The Inertial Labs KERNEL IMU

Interface Control Document

Models:

KERNEL-100
KERNEL-102
KERNEL-108
KERNEL-110
KERNEL-110M
KERNEL-120
KERNEL-201
KERNEL-210
KERNEL-220

Revision 1.42

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CONTACT INFORMATION

Contact Information	
Contact Information	info@inertiallabs.com https://inertiallabs.com Phone: +1 (703) 880-4222 39959 Catoctin Ridge St, Paeonian Springs, VA 20129, USA
Customer Support	Inertial Labs, Inc. offers extensive technical support. Visit the Inertial Labs Technical Support page or contact the support team directly through support@inertiallabs.com with any questions.
Sales Contacts	To communicate with the sales department, contact sales@inertiallabs.com
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1. Scope and Applicability

This Interface Control Document (ICD) provides details on mechanical mounting, electrical connections, powering, and communication between the Inertial Labs KERNEL IMU and a host system. This document is intended for all parties requiring such information, including the engineers and researchers responsible for implementing the interface.

2. Introduction

2.1. Description of the System

The Inertial Labs KERNEL Inertial Measurement Unit (IMU) is an advanced MEMS-based sensor that features a compact, self-contained strapdown system. These devices use three-axis, high-grade MEMS accelerometers and gyroscopes to measure linear acceleration and angular rates. These measurements are determined with low noise and excellent repeatability for both static and dynamic applications.

Figure 2.1. Available KERNEL Models

Inertial Labs provides the following models of the KERNEL IMU (**Figure 2.1**):

- **KERNEL-100** and **KERNEL-102**: Industrial-grade, lightweight systems that operate on our first-generation processing board. Note, the K100 is the only model available in an OEM version as well.

- **KERNEL-110** and **KERNEL-108**: Industrial-grade systems operating on our second-generation processing board.
- **KERNEL-110M**: The K110 enclosed in a case with MIL-STD-1275 protection.
- **KERNEL-120**: Second-generation, industrial-grade model with an additional high-range accelerometer. This allows the IMU to have ±40g and ±90g measurement ranges.
- **KERNEL-201**: Industrial-grade system with the latest MEMS sensor technology, which allows for a faster data rate and a high-range ±4000 deg/sec gyroscope as an option.
- **KERNEL-210**: Third-generation system available in industrial or tactical-grade models.
- **KERNEL-220**: Like the K210, but with an additional high-range accelerometer to measure ±40g and ±90g linear acceleration ranges.

2.2. Coordinate System

All sensors are fully calibrated over their operational temperature ranges and precision-aligned to an orthogonal coordinate system. Refer to **Figure 2.2** to view the calibrated sensor's coordinate system (O_{XYZ}). This is the same for both the standard KERNEL design (left) and the case with MIL-STD-1275 protection shown on the right.

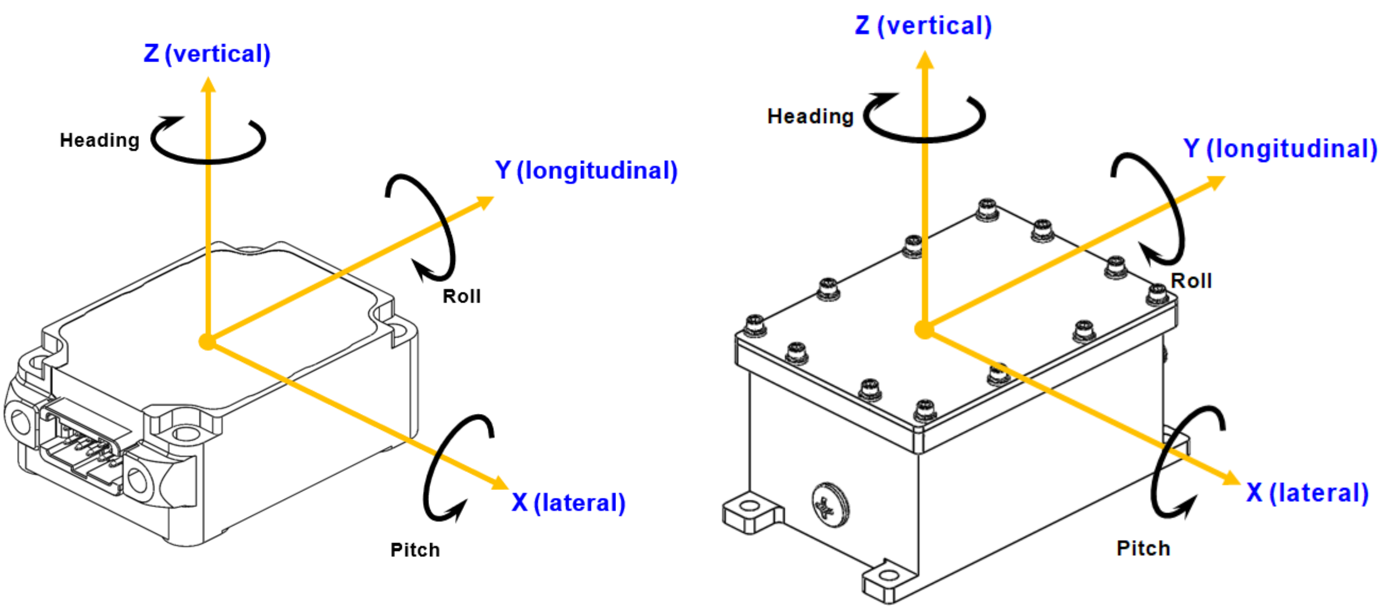

Figure 2.2. Coordinate System

Note: *Non-orthogonality between axes of the body-fixed system is in the order of 0.01°.*

3. Mechanical Interface

3.1. KERNEL-100 and KERNEL-102

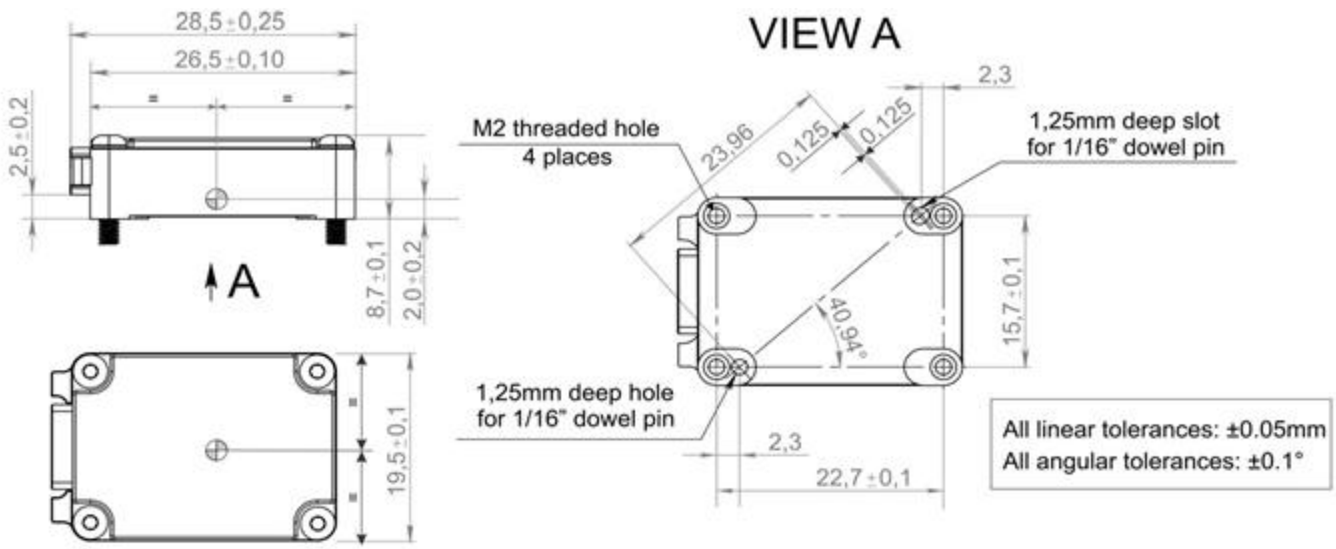

Figure 3.1. KERNEL-100/102 Outline Drawing

Notes:

1. *All dimensions are in millimeters (mm).*
2. *Type III Class 2 hard anodic coating per MIL-A-8625 (black color) surface finish.*

3.1.1. Mechanical Mounting

Figure 3.2 below shows the two mounting options available for the KERNEL-100 and 102. Make sure to use the recommended captive screws for mounting.

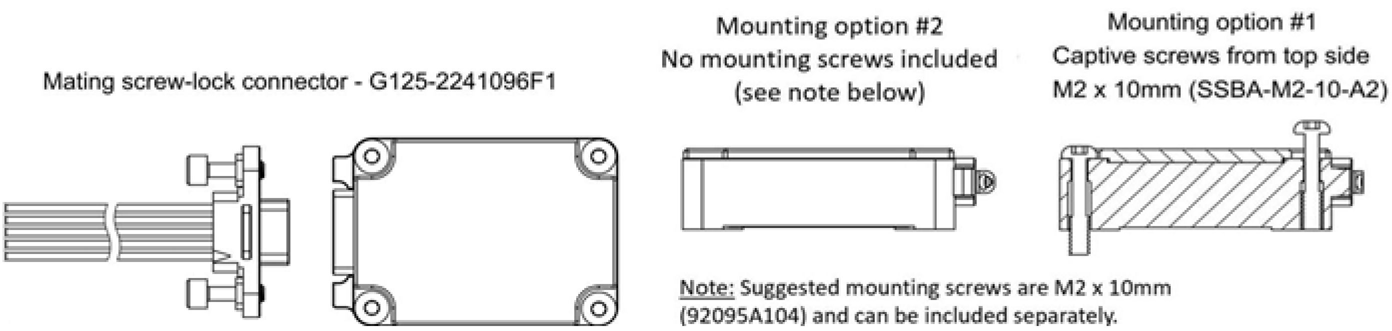

Figure 3.2. KERNEL-100/102 Mounting Options

3.2. KERNEL-108, KERNEL-110, KERNEL-120, KERNEL-210, and KERNEL-220

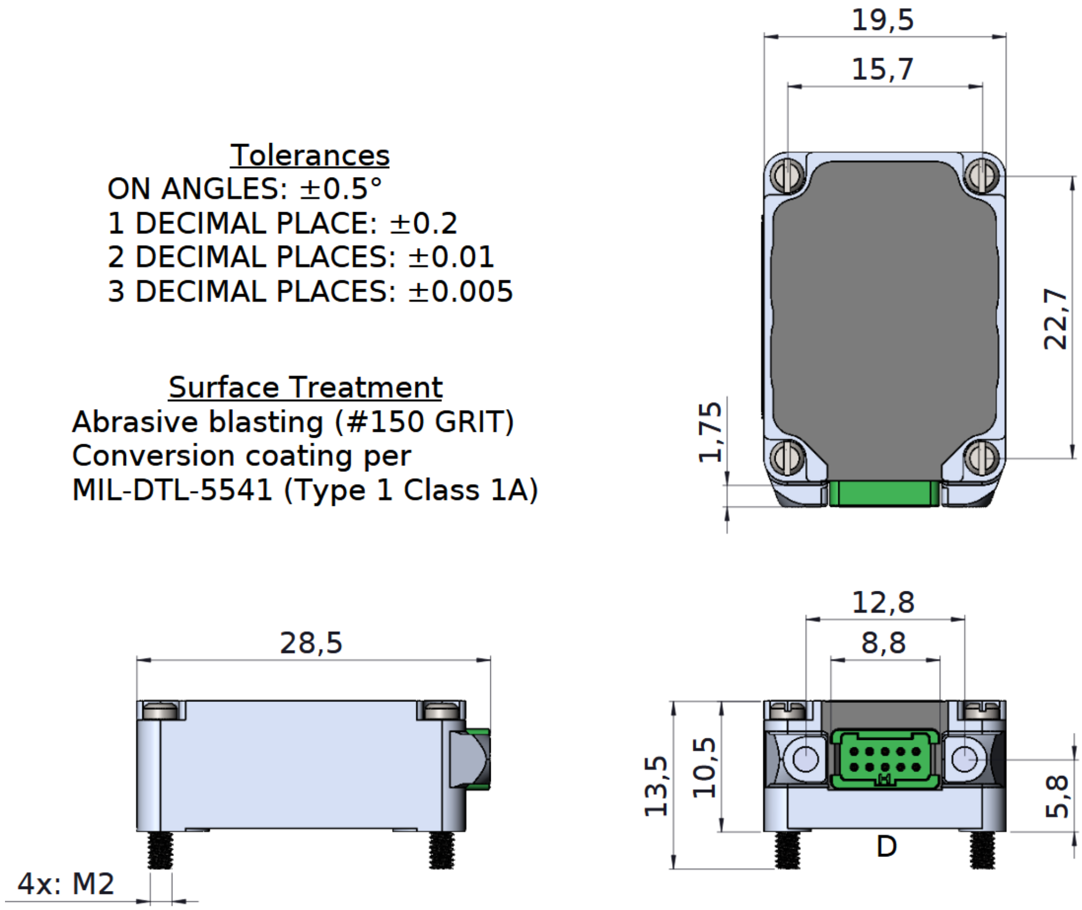

Figure 3.3. KERNEL-108/110/120/210/220 Outline Drawing

Note: *All dimensions are in millimeters (mm).*

3.2.1. Mechanical Mounting

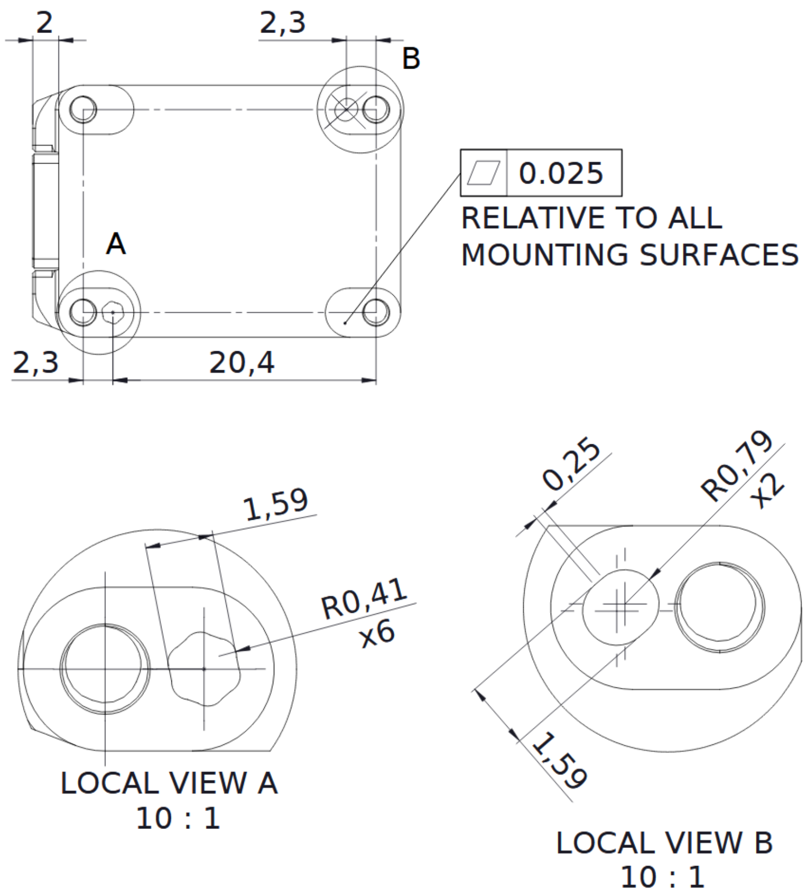

Figure 3.4. KERNEL-108/110/120/210/220 Mounting Details

Notes:

1. *The alignment features shown in local views A and B are designed for usage with a 1/16” dowel pin.*
2. *The product code determines whether the KERNEL is equipped with 10.5 mm or 12 mm captive screws. These mounting screws have a recommended maximum torque of 2.5 in-lbs.*

3.2.2. Center of Navigation

The position of the center of navigation depends on the specific product type. Choose the needed product code from the table below to see the list of applicable drawings.

Product code	Applicable figures
KERNEL-120-G2000-A40A90-TGA-C12-S-V1.2	Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8, Figure 3.9
KERNEL-120-G2000-A15A90-TGA-C12-S-V1.2	Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8, Figure 3.9
KERNEL-120-G2000-A8A90-TGA-C12-S-V1.2	Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8, Figure 3.9
KERNEL-108-G2000-A40-TGA-C12-A-V1.2 KERNEL-110-G2000-A40-TGA-C12-A-V1.2	Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.9
KERNEL-108-G2000-A15-TGA-C12-A-V1.2 KERNEL-110-G2000-A15-TGA-C12-A-V1.2	Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.9
KERNEL-108-G2000-A8-TGA-C12-A-V1.2 KERNEL-110-G2000-A8-TGA-C12-A-V1.2	Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.9

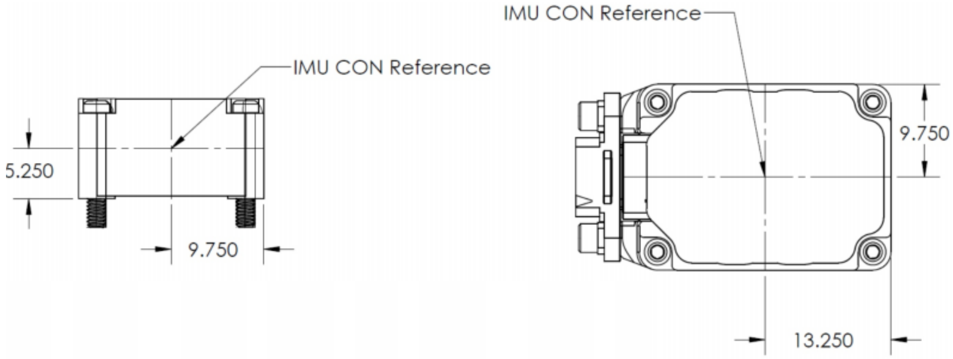

Figure 3.5. IMU Housing Center of Navigation Reference

Axis	X	Y	Z
Gyro XYZ	0.000	0.000	-1.640

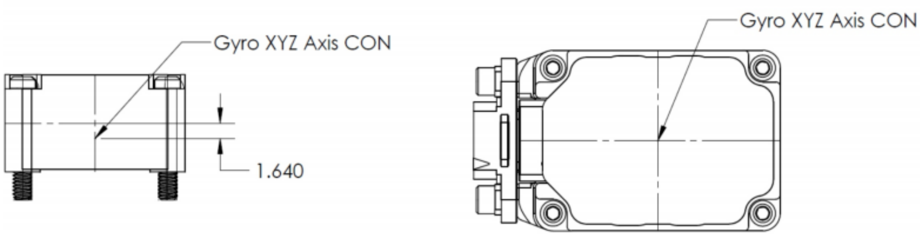

Figure 3.6. Gyro Center of Navigation Reference

Axis	X	Y	Z
XY	0.000	5.230	-0.120
Z	0.000	10.460	-0.570

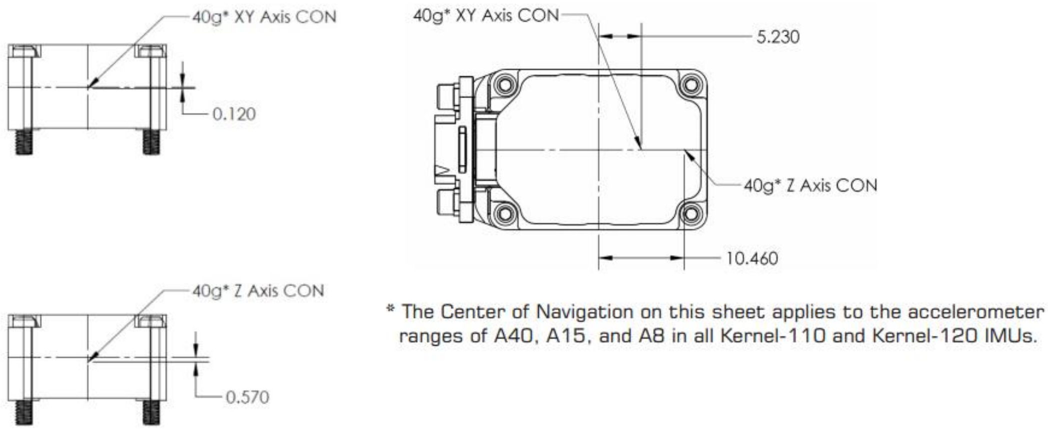

Figure 3.7. 40g Accelerometer Center of Navigation Reference

Axis	X	Y	Z
X	0.000	3.950	-0.370
Y	3.320	-0.070	-3.320
Z	3.320	4.010	-0.570

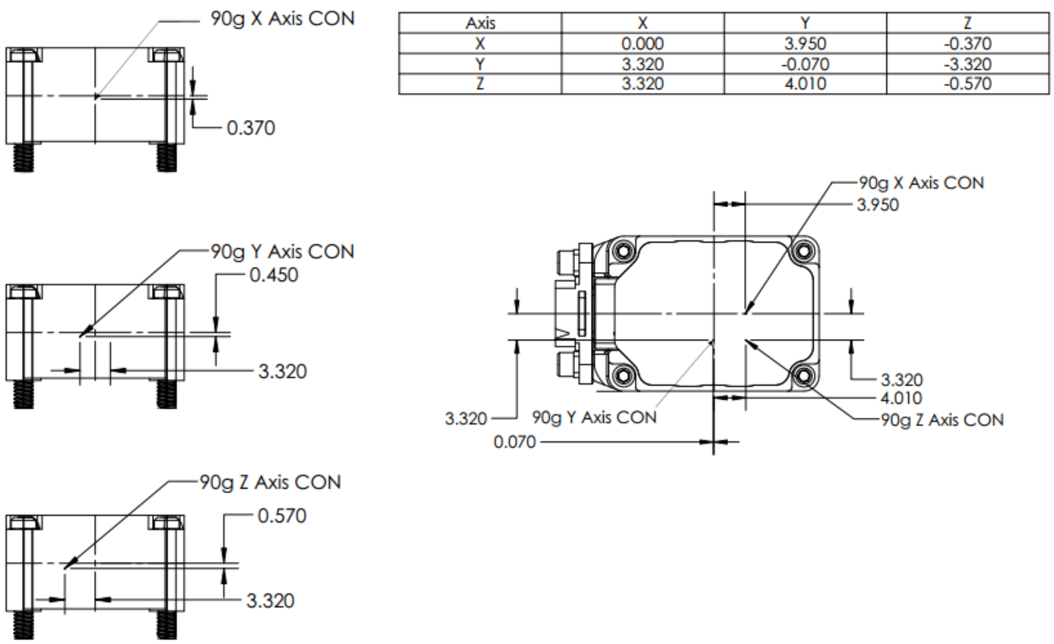

Figure 3.8. 90g Accelerometer Center of Navigation Reference

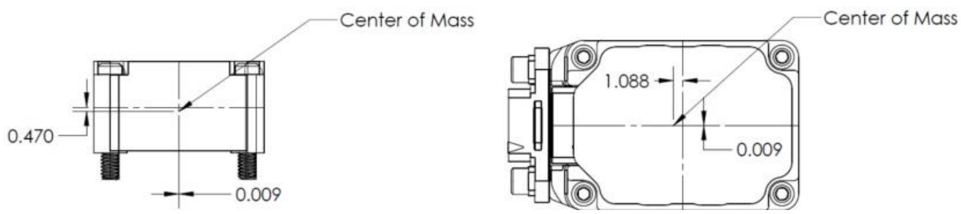

Figure 3.9. IMU Center of Mass with Interface Connector

3.3. KERNEL-110M

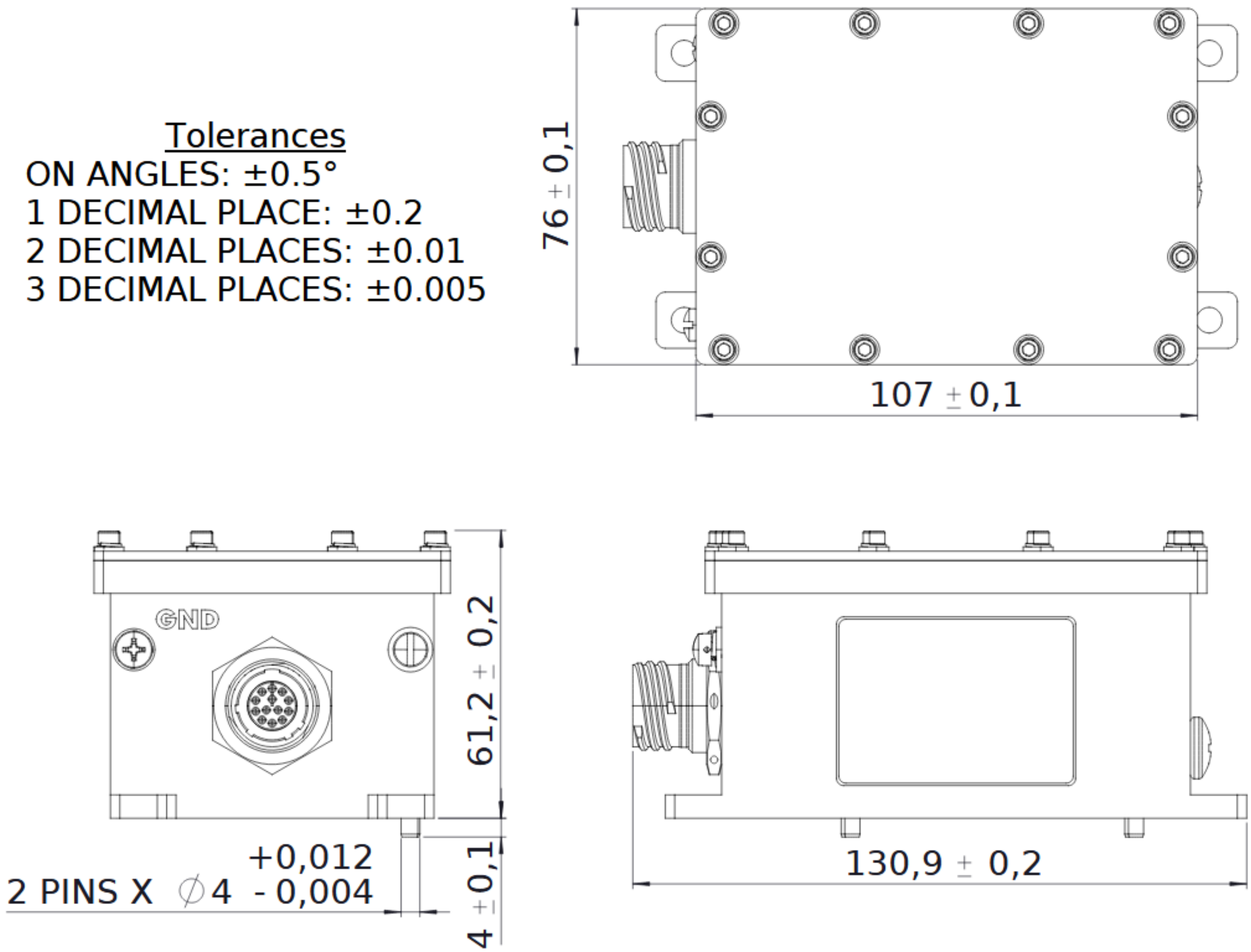

Figure 3.10. KERNEL-110M Outline Drawing

Note: *All dimensions are in millimeters (mm).*

3.3.1. Mechanical Mounting

Refer to **Figure 3.11** below for the measurements needed to mount the K110M. This IMU also includes two pins (**Figure 3.10**) for alignment.

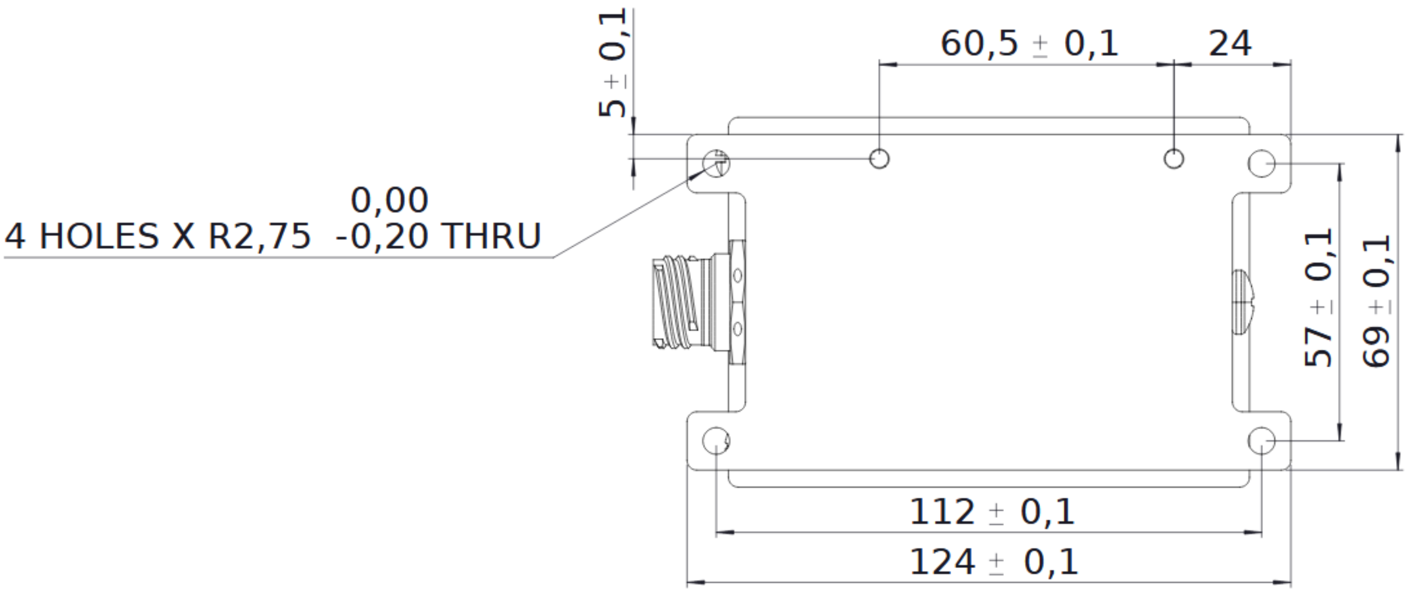

Figure 3.11. KERNEL-110M Mounting Details

The following section highlights the specifications for the enclosure painting and engraving on the KERNEL-110M:

1. **Color –** White (code #27885) according to FEDSTD-595. This applies to the intermediate and topcoat layers, but not the label.
2. **Primer –** One layer of lead and chromate-free Epoxy Primer according to MIL-DTL-53022 and the manufacturer's instructions. The layer thickness is 25-40µm and the drying time before the intermediate application is 8-24 hours at room temperature conditions.
3. **Intermediate –** Two layers of Epoxy Polyamide according to MIL-PRF-22750 and the manufacturer's instructions. Each layer has a thickness of 30-40µm and the drying time between these layers and the topcoat application is 6-48 hours at room temperature conditions.
4. **Topcoat –** Two layers of Polyurethane according to MIL-PRF-85285 and the manufacturer's instructions. Each layer has a thickness of 30-40µm and the drying time between layers is 1-24 hours at room temperature conditions.
5. **Total Thickness –** The total dry film thickness of the whole paint system is 145-200µm.
6. **Label –** Black (code #27038) according to FEDSTD-595 and letters filled with Polyurethane according to MIL-DTL-53039.

3.4. KERNEL-201

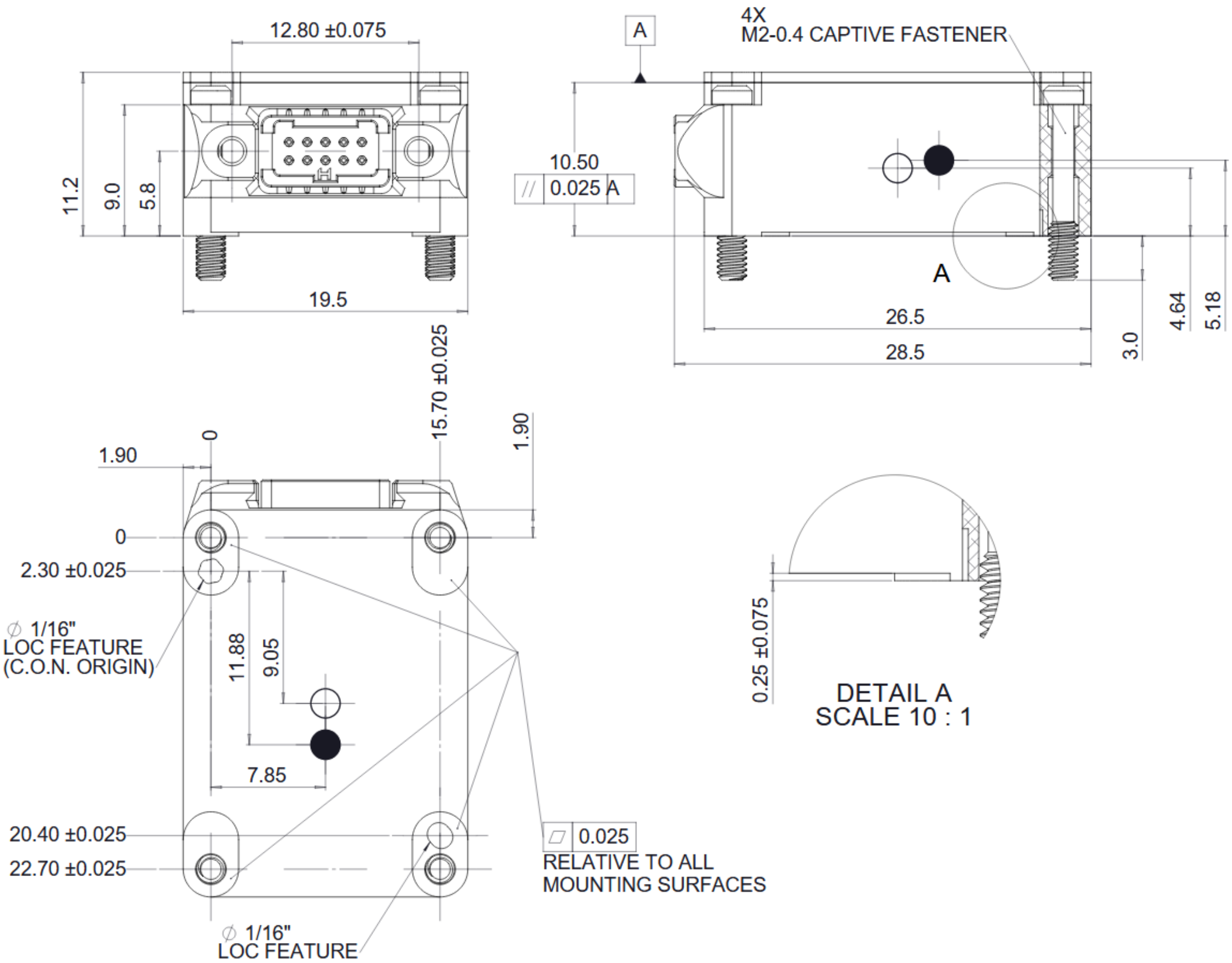

Figure 3.12. KERNEL-201 Outline Drawing

Notes:

1. *All dimensions are in millimeters (mm).*
2. *Surface treatment is Class 4 Grade A black electroless nickel plating per MIL-C-26074C.*

Refer to Table 3.1 for the center of navigation values shown in the outline drawing.

Table 3.1. KERNEL-201 Center of Navigation

Reference Point	X Dimension (mm) Relative to Origin	Y Dimension (mm) Relative to Origin	Z Dimension (mm) Relative to Origin
○ Accelerometer	7.85	9.05	4.64
● Gyroscope	7.85	11.88	5.18

4. Electrical Interface

4.1. Standard Configuration

The standard KERNEL IMU with no MIL-STD-1275 protection uses a 10-pin screw-lock Harwin connector (G125-MV11005L0P). The host system should have the appropriate female 10-pin Harwin cable (G125-2241096F1) to connect to the unit. Refer to **Figure 4.1** below for the electrical configuration of standard KERNEL devices.

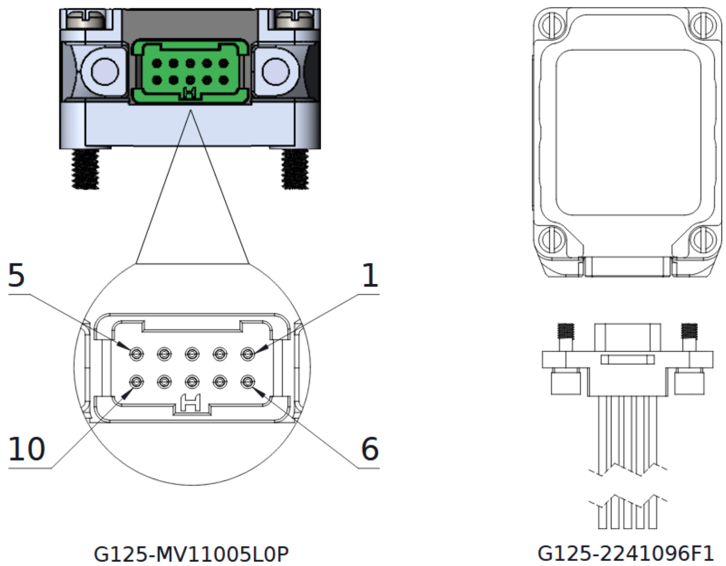

Figure 4.1. Standard Electrical Connection

Table 4.1 below contains the pin diagram for the standard Harwin connector used by KERNEL devices.

Table 4.1. Standard Electrical Pinout

Pin Number	Function	Description
1	POWER	Power Supply Input
2	BOOT	DO NOT CONNECT
3	1PPS	1PPS Input
4	RS422-A	RS-422 Non-Inverting Input
5	RS422-B	RS-422 Inverting Input
6	GROUND	Power Supply Return
7	TOV	Time of Validity Output
8	EXTRIG	External Trigger Input
9	RS422-Y	RS-422 Non-Inverting Output
10	RS422-Z	RS422 Inverting Output

Notes:

1. *Only KERNEL-100/108/110/120/210/220 devices support the EXTRIG function.*
2. *1PPS, TOV, and EXTRIG signals are 3.3V TTL and not 5V tolerant.*
3. *All pins comply with the Level 4 standard of IEC 61000-4-2 ESD protection.*
4. *For the KERNEL-100, the BOOT pin has an internal 10K pull-up resistor to 3.3V. The IMU enters firmware update mode if this pin is held low when supplied with power. Leave the pin floating if this state is unused.*
5. *For the KERNEL-108/110/120/201/210/220, the BOOT pin has an internal 10K pull-down resistor for supply return. As such, the device enters firmware update mode when this pin is held high once powered. If the voltage supply is >3.3V, use a resistive divider shown in Figure 4.2. Leave this pin floating when not in use.*
6. *The 1PPS signal resets the time field (Second Fraction) and sets the corresponding time flag in the GAm message. Refer to Section 3 for details.*

$$R1 = \frac{22k\Omega}{3v} V_{pullup} - 22k$$

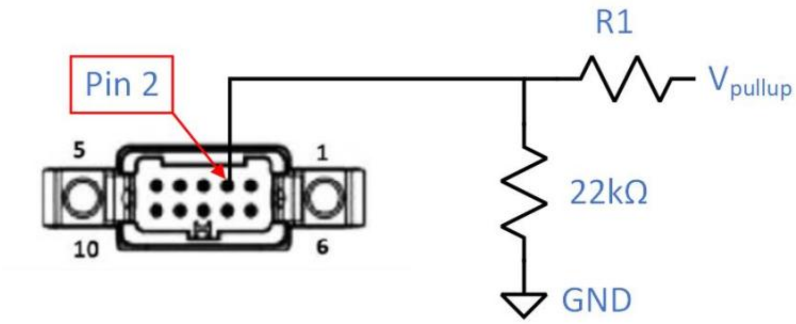

Figure 4.2. Resistive Divider

4.1.1. Electrical Specifications for Standard KERNEL Devices

Table 4.2. Standard KERNEL Power Specifications

KERNEL-100				
	Min	**Typical**	**Max**	**Units**
Supply Voltage	+4.0	+12.0	+15.0	VDC
Power	345	591	677	mW
Current	86	49	45	mA
KERNEL-102				
	Min	**Typical**	**Max**	**Units**
Supply Voltage	+5.0	+12.0	+24.0	VDC
Power	370	434	497	mW
Current	74	36	21	mA
KERNEL-108/110				
	Min	**Typical**	**Max**	**Units**
Supply Voltage	+5.0	+12.0	+30.0	VDC
Power	341	387	474	mW
Current	68	32	16	mA
KERNEL-120				
	Min	**Typical**	**Max**	**Units**
Supply Voltage	+5.0	+12.0	+30.0	VDC
Power	446	499	622	mW
Current	89	42	21	mA
KERNEL-201				
	Min	**Typical**	**Max**	**Units**
Supply Voltage	+5.0	+12.0	+30.0	VDC
Power	273	319	411	mW
Current	54	27	14	mA
KERNEL-210				
	Min	**Typical**	**Max**	**Units**
Supply Voltage	+5.0	+12.0	+30.0	VDC
Power	447	498	609	mW
Current	89	42	20	mA
KERNEL-220				
	Min	**Typical**	**Max**	**Units**
Supply voltage	+5.0	+12.0	+30.0	VDC
Power	465	533	645	mW
Current	93	44	21	mA

Table 4.3 below outlines the timing, interface, and pin specifications for all standard KERNEL IMUs.

Table 4.3. Standard KERNEL Electrical Specifications

Timing		
Start-up Time	<200	ms
RS422 Bitrate	2M	bits/sec
Internal Update Rate	2000 (4000 for K201)	Hz
Max Output Data Rate	2000 (4000 for K201)	Hz
Data latency	The data latency value depends on the KERNEL type. Refer to the device datasheet to find out this value.	-
RS422 Interface		
Start Bit	1	bit
Data Length	8	bits
Parity	None	**-**
Stop Bits	1	bit
EXTRIG Pin		
Low level Input	0.9	V
High level Input	2.1	V
Trigger Edge	Rising	-
Level duration	1	ns
TOV Pin		
Low Level Output	0.4	V
High Level Output	2.6	V
Rise and Fall Time	30	ns

Note: *Sections 4.1.2 - 4.1.4 provide further details on the parameters shown above.*

4.1.2. Data Latency

Data latency is the time between the sensor input and measured output signal. This time consists of:

- **Mechanical Gyroscope Latency**
- **Sampling Latency –** This value depends on the chosen output data rate. For example, the maximum latency that can appear between measurement and transferring time is 0.5ms at a data rate of 2000 Hz.
- **Transfer Latency –** This value depends on the baud rate set and the size of the output data. For example, to output GA data at 2M bps the transfer latency would be 0.16 msec.

Selecting the average data output or using the EXTRIG function increases the latency. Overall, the maximum latency for any standard KERNEL device is less than 2.5 msec.

4.1.3. EXTRIG Function

The host system can use the external trigger pin to signal the device to output a data packet with the latest available data immediately. The EXTRIG pin (#8 in **Figure 4.1**) has an internal 10k pull-up to 3.3V and cannot be used simultaneously with the TOV pin. EXTRIG can have any duty cycle, but the duration of any level should not be shorter than specified. Contact the Support team for additional information.

4.1.4. Time of Validity

KERNEL devices provide Time of Validity (TOV) output. The TOV pin (#7 in **Figure 4.1**) provides a signal indicating when the IMU data is sampled and when transmission is complete. This pin has an internal 10k pull-up to 3.3V and cannot simultaneously be used with the EXTRIG function. Refer to **Figure 4.3** for a TOV time diagram for a sampling value of 300 msec with an output data rate of 1kHz.

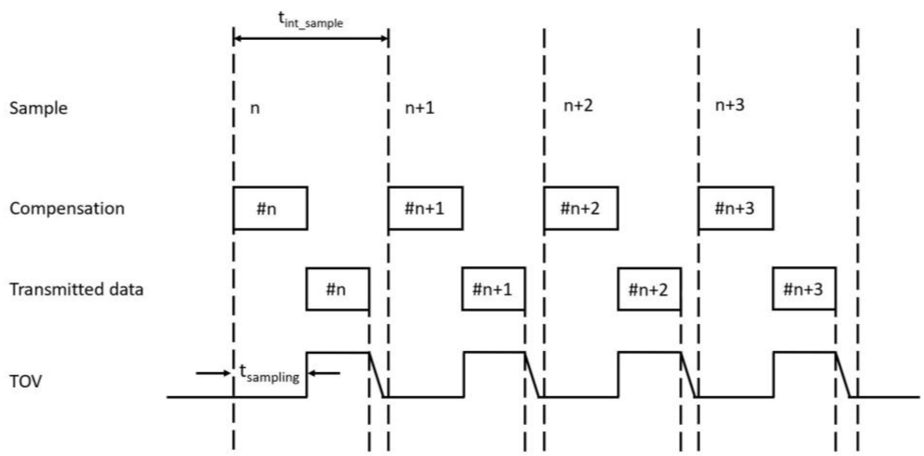

Figure 4.3. TOV Time Diagram

The rising edge occurs when the device's sensors are sampled for the next frame. The falling edge occurs after the last bit of the previous frame has finished transmission. Since the sum of time between the data latency and transmission is longer than the time between samples, this falling edge occurs during the previous sample's transmission.

4.2. MIL-STD-1275 Protection Configuration (KERNEL-110M)

The KERNEL-110M IMU can be equipped with one of the following connectors:

- **Marine Application** – Amphenol Aerospace, part number D38999/23YB35PN
- **Land Application** – Amphenol Aerospace, part number D38999/24WB35PN

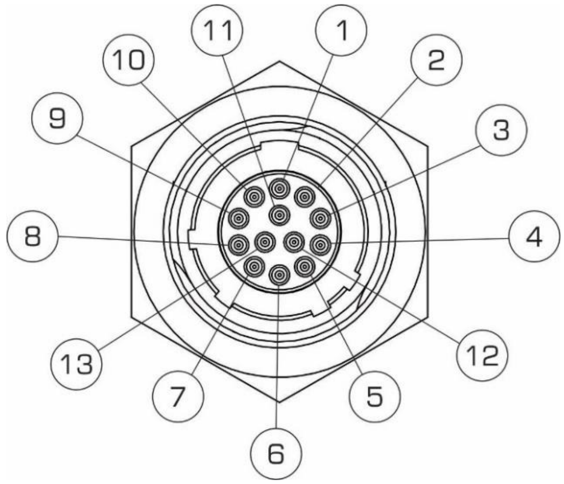

Figure 4.4. KERNEL-110M Mating Connector Pinout

Both connectors have the same 13-pin connector definition, seen in Table 4.4.

Table 4.4. KERNEL-110M Connector Pinout

Pin	Signal Name	Description	Direction	Source	Destination	Notes
1	EXTRIG	Discrete	Input	Host	IMU	Internally pulled to 4VDC via 100K
2	RS422_RXN	RS422	Input	Host	IMU	
3	1PPS (Optional)	Discrete	Input	Host	IMU	Internally pulled to 4VDC via 100K
4	RS422_RXP	RS422	Input	Host	IMU	
5	RS422_TXN	RS422	Output	IMU	Host	
6	RS422_TXP	RS422	Output	IMU	Host	
7	Reserved					
8	Reserved					
9	BOOT	Discrete	Input	Host	IMU	Internally pulled to 4VDC via 10K Pull down for firmware update. Leave floating if not used.
10	Reserved					
11	TOV	Discrete	Output	IMU	Host	Internally pulled down via 10K Output logic low – 0V Output logic high – SUPPLY_IN
12	SUPPLY _RTN	Power	Return	Host	IMU	
13	SUPPLY_IN	Power	Input	Host	IMU	

Table 4.5. KERNEL-110M Electrical Specifications

Power supply KERNEL-110M				
	Min	Typical	Max	Units
Supply voltage	5	24	30	VDC
Power	898	986	1034	mW
Current	50	35	32	mA
Electrical standards				
EMC/EMI	MIL-STD-461E			
Protection	MIL-STD-1275			

5. Software Interface

Refer to Table 5.1 for the default factory configuration of the RS-422 serial port connection from the device to the host.

Table 5.1. Default COM Port Parameters

Baud Rate	Data Bits	Parity	Stop Bits
115200 bps	8	None	1

Note: *Users can set baud rates other than 115200 bits per second. See Section 5.3.7 for more details.*

All commands and messages to/from the KERNEL IMU have the byte structure shown in the table below.

Table 5.2. Byte Structure for All Commands and Messages to/from the KERNEL IMU

Byte Number	0	1	2	3	4, 5	6 … (n+5)	n+6, n+7
Parameter	Header 0	Header 1	Message Type	KERNEL Data Identifier	Message Length	Payload	Check sum
Length	1 Byte	1 Byte	1 Byte	1 Byte	1 Word	n Byte (Variable)	1 Word
Note	0xAA	0x55	0x01	In KERNEL Messages	n+6		

Table 5.2 and all other tables use the following definitions:

- **word** = unsigned 2-byte integer
- **sword** = signed 2-byte integer

Message Type is equal to:

- 0 for commands.
- 1 for transferring data. All KERNEL IMU outputs are data and as such, this parameter is always 0x01.

KERNEL Data Identifier is equal to:

- The command code is sent from the host system to request a specific **data output.** Refer to Table A.1 for a full list of all the available commands and their exact structure.

Message Length is equal to:

- The number of bytes in the message, excluding the header. This value is the payload length (n) + 6 bytes.

Checksum is equal to:

- The arithmetical sum of bytes 2…(n-1). This includes all bytes except the header. Refer to Table 5.3 for the format of the checksum.

Table 5.3. Transmitted Checksum Format

Byte 0	Byte 1
Low Byte	High Byte

Important note: In all multi-byte data, the least significant byte (LSB) transmits first.

5.1. Operational Modes

The KERNEL IMU can work in the following operating modes:

Idle Mode

All sensors and electronics are on while the IMU microprocessor awaits any command from the host computer to start operating.

Continuous Mode

The IMU operates in an endless loop, outputting constant data according to the chosen output data format. Refer to Section 5.2 to view all supported data formats.

Firmware Update Mode

This mode allows the user to update the device's firmware. For additional information, see the separate firmware update guide provided by Inertial Labs.

5.2. Data Output Formats

The following output data formats are available for the KERNEL:

Table 5.4. Available Output Data Formats

Output Data Format	Section
Orientation Data	5.2.1
GA Data	5.2.2
GAm Data	5.2.3
Quaternion Data	5.2.4
Calibrated HR Data	5.2.5
GAA Data	5.2.6
GAAm Data	5.2.7
User Defined Data	5.2.8

Important: *The KERNEL-201 only supports the following data types and corresponding commands: GA, GAm, GAA, GAAm, and UDD. However, the data for the aux accelerometer will be zero.*

5.2.1. Orientation Data Format

This is the default data format, which provides data output from the KERNEL IMU in the form of:

- Three orientation angles (heading, pitch, and roll)
- Calibrated sensors (gyroscopes and accelerometers) output – This data provides information about the current angular rates and linear accelerations of the IMU.

The format of the orientation data block corresponds to Table 5.2, with the payload shown in Table 5.5 below.

Table 5.5. Orientation Data Message Payload

Byte Number	0 – 1	2 – 3	4 – 5	6 – 11	12 – 17	18 – 23
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ
Length	2-Byte Word	2-Byte Sword	2-Byte Sword	3×2-Byte Sword	3×2-Byte Sword	3×2-Byte Sword
Note	Orientation angles, deg*100			Angular rates, deg/s*KG	Accelerations, g*KA	Always equal to 0 (not measured)

Table 5.5 (continued)

Byte Number	24–27	28 – 29	30 – 31	32 – 33
Parameter	Reserved	USW	Reserved	Temper
Length	4-Byte Word	2-Byte Word	2-Byte Word	2-Byte Sword
Note		See Section 5.4		Temperature, °C*10

Notes:

1. *g = 9.8106 m/s²*
2. *KG and KA are scale factors dependent on the gyro and acc. range (Table 5.6).*
3. *Angular rates and linear accelerations use the carrier object axes (X = Lateral Axis, Y = Longitudinal Axis, Z = Vertical Axis). Set the IMU orientation relative to the carrier object axes with the alignment angles (see Appendix B).*
4. *Data from the gyroscopes and accelerometers can be in the form of instant, average, or incremental values*
5. *Temper is the average temperature of gyros in the IMU.*
6. *LSB transmits first.*

Table 5.6. KG and KA Factor Values

Gyroscope Range, deg/sec	450	950	2000
KG	50	20	10
Accelerometer Range, g	**8**	**15**	**40**
KA	4000	2000	500

5.2.2. GA Data Format

This format outputs calibrated gyro and accelerometer data with high resolution. It contains information about the current angular rates and linear accelerations of the IMU. The GA data format corresponds to Table 5.2 with the payload shown below.

Table 5.7. GA Data Message Payload

Byte Number	0 – 11	12 – 23	24 – 25	26 – 27	28 – 29	30 – 31
Parameter	GyroX, Gyro Y, GyroZ	AccX, AccY, AccZ	Counter	USW	Reserved	Temper
Length	3×4-Byte Integer	3×4-Byte Integer	2-Byte Word	2-Byte Word	2-Byte Word	2-Byte Sword
Note	Angular Rates, deg/s*10^5	Accelerations, g*10^6	See Note 3	See Section 5.4		Temperature, °C*10

Notes:

1. *g = 9.8106 m/²*
2. *The angular rates and linear accelerations are in the carrier object axes (X = Lateral Axis, Y = Longitudinal Axis, Z = Vertical Axis). Set the IMU orientation relative to the carrier object axes with the alignment angles (see Appendix B).*
3. *The counter represents the frequency of the internal device computations, in increments of 2kHz.*
4. *LSB transmits first.*

5.2.3. GAm Data Format

The GAm data format provides high resolution gyroscope and accelerometer outputs. Additionally, GAm shows time flag and second fraction information. The structure of this data block corresponds to Table 5.2 with the payload shown in Table 5.8.

Table 5.8. GAm Data Message Payload

Byte Number	0 – 11	12 – 23	24 – 25	26 – 29	30 – 31
Parameter	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	Time Flag	Second Fraction	Temperature
Length	3×4-Byte Integer	3×4-Byte Integer	2-Byte Unsigned Integer	4-Byte Unsigned Integer	2-Byte Signed Integer
Note	Angular rates, deg/s*10^5	Accelerations, g*10^6	Note 2	Second Fraction, nsec	Temperature, °C*10

Notes:

1. *g = 9.8106 m/s²*
2. *The time flags are as follows:*
   - *0x0001 – 1PPS received between the last and current frame.*
   - *0x0008 – No 1PPS for more than one second.*
3. *LSB transmits first.*

5.2.3.1. Second Fraction

The values for the second fraction vary depending on the availability of PPS. Before the device receives the first PPS signal, the second fraction values align to the IMU's power-on. Once the IMU receives the first 1PPS, all future values align to that signal. Note, it is possible to experience drift in these values if the 1PPS is lost. However, the second fraction value immediately re-aligns to the signal once it receives 1PPS again.

5.2.4. Quaternion Data Format

The quaternion data format provides orientation information in both Euler angles and quaternion of orientation. Refer to Appendix C for additional details on the relationship between these angles. The structure of this data block corresponds to Table 5.2 with the payload shown in Table 5.9 below.

Table 5.9. Quaternion Data Message Payload

Byte Number	0 – 1	2 – 3	4 – 5	6 –13	14 – 27	28 – 29	30 – 31	32 – 33
Parameter	Heading	Pitch	Roll	q0, q1, q2, q3	Reserved	USW	Reserved	Temper
Length	2-Byte Word	2-Byte Sword	2-Byte Sword	4x2-Byte Sword	14 Bytes	2-Byte Word	2-Byte Word	2-Byte Sword
Note	Orientation angles, deg*100			Quaternion of Orientation *10000		Section 5.4		Temperature, °C*10

5.2.5. Calibrated HR Data Format

The calibrated HR data format provides KERNEL data in the form of:

- High resolution orientation (relative heading, pitch, and roll) angles
- Calibrated sensors (gyroscopes and accelerometers) output – This data provides high resolution information about the current angular rates and linear accelerations of the KERNEL.
- Additional parameters – counter, USW, and temperature

The structure of this data block corresponds to Table 5.2 with the payload shown in Table 5.10 below.

Table 5.10. Calibrated HR Data Message Payload

Byte Number	0 – 3	4 – 7	8 – 11	12 – 23	24 – 35	36 – 41
Parameter	Heading	Pitch	Roll	GyroX, GyroY, GyroZ	AccX, AccY, AccZ	MagX, MagY, MagZ
Length	4-Byte Integer	4-Byte Integer	4-Byte Integer	3×4-Byte Integer	3×4-Byte Integer	3×2-Byte Sword
Note	Orientation Angles, deg*1000			Angular Rates, deg/s*10^5	Accelerations, g*10^6	0 for KERNELs (not measured)

Table 5.10 (continued)

Byte Number	42 – 43	44 – 45	46 – 47	48 – 49	50 – 51
Parameter	Counter	Reserved	USW	Reserved	Temper
Length	2-Byte Sword	2-Byte Sword	2-Byte Word	2-Byte Word	2-Byte Sword
Note	Note 3		Section 5.4		Temperature, °C*10

Notes:

1. *$g = 9.8106$ m/^{2}*
2. *The angular rates and linear accelerations are in the carrier object axes (X = Lateral Axis, Y = Longitudinal Axis, Z = Vertical Axis). Set the IMU orientation relative to the carrier object axes with the alignment angles (see Appendix B).*
3. *The counter represents the frequency of the internal device computations, in increments of 2kHz.*
4. *Temper is the average temperature of the three gyros.*
5. *LSB transmits first.*

5.2.6. GAA Data Format

Important: *This output data format is intended ONLY for the KERNEL-120 and KERNEL-220 models. Though other models may still run this data format, the accelerometer information will not be accurate.*

The GAA data format is based on the KERNEL GA Data format. The only difference in the message structure is the addition of data from one more accelerometer. The structure of this data block corresponds to Table 5.2, with the payload shown below.

Table 5.11. GAA Data Message Payload

Byte Number	0 – 11	12 – 23	24 – 35	36 – 37	38 – 39	40 – 41	42 – 43
Parameter	GyroX, Gyro Y, GyroZ	Acc1X, Acc1Y, Acc1Z	Acc2X, Acc2Y, Acc2Z	Reserved	USW	Reserved	Temper
Length	3×4-Byte Integer	3×4-Byte Integer	3×4-Byte Integer	2-Byte Word	2-Byte Word	2-Byte Word	2-Byte Sword
Note	Angular rates, deg/s*10^5	Accelerations, g*10^6	Accelerations, g*10^6		Section 5.4		Temperature, °C*10

Notes:

1. *g = 9.8106 m/s²*
2. *The angular rates and linear accelerations are in the carrier object axes (X = Lateral Axis, Y = Longitudinal Axis, Z = Vertical Axis). Set the IMU orientation relative to the carrier object axes with the alignment angles (see Appendix B).*
3. *LSB transmits first.*

5.2.7. GAAm Data Format

Important: *This output data format is intended ONLY for the KERNEL-120 and KERNEL-220 models. Though other models may still run this data format, the accelerometer information will not be accurate.*

The GAAm data format is based on the GAm Data format. The only difference in the message structure is the addition of data from one more accelerometer. The structure of this data block corresponds to Table 5.2, with the payload shown in Table 5.12.

Table 5.12. GAAm Data Message Payload

Byte Number	0 – 11	12 – 23	24 – 35	36 – 37	38 – 41	42 – 43
Parameter	GyroX, GyroY, GyroZ	Acc1X, Acc1Y, Acc1Z	Acc2X, Acc2Y, Acc2Z	Time Flag	Second fraction	Temperature
Length	3×4-Byte Integer	3×4-Byte Integer	3×4-Byte Integer	2-Byte Unsigned Integer	4-Byte Unsigned Integer	2-Byte Signed Integer
Note	Angular rates, deg/s*10^5	Accelerations, g*10^6	Accelerations, g*10^6	See Note 2	in nsec	Temperature, °C*10

Notes:

1. *g = 9.8106 m/s²*
2. *The time flags are as follows:*
   - *0x0001 – 1PPS received between the last and current frame.*
   - *0x0008 – No 1PPS for more than one second.*

The values for the second fraction vary depending on the availability of PPS. Before the device receives the first PPS signal, the second fraction values align to the IMU's power-on. Once the IMU receives the first 1PPS, all future values align to that signal. Note, it is possible to experience drift in these values if the 1PPS is lost. However, the second fraction value immediately re-aligns to the signal once it receives 1PPS again.

5.2.8. User Defined Data Output Format

The User Defined Data (UDD) format allows users to request variable configurations of data types to output via the User_Def_Data command (Appendix A). The structure of the UDD blocks corresponds to Table 5.2, with the payload shown in Table 5.13.

Table 5.13. UDD Payload

Field	Payload Offset, bytes	Size, bytes	Value
Package Number	0	1	Number of data packages present in the payload (N)
Data List	1	N	List of data types, one per byte (refer to Table 5.14 below outlines all available data formats in the UDD format. This includes a brief description of each data type, split into specific groups. Table 5.14 for values)
Data #1	N+1	Variable, depends on data type (refer to Table 5.15 for sizes)	Data according to structure shown in Table 5.15
Data #2	Variable, depends on Data #1 size	Variable, depends on data type	Data according to structure shown in Table 5.15
…	…	…	…
Data #N	Variable, depends on preceding data	Variable, depends on data type	Data according to structure shown in Table 5.15

Table 5.14 below outlines all available data formats in the UDD format. This includes a brief description of each data type, split into specific groups.

Table 5.14. Available UDD Types

Data Group	Data Type	Description
Time Data	0x02	IMU Time
	0x05	Second Fraction (applicable only to certain IMUs)
Orientation Data	0x07	Orientation Angles (Euler)
	0x08	Orientation Angles HR (Euler)
	0x09	Quaternion of Orientation
Sensors Data	0x20	Gyro Data
	0x21	Gyro Data HR
	0x22	Accelerometer Data
	0x23	Accelerometer Data HR
	0x2D	Bias-compensated Gyro Data
	0x2E	Gyro Bias (not supported for K100, K102, and K201)
	0x2F	Aux Accelerometer (applicable only to K120 and K220)
	0x91	Filtered Low-G Accels HR

	0x92	Filtered High-G Accels HR
IMU Service Data	0x50	Supply Voltage
	0x52	Temperature
	0x53	Unit Status Word (USW)
	0x5B	USW Extended

Table 5.15. Detailed Description of UDD Structure

Data Type	Description	Size, bytes	Structure	Notes
0x02*	IMU time	8	Unsigned Integer	The time, in sec*10^9, it takes to get an IMU solution from the time power is applied to the device.
0x05	Second Fraction (applicable only to certain IMUs)	4	Unsigned Integer	The fraction of the second, in nsecs. Refer to Section 5.2.3.1. for more information.
0x07	Orientation Angles	6	Word	Heading, in deg*100
			Sword	Pitch, in deg*100
			Sword	Roll, in deg*100
0x08	Orientation Angles HR	12	Unsigned Integer	High-resolution heading, in deg*1000
			Integer	High-resolution pitch, in deg*1000
			Integer	High-resolution roll, in deg*1000
0x09	Quaternion of Orientation	8	Sword	q0*10^4
			Sword	q1*10^4
			Sword	q2*10^4
			Sword	q3*10^4
0x20	Gyro Data	6	Sword	Instant/Average Data – GyroX in deg/s*KG Incremental Data – GyroX in deg*KG Refer to Section 5.3.6 and Note 1 for details.
			Sword	Instant/Average Data – GyroY in deg/s*KG Incremental Data – GyroY in deg*KG
			Sword	Instant/Average Data – GyroZ in deg/s*KG Incremental Data – GyroZ in deg*KG
0x21*	Gyro Data HR	12	Integer	Gyro X values above with 10^5 resolution
			Integer	Gyro Y values above with 10^5 resolution
			Integer	Gyro Z values above with 10^5 resolution
0x22	Accelerometer Data	6	Sword	Instant/Average Data – AccX in g*KA Incremental Data – AccX in g*s*KA Refer to Section 5.3.6 and Note 1 for details.
			Sword	Instant/Average Data – AccY in g*KA Incremental Data – AccY in g*s*KA
			Sword	Instant/Average Data – AccZ in g*KA Incremental Data – AccZ in g*s*KA
0x23*	Accelerometer Data HR	12	Integer	AccX values above with 10^6 resolution
			Integer	AccY values above with 10^6 resolution
			Integer	AccZ values above with 10^6 resolution
0x2D		12	Integer	Gyro X, in deg/s*10^5

	Bias-compensated Gyro Data		Integer	Gyro Y, in deg/s*10^5
			Integer	Gyro Z, in deg/s*10^5
0x2E	Gyro Bias (not supported for K100, K102, and K201)	12	Integer	Gyro X bias, in deg/s*10^5
			Integer	Gyro Y bias, in deg/s*10^5
			Integer	Gyro Z bias, in deg/s*10^5
0x2F	Aux Accelerometer (only for K120 and K220)	12	Integer	Aux accelerometer X, in g*10^6
			Integer	Aux accelerometer Y, in g*10^6
			Integer	Aux accelerometer Z, in g*10^6
0x91	Filtered Low-G Accels HR	12	Integer	Filtered low-G accelerometer X, in g*10^6
			Integer	Filtered low-G accelerometer Y, in g*10^6
			Integer	Filtered low-G accelerometer Z, in g*10^6
0x92	Filtered High-G Accels HR	12	Integer	Filtered high-G accelerometer X, in g*10^6
			Integer	Filtered high-G accelerometer Y, in g*10^6
			Integer	Filtered high-G accelerometer Z, in g*10^6
0x50	Supply Voltage	2	Word	VDC*100 (Applicable only to K100 and K102)
0x52*	Temperature	2	Sword	The average temperature of the device's three gyroscopes, in °C*10.
0x53*	Unit Status Word	2	Word	Unit Status Word (see Section 5.4)
0x5B	Unit Status Word Extended	2	Word	Provides additional USW information not included in 0x53 (see Section 5.4).

Notes:

1. *KG and KA are scale factors dependent on the gyro and acc. range (Table 5.6).*
2. *g = 9.8106 m/s²*
3. *Angular rates and linear accelerations use the carrier object axes (X = Lateral Axis, Y = Longitudinal Axis, Z = Vertical Axis). Set the IMU orientation relative to the carrier object axes with the alignment angles (see Appendix B).*
4. *LSB transmits first.*
5. *Users may encounter an error when attempting to load data types not marked by an asterisk (*) to KERNEL-201 devices.*

To choose the desired output data types, use the User_Def_Data_Config command. To view the previously set UDD configuration, use the Get_User_Def_Data_Struct command. Refer to Section 5.3.5 for more details.

Note, the package length for the UDD format is variable and dependent upon its data configuration. As such, the maximum data rate for the device's output also varies but can be estimated using Formula 5.1 in Section 5.5. If the data rate exceeds the maximum allowed value at the chosen baud rate, however, the KERNEL will automatically decrease the set data rate to the allowed value. The device then informs the user about this change in response to the User_Def_Data_Config command.

5.3. Control of the IMU

Use the following commands to control the KERNEL IMU:

- KERNEL_Orientation;
- KERNEL_GAData;
- KERNEL_GAmData;
- KERNEL_GAAData;
- KERNEL_GAAmData;
- KERNEL_QuatData;
- KERNEL_CalibHR;
- User_Def_Data;
- Stop;
- GetDevInfo;
- GetBIT;
- SaveFlash;
- ReadRAM;
- CommitBaudRate.

All these commands have the byte structure shown in Table 5.2, with a payload of one byte which contains a code to identify the command. See Table A.1 for the exact structure of these commands.

Important: *Certain commands may not be available for a particular KERNEL type. Contact the Support team for additional details.*

5.3.1. KERNEL_Data Commands

Use the data commands to start the KERNEL IMU in continuous operating mode. Refer to Table 5.16 below to see the available output data formats used with these commands.

Table 5.16. Control Commands for Output Data Formats

Command	Code	Output Data Format	
		Name	Structure
KERNEL_Orientation	0x33	Orientation Data	Inertial Labs binary structure according to Table 5.2, with a payload of one byte containing the command code.
KERNEL_GAData	0x8F	GA Data	
KERNEL_GAmData	0x9B	GAm Data	
KERNEL_GAAData	0xA5	GAA Data	
KERNEL_GAAmData	0xA6	GAAm Data	
KERNEL_QuatData	0x82	Quaternion Data	
KERNEL_CalibHR	0x81	Calibrated High Resolution Data	
User_Def_Data	0x95	User Defined Data	

The KERNEL will respond immediately to acknowledge the commands. This response has the byte structure shown in Table 5.2, wherein the payload is the calculated checksum. This payload should be equal to the checksum in the message sent to the IMU. Verify this is correct before proceeding.

For data formats that output quaternion or orientation angles, the KERNEL will then begin the process of initial alignment. During this time, the unit undergoes gyro bias estimation and fuses inertial data to calculate orientation. As such, it is important not to move the IMU during this process. If disregarded, the accuracy of the orientation solution will decrease. By default, the initial alignment time is two seconds. However, it is best to increase this to the largest possible value (30 seconds).

Important: *If the device must start while the carrier object is in motion or if it is impossible to remain stationary, users may skip the initial alignment process. Setting the initial alignment time to zero seconds will result in a decrease to the device's dynamic accuracy.*

Once the initial alignment is complete, the KERNEL goes into continuous operating mode. During this time, the IMU operates in an endless loop, providing the data from the output format chosen by the user. Note, this happens immediately after the device's checksum response for commands that do not include any quaternion or orientation angles.

5.3.2. Stop Command

0xAA 0x55 0x00 0x00 0x07 0x00 0xFE 0x05 0x01

This command halts all device output, switching the IMU from operating to idle mode. In this mode, the device is ready to receive further commands from the host computer.

5.3.3. GetDevInfo Command

0xAA 0x55 0x00 0x00 0x07 0x00 0x12 0x19 0x00

The GetDevInfo command obtains detailed information about the KERNEL IMU. In response, the IMU sends a message with a structure according to Table 5.2 and the payload shown in Table 5.17.

Table 5.17. Payload of the KERNEL Response to the GetDevInfo Command

Byte	Parameter	Format	Length	Note
0-7	ID_sn	char	8	Device serial number
8-47	ID_fw	char	40	Device firmware version
48	Reserved	byte	1	-
49	IMU_type	byte	1	Type of IMU
50-57	IMU_sn	char	8	Duplicated device serial number
58-97	IMU_fw	char	40	Duplicated device firmware version
98-165	Reserved	byte	68	-

5.3.4. GetBIT Command

0xAA 0x55 0x00 0x00 0x07 0x00 0x1A 0x21 0x00

The GetBIT command is used to identify the IMU current health status. In response, the IMU sends out a message with data according to the Table 5.18.

Table 5.18. Payload of the KERNEL Response to the GetBIT Command

<table>
<tr><th>Byte</th><th>Bit</th><th>Parameter</th><th>Description</th></tr>
<tr><td rowspan="5">0
(Low byte)</td><td>0</td><td rowspan="2">Accelerometer BIT Result</td><td rowspan="2">0 – Okay
2 – Okay
Anything Else – Report issue to Inertial Labs for analysis.</td></tr>
<tr><td>1</td></tr>
<tr><td>2</td><td rowspan="3">Gyroscope BIT Result</td><td rowspan="3">0 – Okay
Anything Else – Report issue to Inertial Labs for analysis.</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td></tr>
</table>

	5		
	6		
	7		
1	8	Reserved	-
	9		
	10	Reserved	-
	11		
	12	Flash Check	0 – Ok Anything Else – Report issue to Inertial Labs for analysis.
	13		
	14	Reserved	-
	15		
2	16-23	Reserved	-
3 (High byte)	24-31	Reserved	-

5.3.5. User Defined Data Commands

The User_Def_Data_Config command allows users to set the desired data set to output through the UDD format:

0xAA 0x55 0x00 0x00 0x07 0x00 0x96 0x9D 0x00

Send this command, followed immediately by a message with the block of parameters listed in Table 5.19. This message has the byte structure shown in Table 5.2, with the code 0x96 in the payload field.

Table 5.19. Payload of Message Sent After UDD Config Command / Response from Get UDD Command

Byte	Parameter	Format	Length	Note
0	Package Number	Byte	1	Number of data packages for output (N)
1 to N	Data List	Byte	N	List of data types, one per byte (refer to Table 5.14 below outlines all available data formats in the UDD format. This includes a brief description of each data type, split into specific groups. Table 5.14 for values)

The KERNEL calculates the checksum of the received message with parameters and returns it for user validation. Additionally, the IMU checks the validity of the data types. The byte structure of the KERNEL response corresponds to Table 5.2, where the payload is shown in Table 5.20.

Table 5.20. Payload of IMU Response to the UDD Config Command

Byte Number	0 – 1	2	3 – 4	5 - 6	7

Parameter	Checksum of the Received Message	Data List Error	Accuracy of Data Types	Maximum Data Rate (Hz)	Reserved
Length	1 Word	1 Byte	1 Word	1 Byte	1 Byte

Notes:

1. *The calculated checksum in bytes 0 – 1 should equal the checksum of the message sent using Table 5.19. Otherwise, the KERNEL will ignore the UDD Config command.*
2. *Refer to Table 5.21 for the values and corresponding descriptions of data list errors.*
3. *Bytes 3 – 4 indicate whether the first 16 ordered data types are correct. If the i-th data type is correct, then the i-th bit of this parameter is zero. If it is not zero, the IMU will ignore this command.*

Table 5.21. Data List Error Codes

Bit	Value and description
0	1 – incorrect structure of the message following the User_Def_Data_config command, with payload listed in Table 5.19 0 – no errors in the message structure
1	1 – incorrect data in the payload (Table 5.19) of the message following the User_Def_Data_config command 0 – no errors in the payload
2	1 – wrong data types are ordered 0 – no errors in data types. Wrong data types are shown in the “Data list correctness” field of the KERNEL response (Table 5.20)
3	1 – ordered list of data is too large for current output data rate and COM-port baud rate; 0 – size of KERNEL output data meets current data rate and COM-port baud rate

Note: *If any bit from 0 – 2 is equal to one, the IMU will ignore the UDD Config command. In this case, the checksum of the message after will not be calculated and bytes 0 – 1 in Table 5.20 will be zero. If bit 3 is equal to one, the IMU will correct the data rate to an allowed lower value. The IMU checks the compliance of the data package size against the data/baud rate for all other data formats too.*

The Get_User_Def_Data_Struct command allows users to check the previously set data structure:

0xAA 0x55 0x00 0x00 0x07 0x00 0x97 0x9E 0x00

As a response to this command, the KERNEL sends out a message with the information shown in Table 5.19 as the payload. Refer to Table 5.2 for the byte structure of this command.

5.3.6. IMU Output Variant

There are three different ways the KERNEL can output data, shown below:

- **Instant Sensors Data** – immediately outputs the exact values as measured by the accelerometers and gyroscopes for all three axes.
- **Average Sensors Data** – computes averages based on the internal algorithm rate, 2kHz. If the device's data rate is also 2kHz, the average data will be "instant". However, if the IMU's data rate is 500 Hz, this output format will compute the mean four values per sensor and per axis. The KERNEL then outputs this calculation as a singular averaged value.
- **Incremental Sensors Data** – outputs the change in each angular rate or acceleration based upon the previous output value. Gyro and accelerometer data is presented here as the angle increment (Delta Theta, deg) and velocity increment (Delta Velocity, g*sec) between the two data messages, divided by the time step of data output.

Use the SaveFlash command to set the device's data variant. To do this, modify the Output_Variant parameter from Table 5.24 or use the IMU GUI.

5.3.7. SaveFlash Command

The SaveFlash command directly changes the value of an individual parameter in the IMU flash memory. Refer to Table 5.24 for a list of parameters available to change. Table 5.22 shows the structure for the SaveFlash command.

Important:

1. *To ensure that all modified parameters are correctly applied and used at startup, the device must be power-cycled after configuration.*
2. *In all multi-byte data LSB is first.*

Table 5.22. SaveFlash Command Structure

Byte	0 – 3	4 – 5	6 – (n-1)	N – (n+1)
Parameter	Header	Command Length	Payload	Checksum
Length	4-Byte Integer	2-Byte Word	Variable	2-Byte Word
Note	0xAA 0x55 0x00 0x00	Variable	See Table 5.23	Variable

Header

The header has permanent value in the SaveFlash command. To ensure the command is sent, do not change the header.

Command Length

Use either of the formulas listed below to calculate the length of the command:
Command Length (n) = Payload Length + 6
Command Length (n) = Whole Packet Length – 2

Payload

Table 5.23. Payload Structure for SaveFlash Command

Byte	0 – 1	2 – 3	4 – 5	6 – ...
Parameter	Command ID	Changing Parameter ID	Changing Parameter Length	Changing Parameter Value
Length	2-Byte Word	2-Byte Word	2-Byte Word	Variable
Note	0xB2 0xFF	Table 5.24	Table 5.24	Table 5.24

Note: *Refer to Table 5.24 for the possible parameters used in the payload.*

Checksum

The sum of bytes starting from byte #2 of the whole packet to the last byte of the payload.

Table 5.24. Parameters Available for Change

<table>
<tr><th>Parameter</th><th>ID
(HEX, LSB)</th><th>Length
(HEX, LSB)</th><th>Value</th><th>Description</th></tr>
<tr><td colspan="5">Devices Options Menu</td></tr>
<tr><td colspan="5">IMU</td></tr>
<tr><td>Data_Rate</td><td>0x12 0x00</td><td>0x02 0x00</td><td>Word
(2 Bytes)</td><td>Output data rate in hertz. The minimum value of this parameter is 1 Hz.</td></tr>
<tr><td>Initial_Alignment_Time</td><td>0x14 0x00</td><td>0x02 0x00</td><td>Word
(2 Bytes)</td><td>The initial alignment time in seconds. The default value is 0 sec.</td></tr>
<tr><td>Alignment_Angles</td><td>0x3A 0x02</td><td>0x0C 0x00</td><td>3*Float
(12 Bytes)</td><td>Heading, pitch, and roll angles used to align the KERNEL on the carrier object. The default value of each angle is 0°.</td></tr>
<tr><td>Baud_Rate</td><td>0xB2 0x03</td><td>0x01 0x00</td><td>Byte</td><td>
<table>
<tr><th>Baud Rate, bps</th><th>Value</th></tr>
<tr><td>115200</td><td>0x00</td></tr>
<tr><td>4800</td><td>0x01</td></tr>
<tr><td>9600</td><td>0x02</td></tr>
<tr><td>14400</td><td>0x03</td></tr>
<tr><td>19200</td><td>0x04</td></tr>
<tr><td>38400</td><td>0x05</td></tr>
<tr><td>57600</td><td>0x06</td></tr>
<tr><td>115200</td><td>0x07</td></tr>
<tr><td>230400</td><td>0x08</td></tr>
<tr><td>460800</td><td>0x09</td></tr>
<tr><td>921600</td><td>0x0A</td></tr>
<tr><td>2000000</td><td>0x0B</td></tr>
<tr><td>375000</td><td>0x0C</td></tr>
<tr><td>1843200*</td><td>0x0D</td></tr>
<tr><td>3686400*</td><td>0x0E</td></tr>
<tr><td>1000000 bps</td><td>0x0F</td></tr>
<tr><td>4000000 bps*</td><td>0x10</td></tr>
</table>
Notes:
1. 1843200, 3686400, and 4000000 bps are for specific purposes only. These baud rates require a particular adaptor for data/commands transmission. Do not apply such values to the KERNEL without Inertial Labs agreement.
2. If the default baud rate for the IMU's COM port changes, set the same baud rate for the host computer's COM port to keep transmission. The newly set
</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td></td><td>baud rate will not take effect until the device is power cycled or receives the CommitBaudRate command.
3. The list of supported baud rates varies from one device to another. In case of any questions related to this, contact the Inertial Labs support team.</td></tr>
<tr><td>Average_Output_Data</td><td>0xE1 0x03</td><td>0x01 0x00</td><td>Byte</td><td>Switches the data variant to averaged output if the data rate is less than the maximum available value. See Section 5.3.6 for more details.<table><tr><th>Output Data Type</th><th>Value</th></tr><tr><td>Instant (Default)</td><td>0x00</td></tr><tr><td>Averaged</td><td>0x01</td></tr></table></td></tr>
<tr><td>Auto_Start</td><td>0xA9 0x03</td><td>0x01 0x00</td><td>Byte</td><td>Configures the KERNEL to start data output immediately after powering on and initializing, without any commands from the host computer (Section 5.2).<table><tr><th>State</th><th>Value</th></tr><tr><td>Disabled (Default)</td><td>0x00</td></tr><tr><td>Output Data Format</td><td>0xXX</td></tr></table>0xXX – The output data format code from Table 5.16.</td></tr>
<tr><td colspan="5">Triggers</td></tr>
<tr><td>Trigger_Control</td><td>0xFA 0x05</td><td>0x01 0x00</td><td>Byte</td><td>Allows users to enable an external trigger input for data synchronization.<table><tr><th>State</th><th>Value</th></tr><tr><td>Disabled (Default)</td><td>0x00</td></tr><tr><td>Enabled</td><td>0x01</td></tr></table></td></tr>
<tr><td>Polarity</td><td>0xFB 0x05</td><td>0x01 0x00</td><td>Byte</td><td>Specifies the polarity of the external trigger pulse.<table><tr><th>State</th><th>Value</th></tr><tr><td>Negative (Default)</td><td>0x00</td></tr><tr><td>Positive</td><td>0x01</td></tr></table></td></tr>
<tr><td>Hold-off_Time</td><td>0xFE 0x05</td><td>0x02 0x00</td><td>Word
(2 Bytes)</td><td>A period, in milliseconds, during which the device ignores all subsequent pulses after the initial pulse.</td></tr>
<tr><td>TOV_Control</td><td>0x99 0x04</td><td>0x01 0x00</td><td>Byte</td><td>The TOV signal identifies when the IMU data is ready for transmission or currently transmitting. Refer to Section 4.1.4 for more information.</td></tr>
<tr><td colspan="5">Correction Options Menu</td></tr>
<tr><td colspan="5">IMU Tilt Algorithm</td></tr>
<tr><td>Motion_Type</td><td>0x12 0x04</td><td>0x01 0x00</td><td>Byte</td><td></td></tr>
</table>

<table>
<tr><td>Gyro_Noise_RMS</td><td>0xEE 0x03</td><td>0x04 0x00</td><td>Float</td><td rowspan="8">Use these parameters to change specific correction data settings in the device’s Kalman Filter. Contact the Inertial Labs support team for additional information regarding these parameters.</td></tr>
<tr><td>Gyro_Scale_Factor_Error</td><td>0xF2 0x03</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Gyro_Bias_Drift</td><td>0xF6 0x03</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Gyro_Bias_RMS</td><td>0xFA 0x03</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Accels_Noise_RMS</td><td>0x06 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Accel_Dynamic_Gain</td><td>0x0A 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Dynamic_LPF</td><td>0x0E 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Align_Gyro_STD_Threshold</td><td>0x14 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>ZUPT</td><td>0x13 0x04</td><td>0x01 0x00</td><td>Byte</td><td>This parameter changes the algorithm used for device initialization. When disabled, the IMU estimates the gyro bias by averaging data. When enabled, the KERNEL uses the Kalman Filter for estimating the gyroscope bias (Section 5.7).
<table><tr><th>State</th><th>Value</th></tr><tr><td>Disabled (Default)</td><td>0x00</td></tr><tr><td>Enabled</td><td>0x01</td></tr></table></td></tr>
<tr><th colspan="5">Additional IMU Filtering</th></tr>
<tr><td>Filter</td><td>0x51 0x04</td><td>0x01 0x00</td><td>Byte</td><td>A cascade of parameters used to filter the transmitted accelerometer and gyroscope signals.
<table><tr><th>Filter</th><th>State</th><th>Mask</th></tr><tr><td>Filter1</td><td rowspan="3">0 – Disabled
1 – Enabled</td><td>0x01</td></tr><tr><td>Filter2</td><td>0x02</td></tr><tr><td>Filter3</td><td>0x04</td></tr></table>Example 1:
Filter1 (Enabled) + Filter2 (Enabled) + Filter3 (Disabled) = 0x03
Example 2:
Filter1 (Enabled) + Filter2 (Enabled) + Filter3 (Enabled) = 0x07</td></tr>
<tr><td>Filt1_Dzeta1</td><td>0x52 0x04</td><td>0x04 0x00</td><td>Float</td><td rowspan="7">Use these parameters to change specific cascade filter parameters for the device. Refer to Section 5.8 for more information.</td></tr>
<tr><td>Filt1_Dzeta2</td><td>0x56 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Filt1_W</td><td>0x5A 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Filt2_Dzeta1</td><td>0x5E 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Filt2_Dzeta2</td><td>0x62 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Filt2_W</td><td>0x66 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><td>Tau</td><td>0x6A 0x04</td><td>0x04 0x00</td><td>Float</td></tr>
<tr><th colspan="5">Sensors Options Menu</th></tr>
<tr><th colspan="5">Settings</th></tr>
</table>

<table>
<tr><td>LPF_Bandwidth</td><td>0xD7 0x03</td><td>0x01 0x00</td><td>Byte</td><td>Specifies the Low-Pass Filter (LPF) bandwidth applied to the sensors output data. Refer to 5.6 for more details.
<table><tr><th>Bandwidth</th><th>Value</th></tr><tr><td>16 Hz</td><td>0x00</td></tr><tr><td>33 Hz</td><td>0x01</td></tr><tr><td>66 Hz</td><td>0x02</td></tr><tr><td>131 Hz</td><td>0x03</td></tr><tr><td>262 Hz</td><td>0x04</td></tr><tr><td>Disabled</td><td>0xFF</td></tr></table>Note: The K201 does not support 16 or 33 Hz bandwidth values.</td></tr>
<tr><td>Output_Variant</td><td>0xD0 0x03</td><td>0x01 0x00</td><td>Byte</td><td>Output data variant for gyro/acc. data.
<table><tr><th>Type</th><th>Value</th></tr><tr><td>Instant (Default)</td><td>0x00</td></tr><tr><td>Average</td><td>0x01</td></tr><tr><td>Incremental</td><td>0x02</td></tr></table>Note: See Section 5.3.6 for details.</td></tr>
<tr><td>IMU-P_Interface</td><td>0x96 0x04</td><td>0x01 0x00</td><td>Byte</td><td rowspan="3">Reserved – Not supported by KERNEL devices.</td></tr>
<tr><td>Min_Vinp_Threshold</td><td>0xDA 0x03</td><td>0x02 0x00</td><td>Word</td></tr>
<tr><td>Max_Vinp_Threshold</td><td>0xDC 0x03</td><td>0x02 0x00</td><td>Word</td></tr>
<tr><td>Sensors Measurement Range
(Read Only)</td><td>0x8F 0x02</td><td>0x01 0x00</td><td>Byte</td><td>This parameter allows users to see the measurement ranges of the device’s gyroscopes and accelerometers.
The four least significant bits are the accelerometer range, and the four most significant bits are the gyroscope range.
Gyroscope Ranges<table><tr><th>Hex</th><th>Bin</th><th>Range, deg/s</th></tr><tr><td>6</td><td>0110</td><td>450</td></tr><tr><td>8</td><td>1000</td><td>950</td></tr><tr><td>9</td><td>1001</td><td>2000</td></tr></table>Accelerometer Ranges<table><tr><th>Hex</th><th>Bin</th><th>Range, g</th></tr><tr><td>3</td><td>0011</td><td>8 g</td></tr><tr><td>5</td><td>0101</td><td>15 g</td></tr><tr><td>6</td><td>0110</td><td>40 g</td></tr></table>Note: See Section 5.3.8.1 for a decoding example of these parameters.</td></tr>
</table>

5.3.7.1. Command Use Examples

Example 1 (Data_Rate Change)

The general structure of the SaveFlash command is:

0xAA 0x55 0x00 0x00 0x0E 0x00 0xB2 0xFF 0x12 0x00 0x02 0x00 0x**RT** 0x**RT** 0x**CS** 0x**CS**

Where **RT RT** is the data rate (2 bytes, word) and **CS CS** is the checksum. To set rate as 2000Hz, the SaveFlash command looks as follows:

0xAA 0x55 0x00 0x00 0x0E 0x00 0xB2 0xFF 0x12 0x00 0x02 0x00 0x**D0** 0x**07** 0x**AA** 0x**02**

Example 2 (Initial_Alignment_Time Change)

The general structure of the SaveFlash command is:

0xAA 0x55 0x00 0x00 0x0E 0x00 0xB2 0xFF 0x14 0x00 0x02 0x00 0x**IA** 0x**IA** 0x**CS** 0x**CS**

Where **IA IA** is the initial alignment time (2 bytes, word) and **CS CS** is the checksum. To set the time as 15 seconds, the SaveFlash command looks as follows:

0xAA 0x55 0x00 0x00 0x0E 0x00 0xB2 0xFF 0x14 0x00 0x02 0x00 0x**0F** 0x**00** 0x**E4** 0x**01**

Example 3 (LPF Bandwidth Change)

The general structure of the SaveFlash command is:

0xAA 0x55 0x00 0x00 0x0D 0x00 0xB2 0xFF 0xD7 0x03 0x01 0x00 0x**ID** 0x**CS** 0x**CS**

Where ID is the bandwidth code and **CS CS** is the checksum. To set the filter to a 262 Hz bandwidth, use the following command:

0xAA 0x55 0x00 0x00 0x0D 0x00 0xB2 0xFF 0xD7 0x03 0x01 0x00 **0x04 0x9D 0x02**

Example 4 (Alignment_Angles Change)

The general structure of the SaveFlash command is:

0xAA 0x55 0x00 0x00 0x18 0x00 0xB2 0xFF 0x3A 0x02 0x0C 0x00 0x**A1** 0x**A1** 0x**A1** 0x**A1** 0x**A2** 0x**A2** 0x**A2** 0x**A2** 0x**A3** 0x**A3** 0x**A3** 0x**A3** 0x**CS** 0x**CS**

where AN AN AN AN - alignment angles (4 bytes, float) and **CS CS** is the checksum. To set the angles as 10°, 20°, and 30°, the SaveFlash command looks as follows:

0xAA 0x55 0x00 0x00 0x18 0x00 0xB2 0xFF 0x3A 0x02 0x0C 0x00 0x**00** 0x**00** 0x**20** 0x**41** 0x**00** 0x**00** 0x**A0** 0x**41** 0x**00** 0x**00** 0x**F0** 0x**41** 0x**84** 0x**04**

Note: *10.0 (dec) = 41 20 00 00 (float)*
20.0 (dec) = 41 A0 00 00 (float)
30.0 (dec) = 41 F0 00 00 (float)

5.3.8. ReadRAM Command

The ReadRAM command allows users to read the data of an individual parameter from the device's RAM. Refer to Table 5.24 for a full list of the available parameters. The ReadRAM command has the same structure as the SaveFlash command shown in Table 5.22, but with the payload shown in Table 5.25 below.

Table 5.25. ReadRAM Command Payload Structure

Byte	0 – 1	2 – 3	4 – 5
Parameter	Command ID	Parameter ID	Parameter Length
Length	2-Byte Word	2-Byte Word	2-Byte Word
Note	0xB1 0xFF	See Table 5.24	See Table 5.24

5.3.8.1. Command Use Examples

Example 1 (Read Data Rate)

The general structure of the ReadRAM command is:

0xAA 0x55 0x00 0x00 0x0C 0x00 0xB1 0xFF 0x**12** 0x**00** 0x**02** 0x**00** 0x**D0** 0x**01**

Where **12 00** is the parameter ID for Data_Rate, **02 00** is the parameter length and **D0 01** is the checksum.

Example 2 (Read Initial Alignment Time)

The general structure of the ReadRAM command is:

0xAA 0x55 0x00 0x00 0x0C 0x00 0xB1 0xFF 0x**14** 0x**00** 0x**02** 0x**00** 0x**D2** 0x**01**

Where **14 00** is the parameter ID for Initial_Alignment_Time, **02 00** is the length of the parameter, and **D2 01** is the message's checksum.

Example 3 (Read Sensors Measurement Range)

The general structure of the ReadRAM command is:

0xAA 0x55 0x00 0x00 0x0C 0x00 0xB1 0xFF 0x**8F** 0x**02** 0x**01** 0x**00** 0x**4E** 0x**02**

Where **8F 02** is the parameter ID, **01 00** is the parameter length, and **4E 02** is the checksum.

The highlighted payload of the response message includes information about the measurement ranges:

0xAA 0x55 0x01 0xB1 0x07 0x00 0x**93** 0x4C 0x01

Where **9** corresponds to a gyro range of ± 2000 deg/s and **3** represents an accelerometer range of ± 8 g. Refer to Table 5.24 to see the values for other ranges.

5.3.9. CommitBaudRate Command

0xAA 0x55 0x00 0x00 0x07 0x00 0xC2 0xC9 0x00

The CommitBaudRate command is used to apply a new COM port baud rate (previously set using the SaveFlash command) without requiring a power cycle.

5.4. The Unit Status Word definition

The Unit Status Word (USW) provides information on the current state of the KERNEL IMU. Refer to Table 5.26 below to see the status and description of each USW bit.

Table 5.26. Unit Status Word Description

Byte	Bit	Parameter	Description
Low Byte	0	Reserved	-
	1	Communication of Internal Sensors	0 – Successful communication between sensors. 1 – Communication failure detected.
	2	Configuration of Internal Sensors	0 – Successful configuration of sensors. 1 – Configuration failure detected.
	3-7	Reserved	-
High Byte	8	Reserved	-
	9	Reserved	-
	10	Angular Rate	0 – X-angular rate is within range. 1 – X-angular rate is out of range.
	11		0 – Y-angular rate is within range. 1 – Y-angular rate is out of range.
	12		0 – Z-angular rate is within range. 1 – Z-angular rate is out of range.
	13	Reserved	-
	14	Environmental Temperature	0 – Temperature is within the operating range. 1 – Temperature is out of the operating range.
	15	Reserved	-

For KERNEL devices with firmware newer than 20-Aug-2021, the parameter USW Extended is available for output. Refer to Table 5.27 for the status and description of each bit.

Table 5.27. Extended Unit Status Word Description

Byte	Bit	Parameter	Description
Low Byte	0	Initial Alignment Status	0 – Initial alignment is in process. 1 – initial alignment is complete.
	1	Gyro Bias Estimation	0 – Successful bias estimation. 1 – Unsuccessful gyroscope bias estimation.
	2-7	Reserved	-
High Byte	8-15	Reserved	-

5.5. Maximum Output Data Rate Limitations

The main COM port baud rate must be capable of handling the chosen output data rate. Use the baud rate and data package length to calculate the maximum acceptable data rate, in hertz, with the equation shown below:

$$\text{Max Data Rate} = \frac{\text{COM Port Baud Rate}}{\text{Bits Per Byte * Package Length}} \tag{5.1}$$

Where the COM port baud rate is in bits per second, the bits per byte is equal to 11 bits per one transferred byte of data, and the package length is the payload length for the chosen output data format plus eight bytes of overhead. Refer to Table 5.5 through Table 5.15 for the payload length of all available binary output data formats.

KERNEL devices can only output at data rates that are factors of 2000 (i.e. 1, 2, 4, 5, 8, 10, 16, 20, 25, 40, 50, 80, 100, 125, 200, 250, 400, 500, 1000, and 2000 Hz). As such, users should round down the data rates calculated using Equation 6.1 to the nearest factor of 2000 listed above. Refer to Table 5.28 for the actual maximum data rates computed this way for each data format.

Table 5.28. Max Data Rate for KERNEL Output Data Formats

Output Data Format	Data Package Length, bytes	COM Port Baud Rate, bps			
		38400	115200	460800	2000000
		Maximum Data Rate, Hz			
KERNEL Orientation	42	80	200	500	2000
KERNEL GA Data	40	80	250	1000	2000
KERNEL GAm Data	40	80	250	1000	2000
KERNEL Quaternion Data	42	80	200	500	2000
KERNEL Calibrated HR Data	60	50	125	500	2000
KERNEL GAA Data	52	50	200	500	2000
KERNEL GAAm Data	52	50	200	500	2000

Notes:

1. *The 1843200, 3686400, and 4000000 baud rate values are only for specific purposes and require a particular adaptor for proper message transmission. Do not apply such values to the KERNEL without the Inertial Labs agreement.*
2. *If the baud rate for the IMU COM port changes, set the same baud rate for the host computer’s COM port to keep proper transmission.*
3. *The list of supported baud rates may vary from one model to another. The supported rates depend on the user's needs. In case of any questions related to this topic, contact the Inertial Labs support team.*
4. *The K201 is the only KERNEL model with a possible maximum measurement rate of 4000 hertz. Contact Inertial Labs for more details.*

5.6. Finite Impulse Response Filter Delay

The KERNEL uses a Finite Impulse Response (FIR) filter delay, a type of low pass filter, to digitally filter transmitted device signals. Users can choose to enable or disable this feature, as well as control its parameters. The filter delay depends on two things: the bandwidth of the filter signal and its order number. Refer to Table 5.29 for these tabulated values.

Table 5.29. Tabulated Values for the FIR Filter Delay

Filter Bandwidth (Hz)	Filter Order (N)	Delay (Seconds)
16	192	0.048
33	96	0.024
66	48	0.012
131	24	0.006
262	12	0.003

Note: *The K201 does not support the 16 or 33 Hz filter bandwidth.*

5.7. Initial Alignment Logic (ZUPT Algorithm)

The KERNEL IMU estimates the gyro biases, accounting for the Earth's rotation, during the initial alignment process. To do so, the initial alignment time must be equal to or higher than one second. The ZUPT parameter also affects the initialization algorithm in the following ways:

- **Disabled ZUPT** – The KERNEL uses averaging to estimate the gyro biases. The object must remain absolutely static and with no vibrations during the entire initial alignment process. With this method, the gyro STD threshold determines whether to accept or reject the bias estimated during alignment.
- **Enabled ZUPT** – The KERNEL uses the Kalman Filter instead of the STD threshold to estimate and accept the gyro bias. With this method, the carrier object should remain static. However, some low-level vibrations are acceptable during this type of initial alignment.

Note: *Use the SaveFlash command to configure the initial alignment time, gyro STD threshold, and ZUPT parameter. Refer to Table 5.24 for details on modifying these parameters. Alternatively, users can do this via the IMU GUI software.*

Output USW Extended data through the UDD format to monitor the IMU's initial alignment status and the success of the gyro bias estimation based on the standard deviation measurement. Refer to Section 5.2.8 and 5.4 for more details.

5.8. Cascade Filter

Users can implement a cascade of filters to sort through the KERNEL's transmitted accelerometer and gyroscope signals. The cascade filter includes a combination of first and second order filters, with the structure defined in Figure 5.1 below.

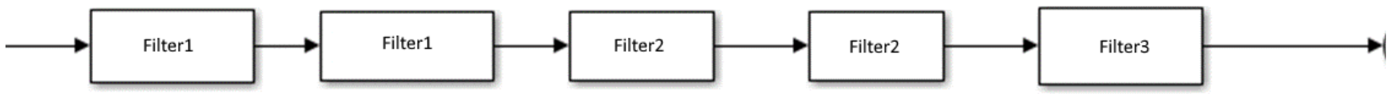

Figure 5.1. Output Filter Cascade

Note: The cascade filter is only for specific operations with particular devices and experienced users. For additional questions, contact the Inertial Labs Support Team.

Filter1 and Filter2 are second order filters with the transfer function:

$$Filter_1(s) = \frac{s^2 + 2\zeta_{11}\omega_1 s + \omega_1^2}{s^2 + 2\zeta_{21}\omega_1 s + \omega_1^2} \qquad Filter_2(s) = \frac{s^2 + 2\zeta_{12}\omega_2 s + \omega_2^2}{s^2 + 2\zeta_{22}\omega_2 s + \omega_2^2}$$

Filter3 is a first order filter with the transfer function:

$$Filter_3(s) = \frac{1}{\tau s + 1}$$

The user can choose to bypass or activate $Filter_1$*$Filter_1$, $Filter_2$*$Filter_2$, or $Filter_3$ and configure the following parameters: ζ_{11}, ζ_{21}, ω_1, ζ_{12}, ζ_{22}, ω_2, and τ. To do so, use the SaveFlash parameter to modify the Filter parameter seen in Table 5.24. Alternatively, the IMU GUI also supports the modification of these parameters. Refer to the User Manual for more information.

The following UDD outputs can be used to view the results of the signal filtering:

- Filtered Low-G Accels HR (id 0x91)
- Filtered High-G Accels HR (id 0x92)
- Bias-compensated Gyro Data (id 0x2D)

Refer to Section 5.2.8 for additional details on these outputs.

6. IMU Automatic Start

Users can enable the INS to automatically start device output after powering on, without any command from the host computer. See Section 5.2 to view the available output data formats for the auto start feature.

The auto start option can be enabled or disabled using the SaveFlash command. To do this, modify the Auto_Start parameter (see Table 5.24). Alternatively, configure the device using the IMU GUI software. Refer to the User Manual for more details. If AutoStart mode is enabled and there is power available, the device automatically starts and acknowledges the command by sending out the following hexadecimal message:

0xAA 0x55 0x01 0x00 0x08 0x00 0x00 0x00 0x09 0x00

The KERNEL then begins to output information according to the chosen data format. Send the Stop command to halt data output. Once the KERNEL receives this message, it stops data calculation, goes into idle mode, and remains ready to receive any command from the host computer.

Appendix A. Full List of the IMU Commands

All KERNEL commands have the byte structure shown in Table 5.2. The payload for all commands has a length of 1 byte and contains the code of the command. Table A.1 below lists all commands with their exact structure in hexadecimal numbers.

Table A.1. KERNEL Commands with Exact Structure

Command	Code	Exact Structure (hex)
Commands for KERNEL Control		
KERNEL_Orientation	0x33	0xAA 0x55 0x00 0x00 0x07 0x00 0x33 0x3A 0x00
KERNEL_GAData	0x8F	0xAA 0x55 0x00 0x00 0x07 0x00 0x8F 0x96 0x00
KERNEL_GAmData	0x9B	0xAA 0x55 0x00 0x00 0x07 0x00 0x9B 0xA2 0x00
KERNEL_GAAData	0xA5	0xAA 0x55 0x00 0x00 0x07 0x00 0xA5 0xAC 0x00
KERNEL_GAAmData	0xA6	0xAA 0x55 0x00 0x00 0x07 0x00 0xA6 0xAD 0x00
KERNEL_QuatData	0x82	0xAA 0x55 0x00 0x00 0x07 0x00 0x82 0x89 0x00
KERNEL_CalibHR	0x81	0xAA 0x55 0x00 0x00 0x07 0x00 0x81 0x88 0x00
Stop	0xFE	0xAA 0x55 0x00 0x00 0x07 0x00 0xFE 0x05 0x01
User_Def_Data	0x95	0xAA 0x55 0x00 0x00 0x07 0x00 0x95 0x9C 0x00
User_Def_Data_config	0x96	0xAA 0x55 0x00 0x00 0x07 0x00 0x96 0x9D 0x00
Get_User_Def_Data_struct	0x97	0xAA 0x55 0x00 0x00 0x07 0x00 0x97 0x9E 0x00
GetDevInfo	0x12	0xAA 0x55 0x00 0x00 0x07 0x00 0x12 0x19 0x00
GetBIT	0x1A	0xAA 0x55 0x00 0x00 0x07 0x00 0x1A 0x21 0x00
SaveFlash	–	Has a variable structure, see Section 5.3.7
ReadRam	–	Has a variable structure, see Section 5.3.8
CommitBaudRate	0xC2	0xAA 0x55 0x00 0x00 0x07 0x00 0xC2 0xC9 0x00

Note: *Not every device model supports all these commands. Contact the Support team for additional details.*

Appendix B. Variants of the IMU Mounting Relative to the Object Axes

The KERNEL IMU can be mounted on the object in any known position (upside-down, backwards, upright, etc.) relative to the object axes. Such mounting does not change the validity of the carrier object orientation calculations if the KERNEL's mounting offset angles are correctly stored in the device's nonvolatile memory.

The angles of the KERNEL position (alignment angles) are set in following order:

- The first alignment angle (heading) is determined by the IMU's rotation around its Z-axis. Clockwise rotation is denoted as positive. The range for this alignment angle is -180° to +180°. As such, this angle sets the misalignment between the longitudinal axes of the IMU and the carrier object in the horizon plane.
- The second alignment angle (pitch) is determined by the IMU's rotation around its X-axis. Counterclockwise rotation is denoted as positive. The range for this alignment angle is -90° to +90°. As such, this angle sets the inclination of the longitudinal axis of the IMU relative to the carrier object horizon plane.

- The third alignment angle (roll) is determined by the IMU's rotation around its Y-axis. Counterclockwise rotation is denoted as positive. The range for this alignment angle is -180° to +180°.

Note: *The default values for the IMU alignment angles are all zeros.*

There are two ways to set alignment angles for IMU mounting: via the IMU GUI or by modifying the Alignment_Angles parameter using the SaveFlash command. Check the validity of the entered alignment angles by using the visualization tab in the IMU GUI. Refer to the User Manual for more information.

Refer to **Figure B.1** below for examples of mounting the KERNEL relative to the carrier object.

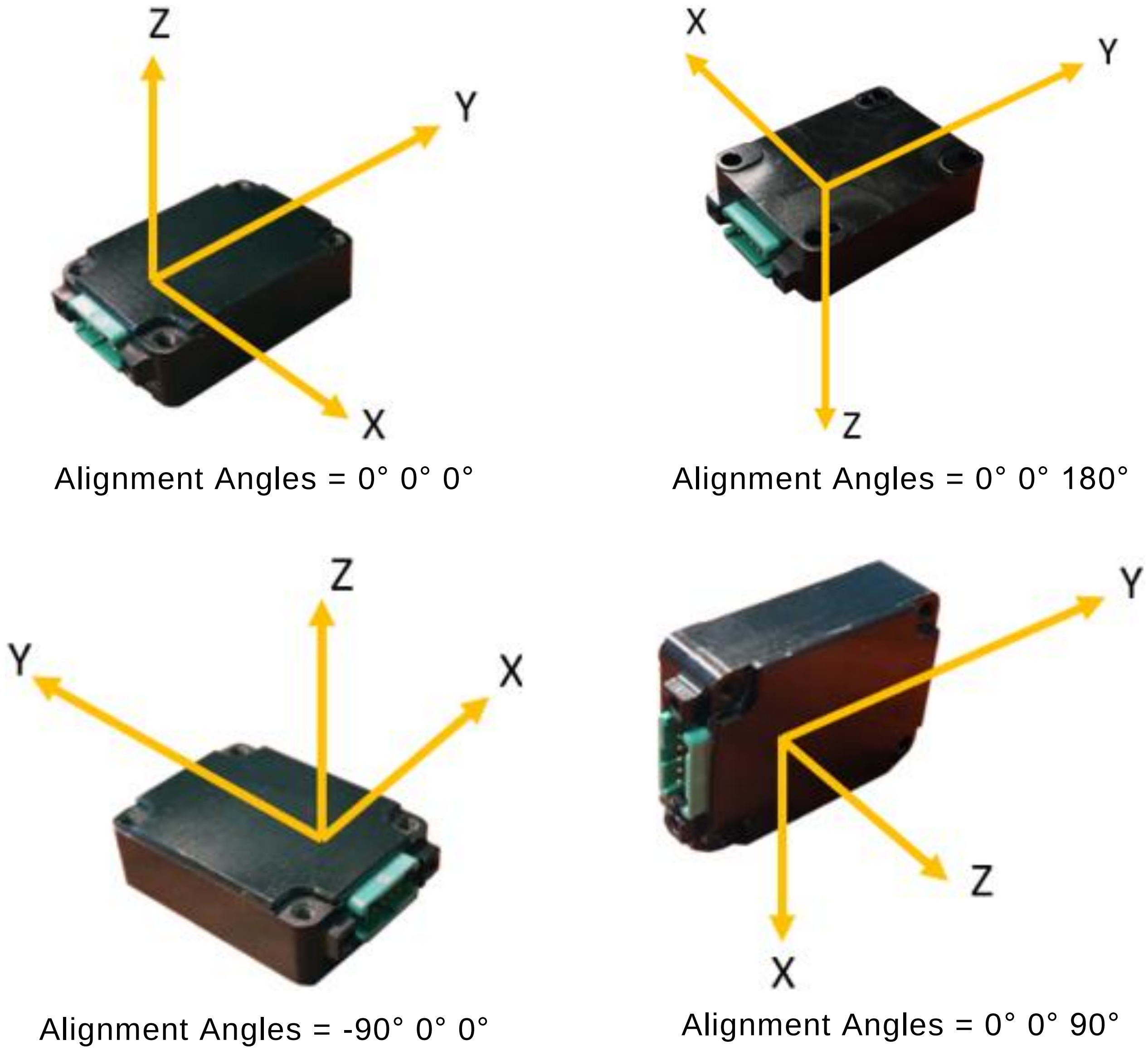

Figure B.1. Carrier Object Mounting Examples

Appendix C. Forms of the IMU Orientation Presentation

The coordinate system is defined as $Ox_oy_oz_o$ fixed to the carrier object, where the Ox_o axis is lateral and directed to the right, the Oy_o axis is longitudinal and directed forward, and the Oz_o axis is normal and directed vertically. Usually, the IMU should be installed parallel to the carrier object axes shown in **Figure 2.2**. However, it is possible to install the INS in any known position relative to the object using the known alignment angles (see Appendix B for details).

The Inertial Labs INS calculates the orientation of the coordinate system $Ox_oy_oz_o$ fixed to the carrier object with respect to the Cartesian geographical reference frame *Oxyz*. In this system, axes *Ox* and *Oy* are level and directed to the east and north, while the *Oz* axis is directed up. This reference frame is also known as ENU (East-North-Up) Earth-level frame. The measured angles are the standard Euler angles of rotation from the Earth-level frame to the object frame: heading *K* is first, then pitch θ, and roll γ as seen in **Figure C.1**

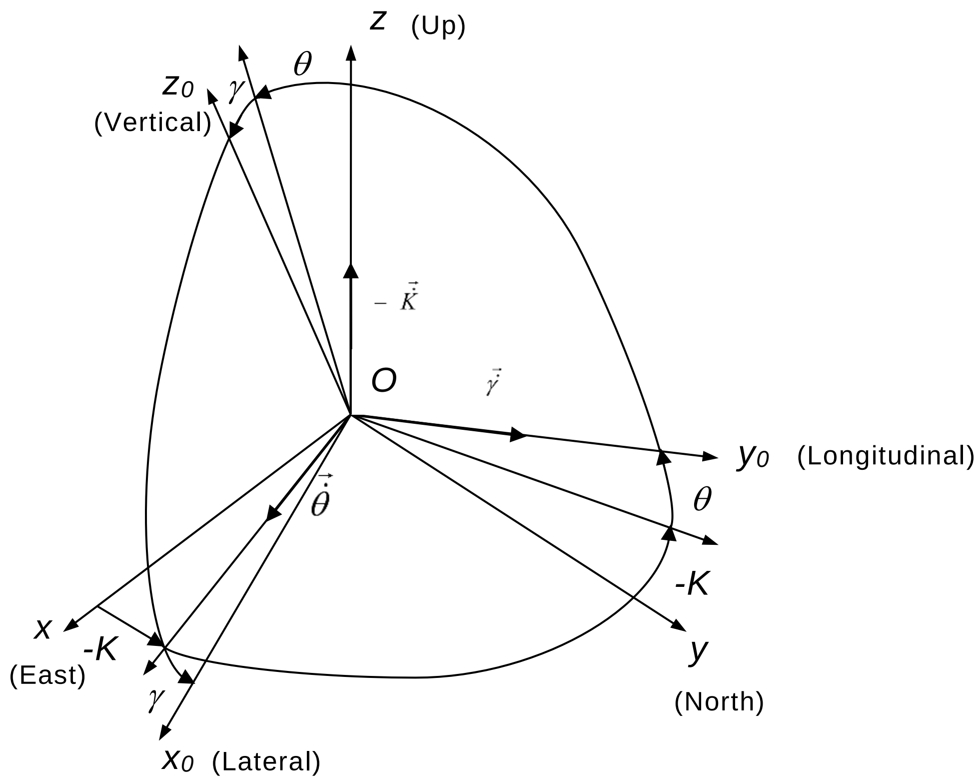

Figure C.1. Transformation of Coordinate Systems

Notes:

1. *Since positive direction of heading is clockwise, heading K is shown with a minus sign in Figure C.1.*
2. *In different applications, "heading" is also known as "azimuth" or "yaw"; "pitch" is also known as "elevation" or "tilt"; "roll" is also known as "bank".*
3. *also known as "elevation" or "tilt"; "roll" is also known as "bank".*

Due to the definition of Euler angles, there is a mathematical singularity when the object longitudinal y_o-axis is pointed up or down (i.e., pitch approaches ±90°). This singularity is not present in the quaternion or directional cosine matrix (rotation matrix) presentation.

The Directional cosine matrix (DCM) is the rotation matrix $\mathbf{C}$ from the object body reference frame $Ox_oy_oz_o$ to the geographical reference frame *Oxyz.* According to **Figure C.1**, DCM can be represented through Euler angles as:

$$\mathbf{C} = \begin{bmatrix} \cos K \cos\gamma + \sin K \sin\gamma \sin\theta & \sin K \cos\theta & \cos K \sin\gamma - \sin K \cos\gamma \sin\theta \\ -\sin K \cos\gamma + \cos K \sin\gamma \sin\theta & \cos K \cos\theta & -\sin K \sin\gamma - \cos K \cos\gamma \sin\theta \\ -\cos\theta \sin\gamma & \sin\theta & \cos\theta \cos\gamma \end{bmatrix} \quad (C.1)$$

The Euler angles can also be calculated from elements c_{ij} of the directional cosine matrix $\mathbf{C}$:

$$K = \arctan\frac{c_{12}}{c_{22}} \qquad \theta = arcsin\, c_{32} \qquad \gamma = -\arctan\frac{c_{31}}{c_{33}} \quad (C.2)$$

Additionally, the Inertial Labs IMU provides orientation output in quaternion ($\mathbf{Q}$) form, which is a hyper-complex number with four components:

$$\boldsymbol{Q} = (q_0, q_1, q_2, q_3) \quad (C.3)$$

where q_0 is the real part and q_1, q_2, q_3 are the vector part. In other words, q_0 represents the magnitude of the rotation, while the other three components represent the axis about which that rotation takes place. With only four components, the quaternion representation of orientation is computationally efficient. However, manipulation of quaternions is not intuitive, so their use in place of directional cosine matrices may increase the chances of unintentional user errors.

Quaternion **Q** is converted to directional cosine matrix **C** using the following expressions:

$$C = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 + q_0q_2) \\ 2(q_1q_2 + q_0q_3) & q_0^2 + q_2^2 - q_1^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 + q_3^2 - q_1^2 - q_2^2 \end{bmatrix} \tag{C.4}$$

The reverse conversation from directional cosine matrix **C** to quaternion **Q** is as follows:

$$q_0 = \frac{1}{2}\sqrt{1 + c_{11} + c_{22} + c_{33}}; \tag{C.5}$$

$$q_1 = \frac{c_{32} - c_{23}}{4q_0}; \qquad q_2 = \frac{c_{13} - c_{31}}{4q_0}; \qquad q_3 = \frac{c_{21} - c_{12}}{4q_0}.$$

Expressions (C.5) are widely used, but they have singularity at $q_0 = 0$. Therefore, the Inertial Labs IMU uses other expressions that have no singularity:

$$q_0 = \frac{1}{2}\sqrt{1 + c_{11} + c_{22} + c_{33}} \qquad q_1 = \frac{1}{2}\sqrt{1 + c_{11} - c_{22} - c_{33}} \cdot sign(c_{32} - c_{23}) \tag{C.6}$$

$$q_2 = \frac{1}{2}\sqrt{1 - c_{11} + c_{22} - c_{33}} \cdot sign(c_{13} - c_{31}) \qquad q_3 = \frac{1}{2}\sqrt{1 - c_{11} - c_{22} + c_{33}} \cdot sign(c_{21} - c_{12})$$

When needing to calculate Euler angles from quaternion, calculate elements c_{12}, c_{22}, c_{31}, c_{32}, c_{33}, according to (C.6), and then use formulas (C.2):

$$K = arctan\frac{2(q_1q_2 - q_0q_3)}{q_0^2 + q_2^2 - q_1^2 - q_3^2} \qquad \theta = arcsin(2q_2q_3 + 2q_0q_1) \tag{C.7}$$

$$\gamma = -arctan\frac{2(q_1q_3 - q_0q_2)}{q_0^2 + q_3^2 - q_1^2 - q_2^2}$$

where arctan is a four-quadrant inverse tangent.

REVISION HISTORY

Revision	Date	Affected Paragraphs	Remarks
1.42	May 15, 2025	5.3.9, Appendix A	1. Added CommitBaudRate command (code 0xC2) description.
		5.3.7	2. Added note on the device power-cycling requirement after using the SaveFlash command to apply modified parameters.
		5.3.7	3. Added note that the newly set baud rate will not take effect until the device is power-cycled or receives the CommitBaudRate command.
		5.2.8	4. Specified that the 'Gyro Bias' output (User Defined Data message, type 0x2E) is not supported for KERNEL-100, KERNEL-102, and KERNEL-201 models.
			5. Removed the Specifications section.
Previous revisions are available upon request.			