White Paper

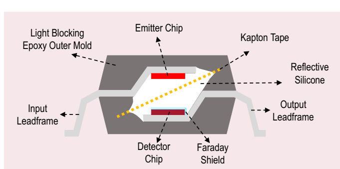
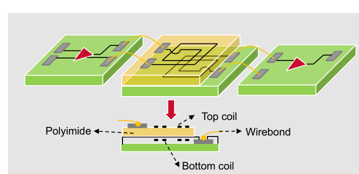
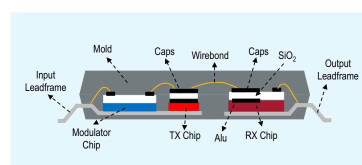
Internal Faraday Shield and Small Ci-o Enhance Broadcom Optocoupler Galvanic Isolation Performance

High-voltage isolation in today's context involves integrating subsystems with large voltage differences and systems ground potentials. This enables isolation applications ranging from power supply, motor control circuit of servo automation systems and industrial robots, battery management systems, photovoltaic (PV) inverters, electric vehicle (eV) inverters, ultra-fast charging and wireless-charging stations to data communication and digital logic interface circuits. Basically, the most important components, isolators (couplers), provide electrical isolation that allows integration of different subsystems by breaking direct conduction paths. Integrated circuits (ICs) can be combined into the isolators for various electrical functions, such as driving power electronic devices, high accuracy current and voltage measurements, analog and digital communications and logic interfaces, and isolated power supply conversions.

Isolation Technology

Three types of isolator technologies are available: optocoupler, magnetic coupler, and capacitive coupler. Table 1 shows the key differences between the different isolation techniques, component safety certifications, and lifetime reliability failure mechanisms.

Table 1: Key Differences between Different Isolation Techniques, Component Safety Certifications, and Lifetime Reliability Failure Mechanisms

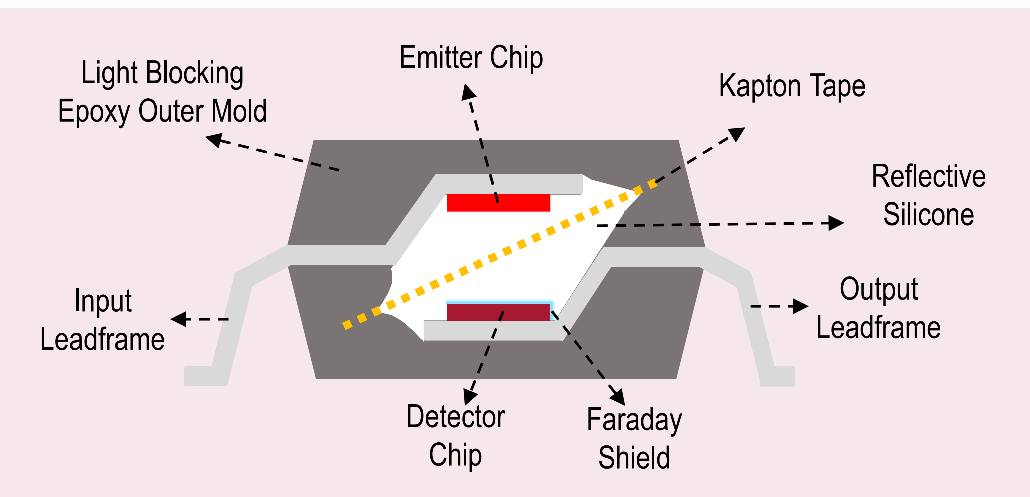
Isolator/Coupler Types	Broadcom Optocoupler	Magnetic Coupler	Capacitive Coupler
Isolation Construction			
Insulation Material	3 layers Silicone/Kapton Tape/Silicone	1 layer Polyimide	1 layer Silicon Dioxide
Insulation Thickness	0.08 mm to 2.0 mm	■ Up to ~0.02 mm for single coil ■ Double coil (~ 0.04 mm)	■ Up to ~0.014 mm for single cap ■ Double cap (~0.028 mm)
Component Certification/ Lifetime Test Method	IEC 60747-5-5 For Optocoupler Only Partial Discharge (PD) Reinforced Isolation	VDE 0884-10 Alternative Isolator Partial Discharge (PD)	VDE 0884-11 Alternative Isolator Partial Discharge (PD)
Lifetime and Reliability Failure Mechanism	Partial Discharge	Space-Charge Degradation	TDDB-Time Dependent Dielectric Breakdown (oxide film degrade over time)

The optocoupler transmits the electrical signal through the isolation barrier by converting the electrical signal to an optical signal using an LED. On the other side of the isolation barrier of thickness 0.08 mm to 2 mm, the optocoupler converts the optical signal back to electrical signal through the photodiodes. In terms of lifetime reliability, the integrity of an optocoupler insulation material can be predicted by partial discharge measurement.

Theoretical dielectric strength values of insulation materials would always apply if optocoupler manufacturers could produce consistently pure insulation barriers. Often, however, high-voltage dielectrics contain defects, such as voids and inclusions of air or other impurities. These voids have lower breakdown strength than the surrounding dielectric and discharge or arc when their breakdown strength is reached. The discharge, however, is limited to the length of the void, and after discharging, the discharge will slowly recharge with the limited current available through the good dielectric. The void eventually recharges to the breakdown voltage and discharges again, as the process continues as long as the applied electric field remains high enough. These discharges are considered “partial” because they occur across the void in a limited portion of the length of the dielectric barrier. Partial discharges, which cannot be detected by leakage current measurements, can over time spread in the insulation that eventually lead to complete insulation breakdown. The problem is to detect the presence of partial discharge during manufacturing test to prevent this phenomenon from degrading devices in the field.

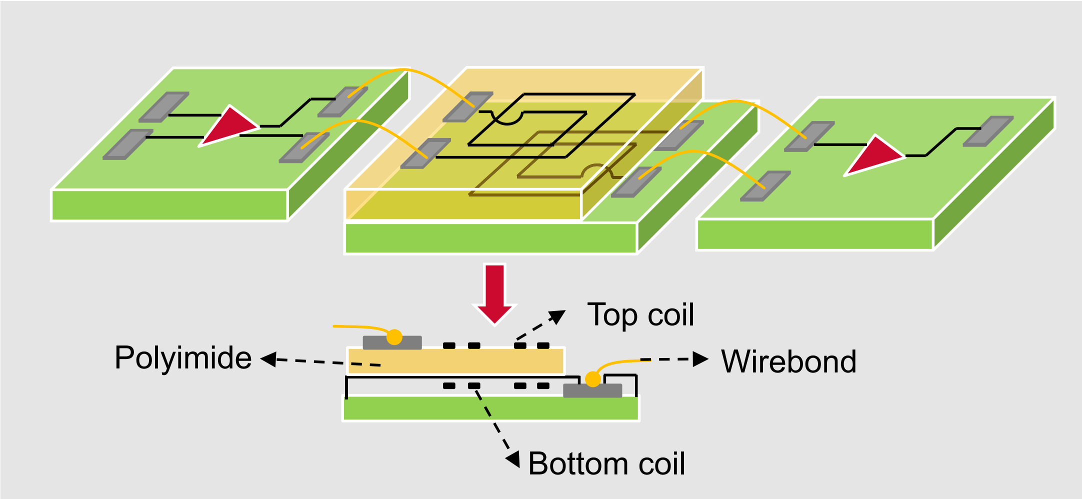
Broadcom optocouplers’ high-voltage insulation strength is further enhanced with three key design methods. The first is by inserting a clear polyimide called Kapton tape in between the LED and photodiode. The second method is the use of a proprietary, low-cost Faraday shield, which decouples the optocoupler input side from the output side. Figure 1 shows the isolation construction of Broadcom® optocouplers. The third method is by a unique package design that is optimized to minimize input-to-output capacitance, Ci-o. The importance of the three design methods is described in this application note with an accompanying high-voltage surge test as proof.

Figure 1: Broadcom Optocouplers Isolation Construction, which Incorporates Kapton Tape and Faraday Shield for Enhanced Insulation Strength



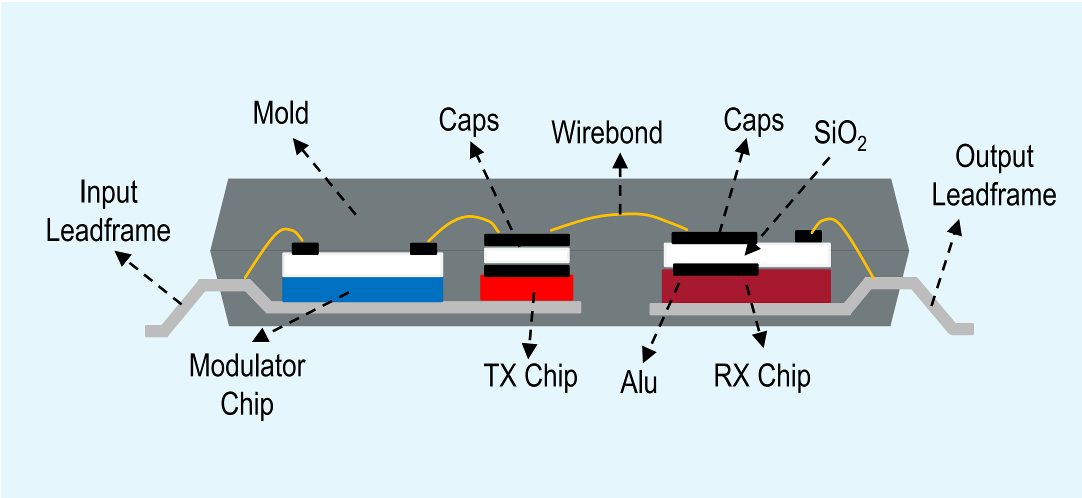
The magnetic coupler uses two coils that are stacked on top of each other with a separating polyimide material of about 0.02 mm in between. The application of an AC signal creates a magnetic field, which in turn induces an electric field in the secondary coil. Because the transmission is by magnetic field coupling, the magnetic coupler is also susceptible to nearby magnetic interference. Figure 2 shows an example of magnetic coupler isolation construction with a single pair of top and bottom coils with polyimide insulation material in between the coils. To double the insulation strength, two sets of magnetic coils are used for one isolation path, achieving an insulation thickness of about 0.04 mm. The failure mode of the magnetic coupler insulation material is space-charge degradation.

Figure 2: Magnetic Coupler Isolation Construction with a Single Pair of Top and Bottom Coils with Polyimide Insulation Material in Between



The construction of a capacitive coupler, as the name implies, is similar to a ceramic capacitor, whereby silicon dioxide (SiO2) dielectric of thickness of about 0.015 mm is sandwiched in between two metal plates, usually aluminium (Al), in close proximity. The SiO2 crystal is grown on top of the Al plate. Transmission of signal through the capacitive isolation barrier is usually through an AC electrical signal. One of the factors that may affect the insulation strength of the capacitive coupler is how well the SiO2 crystal is grown. Defects in the crystal will weaken the insulation material. The lifetime reliability failure mode for the capacitive coupler is time-dependent dielectric breakdown (TDDB). Similar to a magnetic coupler, to double the insulation strength, two sets of capacitors are used for one isolation path and the insulation thickness is doubled to about 0.03 mm. Figure 3 shows a typical double capacitor isolation construction.

Figure 3: Capacitive Coupler Isolation Construction with Two Series Caps where the SiO2 Dielectric Is Sandwiched in Between by Two Alu Metal Layers

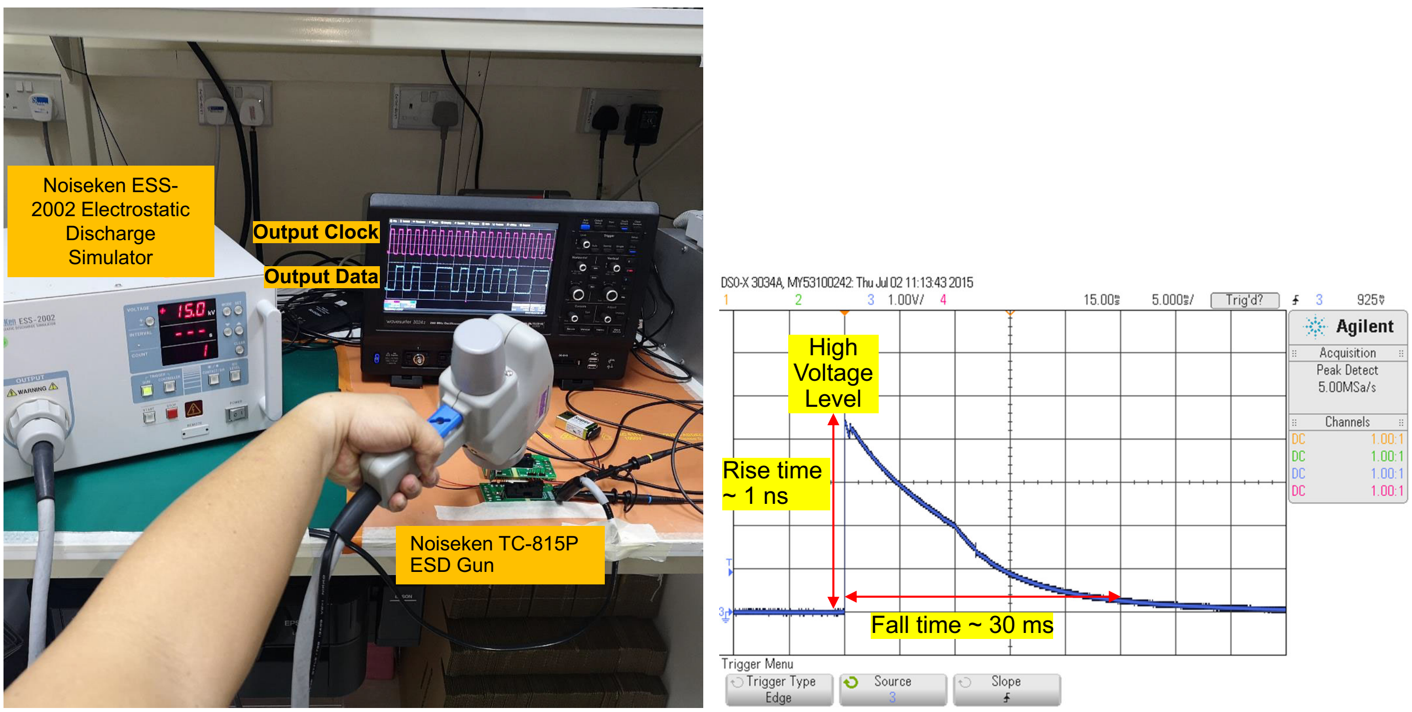


Optocouplers are certified to components' safety certification of IEC 60747-5-5 for reinforced isolation. This international certification recognizes partial discharge as the failure mechanism for insulation material breakdown. As such, the certification applies only to optocouplers. The alternative isolation technologies, such as magnetic and capacitive, are certified by German standard VDE 0884-10/11. Though the insulation material strength is determined by a partial discharge test, this may not be suitable to predict the lifetime reliability of the magnetic (space-charge degradation) and capacitive couplers (TDDB).

High Voltage Surge Test

A bench test setup can be easily assembled to compare the insulation strength of various isolators. Figure 4 shows the test setup where the high-voltage surge is applied using an ESD gun. The voltage profile of the ESD gun has a very fast rise time of about 1 ns and slow fall time of 30 ms. This surge profile is different from the IEC 60060-1 standard surge profile of 1.2 µs/50 µs, but it is sufficient for the purpose of comparisons of high-voltage strength of different isolation technologies.

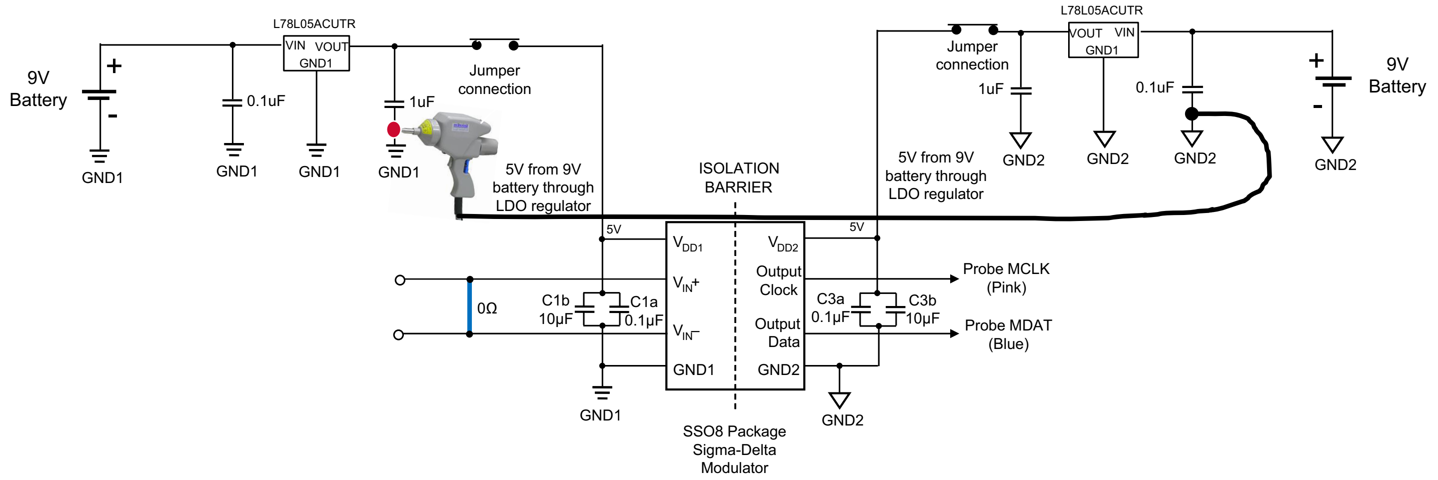
Figure 4: High Voltage Surge Test Setup Shown on the Left and the High Voltage Surge Profile on the Right



Three random samples each from two optocoupler manufacturers, Broadcom and Isolator A, one magnetic coupler (Isolator B) and one capacitive coupler (Isolator C) were selected for this high-voltage surge test. These isolators are high-precision current sensing sigma-delta modulators with an internal clock generator built into 8-pin stretched surface-mount package outline (SSO8). The isolation withstand voltage, Viso of this type of SSO8 package is rated at 5 kVrms per minute and with creepage and a minimum clearance distance of 8 mm.

Figure 5 shows the schematic diagram of the PCB used to hold the device under test (DUT).

Figure 5: Schematic Diagram of a PCB Board Used for the High-Voltage Surge Test

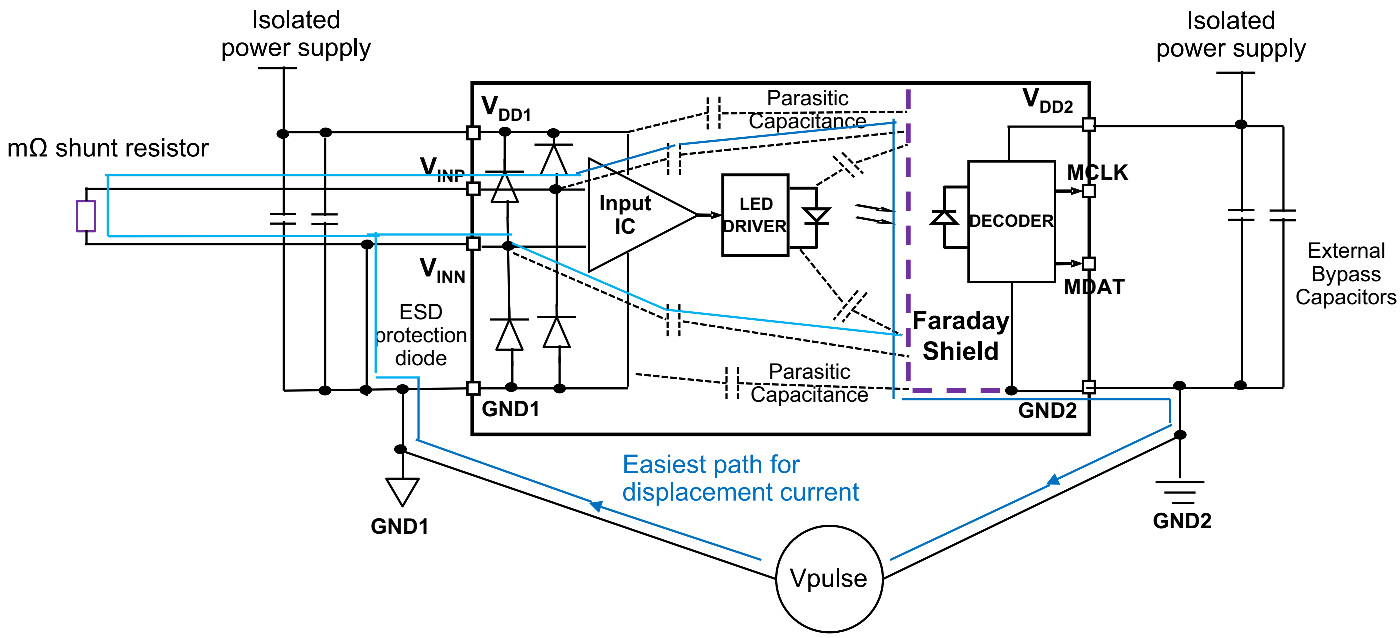


Both isolated side power supplies were provided from 9V batteries separately and regulated down to 5V through an LDO voltage regulator on each side of the isolation. The test was carried out by applying a high-voltage level starting from 15 kV between Gnd1-Gnd2 of the sigma-delta modulators. The output clock and data signal were observed for any anomalies. If the outputs resumed normal functionality after the high-voltage surge, the voltage level was increased by 1 kV, and the test continued up to a 21-kV test limit. If the output clock, data signal, or both latched, the test was stopped.

i. Faraday Shield

The high-voltage surge induces a high-density displacement current from Gnd1 to the input circuitry of the isolator and then transmits over to output circuitry and Gnd2 using capacitive structures or parasitic capacitance formed throughout the isolation barrier. Figure 6 shows the various parasitic capacitance paths formed between the wirebonds of the input circuitry/input leadframe to the Faraday shield of Broadcom optocoupler. The Faraday shield is grounded to Gnd2 and provides an electric and a magnetic shielding to remove the displacement current. In capacitive- or magnetic-coupling solutions, the Faraday shield is not a viable solution. A Faraday shield blocks the electric or magnetic fields used for data transmission in addition to transients.

Figure 6: Various Parasitic Capacitance Paths Formed Between the Wirebonds of the Input Circuitry/Input Leadframe to the Faraday Shield of Broadcom Optocoupler. The Faraday shield is grounded to Gnd2 and helps to remove the displacement current.



ii. Input-Output Capacitance, Ci-o

In addition to the Faraday shield, the Broadcom optocoupler leadframe and package design is optimized for smaller combined input to output capacitance, Ci-o. Table 2 shows the comparisons of Ci-o of various isolators. Displacement current follows the relation of i = c × (dv / dt). With a smaller Ci-o, smaller displacement current is induced during the occurrence of high-voltage surge.

Table 2: Input to Output Capacitance Comparisons Between Various Isolators

Sigma-Delta Modulator SS08 Package	Isolation Technology	Internal Faraday Shield	Typical Ci-o
Broadcom	Optical Coupler	Yes	0.5 pF
Isolator A	Optical Coupler	Yes	1.0 pF
Isolator B	Magnetic Coupler	No	2.2 pF
Isolator C	Capacitive Coupler	No	1.0 pF

Table 3 shows the results of the high-voltage surge test on the isolators with different technologies. As evident from the test, Broadcom optocouplers are the most robust against high-voltage surge, whereby no failure is observed for all the units under test up to the 21-kV test limit. Isolator A (optocoupler) outputs permanently latched starting from 16 kV onwards. Isolator B (magnetic coupler) outputs also latched from 16 kV onwards but recover when a power-on reset (POR) was carried out on either Vdd1, Vdd2, or both. For Isolator C (capacitive coupler), the outputs of the three units of Isolator C permanently latched at 15-kV, 17-kV, and 21-kV levels, respectively. Although Isolators A, B, and C started to fail at about the same level, Isolator C recorded the widest range of the high-voltage surge levels at which the test units failed.

Table 3: Results of High-Voltage Surge Test on Different Isolators

Sigma-Delta Modulator	DUT Number	High Voltage Transient across Gnd1-Gnd2 before Failure Occurs	Failure Mode
Optocoupler	U1, U2, U3	No failure up to 21-kV test limit	No failure observed
Isolator A	U1	16 kV	Output clock latch permanently high
	U2	18 kV	Output clock switches permanently on low voltage level
			Output data latch permanently low
	U3	17 kV	Output clock latch permanently high
			Output data latch permanently low
Isolator B	U1	17 kV	Output clock and data latch high. Recover at Vdd1 POR
	U2, U3	16 kV, 17 kV	Output clock latch low voltage level. Output data switch at low voltage level. Recover at Vdd2 POR.
Isolator C	U1, U2, U3	21 kV, 15 kV, 17 kV	Output clock and data latch permanently low/high

Being one of the advocates for the highly reliable optocouplers galvanic isolation technology, Broadcom's portfolio covers some of the industrials' highly adopted internally clocked sigma-delta modulators for precision shunt-based current and voltage-sensing solutions. Table 4 shows Broadcom product offerings of internally clocked sigma-delta modulators housed in the SSO8 package format.

Table 4: Broadcom Internally Clocked, Optically Isolated, CMOS Output, High-Precision Sigma-Delta Modulators Housed in SSO8 Package Format

Broadcom Part Number	Input Linear Range	Input Full Scale Range	Clock Frequency	Typical Signal to Noise Ratio (SNR)	Typical Offset Temp. Drift (TCVos)
ACPL-C740	± 200 mV	± 320 mV	20 MHz	86 dB	0.3 µV/°C
ACPL-C797	± 200 mV	± 320 mV	10 MHz	78 dB	1.0 µV/°C
ACPL-C797T[a]	± 200 mV	± 320 mV	10 MHz	79 dB	—
ACPL-C799	± 50 mV	± 80 mV	10 MHz	77 dB	0.3 µV/°C
ACPL-C799T[a]	± 50 mV	± 80 mV	10 MHz	77 dB	0.1 µV/°C

a. Automotive AEC-Q100 qualified and Ta, max. = 125°C.

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