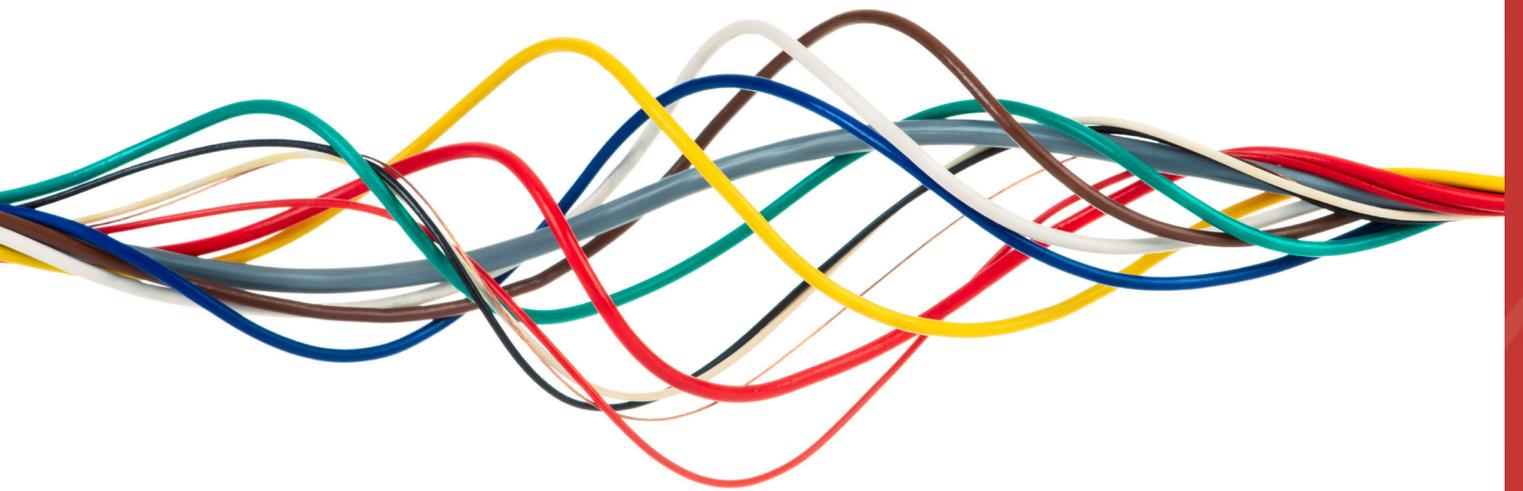
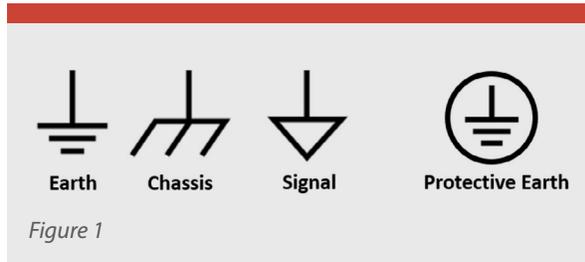


TECHNICAL NOTE TN004 – **GROUNDING, SHIELDING & TERMINATION**



OVERVIEW

An understanding of grounding, shielding and interface signaling is critical to the successful installation of servo drives and servo motor systems. This paper reviews the different grounds found in a typical installation as well as an overview of single-ended signaling, differential signaling, transmission lines and line termination – important concepts for longer cables. Also covered, cable shielding and ground loops and recommendations for general installation best practice.



GROUNDS AND GROUNDING

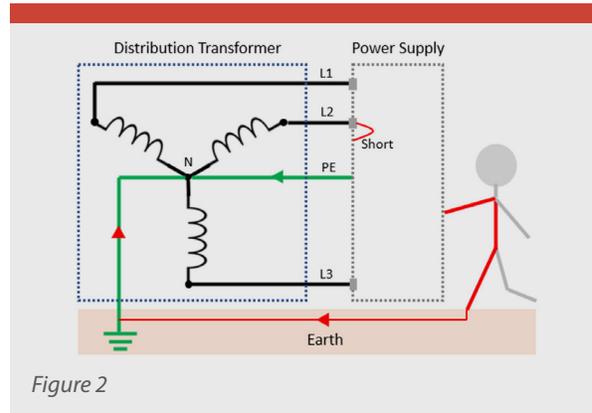
There are three fundamental types of ground as shown in Fig. 1: Earth, Chassis and Signal. As will be discussed, Protective Earth denotes a specific Chassis connection point and fault current return path.

Each type of ground will be discussed in detail. First consider some key points:

- There is no absolute value of voltage. In an electric circuit, voltage is a measure of the potential difference between two points. Ground is often referred to as being at zero volts because it is the reference for all other voltages.
- Individual grounds in an installation may have a potential difference.
- Electric current can only flow in a completed circuit. Current returns to the voltage source via all available paths. More current flows through the path of least impedance.

EARTH GROUND

The earth of the planet is a conductive stable reference universally designated as zero volts. The earth has an unlimited capacity to absorb electric charge and remain neutral. Most AC power distribution transformers are earth-grounded sources as shown in Fig. 2. A ground wire connects the 3-phase transformer neutral to a ground rod embedded in the earth. This protects the transformer from lightning surges by bleeding off charge into earth. Voltage imbalances between transformers are also eliminated.



A side-effect of earth-grounded sources is that we are all standing on one terminal of a potentially large power supply. In Fig. 2, the short connects phase L2 to the metal case of the power supply. If someone touches the case, a circuit is completed via the person and the earth to the transformer neutral resulting in potentially fatal electric shock. Mitigation techniques for this issue vary in three-phase power distribution. The basic concept is to bypass the human with a low impedance path to the transformer neutral as shown in Fig. 2. The Protective Earth (PE) path impedance is low enough to generate a current of sufficient magnitude to trip a circuit breaker so that power is disconnected.

CHASSIS GROUND

Chassis Ground takes various forms depending on the application. As in the example above, Chassis Ground can be a metallic enclosure used to protect against dangerous voltages and to mitigate electromagnetic interference (EMI) issues. Cable shields and a single PE are typically connected to the enclosure. In an automobile, however, Chassis Ground is the return current path to the negative terminal of the battery. Each component in the automobile is connected to the positive terminal and the chassis. The chassis is in turn connected to the negative battery terminal. In portable devices a ground plane is sometimes referred to as Chassis Ground.

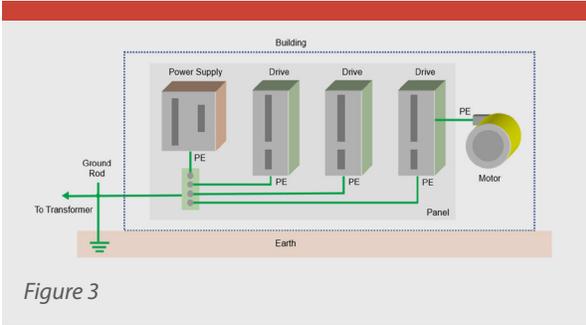


Figure 3

Fig. 3 is a more realistic depiction of PE connections to Chassis Ground for a servo motor and drive installation. Each PE wire is taken to a star connection rather than daisy-chained from device to device. Signal Grounds in the servo drives are typically connected to Chassis Ground. In a daisy-chain implementation fault currents from one drive could raise the potential of Signal Ground on another drive. Star-wiring ground connections is universally considered good practice. The servo motor PE may be routed through the motor cable, and then to the drive Chassis Ground. The PE protects against high voltage shorts to the motor case.

The building incorporating the panel has a ground rod. This is usually not used as a fault current return to the transformer neutral as the impedance may be too high to trip a circuit breaker. The primary function of the ground rod is to protect against lightning.

SIGNAL GROUND

Signal Ground is an arbitrary reference point for voltages in a circuit. It is typically the negative side of a power supply or signal source. There are often multiple grounds for circuits operating from different power supply voltages. There may also be separate grounds for analog and digital circuits. The various grounds are usually tied together at one single point. For analog and digital grounds this point is chosen adjacent to a hybrid component such as an analog-to-digital converter.

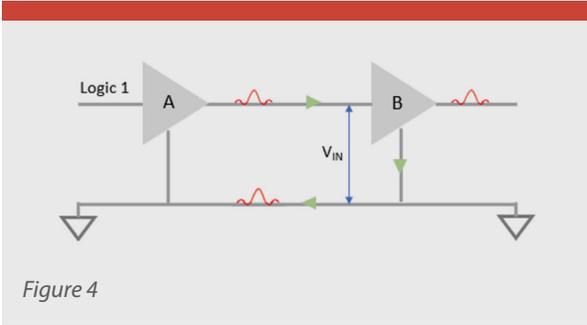


Figure 4

Signal Ground may be tied to Chassis Ground via a capacitor (low impedance to high frequencies) to mitigate radiated emissions.

SINGLE ENDED AND DIFFERENTIAL SIGNALING

Fig. 4 shows an example of a single-ended signal. Gate A in one system is connected to gate B in a second system. Gate B sees an input voltage V_{IN} relative to Signal Ground. The return current from gate A flows through the ground wire back to Signal Ground. If the cable carries multiple signals, the return currents must flow through the same ground wire. If currents are large this could raise the potential of the ground pin on gate A relative to Signal Ground affecting noise immunity. A & B Signal Grounds connected over longer distances can create ground loops especially if the Signal Grounds are also connected to Earth Ground (See Ground Loops).

Noise picked up in the cable will appear at the output of gate B. For this reason, single-ended signaling is not recommended for connecting an encoder to a servo drive. Single ended signaling is primarily used for transferring signals on the same circuit board with a common ground plane.

In differential signaling, an inverted version of the original signal is also transmitted, shown in Fig. 5. Each signal now has an individual return current path. Gate B is a differential receiver which subtracts the voltage on the negative input from

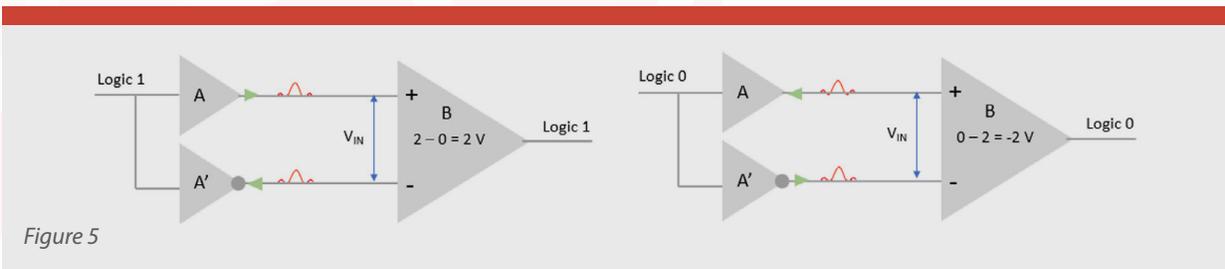


Figure 5

the voltage on the positive input. Noise present on both signals is cancelled out. Differential signals typically use twisted pairs, further enhancing noise immunity.

Lower voltages (logic 0 V > +2V, logic 1 V < -2V) can be used in differential signaling. VIN is no longer referenced to ground, but most standards still require a shared ground to ensure signals stay within the common-mode voltage rating range.

The rising and falling edges of digital signals create crosstalk between wires in a cable. The signals in a differential twisted pair generate electromagnetic fields that are equal in magnitude and opposite in polarity. Emissions from the two wires partially cancel each other so that crosstalk is reduced.

Despite the increased number of wires (two per signal), differential signaling is highly recommended for transferring signals between systems over longer distances and in electrically noisy environments.

TRANSMISSION LINES AND SIGNAL TERMININATION

RULES OF THUMB

In motion control systems, the cable from the motor/encoder to the servo drive may be 100 m or longer. It may be necessary to model the cable as a transmission line. This involves the evaluation of wavefront reflections. Rules of thumb for both analog and digital signals can be applied to determine the need for transmission line modeling. Fortunately, the treatment of transmission lines is straightforward.

Analog Signals. The cable should no longer than one quarter of the highest frequency wavelength. A typical sin/cos encoder with 256 periods per revolution turning at 100 rev/sec produces sinewaves of around 25 kHz which have a wavelength of approximately 8 km. For analog encoder signals it is generally not necessary to treat the cable as a transmission line.

$$\text{Wavelength} = \frac{\text{Light Speed} * \text{Velocity Factor}}{\text{Frequency}} \approx \frac{300 * 10^6 * 0.65}{25 * 10^3} \approx 8 \text{ km}$$

Digital Signals. The propagation delay through the cable should be no greater than 10% of the risetime of the digital signal. A typical RS-422 line driver has a risetime of 10 nsec assuming the requirement for a 10 Mbps transmission rate. This means that the cable can be no longer than approximately 0.2 m. High speed digital signals require that the cable be treated as a transmission line.

$$\begin{aligned} \text{Max. Cable Length} &\approx \text{Light Speed} * \text{Velocity Factor} * \frac{\text{Risetime}}{10} \\ &\approx 300 * 10^6 * 0.65 * 1 * 10^{-9} \approx 0.2 \text{ m} \end{aligned}$$

TRANSMISSION LINE MODEL

An ideal (negligible resistance) transmission line can be modeled as distributed inductance and capacitance, as shown in Fig. 6. (RS is the output impedance of source VS. RT is not in the circuit yet). The propagating wavefront from VS successively charges each distributed capacitor. The relationship of change in voltage divided by change in current at any point is defined as the characteristic impedance of the line ($Z = \Delta V / \Delta I$). Note that the characteristic impedance is not related to transmission line length.

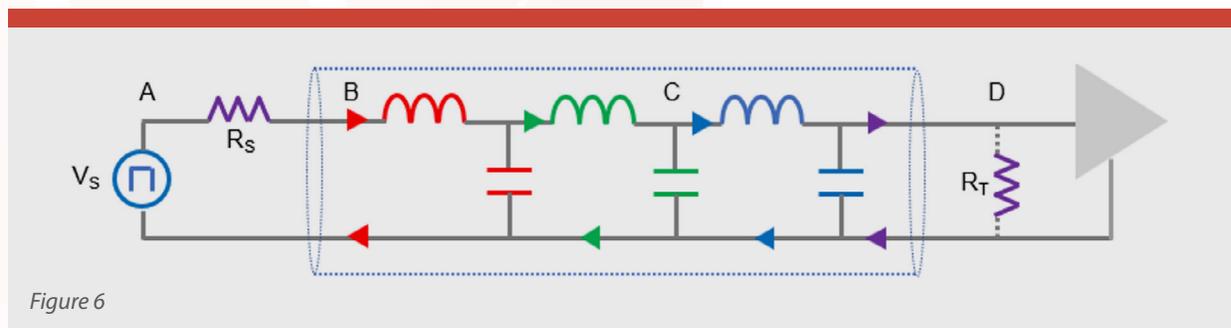


Figure 6

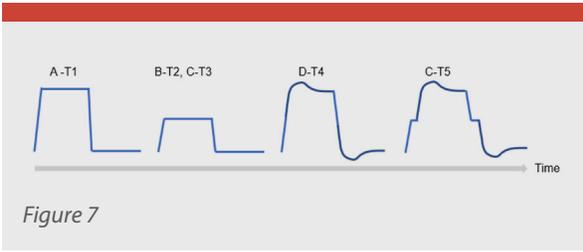


Figure 7

REFLECTIONS

When a propagating wave encounters a change in impedance, reflections occur at the boundary. For a typical twisted pair, $Z = 120 \Omega$. At the end of the line, the logic gate in Fig. 6 presents a very high impedance relative to Z and the wave is reflected as shown in Fig. 7.

The output of the square wave source first sees a potential divider comprising R_S and Z . Assuming $R_S = Z$ the voltage at B and subsequently C is half the source voltage. At D the reflection occurs adding to the incident wavefront. The reflected wave combines with another wavefront at C creating a very distorted wave. This can be a serious problem if there is a tap on the line at C. If R_S is not equal to Z multiple reflections occur producing characteristic ringing on the signal as shown in Fig. 8.

TRANSMISSION LINE TERMINATION

Reflections can be eliminated by terminating the line with a resistor (R_T in Fig. 6) equal to Z . The propagating wave now sees no impedance discontinuity. The voltage at the load gate is half the source voltage due to the resistor divider of R_S and R_T . The impedance seen by the source is quite low so a driver capable of sourcing the necessary current should be used. For differential signals the resistor is placed across the + and - inputs of the differential receiver. For bidirectional, bussed



Figure 8

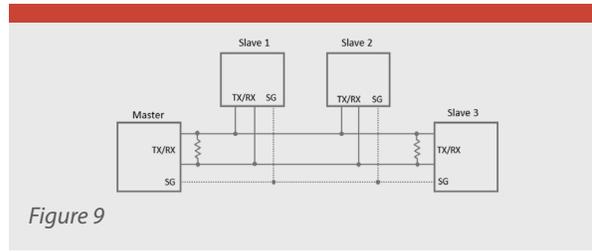


Figure 9

signals like CAN the line is terminated at both ends as shown in Fig. 9. Note the shared ground connection as discussed in Single Ended and Differential Signaling.

CABLE SHIELDING

A Faraday cage is a metal enclosure which acts as a shield to electromagnetic interference (EMI). It is not necessary to ground the cage for it to be effective. However, a Faraday cage is usually grounded to prevent charge building up to unsafe levels. The shield of a cable acts as a Faraday cage, protecting the wires inside from EMI. For maximum effectiveness the shield should have a 360° termination to the chassis via the cable connectors at both ends as shown in Fig. 10. If a flying lead connection is unavoidable, it should be kept as short as possible.

If the cable carries analog signals (encoder sin/cos signals) an internal shield may be used. The internal shield is typically tied to Signal Ground in the servo drive. The shielding is not ideal but does provide some crosstalk protection. If the cable carries analog signals (encoder sin/cos signals) a cable with inner shields over individual twisted pairs and an outer shield may be used as is shown in Fig. 10. The internal shield is typically tied to Signal Ground in the servo drive whereas the outer shield is tied to chassis. The outer shield blocks a large percentage of external noise and the inner shields are effective at blocking any remaining noise.

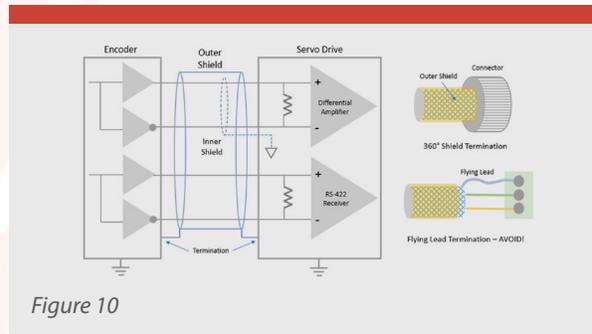


Figure 10

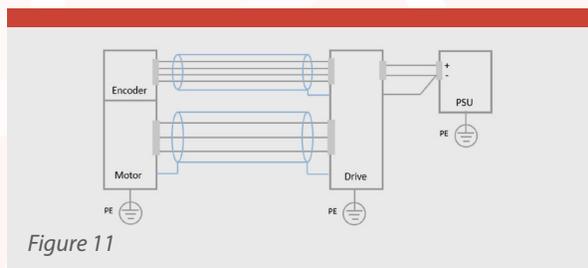
Due to the enormous diversity of motion control installations, some with imperfect grounding schemes, it may be necessary to bend the rules to achieve optimum performance. Fig. 11 shows a shielding scenario often used when noise on encoder signals cannot be eliminated by improved motor case grounding. Note that the motor shield is connected at both ends with the encoder shield connected only at the drive. Also note that the PSU return is connected to Chassis Ground so that noise generated by the drive has a low impedance return path to the PSU.

GROUND LOOPS

Fig. 12 shows two scenarios that result in ground loops: connected signal grounds and a shield terminated at both ends. In both cases a closed circuit is created via the earth. The voltage V_G may have a DC component from differing Earth Ground potentials. V_G may also have an AC component as the ground loop acts as antenna for EMI. It is common for the loop to pick up 50-60 Hz AC power “hum”. The hum in the ground loop may then be coupled into the system.

The severity of the problem depends on the installation. Ground loop mitigation techniques include:

1. Terminating a shield at one end breaks the ground loop, but the effectiveness of the shield is reduced. Inserting a small capacitor (100 pF) between the shield and chassis is another option. The capacitor blocks DC and attenuates lower frequency AC (hum) currents. Special connectors are available with built-in capacitors.
2. Communication interfaces like RS-422 which have a shared ground to keep common mode voltages within specification may recommend the inclusion of a resistor (100 Ω) between Signal Ground and Earth Ground to limit ground loop currents.

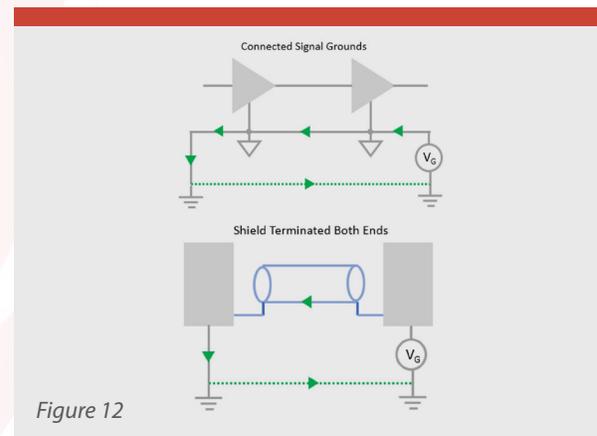


INSTALLATION GOOD PRACTICES

In addition to star grounding, differential signaling, line termination and shielding, the following installation practices also recommended:

1. Follow any guidelines in the servo drive and servo motor installation manuals.
2. Ensure power supply cables, motor cables, and signal cables are routed separately*. If signal cables must cross power cables, try to cross at right angles. Cables that are longer than necessary should not be coiled together.
3. If ground connections are made to painted or anodized surfaces the connection point should be scraped down to bare metal.
4. Ground cable cross sections should follow a tree structure: the trunk cable (Earth star to transformer) must be bigger than the branches (Chassis to Earth star), which must be bigger than the small branches (Signal to Chassis). A thin cable near the root can create disturbances in all devices.
5. Use a line filter between the AC supply and the servo drive power supply input. This may be a requirement for system CE conformance.
6. Consider using an AC supply line reactor to protect against power surges.
7. Consider a choke on the drive 3-phase output to reduce PWM switching noise. This is particularly helpful when motor cables are longer.

* The one-cable solution of Hyperface DSL® and Endat 3 contradicts the recommendation to separate power and signal cables. DSL and Endat 3 cables, however, each have a specific construction. Only approved cable should be used.





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