

## **Application Note: Multipoint Calibration Primer**

### **Introduction**

PNI Corporation's Reference Magnetic Sensor Suites are based on patented technology that delivers breakthrough, cost-effective magnetic sensing performance. The 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's 2-axis RM2000 Reference Magnetic Sensor Suite is comprised of two Sen-XY magneto-inductive sensors and the 3D MagIC ASIC controller. The 3-axis RM3000 Suite adds the z-axis Sen-Z sensor.

The Sen-XY and Sen-Z sensors employ a single solenoid winding 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 3D MagIC outputs a digital signal that can be fed directly into a microprocessor. This eliminates the need for signal conditioning or an 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.

This primer covers the basics of how to determine heading, calibrate out hard iron distortions, and perform sensor gain matching for a 2-axis compass built with the RM2000 Reference Magnetic Sensor Suite. More detailed information regarding how to implement the RM2000 Sensor Suite and the underlying technology can be found on PNI's website. Please refer to the following:

- Manuals – “RM2000/RM3000 Reference Magnetic Sensor Suite Manual”
- White Papers – “Magneto-Inductive Technology Overview”

# Compass Coordinates

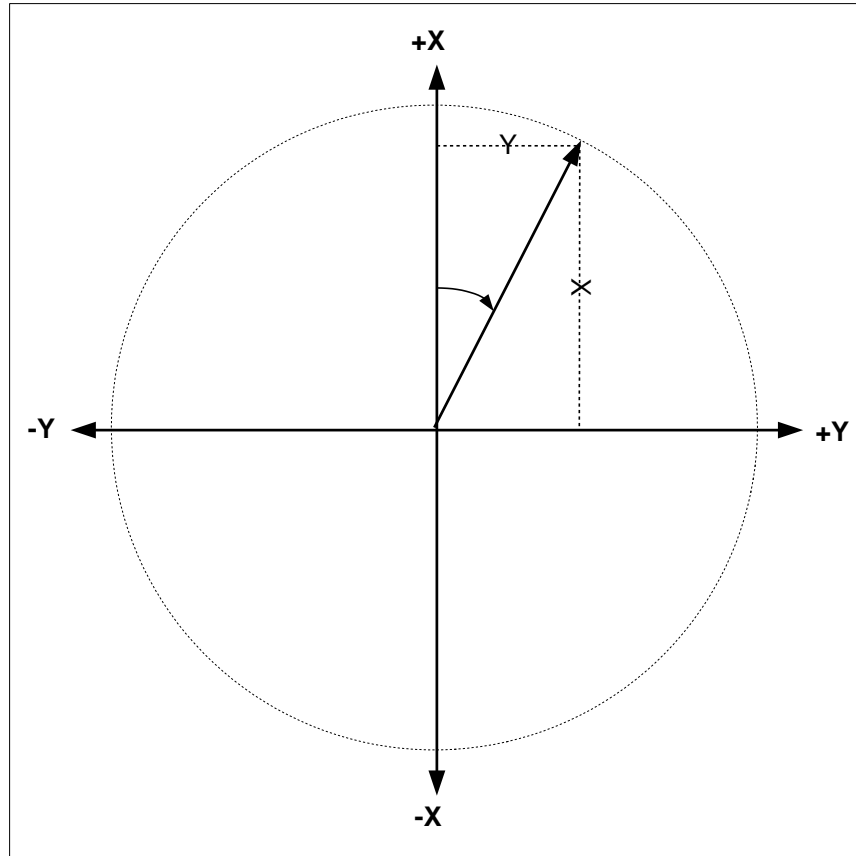


Figure 1

In Figure 1, the +X axis points to magnetic north, while +Y axis points to magnetic east. With this arrangement the heading is the clockwise angle from the +X axis. We calculate the angle to the X axis (+X or -X, and not necessarily the heading) as follows:

$$\text{angle} = \text{atan} ( |Y| / |X| )$$

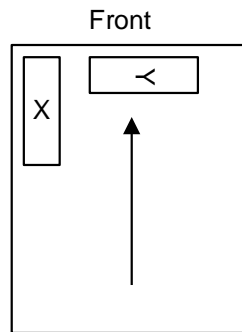
The heading calculation depends on the sign of the X and Y values (the quadrant), and is calculated as follows:

X Value	Y Value	Formula	Quadrant
≥ 0	≥ 0	Heading = angle	+X, +Y (0 – 90)
< 0	≥ 0	Heading = 180 – angle	-X, +Y (91 – 180)
< 0	< 0	Heading = 180 + angle	-X, -Y (181 – 270)
≥ 0	< 0	Heading = 360 – angle	+X, -Y (271 – 359)

## Sensor Orientation

For the heading computation to be valid, the following must be true:

- The sensors are at right angles with respect to each other and lie perpendicular with respect to the Earth's gravity.
- By convention, the positive end of the X axis points north and the positive end of the Y-axis points east. See Figure 2.
- Prior to calibration, the compass must be installed into the host system in its intended operating configuration and in a horizontally level position.



*Figure 2*

## Determine Calibration Values

As the title of this document implies, multiple (X, Y) points must be acquired to properly calibrate the compass. The sensing circuit is composed of the Reference Magnetic Sensors, the 3D MagIC, external bias resistors, an external clock resistor, and external capacitors. (Refer to the RM3000/RM2000 User Manual for the recommended circuit configuration.) Only one sensor can be measured at a time. The user sends a command byte to the 3D MagIC through the SPI port specifying the sensor axis to be measured. The 3D MagIC will return the result of a complete forward - reverse measurement of the sensor in a 24-bit 2's complement format with a range from -8388608 to 8388608.

The sample code below shows how the acquisition phase of the calibration is done.

### **Acquisition Code**

```
int  Xmax, Xmin, Ymax, Ymin; // where you store maximum and
                               // minimum values for X & Y
int  Xraw, Yraw; // values you get from the 3D MagIC

// The numbers here will be 24-bit
// signed values.
// Positive = 0x000000 to 0x7FFFFFFF
// Negative = 0x800000 to 0xFFFFFFFF

Xmax = Ymax = -8388608; // start with lowest possible value
Xmin = Ymin = 8388608; // start with highest possible value

for ( ; ; ) {
    GetRawXY(); // acquire a (X, Y) point

    // now sort it

    If ( Xraw > Xmax )
        Xmax = Xraw

    If ( Xraw < Xmin )
        Xmin = Xraw

    If ( Yraw > Ymax )
        Ymax = Yraw

    If ( Yraw < Ymin )
        Ymin = Yraw
}
```

The above code results in an infinite loop; it should be modified so the loop stops when enough points are acquired. Figure 3 below shows a possible graph of acquired points.

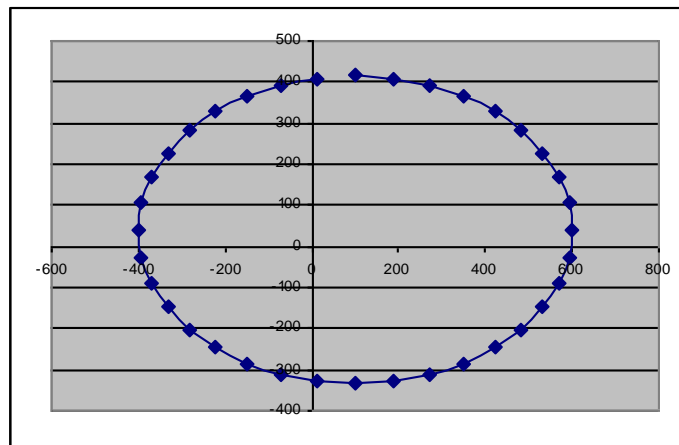


Figure 3

The graph in Figure 3 is elliptical with the major axis along the Y axis. The elliptical nature is due to the Y values having a greater gain than the X values. The center of the ellipse is also displaced. The next section of code demonstrates how to compute the calibration values based on the maximum and minimum X and Y values acquired. These values will later be used to correct the raw X and Y values acquired when computing the heading.

### **Calibration Values**

```

i nt   Xr ange, Yr ange;
i nt   Xof f set , Yof f set ;

Xof f set = ( Xmax + Xmi n ) >> 1; // cal cul at e of f set s
Yof f set = ( Ymax + Ymi n ) >> 1;
Xr ange = ( Xmax - Xmi n ); // cal cul at e t he r ange
Yr ange = ( Ymax - Ymi n );

```

## **Compute Heading**

To compute the correct heading a graph of the points (X, Y) should show a circle with the center in the origin. The following code demonstrates how the raw (X, Y) point is corrected using the calibration values to get a perfect circle at the origin:

### **Compute Heading**

```

f lo at pi = at an( 1 ) * 4; // comput e PI
i nt   Xval , Yval ;
i nt   angl e, headi ng;

Get RawXY(); // get coordi nat es

Xval = Xraw - Xof f set ; // subtr act out the of f set s
Yval = Yraw - Yof f set ;

i f ( Xr ange > Yr ange )
    Yval = ( Yval * Xr ange ) / Yr ange; // per f or m gai n mat chi ng
el se
    Xval = ( Xval * Yr ange ) / Yr ange; // per f or m gai n mat chi ng

angl e = at an( Yval / Xval ) * 180 / pi ; // comput e t he angl e

i f ( Xval >= 0 && Yval >= 0 )
    headi ng = angl e; // quadr ant +X, +Y ( 0 t o 90 )
el se i f ( Xval < 0 && Yval >= 0 )
    headi ng = 180 - angl e; // quadr ant -X, +Y ( 91 t o 180 )
el se i f ( Xval < 0 && Yval < 0 )
    headi ng = 180 + angl e; // quadr ant -X, -Y ( 181 t o 270 )
el se i f ( Xval >= 0 && Yval < 0 )
    headi ng = 360 - angl e; // quadr ant +X, -Y ( 271 t o 359 )

```

Figure 4 shows the plot of the corrected X, Y points using the calibration values. The offsets move the center of the circle back to the origin and the ranges are used to match the gain so the graph becomes a centered circle instead of the original off-center ellipse.

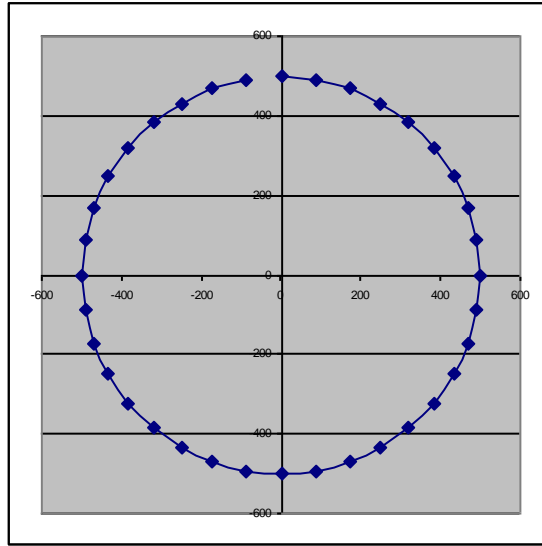


Figure 4

## **Notes**

### ***Declination***

Declination is the angular difference between magnetic north and geographic north headings. There is a difference between the two directions because Earth's magnetic north pole is not in the same location as the geographic north pole. A compass measures Earth's magnetic field, so it points to magnetic north. Also, the difference between magnetic north and geographic north varies from place to place.

Fortunately, there are many ways to obtain declination. Most hiking topographic maps provide the declination value. Declination also can be found at web pages such as the National Geophysical Data Center's site (<http://www.ngdc.noaa.gov/geomag/>).

Declination is defined as "east" if magnetic north falls to the east of geographic north; and "west" if magnetic north falls to the west of geographic north. A positive declination is "east", and a negative declination is "west". For instance, the NGDC website listed above shows that for Mountain View, CA (37N, 122W) the declination is "15d 25.7m". First, it is positive, so it is eastward declination. The "d" stands for degrees; the "m" stands for minutes. 60 minutes = 1 degree, so the declination is 15.4° east.

Once declination is known, the compass heading can be corrected so that heading can be determined relative to geographic north. Add the declination value to the compass measurement to get the geographic heading. For example, if the declination is 15°E, add 15° to the compass measurement. If the declination is 10°W, subtract 10° from the compass measurement.

### ***EL Backlight Disturbances***

When an electro-luminescent (EL) or other backlight is used in a compass system, turning the backlight on may cause a change in the heading reading. This is because the backlight system usually draws enough current during operation to cause the voltage level of a battery-based power supply to drop, and this drop may affect the zero offset of the ASIC. Additionally, if there is backlight support circuitry, such as inductors or other current loops, then the magnetic fields generated by these components can directly affect the sensor readings.

An algorithmic solution to this issue can be implemented during the user calibration procedure. First obtain the standard calibration values (Xoffset and Yoffset) with the backlight turned off. Next, turn on the backlight for 1/2 second and take a single magnetic measurement, Xbacklight\_on and Ybacklight\_on, and another measurement

with the compass orientation unchanged but the backlight off,  $X_{\text{backlight\_off}}$  and  $Y_{\text{backlight\_off}}$ . Calculate the backlight offsets,  $X_{\text{backlight\_offset}}$  and  $Y_{\text{backlight\_offset}}$ , as follows:

- $X_{\text{backlight\_offset}} = X_{\text{backlight\_on}} - X_{\text{backlight\_off}}$
- $Y_{\text{backlight\_offset}} = Y_{\text{backlight\_on}} - Y_{\text{backlight\_off}}$

To calculate the corrected X and Y values when the backlight is turned on, take the raw sensor readings, subtract the standard calibration offsets, and then subtract the backlight offsets. Thus, the X and Y values used to calculate heading would be:

- $X = X_{\text{raw}} - X_{\text{offset}} - X_{\text{backlight\_offset}}$
- $Y = Y_{\text{raw}} - Y_{\text{offset}} - Y_{\text{backlight\_offset}}$

If the backlight is off, then do not subtract the  $X_{\text{backlight\_offset}}$  and  $Y_{\text{backlight\_offset}}$  when performing the heading calculations.