Application Note:
Discrete Circuit for Magneto-Inductive Sensors

Introduction

PNI Sensor Corporation's Magneto-Inductive (MI) sensors are based on patented technology that delivers breakthrough, cost-effective magnetic field sensing performance. These sensors change inductance with different applied magnetic fields. This variable inductance property is used in a patented temperature and noise stabilized oscillator/counter circuit to detect field variations.

PNI Corporation's sensors employ a single solenoid winding for each axis and consume roughly an order of magnitude less power than conventional fluxgate or magneto-resistive technologies. The sensor coil serves as the inductive element in a very simple, low-power LR relaxation oscillator, with its effective inductance being influenced by the magnetic field component parallel to the coil axis. The frequency of the oscillation changes with the magnetic field.

The output of the sensor circuit is inherently digital, and can be fed directly into a microprocessor. This eliminates the need for any signal conditioning or analog/digital interface between the sensor and a microprocessor. The simplicity of the sensor circuit combined with the lack of signal conditioning makes the magneto-inductive sensor easier and less expensive to use in your product design than fluxgate or magneto-resistive sensors.

Circuit Description

PNI Corporation's Magneto-Inductive sensors are sensitive to the magnetic field running through the core of the sensor coil. The sensor is made a part of an inductance-sensitive oscillator circuit whose output will change frequency as the magnetic field parallel to the sensor changes.

To measure the sensor it must be first biased in both directions. That is, one measurement is made with one end of the sensor grounded and the other end oscillating. The connections are reversed, and the first end is allowed to oscillate, while the second end is grounded. This makes the measurement linear in the magnetic field over the sensor's measurement range, and makes the measurement largely temperature independent.

Figure 1, at the end of this document, is a diagram for the basic circuit configuration for a two-axis magnetic measurement along with component values for operation at 5 V and at 3.3 V. **Y1**, **Y2**, **X1**, **X2** are select lines which are grounded ("low") when the measurement is not selected; one line at a time is then connected to VCC ("high") to select that measurement. "X" and "Y" refer to the two magnetic axes with "1" referring to a forward bias, and "2" to reverse bias.

For example, a complete measurement of the magnetic field along the X-axis requires a measurement of **X1** and **X2**. The output of the sensor circuit is seen at the **Output** line which can be looked at with an oscilloscope, or feed this into the input of a microprocessor.

Circuit Assembly

When assembling the circuit, as shown in ***Figure 1***, please make note of the following:

1. It is important that the appropriate resistor values for the sensor and bias voltage combination are used. See the table at the end of this document.
2. Be sure to use bypass capacitors on the IC's and the pull-up resistors R9, R10, R11 and R12.
3. Pins 2 -5 on J1 (X1, X2, Y1 and Y2) are to be connected to switches that toggle between VCC and ground. Leave them low unless selected.
4. The second comparator on the TLC3702 should be configured as shown in ***Figure 1*** to prevent unwanted oscillations.
5. If only one axis of magnetic data is needed, just build the circuitry that connects L1. If three axes of magnetic data are needed, simply add a third sensor and circuitry in parallel with the two shown. This will result in having two more select lines, Z1 and Z2.
6. The sensors are assumed to be at right angles with respect to each other and lie level with respect to the Earth's surface.
7. By convention, the positive end of the X-axis points to the North and the positive end of the Y-axis points East.

When the sensor is connected in this oscillator configuration, the output of the sensor is a square wave. The period of the square wave is proportional to the magnetic field strength parallel to the sensor.

Circuit Operation

The raw sensor measurements are read at pin 1 of J1 (Output). Four sensor values, X1, X2, Y1 and Y2, are needed to determine the 2-axis X and Y magnetometer values. To determine the value of X1, bring pin 2 on J1 (X1) high and period count 256 cycles of the square-wave output on pin 1. The period count is the value for X1.

Assert pin 3 and period count for 256 cycles of the square-wave output on pin 1. This is the value for X2.

Assert pin 4 and period count for 256 cycles of the square-wave output on pin 1. This is the value for Y1.

Assert pin 5 and period count for 256 cycles of the square-wave output on pin 1. This is the value for Y2.

Once all four raw sensor values have been gathered, the two relative magnetic field strengths (Xmag and Ymag) can be calculated.

Xmag	=	X1	-X2
Ymag	=	Y1	-Y2

Note: It is recommend that measurements Xmag, Ymag (and Zmag if needed) are made before proceeding to other calculations. An attempt must be made to minimize the time between measurements to ensure that the measurements of X and Y truly reflect the same magnetic field.

Compass heading can be calculated using Xmag and Ymag as

Heading = arctangent (Ymag/Xmag).

Note: The result of this calculation will be a 2 axis compass heading that has not been compensated for hard iron offsets, soft iron distortions or gain matching of the sensors. For more information on calibrating for offsets and gain matching please see: *"App Note: Multipoint Calibration Primer".*

Notes

Forward Bias -Reverse Bias

It is recommended that two measurements be made on each sensor, with the difference between the two measurements being the actual magnetic field measurement. Using the difference between the forward bias measurement and the reverse bias measurement will automatically compensate the measurement for temperature drift. Any variation in the measurement process arising from temperature drift will affect both the forward bias and reverse bias measurements equally so when the difference between the two cases is taken, the temperature effect is cancelled out.

Magnetic Field Calibration

The quantities Xmag = X1 -X2, and Ymag = Y1 -Y2 do not give the value of the magnetic field measured. Instead, they are proportional to the magnetic field measured. In compassing applications, this is fine since the ratio of Ymag/Xmag is used to divide out the constant of proportionality. In most applications, only relative magnetic field values are needed but if there is a need to know absolute magnetic fields, the sensors will need to be calibrated in a known magnetic field.

PNI Corporation's sensors are very linear over their operating range so they can be calibrated by making a linear fit between the measured Xmag and Ymag values and the true set field. Most of the time, however, it is sufficient to make a relationship between the quantities Xmag, Ymag and some parameter of interest.

Alignment

The sensors need to be aligned as close to perpendicular as possible. Any error in alignment will translate into errors in measurement. For example, in a compassing application, a small error in sensor alignment will give the same error in the calculated heading. If the angle between the X-axis sensor and the Y-axis sensor is only 88°, instead of 90°, the compass will read 2° when it is directed toward magnetic north. Alignment errors can be corrected for through a calibration of the sensor package. The alignment error will act as a "cross-axis" term; a magnetic field along the X-axis will produce a signal on the Y-axis sensor. This error can be measured and then included as a small linear correction term to the measurement process.

For example, if one were to assume a linear relation between a field along the X-axis to the Y-axis sensor as $Y=a_1X$, and a field along the Y-axis to the X-axis sensor as $X=a_2Y$, the measurement of X and Y would be corrected as follows:

$$X_{final} = X + a_2Y$$
$$Y_{final} = X + a_1X$$

These final values would then be used as the actual measurement of the magnetic field.

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Resistor Values

SEN-XY (L1, L2)

Resistors	5VDC	3VDC
R1	13.5K 1%	27.4K 1%
R3	100K 1%	100K 1%
R4	4.7K 1%	10K 1%
R5-R8	200 1%	120 1%
R9-R12	100K	100K

Note: All chips and pull-up resistors should be bypassed at VCC with 4.7 uF and 0.1 uF in parallel.

Component Requirements

The components listed below have been verified by PNI Corporation to work in the circuit as designed. Any substitutions, especially with regards to the comparator, TLC3702I, may cause errors with the circuit and the resulting heading calculations.

- 74AC08 -Quad 2-Input AND Gate
- 74HC4066 -Quad Bilateral Switch
- TLC3702I -Dual Micropower LinCMOS Voltage Comparator

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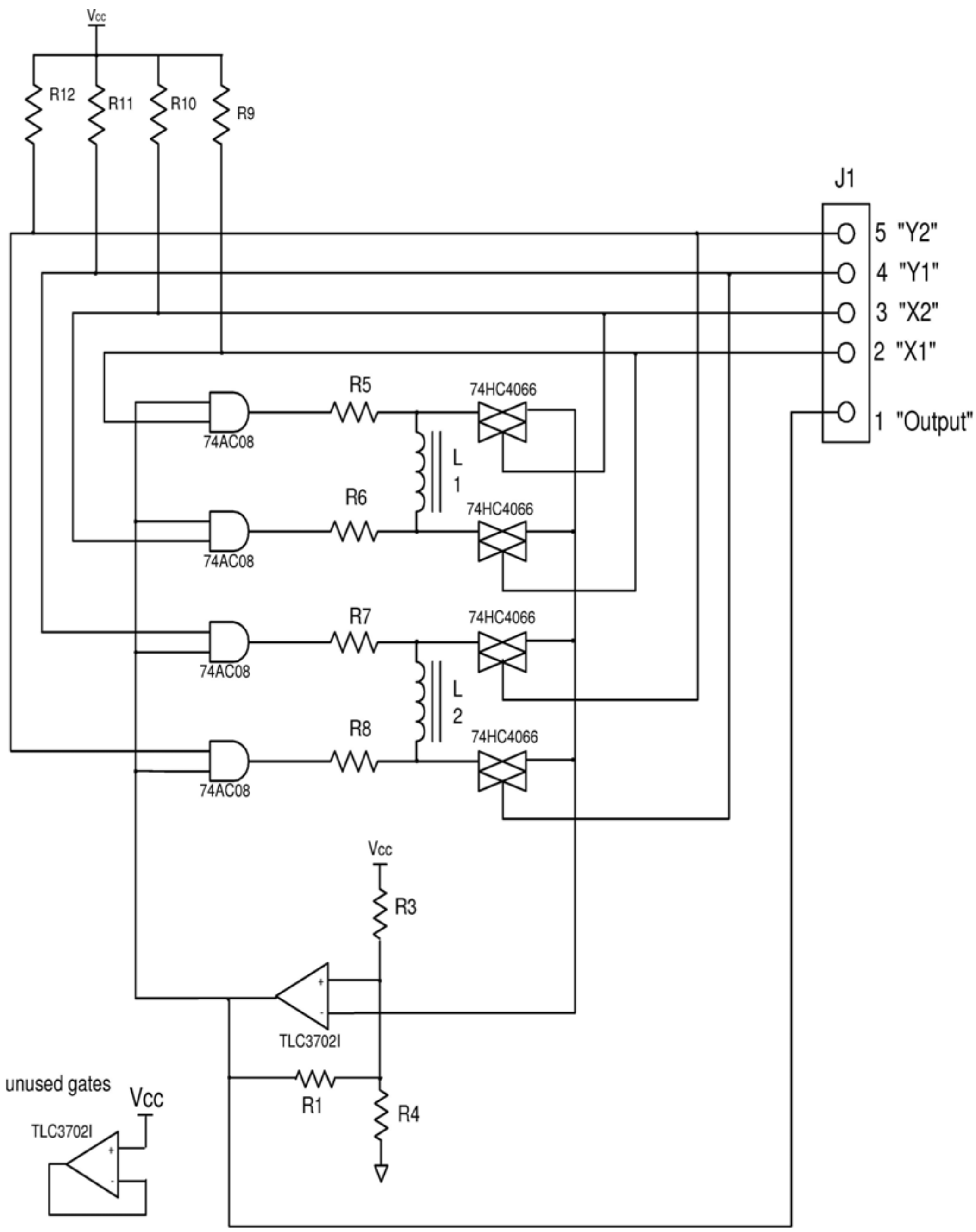

Figure 1: Discrete Circuit Diagram