User Guide

TCM3 & TCM5

Tilt-Compensated Compass Module

PNI SENSOR CORPORATION

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1 Copyright & Warranty Information

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Some states and provinces do not allow limitations on how long an implied warranty lasts or the exclusion or limitation of incidental or consequential damages, so the above limitations or exclusions may not apply to you. This warranty gives you specific legal rights and you may have other rights that vary by state or province.

2 PNI Corporation's TCM3 & TCM5

Thank you for purchasing PNI's TCM3 (pn 12606) or TCM5 (pn 12608) tilt-compensated compass module. You have chosen a product that represents the largest step forward in compass technology for many years. The TCM is a state-of-the-art, low power, high performance electronic tilt compensated compass sensor module.

The TCM uses advanced algorithms, with hard iron and soft iron corrections, to provide highly accurate heading information, in **any orientation** (TCM5 only), at latitudes up to 85°. The output information of the unit will indicate accurate attitude position of the module and can be used in systems requiring full 360° rotation (TCM5 only). This has been accomplished by integrating 3-axis magnetic field sensing, 3-axis tilt sensing, and compass heading into a single module, which is one of the smallest in the market. With its small size, the TCM is capable of fitting into today's size sensitive systems. These advantages make PNI Corporation's TCM the choice for applications that require the highest accuracy and performance anywhere in the world.

The TCM combines PNI Corporation's patented Magneto-Inductive (MI) sensors and measurement circuit technology with a 3-axis MEMS accelerometer for unparalleled cost effectiveness and performance. The magnetic sensors and accelerometers are calibrated to operate from -40 to 85°C; hence the measurement is very stable over temperature and inherently free from offset drift.

The TCM's advantages make it suitable for many applications, including:

- High-performance solid state navigation equipment
- High-performance attitude measurement
- IMU system integration
- 3-axis magnetic field sensing
- Robotics systems
- Laser range finders
- Drilling applications

With its many potential applications, the TCM provides a command set designed with flexibility and adaptability in mind. Many parameters are user-programmable, including reporting units, a wide range of sampling configurations, output damping, and more. We hope the TCM will help you to achieve the greatest performance from your target system. Thank you for selecting PNI's TCM compass.

Note: Several versions of the TCM exist, as the product line has evolved over the years. Throughout this manual the term "TCM" refers to the TCM 3 and TCM 5. Other versions available from PNI include the current TCM XB and TCM 5LT, and the legacy TCM 2.5 and TCM 2.6. (Availability subject to change.)

2.1 Performance Specifications

2.1.1 Heading Specifications

Parameter	TCM3	TCM5	Units
Accuracy with <65º of tilt	0.5º	0.3º	Deg RMS
Accuracy with <80º of tilt	0.8º	0.5º	Deg RMS
Resolution	0.1º	0.1º	Deg RMS
Repeatability[1]	0.05º	0.05º	Deg RMS
Max Dip Angle	85º	85º	Deg

[1] Repeatability is based on statistical data at ±3 sigma limit about the mean.

2.1.2 Magnetometer Specifications

Parameter	TCM3	TCM5	Units
Calibrated Field Measurement Range	±80	±80	µT
Magnetic Resolution	±0.05	±0.05	µT
Magnetic Repeatability	±0.1	±0.1	µT

2.1.3 Tilt Specifications

Parameter	TCM3	TCM5	Units
Pitch Accuracy	0.2º	0.2º	Deg RMS
Roll Accuracy	0.2º for pitch <65º 0.5º for pitch <80º	0.2º for pitch <65º 0.5º for pitch <80º 1.0 for pitch <86º	Deg RMS
Tilt Range	±80º	±90º pitch ±180º roll	Deg
Tilt Resolution	<0.01º	<0.01º	Deg
Tilt Repeatability[1]	0.05º	0.05º	Deg RMA

1] Repeatability is based on statistical data at ±3 sigma limit about the mean.

2.1.4 Calibration

Parameter	TCM3	TCM5
Hard Iron Calibration	Yes	Yes
Soft Iron Calibration	Yes	Yes

2.1.5 Mechanical Specifications

Parameter	TCM3	TCM5	Units
Dimensions (LxWxH)	3.5 x 4.3 x 1.3	3.5 x 4.3 x 1.3	cm
Weight	<7	<7	grams
Mounting Options	Screw mounts/Standoffs Horizontal	Screw mounts/Standoffs Horizontal or vertical	
Connector for RS-232	9-pin	9-pin	

2.1.6 I/O Specifications

Parameter	TCM3	TCM5	Units
Time to Initial Good Data from Power On[1]	<210	<210	msec
Time to Initial Good Data from Sleep Mode[1]	<80	<80	msec
Maximum Sample Rate[2]	~30	~30	samples/sec
RS-232 Communication Rate	300 to 115200	300 to 115200	baud
Output Formats	Binary High Performance Protocol		

[1] FIR taps set to "0".
[2] The maximum sample rate is dependent on the strength of the magnetic field, and typically will be from 25 to 32 samples/sec.

2.1.7 Power Specifications

Parameter	TCM3	TCM5	Units
Supply Voltage	3.8 to 5 V (unregulated)	3.8 to 5 V (unregulated)	VDC
Current Draw at maximum sample rate	20 typical	20 typical	mA
Sleep Mode	0.6 typical	0.6 typical	mA

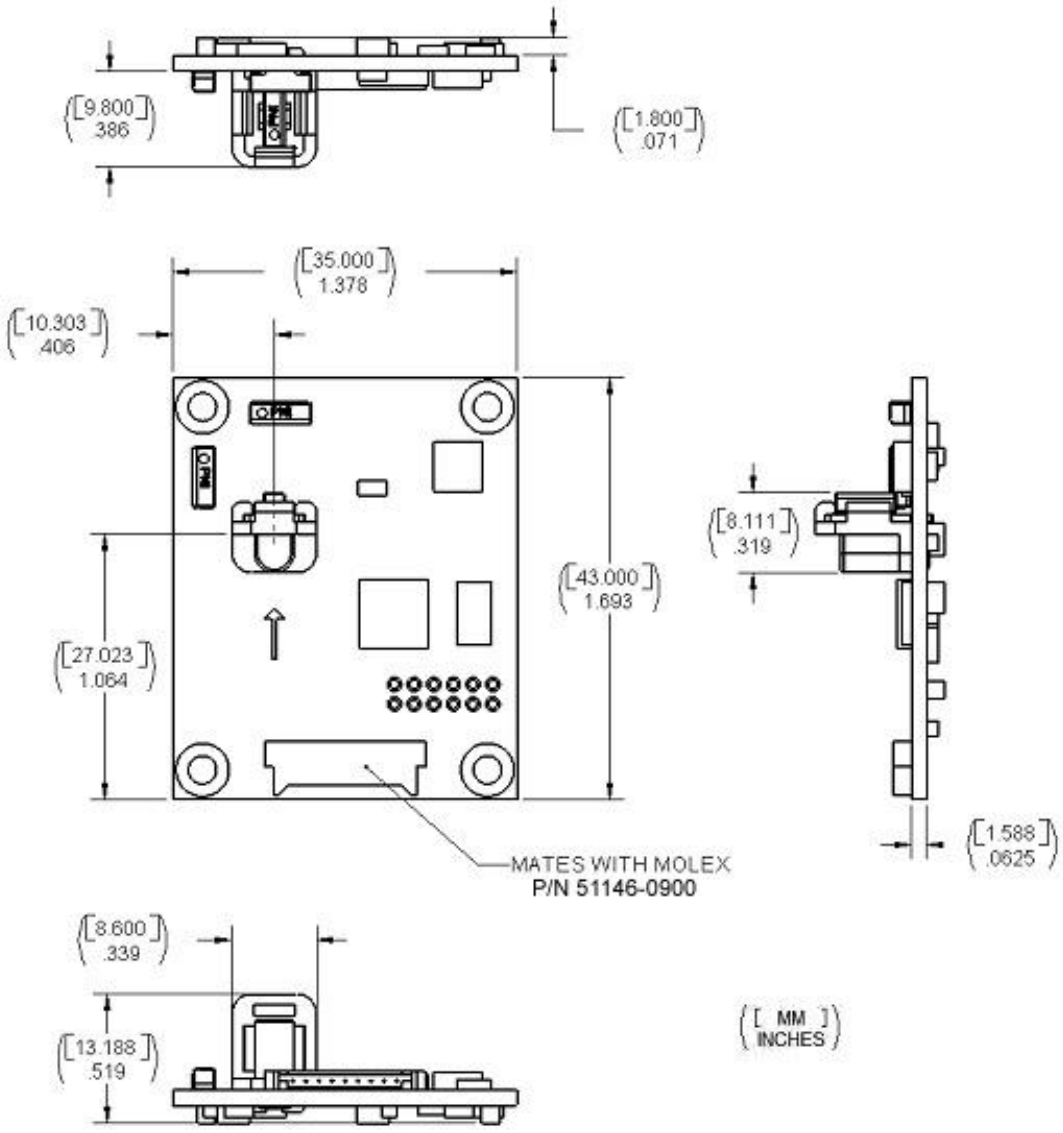
2.1.8 Environmental Specifications

Parameter	TCM3	TCM5	Units
Operating Temperature	-40º to 85º	-40º to 85º	C
Storage Temperature	-40º to 85º	-40º to 85º	C

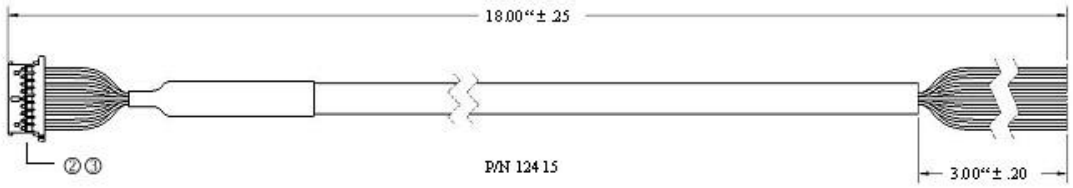
2.2 Mechanicals

2.2.1 Mechanical Drawing

The default orientation for the TCM is for the silk-screened arrow to point in the “forward” direction. That puts the edge opposite of the Molex connector as the front edge of the board.



2.2.2 18 in. Cable Assembly



② Molex p/n 51146-0900

③ Molex p/n 50641-8141

TCM Pin Descriptions

Pin	Wire Color	Description
1	Black	Power Ground
2	Gray	NC
3	Green	R2-232 Ground
4	Orange	NC
5	Violet	NC
6	Brown	NC
7	Yellow	TxD
8	Blue	RxD
9	Red	5 VDC

3 Installation of the TCM

This section describes how to configure, program, and control the TCM in your host system. To install the TCM into your system, follow these steps:

- **Make electrical connections to the TCM**
- **Evaluate the TCM using the included TCM Studio Program**
- **Choose a mounting location**
- **Mechanically mount the TCM**
- **Perform user calibration**

Before you install the module, it can be evaluated with the TCM Studio outside of your system. Please see section 4.1 TCM Studio.

3.1 Electrical Connections

Included with the TCM Interface Kit is a cable to allow for the unit to be connected to your host system. On one end of the cable is the connector needed to mate with the TCM3/5. The cable's wires are color coded as indicated below.

PNI also has a 6-foot cable with a DB9 connector attached. Please contact PNI Corporation for purchasing information.

TCM Pin Descriptions

Pin	Wire Color	Description
1	Black	Power Ground
2	Gray	NC
3	Green	R2-232 Ground
4	Orange	NC
5	Violet	NC
6	Brown	NC
7	Yellow	TxD
8	Blue	RxD
9	Red	5 VDC

3.2 Where to Install

The TCM's magnetometers' wide dynamic range and its sophisticated calibration algorithms allow it to operate in many environments. For optimal performance however, you should mount the TCM with the following considerations in mind:

The TCM's magnetometers should not saturate

The TCM can be user calibrated to correct for large static magnetic fields created by the host system. However, each axis of the TCM's magnetometers has a maximum dynamic range of ±80 μT; if the total field exceeds this value for any axis, the TCM will not give accurate heading information. When mounting the TCM, consider the effect of any sources of magnetic fields in the local environment that when added to the earth's field may saturate the TCM's sensors. For example, large masses of ferrous metals such as transformers and vehicle chassis, large electric currents, permanent magnets such as electric motors, and so on.

Locate the TCM away from local sources of changing magnetic fields

It is not possible to calibrate for changing magnetic anomalies. Thus, for greatest accuracy, keep the TCM away from sources of local magnetic anomalies that will change with time; for instance, electric equipment that will be turned on and off or nearby ferrous bodies that will be changing positions. Make sure the TCM is not mounted close to cargo or payload areas that may be loaded with large sources of local magnetic fields.

The TCM should be mounted in a physically stable location

Choose a location that is isolated from excessive shock, oscillation, and vibration.

Testing

Testing should be performed in the early stages of development to understand the range of any distortion fields and transients so that component placement can take this into consideration.

To determine the range of field distortion, place the compass in a fixed position, then move/energize suspect components while observing the output to determine when they are an influence.

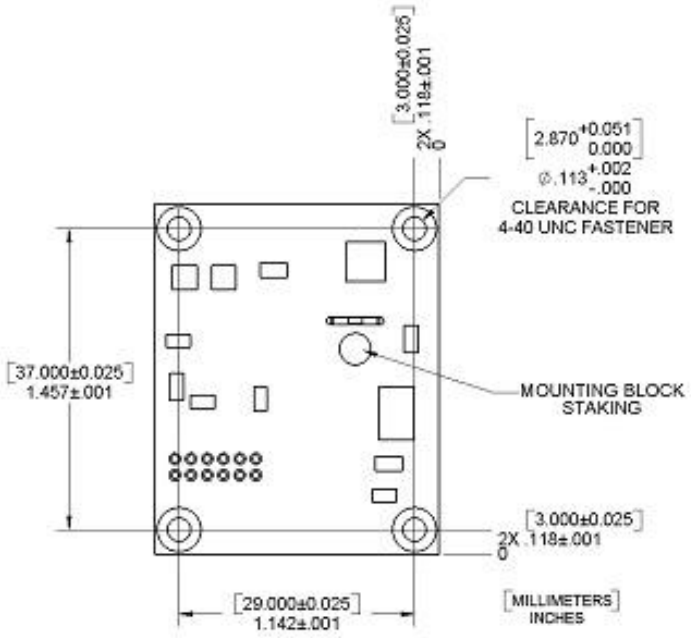
To determine if the mounting locations magnetic field is within the dynamic range of the compass, the following test should be performed:

With the compass mounted, rotate and tilt the systems in as many positions as possible. While doing so, monitor the magnetometer outputs, observing if the maximum dynamic range is exceeded. It is preferable to have some margin before hitting the dynamic range limit of the module.

3.3 Mechanically Mounting the TCM

Refer to the TCM Dimensional Specification later in this manual for the TCM board dimensions and the orientation of the reference frame.

The TCM is factory calibrated with respect to the mounting holes, as shown below, thus it must be aligned within the host system with respect to these mounting holes, not the board edges.



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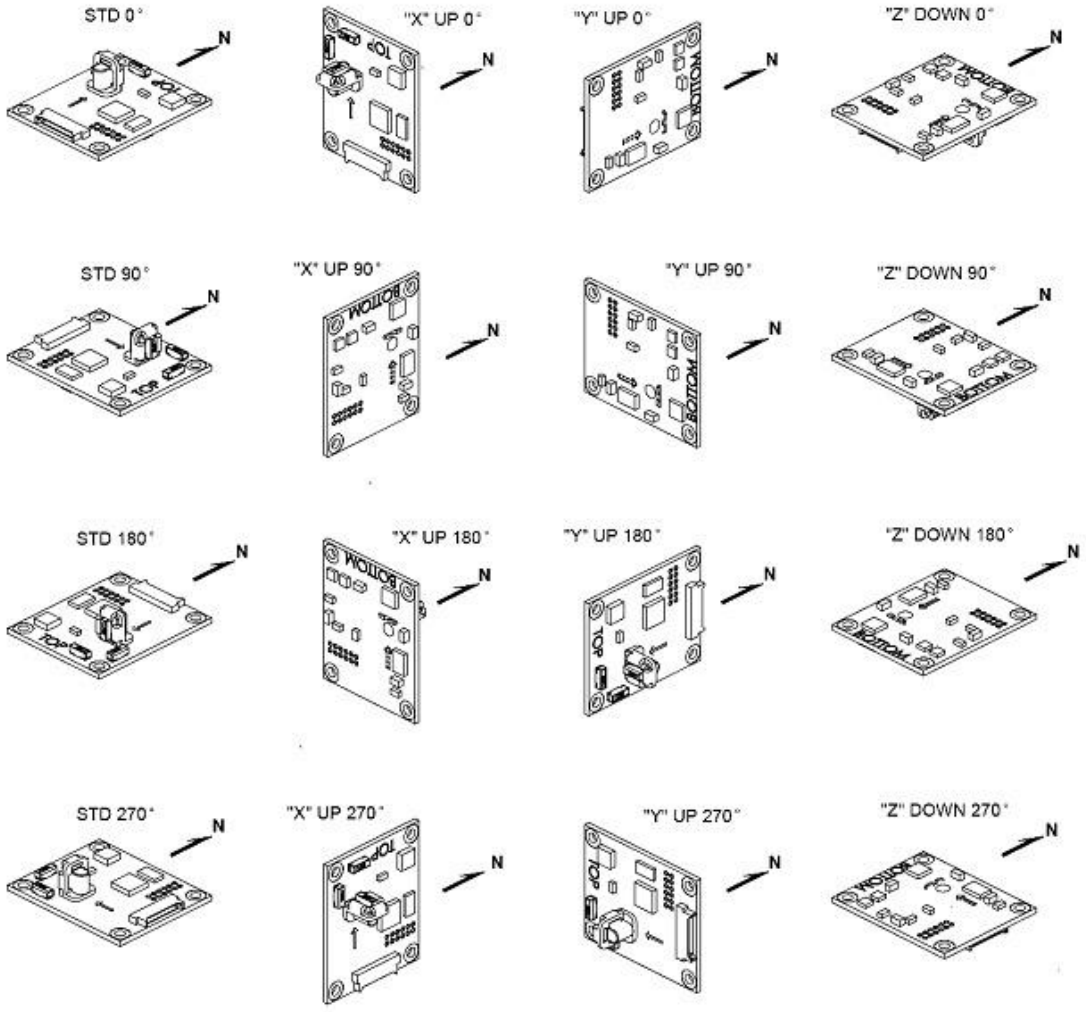
Mounting Options

The TCM is able to be mounted in various positions to allow for greater flexibility. All reference points are based on the white silk-screened arrow on the top side of the board.

Note: *The board depicted below is for illustration purposes only and does not show the actual TCM board.*

TCM3/5 Mounting Options



4 Using the TCM

- TCM Studio
- User Calibration
- Binary Protocol
- Code Examples

4.1 TCM Studio

The TCM Evaluation software communicates with the TCM through the COM port of your PC. It puts an easy-to-use interface onto the Binary command language used by the TCM, so that instead of issuing command codes manually, you can use buttons, check boxes, and dialog boxes. It reads the Binary responses of the TCM output strings and formats its sensor data into labeled and easy-to-read data fields. The program also includes the ability to log and save the outputs of the TCM to a file. All of this is so that you may begin to learn the capabilities of the TCM while using the TCM Studio program's more friendly interface. *Check the PNI website for the latest updates at www.pnicorp.com.*

4.1.1 Install the TCM Studio program onto a Windows system:

1. Drag the "TCM Studio.exe" to the working directory of your computer.
2. Move the Quesa plug-in (Quesa.dll) into either the Windows System or System32 folder. Quesa is the OpenGL rendering engine and the 3D Model of the TCMStudio will not run without it.
    - For Windows 2000/NT copy to: /WinNT/System32 folder
    - For Windows XP copy to: /Windows/System32 folder

To install the TCM Studio program onto a **Mac OSX** system:

1. Drag the "TCM Studio" to the working directory of your computer.
2. Move the Quesa plug-in (Quesa) to: /Library/CFMSupport

4.1.2 Connection Tab

Initial Connection:

1. Select 38400 as the baud rate.
2. Select the serial port the unit is plugged into.
3. Click on the **<Connect>** button.
4. Once a connection is made the "Connected" light will turn green and the Module, Firmware Version and Serial Number will be displayed.

Change Baud Rate:

1. Select new baud rate for the module.
2. Click on the **<Power Down>** button.
3. Select same baud rate for the computer.
4. Click on the **<Power Up>** button.

Change Modules:

Once connection has been made, the TCM Studio will remember the last settings. Any time a module is switched out, clicking on the **<Connect>** button once the new module is attached will reestablish a connection as long as the module baud rate is the same as the previous unit.

4.1.3 Configuration Tab

Note: No settings will be changed in the unit until the <SAVE> button has been selected.

Mounting Options:

Note: If the selection is grayed out or not listed the unit connected does not support this feature. Refer to "Mechanically Mounting – mounting option" section for additional information on mounting options.

Standard: When selected the unit is to be mounted with the main board in a horizontal position (the Z axis magnetic sensor is vertical).

Standard 90 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 90 degrees clockwise from the front of the host system.

Standard 180 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 180 degrees from the front of the host system.

Standard 270 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 270 degrees clockwise from the front of the host system.

X Sensor Up: When selected the unit is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical).

X Sensor Up Plus 90 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical) and rotated 90 degrees clockwise from the front of the host system.

X Sensor Up Plus 180 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical) and rotated 180 degrees from the front of the host system.

X Sensor Up Plus 270 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical) and rotated 270 degrees clockwise from the front of the host system.

Y Sensor Up: When selected the unit is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical).

Y Sensor Up Plus 90 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical) and rotated 90 degrees clockwise from the front of the host system.

Y Sensor Up Plus 180 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical) and rotated 180 degrees from the front of the host system.

Y Sensor Up Plus 270 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical) and rotated 270 degrees clockwise from the front of the host system.

Z Sensor Down: When selected the unit is to be mounted with the main board in a vertical position (the Z axis magnetic sensor is vertical).

Z Sensor Down Plus 90 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the Z axis magnetic sensor is vertical) and rotated 90 degrees clockwise from the front of the host system.

Z Sensor Down Plus 180 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the Z axis magnetic sensor is vertical) and rotated 180 degrees from the front of the host system.

Z Sensor Up Plus 270 Degrees: When selected the unit is to be mounted with the main board in a vertical position (the Z axis magnetic sensor is vertical) and rotated 270 degrees clockwise from the front of the host system.

North Reference:

Magnetic: When the "Magnetic" radio button is selected, heading will be relative to Magnetic North.

True: When the "True" radio button is selected, heading will be relative to True North. To use North Heading in "True" mode, the declination needs to be set in the "Declination" window. Refer to "Using the TCM Declination Value" section for more information.

Endianess:

Use to select either Big Endian or Little Endian; default is Big Endian.

Filter Settings:

Taps: Use to select either a 0 (no filter), 4, 8, 16, or 32 samples and apply the values to a FIR filter prior to calculating the heading. These filters allow for a much more stable reading, but can make the acquisition of the data by the program slower. The default setting is 32.

Acquisition Parameters:

Mode:

- When "Poll" is selected the TCM Studio program requests the data from the unit, and once it has been sent, the program will request the data again at the interval set in the "Poll Time" box. If the time is set to 0 then the TCM Studio will request the data as soon as the previous request has been fulfilled.

- When "Push" is selected the unit will be in **Interval Mode**, which is internal to the unit. Once the unit has been set to **Interval Mode** and the interval time has been set in the "Interval Time" setting box, the unit will send out the preset data at the desired interval without prompting. If the interval is set to 0 then the unit will send the data as soon as the previous data stream has been sent.

Acquire Time:

The "Acquire Time" setting box sets the time between samples taken by the unit. This is an internal setting that is NOT tied to the time with which the unit transmits the data out to the program or host.

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Flush Filters:

The filtering is set to only update the filter with the last sample taken, for example once the initial 32 samples are taken any new sample is added to the end with the first sample being dropped. In the case where the "Acquire Time" is set to a value it would be prudent to set the unit to flush the filter prior to calculating the heading. This flushing will require the unit to take 32 new samples to use for the calculation.

Note: If the "Flush Filters" checkbox is checked, it will take longer for the unit to output updated data.

User Cal Settings:

Stability Checking:

By default the unit will wait for the readings to be stable for 3 consecutive readings when in calibration mode prior to saving the sample for use in the calibration. This is why the unit must be held steady between points during the User Calibration. This stability helps to ensure a proper heading and allow for higher accuracy, but it also takes more time. If the user *de-selects* the check box, then the unit will NOT wait for a stable reading and instead take a reading once the minimum change between points threshold has been met.

Automatic Sampling:

When selected the unit will take a point once the minimum change requirement and the stability check, if selected, has been satisfied. If the user wants to have more control over when the point will be taken then Auto Sampling should be deselected. Once deselected, the **<Take Sample>** button on the ***Calibration*** tab will be active. Selecting the **<Take Sample>** button will indicate to the unit to take a sample once the minimum requirements are met.

Calibration Points:

The user can select the number of points to take during a calibration. The minimum number of points needed for a successful calibration is 12. The unit will need to be rotated through at least 180 degrees in the horizontal plane with a minimum of at least 1 positive and 1 negative Pitch and at least 1 positive and 1 negative Roll as part of the 12 points.

Enable 3D Model:

Some computer systems may not have the graphics capability to render the 3D Model, for this reason it may be necessary to turn off this feature.

Default:

This button will set the TCM Studio program back to the factory default settings.

Revert:

This button will have the TCM Studio program read the settings from the unit and display them on the screen.

4.1.4 Calibration Tab

Note: The default settings of the unit are recommended for the highest accuracy and quality of calibration.

Samples:

1. Click on the **<Start>** button to begin.
2. To take a sample point, the unit will need to be held steady for a short time. Once the window indicates the next number, the unit can be moved some distance and held steady for the next sample. A minimum change of 30 degrees in heading or tilt is required for a sample to be taken. The larger the distance between points the better. The amount of Pitch and Roll during the calibration will determine the amount of Pitch and Roll the unit will be able to compensate for during use. Once the pre-set number of samples has been taken the calibration is complete.

   Note: The minimum points the unit can use for a successful calibration is 12. The unit will need to be rotated through at least 180 degrees in the horizontal plane with minimum of at least 1 positive and 1 negative Pitch and Roll as part of the 12 points.

Results:

1. Once the calibration is complete the “Coverage” window will indicate the quality of the calibration. The X, Y, and Z values show a percentage of each vector that has been covered during the calibration. The only way to get a Z value greater than 50% would be to take some points with the unit upside-down. The value shown in µT refers to the standard deviation of the measured samples when compared to the calculated values. The smaller the number the better. If a better score is needed, click on the **<Start>** button to begin a new calibration.

   Note: The value in µT only refers to the quality of the calibration and NOT the accuracy of the heading. It is possible to have a “good” calibration but poor accuracy if the field the unit is exposed to during use is not the same as that which was present during the calibration.

2. If the calibration is sufficient then click on the **<Save>** button to save the calibration. If this button is not selected then the unit will need to be recalibrated after a power cycle.

Current Configuration:

Stability Checking: Indicates if the Stability Checking option has been selected.

Automatic Sampling: Indicates if the Automatic Sampling option has been selected.

Number of samples is: Indicates the number of samples to be taken for the current calibration.

Options:

Audible Feedback: If selected the TCM Studio will give an audible signal once a calibration point has been taken.

Clear:

This button will clear the user calibration in the unit. Once selected, the unit will revert back to its factory calibration.

4.1.5 Test Tab

Current Reading:

Once the **<GO>** button is selected the unit will begin outputting Heading, Pitch and Roll information. Selecting the **<Stop>** button or changing tabs will halt the output of the unit.

Contrast:

Reverses the background color of the current reading window.

Acquisition Settings:

This window indicates the pertinent setting information.

3D Model:

The helicopter will follow the movement of the attached module and give a clear representation of the module's orientation.

4.1.6 Data Logger Tab

1. Select the data to log in the “Data” window.
2. Use **Shift-Ctrl-Click** and **Ctrl-Click** to select multiple items.
3. Click on the **<GO>** button to start logging; click the **<STOP>** button to stop logging.
4. Click on the **<Export>** button to save the data to a file.
5. Click on the **<Clear>** button to clear the data from the window.

Note: The data logger use ticks for time reference. A tick is 1/60 second.

4.1.7 System Log Tab

Export:

Select the **<Export>** button to save the system log to a file.

Graph

The graph provides a 2-axis (X,Y) plot of the measured field strength. The graph can be used to visually see hard and soft iron effects within the environment measured by the TCM module as well as corrected output after a user calibration has been performed.

4.2 User Calibration

All compasses can perform well in a controlled environment, where the ambient magnetic field consists solely of the earth's field. In most practical applications, however, an electronic compass module will be mounted in a host system such as a vehicle that can contain large sources of local magnetic fields: ferrous metal chassis, transformer cores, electrical currents, and permanent magnets in electric motors.

By performing the user calibration procedure, you allow the TCM to identify the major sources of these local magnetic anomalies and subsequently cancel out their effects when measuring the earth's magnetic field for computing compass headings. When you perform the user calibration procedure, the TCM takes a series of magnetic field measurements. It analyzes these total field measurements in order to identify the components that are created by the earth's field, which is the desired signal, from those components that are generated by the local environment, which we wish to subtract out.

The end goal of the procedure for the TCM is to have an accurate measurement of the static three-dimensional magnetic field vector generated by its host system at its mounting location. This vector is subsequently subtracted out of run-time field measurement to yield the resultant earth's field vector.

One major benefit from the TCM's triaxial magnetometer/triaxial accelerometer system configuration is its ability to compensate for distortion effects in all orientations throughout its usable tilt range. As we have mentioned, a compass must measure the local field vector generated by the host system at its current position within the system in order to accurately calibrate. Because the TCM's magnetometer is strapped-down, or fixed with respect to its host system, this local field vector does not change as the host system's attitude changes, allowing the TCM to accurately compensate in all pitch and roll orientations. Gimbaled fluxgates, for instance, are unable to provide accurate calibration in non-level orientations because its magnetometers, being gimbaled, change position with respect to the host system as attitude changes. This presents a different local distortion field than that measured during calibration.

Key Points

- The minimum points the unit can use for a successful calibration is 12.
- The unit will need to be rotated through at least 180 degrees in the horizontal plane including at least 1 positive and 1 negative Pitch and Roll movement.
- Tilt as much as possible during the calibration. This allows the compass to take full advantage of the 3-axis magnetometer.
- You are trying to get an even sampling of the magnetic field over as many headings and tilts as possible, including upside down if possible.
- Pay attention to the coverage percentage. The lower the percentage the less accurate the compass.

4.2.1 Calibration Theory

The exact calibration method will depend on the actual settings of the calibration parameters. An example of the various settings and their effect can be seen in the **TCM Studio – Evaluation Software** section.

The main object of the calibration is to allow the TCM to calibrate out any distortions to the magnetic field caused by the host system. To that end the TCM needs to be mounted within the host system and the entire application needs to be moved as a single unit during the calibration. Movement should include at least 180˚ of horizontal rotation, but to achieve the highest accuracy a full 360˚ of horizontal rotation with as many different tilt angles as possible during the rotation is required.

To achieve the highest accuracy throughout the TCM's entire tilt range, the unit will need to be tilted through the entire range. For example, if the unit is only tilted through 40˚ of pitch and roll, then the heading information from the TCM will only be accurate through 40˚ of pitch and roll. For maximum performance the TCM should be exposed to tilt angles covering a full 360°, meaning upside down.

Recommended calibration procedure for taking the minimum number of sample points follows.

4.2.2 Hard and Soft Iron Effects

Hard iron distortions are caused by permanent magnets and magnetized steel or iron object within close proximity to the sensors. This type of distortion will remain constant and in a fixed location relative to the sensors for all heading orientations. Hard-iron distortions will add a constant magnitude field component along each axis of sensor output and can be easily compensated for using a simple saturation method.

Soft-iron distortions are the result of interactions between the Earth's magnetic field and any magnetically "soft" material within close proximity to the sensors. In technical terms, soft materials have a high permeability. The permeability of a given material is a measure of how well it serves as a path for magnetic lines of force, relative to air, which has an assigned permeability of one.

The TCM 3-axis digital compass features soft-iron and hard-iron correction.

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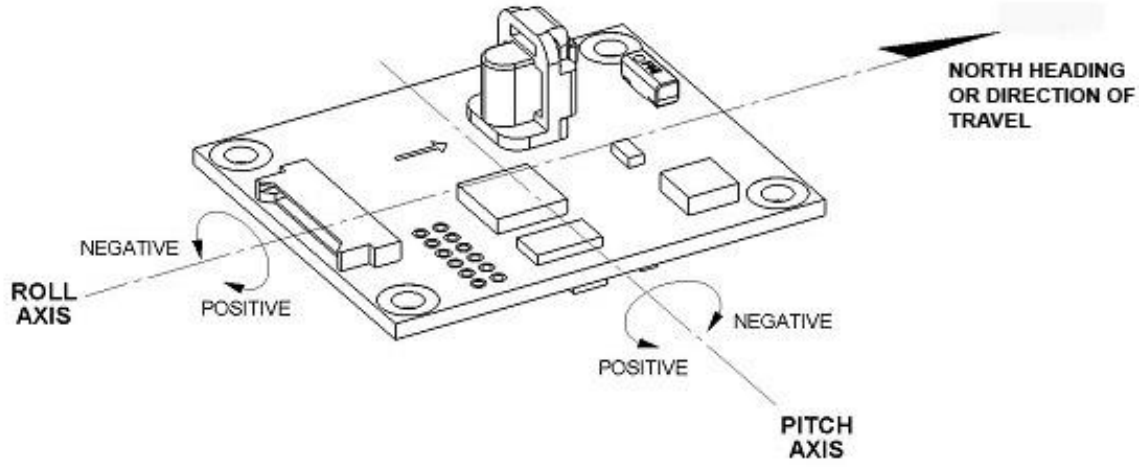
4.2.3 Pitch and Roll

The TCM uses accelerometers to measure the orientation of the compass with respect to gravity. Since the compass also measures the complete magnetic field, the TCM can correct for the tilt of the compass to provide an accurate heading.

The TCM utilizes Euler angles as the method for determining accurate orientation. This method is the same used in aircraft orientation where the outputs are Heading (Yaw), Pitch and Roll. When using Euler angles pitch and roll are defined as the angle rotated around an axis through the center of the fuselage; pitch is rotation around an axis through the center of the wings. These two rotations are independent of each other since the rotation axes rotate with the plane body.

For the TCM a *positive pitch* is when the *front edge of the board is rotated upward* and a *positive roll* is when the *right edge of the board is rotated downward*.



TCM Standard Mounting

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4.2.4 Recommended Calibration Procedure For Taking The Minimum Number Of Sample Points

This procedure provides instructions for performing a user calibration of the TCM 3/5/5L family of modules using the TCMStudio application and demo cable. All of the TCMStudio application functions are available in the TCM unit's binary protocol allowing for this procedure to be translated into a user's imbedded solution. The scope of this procedure covers the calibration process only, for connecting to the unit or other issues refer to the quick start guide or users manual. This calibration sequence demonstrates a good distribution of the minimum sample points, additional points may be added.

1) With the TCM module connected and communicating with TCMStudio, go to the configuration page.
2) Configure the unit as follows:
   In the Filter Settings window set Taps to 32
   Calibration Settings: Select Stability Checking check box
   Select Automatic Sampling
   Choose Calibration points: 12
3) Press the Save button.
4) Go to the calibration page.

Note: Once you begin taking calibration points, pausing between desired calibration points will cause unintentional points to be taken with auto sampling enabled.

You will move the module to the following positions noting that **these are not absolute heading directs but rather approximate heading changes referenced to your first heading sample.** You do not need to know which way north is. The following 12 samples points will be taken:

Module with slight pitch (-5° to +5°)

- 0° yaw with 10°-20° positive roll (initial starting position)
- 90° yaw with 10°-20° negative roll
- 180° yaw with 10°-20° positive roll
- 270° yaw with 10°-20° negative roll

Module with large positive pitch (>+45°)

- 30° with 10°-20° positive roll
- 120° with 10°-20° negative roll
- 210° with 10°-20° positive roll
- 300° with 10°-20° negative roll

Module with large negative pitch (<-45°)

- 60° with 10°-20° positive roll
- 150° with 10°-20° negative roll
- 240° with 10°-20° positive roll
- 330° with 10°-20° negative roll.

5) Hold the module level and stable.
6) Press the Start button and wait for a sample to be taken.
7) Rotate the module to the next heading, approximately 90 degrees, and hold the module stable until the next sample is taken.
8) Repeat this until all 12 samples are taken.
9) Press the Save button.
10) Calibration results will be displayed in the Results window with Coverage X, Y and Z in % and Std Deviation of Magnetic Field Magnitude in uT. The Coverage score is how much of the sphere was each sensor exposed to in percent to describe the shape of the distortion to be corrected for. You want a score of 85% or better for X and Y, with the above method Z will be below 50%. The Std Deviation score should have a result of 0.1uT or better. The Std. Deviation score represents how well the distortion was able to be described and compensated for. A poor score will result if sources of distortion to be calibrated out moved during the user calibration relative to the module. A magnetically noisy environment will also result in a poor calibration.

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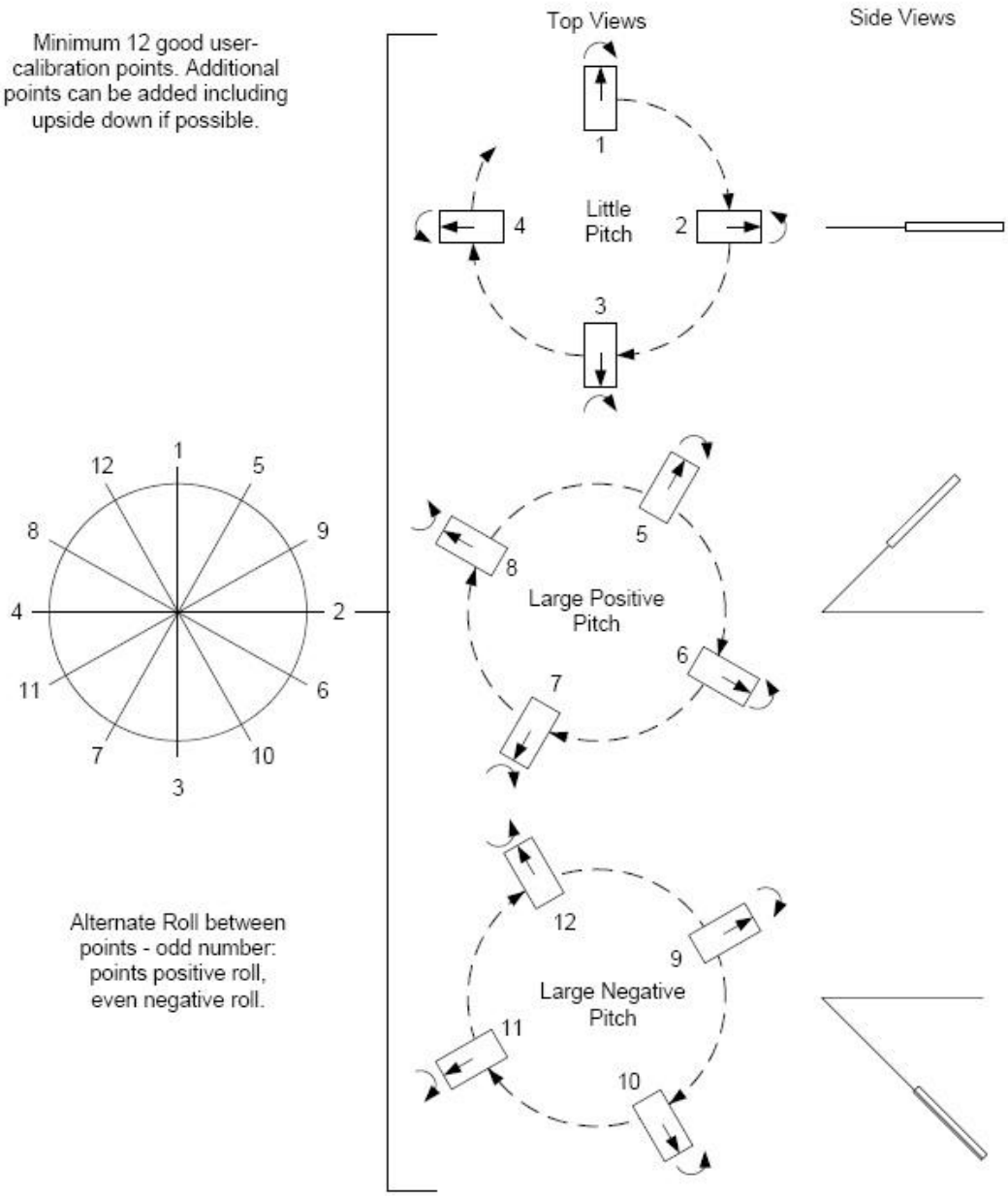

4.2.5 Declination Value

Declination, also called magnetic variation, is the difference between true and magnetic north, relative to a point on the earth. It is measured in degrees east or west of true north. Correcting for declination is accomplished by storing the correct declination angle, and then changing the heading reference from magnetic north to true north. Declination angles vary throughout the world, and change very slowly over time. For the greatest possible accuracy, go to the National Geophysical Data Center web page below to get the declination angle based on your latitude and longitude: http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp

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4.2.6 Other Limitations

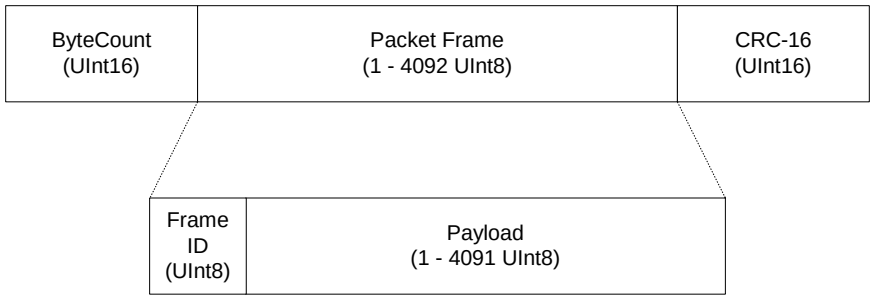
As discussed, the TCM models local disturbances as a static magnetic vector contribution to the earth's field. Any local fields, which are not static, will create errors. You cannot calibrate for anomalies that are not fixed with respect to the compass. For example, you may know that the TCM will be used in close proximity to other vehicles. You cannot calibrate for the effects of these other vehicles, as they will be moving with respect to the TCM. This is a limitation universal to all compasses. Consider, therefore, the TCM's position relative to any potential sources of field that will not be static: magnetic cargo or payloads that may be placed in close proximity, fans or other electrical equipment that may be turned on and off, and so on.

The TCM can calibrate for any environment that creates a magnetic field that does not exceed the dynamic range of its magnetometers.

4.3 Binary Protocol – RS232 Interface

4.3.1 Datagram Structure

Transport Layer for RS-232 communication:



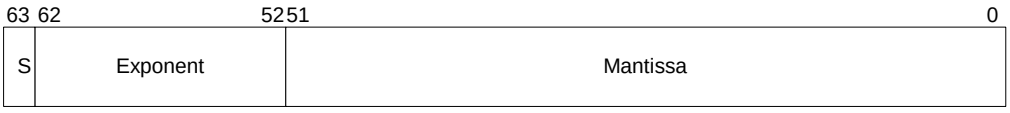
Note:

1. ByteCount is the total number of bytes in the packet including the CRC-16
2. CRC-16 is calculated starting from the ByteCount to the last byte of the Packet Frame (see included C function at end of document).
3. ByteCount and CRC-16 are always transmitted in BIG ENDIAN.

4.3.2 Parameter Formats

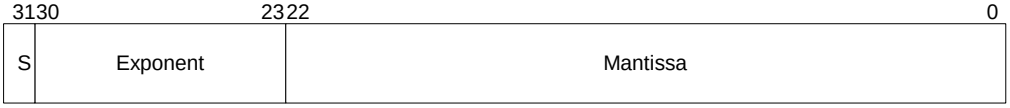
Floating Point
The floating-point based parameters are in the IEEE standard format, ANSI/IEEE Std 754-1985.

64-Bit (double precision floating point)
Shown below is the 64-bit float format in big endian, in little endian bytes are in reverse order in 4 byte groups (ie: big endian:ABCDEFGH little endian: DCBA HGFE).



The value (v) is determined as (if and only if 0 < Exponent < 2047): $v = (-1)^{S} * 2^{(Exponent-1023)} * 1.Mantissa$

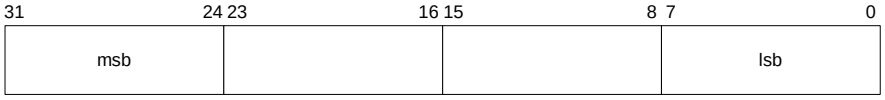
32-Bit (single precision floating point)
Shown below is the 32-bit float format in big endian, in little endian all 4 bytes are in reverse order (LSB first).



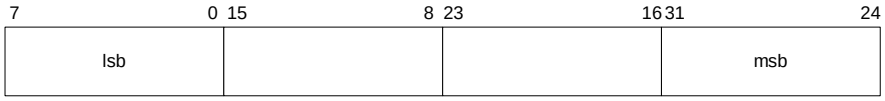
The value (v) is determined as (if and only if 0 < Exponent < 255): $v = (-1)^S * 2^{(Exponent-127)} * 1.Mantissa$

Note: Please refer to ANSI/IEEE Std 754-1985 for more information. It is also recommended that you refer to the compiler you are using on how it implements floating-point formats.

Signed 32-bit Integer (SInt32)
SInt32 based parameters are signed 32 bit numbers (2's compliment). Bit 31 represents the sign of the value (0=positive, 1=negative)

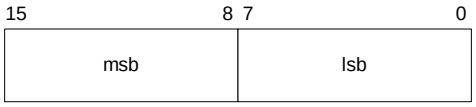


Big Endian

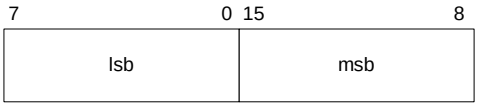


Little Endian

Signed 16-bit Integer (SInt16)
SInt16 based parameters are signed 16 bit numbers (2's compliment). Bit 15 represents the sign of the value (0=positive, 1=negative)



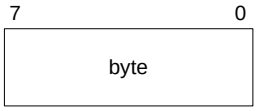
Big Endian



Little Endian

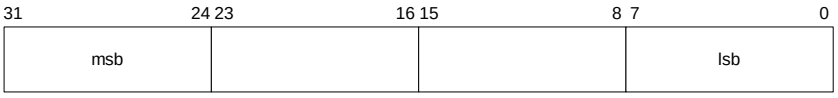
Signed 8-bit Integer (SInt8)

UInt8 based parameters are unsigned 8-bit numbers. Bit 7 represents the sign of the value (0=positive, 1=negative)

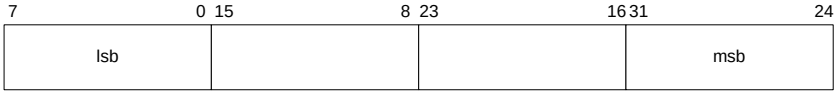


Unsigned 32-bit Integer (UInt32)

UInt32 based parameters are unsigned 32 bit numbers.



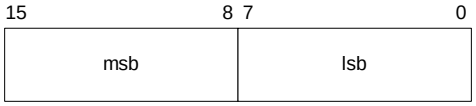
Big Endian



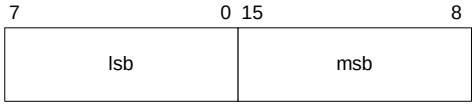
Little Endian

Unsigned 16-bit Integer (UInt16)

UInt16 based parameters are unsigned 16 bit numbers.



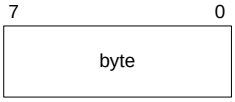
Big Endian



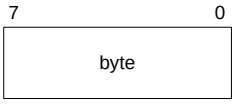
Little Endian

Unsigned 8-bit Integer (UInt8)

UInt8 based parameters are unsigned 8-bit numbers.



Boolean
Boolean is a 1-byte parameter that MUST have the value 0 (false) or 1 (true).



4.3.3 Commands & Communication Frames

Overview:

Frame ID	Command	Description
1	kGetModInfo	Queries the modules type and firmware revision number.
2	kModInfoResp	Response to kGetModInfo
3	kSetDataComponents	Sets the data components to be output.
4	kGetData	Queries the module for data
5	kDataResp	Response to kGetData
6	kSetConfig	Sets internal configurations in the module
7	kGetConfig	Queries the module for the current internal configuration value
8	kConfigResp	Response to kGetConfig
9	kSave	Commands the module to save internal and user calibration
10	kStartCal	Commands the module to start user calibration
11	kStopCal	Commands the module to stop user calibration
12	kSetParam	Sets the FIR filter settings for the magnetometer & accelerometer sensors.
13	kGetParam	Queries for the FIR filter settings for the magnetometer & accelerometer sensors.
14	kParamResp	Contains the FIR filter settings for the magnetometer & accelerometer sensors.
15	kPowerDown	Used to completely power-down the module
16	kSaveDone	Response to kSave
17	kUserCalSampCount	Sent from the module after taking a calibration sample point
18	kUserCalScore	Contains the calibration score
19	kSetConfigDone	Response to kSetConfig
20	kSetParamDone	Response to kSetParam
21	kStartIntervalMode	Commands the module to output data at a fixed interval
22	kStopIntervalMode	Commands the module to stop data output at a fixed interval
23	kPowerUp	Sent after wake up from power down mode
24	kSetAcqParams	Sets the sensor acquisition parameters
25	kGetAcqParams	Queries for the sensor acquisition parameters
26	kAcqParamsDone	Response to kSetAcqParams
27	kAcqParamsResp	Response to kGetAcqParams
28	kPowerDownDone	Response to kPowerDown
29	kFactoryUserCal	Clears user calibration coefficients
30	kFactorUserCalDone	Response to kFactoryUserCal
31	kTakeUserCalSample	Commands the unit to take a sample during user calibration

kGetModInfo (frame ID 1)

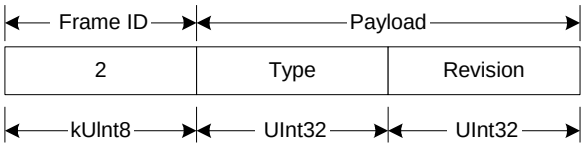
This frame queries the module's type and firmware revision number. The frame has no payload. The complete packet for the kGetModInfo command would be:

0005	01	EFD4

with 0005 being the byte count
01 kGetModInfo command
EFD4 CRC-16 checksum

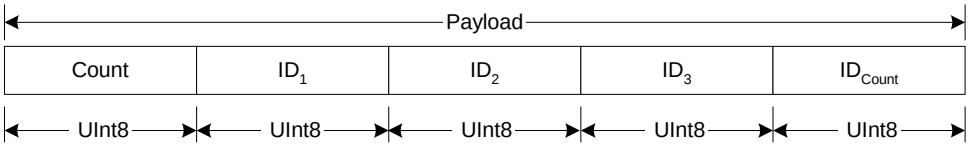
kModInfoResp (frame ID 2)

This frame is the response to kGetModInfo frame. The payload contains the module type identifier followed by the firmware revision number.



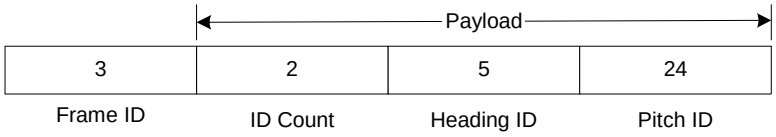
kSetDataComponents (frame ID 3)

This frame sets the data components in the module's data output. This is not a query for the module's data (see kGetData). The first byte of the payload indicates the number of data components followed by the data component IDs.



Example:

To query the heading and pitch, the payload should contain:



When querying for data (kGetData frame), the sequence of the data component output follows the sequence of the data component IDs as set in this frame.

Component Identifiers

Component	DataComponentID (decimal)	Format	Units	Range
kHeading	5	Float32	degrees	0.0˚ to 359.9˚
kTemperature	7	Float32	˚ Celsius	-40˚ to 85˚
kDistortion	8	Boolean	True or False	False (Default) = no distortion
kCalStatus	9	Boolean	True or False	False (Default) = not calibrated
kPCalibrated	21	Float32	G	-1.0 to 1.0
kRCalibrated	22	Float32	G	-1.0 to 1.0
kIZCalibrated	23	Float32	G	-1.0 to 1.0
kPAngle	24	Float32	degrees	-90.0˚ to 90.0˚
kRAngle	25	Float32	degrees	-180.0˚ to 180.0˚
KXAligned	27	Float32	µT	
KYAligned	28	Float32	µT	
KZAligned	29	Float32	µT	

Component Types for kSetDataComponents & kDataResp frames

kHeading Compass heading output.

kTemperature This is sampled from the internal temperature sensor of the module. Its value is in ° Celsius and has an accuracy of +/- 3° C.

kDistortion Read only flag that indicates that at least one magnetometer axis reading is beyond +/- 80 µT.

kCalStatus Read only flag that indicates user calibration status. False (Default) = Not calibrated.

kPCalibrated, kRCalibrated & kIZCalibrated Factory calibrated Earth's acceleration vector (G) component output.

kPAngle, kRAngle Pitch and Roll angle outputs. Pitch is equal to -90.0˚ to 90.0˚ and Roll is equal to -180.0˚ to 180.0˚.

kXAligned, kYAligned, kZAligned User calibration Earth's magnetic field (M) vector component output.

kGetData (frame ID 4)

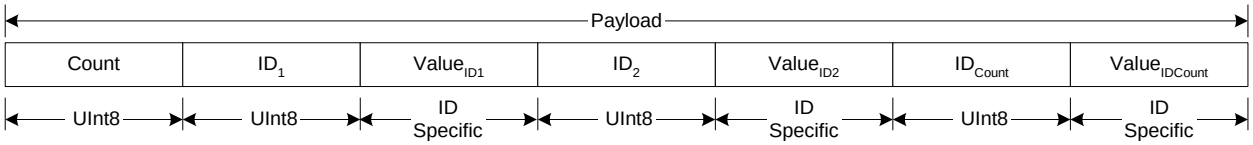
This frame queries the module for data. The frame has no payload. The complete packet for the kGetModInfo command would be:

00 05	04	BF71

with 00 05 being the byte count
04 kGetData command
BF71 CRC-16 checksum

kDataResp (frame ID 5)

The frame is the response to kGetData frame. The first byte of the payload indicates the number of data components then followed by the data component ID-value pairs. The sequence of the components Ids follows the sequence set in the kSetDataComponents frame.



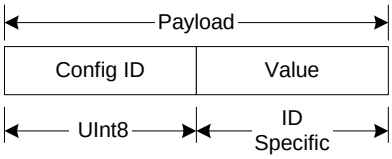
Example:

If the response contains the heading and pitch output, the payload would look like:

2	5	359.9	24	10.5
ID Count	Heading ID	Heading Output (Float32)	Pitch ID	Pitch Output (Float32)

kSetConfig (frame ID 6)

This frame sets internal configurations in the module. The first byte of the payload is the configuration ID followed by a format specific value. These configurations can only be set one at time.



Example:

To configure the declination, the payload would look like:

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1	10.0
Declination ID	Declination Angle (Float32)

Configuration Identifiers

Settings	Configuration ID	Format	Units/ Range	Default Values
kDeclination	1	Float32	-180˚ to 180˚	0˚
kTrueNorth	2	Boolean	True or False	False
kBigEndian	6	Boolean	True or False	True
kMountingRef	10	UInt8	1 = Standard 2 = X axis up 3 = Y axis up 4 = -90° heading offset 5 = -180° heading offset 6 = -270° heading offset 7 = Z down 8 = X + 90° 9 = X + 180° 10 = X + 270° 11 = Y + 90° 12 = Y + 180° 13 = Y + 270° 14 = Z down + 90° 15 = Z down + 180° 16 = Z down + 270°	1
kUserCalStableCheck	11	Boolean	True or False	True
kUserCalNumPoints	12	UInt32	12 – 50	50
kUserCalAutoSampling	13	Boolean	True or False	True
kBaudRate	14	UInt8	0 – 300 1 – 600 2 – 1200 3 – 1800 4 – 2400 5 – 3600 6 – 4800 7 – 7200 8 – 9600 9 – 14400 10 – 19200 11 – 28800 12 – 38400 13 – 57600 14 - 115200	12

kDeclination This sets the declination angle to determine True North heading. Positive declination is easterly declination and negative is westerly declination. This is not applied until TrueNorth is set to true.

kTrueNorth *Flag to set compass heading output to true north heading by adding the declination angle to the magnetic north heading.*

kBigEndian Flag to set the Endianness of packets

kMountingRef This sets the reference orientation for the module.

Standard: When selected the unit is to be mounted with the main board in a horizontal position (the Z axis magnetic sensor is vertical).
X Sensor Up: When selected the unit is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical).
Y Sensor Up: When selected the unit is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical).
Standard 90 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 90 degrees counterclockwise to the front of the host system.
Standard 180 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 180 degrees counterclockwise to the front of the host system.
Standard 270 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 270 degrees counterclockwise to the front of the host system.

kUserCalStableCheck This flag is used during user calibration. If set to FALSE, the module will take a point if the magnetic field has changed more than 23 µT in either axis. If set to TRUE the unit will take a point if the magnetic field has a stability of 30µT in each direction and the previous point changed more than 5µT and acceleration vector delta within 2 mg.

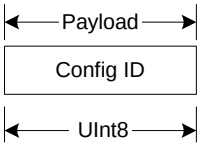
kUserCalNumPoints The maximum number samples taken during user calibration.

kUserCalAutoSampling This flag is used during user calibration. If set to TRUE, the module continuously takes calibration sample points until the set number of calibration samples. If set to FALSE, the module waits for kTakeUserCalSample frame to take a sample with the condition that a magnetic field vector component delta is greater than 5 micro Tesla from the last sample point.

kBaudRate Baud rate index value. A power-down power-up cycle is required when changing the baud rate.

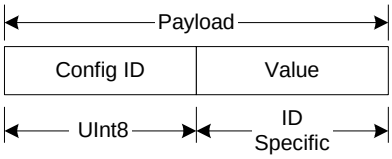
kGetConfig (frame ID 7)

This frame queries the module for the current internal configuration value. The payload contains the configuration ID requested.



kConfigResp (frame ID 8)

This frame is the response to kGetConfig frame. The payload contains the configuration ID and value.



Example:
If a request to get the set declination angle, the payload would look like:

1	10.0
Declination ID	Declination Angle (Float32)

kSave (frame ID 9)

This frame commands the module to save internal configurations and user calibration to non-volatile memory. Internal configurations and user calibration is restored on power up. The frame has no payload. This is the ONLY command that causes the module to save information into non-volatile memory.

kStartCal (frame ID 10)

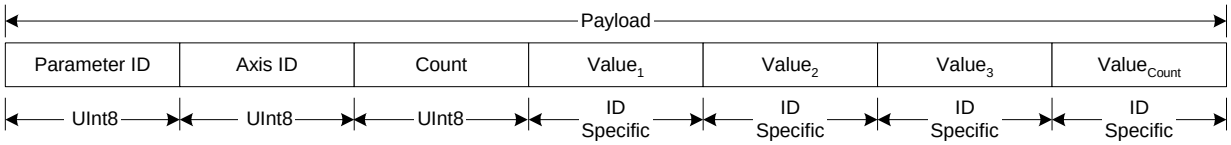
This frame commands the module to start user calibration with the current sensor acquisition parameters, internal configurations and FIR filter settings.

kStopCal (frame ID 11)

This frame commands the module to stop calibration points sampling and calculate the calibration score and coefficients.

kSetParam (frame ID 12)

This frame sets the FIR filter settings for the magnetometer and accelerometer sensors. The second byte of the payload indicates the x vector component of either the magnetometer or accelerometer. This is to differentiate whether to apply the filter settings to the magnetometer or accelerometer. The third byte in the payload indicates the number of FIR taps to use then followed by the filter taps. Each tap is a Float64. The maximum number of taps that can be set is 32 and the minimum is 0 (no filtering). (See Recommended FIR Filter Taps).



Parameter Identifiers

Settings	Parameter ID	Format
KFIRConfig*	3	AxisID (UInt8) + Count (UInt8) + Value (Float64) + Value (Float64) + …

Recommended FIR Filter Tap Value

2 Count	4 Tap Filter	8 Tap Filter	16 Tap Filter	32 Tap Filter
1	04.6708657655334e-2	01.9875512449729e-2	07.9724971069144e-3	01.4823725958818e-3
2	04.5329134234467e-1	06.4500864832660e-2	01.2710056429342e-2	02.0737124095482e-3
3	04.5329134234467e-1	01.6637325898141e-1	02.5971390034516e-2	03.2757326624196e-3
4	04.6708657655334e-2	02.4925036373620e-1	04.6451949792704e-2	05.3097803863757e-3
5		02.4925036373620e-1	07.1024151197772e-2	08.3414139286254e-3
6		01.6637325898141e-1	09.5354386848804e-2	01.2456836057785e-2
7		06.4500864832660e-2	01.1484431942626e-1	01.7646051430536e-2
8		01.9875512449729e-2	01.2567124916369e-1	02.3794805168613e-2
9			01.2567124916369e-1	03.0686505921968e-2
10			01.1484431942626e-1	03.8014333463472e-2
11			09.5354386848804e-2	04.5402682509802e-2
12			07.1024151197772e-2	05.2436112653103e-2
13			04.6451949792704e-2	05.8693165018301e-2
14			02.5971390034516e-2	06.3781858267530e-2
15			01.2710056429342e-2	06.7373451424187e-2
16			07.9724971069144e-3	06.9231186101853e-2
17				06.9231186101853e-2
18				06.7373451424187e-2
19				06.3781858267530e-2
20				05.8693165018301e-2
21				05.2436112653103e-2
22				04.5402682509802e-2
23				03.8014333463472e-2
24				03.0686505921968e-2
25				02.3794805168613e-2
26				01.7646051430536e-2
27				01.2456836057785e-2
28				08.3414139286254e-3
29				05.3097803863757e-3
30				03.2757326624196e-3
31				02.0737124095482e-3
32				01.4823725958818e-3

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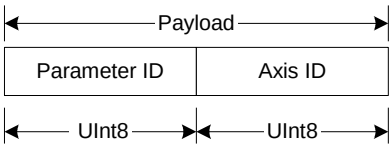
kGetParam (frame ID 13)

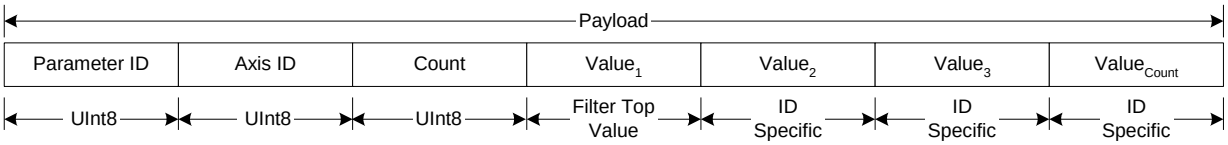
This frame queries the FIR filter settings for the magnetometer and accelerometer sensors. The first byte of the payload is the kFIRConfig ID followed by the vector axis ID (byte).



Axis IDs
kXAxis = 1
kYAxis = 2
kZAxis = 3
kPAxis = 4
kRAxis = 5
KIZAxis = 6

kParamResp (frame ID 14)

This frame contains the current FIR filter settings for either magnetometer or accelerometer sensors. The second byte of the payload is the vector axis ID, the third byte is the number of filter taps then followed by the filter taps. Each tap is a Float64.

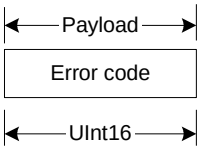


kPowerDown (frame ID 15)

This frame is used to completely power-down the module. The frame has no payload. The unit will power down all peripherals including the RS-232 driver but the driver chip has the feature to keep the Rx line enabled. Any character sent to the module causes it to exit power down mode. It is recommended to send the byte oxFFh.

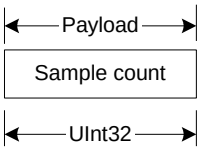
kSaveDone (frame ID 16)

This frame is the response to kSave frame. The payload contains a UInt16 error code, 0000h indicates no error, 0001h indicates error when attempting to save data into non-volatile memory.



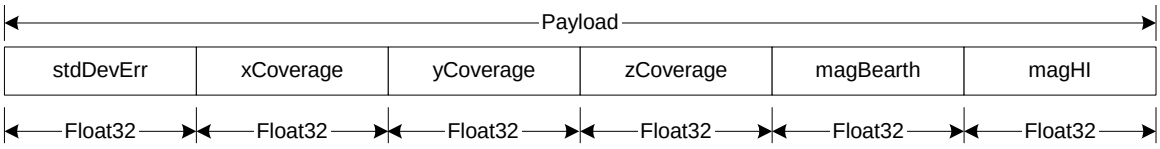
kUserCalSampCount (frame ID 17)

This frame is sent from the module after taking a calibration sample point. The payload contains the sample count with the range of 1 to 50



kUserCalScore (frame ID 18)

This frame's payload contains the calibration score, which is a series of Float32 values: stdDevErr, xCoverage, yCoverage, zCoverage, magBearth, magHI.



StdDevErr : The compass samples magnetic field standard deviation error.
XCoverage : Percentage of how much of the X magnetometer axis was covered by the sampling.
YCoverage : Percentage of how much of the Y magnetometer axis was covered by the sampling.
ZCoverage : Percentage of how much of the Z magnetometer axis was covered by the sampling.
MagBearth : The calculated Earth's magnetic field magnitude from the calibration samples.
MagHI : Reserved value; always 0.

kSetConfigDone (frame ID 19)

This frame is the response to kSetConfig frame. The frame has no payload.

kSetParamDone (frame ID 20)

This frame is the response to kSetParam frame. The frame has no payload.

kStartIntervalMode (frame ID 21)

The frame commands the module to output data (push mode) at a fixed time interval (See kSetAcqParams). The frame has no payload.

kStopIntervalMode (frame ID 22)

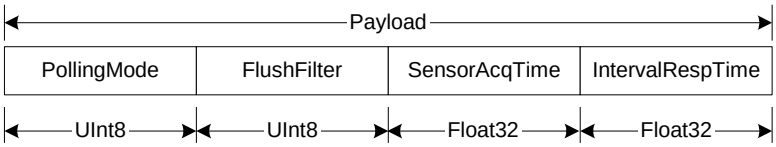
This frame commands the module to stop data output at a fixed time interval. The frame has no payload.

kPowerUp (frame ID 23)

This frame is sent from the module after wake up from power down mode. The frame has no payload. Since the module was previously powered down which drives the RS-232 driver TX line low (break signal), it is recommended to disregard the first byte.

kSetAcqParams (frame ID 24)

This frame sets the sensor acquisition parameters in the unit. The payload should contain the following:



PollingMode: Flag to set push/poll data output mode. Default is TRUE (poll mode).

FlushFilter: Flag to set FIR filter flushing every sample. Default is FALSE (no flushing).

SensorAcqTime: The internal time interval between sensor acquisitions. Default is 0.0 seconds, this means that the module will reacquire immediately right after the last acquisition.

IntervalRespTime: The time interval the module output data in push mode. Default is 0.0 seconds, this means that the module will push data out immediately after an acquisition cycle.

kGetAcqParams (frame ID 25)

This frame queries the unit for the acquisition parameters. The frame has no payload.

kAcqParamsDone (frame ID 26)

This frame is the response to kSetAcqParams frame. The frame has no payload.

kAcqParamsResp (frame ID 27)

This frame is the response to kGetAcqParams frame. The payload should contain the same payload as the kSetAcqParams frame.

kPowerDownDone (frame ID 28)

This frame is the response to kPowerDown frame. This indicates that the unit successfully received the kPowerDone frame and is in the process of powering down. The frame has no payload.

kFactoryUserCal (frame ID 29)

This frame clears the user calibration coefficients. The frame has no payload. This frame must be followed by the kSave frame to change in non-volatile memory.

kFactoryUserCalDone (frame ID 30)

This frame is the response to kFactoryUserCal frame. The frame has no payload.

kTakeUserCalSample (frame ID 31)

This frame commands the unit to take a sample during user calibration. The frame has no payload.

4.4 Code Examples

4.4.1 Binary TCM High Performance Protocol C Header File & CRC-16 Function

```
// type declarations
typedef struct
{
     UInt8 pollingMode, flushFilter;
     Float32 sensorAcqTime, intervalRespTime;
} __attribute__ ((packed)) AcqParams;

typedef struct
{
     Float32 stdDevErr;
     Float32 xCoverage;
     Float32 yCoverage;
     Float32 zCoverage;
     Float32 magBearth;
     Float32 reserve1;
} __attribute__ ((packed)) CalScore;

enum
{
     // Frame IDs (Commands)
     kGetModInfo = 1,      // 1
     kModInfoResp,         // 2
     kSetDataComponents,   // 3
     kGetData,             // 4
     kDataResp,            // 5
     kSetConfig,           // 6
     kGetConfig,           // 7
     kConfigResp,          // 8
     kSave,                // 9
     kStartCal,            // 10
     kStopCal,             // 11
     kSetParam,            // 12
     kGetParam,            // 13
     kParamResp,           // 14
     kPowerDown,           // 15
```

```
    kSaveDone,           // 16
    kUserCalSampCount,   // 17
    kUserCalScore,       // 18
    kSetConfigDone,      // 19
    kSetParamDone,       // 20
    kStartIntervalMode,  // 21
    kStopIntervalMode,   // 22
    kPowerUp,            // 23
    kSetAcqParams,       // 24
    kGetAcqParams,       // 25
    kAcqParamsDone,      // 26
    kAcqParamsResp,      // 27
    kPowerDoneDown,      // 28
    kFactoryUserCal,     // 29
    kFactoryUserCalDone, // 30
    kTakeUserCalSample,  // 31

    // Param IDs
    kFIRConfig = 1,      // 3-AxisID(UInt8)+Count(UInt8)+Value(Float64)+...


    // Data Component IDs

    kHeading = 5,         // 5 - type Float32
    kTemperature = 7,     // 7 - type Float32
    kDistortion = 8,      // 8 - type boolean
    kPCalibrated = 21,    // 21 - type Float32
    kRCalibrated,         // 22 - type Float32
    kIZCalibrated,        // 23 - type Float32
    kPAngle,              // 24 - type Float32
    kRAngle,              // 25 - type Float32
    kXAligned = 27,       // 27 - type Float32
    kYAligned,            // 28 - type Float32
    kZAligned,            // 29 - type Float32

    // Configuration Parameter IDs
    kDeclination = 1,     // 1 - type Float32
    kTrueNorth,           // 2 - type boolean
    kMountingRef = 10,    // 10 - type UInt8
    kUserCalStableCheck,  // 11 - type boolean
    kUserCalNumPoints,    // 12 - type UInt32
    kUserCalAutoSampling, // 13 - type boolean
```

```
    kBaudRate,            // 14 - UInt8

    // Mounting Reference IDs
    kMountedStandard = 1, // 1
    kMountedXUp,          // 2
    kMountedYUp,          // 3
    kMountedStdPlus90,    // 4
    kMountedStdPlus180,   // 5
    kMountedStdPlus270,   // 6

    // Result IDs
    kErrNone = 0,         // 0
    kErrSave,             // 1
};



// function to calculate CRC-16
UInt16 CRC(void * data, UInt32 len)
{
    UInt8 * dataPtr = (UInt8 *)data;
    UInt32 index = 0;
    // Update the CRC for transmitted and received data using
    // the CCITT 16bit algorithm (X^16 + X^12 + X^5 + 1).
    UInt16 crc = 0;
    while(len--)
    {
        crc = (unsigned char)(crc >> 8) | (crc << 8);
        crc ^= dataPtr[index++];
        crc ^= (unsigned char)(crc & 0xff) >> 4;
        crc ^= (crc << 8) << 4;
        crc ^= ((crc & 0xff) << 4) << 1;
    }
    return crc;
}
```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4.4.2 Binary TCM Protocol C++ Communication Examples

The following 4 example files, CommProtocol.h, CommProtocol.cp, TCM5.h and TCM5.cp would be used together for proper communication with a TCM3, TCM5 or TCM5L module.

***NOTE**: The follwing files are not included in the samples code: SystemSenPort.h; Processes.h, TickGenerator.h.*

4.4.2.1 CommProtocol.h File:

```
#pragma once

#include "SystemSerPort.h"
#include "Processes.h"

//
//    This file contains objects used to handle the serial communication with the unit.
Unfortunately, these files are not available as the program was written on a non-PC computer.
The comments in the code should explain what is expected to be sent or received from these
functions so that you can write this section for your specific platform.  For example, with the
TickGenerator.h, you would need to write a routing that generates 10msec ticks.
//



//
//  CommHandler is a base class that provides a callback for incoming messages.
//
class CommHandler
{
     public:
          // Call back to be implemented in derived class.
          virtual void HandleComm(UInt8 frameType, void * dataPtr = NULL, UInt16 dataLen = 0) {}
};

//
//  CommProtocol handles the actual serial communication with the unit.
//  Process is a base class that provides CommProtocol with cooperative parallel processing.  The
Control method will be
//  called by a process manager on a continuous basis.
//
class CommProtocol : public Process
{
     public:
          enum
          {
```

```
            // Frame IDs (Commands)
            kGetModInfo = 1,          // 1
            kModInfoResp,             // 2
            kSetDataComponents,       // 3
            kGetData,                 // 4
            kDataResp,                // 5

            // Data Component IDs

            kHeading = 5,             // 5 - type Float32
            kTemperature = 7,         // 7 - type Float32
            kPCalibrated = 21,        // 21 - type Float32
            kRCalibrated,             // 22 - type Float32
            kIZCalibrated,            // 23 - type Float32
            kPAngle,                  // 24 - type Float32
            kRAngle,                  // 25 - type Float32
        };

        enum
        {
            kBufferSize = 512,        // maximum size of our input buffer
            kPacketMinSize = 5        // minimum size of a serial packet
        };

        // SerPort is a serial communication object abstracting the hardware implementation
        CommProtocol(CommHandler * handler = NULL, SerPort * serPort = NULL);

        void Init(UInt32 baud = 38400);

        void SendData(UInt8 frame, void * dataPtr = NULL, UInt32 len = 0);
        void SetBaud(UInt32 baud);

    protected:
        CommHandler * mHandler;
        SerPort * mSerialPort;

        UInt8 mOutData[kBufferSize], mInData[kBufferSize];
        UInt16 mExpectedLen;
        UInt32 mOutLen, mOldInLen, mTime, mStep;

        UInt16 CRC(void * data, UInt32 len);
        void Control();
};
```


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4.4.2.2 CommProtocol.cp File:

```
#include "CommProtocol.h"

// import an object that will provide a 10mSec tick count through a function called Ticks()
#include "TickGenerator.h"


//
//  SerPort is an object that controls the physical serial interface.  It handles sending out
//  the characters, and buffers the characters read in until we are ready for them.
//
CommProtocol::CommProtocol(CommHandler * handler, SerPort * serPort)
 : Process("CommProtocol")
{
     mHandler = handler;                    // store the object that will parse the data when it
is fully received
     mSerialPort = serPort;
     Init();
}

//
//  Initialize the serial port and variables that will control this process
//
void CommProtocol::Init(UInt32 baud)
{
     SetBaud(baud);
     mOldInLen = 0;                         // no data previously received

     mStep = 1;                             // goto the first step of our process
}

//
//  Put together the frame to send to the unit
//
void CommProtocol::SendData(UInt8 frameType, void * dataPtr, UInt32 len)
{
     UInt8 * data = (UInt8 *)dataPtr;       // the data to send
     UInt32 index = 0;                      // our location in the frame we are putting together
     UInt16 crc;                            // the CRC to add to the end of the packet
     UInt16 count;                          // the total length the packet will be

     count = (UInt16)len + kPacketMinSize;

     // exit without sending if there is too much data to fit inside our packet
     if(len > kBufferSize - kPacketMinSize) return;
```

```
    // Store the total len of the packet including the len bytes (2), the frame ID (1),
    // the data (len), and the crc (2).  If no data is sent, the min len is 5
    mOutData[index++] = count >> 8;
    mOutData[index++] = count & 0xFF;

    // store the frame ID
    mOutData[index++] = frameType ;

    // copy the data to be sent
    while(len--) mOutData[index++] = *data++;

    // compute and add the crc
    crc = CRC(mOutData, index);
    mOutData[index++] = crc >> 8 ;
    mOutData[index++] = crc & 0xFF ;

    // Write block will copy and send the data out the serial port
    mSerialPort->WriteBlock(mOutData, index);
}



//
//  Call the functions in serial port necessary to change the baud rate
//
void CommProtocol::SetBaud(UInt32 baud)
{
    mSerialPort->SetBaudRate(baud);
    mSerialPort->InClear();                // clear any data that was already waiting in the
buffer
}

//
// Update the CRC for transmitted and received data using the CCITT 16bit algorithm (X^16 + X^12
+ X^5 + 1).
//
UInt16 CommProtocol::CRC(void * data, UInt32 len)
{
    UInt8 * dataPtr = (UInt8 *)data;
    UInt32 index = 0;

    UInt16 crc = 0;
    while(len--)
    {
        crc = (unsigned char)(crc >> 8) | (crc << 8);
        crc ^= dataPtr[index++];
        crc ^= (unsigned char)(crc & 0xff) >> 4;
```

```
            crc ^= (crc << 8) << 4;
            crc ^= ((crc & 0xff) << 4) << 1;
        }
        return crc;
}

//
//  This is called each time this process gets a turn to execute.
//
void CommProtocol::Control()
{
        // InLen returns the number of bytes in the input buffer of the serial object that are
available
        // for us to read.
        UInt32 inLen = mSerialPort->InLen();

        switch(mStep)
        {
                case 1:
                {
                        // wait for length bytes to be received by the serial object
                        if(inLen >= 2)
                        {
                                // Read block will return the number of requested (or available) bytes that
are in the
                                // serial objects input buffer.
                                // read the byte count
                                mSerialPort->ReadBlock(mInData, 2);

                                //  byte count is ALWAYS transmitted in big endian, copy byte count to
mExpectedLen to
                                // native endianess
                                mExpectedLen = (mInData[0] << 8) | mInData[1];

                                // Ticks is a timer function.  1 tick = 10msec.
                                // wait up to 1/2s for the complete frame (mExpectedLen) to be received
                                mTime = Ticks() + 50 ;
                                mStep++ ;                       // goto the next step in the process
                        }
                        break ;
                }

                case 2:
                {
                        // wait for msg complete or timeout
                        if(inLen >= mExpectedLen - 2)
                        {
```


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```
                    UInt16 crc, crcReceived;      // calculated and received crcs.

                    // Read block will return the number of requested (or available) bytes that
are in the
                    // serial objects input buffer.
                    mSerialPort->ReadBlock(&mInData[2], mExpectedLen - 2);
                    // in CRC verification, don't include the CRC in the recalculation (-2)
                    crc = CRC(mInData, mExpectedLen - 2);
                    // CRC is also ALWAYS transmitted in big endian
                    crcReceived = (mInData[mExpectedLen - 2] << 8) | mInData[mExpectedLen - 1] ;

                    if(crc == crcReceived)
                    {
                         // the crc is correct, so pass the frame up for processing.
                         if(mHandler)  mHandler->HandleComm(mInData[2],  &mInData[3],  mExpectedLen
- kPacketMinSize);
                    }
                    else
                    {
                         // crc's don't match so clear everything that is currently in the input
buffer since
                         // the data is not reliable.
                         mSerialPort->InClear();
                    }

                    // go back to looking for the length bytes.
                    mStep = 1 ;
               }
               else
               {
                    // Ticks is a timer function.  1 tick = 10msec.
                    if(Ticks() > mTime)
                    {
                         // Corrupted message. We did not get the length we were expecting within
1/2sec of receiving
                         // the length bytes. Clear everything in the input buffer since the data
is unreliable
                         mSerialPort->InClear();
                         mStep = 1 ;                    // Look for the next length bytes
                    }
               }
               break ;
          }

          default:
               break ;
     }
```

```
}
```

4.4.2.3 TCM5.h File (For TCM3, TCM5 and TCM5L Modules):

```
#pragma once

#include "Processes.h"
#include "CommProtocol.h"


//
//  This file contains the object providing communication to the TCM.  It will set up the unit
and parse packets received
//  Process is a base class that provides TCM with cooperative parallel processing.  The Control
method will be
//  called by a process manager on a continuous basis.
//
class TCM : public Process, public CommHandler
{
     public:
          TCM(SerPort * serPort);
          ~TCM();

     protected:
          CommProtocol * mComm;

          UInt32 mStep, mTime, mResponseTime;

          void HandleComm(UInt8 frameType, void * dataPtr = NULL, UInt16 dataLen = 0);
          void SendComm(UInt8 frameType, void * dataPtr = NULL, UInt16 dataLen = 0);

          void Control();
};
```

4.4.2.4 TCM5.cp File (For TCM3, TCM5 & TCM5L Modules):

```
#include "TCM.h"
#include "TickGenerator.h"

const UInt8 kDataCount = 4;        // We will be requesting 4 componets (Heading, pitch, roll,
temperature)
//
//  This object polls the TCM unit once a second for heading, pitch, roll and temperature.
//

TCM::TCM(SerPort * serPort)
 : Process("TCM")
{
     // Let the CommProtocol know this object will handle any serial data returned by the unit
     mComm = new CommProtocol(this, serPort);

     mTime = 0;
     mStep = 1;
}

TCM::~TCM()
{
}

//
//  Called by the CommProtocol object when a frame is completely received
//
void TCM::HandleComm(UInt8 frameType, void * dataPtr, UInt16 dataLen)
{
     UInt8 * data = (UInt8 *)dataPtr;

     switch(frameType)
     {
          case CommProtocol::kDataResp:
          {
               // Parse the data response
               UInt8 count = data[0];        // The number of data elements returned
               UInt32 pntr = 1;              // Used to retrieve the returned elements

               // The data elements we requested
               Float32 heading, pitch, roll, temperature;

               if(count != kDataCount)
               {
                    // Message is a function that displays a C formatted string (similar to
printf)
```

```
                    Message("Received %u data elements instead of the %u requested\r\n",
(UInt16)count,
                     (UInt16)kDataCount);
                    return;
               }

               // loop through and collect the elements
               while(count)
               {
                    // The elements are received as {type (ie. kHeading), data}
                    switch(data[pntr++])     // read the type and go to the first byte of the
data
                    {
                         // Only handling the 4 elements we are looking for
                         case CommProtocol::kHeading:
                         {
     // Move(source, destination, size (bytes)).  Move copies the specified number of
     // bytes from the source pointer to the destination pointer.
     // Store the heading.
                              Move(&(data[pntr]), &heading, sizeof(heading));

                              // increase the pointer to point to the next data element type
                              pntr += sizeof(heading);
                              break;
                         }

                         case CommProtocol::kPAngle:
                         {
                              //  Move(source, destination, size (bytes)).    Move copies the
specified number of
                              // bytes from the source pointer to the destination pointer.
                              // Store the pitch.
                              Move(&(data[pntr]), &pitch, sizeof(pitch));

                              // increase the pointer to point to the next data element type
                              pntr += sizeof(pitch);
                              break;
                         }

                         case CommProtocol::kRAngle:
                         {
                              //  Move(source, destination, size (bytes)).    Move copies the
specified number of
                              // bytes from the source pointer to the destination pointer.
                              // Store the roll.
                              Move(&(data[pntr]), &roll, sizeof(roll));
```


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```
                    // increase the pointer to point to the next data element type
                    pntr += sizeof(roll);
                    break;
                }

                case CommProtocol::kTemperature:
                {
                    //  Move(source,  destination,  size  (bytes)).    Move  copies  the
specified number of
                    // bytes from the source pointer to the destination pointer.
                    // Store the heading.
                    Move(&(data[pntr]), &temperature, sizeof(temperature));

                    // increase the pointer to point to the next data element type
                    pntr += sizeof(temperature);
                    break;
                }

                default:
                    // Message is a function that displays a formatted string (similar
to printf)
                    Message("Unknown type: %02X\r\n", data[pntr - 1]);
                    // unknown data type, so size is unknown, so skip everything
                    return;
                    break;
            }

            count--;                // One less element to read in
        }

        // Message is a function that displays a formatted string (similar to printf)
        Message("Heading: %f, Pitch: %f, Roll: %f, Temperature: %f\r\n", heading, pitch,
roll,
         temperature);
        mStep--;                    // send next data request
        break;
    }

    default:
    {
        // Message is a function that displays a formatted string (similar to printf)
        Message("Unknown frame %02X received\r\n", (UInt16)frameType);
        break;
    }
  }
}
```


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```
//
//  Have the CommProtocol build and send the frame to the unit.
//
void TCM::SendComm(UInt8 frameType, void * dataPtr, UInt16 dataLen)
{
     if(mComm) mComm->SendData(frameType, dataPtr, dataLen);
     // Ticks is a timer function.  1 tick = 10msec.
     mResponseTime = Ticks() + 300;          // Expect a response within 3 seconds
}

//
//  This is called each time this process gets a turn to execute.
//
void TCM::Control()
{
     switch(mStep)
     {
          case 1:
          {
               UInt8 pkt[kDataCount + 1];    // the compents we are requesting, preceded by the
number of...
                                                  // ...components being requested

               pkt[0] = kDataCount;
               pkt[1] = CommProtocol::kHeading;
               pkt[2] = CommProtocol::kPAngle;
               pkt[3] = CommProtocol::kRAngle;
               pkt[4] = CommProtocol::kTemperature;

               SendComm(CommProtocol::kSetDataComponents, pkt, kDataCount + 1);

               // Ticks is a timer function.  1 tick = 10msec.
               mTime = Ticks() + 100;        // Taking a sample in 1s.
               mStep++;                      // go to next step of process
               break;
          }

          case 2:
          {
               // Ticks is a timer function.  1 tick = 10msec.
               if(Ticks() > mTime)
               {
                    // tell the unit to take a sample
                    SendComm(CommProtocol::kGetData);
                    mTime = Ticks() + 100;   // take a sample every second
                    mStep++;
               }
```

```
                break;
            }

            case 3:
            {
                // Ticks is a timer function.  1 tick = 10msec.
                if(Ticks() > mResponseTime)
                {
                    Message("No response from the unit.  Check connection and try again\r\n");
                    mStep = 0;
                }
                break;
            }

            default:
                break;
        }
}
```