

New Digital Capacitive Isolator Training Guide

ISO74xx & ISO75xx

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Why new Isolators?

An important trend in industrial automation is the continual increase in networking performance, system reliability, and energy efficiency.

The new ISO74xx and ISO75xx families of digital isolators from Texas Instruments satisfy these demands by providing:

- High data rates
- High isolation voltage and thus long life expectancies
- Low supply currents

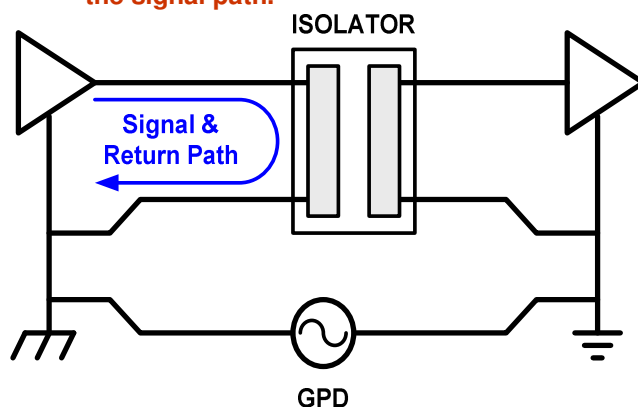
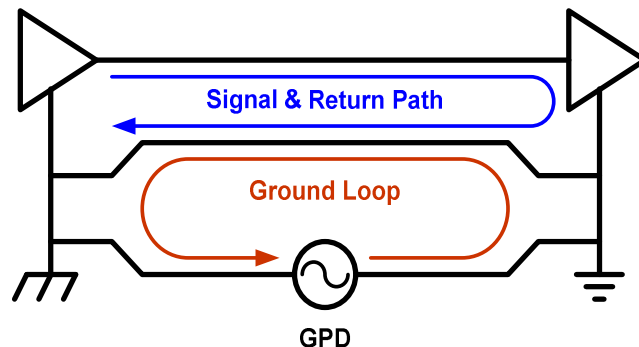
What is (Galvanic) Isolation?

Isolation

- is a means of preventing current from flowing between two communicating points while allowing the transmission of data or power between these points.
- is used to eliminate ground loops while withstanding large ground potential differences (GPDs).

Eliminating Ground Loops

- 1) Electrical Installation can cause large GPDs between two remote nodes.
- 2) A direct ground connection between the nodes closes the ground loop.
- 3) Noise sources (i.e. electric motors) inducing large currents into the ground modulate the ground loop current.
- 4) This ground noise then appears in the signal path.



- 1) An isolator breaks the ground loop, thus removing signal path noise.
- 2) The GPD yet still exists and the isolator must be robust enough to withstand the large voltage differences.

For more information please see [slyt298](#) on www.ti.com

For data transmission systems it is common to use local grounds as reference potential. Remote located network nodes of a communication network usually draw their supply from different points in the electrical installation system (see [slyt298](#) on www.ti.com). Remote located power sources, however, can experience large ground potential differences due to multiple, non-standardized, earthing techniques, which are also the cause for multiple ground paths.

Then, when providing a direct connection (i.e. a ground wire) between the transmitter ground and a remote receiver ground, a ground loop has been created. Ground loop currents can be extremely high, because they connect different ground potentials via low-impedance wire.

Thus high loop current can induce voltages into transmission signal wires causing signal distortion and possible data errors.

Breaking ground loops through galvanic isolation not only prevents loop currents but also presents the most reliable method of dealing with high ground potential differences.

Terminology

- Working or Operating Voltage (Vpk)
- Isolation or Transient Voltage (Vrms)
- Basic or Functional Isolation
- Reinforced Isolation
- Common Mode Transient Suppression
- Creepage and Clearance

Working voltage is the voltage that may be applied continuously across the Isolation barrier. The two most common voltage levels are 560Vpk and 890 Vpk.

Isolation voltage is the voltage that may occur temporarily across the barrier. Typical test durations are 10 sec (UL) or 1 min (VDE). Typical test levels are 4 kV or 6 kV.

Basic Isolation assumes a single level of isolation rated for 560Vpk working and , 4kVpk transient voltage. It is applicable for most industrial applications and AC-equipment $\leq$ 400Vrms, and for consumer electronics.

Reinforced Isolation assumes a single level of isolation providing the same reliability as a two-layer isolation. It is mostly rated at 890Vpk working voltage, 6kVpk transient voltage, and/or 10kV surge voltage. It is applicable for future medical applications and today's AC-equipment $>$ 400Vrms.

Up to now, Medical only requires 5kVrms transient..

Common Mode Transient Suppression (CMTS) discusses the quick change in ground potential (primary to secondary). It's given as the dV/dt up to which no false toggling of the output will occur (e.g. 35kV/us).

Creepage and Clearance discusses the surface-distance that may conduct if wet/polluted, respectively the air-distance. For 560V/4kV mostly 5mm is sufficient, for 890V/6kV mostly 8mm is needed.

Digital Isolator Overview

- Operation
- Construction
- Design Implementation
- Reliability
- Current Consumption
- Power Supply
- Summary

The new generation of capacitive isolators is discussed in the sequence of topics listed above.

Operation explains the functional principle of the isolator internal signal paths,

Constructions gives an insight in the structure and materials of the high-voltage capacitor

Design implementation show where to place the isolator in the signal chain,

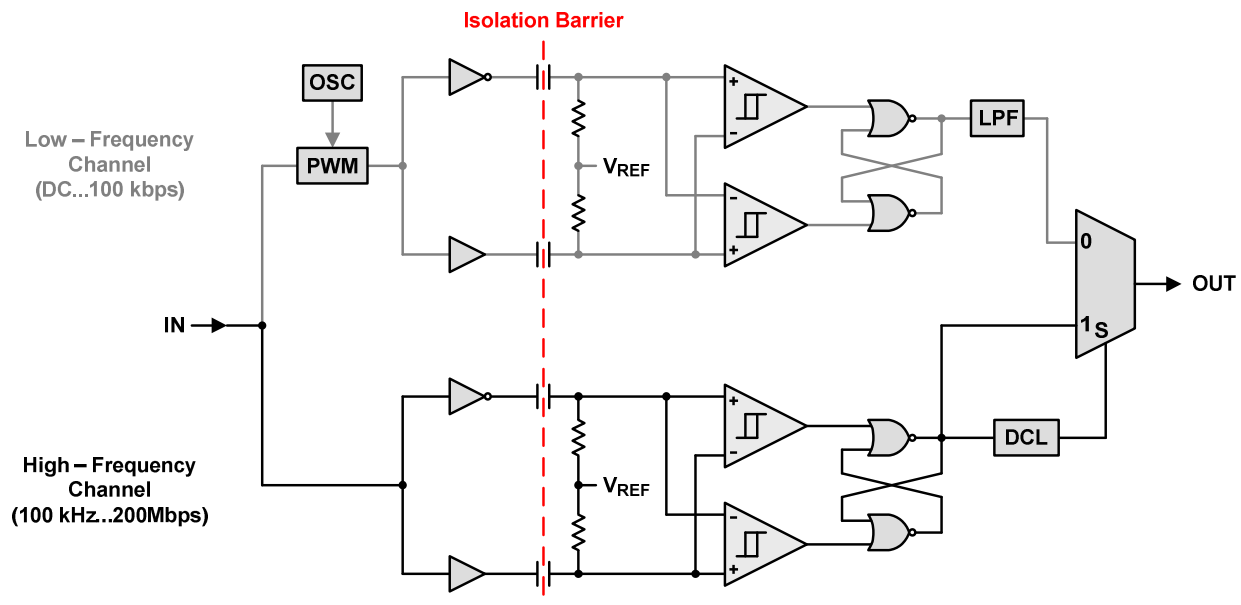
Reliability compares various parameters of different technologies and also compares the life expectancy of capacitive isolators with those of inductive ones

Currents consumption reveals why capacitive isolators are the better choice despite the low DC-current if inductive parts

Power Supply presents a new current-mode converter for isolated DC-DC applications

Summary presents the main benefits of capacitive isolators

How do they work?



- The LF channel assures correct output signal polarity during loss of input signal (i.e. wire-break)
- HF and LF channels use differential signaling for high noise immunity

💡 Other isolation technologies lack these features, which makes them highly unreliable 🚫

The capacitive isolator consists of two data channels, a high-frequency channel (HF) with a bandwidth from 100 kbps up to 200 Mbps, and a low-frequency channel (LF) covering the range from 100 kbps down to DC.

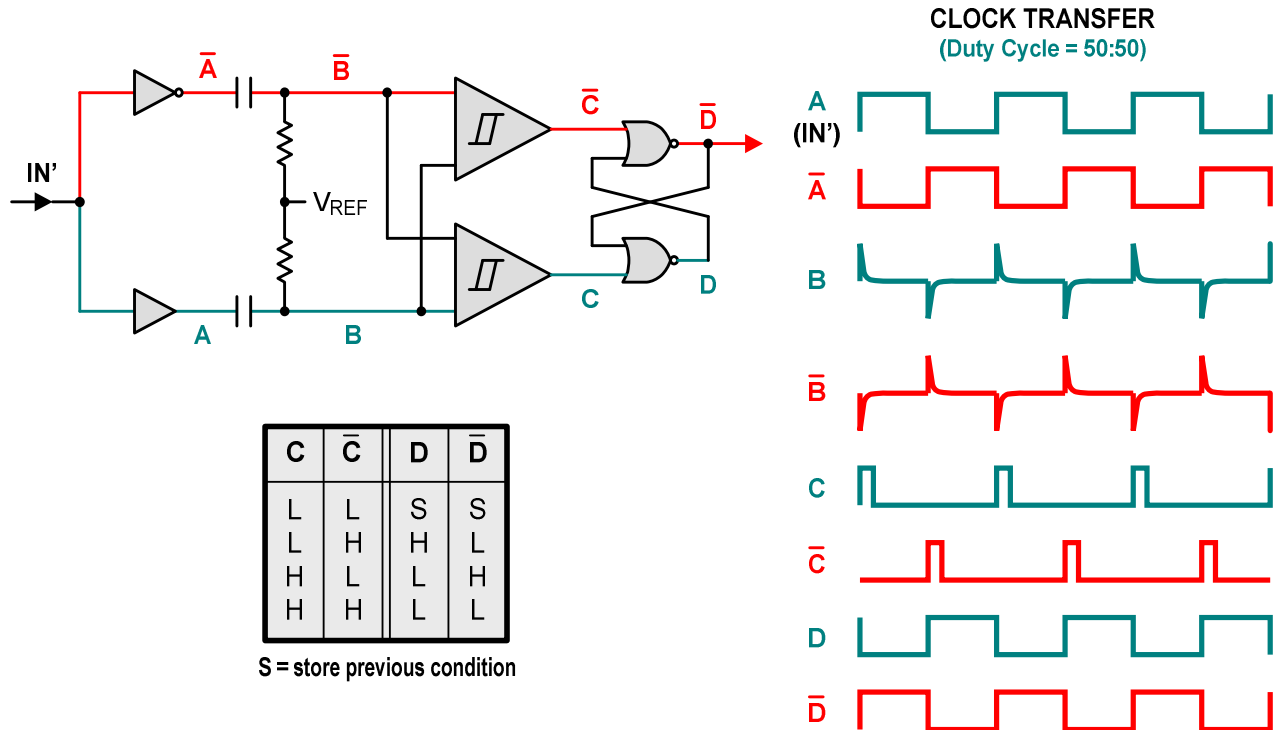
While the HF channel performs the normal, high-speed data transfer, the DC channel is necessary to detect low-frequency signals, or even the loss-of-signal (LOS) in the case of a wire-break, and to assure the correct signal polarity at the input is transferred to the output.

In principle, a single-ended input signal entering the HF-channel is split into a differential signal via the inverter gate at the input. The following capacitor-resistor networks differentiate the signal into transients, which then are converted into differential pulses by two comparators. The comparator outputs drive a NOR-gate flip-flop whose output feeds an output multiplexer. A decision logic (DCL) at the driving output of the flip-flop measures the durations between signal transients. If the duration between two consecutive transients exceeds a certain time limit, *(as in the case of a low-frequency signal)*, the DCL forces the output-mux to switch from the high- to the low-frequency channel.

Because low-frequency input signals require the internal capacitors to assume prohibitively large values, these signals are pulse-width modulated (PWM) with the carrier frequency of an internal oscillator, thus creating a sufficiently high frequency, capable of passing the capacitive barrier. As the input is modulated, a low-pass filter (LPF) is needed to remove the high-frequency carrier from the actual data before passing it on to the output multiplexer.

High-Frequency Channel

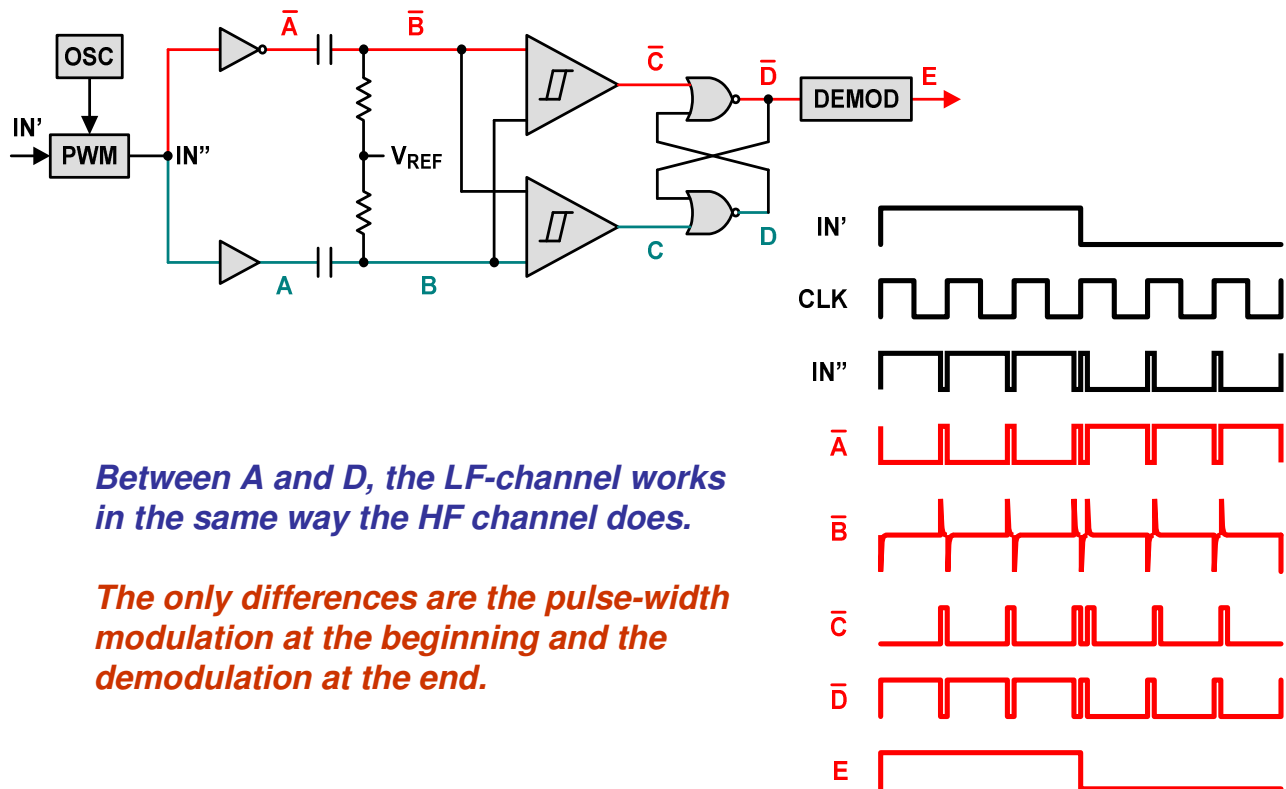
for a 50:50 duty cycle



This slide presents the high-frequency channel and the waveforms at specific points of the signal chain. The single-ended input signal is split into the differential signal components A and $\bar{A}$. Each signal component is then differentiated into the transients B and $\bar{B}$. The following comparators compare the differential transients to one another. As long as the positive input of a comparator is on higher potential than its negative input, the comparator output will present a logical High, thus converting an input transient into a short output pulse.

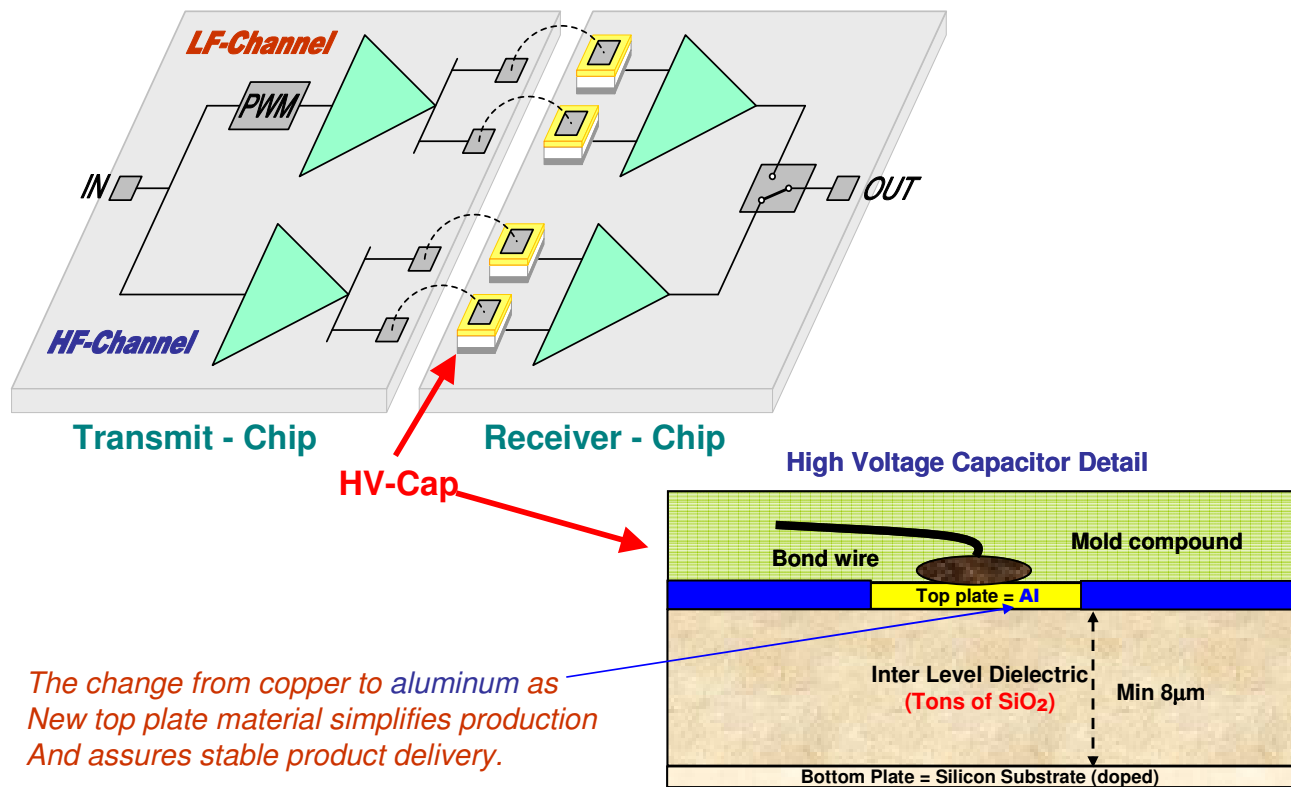
The output pulses set and reset a NOR-gate flip-flop. From the truth table we see that the NOR-gate configuration presents an inverting flip-flop, meaning that a High at input C sets output $\bar{D}$ to High, and a High at $\bar{C}$ sets D to High. Because the comparator output pulses are of short duration, there will be times where both outputs are low. During this time the flip-flop stores its previous output condition. Since the signal at $\bar{D}$ is identical in shape and phase with the input signal, $\bar{D}$ becomes the output of the high-speed channel and is connected to the output multiplexer.

Low-Frequency Channel



In the LF channel slow input signals are pulse-width modulated with a high-frequency carrier such, that a High-level yields a 90:10 duty cycle and a Low level a 10:90 duty cycle at location A. From there on, signal processing is identical with the one in the high-speed channel. The only exception is, that the high-frequency content of the low-speed channel (/D) is filtered by an R-C low-pass before being passed on to the output multiplexer (E).

How are they constructed?



Internally a capacitive isolator consists of two dies (chips), a transmitter chip and a receiver chip. The receiver chip contains the four, vertically structured, high-voltage capacitors and the receiver logic.

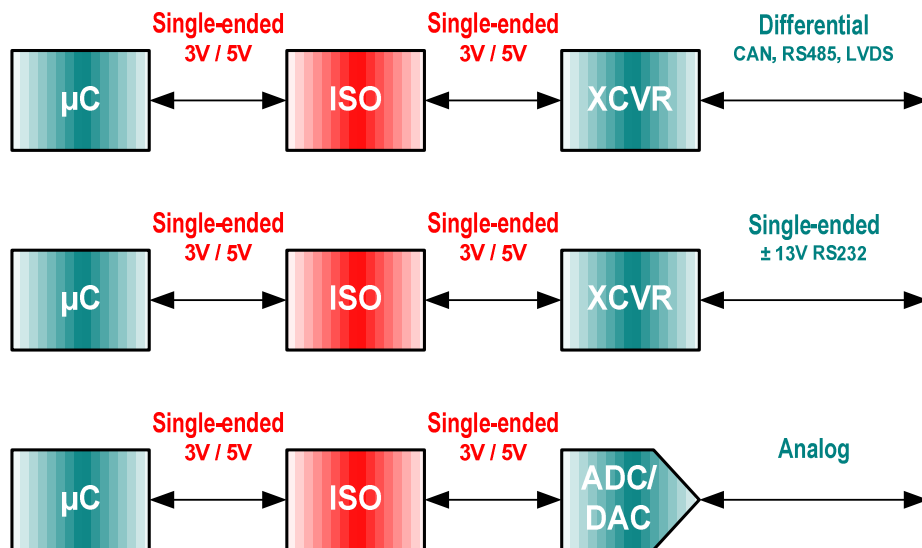
The cross cut through a capacitor shows the top plate made of aluminum, which connects to the transmitter chip via bond-wire. The bottom plate consists of doped silicon substrate and connects to the receiver logic.

In between the plates is an 8μm thick layer of silicon-dioxide, SiO₂, also known as Glass.

The main advantage of SiO₂ is its small aging effect which translates directly into high reliability and long life time expectancy of > 28 years.

Another benefit of using SiO₂ in isolators is, that it can be produced using standard semiconductor manufacturing processes, which translates to lower production cost and thus lower cost to the customer.

How are they implemented?



- do not conform to any specific interface standard
- use 3V/5V logic switching technology
- **only isolate digital, single-ended data lines**
- sit in close vicinity to corresponding data sinks and sources

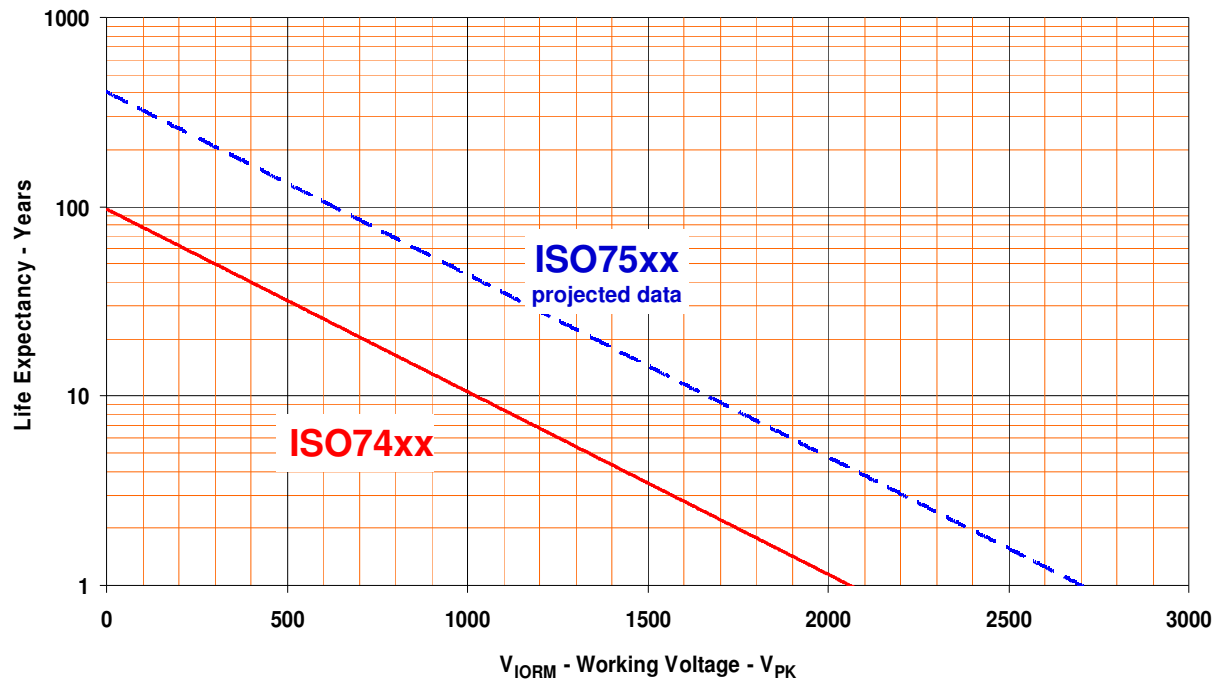
All digital isolators utilize single-ended, 3V/5V CMOS – logic, switching technology. Their nominal supply voltage range is specified from 3.3V to 5V for both supplies, VCC1 and VCC2, and allows any combination of these values.

When designing with digital isolators, it is important to keep in mind that due to the single-ended design structure, digital isolators do not conform to any specific interface standard and are only intended for isolating single-ended, 3V/5V digital signal lines.

How reliable are they?

	Opto	Magnetic	Capacitive
Signaling Rate (Mbps)	50	150	200
Propagation Delay Time (ns)	20	32	12
Pulse Width Distortion (ns)	2	2	1.5
Channel-to-Channel skew (ns)	16	2.0	1.6
Part-to-Part Skew (ns)	20	10	2
ESD on all Pins (kV)	± 2	± 2	± 4
CM Transient Immunity (kV/us)	20	25	25
Temperature (°C)	-45..125	-40..125	-55..125
MTTF @ 125°C, 90% Confidence (yrs)	8	1746	2255
FIT@ 125°C, 90% Confidence	14391	65	50
Radiated Electromagnetic-Field Immunity <i>IEC61000-4-3 (80MHz-1000MHz)</i> <i>MIL-STD 461E RS103 (30MHz-1000MHz)</i>	- -	Fails Fails	Complies Complies
High-Voltage Lifetime Expectancy (yrs)	-	< 10	> 28

Isolator Life Expectancy



Time-dependent dielectric breakdown (TDDB) is an important failure mode for dielectric materials like silicon dioxide (SiO_2) as it determines the life time expectancy of an isolator.

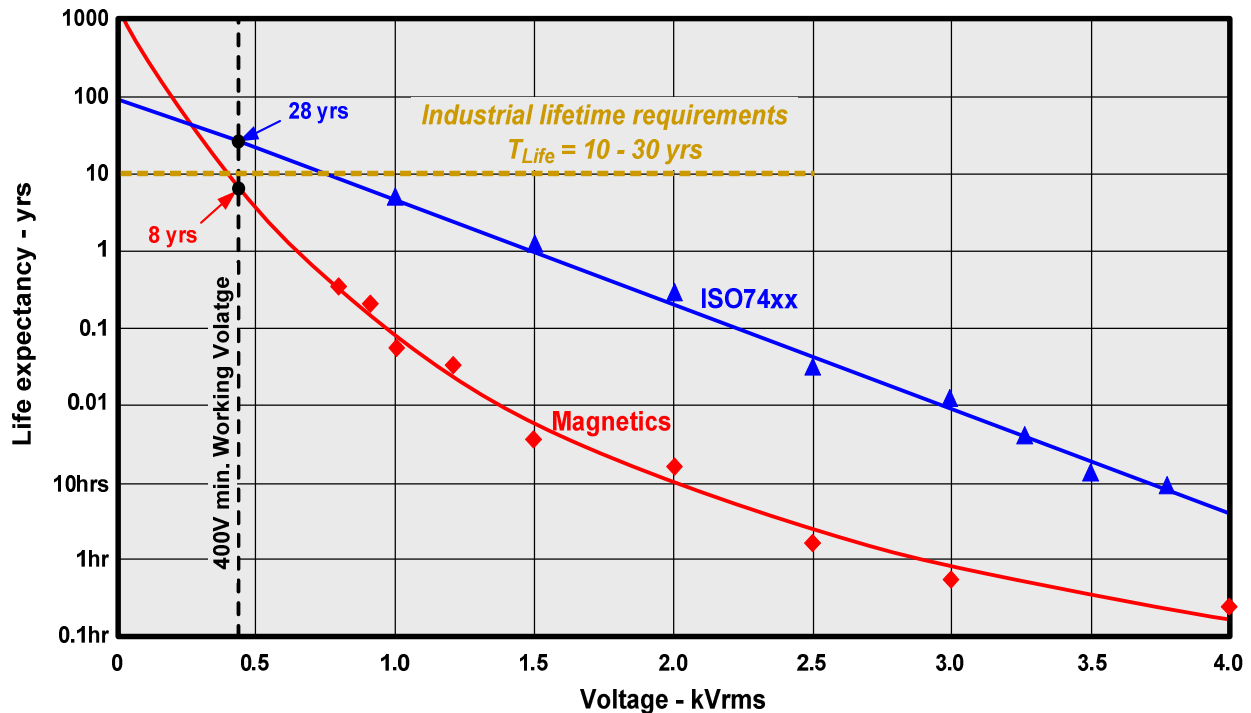
Dielectrics have impurities and imperfections due to manufacturing which cause the insulation properties to change over time and result in the eventual failure of the dielectric. These changes are accelerated by applying an electric field across the dielectric and/or by increasing its temperature.

The slide above shows the life expectancy of the new capacitive isolators as a function of the working voltage at 150 °C ambient temperature. The determination of the life expectancy is based on the TDDB E-model, the most widely accepted and used model for capacitor breakdown. The E-model is backed by a theoretical physical degradation mechanism and is considered as the most conservative of all models in the literature.

The basic test methodology is the application of a stress voltage from the input to the output of the isolator under test using a high-voltage source, while maintaining the still-air, ambient temperature at 150 °C. The start of the test activates a timer; this timer stops when the current in the circuit exceeds 1 mA, which means that the dielectric had failed. The TF (Time-to-Failure) is noted for each applied test voltage.

TI's preference for using the TDDB E-model is based on the fact that the E-model is conservative and results in high-confidence predictions compared to any other models or a best data fit methodology.

Isolator Lifetime Comparison



A comparison between the TDDDB curves of the ISO74xx isolators and inductive isolators shows that the lifetime prediction for capacitive isolators follows the E-model, while the magnetics utilize the 1/E-model.

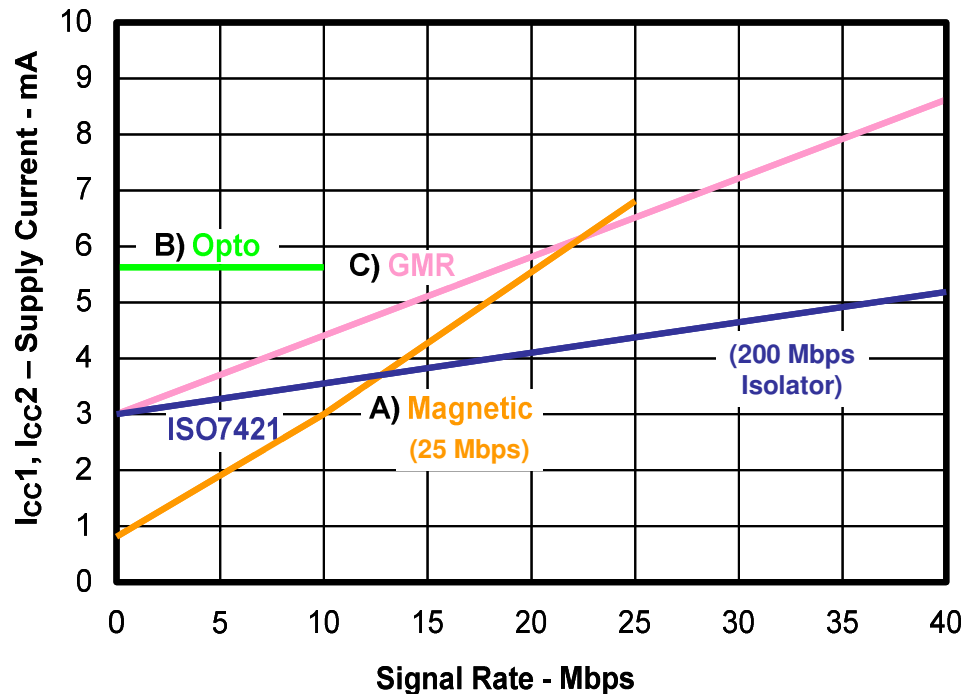
For inductive isolators the extrapolated lifetime with 8 years at 400V is in alignment with the life expectancy shown in the previous reliability table of < 10 years.

The ISO74xx series of capacitive isolators shows a significant longer lifetime of 28 years at 400V. It's E-model representation is fully backed by the latest measurement data over a 5 year range. Here, in a major stress test 240 isolators are continuously exposed to a working voltage of 1 kVrms. The test started on 15th December 2005 and has not yield a failing unit yet.

Note that typical industry lifetime expectations range from 10 to 30 years. As can be seen, above the 10-year line, the capacitive solution allows for twice as much working voltage as the inductive one.

How much current do Duals consume?

Total Icc for Lower Bandwidth, Dual Isolators



A comparison of various dual channel isolators shows the magnetic type with the lowest supply current at DC, or when idling.

Fortunately industrial data acquisition systems, PLCs, and digital and analog I/O modules aren't built for idling and doing nothing.

They have been designed to transfer data from sensors to control units and from control units to actuators. And they must do this fast, reliable, and continuously.

What's the big deal then about low DC current consumption, and is the magnetic type really low in current consumption?

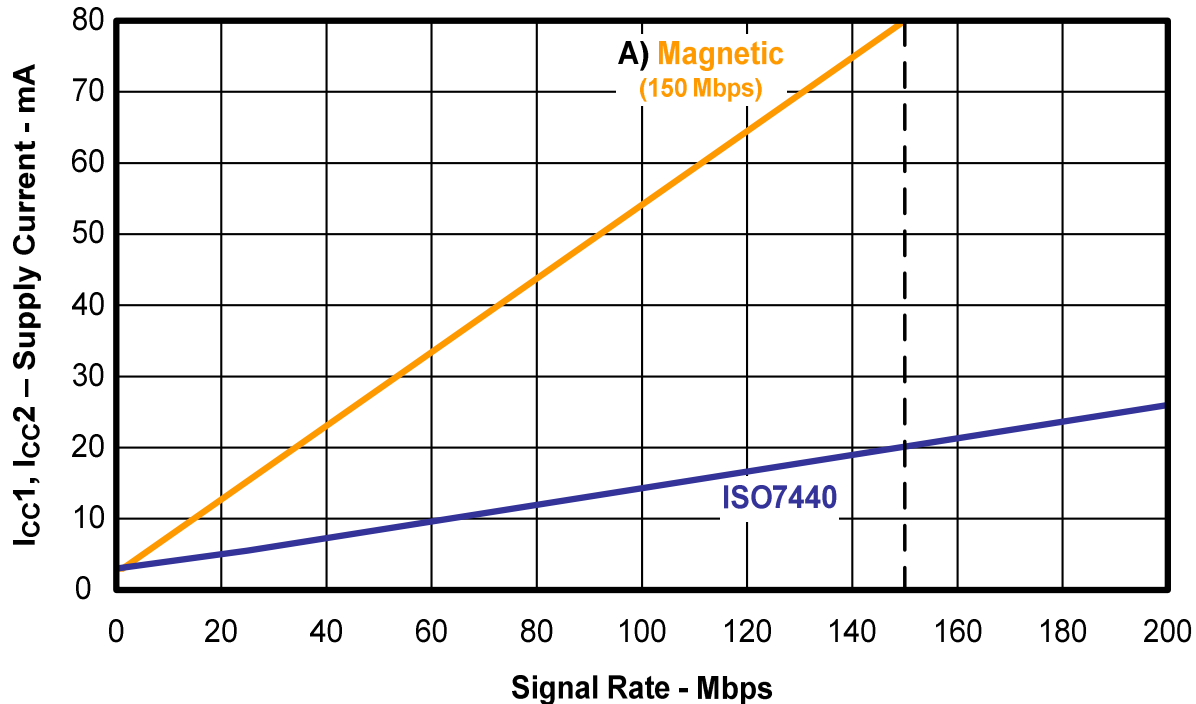
The magnetic device consisting of two signal channels only, shows a steep increase in supply current over frequency.

In comparison the dual isolator, ISO7421, comprises 4 channels, two HF and two LF channels. Its DC supply current is of course higher, but so is its reliability by assuring the correct output polarity in the case of an input signal loss.

At 12 Mbps (or 6 MHz frequency), the ISO7421 already starts to consume less power than the magnetic type.

How much current do Quads consume?

Total I_{cc} for High-Bandwidth, Quad Isolators



Emphasizing the low-power performance of the new ISO&4xx and ISO75xx families the slide above compares the supply currents of four channel isolators.

It might come at a surprise that the DC current of quad isolator ISO7440 is only slightly higher than the one of the dual channel device, ISO7421. The reason for that is that the quad isolator includes only one LF-channel, which is time-multiplexed across four HF channels.

The magnetic quad isolator however has more than doubled its DC current. This is not only because of twice the amount of channels but also because of its higher speed capability.

Both technologies' DC performance now being equal, the ISO744x series outperforms the magnetic type across the entire bandwidth.

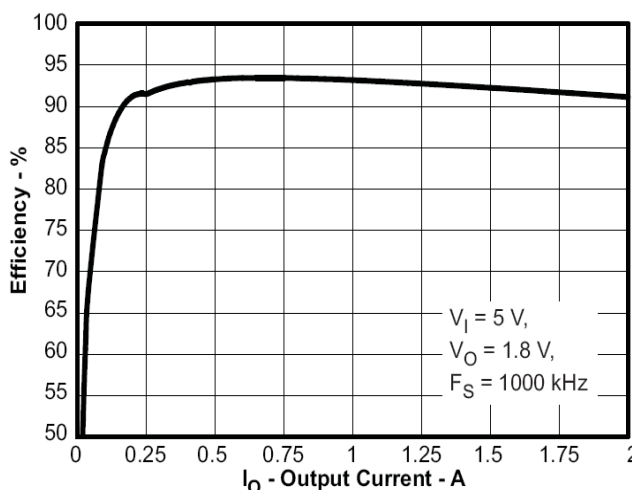
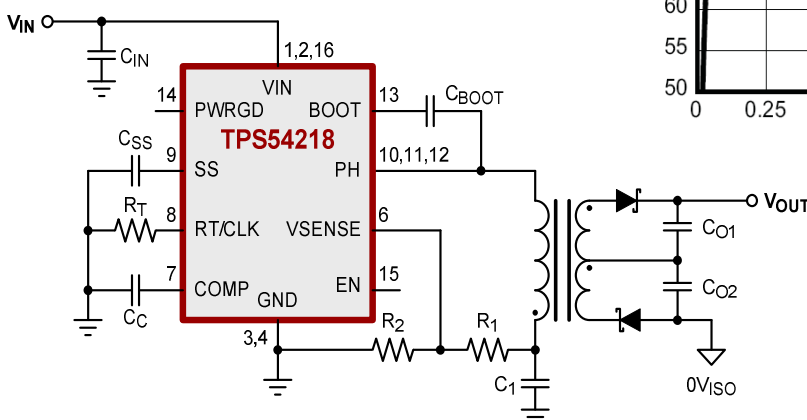
Quad isolators are often used in interfaces comprising data and control lines. Typical applications are data converters with SPI compatible interfaces.

When considering that many industrial interfaces, accessing multiple data converters and I/Os, operate at or above 20 Mbps, the power savings accomplished by the new capacitive isolators in comparison to other technologies are tremendous.

Low-Cost Isolated Power Supply

Features

- Low-Cost (~ \$5.00 @ 1ku)
- High Efficiency
- 3mm x 3mm 16-pin QFN
- For Isolation Transformers (1kV – 6kV)
- $V_{in} = 2.95V - 6.0V$
- V_{out} from 3.3V to 5.0V
- $I_{out-max} = 2A$



The TPS54218 device is a full featured 6V, 2A, synchronous step down current mode converter with two integrated MOSFETs.

The TPS54218 enables small designs by integrating the MOSFETs, implementing current mode control to reduce external component count, reducing inductor size by enabling up to 2 MHz switching frequency, and minimizing the IC footprint with a small 3mm x 3mm thermally enhanced QFN package.

The TPS54218 provides accurate regulation for a variety of loads with an accurate $\pm 1\%$ Voltage Reference (V_{ref}) over temperature.

Efficiency is maximized through the integrated 30m Ω MOSFETs and 350 μ A typical supply current. Using the enable pin, shutdown supply current is reduced to 2 μ A by entering a shutdown mode.

Undervoltage lockout is internally set at 2.6 V, but can be increased by programming the threshold with a resistor network on the enable pin. The output voltage start up ramp is controlled by the slow start pin. An open drain power good signal indicates the output is within 93% to 107% of its nominal voltage.

Frequency fold back and thermal shutdown protects the device during an over-current condition.

Summary

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The new Isolators excel through...

- **functional isolation up to 4 kV & 5 kV**
- **highest reliability**
- **longest lifetime**
- **widest bandwidth**
- **low quiescent current at DC**
- **lowest supply current > 12 Mbps (DUALS),
and > 2 Mbps (QUADS)**