Application Report
SLLA143 - May 2003

RS-485 for Digital Motor Control Applications[1]

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ABSTRACT

This application report focuses on the benefits of using RS-485 signaling for motor control and motion control applications. This technology has several benefits for these applications in terms of noise immunity, wide common-mode voltage range, adequate data rate, and multipoint capability. Other applications also use RS-485 signaling to take advantage of these same benefits. Applications such as process control networks, industrial automation, remote terminals, building automation and security systems apply RS-485 extensively to solve their requirements for robust data transmission over relatively long distances.

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[1] Originally featured on *ChipCenter Analog Avenue* at www.chipcenter.com/knowledge_centers/analog/

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1 Introduction

Digital motor control refers to using digital processors to control the motion of electric motors. Typically one or more methods of feedback are available to the digital processor, making this a closed–loop system (See Figure 1). This contrasts to analog control systems and open-loop motion systems.

Digital motor control is found in many applications. These include storage devices (such as disk drives), industrial robotics, high-precision semiconductor manufacturing, and copiers.

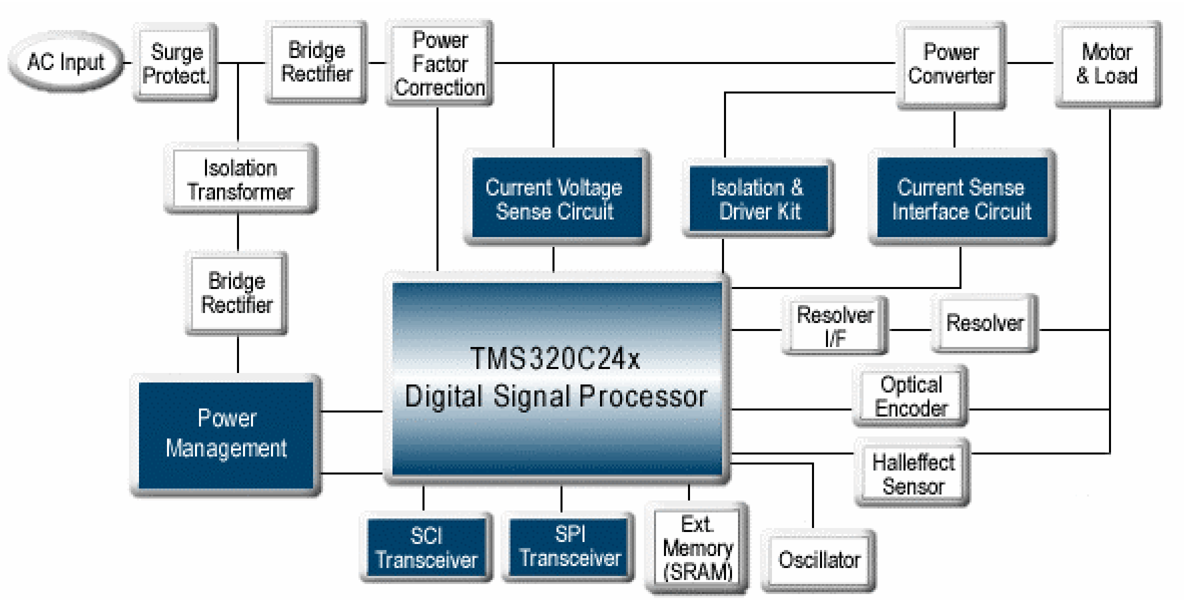

Figure 1. Digital Motor Control Block Diagram Showning Components Offered by Texas Instruments

1.1 Motor Devices

The motor involved in digital motor control may be one of several types. The most common is the subfractional horsepower rotary motor (see Figure 2a). These may be further classified as ac, dc brush, or dc brushless type, depending on the method of commutation. Small motors are typically sized according to their frame size and power in watts. Larger motors, typically ac type, are classified by their power in horsepower. Although rotary motors are the most common, other configurations are available, such as linear motors (see Figure 2b), and gearhead motors with various implementations of actuators built on.

(a) Rotary Electric Motor (b) Linear Electric Motor

Figure 2. Rotary and Linear Electric Motors

1.2 Feedback

In order to provide feedback on the position, speed, torque or other dynamic properties of the motion system, feedback sensors are necessary. Perhaps the most common feedback sensor is a rotary encoder, consisting of a wheel with alternating stripes, mounted on the motor shaft. As the motor rotates, an optical sensor detects the passing of the stripes, and produces electrical signals, which a controller can use to determine the motor’s motion. Other types of sensors are tachometers, synchros and resolvers, which are induction-based sensors, Hall-effect sensors, which are magnetic-based, and potentiometers, which are resistance-based.

No matter which sensor method is used, the digital controller must repetitively sample the sensor signal, in order to constantly maintain current knowledge of the system’s dynamic motion. Depending on the system requirements for speed, dynamic response and accuracy, the rate of feedback sampling may be over several thousand samples per second.

1.3 Controllers

The controller, whether digital or analog, compares the commanded motion and actual dynamics of the system, and processes these inputs to create a control signal to the actuator. In the case of digital controllers, additional tasks may include system start-up routines, diagnostics, communications control, and sampling multiple sensors.

Digital controllers may be as complex as dedicated computer processors, or as simple as single-chip programmed gate arrays. Texas Instruments offers digital signal processors with features optimized for motion control, and microcontrollers with varying features for best-fit solutions to a wide array of applications. For more information, search on *Digital Control* on the Texas Instruments web site at www.ti.com.

1.4 Data Transmission

This discussion focuses on the benefits of using RS-485 signaling for motor control and motion control applications. As discussed below, this technology has several benefits for these applications in terms of noise immunity, wide common-mode voltage range, adequate data rate, and multipoint capability. Other applications also use RS-485 signaling to take advantage of these same benefits. Thus applications such as process control networks, industrial automation, remote terminals, building automation and security systems apply RS-485 extensively to solve their requirements for robust data transmission over relatively long distances. Often the RS-485 signaling is bundled with a protocol such as Profibus, Interbus, Modbus or BACnet, each tailored for the specific requirements of the end user.

Other signaling technologies may be used when the features of RS-485 are not the best fit. For example, RS-232 or RS-422 signaling may be adequate in some applications—sometimes controller area network (CAN) or EtherNet/IP (Industrial Protocol) are preferred due to compatibility with an existing network. For higher speed applications, and where long distance and common-mode voltages are not as rigorous, M-LVDS can provide lower power dissipation. Several of these alternatives are discussed in the application note *Comparing Bus Solutions*, available on the TI web site.

1.5 Basic Topology

In the motion control application example shown in Figure 3, there are several different interfaces that may require special attention with regard to data transmission. Table 1 identifies several categories of signals, and summarizes the critical characteristics of signaling speed and signal level.

Table 1. Signals in a Typical Motion Control System

SIGNAL	DESCRIPTION	TYPICAL SPEED	SIGNAL LEVELS
Motion Commands	Digital (pulse or encoded binary)	Up to 10 Mbps	TTL or CMOS logic
	Analog	Up to the servo bandwidth of the system	±10V typical range
Motion Feedback	Digital (pulse or encoded binary)	Up to 10 Mbps	TTL or CMOS logic
Position Feedback	Synchro, Resolver (sinusoidal)	Up to 10 kHz	>20 Vac
	Encoder, digital outputs (A, B and Index pulses)	Up to 10 Mbps (after interpolation)	TTL or CMOS logic
Drive Voltage	Motor coil voltage, one to three phases	Up to 100 kHz depending on commutation scheme	Up to 200 V depending on motor power and winding
Commutation Signals	Binary signals, usually three phases, for determining motor commutation based on winding position	Up to 3 kbps	TTL or CMOS logic
Tool/Load Commands	Application-specific command signals, usually coordinated with motion trajectory	Application specific	Application specific
Actuator Limits/Status	Limit switches, interlocks, homing sensors, etc.	Up to 1 kbps	TTL, CMOS or up to 24V

From this table it can be observed that any data transmission scheme must have a wide range of operation to fit the spectrum of digital motion control needs. RS-485, with signaling from dc to rates of over 10 Mbps and robust signal levels, suits most of these requirements well. These signals are illustrated in Figure 3. Note this figure shows a single-axis system; multiaxis systems may share the same controller and have coupled mechanics to the same tool or load.

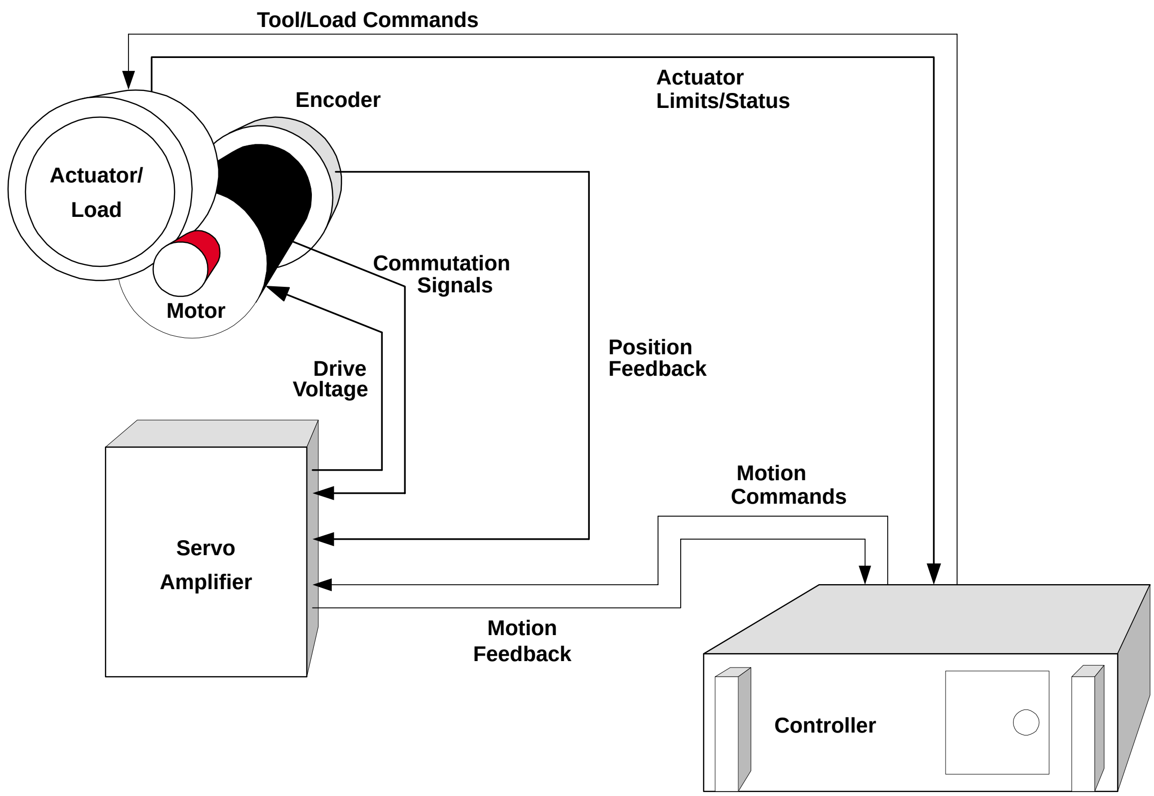

Figure 3. Interfaces in a Motor Control System (Single-Axis Shown)

Depending on the physical arrangement of the specific application, there may be significant distance between the controller, servo amplifiers, motors, and load. In addition to distance, other factors such as electrical noise, temperatures, and cable faults should be considered when designing these systems. The goal of effective data transmission should be to provide reliable communication between these components, regardless of the distance or environmental conditions.

2 Data Transmission Concerns and How RS-485 Addresses Each

Digital motion control applications pose several challenges to reaching the goal of efficient, robust communication between system components. Inherently an electromechanical actuator is involved, with its associated electrical noise and relatively high current levels. Safety and dependability further require that the communication path is very reliable for controlling the moving mechanism. Also associated with the moving application are constraints on cable routing, which may require extra lengths of cabling. Stability of the servo system also puts additional demands on the signaling rate. In the following paragraphs, the suitability of RS-485 to meet these needs is discussed.

2.1 Environment

2.1.1 EMI/Noise Immunity

Electromagnetic interference (EMI) can corrupt the signals in a motor control system. Typical sources of EMI are motor drive voltages, motor brush noise, tool sources, and electrical noise from clocks, displays, and other computer-based components. In an analog system, noise signals might cause unwanted motion or instability. Due to the inherent signal-to-noise ratio of binary coding, the main concern with digital systems is spurious pulses, which may be interpreted as commands or feedback signals.

The RS-485 signaling standard includes features that are well suited to these EMI concerns. RS-485 signaling is balanced and differential, and is typically transmitted over twisted wire pairs. This results in any electrical noise being coupled nearly equally onto both lines. This noise is therefore rejected, while the difference in the voltages continues to carry the signal information.

The RS-485 signal levels are defined such that for any active driver, one line is driven high and one is driven low. The magnitude of the difference between the voltages on the two lines must be greater than 1.5 V at the driver to transmit a valid state. This is true for all valid loading conditions.

The receiver specifications are very important for EMI noise rejection. The RS-485 standard requires detection of a valid state when the received differential signal has amplitude of 200 mV or more. This sensitivity accounts for losses in the cable that reduce the signal at the receiver below the 1.5 V amplitude generated by the driver.

Also important, and not specified by the RS-485 standard, is the receiver hysteresis (shown in Figure 4), which is the difference between the thresholds for low-to-high and high-to-low transitions.

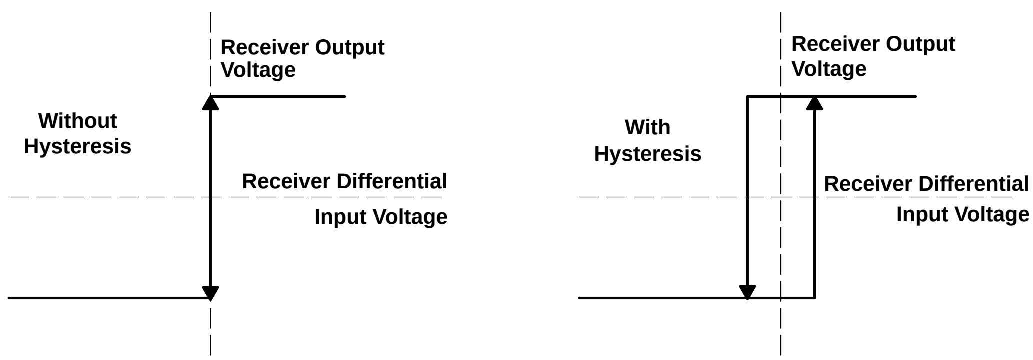

Figure 4. Receiver Function With and Without Hysteresis

Because no wire pair is perfectly balanced, there will be some differential-mode noise induced by EMI sources. Without receiver hysteresis, the receiver would change state each time the inputs intersect (a differential voltage of zero), whether due to valid signal changes or in response to noise (see Figure 5). Therefore hysteresis is needed to avoid spurious pulses, especially during idle-bus or transition periods. These spurious pulses could be interpreted as encoder counts, step commands, or actuator signals, depending on the location in the system where they occur. Receivers with higher values of hysteresis are more immune to EMI noise. Typical RS-485 receivers have 40 mV to 60 mV of hysteresis; Texas Instruments offers receivers with up to 100 mV of hysteresis for especially harsh electrical noise environments, such as digital motor control.

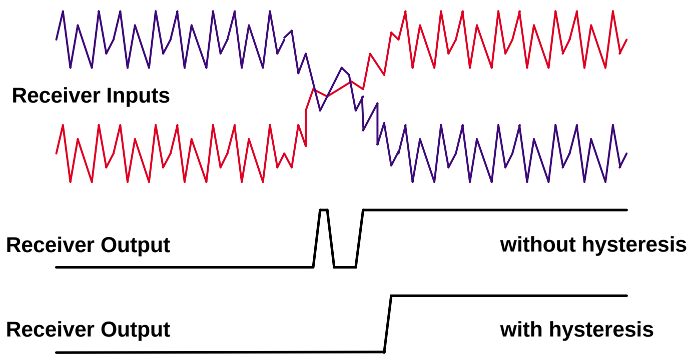

Figure 5. Hysteresis Eliminates Spurious Transitions

2.1.2 Ground Potentials/Common Mode

Another type of electrical challenge that can affect communication in a motion control application is offsets in the ground reference between the driver and the receiver nodes. Current loading, such as may occur with a high-power tool, can cause this type of problem. Localized voltage surges may also occur due to motor back-emf, equipment failures, and secondary surges from nearby lightning strikes.

Figure 6 illustrates how ground offset can occur in a motion control application. Consider a typical motor and amplifier/controller, with some length of cable connecting them for communication and providing electrical power.

If the 24-V power supply between node 1 and node 2 is connected by 50 meters of 14 AWG cable, we expect R_{COPPER} to be approximately 0.5 Ω. Under normal operation, we assume the motor current is less than 2 A. But under a stall fault condition, the current may quickly spike to 10 A. This causes a difference between GND_1 and GND_2 of 5 V, due to the drop across the ground line. Therefore any signal referenced to GND_1 appears to be shifted by –5 V when received at node 2. Since all signals are affected by a common offset, this is known as a common-mode voltage shift.

While this scenario prevents reliable communications with single-ended data transmission, a 5-V ground shift is within the standard RS-485 common-mode voltage (V_{CM}) range. Since the signals from node 1 are both shifted equally, the differential-mode signal is still valid, and the RS-485 receiver reliably receives the correct signal.

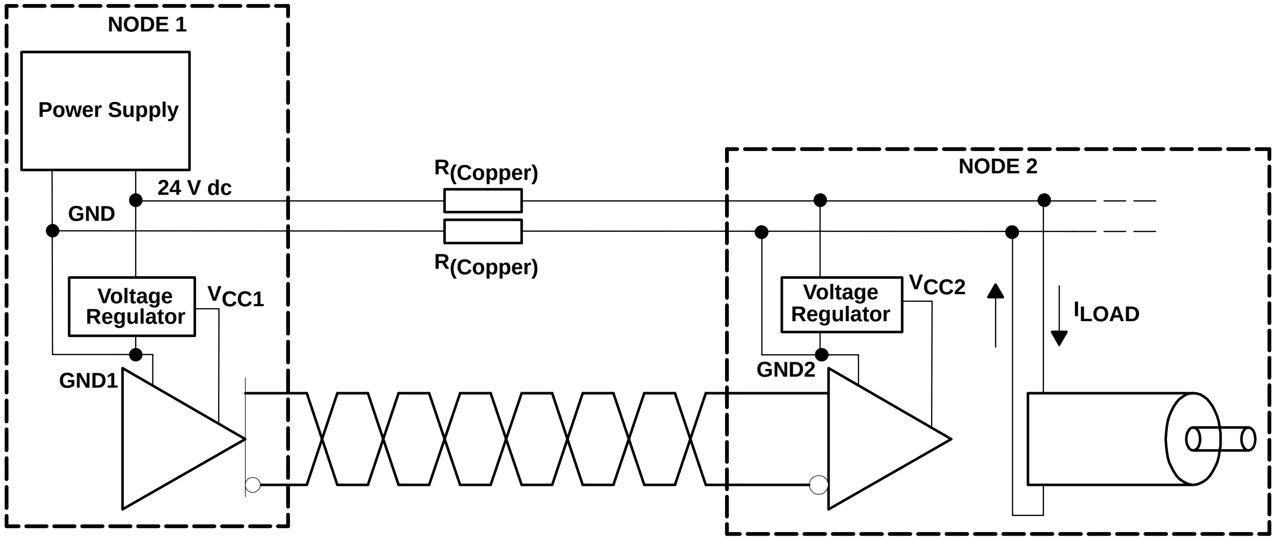

Figure 6. System With Ground Potential Shift

All of Texas Instruments' RS-485 transceivers meet or exceed the requirements of the TIA/EIA-485 standard for operation with a common-mode voltage range of –7 V to 12 V. For operation over an even wider range of V_{CM}, new products such as the SN65HVD22 operate with a common-mode range of –20 V to 25 V.

2.1.3 Electrostatic Discharge

Electrostatic discharge (ESD) is a hazard for any circuit that is connected via a cable, and which may be exposed to handling or external high voltages. Various test methods, such as the JEDEC human body model (HBM) and the IEC ESD immunity test (IEC 61000-4-2) are used to simulate different ESD hazards. Texas Instruments offers a selection of transceivers with ESD protection integrated into the bus circuits.

Typical levels of protection range from 2 kV to 15 kV. Some transceivers, such as the SN65LBC184, providing protection to events of over 30 kV. The level of protection needed by any particular application is difficult to predict, but designers should consider such factors as:

- The electrical environment where the transceiver is located
- Handling conditions and frequency of cable access
- Diagnostic procedures to determine failure points
- Replacement downtime and associated labor costs

Another type of electrical hazard is damage due to transient (surge) overvoltages. This type of event can be caused by lightning strikes coupled through a power transformer secondary, or by localized power faults due to machine failures. Test methods for this type of hazard are documented in IEC61000-4-5. External protection diodes are typically added to provide a safe path for this energy to dissipate. Texas Instruments offers the SN65LBC184 with integrated transient voltage suppression circuits, capable of protecting the bus inputs to over 400 W of surge power.

2.1.4 General Ruggedness

Because digital motor control products must frequently operate in harsh environments, there are additional considerations when specifying transceivers. For high-power and industrial applications, performance over an extended temperature range may be required. TI offers RS-485 transceivers specified for commercial, industrial, automotive, and military temperature ranges.

Another concern may be the power supply for the transceiver and the power supply tolerance. Recognizing that high-current motor applications may induce voltage sag in the power supplies, TI offers a selection of transceivers which meet full performance specifications with either 5% or 10% variation in the supply. In most cases, RS-485 transceivers operates over even wider power supply variation, but may not meet all parametric specifications. TI's selection of transceivers includes products for 5 V and 3.3 V supplies, as well as the SN65HVD08 transceiver which operates with all power supply voltages in the range of 3 V to 5.5 V.

2.2 Speed

2.2.1 Feedback Loop Delay

One concern of engineers designing communications for digital motor control is whether the communications components add significant delay to the servo loop. In general, the propagation delay associated with RS-485 data transmission is negligible for typical systems. The communications delays can be categorized into:

- The propagation delay of the transceiver and media
- The signaling rate (synchronization) delay
- The overhead added by coding

2.2.2 Propagation Delay (Cable Transmission Delay, Transceiver Delay...)

The propagation delay of the transceiver and media is due to the physics of transmitting an electrical signal through the semiconductor devices and through the copper wire. Typical propagation delay through a transceiver is on the order of tens to hundreds of nanoseconds. Propagation delay through a cable, such as twisted-pair wires for RS-485, is about 5 ns per meter.

For comparison, consider a very high-performance system, with a servo bandwidth of 10 kHz. Therefore, even for this very quick system, a transceiver delay of a microsecond (1000 ns) corresponds to a phase shift of less than 4 degrees. For cable lengths less than 100 meters, the phase shift due to less than 500 ns of cable delay is also negligible.

2.2.3 Signaling Rate

If the data transmission is such that the data is sent and received as soon as it is available, the signaling rate is typically limited only by the data source, not by the data transmission chain. An example would be an encoder, which sends pulses asynchronously, as soon as motion is detected. Rotary encoders may be able to produce 8192 or even up to 32000 counts per revolution, at rates of over a million counts per second. If coupled directly to a transceiver, these pulses are transmitted starting in less than a microsecond, with typically negligible delay to the system. However, if a controller clocks the transceiver synchronously, the signaling rate may be much slower, and this can be a constraint on system performance. Typical synchronous signaling rates are 9600 bits per second, 19200 bits per second, 115 kbps, etc. The system designer should consider the impact of this signaling rate delay on the latency of the data, and on the performance of the system.

2.2.4 Larger Payload for Serial Communication

Besides propagation delays and synchronous signaling delays, there may be delays due to encoding format associated with the protocol of the data. Encoding may be incorporated in the data transmission scheme for several reasons. One reason is to provide a means for error checking. A typical example is the parity bit commonly used to verify the fidelity of each set of 8 data bits. Another example is the start and stop bits used to signal the beginning and end of a message. Description bits such as command/status codes may also be part of the message protocol, if the data source has sufficient complexity to support these elements.

These added bits provide additional features to the data transmission scheme, but also require time to transmit and decode. Therefore, the system designer must be sure to allow margin for these *overhead* bits when setting the system speed requirements and signaling rate. For example, consider an application with an encoder providing absolute position data in the form of three 8-bit words. With a signaling rate of 9600 bits per second (bps), a feedback speed of 400 positions per second can be achieved. However, if the message protocol requires 8 additional bits per message (to determine most-significant word, start bit, stop bit, parity, etc.) then the effective update rate drops to 300 position updates per second (9600 bits/sec x 1 update/ 32 bits = 300 updates/sec).

2.3 Multipoint Topologies

Another consideration is whether more than two nodes communicate on the same bus. If one node transmits to several receivers, this is called a multidrop configuration. If any one of several nodes can take control of the bus and transmit to the other nodes, this is denoted as a multipoint architecture. Of course, as the complexity of the system increases, the signaling protocol must include procedures for determining which node will transmit at any one time. This avoids bus contention, where two line drivers may fight each other to set the bus voltages. As a safeguard, the RS-485 standard also requires that each transceiver include protection against damage due to bus contention. That is, if two drivers should happen to be active with opposite states, neither shall be damaged by the contending voltage levels on the shared bus lines.

With available RS-485 signaling technology, up to 32 nodes with standard (unit–load) transceivers (or up to 256 nodes if using sub-unit-load transceivers) can be connected to the same twisted pair cable in a multipoint arrangement. This can simplify the wiring in a multiaxis, multisensor system.

The signaling rate should be selected high enough to allow all nodes to meet their individual update requirements. The TIA/EIA-485 standard suggests signaling speeds up to 10 million bits per second (10 Mbps). While this is more than adequate for most systems, Texas Instruments offers transceivers with signaling rate capability of over 30 Mbps, for the most demanding high-speed systems.

There are several standard protocols which use signaling based on RS-485. These protocols implement various methods for setting message formats, error checking, multipoint bus control, and negotiating signaling rates. Common protocols that may be used for motor and motion control are Modbus, Profibus, and Interbus-S. Each is championed by different vendors and trade organizations, and is optimized for different network conditions.

3 Application Example

3.1 Encoder Feedback Signals From High-Resolution Incremental Encoder

One application example is shown in Figure 7 where RS-485 signaling is being used to report encoder information to a motion controller. It may be necessary to locate the motion controller some distance from the encoder, due to space constraints or the need to access the controller easily.

In this example, there are four signals in a point-to-point configuration, so a quad driver and quad receiver are needed. Termination resistors are needed at the receiving end of the bus to match the cable impedance and thereby eliminate signal reflections. Selection of the optimum driver and receiver chips will depend on several factors:

- The distance from the encoder to the controller
- The maximum speed of motor rotation
- The interpolation factor, which determines the encoder resolution
- Requirements for ESD protection, power dissipation, and cost

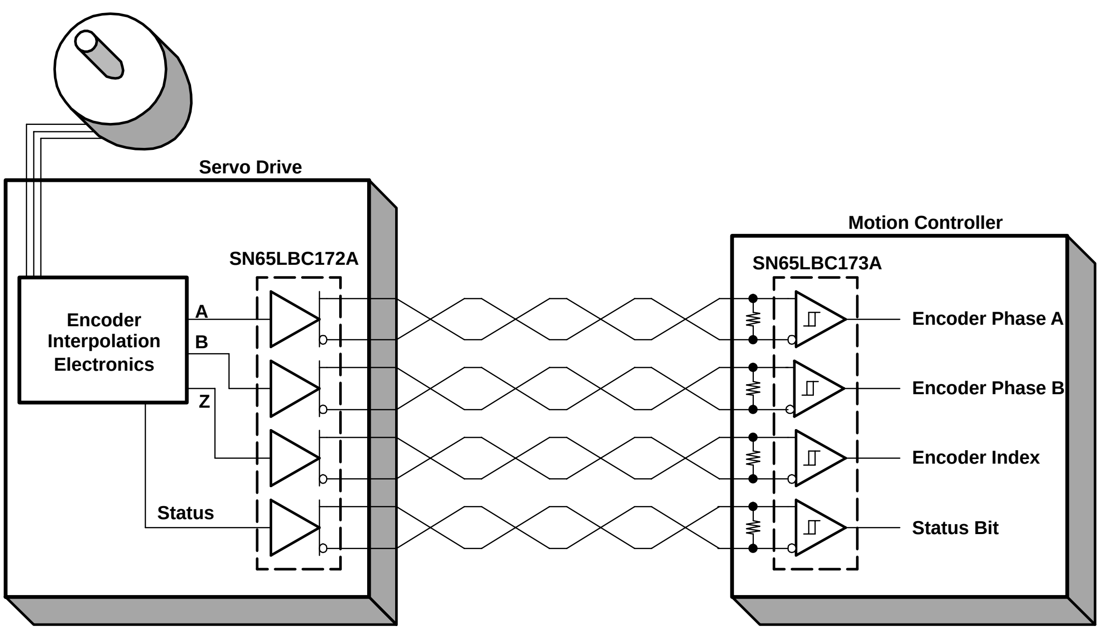

Figure 7. Typical Application, Encoder Feedback Signals

4 Conclusion

RS-485 signaling provides solutions for many of the challenges of digital motor control communications.

- It overcomes electrical noise with high driver output voltages and substantial receiver hysteresis.
- For long distances, the strong differential drivers and wide common-mode capability ensure reliable signaling.
- ESD protection and surge survivability are available as integrated features; these enhance reliability in harsh environments.
- The speed available with RS-485 signaling is sufficient to have negligible impact on servo performance, even when burdened with error checking and protocol overhead.
- The capability to operate in multipoint architectures makes RS-485 flexible and expandable for advanced, networked applications.

Overall, the moderate signaling rate, robust features, and wide selection of available transceivers make this technology a good fit for most digital motion control applications.

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