INTERFACING THE COTO TECHNOLOGY REDROCK RR110 TO AN ADC USING A LOW POWER ANALOG INTERFACE CIRCUIT

Background

Portable medical devices, such as personal insulin pumps, have gotten smaller with time, allowing them to be conveniently carried by the user. This convenience has been made possible by intelligently and accurately dispensing product when active, and ensuring very low quiescent current when not active. Sensing technologies used to monitor the position of the plunger, therefore, need to be accurate in order to ensure the correct dosage, while being extremely frugal on power demand in order to fit within the operation profile of the device with the chosen battery. The RR110 analog sensor – from Coto Technology's RedRock Series sensor product line – has high sensitivity and operates with ultra-low current, making it ideally suited for these applications.

The RR110 is a two-terminal, passive analog magnetic sensor based on the Tunneling Magnetoresistance (TMR) principle. Resistance of the Magnetic Tunneling Junction (MTJ) changes from approximately 65kΩ with zero magnetic field, to approximately 40kΩ in the presence of ~10mT magnetic field (Figure 1) and can be used reliably with a current as little as 1µA to measure the resistance change as a change in voltage.

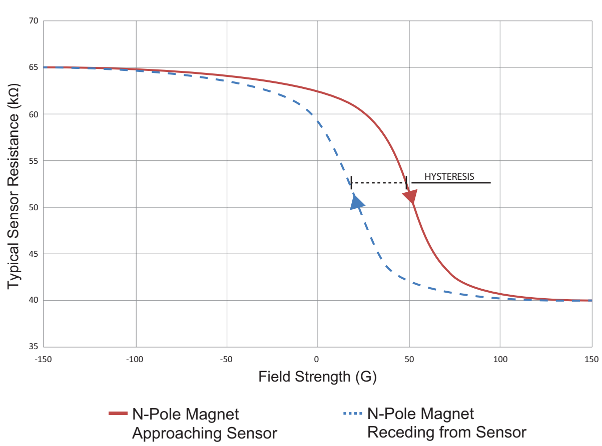

Figure 1: Resistance change of RR110 in a magnetic field

With a 3v supply, the RR110 can be used in a voltage divider network, with an ADC measuring the voltage at the junction, as shown in Figure 2. A 2MΩ biasing resistor will keep the current to approximately 1.2µA . However over the full range of magnetoresistance, the voltage change at the junction will be quite small, and a high resolution ADC will not measure the change with sufficient resolution.

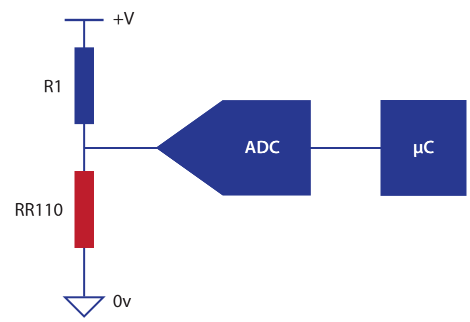

Figure 2: Simple RR110 output measurement with ADC

A better approach is to use an interface circuit with the RR110, in order to [1] reduce the offset from sensor resistance at zero magnetic field, and [2] amplify the small resistance change in the RR110 to a larger voltage range, better matching the input voltage range of the ADC, as shown in Figure 3. In this way, the ADC's full resolution range is utilized for the measurement.

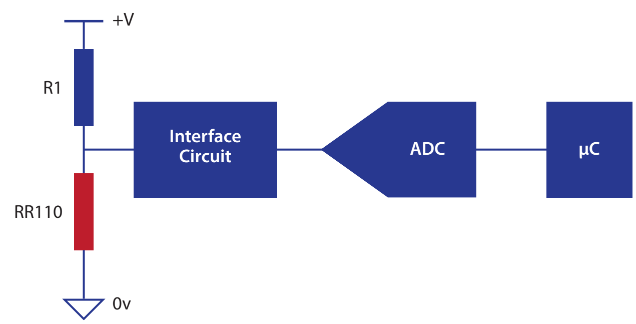

Figure 3: Improved RR110 output measurement using analog interface circuit to match ADC input range

The analog interface circuit shown in Figure 4 provides an example implementation using a micro power dual op-amp device, TLV2402. Supply voltage range of the TLV2402 matches that of the RR110; therefore the circuit may be powered from 2.7 to 16V single supply, or a +/-1.5 to +/-8v bipolar supply, with total power dissipation less than 20µW.

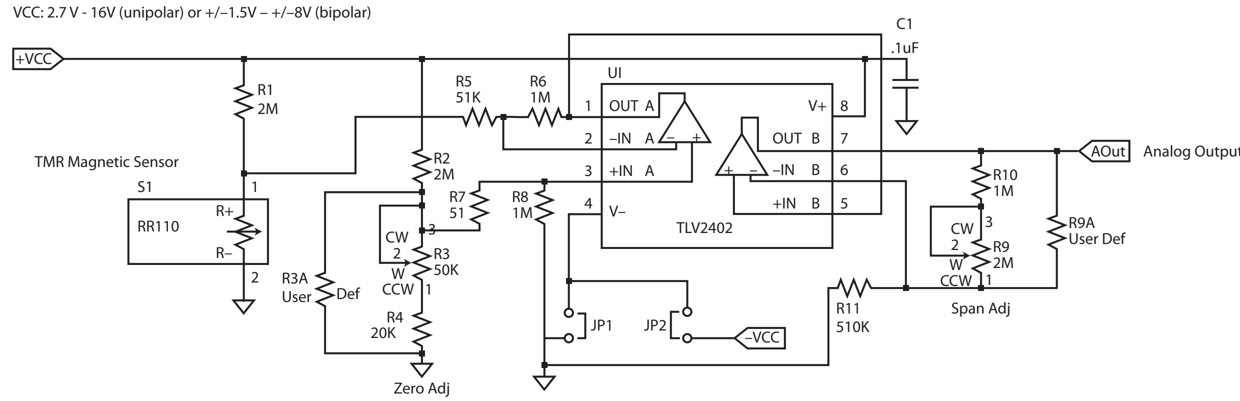

Figure 4: Analog interface circuit for RR110

Circuit Description

The RR110 sensor (S1) is biased directly from Vcc through a 2M resistor (R1), to form a variable voltage divider. In a 3v single supply application – such as from a CR2032 coin cell; this drives the RR110 with approximately 1.2µA. Voltage at the junction varies from 95mV (zero field) to 59mV (maximum field), creating a span of -35mV with a 94mV offset.

The first half (A) of the dual operational amplifier U1, along with resistors R5, R6, R7, R8, is configured as a 20x gain, differential amplifier. R5, R6, R7, R8 should be 1% resistors for best amplifier performance. The ratio (R5=R7)/(R6=R8) may be changed for another gain value. Inputs to the differential amplifier are (a) from the R1-S1 junction, and (b) from the wiper of potentiometer R3, which, when combined with resistors R2 and R4, form the zero-adjust circuit. R3 can be adjusted so that voltage at its wiper precisely matches the zero field voltage value at the R1-S1 junction, thereby cancelling the zero-field offset. Alternately, precise zero adjustment can be sacrificed for reduced component count by replacing R3 and R4 with a fixed resistor R3A, of value matching the zero field resistance of RR110 sensor (65kΩ).

After the offset is cancelled, U1A amplifies the signal resulting from a change in RR110 resistance, and also inverts the sign. Output from U1A therefore increases with increasing magnetic field. This signal is the input to the second operational amplifier (B) in U1. U1B, along with potentiometer R9 and resistors R10 and R11, is configured as a 3x-7x adjustable gain, non-inverting amplifier. Potentiometer R9 can be adjusted to tailor the output voltage range, so it best matches the input voltage range of the downstream analog to digital converter. Once a suitable gain value is determined, the potentiometer R9 and resistor R10 may be replaced with a fixed scaling resistor R9A.

For the configuration shown, full scale analog output voltage is calculated as:

$$\text{Full Scale Vo} = \left(1+\frac{R9A}{R11}\right) * V_{cc} * \left(\frac{R6}{R5}\right) * \left(\frac{R_{max}}{R1 + R_{max}} - \frac{R_{min}}{R1 + R_{min}}\right)$$

The equation can be rearranged to determine value of the scaling resistor R9A to match the circuit output to the full scale input voltage Vi of the ADC input

$$R9A = R11 * \left(\frac{V_{iADC}}{V_{cc} * \left(\frac{R6}{R5}\right) * \left(\frac{R_{max}}{R1 + R_{max}} - \frac{R_{min}}{R1 + R_{min}}\right)} - 1\right)$$

Where R_{max}= RR110 resistance at minimum field and R_{min}=RR110 resistance at maximum field.

A few items are noteworthy about this example circuit.

1. The output voltage is ratiometric with Vcc. Therefore, as the battery voltage drops over time, the output voltage from the circuit will be correspondingly lower when the RR110 is subjected to the same magnetic field. In order to make the ADC output relatively independent of Vcc, two strategies can be adopted: [a] choose an ADC with an input range referenced to Vcc, or [b] use a reference voltage device to power the RR110 voltage divider and to serve as reference voltage to the ADC.

2. When using a unipolar power supply, the output of the differential amplifier (U1A) can only swing to 25mV from ground, and this will be amplified by the selected gain in U1B. This will therefore prevent the circuit output from reaching 0V. At Vcc=2.7V, minimum output from the circuit will be approximately 130mV, increasing to 180mV

at Vcc=15v. With a bipolar power supply, potentiometer R3 can be adjusted to ensure the output is 0v at minimum magnetic field.

3. A downstream ADC may capture data from the circuit as fast as the application requires. Acquisition rate will be limited only by the conversion time of the ADC. If low pass filtering is needed, simple R-C filter may be placed at the output of U1B. When signal synchronization is important, phase delay from the RC network, propagation delay in U1A and U1B, and response time of the RR110 must be considered.

Estimating Power Consumption

The power consumed by this example circuit has three contributions:

$$P_{total} = P_{sensor} + P_{biasFB} + P_{quiescent}$$

1. P_{sensor} = Operating current of the RedRock RR110 sensor, S1, set by its bias resistor R1 and also mirrored in the zero offset network. It should be noted that since resistance of the RR110 decreases in the presence of a magnetic field, it will draw more current when a magnet is close to the sensor.

2. P_{biasFB} = Bias currents in the feedback network of U1.

3. $P_{quiescent}$ = Quiescent power requirements of the amplifier U1. The power consumption will scale with Vcc^2. The following equations may be used to estimate power consumption:

In the worst case scenario, when the magnet is against the sensor and its resistance is at the minimum value,

$$P_{sensor} \sim 2 * Vcc^2 / (R_{min}+R1) \ (\mu W)$$

Amplifier bias and feedback

$$P_{biasFB} = 5\mu W + 0.36 * V_{cc}^2 \ (\mu W)$$

Amplifier quiescent power

$$P_{quiescent} = 2\mu A * V_{cc} \ (\mu W)$$

Operating at 3v, such as from a CR2032 coin cell, and substituting R_{min}=40K, R1=2M, we calculate:

$$P_{total} = 23.05 \ \mu W \quad \text{Therefore, } I_{total} = P_{total} / V_{cc} = 7.68 \ \mu A$$

This circuit is estimated to draw approximately 7.68µA from the coin cell during operation. Operating current will be slightly greater at higher operating voltages, increasing with the square of operating voltage.

In order to estimate how this impacts battery usage, consider a fresh CR2032 cell from Maxell, with a 200mAh energy capacity. Absent any other current draw, time to depletion is

$$T_{battery} = (200000uAh/7.68\mu A)/(24*365) = 2.97 \text{ years}$$

For a more accurate, in-application estimate, power requirements by downstream systems should be correctly mapped and accounted for.

Conclusion

The RedRock RR110 analog sensor from Coto Technology can be used to implement ultra-low power solutions for sensing position by utilizing a magnet embedded in a moving part. Utilizing an analog interface circuit, an ADC can measure response from the RR110 with good accuracy and resolution. The RedRock RR110 and related switch devices RedRock RR120 and RR130 are ideally suited for applications that must conserve battery power while accurately monitoring position.

For further application assistance, please contact Coto Technology's Sales and Applications Engineering team. (appsupport@cotorelay.com).

