True North™

Revolution™ Compass
Technical Manual

Revisions

Mar 2003, Rev A, First Release
Aug 2003, Rev B, Add 2X options
Nov 2004, Rev C, Clarify tilt, add cabling
Aug 2006, Rev D, Add pin numbers Fig. 4

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1 Introduction

This document provides a technical description of the Revolution compass and its companion PDA or PC software. The bare compass is an electronic, strap-down circuit board with no moving parts. It combines a 3-axis solid-state magnetometer and a 2-axis electrolytic tilt sensor to provide accurate heading and tilt measurements over a wide range of environmental conditions. The board sends heading, pitch, and roll information to a host computer using an NMEA 0183 compatible protocol via an RS232 or RS485 serial port.

A key advantage of the Revolution is its quick-connect, external serial interface. While the compass is in place, and without disconnecting system wiring, a PDA or PC can be temporarily connected via the RJ12-style modular jack. This allows easy access during installation for calibration and tuning. True North software can be used to program and calibrate the compass so that these functions do not have to be programmed into the host computer.

The Revolution features on-board EEPROM for non-volatile storage of operating parameters and calibration coefficients. Contents include the measurement mode (continuous or sampled); the extent of filtering or smoothing; alarm tuning; and parameters to compensate for any local permanent and induced magnetic fields. These settings are typically changed only once, when the compass is initially installed.

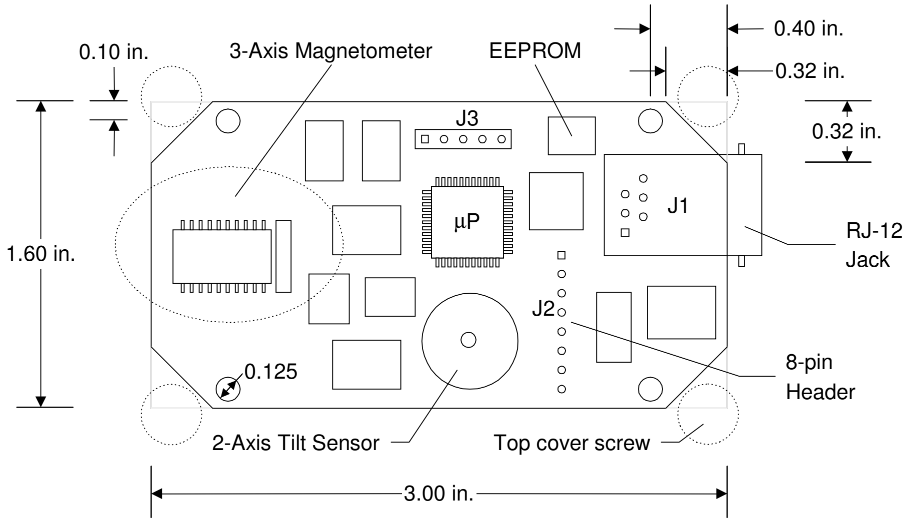

Figure 1 – Top View of Compass Card

The diagram in Figure 1 shows the compass card without its ABS enclosure. The board is 3.0" long by 1.6" wide and requires 0.75" clearance in height. The four mounting holes are on 1.4” by 2.2” centers. They accept #4 size screws. The corners of the card are chamfered to allow clearance for screws that fasten the top cover.

1.1 Background

The ultimate accuracy of any electronic compass depends on the quality of its compensation for local permanent and induced magnetic fields. This compensation must be performed after the compass is installed in its target location. It needs to be performed only once or when the magnetic characteristics of the local environment change.

To compensate for this local magnetism, it must first be measured. This is accomplished by rotating everything together in the earth's fixed magnetic field. Local effects rotate with the compass card and remain the same for each axis. Contributions from the earth's magnetic field vary with the angular position of each axis. The varying and constant components can be separated algorithmically, and optimal compensation coefficients can then be calculated.

Without a graphical user interface, it is difficult to both collect good data and to assess how well the compensation coefficients derived from this data improve accuracy. During data collection, the user interface shows where the set of points has been collected. It can display noise, magnetic anomalies, and feedback information about how to proceed with data collection. Once compensation coefficients have been calculated and applied, the interface displays information related to how much accuracy is improved or degraded.

In normal operation, a user interface for the Revolution compass is neither required nor desired. The compass is intended to be an embedded component that performs as a reliable sensor. Nevertheless, its accuracy and repeatability depend on programming that is specific to its environment. The design challenge is to provide a cost-effective, reliable sensor that can be easily adapted to different applications and environments.

Our solution is to separate the functions into two independent devices: one is the sensor, our Revolution compass; and the other is a PDA or PC-compatible device that provides tuning, calibration, and the user interface functions. The PDA and compass are completely independent devices. Any PDA can be connected to any Revolution compass, and the Revolution operates as programmed without being connected to a PDA.

The compass is a refinement of True North's previous generation of OEM devices based on the same magnetometer and inclinometer components. Improvements in signal conditioning components, digital signal processing algorithms, and compensation techniques have led to reduced noise and improved repeatability. A new sensor interplay algorithm has also been added to improve inclinometer stability when high frequency vibration is present.

Although the PDA is a new device, some of its functions were previously available with demonstration software, but the user had to provide the hardware; typically a laptop PC running Microsoft Windows. We chose Palm OS as a second platform because the PDA devices it supports are small and battery friendly. New algorithms for collecting calibration data and then determining optimal compensation coefficients are implemented for both platforms. Functions to simplify installation and maintenance have also been added.

1.2 Definitions

Azimuth	The horizontal angular distance measured clockwise from a reference direction, usually geographic north.
Heading	Horizontal direction in which an object points or moves, measured from 0° at a reference direction (generally true north or magnetic north) clockwise through 359.9°.
Deviation	Angle between the magnetic meridian and the axis of the compass card, expressed in degrees east (+) or west (-) to indicate direction in which the northern end of the compass card is offset from magnetic north. Add deviation to measured heading to obtain magnetic heading of compass card axis.
Variation	Angle between magnetic and geographic meridians expressed in degrees east (+) or west (-) to indicate the direction of local magnetic north from true north. Add variation to magnetic heading to obtain true heading.
Declination	same as variation
Dip angle	Angle that the earth's magnetic field makes with the horizontal plane in a specific geographic location.
Inclination	same as dip angle
Hard Iron	A local source of permanent magnetism that moves with the body of the compass. By rotating both the compass and this source together in a uniform external field, i.e. the earth’s magnetic field, both the magnitude and direction of the locally generated field can be determined.
Soft Iron	A local source of induced magnetism that moves with the compass. Ferrous material gains and loses magnetization depending on its orientation to the earth’s magnetic field. As it rotates with the compass, the effect is to warp an otherwise circular locus of points into an elliptical shape.
Pitch	Angular displacement of the compass card about its lateral axis, measured vertically from the horizontal plane.
Roll	Angular displacement of the compass card about its lengthwise axis, measured vertically from the horizontal plane.

1.3 Features and Limitations

The compass delivers high accuracy for its small size, low cost, and low power consumption. It provides both RS-232 and RS-485 communication links. For battery operation, a low-power standby mode is incorporated to reduce required current to 1mA. Wake up from standby requires less than 1 millisecond.

Additional features of the compass include:

- Single supply operation: 5 to 30V
- Current consumption only 20 mA at full bandwidth
- Measurement rate of 14 samples per second
- Magnetic field measurement range: ±1.6 Gauss (gain 100)
- Magnetic field measurement sensitivity: 0.3 milliGauss (gain 500)
- Hard and soft iron compensation
- Continuous (RUN) or SAMPLE mode operation
- Angles in degrees (0.0 to 359.9°), mils (0 to 6399), milliradians (0 to 6282), or 16-bit integer (0 – 65535)
- NMEA 0183 output data format with the following available sentences:
  - ⇒ HDT (True heading)
  - ⇒ HDG (Heading, deviation, and variation)
  - ⇒ XDR (Transducer data: pitch, roll, magX, magY, and magZ)
  - ⇒ HTM (Heading, tilt, and magnetic field)
  - ⇒ NCD (Normalized compass data)
  - ⇒ CCD (Conditioned compass data)
- Output data available:
  - ⇒ Heading, pitch, and roll
  - ⇒ Magnetometer X, Y, Z, and calculated total field
  - ⇒ N, E, H, and V – normalized magnetic field components
  - ⇒ Magnetic inclination (dip angle)
- Selectable averaging time in SAMPLE mode
- Separate magnetic and tilt IIR single-pole filters in RUN mode
- Tunable heading filter in RUN mode for quick response in hand-held applications where fast movements should be ignored
- Tunable alarm on horizontal magnetic field deviation in RUN mode
- Serial EEPROM for calibration coefficients and setup parameters

The companion PDA features a graphical touch-screen display, 8 Mb memory, and replaceable AAA batteries. True North's Compass program provides functions for verification, calibration, tuning, and data capture. These functions can be performed without disconnecting system wiring, and without affecting the host computer.

Features of the PDA software include:

- Database of calibration, tuning, and capture data that can be transferred to a PC or laptop using HotSync®
- A single PDA can be used with more than one compass. Stored data is automatically tagged with compass device ID
- Graphical user interface layout and navigation similar to what is used with PC software (Revolution PC program)
- Serial port hardware is turned off so that compass can automatically enter low-power standby mode when measurements are not needed. Also reduces PDA battery drain
- Straightforward calibration procedures that minimize required user interaction and generate optimal compensation coefficients

The PC software provides a similar set of features, but it does not manipulate the serial port hardware like the PDA. The low-power operating mode available with the PDA is not supported. However, the PC software does provide a few functions that are not provided on the PDA. These include:

- A separate, windowless ActiveX control (Compass.ocx) that implements the compass serial interface, calibration functions, and Palm PDA data conversion routines. This control can be used separately to simplify the task of integrating the compass into an end-user system.
- Capture and storage of an ASCII communication log that shows all serial I/O with the compass
- Enhanced graphical displays for magnetometer calibration routines and cockpit attitude data
- Transfer PDA data and convert it to text files

While there are many more features than limitations, the Revolution will not work in all environments and may not perform adequately under some conditions. It cannot operate reliably if any of the following conditions exist:

- Local permanent magnetic field greater than 1 gauss
- Pitch or roll angles greater than 42 degrees
- Ambient temperature less than -40°C or greater than 85°C
- Input voltage less than 5V

Accuracy may be compromised under the following circumstances:

- Low bandwidth (less than 10 Hz) changes in the local permanent or induced magnetic field. This could be caused by repositioning ferrous material relative to the compass, or by turning DC currents on or off in nearby wires. In such cases, the magnetometer calibration is no longer valid.
- Any horizontal component of linear acceleration. This is a problem with any non-gyroscopic compass that measures tilt based on the acceleration

due to gravity. A 0.1g horizontal acceleration produces a false tilt angle of magnitude 5.7°. This produces a peak compass error of greater than 15° where the dip angle is 69° or more.

- Operation after severe shock oriented in the plane of the board. Shock in excess of 100g may cause the tilt sensor electrodes to shift, thereby invalidating the factory calibration.
- Operation at tilt angles greater than 10° for up to 40 hours after being inverted. When the compass is turned upside down, a small volume of fluid can be trapped on the top surface of the sensor. This affects the scale factor, or gain, of the sensor. The trapped fluid slowly migrates down the walls, but the process can take more than a day at room temperature. Immediately after being upside down, the error is typically 0.5° at 25° tilt, but the gain error can vary from 0 to 4% depending on the device. A planned upgrade to the Revolution will greatly reduce this problem by automatically compensating for the reduced volume of fluid.

1.4 Revolution Sensors

The compass determines azimuth by measuring two fundamental fields: the earth's magnetic field and its gravitational force field. A magnetometer is used to measure the magnitude and direction of the earth's magnetic field. An inclinometer measures the orientation of the compass card relative to the vertical gravity vector.

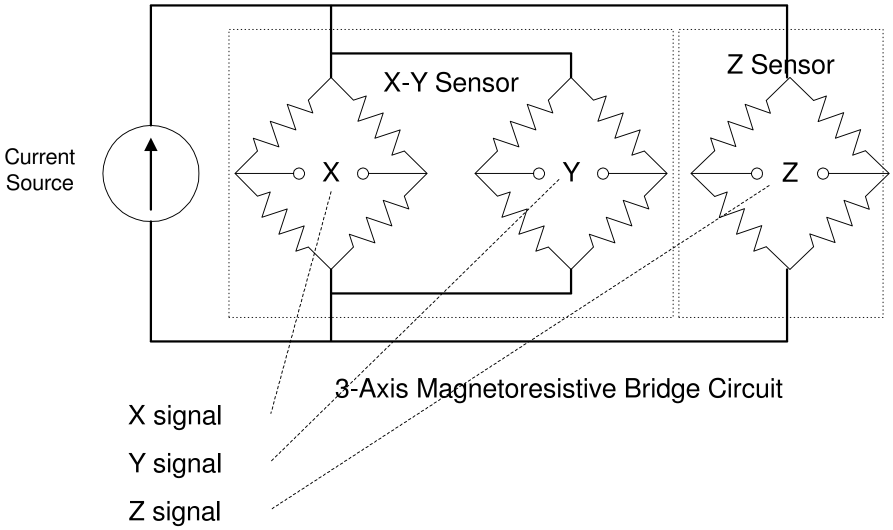

Figure 2 - Three Axis Magnetometer Schematic View

The magnetometer is composed of three anisotropic magneto-resistance (AMR) sensors arranged so that their sensitive axes are mutually orthogonal. The electrical resistance of each sensor changes in direct proportion to the strength of the magnetic field along its sensitive axis. Both the magnitude and direction of the earth's magnetic field are determined by calculating the vector sum of the three signals. The measured direction is relative to the orientation of the magnetometer on the compass card, so it must be rotated to a terrestrial frame of reference to determine azimuth.

The AMR sensors have a linear range of ±2 Gauss and produce an output signal of 15 mV per Gauss along the sensitive axis. A gain of 300 is required to amplify the earth's nominal 0.5 G field to the full-scale range of the A/D converter. The gain can be adjusted from 100 to 500. A lower gain is needed when there is a large local permanent magnetic field (hard iron) that cannot be eliminated.

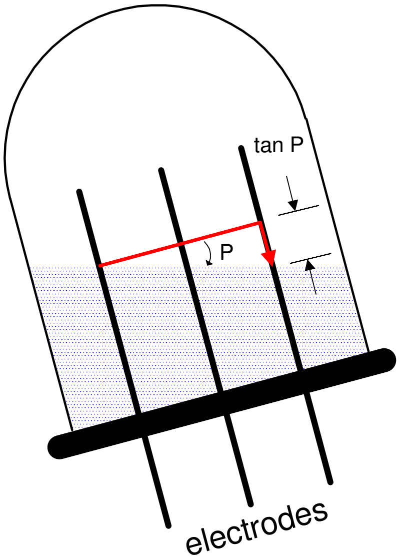

Figure 3 - Tilt Sensor, Single Axis View

The inclinometer is based on a dual-axis electrolytic tilt sensor. The diagram in Figure 3 shows one axis of the sensor tipped at approximately 15°. The sensor is partially filled with an electrically conductive fluid, the electrolyte, whose surface remains level as the sensor body tilts. Pitch and roll angles are determined by measuring conductivity between orthogonal pairs of electrodes immersed in the fluid. Note that these angles are measured in the tilted frame of reference of the sensor and are not the angles needed to perform a coordinate transformation, say θ and ρ, which are independent rotations about orthogonal axes of the compass card. If we arbitrarily perform the roll rotation first (i.e. $\rho = R$), then θ can be determined using the following trigonometric relation:

$$\sin\theta = \frac{\tan P}{\sqrt{1+\tan^2 P+\tan^2 R}} \ ,$$

where P and R are the measured pitch and roll angles.

The electrolyte is an alcohol-based fluid that has an operating temperature range of -40℃ to 100℃ and a storage range of -55℃ to 125℃. Ionic salts dissolved in the fluid give it its electrical conductivity. The sensor is excited with alternating current to keep the salts from plating onto the electrodes. Excitation with direct current would initially change conductivity and ultimately destroy the sensor.

1.5 Serial Interface

The Revolution's serial interface is a unique combination of hardware and firmware designed to allow a temporary connection to a PC or PDA for installation and calibration. The internal 8-pin header provides a rugged, hard-wired connection for permanent installation. When a plug is inserted into the external RJ-12 jack, it overrides communication on this connector to interrogate and change settings. The RJ-12 jack can also be used independently, without wiring to the internal header; it provides all the required connections for power, ground, and RS-232 signals.

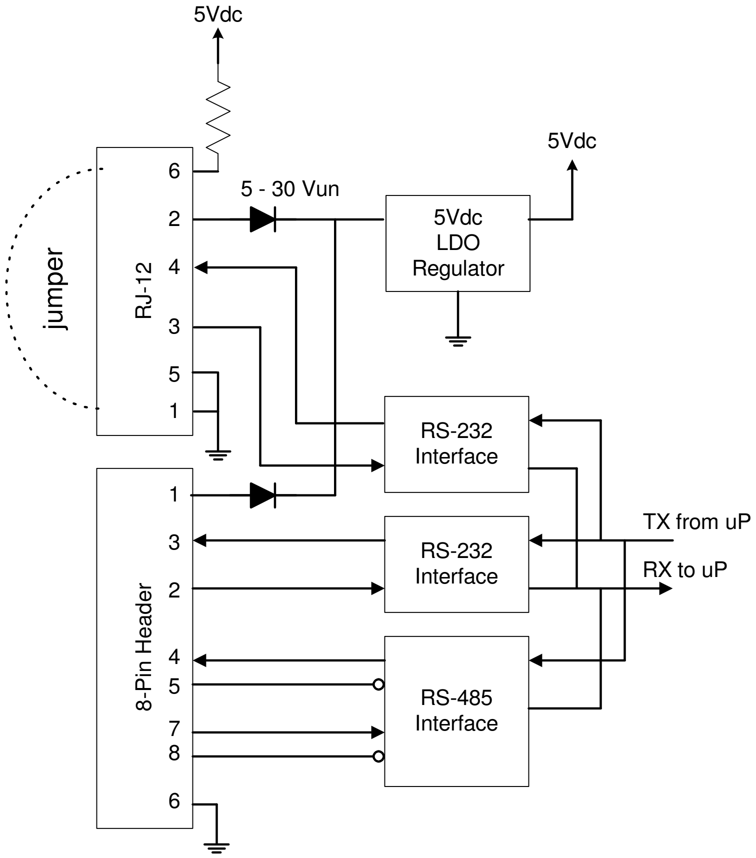

Figure 4 - Serial Interface Block Diagram

There are three physical data links: RS-232 on the RJ-12 jack and both RS-232 and RS-485 on the 8-pin header. A special plug with the outer pins shorted is used in the RJ-12 jack to signal that an external device is connected. When this occurs, and a valid RS-232 signal is present, the RS-485 input is disabled. The jack is continuously monitored to determine when the external device is disconnected so that RS-485 input can be restored.

2 Description of Operation

A block diagram of the compass is shown in the figure on the following page. The central component is an 8-bit microcontroller operating at 5MHz. It incorporates:

- 32K bytes program memory, and 1.5K bytes RAM
- 8-channel, 10-bit A/D converter
- UART for serial I/O
- I^2C and SPI serial interfaces for on-board communication

The two interface connectors are shown on the left-hand side of the figure. The RJ-12 is a 6-position modular jack that provides RS-232 and power connections. A PDA or laptop PC can be temporarily connected here for tuning and calibration. The 8 pin header is the internal system wiring connector that provides both RS-232 and RS-485 ports as well as power connections.

Protection diodes are provided to allow the compass to be powered from either connector. If power sources are connected to both, the source with the highest voltage will supply current. The diode in line with the lower voltage source will block current that would otherwise attempt to charge the source. Schottky diodes with a typical forward drop of less than 0.4 volts are used.

A low drop out (LDO) linear regulator isolates the compass 5V power rail from external fluctuation. Loss of regulation occurs when the input drops below 5.3 volts. Thus, if voltage at the connector is less than 5.7 volts, then it should be from a regulated source.

The magnetometer consists of two Honeywell integrated circuits: the HMC1002, an X-Y sensor that incorporates two bridge circuits oriented perpendicular to each other; and the HMC1001, a separate Z sensor. The sensors are powered by a constant current source that is only turned on while making a measurement. The box labeled “Set-Reset Control” includes a charge pump converter that generates 20V for the required flipping pulses.

The inclinometer is based on a Spectron SP-5003, dual-axis, electrolytic tilt sensor, labeled “X-Y Tilt Sensor” in the diagram. The drive control excites one axis at a time, alternating between pitch and roll at a 27.5 Hz rate. The duration of a single pulse is roughly 0.5 milliseconds. Pulses of opposite polarity occur back to back on the same axis. Pitch and roll measurements are each updated at a 13.75 Hz rate.

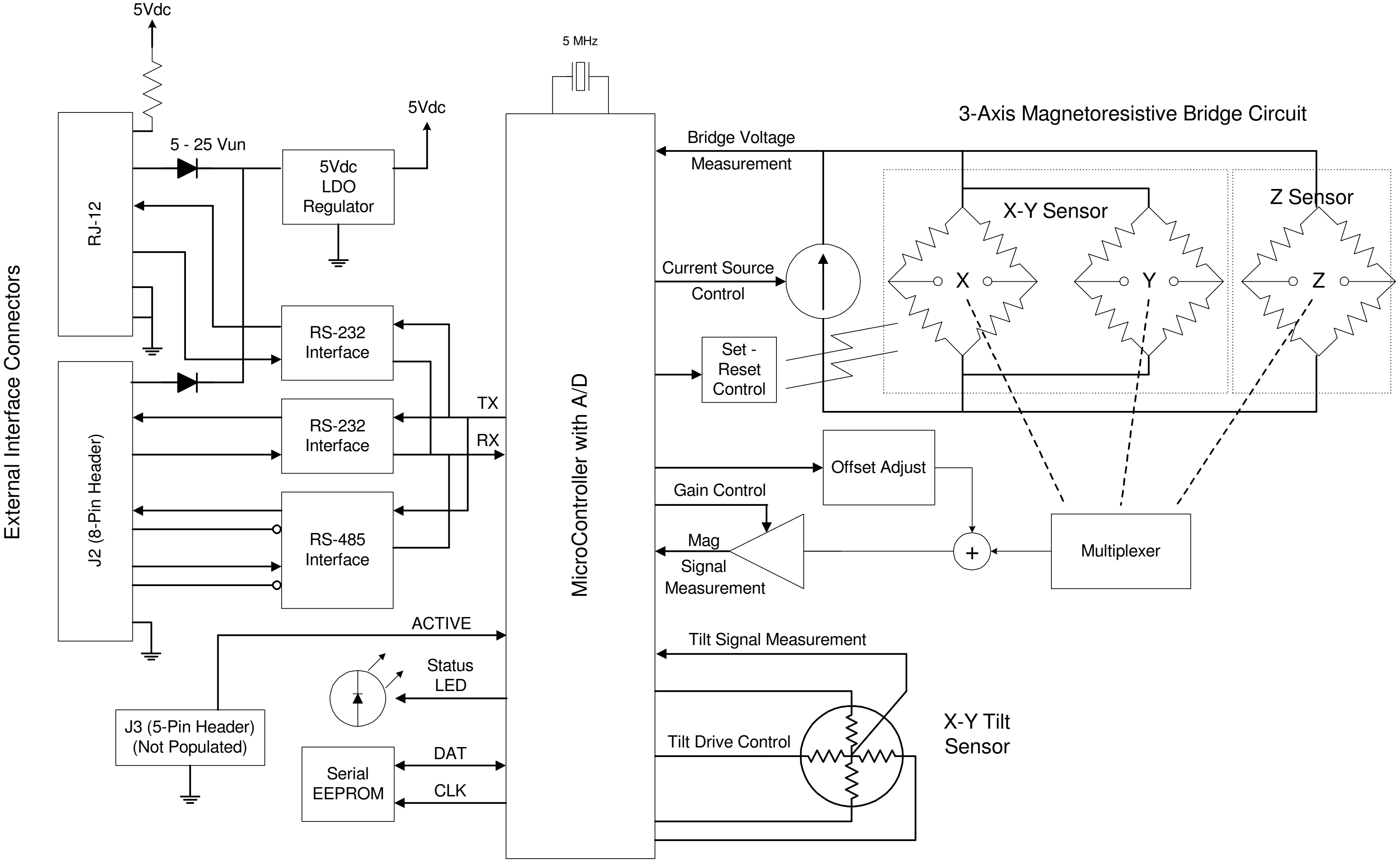

Figure 5 - Revolution Block Diagram

The microcontroller powers and drives signals to the magnetometer and tilt sensor, sequencing the sensors in a precise, repeatable manner to collect five raw data values: X, Y, and Z magnetic readings; and P and R tilt readings. X, Y, and Z represent three orthogonal directions with the tilt sensor precisely aligned so that its P and R axes are parallel to the corresponding magnetometer X and Y axes.

Magnetometer readings are the orthogonal components of the earth's magnetic field vector plus any local disturbance vector. Tilt readings are used to determine the gravity vector. The processor performs trigonometric computations required to determine compass heading from the two measured vectors (magnetic field and gravity). Pitch and roll measurements are *vertical* angles derived directly from the P and R tilt measurements.

The processor controls analog gain and offset so that magnetometer and tilt readings are scaled within range of the 10-bit A/D converter. While the earth's magnetic field varies from approximately 0.4 to 0.6 G (gauss or Oersted), magnetometer outputs are scaled so that the A/D range is approximately ±1.0 G. Stray magnetic fields in excess of 0.4 G may cause the input to saturate and prevent the calculation of heading. For situations where hard iron is excessive, the range can be increased to approximately ±2.0 G.

Unit-to-unit variations in both the tilt and magnetic sensors make it essential to calibrate each device individually to achieve good accuracy. Alignment of the tilt sensor relative to the magnetometer and orientation of the magnetometer axes are corrected electronically prior to shipment. This operation is performed in a clean magnetic environment free of mechanical vibration.

The microcontroller performs the matrix operations required for both hard and soft-iron calibration using coefficients stored in the serial EEPROM. It also provides a calibration mode of operation that automatically sends the low-level data required to calculate new coefficients. A separate processor capable of performing double precision floating point calculations and supporting more memory is used to calculate new coefficients.

In RUN mode, an alarm on the calculated horizontal magnetic field strength can be setup to prevent sending heading data when either of two disturbances is present:

1. Horizontal components of acceleration affecting the tilt sensor, or
2. Stray magnetic fields affecting the magnetometer.

Also in RUN mode, a sensor interplay algorithm can be enabled to stabilize tilt sensor readings when mechanical vibration causes the liquid to oscillate. The algorithm allows tilt measurements to be heavily smoothed to eliminate the oscillation, yet provides for fast response to changes in tilt. It requires that the magnetometer first be compensated for any local hard and soft iron.

2.1 Initial Power On

When power is applied, the Revolution first performs a sequence of tests to verify that hardware components are working properly. One of the tests checks that the watchdog timer is operating properly. To accomplish this, the timer is allowed to expire so that it resets the microcontroller.

During this interval, which lasts about 0.25 second (0.5 maximum) , the on-board LED is illuminated. If the test completes correctly, the LED is extinguished and startup continues. If not, the LED remains on and the microcontroller is tied up waiting for a reset to occur.

The serial EEPROM is read during the next phase of startup. This is the only time that the EEPROM is read. Its contents are copied to microcontroller RAM, and are accessed there to control operation of the compass. Note that the address mapping from EEPROM to RAM is not one-to-one.

If an error occurs reading the EEPROM or if the contents are corrupted, then operation proceeds using factory defaults stored in microcontroller program memory (ROM). When this happens, the “EEPROM read error” serial status bit is set, and the compass unit ID is hexadecimal DEFA (57082 or -8454 decimal). The compass operates in RUN mode at 19,200 baud with no hard or soft iron calibration and no tilt calibration.

When the EEPROM is read successfully, the desired serial baud rate (stored in the EEPROM) is determined. The stored value is an index into a table of possible rates. If the index is out-of-range, 2400 baud is selected. Otherwise, the indexed value is used.

The baud rate can be overridden by external signals applied during startup. If the signal on J3.4 is low, then the serial receive data line (RX input) is tested for a continuous low signal (RS232 space, start bit state). If it is low for one second, then the baud rate is set to 2400 baud and the operating mode is forced to SAMPLE.

J3 is a 5-pin unpopulated connector that can only be accessed by removing the cover. J3.4 is driven low by connecting it to J3.3. The RX input is driven low by asserting a break condition on either RS-232 input (J1.4 or J2.3) or the RS-485 input (J2.4 and J2.5).

2.2 Normal Operation

After configuring the serial port with the selected baud rate, the microcontroller starts a 220 Hz timer and enables interrupts. The timer triggers a sequence of 16 states that direct the progress of the measurement cycle. It is also divided by 11 to generate a 20 Hz signal needed for some NMEA sentence output rates.

What the processor does next depends on the settings in EEPROM and the state of the ACTIVE input on J3.4. If J3.4 is pulled low, the microcontroller enters a low-power, standby mode of operation. The main oscillator is stopped. The compass will remain dormant until J3.4 is pulled high or disconnected.

When J3.4 signals the active state, continuing operation depends on the mode bit in EEPROM. In RUN mode, the processor automatically starts a measurement cycle and updates all measurements every 73 milliseconds. In SAMPLE mode, the processor waits to receive an NMEA query sentence or a setup command before starting a measurement cycle.

When measurements are in progress, the Set-Reset flipping circuit generates an audible ticking at the 13.75 Hz cycle rate. Set-Reset flipping is used on each measurement to reduce cross-axis error (see Honeywell AN-205 for a detailed technical explanation). The ticking sound is due to short duration, high-current pulses (10 µsec, 4 Amp) that realign magnetic domains in the Permalloy film of the sensors.

The magnetic field sensors require offset adjustment so that their small differential signals can be amplified without saturating the output. A typical sensor produces 16 mV per Gauss signal strength, while the sensor offset can be as large as 40 mV. The ±8 mV signal due to the earth's magnetic field may be swamped by the offset.

The adjustment procedure is based on a half-interval search algorithm that requires 8 measurement cycles to complete. During this time, the magnetometer measurements should not be used. The heading field is null in HDT, HDG, HTM, NCD, and CCD sentences; and the magnetic status field in HTM is set to C. (For details, refer to the section describing the HTM sentence in Serial Communication Reference).

The procedure begins with the first measurement cycle after power on, and is only invoked thereafter when one of the three offsets changes by 1 mV. Since the offset temperature coefficient is nominally 10 ppm / °C with Set-Reset flipping, an offset should change by no more than 0.04 mV over a 100°C temperature span. Thus, the offset adjustment procedure is invoked only once.

2.2.1 RUN Mode

In RUN mode, the compass takes measurements and calculates heading 13.75 times per second. It also iterates filters and trigonometric functions in the signal path at this same rate. This mode consumes the most power, but it also provides the fastest response to changes in direction and inclination.

The diagram in Figure 6 shows the signal processing functions performed in RUN mode. Starting at the left of the diagram, the magnetic field vector is first multiplied by a 3x3 gain matrix intended to compensate for soft iron effects. Next, hard iron offsets are subtracted, and then each signal is smoothed using low-pass filters. Filtered outputs are directed to both an axis-rotation function and to an optional rate enhancing function.

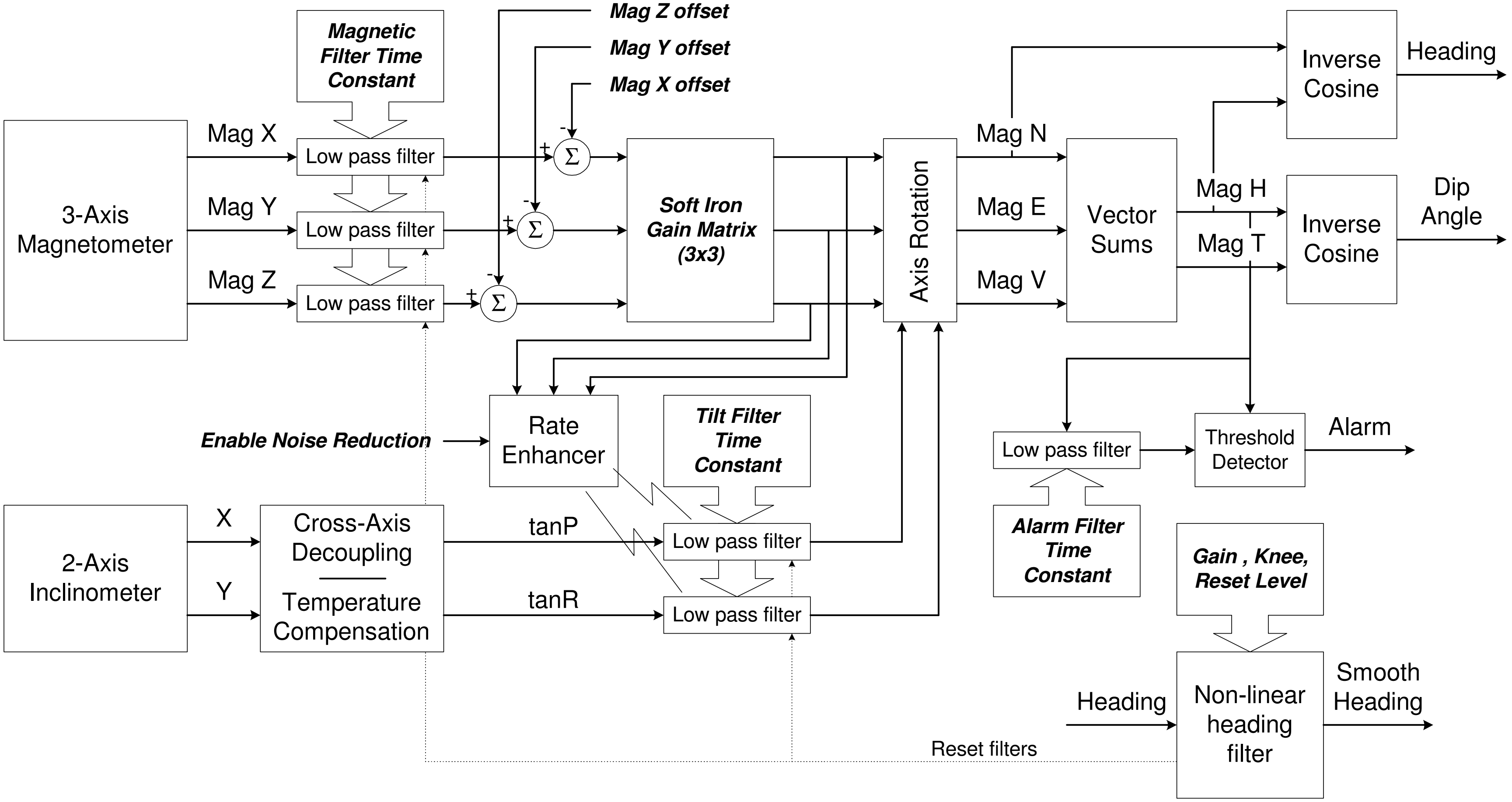

Figure 6 - RUN Mode Signal Processing

Signals from the dual-axis tilt sensor are first decoupled and aligned to the measurement axes of the magnetometer, and then they are gain adjusted for temperature. Calibration curves stored in EEPROM are used to generate linear pitch and roll signals. Pitch and roll signals are then smoothed using the time constant specified for tilt. Filter outputs are used in the axis-rotation function to determine horizontal magnetic field components.

The signals shown as Mag N, Mag E, and Mag V in the diagram correspond to components of the earth's magnetic field in the North, East, and Vertical (down) direction. When a component value is negative, it is oriented South, West, or up. The positive direction for the vertical component is selected to be down so that the coordinate system is right-handed. When the compass card is level,
Mag N = Mag X, Mag E = Mag Y, and Mag V = Mag Z.

Measured pitch and roll angles are not independent rotations about the lengthwise and lateral axes of the compass card. Instead, they are angles measured from the tilted plane of the compass card to the horizontal plane (surface of the liquid) along the pins of the tilt sensor (which are normal to the compass card). To rotate measurements from the compass card's tilted frame of reference to the earth's horizontal frame of reference, the transformation is:

$$\begin{bmatrix} N \\ E \\ V \end{bmatrix} = \begin{bmatrix} \dfrac{1+r^2}{\sqrt{1+r^2}\sqrt{1+p^2+r^2}} & \dfrac{p \cdot r}{\sqrt{1+r^2}\sqrt{1+p^2+r^2}} & \dfrac{p}{\sqrt{1+r^2}\sqrt{1+p^2+r^2}} \\ 0 & \dfrac{1}{\sqrt{1+r^2}} & \dfrac{-r}{\sqrt{1+r^2}} \\ \dfrac{-p}{\sqrt{1+p^2+r^2}} & \dfrac{r}{\sqrt{1+p^2+r^2}} & \dfrac{1}{\sqrt{1+p^2+r^2}} \end{bmatrix} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix},$$

where N, E, V, X, Y, and Z are magnetic field components; and p and r are tangents of the reported pitch and roll angles. For small angles, or when either pitch or roll is zero, this transformation is the same as a three dimensional coordinate rotation.

In other signal processing, the diagram in Figure 6 shows three features only available in RUN mode. They are

1. the rate limiting or tilt noise reduction function,
2. the non-linear heading filter, and
3. alarm on horizontal magnitude deviation.

Tilt noise reduction may be needed in environments where the liquid in the tilt sensor oscillates due to mechanical vibration. Pitch and roll are stabilized by employing a sensor interplay algorithm that uses magnetometer measurements to control an amount of phase-lead, or derivative action, in the individual pitch and roll signal paths. When the rate enhancing function is enabled, pitch and roll respond quickly to changes in inclination while noise is minimized by using extra smoothing in the low-pass filter.

The non-linear heading filter provides more smoothing for small changes in heading and no smoothing for large changes. As the difference between the filter input and output increases, the amount of smoothing decreases according to a 2nd order function. An example transfer function is shown in Figure 7. Both the transition region (Knee) of the curve and its slope near zero (Gain) can be tuned.

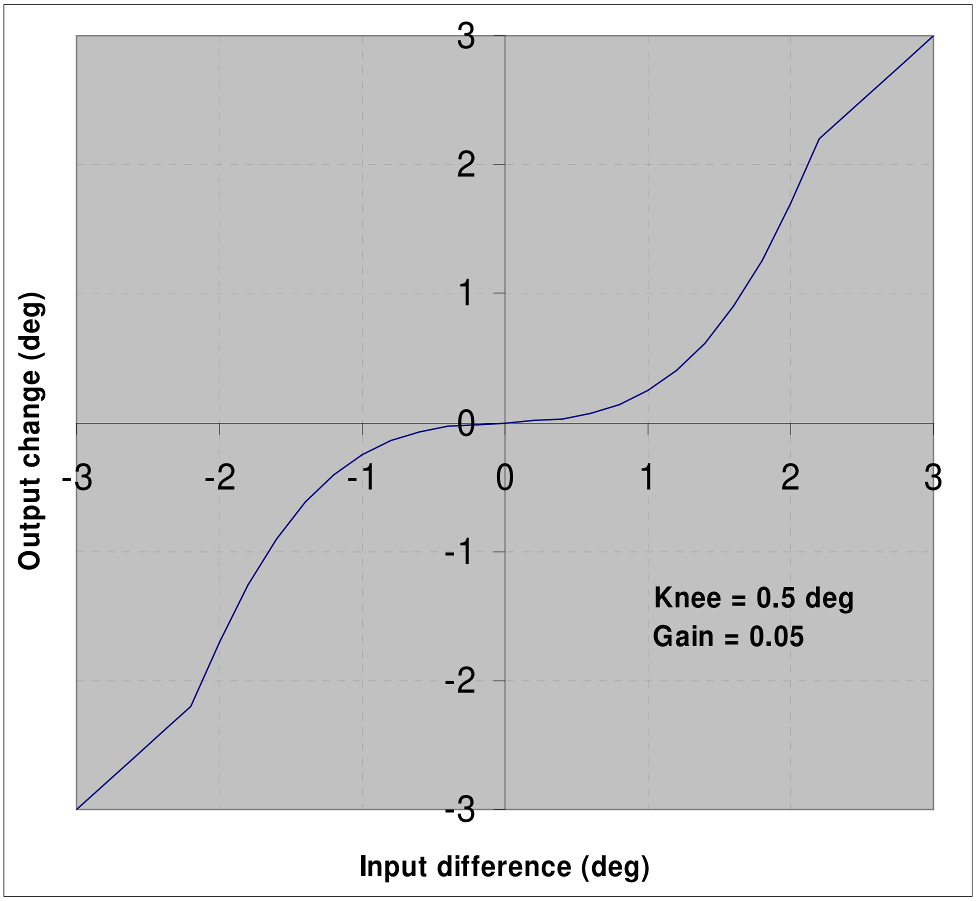

Figure 7 - Non Linear Heading Filter Transfer Function

The algorithm for this filter is shown in the following. Calculations are iterated at the 13.75 Hz measurement rate.

Parameters	K = transition knee	(angle units, 0 = disable)
	G = gain	($0 < G < 1$, 0 = disable, max = 0.999985)
Variables	I = current heading input	
	O = smoothed heading output	
	D = input difference	
Calculate	$D = I - O_{i-1}$	(input difference)
	$P = G + G * (D/K)^{**}2$	(saturate P as D/K gets large, $G <= P <= 1$)
	$O_i = O_{i-1} + D * P$	(note that $O = I$ for $P = 1$)

The third feature available only in RUN mode is the ability to alarm on an excessive deviation in the calculated horizontal component of the earth’s magnetic field. For a properly calibrated compass, the calculated horizontal magnetic field strength, MagH, should remain constant in a restricted geographic area. Deviations can be caused by spurious magnetic anomalies, like passing under a steel bridge; by hard or soft iron errors; by tilt measurement errors; and by errors induced by horizontal acceleration.

2.2.2 SAMPLE Mode

In SAMPLE mode, the compass waits for one of the NMEA query sentences to be received before making any measurements. This mode consumes less power than RUN mode because the magnetometer and inclinometer are normally turned off. When a request for data is received, the compass temporarily enters the RUN mode state and accumulates measurements until it responds with the requested average data. Once the requested data is sent, the magnetometer and inclinometer are turned off and the compass resumes waiting for the next data request.

The diagram in Figure 8 shows the signal processing chain in this mode. Following a request for data, measurement cycles are performed in a manner identical to those in RUN mode. One or more of the first measurement cycles may be ignored depending on the setting of the parameter stored in EEPROM named “Sample Ignore Count.” The measurement cycle rate is 13.75 Hz, as in RUN mode. Measurements are accumulated until the number saved in EEPROM, “Sample Mode Count,” has been taken. The accumulated results are averaged and plugged into the requested NMEA sentence, which is then sent via the serial port.

Both tilt and magnetic data are accumulated and averaged for the same amount of time. This is different from RUN mode, where separate time constants are used to smooth tilt and magnetic data. In addition, only one sentence that contains the final averaged data is sent in SAMPLE mode. In RUN mode, sentences can be sent continuously.

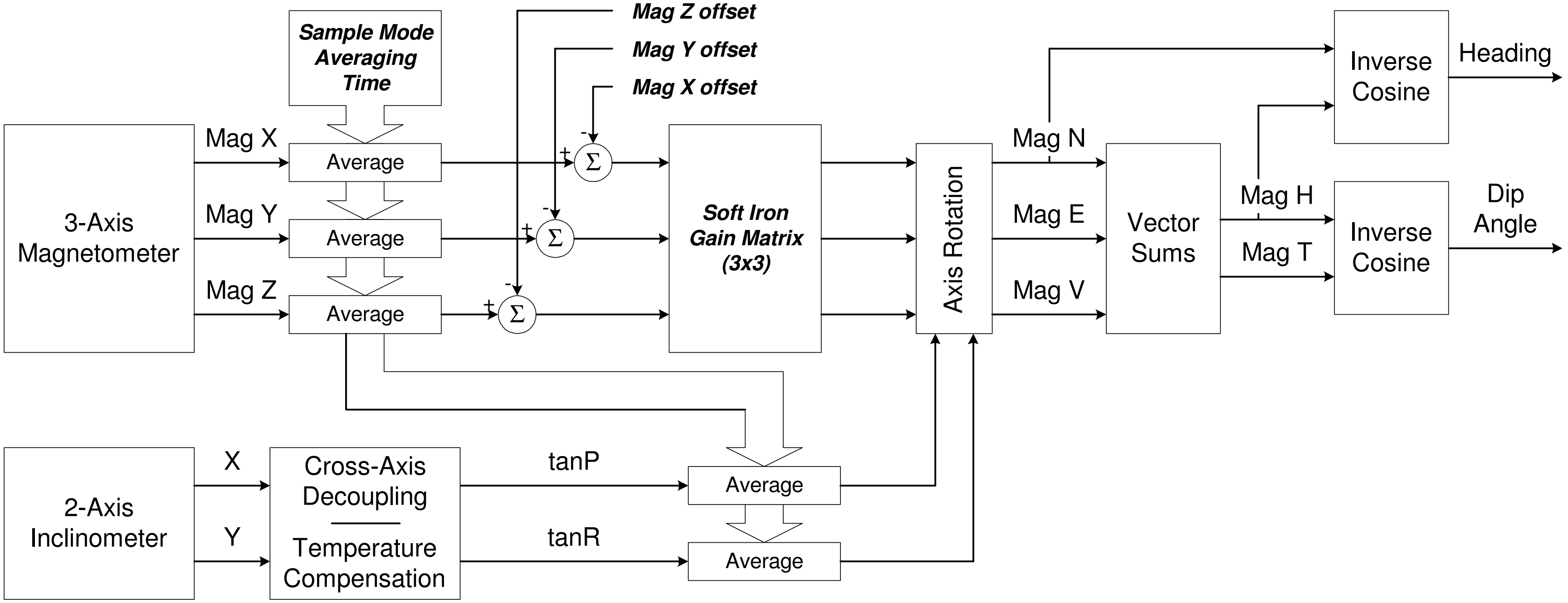

Figure 8 - SAMPLE Mode Signal Processing

2.3 Standby Operation

Power consumption is reduced to an absolute minimum when the compass operates in standby mode. Analog components are turned off, and the microcontroller's main oscillator is stopped. Serial communication is disabled, and the RS-485 and RS-232 drivers are dormant.

Standby operation can be invoked in either of two ways: by connecting the logic-level input on J3.4 (see Figure 5) to ground; or by disconnecting RS-232 signals while plugged into the external RJ-12 jack. The first method is intended for embedded applications where a logic-level connection can be made to the compass. The second method is designed to conserve battery power when the PDA is connected.

The Revolution's RS-232 IC can detect when a valid RS-232 signal is present at either input. When both input signals are greater that -3V and less than 3V for more than a microsecond (i.e., disconnected), then the IC indicates that no valid RS-232 signal is present. In this case, the microcontroller enables the RS-485 signal input and can optionally be set up to switch to standby operation.

When an RJ45 plug with pins 1 and 6 shorted is inserted into the jack, the compass disconnects the RS-485 input and begins checking for a valid RS-232 input signal on either of two channels. If neither signal is valid, operation depends on the setting of a volatile flag in the microcontroller's RAM. When power is first applied, the flag is reset and the compass will not enter standby mode. Once the control flag has been set, the compass will automatically enter and exit low-power standby mode depending on the states of both input signals. Allow at least 1 millisecond after setting the RS-232 signal to a valid marking level before sending the first character.

Two conditions must be met to allow standby operation. First, pins 1 and 6 of the RJ-12 connector must be shorted. This indicates that the external connection is being used. Second, the SleepWithout232 control flag must have been set to TRUE. This is a volatile control flag (not stored in EEPROM) that is initially cleared to FALSE when the microcontroller is reset. The command string to set this flag is: `@F29.4=1*5B<cr><lf>.` Refer to the Setup Protocol section for an explanation of the fields in this string.

To exit standby operation, allow J3.4 to float high or apply a valid RS-232 signal to one of the input channels. Wait at least 250 µsec before starting a serial transmission. This allows the microcontroller time to start up its oscillator and begin executing instructions.

3 Optimizing Performance

The performance of the Revolution depends on how well its parameters are adjusted for the operating environment. Accuracy, repeatability, speed of response, rejection of anomalous data, and power consumption can be optimized by careful tuning of coefficients that adapt the compass to different conditions. For example, in a hand-held surveying application, low power consumption and high accuracy are important for intermittent samples. Operating in SAMPLE mode would be appropriate, and automatically entering sleep mode between samples would minimize power consumption. Parameters used only in RUN mode can be ignored. These include settings for magnetic and tilt filters; settings for the magnetic alarm; and settings for the non-linear heading filter.

In contrast, automatic antenna positioning requires continuous measurements in the presence of mechanical noise and magnetic anomalies. The RUN mode of operation is required, and settings for filters and alarms must be adjusted to account for operating conditions. If fast, large-angle movements are to be ignored, the non-linear heading filter should be enabled. If vibration from engine noise, ocean waves, or nearby heavy equipment causes tilt sensor oscillation, improved performance may result from enabling the sensor interplay algorithm to stabilize the measurements.

For all applications, the compass accuracy must be verified in-situ by performing a magnetic calibration. This entails first capturing a vertical reference in a nearby location free of magnetic interference, then taking measurements about a circle with the compass mounted in place. The vertical reference can be skipped only if you are convinced that there is no vertical component of hard iron.

3.1 Factors Affecting Accuracy

As mentioned in the section on Features and Limitations, there are a number of factors that can potentially affect the accuracy and repeatability of the compass. The following list explains the mechanism of each factor and presents an order of magnitude of its affect on accuracy.

3.1.1 Static Permanent Magnetism

The source of a local permanent magnetic field can be a piece of hard iron (hence the common name), a constant DC current, or some other type of magnet. This source of error can be significantly reduced by calibration. The curve in Figure 9 shows that a residual error of 0.1% of the earth's magnetic field on both X and Y axes produces a peak accuracy error of 0.20° at 66° inclination (middle US).

The error varies sinusoidally with direction and produces a single cycle for each rotation of the compass. Phase depends on the signs and magnitudes of errors on each axis. The magnitude of the error depends on inclination because the residual hard iron error is expressed as a fraction of the total field strength.

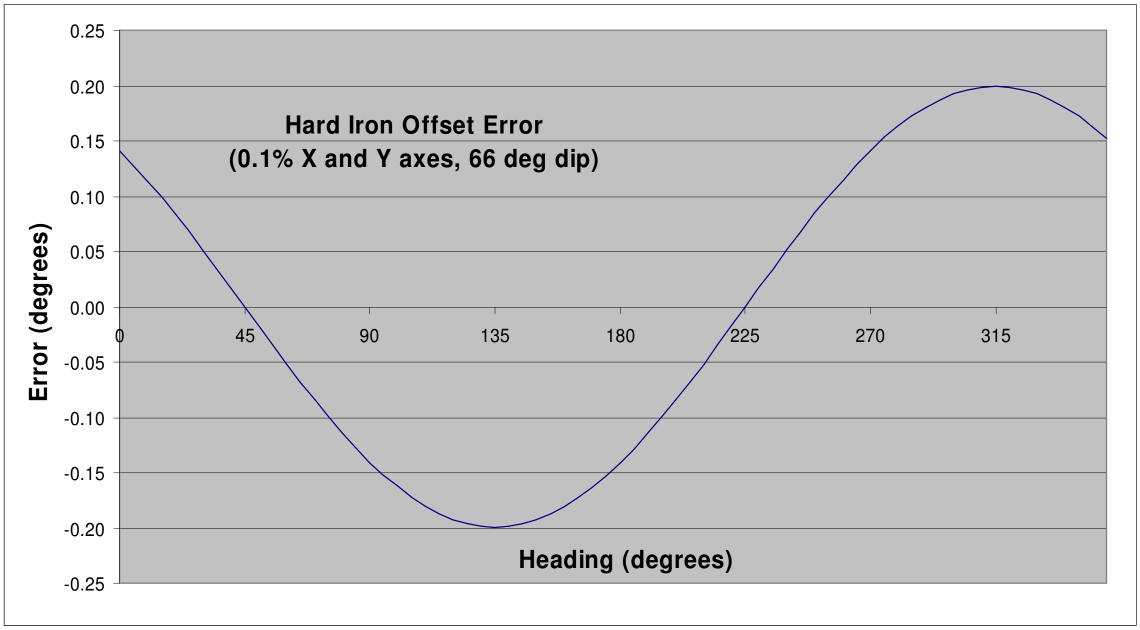

Figure 9 - Hard Iron Heading Error

Fortunately, a residual Z-axis error is less critical. This error comes into play only when the compass card is tilted from level. At 30° tilt, a Z-axis error of 0.3% would be required to produce the same 0.2° peak accuracy error at 66° dip. The accuracy error decreases with decreasing tilt.

This is fortunate because it can be difficult to determine the Z-axis hard iron coefficient. When the compass is mounted in a large vehicle, it may be impossible to turn the vehicle over in order to get good calibration data. An estimate of the Z coefficient can be made so long as some tilted data is collected, but a reasonable estimate may still require tilt angles that can’t be achieved.

To eliminate this problem, the Revolution uses a two-step Z-axis calibration. Reference data is first collected outside the vehicle, in an area free of magnetic interference. When the compass is mounted in the vehicle, the measured vertical component is compared to the reference data to calculate the coefficient. So long as the compass is within a few degrees of level during both measurements, the calculated result is accurate.

3.1.2 Static Induced Magnetism

Bring a magnet in contact with a metal paper clip and the paper clip becomes magnetized. When the magnet and paper clip are separated, the paper clip retains none of its temporary, or induced, magnetism. Soft iron, alloys of iron and nickel, common steel, and some types of stainless steel can all be easily magnetized, even in a weak field.

When these materials are in the vicinity of the compass and rotate with the compass, they become magnetized and demagnetized depending on their orientation with respect to the earth's magnetic field. Instead of seeing a constant field that would produce a perfect circle as the compass turns, the compass sees a field of varying magnitude that maps an elliptical shape. This induced magnetism gives rise to a heading accuracy error as shown in the example of Figure 2.

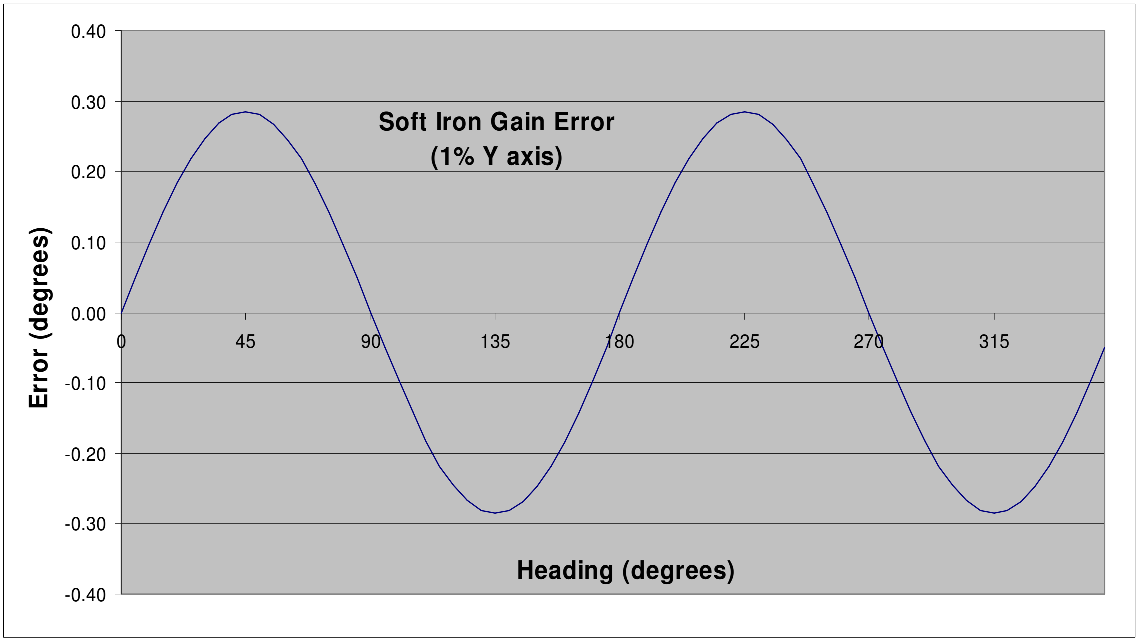

Figure 10 – Soft Iron Heading Error

When the compass is rotated in a level plane, the error varies sinusoidally and produces two cycles per revolution of the compass. In the figure, peaks are located at 45°, 135°, 225°, and 315° because the gain error is aligned with the Y axis, which would be the major axis of the ellipse. In practice, the major axis could be aligned at any angle.

In three dimensions, the locus of points would map to an ellipsoid instead of a perfect sphere. In this case, a 3x3 matrix of gain coefficients is needed to compensate. A minimum of 12 independent measurements is needed to determine 9 soft-iron gains and 3 hard-iron offsets.

If the compass is only being used near level, then a simpler, two-dimensional compensation may be adequate. The Revolution PDA and PC software include an algorithm to estimate 2D soft-iron coefficients based on the approach set forth in "Direct Least Squares Fitting of Ellipses," by Fitzgibbon et al. in IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 21, No. 5, May, 1999. The software reports the ellipticity, in percent, of the ellipse that best fits the collected data. This metric can be used to decide if soft-iron compensation is needed.

In situations where soft-iron is significant, it may be better to relocate the compass. First, a two-dimensional compensation is only approximate, and small variations in tilt may produce dramatic changes in the soft-iron ellipse. Proper compensation may require that three-dimensional data be collected and analyzed to produce the full 3x3 gain matrix.

Secondly, soft magnetic materials that give rise to induced magnetism also exhibit varying degrees of remanence, the tendency to remain magnetized after a magnetizing force is removed. The magnetization of the material may change over time due to exposure to vibration, temperature changes, and varying electrical and magnetic fields. This results in hard-iron errors that must be periodically compensated to maintain accuracy.

3.1.3 Time Varying Magnetic Fields

A time varying magnetic field in the vicinity of the compass cannot be compensated. Either its frequency must be above the pass band of the compass (i.e. greater than 30 Hz), or it must be eliminated. The Revolution's measurement cycle rate of 13.75 Hz is chosen to maximize attenuation of 50 Hz to 60 Hz signals associated with AC power systems.

To estimate the order of magnitude effect of a DC current near the compass magnetometer, use Ampere's law to calculate the magnetic field near a long wire: $B = \frac{\mu_0 i}{2\pi r}$, where $\mu_0 = 4\pi \times 10^{-3}$ Gauss-meter / amp. A long wire carrying 25 mA of current located 50 mm from the magnetometer produces a 1 mG (100 nT) magnetic disturbance at the sensor. In the middle US, where inclination is roughly 66° and the earth's magnetic field strength is about 500 mG, this can result in almost 0.3° heading error.

3.1.4 Tilt Measurement Errors and Horizontal Acceleration

Errors in pitch and roll measurements give rise to single-cycle heading errors that cannot be differentiated from heading error caused by residual hard-iron. The plot in Figure 11 shows how an error as small as 0.1° on both X and Y axes affects heading accuracy at 66° magnetic inclination. The phase of this curve depends on the relative signs and magnitudes of the separate X-axis and Y-axis errors.

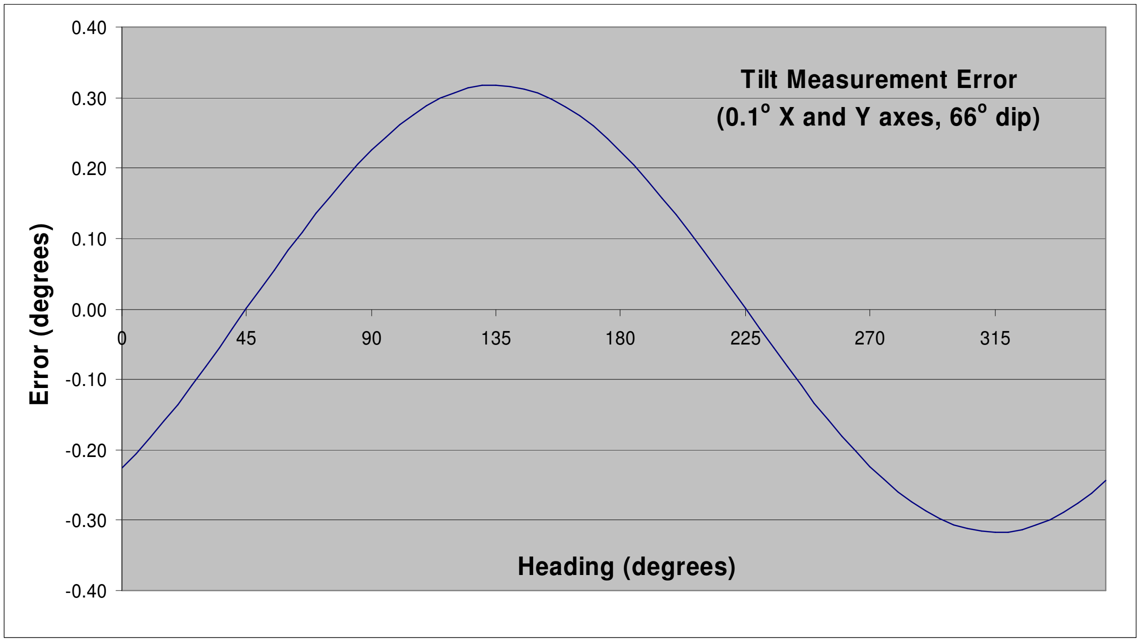

Figure 11 – Affect of Tilt Error on Heading Accuracy

Compare the shape and phase of the curve in Figure 11 to the hard-iron error curve in Figure 9. In this case, the curves are not in phase, and the two sources of error tend to cancel each other. The resulting peak error is reduced by a factor of three as shown in the curve labeled “Errors Cancel” in Figure 12. But change the signs on both pitch and roll errors, and the two curves align in phase, producing the result also shown in Figure 12.

Tilt measurement errors can be caused by one or more of the following:

1. sensor offset and/or gain errors
2. sensor cross-axis coupling
3. misalignment of tilt and magnetic sensor axes
4. horizontal acceleration

In applications where the compass cannot be held perfectly steady, the error due to horizontal acceleration is most pronounced. For a modest horizontal acceleration of 0.05g (roughly 1 mile per hour per second), the tilt measurement error is 2.9° (obtained by calculating $\tan^{-1}0.05$). For the example 66° inclination used above, this results in a sinusoidal heading error of 6.5° peak magnitude.

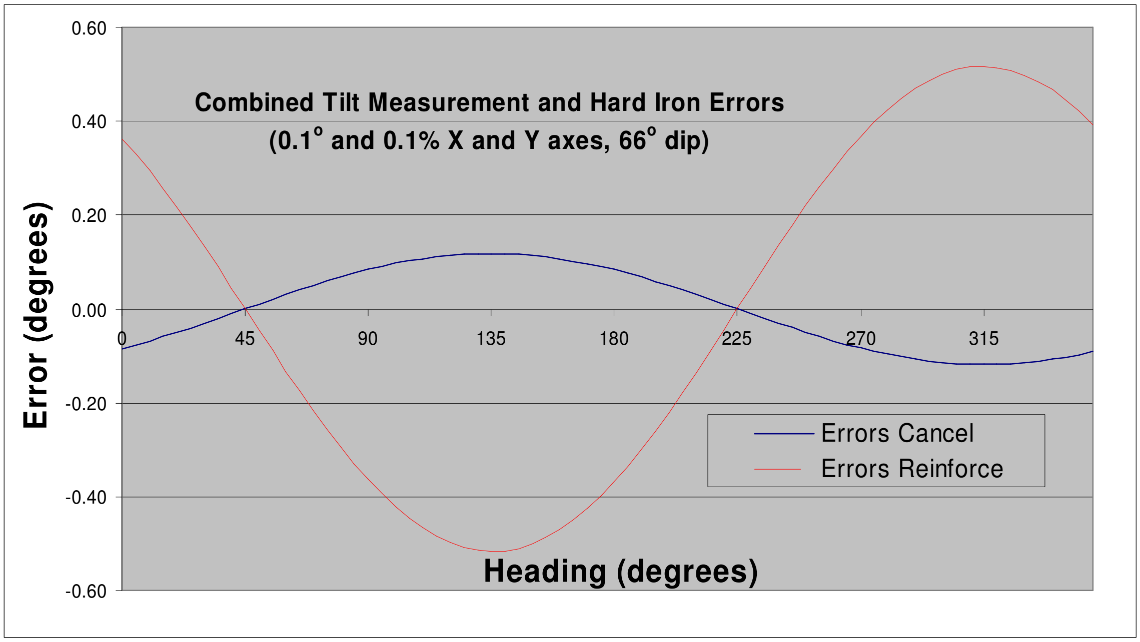

Figure 12 – Combined Affect of Hard Iron and Tilt Errors

3.1.5 Magnetic Inclination (Dip Angle)

Near its magnetic poles, the overall strength of the earth's magnetic field increases. But the horizontal component decreases substantially, making navigation by magnetic compass nearly impossible. For mechanical compasses, the needle dips excessively, trying to align with almost vertical lines of force. For an electronic compass, accuracy decreases because the horizontal field is smaller, and because the affect of tilt errors is more pronounced.

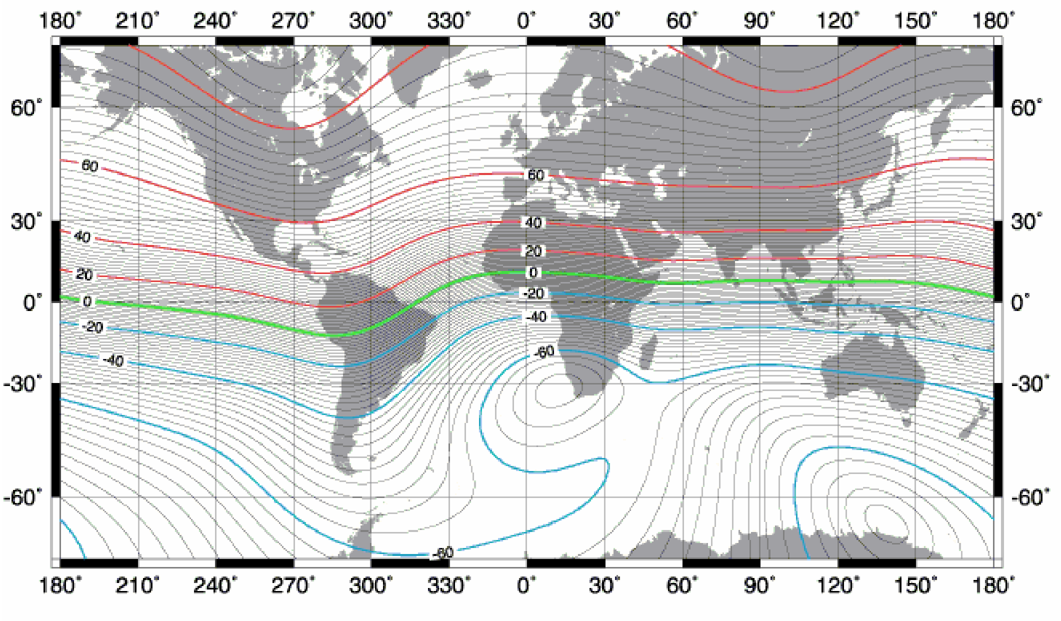

Figure 13 – Magnetic Inclination Contour Lines (in degrees)

The map in Figure 13 shows lines of constant dip angle around the globe. Each of the lines is separated by 2°. The map is based on the US/UK world magnetic model for the year 2000.

Near the magnetic equator, tilt measurement errors have very little influence on compass heading. Between ±5° dip, a 1° error in tilt produces no greater than 0.09° heading error. In northern Alaska (80° dip), the same 1° tilt error results in as much as 6° heading error.

3.2 Calibrating the Compass

The compass EEPROM stores 12 coefficients used to correct for local magnetic fields, both permanent and induced, that remain in a fixed orientation relative to the magnetometer. There are 3 offsets and 9 gains that transform the measured magnetic components - X, Y, and Z - as follows:

$$\begin{bmatrix} MagX \\ MagY \\ MagZ \end{bmatrix} = \begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{bmatrix} \bullet \begin{bmatrix} (X - Xoffset) \\ (Y - Yoffset) \\ (Z - Zoffset) \end{bmatrix}.$$

The purpose of a calibration procedure is to determine values for these 12 coefficients when the compass is operating in its chosen location. For a perfectly calibrated magnetometer, the locus of points (MagX, MagY, MagZ) maps to a sphere centered at the origin. A local permanent magnetic field moves the center of the sphere from the origin, affecting one or more of the 3 offsets. An induced local field distorts the shape of the sphere into a three dimensional ellipsoid. The ellipsoid's 3 orthogonal semi-axes are, in general, rotated relative to the magnetometer X, Y, and Z axes. The gain matrix in the transformation above is determined by finding the relative lengths of the semi-axes and then rotating the resulting vector to the magnetometer X-Y-Z frame of reference.

Successful calibration requires that the magnetometer and the local magnetic effects be pointed in at least 12 different orientations in a fixed external field. Best results are obtained when the points are equally spaced about the 3D spheroid. With measurement noise, more than 12 points is generally needed to produce acceptable results. The extra data can be used to algorithmically determine the ellipsoid that is a best fit based on a least-square error criterion.

In many applications, it can be difficult or impossible to collect sufficient 3D calibration data. When the compass is mounted in a boat, truck, tractor, or RV, turning everything upside down is unreasonable. In these cases, a compromise that results in acceptable accuracy for normal operating conditions is needed.

The Revolution calibration procedures result in such a compromise. These procedures are based on the following key assumptions:

1. the compass is operated and calibrated in a nearly horizontal position,
2. the Z-axis offset can be estimated using the vertical component of the earth's magnetic field, and
3. where the soft-iron effect is significant, the shape of the ellipsoid in the plane of the compass card does not vary radically with small pitch and roll angles.

If the compass is oriented horizontally during calibration, then the Z-axis is nearly vertical. The Z-axis offset can be estimated by first saving a vertical field reference in a magnetically clean area (i.e., out of doors, away from steel structures) and then calculating the vertical field strength during calibration. The Z-axis offset is the difference between these two values. The error in the estimate is proportional to $(1 - \cos\theta)$, where θ is the inclination. This is less than 1% when compass card inclination is less than 8°.

The X and Y axis offsets are determined by a similar estimation procedure. Measurements are captured at multiple points about a circle while the compass card remains within a few degrees of horizontal. Inclinometer readings are then used to project the measurements into the horizontal plane. Like the Z-offset, if inclinometer readings are accurate, then the error in the estimates will be small.

A problem is that the inclinometer is affected by horizontal components of acceleration, which may be substantial for circular motion, even when moving at a constant speed. A vehicle moving at 5 mph on a circle of radius 70 ft. will traverse the circle in the recommended 1 minute. The centripetal acceleration is 0.77 ft/sec^2, or 24 mg. This results in a 1.3° error in inclination, which at 66° dip angle gives rise to a peak heading error of 3° after calibration.

To avoid this problem, the preferred method of collecting calibration data is to first stop at a measurement point and then average a number of readings to produce a value. This eliminates horizontal components of acceleration. Care must be exercised to insure that the vehicle is completely stopped before acquiring data.

The calibration procedure cannot be performed in some conditions such as within, above, or below a steel structure like a parking garage or office building. In these locations, the earth's magnetic field may not remain constant over the area required for calibration. To determine if a site is appropriate, perform a survey with a hand-held compass to map variations in the horizontal and vertical components of the field.

When the Revolution calibration procedures are not appropriate, there are two additional options for hard and soft-iron calibration. First, you can capture 3D data separately and determine appropriate coefficients using a method of your choosing. Refer to the Command Reference section of this document for instructions on tuning new coefficients.

An independent technique based on the maritime procedure for magnetic compass adjustment can also be used. The resulting deviation tables are stored in the compass EEPROM and are used to automatically correct for compass error. See the PDA or PC software help for instructions on using the tables.

3.3 Configuring RUN Mode Filters

With the compass operating in RUN mode, there are three sets of functions that control the stability and speed of response of heading output:

1. low-pass filters for tilt and magnetic measurements,
2. the non-linear heading filter, and
3. the magnetometer controlled rate limiter for tilt noise reduction.

These functions are shown in Figure 6 and described briefly in the section on RUN Mode Operation. This section focuses on adjusting tuning parameters to optimize performance.

There are three single-pole low-pass filters for magnetic signals - MagX, MagY, and MagZ - and two for tilt - tanP and tanR (tangents of pitch and roll). One time constant sets the 3 dB point for the three magnetic signal filters, and a separate parameter controls filtering for the two tilt signals. For fastest response but least stability, set both time constants to zero. This disables both filters.

Some amount of filtering, or smoothing, is generally advisable to reduce noise in the measurement. But even a small time constant can dramatically affect speed of response. For example, in a tracking application with the compass rotating at 1 rpm (6°/sec), the factory-set magnetic time constant of 0.4 sec results in a 2.4° tracking error ($2.4° = \tan^{-1}[0.4*2\pi/60]$). With a time constant of zero, the tracking error is less than 0.5°.

Another consideration for choosing an appropriate time constant is output settling time. For a step change in the input, filter output changes exponentially and is within 1% of its final value after 5 time constants ($1 - e^{-5} = 0.99$). For the factory-set time constant of 0.4 sec allow 2 seconds for the magnetic signals to settle after a quick rotational change.

When a time constant is changed, the affected filters immediately reset and initialize their internal accumulators so that the output equals the input. This also occurs when changing from SAMPLE to RUN mode and when the reset level specified for the non-linear heading filter is exceeded. Command flags are also available to reinitialize the tilt and magnetic filters separately. These flags are located at hex addresses 28.2 for tilt and 28.3 for magnetic filters.

In applications where mechanical vibration causes the liquid in the tilt sensor to oscillate, it should be possible to stabilize the measurements by enabling the tilt noise reduction feature. First, with the compass stationary and the offending vibration present, set the tilt low-pass filter time constant high enough to achieve the desired stabilization. Then enable the Rate Enhancer in Figure 6 by setting the tilt noise reduction flag (section 4.2.3.8). Since the rate enhancing function relies on magnetometer measurements, make sure that hard and soft iron are compensated before proceeding.

In applications where there is a fast large-scale change followed by a period of stopped motion to acquire a reading, the best response may be achieved by enabling the non-linear heading filter. Set the reset level to be 2 or 3 degrees and the knee and gain as desired. Also use larger time constants on the tilt and magnetic signal filters. The fast movement will cause the low-pass fitters and the non-linear heading filter to be reset. This circumvents the lag time that would normally be required for the exponential filter output to stabilize.

3.4 Enabling and Configuring Alarms

When operating in RUN mode, the compass can generate an alarm on deviations of the calculated horizontal component of the measured magnetic field. If the compass is properly calibrated and there is no horizontal acceleration and no magnetic disturbance, then the horizontal magnetic field strength remains constant within a particular geographical area. As the compass rotates and tilts, the stability of the horizontal field strength is a measure of the accuracy of the heading output.

Configuring the alarm requires that the following three parameters be set:

1. The low-pass filter time constant that produces a smoothed reference from horizontal field strength measurements. The setting may be as high as 10 to 15 seconds or more, depending on the application.
2. The reference acquisition time that is the minimum amount of time required to determine a reference value after an alarm is triggered.
3. The alarm threshold in percent of the calculated smoothed reference. If the current field strength is outside the reference value plus or minus this percentage, then an alarm is triggered.

After an alarm is triggered or the magnetic signal filters are reset, the compass remains in alarm while the acquisition time expires. The horizontal field is averaged, and the current field strength is tested against the average for excessive deviation. The acquisition time counter and the average are reset if a deviation exceeds the alarm threshold. The alarm is not cleared until deviations remain within the threshold for the entire duration.

The alarm is only annunciated in the HTM sentence and does not cause the heading to be blanked. The magnetometer status character will be M if the deviation was below the reference or O if above. The only way to determine the state of this alarm is to test the value of this character.

As a rough guide, set the threshold to 2% to have confidence that the heading error is less than 1°. Where horizontal acceleration affects the tilt sensor, increase the acquisition time so that the alarm remains while braking or speeding up. Keep the acquisition time short when the compass is held steady after fast transients.

4 Serial Communication Reference

Revolution serial communications are governed by a simple, asynchronous, ASCII protocol modeled after the NMEA 0183 standard. Either an RS-232 or an RS-485 electrical interface can be used. ASCII characters are transmitted and received using 1 start bit, 8 data bits (LSB first), no parity (MSB always 0), and 1 stop bit; 10 bits total per character. Baud rate can be 2400, 4800, 9600, or 19200 (also 38,400 for Revolution 2X).

The communication link is full duplex (separate transmit and receive circuits), and the protocol requires two-way simultaneous operation. This means that the Revolution will always accept input, even while transmitting unsolicited output. The response to an input may be delayed until an unsolicited output string is completed.

There are two types of serial transactions with the compass: data and setup. Data requests and responses begin with $ and adhere closely to the NMEA standard. Setup commands and responses begin with @ and use a similar sentence format. The setup protocol is more involved than the data transactions and is usually not needed for normal operation.

The compass is intended to be an embedded component of a navigation system. The companion PDA and PC software are provided to assist with one-time setup and calibration procedures. Once the compass is set up to operate as needed, the user's host computer need only deal with NMEA 0183 format data.

A helpful resource for examples is the communication log maintained by the PC software. The log shows all strings that are transmitted to and received from the compass. Following is an example from the start of a communication session. The PC output is marked as "Send." The beginning of the string is a time stamp with resolution that depends on the PC timer capability.

```
=== 12/19/2002 ===
09:09:59.560 *** Start of Session ***
09:09:59.950 Send: @X?*67
09:09:59.950 Recv: @ TNT1500 Rev 2.20 - PCB 1510 Rev C - 11/27/02 !0040*41
09:09:59.950 Send: @W2F4?*28
09:10:00.000 Recv: @11009*39
```

The first Send command requests the firmware ID and device status. The !0040 indicates a power-on reset. The second Send command is used to read the device ID, which is 11009 in this case.

4.1 NMEA 0183 Format Data

An NMEA sentence has the following general form:

```
$aaaaa,x.x,x.x,....*hh<cr><lf>
```

All sentences start with a "$" followed by a 4 to 7 character identification field and then one or more data fields (x.x) delimited by commas. The sentence ends with carriage return and line feed, <cr><lf>. A checksum field, hh, appears at the end and is preceded by an asterisk (“*”).

If the contents of a data field cannot be determined, then that field can be null. In this case, there would be two successive commas with no intervening space. A null heading field is transmitted when heading cannot be calculated due to a problem with either the inclinometer or magnetometer.

The number radix for data fields is decimal. Angle data - heading, pitch, roll, and dip - will include a decimal point if the unit of measurement is set to degrees (default). Angles can also be transmitted in mils (0 – 6399), milliradians (0 – 6283), or 16-bit integer (0 – 65535).

There are three types of sentences: standard, query, and proprietary. The length of the identification field depends on the sentence type. The Revolution can send three standard sentences and four proprietary sentences:

4.1.1 Standard Sentences

1. Heading, True: `$HCHDT,x.x,T*hh<cr><lf>`
2. Heading, Deviation, & Variation: `$HCHDG,x.x,x.x,a,x.x,a*hh<cr><lf>`
3. Transducer measurements: `$HCXDR,A,x.x,D,PITCH,…*hh<cr><lf>`

4.1.2 Proprietary Sentences

1. Heading, Tilt, & Magnetic Field: `$PTNTHTM,x.x,a,x.x,a,…*hh<cr><lf>`
2. Normalized Compass Data: `$PTNTNCD,x.x,x.x,x.x,…*hh<cr><lf>`
3. Conditioned Compass Data: `$PTNTCCD,x.x,x.x,x.x,…*hh<cr><lf>`
4. Raw Compass Data: `$PTNTRCD,x.x,x.x,x.x,…*hh<cr><lf>`

The proprietary HTM sentence is the workhorse of the Revolution compass. It provides the entire set of measurements normally required by an application:

- Heading, pitch, and roll angles (attitude data)
- Dip angle (magnetic inclination)
- Relative magnitude of horizontal component of magnetic field
- Magnetic field and tilt alarm status

Generally, the heading, pitch, and roll angles are the measurements of interest. The dip angle and horizontal component are diagnostic measurements that can be used to assess the reliability of the primary data. Both values should remain constant in a particular geographic area, provided that the compass is properly calibrated and is not being accelerated.

When the compass operates in RUN mode, it can be programmed to send one or more data sentences automatically. Each sentence has a separate rate that can be set from 0 to 1200 sentences per minute (0 to 2400 for the Revolution 2X). The rates are stored in EEPROM.

In both SAMPLE and RUN modes, the compass sends the requested data sentence in response to one of the following queries:

4.1.3 Query Sentences

1. Send HDT: `$TNHCQ,HDT*34<cr><lf>`
2. Send HDG: `$TNHCQ,HDG*27<cr><lf>`
3. Send XDR: `$TNHCQ,XDR*22<cr><lf>`
4. Send HTM: `$PTNT,HTM*63<cr><lf>`
5. Send NCD: `$PTNT,NCD*7B<cr><lf>`
6. Send CCD: `$PTNT,CCD*76<cr><lf>`
7. Send RCD: `$PTNT,RCD*67<cr><lf>`

For the first three queries, any 2-character talker ID is accepted in place of TN provided that the checksum characters are correct. The checksum characters are generated by accumulating the bitwise exclusive OR (XOR) of the binary numeric values corresponding to the characters between $ and *. For example, the checksum for the HDT query is calculated as follows ("^" denotes XOR and the radix for numeric values is hexadecimal):

```
T    N    H    C    Q    ,    H    D    T
54 ^ 4E ^ 48 ^ 43 ^ 51 ^ 2C ^ 48 ^ 44 ^ 54 = 34
```

4.1.4 Data Field Contents

4.1.4.1 HDG Heading, Deviation, & Variation

`$HCHDG,x.x,x.x,a,x.x,a*hh<cr><lf>`

Field contents, in order:

1. measured compass heading (e.g. 259.3),
2. magnitude of programmed or calculated deviation angle (e.g. 6.3),
3. deviation direction, the single character E or W,
4. magnitude of programmed variation (e.g. 10.7),
5. variation direction, E or W.

The magnetic heading field may be null. If either deviation or variation has not been programmed, the corresponding field will contain a value of zero. Add easterly (E) deviation to compass heading to get magnetic heading. Add easterly variation to magnetic heading to get true heading.

4.1.4.2 HDT Heading, True

`$HCHDT,x.x,T*hh<cr><lf>`

The heading field may be null.

4.1.4.3 XDR Transducer Measurements

```
$HCXDR,A,x.x,D,PITCH,A,x.x,D,ROLL,G,x.x,,MAGX,
G,x.x,,MAGY,G,x.x,,MAGZ *hh<cr><lf>
```

Each of the five sensor measurements - pitch, roll, and magnetic x, y, and z - can be individually included in or excluded from the message (see "XDR has …" parameters). There are four subfields for each of the included measurements: Type, Data, Units, and ID. See NMEA 0183 for a detailed description of the "Type-Data-Units-ID" field encoding. The data field of an included measurement will be null if its contents cannot be determined.

MAGX aligns with the lengthwise axis of the compass board, which is also the axis about which ROLL is measured. MAGY is in the direction of the lateral axis, which is the axis about which PITCH is measured. MAGZ is perpendicular to the plane of the compass board.

4.1.4.4 HTM Heading, Tilt, & Magnetic Field

```
$PTNTHTM,x.x,a,x.x,a,x.x,a,x.x,x.x*hh<cr><lf>
```

This sentence combines the primary measurement and diagnostic data required by most applications. Heading, pitch, and roll measurements are included as well as status and diagnostic data.

HTM data fields represent, in order:

1. true heading (compass measurement + deviation + variation)
2. magnetometer status character – C, L, M, N, O, P, or V (see below)
3. pitch angle
4. pitch status character – N, O, P (see below)
5. roll angle
6. roll status character – N, O, P (see below)
7. dip angle
8. relative magnitude horizontal component of earth's magnetic field

Status field characters have the following meanings:

1. C = magnetometer calibration alarm
2. L = low alarm
3. M = low warning
4. N = normal
5. O = high warning
6. P = high alarm
7. V = magnetometer voltage level alarm

If any of the three status fields indicates alarm, then the heading field will be null as well as the corresponding measurement field. Thresholds for alarm and warning levels can be changed in the EEPROM.

4.1.4.5 NCD Normalized Compass Data

`$PTNTNCD,x.x,x.x,x.x,x.x,x.x,x.x,x.x*hh<cr><lf>`

This sentence provides conditioned tilt and normalized magnetic measurements for diagnostic use. The fields are, in order:

tanP	same as tanP in CCD sentence: 32768 times tangent of angle between compass board lengthwise axis and level plane. The angle is measured vertically from the horizontal plane to the plane of the compass card. It is a rotation about the lateral axis of the card.
tanR	same as tanP but for the compass board lateral axis (roll) same as tanR in CCD sentence
magN	normalized and filtered magnetic field strength calculated in the direction of magnetic north
magE	same as magN but calculated in the direction of magnetic east
magH	calculated horizontal component of earth's magnetic field
magV	calculated vertical component of earth's magnetic field
heading	calculated heading based on the magnetometer and inclinometer data in this sentence. This field will be null if the heading cannot be calculated.

4.1.4.6 CCD Conditioned Compass Data

`$PTNTCCD,x.x,x.x,x.x,x.x,x.x,x.x,x.x*hh<cr><lf>`

This sentence provides conditioned tilt and magnetic measurements for diagnostic use. The fields are, in order:

tanP	same as tanP in NCD sentence: 32768 times tangent of angle between compass board lengthwise axis and level plane. The angle is measured vertically from the horizontal plane to the plane of the compass card. It is a rotation about the lateral axis of the card.
tanR	same as tanP but for the compass board lateral axis (roll) same as tanR in NCD sentence
magX	normalized and filtered magnetic field strength measured along the lengthwise axis of the compass board.
magY	same as magX but along the compass board lateral axis.
magZ	same as magX and magY but along an axis perpendicular to the plane of the board.

magT	same as MagT field in XDR sentence
heading	calculated heading based on the magnetometer and inclinometer data in this sentence. This field will be null if the heading cannot be calculated.

4.1.4.7 RCD Raw Compass Data

```
$PTNTRCD,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x*hh<cr><lf>
```

This sentence provides raw tilt and magnetic measurements for diagnostic use. Contents of each field represent A/D readings for, in order: tiltAp, tiltAm, tiltBp, tiltBm, magA, magB, magC, magAsr, magBsr, magCsr. All values represent the A/D readings from the most recent conversions. Mag_sr values represent the sum of the most recent Set and Reset pulse measurements for each magnetometer sensor. The A direction lies along the lengthwise axis of the board; B is along the lateral axis, and C is perpendicular to the board. There are never any null fields in this sentence.

4.2 Setup Protocol

Instead of using pseudo-English mnemonics for parameter names and operating commands, the setup protocol allows parameter and data memory to be read or written using byte addresses and generic data types. Memory can be accessed in 1, 8, or 16-bit increments. Access to some areas of memory is either prohibited or restricted, depending on the contents.

To start a setup transaction, the host sends a command string and waits for a response from the compass. Only one command can be issued at a time. The host must wait for a response before sending the next command string. The response may be delayed by an unsolicited output string that is being sent when the command is received.

4.2.1 Command Input Syntax

A command to the compass has the following general form:

```
@<type><adr><r/w>x.x,x.x,…*hh<cr><lf>
```

Command sentences start with a "@" followed by an access type character; then the address, a read or write indicator, and data. The sentence ends with carriage return and line feed, <cr><lf>. The checksum field, hh, at the end is preceded by an asterisk (“*”) and, as with NMEA sentences, is the XOR of characters between @ and *.

A graphical representation of this syntax is shown in Figure 14. Traverse the diagram from left to right, taking branches allowed for by gradual turns. Optional branches are shown on top of one another. Only one such branch is selected per command string. The indicated characters should be transmitted as they are encountered in the diagram. Note that no character is sent when traversing a blank branch.

Lower case letters in the diagrams denote the following:

a = alphanumeric character in the range A-Z or 0-9.
n = numeric digit in decimal or hexadecimal notation (0-9, A-F)
h = hexadecimal digit (0-9, A-F)
b = bit position (0-7)
cr = carriage return (ASCII decimal code 13)
lf = line feed (ASCII decimal code 10)

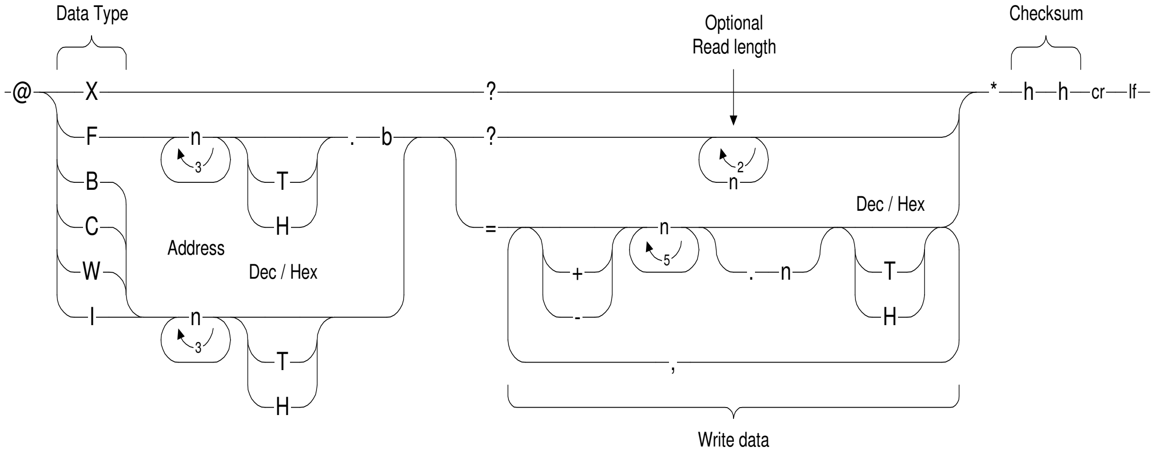

Figure 14 – Command Syntax Diagram

There are several places in the diagram where a feedback loop is encountered. The number inside the loop designates the maximum number of times the loop can be traversed. Note that three of the feedback loops require at least one digit be transmitted, while one allows for zero to two digits.

The access type character can be one of the following:

F	is used to read or write individual flag bits. A bit designator, 0-7, must follow the byte address of the flag. A flag's value can be either 0 or 1.
B	designates an unsigned byte value (0 to 255)
C	means a character, or signed byte value (-128 to 127)
W	indicates a word, or unsigned 2-byte value (0 to 65535)
I	means an integer, or signed 2-byte value (-32768 to 32767)
X	is a special type used to query for an identification string. The returned string includes:

- Hardware and firmware identifiers (from program memory)
- Firmware revision level and date code (from program memory)
- Unit status (e.g. power-on, EEPROM error, time-out reset, etc.)

A byte address of one to three digits follows the access type. By default, address digits are interpreted as hexadecimal if neither T (decimal) nor H (hex) follows the digits. Upper case T is used to indicate the decimal radix to avoid confusion with the valid hexadecimal numeral D.

Following the address, the host sends either '?' for read, or '=' for write. A read operation can specify that a sequence of data be returned, and a write operation can specify multiple sequential values in a single message. For read requests, the number of requested sequential data values must be such that the maximum output string length of 110 characters is not exceeded. If the requested read length is too long, only as many values as can fit in the maximum string length are returned. The read length digits are interpreted as hexadecimal if an explicit radix indicator (T or H) is not sent.

For write requests, the maximum input buffer length of 110 characters cannot be exceeded. If the input message is too long, an error response is generated and none of the data is written. In addition, if the format for any one data value is corrupted, then an error response is generated and none of the data is written. Multiple values must be separated by a comma with no additional white space. Data value digits are interpreted according to the default radix in EEPROM if an explicit digit type (T or H) is not sent. Multiple values are written to sequential addresses starting from the address supplied. For bit data, only a single bit can be read or written with each command.

4.2.2 Response Output Syntax

The syntax for the compass response to a command is shown in Figure 15. The response begins with @ and is followed by the requested data or a status string. The checksum characters at the end are the XOR of characters between @ and *.

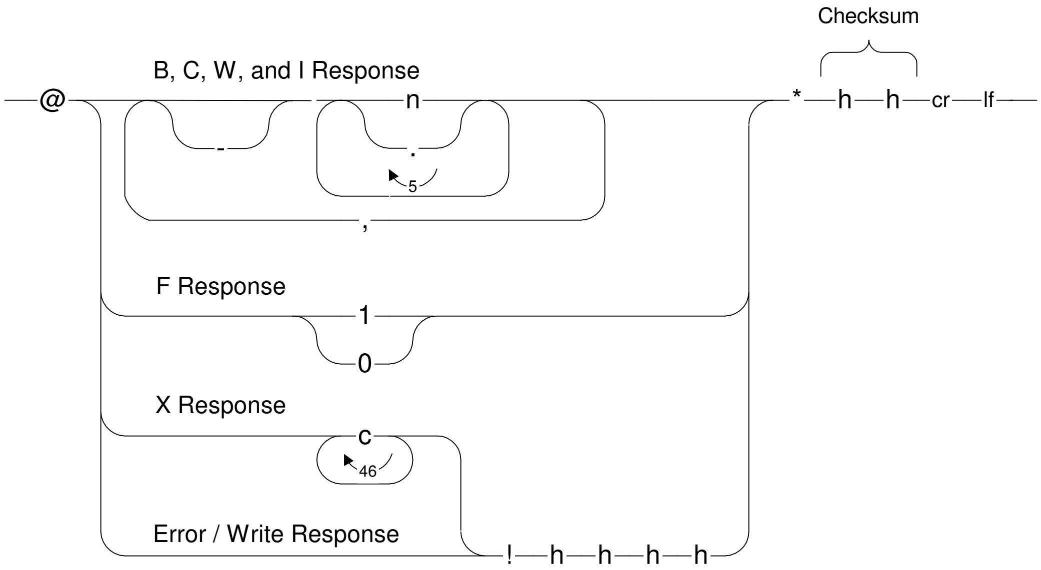

Figure 15 - Response Syntax Diagram

The top branch shows the Revolution’s response to an 8 or 16-bit read request. When more than one value is requested, sequential values are separated by a comma. Each value is presented in decimal or hexadecimal notation according to the setting in EEPROM. If any byte location in the requested sequence is prohibited from being accessed, then an error message is returned.

Remaining branches show semantically simpler responses for special conditions. The second branch shows that values for the F data type can only be 0 or 1. In the third branch, the diagram depicts Revolution’s response to the X command as a string of characters. The bottom branch shows the response to a write command and the error response. The first 2 hex digits following the exclamation point contain an error code that indicates one of the following:

- 00H = OK
- F1H = Error in contents of access type field
- F2H = Syntax error in input string
- F3H = Address not allowed
- F4H = Flag number out of range 0 - 7
- F5H = Error in data length field
- F6H = Write protect error
- F7H = Error in contents of data field
- E8H = Error writing EEPROM
- 80H = Badly formed input sentence
- 81H = Missed LF at end of sentence
- 82H = Missed @ or $ start of sentence

The last two hex digits contain flag bits that are cleared after they are sent. Individual bits have the following meanings:

- 01H = Receive data overrun
- 02H = Receive character framing error
- 04H = 110 character receive buffer overrun
- 08H = Receive sentence checksum error
- 10H = Received unknown sentence
- 20H = EEPROM read error
- 40H = Power on reset occurred
- 80H = Time out reset occurred

4.2.3 Command Reference

This section presents the details of commands to change compass operating parameters. Related sets of parameters are described in a single section.

4.2.3.1 Operating Mode: RUN = 1, SAMPLE = 0

OCX Parameter Index: 1
Access Type Character: F
Hex Address: 0.3
Read Example: @F0.3?*54
Write Example: @F0.3=0*66

This stored flag specifies the compass operating mode.

4.2.3.2 Angle Units: Degrees, MilliRadians, Mils, or 16-bit Integer

OCX Parameter Index: 12, 13, 14
Access Type Character: F
Hex Address: 2.2, 2.3, 2.4
Read Example: @F2.2?*57
Write Example: @F2.2=0*65

Set one of these three stored flags to specify the desired angle units. If none of the flags is set, angles are presented as 16-bit integers, i.e. the range 0 to 65535 or -32768 to 32767 represents one complete revolution. If more than one flag is set, then degrees takes precedence over mils, and mils takes precedence over milliradians. One revolution is 6400 mils, 6283 milliradians, or 360.0 degrees.

4.2.3.3 Reset Compass

OCX Parameter Index: 43
Access Type Character: F
Hex Address: 28.6
Write Example: @F28.6=1*58

Set this flag to 1 to reset the compass.

4.2.3.4 Baud Rate Index

OCX Parameter Index: 19
Access Type Character: B
Hex Address: 6
Read Example: @B6?*4B
Write Example: @B6=3*7A

This stored byte value is a selector that specifies the serial communication rate used by the compass. The value 1 selects 2400 baud, 2 is 4800, 3 is 9600, and 4 is 19200 baud (5 is 38400 baud on the Revolution 2X only). Any other value results in 2400 baud operation. The new value does not take effect until the compass is reset (see ***Reset Compass*** section).

4.2.3.5 Output Rate Indices: HDG, HDT, XDR, HTM, RCD, CCD, NCD

OCX Parameter Index: 20, 21, 22, 23, 24, 25, 26
Access Type Character: B
Hex Address: 7, 8, 9, A, B, C, D
Read Example (for HTM rate): @BA?*3C
Write Example (for HTM rate): @BA=0*0E

These are byte values that specify the automatic output rate for NMEA sentences in RUN mode. Each value is an index into a table of available output rates. Index 0 turns off the automatic updates. There are 26 additional rates, in sentences per minute, shown in Table 1.

Index	Rate	Index	Rate	Index	Rate
1	1	9	120	17	118 (7)
2	2	10	180	18	59 (14)
3	3	11	300	19	31 (27)
4	6	12	413 (2)	20	15 (55)
5	12	13	600	21	8 (110)
6	20	14	825 (1)	22	4 (220)
7	30	15	1200	23	2 (440)
8	60	16	206 (4)	24	1 (880)

Table 1 - Automatic NMEA Sentence Rates

Rates marked with parentheses are synchronized with the basic 13.75 Hz measurement cycle rate of the compass. The value in parentheses is the divisor.

For the Revolution 2X, there are two additional rates: index 25 selects 1650 sentences per minute and index 26 selects 2400. The Revolution 2X measurement cycle rate is 27.5 Hz. Double the parenthetical divisors in Table 1 when using this device.

Values from 25 (27 for the 2X) to 255 will be accepted by the compass, but they will index beyond the table and produce unknown results. When changing from a slow rate to a faster rate, the remaining time interval must expire before the new rate takes effect. This is most noticeable when switching from 1 to 825 sentences per minute. In this case, it is faster to first set 0 and then 825. Wait at least one measurement cycle (73 msec) between commands.

These parameters are ignored in SAMPLE mode.

4.2.3.6 XDR Sentence Contents: Pitch, Roll, MagX, MagY, MagZ

OCX Parameter Index: 5, 6, 7, 8, 9
Access Type Character: F
Hex Address: 1.0, 1.1, 1.2, 1.3, 1.4
Read Example (for MagZ): @F1.4?*52
Write Example (for MagZ): @F1.4=0*60

These are stored flags that specify the contents of the XDR sentence. When a flag value is 1, the corresponding sensor data is included in the sentence.

4.2.3.7 Time Constants: Tilt, Magnetic, Alarm

OCX Parameter Index: 16, 17, 18
Access Type Character: B
Hex Address: 3, 4, 5
Read Example: @B3?*4E
Write Example: @B3=55*4C

These are stored values that specify the normalized time constant for tilt, magnetic, and alarm IIR filters (single pole). Each value can range from 0 to 255. A value of zero disables the filter. Divide the value entered by 13.75 to get the equivalent time constant in seconds. For example, set the value 55 to specify a 4.0 second time constant.

These settings are ignored in SAMPLE mode.

4.2.3.8 Tilt Noise Reduction

OCX Parameter Index: 90
Access Type Character: F
Hex Address: 2.5
Read Example: @F2.5?*50
Write Example: @F2.5=1*63

This stored flag enables the sensor interplay algorithm for tilt signal noise reduction. The magnetometer should be calibrated in-situ before setting this flag to zero. The tilt time constant must be set high enough to smooth out the noise while the compass remains stationary.

This setting is ignored in SAMPLE mode.

4.2.3.9 Magnetic Alarm Acquire Time

OCX Parameter Index: 95
Access Type Character: B
Hex Address: 15
Read Example: @B15?*79
Write Example: @B15=69*74

This stored value specifies the number of cycles at 13.75 Hz to acquire a MagH reference for the magnetic deviation alarm function. Specify a value in the range of 1 to 255. Divide the value set by 13.75 to get the acquisition time in seconds.

During the acquisition time, the magnetometer status character in the HTM sentence will be either M (low) or O (high), depending on whether the last detected excursion was above or below the nominal reference.

This setting is ignored in SAMPLE mode.

4.2.3.10 Magnetic Alarm Deviation Limit

OCX Parameter Index: 57
Access Type Character: W
Hex Address: 2A4
Read Example: @W2A4?*2F
Write Example: @ W2A4=3277*2C

This stored value specifies the allowed deviation of the current calculated magH about the smoothed magH reference. If the deviation is above this limit, the magnetometer status character in the HTM sentence will be O (high). If it is below the negative limit, the status character will be M (low). Set a value from 0 to 65555 that designates the range from 0 to 99.998% of the reference value. In other words, to allow deviation within ± 1% of the reference, set the value 655. Set the value 0 to disable this alarm.

This setting is ignored in SAMPLE mode.

4.2.3.11 Sample Time, Samples to Ignore

OCX Parameter Index: 27, 28
Access Type Character: B
Hex Address: E, F
Read Example: @BE?*38
Write Example: @ BE=42*2C

These stored values specify the number of measurement cycles that occur in SAMPLE mode following receipt of an NMEA query message. The sample time sets the number of samples to average. Set a value from 1 to 255. Divide this number by 13.75 to get the sample time in seconds.

Before averaging begins, the compass discards the number of samples to ignore. Generally one or two samples are sufficient. If a delay is required between the NMEA query and the average measurement, set this value to a maximum of 255.

These settings are ignored in RUN mode.

4.2.3.12 Magnetometer Gain

OCX Parameter Index: 33
Access Type Character: B
Hex Address: 14
Read Example: @B14?*78
Write Example: @B14=251*4C

This stored value is an index for a 256 tap digital potentiometer that sets the magnetometer signal gain. Set a value from 0 to 255 to adjust gain from 100 to 500. The equation that relates tap index, N, to signal gain, G, is:

$$G = 100 + \frac{25600}{2624 - 10 \bullet N}.$$

Perform a magnetic calibration after changing this gain.

4.2.3.13 Magnetic Field Vertical Reference

OCX Parameter Index: 62
Access Type Character: I
Hex Address: 2AE
Read Example: @I2AE?*40
Write Example: @I2AE=32767*75

This stored value is used in the magnetic calibration procedure to determine an estimate of the magnetometer Z-axis offset. It is set automatically at the end of the vertical reference determination procedure. The value 32767 is used to designate that no vertical reference has been saved.

4.2.3.14 Hard Iron Offsets: MagXoffset, MagYoffset, MagZoffset

OCX Parameter Index: 58, 59, 61
Access Type Character: I
Hex Address: 2A6, 2A8, 2AC
Read Example: @I2A6?*33
Write Example: @I2A6=42*37

These stored values are compensation coefficients for hard iron. They are set automatically at the end of the magnetic calibration procedure. There is also an internal Z offset at target address 2AA that should not be changed.

4.2.3.15 Soft Iron Gains: Gxx, Gxy, Gxz, Gyx, Gyy, Gyz, Gzx, Gzy, Gzz

OCX Parameter Index: 64, 65, 66, 67, 68, 69, 70, 71, 72
Access Type Character: I
Hex Address: 2B2, 2B4, 2B6, 2B8, 2BA, 2BC, 2BE, 2C0, 2C2
Read Example: @I2B2?*34
Write Example: @I2B2=16384*0E

These stored values are compensation coefficients for soft iron. When the Revolution is delivered new, the nine values comprise an identity matrix (i.e., Gxx = Gyy = Gzz = 1.0 and other elements are zero). Set a value from -32768 to 32767 to designate a gain in the range from -2.0000 to 1.9999. Use 16384 for a gain of 1.0000.

4.2.3.16 Do Soft Iron and Apply Soft Iron to CCD

OCX Parameter Index: 0, 89
Access Type Character: F
Hex Address: 0.1, 0.2
Read Example: @F0.1?*56
Write Example: @F0.1=1*65

These stored flags tell the compass whether to apply soft-iron gains to the data, and if so, whether to apply the gains to tilted (CCD) or rotated (NCD) data. The ***Do Soft Iron*** flag enables and disables gain compensation. It can be set at any time but has no effect if the gain matrix is the identity matrix.

Set ***Apply Soft Iron To CCD*** true to multiply magnetic field X, Y, and Z components (values in the CCD and XDR sentences) by the gain matrix. If the flag is set to zero, then N, E, and V components in the NCD sentence are multiplied by the gains. This puts the matrix multiply block after the axis rotation block in the diagrams of Figure 6 and Figure 8.

4.2.3.17 Deviation and Variation

OCX Parameter Index: 48, 49
Access Type Character: I
Hex Address: 290, 292
Read Example: @I290?*4D
Write Example: @I290=-12.6*79

These stored values specify the corrections used to determine magnetic bearing and true bearing from compass reading. The deviation value is used only when the Single Deviation flag is set true. Otherwise deviation is calculated automatically from corrections supplied in the deviation table.

Data is read and written in the angle units currently specified.

4.2.3.18 Single Deviation and Use Degauss On Table

OCX Parameter Index: 91, 92
Access Type Character: F
Hex Address: 2.6, 2.7
Read Example: @F2.6?*53
Write Example: @F2.6=1*60

These stored flags specify how compass deviation is determined. Set the ***Single Deviation*** flag true to use the value stored in ***Deviation***. To use the electronic compass card, or deviation table, set ***Single Deviation*** to zero. One of the two saved deviation tables, degauss on and degauss off, is specified by the ***Use Degauss On Table*** flag.

4.2.3.19 Pitch and Roll Offsets

OCX Parameter Index: 52, 53
Access Type Character: I
Hex Address: 298, 29A
Read Example: @I298?*45
Write Example: @I298=2.4*6F

These stored values are subtracted from pitch and roll measurements to output adjusted angles. They do not affect pitch and roll used to compute heading.

Data is read and written in the angle units currently specified.

4.2.3.20 Tilt Alarm and Warning Levels

OCX Parameter Index: 50, 51
Access Type Character: W
Hex Address: 294, 296
Read Example: @I294?*57
Write Example: @I294=30*48

These stored values are the thresholds above which pitch and roll measurements are too high. Measurements are blanked along with heading above the alarm level. Status characters in the HTM sentence indicate when the warning level is exceeded.

Data is read and written in the angle units currently specified.

4.2.3.21 No Data to J2 and Sleep Without RS232

OCX Parameter Index: 44, 45
Access Type Character: F
Hex Address: 29.2, 29.4
Read Example: @F29.4?*68
Write Example: @F29.2=1*5D

These volatile flags are only used when the RJ-12 port is connected. NMEA sentences are only sent to the RJ-12 port when ***No Data to J2*** is set. This is intended to prevent confusion during maintenance, so the host computer does not receive data requested by a plug-in device.

When ***Sleep Without RS232*** is set, the compass will enter its low-power standby mode when both RS-232 input signals become invalid. This is intended to automatically conserve battery power when a plug-in PDA turns its RS-232 driver off.

Both flags are initialized to zero when the compass powers up or is reset. Both flags are ignored when the RJ-12 plug is removed. The ***Sleep Without RS232*** flag is ignored when the compass is operating in calibration mode.

4.2.3.22 Non-Linear Heading Filter: Knee, Reset Level, and Gain

OCX Parameter Index: 54, 31, 55
Access Type Character: W
Hex Address: 29C, 29E, 2A0
Read Example: @W29C?*20
Write Example: @W29C=2.0*0E

These stored parameters specify the operation of the non-linear heading filter described on page 16 in the section describing RUN Mode. The knee and reset level are angles that are read and written in the units currently specified. Set the gain from 1 to 65535 to specify maximum to minimum smoothing.

Both the knee and gain values must be non-zero to enable the filter.

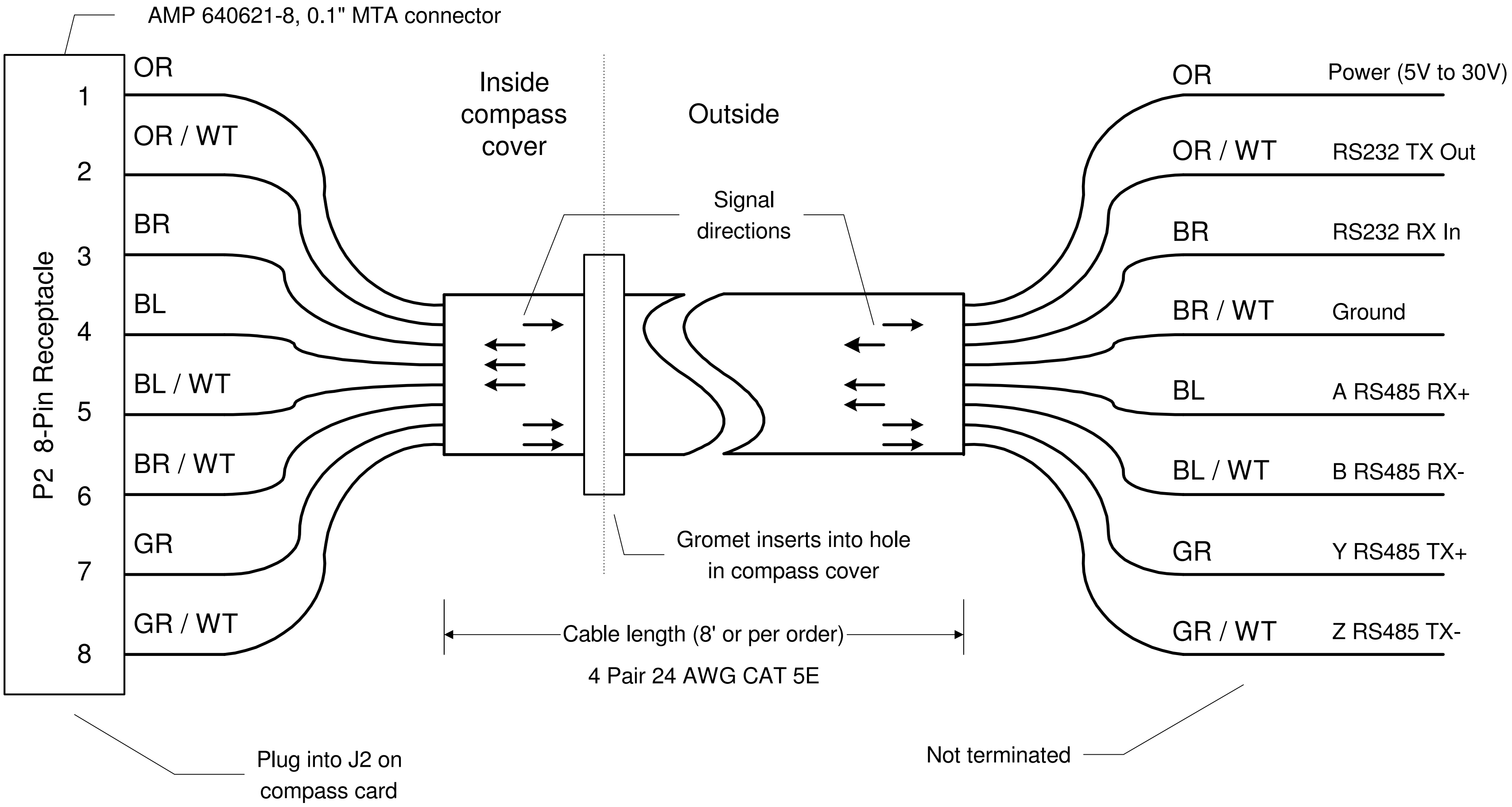

Figure 16 – Revolution System Wiring Cable (TNT 1580)

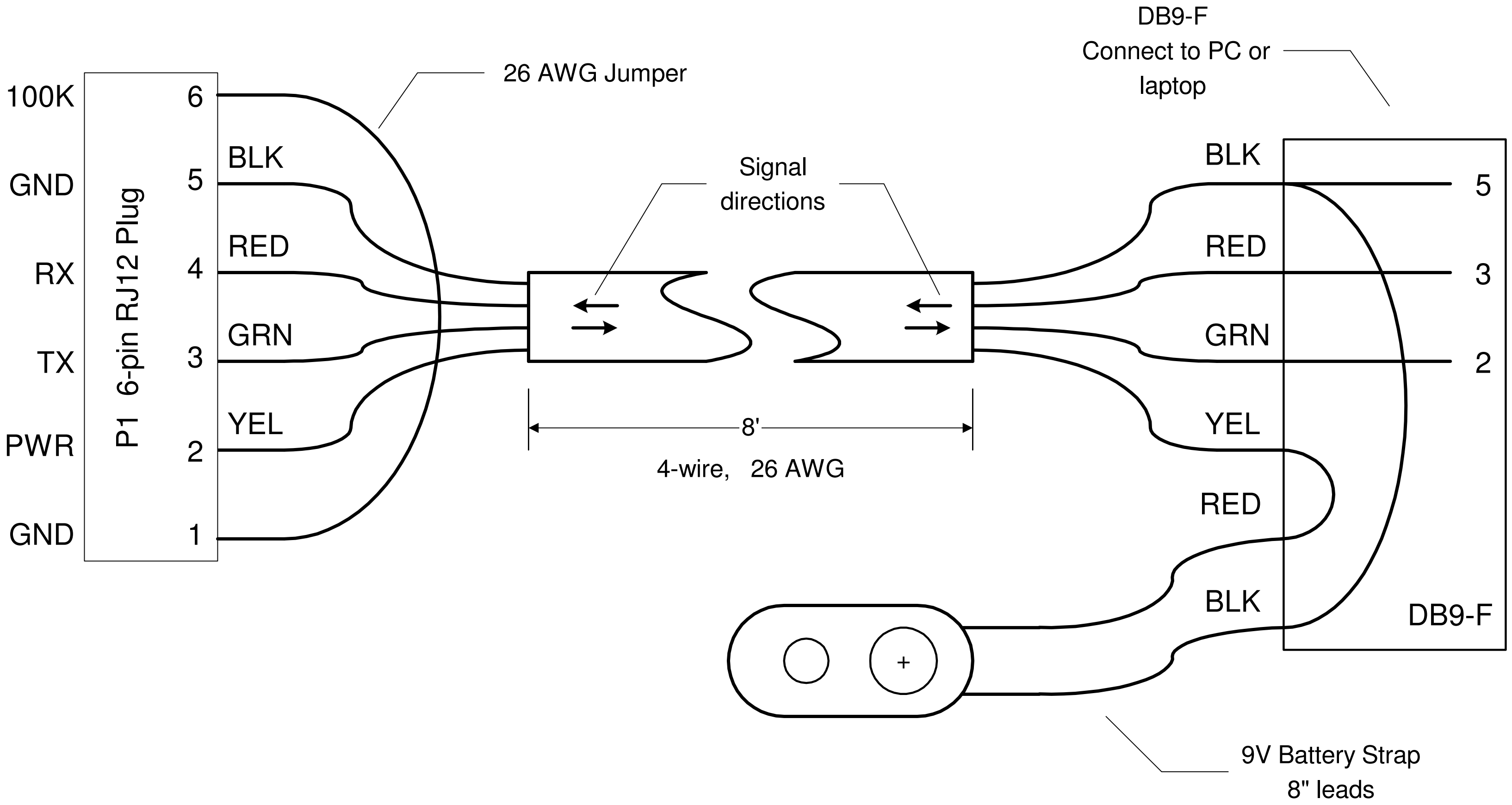

Figure 17 – Revolution PC Interface Cable (TNT 1540)