LINEAR TECHNOLOGY

Journal of
Analog Innovation

October 2014 Volume 24 Number 3

IN THIS ISSUE

Rugged IO-Link Solutions

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Industrial automation systems are growing more interconnected and intelligent to accommodate demands for centralized control, optimized production and reduced cost. IO-Link® is becoming an increasingly popular interface to smart sensors and actuators, combining signaling with power-over-cable technology. The interface electronics must be rugged, power efficient and compact. Two new parts capably meet these requirements. The LTC®2874 is a highly integrated IO-Link master-side physical layer interface (PHY) for four ports. The LT®3669 is a device-side PHY incorporating a step-down regulator and LDO. To appreciate the numerous features of these devices, it helps to review the requirements of IO-Link. This article begins with a brief overview of IO-Link technology, and follows with LTC2874 and LT3669 functions and features.

The LTC3882 POL controller with built-in digital power system management (see page 16)

IO-LINK: POWER AND COMMUNICATION FOR SMART DEVICES

Combining a power feed and a data link inside a cable assembly isn't new,[1] but its presence in the world of industrial automation is. IO-Link[2] emerged in 2009 as a communication interface between automation control systems (masters) and intelligent sensors and actuators (devices). In 2013 it evolved into an international standard for programmable controllers, IEC 61131-9 single-drop digital communication interface for small sensors and actuators (SDCI), whose purpose "extends the traditional digital input and digital output interfaces as defined in IEC 61131-2 towards a point-to-point communication link [enabling] the transfer of parameters to Devices and the delivery of diagnostic

(continued on page 4)

To solve the problems of inrush current control and fault isolation, the LTC2874 generates L+ power supply outputs using a Hot Swap controller and n-type power MOSFETs. The resistance of the power path is kept low using external components for the MOSFETs and sense resistors, reducing IC heat dissipation and maximizing power efficiency during operation.

(LTC2874/LT3669, continued from page 1)

information from the Devices to the automation system."[3] This technology allows a distributed control system linked by fieldbus networks to operate actuators such as valve terminals; to operate, monitor and collect data from sensors; and to dynamically reconfigure their settings.

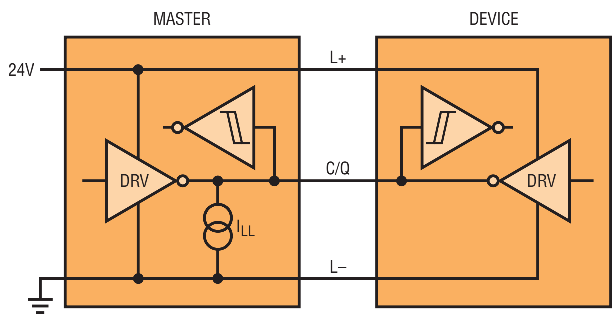
While IO-Link is fully described by a protocol stack that includes data link and application layers, it's built upon physical layer interfaces, or PHYs (Figure 1), normally connected by 3-wire cables up to 20m long and terminated by standard M5, M8 or M12 connectors. Two wires (L+ and L–) supply 200mA at 24VDC from master to device, and a third wire is a point-to-point, half-duplex data line (CQ) that operates at up to 230.4kb/s and shares the L– return. Optionally, a fourth wire can serve as a 24V digital line. In specialized configurations, this wire, along with a fifth, supply additional power for actuators.

Inherent to IO-Link systems is backward compatibility. For example:

- IO-Link tolerates unshielded connections, allowing reuse of standard industrial wire in existing installations.
- IO-Link devices can operate without an IO-Link master in a legacy digital switching mode called Standard I/O (SIO). Likewise, IO-Link masters can operate legacy devices using SIO.

A built-in load current on the CQ line at the master side (ILLM) facilitates operation of older sensors with discrete PNP-type outputs, which only drive high.

Figure 1. IO-Link physical layer interface (PHY). The device side consists of a high side (and optionally, low side) driver and a receiver. The master side has a push-pull driver, receiver, and a current sink that operates as a load for high side device outputs.



Any overview of IO-Link must introduce the scheme known as wake-up. Before IO-Link communication can commence, an IO-Link master must determine whether a connected device is compatible, and, if it is, identify the highest transmission rate supported: 230.4kb/s (called COM3 mode), 38.4kb/s (COM2), or 4.8kb/s (COM1). This requirement, combined with another—an IO-Link device must start up enabled to operate in SIO mode outside of an IO-Link system—poses a problem: how to gain the attention of an IO-Link device that's dutifully transmitting its sensor output.

The answer is by shouting. The master gains the attention of the device by issuing a wake-up request (WURQ), an 80μs, 0.5A current pulse, which is guaranteed to exceed the drive strength of an IO-Link device so that, upon detecting the pulse, it may stop driving and participate in a signaling exchange of data that informs the master of its maximum communication rate.

Once operating in communication mode, a master and device exchange data asynchronously in frames consisting of 11 bits (Figure 2a). Most of these UART frames are organized into larger units called M-sequences (Figure 2b), which begin with a message sent by the master paired with a reply message from the device.

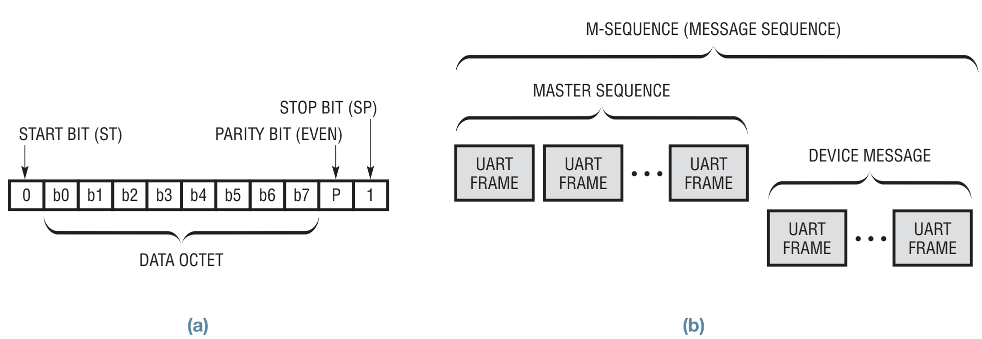
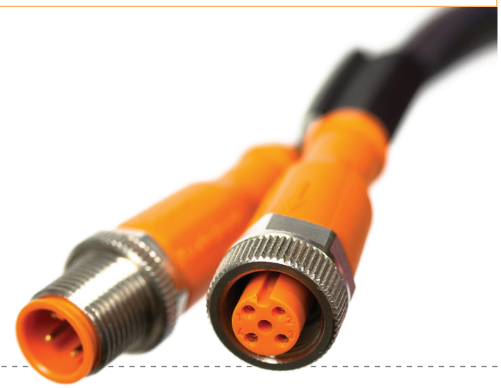


Figure 2. (a) IO-Link UART frames contain 11 bits of data. (b) Cyclic data is organized into paired exchanges of UART frames between master and device called M-sequences.



Two new interface parts target the first I/O technology for communication with sensors and actuators to be adopted as an international standard.

M-sequences transmit process data at predetermined rates in various available formats based on the type of device. Other transmission modes support configuration, maintenance and diagnostic functions.

HOT SWAP CONTROLLER PROTECTION AND ADVANTAGES

The IO-Link standard has little to say about the L+ power-over-cable supply, suggesting only that 200mA and perhaps a power switch are needed. But potential problems abound when power is connected to arbitrarily large loads. Although high inrush current shouldn't damage the sturdy connectors used for IO-Link, it can still cause connector sparks and supply droop that can lead to system resets. Although the power-over-cable (POC) requirement of IO-Link (4W minimum) is modest compared to alternative technologies such as Power over Ethernet, anyone who has experienced faults at 24VDC knows they can be disruptive or catastrophic, leading to the question "is something burning?"

To solve the problems of inrush current control and fault isolation, the LTC2874 generates L+ power supply outputs using a Hot Swap controller and n-type power MOSFETs. The resistance of the power path is kept low using external components for the MOSFETs and sense resistors, reducing IC heat dissipation and maximizing power efficiency during operation. This arrangement gives users flexibility in MOSFET selection. Because this application requires the MOSFET to operate in linear mode during current limiting, older planar process MOSFETs such as Fairchild's FQT7N10 are recommended in order to avoid damage-causing hot spots that some newer versions and especially trench transistors can develop in this mode.[4] The controller provides SPI-operated on/off control, current limiting, and a programmable, timed circuit breaker function.

The LTC2874 adds flexibility to inrush current control by raising output supplies in a controlled manner determined either by current limiting (Figure 3a) or, for load independence, by an external RC network (Figure 3b). When enabled by a SPI register bit, the LTC2874 applies foldback behavior to the current limit in order to minimize power dissipation in the MOSFET during start-up and overcurrent conditions. An optional cable-sensing mode keeps the L+ power disabled until a cable is connected to the port.

Because IO-Link devices usually require cable-supplied power to operate and communicate, there's normally no way for them to notify their master that power is absent. In such scenarios, master-side diagnostic capabilities are especially valuable. The LTC2874 reports changes to output supply "power good" status—along with a host of other conditions including overtemperature, input

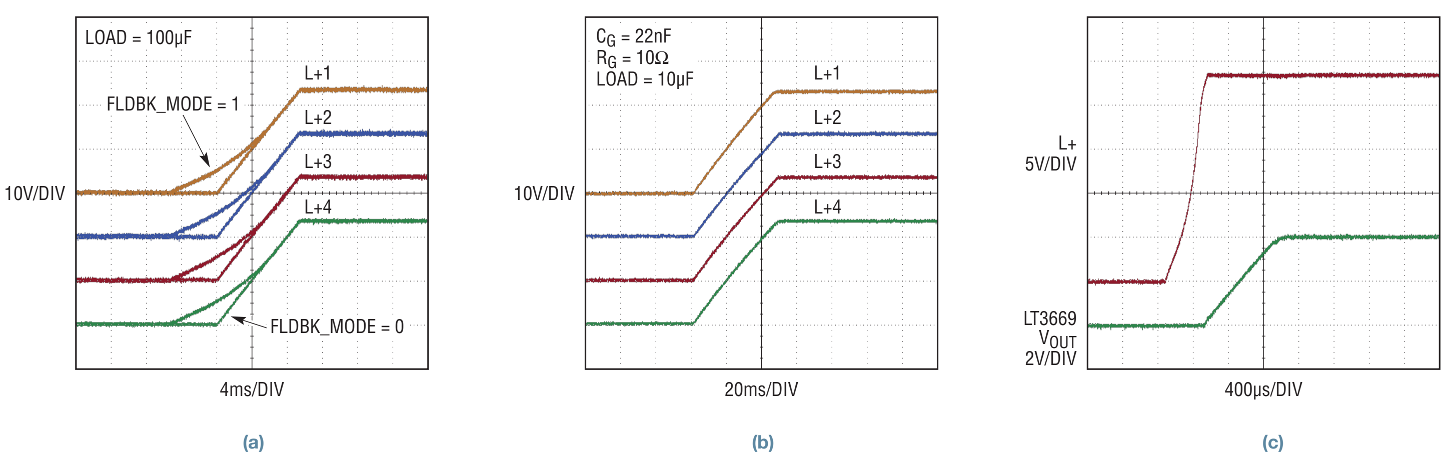


Figure 3. L+ power supply output start-up (a) in current limit, (b) defined by a GATE resistor-capacitor network, and (c) for LT3669 application circuit configured for 4V buck output.

In IO-Link applications, the LTC2874 and LT3669 simplify wake-up request (WURQ) handling for their respective microcontrollers. On the master side, the LTC2874 generates WURQs of the correct polarity and timing automatically when a SPI register pushbutton bit is set. An interrupt request ($\overline{\text{IRQ}}$) provides a handshake to the microcontroller. On the device side, the LT3669 pulls the $\overline{\text{WAKE}}$ output flag low under certain conditions.

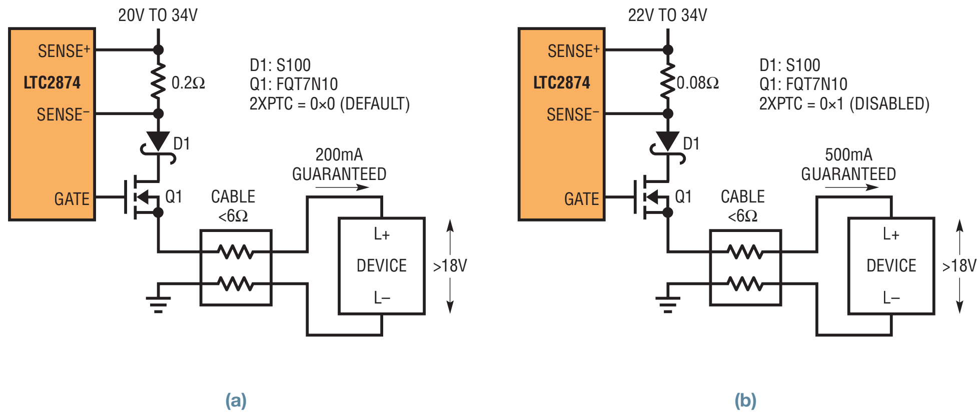
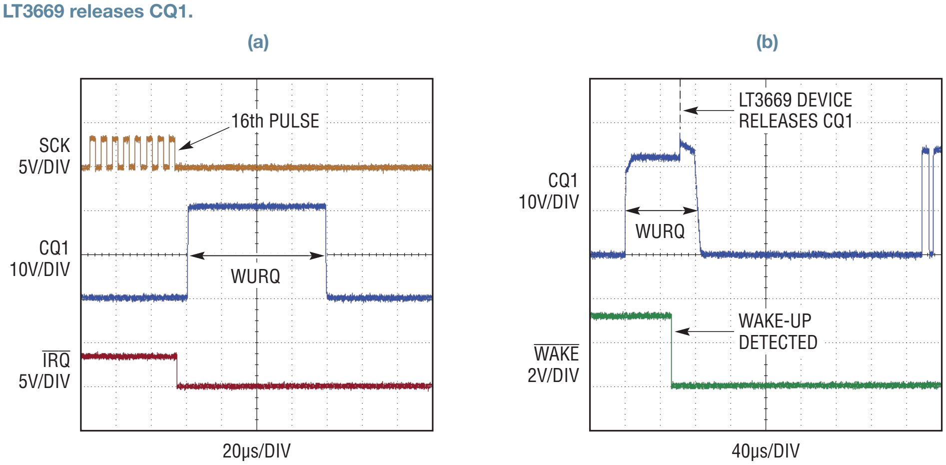


Figure 4. (a) LTC2874 configured for IO-Link-compliant 200mA device supply. Optional D1 provides supply isolation. (b) Alternative configuration for 500mA.

supply voltage level, and output supply overcurrent—to the microcontroller via its SPI port and interrupt request line. These monitoring capabilities enable the software to guide operators toward making faster repairs with less down time.

While L+ outputs must normally supply 200mA, the IO-Link standard requires a boosted current pulse capability at start-up, guaranteeing 400mA for 50ms upon reaching 18V. This requirement can be met indirectly by configuring the sense resistors for higher current and constraining the input supply (Figure 4b). A better approach (Figure 4a) uses the LTC2874's optional SPI-controlled current pulse function to meet the start-up requirement while preserving DC operating margin relative to the safe operating area (SOA) of the MOSFET. In both cases, the optional current-limit foldback helps protect the operating margin at lower output voltages where power dissipation in the MOSFET is highest.

Figure 5. (a) Self-timed 80µs 500mA wake-up request for an unloaded CQ line. (b) LTC2874-generated WURQ overdriving an LT3669 device PHY. Upon notifying its microcontroller that a WURQ pulse was detected, the LT3669 releases CQ1.



EASY WAKE-UP GENERATION AND DETECTION

In IO-Link applications, the LTC2874 and LT3669 simplify wake-up request (WURQ) handling for their respective microcontrollers. On the master side, the LTC2874 generates WURQs of the correct polarity and timing automatically when a SPI register pushbutton bit is set (Figure 5a). An interrupt request ($\overline{\text{IRQ}}$) provides a handshake to the microcontroller.

While sensors built with digital IO-Link interface are likely less susceptible to noise than older analog-output models, their wide-swing (24V), single-ended signaling through unshielded wire can produce electromagnetic interference (EMI). The CQ line drivers of both the LTC2874 and LT3669 use slew-rate limiting circuitry to reduce the high frequency content of signaling emissions. Both products also offer a slow edge rate mode.

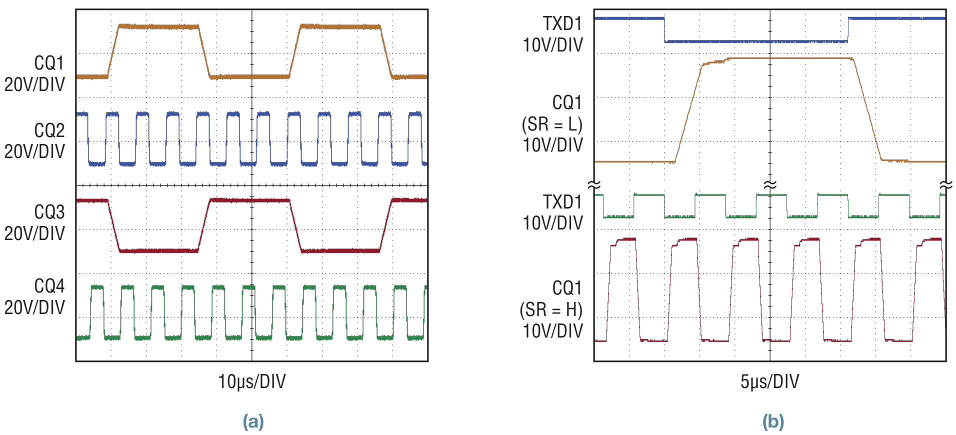


Figure 6. (a) LTC2874 CQ outputs operating with slow edge rate slew control active on two ports. Ports 1 and 3 are shown operating at COM2, or 38.4kb/s, while ports 2 and 4 operate at COM3, or 230.4kb/s. (b) LT3669 CQ1 output with slow and fast edge rate slew control applied for COM2 and COM3 operation, respectively.

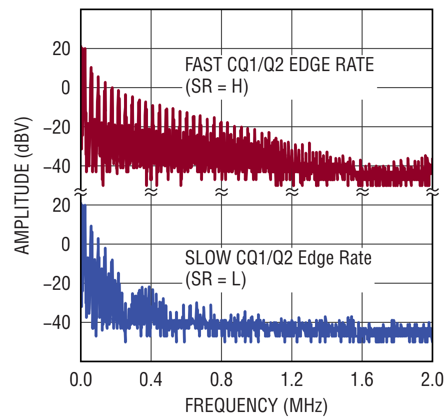


Figure 7. High frequency EMI reduction of LT3669 operating at 38.4kb/s with slow edge rate control (bottom) compared to fast edge rate control (top).

On the device side, the LT3669 pulls the $\overline{\text{WAKE}}$ output flag low (Figure 5b) when either of two conditions persists for more than 75µs:

- CQ1 does not approach its targeted rail within 2.95V while the driver is enabled (TXEN1 high);
- CQ1 is higher than V_{L+} – 2.95V while the driver is disabled (TXEN1 low).

The device side microcontroller can then respond by disabling the driver as needed, handshaking with the LT3669 (by toggling TXD1 while TXEN1 is low) to reset its WAKE state, and listening for a start-up protocol to be initiated by the master. Decision-making and response is left to the microcontroller, which, based on mode and context, must discern between valid WURQ signaling and invalid cases. The LT3669's straightforward approach to detection maximizes flexibility.

CONTROLLED EDGE RATES REDUCE EMISSIONS

While sensors built with digital IO-Link interface are likely less susceptible to noise than older analog-output models, their wide-swing (24V), single-ended signaling through unshielded wire can produce electromagnetic interference (EMI). The CQ line drivers of both the LTC2874 and LT3669 use slew-rate limiting circuitry to reduce the high frequency content of signaling emissions. Both products also offer a slow edge rate mode (Figure 6) that can be selected at lower data rates, suppressing the HF content further. The improvement achieved by the LT3669 slew rate control is shown in Figure 7.

RUGGED INTERFACES TOLERATE ABUSE

Any cable interface risks exposing sensitive electronics to uncontrolled harsh conditions. IO-Link requirements compound the problem, demanding a combination of operating voltage (up to 30V) and guaranteed current (200mA for each L+ output, 100mA DC for each CQ driver output, and 500mA for wake-up request pulses) that, in the event of an overload or shorted output, can result in high power dissipation in the driving MOSFET or IC. Consequently, the LTC2874 and LT3669 are designed to withstand a wide range of operating conditions, abuse and fault modes on their cable interfaces.

The LTC2874 tolerates cable voltages well outside its operating range (for example, 50V above GND for L+ and 50V from opposite rails for CQ) and has multiple ways to protect against an overload. First, current-limiting responds quickly

Table 1. Typical line interface electromagnetic compatibility (EMC) results when data sheet recommendations are followed.

	LTC2874	LT3669	CONDITIONS/NOTES
HUMAN BODY MODEL (ESD)	±8kV	±4kV	Without TVS Clamps
IEC 61000-4-2 (ESD)	±8kV (Level 4)	±6kV (Level 3)	Contact discharge DC1880A/DC1733A demo boards C_{PIN} = 470pF
IEC 61000-4-4 (EFT/Burst)	±4kV (Level 4) ±4kV (Level 4)	±4kV (Level 4) ±4kV (Level 4)	5kHz/15ms 100kHz/0.75ms
IEC 61000-4-5 (Surge)	±2kV (Level 2)	±2kV (Level 2)	1.2/50μs–8/20μs
TVS CLAMP	SM6T36A	SM6T39A	

to prevent damage and reduce power dissipation in the IC or (in the case of the L+ output) MOSFET. The current limit is fixed for CQ outputs and resistor-configurable for L+ outputs. If the overcurrent condition persists after a predefined timeout (mode-specific for CQ, programmable for L+), a circuit breaker function disables the output. After allowing a programmable time for cooling, the LTC2874 auto-retry function optionally re-enables the output. The pattern repeats, pulsing the output at a safely low duty cycle until either the overload is removed or a controller intervenes. Additionally, the IC has built in protection against overtemperature and supply overvoltage conditions.

The LT3669 is similarly well protected. It is reverse polarity protected and tolerates up to ±60V between any combination of L+, CQ1, Q2 and GND pins. This high voltage protection allows the use of standard TVS diodes for additional surge protection while still enabling operation with L+ voltages of up to 36V. This feature is especially attractive for devices operating in SIO mode above the operating voltage range of IO-Link.

The CQ1 and Q2 drivers are current-limited to a value defined by an external resistor. In the case of heavy loads or short circuits, additional high speed current limit clamping and a pulsing scheme keep power dissipation at a safe level.

During pulsing, the on-time depends on the voltage level of the active outputs and the off-time is fixed (2.2ms typical), resulting in a duty cycle that adjusts downward as the output dissipates more power, keeping the IC safe and optimizing the time to drive heavy loads fully.

Like its master-side counterpart, the LT3669 has precise built in thermal shutdown and supply overvoltage protection. For junction temperatures above 140°C (typical), both line drivers are disabled while the LDO and V_{OUT} outputs continue to operate. Short-circuit flags $\overline{SC1}$ and $\overline{SC2}$ report a thermal shutdown event to the microcontroller.

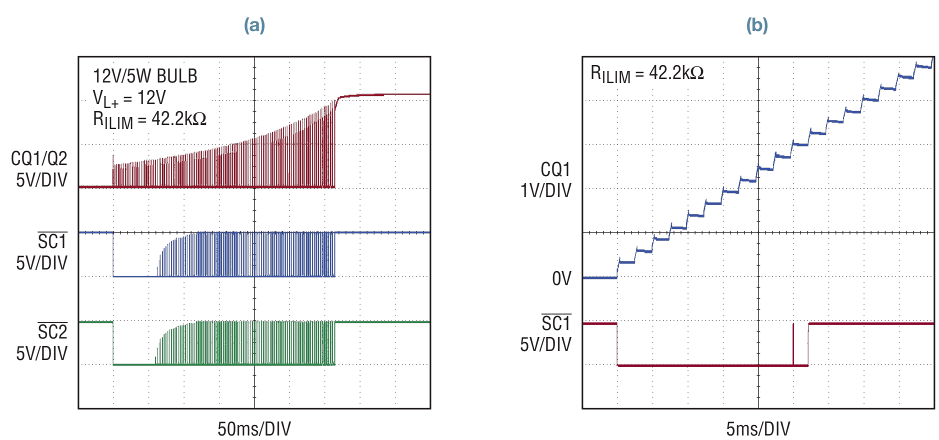
The cable interfaces of both the LTC2874 and LT3669 have built-in protection against electrostatic discharge and are easy to protect against a high level of electromagnetic interference (EMI) using standard TVS clamps (Table 1).

DRIVING HEAVY LOADS

While IO-Link drivers normally see capacitive loading of at most 4nF when connected by cable to another IO-Link PHY, the LTC2874 and LT3669 can drive more than 100mA (up to 250mA for the LT3669) for compatibility with legacy sensors and a variety of industrial loads. For example, this drive strength is sufficient to operate miniature incandescent lamps used in 12V and 24VDC systems.[5]

Turning on an incandescent lamp is nontrivial for an IC driver. Common tungsten

Figure 8. (a) LT3669 lighting a 12V 5W lamp and (b) driving a 470μF load. Short-circuit flags $\overline{SC1}$ and $\overline{SC2}$ are active if the driver's voltage is within 2.95V from the rail opposite the targeted one while the drivers are externally enabled.



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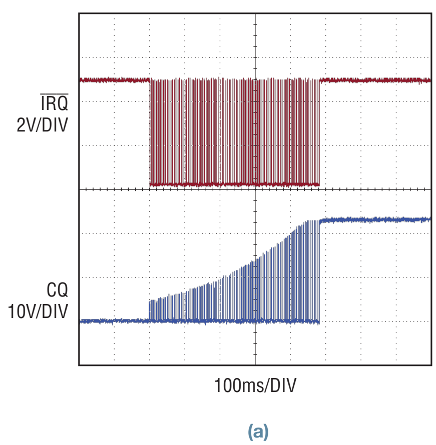


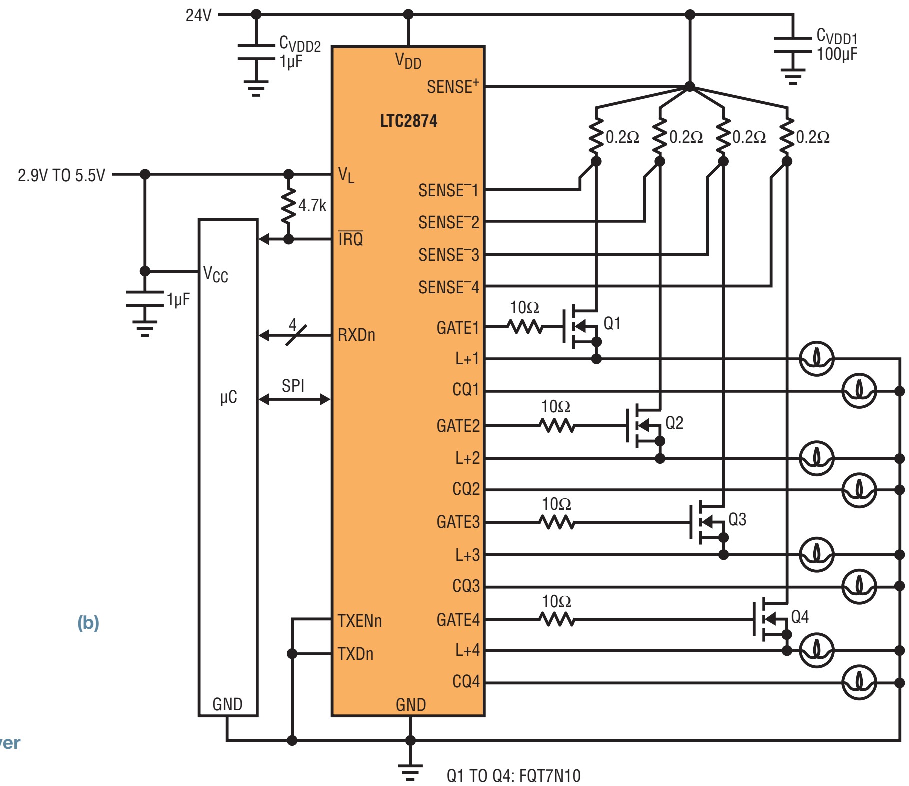


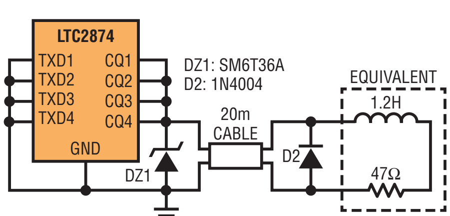
Figure 9. (a) LTC2874 turning on a 24V 2W lamp (b) octal lamp driver

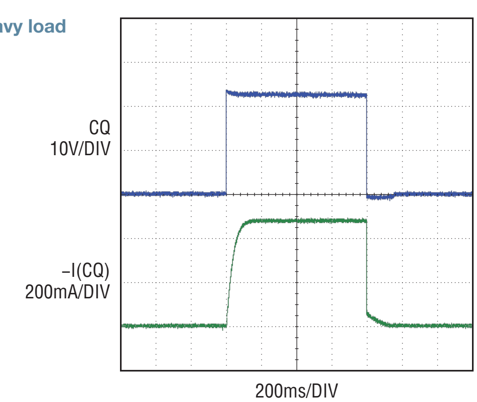
filaments are about 15 times more conductive when cold compared to when glowing hot. Consequently, while lighting a bulb, the driver must cope with a near short-circuit condition without overheating.

The LT3669 protects itself under such conditions by pulsing the output to limit the driver power dissipation. Figure 8a shows a 12V 5W bulb being turned on by the combined output of both LT3669 drivers (up to 500mA combined driving capability), and illustrates the variable load during this process. As the filament heats up, an increasing portion of the voltage is transferred to the lamp. Diagnostic flags $\overline{\text{SC1}}$ and $\overline{\text{SC2}}$—which pull low to indicate short-circuit conditions on the CQ1 and Q2 drivers, respectively—track the progress toward fully driving the light bulb.

The case of driving a large capacitor (Figure 8b) similarly flags a short-circuit condition at the start of the charging phase but only while the driver's voltage is less than 2.95V from the rail opposite the targeted one. Proper processing of these short-circuit flags allows the

Figure 10. Four dotted LTC2874 CQ outputs driving a heavy load





The cable interface of the LTC2874 and LT3669 can drive a variety of 12V and 24V relays. The CQ outputs can operate either high side or low side. In the case of the LTC2874, using the L+ power supply outputs as high side relay drivers, the CQ pins can sense the state of each relay, providing a handshake to the microcontroller via either the RXD outputs or the SPI bus. The LTC2874 can operate eight relays when driving with both CQ and L+ pins.

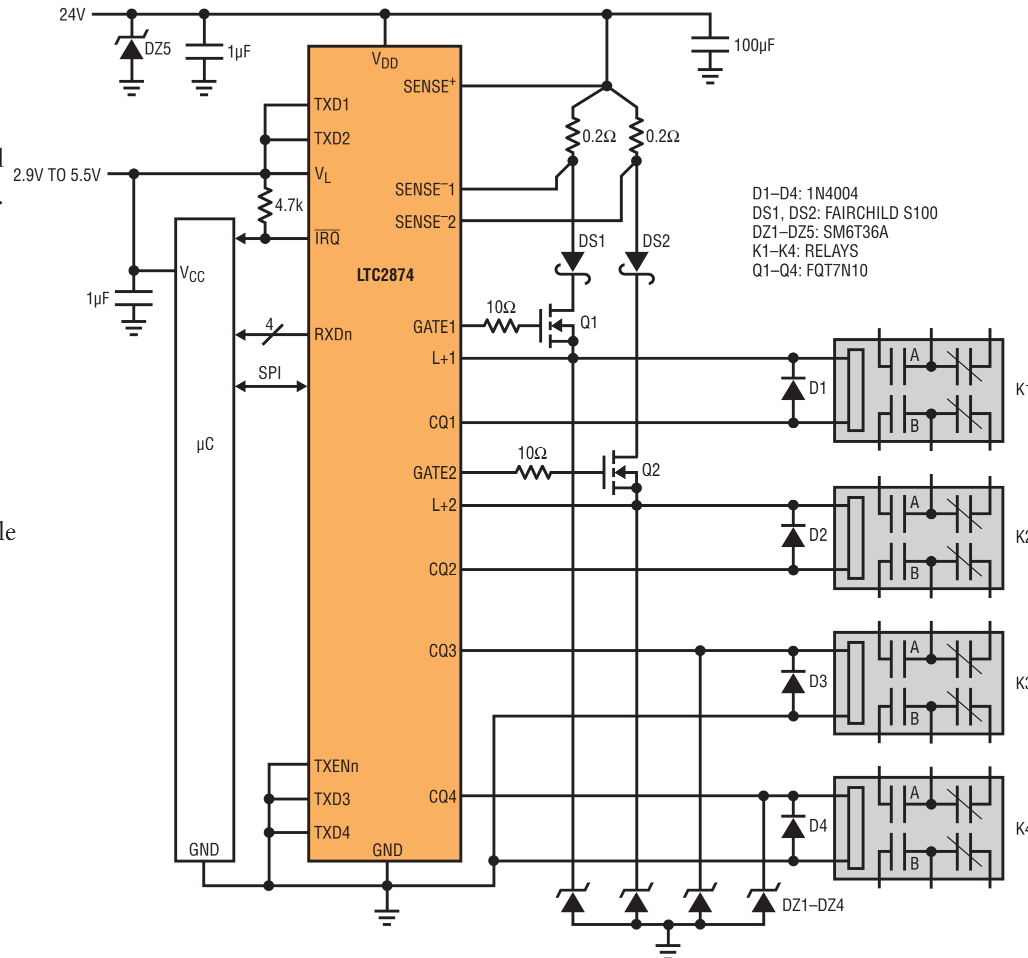
microcontroller to distinguish between real short circuits and heavy loads.

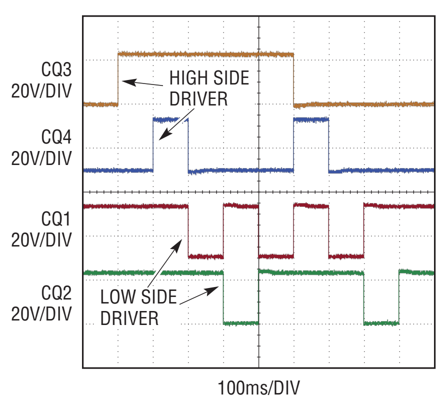
The LTC2874, too, can drive large loads without damage from overheating. Protective pulsing defined by the built-in circuit breaker and auto-retry timers will successfully turn on 1W miniature lamps. Larger lamps can be driven using more aggressive microcontroller-defined timing (Figure 9a) by connecting CQ drivers in parallel, or even by operating the L+ power supply outputs (configured for sufficient current) as high side drivers. Relying on all individual outputs, the LTC2874 can operate eight lamps (Figure 9b). Higher DC current is available when outputs are combined (Figure 10).

Driving unterminated, sometimes inductive, cable-connected industrial loads commonly produces ringing. The receivers of both parts contain programmable (LTC2874) or mode-specific (LT3669) noise suppression filters to ensure that

Figure 11. Each CQ output guarantees twice the current required to operate a Potter and Brumfield (Tyco) KRPA-11DG-24.

Figure 12. SPI-operated quad "ice cube" relay driver demonstrating both low side and high side operation.





The LTC2874 and LT3669 are designed to withstand a wide range of operating conditions, abuse and fault modes on their cable interfaces.

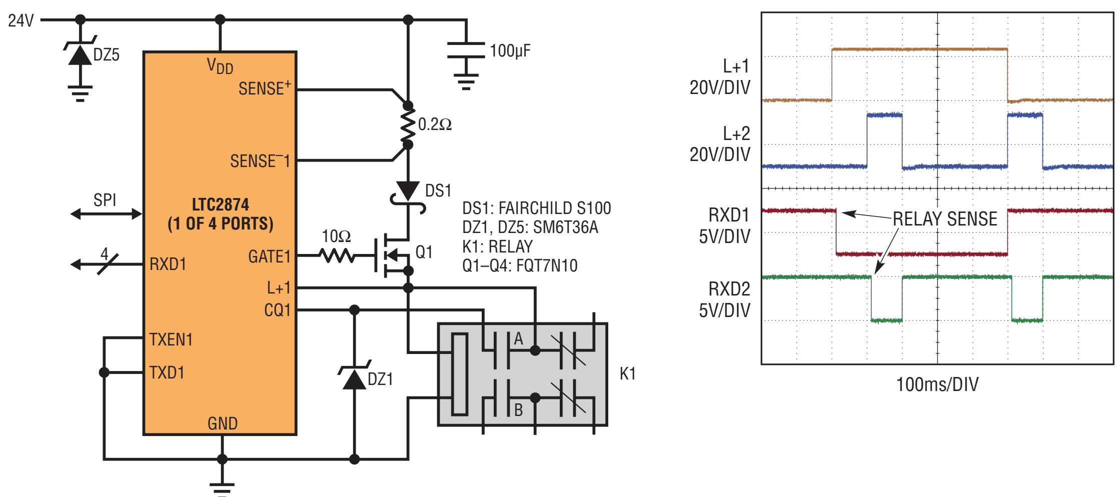


Figure 13. When L+ outputs operate relays, the CQ lines can sense the state of each relay.

microcontrollers see clean transitions, whether switching in SIO mode or communicating at the fastest IO-Link rate (COM3).

DRIVING RELAYS

The cable interface of the LTC2874 and LT3669 can drive a variety of 12V and 24V relays (Figure 11). The CQ outputs can operate either high side or low side (Figure 12). In the case of the LTC2874, using the L+ power supply outputs as high side relay drivers, the CQ pins can sense the state of each relay (Figure 13), providing a handshake to the microcontroller via either the RXD outputs or the SPI bus. The LTC2874 can operate eight relays when driving with both CQ and L+ pins.

EFFICIENT AND FLEXIBLE POWER CONVERSION KEEPS TINY SENSORS COOL

Sensors typically incorporate a transducer that converts a physical parameter to an electrical signal, a microcontroller that performs analog-to-digital conversion and signal processing, and a PHY interface that level shifts to the high voltage at the cable interface. Typically, transducers operate from 3.3V to 15V and microcontrollers operate from 1.8V to 5V. Given the IO-Link L+ typical operating voltage of 24V, it's clear that some sort of power conversion is required for proper operation of these lower voltage sensor parts.

While a simple linear regulator is capable of this task, internal power dissipation limits its application to smaller loads. For example, for an LDO generating 5V from 24V, at 10mA the pass transistor dissipates 190mW, which is

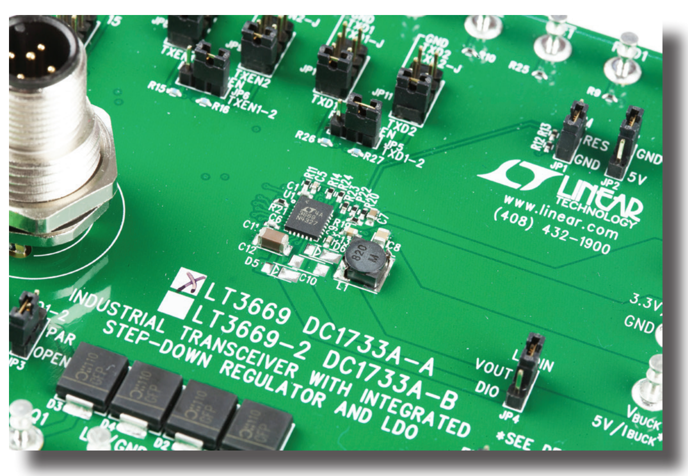


Figure 14. Compact device-side IO-Link PHY and dual power supply solution using the LT3669

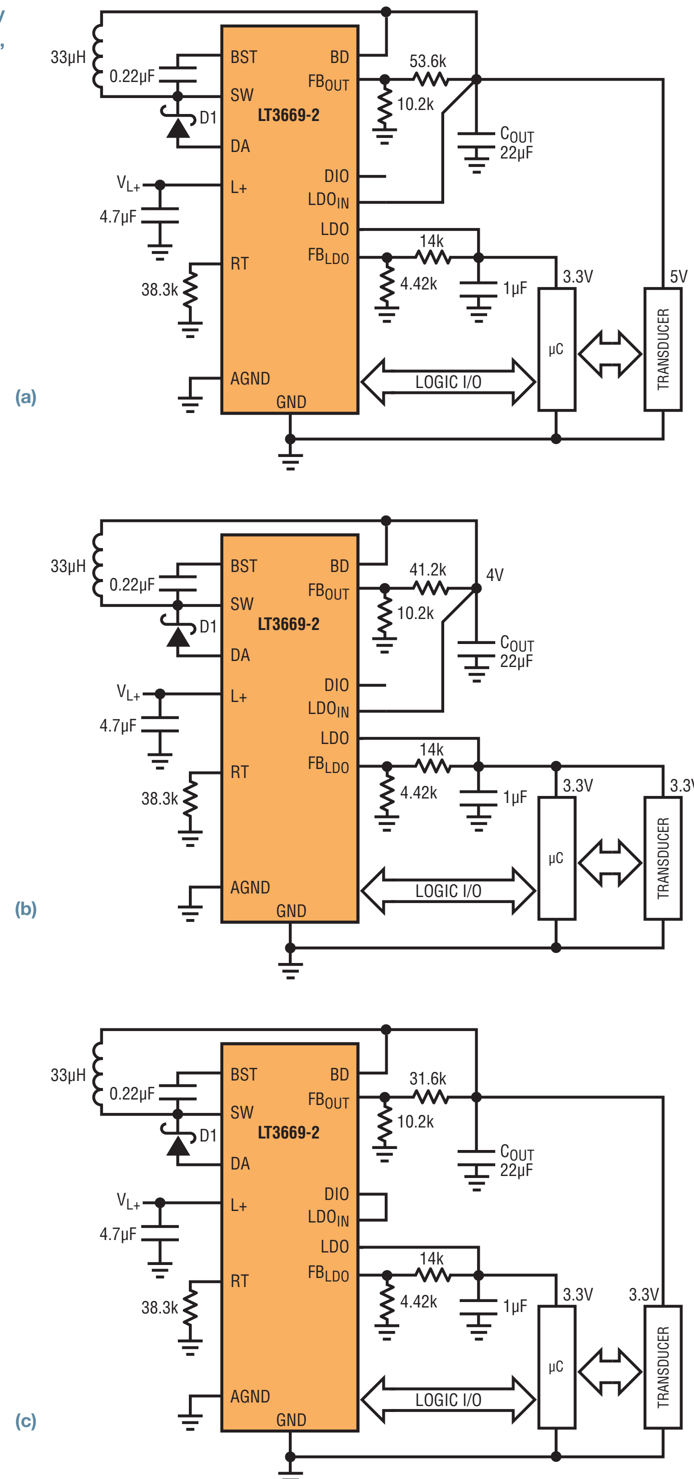
> Sensors offer a wide breadth of physical measurement capabilities, and with that just as many varied power requirements. It is impossible to meet this range of requirements with just a switching regulator or LDO. Both are built into the LT3669 and LT3669-2, allowing these devices to meet most power requirements without additional converters.

tolerable, but at 100mA the wasted power increases to 1.9W, which would significantly raise the die temperature.

At these power levels, a switching regulator offers a clear advantage: by reducing the internal power dissipation, the sensor can operate reliably at much higher ambient temperatures. Both the LT3669 and LT3669-2 integrate a step-down switching regulator in addition to an LDO. The LT3669-2 targets applications requiring medium to high power levels for the sensor's low voltage circuitry. With this in mind, it does not incorporate the catch diode, keeping that external. With an external catch diode, it typically achieves 78% efficiency for 24V-to-5V conversion at its rated load current of 300mA, corresponding to 423mW of internal power dissipation. Although efficiency falls to 69% at 100mA, the internal power dissipation is still only 225mW, 8 times lower than the linear regulator equivalent. For less power demanding circuitry, the LT3669 (Figure 14) reduces cost and area by integrating the catch diode, attaining slightly lower efficiency of 64% at its maximum load current of 100mA.

Sensors offer a wide breadth of physical measurement capabilities, and with that just as many varied power requirements. It is impossible to meet this range of requirements with just a switching regulator or LDO. By having both built into the LT3669 and LT3669-2, these devices can meet most power requirements without additional converters, saving significant space, design time and cost.

Figure 15. Various power supply configurations for the LT3669-2, with pin LDO_{IN} connected to the buck regulator output in (a) and (b) for best efficiency and to pin DIO in (c).

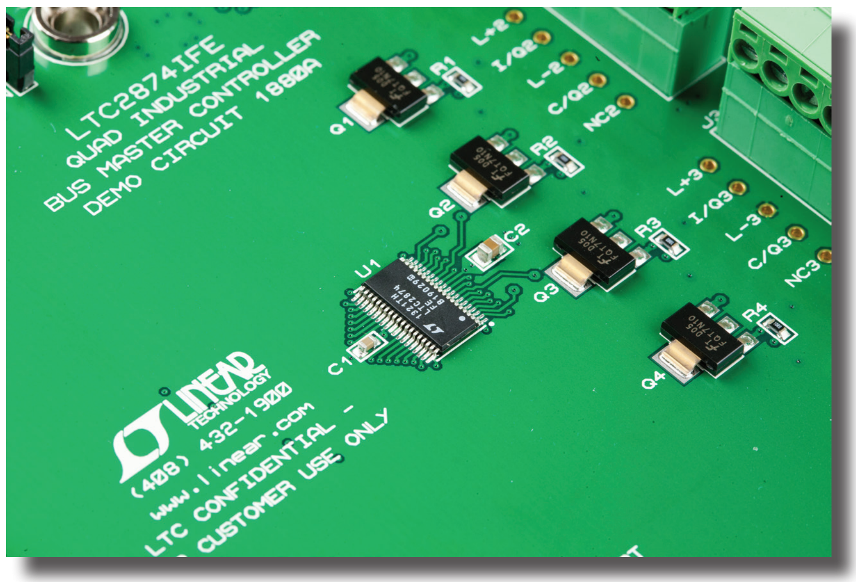


The LDO delivers up to 150mA of load current, depending on the setup. With a dedicated input pin LDO_{IN}, it can be configured to take power from any power source from 2.25V to 40V. The LDO can operate either from the switching regulator output, or separately. Figure 15 shows a number of possible supply configurations. Connecting the LDO input pin to the output of the switching regulator (Figures 15a and 15b) yields the highest efficiency. If this isn't possible, the LDO's input pin can take power from L+ indirectly by connecting it to DIO (an internal diode connects between L+ and DIO) to preserve reverse polarity protection, as shown in Figure 15c. In this case the LDO's maximum load current is reduced due to current limit foldback.

BUILDING LARGER MULTIPORT MASTERS

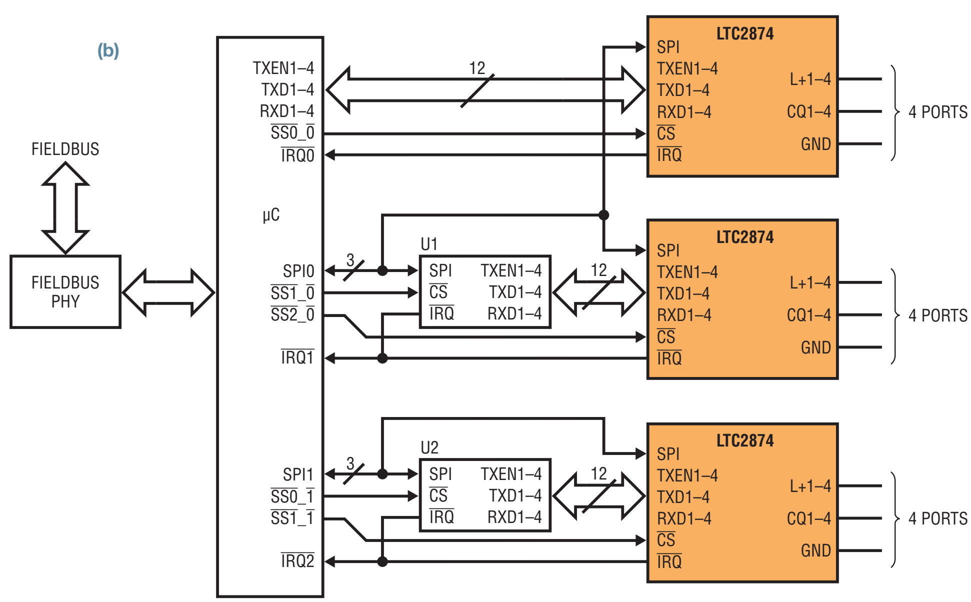
The dense integration of a quad IO-Link master PHY into QFN (Figure 16a) and TSSOP packages makes the LTC2874 ideal for building larger multiport masters. For example, a 12-port master is shown in Figure 16b. Four ports connect to the microcontroller's built-in UARTs; the rest are serviced via SPI port expanders (U1, U2), where their UARTs are implemented using dedicated ARM microcontrollers running optimized code. This system is extendable, limited only by the bandwidth and capabilities of the primary microcontroller. Linear Technology's demonstration circuit DC2228A (Figure 17a), a multiport master built in this way, supports connections to eight IO-Link devices such as the DC2227A (Figure 17b).

Figure 16. (a) Dense integration enables compact multiport masters to be built using the 4-port LTC2874. (b) Master power and communications PHY for 12 ports.

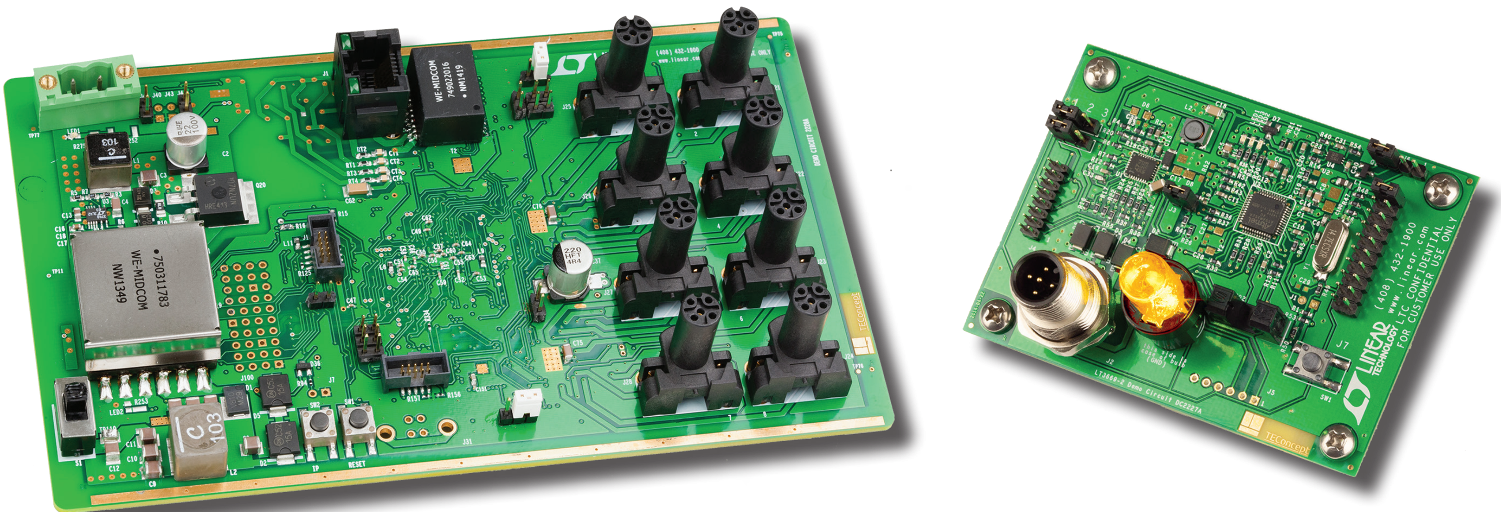


(a)

(b)



The dense integration of a quad IO-Link master PHY into QFN and TSSOP packages makes the LTC2874 ideal for building larger multiport masters.



(a) (b)

Figure 17. IO-Link application demonstration circuits (a) DC2228A, an 8-port master built with LTC2874 and powered optionally by 90W Power over Ethernet (LTPoE++™), and (b) DC2227A, a device-side sensor application built with LT3669-2, a high precision temperature sensor, a photoelectric sensor, and a 28V 100mA incandescent lamp

IEC 61131-2 SUPPORT

The cable interfaces of both parts are, as part of the IO-Link definition, loosely compatible with IEC 61131-2, an older standard specifying digital I/O in programmable logic controller (PLC) applications.[6] This compatibility includes the optional second driver Q2 on the LT3669. Additionally, the LTC2874's built-in current-sinking loads have a setting that meets the requirements for Type-1 inputs while keeping power dissipation to a minimum.

COMPLETE IO-LINK COMPATIBLE POWER AND SIGNALING INTERFACE

Both sides of an IO-Link application, each with its own microcontroller, are shown in Figure 18. The master-side LTC2874 supports four such ports. The device-side LT3669 guarantees 100mA at the 5V switched output, the 3.3V LDO output, and both driver outputs. Connector pin 2 is optional, supported only at the device side.

CONCLUSION

The LTC2874 and LT3669 offer unmatched integration and flexibility for building IO-Link systems. The LTC2874 includes power, signaling, control and diagnostic capabilities for four ports, simplifying the design of larger multiport masters. The LT3669 includes a spare driver (Q2), LDO, and a step-down regulator that helps minimize temperature rise in compact sensor assemblies. The wide operating ranges of these devices (8V to 34V for the LTC2874, and 7.5V to 40V for the LT3669), allow them to drive a variety of industrial loads. Both parts are ruggedized for the harsh environment of 24V automation. ■

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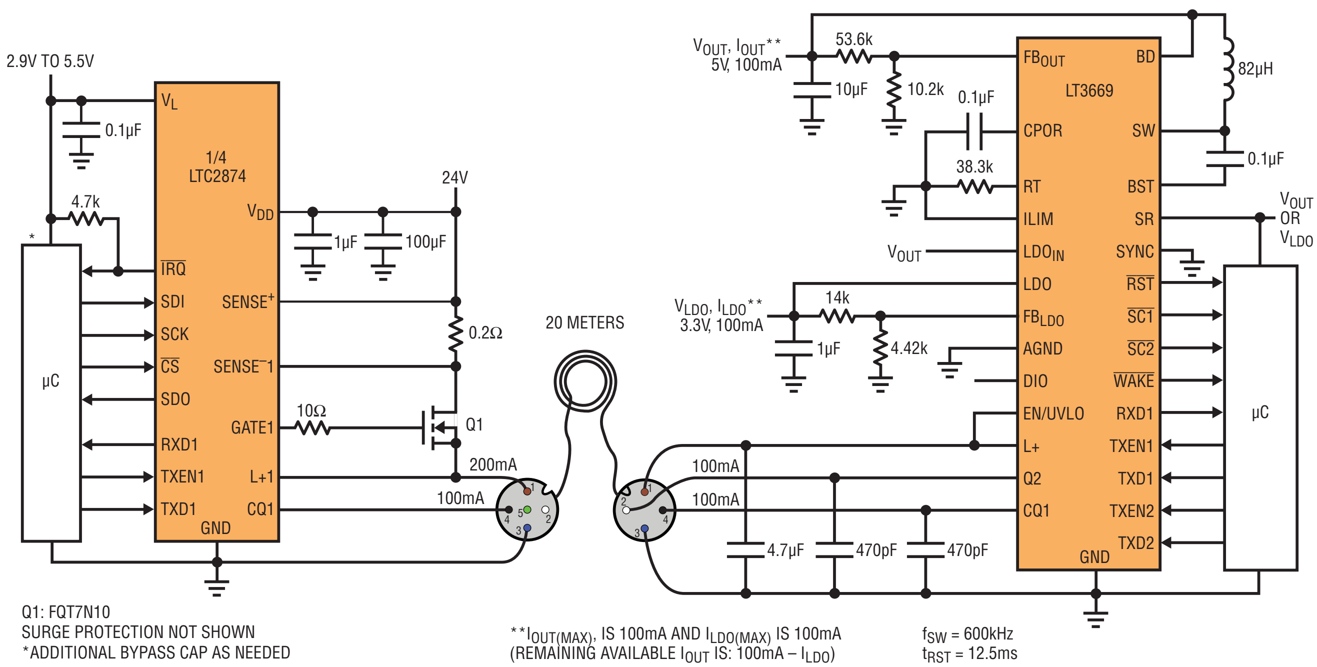

Figure 18. Complete 24V 3-wire power and signaling interface to sensor or actuator. One of four available master ports is shown.

Notes

[1] Tsun-kit Chin and Dac Tran, "Combine power feed and data link via cable for remote peripherals," *EE Times*, November 10, 2011.

[2] www.io-link.com. IO-Link is a registered trademark of PROFIBUS User Organization (PNO).

[3] IEC 61131-9 ed.1.0

[4] Paul Schimel, "MOSFET Design Basics You Need To Know," Parts 1 and 2, *Electronic Design*, April 4 and April 21, 2010.

[5] "Safely Light Miniature Incandescent Lamps Using LTC2874," Kevin Wrenner, January 2014. http://www.linear.com/solutions/4534

[6] IEC 61131-2, Third edition, 2007-07.