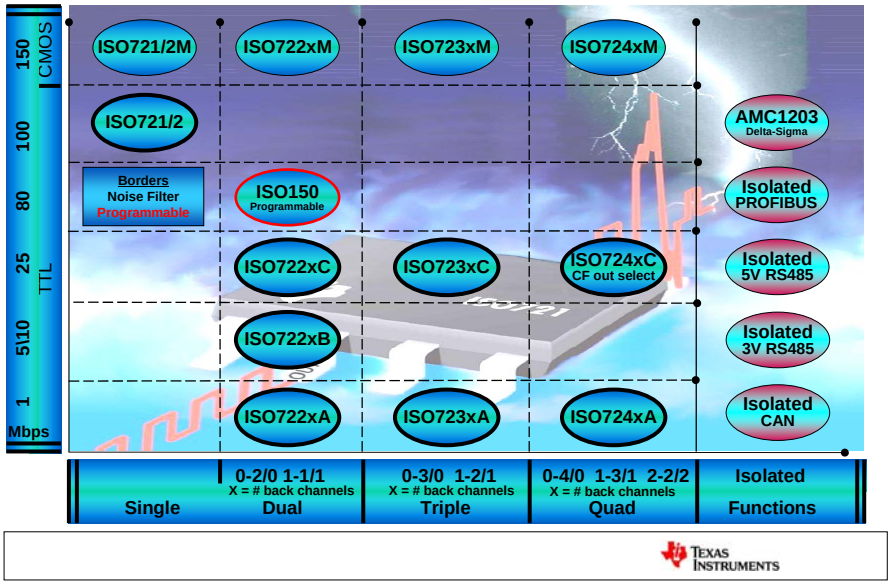
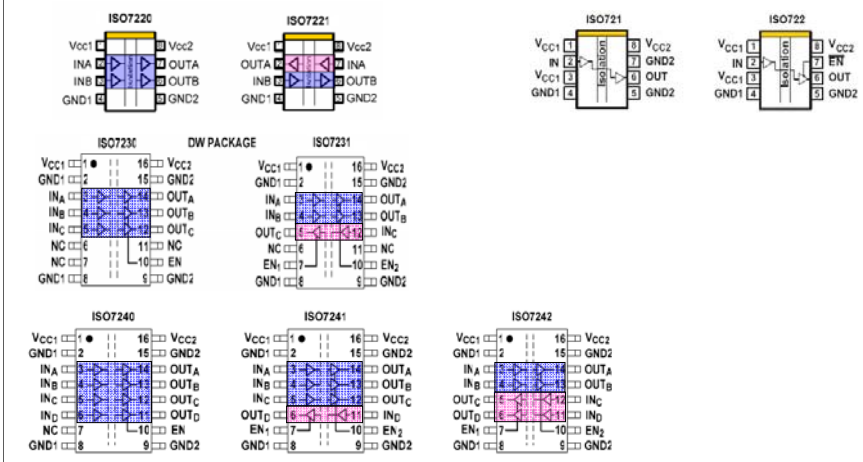
Digital Interface Isolation Portfolio

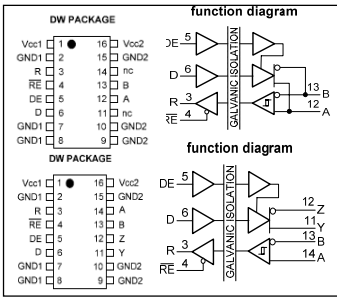


General Purpose Isolators



x designates speed option: A = 1Mbps; C = 25Mbps; M = 150Mbps

Isolated 485 Transceivers

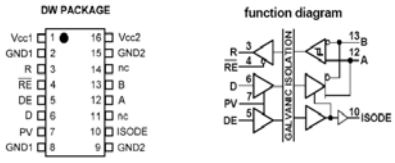


ISO3082, ISO3088 RS-485
- 5V Half-duplex 200kbps & 20Mbps

ISO15 RS-485
- 3.3V Half-duplex 200kbps

ISO3080, ISO3086 RS-485
- 5V Full-duplex 200kbps & 20Mbps

ISO35 RS-485
- 3.3V Full-duplex 1Mbps



ISO1176 : Isolated RS/485 ProfiBus transceiver
- 5V
- half-duplex
- 40Mbps
- optimized for Profibus-Applications and Speed
- ISODE available
- Samples:3Q07
- RTM: 4Q07

AMC1203

16-Bit, Isolated 10Mhz Delta-Sigma Modulator

Features

- 10Mhz 2nd Order Delta-Sigma Modulator
  - +/- 3 LSB Max INL
  - +/- 1 LSB Max DNL
  - 85db SNR
- Integrated Capacitive Digital Isolation
  - 560V Maximum Working Isolation Voltage
  - 4000V Maximum Transient Over Voltage
  - 15kV/uS Transient Immunity
- Available In Several Standard Package Options
  - DUB-8
  - SOIC-16 Under Development

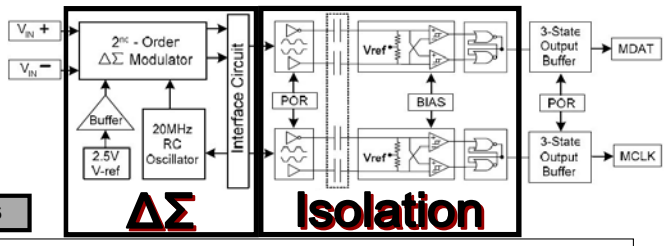
Benefits

- Stand Alone Modulator Allows For Flexible Designs Using Custom Digital Filter or TI's AMC1210 IC Solution
- Single Chip Solution Simplifies System Design And Has Excellent Magnetic Immunity
- Simple Drop-In Upgrade For Competing Isolated Modulators
  - AD7400
  - HPCL7860

Applications

- Current Measurement
- Process Control
- Chromatography
- Portable Instrumentation
- Motor Control

1kU - $3.55



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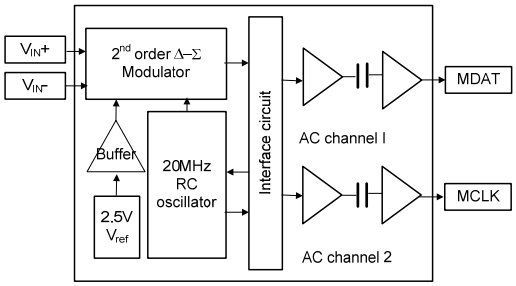
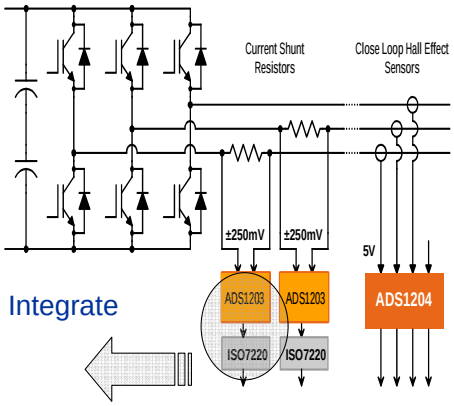
Applications: Motor Control
Current sense block: AMC1203



AMC1203



Integrate

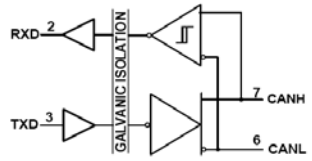
ISO1050
4kV Isolated - 5V CAN

Features

- Industry's first Isolated CAN transceiver
- Meets or Exceeds ISO 11898
- Isolated CAN with Ultra low loop time
- Very Low EME (Electro-Magnetic Emissions)
- Silicon Integrated SiO_2 Insulation
  - 4kVmax/2.5kVrms Insulation 560V Working
  - 6.1mm and 8.3mm Clearance packages
  - UL1577 ; IEC ; CSA Approval Pending

Benefits

- Reduce Components and Board Space
- Meets DeviceNet and CAN timing requirements
- High Speed Isolation allows longer buses
- Reduces interference with other devices
- Proven Reliability of SiO_2 Insulation, Stable over Time, Temperature & Moisture
  - Life Span > 25 years @ 105°C



3V-5V Vcc1 5V Vcc2

- Compatible with 75+ TI Processers with CAN controllers
  - •C2000
  - •TMS470 ARM
  - •LM3Sxxxx ARM3 Cortex - M3
  - •OMAP3505/3517

Applications

- -55 to 105C
- Motor Control
- Industrial Automation
- DeviceNet™ Data Buses
- SAE J1939 Standard Data Bus Interface
- ISO 11783 Standard Data Bus Interface
- NMEA 2000 Standard Data Bus Interface

EVM

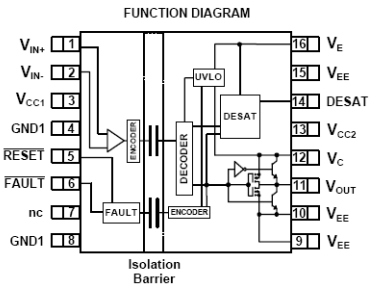
ISO1050EVM

1ku @ $1.55

Texas Instruments

Isolated Single Drivers

Preview Q4 2009



	Current	ISO5500
Max Prop delays	500ns	150ns
Part to part skew	350ns	25ns

ISO5500

- Cross with HCPL-316J
- 6KV VIOTM
- 15KV/us minimum transient immunity at 1KV
- Integrated IGBT protection options: V_{CE} DESAT, UVLO
  - FAULT signal on V_{CE} desaturation detect
  - UVLO set at 12.3V
  - Soft turn off on DESAT detect
- V_O: 15-30V, 35V(max)
- Propagation delay: 80ns typical
- I_O: 2.5$A_{(peak)}$

TI Makes Isolators Easy to Use

www.ti.com/iso721

(Click on above link for web info)

Get Started Today

- Evaluation modules
- Samples
- Applications support
- IBIS models
- Data sheets
- Technical documentation
- Application notes on:
  - High-Voltage Lifetime
  - Magnetic Field Immunity
  - ISO72x Family of Digital Isolators
- Complements TI's industrial product portfolio: interface, data converter, DSP, MCU, amplifier, power & logic

Texas Instruments

EVM will be available for purchase through the distribution channel. Samples are free through the TI web site.

All the support items, including three app notes are now available on the web

The EVM price is $49-$50.