

SERVOSTAR®

Digital Incremental Encoder Types

The **SERVOSTAR S**, **SERVOSTAR CD**, and **SERVOSTAR SC** products include models designed for use with incremental digital encoders (SE and CE models). Encoders are available in different configurations from a variety of manufacturers using different nomenclature and conventions, making this topic somewhat confusing. Encoders can be as simple as having only A and B output channels or as complex as 6 channels of outputs. The **SERVOSTAR** supports many of these variants using the variable, **MENCTYPE**. The variable is set according to the features of the encoder. This document explains the different applications of the various **MENCTYPE**s. A basic understanding of encoders is valuable for this discussion.

Encoder Basics: A Review

Encoders used with the **SERVOSTAR** provide incremental motor position information via two channels, referred to as the A Channel and B Channel. These channels output pulses for a unit of shaft motion. These pulses are typically generated within the encoder, using an optical disk that is directly connected to the motor shaft. The disk has etchings that either transmit or block light passing through the disk. An optical transmitter and receiver are on either side of the disk. The rotation of the disc (and motor shaft) interrupts light transmission from source to receiver, creating the pulses. The interruptions on the disk are called lines and result in the encoder ratings of lines-per-revolution (LPR) or pulses-per-revolution (PPR). The two channels provide the same information (pulses-per-unit of motion), but have a phase shift of 90° between each other (See Figure 1). The 90° electrical phase shift between the two channels is referred to as "quadrature-encoded." The encoder output appears as a frequency, but the pulse rate is dependent on the motor's rotational velocity, not time.

Since the two channels are phase-shifted by 90°, there are actually four states available per electrical cycle of these signals (see Figure 1). The **SERVOSTAR** is able to receive four counts for position feedback for one line of motion of the encoder. The actual decode of the four position counts-per-line of the encoder is called "quadrature decode." Additionally, since the encoder signals A and B are phase shifted by 90°, it is easy to design electronics that recognize whether A came before B or B came before A, thus supplying directional information.

Encoders are often provided with an additional channel called a "Marker" channel, Zero Pulse, or an "Index" channel - different names for the same function. This channel outputs one pulse per revolution and is typically an extremely narrow pulse equating to roughly ¼ of the width of an A or B channel pulse but can be wider. This is a reference position marker used for homing (absolute position reference) and commutation alignment.

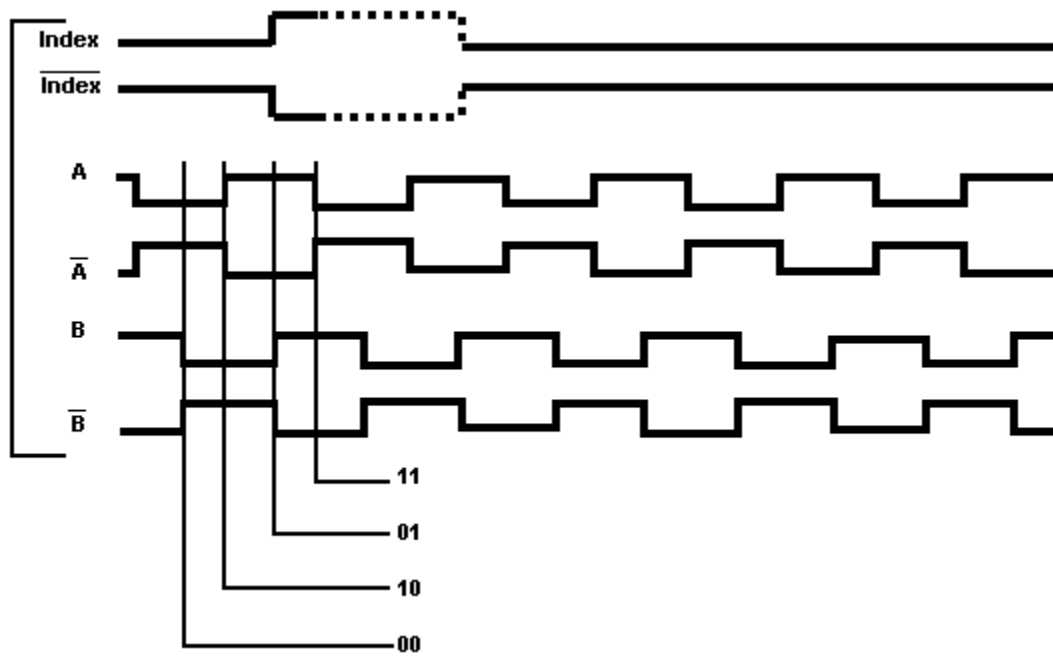


Figure 1: Basic Encoder Signals (Differential)

One challenge when using encoders is that they are incremental rather than absolute devices. When using an absolute device (such as a resolver) to determine the motor shaft position within the rotation, the transmitted code is unambiguous. In other words, at power-up, the system knows the position of the motor shaft.

Incremental encoders only detect how far the motor shaft has moved from its original position. This presents a problem with three-phase brushless motors in terms of commutation alignment. Generally, it is extremely important to establish the appropriate commutation angle within the controller. (Commutation refers to the alignment of the electromagnetic field armature winding to the permanent magnet fields to create optimal torque.)

For this reason, encoders or motors are often provided with additional channels sometimes called "commutation tracks" or "Hall emulation tracks" which provide 1-part-in-6 absolute position information (See Figure 2). The hall channels can be synthesized in the encoder or can be discrete devices integrated in the motor windings. Commutation tracks (hall channels) provide three digital channels that represent alignment to the A-phase, B-phase, and C-phase back EMF of the motor. An encoder with Hall channels must have the correct output for the given pole count of the motor as the Hall signals are referencing the motor's BEMF waveform.

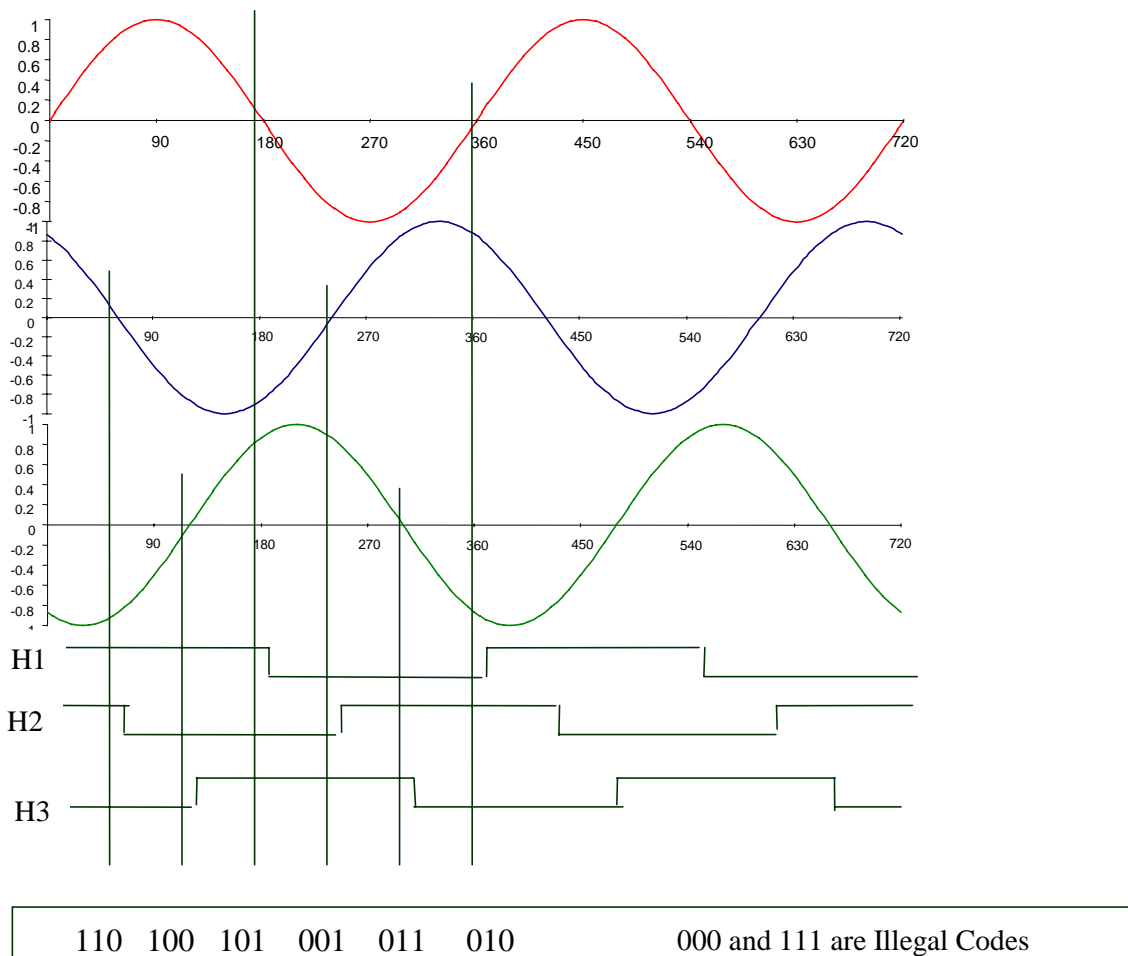


Figure 2: Hall Channel Signals

Note: *Some systems use only hall channels for motor feedback data. The channels provide enough information to commute a motor in an ON and OFF (trapezoidal) format but do not provide enough information to properly commute a motor using sinusoidal control. Further, the coarse data is insufficient to control velocity below a few hundred RPM. The SERVOSTAR product is a high-performance controller and does not support hall-only operation.*

Since encoders are incremental devices, a loss or gain of a pulse creates system errors. Electrical noise is the single biggest factor in miss-counts. Transmitting the signals differentially provides the largest margin of noise rejection and the best signal fidelity. The SERVOSTAR is designed to receive only differential signals. Some "less expensive" encoders provide TTL or "Open Collector" signals. These are not compatible with the SERVOSTAR.

SERVOSTAR Encoder Types

The idea of obtaining velocity or position information from the series of pulses generated from the encoder is not difficult to understand. Permanent magnet brushless DC servo motors require commutation. As stated earlier, commutation is simply the positioning of the electromagnetic fields in alignment with the permanent magnet fields such that optimal torque is produced. This requires that the motor shaft position be known at all times. The use of incremental encoders requires some form of initialization to determine this motor shaft position at power up. It is this commutation initialization process that can lead to confusion.

Since the **SERVOSTAR** supports operation with many encoder types, it must be told which signals to expect to see and which initialization algorithm to perform. This is the purpose of the **MENCTYPE** variable. The following section explains the **MENCTYPE** variable and its setting for each encoder type.

MENCTYPE 0: Incremental with A/B/I and Hall Channels

MENCTYPE 0 is the most robust encoder system. It is used to tell the drive to expect the signals as feedback from the motor. The hall channels can be synthesized in the encoder or can be discrete devices (Hall sensors) integrated in the motor windings. On power-up, the hall effect channels are read and a code is sent to the microprocessor to give it a coarse position for the motor. This position is accurate to within ± 30 electrical degrees of the optimal commutation angle. The **SERVOSTAR** assumes that the actual motor position is half-way between the hall code settings for a maximum commutation error of ± 30 electrical degrees. Even with this amount of error the motor is still capable of producing torque with an efficiency of 86%. As the motor rotates, the first hall boundaries quickly traverse, providing the **SERVOSTAR** with enough information to better establish commutation angle. The **SERVOSTAR** further corrects the commutation angle after it sees the marker pulse according to the value of **MENCOFF** (See below).

MENCTYPES 1 and 2: Encoders with A/B/I channels

Some systems do not have hall channels, so this mode tells the **SERVOSTAR** not to expect them. The initialization process occurs in two steps. The first step is the 'wake-and-shake' initialization process (see **MENCTYPES 3 and 4** for "wake and shake" details) which gets the commutation alignment initialized after power up. The second step occurs when the index pulse is seen. Then, the **SERVOSTAR** aligns the commutation angle according to the setting of **MENCOFF** (see below). **MENCTYPE 1** initialization begins only when commanded through the serial port by using the **ENCSTART** command. When selecting **MENCTYPE 2**, the process can be initialized using **ENCSTART** or performed automatically upon power-up when the drive is enabled.

Note: *The 'wake and shake' initialization process is not required if the marker location can be traversed without requiring the **SERVOSTAR** to move the motor to traverse the marker.*

MENCTYPES 3 and 4: Encoders with A and B channels only

The simplest of encoders provide only an A and B Channel. MENCTYPES 3 and 4 configure the **SERVOSTAR** for these signals. These encoders provide no power-up information about where the motor is positioned, so this information is obtained through a special initialization process known as 'wake and shake'.

When using MENCTYPE 3, initialization is required but it is triggered by the serial command, ENCSTART. When using MENCTYPE 4, the process for initialization is automatically triggered on power-up when the drive is enabled or by using ENCSTART.

During the initialization process, "wake and shake," the **SERVOSTAR** puts current through two phases of the motor causing the motor shaft to rotate into a "torque detent." The magnets simply align the motor shaft to a position the **SERVOSTAR** understands. The motor is then rotated to the next pole position by energizing the windings in a slightly different manner. The **SERVOSTAR** then has enough information to establish an appropriate commutation angle using the number of motor poles (MPOLES) and the number of counts for the encoder (MENCRES).

This method of initialization has the advantage of allowing an extremely cost-effective feedback device. However, the requirement to pull the motor into these torque detents is subject to outside influences (such as friction) and can prevent the motor motion from occurring very effectively or even at all! Additionally, large inertia loads can overshoot and oscillate during this pull-in position, giving the microprocessor false readings. These MENCTYPES are best for systems with specific criteria requirements such as low friction, low cost, and low inertial loads. The amount of electrical current used in this initialization mode is adjustable using the IENCSTART variable and may need to be adjusted to optimize performance for large inertial loads.

MENCTYPE 5: Not supported

MENCTYPE 6: Incremental with A/B and Hall Channels

MENCTYPE 6 supports encoders as described in MENCTYPE 0, but lacking the marker or index channel. This device is selected using MENCTYPE 6 and follows the same process used in MENCTYPE 0 with the exception of the final search for the marker pulse. The system establishes the commutation angle based on the Hall effect edge. MENCTYPE 6 is most commonly used with linear motors.

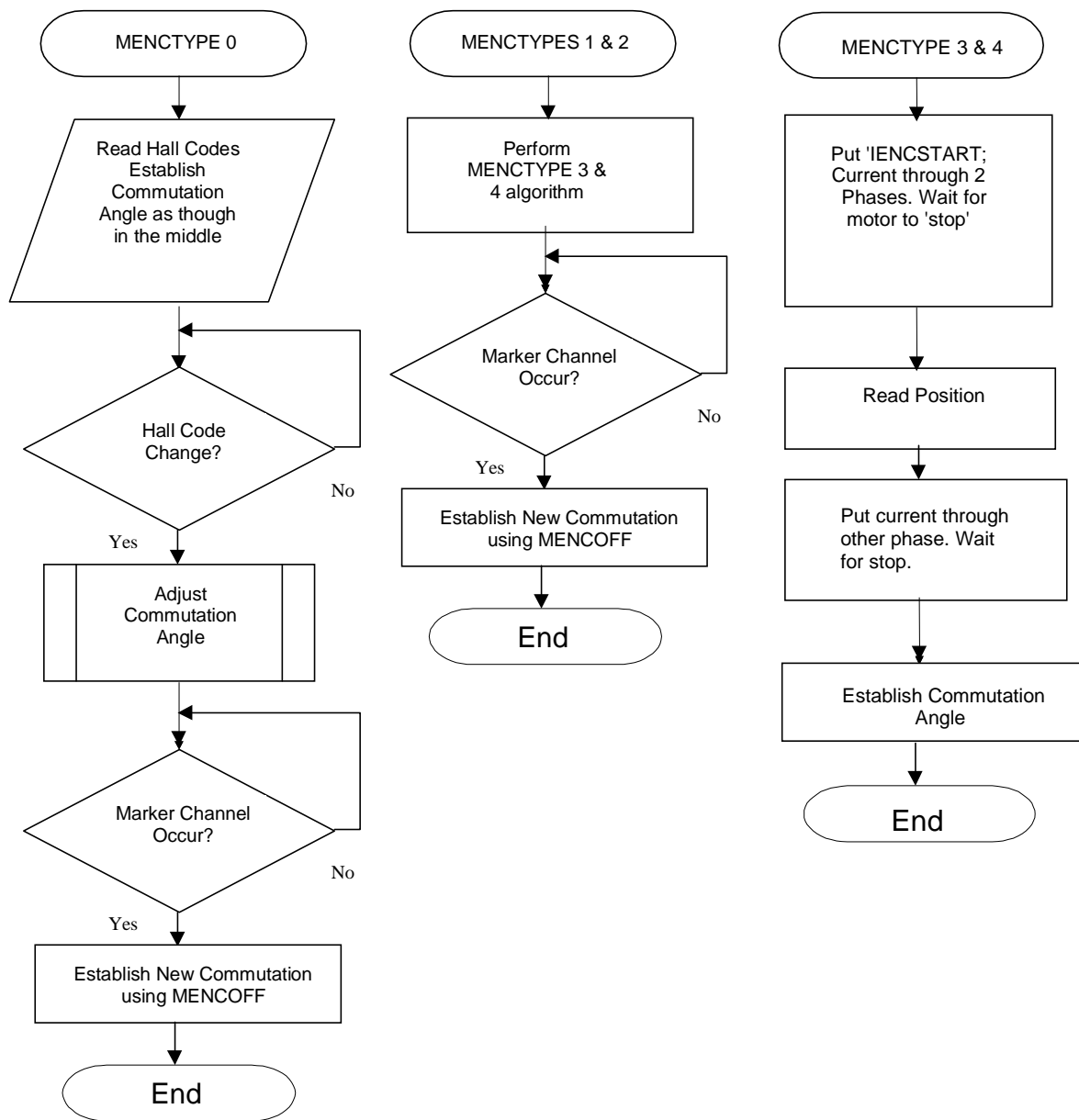


Figure 3: Initialization Flow Charts for Incremental Encoders

Commutation Accuracy

The accuracy of the commutation alignment within the drive affects the overall system efficiency. Misalignment also causes greater torque ripple. As a general estimator, the following equation holds:

$$K_{t\text{ effective}} = K_{t\text{ Rated}} * (1 - \text{Cosine}(\text{Alignment Error}))$$

Inaccuracy of commutation alignment can occur from multiple sources when using encoders. The accuracy of the hall channel devices, if they are provided from an encoder using an optical disc, are typically accurate to 5° or better electrically. When they are integral to the motor, they may have an error of up to 15°.

The accuracy of the 'wake and shake' algorithms used in MENCTYPES 1 through 4 are subject to many outside influences, such as friction and inertia. These algorithms are not robust and are subject to varying amounts of error.

Incorrect commutation alignment also causes differences in efficiency according to direction. In an exaggerated example, a misaligned commutation angle may allow a 1500 RPM motor to go 2000 RPM in one direction and only 1000 RPM in the other.

Physical Encoder Alignment

The SERVOSTAR provides a number of features (variables) to allow adjustment of the encoder signal alignment through the software. These features can be very useful, but you must be careful when using them. If the alignment of the encoder to the motor is left to chance, swapping out the motor or encoder requires that these variables be recalibrated for the new alignment. Is this acceptable in the given application? You may not be certain that the knowledge to do so will remain in the future. A better method is to align the encoder on the motor. This makes swap-out a simpler process.

MENCTYPE 0 (A/B/I and Halls) has hall channels aligned to the motors back EMF as indicated in Figure 2. This is accomplished by rotating the motor, monitoring the signals from the hall effect channels while monitoring the voltage generated by the motor and rotating the encoder housing until the waveforms overlap. The encoder mounting screws are then secured. This aligns the hall channels and the marker channel must then be aligned using the MENCOFF variable described below. Caution must be exercised as motors may generate lethal voltages when rotating.

MENCTYPES 1 and 2 (A/B/I without Halls) require the marker to be aligned to the motor's BEMF waveform. Kollmorgen has not defined any particular alignment standard. Defining your own alignment standard could be beneficial.

MENCTYPES 3 and 4 (A/B only) require no alignment or adjustments.

MENCTYPES 6 (A/B/I with Halls) require the same alignment as MENCTYPE 0 but do not require that MENCOFF be set.

When it is not practical to perform mechanical alignments, the software adjustment method can be used. The MPHASE variable holds an offset for the Hall channels and can be used to effectively 'shift' the Hall channel position. It is possible to invert the effective direction as established by the A and B channels using the MFBDR variable. It is also possible to invert any one or all of the hall channels. The MHINVA, MHINVB, MHINVC variables allow the drive to receive the hall channels and act upon them from an inverted nature.

Establishing MECNOFF Setting

The MENCNOFF variable holds a marker offset and is used to align the commutation in MENCNTYPES 0, 1, and 2.

To determine the setting for MENCNOFF perform the following steps using the MOTIONLINK[®] terminal mode with power on the drive and C3 unplugged (disabled):

1. Enter 'ENCINIT'.
2. Rotate the motor shaft two turns clockwise, either by hand or using the JOG (J) command.
3. Verify that the process is complete by entering 'ENCINITST'. The SERVOSTAR should return '2' if complete.
4. If not, repeat steps 2 and 3.
5. Enter 'SAVE'.
6. Use caution to continue testing the system.
7. The MENCNOFF variable may be manually trimmed for best performance.

When using MENCNOFF with MENCNTYPES 3 and 4, the correct value must be determined through trial and error. Pick a setting and trim it, watching for the speed (V) to be equal in both directions when applying torque in OPMODE 2.

It is common for repeated tries of this procedure to return values that are significantly different due to the software's reference point being different from try-to-try. This is normal.

Note: The motor shaft must be free to rotate uncontrolled without damage to equipment or personnel.

System Phasing

With so many signals coming from the encoder back to the drive and then the signals going to the motor, it can become quite frustrating to make sure that each signal is of the appropriate phase. The following diagram shows the phase relationship to each device.

SERVOSTAR COMMUTATION DIAGRAM
 FOR CLOCKWISE ROTATION VIEWING SHAFT END - PRD COUNTS UP

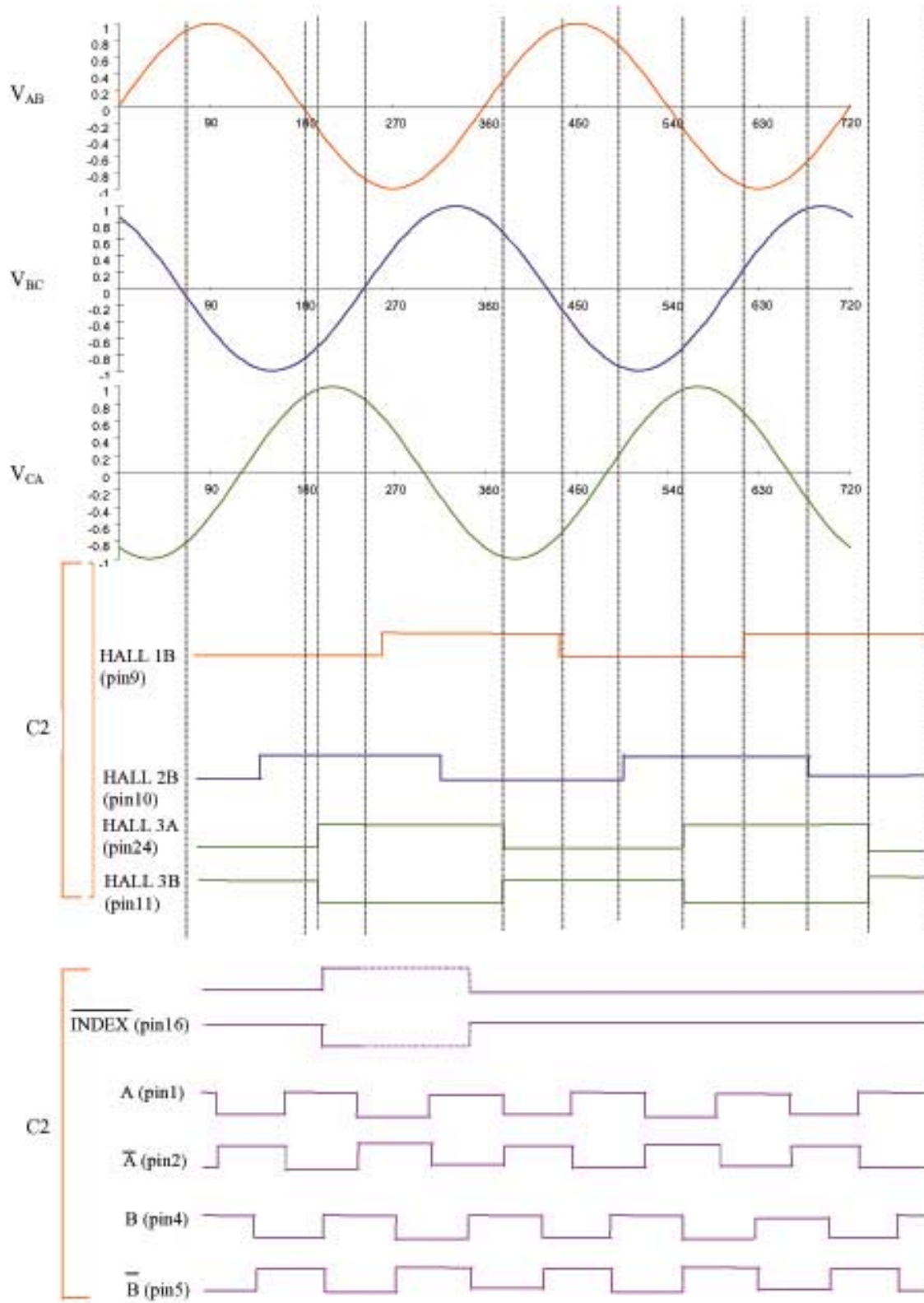


Figure 4: System Phasing Diagram

Troubleshooting Notes

Several problems can occur with encoder-based systems. The most common problem is miswiring. The section on system phasing (above), provides the necessary troubleshooting information.

Miswired Hall channels can cause intermittent problems. With miswired Hall channels, the motor operates correctly sometimes, but will occasionally not operate correctly after cycling power. It is very important to physically verify the Hall effect channels. There is a command in the **SERVOSTAR** manual called, "HALLS." It returns the hall code as "read." It is important that the installation and startup procedures for the machine sequence the motors through all the appropriate hall codes to make sure they are present and in the right sequence, as provided in Figure 2.

An 'illegal hall code' error occurs if the Hall channels go to all low or all high conditions. A broken wire or misphased channel can cause this problem.

It is important that the A and the B channels be wired appropriately to the **SERVOSTAR** drive to ascertain the correct directional drive information. This can be verified by displaying the PFB variable while rotating the motor shaft clockwise. The PFB variable should be counting in a more positive direction. If it counts in a negative direction, the A and B channels are inverted. This can be fixed by swapping the A and /A wires from the encoder or by using the MFDIR command.

A/B Line Break errors may occur and can be misleading. The **SERVOSTAR** receives the A/B/I channels in a differential format. Each channel is fed into a bridge rectifier to create a DC voltage that is monitored for presence. Absence of any one of these three voltages (except the I channel in MENCTYPES 3, 4, and 6) cause an A/B line break fault.

Line Drivers, Receivers, and Terminations

Counting pulses sent over cables going through an industrial environment requires that care be taken to prevent noise induction on the cable that looks like an encoder pulse. Running wires in a "clean" raceway is one requirement.

Another common sense approach is to use differential transmission for the signals to provide the highest degree of noise immunity. Differential line drivers are required by the **SERVOSTAR**. The differential line signals follow the RS-485 format where pulses are sent up and down a 120 Ω cable. Termination is expected at both ends and the **SERVOSTAR** provides the required termination. Deviations from a 120 Ω characteristic impedance cable when using long cables can result in poor performance.

Design Considerations

The **SERVOSTAR** has a maximum frequency input for incremental encoders of 2.5 MHz. This cannot be exceeded under any circumstance.

Encoders consume 5V. The 5V is typically regulated inside the drive through a cable to the encoder. Tolerances on the 5V must be considered for IR loss within the cable. An 18 AWG conductor pair providing the 5V at a 250 mA drive result in approximately ¼ V drop and become the limits from the encoder's 5V rating perspective. Consideration of cable length 5V current draw is extremely important for good system design. The SERVOSTAR's encoder supply is 5V ± 2% with 250mA maximum draw.

When using incremental encoders, the SERVOSTAR receives the encoder pulses, buffers them electrically and then outputs them to the encoder equivalent output port. The phase delay in the transport of these signals is extremely small.

Be sure to run all encoder cables in conduit or wire tray that is free from wires carrying or emitting electrical noises such as solenoid wires and armature cables.

Reference Variables

ENCINIT - This command triggers the encoder initialization process.

ENCINITST - This variable may be queried and returns status of the initialization process. This variable assumes one of three values:

0 = The initialization process has not started.

1 = The initialization process is in progress.

2 = The index position has been determined and the initialization process is complete. The flag is reset to zero when you manually set the index position.

HALLS - Read the states on the Hall channels.

IENCSTART - Set the "wake and shake" initialize current level.

MENCOFF - Tell the SERVOSTAR where the marker is relative to hall edge (MENCTYPE 0) or relative to torque detent (MENCTYPES 1 and 2).

MENCRES - Tell the SERVOSTAR how many lines there are on the encoder.

MENCTYPE - Tell the SERVOSTAR what encoder signals are present.

MHINVA - Invert the active level of Hall channel A.

MHINVB - Invert the active level of Hall channel B.

MHINVC - Invert the active level of Hall channel C.

MPHASE - Allow Hall channel offset (MENCTYPES 0 and 6).