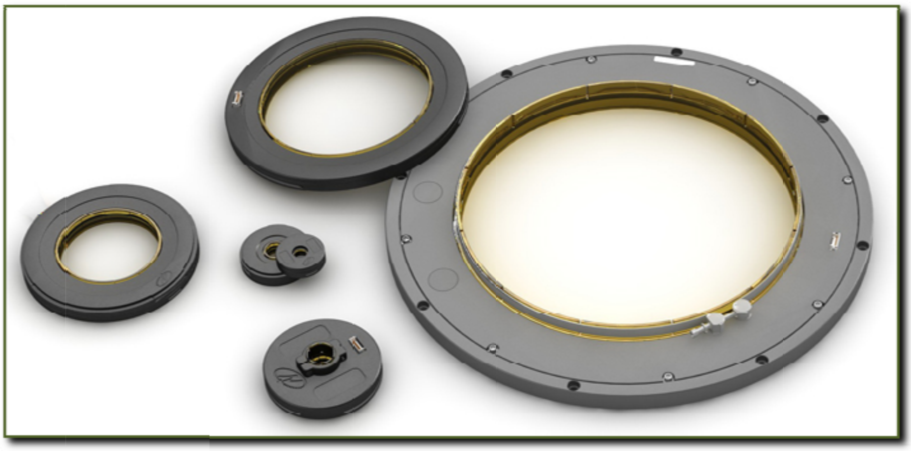
Application Note 02 – Electrically Interfacing DS Electric Encoders™

Electric Encoder ; DS product line - angular position sensors



Document No. : AN-02, – Electrically Interfacing DS Electric Encoders™
Version: 1.0 , Jan 2009

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1. General

All sine/cosine **Electric Encoder**s of the **DS** family share the same electrical interface; however, some of them differ in mechanical mounting details.

In general installation involves the following steps:

1. Mechanical mounting the encoder (stator & rotor) - see Mechanical IG of each encoder.
2. Validating proper Fine channel amplitude
3. Validating fine channel Sine and Cosine noise at stand still

2. Electrical interface

The internally shielded **Electric Encoder™** is highly immune to external interferences, due to either magnetic or electric fields. Any parasitic common-mode pickup inside the encoder useful frequency band (typically to 1 kHz) can be eliminated by a differential input receiver due to the differential output of the encoder. On the other hand, contamination by PWM or digital clock interference that may couple to the cabling or to the receiving side in a manner that is not a common mode can be rejected by simple low pass filtering. This enables a robust interface as shown in **Figure 1** which in most cases is sufficient even without using a shielded cable and provides:

1. Conversion of the sine cosine inputs into single ended signals referenced to the A/D converters.
2. Matching the amplitudes with the input range of the A/D converters
3. Rejection of common mode parasitic interference inside the encoder pass-band.
4. Filtering out high frequency interference above the encoder pass-band.

In order to preserve the inherent tight amplitude matching of the sine and cosine signals the gain of the two differential amplifiers should be tightly matched; otherwise the **2_{nd} harmonic error** - a cyclic error repeating twice per electric cycle - would result. Gain matching can be accomplished by matched resistors - typically 0.1%, or by software after A/D conversion. Note that although the encoder signal amplitude matching is maintained regardless of the rotor axial position, some allowance should be made for amplitude variations due to rotor axial motion.

Operational amplifier based circuitry was found to be more flexible than instrumentation amplifiers for this application. The capacitors should be selected to provide a cutoff frequency of typically twice that of the encoder for rejecting residual noise pickup, such as PWM spikes, and should be matched to 1%.

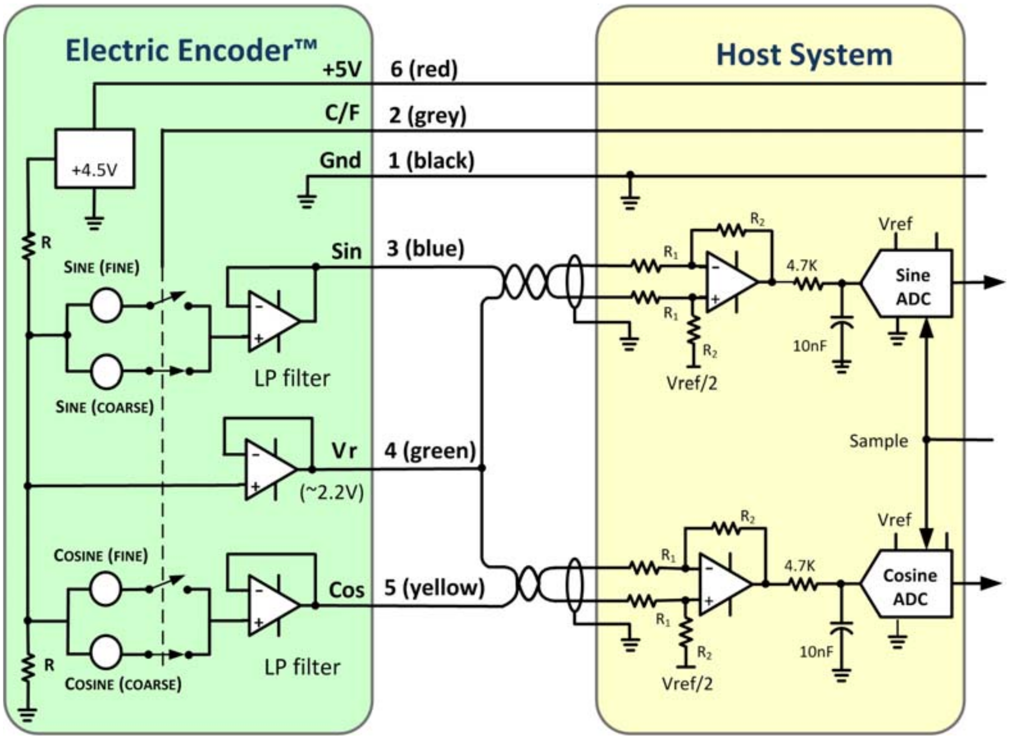
Another, though usually uncommon, potential source of interference is intense RF field picked up by the interconnect cabling. Although this pickup lies much above the relevant bandwidth, and may be unnoticed, it may be rectified by parasitic P-N junctions in the silicon chip of the receiving circuitry, and manifest as an unstable DC offsets. Ferrite beads preceding the differential amplifier usually provide an effective remedy.

Because of the low current consumption of the **Electric Encoder™** there is a very low voltage drop on the power lines, this combined with the low frequency of the signals, enable very long interconnect cables. Also due to the low frequency range of the signals no line terminations are needed - unlike in optical sine/cosine encoders and a shield may be needed only for long cables. The shield should encompass all six wires and be grounded at the receiver end. Twisting the signal wires may be required only when the cables are surrounded with AC magnetic fields.

3. Noise measurement

The inherent random noise of the DS encoders inside the signal bandwidth of 1 kHz ranges between 150µV p-p and 300µV p-p. With a 1V p-p signal this constitutes a range of 5000 i.e., 12 bits. The angular resolution is higher, depending on the number of EC/Rs – see **AN-05**. The interconnect robustness can, therefore, be assessed by validating the noise prior to digitizing. However, verifying such low noise may prove a difficult task without a dedicated measurement setup and a relevant experience. Also the encoder must be mounted with the rotor tightly secured to a clamped shaft. Using mains operated equipment without extreme caution is almost certain to result in spurious noise that will make the measurement useless, and the use of high-sensitivity, battery operated, oscilloscope may prove to be the most practical approach. The oscilloscope, which is intended to validate that the measured voltage is random with no trace of interference, or mains hum, should preferably be augmented with a parallel Digital Volt Meter with a 2kHz cut-off passive R-C low-pass filter at its input. Since the ratio of peak-to-peak to rms of a Gaussian noise is nearly 5.5 this test provides a reliable check of the interface quality.

Figure 1



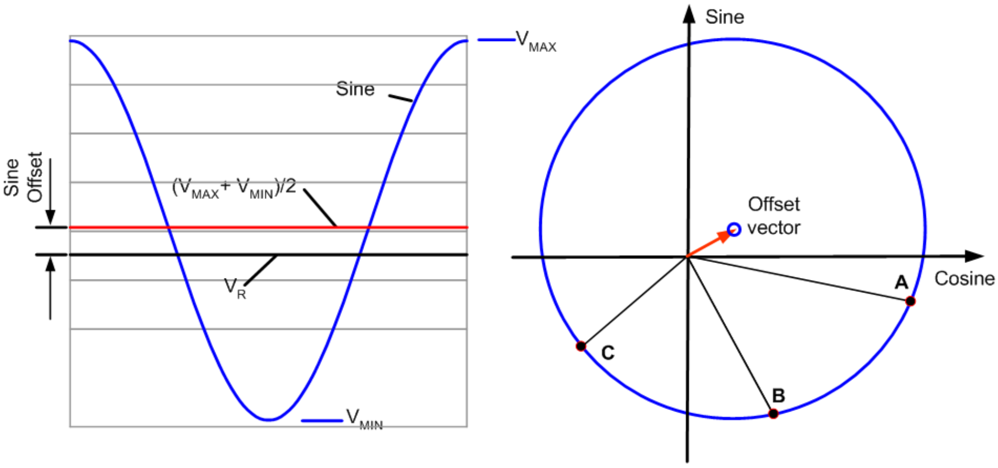
4. Offset voltage measurement and compensation

Even though the inherent offset voltages of the Sine and Cosine outputs are in the mV range, not compensating them would result in a first harmonic error (once per electric cycle) – see **AN-05**. The first harmonic error in the fine channel would impair the output angle accuracy while in the coarse channel it may impair the reliability of the absolute position determination.

The offset voltages is given by $(V_{MAX}+ V_{MIN})/2$ where V_{MAX}, and $-V_{MIN}$ are the measured positive and negative peak values relative to V_R. The measurement can be made manually by connecting the (+) terminal of a peak reading DVM to the Sine (Cosine) output and the (-) terminal to V_R - see **Figure 2.** The measured values are very nearly the same for each electric cycle.

The offset compensation can preferably be accomplished on the digitized signals; this would take into account potential contributions of the differential amplifier and the A/D converter and is detailed in **AN-03**.

Figure 2



A different method, which is adaptable to automated offset compensation, may be applicable in some full rotation applications. The method is based on rotating the shaft at a relatively high speed; the output voltage would then comprise the offset DC component and a 1V p-p AC component at a frequency proportional to the rotation speed, low pass filtering that suppresses the AC signal leaves the desired DC offset voltage.

If the application does not allow full rotation then fast nodding the shaft by an integer multiple of the fine period (not necessarily coinciding with any portion of the rotor pattern) would achieve the same result. The non offset-compensated encoder itself can be used for controlling the nodding motion since its offset induced error can be shown to be immaterial.

In case the mechanical excursion is less than one electric period the offset voltages - shown as a vector in **Figure 2,** can still be determined, though less easily. Since a circle is defined by three points, sampling the sine and cosine at three separate angles **A**, **B**, and **C** determine the circle and, consequently, its center point which defines the offset vector. Obviously, the closer the sampled points to each other the more sensitive is the calculated offset to measurement error, the chosen points should, therefore, be spread as widely as possible over the excursion range.

5. 4th harmonic error compensation

The 4_{th} harmonic error - see **AN-05**, repeats 4 times in each electrical cycle. This error is normally negligible and results from electric field distortion inside the encoder, it is repeatable from unit to unit of the same type. This error can be modeled as a third order non-linear distortion in the internal gain and can thus be compensated by to obtain the third order corrected Sine and Cosine from which the electric angle is calculated:

$$R = \sqrt{\sin^2 + \cos^2}$$

Use the offset compensated Sine and Cosine signals to find the local amplitude:

1. Normalize the offset corrected Sine and Cosine to obtain : S=Sin/R C=Cos/R

2. Generate the corrected Sine and Cosine as follows: $S_T = S - K_3 S\text{\^{}}3 \quad C_T = C - K_3 C\text{\^{}}3$

For actual value of K_3 contact company.

6. Signal processing for obtaining the absolute rotation angle

Obtaining the absolute shaft angle from the Coarse and Fine signals (electric angle) is detailed in application note **AN-03.** It is based on sampling the Coarse-channel outputs on system turn-on, then permanently switching to the Fine-channel. The offset-corrected Coarse and Fine sine/cosine pair are sampled and converted to corresponding electric angles Θ_C and $\Theta_{F.}$ The computation algorithm employs the amplitudes ratio of the sine and cosine and is insensitive to their amplitudes. Also, by always dividing the smaller value by the larger one a division by zero is avoided.

Since **N** - the number of EC/Rs in the Fine channel, and **M** -the corresponding number in the Coarse channel, do not have a common denominator the mechanical rotation angle is found unambiguously based on Θ_C and Θ_F.

The Coarse channel information is no longer needed after initiation and the absolute mechanical angle is computed based on the instantaneous Fine channel electric angle (which is absolute within the current period) and the accumulated number of periods. Even though the mechanical rotation angle is computed based on counting, the unlikely event of miscounting can be easily detected and rectified by continuously computing and monitoring the acceleration. This is because the angular span of a Fine channel period is significant (e.g, compared with an incremental count in an optical encoder) a miscount will imply an infinite acceleration and will be rejected.