MMQ™VG-200-400
MMQAHRS-200-400
User's Guide

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Information to the user - *The user of this device is cautioned that changes or modifications not expressly approved by SDI could void the user's warranty.*

TABLE OF CONTENTS

TABLE OF FIGURES

Chapter 1- Introduction

MMQVG MMQAHRS

Overview

Systron Donner Inertial (SDI) has developed a family of vertical gyro and attitude and heading reference products (VG and AHRS) that use the latest solid-state inertial sensor technology.

The MMQ VG offers a unique combination of the Systron Donner Inertial solid-state Inertial Measurement Unit (IMU) and advanced software that calculates a Vertical Gyro (VG) solution from the gyro and accelerometer sensors. The MMQ VG's MEMS quartz rate sensors and MEMS accelerometers make up an IMU system that is used to calculate a highly accurate Roll and Pitch angle solution in varying dynamic applications.

The MMQ AHRS expands on the MMQ VG model by combining the Systron Donner Inertial solid-state Inertial Measurement Unit (IMU) and advanced software that calculates an Attitude and Heading Reference (AHRS) solution from the gyro and accelerometer sensors, and an external 3-axis magnetometer. The MMQ AHRS's MEMS quartz rate sensors and MEMS accelerometers make up an IMU system that is used to calculate a highly accurate Roll, Pitch and Heading angle solution in varying dynamic applications. As in the MMQ VG, Roll and Pitch are stabilized by the accelerometers, and Heading is stabilized by an external 3-Axis magnetometer.

The user can configure the MMQ VG and MMQ AHRS to output data at various sample rates with extremely low output rate jitter, and the data output format is simple to understand containing the 6 sensor outputs, the angle outputs, a Built-In-Test (BIT) word output and a multi-parameter revolving word output that provides system information including version string. The MMQ AHRS combines tremendous performance and versatility with an extremely compact size, low power consumption and low weight.

These solutions offer an affordable suite of compact and lightweight systems that are ideally suited for
Heading and Attitude Applications, Targets and drones, EO/IR Stabilization, Unmanned Aerial Vehicles, Remotely Operated Vehicles (Underwater), General Aviation (Experimental), Land Navigation, Robotics, and Electronic Flight Instrumentation System (EFIS) Integration

Additional technical data, physical characteristics, operation, and system integration information for the MMQ VG and MMQ AHRS products are presented in subsequent chapters of this guide.

About This Book

This guide provides basic attitude determination concepts, configuration, operation, and characteristics of the system, and defines the mechanical, electrical, and data interfaces of MMQ VG and MMQ AHRS to the Host Vehicle (HV).

This guide will discuss and illustrate some possible system applications for commercial and military markets, and will help the end-user determine how to use the MMQ VG and MMQ AHRS features.

The glossary contains abbreviations of terms commonly used by SDI and in the navigational and inertial fields, as well as some terms common to commercial electronics and software fields.

Note pages have been included to allow the designer to jot down notes for quick easy reference that might otherwise be misplaced.

Chapter 2- Attitude Determination Concepts

What is Attitude Determination?

Attitude Determination is the art and science of estimating a vehicle's attitude angles roll, pitch and heading. When navigating for long periods of time, a slight error in direction will create a sizable distance off course. This shows that the efficiency of a vehicle depends ultimately on the attitude determination accuracy.

The science of attitude determination can be reduced to five basic questions, and the algorithm must be capable of obtaining quick and accurate answers to them.

- What is the vehicle's *heading*?
- What is the vehicle's *attitude* (roll and pitch)?
- What is the vehicle's *acceleration*?
- What is the vehicle's *rate of rotation*?

Answer these questions and you have the solution to and attitude determination system. With proper equipment, these questions can be answered with reasonable accuracy.

The primary task of attitude determination is the estimation of a vehicles present orientation. *Inertial attitude propagation* is the method of accurately and continuously extrapolating a vehicle's attitude and heading, by processing changes in its motion as sensed by inertial instruments.

A *Vertical Gyro* (VG) and an *Attitude and Heading Reference System* (AHRS) measure changes in the vehicles body rates through the use of accelerometers, gyroscopes and an internal or external tri-axial magnetometer. This information is fed to a computer that is used to keep track of attitude and to control any attitude drift using the acceleration gravity vector and earth's magnetic field vector to continuously stabilize an indication of attitude and heading. Today these same instruments typically provide rate and state data to other avionics subsystems such as weapon computers, flight controls, or radar sensors.

VG and AHRS systems make their measurements with respect to *inertial space*. Inertial space is a reference frame, consisting of a set of axes that do not rotate, and has no acceleration from its origin relative to the average position of the fixed stars. Any set of rigid axes moving with constant velocity, and without rotation relative to inertial space, also constitutes an inertial reference frame.

Heading

Heading is commonly known as *compass direction*, or the direction that the vehicle points. True heading is defined as the angle in the local horizontal plane measured clockwise (about a downward vertical) between North and a vertical plane, containing the ship's, aircraft's, or other vehicle's longitudinal axis (with an aircraft, this axis is known as the *thrust* axis).

Attitude

Attitude is defined as the angular position of a ship, aircraft, or other vehicle, determined by the relationship between its axes and a reference datum, such as the horizon or a particular star. Attitude parameters are defined in terms of three "Euler" angles: true heading, pitch, and roll. See the previous paragraph for true heading.

Pitch is the angle measured in the vertical plane between a vehicle's longitudinal axis and the horizontal axis (nose up in an aircraft would be positive).

Roll is the angle measured about the vehicle's longitudinal axis that will rotate the vehicle from a horizontal orientation (such as an aircraft's wings being normally horizontal, to the actual flight orientation).

An example of roll is a climbing right hand turn from a level northerly flight path direction, generating a positive heading, pitch, and roll angle. A *drift angle* can be generated by crosswinds, causing the aircraft to point in the direction of the wind, rather than along the ground-referenced velocity direction.

Acceleration

Since the velocity of a body has both magnitude and direction, a change in velocity occurs whenever:

- The body's *rate* of motion changes while its direction remains the same.
- The body's *direction* of motion changes while its rate of motion remains the same.
- The body's *rate* and *direction* of motion change simultaneously.

Whenever the velocity of a body changes in any manner, the body is said to be *accelerating*.

Gravity

In addition to the forces caused by the motions of the vehicle and the Earth, the system is subject to the mass attraction, or *gravitational force* of the Earth, which is the most significant force acting on inertial instruments.

Gravity's interaction with the Earth's rotational forces is responsible for the very shape of the Earth itself. The shape of the Earth is fundamental to terrestrial navigation, since the designation of a system's position is only as precise as the relationship between the describing coordinates and the Earth's shape. Gravitational attraction is a property of matter (inertial mass) that is possessed by all material bodies.

Earth Magnetic Field

The earth's magnetic field provides a constant vector from north (magnetic north) can be derived. Created by the relative motions of the earth's inner core, the earth's magnetic field is not actually static and does drift or move over the course of time. However the amount of motion is negligible compared to the determination of a vehicle's instantaneous forward heading.

Quartz IMU General Theory

The IMU (Figure 1) is designed around six single-axis sensors, three *Quartz Rate Sensors* (QRS) and three *Accelerometers*.

The QRS output is an analog sinusoid, which is converted to a digital signal by the electronics portion. The IMU also monitors health, and provides sensor compensation.

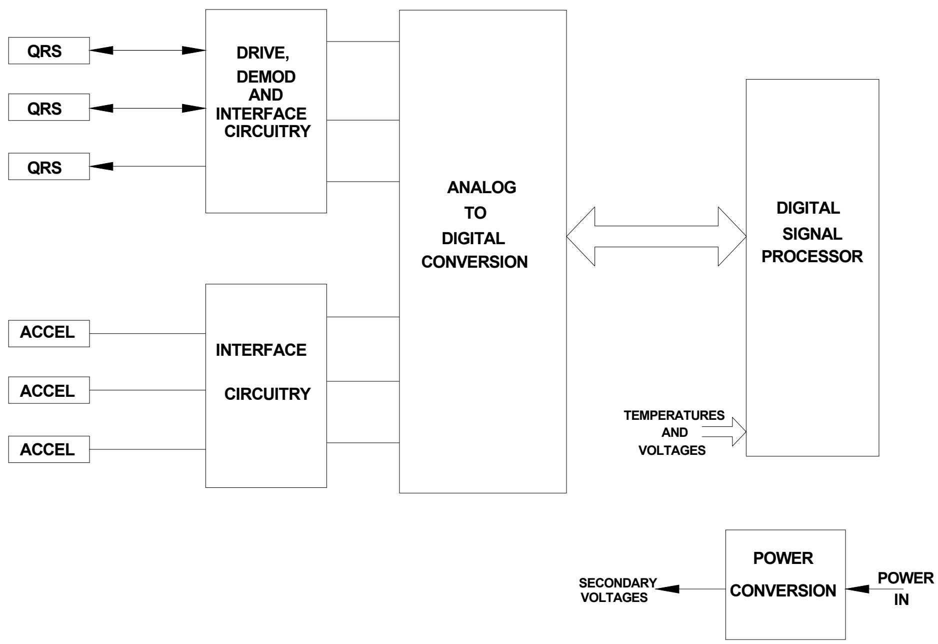


Figure 1 MMQ IMU Functional Block Diagram

The IMU portion of the MMQ VG and MMQ AHRS contains the electronics that process the raw sensor signals for compensation. It provides gyro rate information and acceleration information that is used by the VG and AHRS algorithms to determine vehicle attitude.

Accelerometer Principles

The basic principle of the open loop Accelerometer is to measure the deflection of a mass on the end of a flexible beam. The displacement of this mass is then used to measure the specific force applied to the sensor.

An *acceleration sensor* can be designed using a proof mass, so that the force transmitted from the case of the accelerometer through the beam to the proof mass is proportional to acceleration.

The deflection resulting from this force will vary according to the acceleration, and may be measured by the change in capacitance between the proof mass and fixed, parallel plates placed either side of the mass.

QRS Principles

The MMQ IMU uses a *dual tuning fork design* shown in Figure 2. The drive fork is set into oscillation at its natural frequency. When the device is rotated about the vertical axis, the Coriolis force causes the tines to oscillate at the drive frequency, which is orthogonal to the plane of the fork

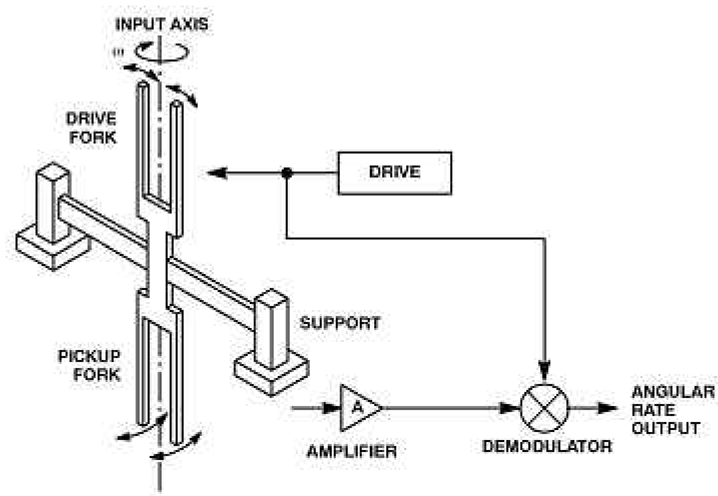


Figure 2 Simplified Block Diagram Quartz Rate Sensor

The Coriolis motion is transmitted to the pickoff tines, causing them to oscillate orthogonal to the plane of the fork. The amplitude of the pickoff motion is proportional to the velocity of the drive tines and the angular rate.

The pickoff motion is detected by electrodes attached to the pickoff tines. This pickoff signal is demodulated with respect to the reference drive signal, to give a DC output proportional to the input rate.

To maintain scale factor stability, an automatic gain control loop around the drive tines ensures a constant oscillation amplitude over temperature.

QRS Technological Advances

Micromachining has opened up the potential of using crystalline structures as the complete sensor element.

The technological approach of *micromachining* has opened up the potential for using crystalline structures as the complete sensor element. This approach is used in manufacturing the MMQ VG and MMQ AHRS by using quartz for the fork material, and by using deposited electrodes on both the drive and pickoff sides.

The mount that supports the quartz element provides isolation to maximize Coriolis coupling torque into the pickoff tines. Drive and pickup voltages are also routed via the mount.

The drive and signal processing electronics are contained within an *Application Specific Integrated Circuit* (ASIC) chip, providing a direct current (DC) input/output capability for ease of interfacing.

Attitude Determination General Theory

Attitude determination is divided into two separate entities, an attitude state propagation, and an attitude state stabilizer.

In the first entity rate sensor measured angular rate information is integrated in time to propagate the attitude state in a component referred to as attitude processor. If the initial attitude of the vehicle was known exactly and if the rate sensors provided perfect readings then the attitude processor would suffice. However the initial attitude is unknown and rate sensors typically provide corrupted data due to bias drift and turn-on instability.

In the second entity, a VG and AHRS attitude stabilizing component provides on-the-fly corrective signals to the attitude processor trajectory (referred to as a corrective rate signal). The accelerometers provide a roll and pitch angle attitude reference using gravity for the VG solution, and the magnetometers provide a magnetic north heading reference using the earth's magnetic field for the AHRS solution.

The primary functions of the MMQ VG are:

1. Sense inertial motions, specifically, linear acceleration and rotational rate
2. Sense internal thermal states (instrument temperatures) and voltages
3. Convert sensed analog inputs to digital values (both inertial and thermal inputs)
4. Digitally filter inertial inputs
5. Compensate filtered inertial inputs for thermal fluctuations and voltage levels
6. Initialize a system cosine rotation matrix for roll and pitch angles using the accelerometers as level indicators
7. Convert the cosine rotation matrix into a system quaternion
8. Use the compensated rotational rates to propagate a system quaternion
9. Use the accelerometers gravity reference to generate restoring rates that stabilizes the system quaternion for the roll and pitch channel
10. Extract roll and pitch angles from the stabilized quaternion
11. Prepare and deliver roll and pitch data on the serial output channel

The primary functions of the MMQ AHRS are:

1. Provide the calculations performed in the VG component

2. Provide and interface for continual Magnetometer vector input (via an input message)
3. Initialize a system cosine rotation matrix for roll, pitch and heading angles using the accelerometers as a level indicator and the magnetometers as a heading indicator
4. Use the system roll and pitch angles to level the magnetometer vector
5. Calculate a leveled magnetic heading
6. Provide a method of calibration for the magnetometers to compensate for hardiron and softiron effects
7. Use the magnetic heading reference to generate a restoring rate that stabilizes the quaternion for the yaw channel
8. Extract the system roll, pitch and heading angles from the stabilized quaternion
9. Prepare and deliver heading data on the serial output channel

Chapter 3- System Overview

System Configuration

The MMQ VG and MMQ AHRS have been designed to provide a low-cost solution for applications that require a vertical gyro or attitude and heading reference system. As introduced earlier in this guide, the MMQ VG and AHRS are composed of two basic elements: the IMU portion (based on the original MMQ50 IMU) and advanced attitude determination software.

The IMU portion provides gyro rate and acceleration information about three axes at a 400 Hz rate. The IMU uses micro-machined quartz rate sensors and silicon accelerometers to achieve low cost, weight, and volume.

System Technical Description

The MMQ VG and MMQ AHRS systems, shown in Figure 3, combines the SDI MMQ50's high-rate, inertial gyro rate and accelerometer outputs, and advanced attitude processing software to compute a complete attitude and heading solution.

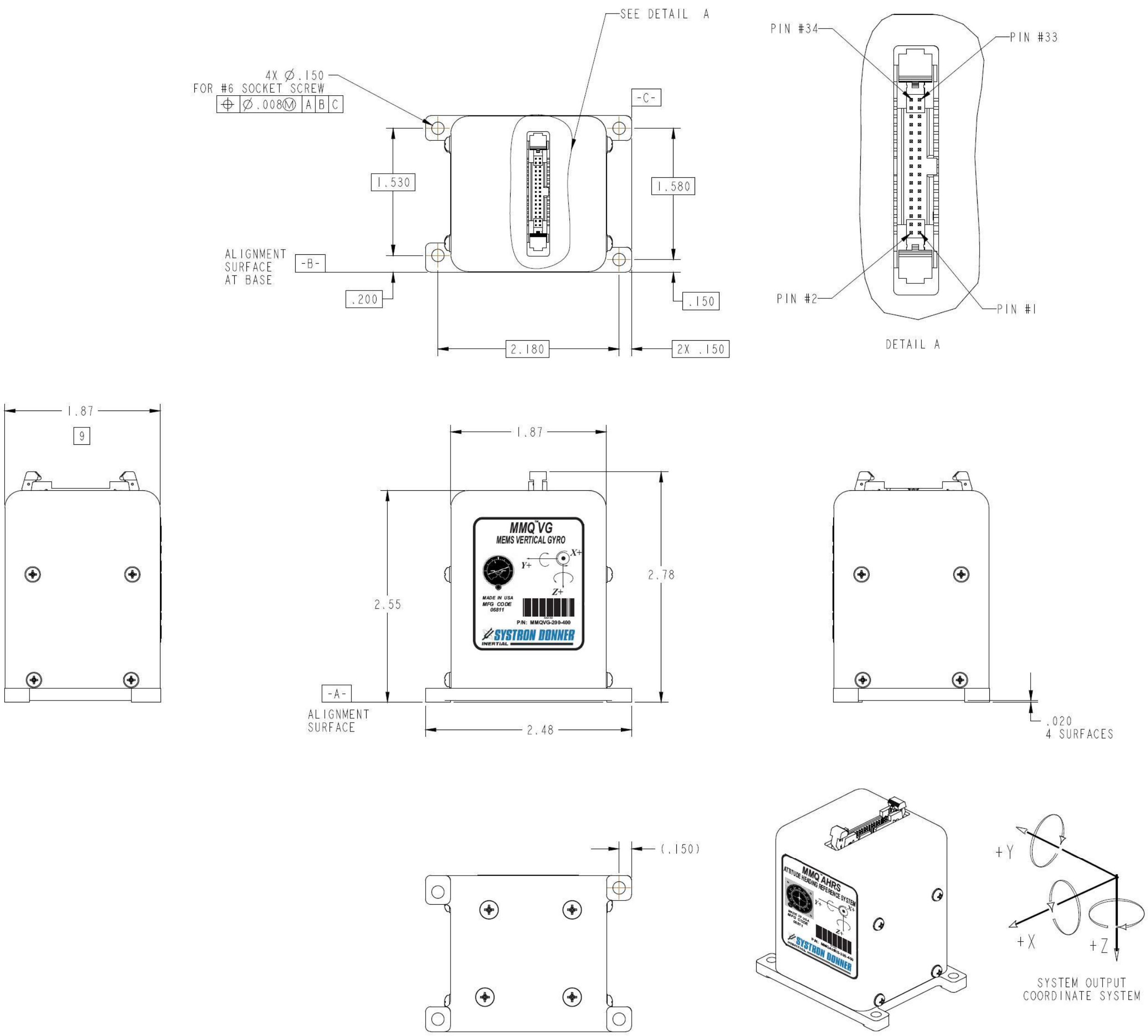


Figure 3 MMQ VG and MMQ AHRS Form Factor

In normal operation attitude and heading are computed based on integrated inertial data. This inertial solution is corrected using a feedback rate control algorithm, which uses the accelerometers and external magnetometer data to stabilize the roll, pitch and heading outputs.

The MMQ VG and AHRS initialize the roll, pitch and heading angles based on the first set of available sensor data. Although a static initialization is preferable, the system can be initialized in both stationary and dynamic environments. For a dynamic environment, there could be a large initial attitude angle error if the initialization occurs during an acceleration maneuver. As the dynamics subside and a straight and level condition is achieved, then angles will automatically stabilize to the proper solution.

System Operation

Operation of the MMQ VG and MMQ AHRS systems requires conditioned power, and an RS-232 bi-directional serial port to interface with MMQ VG and MMQ AHRS data.

The bi-directional serial port is used to output the standard message containing gyro rates, accelerations, Euler angles, status information and a revolving parameter word. Input control commands are received on this port.

In a stationary or dynamic environment, the MMQ VG and MMQ AHRS power up and perform a power-on Built In Test (BIT). The MMQ then waits for stable sensor performance. Once the sensors have stabilized, then the VG and AHRS algorithms initialize. The attitude vector (roll, pitch and yaw) is initialed using the accelerometer and input magnetometer data.

Then the MMQ system starts the attitude processor and attitude stabilizer portions of the algorithm. The normal output message then begins to output at the user desired rate. The default rate is 100 Hz, but the user can command 50Hz, 100 Hz, 200 Hz and 400 Hz output rate.

Product Performance

MMQ VG Specifications

The MMQ VG performance specifications are detailed in the Table 3-1 below.

Table 3-1. MMQ VG Specifications	
PHYSICAL CHARACTERISTICS	
Part Number	MMQ VG-200-400
Size (Vol.)	9.0 in^3 (1.88"W x 1.88"D x 2.55"H) (48 mm x 48 mm x 65 mm)
Weight	<0.50 lbs (<0.227 kg)
Power	+ and – 12 Vdc at < 5 watts total
I/O	RS-232 – 400 Hz Output Rate with < 100 microsecond jitter
ATTITUDE PERFORMANCE	
Static Accuracy (Roll/Pitch)	< 0.5 Deg
Dynamic Accuracy (Roll/Pitch)	1.5 Deg RMS – **Tested to TSO-C4c bank and pitch performance standards**
RATE CHANNELS	
Range	200°/ sec
Bias Turn-on to turn-on Stability (fixed temp)	≤100°/hr, 1 σ
Bias In-run Stability (at any temperature)	50-200°/hr, 1 σ
White Noise (angle random walk)	0.3 °/rt-hr (0.005 °sec/rt-Hz)
Scale Factor error	≤5000 ppm (0.5%)
Alignment	≤5 mrad
Bandwidth	50 Hz, nominal
ACCELERATION CHANNELS	
Range	+/- 10g
Bias Turn-on to turn-on Stability (fixed temp)	≤2.5 mg, 1σ
Bias In-run Stability (at any temperature)	≤3 mg, 1 σ
White noise (velocity random walk)	0.5 mg/rt-Hz
Scale Factor Error	≤5000 ppm (0.5%)
Alignment	≤5 mrad
Bandwidth	50 Hz, nominal
ENVIRONMENTAL	
Temperature Range	-54°C to +70°C (operating)
Vibration, random	6.0g rms, 20Hz –2kHz, flat **Meets DO-160D Curves C, C1**
Shock, operating	30g, powered **Meets DO-160D operational shock and crash safety**
Altitude	35,000 ft. **Meets DO-160D Category C**

MMQ AHRS Specifications

The MMQ AHRS performance specifications are detailed in the Table 3-2 below.

Table 3-2. MMQ AHRS Specifications	
PHYSICAL CHARACTERISTICS	
Part Number	MMQ AHRS-200-400
Size (Vol.)	9.0 in^3 (1.88"W x 1.88"D x 2.55"H) (48 mm x 48 mm x 65 mm)
Weight	<0.50 lbs (<0.227 kg)
Power	+ and – 12 Vdc at < 5 watts total
I/O	RS-232 – 400 Hz Output Rate with < 100 microsecond jitter
ATTITUDE AND HEADING PERFORMANCE	
Static Accuracy (Roll, Pitch, Heading)	< 0.5 Deg
Dynamic Accuracy (Roll/Pitch)	1.5 Deg RMS – **Tested to TSO-C4c roll and pitch performance standards**
Dynamic Accuracy (Heading)	3.0 Deg RMS – **Tested to TSO-C6d heading performance standards**
RATE CHANNELS	
Range	200°/ sec
Bias Turn-on to turn-on Stability (fixed temp)	≤100°/hr, 1 σ
Bias In-run Stability (at any temperature)	50-200°/hr, 1 σ
White Noise (angle random walk)	0.3 °/rt-hr (0.005 °sec/rt-Hz)
Scale Factor error	≤5000 ppm (0.5%)
Alignment	≤5 mrad
Bandwidth	50 Hz, nominal
ACCELERATION CHANNELS	
Range	+/- 10g
Bias Turn-on to turn-on Stability (fixed temp)	≤2.5 mg, 1σ
Bias In-run Stability (at any temperature)	≤3 mg, 1 σ
White noise (velocity random walk)	0.5 mg/rt-Hz
Scale Factor Error	≤5000 ppm (0.5%)
Alignment	≤5 mrad
Bandwidth	50 Hz, nominal
ENVIRONMENTAL	
Temperature Range	-54°C to +70°C (operating)
Vibration, random	6.0g rms, 20Hz –2kHz, flat **Meets DO-160D Curves C, C1**
Shock, operating	30g, powered **Meets DO-160D operational shock and crash safety**
Altitude	35,000 ft. **Meets DO-160D Category C**

System Power Requirements

The following is a brief overview of MMQ VG and MMQ AHRS power requirements, including input voltage, current and over voltage protection.

Input Voltage

The prime power input voltage to the MMQ is +/-12V Vdc as measured at the input. The nominal range is 11V to 13Vdc.

Current

The typical start-up current drawn by the unit is up to 400mA on the positive supply and 280mA on the negative supply during the first 500msec. The typical steady-state current drawn by MMQ-G is +280mA at +12v and –80mA at –12V.

Input Voltage Transient Protection

MMQ contains a transient absorption zener diode that clamps both the positive and negative input voltages at 17V.

Signal Interface Environment

MMQ provides one full-duplex, asynchronous RS-232 serial data port for communicating with the Host Vehicle.

Physical Dimensions

This section describes the MMQ envelope dimensions, installation requirements, mass properties, coordinate systems, and polarities.

Envelope Dimensions
The MMQ envelope dimensions are shown in Figure 4: Width = 2.48”, Depth = 1.87”, Height = 2.78”, Volume = 12.9 cu in.

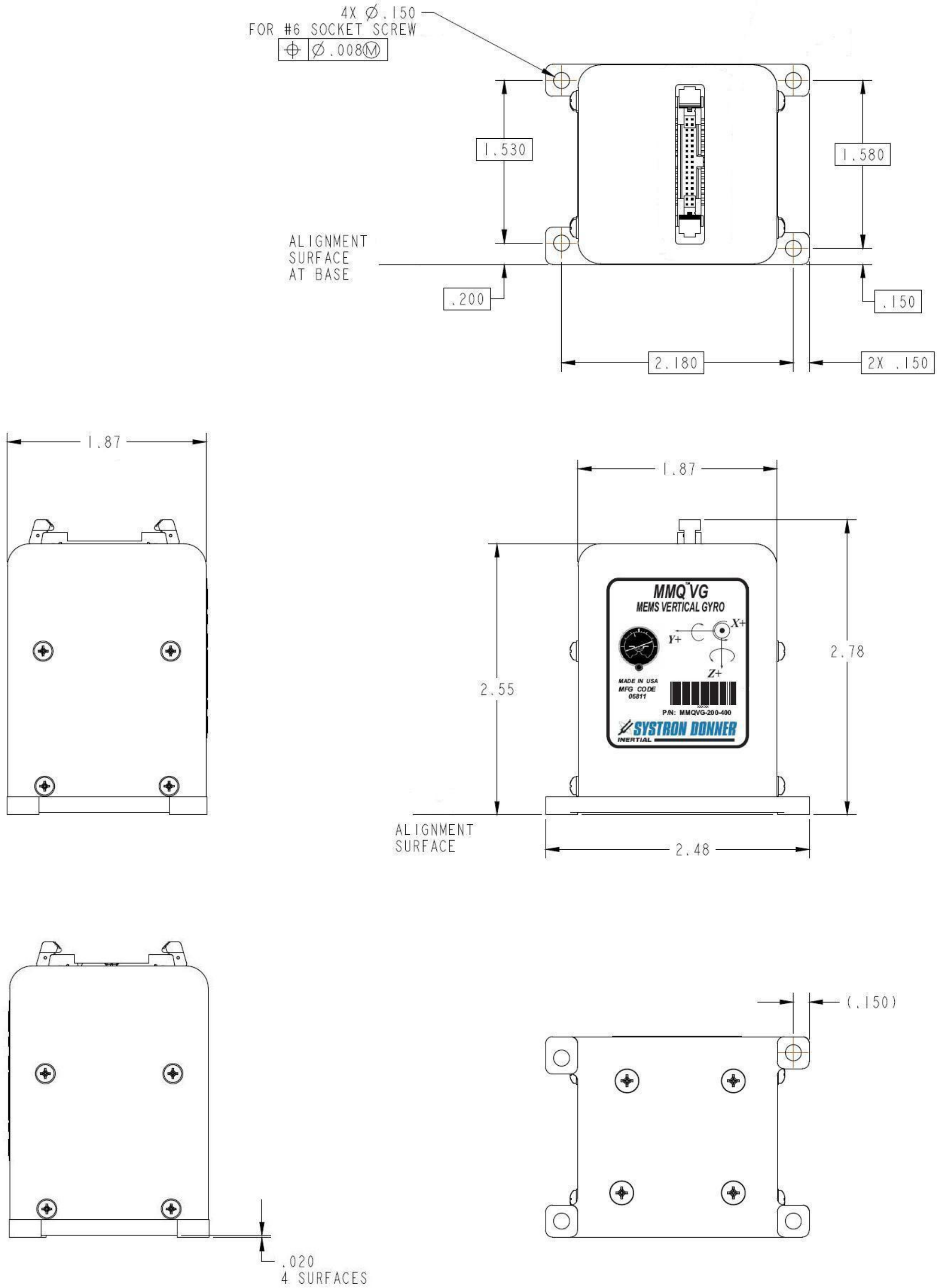


Figure 4 MMQ VG and MMQ AHRS Dimensions

Installation Requirements

The MMQ must be mounted to the host vehicle using four #6 socket cap screws, tightened to a torque between 8-12 in-lbs.

IMPORTANT!

The MMQ must be securely mounted to a good thermally conducting (metal) surface during operation to prevent thermal damage. (Nominal Power dissipation is approximately 4.3W, and the mounting base temperature must be kept below 85°C.)

Mass Properties

The weight of the MMQ is <0.23 kilograms (<0.50 pounds).

Boresight / Axis Alignment

Mechanical system axes are a right-hand orthogonal set labeled x, y, and z, as shown in Figure 5.

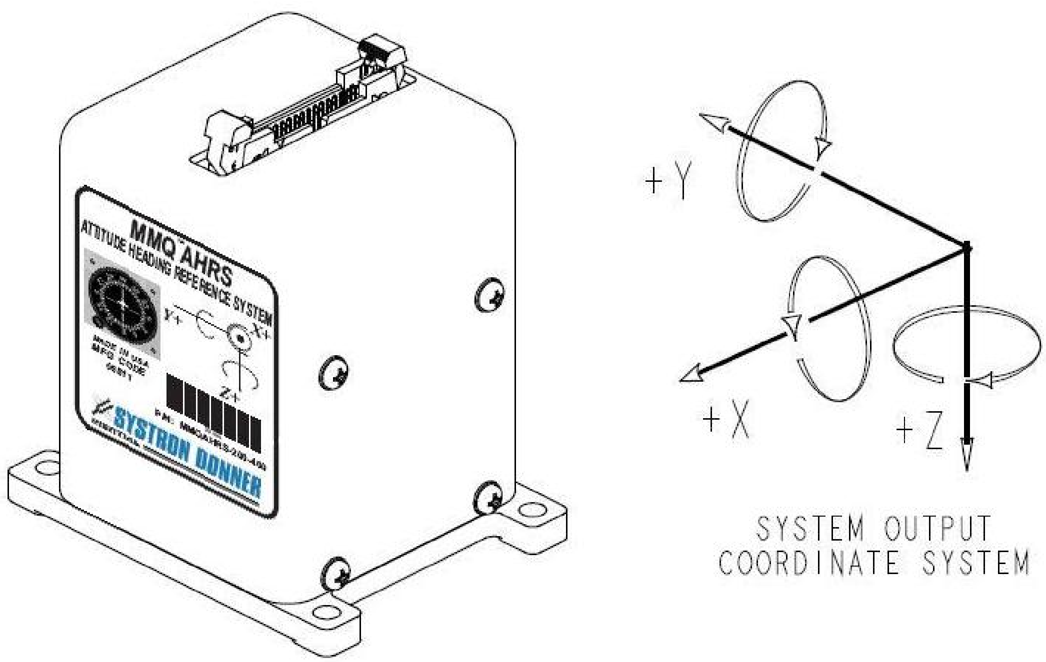


Figure 5 MMQ VG and MMQ AHRS Axis Definition

Environmental Specifications

The MMQ environmental specifications are provided in Table 3-3. These conditions are without safety and/or intensification factors. Under these conditions the MMQ will perform within the limitations defined herein.

Table 3-3. MMQ Environmental Specifications

Test Condition	Test Method	Specification	A	T
Altitude	MIL-STD-810 F, Section 500.0	Extended to 60,000 ft		
Operating				X
Storage				X
Temperature Range				
Operational	MIL-STD-810 F, Section 501.3	-40 to +71°C		X
Storage (non-operational)	MIL-STD-810 F, Section 502.3		X	
Temperature Shock	MIL-STD-810 F, Section 503.3	-40 C to + 71 C, 0.42 C/s		X
Humidity	MIL-STD-810 F, Section 507.3			X
Acceleration, Operating	MIL-STD-810 F, Section 513.4	4 G (performance), 20 G (endurance)		X
Vibration, Performance	MIL-STD-810 F, Section 514.5, Procedure I.	6 G rms, flat spectrum, 20 Hz–2 kHz		X
Vibration, Transportation	MIL-STD-810 F Method 514.5, Section 2.2.1 (Category 4)	0.2, 0.74, 1.04 grms, 3 hr/axis, flat spectrum, 20 Hz-2 kHz		X
Shock, Endurance	MIL-STD-810 F, Section 516.4	30 G, 11ms		X
Shock, Operating	MIL-STD-810 F, Section 516.4	20 G, 11ms		X
Dynamics				
Velocity		500 m/s	X	
Acceleration, Perf.		4 G		X
Acceleration, Oper.		20 G		X
Angular Rate Range		200 deg/sec		X
Angular Rate, Calibrated		200 deg/sec		X

A = Verified through analysis T = Verified through test

Temperature

The MMQ will meet its performance requirements during and after exposure to temperatures from -40 degrees C to + 71 degrees C. Heat is dissipated by conduction through the base mounting plate.

Vibration, Performance

The MMQ will meet its performance requirements during and after exposure to a 6 GRMS random vibration levels, flat profile 20-2,000Hz, in each of the three orthogonal axes.

Shock

The MMQ will meet its performance requirements after exposure to a 30 g, 11 millisecond, half-sine shock applied in each direction of the three orthogonal axes. MMQ will operate with full accuracy during and after exposure to shocks less than or equal to 20 g, 11 ms, half-sine pulse.

Electro-Magnetic Interference and Compatibility (EMI/EMC)

The MMQ is intended to be embedded in a system that provides EMI/RFI protection. Contact your local SDI applications engineer for details.

MMQ Reliability

The Mean Time Between Failures (MTBF) of MMQ is no less than the values shown in Table 3-4. These values were established using MIL-HDBK-217F analysis methods and supplemented by commercial parts data.

Table 3-4. Mean Time Between Failures

MIL-HDBK-217 Environment	MTBF, hours
Ground, Benign @ 35 C	44,736
Airborne, Uninhabited Fighter @ 35 C	15,485

Chapter 4 - Operation

Operating Modes

The processing state of the MMQ-G at any particular time is defined by a mode. MMQ-G utilizes the following operating modes:

- *Test*
- *Normal*

After startup, the MMQ-G sequences automatically through Test mode to *Normal* mode. In *Normal* mode, attitude estimation is performed based on INS data.

The processing performed by MMQ VG and MMQ AHRS during the two modes is described below.

Test Mode

Test mode is in effect while *Built-In Test (BIT)* is being performed as a part of normal startup sequence. The BIT function is entered immediately after power-on or after software reset. BIT tests the functional areas of MMQ.

Normal Mode

Normal mode is in effect after completion of BIT. In *Normal* mode the MMQ VG performs the following primary functions:

1. Sense inertial motions, specifically, linear acceleration and rotational rate
2. Sense internal thermal states (instrument temperatures) and voltages
3. Convert sensed analog inputs to digital values (both inertial and thermal inputs)
4. Digitally filter inertial inputs
5. Compensate filtered inertial inputs for thermal fluctuations and voltage levels

6. Initialize a system cosine rotation matrix for roll and pitch angles using the accelerometers as level indicators
7. Convert the cosine rotation matrix into a system quaternion
8. Use the compensated rotational rates to propagate a system quaternion
9. Use the accelerometers gravity reference to generate restoring rates that stabilizes the system quaternion for the roll and pitch channel
10. Extract roll and pitch angles from the stabilized quaternion
11. Prepare and deliver roll and pitch data on the serial output channel

In *Normal* mode the MMQ AHRS performs the following primary functions:

1. Provide the calculations performed in the VG component
2. Provide and interface for continual Magnetometer vector input (via an input message)
3. Initialize a system cosine rotation matrix for roll, pitch and heading angles using the accelerometers as a level indicator and the magnetometers as a heading indicator
4. Use the system roll and pitch angles to level the magnetometer vector
5. Calculate a leveled magnetic heading
6. Provide a method of calibration for the magnetometers to compensate for hardiron and softiron effects
7. Use the magnetic heading reference to generate a restoring rate that stabilizes the quaternion for the yaw channel
8. Extract the system roll, pitch and heading angles from the stabilized quaternion
9. Prepare and deliver heading data on the serial output channel

IMU Operation

The IMU is designed to provide internally compensated, body referenced, orthogonal, simultaneous measurements of delta velocity information in three axes and delta attitude information in three axes at up to a 400-Hz rate.

The IMU consists of three block mounted, mutually orthogonalized Quartz Rate Sensors (QRS) in a shock-mount configuration, and three mutually orthogonalized Accelerometers, and associated electronics.

The electronics portion contains the interface electronics to the inertial instruments and provides the signal processing and computational capability required to convert the inertial instrument outputs to formatted inertial data. A summary of error sources used to characterize MMQ VG and MMQ AHRS is shown in Table 4-1.

Table 4-1. MMQ VG and MMQ AHRS IMU Error Budget

	Units	Meas.	MMQ
Gyro Channel			
Bias	deg/sec	1σ	0.25
Bias - In run stability (not including turn-on)	deg/h	1σ	**200**
SF stability (all causes)	ppm	1σ	5000
Angle Random Walk	deg/root-h	nom.	0.3
Rate Noise (noise floor, @ 15 minute)	deg/hr rms	max.	4-15
Δθ Noise	μrad rms	max.	20
Bias G Sensitivity	deg/h/g	1σ	50
Gyro drifts due to vibration rectification	deg/sec/g-rms	1σ	0.01
Angular rate quantization (LSB) (1)	micro-rad/s	nom.	4.7×10^{-2}
Angular change quantization (LSB) (1)	micro-rad	nom.	4.7×10^{-4}
IA alignment to case stability	milli-rad	1σ	5
Data Latency	milli-sec	nom.	16
Bandwidth, Gain (3 dB)	Hz	nom.	42
Bandwidth, Phase (-90°)	Hz	nom.	18
Accelerometer Channel			
Bias	milli-g	1σ	17.5
Bias - In run stability, (not including turn-on)	micro-g	1σ	7.5
SF stability (all causes)	ppm	1σ	5000
Velocity random walk	milli-g/root-Hz	1σ	0.5
Acceleration Noise	milli-g rms	Max	0.5
Velocity Noise	ft/sec rms	Max.	5×10^{-3}
Accelerometer vibration rectification	$mg/grms^2$	Max.	1.5
Acceleration quantization (LSB) (1)	milli-g	Nom.	9.7×10^{-3}
Velocity change quantization (LSB) (1)	mm/s	Nom.	0.95×10^{-3}
IA alignment to case stability	milli-rad	1σ	5
Data Latency	milli-sec	Nom.	16
Bandwidth, Gain (3 dB)	Hz	Nom.	41
Bandwidth, Phase (-90°)	Hz	Nom.	17
Operating Range			
Angular Rate - Dynamic Range	deg/s	Nom.	200
Angular Rate - Calibrated Range	deg/s	nom.	200
Acceleration - Dynamic Range	g	nom.	10 (saturates ~25g)
Acceleration - Performance Range	g	nom.	4

(1) With default data scaling/dynamic range as measured in serial output.
Note: for purposes of this user's guide, a standard g is defined as 9.80665 m/sec^2.

Chapter 5- Hardware Integration

Overview

The MMQ VG and MMQ AHRS systems are designed to be integrated into a navigation or flight control system by a systems integrator. The system can be implemented in many end-product solutions, including missiles, aircraft, guided munitions, and other military and commercial applications; however, it is not limited to these markets.

This chapter describes the various hardware-related features of the MMQ VG and MMQ AHRS that should be considered for efficient and effective system integration.

Electrical Interface

Signal Types

The characteristics defined in this section are for the MMQ connector inputs Jl. The two types of digital signals are defined in Table 5-1. The Jl connector contains these two types of digital signals and power inputs (see Figure 6).

Table 5-1. Signal Type Definitions
LVTTL:
High-level input voltage (logic 1): $2.0 \leq V_{IH} \leq 3.3$ volts
Low-level input voltage (logic 0): $0 \leq V_{IL} \leq 0.8$ volt
High-level output voltage (logic 1): $2.4 \leq V_{OH} \leq 3.3$ volts
Low-level output voltage (logic 0): $0 \leq V_{OL} \leq 0.5$ volt
Maximum input current: ±10 µAmp
Maximum rise and fall times: 50 nsec
Note: The LVTTL devices used in the MMQ-G are TTL level tolerant, and can accept 5V inputs without damage
RS232:
High-level input voltage: $2.4 \leq V_{IH} \leq 30.0$ volts
Low-level input voltage: $-30.0 \leq V_{OL} \leq 0.8$ volts
Input resistance: 3 kOhms $\leq R_{IN} \leq$ 7 kOhms
High-level output voltage (R_L=3 kOhm): $5.0 \leq V_{OH} \leq 15.0$ volts
Low-level output voltage (R_L=3 kOhm): $-15.0 \leq V_{OL} \leq -5.0$ volts
Transition slew rate: $6.0 \leq T_{SR} \leq 30$ V/µsec
Maximum data rate: 115.2 kbits/sec

PIN#	PIN NAME		COMMENT
1	NC	NC	
2	NC	NC	
3	NC	NC	
4	NC	NC	
5	RS232TX_I	OUT	DATA TO HOST VEHICLE
6	RS232RX_I	IN	DATA FROM HOST VEHICLE
7	NC	NC	
8	NC	NC	
9	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
10	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
11	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
12	-VIN	IN	NEGATIVE POWER INPUT
13	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
14	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
15	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
16	XRS	IN	FACTORY USE ONLY - DO NOT CONNECT
17	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
18	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
19	NC	NC	
20	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
21	NC	NC	
22	+VIN	IN	POSITIVE POWER INPUT
23	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
24	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
25	NC	NC	FACTORY USE ONLY - DO NOT CONNECT
26	SYSFAULT	OUT	SYSTEM FAULT (BIT STATUS)
27	PWR_GD	OUT	POWER GOOD (BIT STATUS)
28	DTA_GD	OUT	DATA GOOD (BIT STATUS)
29	GND	POWER GND	POWER GND
30	CHGND	IN	CHASSIS GND
31	NC	NC	
32	NC	NC	
33	NC	NC	
34	NC	NC	

Figure 6 MMQ (J1) Electrical Interface

"NC" denotes "no connection". No connection is to be made to these pins, even to an unterminated wire in a cable bundle. They are for factory test and programming use only.

Power Interface

Input Voltage

The input voltage to MMQ is nominally +/-12V, and should be within +11Vdc to +13Vdc, and –11Vdc to –13Vdc, as measured at the input, referenced to power return/ground (“GND”).

Current

The typical steady-state current drawn by MMQ is 280mA on the positive supply, and –80mA from the negative supply, when used with +/-12V supplies. The typical startup current consists of a series of surges during the first 500 msec of up to +/-400 mA on the positive supply and 280mA on the negative supply.

Power Supply Considerations

The primary function of any regulated power supply is to hold the voltage in its output circuit while maintaining the current delivery over temperature. It is quite evident that power, current, and ripple under full load are important.

The system integrator needs to account for noise contributors when placing a power supply in a system. Even though the power supply required for a MMQ system is dependent on the application, care should be taken to specify the electrical and mechanical characteristics of the power supply.

In a system design using a switching power supply, EMI is a natural by-product of the on-off switching. The interference can be conducted to the load, resulting in higher output ripple and noise. It also can be conducted back into the AC line in the case of AC-to-DC switchers, and can be radiated into the atmosphere and surrounding equipment. Shielding and filter networks may be needed to reduce the ripple and noise.

Ground

The power ground and chassis ground signals, GND, and CHGND, are tied together inside MMQ. It is generally recommended that they be also be tied together close to the MMQ.

Digital Interface

Host Vehicle (HV) Serial Interface

The HV interface is a full-duplex asynchronous RS-232 serial data communication port. This port is the interface for command and control of the MMQ by the HV. Message format, communications, and control protocol are defined in Chapter 7- Software Integration.

The interface consists of the following signals with the signal types and interface descriptions defined earlier in Table 5-1. Both of these signals are referenced to GND.

- **RS232OUT**: Data transmitted by MMQ to the external equipment. The interface circuit for this signal is shown in Figure 7.

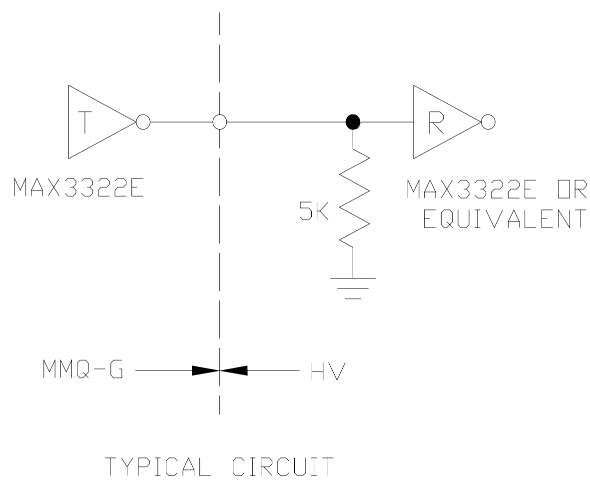


Figure 7 Host Vehicle RS-232 Output Circuit

- **RS232IN**: Data received by the MMQ from external equipment. The interface circuit for this signal is shown in Figure 8.

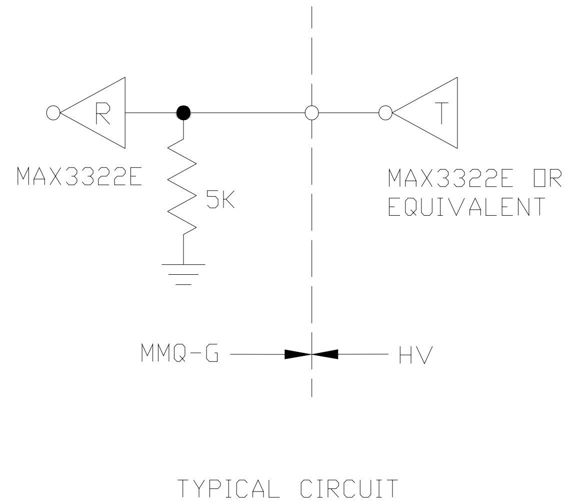


Figure 8 Host Vehicle RS232 Input Circuit

Data is transmitted and received within a UART-compatible frame. The default frame format is:

- One start bit.
- 8 data bits (least significant bit first).
- One parity bit (odd parity).
- One stop bit.
- Data rate of 115200 baud.

The interface supports reconfiguration of data rates and frame formats as follows:

- Data rates for transmit and receive are factory set to 115200 baud.
- The parity bit is odd parity.
- Start and stop periods are fixed at one bit.
- Data is fixed at 8 bits.
- Port idle is nominally a logical low (-5 Vdc).

Connector Types

The connector that is used to interface MMQ to the Host Vehicle is defined in Table 5-3. Examples of mating connectors are included in the table.

Table 5-3. MMQ-G Connector Types

Connector Designation	Type	Example Mating Type
J1 - I/O Interface	Samtec "EHF" series, 34 pin, dual row	Samtec EHF series ribbon cable connector, Samtec P/N FFSD-17-01-N

Input/Output (I/O) Interface (J1) Connector

The I/O interface is through a 34-pin receptacle of the Samtec EHF series.

Representatives/distributors carrying Samtec connectors may be found at www.samtec.com.

Cable Considerations

The choice of cable is application-dependent. There are many cables manufactured that will meet the performance requirements for specific applications that mate with a variety of connectors.

The primary consideration in choosing a cable is the net attenuation at the desired frequency. The secondary consideration is the shielding of the cable. Other considerations such as flexibility, jacketing, size, and cost need to be factored into the selection process.

Cable Attenuation

The attenuation a cable exhibits at the desired frequency is important to the system design. The materials of a cable directly relate to the attenuation characteristics it exhibits. The center conductor of a good quality cable is typically copper or aluminum with a copper coating. Copper is a good electrical conductor with relatively low DC resistance per meter. This is important in the event a preamplifier needs to be powered via the center conductor for extra system gain.

Cable Dielectric

The dielectric material is the key to the characteristic impedance of a cable. RF applications generally use a cable with a polyethylene dielectric material. Polyethylene has a low dielectric constant that provides low capacitance and low electrical loss. This material is also lightweight and water-resistant. The outer conductor plays a role in the characteristic impedance of the cable, as well as its shielding effectiveness.

Cable Shielding

There are numerous outer conductor (shield) designs. The outer conductor can be made of braided mesh, a solid foil, or a solid shell. Braided shields of copper or aluminum are ideal for minimizing low frequency interference and exhibiting a low DC resistance. This type of shield provides good structural integrity and flexibility. As a rule, higher braid coverage yields a more effective shield.

Foil shields are made of aluminum and are laminated to a polypropylene film to provide mechanical strength to the foil. The DC resistance of a foil shield is not as low as a braided shield, but the foil shield provides 100 percent coverage of the center conductor. This shield is more cost effective, but has less structural integrity than a braided shield. Solid shields afford the best performance, but are inflexible and expensive.

Shields can be arranged in many different combinations. Combination shields consist of more than one layer of shielding. Typical combinations can include a braid or a braid with foil. A braid-type shield significantly lowers the DC resistance of the overall shield, while a braid-foil type shield provides the low DC resistance and structural strength of the braid plus 100 percent shielding of the foil.

The outside jacketing of a cable does not provide any EMI/RFI shielding to a cable. The jacket provides resistance to weather deterioration, mechanical abuse, and heat.
For most MMQ applications where the cable runs are relatively short, a cable can be selected with any of the characteristics previously described. If an application requires extensive lengths of cable (> 30 ft) other types of cable commonly larger in diameter with solid copper outer conductors should be considered. These types of cables exhibit very low attenuation and excellent shielding, but tend to be larger, costing more per linear meter.

Chapter 6- Magnetometer Interface

Overview

The MMQ AHRS requires integration with an external magnetometer. Body-axis three dimensional magnetic vector data is input into the MMQ AHRS via a proprietary Systron Donner Inertial message format. In both instances the data is sent into the MMQ AHRS via the RS-232 UART interface. Since the messages are coming in through the MMQ AHRS RS-232 interface, the receiving BAUD rate will be the same as for any input message, and is set when the choice is made to configure the BAUD rate on the MMQ AHRS RS-232 port (Please see Chapter 7- Software Integration). The body-axis magnetic data is transformed inside the MMQ AHRS into heading reference data, which is then used by the AHRS algorithm to stabilize heading. Note that the MMQ AHRS system heading is referenced magnetic north.

Magnetic Measurement

Three axes magnetometer systems use a set of sensitive magnetometers to measure the Earth's three-dimensional magnetic field vector. This vector data can be used to calculate magnetic heading. Because the earth's field is very weak, small amounts of moving magnetic material near the magnetometer can have large effects on a magnetic heading calculation. The magnetometer should be isolated from magnetic material as much as possible. Magnetic material will distort the magnetic field near the sensing elements, which can then affect the accuracy of a heading calculation. A magnet can be used to test materials that will be near the magnetometer, such as iron, carbon steel, some stainless steels, nickel and cobalt. Essentially any material that will stick to a magnet should be avoided. The MMQ AHRS contains magnetic disturbance compensation algorithms designed to correct for the effect of these disturbance magnetic fields as long as the disturbance is stationary. Materials that will not affect the magnetometer measurements include aluminum, brass, plastic, titanium, wood, and some high-quality stainless steels. Again, if in doubt, try to stick a magnet on the material. If the magnet doesn't stick then the material will not affect the magnetometer. Stationary magnetic objects will be compensated for by the compensation algorithms. Moving ferrous objects within 24 inches cannot be fully compensated by the algorithm, so the magnetometer should not be located within 24 inches of any large moving ferrous metal objects such as landing gear components, electric motors, control linkages, etc. Ferrous metal objects that may change position during flight operations, such as landing gear, flap actuators, and control linkages should not be within 24 inches of the magnetometer. The magnetometer should not be located close to high current DC power cables or 400 cycle AC power cables and their associated magnetic fields.

Hardiron/Softiron Calibration

Magnetometer magnetic heading reference data will need to be calibrated for hard and soft iron compensation before use in any final installation. The MMQ AHRS uses the magnetometer heading magnetic vector data to compute heading. Ideally, the magnetic sensors would be measuring only earth's magnetic field to compute the heading angle. In the real world, however, residual magnetism in your system will add to the magnetic field measured by the magnetometer.

Static magnetic disturbance behaves as a bias offset error in the magnetometer measurement if it is not compensated. This magnetic field bias offset is called hard iron magnetic error. In addition, magnetic material can change the direction of the magnetic field as a function of the input magnetic field. This dependence of the local magnetic field on input direction acts as a scale factor error on the magnetometer data, and is referred to as soft iron.

The MMQ AHRS can measure any disturbance constant magnetic field that is associated with the MMQ AHRS itself, or the user system, and corrects for it during the calibration procedure. The MMQ AHRS also makes a correction for some soft iron effects. The process of measuring these non-ideal effects and correcting for them is called hard iron and soft iron calibration. Calibration corrects for magnetic fields that are fixed with respect to the user system. It cannot compensate for time varying fields, or fields created by parts that move with respect to the magnetometer.

The MMQ AHRS accounts for the extra magnetic fields by making a series of measurements from the magnetic heading reference data. The MMQ AHRS uses these measurements to model the hard iron and soft iron environment in the installation.

The magnetometer calibration mode should only be performed once the MMQ AHRS system is in *Normal* Mode. The hard and soft iron calibration procedure control is performed using the commands defined in Chapter 7-Software Integration. The process is monitored using the system status word in the output message, and the status of the magnetometer calibration data present in non-volatile memory is observed using the revolving word in the output message.

Send the appropriate "Magnetometer Calibration Control Command" to turn on the calibration process. Once the MMQ AHRS has received the calibration on command, the system status word will display the proper "Magnetometer Calibration" bit signifying that the MMQ AHRS is in magnetometer calibration mode. The user system will then need to be rotated through at least three complete circles. At this point, the MMQ AHRS should have collected enough data for a good magnetometer compensation calibration. Send the appropriate control message to turn off the calibration process. Once the MMQ AHRS has received the calibration off command the status word will display the proper bits signifying that the MMQ AHRS is no longer in magnetometer calibration mode. The MMQ AHRS will now store these as calibration constants in the EEPROM for use upon subsequent power cycles. Note that the process of storing this data in the EEPROM is the same as storing the system information into the EEPROM, as described in Chapter 7- Software Integration, and there will be an interruption of data communications of approximately 2 seconds. The revolving byte word will now display the proper bits signifying that the magnetometer calibration has been stored properly.

Once the calibration process is complete, the MMQ AHRS can be restarted through a power cycle to re-initialize the system angles. Once the MMQ AHRS has entered *Normal* mode and is receiving proper magnetometer heading reference data, the magnetometer calibration can be then be tested by comparing the system heading output of the MMQ AHRS with a known reference (compass or compass markers). Position the user system at each of the cardinal headings (0 degrees (north), 90 degrees (east), 180 degrees (south) and -90 degrees (west). At each cardinal position, allow the MMQ AHRS at least 2 minutes to properly stabilize, and then observe the system heading parameter. It should be within +/- 2 degrees of the cardinal heading. If there is still some residual magnetic disturbance (as observed by a system heading error of more than +/- 2 degrees), then the magnetometer calibration can be performed again. All subsequent magnetometer calibrations build on the previous calibration by using the previously magnetometer calibration coefficients throughout the calibration process. It is this way that a "fine tuning" of the magnetometer calibration can be achieved. If the user desires to start over, or if a major configuration change to the installation is performed, such as moving the installation of the magnetometer or locating a new large magnetic ferrous disturbance near to the magnetometer, then the calibration coefficients can be erased from the MMQ AHRS by sending the proper erase magnetometer calibration data command and restarting the MMQ AHRS system.

Magnetometer Data Interface

The MMQ AHRS supports direct communications with an external magnetometer and will accept input magnetometer data via a Systron Donner proprietary format message. Please refer to Chapter 7- Software Integration for a complete description of this input message. The MMQ AHRS also outputs Magnetometer data in the revolving byte word which contains information directly related to the input magnetometer data. These outputs are designed to provide the user enough direct information about the magnetometer input data. Please refer to the description in Chapter 7- Software Integration for a complete description of the magnetometer data in the revolving byte.

Chapter 7- Software Integration

MMQ VG and MMQ AHRS to Host Vehicle Data Interface/Definitions

The MMQ VG and MMQ AHRS provide a bi-directional RS-232 serial port to support serial interface between the MMQ and the *Host Vehicle* (*HV*). This allows the user to receive the *output message* describing the MMQ status and attitude state, send *input messages* to the MMQ to initialize it, and change its processing state.

The HV *Input/Output (I/O)* consists of various *data input messages* and one main *output messag*e that are identified by data message numbers. The detailed content and structure (definitions) of these data blocks will be specified in this chapter.

The data transmit rate and message output rate are currently both factory set at 115200 baud and 100 Hz. Refer to the control commands in this chapter for information on selecting/reprogramming the MMQ baud rate and output message rate.

Serial Interface Functionality

MMQ Normal Mode Serial Input Descriptions

Input messages are received in normal mode only. The input messages are input through the same RS-232 UART that the output data comes out over. The structure of all input messages is:

MSG_ID word
0 to 4 words of data (each word is 2 bytes or 16 bits of data)
Checksum of the MSG_ID and all data words

Reset Message

Flashes any changes to message rate or baud rate to Flash Sector B and then resets the DSP software. The Message ID = 0x5A51, and there is no data word.

Set Normal Mode Output Message Rate Message

The allowable normal mode output message rates are:

400 Hz (Data Word 0 Value=1)
200 Hz (Data Word 0 Value=2)
100 Hz (Data Word 0 Value=4)
50 Hz (Data Word 0 Value=8)

The message is made up of the Message ID = 0x5A52, one Data Word 0 (16 Bits) = 1,2,4,8, and a checksum.

Set Input/Output Baud Rate Message

The allowable RS-232 Baud rate values are:

115.2 KBaud (Data Word 0 Value=1)
57.6 KBaud (Data Word 0 Value=2)
38.4 KBaud (Data Word 0 Value=4)
19.2 KBaud (Data Word 0 Value=8)

The message is made up of the Message ID = 0x5A53, one Data Word 0 (16 Bits) = 1,2,4,8, and a checksum.

Magnetometer Input Data Message

For proper MMQ-AHRS operation, 3-axis magnetometer data from a remote magnetometer is required. The magnetometer data is transferred into the format of the Magnetometer Input Data Message, and is required at a minimum of 1 Hz for proper operation. The nominal input rate tested is 10Hz. The remote magnetometer and the MMQ-AHRS must be mounted co-aligned in axes, and together they define the system that allows the MMQ-AHRS to work as a heading indicator. The message contains data from the remote magnetometer measuring the earth's magnetic field and contains magnetometer data for the X (MagX), Y (MagY) and Z (MagZ) axes of the system. The magnetometer data is scaled such that 1 bit = 13 nanoTesla. When converted then a magnetometer integer value of 32767 = +4.26 Gauss, and an integer value of -32768 = -4.26 Gauss. The message is made up of the following:

Message ID = 0x5A54
Data Word 0 (Signed 16 Bit Integer) = MagX (counts from Magnetometer X)
Data Word 1 (Signed 16 Bit Integer) = MagY (counts from Magnetometer Y)

Data Word 2 (Signed 16 Bit Integer) = MagZ (counts from Magnetometer Z)
Checksum

Start Magnetometer Calibration

This message starts the MMQ-AHRS internal magnetometer hardiron/softiron compensation process. It is made up of a Message ID = 0x5A56 and no data word.

Stop Magnetometer Calibration

This message stops the MMQ-AHRS internal magnetometer hardiron/softiron compensation process. It is made up of a Message ID = 0x5A57, no data word. Once this message is received, the resultant hardiron and softiron calibration parameters are flashed into the EEPROM for permanent recall. Upon the next power up of the MMQ-AHRS, the stored hardiron and softiron data will be applied to the leveled magnetometer vector.

Erase Magnetometer Calibration

This message erases all stored MMQ-AHRS internal magnetometer hardiron/softiron compensation data from system memory and the Flash EEPROM. It is made up of a Message ID = 0x5A58, no data word.

MMQ Normal Mode Serial Output Descriptions

Normal Mode Data Message

The MMQ Normal Mode Message has 14 words. The message rate is user-selectable at 400, 200, 100, 50 Hz (See Serial Inputs Description Chapter). MMQ-VG and MMQ-AHRS have the same normal mode output message definition. For the MMQ-VG, Roll and Pitch are valid, but Yaw angle output data is always 0.0. For the MMQ-AHRS, all three Roll, Pitch and Yaw angle output data is valid.

The message contains a header word followed by the data words, and a checksum at the end of the message. Serial data is byte wise with one start and one stop bit per byte, no parity. Serial data output messages are all even word length, a word being considered to be 16 bits. Transmission is sent Low-byte, High Byte with Least Significant bit first in each case. The 16-bit checksum at the end of the message is the sum of the previous 13 16-bit words in the message, including the header.

The normal mode message is defined in Table 7-1.

Table 7-1. MMQ Normal Mode Message		
Index	Name	Comments
0	Header	0x7FFF
1	CompAccelX	Compensated data , signed 16-bit word, 3200 counts per g
2	CompGyroX	Compensated data , signed 16-bit word, 100 counts per deg/sec
3	CompAccelY	Compensated data , signed 16-bit word, 3200 counts per g
4	CompGyroY	Compensated data , signed 16-bit word, 100 counts per deg/sec
5	CompAccelZ	Compensated data , signed 16-bit word, 3200 counts per g
6	CompGyroZ	Compensated data , signed 16-bit word, 100 counts per deg/sec
7	BIT	See below for details
8	Frame Counter	Counts message packets sequentially from 0 to 65535
9	Revolving Parameter	See below for details
10	Phi/Roll	Signed 16-bit word, 90 counts / degree, VG/AHRS model only
11	Theta/Pitch	Signed 16-bit word, 90 counts / degree, VG/AHRS model only
12	Psi/Yaw	Signed 16-bit word, 90 counts / degree, AHRS model only
13	Checksum	Sum of the previous 13 16-bit words in the message with header

Table 7-2. Normal Mode Data Message BIT Word Definition								
Bit Position	0x8000	0x4000	0x2000	0x1000	0x800	0x400	0x200	0x100
Value	Watchdog timer fired	Code checksum failed	GyroZ output over range	AccelZ output over range	GyroY output over range	AccelY output over range	GyroX output over range	AccelX output over range
Bit Position	0x80	0x40	0x20	0x10	0x8	0x4	0x2	0x1
Value	Note 1.	Voltage Sensor ID bit2	Voltage Sensor ID bit1	Voltage Sensor ID bit0	Temp Sensor ID bit3	Temp Sensor ID bit2	Temp Sensor ID bit1	Temp Sensor ID bit0

Note 1: Not used in VG mode. For AHRS mode, this bit displays Magnetometer Timeout. This bit will display a “1” when there is no magnetometer data for more that 1 second.

The Voltage Sensor ID and Temp Sensor ID fields are defined in the following tables:

Table 7-3. Normal Mode Data Message BIT Word Definition	
Value	Meaning
0	All pass
1	5V failed
2	3.3V failed
3	1.9V failed
4	+12V failed
5	-12V failed
6	1.25V failed

Table 7-3. Normal Mode Message BIT Word Temp Sensor ID	
Value	Meaning
0	All pass
1	AccelX failed
2	GyroX failed
3	AccelY failed
4	GyroY failed
5	AccelZ failed
6	GyroZ failed
7	ADC temp failed
8	DSP temp failed

The revolving parameter is defined in Table 7-4 below. For the data represented by the revolving parameter, all voltages and temperatures are signed 16 bit integer values such that a value of 1 represents 3.90625 mV or mDeg. The range of the data then is -128.0 (0x8000) to +127.996 (0x7FFF), and 0x0000 = 0.0 volts or degree. Thus a value of 256 would represent 1 volt or 1 degree C respectively. Also all magnetometer data is signed 16 bit data and scaled such a value of 10000 represents 1 gauss, and a value of 1 represents 0.0001 gauss.

Table 7-4. Normal Mode Message Revolving Parameter	
Low 6 bits of Frame Counter	Revolving Parameter Index
0	AccelX Temperature
1	GyroX Temperature
2	AccelY Temperature
3	GyroY Temperature
4	AccelZ Temperature
5	GyroZ Temperature
6	ADC Temperature
7	DSP Temperature
8	5.0 volt PS
9	3.3 volt PS
10	1.8 volt PS
11	+12 volt PS
12	-12 volt PS
13	1.25 volt PS
14	Message rate in Hz.
15	Baud rate in KHz
16	Magnetometer Calibration Data Present
17	Magnetometer Hard Iron XAXIS
18	Magnetometer Hard Iron YAXIS
19	Magnetometer Hard Iron ZAXIS
20	Magnetometer Soft Iron XAXIS
21	Magnetometer Soft Iron YAXIS
22	Magnetometer Soft Iron ZAXIS
23	Leveled Magnetometer XAXIS
24	Leveled Magnetometer YAXIS
25	Leveled Magnetometer ZAXIS
26	Uncompensated Raw Filtered Accelerometer X
27	Uncompensated Raw Filtered Gyro X

28	Uncompensated Raw Filtered Accelerometer Y
29	Uncompensated Raw Filtered Gyro Y
30	Uncompensated Raw Filtered Accelerometer Z
31	Uncompensated Raw Filtered Gyro Z
32	Magnetometer Data Packets Received in Last 10 sec
33-64	Not Defined

Note that all magnetometer data (leveled magnetometer output and Magnetometer calibration parameters) is output only for the MMQ-AHRS model. The Leveled Magnetometer data output only changes when there is a new input Remote Magnetometer data input, otherwise it will output the same most recent Magnetometer vector values. The Leveled Magnetometer data is the input Remote Magnetometer Data Vector rotated into the navigation frame and compensated for hardiron and softiron data if present. The Baud Rate parameter is defined in Table 7-5 below.

Table 7-5. Normal Mode Message Revolving Parameter Baud Rate Value Definition

Baud Rate Value	Meaning
115	115.2 KBaud
57	57.6 KBaud
28	28.8 Kbaud
14	14.4 KBaud

Chapter 8- End Product Applications

Overview

The MMQ VG and MMQ AHRS can be used for a variety of applications. Use of the various system features and interfaces varies widely from customer to customer. The information presented here is designed to guide the first-time user on what might be required for his/her specific application. Regardless of the application, *power* must be supplied to the MMQ unit. All users will need to communicate with the system's asynchronous RS-232 *serial interface*. This interface provides attitude solution and sensor data to the user, and accepts initialization and control data from the user.

Product Application Examples

The MMQ VG and MMQ AHRS can be implemented in many end-product solutions. Some examples of MMQ VG and MMQ AHRS use and applications are described below.

Use: Attitude Determination System

- *Applications*: Manned or remote controlled dynamic platforms.
- *Examples*: Airplanes, Helicopters, remote controlled Unmanned Aerial Vehicles (UAVs), Mobile Land Vehicles, and Mobile Marine Vehicles.

Use: Guidance, Navigation, and Control

- *Applications*: Unmanned Vehicles.

- *Examples*: Autonomous UAVs, Missiles, Targets, Drones, Guided Munitions.

Use: Pointing

- *Applications*: Camera and other pointing applications.
- *Examples*: Aerial Photomapping, Radar Pointing/Steering, Land/Sea Launched Weapon Platforms.

Since MMQ can be integrated into a wide range of end-product solutions, each unique system requires different inputs and outputs to satisfy the application. The system integrator should help the development team determine how to use MMQ features and software data sets within the specific product or application.

Appendix A- Frequently Asked Questions

I apply power to the unit and the unit doesn't run. What can I do?

Inspect the power supply and cabling to the unit. Verify the proper voltage level at the power supply and at the unit connector pins.

- The DC power supply that you are using may not have an adequate current capacity for the unit. Although the unit draws +280mA/-80mA steady state current, turn-on inrush current can be as high as +/-400mA during the first half second. It's a good idea to use a power supply rated at least 1 amp for each supply.

I can't communicate with the unit via the RS-232 port. Why?

Generally, if you are having trouble communicating with the unit and are sure that your RS-232 communications parameters are set correctly; try viewing the data using an RS-232 monitor program. This will verify the communications parameters, as well as the message data content, handshaking, and timing. Remember that the data on the RS-232 port is binary, not ASCII coded numbers. See Chapter 7- Software Integration for data formats. Also, verify the following:

- Check that the serial data connections are complete in the cable that you are using. (Can you see data on an oscilloscope or via an RS-232 monitor program right at the data pins on the unit connector?)
- Verify that a null modem cable configuration is being used (i.e., is your system's Transmit data line going to the

unit’s receive data line and your system’s Receive data line going to the unit’s transmit data line).

- Check that the proper baud rate, data bits, stop bits, and parity are being used. You should be using the proper baud rate, eight data bits, one stop bit, and odd parity.
- Verify that you have set up your UART correctly. On a PC, the UART’s OUT 2 signal must be asserted for the UART to function properly.
- If your program is interrupt-driven, verify that the interrupt handling routine functions correctly using a dumb terminal or simulated message input.

Why am I getting unintelligible data over the RS-232 port?

The RS-232 data is sending byte information in reverse order from the unit. (At your PC, observe the message traffic, or at your printer, if you are using one, get a sample printout.) If you’re using a PC to receive data, you must be sure to place the data in memory in the correct order for your program to interpret the data.

- Verify that poor cable connections are not causing RS-232 signal degradation. If the received data bytes have parity, break, or framing errors, then you are either using the wrong communications parameters, or there is a problem with the cabling.

My program can’t detect the start of a new message block, but there appears to be data being sent by the unit. Why?

The message start identification word “7FFF” is sent LSB first, so a program should check that an “FF” is received, then that an “7F” is received to indicate the start of an incoming message.

I can receive data from the unit, but I can’t send data to the unit. What should I do?

- Verify that the unit transmit cable connection is complete to your processor.
- Verify that the message format for the data that you are sending the unit is proper. (Are the checksums for the header and data portions of the message correct?) If the handshake protocol indicates that your message has been rejected, chances are that your message format is in error.

Appendix B- Getting Started

Setup

The following information will guide the system integrator in effectively integrating the MMQ VG or MMQ AHRS system with the HV. For commonly asked questions regarding system integration, refer to Appendix A- Frequently Asked Questions. For questions concerning your specific application, please contact an SDI applications engineer.

Support Equipment Required

Power Supply

MMQ requires a power input of +/-12V (nominal, 11v-13V limit) as measured at the input. The typical steady-state current drawn by MMQ is +280ma and –80mA at +/-12 Vdc. Turn-on (inrush) current during the first half second can be as high as +/-400mA on the positive supply and 280mA on the negative supply, It's a good idea to use a power supply rated at least 1 amp for each supply.

Connectors/Cables

The J1 I/O connector and cable requirements are defined in Chapter 5- Hardware Integration. If used in a hostile electromagnetic environment, care should be given to overbraid the interface cable to obtain the best overall EMI protection.

Communication Via RS-232 Asynchronous Port

As part of getting started, a Windows compatible computer equipped with a RS-232 COM port supporting up to 115.2kBd can be used as the Host Vehicle system. The host vehicle I/O interface will enable the user to send initialization and control data to the MMQ, as well as display or record its output information. Refer to the *Digital Interface* section in Chapter 5- Hardware Integration for information on the data rates and frame format selection of the serial data.

Additional Support for Integration

PC-based integration software, SYSTRON DONNER VIEWER is available with MMQ VG and MMQ AHRS. This software will aid the user in communication through the host vehicle port. The software serves only as a guide in helping the user get started using MMQ and to observe the contents of the normal mode data message. However, it is the responsibility of the user to develop software to meet his specific application.

Installation

It is recommended that MMQ be mounted using four #6 socket cap screws, tightened to a torque between 8-12 in-lbs. The mounting hole pattern is shown in Figure 4.

Using MMQ

This section is intended as an operational overview of the MMQ VG and MMQ AHRS. Examples are provided using the SYSTRON DONNER VIEWER software, running on a standard Windows compatible computer. The following section will provide information necessary to help the user set up their system to properly interface the MMQ.

MMQ-G Operational Overview

Once power is applied, the MMQ VG and MMQ AHRS will go through power-on initialization, and will sequence up to *Normal* mode. This entire process takes approximately 7 seconds to complete.

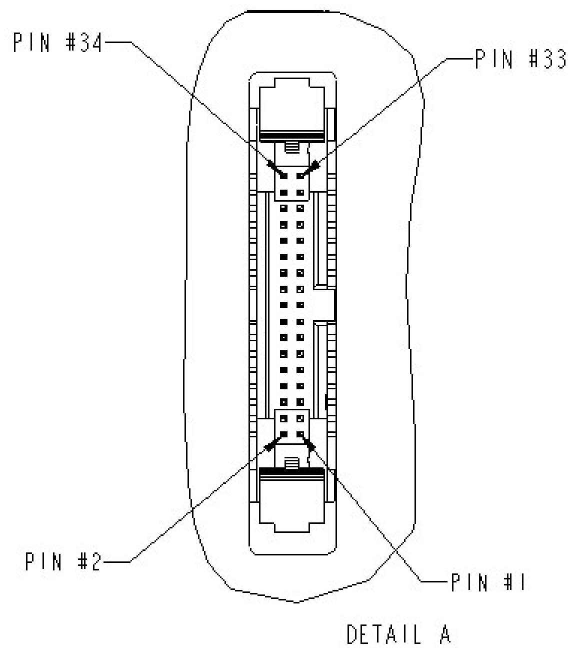
Before You Begin

Warning

Improper wiring of the user cable connecting to MMQ can cause irreversible damage that is not covered under product warranty. Common mistakes include incorrectly identifying pin assignments (e.g., mirror image wiring assignments), resulting in power being applied to the wrong pins.

<u>Before</u> applying power, verify that it is being supplied to the correct pins; see table below and Detail “A” (outside view of MMQ connector J1).

Signal	Pin
+12 Vdc	22
-12 Vdc	12
Antenna DC Power (optional)	31
+3v “keep alive” power (optional)	32
Power Return (Ground)	29
Chassis (internally connected to Ground)	30



1. The cable’s RF noise environment and shielding requirements should be taken into consideration prior to fabrication.
2. Verify cable configuration of RS-232 port is correct. Your system’s transmit data line should go to the MMQ receive line and your system’s receive line should go to the MMQ transmit line. (i.e. null modem connection)

For reference, Table A-1 provides the standard pin assignments for the relevant RS-232 signals typically found on a compatible computer with COM port. The MMQ requires only use of the **Transmit** and **Receive** data signals (**TD**, **RD**) and **Signal Ground**.

Table A-1. RS-232 Pin Assignments			
Description	**Computer Pin # (25-Pin)**	**Computer Pin # (9-Pin)**	**Abbreviation**
Transmit Data	2	3	TD
Receive Data	3	2	RD
Signal Ground	7	5	SG
Protective Ground	1	-	FG

3. Verify that the cable configuration of +/-12 Vdc main power and +3 Vdc battery input (optional) are correct.

4. Insert the available SYSTRON DONNER VIEWER CD in the CD drive, and install SYSTRON DONNER VIEWER on your computer. The SYSTRON DONNER VIEWER software will provide the ability to interface between MMQ and a Windows-based PC simulating the user's host vehicle communication device. Refer to Appendix C for the details of the installation.

5. Create a short cut on screen for easy access. Double click on the SYSTRON DONNER VIEWER shortcut, the SYSTRON DONNER VIEWER command and control window should appear on the screen.