Incremental Rotary Encoder Design Considerations

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Incremental rotary encoders transduce rotational movement into electrical signals. Unlike absolute encoders that measure angle, incremental encoders generate high/low pulses as turning occurs.

Applications include computer mouse wheels, fluid flow meters, knobs, wheel speed sensors, stepper motor feedback for detecting missed steps, and brushed DC motor sensors for automotive windows, sunroofs, seats, and mirrors.

Output signals

When only one direction of rotation needs to be measured, an encoder with a single toggling output can be used.

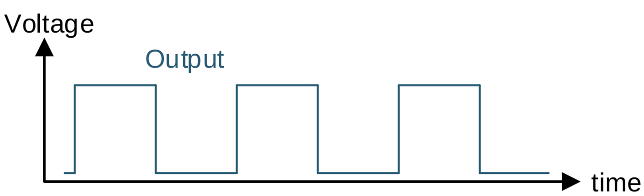

Figure 1. Single Output

If clockwise versus counterclockwise movement must be distinguished, two encoder outputs with a phase offset can accomplish this. Then the order of 2-bit states describes the direction turned.

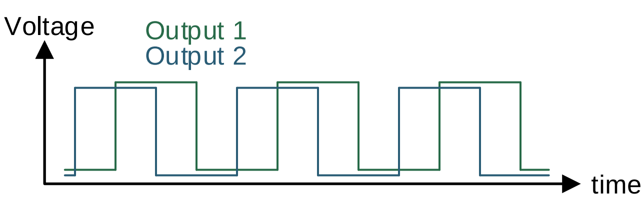

Figure 2. 2-Bit Quadrature Output

Using a 90° phase offset ("quadrature") maximizes the timing margin between each state, which prevents errors in the presence of mechanical tolerance, sensor mismatch, and signal jitter.

Technologies

The 3 most commonly employed technologies for generating pulses from rotation are *contact*, *optical*, and *magnetic*.

1. Contact: This relies on mechanical contacts to make or break electrical connections. Typically, the stationary component has islands of metal throughout a ring. The piece above it is free to rotate and has metal brushes that momentarily make contact with the islands, connecting them to ground. Figure 3 shows the electrical schematic.

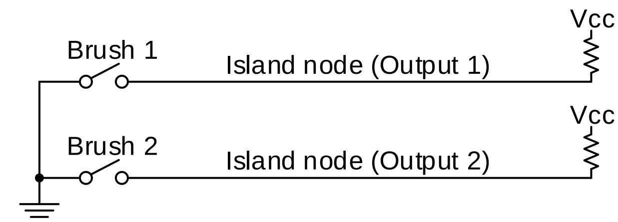

Figure 3. Typical Contact-Based Encoder

While contact-based encoders only use passive electronics, they tend to be mechanically complex. Pre-built modules are available, and include the encoder, knob, and detents for tactile feedback. This integration also comes with design constraints, special assembly requirements, and a price. The metal brushes on these encoders often require milliseconds of de-bouncing time to settle, which limits the sensing bandwidth. Reliability can also be limited, since the contacts wear out over time due to friction, corrosion, or contaminants.

2. Optical: A simple optical encoder can be built using a disc with slits cut out to let light through certain areas, along with an LED, and two photodiodes on the opposite side. If it's mechanically aligned, the photodiodes will see the light in a quadrature sequence. Optical encoders can provide the highest resolution of all the encoder types, and they also scale well to inexpensive low-end applications. However, they can be bulky in size, and reliability is limited by the LED lifetime (which is reduced at high temperatures) and any contaminants that block the light.

3. Magnetic: Magnetic incremental encoders use a circular magnet with multiple north and south magnetic poles. Typically, two Hall Effect Latch devices are placed nearby, and generate quadrature outputs as the magnet turns.

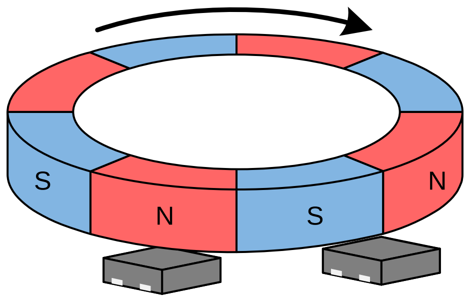

Figure 4. Magnetic Incremental Encoder

Magnetic encoders can be inexpensive, compact, and extremely reliable for these reasons:

- There's no contact, and the sensors are solid-state electronics.
- Magnetic fields pass right through most contaminants (water, oil, dirt), and the PCB can be sealed from the environment.
- The input sensing and output signaling is effectively digital, giving high noise immunity.

Increments Per Revolution

Based on the feature size of an encoder, it can produce a different number of output states per revolution, and there are tradeoffs to consider.

Motor systems that use closed-loop speed control require sufficiently fast feedback, depending on the allowable speed tolerance, the possible changes in load torque, and the motor's inertia. The required feedback rate can determine what is needed from the encoder. Rotational speed is usually stated in RPM (Revolutions Per Minute); dividing by 60 equals the revolutions per second, and multiplying by the number of encoder states per revolution equals the system's feedback rate (in Hertz).

In slow-turning applications, the primary concern is usually the number of degrees between each increment. If, for example, an event every 10° is needed, an encoder with 36 output states per revolution would be suitable.

The downside of higher encoder resolution is that it requires tighter mechanical and sensor tolerances. Magnets for encoders have a practical limit of about 1 mm for the width of each pole, and that also brings smaller air gap and threshold requirements.

Magnetic Sensors

TI offers the DRV5012 and DRV5013 Hall Effect Latch sensors for high-performance encoder applications.

- The DRV5012 has ultra-low power consumption, and a pin-selectable bandwidth that sets either 20-Hz sampling using 1.3 µA, or 2.5-kHz sampling using 142 µA (at 1.8 V). The device also has a low 3.3 mT maximum magnetic threshold, which enables using larger air gaps and smaller magnets.
- The DRV5013 operates from a wide 2.5- to 38-V range, has automotive-qualified options, supports up to 175°C junction temperature, and has a fast 30-kHz sampling rate.

To create a quadrature output, the two Hall sensors should be spaced apart by the width of each magnet pole, plus any integer number of widths (as Figure 4 illustrates). The number of 2-bit states per revolution is 2 times the number of poles. In order for the sensors to detect each pole as it moves by, the sensor sampling rate should be higher than 2 times the number of poles per second, and ideally at least 3 times higher. Additional information can be found in the DRV5012 datasheet application section.

Using Linear Hall Sensors

Linear Hall sensors like the DRV5053 can also be used for incremental encoding. Unlike latch devices that have an open-drain output and predefined magnetic threshold, linear Hall sensors output an analog voltage that's proportional to magnetic flux density. As a circular magnet turns, the magnetic flux density at a point in space nearby generally changes sinusoidally. Placing two linear Hall sensors for quadrature enables the production of sine and cosine signals. This can be used for absolute angle encoding (using a 2-pole magnet), as well as for incremental encoding with a programmable number of increments per revolution. The following logic can be implemented in code to determine the direction of each event:

- If the voltage of one sensor changed significantly while the other didn't, check if the one that didn't is generally high or low, and for the sensor that did change check if the new value is larger or smaller than before.
- If the voltage of both sensors changed significantly, check which sensor is larger than the other, and compare new versus old values. There are 12 possible combinations, and 6 correspond to each direction.

TI reference designs for magnetic encoders include TIDA-00480 and TIDA-01389.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
DRV5015	2 mT maximum threshold	Lower hysteresis

Table 2. Adjacent TechNotes

SBOA196	Power Gating Systems with Magnetic Sensors
SBOA174	Current Sensing in an H-Bridge