Optical Encoder Applications

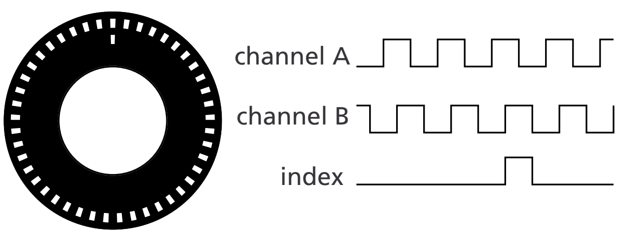
Optical encoders are devices that convert a mechanical position into a representative electrical signal by means of a patterned disk or scale, a light source and photo-sensitive elements. With proper interface electronics, position and speed information can be derived. Encoders can be classified as rotary or linear for measurements of respectively angular and linear displacements.

Rotary encoders are available as housed units with shaft and ball-bearings or as "modular" encoders which are usually mounted on a host shaft (e.g. at the end of a motor).

All COPI encoders are constructed with a single gallium aluminum arsenide light emitting diode with collimating optics as a light source and a silicon monolithic readout array as photo-element.

Incremental Encoders

The disk of an incremental encoder is patterned with a single track of lines around its periphery. The disk count is defined as the number of dark/light linepairs that occur per revolution ("cycles / revolution" or "c/r").

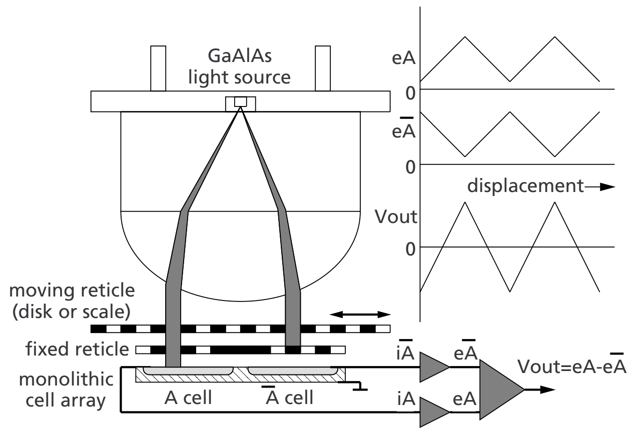


As a rule, a second track is added to generate a signal that occurs once per revolution (index signal), which can be used to indicate an absolute position.

To derive direction information, the lines on the disk are read out by two different photo-elements that "look" at the disk pattern with a mechanical shift of 1/4 the pitch of a linepair between them. This shift is realized with a "reticle" or "mask" that restricts the view of the photo-element to the desired part of the disk lines. As the disk rotates, the two photo-elements generate signals that are shifted 90° out of phase from each other. These are commonly called the quadrature "A" and "B" signals. The clockwise direction for most encoders is defined as the "A" channel going positive before the "B" channel.

If the readout of the disk is obtained by a single photo-element for each of the A and the B channels, it is called a "single-ended" readout. This type of readout generates signals that are very susceptible to disk runout ("wobble"), slight imperfections in disk etching, etc. A much more effective and accurate readout system is called "push-pull" where the A and B channels are generated by two photo elements for each channel.

The push-pull readout synthesizes the A and B channels by combining two individual signals for each of the channels, generated by photo elements that are shifted by half the pitch of a linepair. This way, when one photo-element looks at a dark line, the other is fully illuminated. The resulting signals are combined in an amplifier or in a comparator with a significant increase in stability and accuracy. All COPI incremental encoders are constructed with push-pull readouts.

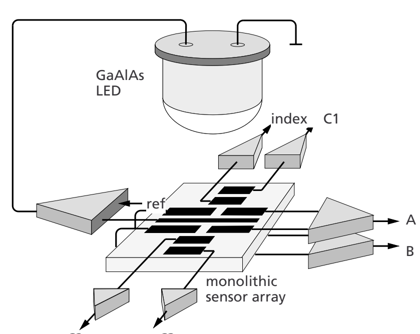


push-pull readout configuration
("A" channel only)

All optical encoders are inherently analog devices. The disk or scale moves with a finite speed and gradually cuts off or admits light to the photo-elements.

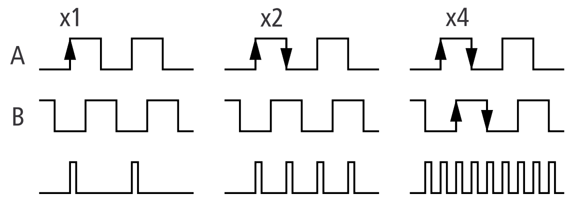
If the second stage in the diagram above has finite gain (e.g. a differential amplifier), the A and B signals will be sinusoidal (triangular for low counts per revolution).
If the second stage has infinite gain (e.g. a comparator), the output will be a digital pulsetrain with state changes defined by the crossover between the cellpairs that form the A or B channel.

In order to stabilize the LED, which has a severe negative temperature gradient (- 0.8% per °C), and allow digitizing and differentiation of the signals of the sine/cosine encoders (see "infinite resolution encoders",CP-200, CP-300 & CP-800), COPI adds for most of their encoder models a separate feedback channel to achieve constant light levels over time end temperature. The following shows the standard COPI electro-optical configuration:



Electronic Multiplication

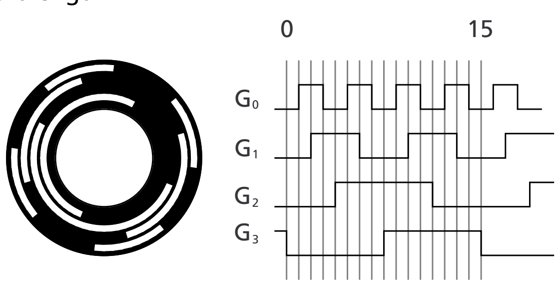
The resolution of a digital-output incremental encoder can be increased by electronic multiplication of the channels. By considering the positive edge of the A channel only, the resolution is the same as the linepair count of the disk. If both the positive and negative going edge is used, twice the count/revolution of the disk is achieved. By adding the edges of the B channel, the resolution becomes four times the linecount of the disk. Some care must be taken with the four times resolution : if the quadrature phaseshift is not close to 90° (electrical), the positions will not be evenly divided and accuracy will suffer. Commercial IC's are available to perform the x4 multiplication function and extraction of the direction information.(e.g. LSI Computer Systems, Inc. p/n LS 7083/7084)



Absolute Encoders

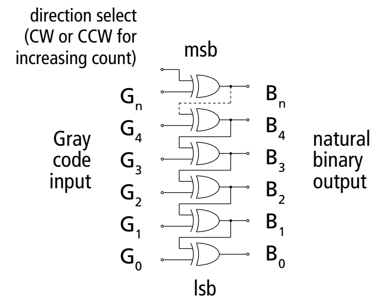
The disadvantage of incremental encoders is the loss of position data at power-down. This is not a problem if the system can be re-initialized on power up by searching for the index and re-setting the position counters. Where this is impractical, an absolute encoder should be used. With this type of encoder, position information is instantly available as a digital word on power-up. COPI absolute encoders are available with a wordlength of 8, 10, 12 and 14 bits for single-turn encoders and 24 bits for the CP-850-24MT multi-turn encoder.

The disk of an absolute encoder is patterned with a number of discrete tracks, corresponding to the wordlength:



The pattern shown for this 4 bit encoder is "reflected binary" or "Gray" code. The advantage of this pattern is that from position to position only one bit changes state. Gray code is used in all COPI encoders because of the practical difficulties a "natural" or "straight" binary pattern would represent in manufacturing. Small differences in gain of the photo-elements would make the individual channels switch at slightly different positions, causing potentially large differences in the binary representation.

Converting Gray code output to binary can be done with a few lines of programming in a PLC or electronically with an array of exclusive-OR gates:



$(B_n = G_n \bullet B_n + 1 + G_n \bullet B_{n+1})$

Various COPI encoders have built-in translators to convert the Gray code generated by the disk into natural binary (CP-850-12NB) or into binary coded decimal (CP-850-12BCD). These are not "handshake" outputs (no "data ready" line) : if used with a processor or PLC a few "read" and "compare with previous value" instructions must be performed to make sure the outputs have stabilized from the internal Gray code through the translator EOR gates to the outputs.

A better alternative is to use a Gray-code encoder and convert to binary by means of a short software routine (12 bit encoder):

```
BEGIN: set B0 through B11 = 1
B11 = G11
IF B11 = G10  THEN B10 = 0
IF B10 = G9 THEN B9 = 0
IF B9 = G8 THEN B8 = 0
IF B8 = G7 THEN B7 = 0
IF B7 = G6 THEN B6 = 0
IF B6 = G5 THEN B5 = 0
IF B5 = G4 THEN B4 = 0
IF B4 = G3 THEN B3 = 0
IF B3 = G2 THEN B2 = 0
IF B2 = G1 THEN B1 = 0
IF B1 = G0 THEN B0 = 0
DONE
```

For fast conversions, a 4096 words x 12 bit matrix can be set up, using the Gray code as an address.

To convert binary code into Gray code, the word to be converted is added without carry to the same word one position right-shifted, disregarding the rightmost digit of the result:

```
binary:    1 0 1 1   (= 11)
             1 0 1 1
Gray:      1 1 1 0 1
```

In addition to the strictly parallel binary format, COPI manufactures encoders that internally convert the digital word into an analog output by means of a D/A converter for 0 - 10 V output or a further conversion of the analog voltage into a 4 - 20 mA loop transmitter. These encoders can be used in situations where excessive wear would make traditional contacting potentiometers impractical or unreliable. Custom patterns, e.g. for valve control, can be readily made by changing the code pattern on the disk. It is, for instance, possible to have a 1° resolution per position repeated twice over a full revolution.

Optical Encoder Applications

Sine/Cosine Encoders

In optical incremental encoders, the basic signal generated is a sinusoid. For a low number of counts per revolution the waveform approaches a triangle while at higher counts the waveform becomes sinusoidal.

In most encoders, this waveform is "squared off" internally because of the greater familiarity of systems designers with digital signals. This is unfortunate because much useful information can be derived from the original encoder signal:

- continuous position information (up to the system noise limit) rather than a series of points with total loss of information between these points and
- continuous speed information by processing the position signal

For this information to be valid and useable, the encoder signals have to be linear and accurate:

- balanced amplitude of the channels,
- low offset
- low distortion of the signal
- 90° phaseshift between the A and B channels

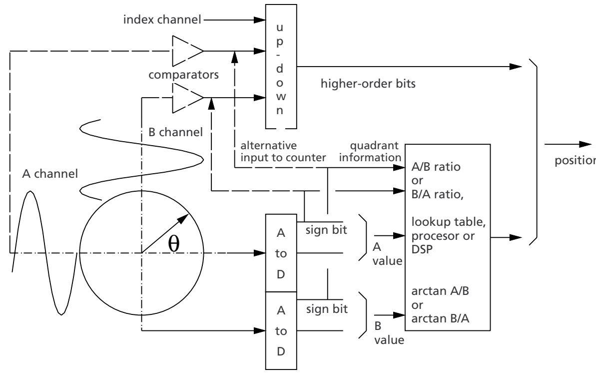
If these criteria are met, it is possible with relatively simple electronics to vastly augment the usefulness of the encoder in incremental motion and measuring systems.

The **CP-200**, **300**, **500**, **800** and **900** encoders are specifically designed to be used as continuous feedback devices.The LED light source is servo controlled to assure constant light output over time and temperature.The disk and reticle apertures are optimized either for linearity or to obtain a very low distortion sine/cosine signal.The A and B channel peak values are computer trimmed to within 2% of each other and offset is virtually eliminated. Careful dynamic centering of the disk and adjustment of the read head yields phase shifts of 90°± 5% even for high linecount encoders.

The **CP-1064** interpolator will interface sine/cosine encoders with traditional A/B controllers for use in relatively slow moving systems (200 kHz maximum frequency for either the interpolated A or B channel). The interpolation factor is x 16, x 32 or x 64.

The **CP-850-HCE** and **CP-950-HCE** are sine/cosine encoders with a built-in interpolator, available with vitually any count per revolution between 16,000 c/r and 360,000 c/r, corresponding to 64,000 and 1,440,000 measuring steps, 1,296,000 (one arcsecond) included.

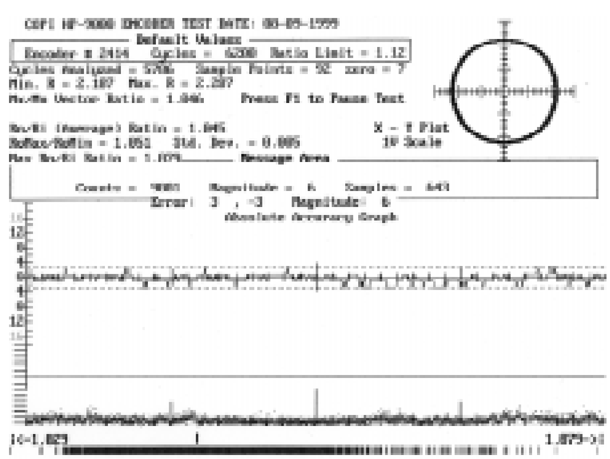
For all sine/cosine encoders, absolute accuracy graphs are available as well as distortion plots of the waveforms (see sample). In these graphs, the sine and cosine are vectorially added to obtain a “Lissajous” circle. The circle is analyzed and the ratio between the largest and smallest radius plotted for each circle, which corresponds to one complete sine/cosine cycle. This way, distortion and offset can be defined in a single number to determine the quality of the signal.



Incremental motion systems

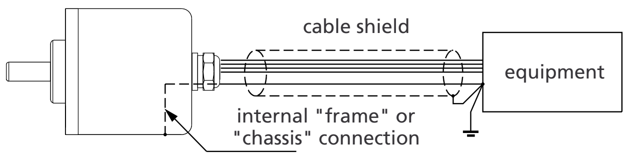
For faster incremental motion systems, a very effective continuous velocity extraction scheme is possible with a DSP, discrete processor or ROM matrix where the position information is derived by taking the ratio of the A and B signals (θ = arctangent A/B). This position information, together with the higher bits provided by the traditional digital A/B position counter, can be numerically differentiated to obtain velocity ($\omega = \theta / t$). The interpolator does not need to be particularly fast since the lower order bits are not significant at high speed. When the speed drops, the “fine” bits become significant and start to play a role in the definition of the position and velocity extraction. A number of controller manufacturers offer interpolating front-end processing for their products (e.g. Delta Tau’s PMAC 2).

This scheme allows a large dynamic range. If, for instance, in a direct drive axis a sample rate of 500 μs is needed for good dynamic behavior at 0.1 RPM, the linecount for a traditional digital encoder would have to be 300,000 c/r (1,200,000 measuring steps). This is clearly not practical, especially since the required maximum frequency of the encoder would be 30 MHz at 6,000 RPM. A 1,000 c/r sine/cosine encoder with a 12 bit interpolation scheme wil yield 2,048,000 measuring steps (one bit is lost in synchronizing the A/B counter with the “fine” bits) and so easily satisfies the resolution requirement at low speed. At 6,000 RPM, only the higher order bits from the A/B counter are significant while the required maximum encoder frequency response is a modest 100 KHz.



Interfacing

In heavy machinery environments, appreciable ground potential differences exist due to high currents created by electrical motors, remote control switches and magnetic fields. In such applications, the rule is to connect the cable shield and frame connection to ground at the equipment end only:

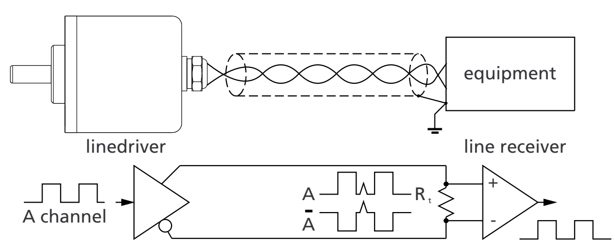


For cable lengths of more than 6m (20 feet), linedrivers are recommended. These are devices that meet the requirements of EIA standard RS-422-A, Federal Standard 1020 and DIN 66259 (Teil 3). Linedrivers have complementary outputs (= signal output and the inverse signal output) and high current capability for driving balanced lines such as twisted-pair or parallel-wire transmission lines.

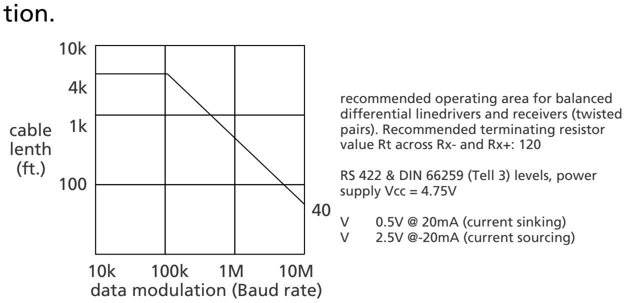
Recommended input circuitry on the equipment side are line receivers for common-mode noise suppression. Linedriver outputs are TTL compatible and the signal or inverse signal can be used to directly drive TTL devices or opto-couplers as found in programmable logic controllers.

Most COPI incremental and absolute encoders that work off 5 Vdc power supplies have linedrivers either as standard output or as an option.

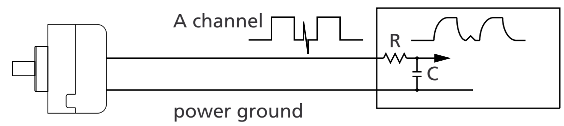
Some models (CP-360 and CP-270) have special internal cicuitry and linedriver outputs that will allow power supplies and corresponding outputs ranging from 4.75 Vdc to 30 Vdc.



The value of the terminating resistance should ideally equal the characteristic impedance of the line. A good value is 120 for a twisted-pair or parallel-wire connection.

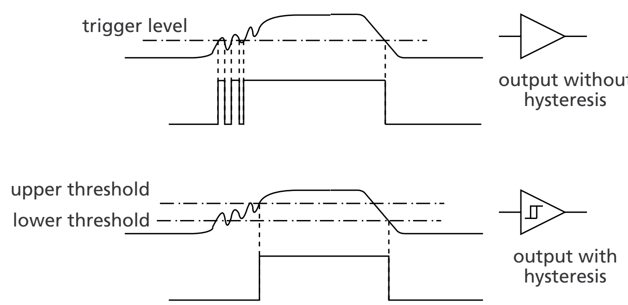


For short distances in a noisy environment (e.g. a modular encoder at the end of a PMDC motor), an RC low-pass filter will be effective in preventing noise spikes entering the controller logic. The value of the components depends on the maximum count frequency expected. The values suggested in the table will allow the maximum indicated count rate in kHz.



kHz	1			10			50		
R(k)	2.2	10	47	2.2	10	47	2.2	10	47
C(nF)	220	47	0	22	4.7	1	4.7	1	0.22

If also slow-moving disturbances are present, a Schmitt-trigger input device should be used in addition to the low-pass filter to avoid multiple triggering. Schmitt-triggers have two threshold levels, one for positive-going signals and one for negative-going signals. The difference is called the "hysteresis" voltage. Signal changes less than the hysteresis value will be ignored.



Severe Environments

For absolute noise and EMI immunity, fiberoptic links between encoders and control equipment should be considered (CP-860 series). The communications-grade fiber cable used for interconnects is extremely rugged and has a small diameter to allow easy integration in existing motor power supply line conduits etc.

In RFI environments, strong magnetic fields, high mechanical stress and at ambient temperatures above 100°C, all-fiberoptic encoders can be used with excellent results (FD22 and FD850).

COPI manufactures special all-fiberoptic encoders that are used in the following applications:

- radar antenna control (strong RF field)
- nitrogen valve control in galvanizing operations
- ultrasonic tranducer control (in-liquid operation)
- missile valve control (extreme acceleration and temperature)
- MRI scanners (strong magnetic and RF fields)