

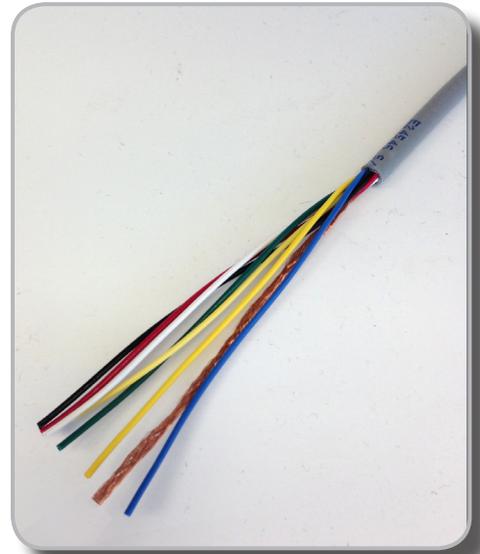
Encoder Wiring Made Simple

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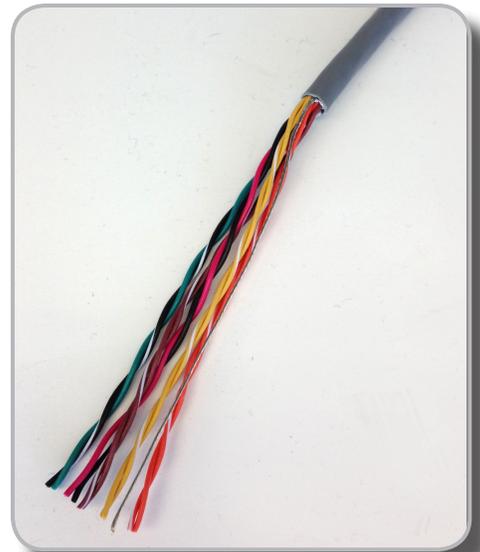
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Structured Cables



Twisted Pair Cabling



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Encoders play an essential role in motion and automation, sending a constant stream of feedback to the motor drives and/or controller to ensure that the load arrives at the specified position at the required time. Of course, generating feedback is only part of the battle. Even best-in-class components will fail to deliver if they're not properly connected. Faced with demanding requirements, tight budgets, and punishing deadlines, it's easy for OEMs to set aside the encoder cabling assembly for last, and yet when it comes to performance, that wiring may well be the most critical element of the entire system.

Depending on the design, an encoder can require between three and 14 individual conductors. The problem is that cabling is the single most common point of failure in motion systems. The failure modes are many: Repeated flexing can fracture the cladding and conductors, internal capacitance can drive up current draw, external interference may introduce noise spikes that the system interprets as motion, and so on. Although repurposing a commercial off-the-shelf (COTS) cable might appear to be an economical solution, that approach may well cost more money in the long run as a result of downtime and substandard performance. In this article, we'll review the nuances of choosing the right cable and the installation best practices that will yield a reliable system that performs as desired for the lowest possible price tag.

Wiring schemes

In addition to source and ground wires, each channel of an encoder must be connected to the drive and/or controller to deliver the signal. The number of cables depends on the type of encoder. Encoders can be classed as incremental or absolute.

Incremental encoder types include:

- Single-channel designs (A channel) for monitoring displacement and speed
- Quadrature designs (A and B channels), which have the ability to sense the direction of motion; an additional index channel (Z channel) allows the system to establish a home position
- Indexed quadrature designs (A, B, and Z channels) that also provide commutation capabilities (U, V, and W channels).

Incremental encoders can be connected with single-ended or differential wiring. For single-ended wiring, as the name suggests, each channel of the encoder requires only one wire. A single-channel, single-ended encoder would use three conductors, for example: V_{cc} , ground, and channel A. At the other end of the spectrum, a single-ended quadrature encoder with an index and commutation feedback would require eight wires: V_{cc} , ground, and one wire each for sensing channels A, B, and Z and commutation channels U, V, and W.

Although single-ended wiring is a good fit for cost-conscious designs, applications operating with extremely long runs or in high-noise environments work better with differential wiring. In a differential encoder, a differential line driver outputs two signals for each channel: the primary signal and its complement (e.g., A and A'). At the receiving end, any noise added during transmission is common mode and can be easily subtracted out (see figure A). Incremental encoders with differential wiring can support cable runs of up to 100 m.

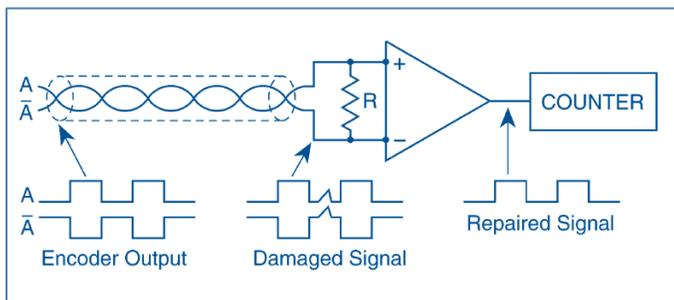


Figure A: By sending the signal and its complement, differential wiring makes it easy to identify and filter out common-mode noise.

The downside of the differential scheme is that each channel requires two conductors: one for the basic and one for the complement. As a result, a quadrature encoder with commutator feedback will use up to 14 wires. More wires means more material outlay and more opportunities for faults. In other words, the trade-off for longer runs and increased noise immunity is higher cost and lower mean time between failures.

Although incremental encoders provide good solutions for a wide range of applications, in some cases only an absolute encoder will deliver the desired performance. Absolute encoders can be wired in parallel, over a bus, or point-to-point (see table 1). In parallel wiring, the encoder is connected to the receiving device directly. Bus encoders operate on a ring topology, so they communicate with other devices on the network on a peer-to-peer basis. In point-to-point networks, the devices are connected in a master-slave scheme. In terms of the various bus and point-to-point solutions, the standards documents specify the characteristics of the cables, although shielding levels, for example, may vary.

Table 1: Absolute encoder wiring schemes

Type	Examples	Number of wires
Parallel	Individual wires	One per bit
Bus	DeviceNet, Profibus, Modbus, Interbus. etc.	4 (power, ground, data high, data low)
Point-to-point	BiSS, SSI	6 (power, ground, clock high, clock low, data high, data low)

For simple implementations like connecting a single encoder over less than 3 meters, a parallel encoder would be the best solution. Bus encoders like DeviceNet or Profibus deliver good performance and accuracy over longer runs, for example in general automation.

Extremely deterministic applications like high-speed packaging that require very good accuracy and resolution benefit most from point-to-point schemes like BiSS.

Cable types

Any time the primary task is communication, noise becomes a concern. It is essential to choose the correct wiring for the task at hand. Conductors can be classed as stranded, in which multiple thin metal strands are twisted into a single conductor, and solid core, which is monolithic. Stranded wiring is more flexible and better suited to high-bend applications. Although solid-core wiring can be used, its brittleness makes it a poor fit for motion applications.

The simplest encoder wiring is a **flying-lead wiring**, which consists of individual wires running from the encoder connector (see figure B). Flying-lead wiring can be economical but lacks the additional strength, shielding, and noise protection that a structured cable offers, making it suitable only for runs on the order of a meter or two.

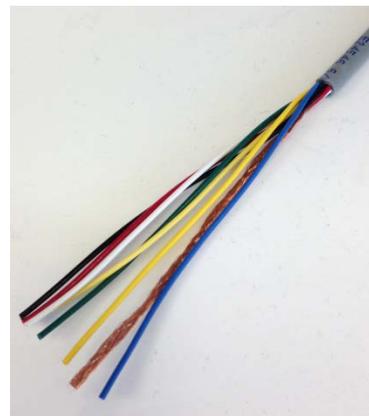


Figure B: Flying-lead wire

The next step up the performance ladder is a **multi-conductor cable**, which collects multiple wires together in a single bundle with strength elements, cladding, and factory- or user-installed couplers. Multi-conductor cables can be either stranded or solid core. They can be a good solution for low-noise environments and distances on the order of a few meters.

The longer the run, the greater the likelihood of signal degradation. For differential encoders, especially, **twisted-pair cabling** works best (see figure C). The effect of the twist is to cancel inductance and minimize crosstalk. Each twisted-pair can conduct the signals for a

given channel, with one wire of the pair carrying the main signal and the other carrying the complement. Twisted pairs are essential for high-noise environments and can support runs as long as 40 m.



Figure C: Twisted-paired cable

In an extremely noisy environment, a simple twisted-pair may not be enough to prevent the introduction of spurious pulses and signal distortion. These situations require **structured cables with shielding and strength members**. Basic shielding—a foil jacket and a drain wire—provides moderate noise protection for cost-sensitive applications. For high-speed, high-frequency applications, however, braided shielding ensures optimal performance. Applications in which interference is of particular concern may benefit from both foil and braided shielding. Foil-wrapped twisted shielded pair in a braided shielded cable can deliver good performance over distances of 100 m or more, depending upon the type of output driver used.

One of the most common mistakes users make is improperly grounding the shielding—either grounding it unnecessarily, which creates an interference-producing ground loop, or failing to ground it when they should. The correct approach depends on the cabling assembly and connector type. In general, an encoder is grounded to its mounting, making it unnecessary to ground the shielding so long as the shielding is contacted to the encoder. If the encoder is not grounded, then the shielding must be, for example by adding a separate wire to the encoder case that would be grounded to the drive/controller.

Output drivers

The output driver plays a key role in encoder performance by amplifying the current output capability of the raw square wave produced by the sensor. A driver might amplify the voltage output from a 5-V TTL signal to a 5- to 26-V or 10- to 30-V square wave, for example. There are three basic types of output drivers: open collector, push-pull, or line driver. Depending on the driver IC, the same encoder can produce any of the three types of output. First and foremost, the output driver type must be compatible with the receiving electronics. After that, the requirements of the application and choice of encoder come into play.

Probably the simplest, most economical output driver is the open collector[[link to 7273 datasheet](#)], which is based on an output transistor with the collector floating (open). These devices are typically implemented with a resistor designed to pull the output to a set voltage in the absence of current. The pull-up resistor causes the voltage to rise to the level required to indicate a logical high in an open condition, then drop to ground (0 V) when a load is applied. The result is the familiar square wave output that gets converted into counts or speed by external electronics.

The open-collector output driver is considered a sinking driver. It does not carry a voltage when it is not connected to a load, hence the need for the pull-up resistor. Open collectors are most commonly used with single-ended incremental encoders to provide a simple, economical solution for low-end applications like counters. They can be vulnerable to noise, however, and should only be used for runs of 3 m or less.

What to consider before wiring your encoder?

1. *How far does the cable need to run?*
2. *Will the system be exposed to EMI?*
3. *How much and how frequently will the cable need to flex?*
4. *Will the encoder be grounded?*
5. *What is the operating temperature range?*

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For environments with more interference, a push-pull or totem-pole output driver[[link to 7272 datasheet](#)] provides a better solution. As the name suggests, with a push-pull driver, the current can go both directions—it can be produced as the pulsing signal from the line driver or it can be sunk through the output of the encoder. The output driver can convert the output from a 5-V TTL to an open collector type output (ex. 7273)A push-pull driver is typically used with a DC-sourced signal and implemented with a single-ended incremental encoder to deliver A, B, and Z signals. When the output transistor is open, the driver produces a logical high; when it is closed, the driver produces a logical low. This approach makes the design far more noise tolerant, and works well for distances of up to 10 m.

A line driver[[link to 4469 datasheet](#)], or sourcing driver, is basically the converse of an open collector. The line driver generates a voltage whether or not it is connected to a load. A signal input to the differential line driver generates an output signal and its complement; hence, these drivers are primarily used for differential encoders in motion control applications, for example packaging lines or printing machines.

Managing current draw

Capacitance in a cable can increase RMS current draw, making the capacitance per meter (C_m) a key metric for encoder applications. It's important to remember that the current draw specified on the datasheet for the encoder does not include load. Both the cable and the receiving device draw current. An encoder might be rated for 40 mA at the output driver, but a high-capacitance cable can easily exceed that number. In the worst-case scenario, the wrong cable operated at high speeds over a sufficiently long run could draw enough current to send an encoder into thermal shutdown. Recovery requires letting the encoder cool for a time, then restarting the system. That not only introduces delays, it can cost money in terms of lost production.

Capacitance can also distort the encoder's output signal. Although the output of an encoder is theoretically a square wave, the signal requires a certain amount of time to transition from one state to the other, during which the receiving electronics interpret the signal as undefined. Ideally, transition time should be less than 1 μ s. Line capacitance can smear the leading edge of the waveform, increasing transition time (see figure B). In the limit, the process can convert a square wave into something that looks closer to a sawtooth, eventually causing the encoder to gain or lose counts.

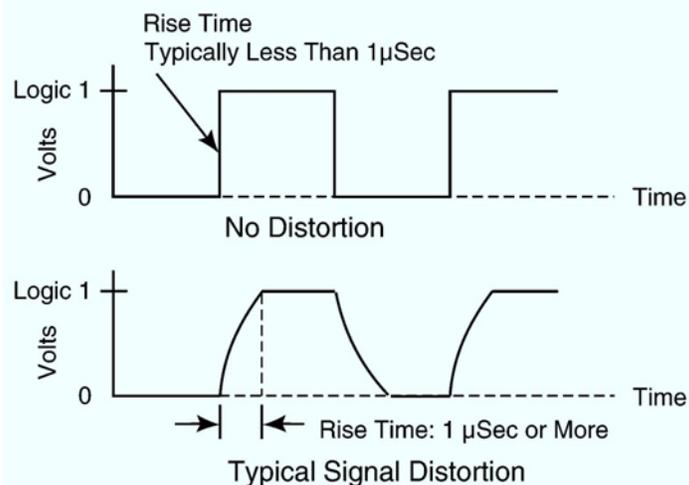


Figure B: Line capacitance can smear the square wave output of an encoder, increasing the rise time and potentially introducing error.

The best way to get the most out of the money invested in the encoder is to use cabling recommended by the manufacturer, which has been engineered to deliver optimal performance. That's not always possible however. In such a case, a good solution is a 22- to 28-gauge solid conductor with a C_m of less than 130 pF/m.

Proper installation also plays a role. Cables need to be fitted with strain relief to a minimum of seven pounds of pull force, which prevents stress on the encoder. Installers should take care to avoid going below the specified bend radius, or strapping the cable in place tightly enough to deform it. Another factor easily overlooked is temperature. In a very cold environment, both conductor and structural elements become brittle. In a high flex application, conductors and cladding can break prematurely if not properly specified.

The effectiveness of an encoder rests entirely on its ability to deliver accurate data to the driver or controller. Designers must take cabling design into consideration as part of the project from the very beginning. By following the guidelines above and working with application-specific cables designed by the manufacturer for optimal performance, OEMs can deliver an effective product to market with a minimum of effort.

Table 2: Wiring options at a glance

	Distance	Noise tolerance
Wiring scheme		
Single ended		
Open collector	< 3 m	low
Push-pull	< 10 m	medium
Differential		
Line driver	> 10 m	high
Wire type		
Flying lead	< 1-2 m	low
Multi-conductor cable	several meters	medium
Twisted-pair	40 m	higher
Shielded twisted pair	100+ m	highest

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