

INTERFACE CHIPS MUST MEDIATE BETWEEN EVER-LOWER LOGIC VOLTAGES AND REAL-WORLD LOADS. HERE ARE THE CIRCUITS AND TECHNIQUES YOU NEED TO KNOW.



INTERFACE CHIPS: between logic and a hard place

BY PAUL RAKO • TECHNICAL EDITOR

Logic signals have fallen from the 15V of the old CMOS 4000 series to 5V TTL (transistor-to-transistor logic) to modern CMOS levels of 3.3, 2.7, and 1.8V. Advanced processes use digital logic that operates at 1V or lower, although they offer higher I/O voltages. These ever-dropping logic voltages still must drive solenoids, twisted-pair wiring, and discrete-semiconductor-power stages, so they require external interface circuits. You need to understand these circuits, which run the gamut from FET drivers to open-collector solenoid drivers to LVDS (low-voltage-differential-signaling) and isolated drivers.

Interfacing between circuits is difficult because it connects signals of different voltage levels or across different impedances. Another hardship is the brutality of the real world. Anyone who has tried to pass CE (Conformité Européenne) immunity tests can confirm that any device or signal that connects to the

real world must face voltage surges and spikes to survive. In addition to these difficulties, many interface ICs are operating at higher frequencies. The high speeds of these new interface ICs add a whole new set of challenges.

Let's begin our journey through the perilous waters of interface with one of

the most basic devices, the bipolar transistor. Because silicon transistors turn on with a base voltage of 0.6V, you can, in principle, drive a transistor from almost any logic family. One approach is to put a series resistor in the base connection (Figure 1). You can drive the transistor directly from logic, but it is poor design practice to rely on the internal resistances in the logic IC to limit the current into the transistor. Because the base of a bipolar transistor stays at 0.6V when you turn it on, the logic IC experiences a short circuit on its output.

So, even something as prosaic as hanging a transistor onto the output of a gate requires some engineering. Look up the transistor's beta over the temperatures at which you expect the circuit to operate. Use that figure to determine the base current you need to turn on the transistor at the highest expected load. Remember that the load current

may also be a function of temperature. Then, look at the data-sheet charts of the logic part you are using. Once again, you may have to factor in temperature to see the actual drive current available. The drive current depends on the voltage drop. The transistor base is at 0.6V, whereas a CMOS-logic IC tries to swing the output to the power-supply rail, and a bipolar-logic family can get to within a diode drop, or 0.6V, of the power rail. Knowing the voltage drop and the current that the transistor needs, you can work out a nominal value for the resistance. It is usually advisable to halve the value of the resistor—from 150 to 75Ω, for example—to ensure that the transistor will fully turn on. Then, you must look at the power that the logic IC loses and make sure that it does not exceed any power-dissipation specs. Using all eight outputs of an octal buffer can cause the part to burn up, especially if the part comes in a TSSOP or another tiny package that cannot dissipate much heat. Also, the logic part has its own temperature derating of power dissipation, so you may have to factor that figure in to ensure that you are not overstressing the part. Remember: If you use a base resistor with too low a value, or if you entirely omit the resistor, then you will drive the transistor into heavy saturation, and it will take longer to turn off. This situation occurs because all the excess hole-electron pairs you have injected into the base-emitter junction must recombine before the collector-emitter current can go to zero.

All of these calculations apply to the use of a bipolar transistor to buffer a logic output. Using a MOSFET creates another set of criteria. FETs require no current to turn on; a voltage on the gate causes the source and drain to become low-impedance. The benefit of FETs is that they can conduct current with lower losses, and some parts, such as those from Supertex, can handle very high voltages. Older FETs needed 10V to turn on. Process engineers used ion implantation to lower the gate-to-source threshold voltage. Be aware, however, that developers designed these logic-level FETs for 5V logic. You must examine the data sheet to ensure that a part will turn on with 3.3V or lower logic. In addition to the drive-voltage prob-

AT A GLANCE	
▣	Interfaces can be as simple as a transistor or as complex as a FireWire chip.
▣	Using interface ICs alleviates many engineering problems.
▣	RS-232, RS-422, and RS-485 are older legacy interfaces.
▣	USB (Universal Serial Bus), FireWire, SATA (Serial Advanced Technology Attachment), and PCIe (Peripheral Component Interconnect Express) are modern interfaces.
▣	New ICs ease the design of isolated interfaces.

lem, the digital-logic part that drives the FET gate sees that gate as a capacitor. The bigger the FET, the larger the capacitance the digital part sees. Because both CMOS and bipolar logic can drive only so much current, the effect of the FET-gate capacitance slows the FET's turn-on. Again, you need to review the worst-case specs in the logic's data sheet, based on operating the logic at the lowest expected power-supply voltage to ensure that the FET will turn on and off fast enough to meet your design intent.

Concerns such as these have given rise to integrated ICs, such as the Microchip TC4468 and the Texas Instruments SN75372 dual-MOSFET driver, which interface to MOSFETs. You can also use amplifiers to drive large MOSFETs, but be careful. Driving large FETs from amplifiers may cause the output to oscillate due to the capacitive load that the FET presents to the amplifier.

On top of all these concerns, you must also consider Miller capacitance: a small stray capacitance between the gate and the drain in a FET or between the base and the collector in a bipolar transistor. Raising the gate causes the drain's voltage to drop, and this drop "fights" the signal that is trying to raise the voltage on the gate (**Reference 1**). Thus, you must make sure that the

transistor switches as desired under real-world operating conditions. If you need to control more than one device, you can use an integrated transistor array rather than a discrete power transistor. Allegro and other companies offer arrays of transistors on single chips. Typing "transistor array" into Digi-Key's search box returns a list of 16 companies.

It's remarkable that you need to put all this work, study, and calculation into the simple act of buffering a logic output with a transistor. But this work illustrates the difference between a hobbyist and an engineer: An engineer uses specifications and calculations to ensure that a circuit will work as he intends—not only in the lab, but also through an entire production run. For example, engineer John Massa, currently owner of a service bureau, has worked at Houston Instruments, Teledyne, and Quantum Disk Drives. Back then, he would counsel his fellow engineers that driving an LED with a 74LS244 octal buffer would not work. Many of these engineers were incredulous, saying that they had successfully done so many times. Massa would only smile and advise them to read the data sheets. The data sheet for the Texas Instruments SN74LS244 and a typical 20-mA LED in use at the time shows why Massa would take this position (**references 2 and 3**). The Texas Instruments part shows a guaranteed output voltage of 2.4V at only 3-mA output current. The Chicago Miniature Lamp red-LED 5306H1 has a maximum forward voltage of 3V at 10 mA. If you

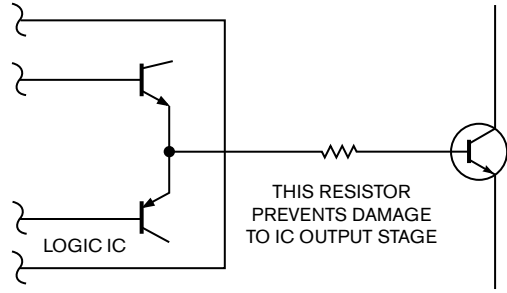


Figure 1 Be sure to use a series resistor when connecting logic outputs to a transistor. Large FETs with substantial input capacitance may also need a series resistor to protect the logic-output stage. The resistor slows FET switching, but the resistive damping stabilizes the circuit.

expect the LED to shine at full intensity based on a 20-mA current, this circuit is not guaranteed to work, just as Massa warned. Now, interface is an analog phenomenon, and, yes, you can usually drive an LED from an LS244 octal-bus driver. This approach may be acceptable for a consumer product, but not for a life-critical medical device or a military application; the part's specified limits do not guarantee that the LED will shine at required brightness—or any brightness at all.

Moving up the evolutionary chain from the simple interface transistor, you come to ICs that provide interface capability much like the aforementioned MOSFET-driver ICs. The 4000 series CMOS-logic hex-inverting CD4009 or noninverting CD4010 logic-buffer IC is one of the oldest of these interface ICs. Texas Instruments still makes these venerable parts. The 4000 series has the benefit of working at 15V, providing for remarkable noise immunity and assisting in directly driving interface signals. One benefit of CMOS logic, whether the 15V 4000 series or any low-voltage CMOS, is that you can tie multiple outputs together to increase the current drive of the circuit (**Figure 2**). The FET transistors are resistive when you turn them on, so they share current, whereas bipolar transistors in this configuration may hog current—that is, one bipolar output transistor becomes hot, causing it to conduct more current, in turn becoming even hotter, and finally becoming damaged. To prevent this situation, you can insert 5 or 10 Ω resistors in series with each of the outputs, but this step is more costly and complex than using a CMOS chip.

The need for driving solenoids or other difficult loads has spawned entire series of interface ICs. Some of the most ubiquitous of these are the SN and DS series from Texas Instruments and other vendors. These parts range in variety from the SN55462 dual-high-voltage peripheral drivers to the DS3680 quad-telephone-relay driver. Also notable for this class of ICs is Freescale, a spin-off of Motorola, whose name implies the automotive radios that gave the company its start. As you would expect, Freescale makes interface ICs that can take the higher temperatures and voltage surges of the automotive environment. Free-

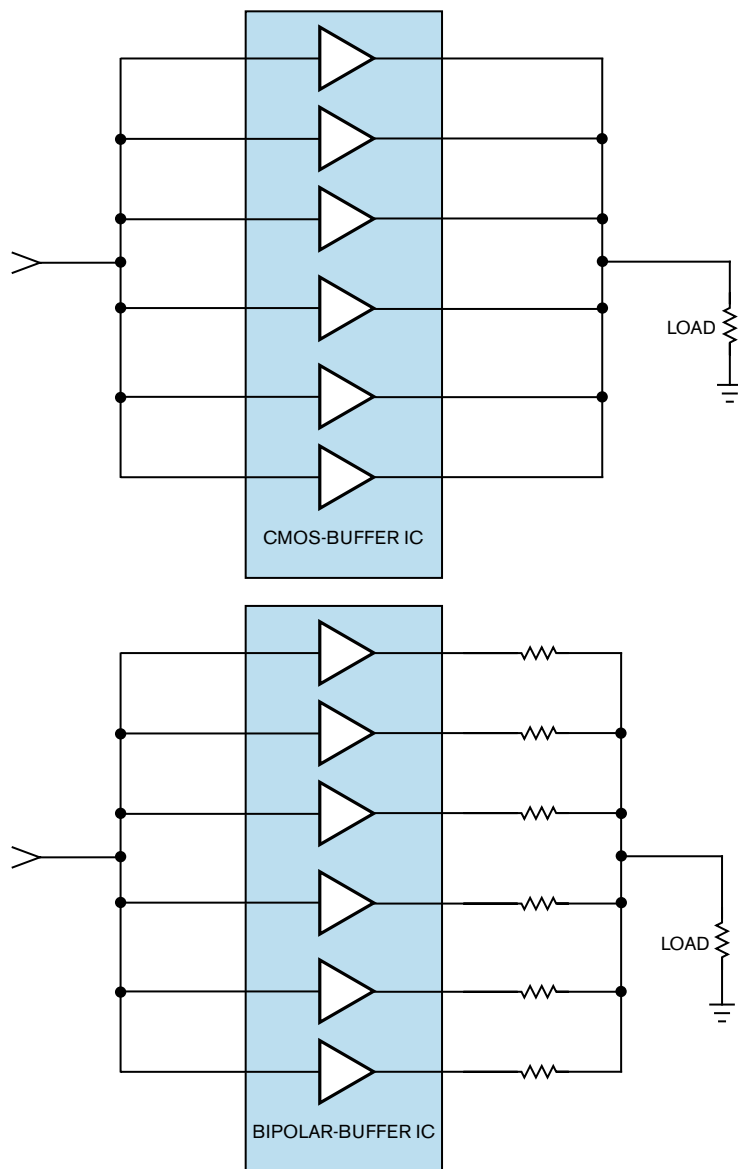


Figure 2 CMOS-family logic, such as CD4000 and 74HCxxx, can have connected outputs because MOSFETs share current. Bipolar-logic families would need low-value resistors in each output leg to prevent current from hogging the bipolar-output stages.

scale offers low-side switches; high-side switches; and H-bridge, predriver, power-train, and squib ICs. (Military designers will recognize squibs as the explosive bolts that blow to allow rocket stages to separate. In this context, a “squib” is the explosive canister that deploys automotive air bags.)

Speaking of high-side and low-side switches, it might seem logical to put a semiconductor switch on the low side of the load. The problem with low-side switching, though, is that when you turn

off the switch, you leave the load floating at the positive-power-supply voltage. In a world that has been using simple mechanical switches for more than a century, you would expect to be able to simply switch off the power, rather than interrupt the ground side of the load. It may also be beneficial to keep the load grounded for noise reasons or to monitor currents, voltages, or temperatures. This problem has given rise to the use of high-side ICs.

One way to design a high-side switch

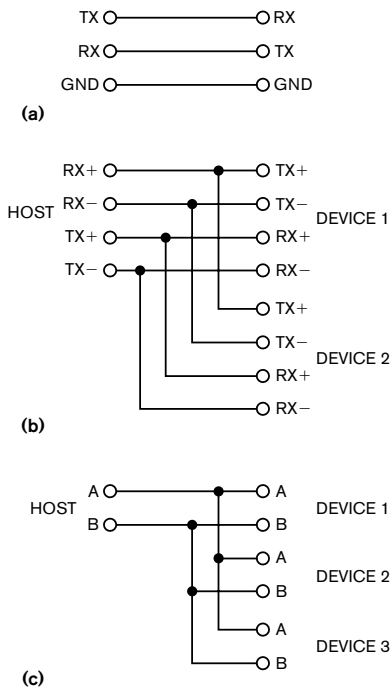


Figure 3 RS-232 started as a telecom standard to connect modems to computers (a). It used all 25 pins of a DB-25 connector. It has since evolved to a simple three-wire connection. The multidrop RS-422 standard can have 10 receivers (b), and RS-485 is a bidirectional bus with as many as 32 receivers and transmitters (c) (courtesy Omega Engineering).

is to use PNP or P-channel FETs and live with the greater losses. Because electron mobilities are higher in N-type material, however, NPN-bipolar and N-channel MOSFETs can conduct current with lower losses. A more sophisticated technique uses a charge pump to boost voltage, which then turns on an N-channel MOSFET through a level-shifting circuit. One caution here involves gate capacitance. Data sheets may show a typical turn-on time for a charge-pump high-side driver, but manufacturers base that time on a specific load capacitance. If you try to control a large MOSFET, it takes a long time to charge the huge gate capacitance. As a result, the part may linger too long in the linear mode, causing excessive power dissipation. Just

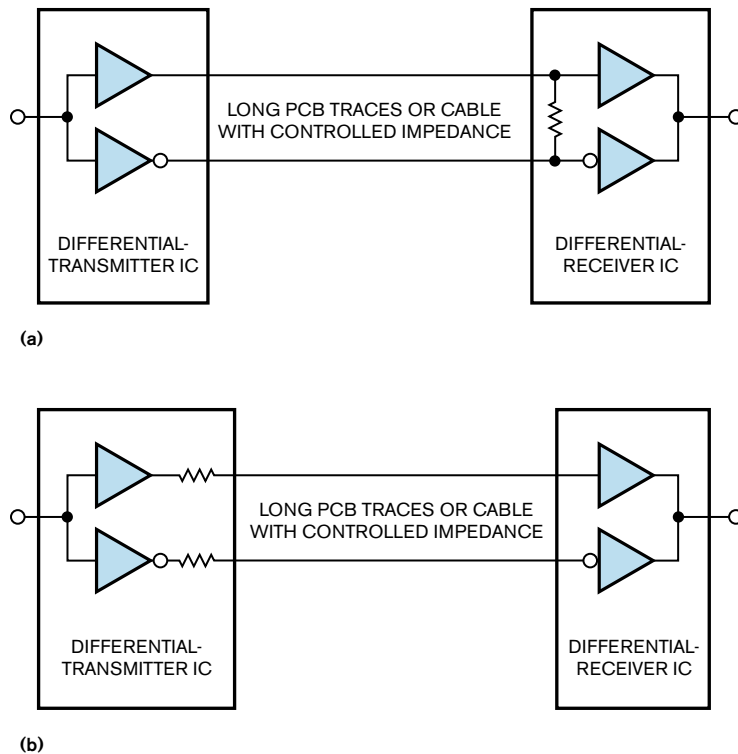


Figure 4 Differential signaling uses a pair of wires operating on opposite polarities. You can use a 100Ω shunt termination at the receiver or two 50Ω terminations in series to eliminate reflections (a). The series termination does not dissipate dc power (b). Differential signaling is the basis for LVDS, USB, SCSI, SATA, PCIe, CameraLink, and many other interfaces. The transmitter does not start and stop its operating current; it just switches it between the two wires, making decoupling the power pins less critical.

as seriously, the part may not quickly enough connect a power source, causing the system that the high-side switch is feeding to become unstable or to reboot.

One of the best known brands of high-side FETs is NXP's TopFET. This part integrates a power FET along with protection features for overcurrent, overtemperature, and overvoltage conditions. In addition, the part offers reverse-polarity protection, making it ideal for replacing both switches and fuses. NXP has minimized charge-pump noise to make the part suitable for a wide range of applications. Infineon makes the ProFET smart high-side switch with similarly robust features. This unit complements Infineon's line of low-side switches and motor controls. STMicroelectronics is also involved in difficult interface applications in the automotive environment. It

has pioneered work involving minimizing electromigration and improving the thermal fatigue of high-side switches. This work brings designers ever closer to the ideal of a device with the robustness of silver contacts and the intelligence, fault protection, and monitoring of semiconductor devices.

SIGNAL INTERFACES

The term "interface" has grown to mean more than driving solenoids and other loads from logic voltages. It also refers to the several standards to connect digital systems. RS-232 was one of the earliest of these standards. Other early serial-interface ICs supported RS-422 and RS-485 (**Figure 3** and **references 4** and **5**). Whereas RS-232 has one wire for transmitting and one for receiving, RS-422 uses differential pairs for communications and needs two pairs

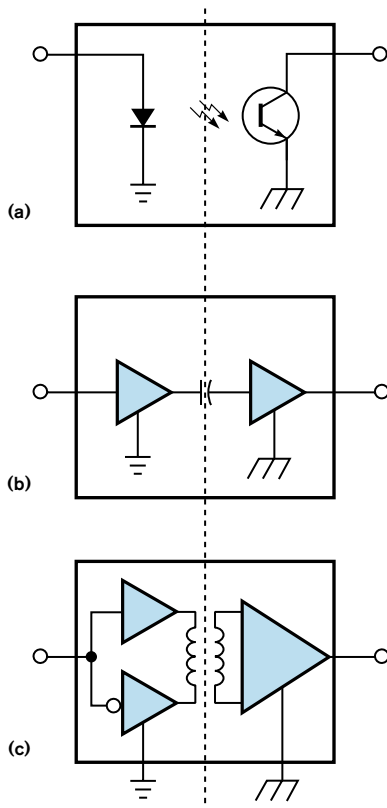


Figure 5 You can achieve digital isolation using optical means with chips such as these from Avago (a), capacitive means as in these chips from Texas Instruments (b), or inductive means as in these chips from Analog Devices (c).

to send and receive. The advantage is that it can work over longer distances—even kilometers—and can have as many as 10 receivers listening to one transmitter. The differential RS-485 interface combines transmission and reception on the same pair of wires. It can support 32 transmitters and receivers on the same bus.

One problem with older standards, such as RS-232, is that designers do not rigorously follow them. This lack of compliance applies to both the pins in the connectors and the voltage levels in the transmission. RS-232 started as a standard for connecting modems to computers. For this reason, it does not need such signals as RD (ring detect) to connect two computers or a computer to a peripheral drive. All the potential pin, cable, and voltage configurations have often caused designers to call the RS-

232 standard the nonstandard standard.

In this regard, engineer Massa points out, many people design RS-232 interfaces for 5V operation rather than for the voltage the standard dictates: $\pm 12\text{V}$. The input-structure circuit diagram of a common RS-232 receiver, he notes, takes only one diode drop—0.6V—to turn on the input, so designers believe that 5V would do this job as well as 12V would. When the signal line goes to 0V instead of -12V , they reason, the input would turn off. Massa disagrees, however. “Remember: You have violated the standard by running the interface at 5V,” he says. “You will have far worse noise immunity, and the length of cable runs you can achieve will be far less. Nevertheless, if all you are doing is trying to get a connection to a PC over two feet of wire, a 5V signal can function on an RS-232 line.” Maxim and other companies provide a benefit by selling RS-232-interface chips that operate at 5V, use internal charge pumps to generate $\pm 10\text{V}$ or higher, and provide 15-kV ESD (electrostatic-discharge) protection on the line. Having a serial interface that conforms to the standard and having fault protection to boot can provide considerable peace of mind to a design engineer.

You can gauge the tremendous popularity and proliferation of these early interface standards by examining Texas Instruments’ offerings in this area. The company offers 63 RS-422 parts ranging from dual-line drivers selling for approximately 25 cents to parts with three differential-transceiver channels that cost several dollars. TI’s RS-232 line comprises 95 parts, starting with drivers costing less than a quarter, to complete interface ICs, including charge pumps and ESD protection, selling for more than \$4. For the RS-485 standard, TI offers 101 parts, with a broad range of capabilities, all with commensurate prices.

Faster standards, such as USB (Universal Serial Bus) and Apple-developed FireWire, now augment these older RS standards. These bus standards operate at higher speeds and with more sophistication than the RS-485-bus standard. USB and FireWire tout not only standardized electrical interfaces, but also standardized higher level protocols. The old serial-communication port still ex-

ists as a protocol in USB, even though the electrical spec differs. Despite the modernity of these standards, they face the same environmental challenges as the older RS standards face. The fact that a long cable is extending from your digital system creates the same potential for havoc. The cable can receive EMI (electromagnetic interference) and RFI (radio-frequency interference) and may cause your system to malfunction, or the cable can radiate digital noise from your system. ESD from people or other systems also can damage your system unless the interface IC protects against this phenomenon. As you would expect with such popular standards, a surfeit of vendors makes USB- and FireWire-interface chips. USB also delivers power, and vendors offer interface circuits to address the need to manage and protect the power lines in the USB port. For example, Raychem and Fairchild offer fuses and switches, respectively, to handle this problem.

The need to transmit faster data rates between chips and subsystems has caused designers to consider differential signaling (**Figure 4**). By using differential pairs, designers can maintain impedance control and balanced currents over large distances. The SCSI (Small Computer System Interface) disk-drive standard, which Shugart Associates developed in 1979, exemplifies this technique. SCSI became a standard in 1986, and Apple Computer used it in the Apple II (**Reference 6**). Texas Instruments lists SCSI chips under the “interface” section of its Web site. The utility and advantages of differential signaling have caused developers to adopt it in SATA (Serial Advanced Technology Attachment) disk-drive interfaces and the PCIe (Peripheral Component Interconnect Express)-bus interface. Many of these differential interfaces use a variation of LVDS. The industry first applied this term to the signals in the ribbon cable that connects laptop-LCD panels to the video chip. The video interface had to reside on a ribbon cable because the laptop screen had to tilt and close. A further benefit of differential signaling is that it radiates less electrical noise because the signals are differential and closely coupled. This feature allowed the fast transmission of digital video over a ribbon cable in

a laptop product that had to pass strict Federal Communications Commission standards for radiated noise in consumer electronics. National Semiconductor was an early champion of LVDS and also used it in the CameraLink standard, which connects industrial cameras to video-capture hardware (**Reference 7**). SCSI, SATA, PCIe, and LVDS do not connect logic to a high-voltage peripheral, instead connecting two digital systems at high speeds over long distances. CameraLink can work over distances of meters, and LVDS cables can run for hundreds of meters if you properly shield and design them. National Semiconductor has an impressive portfolio of LVDS chips, and many other vendors, such as TI and STMicroelectronics, also make these products.

BY USING DIFFERENTIAL PAIRS, DESIGNERS CAN MAINTAIN IMPEDANCE CONTROL AND BALANCED CURRENTS OVER LARGE DISTANCES.

A special type of LVDS interface, SERDES (serializer/deserializer) serializes parallel data, such as a computer bus or several bytes of video data, into a high-speed LVDS pair. These chips often operate at speeds in excess of 1 Gbps. Once the SERDES serializes the parallel data and sends it over the pair of differential wires, the deserializer extracts a clock from the serial-bit stream and converts the data back into a parallel bus. National Semiconductor, TI, Intersil, Fairchild, and a host of other companies make these types of chips. SERDES chips are finding applications in cell phones in which screen and camera data must traverse the hinge of the phone. This task is easier with one pair of wires as opposed to a parallel bus.

Another class of interface chip supports isolated communications using optical, capacitive, or magnetic isolation to allow digital signals to communicate to systems without conducting ground loops or hazardous voltages (**Figure 5**). The

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developers of the MIDI (Musical Instrument Digital Interface) standard for musical instruments based the technology on optical isolation. Avago Technologies offers optical-isolation chips that withstand thousands of volts and can transmit megabits per second of data. Both Texas Instruments and Analog Devices have chips that can provide thousands of volts of isolation and transmit signals in the hundreds of megahertz. The availability of these remarkable chips is changing the nature of some analog design. Previously, it was more common to achieve isolation in the analog section, such as with the Linear Technology LTC1531 isolated comparator. With the availability of these digital-isolator chips, it is now common practice to use an isolated regulator to power the analog section and employ a data converter on the isolated side. You can isolate the digital signals from this converter with a digital-isolation chip.

Interface issues are important; pay attention to them. A plethora of approaches is available from a large number of suppliers. If you consider how complex it is just to hook a transistor to a logic output, you can appreciate the need and desirability of using a specialized interface chip to do the job. If you are sending gigabit signals over the length of a large PCB (printed-circuit board) or onto a cable, you must use some of these sophisticated interface chips. The combination of capabilities and protection features is essential for most applications. It is a cruel world out there, and these interface chips can make your design far more resistant to many indignities. **EDN**

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