TWO-WIRE AND THREE-WIRE SENSOR INTERFACES

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Introduction

Electrical interfaces for active sensor integrated circuits (ICs) include both two-wire and three-wire interfaces. These two technology styles are named for the number of required connections needed to communicate the sensor output. This application note discusses use and tradeoffs of both interface styles.

Three-Wire

A three-wire configuration requires the user to have three discrete electrical connections to the IC. The naming convention derives from use of wires in a wiring harness. First, consider a simple sensor which conveys a digital output. One would need two dedicated lines to supply power and ground to the IC (labeled as VCC and GND in Figure 1). A third line can be dedicated to the digital signal; this digital level can be conveyed via open-drain or open-collector transistor, as shown in Figure 1.

In Figure 2, V_{SUPPLY} and V_{PULLUP} are separately noted for sake of clarity; the two can be the same source. One then only needs to note that datasheets refer to I_{CC} as current into the supply pin; current flowing through R_{PULLUP} should be accounted for separately.

Two-Wire

A two-wire sensor only requires two electrical connections. Power supply and ground contacts are still required, and so the digital output is conveyed using multiple current levels.

As sensor output is communicated along the supply lines, this saves the user the cost of a third line, as only two wires in the harness are necessary for operation.

Figure 4 illustrates two-state (digital) output levels of an example two-wire IC. Valid output levels are I_{CC(LOW)} and I_{CC(HIGH)}; any other current level indicates a fault. As such, two-wire interfaces have inherent diagnostic ability. Note the fault conditions shown in Figure 4 are not actively determined by the IC but would occur due to errors in the circuit.
Two-Wire Interface Circuits

Electrical interface for a two-wire IC is slightly more complicated than for a three-wire, the latter being directly compatible with many logic systems. One common interface for a two-wire IC is to use an inline sense resistor, as shown in Figure 5. The voltage across the sense resistor is routed to a comparator to create a digital output voltage.

\[ V_{TH} = R_{SENSE} \times \left( \frac{(I_{CC(HIGH)}(min) + I_{CC(LOW)}(max))}{2} \right) \]

\[ V_{TH} = R_{SENSE} \times \left( \frac{(I_{CC(HIGH)} + I_{CC(LOW)})}{2} \right) \]

Additional comparators can be implemented to detect fault conditions shown in Figure 4. Alternately, the \( V_{OUT} \) signal can be used with an analog-to-digital converter to detect desired signals and fault conditions.

The sense resistor (\( R_{SENSE} \)) location in Figure 5 is referred to as ‘low-side.’ This arrangement has the benefit that \( V_{TH} \) is referenced to system ground. Figure 6 shows the sense resistor in both a low-side and high-side location. The signal amplitude on the resistor is the same, but absolute \( V_{OUT} \) is dependent on \( V_{SUPPLY} \). Figure 6 shows that the relative polarity of the voltage signal changes between high-side and low-side sensing.

In a low-side configuration, note that IC GND is not the same as system ground. To reduce potential confusion, sometimes the GND connection from the IC is referred to as the RETURN line.

A sense resistor is not required for IC operation. As such, the user could implement other methods of sensing the output current. For example, the Allegro A6850 interface IC uses a current mirror.

Two-Wire Supply Voltage

It is critical for supply voltage to be compatible with the selected sense resistor value. A datasheet \( V_{CC(min)} \) does not account for I-R drop on the sense resistor. Accounting for voltage across \( R_{SENSE} \):

\[ V_{SUPPLY} \geq V_{CC(min)} + I_{CC(HIGH)}(max) \times R_{SENSE} \]

A very common mistake is to use a \( V_{SUPPLY} = 5 \) V with a 100 Ω resistor on an IC with 4 V minimum operating voltage. Applying the equation above, one quickly sees that with a 16 mA current, the voltage across the IC pins would only be 3.4 V.

Rise and Fall Times

In a three-wire IC, the output is actively driven to the low state. Thus, the fall time and low voltage level are dominated by IC function. The rise time and high voltage value are controlled entirely by the passive components in the circuit.

In a two-wire IC, output rise and fall times are governed by the IC’s current drive and the interfacing load circuit. The value of capacitor \( C_L \) (in Figure 5) and one connected between VCC and GND (not shown) have a direct impact on the rise and fall time measured on \( R_{SENSE} \).

A change in the output rise and fall times are a consideration...
if additional passives are paired with an IC to improve electromagnetic immunity. For example, with a three-wire IC, a capacitor can be added to the supply line without changing output. This is not true for a two-wire IC.

**Multi-Level Outputs**

Examples up to this point consider ICs with two-level outputs, but it is possible for both two-wire and three-wire ICs to have additional output states. For example, some two-wire ICs use an output protocol with three operating $I_{CC}$ states: low, middle, and high. Or an additional diagnostic state of $I_{FAULT}$ may be used to indicate the IC failed a self-diagnostic.

Similarly, a three-wire output can be configured to operate in two normal states and have two additional states that convey open or short electrical conditions and/or failure of a self diagnostic.

**Additional Thoughts**

It is possible to convert a three-wire device into a two-wire sensor, as is shown in Figure 8, with proper selection of $R_{PULLUP}$ and supply voltage. The user must make close note of $I_{CC}$ specifications, particularly across temperatures, as a three-wire IC generally has looser design requirements. Two-wire ICs are carefully designed to attain constant $I_{CC}$ values across temperature and voltage and are thus far preferable for a two-wire sensor.

Multiple two-wire ICs may also be operated from a single supply line, as shown in Figure 9. This can further reduce wiring needs if the ICs are located in close proximity. The designer should consider system failure modes, as breakage of this supply wire would then disable two sensor ICs.
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