SX Series
Inertial Measurement Unit (IMU)
Technical User Guide

- LMRK01
- LMRK005
- LMRK007
- LMRK007X
- LMRK60
- LMRK60 LX
- LMRK60 VG
- MRM60
- LMRK65
- G300D

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3 SAFETY AND HANDLING INFORMATION

- Always use caution when using the Gladiator IMU!
- **Please refer to your specific product datasheet to determine which appropriate input voltage to use.**
- **IMUs are sensitive scientific instruments containing shock and vibration sensitive sensors. Excessive shock and/or vibration can damage these sensors and can adversely affect sensor performance and unit output.**
- Avoid exposure to electrostatic discharge (ESD). Observe proper grounding whenever handling the IMU.
- Properly attach the connector and ensure that it has been wired correctly before applying power to the IMU.
- Units are shipped from factory in the following default settings, unless otherwise required for customer application:
    - 2500 Hz IMU Mode
    - 921,000 Baud Rate
    - Max Bandwidth filter
    - 1 Stop Bit
    - 16-bit Output Resolution

4 GETTING STARTED

This section contains directions and references for a quick start to using the IMU. This guide is also suitable for the G300D (no accelerometer outputs) and its product variants.

For additional support, please contact the distributor representing your location. If there isn't a local representative for your location, please contact our Headquarters for assistance and someone from our Sales Team will assist you.

The IMU Software Development Kit (SDK) is an optional product to assist first time users of a Gladiator IMU. This kit provides the user everything they need to facilitate a rapid setup and test of the unit. The SDK includes display software with user-defined options including the following components and is seen in Figure 1:

- Turn-Key Solution for IMU on User PC (all cabling/connectors/software included)
- Easy Integration of Direct IMU RS-422/485 to PC USB Port (digital)
- Includes PC Display Software for IMU
- Data Recording Capability
- Multiple User-Selected Field Options for Programming and Initializing the Unit
- User Defined Bandwidth Settings and Data Output Rate on IMU
- Self-Test Button

Figure 1 Gladiator SDK with USB Converter box, SDK to PC USB cabling, and CD-ROM

If multiple units are purchased, the respective test data for each unit is placed on this CD for reference.

4.1 *USB Converter Box and Accessories*

Contained in the Software Development Kit is a complete RS-422/485 to USB Converter box, which includes a Self-Test button (Figure 1). The USB Converter box uses USB power to operate (+5 V standard). Some USB Converter boxes have red (power) and black (ground) to adequately supply units that require higher input voltage levels (> +5 V). Others may have yellow (sync in) and gray (signal ground) banana jacks for applying an external sync signal (Fig. 14).

An RS-422/485 to USB converter (requires additional drivers that are included in a CD-ROM) is also included.

This power supply converter cable and Self-Test button enables the user to quickly connect the IMU to their PC to ease integration and testing. Connect the cable to the unit and the power converter cable to the PC (via USB). The user should not turn on the power switch until all of the software is properly installed.

Figure 2 Typical IMU connectors include: 9 (L) or 15 (C) pin Glenair connector, or Omnetics connector (R)

4.2 *Glamr Installation*

4.2.1 *Introduction*

The LINX SDM-USB-QS-S module requires that device drivers be installed on the host PC before they can interact. The drivers tell the PC how to talk to the module. These drivers are for Windows 7, 8, and 10. The set for Windows are the direct drivers, which offer program functions that allow a custom application to directly control the module through the USB port.

Figure 3 SDK Installation CD-ROM

To install the Glamr SDK application, run the Glamr setup executable found on the CD-ROM sent with your IMU (Figure 4).

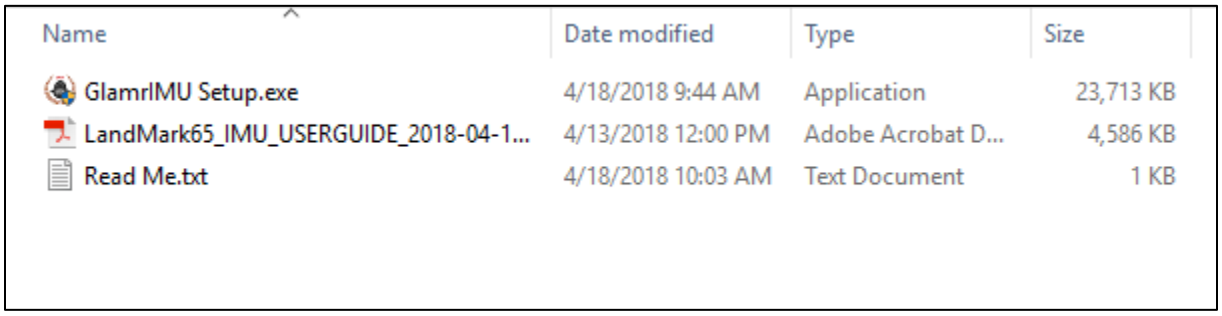


Figure 4 Glamr setup location on SDK CD-ROM

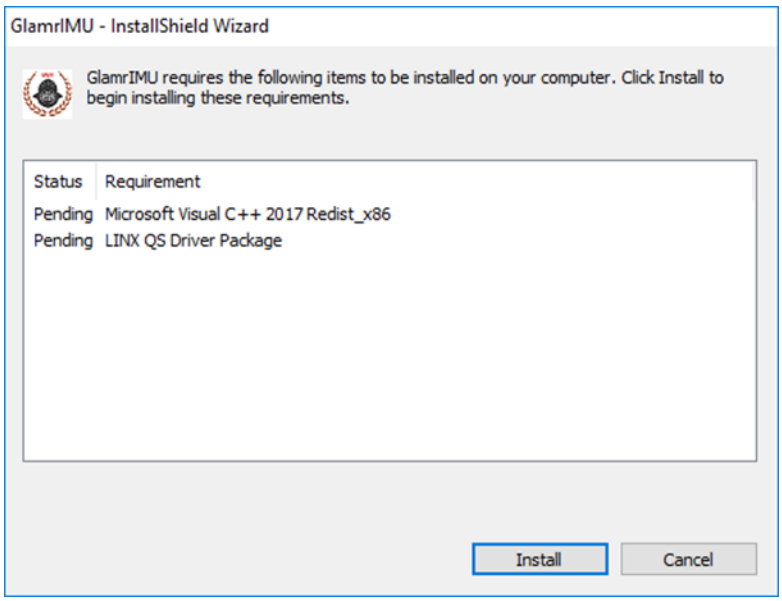


Figure 5 Glamr prerequisite installations

ATTENTION: Do **NOT** use the FTDI device driver that Windows 10 provides. It does not work with the LINX product even though they are using the FTDI parts. The PID was changed so it is unique.

Installing Glamr will place a shortcut to the application on the desktop and in the Start Menu.

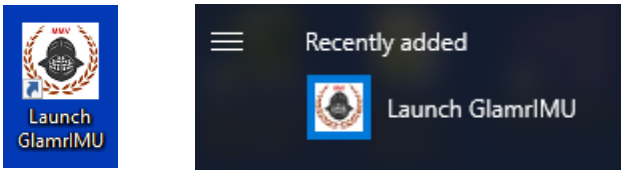


Figure 6 Glamr shortcut locations

The default Glamr installation directory is:

C:\Program Files (x86)\Gladiator Technologies

In addition to these shortcuts, the installation will also place a Glamr.ini file into:

C:\Users\"username"\AppData\Roaming\Gladiator Technologies

NOTE: Plug the connector cable into the USB port before you turn the device power on to avoid Windows loading as a mouse driver.

With Glamr successfully installed, open the program and a window will appear as in Figure 7.

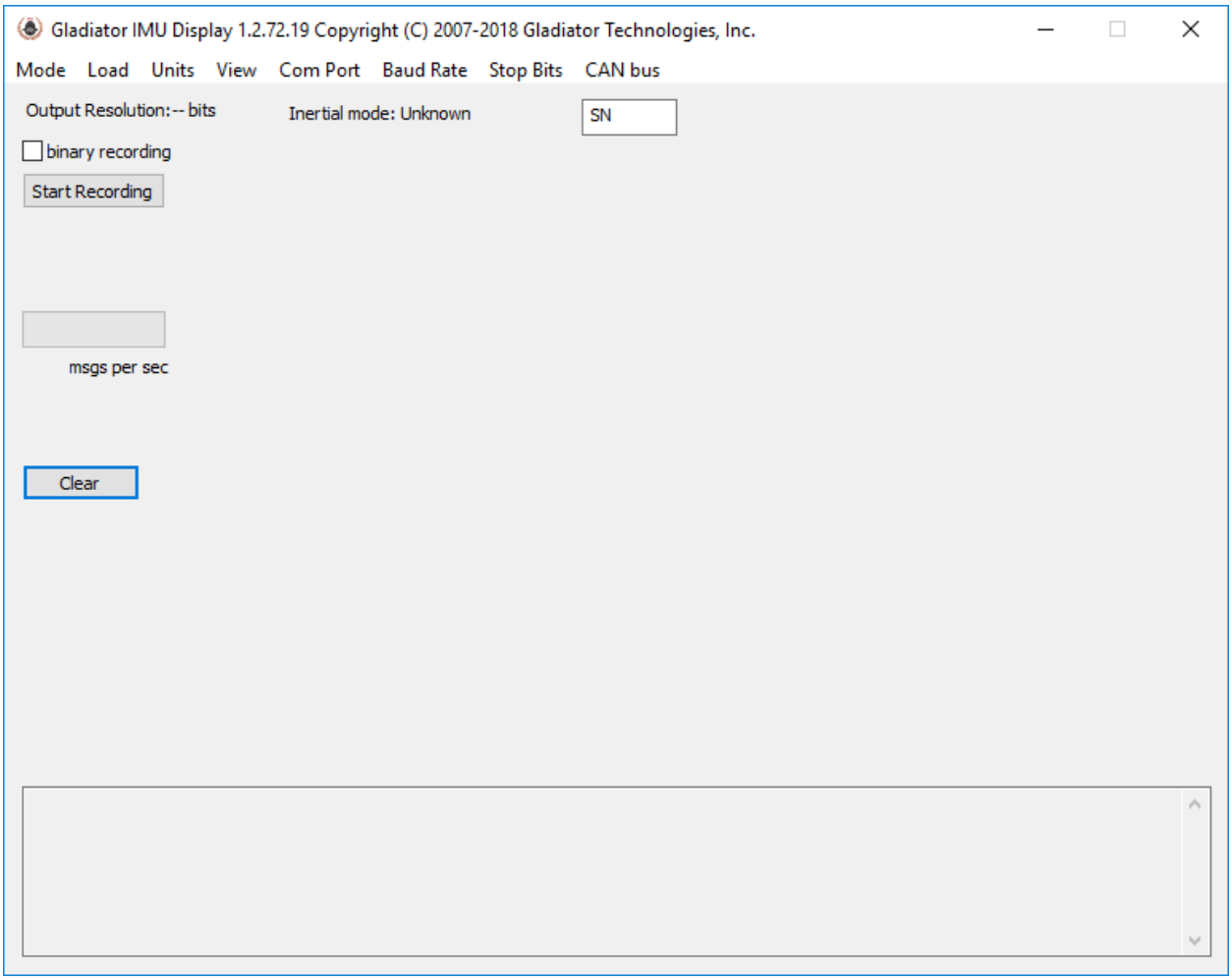


Figure 7 Glamr screen before selecting correct COM port settings.

The bottom of the Gladiator IMU Display may read “IMU serial port (LINX SDM-USB, 115200, 8E1) ERROR opening.” The installer defaults the baud rate to 921600 Mbps, so check the Baud Rate menu to ensure this is the case.

Only one copy of Glamr can be open at a given time. Always make sure there is not another copy open on the task bar. If there are multiple copies of Glamr open, a COM port error will appear when the user tries to interact with the unit.

Now reconnect the USB plug to the SDK. The “LINX” port should have a checkmark next to it. The bottom of the window should now read “IMU serial port (LINX SDM-USB, 115200, 8E1) success.” If Glamr is open and no unit is detected, Glamr will attempt to find it by cycling through different baud rates as shown in Figure 8.

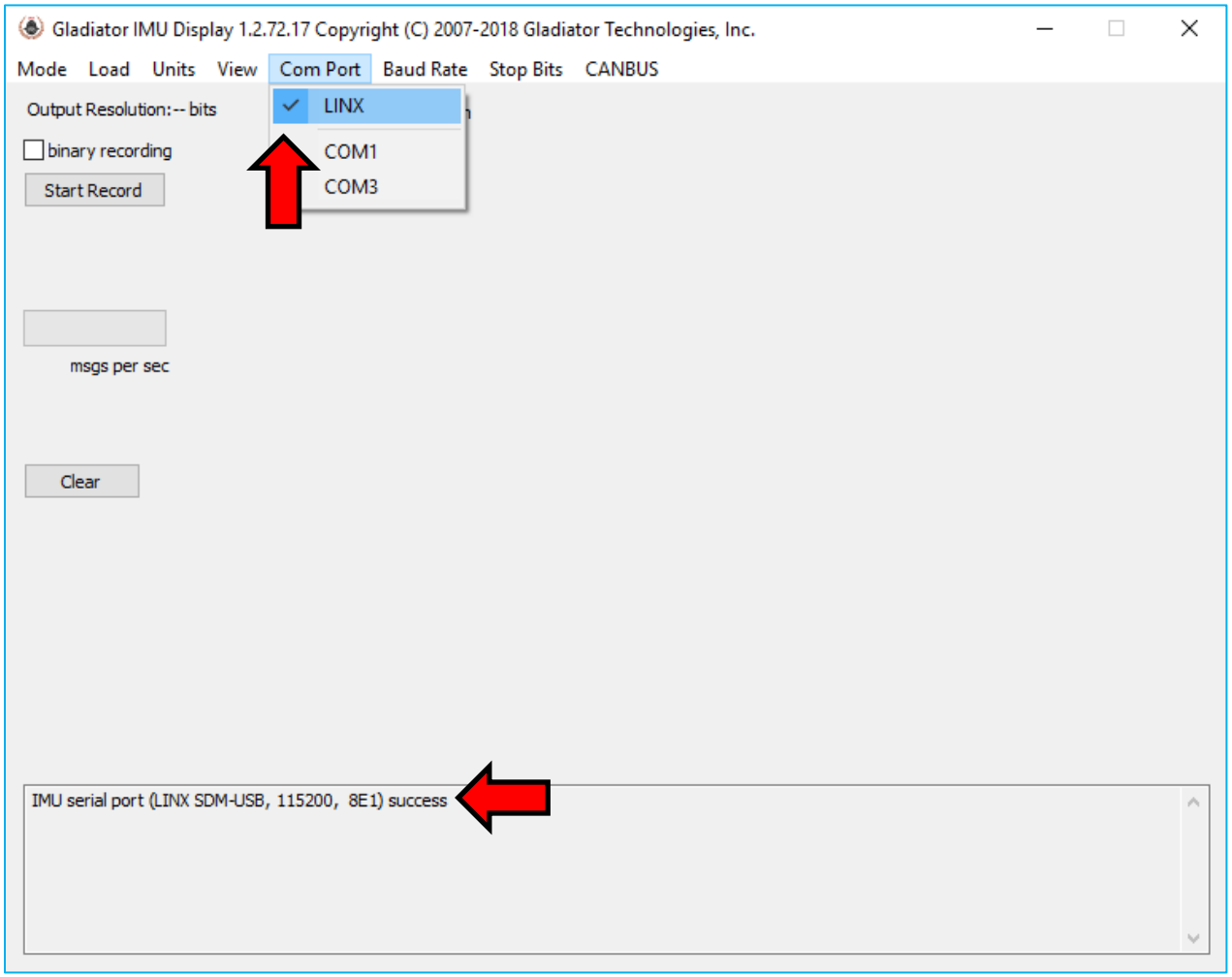


Figure 8 Confirmed correct LINX port with message "success."

Next, open the Windows Device Manager and expand the *Ports (COM & LPT)* section. Right-click on the device labeled “LINX SDM-USB-QS-S” and select “Properties.” Open the “Port Settings” tab and then click the “Advanced” button.

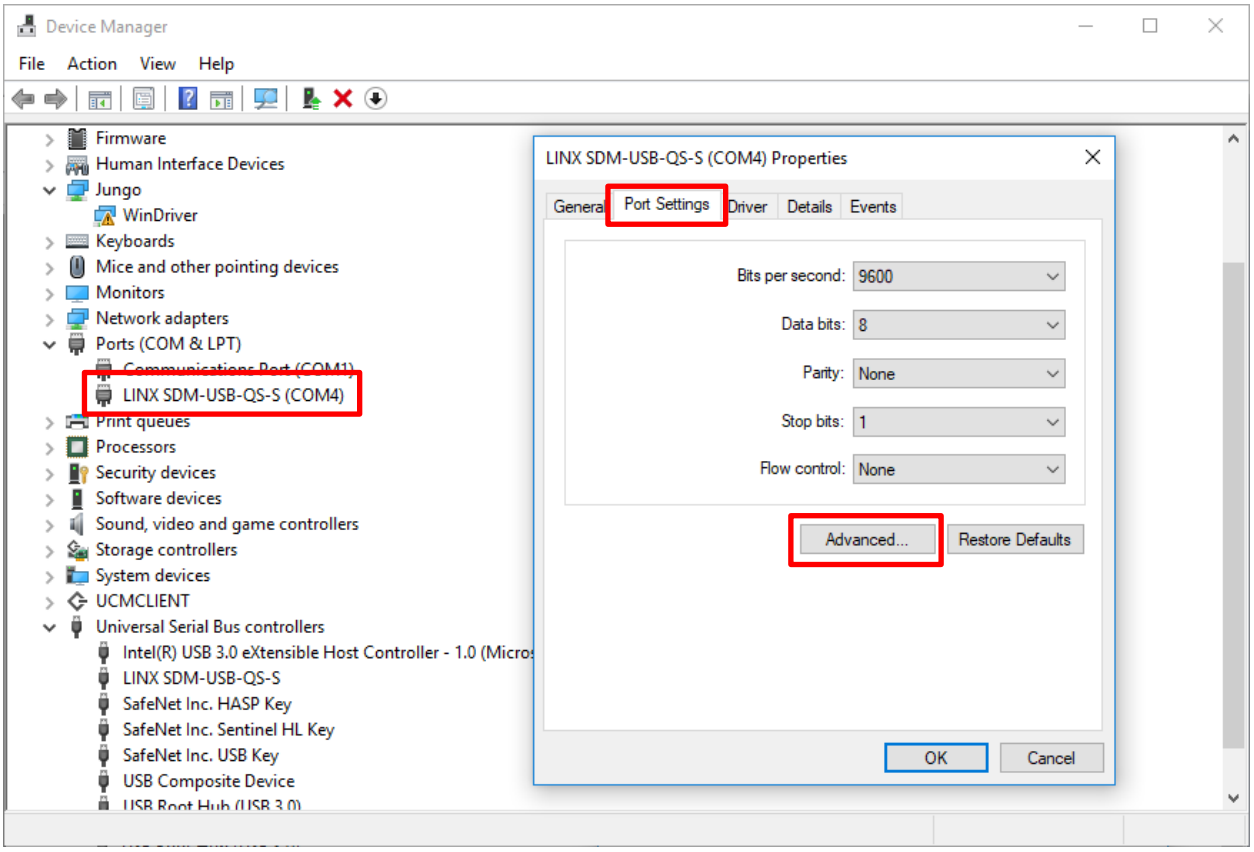


Figure 9 Device Manager LINX-SDM-USB-QS-S port Properties

Now change the Latency Timer drop-down setting to 1 msec (from the default 16 msec). Select OK and apply all changes. This setting is necessary for the Windows PC to receive IMU message data at higher message rates (>1 kHz) without errors.

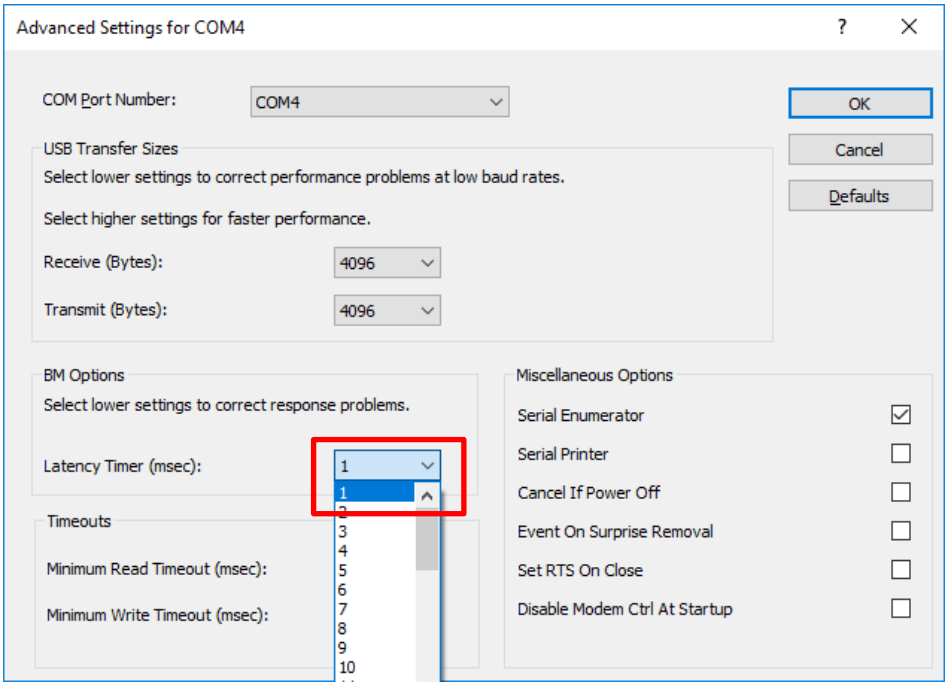


Figure 10 Advanced Settings for COM port Latency Timer

Turn on the power switch on the USB Converter box and you should see data appear in the window as shown in Figure 12 (colored boxes). You should be able to move the IMU with your hand and see changes in rate and acceleration for each axis located on-screen. To see rapid change, the record function will capture real time data without the filter effect of the Glamr display.

4.3 *Select Applicable Baud Rate*

The baud rate needs to be at least 20% higher than the message rate times the number of bits per message so that IMU may receive commands from the PC. Note that the serial port is half-duplex, so communication between device and host can only go one way. Here is a guideline of the relationship between baud rates and message rates:

		Serial Baud Rate →					
Message Data Rate ↓		115200	921600	1.5 M	3.0 M	6.0 M	Bits/second
	100	Yes	Yes	Yes	Yes	Yes	19800
	200	Yes	Yes	Yes	Yes	Yes	39600
	500	*	Yes	Yes	Yes	Yes	99000
	1000		Yes	Yes	Yes	Yes	198000
	2500		Yes	Yes	Yes	Yes	495000
	5000			Yes	Yes	Yes	990000
	6000			Yes	Yes	Yes	1188000

*Note that 500 Hz Data Mode at 115,200 baud is a special case. In this data mode and baud rate, the bits/second is below the 20% threshold requirement and therefore requires additional steps to change the IMU to other data modes. When changing to another appropriate data rate (i.e. 100 Hz, 200 Hz), Glamr will prompt the user to cycle power on the IMU as in Figure 11.

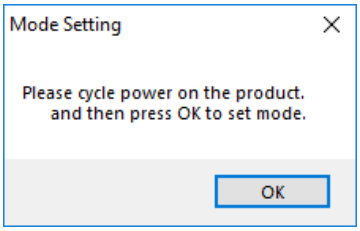


Figure 11 Cycle power warning

After power cycling the IMU, the unit will resume normal functionality.

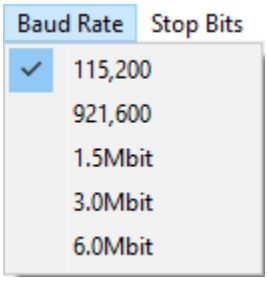


Figure 12 Baud Rate menu

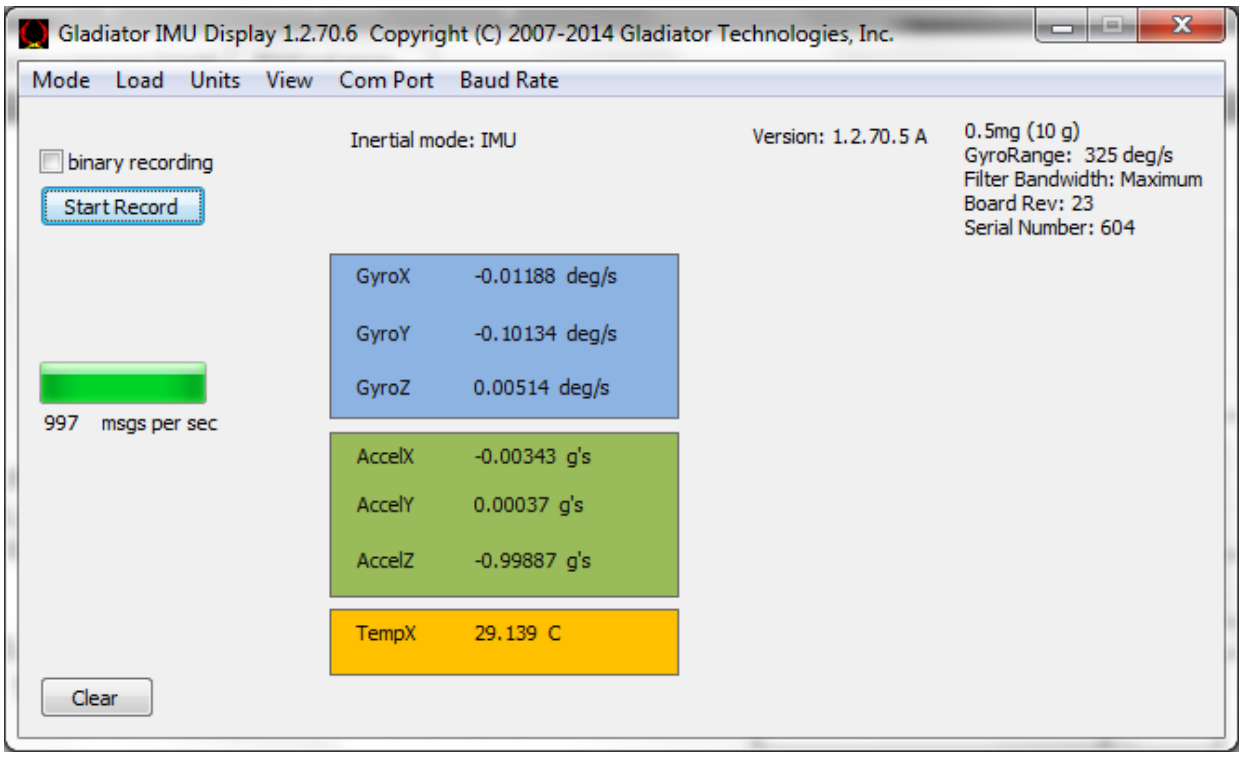


Figure 13 IMU rata in Full Mode at 1000 Hz data rate

The next message “Msg out-of-sequence: exp XX, act YY” indicates that the program saw a skip in the message count, where XX and YY can be any integer value. This case can happen at start-up and can be ignored.

4.4 *Self-Test in Glamr*

Glamr includes a self-test function. The user can initiate the Self-Test by the button (Fig. 14), found on the USB Converter box that is included in the IMU SDK.

Press the button to activate a self-test of the sensors. The Glamr display will now show “Self-Test” is activated while also showing the data outputs. This message is located just above the data rate status bar. User should see a delta change in the X, Y, and Z sensor outputs per the data sheet (Fig. 15) when Self-Test is initiated.

Refer to the IMU datasheet to see typical activated sensor values.

Figure 14 USB Converter Box Power, Self-Test Button, Ext Sync Jacks

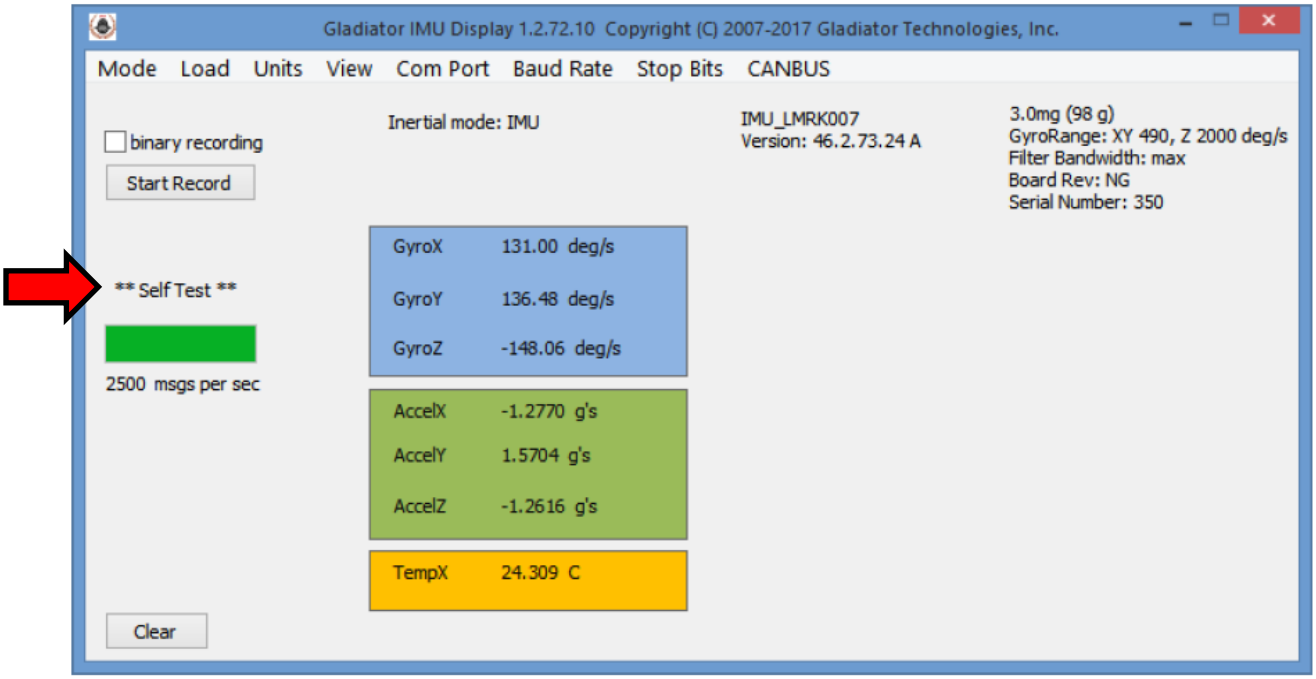


Figure 15 Self-Test display when activated

4.5 *Setting the Data Rate*

Glamr enables the user to quickly adjust the data rate. This feature is found in the Mode menu as shown in Figure 16. Raising or lowering the data rate determines how frequently data is sent from the unit to the host. Lower rates will benefit from additional sample averaging.

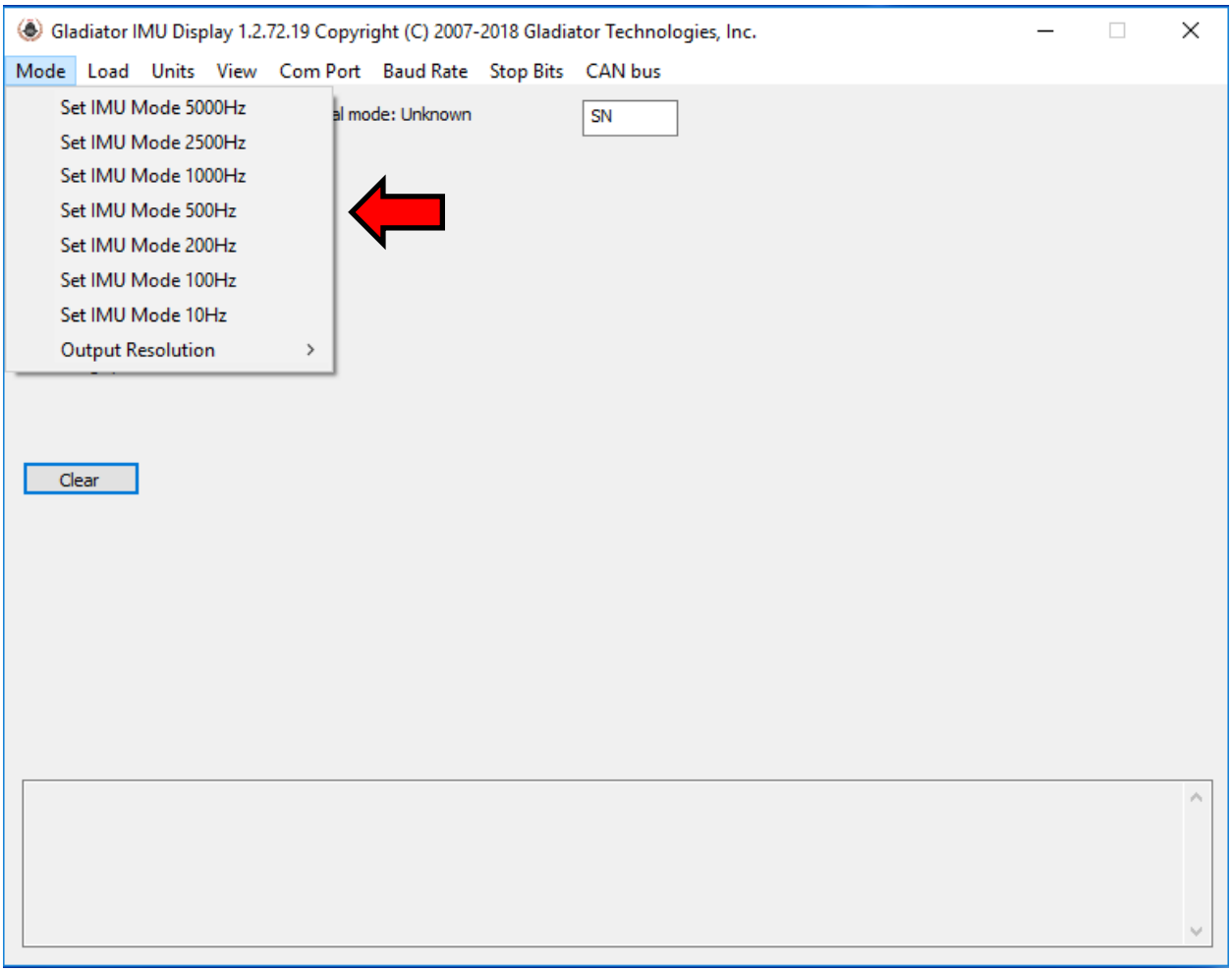


Figure 16 Mode selection/data rate

4.6 *Select Applicable Stop Bits*

When using the IMU, the number of stop bits is one or two as selected by the user. This can be chosen in the Stop Bits drop-down menu and selecting either 1 or 2 per Figure 17. The SX series default is a single Stop Bit, but older units may use a default of 2 stop bits. Refer to the data sheet for your unit for more information.

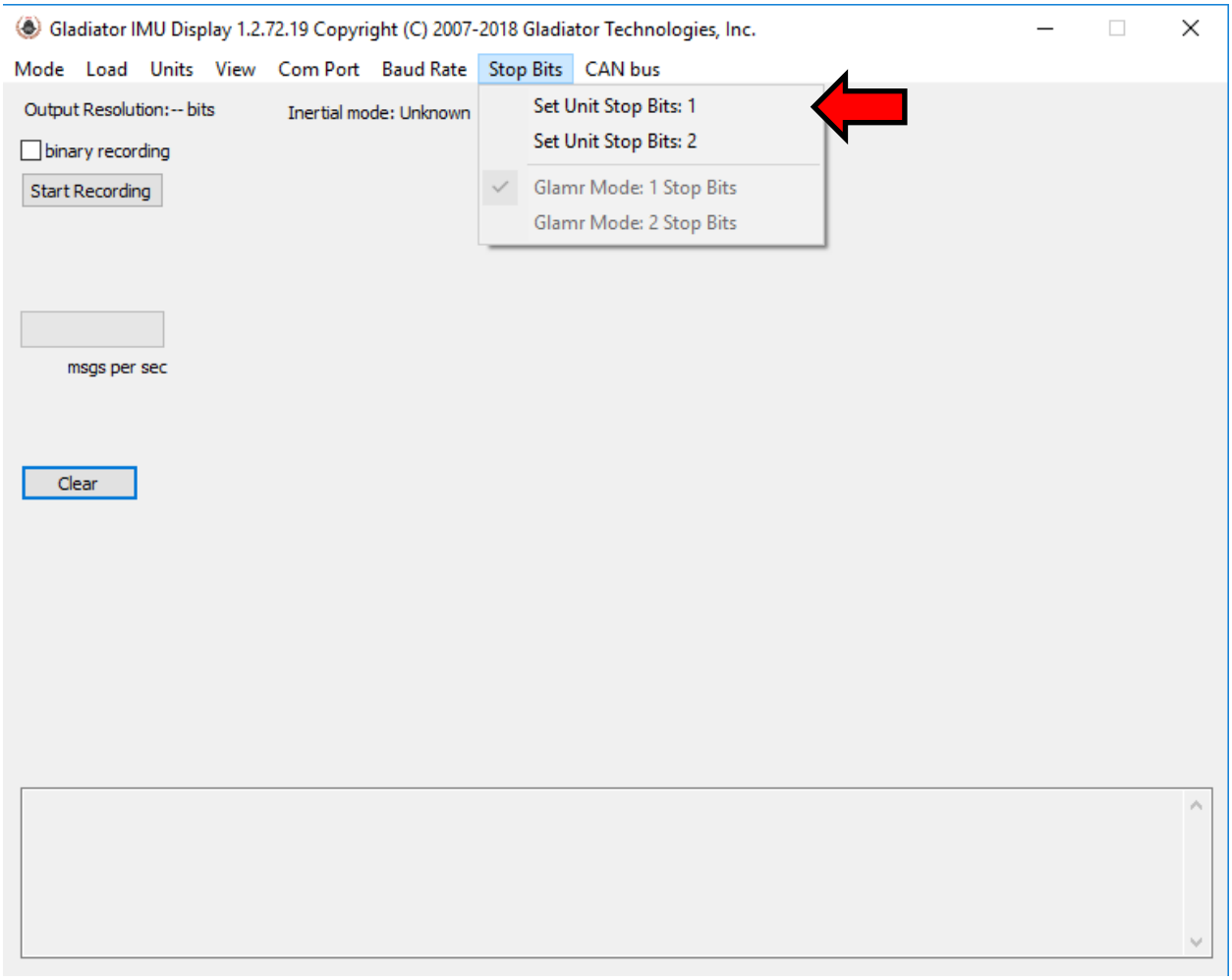


Figure 17 Stop Bit selection menu

4.7 *Sensor Display Options*

The SDK software also can set the dimensional units of the display. This is selected under Units, as seen in Figures 18-19.

4.7.1 *Gyroscope Unit Selection*

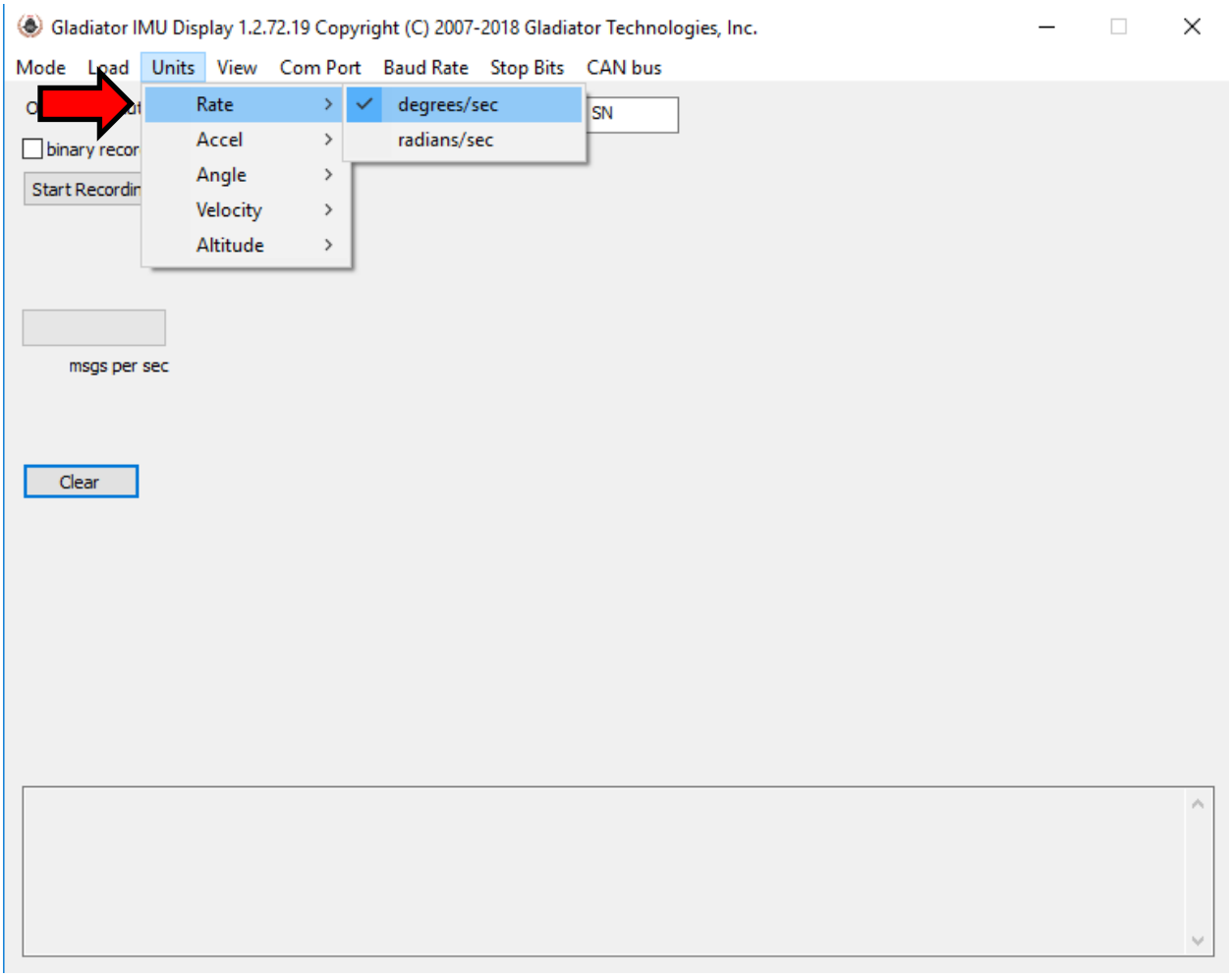


Figure 18 Gyroscope units of measure selection options

4.7.2 *Accelerometer Unit Selection*

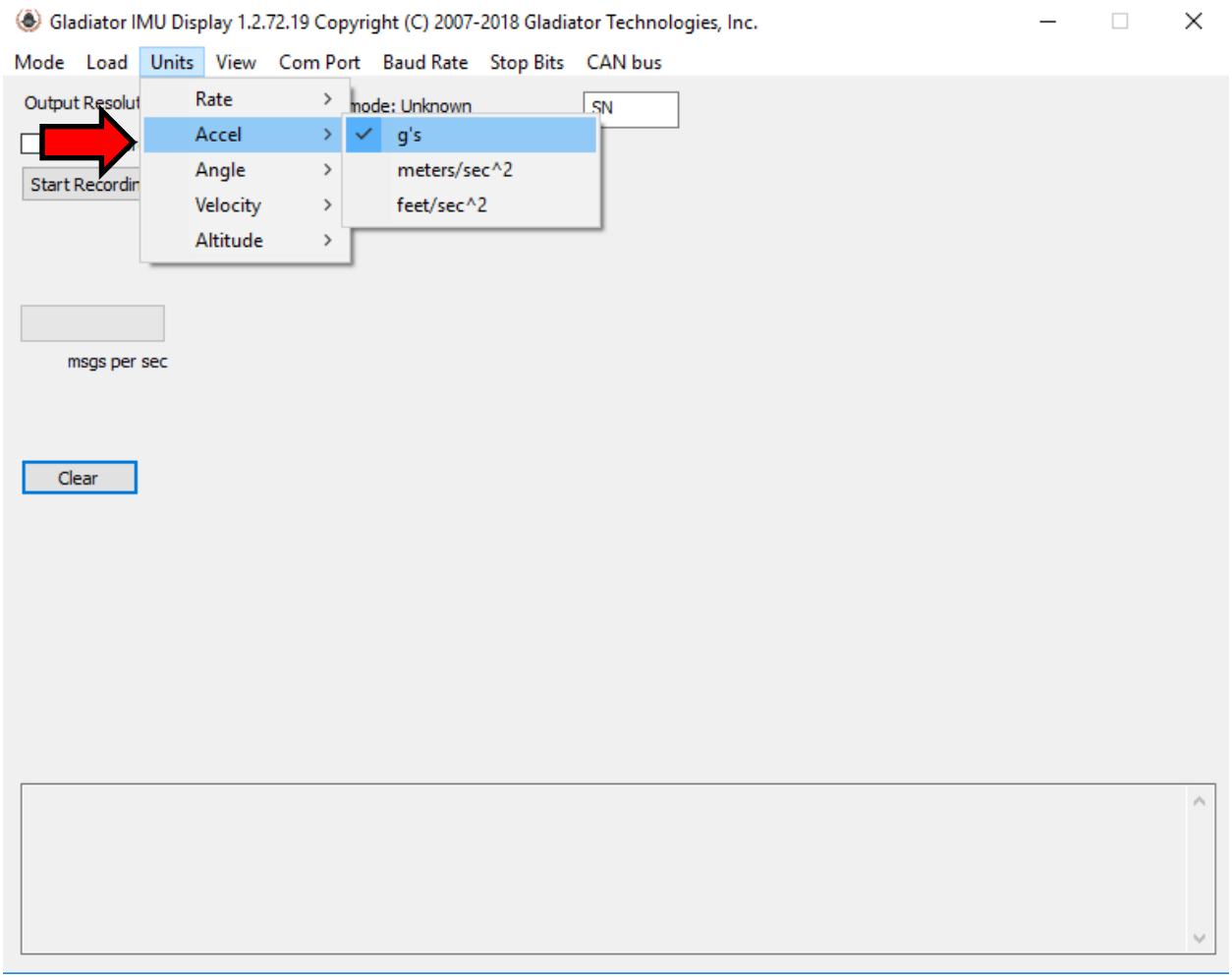


Figure 19 Accelerometer units of measure selection options

4.8 *Data Record Feature*

The SDK software also has a data record feature that captures data outputting from the IMU and puts it into .csv format. This enables the user to easily convert these data files to Excel or database format. The user should click the Start Recording button (Fig. 20) to initiate the data record function.

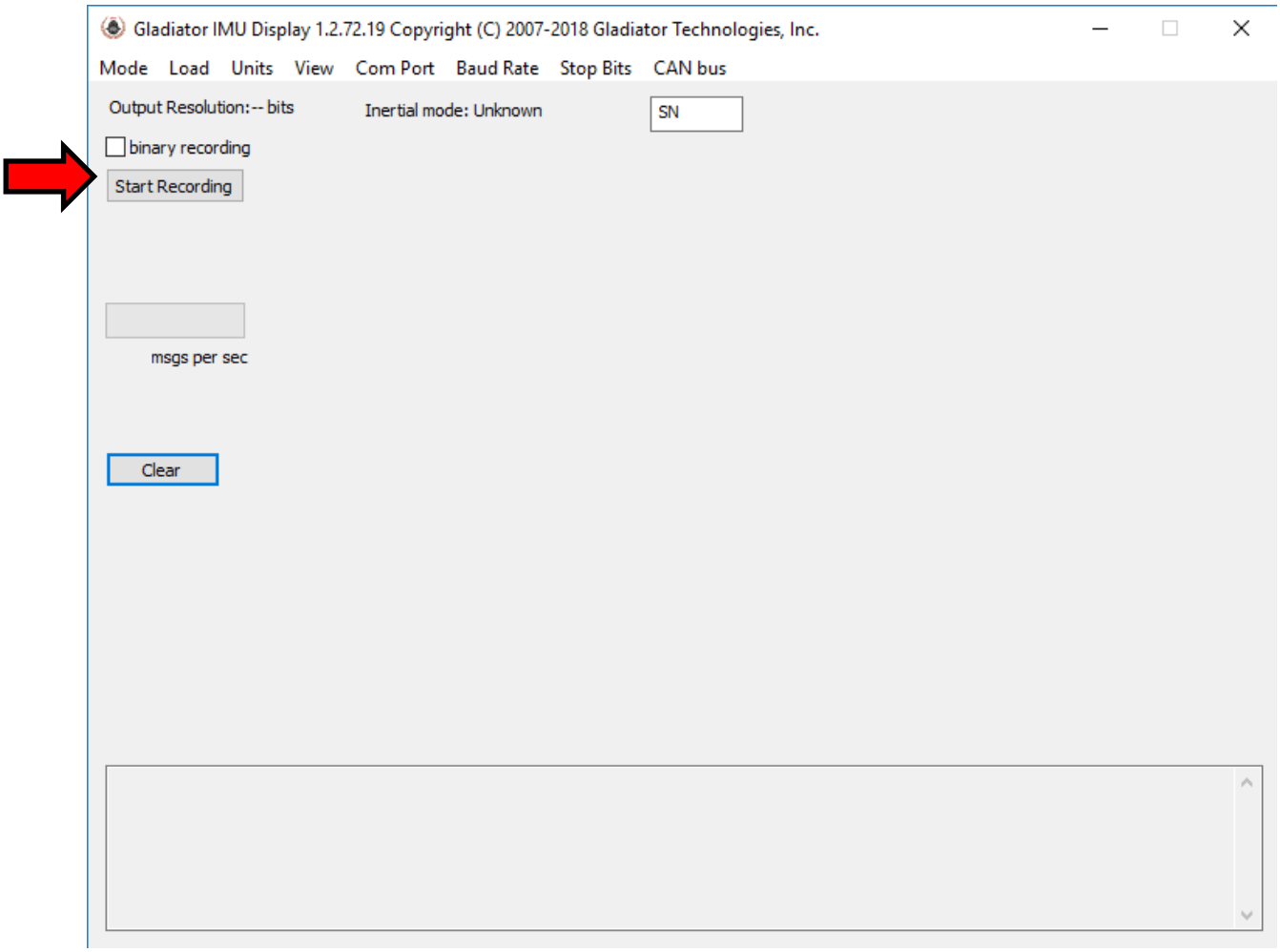


Figure 20 Data Recording button

After selecting “Start Recording,” Glamr will prompt the user to designate a filename and location before the beginning the recording. Note that writing to pre-existing filename will not append the data and instead overwrite it with the new recording. At this prompt, click Open as shown in Figure 21. After the filename and location are selected, click the desired length of time to record then click OK.

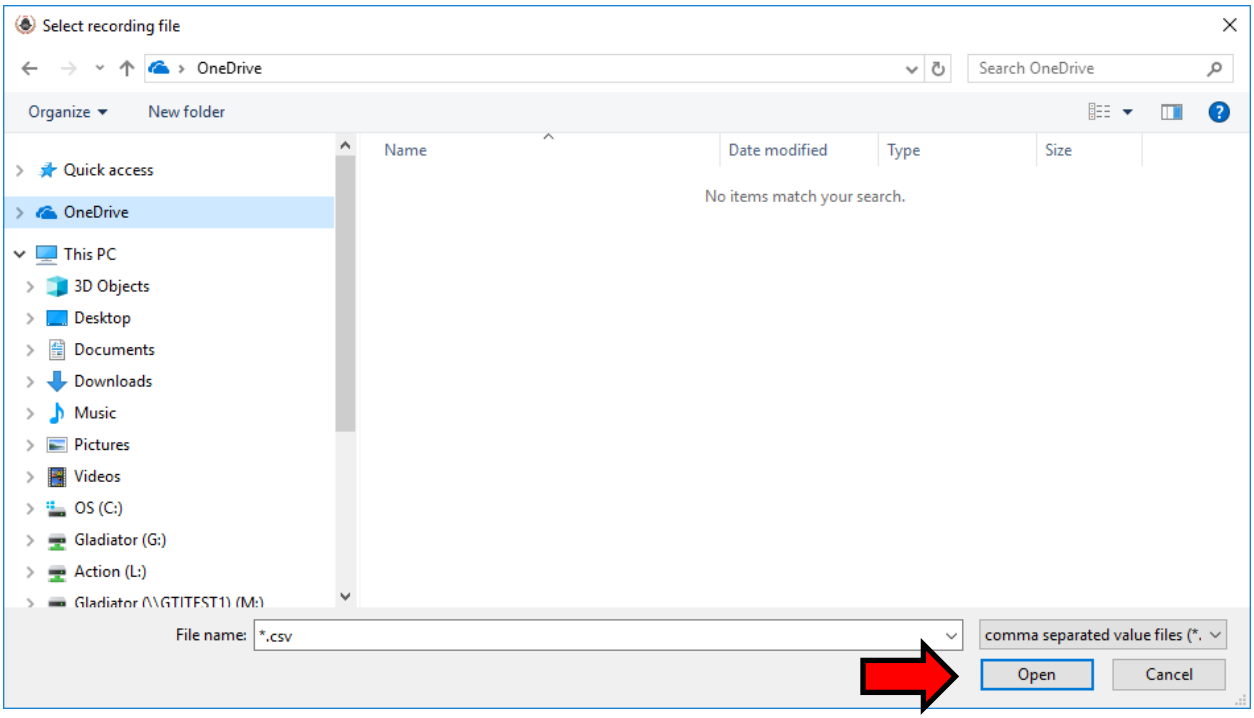


Figure 21 Saving recorded data files

If a recording time was specified by the user, the time remaining will appear below the Start Record button. To stop recording, simply click the “Stop Recording” button.

4.9 *Bandwidth Filtering Capability*

Effective with IMU SDK, Gladiator Technologies offers the end-user the capability to set bandwidth filtering in permanent memory that enables the end-user to set lower bandwidth levels than 250 Hz/maximum and benefit from the reduced noise of the sensors in the IMU. To utilize this capability, select the Set Filter from the Load drop-down menu.

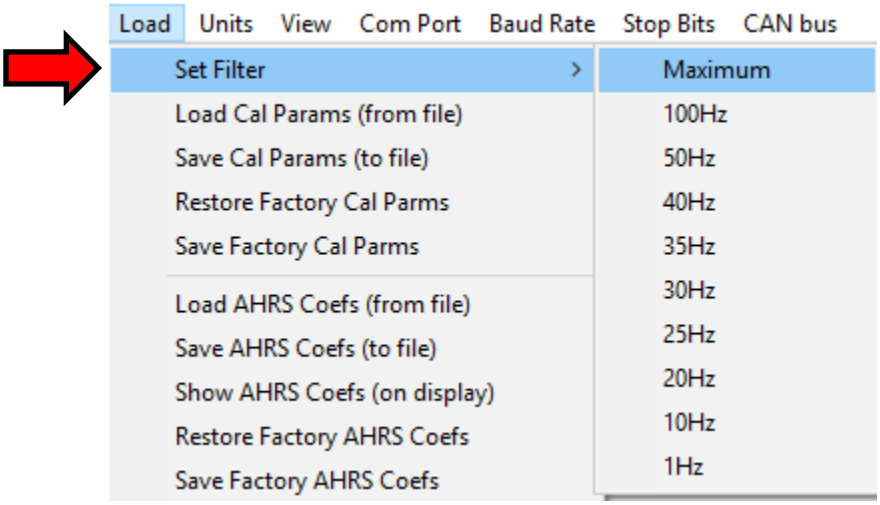


Figure 22 Select desired bandwidth filter from Set Filter menu (via Load menu)

Then select the desired true bandwidth of the IMUs with the software filter. The user can select from Maximum (standard units are shipped with this setting) or from the other bandwidth options all the way down to 1 Hz. Once this is set and the user takes and confirms data with this new setting the IMU bandwidth filter setting will remain at the setting until the user changes it in the same manner as detailed above.

4.10 *Troubleshooting with Messages*

If you are experiencing difficulties interfacing the IMU to your system, Glamr can be commanded to display messages to and from the unit in the message window. This is done via the View menu per Fig. 23.

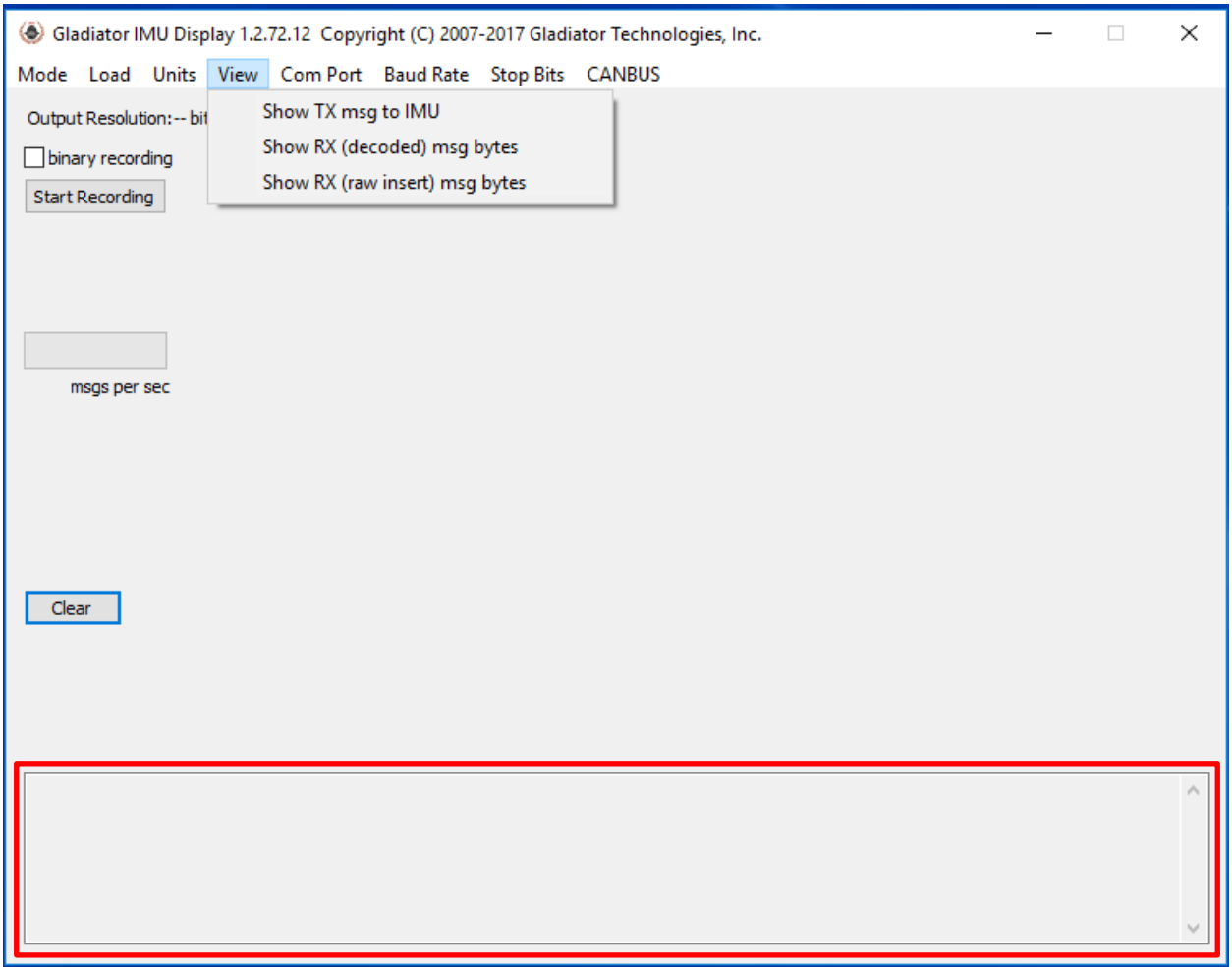


Figure 23 Message options for troubleshooting (View menu)

4.11 *LSB Resolution Settings*

Glamr defaults to 16-bit LSB resolution for its sensor outputs, but now provides higher resolutions, as well. This option is user selectable, and the resolution may be changed to 24-bit or 32-bit via the Mode menu. At the bottom of the Mode menu, click Output Resolution, then select the desired resolution per Figure 25. The detailed recommended LSB resolution settings for your IMU can be found in the Gladiator Software Reference Manual.

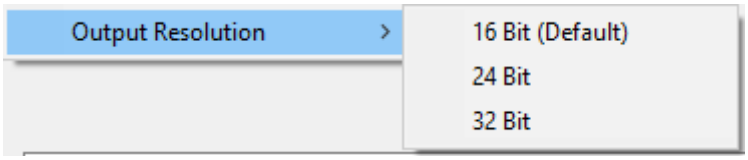


Figure 24 Output Resolution selections

Least Significant Bit (LSB) Resolution

Gyro (d/s)	16 bit	24 bit	32 bit
250	0.0076	0.000030	0.000000116
490	0.0150	0.000059	0.000000229
1000	0.0300	0.000117	0.000000458
2000	0.0600	0.000234	0.000000916

Accel (g)	16 bit	24 bit	32 bit
65	0.0020	0.000008	0.000000031
98	0.0030	0.000012	0.000000046
131	0.0040	0.000016	0.000000061

Figure 25 LSB resolution table

4.12 *CAN bus*

Some IMUs have the capability to output CAN bus data. The DBC file that describes the CAN bus interface can be auto-generated by Glamr based on the current settings using the CAN bus menu item while the unit is connected and active with the device (Fig. 26). For message sequence information, see Section 12.3.2.

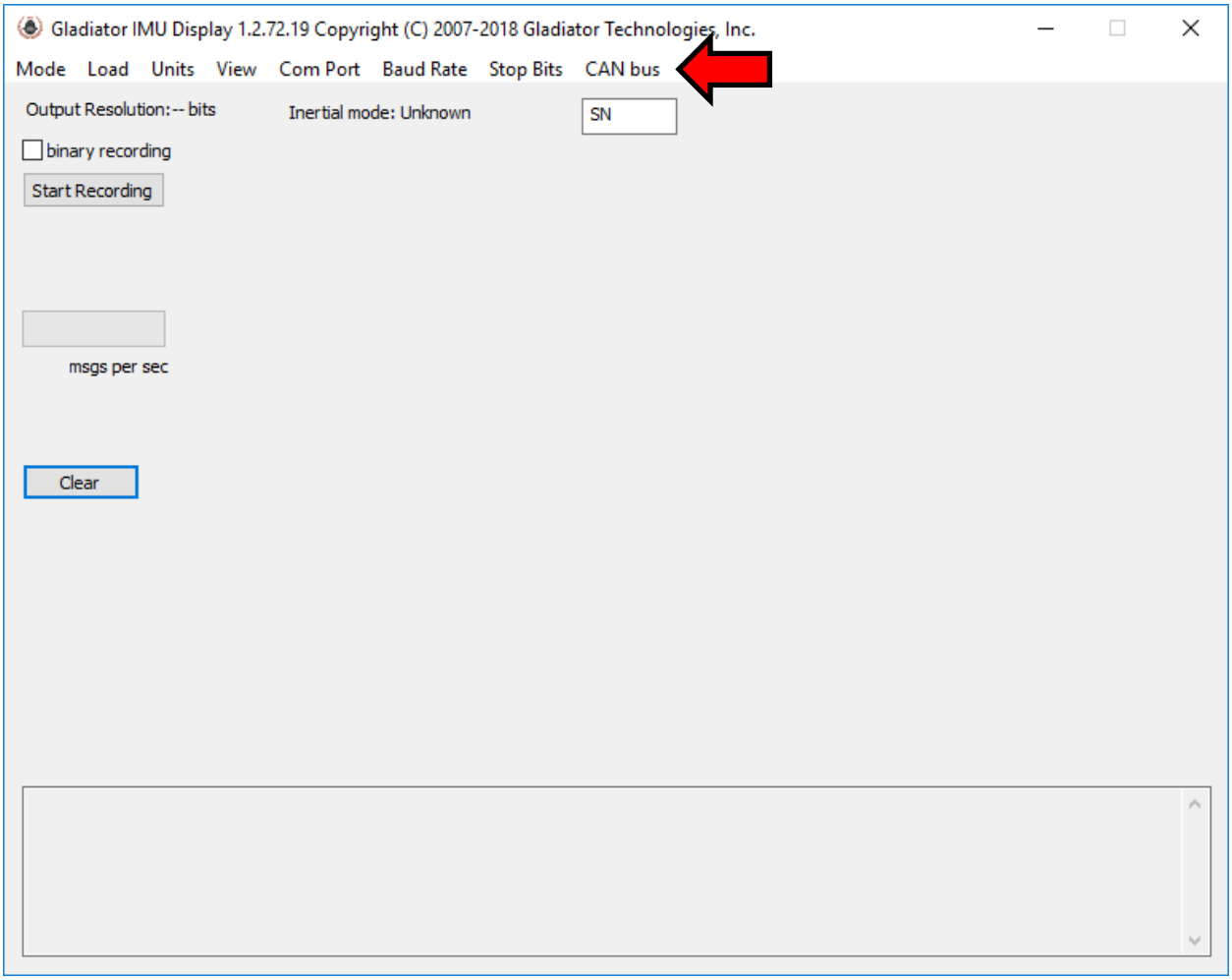


Figure 26 CAN bus menu

5 PATENT AND TRADEMARK INFORMATION

All Gladiator Technologies SX Series IMUs are newly developed units containing significant intellectual property and are expected to be protected by United States of America (USA) and other foreign patents pending. LandMark™ is an official and registered Trademark that identifies Gladiator Technologies brand name for our digital inertial and integrated GPS systems products.

6 APPLICABLE EXPORT CONTROLS

LandMark IMUs have been self-classified by Gladiator Technologies with pending Commodity Classification by the U.S. Department of Commerce under the Export Administration Regulations (EAR), as ECCN7A994 and as such may be exported without a license using symbol NLR (No License Required) to destinations other than those identified in country group E of supplement 1 to Part 740 (commonly referred to as the T-5 countries) of the Export Administration Regulations. Items otherwise eligible for export under NLR may require a license if the exporter knows or is informed that the items will be used in prohibited chemical, biological, or nuclear weapons or missile activities as defined in Part 774 of the EAR. Copies of official U.S. Department of Commerce Commodity Classifications are available upon request.

7 USER LICENSE

Gladiator Technologies grants purchasers and/or consignees of Gladiator IMUs a no-cost, royalty-free license for use of the following software code for use with Gladiator IMUs. Companies or persons not meeting the criteria as a purchaser or consignee are strictly prohibited from use of this code. Users in this category wanting to use the code may contact the factory for other user licensing options.

8 STANDARD LIMITED WARRANTY

Gladiator Technologies offers a standard one-year limited warranty with the factory's option to either repair or replace any units found to be defective during the warranty period. Opening the case, mishandling or damaging the unit will void the warranty. Please see Gladiator Technologies' Terms & Conditions of sale regarding specific warranty information.

9 QUALITY MANAGEMENT SYSTEM

Gladiator Technologies' Quality Management System is third party certified to AS9100 Requirements for Aviation, Space and Defense (latest revision). To view our current certificate please go to www.gladiatortechnologies.com or www.lkdaerospace.com.

10 THEORY OF OPERATION

The LandMark™ IMU product line contains several different product variations to meet customer demands. Currently, Gladiator IMUs support:

- Digital 3 Degree of Freedom (DOF) MEMS (Micro Electro-Mechanical System) IMU that provides delta theta information, as well as temperature.
- Digital 6 DOF MEMS IMU that outputs x-, y-, and z-axis angular rates, x-, y-, and z-axis linear acceleration data, as well as temperature.
- Analog 6 DOF MEMS IMU that outputs x-, y-, and z-axis angular rates, x-, y-, and z-axis linear acceleration data, as well as temperature. This is the MRM product line.
- Digital 6 DOF MEMS Vertical Gyro (VG) that outputs x-, y-, and z-axis angular rates, x-, y-, and z-axis linear acceleration data, pitch & roll Euler angles, analog airspeed, as well as temperature.
- Utilizing Gladiator's proprietary thermal modeling process, these IMUs are fully temperature compensated, with temperature-corrected bias and scale factor, plus corrected misalignment and g-sensitivity.

IMU Features:

- The RS-422/485 serial digital interface provides serial data outputs enabling the user to monitor the outputs during use. Internal sampling is done at 5 kHz. Over-sampling is done on the IMU output rate (2X) when set at 2.5 kHz and then averaged to improve the noise of the MEMS sensors. The nominal output rate in the IMU is 2.5 kHz ±5%. An RS-422/485 to USB converter is available in Gladiator's IMU Software Development Kit (SDK) to enable a quick IMU to PC integration. For external sync sampling information, please refer to Section 12.4.
- Three MEMS gyro signals with active filtering and 2X over sampled when set at 2.5 kHz with a 16-bit A/D converter. Gladiator IMUs are available in the following standard gyroscope ranges:
    - ±250°/sec
    - ±490°/sec
    - The LMRK007, LMRK007X, and LMRK65 support gyroscopic ranges of up to ±2000°/sec

- Three MEMS accel signals with digital filtering and 2X oversampled when set at 2.5 kHz with a 16-bit A/D converter. Gladiator IMUs are available in the following standard accelerometer ranges:
    - 6g
    - 10g
    - 15g

  Gladiator has several IMUs that are capable of higher g-ranges to meet customer demands. These include:
    - LMRK65 up to 40g
    - LMRK007 up to 98g
    - LMRK007X up to 200g

NOTE: Be aware that any selection of these higher ranges will potentially result in export categorization of the product as ECCN7A003 and require a U.S. Department of Commerce Export License for some foreign destinations and/or end-use applications.

- The internal temperature sensors outputs are 2X over sampled when set at 2.5 kHz with a 16-bit converter. These temperature measurements are co-located with the x-, y-, and z-axis IMUs to enable accurate temperature compensation of the IMU outputs. The x gyro (XGYR) temperature is reported to the user.

- The calibration process measures temperature at a minimum of five set points from -50°C to +85°C and a nine-point correction table is generated that identifies temperature-based offsets for each of the IMU data sets. Depending upon the variable, up to a 4^{th} order thermal model is used to create a correction model.

- Though a precision orthogonal mounting block is used in testing LandMark™ IMUs, misalignment error correction is also essential in enabling high performance navigation from a MEMS inertial sensor assembly. The calibration process also corrects and compensates for internal misalignment errors for all sensors in all three axes.

- G-sensitivity errors associated with the IMUs are also modeled and calibrated to correct these performance errors associated with acceleration inputs in all three IMU axes.

- All calibration data is loaded into an internal memory EEPROM enabling a look-up table for thermal modeling correction of the outputs during use.

Gladiator has a form, fit, and function derivative of the digital LMRK60, the MRM60. This analog unit features:

- A digital interface to 16-bit DAC enables accurate output during use. A low pass filter is used to reduce the noise of the MEMS sensors. The nominal output rate of the MRM is 500 Hz.
- Analog outputs are independently buffered for ease of use.
- An internal power switching regulator enables clean input power from +7 V to 36 V enabling lower power usage as demanded in many applications today. Units are calibrated at a nominal +12 V ±0.2 V input power.

LandMark IMU datasheets are available via download on our website. The latest version of all documentation can be found on the Gladiator Technologies website at www.gladiatortechnologies.com. Copies of the User's Guides are available upon request at support@gladiatortechnologies.com.

The LandMark IMU SDK software design enables updates to the IMU interface. As these software enhancements and upgrades become available, Gladiator will make these available to our IMU customers.

11 LandMark IMU PRODUCT DESCRIPTION

The SX Series LandMark IMU is our premium performance model featuring both our lowest noise MEMS gyroscopes and accelerometers that offer outstanding bias in-run and bias over temperature. This Non-ITAR MEMS IMU provides internally temperature-compensated RS-422/485 output of delta thetas and delta velocity.

Designed for commercial stabilization and aircraft applications, the LandMark IMU is ideal for commercial applications requiring high inertial performance approaching "small RLG or open loop FOG-Class," yet available at a much lower cost. Other key advantages include low power consumption, small size, light weight, and no inherent wear out modes for long life. The signature features of the LandMark IMU are the exceptionally low noise and bias performance.

The unit is environmentally sealed in a rugged enclosure and has a MIL-SPEC connector in order to withstand environmental vibration and shock typically associated with commercial aircraft requirements. LandMark IMUs are well suited for demanding commercial applications including: rail track telemetry, navigation, flight control, precision imaging, platform and antenna stabilization, flight testing, and laboratory use.

For the exact specifications of your IMU, please refer to the datasheet on the website.

11.1 *Outline and 3D Solid Models*

Please visit the product page of your IMU on the Gladiator website at http://www.gladiatortechnologies.com/imu. Here you can download the 3D Solid Model, 2D outline drawing, and other product information.

11.2 *Center of Gravity*

Some applications need to know the center of gravity (CG) of the package. Please refer to the mechanical drawing for details.

11.3 *Sensor Bandwidth*

The bandwidth of a typical Gladiator sensor can be seen in Figures 27-28. The maximum bandwidth of our gyroscopes is 250 Hz (Fig. 27) and the maximum bandwidth of our accelerometers is 1600 Hz (product dependent). The filter bandwidth of the accelerometers is programmable via integer values between 1 and 8 (this can be set via the *Show AHRS Coefs* option under the Load menu in Glamr). To verify these values, we collect one minute of data at 2500 Hz, then perform a Fast Fourier Transform and plot the result. Note that the specified bandwidth values are indicated by a vertical red line on the plots.

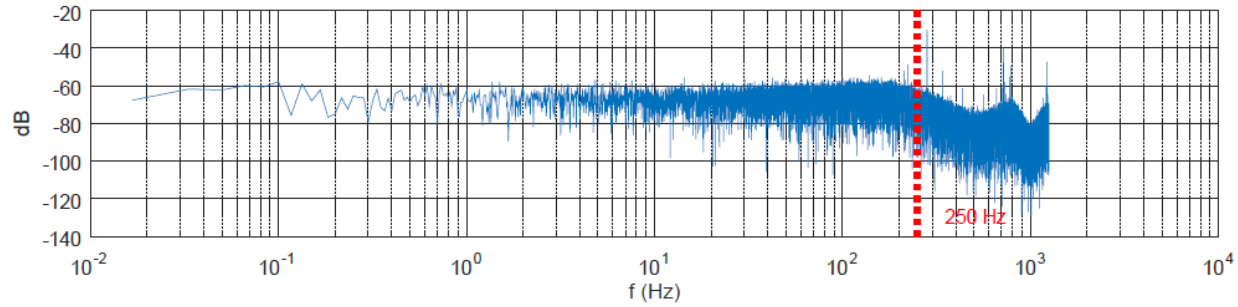


Figure 27 Typical gyroscope bandwidth (250 Hz) of LMRK005

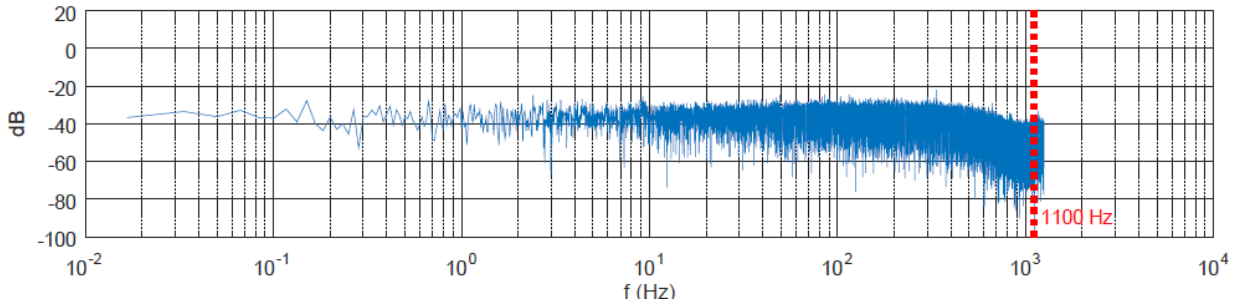


Figure 28 Typical accelerometer bandwidth (1100 Hz) of LMRK005

11.4 *IMU Block Diagram*

Gladiator IMUs have internal functionality which can be represented with a block diagram. Figure 29 is a high-level representation of the LMRK007 IMU.

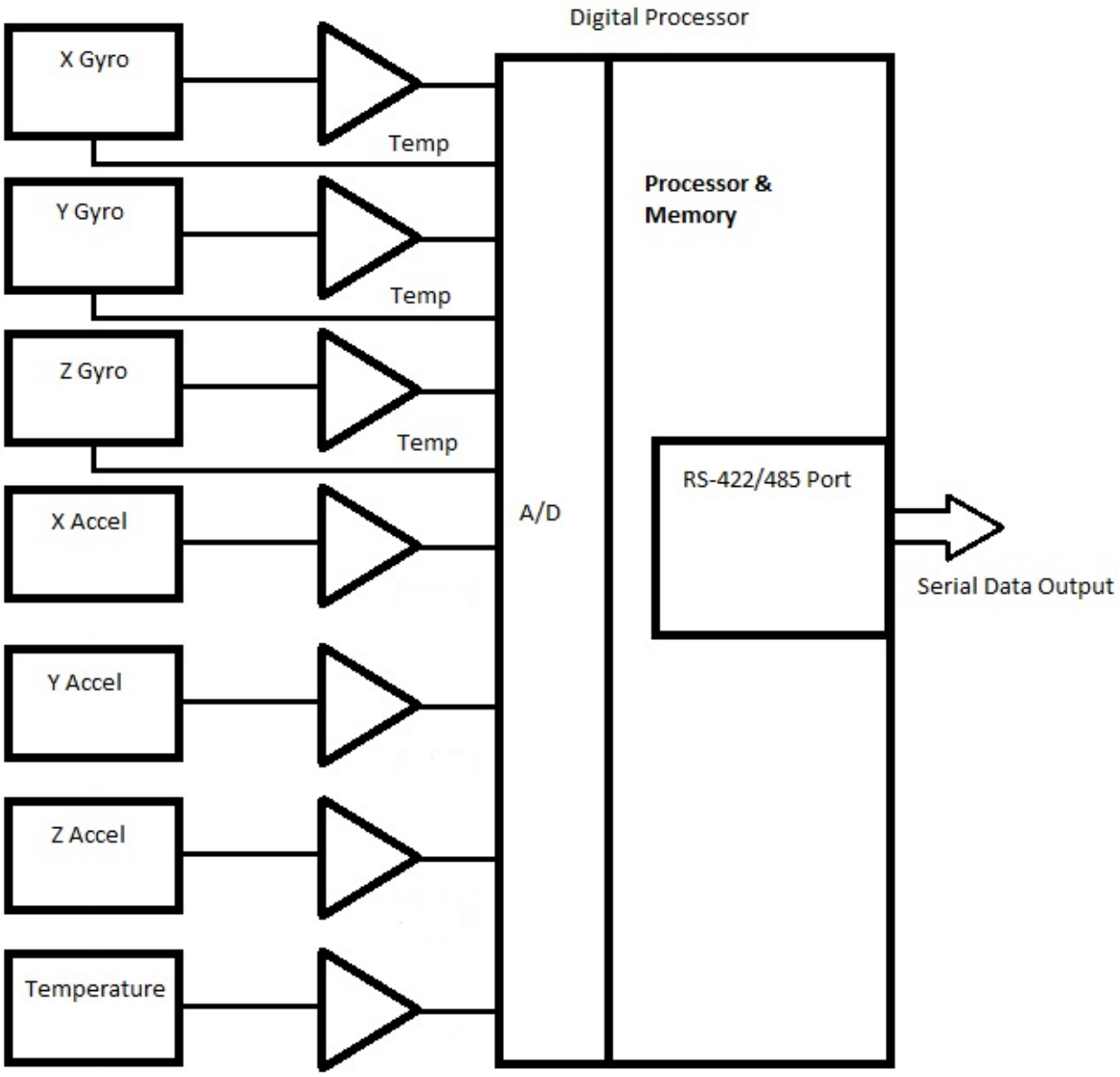


Figure 29 LMRK007 IMU block diagram

11.5 *Reading MRM60 Signals*

Apply power between Pin 5 (V_{IN}) and Pin 3 (Power Ground). Input voltage can range from +7 V to +36 V single-sided (nominal +12 V).

Note that the sensors all have the same nominal 0 V signal ground reference.

Temperature can be read with respect to Pin 8 (Signal Ground) at a nominal voltage level at 25°C with a mV/°C scale factor dependent upon the configuration of the unit. Please review the data sheet for these specifications.

Self-Test (Pin 9) is activated by a logic level voltage of 3.3 V. This can be deactivated by leaving the pin open or by applying a low logic level of < 1 V to the pin. The results of activating the Self-Test pin is to increase the differential reading on all gyros and/or all accelerometers. Please review the data sheet for these specifications.

NOTE: Pins 1 and 2 are available as a digital serial port for data recording with Glamr. If these signals are not used, it is recommended that the pair be twisted and terminated with a 10 kΩ resistor to avoid the pickup of unwanted digital edges that may upset normal operation.

If there are no wires in Pins 1 and 2, then no termination resistor is required. Pin 9 is Self-Test and may be connected to a logic level signal source – if not being used, Pin 9 should be grounded.

12 IMU MESSAGE PROTOCOL

12.1 *Serial Communication Settings*

IMUs are shipped to the customer in a standard configuration of 921,600 baud (in 2500 Hz IMU Mode) and 1 Stop bit.

Parameter	Value
Bits/second:	115200, **921600**, 1.5 Mbit/s, 3.0 Mbit/s, 6.0 Mbit/s
Start bits:	1
Data bits:	8
Parity:	E
Stop bits:	1 or 2 (Glamr setting)

Figure 30 Serial communication settings values

12.2 *IMU Message Packet Format*

At power-up, the IMU enters operational mode using the last commanded mode setting. Please refer to the Gladiator Technologies Software Reference for additional information.

12.3 *Sample Data Format*

Figure 31 provides a sample IMU data format output in Excel. The real output includes both the header information and data (see rows with MSGCOUNT) that contain actual output data. Also included are the multiplier information, averages, and units of measure for additional clarity.

MSGCOUNT	GYRX (°/s)	GYRY (°/s)	GYRZ (°/s)	ACCX (mg)	ACCY (mg)	ACCZ (mg)	TEMPX (C)
32	-0.24	0.1	0	52	-8	-1060	23.6
33	-0.27	0.09	0	48	-4	-1088	23.57
34	-0.25	0.04	0.06	12	-16	-1100	23.62
35	-0.24	0.04	0	100	-4	-1004	23.65
36	-0.22	0.13	0.12	8	40	-972	23.65
37	-0.33	0.07	0.12	20	12	-1084	23.63
38	-0.25	0.1	0	12	-4	-1144	23.62
39	-0.25	0.12	0.12	32	28	-1152	23.59

Figure 31 Sample IMU data

Please note that when a customer uses the Glamr interface the program automatically rescales the IMUs. This is displayed in Figure 31.

12.3.1 *Interfacing without Glamr*

If you are not using the Glamr interface be aware that the accelerometers require a divide by function. Additionally, you should use the LSB's noted per your IMU datasheet. For example, for a 490°/sec rate range IMU the 16-bit LSB is 0.015 deg/sec:

$$LSB = \frac{(Sensor\ Range)}{2^{Bit\ Resolution-1}} = \frac{490\ deg/sec}{2^{15}} = 0.015\ deg/sec$$

The calculations for higher bit resolutions are as follows:

$$\frac{490\ deg/sec}{2^{23}} = 0.00006\ deg/sec$$

$$\frac{490\ deg/sec}{2^{31}} = 0.00000023\ deg/sec$$

For a 2000 deg/sec gyro at 16-bit:

$$\frac{2000\ deg/sec}{2^{15}} = 0.061\ deg/sec$$

For temperature, 0.01 degrees should be used. Note that in the exponent, one bit is subtracted from the total bit resolution to account for both positive and negative values (effectively dividing it by two).

12.3.2 *CAN bus Output Messages*

The table in Figure 32 summarizes the data stream messages from Gladiator IMUs capable of CAN bus 2.0B output. The transmit sequence follows from top to bottom in the table, with the start of message byte transmitted first and the checksum transmitted last in all cases. At power-up, the device reads the operation mode (i.e. Full, Spec, etc.) from its flash storage and begins to transmit data in that mode. Figure 32 is an example of CAN output.

High-Speed CAN (HSC)		1000	kbps								
Identifier A (11 bits)		0x47 or 'G'	Programmable Identier, default								
	Identifier B	Rate (Hz)	Bytes	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
To PC											
	07000H	100	2	Count	Status						
	07010H	100	4	Product	Level	Major	Minor				
	07011H	100	6	ASCII	ASCII	ASCII	ASCII	ASCII	ASCII		
	07012H	100	6	ASCII	ASCII	ASCII	ASCII	ASCII	ASCII		
	07020H	1000	8	ScaleLSB	ScaleMSB	XgyroLSB	XgyroMSB	YgyroLSB	YgyroMSB	ZgyroLSB	ZgyroMSB
	07021H	1000	8	ScaleLSB	ScaleMSB	XacclLSB	XacclMSB	YacclLSB	YacclMSB	ZacclLSB	ZacclMSB
	07022H	100	4	ScaleLSB	ScaleMSB	TempLSB	TempMSB				
CAN 2.0B Message Format											
	Start bit	1									
	Identifier A bits	11									
	SRR bit	1									
	IDE bit	1									
	Identifier B bits	18									
	RTR bit	1									
	Control bits	6									
	Data Bits (8 bytes)	64									
	CRC bits	15									
	Stuff bits	23									
	CRC delimiter	1									
	ACK slot	1									
	ACK delimiter	1									
	EOF bits	7									
	IFS bits	3									
		154	bits/message								
	MaxMessage/Sec	6493.50649									

Figure 32 Sample IMU CAN output

Refer to Section 4.12 for information on how to generate the associated CAN database file.

12.4 *External Sync Input*

The optional input to the IMU is a sync square wave to the External Sync Input pin. This allows the data stream to be synchronized to an external clock. For example, if the user wants to supply and sync an external GPS to the IMU, the GPS can generate a 2.5 kHz square wave, which is sent to the IMU when the GPS signal is valid. However, any external valid clock of logic level can be used to synchronize the data. Refer to the IMU datasheet to find the maximum external sync frequency and the pin location. Gladiator IMUs are capable of single-ended external sync by default, but some unit variations are configured to enable differential signals, as well. This helps to reduce noise compared to single-ended signals. Please refer to the product page on the website to see if your IMU is available with differential external sync. Please note that when an external sync signal is applied there is no oversampling of the sensor outputs.

12.4.1 *Specification*

- Datasheet-specified clock ± 5% square wave (40% – 60% duty cycle not critical, 50% nominal)
- Data sample starts on the rising edge only (falling edge ignored)
- 3.3 V logic is suggested (-0.3 V < "0" < 0.8 V and 2.0 V < "1" < 5.3 V) with respect to signal ground
- Glitch filter to ignore spurious transitions < 10 ns
- Input has diode protection to protect the CPU for our two standard input voltage ranges:

Standard Input Voltage (V)	Protected Lower Range (V)	Protected Upper Range (V)
+5, +12	> -0.7	< 10.5

Note that excessive input voltage levels may cause degradation of unit performance.

12.4.2 *Sample Timing Diagram*

Timing diagrams offer a way to understand and visualize the timings and relationships between different signals of the IMU. Figure 33 is a sample timing diagram. Your specific IMU timing diagram can be found on the Gladiator website or by contacting Gladiator support.

Timing (2.5kHz)	0.2 msec	0.4 msec	0.6 msec	0.8 msec	1.0 msec	1.2 msec	1.4 msec	1.6 msec	1.8 msec	2.0 msec
Data Reads	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS	GYROS ACCELS
Processor samples		1		2		3		4		5
Average delay Gyro			8.5µs±62.5µs							
Accel		-60µs±156µs								
Processor Starts										Samples
Process Ends			27µs							Repeat
Transmission Starts										
3M baud Ends			79µs							
Total Delay Gyro			106µs±62.5µs	=	168.5	µsec ave				
Accel			166µs±156µs	=	322	µsec ave				
Degrees at 2200Hz = Gyro						360*0.1685/0.454=	133.45	degrees		
Accel						360*0.322/0.454=	255.02	degrees		
Degrees at 50 Hz = Gyro						133.45/50=	2.7	degrees		
Accel						255.02/50=	5.1	degrees		
256Hz Single Pole							11.1	degrees		
Accel										
320Hz Single Pole									8.9	degrees
N=5							Gyro	Accel		
Total Degrees at 50Hz							13.7	14.0	degrees	

Figure 33 Sample 2.5 kHz timing diagram

12.5 *Bandwidth vs. Noise*

Gladiator IMUs are optimized for high bandwidth, meaning the gyro bandwidth is 250 Hz while the accel bandwidth is closely aligned to this frequency. However, this exact value varies based on the specific IMU. This is set by factory default to align the accels with the gyros to reduce the phase lag between the two.

While the accel bandwidth is programmable, please contact technical support for information on adjusting it (reference ACCEL_FILTER_N).

For the bandwidth of both gyros and accels, refer to the LPF K equation:

$$LPF\ K = 1 - e^{-2\pi(\frac{Bandwidth}{Rate})}$$

Note that Message Rate > Bandwidth, otherwise use 1.0.

True bandwidth includes the data sampling effects and has the -3 dB point, which is approximately half of the sample frequency. These are the settings for the standard unit when shipped and the noise may not be optimized for an end-user's specific application. The high bandwidth is ideal for dynamic applications where high bandwidth would be required to close control loops in flight control in a UAV, for example. However, in UAV navigation, a lower bandwidth would be preferable, and the unit would demonstrate an improvement in peak-to-peak noise. Laboratory uses, automotive monitoring, or stabilization applications would likely prefer improved (lower) noise and could tolerate reduced bandwidth.

The IMU Software Development Kit offers the end-user the capability to set bandwidth filtering in permanent memory. This enables the end-user to set lower bandwidth levels than the default sensor bandwidth to benefit from reduced peak-to peak noise of the sensors in the IMU. The gyro bandwidth can be customized in Glamr by navigating to the *Load* menu, selecting *Set Filter*, then clicking *Other*. Refer to Figure 34 for more information on bandwidth versus output data rate.

	Output Data Rate					
Bandwidth	100	200	500	1000	2500	5000
250	N/A	N/A	1.0000	1.0000	1.0000	1.0000
230	N/A	N/A	0.9444	0.7643	0.4390	0.2510
200	N/A	1.0000	0.9190	0.7154	0.3951	0.2222
180	N/A	0.9965	0.8959	0.6773	0.3639	0.2024
150	N/A	0.9910	0.8482	0.6103	0.3141	0.1718
125	N/A	0.9803	0.7921	0.5441	0.2696	0.1454
100	0.9981	0.9568	0.7154	0.4665	0.2222	0.1181
75	0.9910	0.9052	0.6103	0.3758	0.1718	0.0899
50	0.9568	0.7921	0.4665	0.2696	0.1181	0.0609
40	0.9190	0.7154	0.3951	0.2222	0.0956	0.0490
35	0.8891	0.6670	0.3558	0.1974	0.0842	0.0430
30	0.8482	0.6103	0.3141	0.1718	0.0726	0.0370
25	0.7921	0.5441	0.2696	0.1454	0.0609	0.0309
20	0.7154	0.4665	0.2222	0.1181	0.0490	0.0248
10	0.4665	0.2696	0.1181	0.0609	0.0248	0.0125
1	0.0609	0.0309	0.0125	0.0063	0.0025	0.0013

Figure 34 IMU Output Data Rate vs Bandwidth

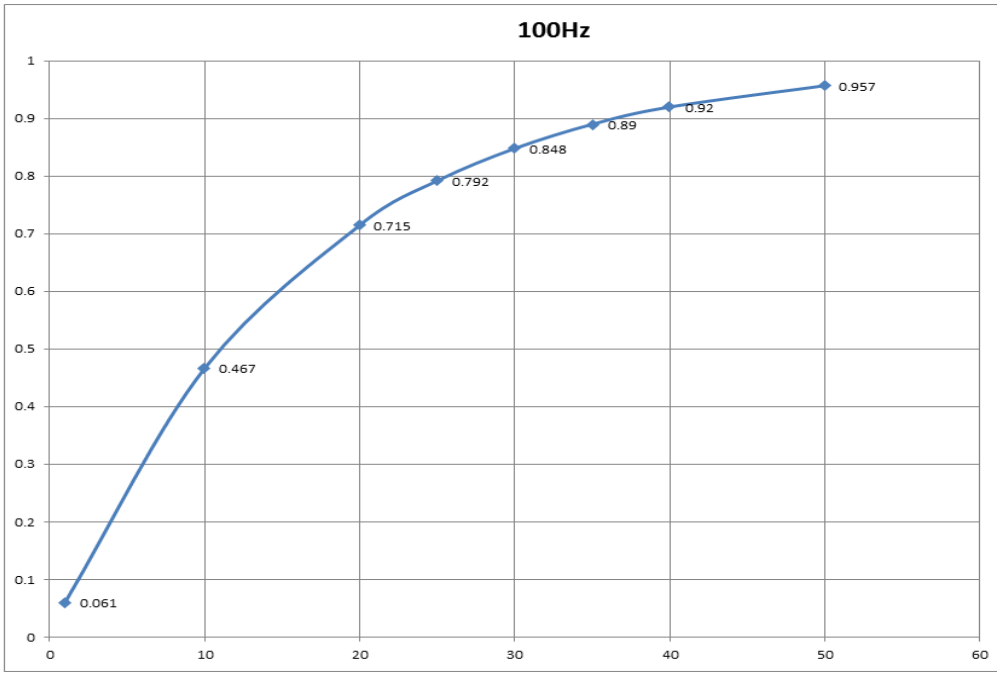


Figure 35 IMU Bandwidth vs. Peak-to-Peak Noise 100 Hz

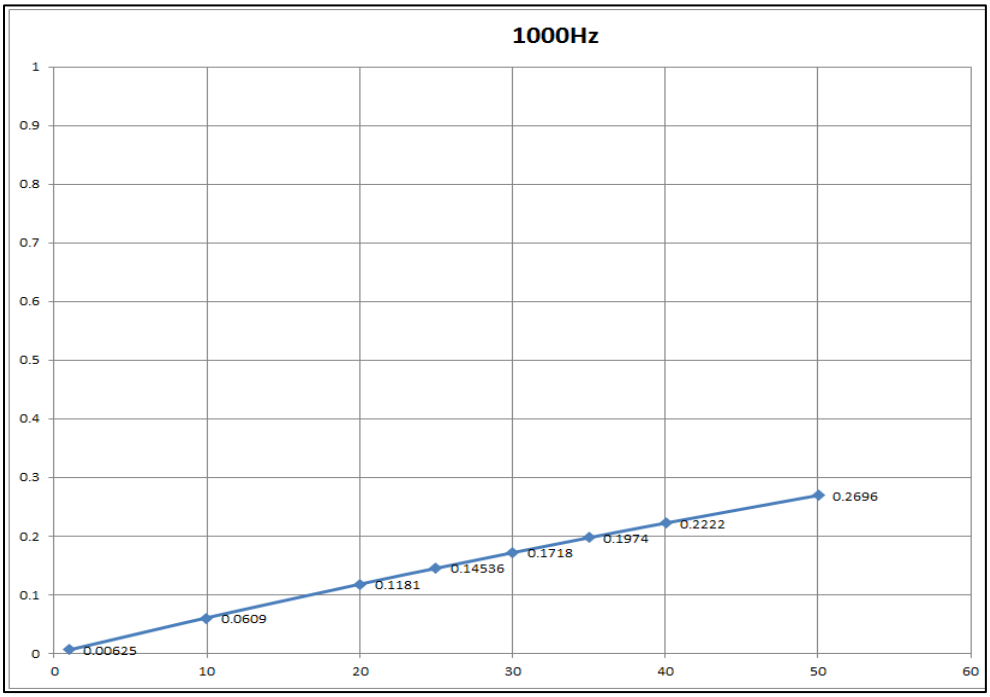


Figure 36 IMU Bandwidth vs. Peak-to-Peak Noise 1 kHz

13 SUMMARY OF TEST METHODS

Units are continuously powered-on, tested at ambient (around 23°C), and data is typically collected at 100 Hz. There are several tests where the data rate is increased for greater resolution. For unit-specific specifications, please see the datasheet for your IMU. The standard temperature range is from -50°C to +85°C.

13.1 *Calibration*

From a default setting for each product configuration, the initial scale factors, biases, and misalignments are calculated from -50°C to +85°C and applied to the unit as a starting point for the rest of testing.

13.2 *Environmental*

13.2.1 *Sensor Validation*

All sensors are checked for ARW/VRW and bias over temperature performance (including hysteresis).

13.2.2 *Shock*

Units are placed on a shock hammer to ensure there are no loose components in the assembly and that the unit is functional after the impact. The unit is powered off for this test.

13.2.3 *Temperature Cycle*

Units are taken from -50°C to +85°C several times to help break-in and acclimate the sensors to the mounting frame.

13.2.4 *Burn-In*

Units are left unmonitored at +70°C for approximately 50 hours to remove mounting stresses.

13.2.5 *Trend*

Units are left at +70°C to monitor any bias drifts in the sensors.

13.2.6 *Sensor Saturation*

Units are rotated quickly to verify that the gyroscopes saturate to their respective maximum value on each axis. Units are then placed on a shock fixture with an external reference piezo accelerometer to verify correct accel saturation.

13.3 *Random and Sine Vibration*

13.3.1 *Random Vibration*

The unit is subject to random frequencies with an energy total contained in the vibration profile up to $15g_{RMS}$, depending on the customer application (see datasheet). The delta shift for each IMU is measured before and after the run. Also measured during vibe are the Vibration Rectification Coefficients (VRC) of the unit. This is also used to validate the g-sensitivity correction on the gyros via the accels.

13.3.2 *Sine Vibration Test*

The unit is subject to a sine sweep of various frequencies from 30 Hz to 3000 Hz and delta shifts are calculated before and after the run. The total energy in the test profile is up to 15g's peak. Also measured during vibe is the VRC of the unit. This is also used to validate the g-sensitivity correction on the gyros via the accels.

13.4 *Rate Linearity*

Some Gladiator products, such as the LMRK007, require additional testing to accurately calibrate the proper scale factors. Each axis of the unit is tested for proper gyro cross-coupling and misalignment, then corrected via additional runs. This is performed on a highly accurate rate table capable of spinning up to the full range of 2000 degrees/second. Ambient scale factors are also calculated and carried forward.

13.5 *Thermal*

The unit is tested from -50°C to +85°C at a minimum of five set points to begin tuning the correction model. A second order model is applied to scale factors and biases for all sensors.

13.6 *Bias and Scale Factor Over Temperature (Verify)*

The temperature calibration process measures temperature at a minimum of 10 set points from -50°C to +85°C at a slew rate of approximately 1-2°/minute. Depending on the variable, up to a 4^{th} order thermal model is used to create a correction model. This dials in scale factors and biases over the temperature range of the test. Residuals (PPM error) are calculated from the thermal coefficient scale factor deviation from the model.

13.7 *ATP (Acceptance Test Procedure)*

13.7.1 *Rate Spin*

The unit is mounted on an orthogonal test fixture and spun at about half of the full-scale rate range. Rate scale factors and IMU misalignments are corrected.

13.7.2 *IMU Tumble*

The unit is mounted on an orthogonal test fixture and placed in ± 1g and ± 0g in this test. During this test both the IMU biases and g-sensitivity are measured.

13.8 *FAST-TOT*

Similar to TOT, this test is at 3°C/min in slew rate over the full temperature range of -50°C to +85°C. This is used to create a preliminary model which the longer TOT validates and applies final corrections. The unit is powered off then turned on and data is recorded for a short period.

13.9 *Turn-On to Turn-On over Temperature (TOT)*

This test is performed only if determined it is beneficial to your specific application. T The unit is powered off until a temperature set point is reached. The profile runs over an entire temperature cycle from -50°C to +85°C with set points every 5°C. At each set point, the unit is turned on and data is recorded for approximately 30 seconds. This simulates and corrects for any turn-on bias over the temperature range of the IMU.

13.10 *Bias Turn-On from a Cold Start (Long Run)*

Test conditions assume a unit has been powered off for a minimum of at least five minutes and then data is taken at ambient temperature from initial power-on to determine sample turn-on transient performance (25 minutes). It should be noted that most of the turn-on transient occurs during the initial two minutes after power-on and after that it essential performs near the specified Bias In-Run performance level.

13.11 *Bias In-Run*

The unit is placed on an orthogonal test fixture. Then the bias of the accelerometers and gyroscopes are measured at 1 Hz average. After a five-minute warm-up period, the data is taken for five minutes at ambient temperature. The test conditions should be similar to what a user should likely have during initial setup approximately within five minutes after turn-on.

13.12 *Angle Random Walk and Allan Deviation*

The unit is mounted on a flat fixture and is turned on and warmed up for 30 seconds. Data is captured at 200 Hz data rate for 30 seconds. The white noise due to angular rate is measured. ARW is typically expressed in our datasheets in degrees per second per square root hertz (°/sec/√Hz), which is standard for most MEMS IMUs. However, our performances are now commensurate with higher performing small open loop FOGs and small RLG's, so we also denote ARW in degrees per square root hour (°/√h).

13.13 *Velocity Random Walk and Allan Deviation*

The unit is mounted on a flat fixture and is turned on and warmed up for 30 seconds. Data is captured at 200 Hz data rate for 30 seconds. Gladiator measures the velocity error accumulating with time, due to white noise in acceleration. VRW is typically expressed in our datasheets in milli-g per square root hertz (mg/√Hz), which is standard for most MEMS accelerometers. However, our performances are now approaching higher performing quartz-based servo accelerometers, so we also denote VRW in meters per second per square root hour ((m/s)/√h).

13.14 *Ambient Power Switching TOT (APSTOT)*

Data is captured at 200 Hz data rate. Test conditions assume a unit has been powered off for a minimum of at least five minutes and then data is taken from initial power-on and averaged over two minutes to determine initial offset bias and repeated for five cycles to determine sample turn-on to turn-on repeatability performance.

13.15 *Power Supply Sensitivity (PSS)*

Sensor biases and unit current draw are monitored via 15 second samples over multiple set points spanning the input voltage range. At each set point, there is a short pause before recording to reduce the impact of any transient response. This test ensures that the unit is functioning properly at any appropriate input voltage level.

14 Mounting

Mounting for the IMU accommodates both metric and U.S. mounting screws. Mount the unit to a flat surface with 4ea 8/32 screws (U.S.) or 4ea M4 metric stainless steel screws. The minimum torque requirement is 32 in/oz. Be sure that the surface that you are mounting to is as clean and as level as possible in order to eliminate potential alignment errors. Adequate mounting to a surface should fall within a flatness of +/- 0.001" or +/- 0.025 mm.

Failing to mount the unit in this fashion can result in unaccounted stress in the sensors and therefore may affect data output. Gladiator Technologies strongly encourages the user to mount the unit correctly in the described manner to ensure proper functioning.

15 Operation and Troubleshooting

15.1 *Technical Assistance*

Please contact the factory or your local Gladiator Technologies sales representative's office for technical assistance.

Technical Support - USA
Gladiator Technologies
Attn: Technical Support
8020 Bracken Place SE
Snoqualmie, WA 98065 USA
Tel: 425-396-0829 x241
Fax: 425-396-1129
Email: support@gladiatortechnologies.com
Web: www.gladiatortechnologies.com

15.2 *Authorized Distributors and Technical Sales Representatives*

If you need additional assistance, please contact your local distributor and/or the factory for further technical support:

http://www.gladiatortechnologies.com/international-customers/

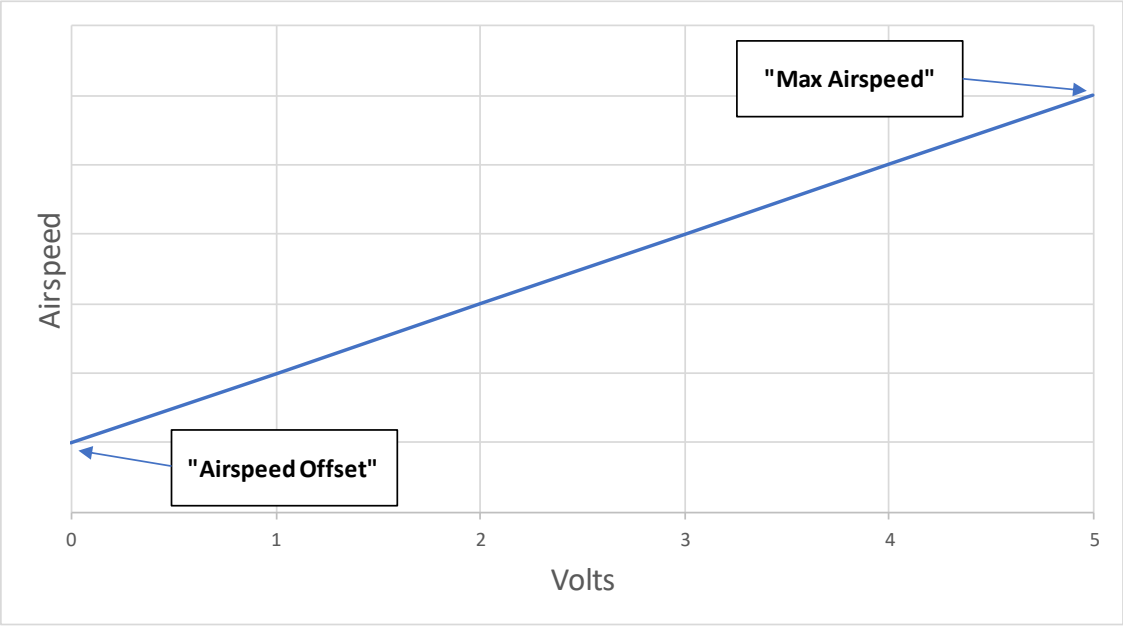
Appendix A – Vertical Gyro (VG)

The Gladiator Technologies Vertical Gyro is a variant of a typical IMU that outputs calibrated and velocity-compensated Euler Pitch & Roll angles along with the typical three-axis gyroscope and accelerometer outputs.

This requires that the VG operate in *FULL* mode as opposed to the usual *IMU* mode. FULL mode contains more information, and therefore, takes longer to transmit data packets at the same rates. This may require a higher baud rate to be used for communication. Please see the *Gladiator AHRS/INS Software Reference Manual* for more messaging details.

The Gladiator Technologies VG also allows the user to input a digital or analog airspeed (velocity) signal to assist the system with acceleration corrections. This signal can either be an analog voltage ranging from 0 to 5 V, or it can be a PWM (pulse) signal generated by a wheel counter. If a wheel counter signal is desired, then the user must set the AHRS coefficient “Wheel Diameter” to a value greater than zero.

The following chart describes the linear relationship between input analog airspeed voltage and the airspeed output of the system. The AHRS coefficients can be used to modify this relationship:



Note: If the unit is being tested in a zero-velocity scenario (on a bench), then the airspeed input should be tied to ground to prevent erroneous velocity values.

The VG also operates with certain limitations not present on other IMUs. These include:

1. Data resolution limited to 16-bit operation.
2. Output data rate (ODR) limited to 500 Hz.
3. Pitch & Roll angular rates limited to less than the configured rate-range (i.e. 490 °/s). This can be configured by AHRS coefficients at the cost of system noise-rejection.
4. FULL mode messages contain zeros for the following data:
    a. Magnetometers X, Y, Z
    b. Pressure
    c. Yaw angle
    d. Velocities X, Y, Z
    e. Altitude
    f. Alternate Temperature