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BEST OF...
INTERFACE IC's

BEST OF... INTERFACE IC's

INTRODUCTION

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Content Director

INTERFACE IC's play a key role in providing important functions such as interconnection, electrical isolation, and voltage and current protection in a wide variety of applications. Here's a look at some of the latest solutions, including new capacitive isolators for filtering electronic noise and the use of RS-485 transceivers for RS- electrical-fast-transient (EFT) protection We also look at interface IC solutions for automotive applications, including the multi-switch detection interface; the Local Interconnect Network (LIN) for applications that don't require high data speeds and where operations are of the on-off type, such as power door locks and windshield wipers; and high-efficiency, switched-mode power supplies.

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CHAPTER 1:

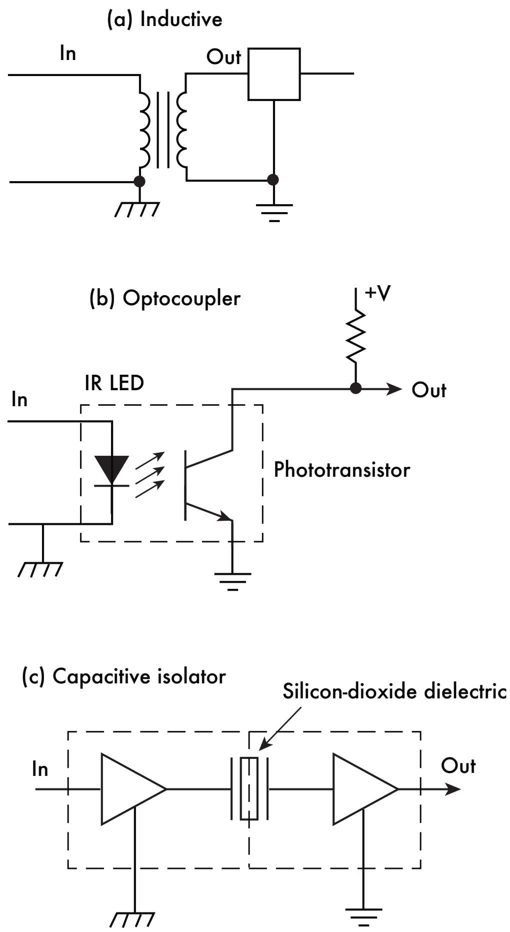
Need Isolation? Capacitive Solutions Outperform Opto, Magnetic Options

Industrial and medical applications can benefit from capacitive-isolator ICs, which offer a lower-power, simpler means of protection from ESD and other electrical surges.

By LOU FRENZEL, Contributing Editor

If you're designing circuits and equipment that require electrical/electronic isolation, it may be time to consider electronic isolation via capacitance. Of the methods available, capacitive isolation provides outstanding advantages over magnetic isolation by transformer or optoisolation with an LED and photodetector.

Such isolation is a common requirement in most industrial and medical applications. That's where capacitive-isolation ICs, which have been developed and refined for implementation into these critical designs, step in.



1. Common electrical isolation methods include inductive (a), optocoupler (b), and capacitive (c).

ISOLATION DEFINED

Isolation is the process of blocking some signals and electrical connections while allowing others to occur. Known as galvanic isolation, this process prevents direct electrical contact between input and output, but allows for the transfer of signals. For instance, a typical isolator prevents dc or ac supply voltages from being passed on, yet at the same time permits data signals to pass.

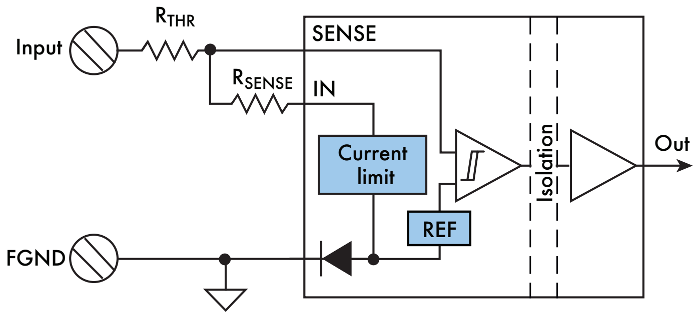
A major function of isolators is to separate the common grounds of input-signal devices and the equipment receiving the signals. Using a single common ground almost always introduces ground loops and the attendant unwanted offset voltages.

Keeping high voltages as great as 10 kV from industrial equipment away from computers, sensitive equipment, and human operators is another function of isolators. In addition, isolators protect sensitive equipment from electrostatic discharge (ESD), electrical fast transients (EFTs), and other variations from electrical surges that are common in an industrial setting.

Such protection gives isolated equipment good electromagnetic compatibility (EMC) as required to meet selected certification standards. Capacitive-isolation ICs meet all of these requirements while supporting high-speed data rates and lower power consumption over other methods.

COMMON ISOLATION METHODS

Figure 1 shows the three common isolation methods. The transformer in Fig. 1a is the most obvious—it uses two



2. Shown is a functional block diagram of a capacitive isolator such as the TI ISO1211.

electrically isolated windings on a common magnetic core. Signals are passed by magnetic induction from primary winding to secondary winding. The isolation is excellent, but transformers have some downsides. They're typically larger, heavier, and more expensive than other options. Though they do a good job of blocking dc, their frequency response can limit data rate unless special high-speed transformers (e.g., Ethernet) are used.

Optocoupler ICs have long been a popular isolation device *(Fig. 1b)*. The signals to be passed are sent to an internal IR LED that switches off and on with the logic signal input to activate a phototransistor that turns off and on at the output. Isolation is excellent because of the insulated separation of the LED and photodetector.

The third option is capacitive *(Fig. 1c)*. The signal path is via a capacitor with its insulating dielectric. A capacitive isolator readily blocks dc, but easily passes high-speed data signals and provides the ESD and transient protection indicated earlier.

Modern capacitive-isolated digital input receivers can also help simplify system design. When compared to optocouplers and other techniques, this new design approach results in advantages that include lower power dissipation, smaller boards and modules, simplified system design, and higher-speed operation.

HOW CAPACITIVE ISOLATORS WORK

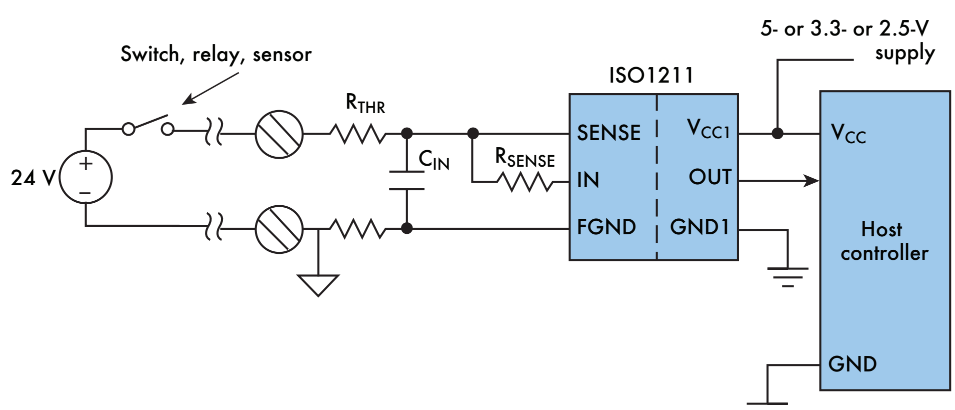
Figure 2 shows a simplified diagram of a capacitive isolator. The input is applied to two resistors: a sense resistor (R_{SENSE}) that establishes the amount of current drawn from the input sensor or device, and a threshold resistor (R_{THR}) that sets the input logic thresholds. A comparator with hysteresis shapes the input data signal for transmission to the output across a silicon-dioxide isolation barrier.

Since capacitive coupling blocks dc, how do logic signals get from input to output? The answer is modulation. Capacitive isolators implement a transmitter that uses on-off keying (OOK) modulation to pass the input data through the capacitive-isolation barrier. OOK is a variant of amplitude-shift keying (ASK). A binary 1 (typically +24 V) input turns on a high-frequency carrier that's transmitted through the capacitor barrier. A binary 0 produces no carrier. The receiver circuitry demodulates the OOK signal envelope and reproduces the data by way of an output buffer stage.

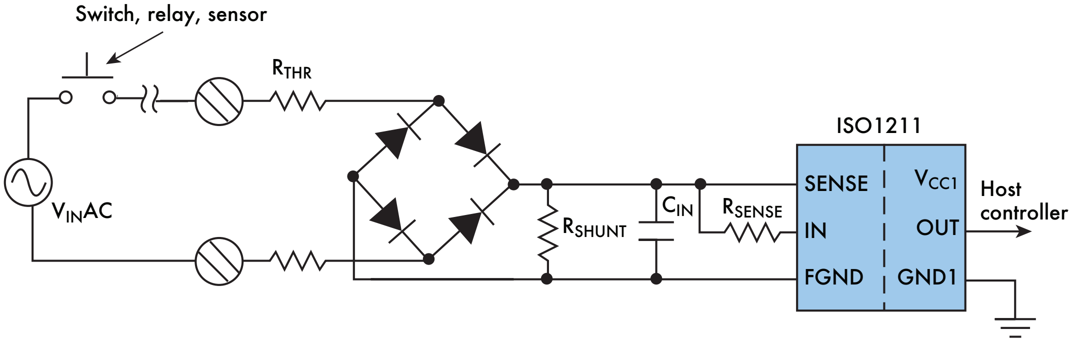
Representative of the capacitive isolators available today are Texas Instruments' ISO1211 and ISO1212. These devices have digital input receivers that can operate over a 9- to 300-V dc (24 to 60 V typical) or ac input range with external resistors setting the current and voltage limits. They're compliant to IEC 61131-2 specifications for Types 1, 2, and 3 inputs, and don't require a field-side power supply. The ISO1211 is a single channel device, while the ISO1212 has two channels.

These devices can operate with a dc supply voltage in the 2.25- to 5.5-V range with low power dissipation. Input voltage protection is inherent with reverse voltage protection (±60 V). The ICs offer an excellent alternative to optocouplers for programmable logic controllers (PLCs), motor controls, and other industrial equipment. They support clock rates up to 4 MHz where typical optocouplers are limited to rates of about 20 kHz. Typical propagation delay is 140 ns compared to about 20 µs for an optocoupler.

An evaluation module for the ISO1211 is available for experimentation (SLLU258A).



3. A 24-V or other dc source is connected to the IN and SENSE pins of the TI ISO1211.



4. To monitor an ac source, a bridge rectifier is used to condition the ac into a proportional dc. CIN filters out the ripple.

DESIGN EXAMPLES USING CAPACITIVE ISOLATORS

Isolation modules are used in wide range of industrial applications. PLCs, motor drives, and CNC-controlled machines in factories, process control plants, and warehouses represent several examples. This equipment gets its inputs from switches, sensors, or dc and ac voltage sources.

Isolators are used to eliminate the ground-loop problems associated with long lines connecting two sources and to provide high-voltage protection. One typical arrangement is shown in *Figure 3*. A switch, relay, or sensor connects 24 V dc to the isolator through a threshold resistor (R_{THR}) and a sense resistor (R_{SENSE}). The isolator output connects to a host microcontroller.

Some applications require monitoring remote dc or ac voltages from power supplies, battery monitors, or some relay-controlled device. To monitor ac, a bridge rectifier like that in *Figure 4* is used. The ac is rectified into dc and filtered with C_{IN} to minimize ripple to the SENSE input on the IC. Resistors limit the input voltage to the isolator. A dc source may be monitored via the capacitive isolator through a voltage divider to bring the input voltage below the upper limit of the isolator using the arrangement in Fig. 3.

Capacitive-isolated comparators offer a reliable and low-power alternative to optocouplers for ±48-, 110-, and 240-V dc and ac detection. Advantages of using isolated digital inputs include precise voltage thresholds, low input current draw, higher speed, lower failures in time (FITs) higher reliability, and operation up to 125°C.

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CHAPTER 2:

Neutralize the Noise in Industrial RS-485 Networks

The RS-485 transceiver is a key player in determining EMI resistance for a data network, and it's important that it can withstand the rigorous transient testing.

By LOU FRENZEL, Contributing Editor

The RS-485 standard defines a popular and widely used serial data interface and network that's been in use for over 30 years. It's found in factories, process control plants, building automation, and other industrial applications. RS-485 popularity stems from its differential transmission format that minimizes the noise inherent in most industrial settings.

Such noise tolerance and immunity is critical to the adoption of a data network for industry, as well as the selection of its cabling and transceivers. For example, a key performance characteristic for RS-485 transceivers is electrical-fast-transient (EFT) protection.

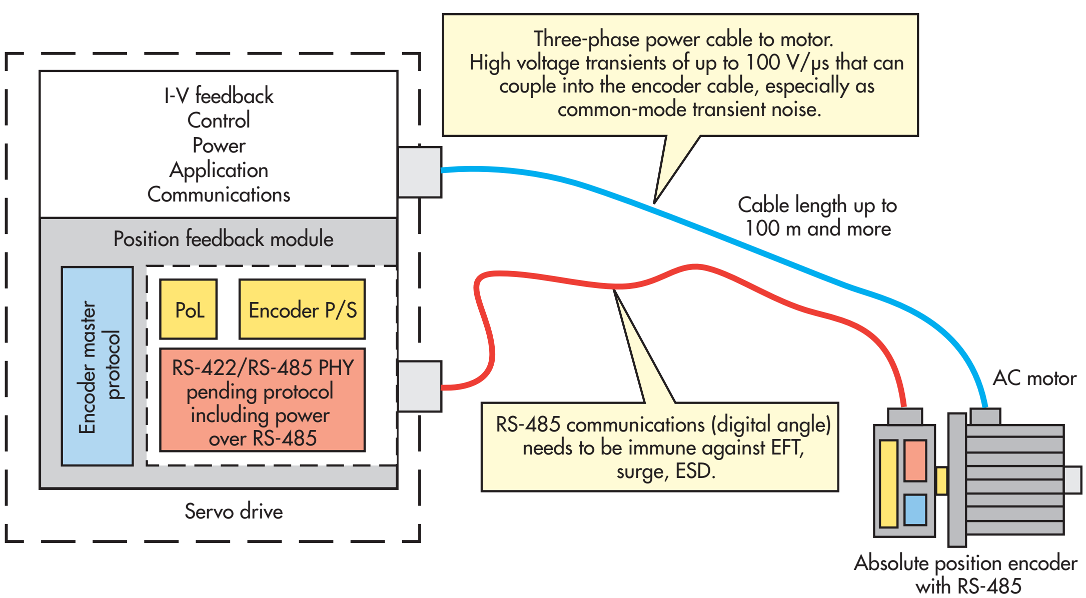
Let's take a closer look at the RS-485 standard, and where ETF protection is achieved.

A BRIEF SUMMARY OF RS-485

RS-485, a standard of the Electronic Industry Alliance (EIA) and the Telecommunications Industry Association (TIA), is designated as EIA/TIA-485-A. The American National Standards Institute (ANSI) also recognizes this standard. Its main features include:

- Unshielded twisted-pair (UTP) transmission line (like CAT5).
- Differential transmission.
- Mulitpoint drops or connections for up to 32 nodes.
- Half-duplex operation (single cable), full-duplex (two cables)
- Maximum range up to 5000 feet.
- Data rate depends on network length, from 100 kb/s to 50 Mb/s.

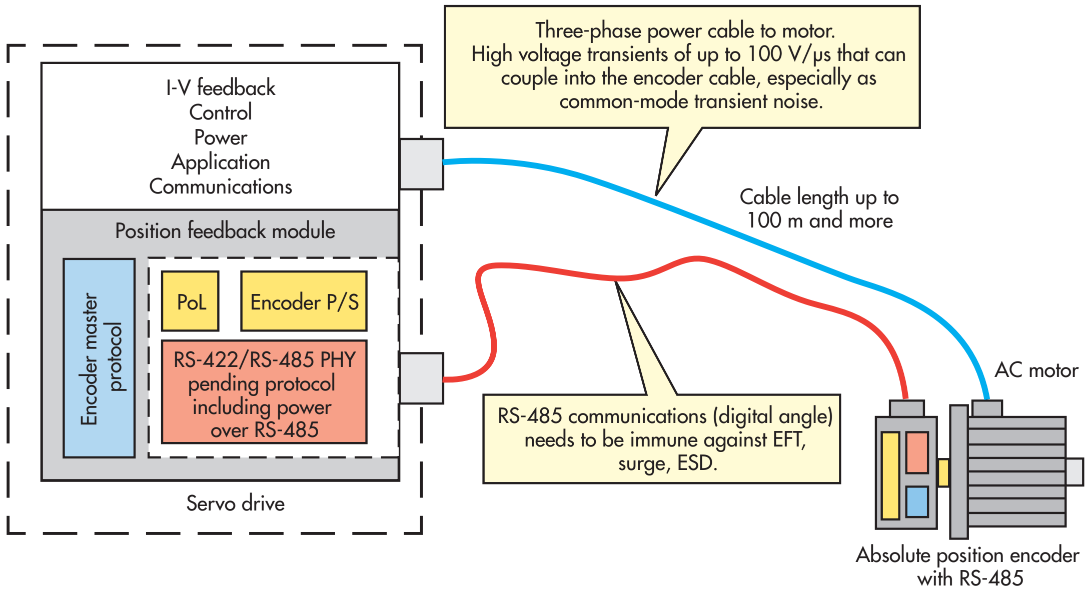
Though no formal data protocol is specified, the UART format with start and stop bits and up to 8 bits of data



1. The RS-485 network is implemented with unshielded twisted-pair cable, such as CAT5. Up to 32 nodes can tap into the line with a transceiver. (Source: Texas Instruments)

is commonly used, as are other proprietary protocols. Specific connectors haven't been defined.

Figure 1 shows the basic network configuration. The twisted-pair line must be terminated in its characteristic impedance (typically 120 Ω). Each node contains an IC transceiver. While the UTP balanced line is effective in canceling noise, it's the transceiver that must provide protection, especially from extreme transients generated mainly by inductive switching commonly found in industrial settings.



2. A typical RS-485 application is illustrated in the TI's "High EMC Immunity Reference Design for Absolute Encoders." Signal integrity and transient protection are essential to the system's performance. (Source: Texas Instruments)

WHAT IS AN EFT?

An electrical fast transient is a very-high-voltage pulse or spike that occurs as the result of an inductive discharge. It's usually produced by the switching action of inductive loads, such as a motor winding, relay, contactor, or solenoid, which are plentiful in industrial applications. The EFT generally occurs when a switching action terminates the current to an inductive load. That abrupt switching action causes the magnetic field in the inductor to quickly collapse, thereby inducing a very high voltage pulse. Remember the expression:

$V = -L(di/dt)$

Large inductances and rapid change in current will generate a huge voltage spike. It doesn't last long, but it can be hundreds to thousands of volts. That current spike wreaks havoc in nearby electronic equipment. Its harmonic content is a major contributor to the overall electromagnetic interference (EMI) experienced in a factory or office building.

Such a spike will also propagate to other equipment, including any network wiring. Therefore, the transceivers on that network must be able to withstand the transients with minimal disruption to any data communications over the network. Differential cabling helps dispel the pulse, but often such a transient can kill nearby electronic circuits. That's why certain critical circuits are protected to ensure reliable operation in a hostile, transient-heavy environment.

TRANSIENT TESTING

To determine if a circuit or product can withstand an EFT, several organizations have developed testing procedures for certification purposes. For instance, the International Electrotechnical Commission's (IEC) 61000-4-4 specification defines a form or transient pulse testing that's used to determine the ability of a device or system to survive an EFT without damage. Various industrial or automotive certifying organizations base their testing on these testing procedures.

The testing process generates a series of high-peak-voltage pulses with fast rise times along with a rapid repetition rate. The goal is to ensure that the device or network can continue to function in the presence of high-voltage pulses without failure or to transmit data reliably without error. Other testing procedures evaluate the ability of circuits to survive various types of electrostatic discharge (ESD).

One device that has survived such rigorous testing is Texas Instruments' THVD1550 RS-485 transceiver. It's part of a family of RS-485 transceivers with built-in protection circuits that allow them to hold up under a barrage of IEC test procedures, including:

- ±30-kV HBM (human body model) ESD
- ±18-kV IEC 6000-4-2 ESD contact discharge
- ±25-kV IEC 6000-4-2 ESD air-gap discharge

- ±4-kV IEC 6000-4-4 EFT

The THVD1550 is a low-power-consumption IC that operates from a standard 5-V supply. It's capable of data rates ranging from 500 kb/s to 50 Mb/s. Various package types and sizes are available.

HIGH EMC IMMUNITY RS-485 INTERFACE REFERENCE DESIGN FOR ABSOLUTE ENCODERS

As a validation of the THVD1550's ability to survive EFT and ESD, TI developed the High EMC Immunity RS-485 Interface Reference Design for Absolute Encoders. It's representative of some systems in an industrial setting, such as CNC machine tools, robots, and a wide range of other motor-driven devices.

Figure 2 shows an example arrangement, with a servo drive unit containing the power circuitry to drive a remote ac motor. The power cable could be up to 100 meters long. Attached to the motor is an absolute position encoder that provides digital feedback to the servo-drive control circuitry. The connection is via an RS-485 bus. The RS-485 UTP cabling may run near the power bus and other sources of EMI. THVD1550 transceivers can survive any EFT or ESD disturbance that may occur.

This reference design demonstrates the use of the TI RS-485 transceivers on both the servo drive and within position encoders such as EnDat 2.2, BiSS, Tamagawa, etc. EMC immunity to inverter switching noise is particularly important for position-encoder feedback systems within industrial drives.

SIGNAL INTEGRITY AND TRANSMISSION RATES IN RS-485 NETWORKS

As with any wired network, the data rate and error performance are a function of the cable length. The cable acts as a low-pass filter rounding pulse edges and forcing a slower bit stream. The longer the cable, the greater distortion and the lower the bit rate for a given error percentage. Ambient noise also produces jitter that affects the overall signal quality.

A key measure of signal quality is the amount of jitter that occurs. Remember that jitter is the rapid variation in time of the leading and trailing edges of a bit stream primarily caused by noise. So a longer cable generally means more noise and jitter. There are various ways to measure and express jitter. One method is to state it in terms of peak-to-peak time variation of the pulse transitions, and then express that in terms of a percentage of the transmission bit time. Eye diagrams on an oscilloscope show the jitter performance.

An application note from TI contains lab data on the signal integrity of the THVD1550 RS-485 transceiver device, at various cable lengths and data rates. Jitter measurements were gathered, with the results tabulated and plotted. For example, at 1,000 feet, the maximum data rate was 10 Mb/s with a jitter of 60 ns (43%). At 5,000 feet, the data rate maxed out at 1.5 Mb/s with a jitter of 667 ns.

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CHAPTER 3:

The Multi-Switch Detection Interface: A Cure for Many BCM Ailments

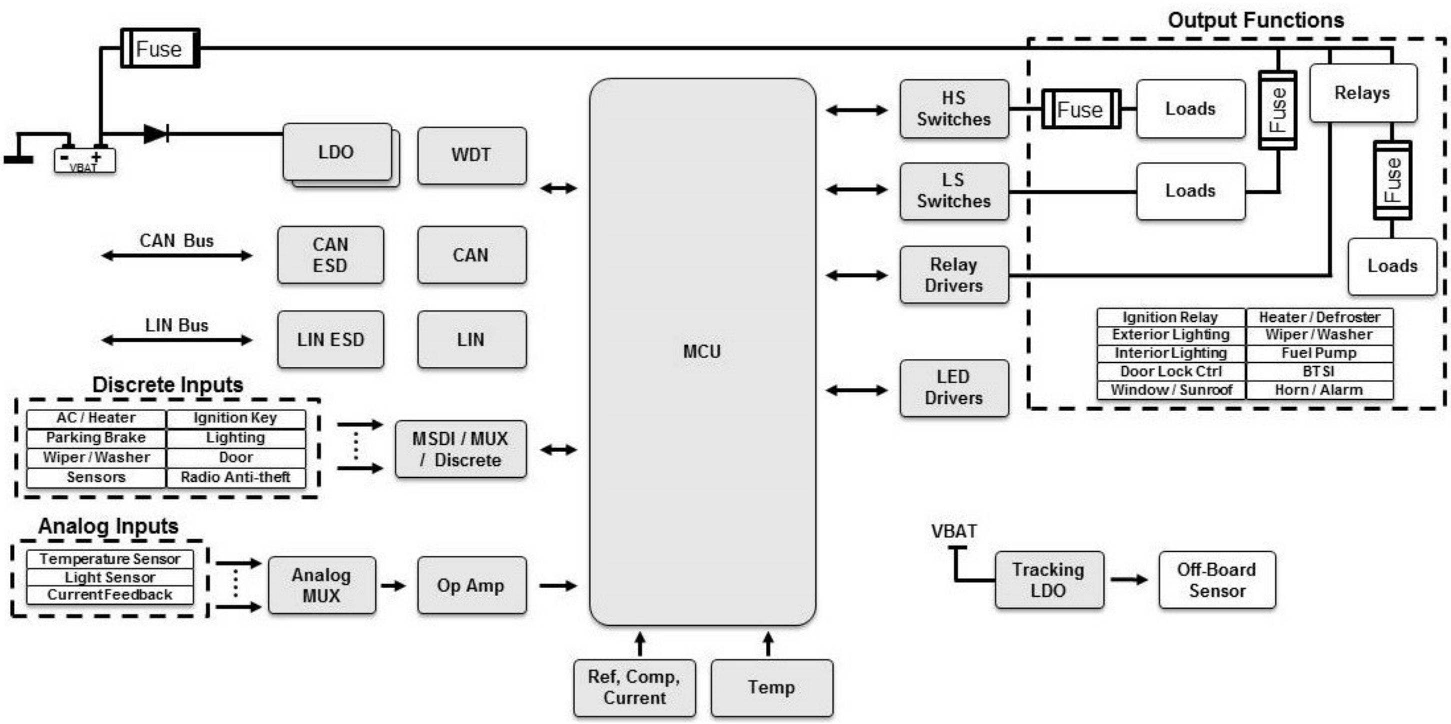
An MSDI device bundles many standard interface requirements in a compact package, giving designers more flexibility when integrating a body control module in ever-more-complex automotive designs.

By PAUL PICKERING, Contributing Editor

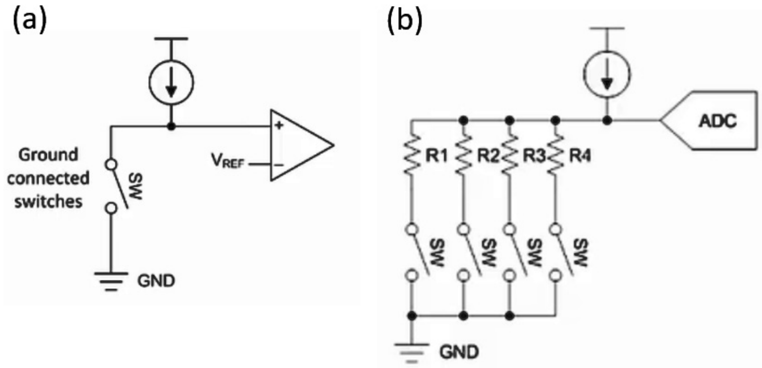
An automotive body control module (BCM) is an electronic control unit (ECU) that manages a wide range of vehicle comfort, convenience, and lighting functions, including the central locking system, power windows, chimes, closure sensors, interior and exterior lighting, wipers, and turn signals.

Figure 1 shows the functional blocks in a BCM. The primary function of the BCM is to monitor the status of discrete switches and analog sensors related to these functions and control high- and low-side switches, relays, and LED drivers. The BCM also exchanges information with other modules over a vehicle network: the Controller Area Bus (CAN) or Local Interface Network (LIN) protocols are both widely used.

The number of switches and sensors varies from one



1. A BCM manages a wide range of comfort, convenience, and lighting functions. (Source: TI blog: "The multi-switch detection interface: integrated feature for smaller, more efficient designs," Fig. 1)



2. Digital (a) and resistive (b) switches are two common options in BCM applications. (Source: TI training: "Challenges in today's Body Control Module (BCM) design")

vehicle to the other, but it can be 100 or more in a high-end implementation. There are two common types of switches in a vehicle *(Fig. 2)*. A digital switch (Fig. 2a) only has two states, open and closed. Examples include the seat-belt engaged switch, rear-window defroster on/off, front and rear fog push button, the trunk switch, and the door-locking switch. The digital switch most commonly switches to ground, but switching to the battery voltage is also possible.

A resistive switch (Fig. 2b) has multiple states or positions. Each state connects a different resistor value to ground when selected. Examples include the ignition key switch, the taillight and headlight control switch, as well as the wiper control switch.

A microcontroller typically monitors the status of the various switches. Each type requires a different interface, but most MCUs feature general-purpose input/output ports (GPIOs) that can be configured to perform multiple functions. A digital switch can be sampled simply by a comparator, since it only has two states. An analog switch outputs a different voltage for each switch position, so the GPIO must connect to an analog-to-digital converter (ADC) to sample the value and determine the selected value.

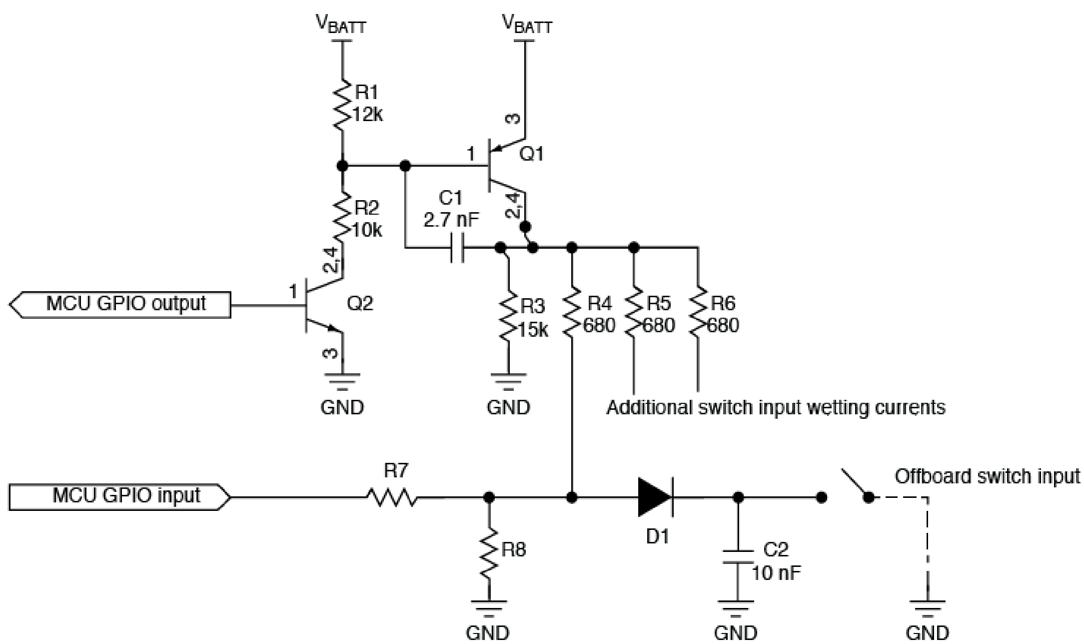
Connecting a mechanical switch to an MCU involves a lot more than hooking up a wire. Two issues pop up: The low-voltage CMOS MCU input must be protected from external transients; and the switch contacts must be provided with a minimum wetting current that establishes a voltage to be measured, and prevents premature failure due to oxidation at the contacts.

Let's look at a simple switch-to-ground interface *(Fig. 3)*. The traditional method of connecting an external ground-referenced switch uses numerous discrete components. For protection, capacitor C2 shunts ESD and transient energy, and diode D1 blocks high voltages. A GPIO output enables and disables the wetting circuit. A logic "high" output from the GPIO turns on the wetting current with the help of transistors Q1 and Q2; resistors R1, R2, and R3; and capacitor C1. Resistor R4 sets the wetting current at the switch. The voltage at the junction of R4 and R8 establishes the value at the GPIO input when the switch is open.

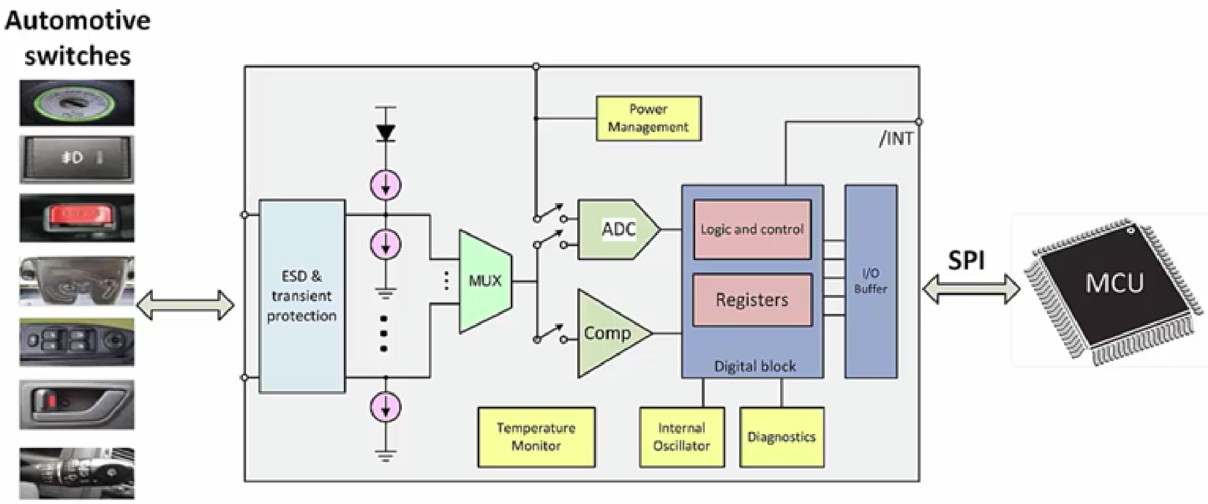
In summary, each switch channel requires as many as five resistors, two capacitors, one diode, two FETs, and one unique GPIO connection.

PROBLEMS WITH THE DISCRETE APPROACH

A discrete implementation such as shown in Fig. 3 poses



3. The interface for a mechanical switch requires multiple discrete components to protect the microcontroller and provide wetting current for the contacts. (Source: TI blog: "The multi-switch detection interface: integrated feature for smaller, more efficient designs," Fig. 2)



4. An MSDI device combines the interface components for many switch inputs into a single device. (Source: TI training: "How MSDI helps solve system-level challenges in BCM design")

several challenges for the designer:

High component count: The first issue is the high component count. For example, a BCM with 24 switch inputs requires a total of 78 resistors, 27 capacitors, 24 diodes, and six FETs. A large component count increases the size of the BCM, and pushes up the BOM and manufacturing costs.

High GPIO count: The 24-switch BCM also requires a total of 28 GPIO—one for each switch, plus four more to control the FET timing. This forces the use of a high-pin-count microcontroller, leading to increased cost and more complex PCB routing.

High power consumption: For fast switch response time, the microcontroller either needs to be active all of the time or be woken up periodically to ensure continuous switch monitoring.

A microcontroller typically draws milliamps of current. This might not be a problem, perhaps, when the vehicle is running and the alternator is charging the battery. However, when the ignition is off, automobile manufacturers require electronic modules to consume minimum quiescent current to prolong battery life. Keeping the BCM microcontroller alive to monitor switches may not be an option.

Variation in wetting current: The wetting current flowing through the switch in Fig. 3 depends on the battery voltage V_{BATT} and resistor R4. Even during normal operation, V_{BATT} can vary by several volts from its nominal value of 14 V due to transient load changes, and drop down to 6 V or less during cranking. Abnormal events such as load dumps and jump starts can cause much larger variations. The wetting current is proportional to the battery voltage. If the battery voltage changes by 20%, say, so does the wetting current.

The wetting current can also change with variations in resistive loading on the switch, especially if it's an analog switch with different resistances for different switch positions. Wetting-current variations complicate the system design. The effects can range from inconvenience to a system malfunction, especially if the BCM reads the wrong switch status.

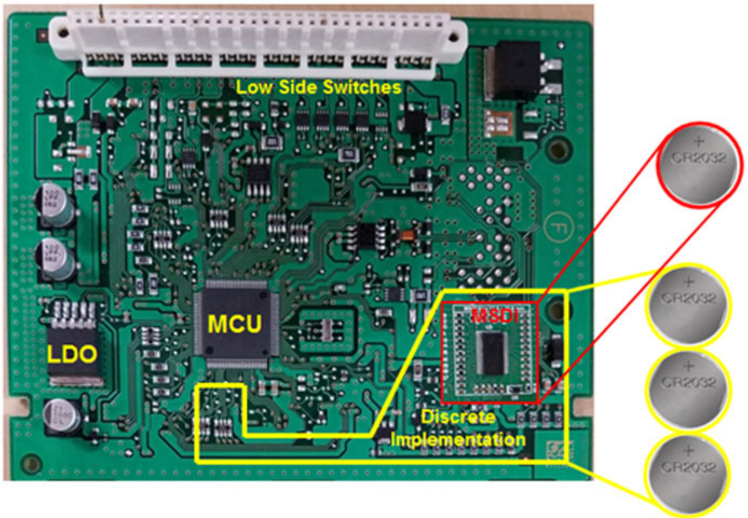
Large ESD capacitor: The discrete design requires a large capacitor on each input to provide system-level ESD protection and prevent damage to other components on the PCB. A large capacitor on the input increases the time needed for the GPIO voltage to settle. This causes delay in the switch response time and forces the microcontroller to stay active longer, increasing the system power consumption.

Sharing of switch status: In some designs, a switch must be monitored by multiple microcontrollers for safety and redundancy reasons. When the same switch is connected to multiple microcontrollers, a blocking diode is typically needed to ensure the current flows only in the desired direction. These diodes increase cost and consume board space.

Design portability and reuse: With the large number of vehicle options available to consumers, creating portable and reusable designs across different platforms is a highly desirable goal. Each switch option (resistive switch, switch to ground, or switch to battery) requires a different discrete design, making it more difficult to create a uniform reference platform for multiple applications. This prolongs the design cycle and consumes more engineering resources.

THE MSDI DEVICE PROVIDES AN INTEGRATED SOLUTION

A multiple switch detection interface (MSDI) is a convenient way to take care of the issues discussed above. The MSDI integrates the discrete components for multiple channels into a single device *(Fig. 4)*. It provides a common interface



5. The MSDI-based solution consumes approximately 66% less board space than a discrete design. (Source: TI blog: "Body control modules—invisible but fundamental for every car")

for multiple analog or digital switches and communicates their status back to an MCU via an industry-standard serial peripheral interface (SPI).

MSDI devices have adjustable wetting currents capable of sinking and sourcing currents for both battery- and ground-connected external switch inputs. These currents are internally monitored and controlled, so they remain consistent over a wide range of battery input voltages. MSDI switch inputs can also handle automotive load dump and reverse-battery voltages without the need for discrete blocking diodes and wetting-current components, saving additional board area and cost.

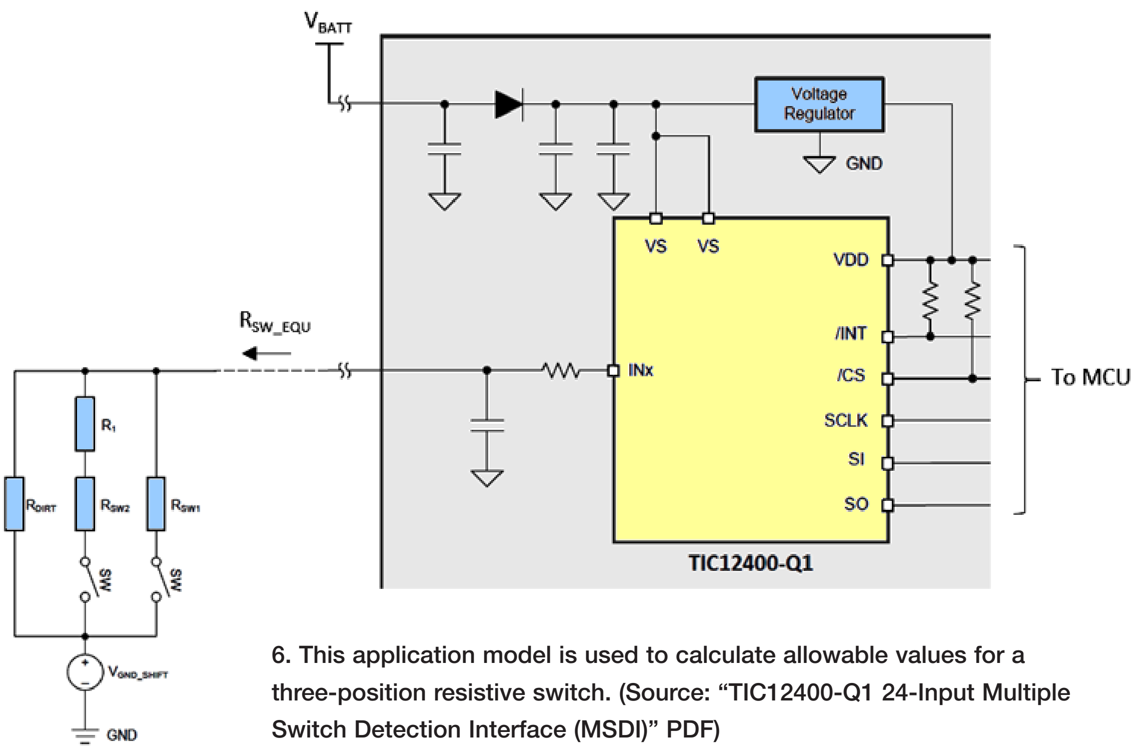
The TIC12400-Q1 is an MSDI device designed for the 12-V automotive environment. The device, which operates independently of the MCU, features a comparator to monitor digital switches, plus a 10-bit analog-to-digital converter (ADC) to monitor multi-position analog switches. Programmable detection thresholds for the ADC and the comparator allow the TIC12400-Q1 to support various switch topologies and system configurations.

The TIC12400-Q1 monitors up to 24 direct switch inputs. Ten inputs can monitor switches connected to either ground or battery. Each input can use one of six selectable wetting-current settings to support different application scenarios.

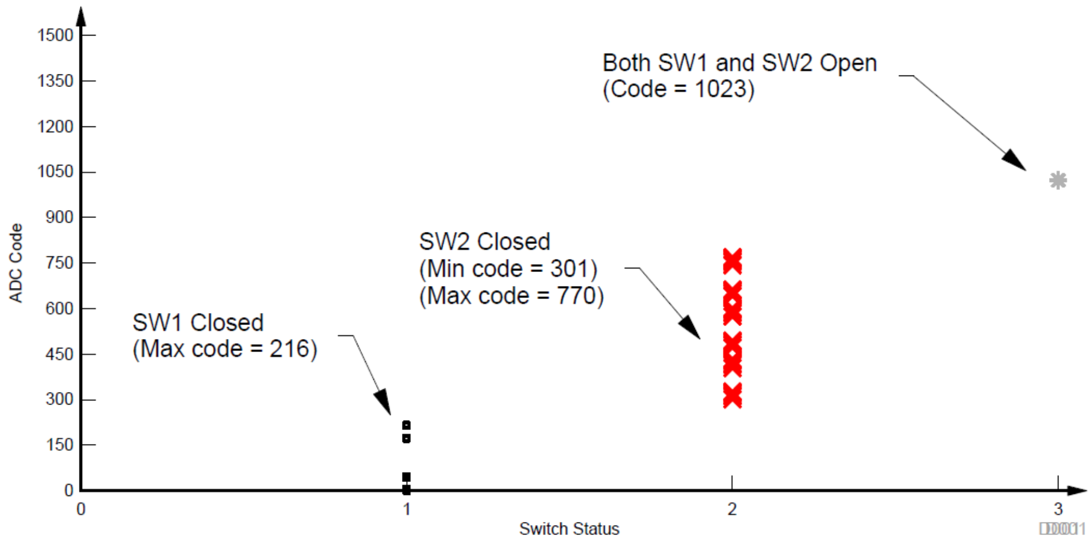
The integrated 10-bit, 0- to 6-V ADC measures the voltages on any input not set in comparator input mode, including any input threshold that requires special programming or any multi-threshold input. In addition, the ADC can directly monitor external analog signals.

The device can monitor all switch inputs while the MCU is in sleep mode. When action is needed, it can wake up the MCU with an interrupt, thus reducing power consumption of the system. The TIC12400-Q1 also offers integrated fault detection, ESD protection, and diagnostic functions for improved system robustness.

The TIC12400-Q1 supports two operational modes: continuous and polling mode. In continuous mode, wetting current is supplied continuously. In polling mode, TIC12400-Q1 turns on the wetting current to sample the input periodically, under control of a programmable timer. Poling mode significantly reduces the system power consumption.



6. This application model is used to calculate allowable values for a three-position resistive switch. (Source: "TIC12400-Q1 24-Input Multiple Switch Detection Interface (MSDI)" PDF)



7. Each of the switch positions will result in a range of valid ADC codes separated by "no-go" bands. This example uses a nominal wetting current of 5 mA. (Source: "TIC12400-Q1 24-Input Multiple Switch Detection Interface (MSDI)" PDF, p. 120)

For automotive applications without resistive multi-position switches, Texas Instruments also offers the TIC10024-Q1. This device has an identical feature set to the TIC12400-Q1, but without the ADC.

Figure 5 shows how the MSDI solution can save space versus a comparable discrete design. The underlying board is a BCM with a discrete switch interface. On it, we've superimposed, at a 1:1 scale, a snippet from the Automotive MSDI reference design—an example implementation using the TIC12400-Q1 device and required external circuitry. Both designs provide wetting current, reverse-blocking diodes, and ESD capacitors. With a two-layer board, the MSDI reference design measures 17.5 by 18.8 mm, one-third the size of the discrete solution.

TIC12400 APPLICATION EXAMPLE: RESISTIVE SWITCH

Using an MSDI certainly simplifies the hardware design and layout of a BCM switch interface. However, designing for the automotive environment requires the designer to pay close attention to a number of variables and tolerance stackups to produce a robust design.

Let's look at an example *(Fig. 6)* of the TIC12400-Q1 decoding the output of an analog resistor-coded switch with three states. When the switch changes state, the TIC12400-Q1 must correctly detect the state transition, store the information, and alert the MCU via an interrupt so that it can retrieve the data from the TIC12400-Q1's status registers. The three states are:

State 1: Both switches open

State 2: SW1 open and SW2 closed

State 3: SW1 closed and SW2 open

Fig. 6 shows the switch specification. R_{DIRT} represents the leakage across the switch in the open state; R_{SW1} and R_{SW2} are the two switch resistances; and R_1 is the discrete resistor added in when switch 2 closes. The *table* shows the minimum and maximum values of these resistances. The TIC12400 sees an equivalent resistance R_{SW_EQU} at the selected input pin IN_X.

To represent the automotive environment, we make the following assumptions: the battery voltage V_{BATT} can vary between 9 and 16 V; and there is a potential ground shift of up ±1 V between the switch reference point and the ground reference of the TIC12400-Q1. The table shows the design specifications.

	SPECIFICATION	MIN	MAX
V_{BAT}	9 V ≤ V_{BAT} ≤ 16 V	9 V	16 V
R_1	680 Ω ± 8%	625.6 Ω	734.4 Ω
R_{SW1}	50 Ω Max when closed	0 Ω	50 Ω
R_{SW2}	50 Ω Max when closed	0 Ω	50 Ω
R_{DIRT}	5000 Ω Min	5000 Ω	∞
V_{GND_SHIFT}	±1 V	-1 Ω	+1 Ω

Design example specifications. (Source: "TIC12400-Q1 24-Input Multiple Switch Detection Interface (MSDI)" PDF, p. 118)

The design begins by calculating the equivalent resistance values at different switch states. After taking into account RDIRT and the 8% resistance tolerance of R_1, each state yields a minimum, nominal, and maximum value for RSW_EQU.

When a switch closes, the current source in the TIC12400-Q1 sources a wetting current that flows through the switch. This current is nominally the set value I_{WETT}, but is subject to variations over temperature and process, resulting in an actual current IWETT_ACT.

The nominal voltage at the IN_X pin is therefore:

VINX = RSW_EQU × IWETT_ACT

The ±1-V ground shift adds further uncertainty: The final measured value of V_{INX} can be within a range of allowable values that all represent a valid switch configuration.

The three-position switch will have three sets of voltage bands *(Fig. 7)*. These translate into three sets of valid ADC digital output codes, separated by code ranges that don't correspond to a valid switch output. The designer can pick a code in the middle of each "invalid" range as the decision point for each switch position.

This example is covered in detail in the TIC12400 datasheet. There's also a reference design, mentioned earlier—the MSDI reference design contains example implementations of a variety of high-voltage (HV) switch inputs using an MSDI device. The switch inputs satisfy a typical automotive requirement. They can withstand transients up to 40 V and reverse battery conditions down to –16 V.

The user guide gives examples of a TIC12400-Q1 or TIC10024-Q1 MSDI handling HV switch inputs for BCM, faceplate, and top-column-module (TCM) applications. In addition, the design utilizes a wide-V_{IN} low-dropout (LDO) TPS7B6733-Q1 automotive regulator to create a fixed 3.3-V supply suitable for powering the BCM MCU.

Conclusion

As the number of comfort and convenience features in automobiles continues to increase, the BCM must interface with large numbers of switches in several different configurations, while simultaneously minimizing current consumption and keeping board small. A multi-switch detection interface (MSDI) device helps designers meet these requirements by bundling many standard interface requirements in a compact package.

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Learn how to handle a variety of high-voltage switch inputs using a multi-switch detection interface (MSDI) device.

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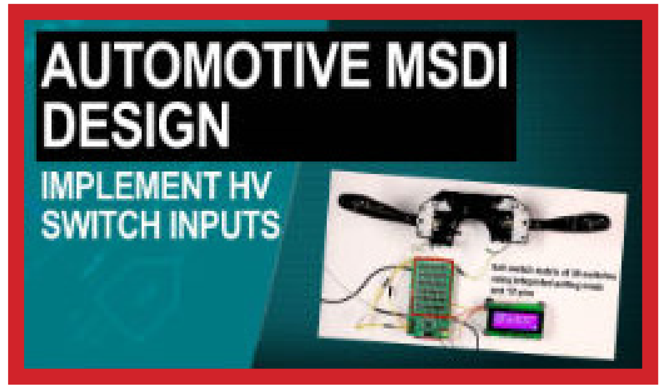


CHAPTER 4:

The LIN Interface and Automotive Interconnects—A Perfect Match

Employing just a single wire, this easy-to-use, inexpensive, low-speed bus dominates automotive subsystem connectivity.

By LOU FRENZEL, Contributing Editor

As more electronic subsystems populated automobiles over the years, engineers discovered the necessity of interconnecting them with serial data networks to minimize wiring and optimize their performance. Today, the modern vehicle contains multiple networks, combining some mix of the Controller Area Network (CAN), Media Oriented Systems Transport (MOST), FlexRay, and even Ethernet. But probably the most widely used interface is the Local Interconnect Network (LIN), which connects a variety of sensors and actuators. LIN is a simple 1-wire bus that's flexible, tolerant, and low cost. Here's a look at how LIN is used in vehicles today.

LIN APPLICATIONS

Most newer vehicles contain at least a dozen LIN nodes. They're used in applications where data speed isn't high and many operations are of the off-on type. Common applications include:

- Power door locks
- Power windows
- Power seats
- Power mirrors
- Windshield wipers
- Seat heaters
- Heating and air-conditioning controls
- Interior lights
- Climate controls
- Steering-wheel controls
- Sun roof
- Trunk

If you want to take a look inside one of today's car models and see where LIN transceivers might be used, check out this blog from Texas Instruments. Within it, an in-cabin virtual view launches and lets you explore a few of the functions that LIN enables today.

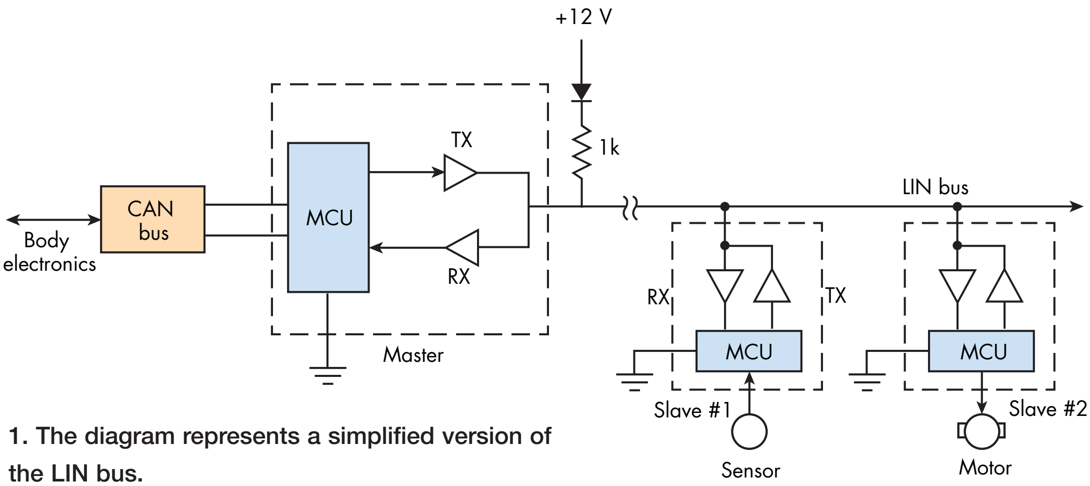
LIN 101

LIN is a single-wire bus that uses the vehicle ground as the return. It was created back in the late 1990s and is sponsored by the LIN Consortium. It's been standardized as ISO17897 and ISO9141. The standard has been revised and updated several times over its lifetime. The LIN standard defines the physical (PHY) and media-access-control (MAC) layers of the OSI networking model.

A LIN bus can accommodate up to 16 drops or nodes. *Figure 1* shows the basic arrangement. The master MCU connects to the LIN bus via an external pull-up resistor and protective diode. Slave nodes may be switches or other sensors for inputs and some controlled device or actuator like a motor, relay, solenoid, or LED. These nodes are usually operated by a dedicated MCU and connected by internal pull-up resistors to the bus. The slave nodes on the bus get their directions from a master microcontroller.

In most vehicles, LIN buses are operated as sub-networks to a CAN bus such as the body electronics bus. Note the connection to CAN in Fig. 1.

The LIN transceivers at each node usually operate from the main 12-V vehicle electrical system. Logic levels are typically 0 V and +12 V. The upper data rate is usually 20 kb/s at the maximum bus range of 40 meters. It has the potential to support rates up to 100 kb/s over shorter distances. Data



1. The diagram represents a simplified version of the LIN bus.

temperature range of –40 to +125°C, comes in multiple package types.

When choosing a LIN transceiver for 24-V vehicles like trucks, forklifts, or buses, it's vital to ensure it's well protected from transients. The power bus in the vehicle experiences a wide variety of transients that include a ~50% drop in voltage during starting, a 120-V load dump spike that can occur if the battery is disconnected from the alternator, induced noise pulses, and reverse polarity potential.

The LIN bus is simple, reliable, rugged, and inexpensive. It's proven itself over and over again in modern automobiles. And, of course, the versatile standard and protocol can be used in other industrial or consumer applications. Get to know it.

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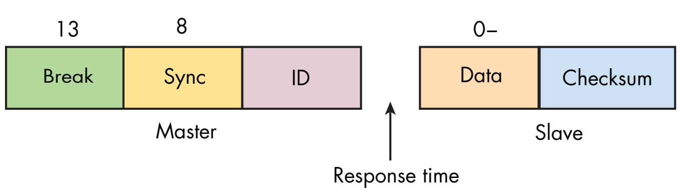
coding is non-return to zero (NRZ).

The LIN protocol frame is illustrated in *Figure 2*. The LIN transceivers use the familiar UART format with 8 bits of data plus start and stop bits. The master node communicates with each node by sending a break field of 13 bits to establish synchronization between master and slave. No precision crystal clock is required. A 10-bit identifier (6 address, 2 parity, start-stop) is used to select the desired node. The addressed slave then responds with 0 to 8 bytes of data, followed by a 10-bit checksum.

In summary, the LIN bus is attractive because it uses a simple 1-wire bus; it operates with the basic automotive battery supply; data synchronizes without a crystal reference; and no license fee is required unlike with CAN and other networks.

A TYPICAL AUTOMOTIVE LIN TRANSCEIVER

LIN transceivers are available in various configurations from multiple manufacturers. A representative device is Texas Instruments' TLIN1029-Q1. It can operate from a supply voltage in the 4- to 36-V range. It's heavily protected from electrostatic discharge (ESD), transients, and thermal overload. A data rate up to 20 kb/s is possible. It has a sleep mode to conserve power and a wakeup feature to signal a transmission. The transceiver, which operates over the



2. For LIN standard protocol frames, each byte of data has a stop and start bit, making 10 bits per character.

CHAPTER 5:

High-Voltage Solutions Take Over HEV/EV Designs

Goodbye 12-V auto electrical systems and hello high-voltage substitutes. To deliver the needed efficiency, though, designers are turning to advanced switch-mode power supplies.

By LOU FRENZEL, Contributing Editor

It should come as no shock that the dated 12-V auto electrical systems are no longer viable in new vehicles, especially hybrid electrical vehicles (HEVs) and the new all-electric vehicles (EVs). The replacement systems use either 48-V batteries for HEVs or 400+-V batteries for EVs. These power-hungry systems rely on the higher voltages as well as switch-mode techniques that give them the efficiency necessary to make them practical.

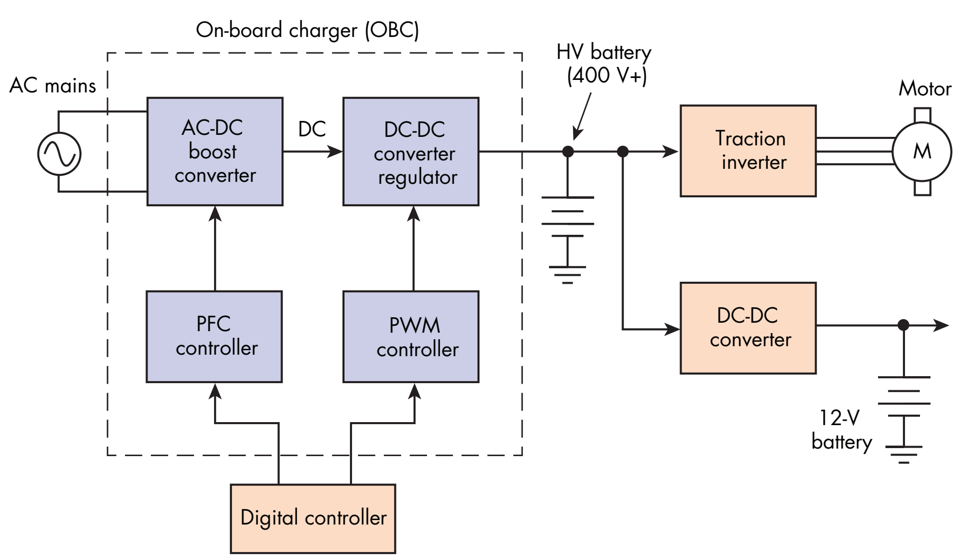
WHY HIGHER VOLTAGE?

As an EE, it should be obvious to you why higher voltages are being adopted. Higher voltages boost efficiency. The dramatic increase in electronics designed into vehicles over the years has revealed the weaknesses of standard 12-V electrical systems. The advanced driver assistance systems (ADAS) now in most new vehicles have added multiple processors and high-current sensors and actuators, in addition to other devices. Processor power has also jumped significantly, leading to added higher I^2R losses in cables, connectors, and PCB connections.

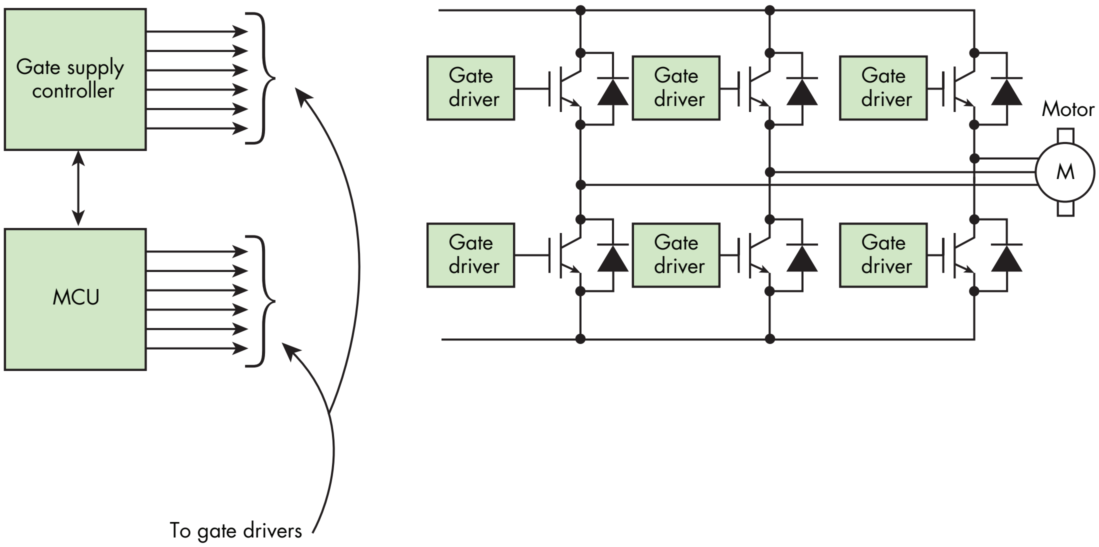
For a given amount of power, higher voltages reduce the current. That means smaller wire can be used, thereby reducing cost and weight. Increasing the 12-V supply voltage by a factor of four to 48 V results in an x16 reduction in power. Most new hybrid vehicles now include a 48-V system, and standard vehicles with internal combustion engines are moving in that direction.

As for EVs, all require high voltage to power the motor. Voltage levels of 400 to 800 V or more are needed to generate sufficient power to run the vehicle. Look for higher voltages to become the norm in vehicle electrical systems.

The challenges facing the automotive industry require innovative high-voltage electronics technology and power management throughout the signal chain. Car manufacturers and Tier-1 suppliers now have a source of advanced semiconductor solutions to support all new designs. The following reference provides more detail.



1. Here's a generalized high-voltage system in an EV that shows a simplified OBC and the traction inverter for the motor.



2. Shown is the traction-motor inverter details highlighting the critical gate drivers for the IGBTs.

SWITCH-MODE POWER SUPPLIES (SMPS)

As you know, there are three basic types of SMPS: ac-dc or rectifier power supplies, dc-dc converters, and dc-ac inverters. EVs and HEVs use all three types. The ac-dc supply is used to charge the batteries. The trend is to put the charger in the vehicle; the on-board charger (OBC) converts the standard ac mains voltage into a dc suitable for battery charging. OBCs greatly simplify and cost-reduce or minimize the need for charging stations.

The dc-dc converters are used in a variety of roles for powering the processors and other electronics such as a 48- to 12-V supply.

Inverters power the ac traction motors used in EVs and HEVs. Such ac motors are used in virtually all electric vehicles because of their greater efficiency. Variable-frequency drives provide the speed control.

Up to now, silicon power MOSFETs have been the primary switching device in most of these supplies. However, these devices have their voltage and current limitations. Beyond the roughly 4- to 6-kW level, other devices are needed. One good alternative is the silicon-carbide (SiC) MOSFET. For even higher power, the best choice is the insulated gate bipolar transistors (IGBT). Both types offer higher breakdown voltages and higher current capability along with the fast switching speeds required to achieve good efficiency ratings.

While SiC MOSFETs and IGBTs can handle the higher power levels demanded by EV and HEVs, they do have special gate-drive and circuit-protection needs. High drive voltages, fast switching speed, and a negative drive voltage are all essential to ensure fast turn-off.

Energy efficiency and electrification of vehicles has become a key global focus. To learn more, check out the white paper "Driving the future of HEV/EV with high-voltage solutions," which details the value of high voltage and switch-mode power supplies, and the advanced power electronics required to handle them.

AUTOMOTIVE SMPS EXAMPLE

Two good examples of SMPS are an OBC and a traction motor inverter. In one OBC design *(Fig. 1)*, the charger uses an initial ac-dc conversion stage with power factor correction (PFC) to help efficiency. The resulting dc is passed to a dc-dc converter controlled by pulse-width modulation (PWM) to provide regulation. This stage charges the HV battery.

The HV battery then drives the traction inverter. *Figure 2* shows that it uses a three-phase half-bridge with IGBTs to operate the motor. Special gate-driver ICs are used on each IGBT. Switching rate is in the 5- to 20-kHz range. Note the special gate supply and microcontroller (MCU) for the gate drivers.

The gate drivers are the critical component in the inverter design. A reference design is available using an automotive-qualified isolated gate-driver solution to drive silicon IGBTs or SiC MOSFETs in a half-bridge configuration. The design includes two push-pull bias supplies for the dual-channel isolated gate driver, and each supply provides +15-V and −4-V output voltages. The reference design contains the two-level turn-off circuit that protects the MOSFETs or IGBTs from voltage overshoot during the short-circuit scenario.

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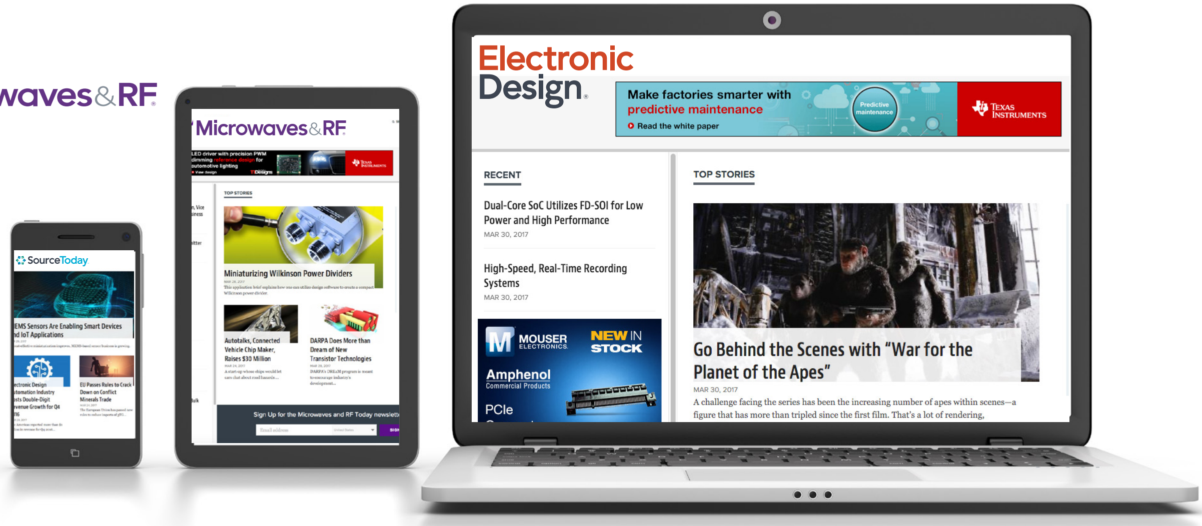

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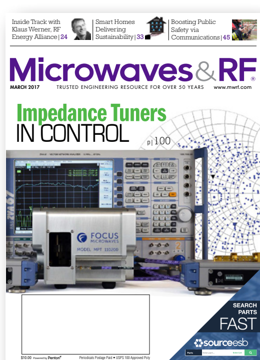

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