

# MMQ™ -G

## User's Guide



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# Chapter 1- Introduction

*MMQ-G Integrated INS/GPS*

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## Overview

Systron Donner Inertial (SDI) has developed a family of Guidance, Navigation, and Control (GN&C) products that use the latest solid-state inertial sensor technology integrated with advanced Standard Positioning Service (SPS) and Precise Positioning Service (PPS) Global Positioning System (GPS) engines.

MMQ-G is a tightly coupled SPS INS/GPS containing a twelve channel, Coarse/Acquisition (C/A) code, L1 frequency GPS engine, and a digital Quartz-based IMU. The two subsystems are integrated together through a Kalman filter mechanization to produce a small, lightweight, synergistic GN&C system. It requires only an antenna, a +/- 12Vdc power supply and any device capable of accepting RS232 asynchronous serial data. The electronics are housed in an aluminum chassis, forming a compact, robust package. Proven off-the-shelf products integrated into one package translate into affordability and low risk. MMQ-G provides all essential GN&C data, including three-dimensional position and velocity, precise time, attitude, heading, angular rate, and acceleration.

MMQ-G configurations can be tailored to meet operational performance requirements, while meeting budgetary constraints to provide affordable, operationally effective system solutions. These integrated solutions offer an affordable suite of compact and lightweight systems that are ideally suited for GN&C applications, such as tactical missiles, guided munitions, unmanned aerial vehicles (targets, decoys, etc.), land vehicles, geolocation, and a host of other uses.

Additional technical data, physical characteristics, operation, and system integration information for the MMQ-G product are presented in subsequent chapters of this guide.

## Why INS/GPS?

Many guidance and control problems in the past have been addressed with stand-alone Inertial Navigation System (INS) or GPS solutions; however, the inherent characteristics of each system do not provide an ideal GN&C solution. By properly integrating the INS and GPS systems, the strengths of one can offset the deficiencies of the other.

An INS is generally characterized as a self-contained, autonomous navigator, whose position and velocity outputs will degrade over time. Alternatively, the GPS is generally described as a navigator relying on external satellite signals, whose high accuracy solution is time independent.

When the two systems are combined, the INS/GPS system will bound the INS error growth, and provide a continuous navigation solution when GPS signals are not available. In addition, high-speed attitude, velocity, angular rate, and acceleration are available at accuracies not achievable by GPS alone.

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## About This Book

This guide provides basic navigation concepts, INS/GPS concepts, configuration, operation, and characteristics of the system, and defines the mechanical, electrical, and data interfaces of MMQ-G to the Host Vehicle (HV). The inertial portion and the Jupiter® Pico GPS engine will be typically referred to in this guide as the *Inertial Measurement Unit* (IMU) and the *GPS receiver*, respectively.

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-G 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- INS/GPS Concepts

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## What is Navigation?

*Navigation* is the art and science of directing a vehicle from one place to another. 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 navigation accuracy.

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

- What is the present *position* (latitude, longitude, and altitude)?
- What is the vehicle's *heading*?
- What is the vehicle's *attitude* (roll and pitch)?
- What is the vehicle's *velocity* (north/south, east/west, total, and vertical)?
- What is the vehicle's *acceleration*?

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

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

An *Inertial Navigation System* (INS) measures changes in velocity through the use of accelerometers and gyroscopes. This information is fed to a computer that is used to keep track of velocity and to continuously maintain an indication of position. Today these same instruments typically provide rate and state data to other avionics subsystems such as weapon computers, flight controls, or radar sensors.

An INS makes its 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.

*The INS needs to be properly initialized and periodically reinitialized.*

As with any dead reckoning system, it is important that an INS be properly initialized and periodically reinitialized. Other methods of navigation, such as Navigation Satellite Timing and Ranging (NAVSTAR) GPS, can be used in conjunction with the INS. Both of these methods are discussed later in this chapter.

### **Inertial Navigation Advantages**

Some of the advantages of inertial navigation are as follows:

- All types of navigation data are determined simultaneously, i.e., position, velocity, heading, and attitude. Most other methods of navigation provide only position data.
- Navigation data is continuously available.
- Even though some errors can be additive, inertial navigators can be made to be very accurate.
- Navigation data is provided at a high rate so vehicle, weapon, or sensor stabilization is possible.

Since the earth is itself moving in inertial space, the relationships between a vehicle, the earth, and inertial space are fundamental to the solution of the inertial navigation problem.

These relationships are defined by the laws of mechanics, which describe the motions and interactions of material bodies in inertial space. The inertial navigation systems that we typically deal with compute and output velocity and attitude parameters, as well as latitude, longitude, and altitude position.

### **Position**

Position is defined as the *location of a body in space*, and can be described completely by referencing the body to an appropriate coordinate system. Usually, rectangular coordinates are used.

## 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.

## Velocity

Displacement indicates *extent of motion*, that is, the magnitude and direction of change in position. Velocity is a measure of *how fast displacement takes place*, or, how much displacement occurs in a given unit of time.

Velocity parameters are typically expressed in terms of the vertical and horizontal components of translational movement relative to the earth. In an example of an aircraft, the vertical component of velocity is called the *altitude rate*. The horizontal component of velocity can be expressed in terms of North and East components, or in terms of the net horizontal velocity component magnitude (commonly called *ground speed*), and horizontal velocity vector direction relative to North (known as the *track angle*).

## 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 INS 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.

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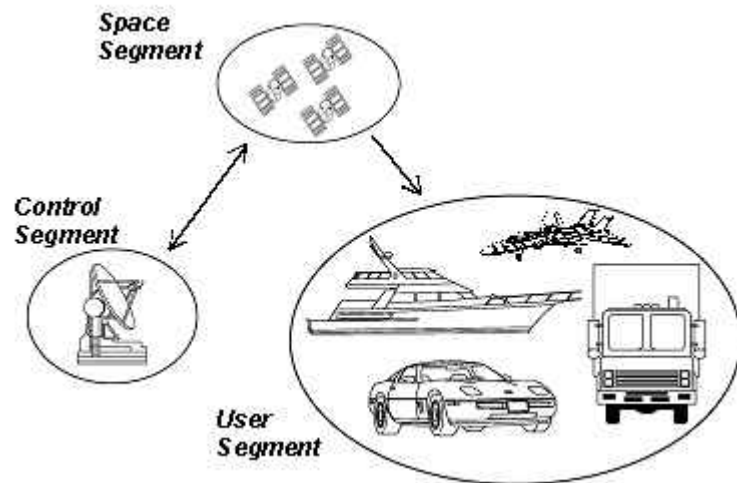
## NAVSTAR GPS General Theory

NAVSTAR GPS is a space-based satellite radio navigation system developed by the United States Department of Defense (DoD).

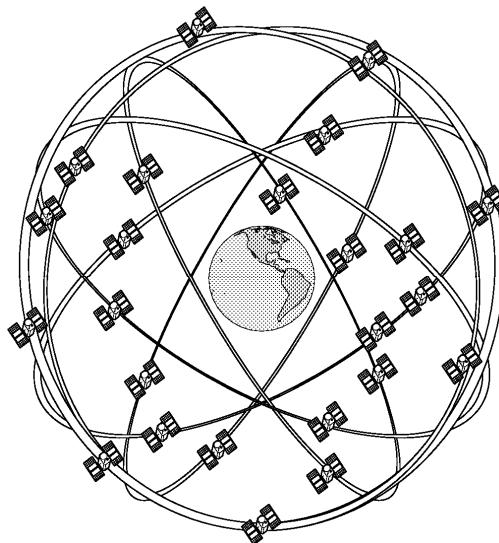
GPS receivers provide land, marine, and airborne users with continuous three-dimensional position, velocity, and time data. This information is available free of charge to an unlimited number of users. The system operates under all weather conditions, 24 hours a day, anywhere on Earth.

### GPS System Design

The GPS system consists of three major segments: Space, Control, and User, as shown in Figure 2-1. Major Segments of the NAVSTAR GPS System.



*Figure 2-1. Major Segments of the NAVSTAR GPS System*



**Figure 2-2. NAVSTAR GPS Operational Satellite Constellation**

The satellites are in circular orbits with a 12-hour orbital period and inclination angle of 55 degrees. This orientation normally provides a GPS user with a minimum of five satellites in view from any point on Earth at any one time. Each satellite continuously broadcasts Radio Frequency (RF) signals at two L-band frequencies. The L1 frequency is 1575.42 MHz and is modulated by a 10.23 MHz clock rate Precise ranging signal (P), or *Precision Code* (P-code), and by a 1.023 MHz clock rate C/A code ranging signal, or *Coarse/ Acquisition Code* (C/A-code). The L2 frequency is 1227.6 MHz and carries P-code only. Non-military navigation sets, such as the MMQ-G, typically have access to the L1 C/A-code only.

Before the P-code and C/A-code are modulated for transmission, they are combined with navigation data, 50 bits per second (bps), by Modulo-2 addition. The navigation data, which is computed and controlled by the GPS Control Segment, includes each satellite's time, clock correction, ephemeris parameters, almanac data, and health status for all GPS satellites. From this information, the user computes the satellite's precise position and clock offset.

Currently, the DoD encrypts P-code ranging signals and thus denies access to the Precise Positioning Service (PPS) by unauthorized users. The Standard Positioning Service (SPS) uses the C/A-code ranging signal, which is intended for general public use.

## **Control Segment**

This segment consists of a Master Control Station, located in Colorado Springs, Colorado, and a number of monitor stations at various locations around the world.

Each monitor station tracks all GPS satellites in view and passes signal measurement data back to the Master Control Station. There, computations are performed to determine precise satellite ephemeris and satellite clock errors.

The Master Control Station generates the upload of user navigation data for each satellite. This data is subsequently re-broadcast by the satellite as part of its navigation data message.

## **User Segment**

This segment is the collection of all GPS receivers and their application support equipment, such as antennas and processors. This equipment allows users to receive, decode, and process information necessary to obtain accurate position, velocity, and timing measurements. This data is used by the GPS receiver's support equipment for specific application requirements.

GPS supports a wide variety of applications including navigation, surveying, and time transfer. Receivers may be used in a stand-alone mode, or integrated with other systems to enhance overall system performance.

## **How The GPS Receiver Determines Position**

The GPS receiver determines its geographic position by measuring the ranges of several satellites and computing the geometric intersection of these ranges.

To determine a range, the receiver measures the time required for a GPS signal to travel from a satellite to a receiver antenna. A timing code generated by each satellite is compared to an identical code generated by the receiver.

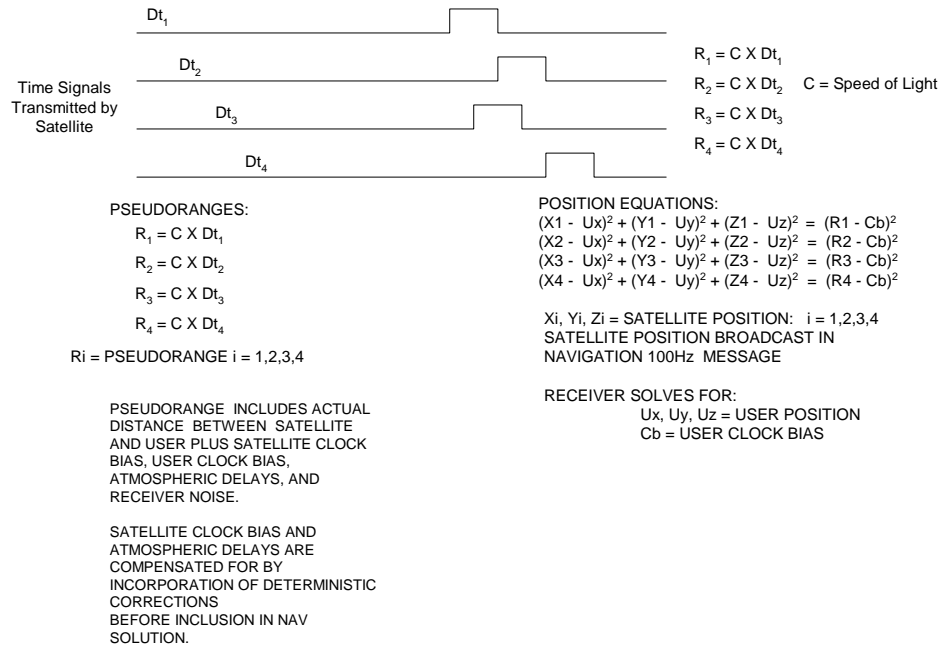
The receiver's code is shifted until it matches the satellite's code. The resulting time shift is multiplied by the speed of light to arrive at the apparent range measurement.

Since the resulting range measurement contains propagation delays due to atmospheric effects, and satellite and receiver clock errors, it is referred to as a *pseudorange*. Changes in each of these pseudoranges over a short period of time are also measured and processed by the receiver. These

*Range is the distance between a satellite with known coordinates in space and the receiver's antenna.*

measurements, referred to as *delta-pseudoranges*, are used to compute velocity.

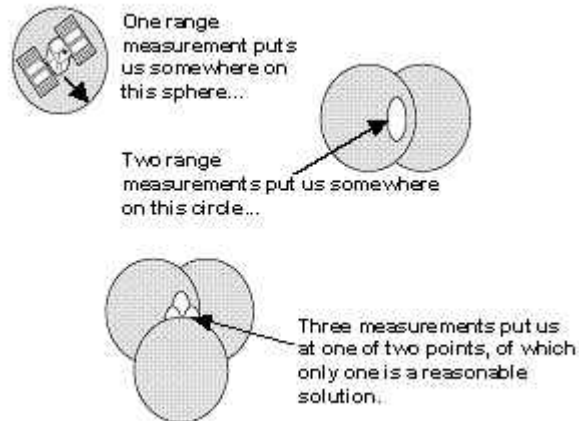
A minimum of four pseudorange measurements are required by the GPS receiver to mathematically determine time and the three components of *position* (latitude, longitude, and altitude). The equations used for these calculations are shown in Figure 2-3. Range Processing Equations.



**Figure 2-3. Range Processing Equations**

The solution of these equations may be visualized as the *geometric intersection* of four ranges from four known satellite locations.

Figure 2-4. Satellite Ranging Intersections illustrates triangulation, which is a way to envision the navigation process. For ease of understanding, time information, which would be derived from a fourth satellite, is not shown.



**Figure 2-4. Satellite Ranging Intersections**

After the four range equations are solved, the GPS receiver has estimates of its position and time. Similar equations are then used to calculate velocity using relative velocities instead of pseudoranges. The position, velocity, and time data are generally computed once per second.

### **GPS Accuracy**

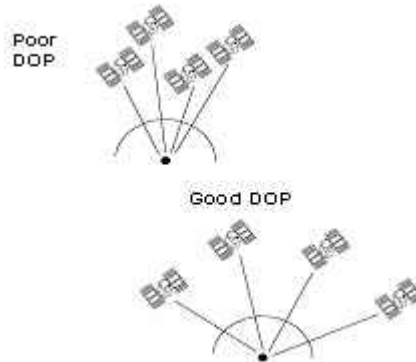
GPS accuracy has a statistical distribution that is dependent on two important factors. The expected accuracy will vary with the *error* in the range measurements, as well as the *geometry* or *relative positions* of the satellites and the user.

#### ***Dilution of Precision (DOP)***

The Geometric Dilution of Precision (GDOP) indicates how much the geometric relationship of the tracked satellites affects uncertainty of the GPS receiver's position, velocity, and time estimates.

There are four DOP components that are commonly used to indicate how the geometry specifically affects errors in horizontal position (HDOP), vertical position (VDOP), three-dimensional position (PDOP), and time (TDOP). DOPs are computed based on spatial relationships of the lines of sight between the satellites and the user. The motion of the satellites relative to each other and the user causes the DOPs to vary constantly. For the same range measurement errors, lower DOPs relate to more accurate estimates.

The errors in range measurements (the measurements that are used for solving position) can be magnified by poor geometry. The least amount of error results when the lines of sight have the greatest *angular separation* between them (see Figure 2-5. Geometric Dilution of Precision).



*Figure 2-5. Geometric Dilution of Precision*

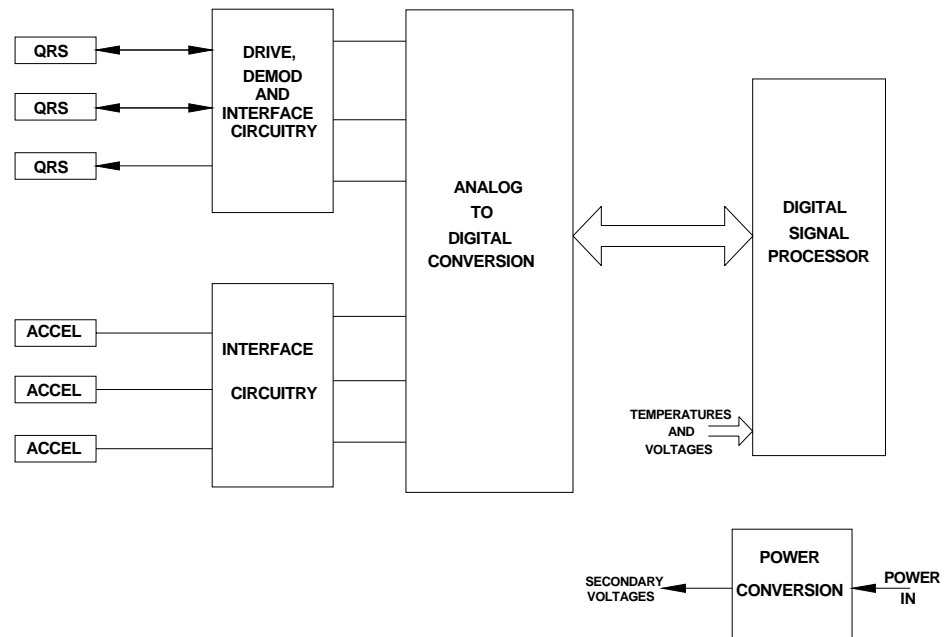
For example, if two lines of sight are necessary to establish a user position, the least amount of error is present when the lines cross at right angles.

#### **Range Measurement Error**

The error in the range measurement is dependent upon one of two levels of GPS accuracy. PPS is the most accurate, but is reserved for use by the DoD and certain authorized users. SPS is less accurate and intended for general public use. This is the level of accuracy used by the MMQ-G GPS receiver.

## Quartz IMU General Theory

The IMU (Figure 2-6. MMQ-G IMU Functional Block Diagram) 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 2-6. MMQ-G IMU Functional Block Diagram*

The IMU contains the electronics that process the raw sensor signals for compensation. It provides the  $\Delta\theta$  and  $\Delta v$  for navigation at 100 Hz.

### 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 DQI uses a *dual tuning fork design* shown in Figure 2-7. Simplified Block Diagram Quartz Rate Sensor. 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

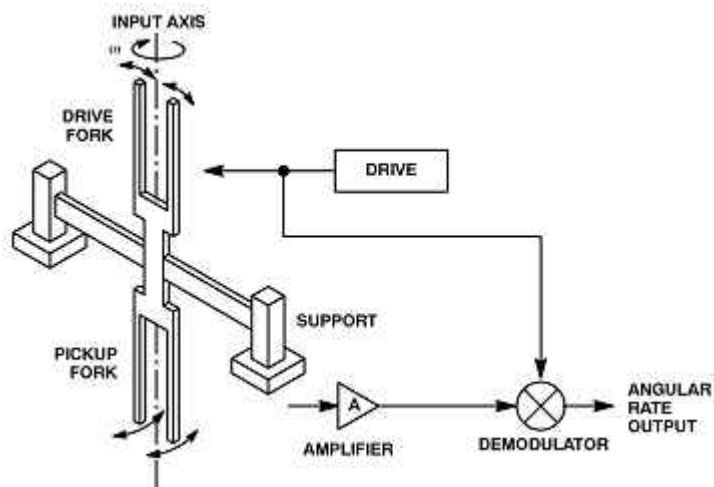


Figure 2-7. Simplified Block Diagram Quartz Rate Sensor

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 IMU 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.

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## INS/GPS General Theory

### Accuracy vs. Time

Inertial navigation systems sense acceleration and angular rate information, which can be integrated to determine position, velocity, and attitude solutions. However, due to inertial instrument imperfections, inertial navigation solution accuracies will deteriorate, or *drift* over time.

*INS position error will drift with time; GPS high accuracy solution is time independent.*

A GPS high accuracy solution is based on 1-Hertz measurements from GPS satellites. As long as GPS satellite signals are available, the accuracy of the GPS solution is time independent. This characteristic allows the GPS solution to be used to bound the error growth in the inertial navigation solution in an integrated INS/GPS system.

### Data Frequency

*INS output is high frequency and relatively quiet; GPS output is low frequency.*

The INS measurement data is high frequency (greater than or equal to 100 Hz), which allows for computation of *position, velocity, and attitude* solutions based on integration of high-rate data.

GPS measurement data is low frequency (typically computed at 1 Hz), which allows for computation of *position, velocity, and time* solutions.

Guidance and control algorithms require accurate, high frequency data. Although some GPS solutions can provide solutions up to 10 Hz, this method is not accurate in dynamic environments when velocities are not uniform over extrapolation intervals.

Therefore, when GPS bounds long-term, IMU-based solution error drift, the IMU provides measurements for computation of accurate, high-frequency solution data for dynamic environments.

### GPS Satellite Signal Dependency

GPS solutions depend on availability of GPS satellite signals. When GPS satellite measurements become unavailable, GPS stand-alone system navigation accuracies quickly degrade due to dead reckoning-based solutions. Although GPS satellite signals are always transmitted, a

*INS is a*

*totally self-contained autonomous operation; GPS is dependent on availability of satellite signals.*

GPS receiver may not be able to track the GPS signals due to the operational environment. Typical conditions that may preclude the ability to track GPS satellites include *jamming* and *antenna masking*.

Jamming can be the result of intentional GPS signal interference or random signal interference. Antenna masking is an obstruction between the antenna and the GPS satellite, such as the wing of an aircraft or a tall building. Regardless of the cause of GPS signal denial, the IMU system is autonomous, which allows an INS/GPS system to continue navigating during periods of GPS signal loss.

The IMU can also be used to aid the GPS in reacquisition after periods of shading or jamming. *Shading* can occur when the line-of-sight GPS signal is obscured by blockage or maneuvers.

### **Attitude Data Capabilities**

*INS provides accurate, high rate attitude data; GPS attitude capability is limited.*

As previously mentioned, inertial navigation systems sense acceleration and angular rate. Angular rate data can be integrated to determine *attitude*. GPS systems inherently do not provide attitude information; however, GPS can be used with multiple antenna inputs to estimate attitude, but is limited by jamming, antenna masking, and shading. GPS attitude determination systems are not robust in dynamic environments, and encounter the same deterioration as GPS position solutions when GPS signal obscuration occurs. In an INS/GPS system, inertial angular rate data can be integrated to determine attitude. In addition, the GPS velocity vector can be used to estimate INS attitude errors. This results in an attitude solution with greatly reduced inertial-based errors. It also enables integrated INS/GPS solutions with low-cost, less accurate IMUs to achieve the attitude accuracy of high-accuracy IMU systems. Error growth over time (an INS-only problem) is also eliminated.

## Initialization Capabilities

*INS requires dynamic-limited initial conditions; GPS can self-initialize on the fly, and “align” the IMU.*

Stand-alone IMU systems make assumptions about gravity and earth rate to self-initialize. This self-alignment process usually takes time, and often requires a stationary platform. When a GPS system is initialized with crude position, velocity, and time data, it can acquire and track satellites in less than a minute. Even without initialization data, a GPS receiver can acquire satellites in a dynamic environment.

This is achieved by using data stored in GPS memory from a prior successful period of navigation, or by executing *cold start* algorithms that search the sky for any GPS satellite signals.

Once the GPS receiver acquires satellites for navigation, the GPS information can be used to align the IMU. This IMU alignment does not require a stationary platform. In fact, this type of alignment requires vehicle dynamics, which provides increased visibility into IMU navigation solution error sources.

To summarize, an integrated INS/GPS system can power up and self-align in a dynamic or stationary environment without cumbersome stationary alignment requirements.

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# Chapter 3- System Overview

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## System Configuration

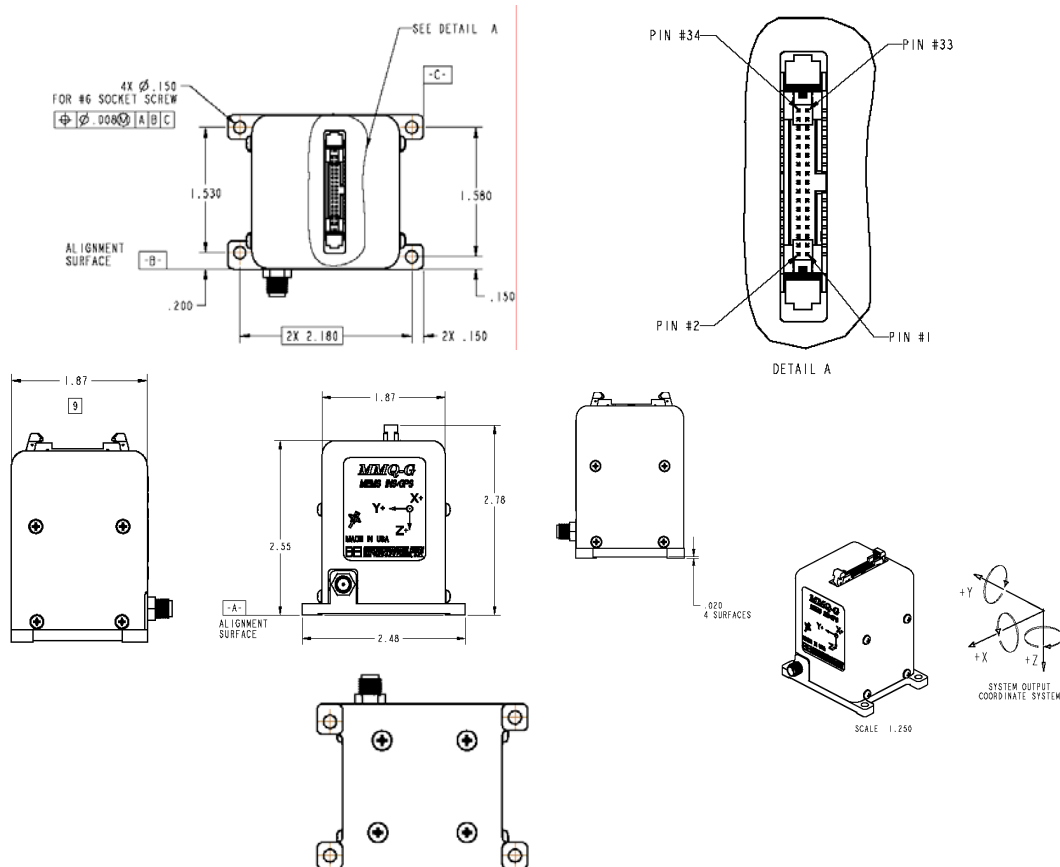
The MMQ-G is designed to provide a low-cost solution for applications that require an Integrated INS/GPS system. As introduced earlier in this guide, MMQ-G is composed of two basic elements: the MMQ50 IMU and the Jupiter Pico GPS receiver.

The IMU provides delta-velocity and delta-theta information about three axes at a 100-Hz rate. The IMU uses micro-machined quartz rate sensors and silicon accelerometers to achieve low cost, weight, and volume.

The Jupiter Pico Receiver is a single board, twelve-parallel channel L1 only Coarse/Acquisition (C/A) code GPS engine. This GPS receiver tracks up to twelve satellites, providing accurate satellite-based positioning data while using minimal power. The GPS receiver is a highly integrated digital receiver incorporating custom devices, including a fully integrated radio frequency (RF) front end. This minimizes the receiver's size to about 8 square centimeters and satisfies harsh environmental requirements.

## System Technical Description

The SDI MMQ-G system, shown in Figure 3-1. MMQ-G Form Factor, combines the IMU's high-rate, inertial delta-velocity and delta-theta outputs, and the Jupiter Pico 1-Hz GPS range and range rate measurements to compute a complete navigation solution.



**Figure 3-1. MMQ-G Form Factor**

In normal operation, a three-dimensional navigation solution (including attitude and heading) is computed based on integrated inertial data. This inertial solution is corrected using a Kalman filter, which processes GPS range and range rate measurements at a 1-Hz rate. This results in a robust navigation solution that reduces inertial sensor errors.

The MMQ-G must complete both inertial system alignment and GPS signal acquisition to achieve an integrated

navigation solution. In this system, inertial alignment can occur in both stationary and dynamic environments.

*Stationary alignment* assumes a motionless platform, and requires heading initialization data. This alignment process requires that the platform remain motionless for a period of three minutes. *Dynamic alignment* assumes a moving platform. This alignment process requires GPS measurement information to compute IMU alignment.

The MMQ-G also offers a hybrid mode designated Large Azimuth Alignment. In this mode the IMU is initialized without *a priori* knowledge of the vehicle's heading. The initial heading is then determined after the alignment process is completed using the vehicles dynamics.

MMQ-G satellite acquisition time is dependent on the initialization data quality and age of GPS almanac. An external battery may be utilized to maintain acquisition critical information such as ephemeris and time.

The length of time required to receive four satellite measurements such that a fully determined three-dimensional solution can be computed is referred to as the Time-To-First-Fix (TTFF). Table 3-1 provides the TTFF information for MMQ-G. The values shown are based on unobscured satellite signals.

Table 3-1. GPS Signal Acquisition TTFF						
Initial Error Uncertainties (3 sigma)			Maximum Almanac Age	Maximum Ephemeris Age	Time-To-First-Fix *	
Position (km)	Velocity (m/sec)	Time (min)	(weeks)	(hours)	Typical (minutes)	90% Probable (minutes)
100	75	5	1	4	0.3	0.4
100	75	5	1	U/A	0.8	1.0
100	75	U/A	1	U/A	2	2.5
U/A	U/A	U/A	52	U/A	8	15

\* = Assumes no GPS signal blockage  
 U/A = Unavailable in real-time to the receiver

## System Operation

Operation of the MMQ-G system requires conditioned power, L1 GPS RF Standard Positioning Service (SPS) signals (1575.42 MHz) from a passive or active antenna, and

an RS-232 bi-directional serial port to interface with MMQ-G data.

The bi-directional serial port is used to output position, velocity, time, and attitude (PVTa), and status information. Input initialization data and commands are received on this port.

In a stationary environment, the MMQ-G powers up in *Initialization* mode. When it receives serial port initialization data including position, heading, and time, MMQ-G will begin IMU alignment. GPS acquisition will start immediately upon power application, and will utilize serial port initialization data only if it has not already acquired GPS satellite signals.

After an alignment period of 3 minutes, the system will transition to *Navigation* mode, using GPS signals when available.

In a dynamic environment, MMQ-G powers up in *Initialization* mode. Once again, GPS satellite acquisition will start immediately upon power application, and will utilize serial port initialization data only if it has not already acquired GPS satellite signals. After satellite acquisition is complete, the GPS position and velocity vector is used to initiate INS dynamic alignment.

IMU alignment quality then becomes a function of system dynamics. A heading change is required for the system to complete alignment and proceed to *Navigation* mode.

## Product Performance

### *Integrated INS/GPS PVTa Accuracy*

The MMQ-G Integrated INS/GPS PVTa which will operate in Standard Position Service (SPS) mode.

Table 3-2. Position, Velocity, Time, and Attitude Accuracies								
State	Position (meters)			Velocity (meters/sec)		Time	Roll/Pitch	Heading
	3D Position SEP	Horizontal Position CEP	Vertical Position VEP	Horizontal (East or North) 1 sigma	Vertical 1 sigma	$\mu$ sec 1 sigma	mrad 1 sigma	mrad 1 sigma
SPS	5 m	3 m	4 m	0.2 m/s	0.2 m/s	1 $\mu$ s	5 mrad	5 mrad
Notes:								
1. Time performance is for GPS time as referenced to Time Mark 1 PPS output pulse.								
2. Attitude accuracies are referenced to the IMU case mounting interface.								
3. Heading accuracy assumes dynamic motion, which allows for IMU instrument calibration.								

SPS performance shall apply when conditions in Table 3-3 are satisfied.

<b>Table 3-3. INS/GPS System Accuracy Assumptions, SPS Operation (Corrected Data Only)</b>	
User range error due to Control/Space Segment errors.	$\leq 6 \text{ m}, 1\sigma$
PDOP (RMS)	$\leq 2.6$
HDOP (RMS)	$\leq 1.45$
VDOP (RMS)	$\leq 2.21$
TDOP (RMS)	$\leq 1.21$
Ionospheric model error, per satellite.	$\leq 5 \text{ m}, 1\sigma$
Tropospheric model error, per satellite.	$\leq 2 \text{ m}, 1\sigma$
Multipath signal error, per satellite.	$\leq 1.2 \text{ m}, 1\sigma$
State 5 J/S (20 MHz BW AWGN)	$\leq 41 \text{ dB}$
State 3 J/S (20 MHz BW AWGN)	$\leq 57 \text{ dB}$

### ***INS Only Performance***

Accuracy during *INS-Only operation* (e.g. during periods of heavy jamming or satellite obscuration) is determined by the level of calibration obtained during *INS/GPS operation* and the level and type of dynamics sustained after GPS is lost. MMQ-G INS-only outputs meet the accuracies shown below, which describe MMQ-G performance under typical conditions. These accuracies assume that MMQ-G is under nominally constant cruise conditions after a period of State 5 INS/GPS operation, and includes a minimum of two, 30-degree turns just prior to the start of *INS-Only operation*. Failure to provide sufficient dynamics for IMU calibration will result in degraded performance.

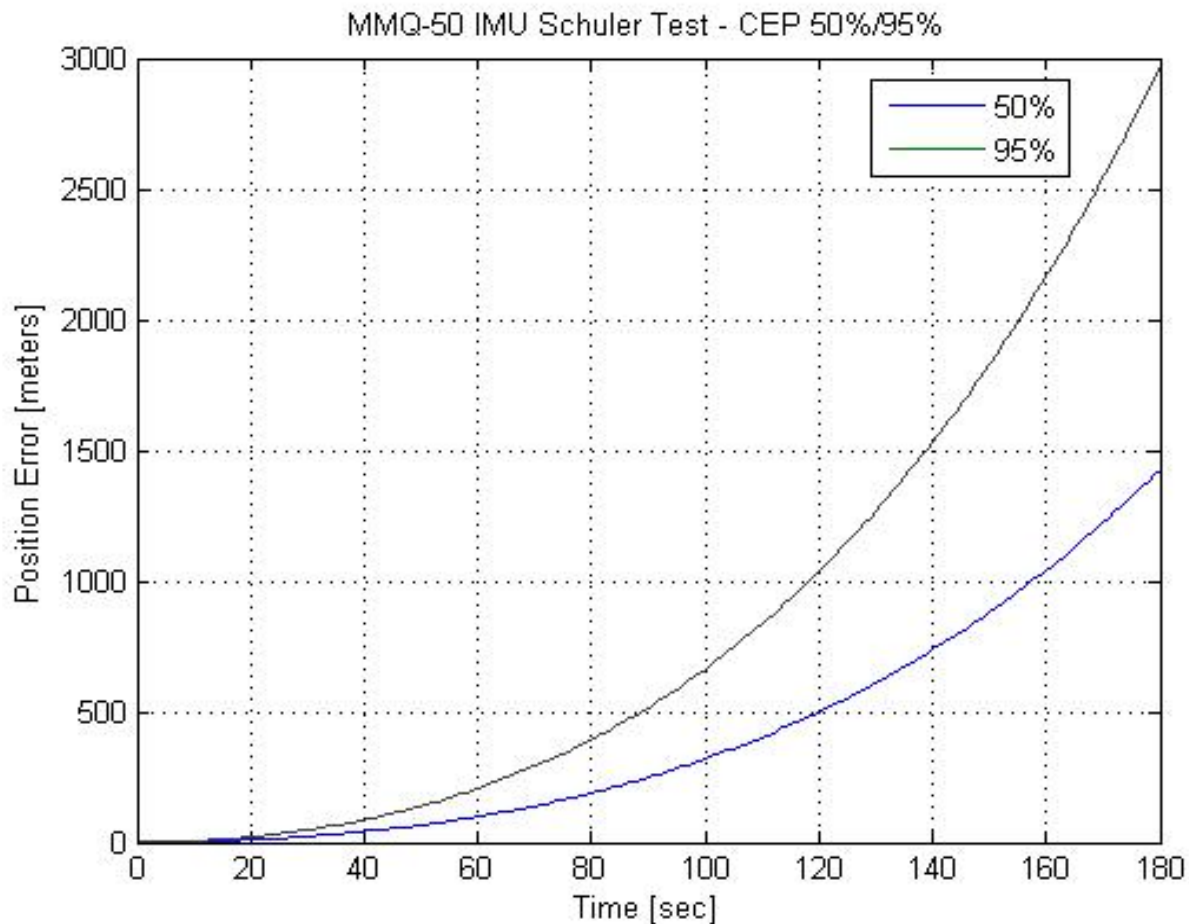


Figure 3-2. Expected INS Only Error Growth

### System Power Requirements

The following is a brief overview of MMQ-G power requirements, including input voltage, current, overvoltage protection, and battery voltage.

#### Input Voltage

The prime power input voltage to MMQ-G 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-G contains a transient absorption zener diode that clamps both the positive and negative input voltages at 17V.

### **Battery Voltage**

MMQ-G provides for an *optional battery input*. This optional input power is used when prime power is off, to maintain a low-power time source and an accurate set of satellite parameters in SRAM.

### **Signal Interface Environment**

MMQ-G provides one full-duplex, asynchronous RS232 serial data port for communicating with the Host Vehicle.

### **Radio Frequency Signal Environment**

The GPS RF input is 1575.42 MHz (L1 band) at a level between -130 dBW and -163 dBW. Burnout protection is provided for a -10 dBW signal within a bandwidth of 10 MHz centered about the L1 carrier frequency.

### **Physical Dimensions**

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

#### Envelope Dimensions

The MMQ-G envelope dimensions are shown in Figure 3-3. MMQ-G Mechanical configuration (Views 1 & 2 of 3): Width = 2.48", Depth = 1.87", Height = 2.78", Volume = 12.9 cu in.

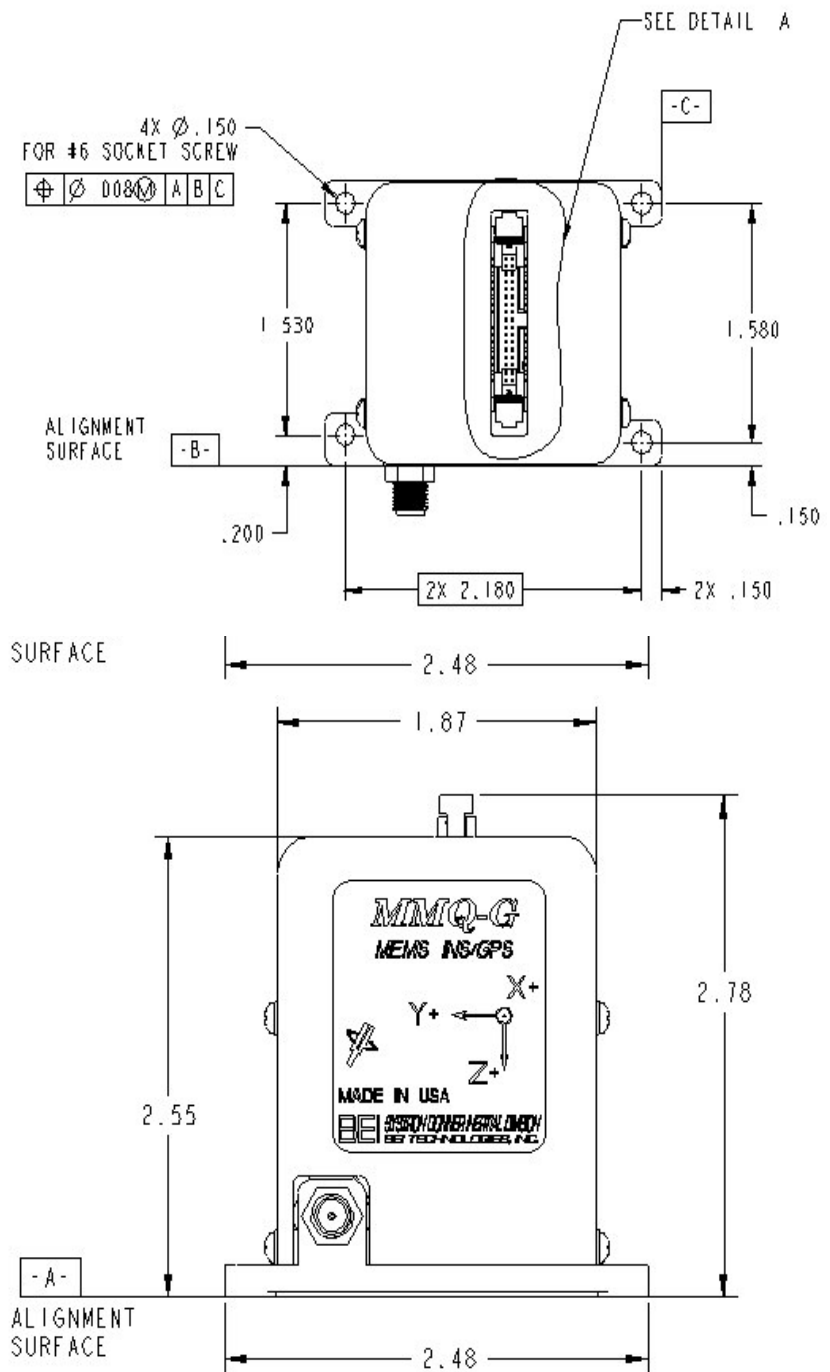


Figure 3-3. MMQ-G Mechanical configuration (Views 1 & 2 of 3)

**Installation Requirements**

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

**IMPORTANT!**

The MMQ-G must be securely mounted to a good thermally conducting (metal) surface during

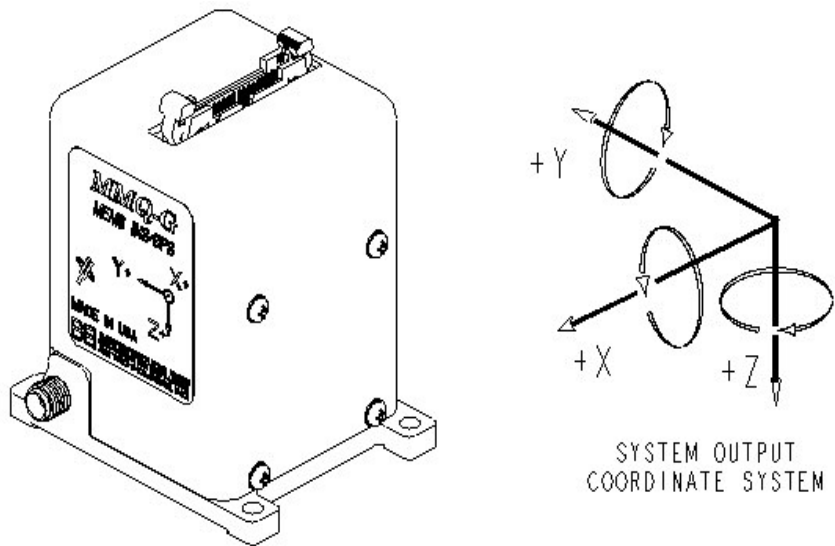
operation to prevent thermal damage. (Nominal Power dissipation is approximately 4.3W, and the mounting base temperature must be kept below 85°C.)

**Mass Properties**

The weight of the MMQ-G 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 3-4. MMQ-G Mechanical Configuration (View 3 of 3).



*Figure 3-4. MMQ-G Mechanical Configuration (View 3 of 3)*

## Environmental Specifications

The MMQ-G environmental specifications are provided in Table 3-5. These conditions are without safety and/or intensification factors. Under these conditions the MMQ-G will perform within the limitations defined herein.

Table 3-5. MMQ-G Environmental Specifications				
Test Condition	Test Method	Specification	A	T
<b>Altitude</b> Operating Storage	MIL-STD-810 F, Section 500.0	Extended to 60,000 ft		X X
<b>Temperature Range</b> Operational Storage (non-operational)	MIL-STD-810 F, Section 501.3 MIL-STD-810 F, Section 502.3	-40 to +71°C	X	X
<b>Temperature Shock</b>	MIL-STD-810 F, Section 503.3	-40 C to + 71 C, 0.42 C/s		X
<b>Humidity</b>	MIL-STD-810 F, Section 507.3			X
<b>Acceleration, Operating</b>	MIL-STD-810 F, Section 513.4	4 G (performance), 20 G (endurance)		X
<b>Vibration, Performance</b>	MIL-STD-810 F, Section 514.5, Procedure I.	6 G rms, flat spectrum, 20 Hz-2 kHz		X
<b>Vibration, Transportation</b>	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
<b>Shock, Endurance</b>	MIL-STD-810 F, Section 516.4	30 G, 11ms		X
<b>Shock, Operating</b>	MIL-STD-810 F, Section 516.4	20 G, 11ms		X
<b>Dynamics</b> Velocity Acceleration, Perf. Acceleration, Oper. Angular Rate Range Angular Rate, Calibrated		500 m/s 4 G 20 G 200 deg/sec 200 deg/sec	X	 X X X X X

A = Verified through analysis    T = Verified through test

### **Temperature**

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

### **MMQ-G Reliability**

The Mean Time Between Failures (MTBF) of MMQ-G is no less than the values shown in Table 3-6. These values were established using MIL-HDBK-217F analysis methods and supplemented by commercial parts data.

<b>Table 3-6. Mean Time Between Failures</b>	
<b>MIL-HDBK-217 Environment</b>	<b>MTBF, hours</b>
Ground, Benign @ 35 C	44,736
Airborne, Uninhabited Fighter @ 35 C	15,485

# Chapter 4 - Operation

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## 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:

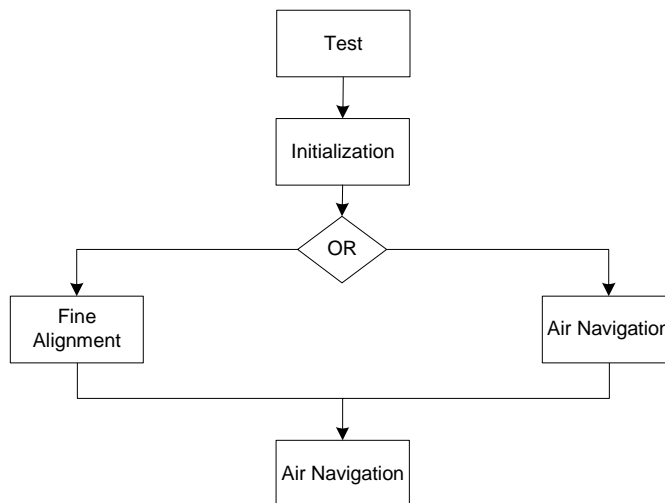
- *Test*
- *Initialization*
- *Fine Alignment, Air Alignment*
- *Air Navigation or Land Navigation*
- *GPS-Only Navigation*

Mode sequencing after a normal startup of the MMQ-G is shown in Figure 4-1. MMQ-G Operational Mode Sequence. After startup, the MMQ-G sequences automatically through Test mode to Initialization mode.

After navigation initialization data is entered by the user and accepted, sequencing continues to one of two alignment modes: *Fine Alignment* or *Air Alignment*. The choice of sequencing is made by user input. (At this time Transfer Alignment is not implemented.) During these modes a Kalman filter is used to estimate IMU parameter errors and vehicle attitude.

After completion of an *Alignment* mode, sequencing continues to the navigation mode: *Air Navigation*. Choice of sequencing, again, is by user input.

In this mode, navigation is performed based on INS data, with updates from GPS data. If GPS data temporarily becomes unavailable, navigation will continue with only INS data.



**Figure 4-1. MMQ-G Operational Mode Sequence**

The processing performed by MMQ-G during the various 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 a software reset. BIT tests the functional areas of MMQ-G.

### Initialization Mode

*Initialization* mode is in effect after completion of BIT, but before navigation initialization data is provided. During this mode, the GPS processor attempts to acquire satellite signals and enter navigation mode. It can succeed in doing this even before navigation initialization data is provided. Navigation initialization data may either be provided by the user, or obtained from the GPS processor after it enters navigation mode. Choice of these options is made by user input. Once navigation initialization data is obtained, then position, velocity, and heading are initialized. Accelerometer data is used to obtain initial coarse estimates of pitch and roll. After this is performed, Initialization mode is exited automatically, and continues to one of the *Alignment* modes.

### Fine Alignment Mode

*Fine Alignment* mode performs alignment when MMQ-G is stationary. Fine Alignment consists of estimation via a Kalman filter of the vehicle orientation, as well as estimation of IMU parameter errors (accelerometer scale factor and

bias, and gyro scale factor and bias). Fine Alignment mode is exited automatically after 180 seconds to Air Navigation mode, or must be commanded to exit if the automatic sequence feature is not selected. For a thorough explanation of the automatic sequencing, please see the section labeled Message 3510 - MMQ-G Control and Initialization on page 121. Information can also be found in Appendix A- Frequently Asked Questions.

### **Air Alignment Mode**

This mode performs alignment using GPS data as a velocity reference. GPS data must be available for the processing of this mode to be complete. The alignment process estimates the vehicle orientation and IMU parameter errors, and also the GPS clock error and antenna lever arm. *Air Alignment* mode is exited to air navigation mode when the Kalman Filter covariances of the heading and the lever arms fall below specified thresholds.

If *Air Alignment* is entered while the vehicle is traveling at speeds greater than 50 m/sec, a submode called *Coarse Air Alignment* will be initiated. This submode is indicated by bit 8 (mask 0x0100) of the System Status Validity word (word 11) of the System Status message, 3500 (see page 137). During this submode, the vehicle should maintain a straight and level course until the submode bit indication is reset. Straight and level flight is defined as the ability to maintain the airplane on a constant altitude and heading. The following parameters should be maintained:

- Airspeed within +/- 10 knots
- Heading constant within +/- 15 degrees
- Altitude within +/- 200 feet

Exceeding these parameters can result in poor performance from the *Coarse Air Alignment* mode, which could result in reduced performance once the system enters Air Navigation mode. Once *Coarse Air Alignment* mode is complete, the MMQ-G will continue in normal *Air Alignment* mode and it will no longer be necessary to maintain a straight and level course. In fact, some maneuvers are advisable to speed up the convergence of the error covariance values that control the exit from *Air Alignment* mode. For further information, see Appendix A- Frequently Asked Questions on Air Alignment.

### **Air Navigation Mode**

This mode is the navigation mode of the MMQ-G. Navigation is performed using IMU data, and the Kalman filter is used to estimate errors in position, velocity, attitude, IMU parameters, and GPS time. The observables for the

Kalman filter are the GPS pseudorange and delta pseudorange measurements.

Figure 4-1 shows the normal mode sequencing of the MMQ-G after startup. Other mode transitions are also possible by user command. Allowed mode transitions and the conditions for them are summarized in Table 4-1 below.

<b>Table 4-1. Mode Transition Table</b>					
<b>From/To</b>	<b>Test</b>	<b>Init</b>	<b>Fine Align</b>	<b>Air Align</b>	<b>Air Nav</b>
Test	-	A	-	-	-
Initialization	C	-	C	C	-
Fine Alignment	C	C	-	-	A
Air Alignment	C	C	-	-	A
Air Navigation	C	C	-	-	-

A = automatic, C = commanded

### Heading Hold Mode

Heading hold feature is another feature implemented inside of the MMQ-G. The heading hold feature can be used when the system is in air navigation mode, and when the system is required to be stationary for a long period of time (Greater than 5 minutes). It will prevent heading from drifting and help to achieve better performance while stationary and afterwards once navigation resumes. The basic concept of heading hold is to use the MMQ-G system heading value at the time the heading hold is commanded, and to maintain that heading value for the entire heading hold period. When in heading hold mode, any external heading reference input, such as magnetometer data, will be ignored and when not in heading hold mode, external heading reference data will be processed if available.

Heading hold control is commanded through Message 3504 - MMQ-G Parameter Control when the MMQ-G is in air navigation mode and stationary. The vehicle must be kept stationary while in the heading hold period. Once motion is desired to resume, a heading hold off command via Message 3504 - MMQ-G Parameter Control has to be sent to the unit to take it out of heading hold mode. Heading hold mode however does have a movement checking function, which checks whether your vehicle is stationary or not. If some movement is detected, then heading hold will be automatically released. However, because of the nature of pure heading change without forward velocity and the velocity resolution from the GPS, performance cannot be guaranteed if the automatic release algorithm is executed. It is highly recommended that the user use the command controls to engage and disengage the Heading Hold mode prior to moving the vehicle. Entry into and exit from

Heading Hold Mode can be monitored through the System Status  
Validity Word in Message 3500 - MMQ-G System Status.

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## GPS Receiver Operation

This section summarizes the operation of the GPS receiver during acquisition of GPS data.

### Satellite Acquisition

The GPS receiver enters acquisition when system power is applied, and continuously on channels that have not already acquired a satellite. Activities performed by the receiver while in acquisition involve searching for satellite signals with which to navigate, acquiring and tracking those satellite signals, and collecting data from the tracked signals, if necessary, before navigating.

### RF Signal Requirements

The signal strength at the RF input into the receiver should support a Carrier-to-Noise density ratio (C/No) of at least 34 dB-Hz. This is required in order for a given satellite to have a 99 percent chance of being successfully acquired in one attempt. The success rates are reduced to less than five percent as the signal-to-noise ratio is reduced to 29 dB-Hz.

### Data Requirements

To begin acquisition activities, the GPS receiver must determine the approximate position and movement of satellites in relation to the position and movement of the receiver's antenna. The receiver will attempt to acquire and track those satellites visible to the receiver antenna at the current time. To do this, the GPS receiver, at a minimum, needs the following:

- Current antenna position
- Current antenna velocity
- Current UTC time
- Satellite almanac

In addition to satellite orbit information, almanac data includes the health status of the satellites. No attempt is made by the GPS receiver to acquire satellites indicated as "unhealthy" in the almanac data. An elevation mask angle value is used to screen out lower elevation satellites, whose signals are likely to be obscured. The default angle for the receiver is 10 degrees

If necessary, the almanac may be initialized by allowing the receiver to track at least one satellite for 15 minutes. A new

almanac should be initialized if the age of the almanac resident in the receiver's memory is greater than six months. In all Navigation modes, the receiver will be updating the almanac with ephemeris data received from the satellites, which will normally be more current than data loaded via the serial port.

## **Data Initialization**

There are two fundamental means by which the data outlined above is initialized. The first, *Initialization*, occurs automatically each time the receiver enters the Operational Mode from either the Off or "Keep-Alive" state. The second, *Commanded Initialization*, is an initialization commanded by the Host Vehicle.

### **Self-Initialization**

The receiver first examines internal RAM and the Real-Time Clock (RTC) to determine if the data required to begin acquisition exists. This is the case if the GPS received battery back-up power (after successfully navigating in Air Navigation Land, or GPS Only mode), and none of the data has become invalid (either the ephemeris is older than 4 hours or it has been corrupted).

If the data is not there, data from the receiver's memory is used as a source of satellite almanac, antenna position, and current week. Also, the antenna velocity components are set to zero, the current time-of-week is set to a default setting of Saturday midnight, and Cold Start is enabled.

Except for Cold Start, a valid current time must be supplied by the Host Vehicle when battery back-up power is not maintained.

### **Commanded Initialization**

A critical step in reducing the acquisition time, or time to first fix (TTFF), is to ensure that the receiver is supplied the correct values for the self-initialization data. If any of the data from self-initialization is incorrect or unavailable, TTFF is increased.

The Host Vehicle can supply data and command the receiver to perform initialization through the use of serial input messages. After powering up the receiver, and receiving the first Time Mark Solution message (message 3623) via serial data output, a serial input Position, Velocity, and Time (PVT) initialization message (message 3510) can be safely transmitted to the receiver for data initialization.

Current user antenna position, velocity, and current time may be initialized to the correct values through the use of the initialization message. Until such a message is input, the self-initialization values of these three data items are shown

in the Time Mark Solution message that is output by the receiver.

If an initialization message is input, then the values in the Time Mark Solution message during acquisition will be replaced by these new values.

When initial position and velocity values are within the uncertainty limits described in Table 3-1, the average TTFF will continue to be reduced as the uncertainties in the supplied values become smaller. The initial Universal Time Coordinate (UTC) time should be within five minutes of actual UTC time.

### **Cold Start**

Lacking position, time, current ephemeris, and almanac data, the receiver can still arrive at a navigation solution. This situation is known by the term "Cold Start". Cold Start is an enhanced algorithm by which the GPS receiver searches the sky to locate visible satellites.

The TTFF for this process is longer than commanded or self-initialization (see Table 3-1).

### **Acquiring Satellites (With the Exception of Cold Start)**

When acquiring GPS data, the GPS receiver determines the approximate positions of all visible satellites. From this group, a set of four satellites with the best GDOP is chosen. This group is called a *Primary* set.

The GPS receiver then begins acquisition of the first satellite by choosing the highest of the primary satellites (by elevation angle) and commanding all twelve receiver channels to search for that satellite, each in a different Doppler frequency range. These frequency ranges are obtained by applying Doppler shifts, computed from the satellite's position and movement, to the L1 satellite signal frequency.

In each channel, the GPS receiver correlates the incoming signal with a locally generated replica of the C/A code sequence for the particular satellite being acquired.

Once the code is detected (i.e., correlated), a pair of tracking loops is activated to track both the code sequence and the signal carrier. As the code and carrier are tracked, the GPS receiver determines the location of the navigational data bit sequence within the signal. This provides additional time-of-day and time-of-arrival data to be used along with the current value of GPS time to compute more precisely the Doppler frequency ranges in which the remaining satellites may be found.

On occasion, the GPS receiver may "miss" the first satellite, or, unable to acquire the satellite within a certain amount of

time. This could be due to an obscuration, incorrect, or old initialization data. If the receiver is unable to find the first satellite, the next highest primary satellite (by elevation angle) is assigned to all twelve channels and the acquisition process restarts. The receiver will continue cycling through the visible satellite list, according to its current almanac, until a satellite is acquired and tracked.

After successful acquisition and tracking of the first satellite has been accomplished, one of the receiver channels continues to track it while each of the remaining channels is released to search for a different visible satellite.

### **Cold Start Acquisition**

In Cold Start operation, the GPS receiver computes a visibility list based on whatever initialization data is available. If no acquisitions occur on the highest four satellites on this list and Cold Start is enabled, Cold Start function will be entered, at which time the remaining satellites will be added to the search queue. The order of search may be modified as time and position data is obtained from tracked satellites.

### **Ephemeris**

Satellite ephemeris data is considered to be valid if its age is within its curve-fit validity window (usually 4 hours). When available in RAM, valid satellite ephemeris is used instead of the almanac to determine visible satellites, their positions, and movements relative to the GPS receiver.

The GPS receiver must have valid ephemeris for at least four satellites being tracked to begin navigating.

Therefore, for each acquired satellite that is to be used for navigation, but has non-existent or invalid ephemeris in RAM, ephemeris data must be collected for the satellite before the receiver begins navigating.

If the ephemeris data is valid, but has been updated by the GPS Control Segment (i.e., the data in RAM is greater than 1 hour old), then new ephemeris data is collected to update the data onboard the GPS receiver. Usually 18 to 36 seconds of uninterrupted tracking of a given satellite is required to obtain ephemeris for that satellite.

Collected ephemeris data may indicate that the satellite is “unhealthy”, in which case the satellite cannot be used for navigation and is replaced with another satellite if one is available. This increases TTFF.

## Acquisition from First Power-Up

When powering up the GPS receiver for first time, initial acquisition data will reflect default factory settings. For a rapid TTFF, it is necessary to send an initialization message containing position and time, or rely on a Cold Start. It also is necessary to input velocity if the 75 m/sec uncertainty limit is exceeded from a default velocity of zero.

## Reducing Time-to-First-Fix

The GPS receiver contains a section of volatile static RAM (SRAM) where navigation data can be maintained for a limited time on battery power while the receiver is off. During this time, the GPS receiver is said to be in the “Keep-Alive” state. After the navigation data is lost, the GPS receiver is said to be in the “Off” state.

### ***Minimized Acquisition Time From Off State***

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When power is applied to the system from the *Off* state, the receiver loses the data retained in SRAM. Through self-initialization, the receiver retrieves position, almanac, and current week data stored in EEPROM. An initialization message containing, at a minimum, UTC time is required to overwrite the default time. *Note: The last stored position in non-volatile memory is not necessarily the last user position just prior to the previous power-down.*

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A new position is stored during a navigation state when both of the following occur:

- The distance to the previously stored position is greater than 100 km.
- The age of the previously stored position is greater than 6 hours.

If the position uncertainty is greater than 100 km (e.g., due to transport of the receiver while in the Off state), then the initialization message should also contain current position.

As before, it will be necessary to include current velocity in this message if the uncertainty is greater than 75m/sec.

If the receiver has been off for a period of time greater than six months, the almanac will be updated when satellite tracking is resumed.

### ***Minimized Acquisition Time from "Keep-Alive" State***

When powering up using backup battery power (or the “Keep-Alive” state), and, assuming there has been prior operation the normal navigational modes and the receiver

has not been removed from its battery power, the receiver has access to the data maintained in volatile memory (SRAM). Therefore, it has the last navigation solution and set of satellite ephemeris that were present at the time of power-down.

The TTFF depends on the age of this data (i.e., the length of time that the receiver was using keep-alive power). The low-power timer will maintain time when utilizing keep-alive power, but position and velocity may require initialization if uncertainties are outside the 100 km and 75 m/sec limits, respectively.

If the receiver was using keep-alive power for a length of time that caused the resident ephemeris to be older than the age allowed by its curve-fit validity window (typically 4 hours), then TTFF will be impacted due to collection of new ephemeris, which takes 18 to 36 seconds (24 seconds average).

## Almanac

Almanac data is used by the receiver to determine where best to search for the satellites' signals. This data is uploaded to the satellites by the GPS Control Segment of NAVSTAR. Although frequently updated, the same set of almanac parameters can be effectively used for several months, except in rare cases when satellites are repositioned or new satellites are launched.

Once a satellite is being tracked by the GPS receiver, ephemeris parameters are used to continue tracking the satellite or re-acquire a satellite if its signal is lost.

Ephemeris data is more accurate than almanac data, but is typically valid for a 4-hour portion of the satellite's orbit. If the GPS receiver remains without power for several months, acquisition time increases.

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*Note: Almanac data for all GPS satellites is broadcast by each satellite, but each satellite broadcasts ephemeris data only for itself.*

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## Solution Time of Validity

GPS receivers provide almost instantaneous position and velocity solutions. In general, GPS receivers take a snapshot of the satellite measured ranges, at a precise moment in time, to calculate the user position. Then, a time-exposed snapshot of the change in ranges is taken to reach the velocity solution.

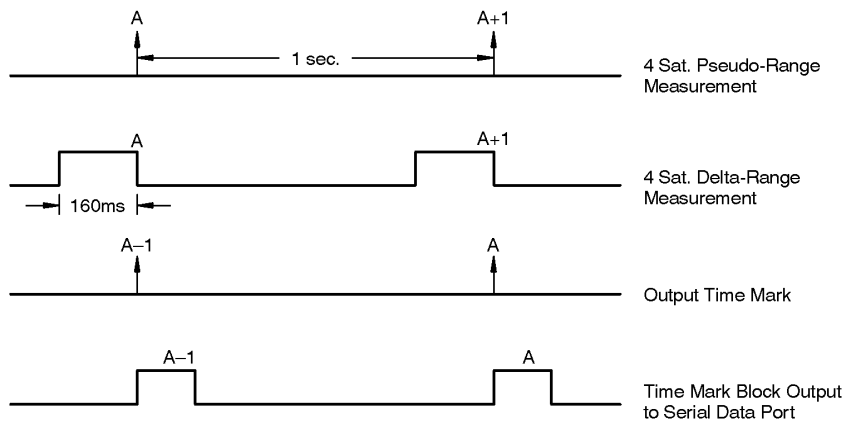
The single snapshot is actually called a pseudorange measurement, while the time-exposed snapshot is called a

pseudorange rate or delta-range measurement. A GPS receiver requires processing time between measurements to calculate the user position and velocity.

During the computations, the receiver compensates for position errors by propagating the user position forward one second, based on the velocity of the user. The user velocity is derived from a delta-range measurement. The delta-range measurement is calculated by monitoring and integrating the Doppler shift between the receiver and a satellite over a finite, predetermined period of time.

At the completion of a delta-range measurement, a pseudorange measurement (see Figure 4-2. Typical Navigation Solution "Time Mark" Output) is performed. This provides the receiver velocity and instantaneous range for each of the receiver channels. The receiver processes this data and calculates a user position and velocity. Since the receiver may be moving during processing time, the data is extrapolated by using the user velocity projected in time by one second (the time required to provide the data at the serial data port).

The GPS receiver provides the user with position and velocity data every second. The system integrator's equipment is provided a Time Mark pulse at the instant the data at the serial port is valid. Figure 4-2. Typical Navigation Solution "Time Mark" Output illustrates a timing diagram for these events.



**Figure 4-2. Typical Navigation Solution "Time Mark" Output**

"A" represents a particular navigation solution, whereas "A-1" and "A+1" represent the prior and future navigation solutions, respectively.

Once the satellite pseudorange and delta-range measurements are made, the data is processed and projected

forward 1 second to prepare for an *Output Time Mark* pulse. At the leading edge of this pulse, the valid navigation data is provided to the *serial data port*.

In some instances, the navigation data will be delayed by a short period of time due to "bus" contention by the Host Vehicle, or by messages previously queued or in progress as a valid transmission by the receiver to the Host Vehicle. In any case, the navigation solution presented is valid at the instant the Time Mark pulse occurred. The MMQ-G output messages contain a time stamp that specifies the time at which the measurements contained within that message are valid.

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## Geometric Dilution of Precision

During navigation modes, MMQ-G maintains a constellation of four satellites (if four are available) that provide the best geometry for an accurate navigation solution. These satellites are referred to as *primary* satellites. The remaining satellites are considered to be *secondary*.

The measure of the quality of a satellite constellation's geometry is called *Geometric Dilution of Precision (GDOP)*. GDOP reflects the influence of satellite geometry on the accuracy of user position estimates and user time. The best geometry is that which produces the lowest GDOP value. GDOP is a multiplier of position error due to other sources.

### Components of GDOP

GDOP is a composite measure. It includes *Position Dilution of Precision (PDOP)*, which reflects the effects of geometry on three-dimensional position estimates, and *Time Dilution of Precision (TDOP)*, which reflects geometric effects on time estimates. The relationship can be expressed as:

$$GDOP = \sqrt{(PDOP)^2 + (TDOP)^2}$$

In turn, PDOP can be expressed in terms of *Horizontal Dilution of Precision (HDOP)* and *Vertical Dilution of Precision (VDOP)*, which are geometric effects on two-dimensional horizontal position estimates and on vertical position (altitude) estimates, respectively. This relationship can be expressed as:

$$PDOP = \sqrt{(HDOP)^2 + (VDOP)^2}$$

## 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 a 100-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-G is shown in Table 4-3.

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

Bandwidth, Phase (-90°)	Hz	Nom.	17
<b>Operating Range</b>			
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<sup>2</sup>.

## INS/GPS Interaction

The MMQ-G system contains IMU software and Integrated INS/GPS software algorithms that reside in the same Central Processing Unit (CPU). The CPU is a Texas Instruments TMS320F2812 processor. An overview of the software architecture is shown in Figure 4-3. MMQ-G INS/GPS Software Algorithm.

INS/GPS interaction is accomplished using a 28-error state Kalman filter. This filter uses GPS range and range rate data inputs to compute corrections for an IMU driven strapdown/navigation solution. The corrections are updated by the Kalman filter at a 1-Hz rate, then provided as controls for the strapdown and navigation algorithms.

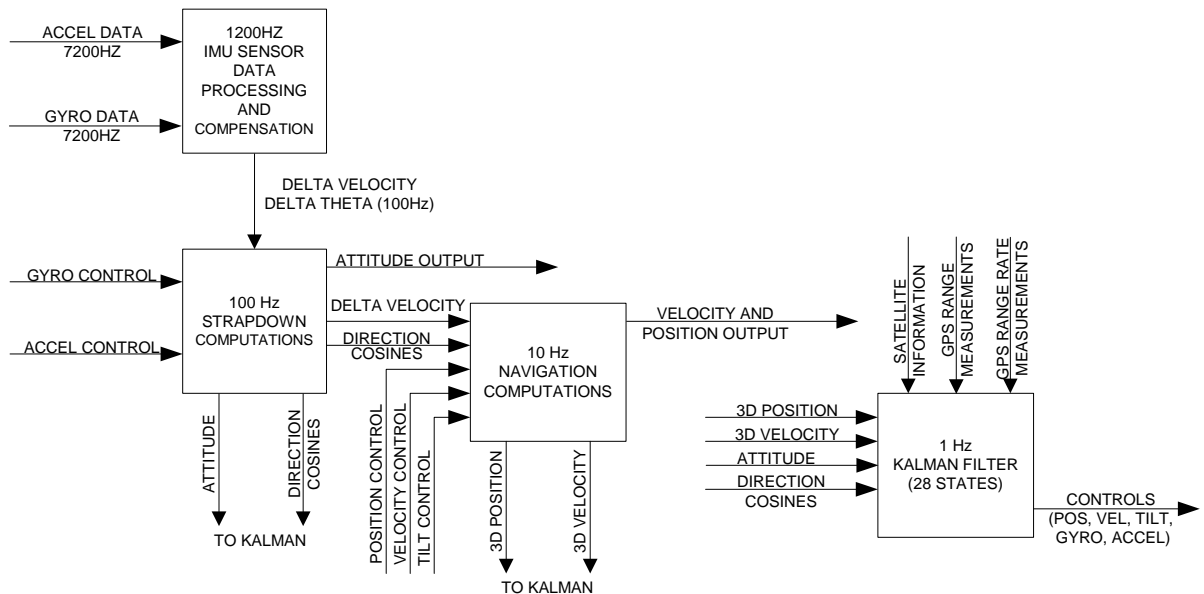


Figure 4-3. MMQ-G INS/GPS Software Algorithm.

# Chapter 5- Hardware Integration

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## Overview

The MMQ-G system is 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-G that should be considered for efficient and effective system integration.

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## Electrical Interface

### Signal Types

The characteristics defined in this section are for the MMQ-G connector inputs J1 and J2. The two types of digital signals are defined in Table 5-1. The J1 connector contains these two types of digital signals and power inputs (see Figure 5-1. MMQ-G (J1) Electrical Interface). A detailed description of these signals for J1 is given in Figure 5-1. MMQ-G (J1) Electrical Interface.

The J2 connector provides the GPS RF antenna input. A description of the GPS RF input is given in Table 5-2.

**Table 5-1. Signal Type Definitions**

<b>Table 5-1. Signal Type Definitions</b>
<b>LVTTL:</b>
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: $\pm 10 \mu\text{Amp}$
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
<b>RS232:</b>
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: $3 \text{ kOhms} \leq R_{IN} \leq 7 \text{ kOhms}$
High-level output voltage ( $R_L=3 \text{ kOhm}$ ): $5.0 \leq V_{OH} \leq 15.0$ volts
Low-level output voltage ( $R_L=3 \text{ kOhm}$ ): $-15.0 \leq V_{OL} \leq -5.0$ volts
Transition slew rate: $6.0 \leq \text{TSR} \leq 30 \text{ V}/\mu\text{sec}$
Maximum data rate: 115.2 kbits/sec

Pin #	Pin Name	Input/Output	Comment
1	RS232TX_2	OUT	Reserved
2	RS232RX_2	IN	Reserved
3	NC		
4	NC		
5	RS232TX_1	OUT	Host Vehicle TX
6	RS232RX_1	IN	Host Vehicle RX
7	NC		
8	NC		
9	NC		
10	NC		
11	NC		
12	-VIN	IN	Negative power input
13	NC		
14	NC		
15	NC		
16	NC		
17	NC		
18	NC		
19	NC		
20	NC		
21	NC		
22	+VIN	IN	Positive power input
23	NC		
24	NC		
25	NC		
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 GNG
31	GPS_ANTENNA_POWER	IN	GPS antenna power
32	GPS_KEEP_ALIVE_BATT	IN	GPS keep alive battery input
33	NC		
34	1PPS_TIMEMARK	OUT	GPS 1PPS Timemark Signal

*“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.*

*Figure 5-1. MMQ-G (J1) Electrical Interface*

## RF Interface (J2)

The MMQ-G RF interface is described below, with the characteristics defined in Table 5-2.

Table 5-2. GPS RF Input Interface Definition		
Signal Name	I/O	Electrical Characteristics
RF_IN	INPUT	50 OHM @ L1 with VSWR OF 2:1 or better

**RF\_IN:** This interface signal provides the path for GPS RF signals from an antenna to MMQ-G. MMQ-G is capable of operating with GPS signals generated by a mixture of all GPS satellite types specified in SS-GPS-300.

### **Impedance**

The input impedance at the RF connector is 50 Ohms, with a VSWR of 2:1 or better.

### **Center Frequency Input**

The input center frequency is 1575.42 MHz.

### **Signal Level Input**

The operational input range is -163 to -130 dBW (with operational satellite signals).

### **Noise Figure Input**

The composite noise figure of a preamplifier, cable, and GPS receiver must be less than 5.0 dB for operation with minimum guaranteed GPS satellite signal levels.

To determine this composite noise figure, a typical noise figure of 4.0 dB is used for the GPS receiver, measured at the RF input port at L1 with a 10-MHz bandwidth.

### **Input Burnout Protection**

The maximum input power level is -10 dBW at the RF port (at L1 with a 10-MHz bandwidth).

### **Delay**

The delay (for example, due to line length) between the antenna and J2 RF connector is not important. The GPS receiver will compute a navigation solution at the phase-center of the antenna.

## **Antenna**

The antenna is required to be right-hand circular polarized, exhibiting a gain of not less than -3 dBiC above a 10-degree elevation.

## **Power Interface**

### **Input Voltage**

The input voltage to MMQ-G 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-G 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-G 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.

## **Keep Alive Battery**

The **BATTERY** input to MMQ-G provides "keep-alive" power to the SRAM and real-time clock in the GPS receiver. This is intended to provide the GPS receiver with a "hot start" capability by maintaining position, time, and ephemeris data in SRAM when primary power is removed from MMQ-G.

The voltage applied to this input should be in the range of +2.5 to +3.5Vdc (3V nominal) referenced to **GND**. Battery current draw is less than 1 microampere.

## Ground

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

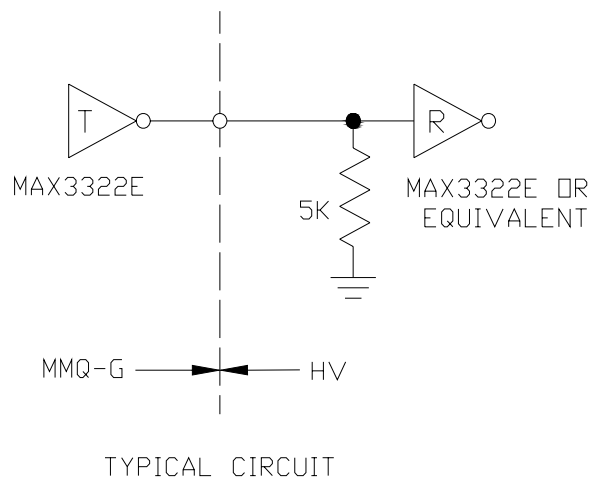
## Digital Interface

### Host Vehicle (HV) Serial Interface

The HV interface is a full-duplex asynchronous RS232 serial data communication port. This port is the interface for command and control of the MMQ-G 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 Tables 5-1 and 5-2. Both of these signals are referenced to GND.

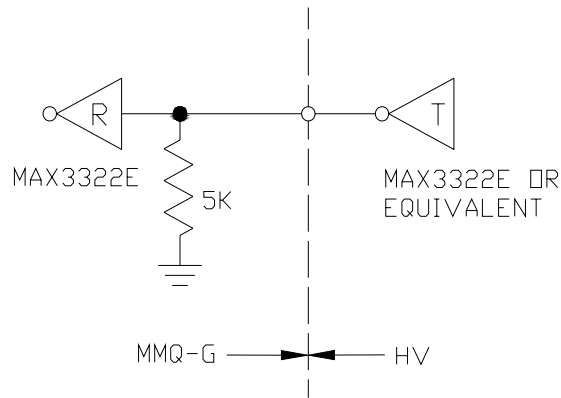
- **RS232OUT**: Data transmitted by MMQ-G to the external equipment. The interface circuit for this signal is shown in Figure 5-2. Host Vehicle RS232 Output Circuit.



*Figure 5-2. Host Vehicle RS232 Output Circuit*

- **RS232IN**: Data received by the MMQ-G from external equipment. The interface circuit for this

signal is shown in Figure 5-3. Host Vehicle RS232 Input Circuit.



TYPICAL CIRCUIT

*Figure 5-3. 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).

### Timemark Signal

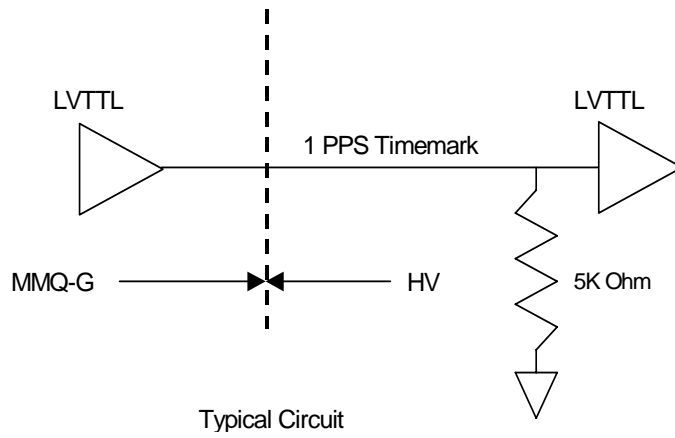
MMQ-G provides a Timemark signal described below. The Timemark signal's type and interface description are previously defined by Tables 5-1 and 5-2.

The Timemark is a one pulse-per second (PPS) output signal to the external equipment. This pulse represents the instant

in time when the navigation solution is valid. The precision of the Timemark output is  $\pm 1 \mu\text{sec}$ .

This pulse is provided for synchronization with the Timemark output message (binary message 3; refer to Chapter 7- Software Integration). This output message contains the local estimate of GPS time and position. The Timemark pulse width is 25.6 msec, and the polarity is Positive.

The navigation solution that is provided subsequent to the pulse contains solution data that is valid at the leading edge of the Timemark pulse. The interface circuit for this signal is shown in Figure 5-4. Timemark Output Circuit.



*Figure 5-4. Timemark Output Circuit*

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## Connector Types

Connectors that are used to interface MMQ-G to the Host Vehicle are 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
J2 - RF_IN	SMA Jack (socket) Receptacle	Any SMA plug (pin) MIL-C-39012 series, Typically RG-400, 50-ohm, coaxial cable used.

### 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](http://www.samtec.com).

### RF Input (J2) Connector

The straight RF input connector is standard SMA jack (female) receptacle of the MIL-C-39012 series. Below is a list of possible mating connector manufacturers for procurement. Final choice of connector is affected by cable selection, which is discussed in Cable Considerations.

AMP, Inc.  
P.O. Box 1608  
Harrisburg, PA. 17105  
Telephone - (800) 522-6752

AMPHENOL  
RF/Microwave Operations  
One Kennedy Avenue  
Danbury, CT. 06810  
Telephone - (203) 743-9272

Avnet  
2211 South 47th Street

Phoenix Arizona 85037  
866 286 3873

Richardson Electronics  
San Jose, CA 95131  
800 737 6937

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## Antenna Considerations

### Antenna Types

Although there is some flexibility in the choice of GPS antennas, there are three essential requirements:

- Right-hand circular polarization.
- A gain minimum of -3 dBiC above 10 degree elevation.
- 50-ohm impedance with < 2:1 VSWR

Two types of commonly available GPS antennas are *Patch* antennas and *Helix* antennas. Each has distinct electrical and physical properties, lending each to different applications. The system integrator must evaluate the performance requirements together with the mechanical size, form, and mounting capability, along with the physical aesthetics of the overall product, to determine the type of antenna to use.

#### **Patch Antennas**

*Patch* antennas are simple in design and predictable in performance, using microstrip technology for their receiving elements. Microstrip *Patch* antennas are typically mass-produced and are inexpensive to manufacture.

The most appealing aspect of the *Patch* antenna, and a major reason for its acceptance, is its low profile. Microstrip designs require only a patch of thin metallic film bonded to a dielectric substrate with a ground plane, allowing the *Patch* antenna to be shaped to meet specific mechanical requirements. The most common shapes produced are rectangles and circles.

*Patch* antenna patterns typically contain one main lobe in the direction normal to their surface. Therefore, the gain of the signal is reduced as a satellite moves from the perpendicular axis of the antenna.

This reduction in gain at the horizon can help reduce multipath interference. Most *Patch* antennas are integrated with a radome. The radome provides essential protection from the environment.

#### **Helix Antennas**

The design of a *Helix* antenna uses a conductor wound in the shape of a screw thread (*Helix*) together with a flat metal plate called a ground plane. This type of antenna is not extremely complicated in design and offers a predictable performance.

The *Helix* antenna demonstrates slightly higher gain and smoother phase than the *Patch* antenna. The patterns of a *Helix* antenna are a main lobe normal to the ground plane and minor lobes at oblique angles to the main lobe. As a result of these patterns, when a satellite moves from the antenna's perpendicular axis, the gain is reduced. However, the minor lobes provide more gain than the *Patch* antenna when the satellite is off axis due to the symmetry of the *Helix* design. Lobing can degrade tracking under certain kinds of motion.

The height and broad bandwidth are disadvantages to the *Helix* antenna. Since the *Helix* antenna is made of a helical coil, the shape is not flat as with *Patch* antennas. In general, the higher the required gain, the longer the coil. *Helix* antennas typically have broader bandwidths than *Patch* antennas, permitting the reception of more interfering signals.

*Helix* antennas require mounting in a filled radome to mechanically stabilize the coil from shock and vibration. These radomes usually are molded in cylindrical or aerodynamic shapes.

If the system's design requires an active antenna and alternative cable types or lengths, SDI application engineers are available to help the system integrator with link budget calculations. Please contact your local sales office for assistance. Also, see the discussion of preamplifiers later in this chapter. The following is a list of antenna manufacturers to contact for procurement.

Sensor Systems Inc.  
8929 Fullbright Avenue  
Chatsworth, CA 91311  
Telephone (818) 341-5366

Tecom Industries, Inc.  
9324 Topanga Canyon Boulevard  
Chatsworth, CA 91311-5795  
Telephone (818) 341-4010

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## Cable Considerations

As with antennas, 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-G 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) from the antenna to MMQ-G, 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.

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## Installation Considerations

When installing MMQ-G, the following areas are of primary concern: *GPS Signal Obscuration, GPS Selective Availability, Multipath Interference, and EMI*. Additional areas of concern are *Feedlines and Preamplifiers, RF Signal Levels, and the Noise Floor*. Each is discussed below.

### GPS Signal Obscuration

Normal operation of MMQ-G requires undisturbed reception of signals from four satellites as discussed earlier in Chapter 2- INS/GPS Concepts. The signals propagating from the satellites cannot penetrate water, soil, walls, dense foliage, or other similar obstacles.

*Antennas and satellites are required to be in a "line of sight" with each other.*

MMQ-G cannot be used in INS/GPS mode for underground navigation in tunnels, mines, or subsurface marine navigation. In surface navigation, the signal will be obscured by buildings, bridges, trees, and other matter that locks an antenna's line of sight to the GPS satellites. In airborne applications, the aircraft's body may block the signal during high banking or pitching maneuvers.

For moving vehicles, signal shading or temporary outages will likely be transitory and will minimally degrade the overall positioning solution. However, a common case of signal blockage occurs in urban areas lined with skyscrapers. In these cases, the signals can be obstructed for long periods of time resulting in accuracy degradation. In aircraft applications, transitory outages may occur due to the location of the antenna on the aircraft. In some instances, the motion of an aircraft can temporarily obstruct the line-of-sight due to its own structure, or can induce dynamics that exceed the capabilities of the MMQ-G's tracking loop.

MMQ-G uses twelve channels to minimize the effects of obscuration. During normal operation, four channels track the four primary GPS satellites while the other channels track the remaining visible satellites and recover the ephemeris data on each one. Therefore, if any of the primary satellites are obscured, MMQ-G contains the data to support a rapid transition to alternate satellites.

#### **Standard Positioning Service (SPS) Policy:**

SPS is a positioning and timing service available to all GPS users on a continuous, worldwide basis with no direct

charge. SPS is provided on the *GPS L1 frequency*, which contains a C/A code and a navigation data message. GPS L1 frequency also contains a P-Code that is not part of SPS, and is not available with the MMQ-G product.

***Precise Positioning Service (PPS) Policy:***

PPS is a military positioning, velocity, and timing service available on a continuous, worldwide basis to users authorized by the DoD. It is not currently available with MMQ-G. PPS is the data transmitted on GPS L1 and L2 frequencies. PPS was designed primarily for U.S. and Allied military use. It is denied to unauthorized users by use of cryptography. The encrypted P-code is called *Y-code*. PPS is available to U.S. Federal and Allied Government (civilian and military) users through special agreements with the DoD.

Limited civilian use of PPS, both domestic and foreign, is considered upon request and authorized on a case-by-case basis provided that:

- It is in the U.S. national interest to do so.
- Specific GPS security requirements can be met by the applicant.
- A reasonable alternative to the use of PPS is not available.

## Multipath Interference

Multipath errors result when data is combined from more than one propagation path. This distorts the signal characteristics from which the range measurements are made, resulting in pseudorange errors. These errors are dependent on the nature and location of a reflective surface peculiar to each user location. The effects are less detrimental for a moving user, since small antenna movements can completely change the multipath characteristics.

In general, multipath interference is caused by signal reflection from buildings or other large objects interfering with a direct signal from a satellite. The effects of surface-replicated multipath interference can be minimized by using an antenna with a sharp gain roll-off near the horizon. A *patch* antenna exhibits this type of pattern while providing nominal gain for the primary satellite signal and attenuation for the undesired multipath signal. Circular antenna polarization also serves to minimize reflected multipath effects.

## Electromagnetic Interference (EMI)

A common source of EMI is the operation of a nearby transmitting RF facility, such as a radio station, television station, or airport. Operation near a facility such as these can result in front-end overload or intrusion into Intermediate Frequency (IF) stages. United States television channels 10, 23, and 66 often have harmonics in the GPS signal band.

EMI can be emitted from black boxes, or electronic systems around the MMQ-G system. An example of this type could be a switching power supply or other circuits operating nearby without proper shielding.

MMQ-G is susceptible to EMI around 1575 MHz. This arises from the high sensitivity required by the GPS receiver to selectively capture the L1 signal at -160 dBW.

Interference degrades the C/No density ratio of the MMQ-G system. The C/No density ratio directly relates to the ability of the GPS receiver to acquire and track the GPS signal.

*The GPS receiver circuitry contains onboard filters to help reject out-of-band signal interference.*

Non-GPS, continuous wave (CW) signals within a  $\pm 2$ -MHz bandwidth of 1575 MHz can cause interference to MMQ-G. The effect on C/No, with the introduction of continuous wave interference, can be characterized by the following equation:

$$C / No(eff) = \frac{C}{No + \left( \frac{Pi}{Rc} \right)}$$

where:

*C/No* = the carrier-to-noise density without interference

*Pi* = the power in Watts of the interfering signal

*Rc* = the coding rate of 1.023 Mbps

*No* = the typical system noise in W/Hz

The system noise in dBW/Hz can be estimated by:

*10 LOG (antenna noise temperature) + cable loss in dB + cascaded receive system Noise Figure (NF) in dB - Boltzmann's Constant*

where Boltzmann's Constant equals -228.6 dBW/Kelvin-Hz and the cascaded receiver system NF is as demonstrated in the *Mechanical Interface* section.

If the system integrator's application requires the MMQ-G system to operate in a signal environment where in-band interference may occur, the GPS receiver should be tested for EMI susceptibility in the unique environment targeted by the system.

C/No data from MMQ-G should be closely monitored during testing of EMI susceptibility to determine the effects of different interference levels and frequencies.

### **Feedlines and Preamplifiers**

When undertaking the design and layout of a system using MMQ-G, careful consideration should be given to using a passive antenna and a short length of low loss feedline. This configuration will yield good results at minimum cost. If a preamp is required to overcome feedline losses or noise sources at the receiver, use the lowest gain device that will set the system NF to the required level.

MMQ-G is equipped with a very sensitive front-end. Under most circumstances, no preamplifier is required. A passive patch antenna is most frequently used which provides approximately 0 dBiC of gain, and 5 to 15 feet of low loss coaxial cable can be used, representing about 0.5 dB of loss.

Figure 5-5. Basic Configuration provides a schematic representation of MMQ-G in its basic configuration.

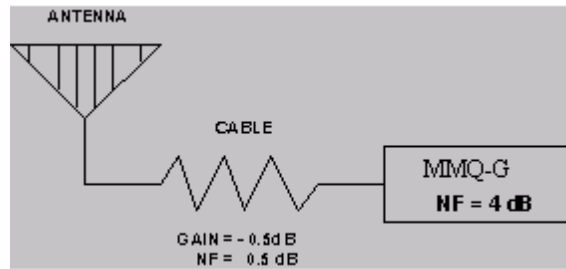


Figure 5-5. Basic Configuration

### Carrier-to-Noise Ratio

To predict the Carrier-To-Noise (C/No) density ratio in the MMQ-G system, a link budget analysis of the available signal compared to the existing noise must be performed. This is accomplished by determining the available signal from the satellites, and then comparing it to the noise floor of the receiver. This yields the C/No density ratio.

The signals received from GPS satellites are a function of the transmission power of the satellites, the gain of the satellite antennas, the free space path loss of the signal, and the gain of the receiving antennas. According to the specifications, the U.S. military guarantees the signal power from GPS satellites to GPS receivers to be at least -160 dBW. This signal level will then be amplified (or attenuated) by the receiving antenna as a function of antenna gain.

### RF Signal Levels

The unobstructed L1 C/A power incident on a user from any Block II satellite is a minimum of -160 dBW. The minimum input signal level of MMQ-G is -163 dBW, providing the systems integrator an additional 3 dB for design margin with GPS antennas and other system components.

This is the minimum free space signal power from the satellite. For the past several years, the satellites have been transmitting signals that are 3 to 6 dB higher than the guaranteed figure. However, good engineering practice dictates that the minimum specified signal power be used for all equipment design and link studies. Table 5-4 shows the link margins for 90 percent probability of acquisition for a system with 4 dB of composite NF, 0 dB of antenna spatial loss, and satellites at a 10-degree elevation angle.

Table 5-4. Typical GPS Link Margins		
GPS Signal Level at Antenna	Acquisition	Track
-160 dBW (guaranteed minimum)	3 dB	10 dB

-156 dBW (current typical levels)	9 dB	16 dB
-----------------------------------	------	-------

MMQ-G is designed to operate with low-cost passive antennas, exhibiting -3 dBiC or greater gain at 5 degrees elevation, and a reasonable length of cable. This feature allows the overall system cost to be minimized. The system integrator should always calculate a link budget for the system.

Most commercial and military users of GPS use a Patch type or Helical antenna, with the Patch antenna being somewhat more popular. In general, the patch antenna exhibits about 2 to 3 dBiC of gain on zenith, and between -4 to 0 dBiC on the horizon. For most "quick" calculations, it is convenient to assume a gain of 0 dBiC.

### The Noise Floor

GPS signals are spread spectrum, so noise power spectral density is used in establishing a signal-to-noise power ratio figure of merit. This important figure is  $C/N_0$ , or the total carrier power-to-noise power spectral density. The resulting units of this ratio are in dB-Hertz.

Noise power is typically modeled as a thermally generated white noise source. The simple model for thermally generated noise power spectral density is expressed by the following equation:

$$Np = K \times T^\circ \times B$$

where:

- K = Boltzman's Constant ( $1.38 \times 10^{-23}$  Watts/Kelvin-Hz)
- $T^\circ$  = The equivalent noise temperature in degrees Kelvin (typical assumption is  $T = 290$  degrees K)
- B = The bandwidth in Hz

In a 1-Hz system at 290°K, the noise power can be seen to be -204 dB W/Hz ( $4.002 \times 10^{-21}$  Watts per Hz). This figure represents the absolute noise floor in a 1-Hz bandwidth at room temperature.

The next contributor to the noise floor is the noise generated internally by the MMQ-G system. This noise is the sum of the noise generated by MMQ-G, attenuation of the feedline, noise of the preamp (if used), and external noise received by the antenna.

There is a general assumption that the antenna, the feed system, any preamplifiers, and the receiver are all properly impedance matched. The standard gross assumption is a 50-Ohm characteristic impedance and *Voltage Standing Wave Ratio* (VSWR) of less than 2:1 (1.6:1 or less is preferred) at each interface.

*Noise Factor* is defined as the signal-to-noise ratio at the input divided by the signal-to-noise ratio at the output. The result is always greater than or equal to one. *Noise Figure* is defined as the noise factor converted to decibels, i.e.  $10\log(NF)$ . The determination of a noise figure is made assuming an input noise source of 290 degrees Kelvin. A noise figure generally is an approximation, and is usually acceptable when receiver noise is the dominant contributor. The system noise factor ( $NF_{SYS}$ ) of several cascaded receiver elements is determined by the following equation:

$$NF_{sys} = NF1 + \frac{NF2-1}{G1} + \frac{NF3-1}{G1 \times G2} + \dots + \frac{NF_n-1}{G1 \times G2 \times \dots \times G(n-1)}$$

where:

NF1	=	Noise Factor of Stage 1
G1	=	Gain (or loss) factor of Stage 1
NF2	=	Noise Factor of Stage 2
G2	=	Gain (or loss) factor of Stage 2
NF3	=	Noise Factor of Stage 3
G3	=	Gain (or loss) factor of Stage 3
NFn	=	Noise Factor of the <i>n</i> th stage
Gn	=	Gain factor of the <i>n</i> th stage

As shown by this formula, the primary contributor of the system noise figure is the noise factor of the first stage (NF1). If the first stage is a low loss feedline, the attenuation of the line will directly add to the system NF. The loss must be entered as a gain term (G or loss), but will be a gain of less than one.

The formula's calculation usually becomes asymptotic after the first couple of stages in a good system design. Typically, the system integrator only needs to be concerned with antenna gain, preamplifier gain if used, coaxial losses, and the specified noise figure of the receiver.

An analysis of MMQ-G in the basic configuration (see Figure 5-6) yields a system NF of 4.5 dB at the junction of the antenna and the coaxial feedline, as shown by the following:

- $NF_{db}$  of the receiver = 4 dB
- NF of the receiver = 2.51
- $NF_{db}$  of the cable = 0.5 dB
- NF of the cable = 1.122
- Gain of the cable = -0.5 dB
- Gain factor of the cable = 0.891

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*Note: For lossy medium such as cable, Gain is always <1, in other words, less than or equal 0*

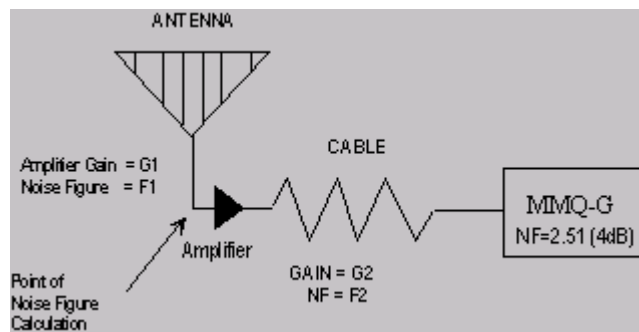


With a 3-dB margin, MMQ-G is quite useable with a passive antenna and a short run of low loss feedline. Outside factors such as foliage or building blockage may reduce the available signal.

It is advised not to significantly reduce the gain of the antenna or increase the feedline loss. As a rule, the feedline losses should be kept to less than 2.5 dB to 3 dB totals, when used with a standard passive GPS patch antenna .

### **Preamplifiers**

Under some circumstances, a preamplified antenna system may be desirable. This configuration is illustrated in Figure 5-6. MMQ-G with Preamplifier. However, it should be emphasized that a preamplifier will not compensate for a poorly located or inferior antenna. The preamp can only amplify what it receives from the antenna.



**Figure 5-6. MMQ-G with Preamplifier**

In addition, the preamp will amplify the noise as well as the signal, and will contribute some internally generated noise of its own. Poor preamp selection may actually *decrease* the C/No density ratio of the receiver's system.

The main reason for selecting a preamp is to optimize the signal-to-noise ratio of a receiver system. As demonstrated by the cascaded  $NF_{sys}$  equation (discussed earlier), the system NF is set primarily by the first active or passive stage encountered after the antenna.

However, if the first stage encountered is a low noise preamp, the system NF can be set and optimized at this point. After thorough analysis, it may be more convenient to think of a preamp as a device that lowers the total system noise rather than raises the signal level.

The preamplifier should be selected to give similar or superior system performance to that of the basic configuration. In other words, the preamp should be selected to set the system NF at 4 dB or better. For example, if the feedline from the Patch antenna to the receiver was measured

to have 6 dB of loss, a preamplifier with 10 dB of gain would need an NF of 2.07 dB to maintain the system NF at 4 dB as follows:

Desired system NF	= 4 dB
	= 2.51 NF
Amplifier gain	= 10 dB
	= 10 Gain
Factor	
Cable gain (loss)	= -6 dB
	= 0.251 Gain
Factor	
Cable NF	= 6 dB
	= 3.981 NF
Receiver NF	= 4 dB
	= 2.51 NF

$$2.51 = NF1 + \frac{3.981 - 1}{10} + \frac{2.51 - 1}{10 \times 0.251}$$

NF1	= 1.61
NF = 10*log(1.61)	= 2.07

The graphs shown in Figure 5-7. Preamplifier Gain and NF for a 3 dB System NF and Figure 5-8. Preamplifier Gain and NF for a 4 dB System NF represent the gain and NF of a preamplifier required to maintain a system NF of 3 and 4 dB, respectively. For example, to maintain a system NF of 3 dB with 6 dB of cable loss, a preamp with 15 dB of gain would require an NF of 2.3 dB. This is certainly an achievable combination with available technology.

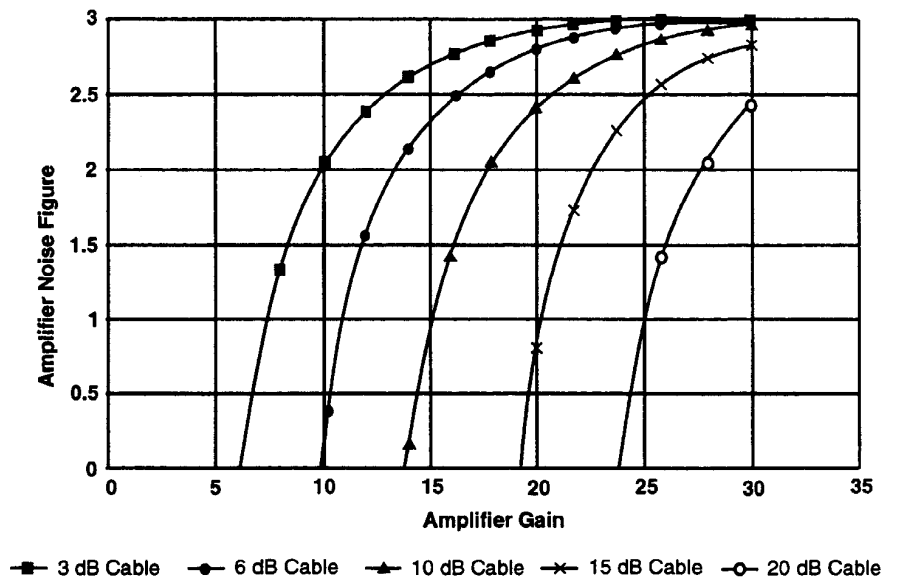


Figure 5-7. Preamplifier Gain and NF for a 3 dB System NF

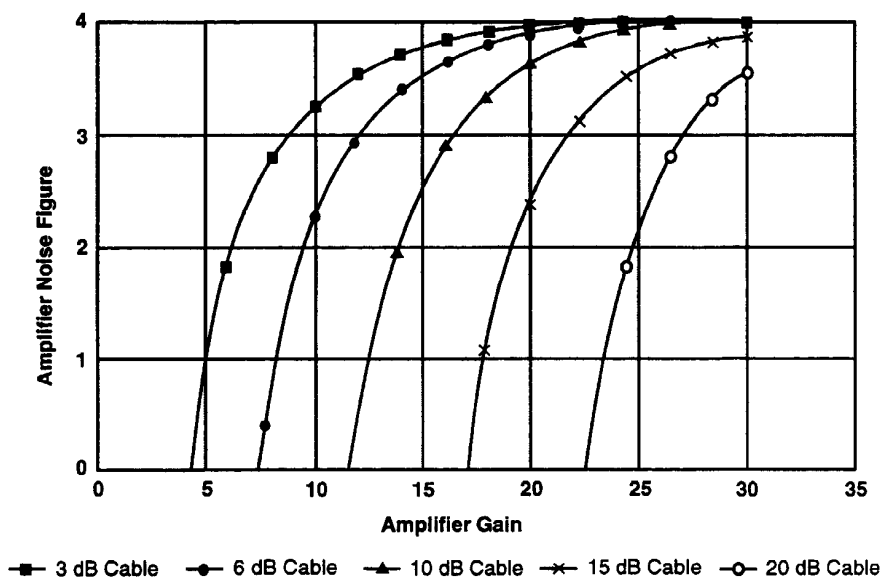


Figure 5-8. Preamplifier Gain and NF for a 4 dB System NF

### Maximum Preamp Gain

Improving preamp specifications can be considered; however, there are a few parameters to address. MMQ-G has a very sensitive front end. Acceptable C/No density ratios are obtained with -163 dBW into a 4 dB system NF (the basic configuration). If a preamp is used, the GPS signal power delivered to MMQ-G must be kept under -130 dBW. As a rule of thumb, select the minimum preamp gain that will provide the desired performance. Amplifier gains of 10 to 20 dB are easily obtainable and should be adequate to set the desired system NF. This maximizes the performance of MMQ-G and minimizes preamp costs. If an amplifier is required, but the overall gain available exceeds the -100 dBm GPS signal limit, an attenuator can be used. The attenuator then must be placed between the amplifier and the receiver.

In conclusion, remember that a preamp will not make up for a poor antenna installation. Adding an amplifier with +10 dB of gain will not compensate for an antenna with -10 dB of gain. Optimum performance from MMQ-G can be achieved by using the best available antenna and good quality feedline.

### Preamplifier Power

The MMQ-G was designed for use with passive or active antennas, but does not provide power for an active antenna, due to the wide variation of antenna power requirements. Should the application dictate an amplified antenna, external power for it must be supplied. The MMQ-G has internal

circuitry to superimpose the DC antenna power onto the RF input via the “GPS\_ANTENNA\_POWER” pin on J1. The current is limited to ~100ma within the MMQ-G.

### ***Amplifier Manufacturers***

If an amplifier is needed for systems integration and application, below is a list of amplifier manufacturers to contact for procurement.

#### **JCA Technology, Inc.**

2580 Junction Avenue  
San Jose, California 95134  
Phone: 408-324-5700  
FAX: 408-324-5705  
email: [jca@jcatech.com](mailto:jca@jcatech.com)

#### **Mini-Circuits**

P.O. Box 350166, Brooklyn, NY 11235 U.S.A.  
Phone: (718) 934-4500 Fax: (718) 332-4661  
[www.mini-circuits.com](http://www.mini-circuits.com)

Miteq  
100 David's Drive  
Hauppauge, NY 11788  
Telephone (516) 436-7400  
[www.miteq.com](http://www.miteq.com)

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# Chapter 6- Magnetometer Interface

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## Overview

The MMQ-G can be integrated with an external magnetometer. Body-axis three dimensional magnetic vector data is input into the MMQ-G via two methods, the industry standard ASCII NMEA protocol “XDR” message, and a proprietary Systron Donner Inertial message format known as message 3530. In both instances the data is sent into the MMQ-G via the RS-232 UART interface. Since the messages are coming in through the MMQ-G 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-G RS-232 port (Please see Chapter 7- Software Integration). The body-axis magnetic data is transformed inside the MMQ-G into heading reference data, which is then used by the GPS/INS algorithm to make heading significantly more stable under low dynamic situations. Note that MMQ-G system heading is referenced to map north, and the reference magnetometer heading reference data is also converted to map north via an internal magnetic variation calculation. Magnetometer data alone is referenced necessarily to magnetic north, and the difference between magnetic north and map north is the magnetic variation. This calculation is a function of the location (Latitude and Longitude) of the system on the face of the earth, which is why the calculation can be accomplished via the GPS positioning information.

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## 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-G 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.

The magnetometer heading measurement is internally corrected for the magnetic variation term. This is done so that the Kalman filter can use magnetic heading as a heading reference by correcting magnetic heading for the local magnetic variation, and thus changing it from a magnetic north reference to a true map north reference. In this way the magnetic heading reference will provide a seamless heading reference for the Kalman filter which will coincide with the derived GPS velocity heading reference, which is only

defined with regards to true map north. The magnetic variation model used inside the MMQ-G is the World Magnetic Model (WMM-2005) published and documented by the National Geophysical Data Center (NGDC). A brief description of the WMM follows as published on the NGDC website: “The WMM consists of a degree and order 12 spherical-harmonic main (i.e., core-generated) field model comprised of 168 spherical-harmonic Gauss coefficients and degree and order 12 spherical-harmonic Secular-Variation (SV) (core-generated, slow temporal variation) field model (determined to degree and order 8). WMM2005 supersedes WMM2000 and should replace this model in navigation systems. Also included with the model is computer software (available in FORTRAN or C) for computing the magnetic field components X, Y, Z, F, D, I, and H in geodetic coordinates. The spherical-harmonic expansions used to compute the magnetic field components are described in the *NOAA Technical Report: The US/UK World Magnetic Model for 2005-2010.*”

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## 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-G 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-G can measure any disturbance constant magnetic field that is associated with the MMQ-G itself, or the user system, and corrects for it during the calibration procedure. The MMQ-G 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-G accounts for the extra magnetic fields by making a series of measurements from the magnetic heading reference data. The MMQ-G 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-G system has been properly initialized and in Navigation Mode. The hard and soft iron calibration procedure control is performed using the MMQ-G parameter control Message 3504 - MMQ-G Parameter Control. The process is monitored using the system status Message 3500 - MMQ-G System Status, and the status of the magnetometer calibration data present in non-volatile memory is observed using the Built-In-Test Results Message 3503 - MMQ-G Built-In-Test Results.

Send the appropriate “Install Magnetometer Calibration Control” bits in Message 3504 - MMQ-G Parameter Control to turn on the calibration process. Please ignore the “Launch Magnetometer Control” feature at this time. Once the MMQ-G has received the calibration on command, Message 3500 - MMQ-G System Status will display the proper “Install Calibration” bits signifying that the MMQ-G 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-G should have collected enough data for a good magnetometer compensation calibration. Send the appropriate control bits in Message 3504 - MMQ-G Parameter Control to turn off the calibration process. Once the MMQ-G has received the calibration off command, Message 3500 - MMQ-G System Status will display the proper bits signifying that the MMQ-G is no longer in magnetometer calibration mode, but in the mode prior to the start of calibration (Navigation Mode). The MMQ-G 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 Message 3510 - MMQ-G Control and Initialization, and there will be an interruption of data communications of approximately 2 seconds. The Built-In-Test Results Message 3503 - MMQ-G Built-In-Test Results will now display the proper bits signifying that the magnetometer calibration has been stored properly.

Once the calibration process is complete, the MMQ-G should be restarted through a power cycle to properly initialize the Kalman filter to the new calibrated heading reference. Once the MMQ-G has entered “Air navigation” 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-G 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-G 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-G by sending the proper bits in Message 3504 - MMQ-G Parameter Control. Send the appropriate “Install Magnetometer Calibration Control” bits in Message 3504 - MMQ-G Parameter Control to erase the magnetometer calibration data, and restart the MMQ-G system.

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## Magnetometer Data Interface

The MMQ-G supports direct communications with an external magnetometer and will accept input magnetometer data via two message formats, the Systron Donner proprietary format Message 3530 - Heading Reference message, and the industry standard NMEA Protocol - XDR Heading Reference magnetometer transducer message. Please refer to Chapter 7- Software Integration for a complete description of these input messages. The MMQ-G also provides a proprietary message output Message 3505 - Magnetometer Data, which contains information directly related to the input magnetometer data and the magnetic variation calculation. Message 3505 is designed to provide the user enough direct information about the magnetometer input data, and if requested, this message will be output at the same rate as the magnetometer message input rate. To connect to this message, please refer to the description in Chapter 7- Software Integration, regarding the proper method of connecting to a message type, and for a complete description of Message 3505 - Magnetometer Data.

# Chapter 7- Software Integration

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## MMQ-G to Host Vehicle Data Interface/Definitions

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

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

The transmit rate (data from the MMQ-G), and the reception rate (data from the HV) are currently both factory set at 115200 baud. Refer to Message 3504 in this chapter for information on selecting/reprogramming the MMQ-G–HV baud rate.

### Message Format

The data and commands transmitted over the MMQ-G-to-HV interface are formatted into *messages*. Each type of message is identified by a unique identification (ID) number. Messages contain a header portion and may or may not contain a data portion. *Header-only-messages* do not contain a data portion.

The maximum number of words a message can contain is 134 (five header words and 129 data words). The message header contains four header words, plus one header checksum word (Words 1 through 5). The message data portion contains a variable number of data words (Words 6 through 5+N ( $0 < N \leq 128$ )), plus one data checksum word (Word 6+N). For a header-only message, only the header portion (no data checksum) is sent.

A message word length is 16 bits on the MMQ-G–HV interface. However, the MMQ-G–HV protocol, which uses a

standard *Universal Asynchronous Receiver Transmitter* (UART), transmits data in 8-bit groups (bytes). This means that two bytes are required in order to make up one message word.

A byte of information is transmitted as a sequence of 11 bits: one start bit, 8 bits of data (least significant bit (LSB) first), one parity bit (odd), and one stop bit. For each 16-bit data word, the least significant byte is transmitted first, followed by the most significant byte. Integer and floating point data types consisting of more than one word are transmitted from the lowest numbered word to the highest numbered word. The one exception to this rule is the time tag, which is output in words 6-9 of each HV output message. The four 16-bit data words are in the following order: 2,1,4,3, where 1 represents the most significant word and 4 the least significant word. Each word is separately byte-reversed.

### **Message Header Format**

The five message words of the header portion of a message are summarized in Table 6-1.

<b>Table 6-1. Message Header Word Definitions</b>	
<b>Word Number</b>	<b>Description</b>
1	Synchronization word (Value = DEL/SOH = 81FF <sub>16</sub> )
2	Message ID number
3	Word count (number of 16-bit words in data portion of message, excluding data checksum; legal range = 0 - 128; value = 0 for header-only messages)
4	Flags word (see description below)
5	Header checksum (2's complement of 16-bit sum of header words 1 - 4)

Word 4 of the message header is a bit-coded *flags word* containing protocol and message-related flags. The word's bit definitions are defined in Table 6-2.

<b>Table 6-2. Flag Word Bit Definitions</b>			
<b>Bit</b>	<b>Description</b>	<b>Input to MMQ-G</b>	<b>Output to HV</b>
0 (LSB)	Spare	Ignored	Always 0
1	Spare	Ignored	Always 0
2	Reserved	Reserved	Reserved
3	Reserved	Reserved	Reserved
4	Reserved	Reserved	Reserved
5	Disconnect	Commands the MMQ-G "disconnect", i.e. discontinue transmitting, the specified message. In addition, this flag, sent with a message ID (header word 2) of 0, causes the	Always 0

		MMQ-G to output only the default messages.	
6	Connect	Commands the MMQ-G to “connect”, i.e., begin transmitting, the specified message to the HV at the scheduled update rate.	Always 0
7	Invalid Data	Ignored	Indicates that an error has rendered the data contained in the data portion of the MMQ-G transmitted message to be questionable.
8	Command Reject	Ignored	Indicates that a command to the MMQ-G from the HV has been rejected (“1”) or accepted (“0”).
9	Handshake	Indicates that the MMQ-G must generate a handshake command accept/reject response to an input message.	Indicates that the MMQ-G-transmitted-message is a response to the HV command. The state of the Reject Flag indicates whether the command has been accepted or rejected.
10	NAK Message	Indicates that a MMQ-G-transmitted-message, with the Acknowledge Request Flag set, has been received by the HV with data errors. Receipt of a Negative Acknowledge Flag by MMQ-G will cause MMQ-G to re-transmit the message in error.	Indicates that the HV-transmitted-message, with the Acknowledge Request Flag set, has been received by the MMQ-G with data errors.
11	ACK Message	Indicates that a MMQ-G transmitted message, with the Acknowledge Request Flag set, has been received by the HV correctly.	Indicates that the HV-transmitted-message, with the Acknowledge Request Flag set, has been received by the MMQ-G correctly.
12	ACK Request	Indicates that the message being transmitted by the HV requires acknowledgment from the MMQ-G.	Indicates that the message being transmitted by the MMQ-G requires acknowledgment from the HV.
13	Reserved	Reserved	Reserved
14	Reserved	Reserved	Reserved
15 (MSB)	Ready	Indicates that the HV is ready to operate under the constraints of the MMQ-G–HV protocol. Whenever the HV is ready to receive a message, the Ready Flag is set to one (Ready = “1”, Not Ready = “0”).	Always 1

### **Message Data Format**

The data portion may contain a maximum of 128 data words, plus one data checksum word (Words 6 through 134). These 16-bit data field message words are completely transparent to the protocol and have no restrictions on bit patterns or character groupings.

The number of data message words “N”, is the same number of words specified in the message word count (message

Word 3 in the header portion). When the message word count is zero, this field does not exist.

The 16-bit checksum field is used to validate the data portion of the message. It is transmitted as the last message word of any message containing data message words. It is computed as the 2's complement of the 16-bit sum of all message data words (words 6 to 5+N).

The data in the MMQ-G messages is encoded in a variety of numerical data formats. These are summarized in Table 6-3 below.

Table 6-3. Numerical Data Formats	
Data Format	Description
I	Integer (16 bits)
DI	Double integer (32 bits)
BIT	Bit-coded 16-bit value
F	Single-precision binary-scaled fixed-point number (32 bits)
DF	Double-precision binary-scaled fixed-point number (64 bits)

For the binary-scaled fixed-point data formats, the encoding is described as F@S or DF@S, where S is the binary scaling. For both formats, the integer representation is a signed binary fraction (MSB = sign, binary point to the right of the sign bit) of the number  $2^S$ .

For a single-precision binary-scaled number, the LSB is  $2^{S-31}$ , and the range is from:  
 $-2^S (= 80000000_{16})$  to  $2^S - 1 \text{ LSB} (= 7FFFFFFF_{16})$ .

For a double-precision binary-scaled number, the LSB is  $2^{S-63}$ , and the range is from:  
 $-2^S (= 8000000000000000_{16})$  to  $2^S - 1 \text{ LSB}$   
 $(= 7FFFFFFFFFFFFFFF_{16})$ .

**Example Illustrating Sample Message Data Byte Ordering and Data Conversion**

The table below contains a sample message 3500 as transmitted to the Host Vehicle by MMQ-G. The byte number represents the time order of data bytes received by the Host Vehicle (i.e. byte 1 is the first byte received, byte 2 is the second byte received, etc.).

Examples of message header and data verification, and data conversion for the various types of numeric data follow.

BYTE #	MESSAGE DATA BYTES							
1	FF	81	AC	0D	10	00	00	80
9	45	F0	2D	78	BA	33	A0	FD
17	7F	D5	02	00	2B	04	00	00
25	00	00	00	00	31	19	34	24
33	00	00	99	19	00	00	F5	6C
41	37	00	A3	B8				

Integer and BIT coded data are sent byte-reversed: the message header data words are as follows:

Word 1 =  $81FF_{16}$  (message synchronization value)

Word 2 =  $0DAC_{16}$  (message identification =  $3500_{10}$ )

Word 3 =  $0010_{16}$  (word count for data portion of message, not including the data checksum word =  $16_{10}$ )

Word 4 =  $8000_{16}$  (flag word, indicating 'ready')

Word 5 =  $F045_{16}$  (The 16-bit twos complement checksum of words 1-4 =  $0 - LSW [81FF_{16} + 0DAC_{16} + 0010_{16} + 8000_{16}]$ ).

Single-precision (32 bit) fixed-point quantities are sent in byte-reversed order. For example, the horizontal position error contained in the example message 3500, (words 16-17, bytes 31-34) is  $00002434_{16}$  scaled at 15 ( $0.141418457$ ) meters.

Double-precision (64 bit) fixed-point quantities are output byte-reversed and the most significant 32 bits of the double-precision quantity output first. For example, the time tag contained in this message 3500, (words 6-9, bytes 11-18) is  $33BA782DD57FFDA0_{16}$  scaled at 20 ( $423759.0223798751140$ ) seconds.

The message data checksum is  $B8A3_{16}$  (The 16-bit twos complement checksum of message words 6 - 21 =  $0 - LSW [+ 782D_{16} + 33BA_{16} + FDA0_{16} + D57F_{16} + 0002_{16} + 042B_{16} + 0000_{16} + 0000_{16} + 0000_{16} + 1931_{16} + 2434_{16} + 0000_{16} + 1999_{16} + 6CF5_{16} + 0037_{16}]$ ).

### Message Acknowledgment/Acceptance Protocol

Messages are grouped according to whether or not they must be *acknowledged* (ACKNOWLEDGE REQUEST flag, in header message word 4, is set or cleared). Commands are a subset of messages that must be acknowledged (since the ACKNOWLEDGE REQUEST flag is always set for commands). Any message not requiring acknowledgment is

considered complete by the transmitting device as soon as it has been sent over the MMQ-G–HV interface.

The receiving device considers the message complete when it arrives successfully. If the message is received in error, it is ignored by the receiving device. Any message transaction requiring an acknowledgment is not considered complete by the transmitting device until a *message acknowledgment* is received.

The protocol for *acknowledge* (ACK) and *negative acknowledge* (NAK) messages are specified in the following paragraphs.

### **Acknowledge (ACK)**

This message is a header-only message with a message ID that is the same as that of the message being acknowledged. The ACK bit is set in the flags word. The ACK message is transmitted in response to a message requiring acknowledgment which was received without word count or checksum errors. If the message is received without word count errors or checksum errors (the header and data checksums produce zero sums) the message is acknowledged within 100.0 ms. If the header checksum results in a non-zero sum, or the message had a framing or parity error, then the header will be assumed invalid (i.e., no flag information is available) and is not acknowledged.

### **Negative Acknowledge (NAK)**

This message is a header-only message with a message ID that is the same as that of the message being acknowledged. The NAK bit is set in the flags word. The NAK message is transmitted in response to a message requiring acknowledgment whose header was received correctly but has a word count error or checksum error in the data portion of the message. If the message is received without word errors in the header, and the header checksum results in a zero sum (i.e., there are no checksum errors in the header or any framing or parity errors which would mean that the message would be ignored), and if there is a non-zero sum for the data checksum, then the message is negatively acknowledged within 100.0 ms.

### **Command Acceptance**

All commands require acknowledgment (ACK or NAK). The receiving device must always ACK or NAK the command to notify the transmitting device, whether or not the command was received in error. In addition to acknowledgment, any commands with the connect/disconnect/request flags or the handshake flag set require additional handshaking. The handshake needs to be performed for command completion.

If the handshake bit is set in a received command, the receiving device will indicate acceptance or rejection of the command by clearing or setting the command reject bit (“1” -- rejected, “0” -- accepted). MMQ-G may reject a command because of the following system constraints:

- Additional messages requested by the command would cause the data rate of the interface to be exceeded.
- The MMQ-G’s operations at the time of receipt of command do not allow the requested operation to be performed.
- The data content of the message had values that are out of range, or not allowed in current MMQ-G operational mode.

For 300 ms following MMQ-G transmission of a command accept message, specific data messages being transmitted from MMQ-G are not constrained to fall within the previous data output configuration or the requested data output configuration. In other words, the MMQ-G is not required to output the previous sequence of messages nor the requested sequence of messages for a period of up to 300 ms. This condition occurs only after a command has been accepted by the MMQ-G and the command modifies the current message output.

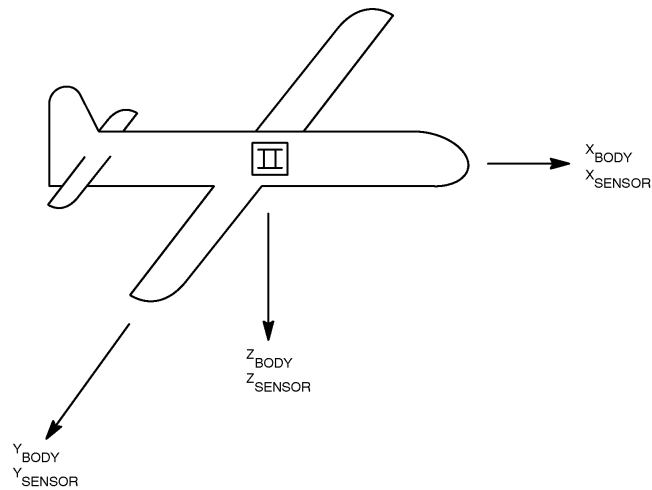
### **MMQ-G Coordinate Frames**

MMQ-G utilizes several different coordinate reference frames.

The *IMU* or *sensor coordinate frame* is fixed to the body of the MMQ-G, and its axes are nominally along the directions defined by the decal affixed to the can. The raw incremental inertial data received from the IMU portion is resolved along these axes, but none of the MMQ-G HV output messages contain data resolved in this frame.

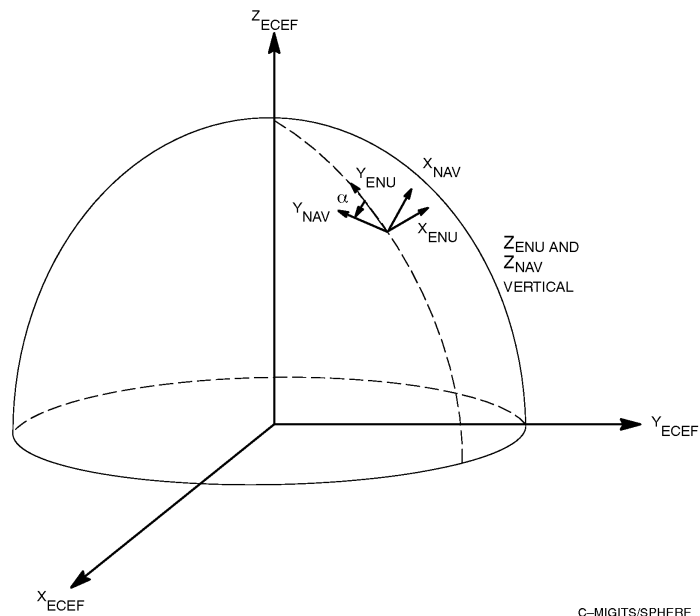
The *body coordinate frame* is also fixed to the body of the MMQ-G, but its orientation may be changed by user input (Message 3511). This is useful in making the MMQ-G attitude outputs (pitch, roll, and heading) meaningful for different orientations of the MMQ-G within a host vehicle. If body axes are defined such that the  $X_{\text{BODY}}$  axis points out the front end of the vehicle, the  $Y_{\text{BODY}}$  axis points out the right side, and the  $Z_{\text{BODY}}$  axis points downward through the

floor, then the attitude angles will have their familiar meanings: i.e. pitch is a right-handed rotation about  $Y_{\text{BODY}}$ , roll is a right-handed rotation about  $X_{\text{BODY}}$ , and heading is a right-handed rotation about  $Z_{\text{BODY}}$ . See illustration below.



The default orientation of the body frame is coincident with the sensor frame, so the default orientation of MMQ-G (i.e. the orientation for which no message 3511 command is necessary to yield meaningful attitude outputs) has the decal X axis pointing out the nose of the vehicle and the decal Z axis pointing down. (i.e. the MMQ mounted with connector upwards)

The *Earth-Centered Earth-Fixed (ECEF) coordinate frame* is fixed to the earth and rotates with it. The  $Z_{\text{ECEF}}$  axis is along the north polar axis of the earth, and the  $X_{\text{ECEF}}$  and  $Y_{\text{ECEF}}$  axes are in the equatorial plane, with the X axis pointing outward through the Greenwich meridian. The latitude and longitude angles output by the MMQ-G are measured relative to the ECEF coordinate system. See illustration below.



The *locally-level east-north-up (ENU) coordinate frame* is centered at the MMQ-G location and has its  $X_{ENU}$  axis pointing east, its  $Y_{ENU}$  axis pointing north, and its  $Z_{ENU}$  axis pointing up. The vehicle velocity is output in this coordinate system.

The *navigation coordinate frame* is also a locally level system centered on the MMQ-G with its  $Z$  axis pointing vertically. It is displaced from the ENU coordinate system by an angular rotation about the  $Z$  axis by an angle  $\alpha$ , called the *wander angle*. The wander angle is initialized to the negative of the initial heading of the vehicle, and in general changes very slowly during navigation, so that the navigation and ENU systems have a roughly constant orientation with respect to each other.

The navigation coordinate system is the fundamental system in which the MMQ-G performs navigation, but none of the MMQ-G output messages contain data resolved in this frame.

# MMQ-G-HV Messages

## Default Messages

Upon transition to *Initialization* mode, MMQ-G will begin outputting the following default data messages on the HV interface automatically. Additional messages may be connected by issuing connect commands (described earlier in this chapter).

- MMQ-G System Status (Message 3500). This message is output at 1 Hz.
- MMQ-G Navigation Solution (Message 3501). This message is output at 10 Hz.
- GPS Processor Timemark Message (Message 3623). This passthrough message is output at 1 Hz as explained below.

## MMQ-G-to-HV Data Messages

The messages output from the MMQ-G to the HV fall into two categories: messages containing MMQ-G status and navigation data, and “passthrough” messages from the GPS processor, which contain status and navigation data. Transmission of these messages may be enabled (connected) or disabled (disconnected) as described earlier in this chapter, and the output rate of some messages may be changed by HV input command. The data messages are summarized in Tables 6-4 and 6-5.

Table 6-4. MMQ-G- to- HV Data Messages			
Message ID	Message Name	Description	Rate
3	MMQ-G Timemark Message	System status and navigation data	1 Hz
3500	MMQ-G System Status	System mode and processing status information	1 Hz
3501	MMQ-G Navigation Solution	Position, velocity, attitude	10 Hz or 1 Hz
3502	MMQ-G Delta Velocity and Delta Theta	Raw delta velocity and delta attitude data from the IMU	100 Hz, 10 Hz, or 1 Hz
3503	MMQ-G Built-In Test Results	Built-In-Test results	Once at startup and at 1 Hz if requested
3505	Magnetometer Data	Magnetic Heading, Magnetometer Vector Data,	The same rate as the

		Magnetometer Hardiron/Softiron Data, Magnetic Variation	Magnetometer message rate
3512	MMQ-G Flight Control	Delta velocity and delta attitude data compensated for IMU error estimates	100 Hz, 10 Hz, or 1 Hz

### GPS Passthrough Messages

GPS messages may be passed through to the host vehicle as received or selected messages may be passed through, with the data translated into the numerical formats used by MMQ-G. By default, passthrough translation is enabled, but this may be changed via message 3504.

When passthrough translation is enabled, generally only the GPS timemark message will be passed through.

Table 6-5. GPS Message Passthrough ID Numbers				
GPS Set	Raw Timemark ID	Translated Timemark ID		
Jupiter PICO	(1)	3623		

### HV-to-MMQ-G Data Messages

The HV-to-MMQ-G data messages are summarized in Table 6-6.

Table 6-6. HV-to-MMQ-G Data Messages		
Message ID	Message Name	Description
0	Universal Reset	Reset MMQ-G output to default messages
3504	MMQ-G Parameter Control	Set system baud rates; set message output rates and configuration; and storage of program data in FLASH
3510	MMQ-G Control and Initialization	Mode commands and position/velocity/time initialization
3511	MMQ-G Configuration Control	Set system configuration data: IMU orientation, lever arms
3530	MMQ-G Magnetometer Interface	Provide magnetometer data input to the MMQ-G to augment the heading solution
NMEA Protocol Message ID "XDR"	Magnetometer Sensor Measurements	Provide magnetometer data input to the MMQ-G to augment the heading solution

### MMQ-G Message Formats

The formats of the MMQ-G messages are specified in the sections that follow.

---

## Message 0 - Universal Reset

MSG NAME : Universal Reset (See Note)	
MSG ID :	0
INVALID FLAG: Never set	Data Word Count: 0
I/O: Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a

### Note to Message 0 - Universal Reset:

To command MMQ-G to output default messages only, Message 0 should be transmitted with the Disconnect Message Flag set to 1.

## Message 3 - MMQ-G Timemark Message

MSG NAME : MMQ-G Timemark Message	
MSG ID:	3
INVALID FLAG: Set when no nav solution	Data Word Count: 52 + (2 × Number of GPS Channels) (See Note 11)
I/O:	Output
XMIT RATE:	1 Hz

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
GPS Time	(Note 1)	6-9	DF@20	sec
UTC Time	(Note 2)	10-13	DF@17	sec
Latitude	(Note 3)	14-15	F@0	semicircles
Longitude	(Note 3)	16-17	F@0	semicircles
Altitude, Absolute	(Note 3)	18-19	F@15	meters
ECEF Position X	(Note 4)	20-21	F@23	meters
ECEF Position Y	(Note 4)	22-23	F@23	meters
ECEF Position Z	(Note 4)	24-25	F@23	meters
Velocity, East	(Note 5)	26-27	F@10	m/sec
Velocity, North	(Note 5)	28-29	F@10	m/sec
Velocity, Up	(Note 5)	30-31	F@10	m/sec
Acceleration, East	(Note 6)	32-33	F@6	m/sec/sec
Acceleration, North	(Note 6)	34-35	F@6	m/sec/sec
Acceleration, Up	(Note 6)	36-37	F@6	m/sec/sec
Attitude, Pitch	(Note 7)	38-39	F@0	semicircles
Attitude, Roll	(Note 7)	40-41	F@0	semicircles
True Heading	(Note 7)	42-43	F@0	semicircles
Current Mode	(Msg 3500, Note 2)	44	I	n/a
System Status Validity	(Msg 3500, Note 3)	45	BIT	n/a
Number Current SVs Tracked	(Msg 3500, Note 4)	46	I	n/a
Number of Position Measurements Processed	(Msg 3500, Note 5)	47	I	n/a

*(continued next page)*

**MMQ-G Timemark Message (cont.)**

Number of Velocity Measurements Processed	(Msg 3500, Note 6)	48	I	n/a
FOM Information	(Msg 3500, Note 7)	49	BIT	n/a
Expected Horizontal Position Error	(Note 8)	50-51	F@15	meters
Expected Vertical Position Error	(Note 8)	52-53	F@15	meters
Expected Velocity Error	(Note 8)	54-55	F@10	m/sec
Equipment Available	(Note 9)	56	BIT	n/a
Equipment Used	(Note 10)	57	BIT	n/a
Channel 1 Measurement State	(Note 11)	58	BIT	n/a
Channel 1 C/No	(Note 11)	59	BIT	n/a
Channel 2 Measurement State	(Note 11)	60	BIT	n/a
Channel 2 C/No	(Note 11)	61	BIT	n/a
Channel N Measurement State	(Note 11)	56 + 2N	BIT	n/a
Channel N C/No	(Note 11)	57 + 2N	BIT	n/a
Data Checksum	-	58 + 2N	I	n/a

**Notes to Message 3 - MMQ-G Timemark Message**

**1. GPS TIME** - GPS Sensor time (time of week in seconds, starting at Saturday 2400 hours/ Sunday 0000 hours) if GPS Time Valid Message 3500 is set to 1, otherwise MMQ-G system time since power up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

**2. UTC TIME** - Universal Coordinated Time (seconds of day) - Not presently implemented.

**3. LATITUDE/LONGITUDE** - These words contain the MMQ-G present position output in Latitude/Longitude coordinates referenced to WGS-84 map datum.

**4. ECEF POSITION X, Y, and Z** - These words contain the MMQ-G present position output in WGS-84 Earth-Centered, Earth-Fixed (ECEF) coordinates.

**5. VELOCITY EAST, NORTH, UP** - These words contain the MMQ-G present velocity in local tangent plane coordinate referenced to the WGS-84 ellipsoid.

**6. ACCELERATION EAST, NORTH, UP** - These words contain the MMQ-G present acceleration. Compensated sensor delta velocity values are used.

**7. ATTITUDE, PITCH and ROLL; TRUE HEADING -**  
 These words contain the MMQ-G present attitude. Positive Pitch values represent nose up. Positive Roll values represent right wing down. Positive Heading values represent clockwise angles relative to North.

**8. EXPECTED ERRORS -** The expected horizontal and vertical position errors and velocity error are derived by taking the square root of the corresponding Kalman filter variances.

**9. EQUIPMENT AVAILABLE -** This word is structured as follows:

Bit Position	Definition
0-2	Reserved
3	External magnetometer heading reference data available
4-15	Reserved

**10. EQUIPMENT USED -** This word is structured as follows:

Bit Position	Definition
0-2	Reserved
3	External magnetometer heading reference data used
4-15	Reserved

**11. GPS CHANNEL MEASUREMENT STATE and C/No -**  
 These words are provided for each channel of the GPS Receiver, so the length of the timemark block is dependent on the type of GPS receiver. These words are structured as follows:

**Channel Measurement State Word**

DATA ITEM	DATA BIT	DEFINITION
Satellite PRN Code	0-4	Range 0-31
Channel Activity	5-7	000=idle 001=C/A code search 101=C/A code tracking
Code Type	8	0= P-code, 1= C/A code
Encryption Type	9	0= P-code, 1= Y-code
Reserved	10	
Reserved	11-14	n/a
Channel Fault	15	1=Fault, 0=No Fault

**Channel C/No Word**

DATA ITEM	DATA BIT	DEFINITION
Reserved	0-7	n/a
C/No	8-13	Integer value of signal-to-noise ratio, range= 1 to 63 dB-Hz
Reserved	14-15	n/a

## Message 3500 - MMQ-G System Status

<b>MSG NAME : MMQ-G System Status</b>		
MSG ID :	3500	
INVALID FLAG:	Never set	Data Word Count: 16
I/O:	Output	XMIT RATE: 1 Hz

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 1)	6-9	DF@20	sec
Current Mode	(Note 2)	10	I	n/a
System Status Validity	(Note 3)	11	BIT	n/a
Number Current SVs Tracked	(Note 4)	12	I	n/a
Number of Position Measurements Processed	(Note 5)	13	I	n/a
Number of Velocity Measurements Processed	(Note 6)	14	I	n/a
FOM Information	(Note 7)	15	BIT	n/a
Expected Horizontal Position Error	(Note 8)	16-17	F@15	meters
Expected Vertical Position Error	(Note 8)	18-19	F@15	meters
Expected Velocity Error	(Note 8)	20-21	F@10	m/sec
Data Checksum	-	22	I	n/a

### Notes to Message 3500 - MMQ-G System Status

**1.** TIME TAG - Contains GPS Sensor time if valid (GPS Sensor has valid GPS time); otherwise, MMQ-G system time since power-up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

**2.** CURRENT MODE - The value of the CURRENT MODE word has the following definitions:

Value	Mode
1	Test
2	Initialization
3	(Not Used)
4	Fine Alignment
5	Air Alignment
6	Transfer Alignment
7	Air Navigation
8	Land Navigation
9	GPS Only

10	Install Magnetometer Calibration (Refer to Chapter 6- Magnetometer Interface)
11	Launch Magnetometer Calibration (Refer to Chapter 6- Magnetometer Interface)

**3. SYSTEM STATUS VALIDITY** - The bits of this word are defined as follows (where bit 0 = LSB):

- bit 0 GPS Measurements Available  
*Set to 1 if GPS Sensor time is valid and GPS Sensor indicates that at least 4 SVs are being used.*
- bit 1 INS Measurements Available  
*Set to 1 when INS sensor data is being received from the INS.*
- bit 2 GPS Data Late  
*Set to 1 when GPS measurement data is not received for the current second.*
- bit 3 GPS Time Valid  
*Set to 1 when valid UTC data has been received from the GPS receiver.*
- bit 4 Timemark Timeout  
*Set to 1 when the 1-PPS timemark pulse from the GPS receiver is not detected.*
- bit 5 BIT Failure  
*Set to 1 when a failure of Built-In Test has occurred.*
- bit 6 Constellation Change  
*Set to 1 when the constellation (current set of SVs) has changed.*
- bit 7 Time Bias Repartition  
*Set to 1 when the GPS receiver resets the partitioning between the time bias estimate and the pseudorange values.*
- bit 8 Coarse Air Alignment submode indicator  
*Set to 1 when the system is in Coarse Air Alignment submode.  
Set to 0 when the system is not in Coarse Air Alignment submode.*
- bit 9  
*Reserved*
- bits 10-12 GPS Receiver Type  
*The following GPS receiver types are defined:*

Value	Type
0	N/A
1	N/A
2	N/A
3	Jupiter Pico

- bit 13 Heading Hold Flag  
Set to 1 when in heading hold mode  
Set to 0 when not in the heading hold mode (Refer to **Error! Reference source not found.**)
- bits 14-15  
Reserved

**4. NUMBER CURRENT SVs TRACKED** - Number of SVs providing usable measurements during the current second. This is not necessarily the number of measurements processed. The following two words indicate how many measurements were actually used.

**5. NUMBER OF POSITION MEASUREMENTS PROCESSED** - Number of position measurements processed this second by the MMQ-G Kalman filter.

**6. NUMBER OF VELOCITY MEASUREMENTS PROCESSED** - Number of velocity measurements processed this second by the MMQ-G Kalman filter.

**7. FOM INFORMATION** - The following figure of merit (FOM) bit definitions have been defined for FOM information:

bits 0-3: Position FOM	
Value	$\sqrt{\text{Variance}}$ (meters)
1	< 3
2	< 10
3	< 25
4	< 50
5	< 100
6	< 200
7	< 500
8	<1000
9	≥ 1000

bits 4-7: Velocity FOM	
Value	$\sqrt{\text{Variance}}$ (m/sec)

1	< 0.2
2	< 1
3	< 5
4	< 25
5	< 50
6	< 80
7	< 150
8	< 300
9	≥ 300

<b>bits 8-11: Heading FOM</b>	
<b>Value</b>	<b><math>\sqrt{\text{Variance}}</math> (milliradians)</b>
1	< 1
2	< 3
3	< 8.66
4	< 17.3
5	< 34.6
6	< 51.9
7	< 86.6
8	< 100
9	≥ 100

<b>bits 12-15: Time FOM</b>	
<b>Value</b>	<b><math>\sqrt{\text{Variance}}</math> (<math>\mu\text{sec}</math>)</b>
1	< 0.001
2	< 0.01
3	< 0.1
4	< 1
5	< 10
6	< 100
7	< 1000
8	< 10000
9	≥ 10000

**8. EXPECTED ERRORS** - The expected horizontal and vertical position errors and velocity error are derived by taking the square root of the corresponding Kalman filter variances.

## Message 3501 - MMQ-G Navigation Solution

<b>MSG NAME : MMQ-G Navigation Solution</b>		
MSG ID :	3501	
INVALID FLAG:	Never set	Data Word Count: 22
I/O:	Output	XMIT RATE: 1,10 Hz (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Latitude	(Note 3)	10-11	F@0	semicircles
Longitude	(Note 3)	12-13	F@0	semicircles
Altitude	(Note 3)	14-15	F@15	meters
Velocity North	-	16-17	F@10	m/sec
Velocity East	-	18-19	F@10	m/sec
Velocity Up	-	20-21	F@10	m/sec
Pitch	(Note 4)	22-23	F@0	semicircles
Roll	(Note 4)	24-25	F@0	semicircles
True Heading	(Note 4)	26-27	F@0	semicircles
Data Checksum	-	28	I	n/a

### Notes to Message 3501 - MMQ-G Navigation Solution:

1. Transmission rate programmable via Message 3504.
2. TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, MMQ-G system time since power-up is reported.. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.
3. LATITUDE, LONGITUDE, ALTITUDE - Referenced to WGS-84 map datum.
4. PITCH, ROLL, TRUE HEADING - Positive pitch values represent nose up. Positive roll values represent right wing down. Positive heading values represent clockwise angle relative to North.

## Message 3502 - MMQ-G Delta Velocity and Delta Theta

<b>MSG NAME : MMQ-G Delta Velocity and Delta Theta</b>		
MSG ID :	3502	
INVALID FLAG:	Never set	Data Word Count: 16
I/O:	Output	XMIT RATE: 1,10, 100 Hz (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Delta Theta X	(Note 3)	10-11	F@0	radians
Delta Theta Y	(Note 3)	12-13	F@0	radians
Delta Theta Z	(Note 3)	14-15	F@0	radians
Delta Velocity X	(Note 3)	16-17	F@10	m/sec
Delta Velocity Y	(Note 3)	18-19	F@10	m/sec
Delta Velocity Z	(Note 3)	20-21	F@10	m/sec
Data Checksum	-	22	I	n/a

### Notes to Message 3502 - MMQ-G Delta Velocity and Delta Theta:

**1.** Transmission rate programmable via Message 3504. The selected rate affects the data time interval. For example, if the message is requested at 10 Hz, the data represents 100 ms of  $\Delta V$  and  $\Delta\theta$ .

*Overflows may occur if high-dynamics data is output at low rates.*

**2.** TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, MMQ-G system time since power-up is reported.. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

**3.** Delta values are incremental sums reported in HV body axis coordinate system where the default orientation is as follows: X = nose, Y = right wing, Z = down. Sensor errors and gravity have not been compensated.

## Message 3503 - MMQ-G Built-In-Test Results

<b>MSG NAME : MMQ-G Built-In Test Results</b>	
MSG ID : 3503	
INVALID FLAG: Never set	Data Word Count: 100
I/O: Output	XMIT RATE: Once at startup or completion of a commanded Built In Test, and at 1 Hz if connected for output. (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Notes 2, A)	6-9	DF@20	sec
BIT Summary	(Notes 3, A)	10	BIT	n/a
Reserved	-	11	n/a	n/a
BIT Validity Word	(Notes 4, A)	12	BIT	n/a
BIT Results Word	(Notes 4, A)	13	BIT	n/a
MMQ-G Memory Test Result	(Notes 5, A)	14	BIT	n/a
MMQ-G Limit Test Result	(Notes 6, A)	15	BIT	n/a
Reserved	-	16	n/a	n/a
Magnetometer Cal Data	(Note 7)	17	BIT	n/a
Reserved	-	18-33	n/a	n/a
Reserved	-	34-35	n/a	n/a
MMQ-G Serial Number	(Notes 8, B)	36-37	DI	n/a
MMQ-G Cal Day	(Notes 9, B)	38-39	DI	n/a
MMQ-G Cal Year	(Notes 10, B)	40-41	DI	n/a
Reserved		42-71	n/a	n/a
GPS Receiver Self Test Results	(Notes 11, C)	72-87	n/a	n/a
Reserved		88-105	n/a	n/a
Data Checksum	-	106	I	n/a

Message 3503 contains the results of all self test processing performed by MMQ-G: Power-On Self Test (POST), Commanded Built-In Test (BIT), and background BIT processing. Refer to the notes below for individual data items to determine when a particular message field is updated.

### Notes to Message 3503 - MMQ-G Built-In Test Results:

1. Message 3503 is transmitted once at start-up, after completion of Power-On Self Test (POST) and once upon each completion of a commanded Built In Test (BIT). It

may also be connected for output in order to monitor the continuous background BIT processing, in which case it will be transmitted at a 1-Hz rate. In general, it is not necessary to have message 3503 connected for continuous output, as the system status message 3500 System Status Validity word, bit 5 indicates the BIT summary pass/fail status.

2. Time Tag - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, MMQ-G system time since power-up is reported.

3. BIT Summary - Contains the overall pass/fail status and type of the current test. The overall test pass/fail status represents the overall test results on the sensor's input, temperature, power supply and flash memory. It is also reported in System Status message 3500, word 11 (System Status Validity), bit 5. The format of this word is as follows.

BIT	Description
0 (LSB) - 12	Reserved
13 - 14	Type of current BIT test: 0 - Background BIT 1 - Commanded BIT 2 - Power-On Self Test (POST)
15	Test pass/fail flag (0 = PASS, 1 = FAIL)

4. BIT Validity and BIT Result words - Bits in the BIT Validity word are Boolean indicators of whether the corresponding bits in the BIT Results word contain valid data. This word is updated each time message 3503 is output. A bit is set to '1' in the BIT Validity word to indicate that this particular subsystem test has been performed, or that this element contains valid data from a previous test. The BIT Results word contains summary test results for various subsystem tests, where a bit is set to '1' to indicate a failure in a particular subsystem test. The bits in these words are updated as indicated by their respective notes. The detailed test results may be examined to determine the exact nature of any failure noted by a subsystem summary test indicated in the BIT Results word. The format of the BIT Validity and BIT Results words are detailed in the following table.

#### BIT VALIDITY and BIT RESULTS

BIT	Note	Description
0 (LSB)	(Note 4.1)	Flash memory test
1		Reserved
2	(Note 4.2)	Temperature sensor limit test

3	(Note 4.3)	Power supply out of range test
4	(Note 4.4)	Inertial sensor limit test
5 -8		Reserved
9	(Note 4.5)	GPS receiver BIT test
10		Time mark synchronization test
11-15 (MSB)		Reserved

### Notes to BIT VALIDITY and BIT RESULTS Words

**4.1** Flash memory Test Summary result represents the composite test results of F2812 flash memory, including code section, calibration parameter section, saved initialization section. See detailed description of memory test result in word 14.

**4.2** Temperature sensors limit test summary result represents the composite test results of all temperature sensor limit test result. If this bit is set, then there is fault of sensed temperature out of range. Bit 8-11 in word 15 will show the ID of the fault temperature sensor.

**4.3** Power supply out of range test summary result represents the composite test results of all parts of power supply to MMQ-G and reference voltage. See detailed description of power supply test on Bits 6-11 in word 15.

**4.4** Inertial sensor limit test summary results represent the composite test results on accelerometers and quartz rate sensors output range. If any sensor's output is out of range, this bit will be set. The fault sensor will be reported on bits 0-5 in word 15.

**4.5** GPS Receiver BIT indicates the summary pass/fail status of the GPS receiver subsystem built-in test. This testing is performed by the GPS receiver subsystem when a built in test command is sent to the MMQ-G. A failure indicates that either: 1) a reply from the GPS receiver was not received within the time-out period when BIT was commanded, or 2) a reply from the GPS receiver was not received correctly. See words 46- 59 for details if the test is successful.

**5.** MMQG Memory Test Results Word – This word gives detailed memory test result. The format of the test results word is as follows:

BIT	Note	Description
0(LSB)-2		Reserved
3	(Note 5.1)	F2812 FLASH Memory test (All sections except calibration section)
4		Reserved
5	(Note 5.1)	F2812 FLASH Memory test (calibration coefficients)

6	(Note 5.2)	Saved initialization data validity
7-10	(Note 5.1)	Flash memory checksum fault block ID
11 - 15		Reserved

### Notes to Memory Test Results:

**5.1 F2812 FLASH Memory bit 3 and 5** – indicate the result of all sections of F2812 flash memory test at power application. A failure indicates that the checksum for this area of memory did not match the pre-stored value, indicating that this area of memory is corrupt. Bit 7-10 show the ID of the failure memory section as follows.

ID #	Section
0	Calibration Coefficients
1	Reserved
2	Save initialization data
3	Code
4	System parameters

If more than one faulted block exists, the ID field will contain the ID of only the lower number fault block.

If the block used for calibration coefficients has a checksum error, its ID will not be placed in the field. It is reported by bit 5 of the Results Word 14.

**5.2 Saved initialization data validity** – indicates the state of user configuration data area of memory (ID=2). When this bit is 0, no data has been saved by the user, or saved data has failed checksum verification and is not usable. When this bit is 1, data has been saved by the user, passed validity tests, and will be used for system initialization.

**6. MMQ-G Limit Test Results** – This word gives the detailed test results on inertial sensors, temperature sensor, power supply and reference voltage out of limit test. The format of the test results are as follows

BIT	Notes	Description
0 (LSB)	(Note A)	X accelerometer limit
1	(Note A)	Y accelerometer limit
2	(Note A)	Z accelerometer limit
3	(Note A)	X rate sensor limit
4	(Note A)	Y rate sensor limit
5	(Note A)	Z rate sensor limit
6	(Note A)	Power supply is under voltage
7	(Note A)	Power supply is over voltage
8-11	(Note A)	Fault temp or voltage ID
12 - 15		Reserved

Bit 6 and 7 will indicate the power supply is under voltage or over voltage if power supply is out of range. When a power supply or a temperature is out of range, i.e., bit 2 or 3 of BIT Results Word is set, a number will be placed in the fault temperature or voltage ID field (bit 8-11) indicating which value is out of range. ID number for these values is as follows:

ID #	Description
0	Accel. X Temperature
1	Gyro X Temperature
2	Accel. Y Temperature
3	Gyro Y Temperature
4	Accel. Z Temperature
5	Gyro Z Temperature
6	ADC Temperature
7	DSP Temperature
8	5.0V
9	3.3V
10	1.8V
11	12V
12	-12V
13	1.25 Ref.
14 - 15	Reserved

If more than one fault exists, the ID field will contain the ID of only the lower number fault block.

**7.** Magnetometer Calibration Data - Contains information regarding the presence of magnetometer calibration data in memory. The format of this word is as follows.

BIT	Description
0 (LSB)	Magnetometer “install” calibration (0 = Not present in memory, 1 = present in memory)
1	Magnetometer “launch” calibration (0 = Not present in memory, 1 = present in memory)
2-15 (MSB)	Reserved

**8.** MMQ-G serial number – Contains an integer number whose hexadecimal value represents the unit’s serial number.

**9.** MMQ-G Calibration day – Contain the day of the year and hour of the day that the unit was calibrated. It is in the form of (Day of the year \*100 + hour). Day of year ranges from 1 to 366 and the hour ranges from 0 to 23.

**10.** MMQ-G Calibration Year – Bits 0 to 7 contain an integer number whose hexadecimal value representing the year that the unit was calibrated. Other bits in the word are reserved.

**11.** GPS receiver self test results - reflect the results of the GPS receiver subsystem self test performed by the Jupiter when a built in test command is received by the MMQ-G. These words are the data portion of the Jupiter BIT results message 1100, exactly as reported by the GPS receiver. It is defined in the following table:

Data	Notes	Word No	Data Type	Units
Set Time	(Note 11.1)	72-73	UDI	10 ms ticks
Sequence Number	(Note 11.2)	74	I	n/a
ROM Failure	(Note 11.3)	75	UI	n/a
RAM Failure	(Note 11.3)	76	UI	n/a
EEPROM Failure	(Note 11.3)	77	UI	n/a
Dual Port RAM Failure	(Note 11.3)	78	UI	n/a
Digital Signal Processor (DSP) Failure	(Note 11.3)	79	UI	n/a
Real-Time Clock (RTC) Failure	(Note 11.3)	80	UI	n/a
Serial Port 1 Receive Error Count		81	UI	# errors detected
Serial Port 2 Receive Error Count		82	UI	# errors detected
Serial Port 1 Receive Byte Count		83	UI	# errors detected
Serial Port 2 Receive Byte Count		84	UI	# errors detected
GPS Receiver Software Version		85	UI	0.01 resolution
Reserved		86-87	n/a	n/a

**11.1** Set Time - This is an internal 10 ms count since power-on initialization enable the processor interrupts. It is not used to derive GPS time, but only serves to provide a sequence of events knowledge. The set time count references the receiver's internal time at which the message was created for output. The range is approximately 71 weeks.

**11.2** Sequence Number – This is a count that indicates whether the data in this binary message has been updated or changed since the last message output.

**11.3** A value of zero indicates a test has passed. A non-zero value indicates a device failure. Missing devices will be reported as failures. Therefore, the OEM's BIT pass/fail should ignore words for components that are not in the system under test.

**Notes on update rates:**

**A.** The data item in this field is updated continuously by background Built-In Test processing. The last update of this field is reported whenever message 3503 is output.

**B.** The data item in this field is updated once during Power-On Self-Test. Subsequent output of message 3503 report the results of this test.

**C.** The data item in this field is updated every time that a Built-In Test is commanded. Subsequent output of message 3503 report the results of the last commanded Built-In Test.

## Message 3504 - MMQ-G Parameter Control

Currently, the MMQ-G-HV transmit and receive baud rate is factory set to 115,200.

<b>MSG NAME : MMQ-G Parameter Control</b>	
MSG ID: 3504	
INVALID FLAG: Never set	Data Word Count: 5
I/O: Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Data Validity	(Note 1)	6	BIT	n/a
Host Vehicle Baud Rate and Magnetometer Calibration Control (Refer to Chapter 6- Magnetometer Interface)	(Note 2)	7	BIT	n/a
GPS Receiver Baud Rate ( <b>Disabled</b> ) and Heading Hold Control (Refer to <b>Error! Reference source not found.</b> )	(Note 3)	8	BIT	n/a
Differential GPS Baud Rate	(Note 2)	9	BIT	n/a
Message Control	(Note 4)	10	BIT	n/a
Data Checksum	-	11	I	n/a

### Notes to Message 3504 - MMQ-G Parameter Control:

1. DATA VALIDITY - This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
Host Vehicle XMIT Rate Valid (See Note 2)	0	0=No data specified
	1	1=Valid XMIT baud rate data
Host Vehicle RCV Rate Valid (See Note 2)	1	0=No data specified
	1	1=Valid RCV baud rate data
GPS Receiver XMIT Rate Valid (See Note 2)	2	0=No data specified
	1	1=Valid XMIT baud rate data
GPS Receiver RCV Rate Valid (See Note 2)	3	0=No data specified
	1	1=Valid RCV baud rate data
DGPS RCV Rate Valid (See Note 2)	4	0=No data specified
	1	1=Valid RCV baud rate data
Message 3501 XMIT Rate Valid	5	0=No data specified
	1	1=Valid XMIT rate for Message 3501
Message 3502 XMIT Rate Valid	6	0=No data specified
	1	1=Valid XMIT rate for Message 3502

Message 3512 XMIT Rate Valid	7	0=No data specified 1=Valid XMIT rate for Message 3512
Message 3512 Configuration Specification Valid	8	0=No data specified 1=Valid configuration for Message 3512
GPS Set Specification Valid	9	0=No data specified 1=Valid GPS set specification
Reserved	10	Set to zero
Magnetometer Calibration Control Valid	11	0=No data specified 1=Valid magnetometer calibration control data
Heading Hold control valid	12	0=No data specified 1 = Valid heading hold control data
Reserved	13	Set to zero
Pass through Control Valid	14	0=No data specified 1=Valid pass through control data
Save Configuration Command Valid	15	0=No data specified 1=Save configuration command valid

Refer to Appendix A- Frequently Asked Questions, for explanation of the Save Configuration command

2. BAUD RATE and Magnetometer Calibration Control
  - Baud rate changes are only processed when the CURRENT MODE (Message 3500) is Initialization. The Magnetometer Calibration Control parameters will be accepted in any mode. This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
XMIT Baud Rate	0-3	0=No Change
		1=115200
		2=57600
		3=38400
		4=19200
Install Magnetometer Calibration Control	4-5	5=9600
		0=No Change
		1=Start Mag Cal
		2=End Mag Cal
XMIT Parity	6-7	3=Erase Mag Cal
		0=No Change
		1=No parity
		2=Even parity
		3=Odd parity

RCV Baud Rate	8-11	0=No Change
		1=115200
		2=57600
		3=38400
		4=19200
		5=9600
		6=4800
Launch Magnetometer Calibration Control	12-13	0=No Change
		1=Start Mag Cal
		2=End Mag Cal
		3=Erase Mag Cal
RCV Parity	14-15	0=No Change
		1=No parity
		2=Even parity
		3=Odd parity

The default setting for the Host Vehicle interface is 115200 baud, odd parity. The default setting for the DGPS interface is 9600 baud, no parity.

3. GPS Receiver Baud Rate (**Disabled**) and Heading Hold Control – GPS Baud rate changes are disabled. The heading hold control is accepted only when in air navigation mode. This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
XMIT Baud Rate	0-3	0=No Change
		1=115200
		2=57600
		3=38400
		4=19200
		5=9600
		6=4800
Heading Hold control	4	0=heading hold off
		1=heading hold on
spare	5	Set to 0
XMIT Parity	6-7	0=No Change
		1=No parity
		2=Even parity
		3=Odd parity
RCV Baud Rate	8-11	0=No Change
		1=115200
		2=57600
		3=38400
		4=19200
		5=9600
		6=4800
spare	12-13	Set to 0

RCV Parity	14-15	0=No Change 1=No parity 2=Even parity 3=Odd parity
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4. MESSAGE CONTROL - This word is structured as follows:

DATA ITEM	DATA BIT	DEFINITION
Message 3501 Transmit Rate	0-1	0=No Change
		1=1 Hz
		2=10 Hz (Default)
Message 3502 Transmit Rate	2-3	0=No Change
		1=1 Hz
		2=10 Hz (Default)
Message 3512 Transmit Rate	4-5	0=No Change
		1=1 Hz
		2=10 Hz (Default)
Message 3512 Transmit Rate	4-5	3=100 Hz
		0=Unknown
		3=Jupiter
Message 3512 Configuration	6-9	Bit 6=Delta attitude
		Bit 7=Delta velocity
		Bit 8=Attitude
		Bit 9=Velocity
GPS Set Specification	10-12	0=Unknown
		3=Jupiter
Reserved	13	Set to zero
Passthrough control	14	0=Pass raw GPS messages
		1=Pass translated GPS messages
Save configuration command	15	0=Erase
		1=Save

## Message 3505 - Magnetometer Data

<b>MSG NAME : MMQ-G Navigation Solution</b>		
MSG ID :	3505	
INVALID FLAG:	Never set	Data Word Count: 38
I/O:	Output	Same as the Magnetometer data input rate

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Magnetic Heading	(Note 3)	10-11	F@0	semicircles
Magnetometer X	(Note 4)	12-13	F@2	gauss
Magnetometer Y	(Note 4)	14-15	F@2	gauss
Magnetometer Z	(Note 4)	16-17	F@2	gauss
Magnetometer X Hardiron	(Note 5)	18-19	F@2	gauss
Magnetometer Y Hardiron	(Note 5)	20-21	F@2	gauss
Magnetometer Z Hardiron	(Note 5)	22-23	F@2	gauss
Magnetometer X Softiron	(Note 6)	24-25	F@4	ratio
Magnetometer Y Softiron	(Note 6)	26-27	F@4	ratio
Magnetometer Z Softiron	(Note 6)	28-29	F@4	ratio
Launch Magnetometer X Hardiron	(Note 7)	30-31	F@2	gauss
Launch Magnetometer Y Hardiron	(Note 7)	32-33	F@2	gauss
Launch Magnetometer Z Hardiron	(Note 7)	34-35	F@2	gauss
Launch Magnetometer X Softiron	(Note 8)	36-37	F@4	ratio
Launch Magnetometer Y Softiron	(Note 8)	38-39	F@4	ratio
Launch Magnetometer Z Softiron	(Note 8)	40-41	F@4	ratio
Magnetic Variation	(Note 9)	42-43	F@0	semicircles
Data Checksum	-	44	I	n/a

### Notes to Message 3505 – Magnetometer Data:

1. Transmission rate is the same as the magnetometer heading reference input message rate, such as message 3530 or XDR. Output available upon connect request.
2. TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, MMQ-G system time since power-up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.
3. Calculated magnetic heading data in semi-circles corrected for magnetic variation (see note 9) used as reference data input for the Kalman filter.

4. Magnetometer vector data in units of gauss. Maximum range is 1.0 gauss.
5. Magnetometer hardiron data in units of gauss. The “install” magnetometer hardiron data is output in these fields after an “install” magnetometer calibration has been conducted.
6. Magnetometer softiron data in unitless ratio data. The “install” magnetometer softiron data is output in these fields after an “install” magnetometer calibration has been conducted.
7. Magnetometer hardiron data in units of gauss. The “launch” magnetometer hardiron data is output in these fields after a “launch” magnetometer calibration has been conducted. Please ignore this portion of message 3505.
8. Magnetometer softiron data in unitless ratio data. The “launch” magnetometer softiron data is output in these fields after a “launch” magnetometer calibration has been conducted. Please ignore this portion of message 3505.
9. Calculated magnetic variation data in semi-circles used to change magnetic north heading data into true map north data for use as reference data input for the Kalman filter.

## Message 3510 - MMQ-G Control and Initialization

<b>MSG NAME : MMQ-G Control and Initialization</b>		
MSG ID :	3510	
INVALID FLAG:	Never set	Data Word Count: 21
I/O:	Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Data Validity	(Note 1)	6	BIT	n/a
Mode Command	(Note 2)	7	I	n/a
Latitude – Degrees	(Note 3)	8	I	degrees
Latitude – Minutes	(Note 3)	9	I	minutes
Latitude – Seconds	(Note 3)	10	I	seconds
Longitude – Degrees	(Note 3)	11	I	degrees
Longitude – Minutes	(Note 3)	12	I	minutes
Longitude – Seconds	(Note 3)	13	I	seconds
Altitude	(Note 3)	14-15	DI	meters
Ground Speed	(Note 4)	16	I	m/sec
Ground Track	(Note 4)	17	I	degrees
Year	(Note 5)	18	I	years
Day of Year	(Note 5)	19	I	days
Hours	(Note 5)	20	I	hours
Minutes	(Note 5)	21	I	minutes
Seconds	(Note 5)	22	I	seconds
True Heading	(Note 6)	23	I	degrees/100
Auto Align/Nav Sequence	(Note 7)	24	BIT	n/a
Reserved	Set to zero	25-26	n/a	n/a
Data Checksum	-	27	I	n/a

### Notes to Message 3510 - MMQ-G Control and Initialization:

**1.** DATA VALIDITY - The bits of this word are defined in the table below. A mode command may be issued in any mode, subject to the limitations of Table 4-1.

Refer to Appendix A- Frequently Asked Questions, for an explanation of various initialization options. The other initialization data will be acted upon only in initialization mode.

DATA ITEM	DATA BIT	DEFINITION
Mode Command Data	0	0=invalid, 1=valid
Position Data (lat/long/altitude)	1	0=invalid, 1=valid
Velocity Data	2	0=invalid, 1=valid
Date/Time Data	3	0=invalid, 1=valid
Heading Data	4	0=invalid, 1=valid
Auto Align/Nav Sequence Data	5	0=invalid, 1=valid
Auto GPS Init Valid	6	0=invalid, 1=valid
Reserved	7-15	Set to zero

**2. MODE COMMAND** - A value of zero enables automatic mode sequencing through alignment into navigation mode, as defined by the Auto Align/Nav sequence word. A value corresponding to a valid mode (see notes for message 3500) will cause a transition to that mode, if necessary through intervening modes as specified by the Mode Transition Table, Table 4-1.

A commanded mode will remain in effect until another mode command is processed. The special mode command values -99 and +99 allow enabling of an “INS-Only” mode where GPS measurements processing is disabled and navigation is performed using only INS data. The value -99 enables INS-Only mode, and the value +99 disables it, i.e. returns to INS/GPS operation.

**3. LATITUDE, LONGITUDE, ALTITUDE** - For latitude, northern hemisphere values are indicated with positive degree, minute, second values; southern hemisphere values are represented with negative degree, minute, and second values. For instance, a southern latitude of 34 degrees, 15 minutes, 25 seconds would be input with a degrees value of -34, a minutes value of -15, and a seconds value of -25. Similarly, for longitude, eastern hemisphere values are indicated with positive degree, minute, and second values; western hemisphere values are represented with negative degree, minute, and second values.

Latitude, longitude, and altitude are geodetic values referenced to WGS-84 datum. The default location at turn-on is the position saved in FLASH by the Save Configuration command of Message 3504, or, if this does not exist, the location is Concord, CA (Lat = 37:57:50, Lon = -122:01:47, Alt = 1.0).

**4. VELOCITY** - A vertical velocity of 0 (level flight) is assumed. Ground track is measured clockwise relative to North. The default is a velocity of zero.

**5. DATE, TIME** - UTC (Paris) date and time. The year is encoded as years since 1900 (1=1901). The day of year

starts at one (1=Jan 1). The hour is encoded in 24-hour time (0=midnight; 13=1 pm).

**6. TRUE HEADING** - Represents actual pointing direction of HV, measured clockwise from North. The value must be specified in the range -180 to +180 degrees in units of deg/100, so the input integer must be between -18000 and +18000. The default heading is zero.

**7. AUTO ALIGN/NAV SEQUENCE** - This word is used to define default sequencing through an alignment mode and into a navigation mode after initialization. If this data is not provided, default sequencing is through Fine Alignment mode into Air Navigation mode. The bit definitions (where 0=LSB) for this word are shown in the table below. The numerical definitions of the modes are found in the notes for message 3500.

<b>DATA ITEM</b>	<b>DATA BITS</b>	<b>DEFINITION</b>
Auto Alignment Sequence	0-3	Alignment mode for automatic sequencing
Auto Navigation Sequence	4-7	Navigation mode for automatic sequencing
Auto GPS Initialization	8	0 = Initialize from user-provided data (default) 1 = Initialize from GPS processor nav solution as soon as GPS processor enters navigation mode
Reserved	9-15	Set to zero

## Message 3511 - MMQ-G Configuration Control

<b>MSG NAME: MMQ-G Configuration Control</b>		
MSG ID :	3511	
INVALID FLAG:	Never set	Data Word Count: 22
I/O:	Input	XMIT RATE: As Required

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Data Validity	(Note 1)	6	BIT	n/a
Sensor-to-Body Transformation Cbs (1,1)	(Note 2)	7-8	F@1	Unitless
Sensor-to-Body Transformation Cbs (1,2)	(Note 2)	9-10	F@1	Unitless
Sensor-to-Body Transformation Cbs (1,3)	(Note 2)	11-12	F@1	Unitless
Sensor-to-Body Transformation Cbs (2,1)	(Note 2)	13-14	F@1	Unitless
Sensor-to-Body Transformation Cbs (2,2)	(Note 2)	15-16	F@1	Unitless
Sensor-to-Body Transformation Cbs (2,3)	(Note 2)	17-18	F@1	Unitless
Sensor-to-Body Transformation Cbs (3,1)	(Note 2)	19-20	F@1	Unitless
Sensor-to-Body Transformation Cbs (3,2)	(Note 2)	21-22	F@1	Unitless
Sensor-to-Body Transformation Cbs (3,3)	(Note 2)	23-24	F@1	Unitless
Lever Arm X	(Note 3)	25	I	cm
Lever Arm Y	(Note 3)	26	I	cm
Lever Arm Z	(Note 3)	27	I	cm
Data Checksum	-	28	I	n/a

### Notes to Message 3511 - MMQ-G Configuration Control:

**1. DATA VALIDITY** - The bits of this word are defined in the table below:

<b>DATA ITEM</b>	<b>DATA BIT</b>	<b>DEFINITION</b>
Sensor-to-Body Transformation Data	0	0=invalid, 1=valid
Lever Arm Data	1	0=invalid, 1=valid
Reserved	2-15	Set to zero

**2. SENSOR-TO-BODY TRANSFORMATION** - This matrix provides the means of transforming delta-velocity and delta attitude data from IMU axes to host-vehicle body axes. This affects the incremental data reported in messages 3502 and 3512 and the attitude data (pitch, roll, and heading) reported in messages 3501 and 3512.

**3. LEVER ARM** - The lever arm is the distance to the GPS antenna from the MMQ-G center of gravity along the MMQ-G body axes.

## Message 3512 - MMQ-G Flight Control

<b>MSG NAME : MMQ-G Flight Control</b>		
MSG ID :	3512	
INVALID FLAG:	Never set	Data Word Count: Note 3
I/O:	Output	XMIT RATE: 1,10, 100 Hz (Note 1)

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	-	5	I	n/a
Time Tag	(Note 2)	6-9	DF@20	sec
Configurable Flight Control Data	(Note 3)	10 - N		
Data Checksum	-	N+1	I	n/a

### Notes to Message 3512 - MMQ-G Flight Control:

**1.** Transmission rate programmable via Message 3504. The selected rate affects the data time interval. For example, if the message is requested at 10 Hz, the data represents 100 ms of  $\Delta V$  and  $\Delta \Theta$ .

*Overflows may occur if high-dynamics data is output at low rates.*

**2.** TIME TAG - Contains GPS Sensor time if GPS Time Valid (Message 3500) is set to 1; otherwise, MMQ-G system time since power-up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.

**3.** The format of Message 3512 is configurable via Message 3504. Message 3512 may be specified to contain any or all of the following data items.

### Notes to Message 3512 - MMQ-G Flight Control (cont.)

DATA	NUMBER OF 16-BIT WORDS	DATA TYPE	UNITS
Compensated Delta Theta (Body coordinates - X,Y,Z)	6	F@0	radians
Compensated Delta Velocity (Body coordinates - X,Y,Z)	6	F@10	m/sec
Attitude (Pitch, roll, heading)	6	F@0	semicircles
Velocity (North, east, up)	6	F@10	m/sec

Included data items appear in the order shown. The size of the data block will vary with the included data items. The default content of message 3512 is the delta-attitude and delta-velocity data. Unlike message 3502, the delta-attitude and delta-velocity values are compensated for estimated IMU errors.

## Message 3530 - Heading Reference

<b>MSG NAME : Heading Reference</b>		
MSG ID :	3530	
INVALID FLAG:		Data Word Count: 6
I/O:	Input	XMIT RATE: 1 to 10 Hz

Data	Word No	Data Type	Units
Message Header	1-4	n/a	n/a
Header Checksum	5	I	n/a
Flag	6	n/a	n/a
Data	7-12		
Data Checksum	13	I	n/a

Message 3530 is a host vehicle input message to MMQ-G. It provides heading reference information via magnetometer vector data for the MMQ-G. The heading reference is therefore an extra navigation aid. The data packet must be sent down to the MMQ-G at a 1Hz or higher rate. Receiving message 3530 at a 10Hz input rate has been tested thoroughly, but any input rate between 1Hz and 10Hz is acceptable.

Message 3530 contains 13 words with a 5 word header, a 1 word flag, 6 words of data and a 1 word data checksum as shown in the above table. Here 1 word equals 16 bits. The header format is the same as for other messages, such as message 3504. The flag word contains various flags to indicate the meaning of the data included and its validation. The flag word is defined as follows:

BIT	Notes	Description
0 (LSB) - 2	010 – Magnetometer Measurement	Message Subtype
3 - 6	Reserved	Not Used
7	1	Measurement Valid
8-15 (MSB)	Reserved	Not Used

The data types and units are as follows:

<b>Data</b>	<b>Word No</b>	<b>Data Type</b>	<b>Units</b>
Reserved	7-8	N/A	
Mag X measurement	9	I	13 nanoTesla/Count
Mag Y measurement	10	I	13 nanoTesla/Count
Mag Z measurement	11	I	13 nanoTesla/Count
Reserved	12	N/A	

## Message 3623 - Jupiter Timemark Message

<b>MSG NAME: Jupiter Timemark Message (Note 1)</b>		
MSG ID :	3623	
INVALID FLAG:	Never set	Data Word Count: 117
I/O:	Output	XMIT RATE: 1 Hz

Data	Notes	Word No	Data Type	Units
Message Header	-	1-4	n/a	n/a
Header Checksum	(Note 1)	5	I	n/a
GPS Time of Week	(Note 2)	6-9	DF@20	sec
UTC Time	(Note 3)	10-13	DF@17	sec
Reserved	-	14	n/a	n/a
Reserved	(Note 4)	15	BIT	n/a
Number of SV's Used	-	16	I	n/a
Reserved	-	17-18	n/a	n/a
UTC Day	-	19	UI	days (1-31)
UTC Month	-	20	UI	months (1-12)
UTC Year	-	21	UI	years (1980-2079)
Latitude	(Note 5)	22-23	F@0	semicircles
Longitude	(Note 5)	24-25	F@0	semicircles
Altitude	(Note 5)	26-27	F@15	meters
Velocity, East	(Note 6)	28-29	F@10	m/sec
Velocity, North	(Note 6)	30-31	F@10	m/sec
Velocity, Up	(Note 6)	32-33	F@10	m/sec
Expected Horizontal Position Error	-	34-35	UDI	cm
Expected Vertical Position Error	-	36-37	UDI	cm
Expected Time Error	-	38-39	UDI	cm
Expected Horizontal Velocity Error	-	40	UI	cm/sec
Clock Bias	-	41-42	DI	cm
Clock Drift	-	43-44	DI	cm
Channel 1 CSW	(Note 7)	45	I	n/a
Channel 2 CSW	(Note 7)	46	I	n/a
Channel 3 CSW	(Note 7)	47	I	n/a
Channel 4 CSW	(Note 7)	48	I	n/a
Channel 5 CSW	(Note 7)	49	I	n/a
Channel 6 CSW	(Note 7)	50	I	n/a
Channel 7 CSW	(Note 7)	51	I	n/a
Channel 8 CSW	(Note 7)	52	I	n/a
Channel 9 CSW	(Note 7)	53	I	n/a

Channel 10 CSW	(Note 7)	54	I	n/a
Channel 11 CSW	(Note 7)	55	I	n/a
Channel 12 CSW	(Note 7)	56	I	n/a
Channel 1 Measurement State Info	(Note 8)	57	BIT	n/a
Channel 2 Measurement State Info	(Note 8)	58	BIT	n/a
Channel 3 Measurement State Info	(Note 8)	59	BIT	n/a
Channel 4 Measurement State Info	(Note 8)	60	BIT	n/a
Channel 5 Measurement State Info	(Note 8)	61	BIT	n/a
Channel 6 Measurement State Info	(Note 8)	62	BIT	n/a
Channel 7 Measurement State Info	(Note 8)	63	BIT	n/a
Channel 8 Measurement State Info	(Note 8)	64	BIT	n/a
Channel 9 Measurement State Info	(Note 8)	65	BIT	n/a
Channel 10 Measurement State Info	(Note 8)	66	BIT	n/a
Channel 11 Measurement State Info	(Note 8)	67	BIT	n/a
Channel 12 Measurement State Info	(Note 8)	68	BIT	n/a
Channel 1 Pseudorange	(Note 9)	69-70	F@26	meters
Channel 1 Deltarange	(Note 10)	71-72	F@14	m/sec
Channel 2 Pseudorange	(Note 9)	73-74	F@26	meters
Channel 2 Deltarange	(Note 10)	75-76	F@14	m/sec
Channel 3 Pseudorange	(Note 9)	77-78	F@26	meters
Channel 3 Deltarange	(Note 10)	79-80	F@14	m/sec
Channel 4 Pseudorange	(Note 9)	81-82	F@26	meters
Channel 4 Deltarange	(Note 10)	83-84	F@14	m/sec
Channel 5 Pseudorange	(Note 9)	85-86	F@26	meters
Channel 5 Deltarange	(Note 10)	87-88	F@14	m/sec
Channel 6 Pseudorange	(Note 9)	89-90	F@26	meters
Channel 6 Deltarange	(Note 10)	91-92	F@14	m/sec
Channel 7 Pseudorange	(Note 9)	93-94	F@26	meters
Channel 7 Deltarange	(Note 10)	95-96	F@14	m/sec
Channel 8 Pseudorange	(Note 9)	97-98	F@26	meters
Channel 8 Deltarange	(Note 10)	99-100	F@14	m/sec
Channel 9 Pseudorange	(Note 9)	101-102	F@26	meters
Channel 9 Deltarange	(Note 10)	103-104	F@14	m/sec
Channel 10 Pseudorange	(Note 9)	105-106	F@26	meters
Channel 10 Deltarange	(Note 10)	107-108	F@14	m/sec
Channel 11 Pseudorange	(Note 9)	109-110	F@26	meters
Channel 11 Deltarange	(Note 10)	111-112	F@14	m/sec
Channel 12 Pseudorange	(Note 9)	113-114	F@26	meters
Channel 12 Deltarange	(Note 10)	115-116	F@14	m/sec
ECEF Position X	(Note 11)	117-118	F@23	meters
ECEF Position Y	(Note 11)	119-120	F@23	meters
ECEF Position Z	(Note 11)	121-122	F@23	meters
Data Checksum	-	123	I	n/a

**Notes to Message 3623 - Jupiter Timemark Message:**

1. Message 3623 represents a re-packaging of various Jupiter messages (Jupiter Messages 1000, 1002, 1007, 1009, and 1102) internal to the MMQ-G. Passthrough translation is enabled, i.e., data formats have been changed to those used by MMQ-G. The message size and checksum values differ from those of any Jupiter message.
2. GPS TIME - GPS Sensor time (time of week in seconds, starting at Saturday 2400 hours/ Sunday 0000 hours) if GPS Time Valid Message 3500 is set to 1, otherwise MMQ-G system time since power up is reported. Data words are in the order 2, 1 (MSW), 4 (LSW), 3.
3. UTC TIME - Universal Coordinated Time (seconds of day).
4. Reserved
5. LATITUDE, LONGITUDE, ALTITUDE - Referenced to WGS-84 map datum. WGS-84 coordinates are ellipsoidal coordinates, hence given in latitude, longitude and altitude above the ellipsoid. Note: In some locations, a WGS-84 altitude of 0 meters above the ellipsoidal surface can differ by as much as 100 meters from actual sea level.
6. VELOCITY EAST/NORTH/UP - Local tangent plane coordinates referenced to the WGS-84 ellipsoid, where velocities are referenced clockwise with respect to true North.
7. CHANNEL STATUS WORD  
These words have the following structure:

**Channel Status Word**

DATA ITEM	DATA BIT	DEFINITION
Weak Signal	0	1 = Weak
High $\Delta\theta$	1	1 = High
Parity Error(s)	2	1 = Errors
Pre-Position Data (not used)	3	1 = Data propositioned
Propagated Track	4	1 = Propagated
Bit Sync Flag	5	1 = Data bit sync not achieved
Frame Sync Flag	6	1 = Frame sync not achieved
Z Count Flag	7	1 = Z Count not recovered

**8. CHANNEL 1, 2, ..., 12 MEASUREMENT STATE INFO** These words are structured as follows:

**Channel Measurement State Word**

DATA ITEM	DATA BIT	DEFINITION
Channel Used	0	1 = Used
Ephemeris Available	1	1 = Available
Measurement Validity	2	1 = Valid
Reserved	3	
SVID	4-9	Satellite PRN, Range 0 to 32
C/No	10-15	Integer value of signal-to-noise ratio, range = 0 to 60 dBHz

- 9. CHANNEL 1, 2, ..., 12 PSEUDORANGE** - The apparent range from the receiver antenna to a GPS satellite, calculated from the signal transmission time, the time of signal reception, and the speed of light.
- 10. CHANNEL 1,2, ..., 12 DELTARANGE** – The time rate of change of pseudorange.
- 11. ECEF POSITION X/Y/Z** - WGS-84 ECEF coordinates. ECEF coordinates are rectangular, Cartesian and are fixed to the earth, hence a rotating coordinate system.

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## NMEA Protocol - XDR Heading Reference

The NMEA protocol is an industry standard messaging scheme designed to allow simple terminal observation of the input/output data for basic avionics system. The serial protocol is ASCII, which enables any terminal emulation software to visibly display the ASCII data. Each message is made up of several components, which are discussed below. The main advantage of this interface, is that if the magnetometer device the user is using supports this NMEA “XDR” message output, then the user can either simply transfer the data bits directly down to the MMQ-G without any further manipulation, or the magnetometer may be directly wired to the MMQ-G’s receive RS-232 channel (Please see Chapter 5- Hardware Integration). It should be noted that the MMQ-G would have to be configured to initialize in an automatic manner if this approach is desired, since the magnetometer would directly be sending data down to the MMQ-G, and the user host computer would no longer be able to.

NMEA Message “XDR” then is a host vehicle input message to the MMQ-G. It provides heading reference information via magnetometer vector data for the MMQ-G. The heading reference is therefore an extra navigation aid.

### *NMEA Protocol Checksum Field*

This absolute value is calculated by exclusive OR operation on the 8 data bits (ASCII code) (no start or stop bits) of each character in the message, between, but excluding “\$” and “\*” characters. The hexadecimal value of the most significant and the least significant 4 bits of the result is converted to two ASCII characters (0-9, A-F) for transmission of the data packet. The most significant character is transmitted first. These characters fill the “hh” positions in each message described below.

The format defined below is an industry standard NMEA protocol message format. If the magnetometer device supports data output in the NMEA standard, then the following message will be correctly interpreted by the MMQ-G.

### *Format of NMEA XDR Output Message*

XDR Transducer Measurements:

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

The “Data” field of an included measurement will be null if its contents cannot be determined due to saturated measurements. Only units of degrees are allowed by NMEA for pitch and roll measurements. Magnetic measurements are transmitted in engineering units (nanoTesla). MAGX aligns with the compass board north-south axis, and MAGZ is perpendicular to the plane of the compass board. MAGT is the total magnetic field strength. It is determined by calculating the square root of the sum of the squares of MAGX, MAGY, and MAGZ.

Example:

\$HCXDR,A,-  
0.8,D,PITCH,A,0.8,D,ROLL,G,122,,MAGX,G,2045,,MAG  
Y,G,-4950,,MAGZ,G,5357.2,,MAGT\*11

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# Chapter 8- End Product Applications

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## Overview

MMQ-G 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-G unit. A *GPS antenna* is a necessity if integrated INS/GPS performance is desired.

The system will operate in *INS only* navigation if a GPS antenna is not present. However, it will not meet specified MMQ-G performance, and the system navigation solution will drift over time.

All users will need to communicate with the system's asynchronous RS-232 *serial interface*. This interface provides navigation solution data to the user, and accepts initialization and control data from the user.

Use of other MMQ-G interfaces and features beyond those just mentioned requires consideration of specific application needs. The sections that follow provide examples of specific application needs and how they should be addressed by the system integrator.

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## Specific Application Examples

If an application has a limited capability to supply MMQ-G with initialization data, providing *battery power* to the unit may solve this potential problem. Providing external battery input to the MMQ-G will allow it to store the last known position and time data.

Presence of this data will improve GPS TTFF. In applications using dynamic alignment, this may reduce the time required to complete alignment and transition to integrated INS/GPS navigation.

If an application needs to time-synchronize MMQ-G data with other external systems, use of the *Timemark* (RS-232) output is required. This discrete output will provide a pulse that corresponds to valid GPS time in output block 3.

If the application control loops can accept 100-Hz data (inertial data), the user may be able to utilize block 3502 on the system serial port. Considerations when using 3502 data at 100 Hz include:

- The system serial port bandwidth, (a function of the baud rate).
- The number of output data blocks connected and/or requested.

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## Product Application Examples

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

### **Use: Navigation 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-G 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-G features and software data sets within the specific product or application.

# Appendix A- Frequently Asked Questions

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## **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 RS232 port. Why?**

Generally, if you are having trouble communicating with the unit and are sure that your RS232 communications parameters are set correctly, try viewing the data using an RS232 monitor program. This will verify the communications parameters, as well as the message data content, handshaking, and timing. Remember that the data on the RS232 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 RS232 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 RS232 port?**

The RS232 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 RS232 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 "81FF" is sent LSB first, so a program should check that an "FF" is received, then that an "81" 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.

**Messages are output with non-sequential timestamps, or seem to be output sporadically or stop being output altogether. What can I do?**

Check to see if the messages that are 'CONNECTED' fit the bandwidth RS232 bus at the baud rate you are using. The unit will behave unpredictably if the data bandwidth is exceeded.

**The unit stays in Initialization mode when I turn it on. Why?**

When the unit is turned on, it will remain in Initialization mode until it has received a valid initialization data message. If you have sent an initialization message and the unit remains in Initialization mode, the message you are sending the unit may have a data or format error.

**The unit exhibits poor performance upon sequencing to INS/GPS Navigation mode. Why?**

- The unit may not have been stationary during the Ground Alignment mode. The Ground Alignment mechanization assumes that the unit is stationary, and will behave unpredictably if this is not the case.
- You may be experiencing problems with GPS operation. See the next question regarding GPS operation.

**The unit will not sequence into INS/GPS Navigation mode.  
What should I do?**

- Check that the GPS satellite signal strengths (C/No) appear normal in the GPS data message. If all signal strengths indicate 0 or are low (< 30 dBHz), then the antenna may not be connected to the unit or the antenna connector, cable, or antenna itself may be broken. If an active antenna, it may not be powered properly. The antenna may be indoors or otherwise obscured (buildings, trees, people, improper orientation), or the cable run to the antenna may be too long.
- You may have sent erroneous initialization information to the unit. In this case, signal strengths for all channels probably indicate 0. Check that the initialization data you have sent is accurate. The GPS initialization process is very sensitive to errors in time initialization. Be sure that you are using UTC (GMT) and not local time. Position data must be in decimal degrees (not radians), in WGS-84 coordinates (not NAD-27), and should be within 100 km of your actual location. Remember that west longitudes (e.g. USA) and south latitudes must be entered as negative numbers.
- If the unit has not been run for several months, the GPS almanac data stored by the GPS processor may be too old to provide quick GPS satellite acquisition. In this case, power the unit up with the antenna connected and let the unit remain in Initialization mode for about 15 minutes after the GPS indicates that it is tracking satellites. This will allow time for the GPS almanac to be updated.

**The unit sequences to INS-Only Navigation mode, but after a little while the position data starts changing erratically. What's wrong?**

The unit is not receiving GPS data or there is a problem with the GPS initialization. The unit depends on receiving GPS data for proper operation. The mode sequencing time line provides adequate time for the GPS subsystem to acquire satellites and begin GPS navigation before Ground Alignment mode is complete.

The unit cannot function as an unaided inertial navigation system for long periods of time. The errors inherent in the inertial instruments will eventually grow unbounded without GPS data available to provide corrections.

### **What is saved by the Save Configuration command?**

The Save Configuration command in message 3504 is used to save a number of system parameters to FLASH so that the parameters will be initialized to the saved values at subsequent turn-ons. These parameters are:

- *Position (Latitude, longitude, altitude)*
- *IMU parameter estimates (gyro bias and scale factor; accelerometer bias and scale factor)*
- *Sensor-to-body coordinate transformation (see notes on message 3511)*
- *Lever-arm body-frame components*
- *Auto align/nav sequence specifiers*
- *Auto GPS init flag*
- *Baud rates (HV, GPS)*
- *Message 3501, 3502, and 3512 output rates*
- *Message 3512 output configuration*
- *Message connect/disconnect states*
- *GPS set type*
- *Passthrough translation setting*
- *Magnetometer Calibration Hard Iron Vector*
- *Magnetometer Calibration Soft Iron Vector*

All of these parameters are saved at once as a group, so it is not possible to save certain parameters while leaving other parameters at their previously saved or default values. In general, it is useful to save the configuration so that the MMQ-G comes up in the desired configuration at turn-on. Care should be taken, however, that the state of the system is known when the Save Configuration command is issued. In particular, the position can become corrupted if the MMQ-G is operated for a long period without GPS available, and the IMU parameter estimates can become corrupted if the unit is moved during Fine Alignment mode.

The configuration should not be saved in either of these situations. If it is desired to erase a saved configuration, the Save Configuration with the Erase option specified can be used.

Notes: The Save and Erase commands can only be issued when MMQ-G is in initialization mode. If the unit is not in initialization, send a mode command of initialization to command the unit to the initialization.

It is recommended to only use the save command for system configuration changes.

### **What is the difference between the Mode Command and the Auto Align/Nav sequence word in message 3510?**

The Mode Command word in Message 3510 is a command to the MMQ-G to sequence to the specified mode, if necessary through intervening modes, while the Auto Align/Nav sequence word defines the default sequencing through an alignment mode to a nav mode, but does not trigger this sequencing. The Mode Command tells the MMQ-G to sequence to the specified mode and no further, so, if the commanded mode is an alignment mode, the system will go to that mode and stay there, regardless of the alignment mode's exit criteria. A mode command of Automatic (0) tells the MMQ-G to go through the mode sequence defined by the Auto Align/Nav sequence word. Generally, for normal upmoding, it is best to send a 3510 message containing a mode command of Automatic and an Auto Align/Nav sequence word specifying the desired sequencing. Only in special situations would commanded upmoding to specific modes be appropriate.

One such situation would be a case where the MMQ-G was to remain stationary for a long period of time; in this case, it would make sense to command Fine Alignment mode to allow the unit to stay in Fine Alignment as long as it was stationary, and then command Automatic mode before start of motion to enable transition to a navigation mode.

Mode commands are also used to command mode transitions, either to command Test mode (*not implemented yet*) to perform Built In Test, or to return to Initialization mode. It is possible, for instance, after having been in navigation mode, to return to initialization mode, and upmode again through a different sequence.

An alignment/navigation sequencing specified in message 3510 becomes the default for subsequent re-upmodes if power to the unit is not turned off. This sequencing can be saved even across power cycles using the Save Configuration command.

## How do I initialize the unit?

Message 3510 offers a number of options for initializing the MMQ-G. The MMQ-G software allows two possible paths for sequencing from startup into navigation:

- *Initialization --> Fine Alignment --> Air Navigation*
- *Initialization --> Air Alignment --> Air Navigation*

In general, the Fine Alignment route is the appropriate option to use if MMQ-G can be kept stationary for three minutes or more after startup. The Air Alignment route is the appropriate option to use if MMQ-G will be moving from the time it is turned on.

One of the parameters which can be specified in the 3510 message is the Auto GPS Initialization flag. This indicator tells MMQ-G whether it should get its position and velocity initialization data from the user, or from the GPS receiver when it acquires satellites and begins tracking. In general, the set of data which must be provided by the user to fully initialize MMQ-G will depend on whether this flag is set or not.

Position and velocity data may be provided in the 3510 message even if the Auto GPS Initialization flag is set, but they will not be used to initialize MMQ-G; they instead will be used to initialize the GPS receiver if it is not already tracking satellites.

The behavior of the initialization sequence is somewhat different for the case in which Auto GPS Initialization is specified and the case in which it is not. If Auto GPS Initialization is not specified, the transition to alignment mode will take place immediately upon acceptance of the 3510 message regardless of whether the GPS is tracking satellites.

If Auto GPS Initialization is specified, the MMQ-G will continue to report Initialization mode until the GPS receiver acquires and tracks four satellites, at which time the unit will transition to alignment mode.

**1. Fine Alignment Initialization** - Fine alignment performs an initial estimation of the IMU parameters, primarily gyro bias and the vertical component of accelerometer bias, using the known fact that the IMU is stationary. In order for this estimation to be valid, the MMQ-G must have a reasonably

good idea of its position and heading, so these quantities must be provided to it before entry to Fine Alignment.

The initial position should be valid to within about 100 miles, and the initial heading should be good to within about 10 degrees. In general, though, the more accurate these values are, the better the IMU calibration will be. Vehicle heading cannot be estimated during Fine Alignment since it is not observable in a stationary situation, so the heading during Fine Alignment will stay at very nearly the initial value provided by the user. Heading can only be estimated via GPS measurements during subsequent motion.

The paragraphs below summarize the data which must be provided for initialization of Fine Alignment both without and with auto-initialization from GPS.

- Without auto-initialization from GPS - In order to initialize Fine Alignment without auto-initialization from GPS, position, time, and heading must be supplied in the 3510 message. Velocity will be ignored even if it is given a non-zero value.
- With auto-initialization from GPS - In order to initialize Fine Alignment with auto-initialization from GPS, only heading must be supplied in the 3510 message. It is helpful to supply position and time also, especially if the GPS receiver has not yet begun tracking satellites. Position will be reinitialized from GPS. Again, velocity will be ignored even if it is given a non-zero value.

**2. Air Alignment Initialization-** Air alignment performs an initial estimate of heading using GPS measurements, and then exits automatically to a navigation mode. Since, as mentioned before, heading is not observable in a stationary situation, movement, in particular acceleration, of the MMQ-G is necessary to get out of Air Alignment mode. Either linear acceleration in a straight line or a turn from one course to another is required for exit. Air Alignment generally does not estimate IMU parameters nearly as well as does Fine Alignment; it is left up to subsequent motion during nav mode to do this.

- Without auto-initialization from GPS - In order to initialize Air Alignment without auto-initialization from GPS, position, velocity, time, and heading must be supplied in the 3510 message. In general, this mode of initialization is not recommended since it may give unreliable results depending on the relative timing of the 3510 message and GPS satellite acquisition.
- With auto-initialization from GPS - The parameters which must be supplied in order to initialize Air Alignment with auto-initialization from GPS depend on how fast the MMQ-G host vehicle is traveling. If the vehicle speed is less than 5 meters/sec, then at least the heading must be supplied in the 3510 message. If the speed is greater than 5 meters/sec, then no parameters are required for initialization.

If heading is not specified, it is computed from the course over ground of the vehicle as seen by GPS, and position and velocity are also initialized from GPS values. As before, it is helpful to supply position, velocity, and time in the initialization message if the GPS receiver has not yet begun tracking satellites. Use of auto-initialization from GPS is the recommended method of initialization for Air Alignment mode.

# Appendix B- Getting Started

## Setup

The following information will guide the system integrator in effectively integrating the MMQ-G system with the HV. For commonly asked questions regarding system integration, refer to Appendix A- Frequently Asked Questions. For questions concerning your specific application, refer to the *Product Support* section. Otherwise, contact an SDI applications engineer.

## Support Equipment Required

### **Power Supply**

MMQ-G requires a power input of +/-12V (nominal, 11v-13V limit) as measured at the input. The typical steady-state current drawn by MMQ-G 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.

The optional battery input to MMQ-G accepts a voltage in the range of +2.5 Vdc to +3.5 Vdc referenced to digital ground to maintain position, time, and ephemeris data when primary power is removed. The typical steady-state current drawn from the battery is 1 micro-amp. In remote applications where using an unlimited power source is not convenient, a lithium battery is recommended to provide long life and voltage stability. If an unlimited power source is needed or desired, care should be taken to ensure that the supply voltage is free of unwanted noise or transients in excess of the input requirements.

### **Antenna**

MMQ-G requires L1 GPS SPS signals (1575.42 MHz), either from a passive or externally powered active antenna. The signal level input shall be between -163 to -130 dBW for normal operation. Signal-to-noise (C/No density measured by MMQ-G) should range approximately between 35 to 45 dBHz on all channels. Additional information on the type of

antenna to use, and whether a preamplifier is needed is given in Chapter 5- Hardware Integration.

### **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.

The straight RF input (J2) mating connector is a standard male SMA type of the MIL-C-39012 series. A 50-ohm coaxial cable and antenna is required for the RF input.

### **Communication Via RS-232 Asynchronous Host Vehicle Port**

As part of getting started, a Windows compatible computer equipped with a RS232 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 MMQ-G, as well as display or record its navigation 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**

MMQ-G provides a Time Mark pulse at one pulse-per-second (PPS) for synchronization of external equipment. The leading edge of the pulse represents the instant in time when the navigation solution is valid. The navigation solution and status at this instant of time is reported in Time Mark output message 3. See Chapter 7- Software Integration for discussion of time validity at the various solutions. PC-based integration software, MIGICOM is available with MMQ-G. This software will aid the user in the configuration, initialization, and communication through the host vehicle port. The software serves only as a guide in helping the user get started using MMQ-G and to observe the contents of each data message. However, it is the responsibility of the user to develop software to meet his specific application.

### **Installation**

It is recommended that MMQ-G 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 3.3.

MMQ-G can be initialized in any orientation. In order for its attitude outputs (pitch, roll, heading) to be meaningful in the coordinate reference frame of the host vehicle, the sensor-to-host vehicle transformation may need to be reset, using data message 3511. See Chapter 7- Software Integration for more details.

## Using MMQ-G

This section is intended as an operational overview of MMQ-G. Examples are provided using the MIGICOM software, running on a standard IBM compatible computer. The following section will provide information necessary to help the user set up their system to make use of the various interfaces and features of MMQ-G.

### ***MMQ-G Operational Overview***

Once power is applied, MMQ-G will go through power-on initialization, and will sequence up to Initialization mode. This entire process takes approximately 7 seconds to complete.

Also at this time, the GPS receiver subsystem will begin searching for a satellite, based on GPS almanac data stored in the receiver's non-volatile memory, together with time and position data from the optional battery backed RAM. The GPS receiver will sequence up into navigation mode once it can track enough satellites. This can take from 10 seconds to 15 minutes, depending on the condition of the receiver's stored data and RF signal quality. MMQ-G will remain in initialization mode until it receives an initialization (message 3510) from the host vehicle.

As a minimum, MMQ-G requires time, position, and heading information for initialization. The GPS receiver acquisition time is directly related to the accuracy of data that is provided to MMQ-G, which uses the data to initialize the GPS receiver. Proper, repeatable operation of the MMQ-G depends on reasonable input data.

MMQ-G is most sensitive to time initialization data (which should be within 10 minutes), followed by heading initialization data (which should be within 10 degrees).

MMQ-G is less sensitive to position data, which should be within 100 kilometers of actual location. Once initialized, the MMQ-G will sequence to one of two possible alignment modes: *Fine Alignment*, *Air Alignment*.

Specification of the alignment mode is done via input message 3510 as described above.

The purpose of each alignment mode is to use a known velocity reference to perform initial estimation of vehicle

attitude and of IMU error parameters (biases and scale factor errors of the gyros and accelerometers).

*Fine Alignment* - The default alignment mode if no mode-up sequence is specified, assumes MMQ-G is stationary for the purpose of estimating IMU parameters. It is thus important that the unit be kept stationary during this mode, which has a duration of three minutes. Movement during this time will result in mis-estimation of IMU parameters and erratic subsequent behavior.

*Air Alignment* - This mode uses GPS measurements as the velocity reference for its estimation process, and it performs estimation of the GPS antenna lever arm (i.e. the distance between the GPS antenna and MMQ-G) as well as of the other parameters.

It is advantageous to move MMQ-G during this mode. In fact, the exit criteria from Air Alignment mode is that the heading and the lever arms have been estimated to a particular level of precision. This generally makes it necessary to move through a trajectory with several changes of direction before this mode can be exited.

After completing the alignment mode, sequencing continues to the navigation mode: *Air Navigation*. Again, choice of sequencing is made via input message 3510. The navigation modes continue estimating attitude and IMU parameters that begun in alignment, but also estimate position and velocity errors using GPS data as a reference.

If available, measurements can be processed from a heading reference, such as a compass, or an altitude reference such as a barometric altimeter. The errors of these reference instruments may be estimated. In the navigation modes, if the GPS receiver is navigating (GPS Measurements Available bit = 1 in message 3500), the navigation solution will represent a combined INS/GPS navigation solution. Once the *INS/GPS* mode is reached, the MMQ-G can be moved, tested or flown. If GPS measurements are not available, the navigation solution represents an "INS-only" navigation solution.

The use of INS data allows MMQ-G to navigate through temporary GPS outages due to the effects of antenna obscuration, jamming, or loss of GPS. The MMQ-G is not intended to be operated as an INS-only system over extended periods of time (several minutes). As with any unaided inertial system, if MMQ-G is left in an INS-only state indefinitely, navigation errors will grow unbounded. The actual performance of MMQ-G during INS-only operation depends on the state of the internal navigation filter when the INS-only state is entered.

Assuming that MMQ-G is operating properly and in a static position, the user should observe the measurement variances (message 3500) and the system velocities (message 3501) decrease during alignment. During this time, the GPS receiver should also acquire satellites and begin navigating. This can be verified by observing the signal strengths and tracking state information provided in the GPS data block (message 3).

Signal strengths (C/No density ratio) should range from the mid 30's to mid 40's dBHz on all channels. If the antenna signals are satisfactory and the initialization data provided was accurate, the GPS receiver should reach navigation mode within 2 minutes more than 95% of the time.

C/No values that are less than 30 dBHz indicate a problem with signal strength or noise, and will prevent the GPS receiver from acquiring satellites. Types of problems that could cause this result are the wrong type of antenna, excessive cable length, obscuration of antenna, or poor cable connection. If the signal strength measurements are too high (C/No > 46 dBHz), then the signal should be attenuated. Excessive signal strengths can confuse the GPS receiver and will result in very erratic operation.

Once MMQ-G is navigating, the system heading will be observed to drift when the unit remains stationary for a period of time. This happens when the navigation filter cannot accurately estimate heading without changes in motion. The inherent accuracy of the inertial instruments do not allow for unaided heading determination.

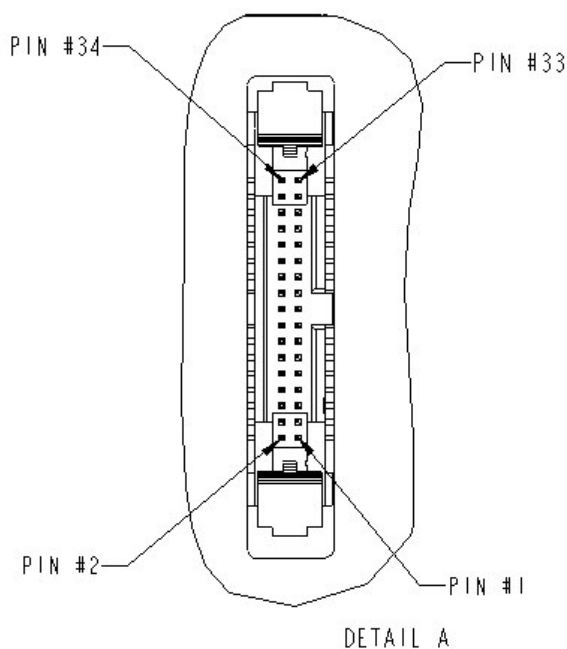
## Before You Begin

### Warning

**Improper wiring of the user cable connecting to MMQ-G 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.

**Before** applying power, verify that it is being supplied to the correct pins; see table below and Detail “A” (outside view of MMQ-G 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-G receive line and your system's receive line should go to the MMQ-G 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 an AT compatible computer with COM port. MMQ-G requires only use of the **Transmit** and **Receive** data signals (**TD**, **RD**) and **Signal Ground**.

<b>Table A-1. RS-232 Pin Assignments</b>			
<b>Description</b>	<b>Computer Pin # (25-Pin)</b>	<b>Computer Pin # (9-Pin)</b>	<b>Abbreviation</b>
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. Verify the antenna power (if required) is correct.

12. Insert the available MIGICOM CD in the CD drive, and install MIGICOM on your computer. The MIGICOM software will provide the ability to interface between MMQ-G and a Windows-based PC simulating the user's host vehicle communication device. Refer to the MIGICOM User's Guide for the details of the installation.

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

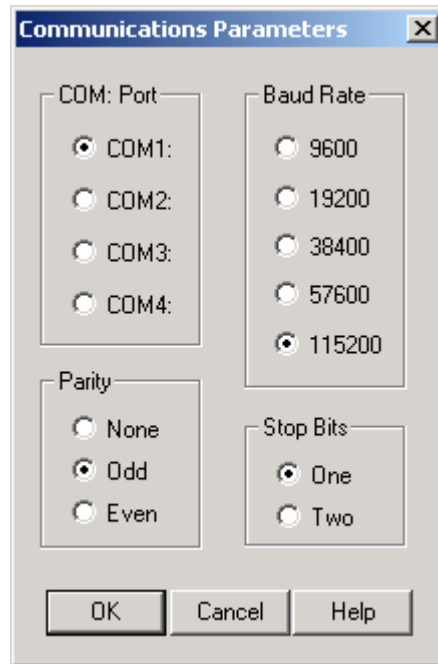
### **Configuring Host Vehicle Communication Port**

The default I/O configuration of MMQ-G as delivered has input and output baud rates set to 115200 bits per second with an odd parity, 8 data bits, one start bit, and one stop bit. These parameters may be changed via message 3504 described in Chapter 7- Software Integration.

Verify that your PC's COM port capability is compatible with the MMQ-G I/O baud rate settings.

Using MIGICOM, set the baud rate to the MMQ-G baud rate. On setup pull down menu, select communication parameters. When the communication parameters dialog box appears (as shown below), choose the COM port your

computer uses, and set the baud rate as, 115200, odd parity, 1 stop bit, and then click OK. MIGICOM is now ready to communicate with MMQ-G.



### Powering Up The System

1. Before connecting the cabling and test equipment to MMQ-G, apply power to the test setup and verify that the correct voltages are seen at the 34-pin I/O connector. (+12V on pin 22, -12V on pin 12, +3V (keep-alive battery power, optional) on pin 32, antenna DC power on pin 31- all referenced to GND, pin 29
2. If the above is not the case, troubleshoot the cable and test equipment to resolve the problem before continuing.
3. With power off, connect the 34-pin I/O connector to MMQ-G and all required cabling to the test equipment. Apply power to the MMQ-G.
4. Verify that the correct amount of current is being drawn according to the specifications given by the power supply requirements.

---

*Note: An excessive or inadequate power reading may be due to miswiring; the unit should be shut off immediately to avoid permanent damage.*

---

- Data should appear on the MIGICOM window as shown below. Message 3500 and 3501 are displayed at the right side of the window, message 3623 is displayed at the bottom of the window. Message 3500, 3501 and 3623 should continuously update the display.

**Mode Initialization**

GPS Time 403896.7504 GPS Delta

Latitude 37:57:50.30 0.802

Longitude -122:01:47.10 -10.748

Altitude 1.000 3.080

Vel North -0.308 -0.149

Vel East -0.493 -0.205

Vel Up 0.344 0.204

Pitch -3.634

Roll -0.487

Heading -84.475 FOM 9

GPS Avail Y GPS Late N

GPS Time OK Y TB Repart N

DGPS Status N TM Timeout N

Const Chg N BIT Failure N

Dynamics Lo Large Az N

Satellites Tracked 0

Position Measurements 0

Velocity Measurements 0

Zoom In Zoom Out Track On Browse Map Redraw

Command:

Response:

GPS Set	Jupiter		GPS Mode		Navigation								
SUs Used	11	DGPS Used	N		4	5	6	7	8	9	10	11	12
Channel	1	2	3		4	5	6	7	8	9	10	11	12
SU	6	10	5		21	2	7	15	18	29	30	26	25
C/No	43	45	45		43	42	39	32	41	37	45	0	39
Valid	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	N	Y
Used	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	N	Y

- If no data appears and only parameter labels are shown, then the serial port may need to be reconfigured.

### Data Display

By default, MMQ-G will display data messages 3500, 3501 and 3623. See Chapter 7- Software Integration for description of the contents of these messages. The following function keys are available and will display each of the above messages:



Message ID 3500 - MMQ-G System Status  
Displayed are the current mode (initialization, fine align, etc.), GPS and INS availability and the current number of satellites tracked. The current mode will

be initialization until the unit is properly initialized as demonstrated later in this section.

**F2** Message ID 3501 - MMQ-G Navigation Solution  
Current position, velocity, and attitude are displayed.

**F4** Message ID 3623 - Jupiter Timemark message  
Navigation information is provided, including position, time, the satellites tracked and the carrier-to-noise ratios.

---

*Note: Message 3623 reports the navigation solution of the GPS processor alone, while message 3501 reports the combined INS/GPS solution.*

---

While viewing any of the data messages, typing map in the command prompt will exit the display.

In addition to the function keys, data messages can be displayed by using the **display** command. To display message 3500, at the command prompt, type the following:

**display 3500** <return>

Message ID 3500 will be displayed as seen earlier. The **display** command may be abbreviated as **db**.

To exit the MIGICOM program, close the MIGICOM command and control window.

### **System Initialization**

The system initialization is accomplished by transmitting message 3510, MMQ-G Control and Initialization. A detailed description of message 3510 can be found in Chapter 7- Software Integration. Using MIGICOM to initialize MMQ-G as follows:

1. On the MIGICOM command and control window, click on the control pull down menu, select initialization, a MIGITS initialization data dialog box will appear.
2. On the MIGITS initialization data dialog box, fill in the correct position, time and heading data of the MMQ-G and select the mode sequence your application needs, then click on the send initialization tab. The 3510 message is sent to the MMQ-G.

A typical 3510 message is as follows

Upon sending 3510 message to the MMQ-G. On the response prompt, an acknowledgement message will be displayed, e.g. 3510 command accepted. The unit will move to Fine Alignment once GPS measurement is available, i.e., when GPS avail field in 3500 turn N to Y. Refer to Chapter 2 of the MIGICOM User's Guide for more details on the initialization.

A restricted version of the 3510 message, containing just a mode command, may be sent by using control pull down menu with mode command option. The mode-name may be any of: Initialization, Fine Alignment, Air Alignment, and Air Navigation. This will cause MMQ-G to sequence to the commanded mode, if necessary through intervening modes. One use of this command is to send the MMQ-G back to initialization mode after it is in an alignment or navigation mode. Another use is to force MMQ-G to remain in a particular mode. For instance, if the system is commanded

to Fine Alignment mode from Initialization, it will remain in Fine Alignment until commanded out, possibly beyond the default three minutes.

### **Message Connection and Disconnection**

Host vehicle messages may be connected and disconnected by typing the **connect** and **disconnect** in the command prompt as shown below:

**connect 3502 3512** <return>

**disconnect 3623** <return>

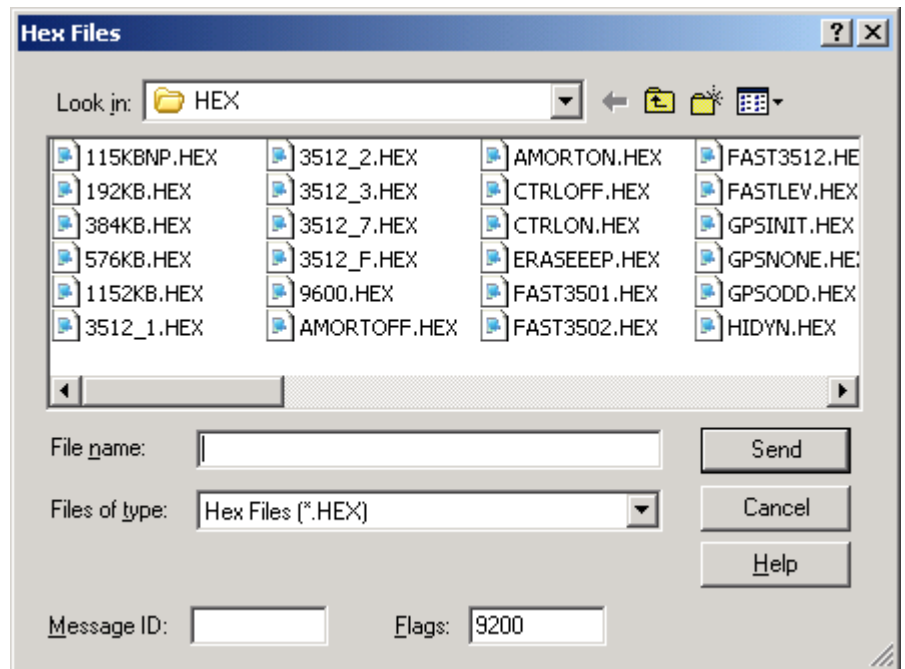
The first command connects messages 3502 and 3512, and the second command disconnects message **3623**.

Connecting an already connected message, or disconnecting an already disconnected message, has no effect. Up to seven message numbers may be specified with either command.

The **connect** command may be abbreviated as **c**, and the **disconnect** command may be abbreviated as **d**. refer to Chapter 2 of the MIGICOM User's Guide for more details.

### **Sending Other Commands**

Other commands to the system, for example, message 3504 and 3511 may be issued using control pull down menu with option of send Hex file. A Hex files dialog box as below will appear, select the Hex file and then click send



By convention, the files which are used have a filename extension of ".hex". They reside in the directory c:\cm2\hex. The hex files are ASCII files containing the successive

words of the data portion of the message as four-nibble hexadecimal numbers. The functions of the various hex files which are distributed with the MIGICOM software are summarized below.

1. Baud Rate – (*default is 115200 baud*). The following hex files may be sent to set the MMQ-G HV interface to the indicated baud rates:

Hex File	Baud Rate
1152kb.hex	115200 baud
576kb.hex	57600 baud
384kb.hex	38400 baud
192kb.hex	19200 baud
9600.hex	9600 baud

After transmission of any of these commands, the baud rate at which MIGICOM is operating needs to be changed in order to communicate at the new baud rate. This may be done by setting up communication parameters via MIGICOM setup pull down menu.

2. Message Rates –Host vehicle output messages 3501, 3502, and 3512 have selectable output rates which may be set using the following hex files:

Hex File	Action
slow3501.hex	Block 3501 @ 1 Hz
med3501.hex	Block 3501 @ 10 Hz
slow3502.hex	Block 3502 @ 1 Hz
med3502.hex	Block 3502 @ 10 Hz (default)
fast3502.hex	Block 3502 @ 100 Hz
slow3512.hex	Block 3512 @ 1 Hz
med3512.hex)	Block 3512 @ 10 Hz (default)
fast3512.hex	Block 3512 @ 100 Hz

Care should be taken, especially when using the 100Hz transmissions that the requested message rates do not exceed the communication channel bandwidth at the current baud rate.

3. Flight Control Message Configuration - The data contained in the flight control message 3512 may be configured using the following hex files with a message-number of 3504:

Hex File	Message 3512 Data
----------	-------------------

3512_1.hex	Delta-attitude
3512_2.hex	Delta-velocity
3512_3.hex	Delta-attitude and Delta-velocity
3512_7.hex	Delta-attitude, Delta-velocity, and Attitude
3512_f.hex	Delta-attitude, Delta-velocity, Attitude, and Velocity

The other ten possible configurations of the 3512 message may be selected by appropriate modifications to the hex files.

4. Save Configuration Command –The Save Configuration command is used to save a number of system parameters to FLASH so that the parameters will be initialized to the saved values at subsequent turn-ons. The parameters saved are summarized in Appendix A-Frequently Asked Questions. The current set of parameters may be saved by sending saveeep.hex The parameters may be erased by sending eraseeep.hex

MMQ-G can only accept these commands when the unit is in Initialization mode.

5. Message Passthrough Translation - The state of the program flag which determines whether GPS passthrough messages are translated to MMQ-G format may be set by sending passtran.hex to turn passthrough translation on, and sending notran.hex to turn it off.

6. Body Frame Orientation - The sensor-to-body coordinate transformation may be changed by message 3511, to whatever orientation is desired. One transformation is to turn the default transformation "upside down" to accommodate the situation where MMQ-G is oriented with the sensor Z axis pointing up (i.e. the plug is facing down). In this orientation, the default coordinate transformation yields a roll value of about 180 degrees. A reorientation of the body axes to yield a roll value of approximately 0 may be accomplished by sending upside.hex.

13. Lever Arm Specification - The body-frame components of the lever arm from MMQ-G to the GPS antenna may also be set using message 3511. Knowledge of the lever arm is important in accounting for the offset and the motion of the antenna relative to the MMQ-G. The MMQ-G mechanization assumes that the GPS antenna is rigidly attached to MMQ-G and rotates with it. If this is not the case (e.g. if a rooftop antenna is being used), it is best to leave the lever arm components at their default value of zero. A sample lever arm specification file [specifying body-frame

components of  $(X,Y,Z) = (100, 49, -84)$ ] is included in the hex directory. It would be invoked by sending `levarm.hex`.

**14.** INS-Only Operation - The MMQ-G can be commanded into an "INS-Only" mode in which GPS measurements are not processed even though they may be available from the GPS receiver. This may be useful in assessing the performance of the MMQ-G when the GPS signal is lost. This option is more convenient than the alternative of disconnecting the GPS antenna, since the GPS receiver continues to track satellites. This mode is entered by sending `inonly.hex` and exited by sending `ninonly.hex`.

**15.** If your application requires the longer Fine Alignment time, you can do so as follows. First send a 3510 message commanding the MMQ-G to the Fine Alignment mode, then send another 3510 message to the MMQ-G commanding the unit to Air Navigation mode when you are ready to launch. The following shows the two 3510 messages using MIGICOM.

Send a 3510 message commanding the unit into Fine Alignment as shown: (specify the true heading of the unit - the unit will move into Fine Alignment mode after GPS is locked and will stay in Fine Alignment)

Send a 3510 message when you want to move the unit to Air Navigation mode as shown below.

The unit will move to the Air Navigation mode once the 3510 message is received. Keep in mind that the minimum time of the Fine Alignment mode is 3 minutes. If the “Command to Air Navigation” message is sent to the unit within the 3 minutes of the Fine Alignment period, then the unit will move into the Air Navigation mode at the end of 3 minutes of Fine Alignment. If the “Command to Air Navigation” message is sent to the unit after 3 minutes of Fine Alignment, then the unit will move into the Air Navigation mode immediately. The system must then be launched within a minute.

**MIGITS Initialization Data** [X]

Mode	<input type="text" value="Air Navigation"/>	Valid	<input checked="" type="checkbox"/>
Position			<input type="checkbox"/>
Latitude	<input type="text" value="37:36:23.43"/> deg:min:sec		
Longitude	<input type="text" value="-122:22:51.23"/> deg:min:sec		
Altitude	<input type="text" value="6.5"/> meters		
Velocity			<input type="checkbox"/>
Ground Speed	<input type="text" value="0.0"/> meters/sec		
Ground Track	<input type="text" value="0.0"/> degrees		
Date/Time			<input type="checkbox"/>
<input checked="" type="radio"/> Use PC Time			
<input type="radio"/> Specify	Date <input type="text"/> Time <input type="text"/>		
Heading			<input type="checkbox"/>
	<input type="text" value="0.0"/> degrees		
Auto Align/Nav Sequence			<input type="checkbox"/>
Alignment Mode	<input type="text" value="Fine Alignment"/>	Navigation Mode	
		<input type="text" value="Air Navigation"/>	
<input type="checkbox"/> Auto GPS Initialization			<input type="checkbox"/>
<input type="button" value="Send Initialization Message"/>			
<input type="button" value="Cancel"/>		<input type="button" value="Help"/>	

# Glossary of Terms

## Abbreviations and Acronyms

The following is a list of abbreviations and acronyms used in this guide and their definitions.

$\Delta\theta$	<i>Attitude change</i>
$\Delta v$	<i>Velocity change</i>
2-D	<i>Two Dimensional</i>
2-Drms	<i>Two-Dimensional root mean square</i>
3-D	<i>Three Dimensional</i>
3-Drms	<i>Three-Dimensional root mean square</i>
AAMP	<i>Advanced Architecture Microprocessor</i>
AMRAAM	<i>Advanced Medium Range Air-to-Air Missile</i>
A/D	<i>Analog-to-Digital</i>
AFSC	<i>Air Force System Command</i>
AP	<i>Application Processor</i>
AS	<i>Anti-Spoofing</i>
ASIC	<i>Application Specific Integrated Circuit</i>
AWGN	<i>Additive White Gaussian Noise</i>
B	<i>Boolean</i>
BIT	<i>Built-In-Test</i>
bps	<i>Bits Per Second</i>
cg	<i>Center of Gravity</i>
C	<i>Celsius</i>

C/A  
*Coarse/Acquisition*

MMQ-G  
*C/A-code Miniature Integrated GPS/INS Tactical System  
(Digital Quartz Inertial Measurement Unit coupled with a 12-  
channel C/A code GPS receiver)*

C/No  
*Carrier-to-Noise density ratio*

COMSEC  
*Communications Security*

cw  
*Continuous Wave*

dBm  
*Decibels Milliwatt (measure of power relative to one  
milliwatt)*

dBW  
*Decibel-Watt (measure of power relative to one watt)*

DC  
*Direct Current*

deg  
*Degrees*

DETF  
*Double Ended Tuning Fork*

DI  
*Double precision Integer*

DIG  
*Digital*

DoD  
*Department of Defense*

DOP  
*Dilution of Precision*

DQI  
*Digital Quartz Inertial Measurement Unit Systron Donner  
Inertial trade name)*

DSP  
*Digital Signal Processor*

DTR  
*Data Terminal Ready*

EEPROM  
*Electrically Erasable Programmable Read Only Memory*

AFP  
*Extended Floating Point*

EMC  
*Electromagnetic Compatibility*

EMI  
*Electromagnetic Interference*

EPRM  
*Erasable Programmable Read Only Memory*

EU  
*Electronics Unit*

FFC  
*Flex Cable*

FLASH  
*Electrically Programmable and Erasable Memory*

FP  
*Floating Point*

g  
*Gravity*

GaAs  
*Gallium Arsenide*

GDOP  
*Geometric Dilution of Precision*

GHz  
*Gigahertz ( $10^9$ )*

GMT  
*Greenwich Mean Time*

GN&C  
*Guidance, Navigation and Control*

GND  
*Ground*

GPS  
*Global Positioning System*

GPSRE  
*GPS Receiver Engine*

Grms  
*G's root mean squared*

HDK  
*Hardware Developer's Kit*

HDOP  
*Horizontal Dilution of Precision*

HVIO  
*Host Vehicle Input/Output*

Hz  
*Hertz*

ICD  
*Interface Control Document*

I  
*Integer*

I/O  
*Input/Output*

IF  
*Intermediate Frequency*

IMU  
*Inertial Measurement Unit*

INIT  
*Initialization (mode)*

INS  
*Inertial Navigation System*

IODE  
*Issue of Data Ephemeris*

ISA  
*Inertial Sensor Assembly*

*kbaud*  
*Kilobaud (10<sup>3</sup>)*

*kHz*  
*KiloHertz (10<sup>3</sup>)*

*km*  
*Kilometer*

*kohms*  
*Kilohms*

*LD/LR*  
*Line Driver/Line Receiver*

*LPTS*  
*Low Power Time Source*

*LRU*  
*Lowest Replaceable Unit, Line Replaceable Unit*

*LSB*  
*Least Significant Bit*

*mA*  
*Milliamp (10<sup>-3</sup>)*

*MFI*  
*Multi-Function Interface*

*MHz*  
*Megahertz*

*MR*  
*Master Reset*

*mrad*  
*Milliradian (10<sup>-3</sup>)*

*MSB*  
*Most Significant Bit*

*ms*  
*Millisecond (10<sup>-3</sup>)*

*m/sec*  
*Meters per Second (units of velocity)*

*m/sec/sec*  
*Meters per Second per Second (units of acceleration)*

*m/sec/sec/sec*  
*Meters per Second per Second per Second (units of impulse or "jerk")*

*MSL*  
*Mean Sea Level*

*MTBF*  
*Mean Time Between Failure*

*MTTR*  
*Mean Time to Repair*

*MUX*  
*Multiplex (bus)*

*mV*  
*Millivolt*

*mW*  
*Milliwatt*

<i>nS</i>	<i>Nanoseconds</i>
<i>NAV</i>	<i>Navigation</i>
<i>NAVSTAR</i>	<i>Navigation Satellite Timing and Ranging</i>
<i>NF</i>	<i>Noise Factor</i>
<i>NMEA</i>	<i>National Marine Electronics Association</i>
<i>NSA</i>	<i>National Security Agency</i>
<i>nsec</i>	<i>Nanosecond (10<sup>-9</sup>)</i>
<i>OEM</i>	<i>Original Equipment Manufacturer</i>
<i>ρ</i>	<i>Pseudo-range</i>
<i>P/N</i>	<i>Part Number</i>
<i>PDOP</i>	<i>Position Dilution of Precision</i>
<i>PSD</i>	<i>Power Spectral Density</i>
<i>P-P</i>	<i>Peak-to-Peak</i>
<i>ppm</i>	<i>Parts Per Million</i>
<i>PPS</i>	<i>Precise Positioning Service; also, Pulse-Per-Second</i>
<i>PPS-SM</i>	<i>Precise Position Service Security Module</i>
<i>PRN</i>	<i>Pseudorandom Number</i>
<i>PSF</i>	<i>Post Select Filter</i>
<i>psia</i>	<i>Pounds Per Square Inch Absolute</i>
<i>PVT</i>	<i>Position, Velocity, and Time</i>
<i>PWB</i>	<i>Printed Wiring Board</i>
<i>QFS</i>	<i>Quartz Flexure Suspension</i>
<i>QRS</i>	<i>Quartz Rate Sensor</i>
<i>RAM</i>	<i>Random Access Memory</i>
<i>RF</i>	<i>Radio Frequency</i>

RFI  
*Radio Frequency Interference*

rms  
*Root Mean Squared*

ROM  
*Read Only Memory*

RSS  
*Root Sum of Squares*

RTCA  
*Radio Technical Commission for Aeronautics*

RTCM  
*Radio Technical Commission for Maritime Services*

rt-hr  
*Root-Hour*

RT  
*Remote Terminal*

RTC  
*Real-Time Clock*

RTN  
*Return*

RTV  
*Room Temperature Vulcanizing*

SA  
*Selective Availability*

SA/AS  
*Selective Availability, Anti-Spoofing*

sec  
*Seconds*

SEP  
*Spherical Error Probable*

SNR  
*Signal-To-Noise ratio (expressed in decibels).*

SPS  
*Standard Positioning Service*

SRAM  
*Static Random Access Memory*

SRU  
*Shop Replaceable Unit*

SV  
*Space Vehicle*

TDOP  
*Time Dilution of Precision*

TSP  
*Twisted Shielded Pair*

TTFP  
*Time to First Fix*

TTL  
*Transistor -Transistor Logic*

TWINAX  
*Two conductor coaxial cable*

<i>TwPr</i>	<i>Twisted Pair</i>
<i>UART</i>	<i>Universal Asynchronous Receiver /Transmitter</i>
<i>μsec</i>	<i>Microsecond (10<sup>-6</sup>)</i>
<i>UBER</i>	<i>Undetected Bit Error Rate</i>
<i>UDRE</i>	<i>User Differential Range Error</i>
<i>URA</i>	<i>User Range Accuracy</i>
<i>UTC</i>	<i>Universal Coordinated Time</i>
<i>VCO</i>	<i>Voltage Controlled Oscillator</i>
<i>Vdc</i>	<i>Volts Direct Current</i>
<i>VDOP</i>	<i>Vertical Dilution of Precision</i>
<i>VQA</i>	<i>Vibrating Quartz Accelerometer</i>
<i>VSWR</i>	<i>Voltage Standing Wave Ratio</i>
<i>ZIF</i>	<i>Zero Insertion Force</i>

## Terms

The following is a list of selected terms used in this document, together with their associated meaning.

### *Algorithm*

*A set of rules for finding a solution to a problem in a finite number of steps.*

### *Almanac*

*A set of orbital parameters that allows calculation of approximate GPS satellite positions and velocities. The almanac is used by a GPS receiver to determine satellite visibility and as an aid during acquisition of GPS satellite signals. The almanac is a subset of satellite ephemeris data and is updated weekly by GPS Control.*

### *Analog Sinusoidal*

*A curve having ordinates proportional to the sine (or cosine) of an angle that is a linear function of time, distance, or both.*

### *Application Processor*

*The processor connected to the Host Vehicle receiver port which controls MMQ-G with command messages and uses data from output messages.*

### *Attenuation*

*The decrease in amplitude of a signal during its transmission from one point to another. It may be expressed as a ratio, or, by extension of the term, in decibels.*

### *Attitude*

*A ship, aircraft, or other vehicle's state in terms of pitch, roll and heading.*

### *Baud*

*bits per second (also referred to as baud rate)*

### *Block I Satellite*

*Satellites designed and built to support GPS development and testing. A total of 10 Block I satellites were successfully launched between February 1978 and October 1989.*

### *Block II Satellite*

*Satellites designed and built to support GPS Space Segment operation. A total of 28 Block II satellites have been built and launched.*

### *Block IIR Satellite*

*Satellites being designed to eventually replace Block II satellites. The first Block IIR satellite was launched in 1997.*

### *Coarse/Acquisition Code*

*A spread spectrum direct sequence code that is used primarily by commercial GPS receivers to determine the range to the transmitting GPS satellite.*

*Circular Error Probable*

*The radius of a circle, centered at the user's true location, that contains 50 percent of the individual position measurements made using a particular navigation system.*

*Clock Error*

*The uncompensated difference between synchronous GPS system time and time best known within the GPS receiver.*

*Cold Start*

*A condition in which the GPS receiver can arrive at a navigation solution without initial position, time, current ephemeris, and almanac data.*

*Control Segment*

*The Master Control Station and the globally dispersed Monitor Stations used to manage the GPS satellites, determine their precise orbital parameters, and synchronize their clocks.*

*Coriolis Force*

*An apparent force that as a result of the earth's rotation deflects moving objects (such as missiles) to the right in the northern hemisphere and to the left in the southern hemisphere.*

*Decibel-Isometric-Circular*

*Measure of power relative to an isometric antenna with circular polarization.*

*Dielectric*

*The insulating (non-conducting) medium between the two plates of a capacitor. Typical dielectrics include air, plastic, mica, and ceramic. A vacuum is the only perfect dielectric.*

*Doppler Aiding*

*A signal processing strategy, which uses a measured Doppler shift to help a receiver smoothly track the GPS signal to allow a more precise velocity and position measurement.*

*Doppler Effect*

*The observed change of frequency of a wave caused by a time rate of change of the effective distance traveled by the wave between the source and the point of observation.*

*Doppler Shift*

*The change observed in the frequency of a wave due to the Doppler effect.*

## *Drift Angle*

*The angle measured in the horizontal plane between the horizontal velocity projection and the horizontal projection of the vehicle's longitudinal axis. In an example of an aircraft, the drift angle is generated from cross-winds, causing the aircraft to point into the direction of the relative wind, rather than along the ground-referenced velocity direction.*

## *Earth-Centered Earth-Fixed*

*A Cartesian coordinate system with its origin located at the center of the Earth. The coordinate system used by MMQ-G to describe three-dimensional location. For the WGS-84 reference ellipsoid, ECEF coordinates have the Z-axis aligned with the Earth's spin axis, the X-axis through the intersection of the Prime Meridian and the Equator and the Y-axis is rotated 90 degrees East of the X-axis about the Z-axis.*

## *Ephemeris*

*A set of satellite orbital parameters that is used by a GPS receiver to calculate precise GPS satellite positions and velocities. The ephemeris is used to determine the navigation solution and is updated frequently to maintain the accuracy of GPS receivers.*

## *Federal Radio Navigation Plan*

*The U.S. Government document which contains the official policy on the commercial use of GPS.*

## *Gauss*

*A unit of measure of magnetic flux density or magnetic field strength.*

## *Geometric Dilution of Precision*

*A factor used to describe the effect of the satellite geometry on the position and time accuracy of the MMQ-G solution. The lower the value of the GDOP parameter, the less the error in the position solution. Related indicators include PDOP, HDOP, TDOP, and VDOP.*

## *Global Positioning System*

*A space-based radio positioning system which provides suitably equipped users with accurate position, velocity, and time data. When fully operational, GPS will provide this data free of direct user charge worldwide, continuously, and under all weather conditions. The GPS constellation will consist of 24 orbiting satellites, four equally spaced around each of six different orbital planes.*

## *GPS Time*

*The number of seconds since Saturday/Sunday Midnight UTC, with time zero being this midnight. Used with GPS Week to determine a specific point in GPS time.*

## *GPS Week*

*The number of weeks since January 6, 1980, with week zero being the week of January 6, 1980. Used with GPS Time to determine a specific point in GPS time.*

## *Gradient*

*Change in the value of a quantity (for example, Gravity) with respect to the change in a given variable (for example, Position).*

*Horizontal Dilution of Precision*

*A measure of how much the geometry of the satellites affects the position estimate (computed from the satellite range measurements) in the horizontal (East, North) plane.*

*Interface*

*The physical terminating points of a data link.*

*Kalman Filter*

*Sequential estimation filter which combines measurements of satellite range and range rate to determine the position, velocity, and time at the GPS receiver antenna.*

*L1 Band*

*The 1575.42 MHz GPS carrier frequency which contains the C/A code, P-code, and navigation messages used by commercial GPS receivers.*

*L2 Band*

*A secondary GPS carrier, containing only P-code, used primarily to calculate signal delays caused by the atmosphere. The L2 frequency is 1227.60 MHz.*

*Mask Angle*

*The minimum GPS satellite elevation angle permitted by a particular GPS receiver design.*

*Measurement Error Variance*

*The square of the standard deviation of a measurement quantity. The standard deviation is representative of the error typically expected in a measured value of that quantity.*

*Multipath Errors*

*GPS positioning errors caused by the interaction of the GPS satellite signal and its reflections.*

*Obscuration*

*Term used to describe periods of time when a GPS receiver's line-of-sight to GPS satellites is blocked by natural or man-made objects.*

*Overdetermined Solution*

*The solution of a system of equations containing more equations than unknowns. The GPS receiver computes, when possible, an overdetermined solution using the measurements from five GPS satellites, instead of the four necessary for a three-dimensional position solution.*

*Piezoelectric*

*A property of crystals which produce a voltage when subject to a mechanical stress, or undergo mechanical stress when subjected to a voltage*

*Port*

*Access point for data input or output*

*Precision Code*

*A spread spectrum direct sequence code that is used primarily by military GPS receivers to determine the range to the transmitting GPS satellite.*

*Parallel Receiver*

*A receiver that monitors four or more satellites simultaneously.*

*Position Dilution of Precision*

*A measure of how much the error in the position estimate produced from satellite range measurements is amplified by a poor arrangement of the satellites with respect to the receiver antenna.*

*Pi (or  $\pi$ )*

*The mathematical constant having a value of approximately 3.14159.*

*Precise Positioning Service*

*The GPS positioning, velocity, and time service which will be available on a continuous, worldwide basis to users authorized by the DoD.*

*Pseudorandom Number*

*The identity of the GPS satellites as determined by a GPS receiver. Since all GPS satellites must transmit on the same frequency, they are distinguished by their pseudorandom noise codes.*

*Q Factor*

*A measure of sharpness of resonance or frequency selectivity of a mechanical or electrical system.*

*Radome*

*Also called a radar dome. The housing that protects a radar antenna from the elements, but does not block radio frequencies.*

*Real Time*

*Refers to Greenwich Mean Time.*

*Selective Availability*

*The method used by the DoD to control access to the full accuracy achievable with the C/A code.*

*Satellite Elevation*

*The angle of the satellite above the horizon.*

*Sequential Receiver*

*A GPS receiver in which the number of satellite signals to be tracked exceeds the number of available hardware channels. Sequential receivers periodically reassign hardware channels to particular satellite signals in a predetermined sequence.*

*Spherical Error Probable*

*The radius of a sphere, centered at the user's true location, that contains 50 percent of the individual three-dimensional position measurements made using a particular navigation system.*

*Standard Positioning Service*

*A positioning service available to all GPS users on a continuous, worldwide basis with no direct charge. SPS uses the C/A code to provide a minimum dynamic and static positioning capability.*

### *Standby SRAM*

*Portion of the SRAM that is powered by a "keep-alive" power supply when prime power is removed to preserve important data and allow faster entry into the Navigation Mode when prime power is restored. All of the SRAM in the receiver is "keep-alive" SRAM.*

### *Strapdown Inertial Navigation System*

*A system in which the accelerometers are directly connected to the vehicle's frame (in the example of an aircraft, the airframe). The accelerometers measure the components of vehicle-specific force acceleration in the body (in this example, the airframe) axes.*

### *Time Dilution of Precision*

*A measure of how much the geometry of the satellites affects the time estimate computed from the satellite range measurements.*

### *Three-Dimensional Coverage (Hours)*

*The number of hours-per-day with four or more satellites visible. Four visible satellites are required to determine location and altitude.*

### *Three-Dimensional (3-D) Navigation*

*Navigation mode in which altitude and horizontal position are determined from satellite range measurements.*

### *Time Mark Message*

*Output message of the receiver that provides the current estimate of position, velocity, and time as well as other data related to the state of the receiver.*

### *Time Mark Pulse*

*A positive going pulse output by the receiver at the instant to which the next solution output will be referenced. The position, velocity, and time values in the next message were the estimated values at the rising edge of the pulse.*

### *Time-To-First-Fix.*

*The actual time required by a GPS receiver to achieve a position solution. This specification will vary with the operating state of the receiver, the length of time since the last position fix, the location of the last fix, and the specific receiver design.*

### *Update Rate*

*The GPS receiver specification which indicates the solution rate provided by the receiver when operating normally.*

### *Universal Coordinated Time*

*This time system uses the second defined true angular rotation of the Earth measured as if the Earth rotated about its Conventional Terrestrial Pole. However, UTC is adjusted only in increments of one second. The time zone of UTC is that of Greenwich Mean Time (GMT).*

## *Velocity*

*A vector quantity indicating both direction of motion and magnitude of speed.*

## *Vertical Dilution of Precision*

*A measure of how much the geometry of the satellites affects the position estimate (computed from the satellite range measurements) in the vertical (perpendicular to the plane of the user) direction.*

## *WGS-84*

*World Geodetic System (1984). A mathematical ellipsoid designed to fit the shape of the entire Earth. It is often used as a reference on a worldwide basis, while other ellipsoids are used locally to provide a better fit to the Earth in a local region. GPS uses the center of the WGS-84 ellipsoid as the center of the GPS ECEF reference frame.*

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