

Crocus Magnetic Sensor

Used for Current Sensing

Relevant Crocus Devices

The concepts and examples in this application note are applicable to all of the following Crocus devices:

CTSR206V-IQ2, CTSR209V-IQ2, CTSR212V-IQ2,
CTSR215V-IQ2, CTSR218V-IQ2, CTSR222V-IQ2

Introduction

The Crocus CTSR2xxV series is a family of magnetic sensors designed for sensing low magnetic fields. These sensors can also be used for current sensing applications. By placing the sensor near a current carrying conductor, the sensor can measure the current through the conductor by measuring the magnetic field produced by the current flow. Refer to the Crocus application note AN101_MagneticFieldvsDistance_for more details on the basic theory.

Crocus Magnetic Sensor

The Crocus Magnetic Sensor is a four terminal device that was designed to sense low magnetic fields. The terminals comprise of two input terminals and two output terminals. Figure 1 shows the schematic symbol of the device and shows the four terminals: I_{IN} , I_{INGND} , V_B and V_{BGND} . The two output terminals of the sensor, V_B and V_{BGND} , connect to the sensor output resistor R_{OUT} that changes resistance while in the presence of a magnetic field. I_{IN} and I_{INGND}

are the two input terminals that are used to bias the sensor in its linear region of operation. More about this later in this application note.

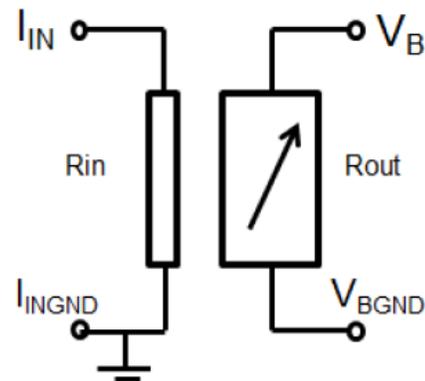


FIGURE 1

The transfer curve of the output resistor R_{OUT} versus the external magnetic field near the device can be seen in Figure 2.

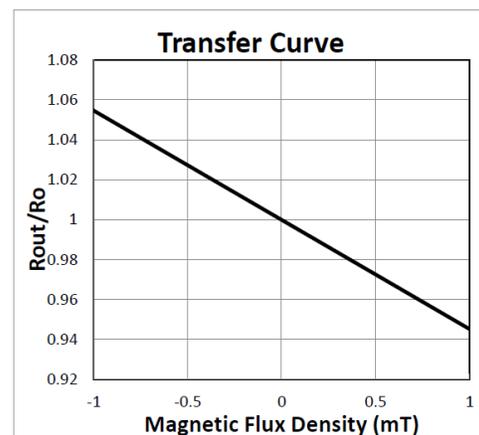


FIGURE 2

Notice that as the external magnetic flux density increases, the R_{OUT} value decreases. Another interesting feature of the sensor that can be seen in Figure 2 is that the sensor reacts to a magnetic field in the positive and negative direction relative to the sensor. Figure 2 shows a narrow region of the output resistance relative to the applied magnetic flux density. If a much stronger field is applied, the output resistance R_{OUT} actually assumes the values that closely resemble a negative hyperbolic tangent function.

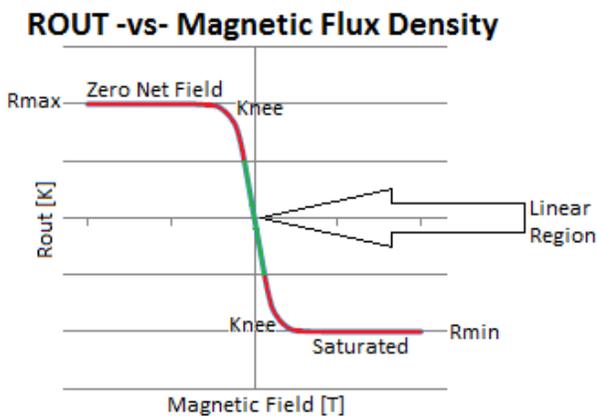


FIGURE 3

Figure 3 shows a generic, negative hyperbolic tangent function with a few labels added. R_{max} and R_{min} show the R_{OUT} resistance values with no external magnetic field applied and with a very high magnetic field applied respectively. Please see the datasheet for the R_{max} and R_{min} values. Notice that the curve is linear in the middle of the region near the $X=0$ and $Y=0$ point, shown in green on the chart, and that it diverges as it gets close to the knee at the top and at the bottom. The chart shown in Figure 2 shows the relationship between the output

resistance R_{OUT} of the sensor and the magnetic flux density in the linear region only. For applications that use the sensor to measure low magnetic fields with a low dynamic range, the sensor can be used without concern for nonlinearity. However, if larger magnetic fields need to be measured and good linearity is required, then signal conditioning will be necessary to achieve this. Later in this application note, we'll see how this is easily accomplished with a very simple closed-loop circuit.

You might be wondering how the device is biased to operate in the linear region if the R_{OUT} resistor is R_{max} with no external magnetic field applied to the sensor. This region is labeled as the "Zero Net Field" region of the curve in Figure 3. The answer to the question is that the device is biased by the R_{IN} input current. R_{IN} can be thought of as a resistor, but in reality, it's simply a current carrying conductor within the device that is very close to the sensing element. The current passing through the R_{IN} conductor is approximately 10mA and creates a magnetic field that biases the sensor in the middle of the curve shown in Figure 3. With the device biased in the middle of the linear region by the R_{IN} current, an increase in the external magnetic field will cause the output resistor R_{OUT} to decrease in value while a decrease in the external magnetic field will cause the output resistor R_{OUT} to increase in value. With no external magnetic field applied to the sensor and 10mA of bias current applied to R_{IN} , the output resistor R_{OUT} will remain in the center of the linear region. Another way to analyze this is to consider the superposition property of magnetic field vectors. Consider that the

magnetic field vector, with an amplitude and a direction, associated with the current flowing through R_{IN} and the magnetic field vector associated with the externally applied magnetic field are simply added together. The resultant magnetic field vector is seen by the sensing element and causes the output resistance R_{OUT} to increase or decrease according to Figure 2.

Closed-Loop Application Circuit

For applications that require good linearity (<.5% full scale error) and high dynamic range of magnetic field sensing, signal conditioning is necessary to assure that the sensor's output resistance R_{OUT} does not enter the non-linear regions shown in Figure 3. A very simple, closed-loop circuit can be used to accomplish this.

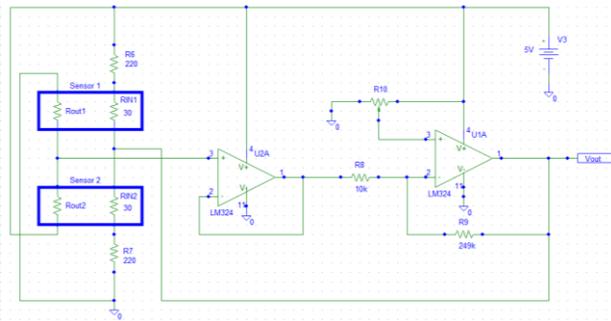


FIGURE 4

The schematic shown in Figure 4 is a closed-loop circuit that uses two Crocus Magnetic Sensors to detect an external magnetic field. The two sensors are mounted on the PCB such that as the external magnetic field increases, one of the sensor's output resistance, R_{OUT} , increases and the other decreases. Figure 5 shows the inverse relationship of the two sensors relative to the external magnetic field that is being sensed. As the external magnetic

field increases, the R_{OUT} for sensor 1 increases while the R_{OUT} for sensor 2 decreases and vice versa.

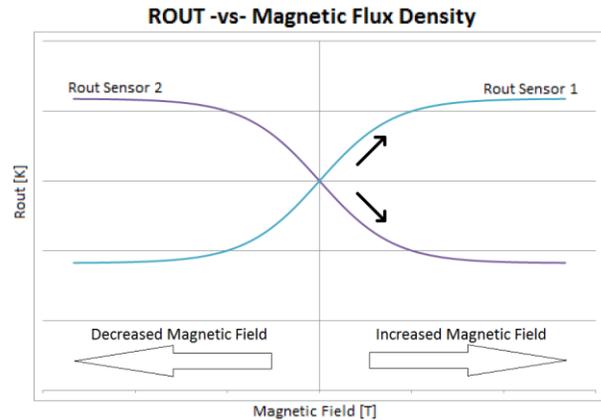
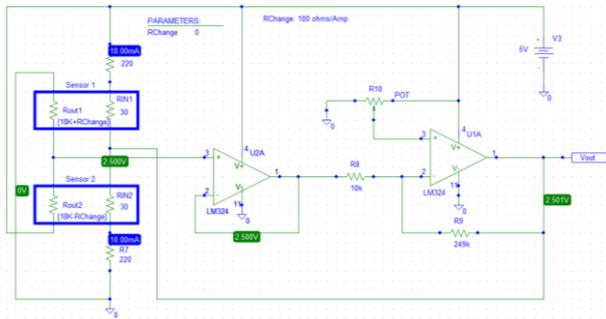


Figure 5

By way of circuit theory, here's how the circuit in Figure 4 works: with no external magnetic field present, R_{10} should be adjusted to set the output voltage of U_{1A} , V_{out} , to +2.5VDC. This +2.5VDC is applied to the node of R_{IN1} and R_{IN2} which are the inputs to the two sensors as described above. R_{IN1} is in series with a 220 ohm resistor, R_6 . The series combination of R_{IN1} plus R_6 add together to make a total resistance of 250 ohms. The voltage drop across $R_{IN1} + R_6$ is $5VDC - 2.5VDC = +2.5VDC$. So the current through R_{IN1} and R_6 is $+2.5/250 = 10mA$. This is the quiescent current through the R_{IN1} while there is no external magnetic field present. Remember that 10mA is the current needed to bias the device in the middle of the linear region of the curve in Figure 3 while there is no external magnetic field present. The quiescent current through R_{IN2} is calculated in a similar way and is also equal to 10mA while there is no external magnetic field present.

When an external field is applied to the device R_{OUT} of sensor 1 will increase and R_{OUT} of sensor 2 will decrease. The output voltage of the voltage divider that is comprised of R_{OUT1} and R_{OUT2} , the sensor output resistances, will change. The voltage will go up from its quiescence voltage. This voltage change is buffered first by U2A and then inverted and amplified by amplifier U1A. The new output voltage V_{out} is then applied to the node of R_{IN1} and R_{IN2} which changes the current through the R_{IN1} and R_{IN2} . In this case, the current through R_{IN1} will increase because the voltage drop across the series circuit R_{IN1} and R_6 will increase as the voltage V_{out} goes down. This increase in current through R_{IN1} will essentially buck the external magnetic field applied to the sensor which will return the output resistance of the sensor to the middle or of the linear region. A similar reaction takes place with the other sensor in the circuit but in the opposite direction. To verify the operation of the circuit, here is the PSpice model used to analyze and test the circuit:



What's really interesting about the circuit analysis is what happens to the input current RIN1 and RIN2 as the output resistances of the sensors are swept. Figure 9 shows the current of RIN1 (green trace) and the current through RIN2 (red trace). Notice that the current through RIN1 increases as the Vout decreases and the current through RIN2 decreases as the Vout decreases. So as the current increases



FIGURE 9

through the RIN1 of the sensor, the output resistance ROUT1 will decrease. Likewise, as the current decreases through the RIN2 of the sensor, the output resistance ROUT2 will increase. This degenerative feedback, from the sensor ROUT to the sensor RIN, serves to essentially cancel the effects of an external magnetic field on the sensor. The net effect of the closed-loop circuit is that the sensor output resistance ROUT will not move from the linear portion of the ROUT curve as seen in Figure 3. This will provide the application with a wide dynamic range as well as good linearity performance.

Current Sensing Application

With the closed-loop application circuit well understood, let's apply the circuit to a real-life application: Current Sensing. We will physically place two Crocus CTSR218 Magnetic sensors in

the circuit of Figure 4 above a current carrying trace on a PCB. As mentioned earlier, the two sensors will be mounted above the current carrying trace in such a way as to be affected by the magnetic field in opposite directions.

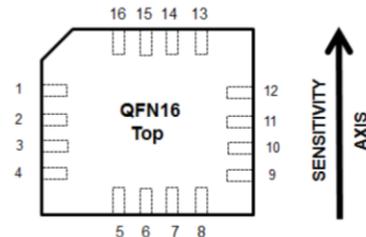


FIGURE 10

From the datasheet, we see that the line of sensitivity for the CTSR218 is in the direction shown in Figure 10. In the current sensing application, the two sensors are mounted in the same direction and the current carrying trace changes direction as illustrated in Figure 11 and Figure 12.

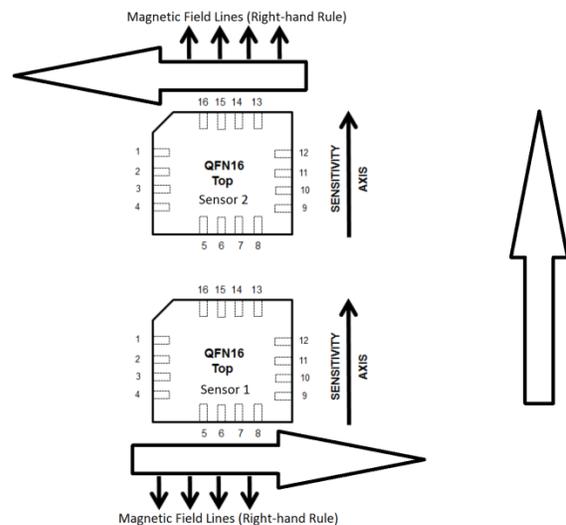


FIGURE 11

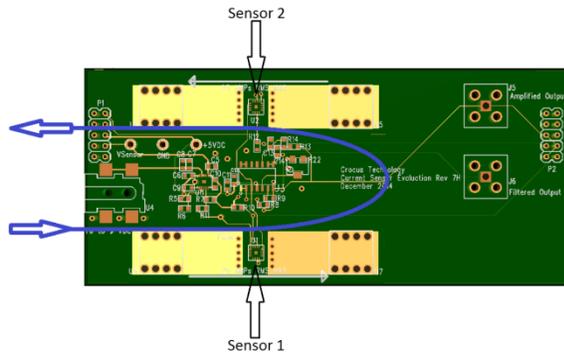


FIGURE 12

Figure 12 shows the layout of the PCB and the placement of the two sensors. The figure also shows the orientation of the sensors relative to the current flowing through the current carrying trace. The blue line indicates the path of the current flow. Please note that the arrows on the blue line are just used for convention and that the current can either be AC or DC and can be in either direction. Since the sensors are mounted in the same orientation on the PCB and the current direction is actually reversed on the PCB, both of the sensors will be affected by the current but the direction of the current seen by each sensor will be in the opposite direction.

Summary

The Crocus CTSR2xxV series of magnetic sensors are designed for sensing low magnetic fields and can be used to measure the current flowing through a current carrying conductor. By implementing a simple, closed-loop circuit comprising of the output resistance R_{OUT} of the Crocus sensor and the input resistance R_{IN} of the sensor, high dynamic range can be achieved as well as good linearity performance. These are two important characteristics of a current sensing application.