TIDA-00480 TI Design Considerations
Automotive Hall Sensor Rotary Encoder

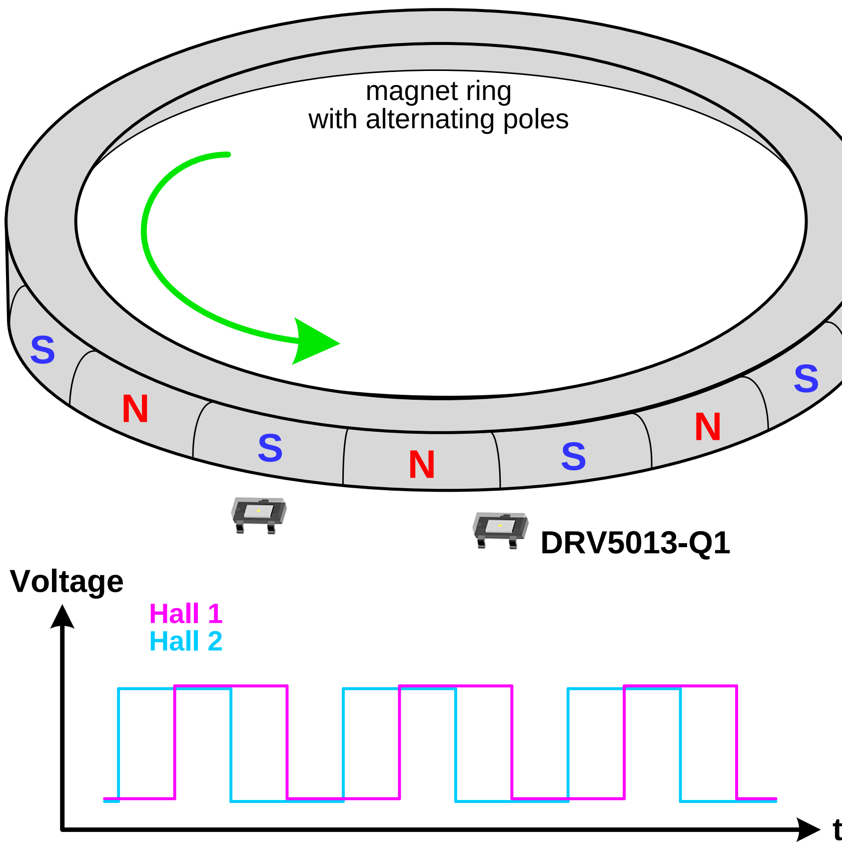
Introduction

Incremental rotary encoders are used to measure the movement of something rotating. The simplest form involves just one sensor that pulses once per revolution, and its frequency equals rotational speed. If the object rotating can change directions (clockwise versus counter-clockwise), one sensor lacks the ability to distinguish direction. Using two sensors can capture direction information, based on the order of transitions between the two.

While this TI Design demonstrates a solution on a handheld knob, rotary encoders are also commonly used on motor shafts, wheels, gears, and impellers.

Functional Operation

The two primary components of this design are a multi-pole ring magnet and Hall Effect sensors. The magnet is circular in shape, and has alternating North and South poles along the surface. Two DRV5013-Q1 Hall Effect latch sensors are placed nearby with a small air gap. Each sensor drives a low voltage when it is nearby a South pole, and the output floats high near a North pole. As the magnet rotates, each sensor transitions high and low repeatedly.



For each 2-bit state, there is a unique adjacent 2-bit state that corresponds to a clockwise increment, and another unique 2-bit state that corresponds to a counter-clockwise increment. A microcontroller can simply use a look-up table to comprehend the movement.

Sensor Placement

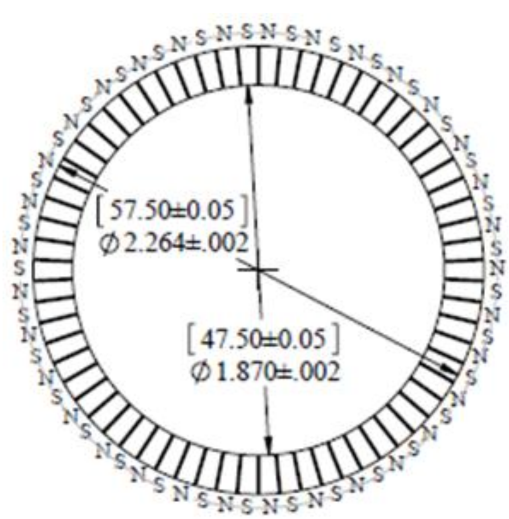
Having a proper 2-bit output requires the sensor outputs to be out of phase with each other. The ideal separation equals 0.5*W + INT*W, where W is the width of each pole on the magnet, and INT is any integer. This causes a sensor transition for each half-pole-width of a turn. Then the outputs are said to be “in quadrature”, which means there’s 90° of phase separation. The number of sensor transitions per 360° revolution equals two times the number of magnetic poles (assuming two sensors are used).

In order for the Hall Effect sensors to toggle, the applied magnetic flux density must exceed their thresholds. In the sensor datasheet, the two numbers to consider are max-B_{OP} and min-B_{RP}. The DRV5013AD used in this design has thresholds of ±5mT. System designers should consider the distance between the magnet and sensor, and select an appropriate magnet material and physical size that produces an adequate flux density at the sensor.

Magnet Characteristics

This design used a 57.5mm diameter ring magnet with 66 poles, provided by Dexter Magnetic Technologies. This size was appropriate for being mounted to the large handheld knob. For other end applications, much smaller magnets can be used (<1cm).

Part Number	11140012
Physical Data	
Number of Poles	66 (33 Pole Pairs)
Pole Spacing	Evenly Spaced
Magnetization	Outer Diameter
Outer Diameter	57.5 +/- 0.05mm
Inner Diameter	47.5+/- 0.05mm
Thickness	3 +/- 0.13mm
Pole to Pole Deviation	1.5° Maximum
Magnetic Characteristics	
Material	Bonded Neodymium
Energy Grade	10 MGOe
Magnetic Field Temperature Drift	"-0.10% / °C"
Maximum Operating Temperature	160 °C
Coating	Black Epoxy



Mechanical Implementation

The knob assembly mounts to the PCB using a threaded bolt as the shaft, hex nuts, and optional rubber washers on either side of the PCB to provide a feeling of resistance when rotating the knob by hand.

Electrical Implementation

1kΩ pull-up resistors were used on the open drain sensor outputs to provide adequate rise times for the fastest knob turns. The resistor size and rise time is a tradeoff of increased current consumption.

The MSP430G2553-Q1 Automotive Ultra-Low-Power Microcontroller reads the 2-bit quadrature output to detect alternating poles as they pass over the sensors and determine the direction of rotation. The sensor output states for rotation in the CW direction are indicated in the table below (a South pole near the marked side of the sensor package results in a low output of "0" and a North pole near the marked side of the sensor package results in a high output of "1").

Hall Sensor U3	Hall Sensor U4
0	0
0	1
1	1
1	0

Three common cathode seven segment LED displays were used to numerically illustrate the detection of alternating poles and direction of rotation. The current through each LED segment was set to approximately 4mA (using 232Ω series resistors), to provide the desired brightness level.

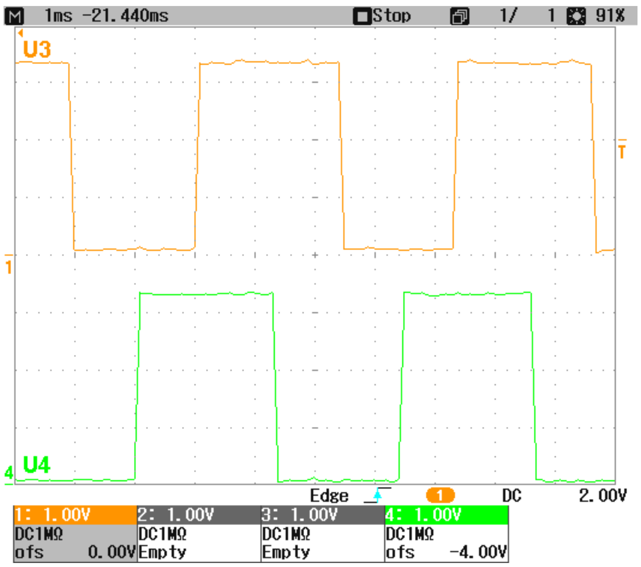
The CD4511B BCD-to-7-Segment LED Latch Decoder Driver interfaces with the MCU to provide the output current capability necessary to drive the LED displays.

An optional 32.768kHz watch crystal enables accurate real time keeping and low-power standby operation.

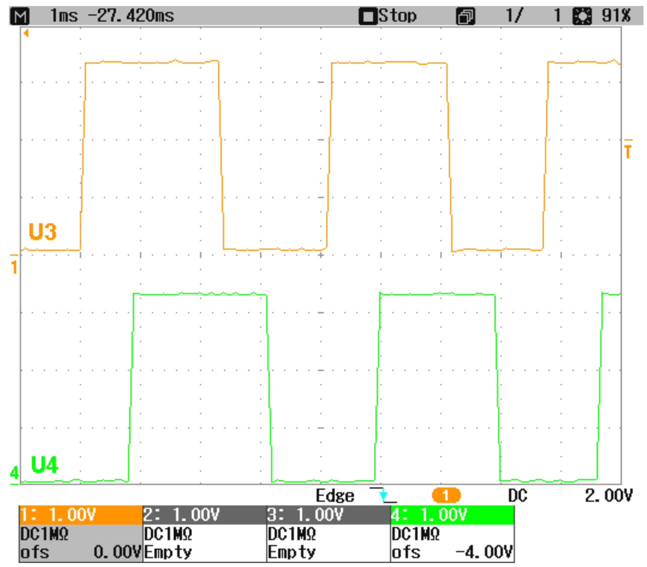
The eZ430-RF2500 tool and Code Composer Studio (CCS) v5.4 were used to program the MSP430G2553-Q1 device.

The TPS61097A-33 Boost Converter provides the 3.3V supply to downstream circuitry from two Panasonic AA Alkaline batteries (Part Number LR6XWA).

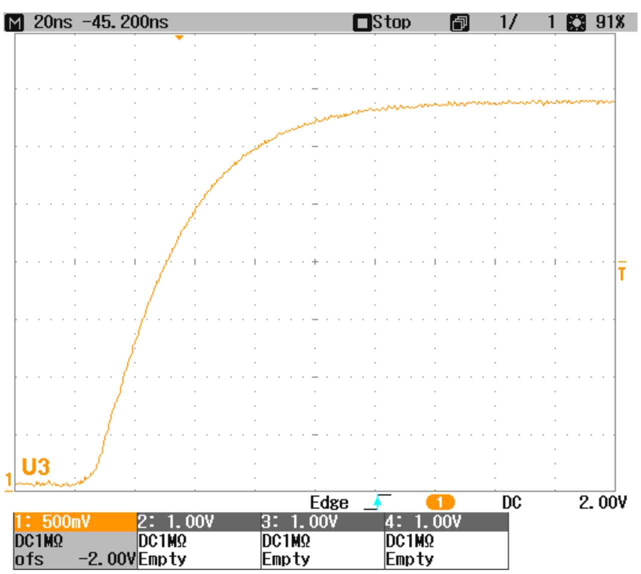
Test Data



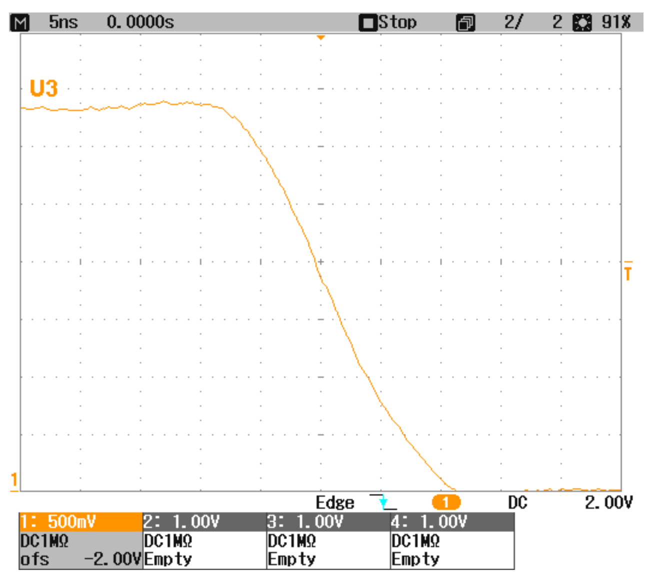
Hall signals during clockwise rotation



Hall signals during counter-clockwise rotation



Hall sensor pullup (1kΩ to 3.3V)



Hall sensor pulldown (open-drain output)

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