BROADCOM®

White Paper

ACML-7400, ACML-7410, and ACML-7420

Reinforced Fast Digital Isolators for Safety in Medical Applications

Introduction

The new 4th edition medical electrical equipment standard (IEC 60601-1-2) addresses today's electromagnetic interference (EMI) threats for medical devices in use outside of hospitals. The electrostatic discharge (ESD) immunity discharge level testing for medical devices was increased in IEC 60601-1-2. Now, the contact discharge is up to 8 kV and air discharge is up to 15 kV.

Patient contacts in medical devices must be isolated from ac mains to protect the patient from hazardous voltage shocks. In medical imaging devices, large quantities of video imaging data needs to be transferred from image sensor to image processor while maintaining high levels of electrical isolation. The electrical isolation of the sensor is necessary to protect the patient from shocks. The high-speed digital data transmission channels between the sensor and image processor require high-levels of isolation while transferring data at up to 100 Mbaud for real-time displays.

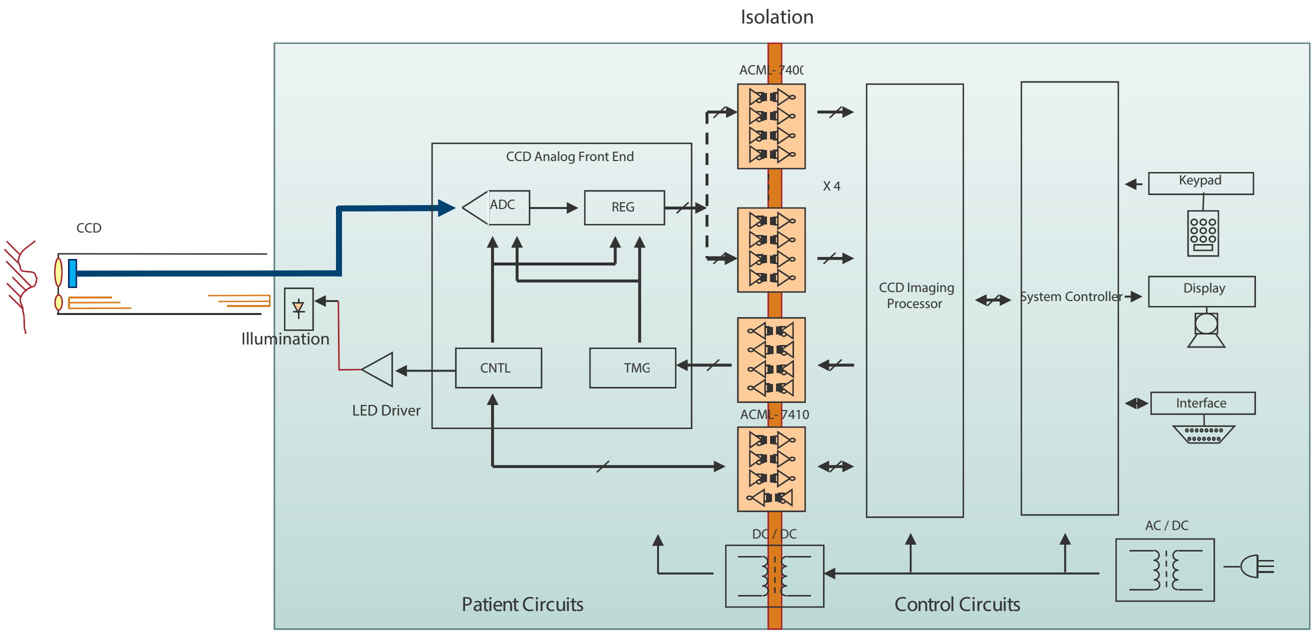
The combination of high speed and stringent safety requirements presents significant challenges to isolation design. The isolation design often resulted in an expensive solution—such as fiber optics. Now with the latest transformer on flex technology developed by Broadcom®, cost-effective isolation solutions meeting both high speed and medical safety requirements are available.

Using magnetic coupling through a thick insulation barrier, the isolators enable high speed transmissions without compromising isolation performance. These isolators consume low power even at high data rates, yet provide excellent transient immunity performance in compact surface mount packages. The devices are qualified to a maximum propagation delay of 36 ns.

Overview of Endoscope System Design and Isolation Requirements

The following figure is the schematic block diagram of a typical endoscope using the ACML isolators family of transformer-on-flex isolators.

Figure 1: Schematic Block Diagram of a Typical Endoscope



The endoscope light guide and CCD image sensor are housed in a flex tube that is introduced into a patient's body. Video signals of what the sensor captures are transmitted to the CCD analog-front-end (AFE) circuit where they are digitized and sent on to an image processor for image reconstruction. Typically, digitized data from the AFE is 16 bits wide and clocked out at the rate of up to 50 MHz or more, depending on image size and resolution requirements.

The control signals configuring ADC behavior and timing units are of lower speed in nature. However, due to the needs for fast throughput and the use of a high-speed clock, it is important that the insertion of digital isolators do not introduce additional pulse-width distortion. Channel-to-channel propagation delay skew should also be kept to a minimum to ensure synchronous data transfer at high data rates. Given a large number of data and control channels, it is desirable to integrate more channels into a single package for space saving.

Patient contact circuits and image processing circuits must be separated electrically from the rest of the system and power supply according to the IEC60601-1 safety requirements. As the potential of patient contact could be raised to the power-line voltage under a single-fault condition, the isolation barrier should be fault tolerant and meet requirements that include two means of patient protection.

High-voltage transients could possibly present across isolation due to ESD since patient contacts are always floating and accessible by patients and medical operators. The conventional methods of ESD protection by high-voltage diodes are not allowed across the isolation barrier since that violates the galvanic safety isolation requirements. Thus the insulation material and construction of the digital isolator must withstand the highest ESD transients without insulation degradation.

The equipment and isolation requirements of a typical medical imaging device in a hospital environment connected to 240 Vac mains are summarized in the following table.

Table 1: Isolation Requirements of Medical Imaging Equipment

Equipment Requirements	Isolator Parameters	Specifications	
High Speed	Data Rate	> = 100 Mbaud	
	Pulse Width Distortion	< = 2 ns	
	Propagation Delay Skew	< = 3 ns	
Medical IEC 60601-1	Continuous Working Voltage across Isolation	> = 120 Vrms	> = 240 Vrms
	Transient Withstand Voltage (1 min)	> = 3000 Vrms	> = 4000 Vrms
	Leakage Current at 400 Vdc	< 10 µA	
Robust Isolation against ESD	ESD across isolation (HBM)	> = 16 kV	

Choices of Isolation

Fiber-optic based connections and pulse transformers can be used for high-speed data isolation. However fiber optic solutions are expensive since they require optical transmitters and receivers. Pulse transformers are bulky if they have to meet medical safety requirements. Also, both solutions cannot achieve sufficient integration to provide a high channel density per unit area.

Optocouplers are another popular choice for their smaller size, enhanced insulation capability, and reasonable cost. The fastest optocoupler available today is the HCPL-0723 from Broadcom, and it can transfer data at rates of up to 50 Mbaud. It can handle medium-speed data transmission as well as provide control-signal isolation.

In the past few years, families of miniaturized multichannel high-speed digital isolators have been introduced for medical applications by a few semiconductor suppliers. Digital signals are coupled through on-chip microtransformers or isolation capacitors. The couplers are available in both single and multichannel configurations. Thanks to the speed improvements and the increase in channel density, it is possible to build smaller and cost-effective medical imaging devices.

While new isolation technologies are breaking limits in speed and channel density, their isolation robustness is seen to be compromised due to the following observations:

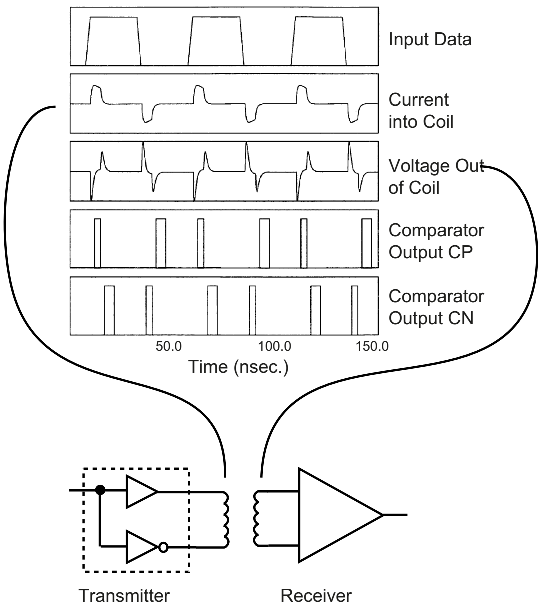
1. Most insulation layers built on the CMOS IC chip are thinner than 20 µm. Such insulation layers can be subjected to very high electrical field strength (V/µm) in which the aging mechanism of insulation material is yet to be understood and proven.
2. Most isolators built with “isolation-on-chip” technology break down under 12 kV of human-body model (HBM) ESD stress.
3. A single layer of thin-film insulation does not meet requirement for two means of protection.

To benefit from IC technology advances without compromising insulation quality, Broadcom recently developed a high-speed multichannel digital isolator family (ACML isolators). The isolators are based on a novel “transformer-on-flex” technology, and are implemented with CMOS input buffers and CMOS output drivers. This implementation eliminates the need for both input limiters and output pull-up resistors. Additionally, refresh circuitry is built in to ensure DC correctness.

When a data stream is fed into the “transmit” side, the logic signals are converted to current pulses. The pulses create the electromagnetic field that is coupled across the insulation barrier to the receive coil. The receive coil translates the pulsed EM field into voltage pulses that the differential-input receiver will translate back into logic signals to recreate the data stream.

The following figure shows how the data inputs are converted.

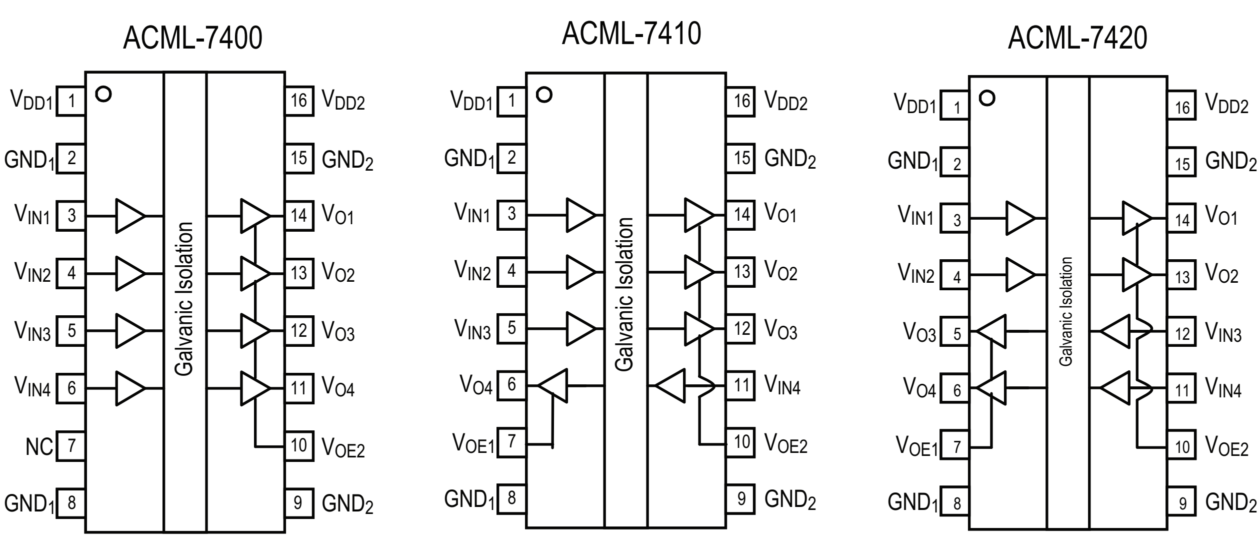
Figure 2: Conversion of Data Inputs into Data



To get across the galvanic isolation barrier, the data inputs are converted into current pulses in the transmitter's primary coil. On the receive side the electromagnetic field generates voltage pulses that are converted back into the data.

The following figure shows the three members in the ACML isolators family.

Figure 3: ACML Isolators



The ACML-7400, ACML-7410, and ACML-7420 each offer four isolated channels—but with differing configurations. The ACML-7400 has four channels oriented in one direction, the ACML-7410 has three channels oriented in one direction and one channel going in the reverse direction, and the ACML-7420 has two channels in each direction.

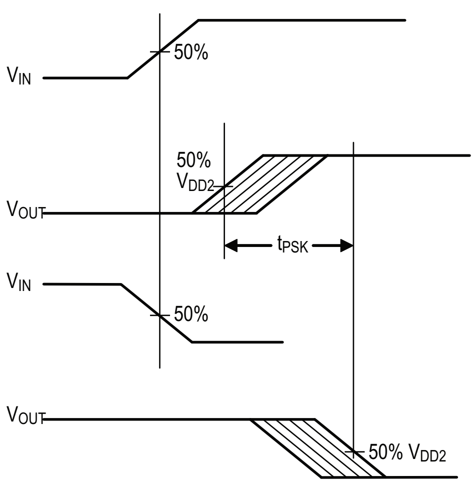
The isolators have CMOS-logic-compatible inputs and outputs and can operate from 3.3V or 5V supplies. When idling using a 3.3V supply, the chips consume less than or equal to 10 mA/channel on the input side, and less than or equal to 11 mA on the output side. With a 25 Mbaud data stream, the input supply current jumps to about 17 mA while the output supply current increases to a similar value. With a 100 Mbaud data stream, supply currents increase to about 30 mA on the input and output sides. Supply currents are slightly higher with 5V power sources.

Pulse width distortion is less than 3 ns, which minimizes potential data transmission errors. Additionally, the transmitter provides a differential output and the receiver has differential inputs, thus maximizing common-mode noise rejection and allowing the channel to provide a cleaner signal.

Propagation delay skew (t_{PSK}) is an important parameter to consider in parallel data applications where synchronization of signals on parallel data lines is a concern. If the parallel data is sent through a group of isolators, differences in propagation delays will cause the data to arrive at the outputs of the isolators at different times. If this difference in propagation delay is large enough, it will determine the maximum rate at which parallel data can be sent through the isolators.

Propagation delay skew is defined as the difference between the minimum and maximum propagation delays, either t_{PLH} or t_{PHL} for any given group of isolators that are operating under the same conditions (such as the same drive current, supply voltage, output load, and operating temperature). If the inputs to a group of isolators are switched either ON or OFF at the same time, t_{PSK} is the difference between the shortest propagation delay (either t_{PLH} or t_{PHL}) and the longest propagation delay (either t_{PLH} and t_{PHL}). The following figure shows the difference between the minimum and maximum propagation delays.

Figure 4: t_{PSK}

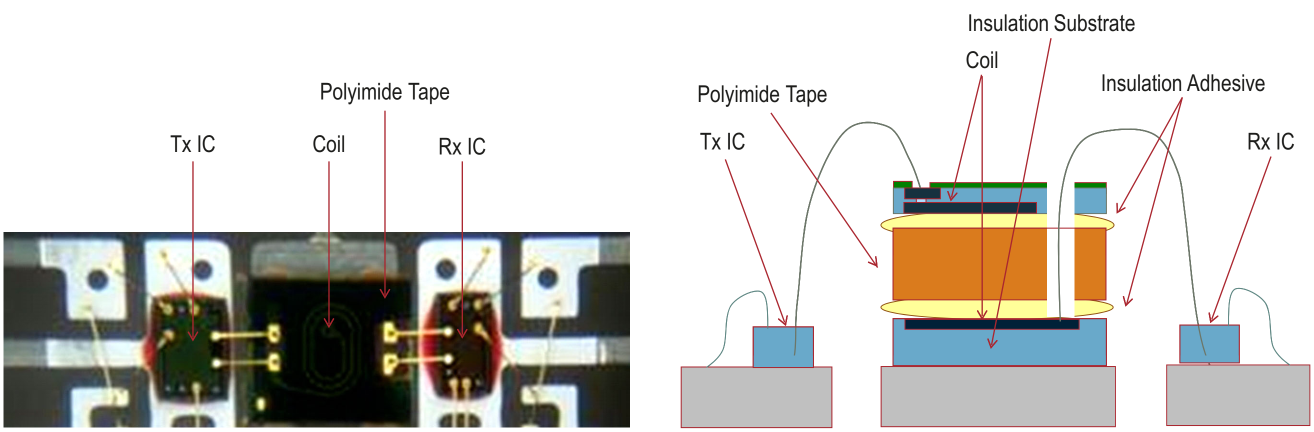


The ACML series isolators offer the advantage of guaranteed specifications for propagation delays, pulse-width distortion, and propagation delay skew over the recommended temperature and power supply ranges.

Similar to other multichannel high-speed digital isolators, the digital input signal is coupled through high-speed microtransformers. However, isolation between primary and secondary coils is based on flex tape. Flex tape is made from a polyimide material commonly known as Kapton. Unlike “isolation-on-chip” technology, the polyimide tape is much thicker—about 50 µm. Such tape has been widely used for insulation purposes in medical and industrial applications for many years. With the additional 30 µm of insulation adhesive between coil and tape, the total distance through insulation adds up to 80 µm, a thickness approaching the isolation distance in many optocouplers. As a result, the insulation property and dielectric strength are similar to that of optocoupler, which is well understood and proven since its first introduction in early 1970s.

The following figure is the top view and cross sectional view of Broadcom's new digital isolator. It comprises of a transmitter IC (Tx) on the left, a microtransformer mounted on the flex polyimide tape in the middle, and a receiver IC (Rx) on the right—all mounted on substrates. In the cross sectional view insulation tape, adhesives, and transformer windings are shown. The complete structure with molding passes ESD stress of more than 16 kV across the isolation while other manufacturer's thin layer isolation-on-chip structure fails below 12 kV.

Figure 5: View of a "microtransformer-on-Flex" 100 Mbaud Digital Isolator



The following table summarizes the key electrical and isolation differences of various high speed digital isolation technologies.

NOTE: The data source for the following table is the manufacturer's datasheet and the Broadcom benchmarking test.

Table 2: Electrical and Isolation Performance Comparison for High-Speed Digital Isolators

		Broadcom ACML Isolators	**Supplier A**	**Supplier B**
Isolation Technology	**Unit**	**Isolation on Flex**	**Isolation on Chip**	**Isolation on Chip**
Coupling Technology	—	Magnetic	Magnetic	Capacitor
Insulation Material	—	Polyimide Tape	Spin on Polyimide	SiO2
Data Rate	Mbaud	100	90	150
Pulse Width distortion	ns	2	2	2
Propagation Delay Skew	ns	3	5	2
Number of Insulation Layers	—	3	1	1
Distance Through Insulation	µm	80	20	8
Transient Voltage Rating (1 min)	Vrms	5600	5000	2500
Highest Passing ESD Voltage (HBM)	kV	> 16 kV	10 kV	4 kV
Leakage Current at 400 Vdc before ESD Zap (HBM)	µA	0.00018	0.00028	0.00024
Leakage Current at 400 Vdc after ESD Zap (HBM)	µA	0.00023 (Zap at 16 kV)	35 (Zap at 12 kV)	180 (Zap at 6 kV)

Conclusion

Medical imaging devices require high speed and multichannel digital isolators to transmit large quantity of data from isolated patient circuits to image processing circuits. While many of the latest isolation-on-chip technologies are providing promising digital isolators that meet demands for high speed and high channel density, it is critical to select the right isolation components without compromising on insulation quality. Besides complying with medical safety standards (IEC 60601-1-2), the higher requirement for ESD rating across isolation and multilayer insulation are crucial—for patient safety, tolerance of human mishandling, and tolerance of material defects.

Broadcom's latest high speed digital isolator is built on fault tolerant multilayer insulation material with very high ESD handling capability—more than 16 kV. It operates at high data rates in multichannel configurations, hence is an ideal choice for the next generation of medical imaging devices.