Integrated digital output drivers simplify sensor designs

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Highly integrated digital output drivers expand digital sensor functionality and improve robustness while reducing design complexity.

Improvements in automation technology are enabling factories to become increasingly flexible, efficient and intelligent. To realize these improvements, though, requires the ability to continuously monitor various operating conditions, environmental factors and process variables at all stages of production. Increased monitoring drives the need for smaller, more robust and more cost-effective sensors of all types. This white paper focuses on digital output sensors, which are commonly used in factory automation and process automation applications when analog reporting is not needed.

Digital output sensors

Digital output sensors translate a real-world variable like pressure, temperature or target proximity into a binary state based on a transducer threshold level. The sensor expresses this binary state electrically as a high voltage, low voltage or high impedance, and sends an output to either a programmable logic controller (PLC) or a binary actuator so that an action can occur based on a change in the sensor's value. Sensors commonly use three types of digital outputs: p-channel n-channel p-channel (PNP), n-channel p-channel n-channel (NPN) and push-pull. These three output types are illustrated in **Figure 1**; a PNP output is shown at left, an NPN output is shown in the center, and a push-pull output is shown at right.

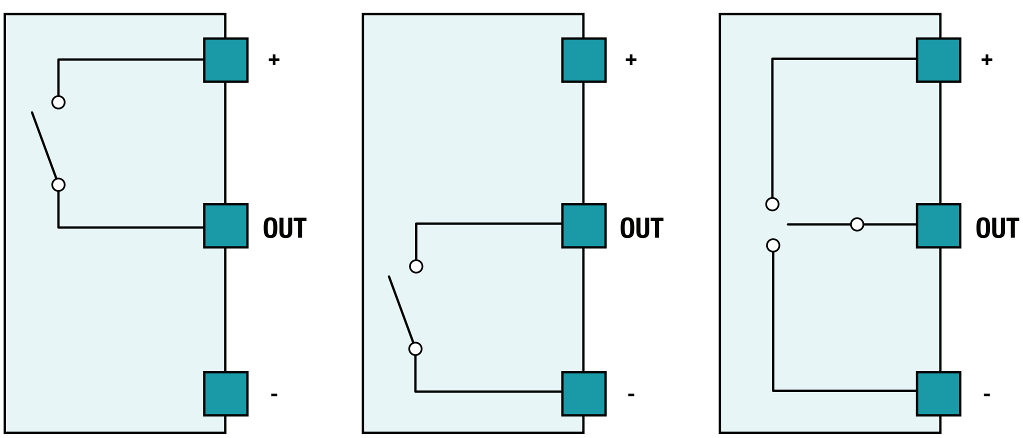

***Figure 1**. PNP (left), NPN (center) and push-pull (right) output types.*

Discrete implementations

Given the seeming simplicity of a binary output, many designers opt to pursue a discrete implementation based on individual transistors. **Figure 2** shows example implementations for PNP (top), NPN (center) and push-pull (bottom) outputs.

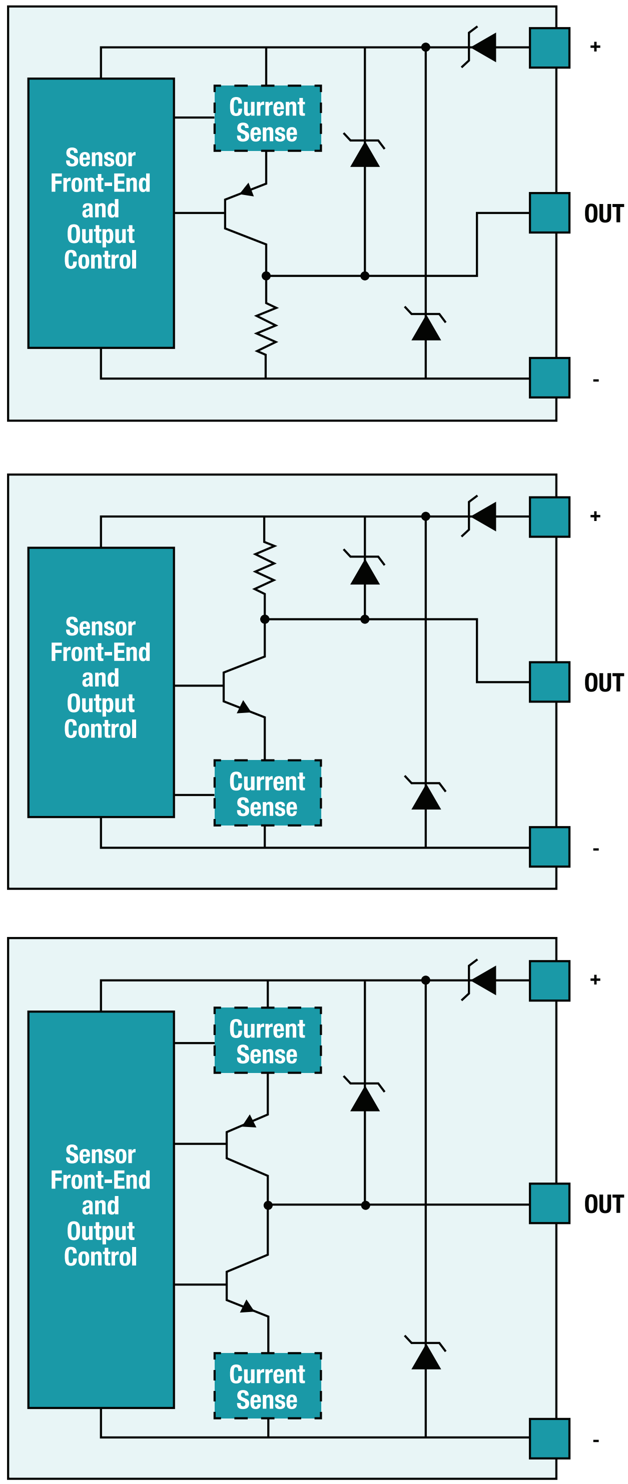

Figure 2. *PNP (top), NPN (center) and push-pull (bottom) output implementations.*

Although a single transistor is sufficient for basic output-switching functionality, you'll need several other components in order for the sensor to meet common system requirements:

- As sensors are installed in the field, there is a chance for miswirings to occur such that the positive and negative power supplies are reversed or connected to the sensor output. To prevent such conditions from damaging the sensor, you must use a reverse-polarity blocking diode.
- During operation, sensor outputs and power rails may be subject to transient stresses such as electrostatic discharges or voltage surges coupling onto the wiring. Transient voltage suppression (TVS) diodes are frequently used to protect against these stresses. Care must be taken in component selection, though, since the TVS must be able to clamp the voltage within the supported voltage range of the sensor even during high-current surge events.
- Overcurrent protection is necessary in order to prevent excess power dissipation in the transistor, since thermal damage could occur if not controlled. This protection requires a current-sensing circuit placed in series with the transistor, which unfortunately can result in a drop in voltage at the sensor output. In some cases, this extra voltage drop prevents the sensor from meeting the input-voltage specifications of the digital input to which it connects. You will also need some additional logic (not shown in **Figure 2**) to control the output transistor accordingly so that it is disabled (high impedance) when an overcurrent condition persists.
- External pull-up and pull-down resistors on the sensor output lines keep the output voltage fully high or low, even when connected to a high-impedance digital input.
- Many sensors require a lower-voltage power rail (for example, 5 V or 3.3 V) in addition to a high-voltage DC field supply. This lower-voltage rail may power certain sensor elements, microcontrollers or other logic circuits, which then necessitates the inclusion of an additional voltage regulator such as a linear regulator or switched-mode DC/DC converter.
- For sensors designed to operate from lower-voltage rails, you may need additional driver circuitry in order to translate low-voltage sensor outputs to a high-enough signal to fully enable the PNP output transistor.

A further drawback of a discrete implementation is that it is relatively inflexible. The sensor isn't reconfigurable between PNP, NPN and push-pull modes, and any output current limits (if implemented) would be fixed values. This means that designers may need to keep an inventory of several different sensor devices to interface with different input types.

Integrated implementations

Semiconductor vendors have responded to the market need for smaller, more robust and more flexible sensors by developing highly integrated solutions that implement all of the functionality shown in **Figure 2** in a single integrated circuit. **Figure 3** shows an example of such a device, TI's TIOS101.

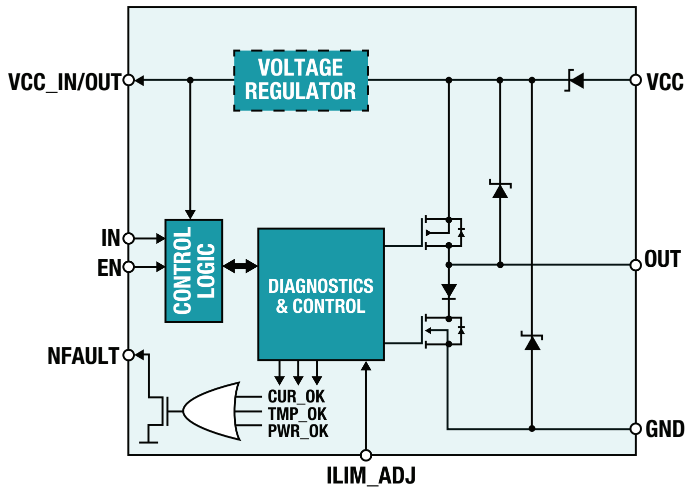

Figure 3. *TIOS101 block diagram.*

This integrated approach has several key advantages. One major advantage is that you can implement a high degree of transient protection. In the case of the TIOS101, it's possible to achieve system-level immunity to electrostatic discharge (ESD) (per International Electrotechnical Commission [IEC] 61000-4-2) up to ±16 kV, electrical fast transient (per IEC 61000-4-4) up to ±4 kV and surge (per IEC 61000-4-5 with 500-Ω source impedance) up to ±1.2 kV with no external components. If you need additional protection, the device's tolerance to ±65-V transients enables the use of small, cost-effective TVS diodes.

In addition to improved transient immunity, integrated devices are also capable of tolerating DC stresses. Integrated reverse-polarity blocking diodes prevent damage in the event of any miswiring. Implementing output overcurrent protection and overtemperature shutdown can prevent fault conditions, such as short circuits on the output line and the resulting high power dissipation, from damaging the sensor. In the case of the TIOS101 device, you can configure the output overcurrent threshold over a wide range by varying a single external resistance, and thus use the same design for a variety of applications.

When the output current exceeds the configured threshold for a certain amount of time, the output driver automatically shuts itself off, indicates a fault condition via a single logic output pin and waits a fixed amount of time before reactivating. This feature eliminates the need for external logic such as timers to help manage fault states. The TIOS101 output driver's ability to source or sink large currents for short periods before activating overcurrent protection enables the sensor to interface directly with loads that require significant demagnetization (in the case of inductive loads) or discharge (in the case of capacitive loads).

Devices like the TIOS101 also help sensor designers support multiple different output types with a common hardware implementation. Sensors are reconfigurable as NPN, PNP or push-pull through the control of just two logic lines. A single design for all three output types simplifies development, product qualification and inventory management on the back end.

Finally, with an integrated device, it is possible to include other functions outside of simple output switching. For example, the TIOL101-5 integrates a linear voltage regulator in addition to a digital output driver, thus reducing the number of components needed for sensors implementing low-voltage, low-current power rails.

Even with all of these advantages, integrated digital output drivers still maintain a small footprint on a printed circuit board. The TIOS101 device is just 2.5 mm wide and 3 mm long. These dimensions, coupled with flowthrough signal routing, enable sensors with extremely small form factors.

Conclusion

Advancing the trend of more efficient and intelligent industrial production requires digital output sensors that are small, robust and flexible. Although fully discrete output driver implementations are pervasive, a new class of highly integrated devices can improve performance and expand functionality while decreasing component count and solution size.

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