

USER MANUAL

Tri-Axial Gyro Inclinometer, SAE J1939

P/N: AX060900 – Two M12 Connectors

P/N: AX060910 – Two M12 Connectors, Extended Dynamic Range

ACRONYMS

3D	Three-Dimensional
ARI	Angular Rate Information (PGN 61482)
CAN	Controller Area Network
CE	The CE mark, or formerly EC mark, is a mandatory conformity marking for certain products sold within the European Economic Area (EEA) since 1985
DM	Diagnostic Message. Defined in J1939/73 standard
EA	The Axiomatic Electronic Assistant, a PC application software from Axiomatic, primarily designed to view and program Axiomatic control configuration parameters (setpoints) through CAN bus using J1939 Memory Access Protocol
ECU	Electronic Control Unit
EEPROM	Electrically Erasable Programmable Read-Only Memory
EKF	Extended Kalman Filter
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
G	Gravitational Acceleration on Earth
GPS	Global Positioning System
Grms	Root Mean Square Acceleration in G units
Hz	Hertz
IEC	International Electrotechnical Commission
LSB	Less Significant Byte
MEMS	Microelectromechanical System
NED	North-East-Down coordinate system
PC	Personal Computer
PGN	Parameter Group Number. Defined in J1939/73 standard
P/N	Part Number
RoHS	Restriction of Hazardous Substances
SAE J1939	CAN-based higher-level protocol designed and supported by Society of Automobile Engineers (SAE)
SAE J670	Vehicle Dynamics Terminology standard designed and supported by Society of Automobile Engineers (SAE)
SSI	Slope Sensor Information (PGN 61459)
SSI2	Slope Sensor Information 2 (PGN 61481)
UM	User Manual
USB	Universal Serial Bus
UTP	Un-shielded twisted pair
VDS	Voltage Direct Current or Vehicle Direction/Speed (PGN 65256)
VDS2	Vehicle Direction/Speed 2 (PGN 64905)
XOR	Exclusive OR, a logical operation

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1 INTRODUCTION

The following user manual describes: architecture, functionality, configuration parameters and flashing instructions for Tri-Axial Gyro Inclinometers. It also contains technical specifications and installation instructions for the devices.

The application firmware version numbers described in the user manual, together with the Axiomatic EA version numbers supporting all inclinometer configuration parameters, are shown on the user manual front page.

The user manual is usually valid for application firmware with the same major version number as the user manual. For example, this user manual is valid for any inclinometer application firmware version 7.xx.

Updates specific to the user manual are done by adding letters: A, B, ..., Z to the user manual version number.

The user should check whether the application firmware installed in the inclinometer is covered by this user manual. It can be done using Axiomatic Electronic Assistant (EA) software through CAN bus.

The inclinometers support SAE J1939 CAN interface. It is assumed, that the user is familiar with the J1939 group of standards. The terminology from these standards is widely used in this manual.

2 INCLINOMETER DESCRIPTION

The inclinometer is designed to measure pitch and roll inclination angles in the presence of dynamic disturbances: linear accelerations, vibrations, etc., in a full ± 180 -degree orientation range. The device can also output gravity angle, accelerations and angular rates in three orthogonal directions.

The inclinometer transmits data over CAN bus using a standard J1939 protocol.

The J1939 inclinometer can operate at standard 250kbit/s and 500kbit/s baud rates or non-standard 667kbit/s and 1000kbit/s (1Mbit/s) baud rates. The required baud rate is detected automatically upon connection to the CAN network.²

² *Inclinometers with firmware V1.xx...4.xx could operate only at 250 kbit/s baud rate, and with firmware V5.xx...6.xx – at 250, 500, and 1000 kbit/s baud rates.*

The inclinometer can be configured through a set of configuration parameters to fit the user-specific application requirements using Axiomatic Electronic Assistant software.

2.1 Inclinometer Modifications

The inclinometer comes in two modifications: with regular (AX060900) and extended dynamic range (AX060910) sensors.

The extended dynamic range inclinometer (AX060910) has an accelerometer and gyroscopes with a larger measurement range, which allow the inclinometer to operate without saturation in a wider range of dynamic disturbances. A separate precision accelerometer is added in this modification to provide accurate static measurements of all inclination angles.

2.2 Theory of Operation

2.2.1 Unit Coordinate System

The inclinometer uses a standard right-handed Z-down Cartesian coordinate system, see Figure 1.

The arrows in Figure 1 represent a direction of motion that produces a positive change of the parameter. For a_x , a_y , a_z accelerations, the positive acceleration direction is the same as the axis direction. For θ , ϕ , ψ rotation angles the positive direction is counterclockwise about the axis of rotation (right-hand rule).

The Z-down coordinate system is described by in the SAE J670 standard for automotive applications. It is used in SAE J1939 slope sensor PGN definitions. This system is similar to the NED (North-East-Down) coordinate system used in aerospace and navigation, but without reference to the cardinal directions.

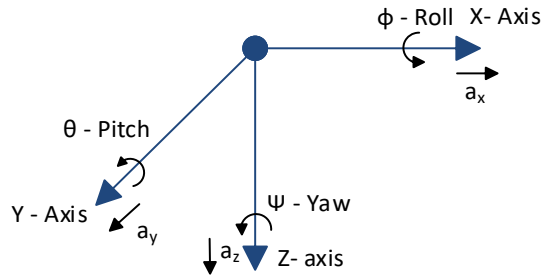


Figure 1. Inclinometer Coordinate System

2.2.2 Unit Reference Frames

Several Z-down coordinate systems or frames are used to describe the inclinometer orientation.

The (X,Y,Z) coordinate system attached to the unit forms a unit or inclinometer frame, see Figure 2. The original (default) unit frame orientation is shown on the inclinometer label. It can be changed using configuration parameters to facilitate the unit installation.

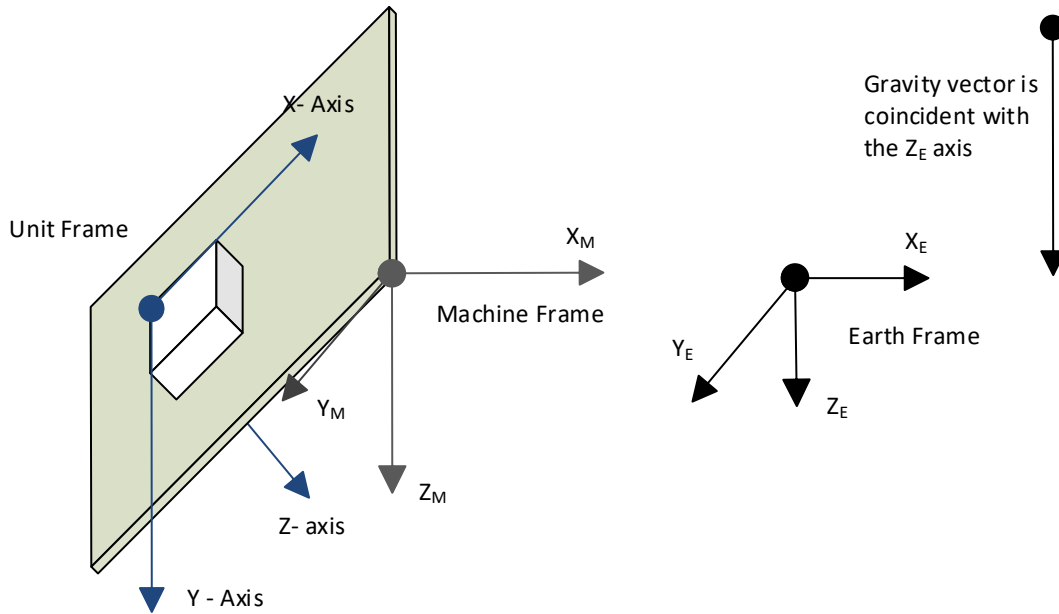


Figure 2. Inclinometer Reference Frames

The (X_M, Y_M, Z_M) coordinate system attached to the machine, where the inclinometer is installed, defines a machine frame. The Earth coordinate system (X_E, Y_E, Z_E) , aligned with the Earth gravity, defines the Earth absolute reference frame.

The machine frame is coincident with the Earth reference frame in the initial null-angle position of the machine when it is leveled on the operation area.

The unit calculates accelerations, angles and angular rates referred to the machine frame (X_M, Y_M, Z_M) . Conversion from the unit frame (X, Y, Z) to the machine frame (X_M, Y_M, Z_M) is performed internally using the unit initial installation angles. They are set to zero by default.

After the inclinometer is installed on the machine at the customer site, the customer can set-up the unit initial installation angles through configuration parameters.

To simplify further description of inclinometer operations, unless specially mentioned, it will be assumed that the unit frame orientation is original, initial installation angles are zero and all inclinometer parameters are referred therefore to the unit frame (X,Y,Z).

2.2.3 Angle measurements

2.2.3.1 Static Condition

In the static condition, the inclination angles are measured by a three-axis MEMS accelerometer. The accelerometer senses accelerations in three orthogonal directions X, Y and Z: $\vec{a} = (a_x, a_y, a_z)$.

This acceleration vector is a superposition of external accelerations applied to the unit and the gravity acceleration:

$$\vec{a} = \vec{A} - \vec{g}, \quad (1)$$

where: $\vec{A} = (A_x, A_y, A_z)$ – external accelerations applied to the unit,

$\vec{g} = (g_x, g_y, g_z)$ – gravity acceleration.

Since the external accelerations are absent in the static condition ($\vec{A} = 0$), the gravity acceleration vector is:

$$\vec{g} = -\vec{a}. \quad (2)$$

The inclinometer angular displacement can be presented as a rotation of the unit coordinate system (frame) from the original position, with the predefined value of the gravity vector, to the current position with the measured value of the same gravity vector. For example, if the original position is defined in the absolute Earth frame, then $\vec{g}_E = (0, 0, 1)$ and the gravity vector in the unit frame $\vec{g} = \vec{g}_U$ is:

$$\vec{g}_U^T = R_E^U \vec{g}_E^T, \quad (3)$$

where R_E^U – rotation matrix converting \vec{g}_E into \vec{g}_U (symbol T states that the vectors are transposed for this operation).

The θ – pitch, ϕ – roll, and ρ – gravity angles can be calculated from the rotation matrix elements, which themselves can be calculated from \vec{g}_U . There is not enough information based only on the gravity vector to calculate the ψ – yaw angle.

2.2.3.2 Dynamic Condition

In dynamics, the inclination angles are measured using three single-axis MEMS gyroscopes. The gyroscopes provide angular rates about three orthogonal directions X, Y and Z: $\vec{\omega} = (\omega_x, \omega_y, \omega_z)$.

When the inclinometer rotation is described by a quaternion $\mathbf{q} = \mathbf{q}(t)$, the rotation dynamics is defined by the following differential equation:

$$\dot{\mathbf{q}} = \frac{1}{2} \Omega \cdot \mathbf{q} \quad (4)$$

where: $\Omega = \begin{bmatrix} 0 & -\omega_x & -\omega_y & -\omega_z \\ \omega_x & 0 & \omega_z & -\omega_y \\ \omega_y & -\omega_z & 0 & \omega_x \\ \omega_z & \omega_y & -\omega_x & 0 \end{bmatrix}$ – rotation matrix for quaternion, derived from angular rates.

The inclinometer angular displacement can be found by integrating this equation over time and converting the result to the corresponding rotation matrix and the estimate of the gravity vector in the unit frame \vec{g}_U . This estimate can be used for calculating: $\hat{\theta}$ – pitch, $\hat{\phi}$ – roll, and $\hat{\rho}$ – gravity angles the same way as for the inclinometer static condition.

2.2.3.3 Sensor Fusion

Both static and dynamic angular measurements have their own advantages and disadvantages. The static measurements based on the accelerometer data are susceptible to parasitic accelerations normally present in a moving machine.

The dynamic measurements, on the other hand, accumulate integration errors of the gyroscope angular rates and are very sensitive to short-term sensor saturations that void any further measurements. This does not allow using dynamic measurements alone. They need to be constantly corrected by the static measurement data.

To combine the advantages of both methods, the inclinometer angular displacements, calculated using accelerometer and gyroscope data, are fused together using the Extended Kalman Filter (EKF).

This technique removes excessive noise from the accelerometer angular measurements while providing a fast and accurate response to angular changes using the gyroscope data.

2.2.4 Tilt and Rotation Angles

The unit calculates: θ – pitch, ϕ – roll, and ρ – gravity angles from the rotation matrix elements.

The pitch and roll angles can be calculated in two different ways: as tilt or rotation angles. The gravity angle is always a tilt angle.

2.2.4.1 Tilt Angles

The pitch and roll tilt angles define the inclination of the unit relatively to the ground plane. The gravity angle defines the inclination of the unit relatively to the gravity vector.

The pitch θ^t and roll ϕ^t tilt angles define the inclination of the unit relatively to the (X_E, Y_E) ground plane parallel to the Earth surface in the Earth frame (X_E, Y_E, Z_E) , see Figure 3. The pitch angle θ^t is an angle between the vertical projection $X_{E(XY)}^*$ of the unit X axis onto the ground plane and the X axis. Similarly, the roll angle ϕ^t is an angle between the vertical projection $Y_{E(XY)}^*$ of the unit Y axis onto the ground plane and the Y axis.

The angle between the axis projections $X_{E(XY)}^*$ and $Y_{E(XY)}^*$ is not 90° in general case. It is 90° when the unit is parallel and 180° – when perpendicular to the ground plane.

The gravity angle ρ is an angle between the Z_E axis of the Earth frame and the unit Z axis.

The sign of the pitch and roll tilt angles is defined by the right-hand rule and presented by arrows about the Y and X axes. Since the pitch angle θ^t direction in Figure 3 is the same as the positive direction defined by the yellow arrow about the Y axis, the angle is positive. The same way, the roll angle ϕ^t direction is the opposite to the positive direction defined by the green arrow about the X axis. Therefore, the roll angle ϕ^t in Figure 3 is negative.

Pitch and roll tilt angles can be calculated either in the $\pm 90^\circ$ or $\pm 180^\circ$ measurement range depending on the application requirements.

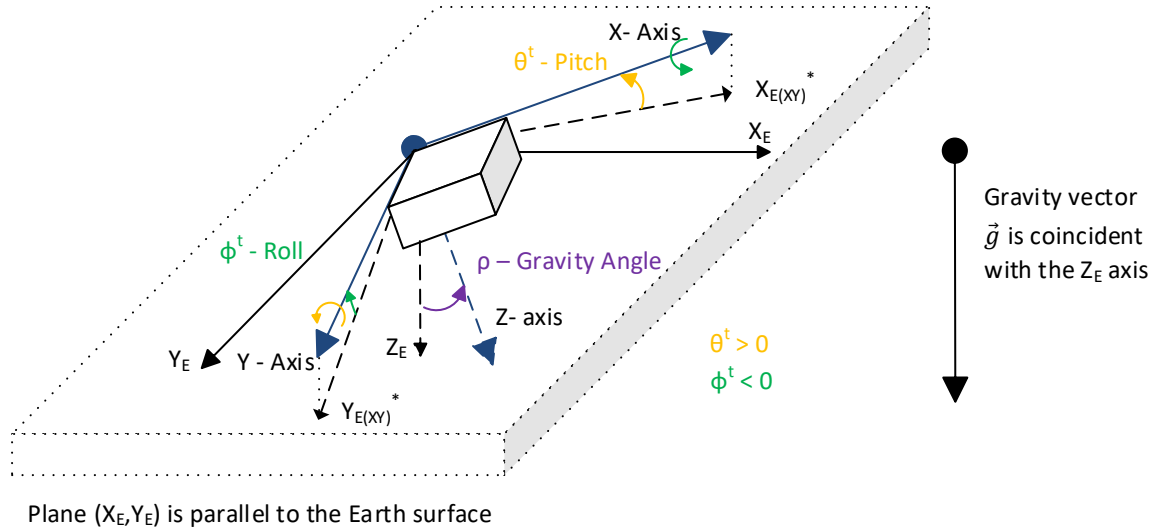


Figure 3. Tilt Angles

In the static condition, for tilt angles in the $\pm 90^\circ$ range:

$$\theta^t = \text{atan2}(-g_x, \sqrt{g_y^2 + g_z^2}), \quad \theta^t \in [-90^\circ; 90^\circ], \quad (5)$$

$$\phi^t = \text{atan2}(g_y, \sqrt{g_x^2 + g_z^2}), \quad \phi^t \in [-90^\circ; 90^\circ],$$

For tilt angles in the $\pm 180^\circ$ range:

$$\theta^t = \text{atan2}(-g_x, \text{sign}(g_z) \cdot \sqrt{g_y^2 + g_z^2}), \quad \theta^t \in [-180^\circ; 180^\circ], \quad (6)$$

$$\phi^t = \text{atan2}(g_y, \text{sign}(g_z) \cdot \sqrt{g_x^2 + g_z^2}), \quad \phi^t \in [-180^\circ; 180^\circ],$$

$$\text{where: } \text{sign}(x) = \begin{cases} -1, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

and: $\vec{g} = (g_x, g_y, g_z)$ – measured gravity vector.

When measured in the $\pm 90^\circ$ range, the tilt angles are the angles that a dual-axis inclinometer (or two single-axis inclinometers placed in orthogonal directions) will measure in the same position as the unit. They will not detect a roll-over condition.

To detect a roll-over, the gravity angle can be used. The gravity angle is calculated using the following formula:

$$\rho = \text{atan2}(\sqrt{g_x^2 + g_y^2}, g_z), \quad \rho \in [0^\circ; 180^\circ]. \quad (7)$$

When $\rho > 90^\circ$, the roll-over occurs.

When pitch θ^t and roll ϕ^t angles are measured in the $\pm 180^\circ$ range, the tilt angles will detect a roll-over when: $|\theta^t| > 90^\circ$ or $|\phi^t| > 90^\circ$, but they will lose a smooth angular transition in the roll-over points.

When the unit is parallel to the Earth surface, all tilt angles are zero: $\theta^t = \phi^t = \rho = 0^\circ$.

2.2.4.2 Rotation Angles

In opposite to tilt angles that measure an inclination angle of the unit from a certain reference plane or a vector, the rotation angles measure a rotation angle of the unit about a certain axis.

The unit can measure two types of rotation angles: unit rotation angles and Euler angles.

2.2.4.2.1 Unit Rotation Angles

The unit rotation angles define rotations about the axes in the unit frame (X,Y,Z) the following way, see Figure 4.

The rotation about the Y axis defines the pitch angle θ^u and the rotation about the X axis – the roll angle ϕ^u . The pitch angle θ^u is an angle between the horizontal projection $X_{E(XZ)}^*$ of the unit X axis onto the (X_E, Z_E) plane and the X_E axis. Similarly, the roll angle ϕ^u is an angle between the horizontal projection $Y_{E(YZ)}^*$ of the unit Y axis onto the (Y_E, Z_E) plane and the Y_E axis.

The (X_E, Z_E) and (Y_E, Z_E) planes are perpendicular to the Earth surface (X_E, Y_E) in the Earth frame (X_E, Y_E, Z_E) . The angle between $X_{E(XZ)}^*$ and $Y_{E(YZ)}^*$ is always 90° .

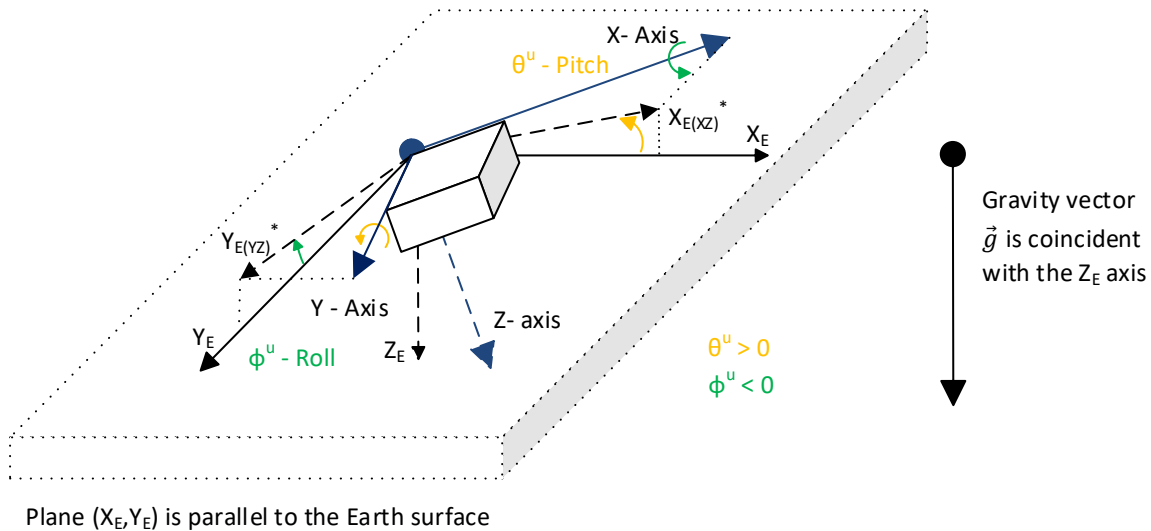


Figure 4. Simple Rotation Angles

The rotation about the Z axis (yaw angle) is not shown in Figure 4. It cannot be calculated based on the gravity acceleration \vec{g} .

The sign of the pitch and roll angles is defined by the right-hand rule and presented by arrows about the Y and X axes. Since the pitch angle θ^u direction in Figure 4 is the same as the positive direction defined by the yellow arrow about the Y axis, the angle is positive. The same way, the roll angle ϕ^u direction is the opposite to the positive direction defined by the green arrow about the X axis. Therefore, the roll angle ϕ^u in Figure 4 is negative.

In the static condition, the unit rotation angles are calculated using the following formulas:

$$\theta^u = \text{atan2}(-g_x, g_z), \quad \theta^u \in [-180^\circ; 180^\circ], \quad (8)$$

$$\phi^u = \text{atan2}(g_y, g_z), \quad \phi^u \in [-180^\circ; 180^\circ],$$

where: $\vec{g} = (g_x, g_y, g_z)$ – gravity vector measured by the unit.

The roll-over condition is observed when: $|\theta^u| > 90^\circ$ or $|\phi^u| > 90^\circ$.

When the unit is parallel to the Earth surface, the unit rotation angles are zero: $\theta^u = \phi^u = 0^\circ$.

The unit rotation angles do not uniquely define the unit angular position in space. If this is required, the Euler angles should be used.

2.2.4.2.2 Euler Angles

The Euler angles are coordinate system rotation angles performed in a specific order to rotate the unit from its original position, parallel to the Earth surface, to its current position.

The Euler angles: θ^E and ϕ^E , together with the ψ^E , are rotation angles about the Z_E , Y_{E^*} and X axes performed in a standard (yaw, pitch, roll) rotation sequence used in aerospace and defined in SAE J670 standard for automotive applications, see Figure 5.

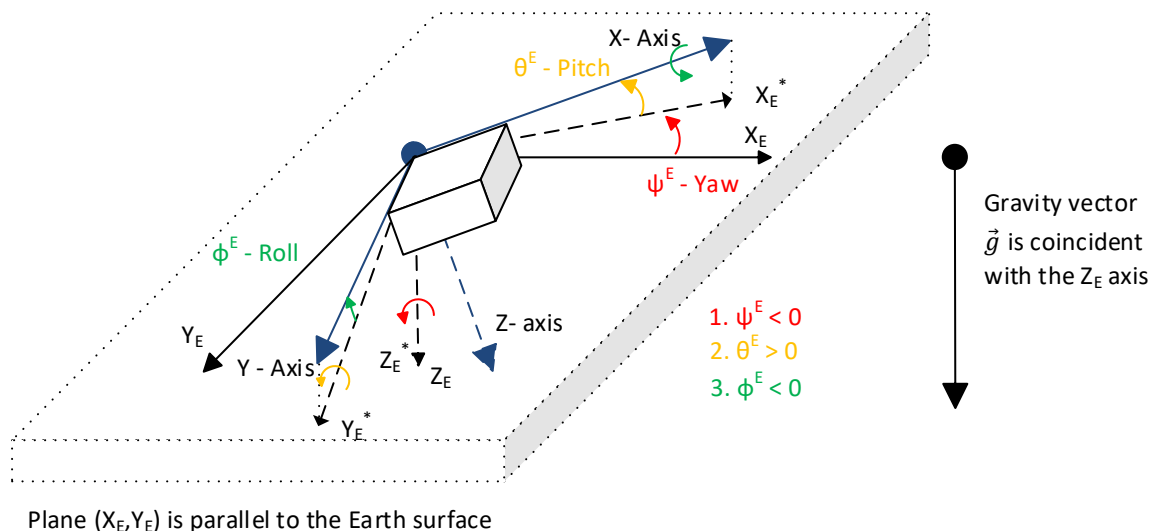


Figure 5. Euler Angles

The first rotation defines the ψ^E – yaw angle. It is performed about the Z_E axis of the Earth-fixed coordinate system (X_E, Y_E, Z_E) from the X_E axis to the X_{E^*} axis. An intermediate coordinate system $(X_{E^*}, Y_{E^*}, Z_{E^*})$ is a Z-down coordinate system whose X_{E^*} and Y_{E^*} axes are parallel to the ground plane (X_E, Y_E) , with the X_{E^*} axis aligned with the vertical projection of the X axis onto the ground

plane. Since the yaw rotation ψ^E on Figure 5 is opposite to the positive rotation direction, shown by the red arrow about the Z_E axis, the resulted angle is negative.

The second rotation defines the θ^E – pitch angle. It is performed about the Y_{E^*} axis of the intermediate coordinate system $(X_{E^*}, Y_{E^*}, Z_{E^*})$ from the X_{E^*} axis to the X axis. The pitch rotation θ^E on Figure 5 is in the positive rotation direction, defined by the yellow arrow about the Y_{E^*} axis, and the resulted angle is therefore positive.

The final third rotation defines the ϕ^E – roll angle, as a rotation about the X axis from the Y_{E^*} axis to the Y axis. The roll rotation ϕ^E on Figure 5 is negative. It is performed in the direction opposite to the positive rotation direction shown by the green arrow about the X axis.

The set of the three: yaw, pitch, and roll Euler angles fully represents the angular position of the inclinometer in space.

In the static condition, the Euler angles are calculated using the following formulas:

$$\theta^E = \text{atan2}(-g_x, \sqrt{g_y^2 + g_z^2}), \quad \theta^E \in [-90^\circ; 90^\circ], \quad (9)$$

$$\phi^E = \text{atan2}(g_y, g_z), \quad \phi^E \in [-180^\circ; 180^\circ],$$

where: $\vec{g} = (g_x, g_y, g_z)$ – measured gravity vector.

There is not enough information for the unit to calculate the yaw angle based only on the measured gravity vector in the static condition.

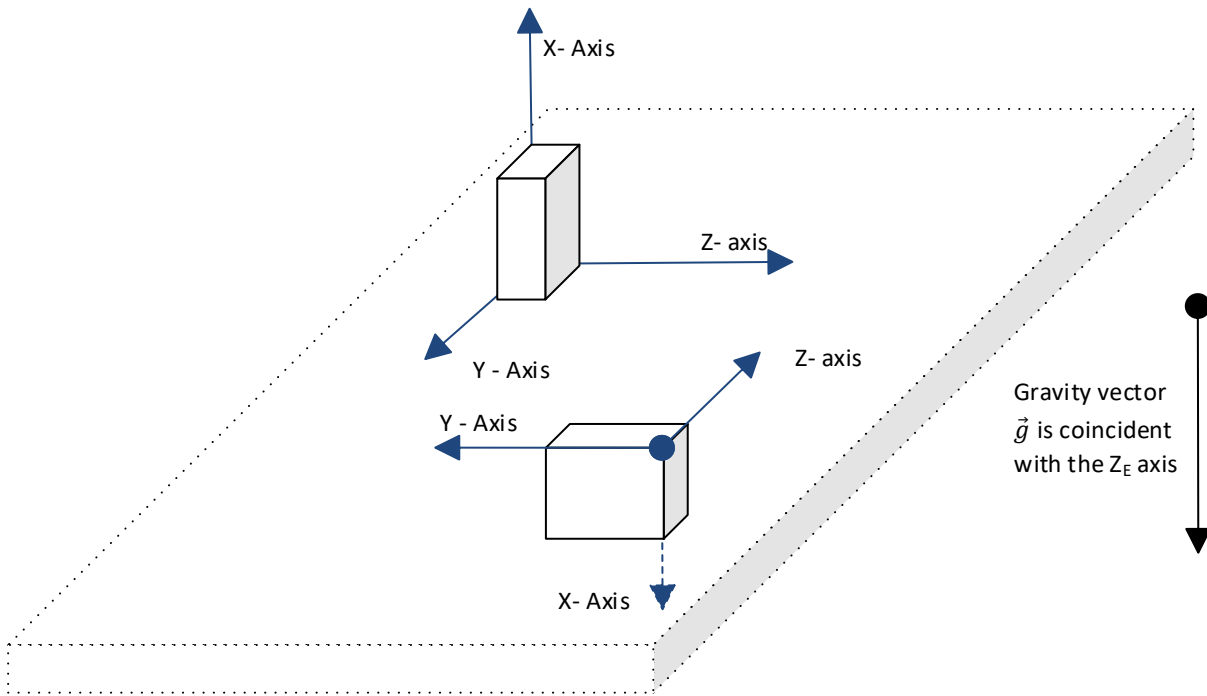
The roll angles for both: the unit rotation and Euler angles are the same: $\phi^u = \phi^E$.

The roll-over condition is observed when: $|\phi^E| > 90^\circ$.

When the unit is parallel to the Earth surface, the Euler angles are zero: $\theta^E = \phi^E = 0^\circ$.

2.2.4.2.3 Gimbal Lock

The formulas for the roll angle ϕ^E and ϕ^u are numerically unstable when both: $g_y = g_z = 0$. This condition, called a gimbal lock, happens when the unit is placed in the vertical position with the X axis parallel to the gravity vector, see Figure 6. When this happens, the unit effectively loses one degree of freedom and the roll angles ϕ^E and ϕ^u become undefined and can take any random value.



Plane (X_E, Y_E) is parallel to the Earth surface

Figure 6. Gimbal Lock

The same condition occurs with the pitch angle θ^u when both: $g_x = g_z = 0$.

The gimbal lock should be avoided in the inclinometer initial installation position. It should be also avoided in the inclinometer working range when it leads to unstable angular measurements.

The user can avoid the gimbal lock condition by changing orientation of the unit frame (a coordinate system attached to the unit) using configuration parameters when necessary.

2.2.4.3 Maximum Gravity Acceleration Error

All angular measurements in the static condition are based on the assumption that the only acceleration applied to the unit is the gravity acceleration \vec{g} , see (2). This is not entirely true when the inclinometer is installed on a moving machine and is experiencing various external accelerations. These accelerations will affect the angular calculations and, at some point, will make the accuracy of the calculations unacceptable.

To monitor the validity of the angular calculations, the inclinometer is calculating the *Gravity Acceleration Error* δ_g as a difference between the measured gravity acceleration \vec{g} and its expected theoretical value:

$$\delta_g = \left| 1 - \sqrt{g_x^2 + g_y^2 + g_z^2} \right| \quad (10)$$

When the difference exceeds a predefined value $\delta_g > \delta_g^{(max)}$, the angular calculations are considered invalid and the inclinometer sets the error state in the [Angular Figure of Merit](#).

The *Maximum Gravity Acceleration Error* $\delta_g^{(max)}$ is set by the user normally above the expected external accelerations at the customer site during normal operation conditions.

Please remember that even when $\delta_g \leq \delta_g^{(max)}$, the rated inclinometer static parameters including accuracy are not guaranteed during external accelerations. The $\delta_g^{(max)}$ only sets a threshold to notify the user that the external accelerations are too high for the angular measurements.

The *Maximum Gravity Acceleration Error* $\delta_g^{(max)}$ is not used to void the angular measurement results when the sensor fusion is enabled¹.

¹The Gravity Acceleration Error was used in firmware versions 1.xx, ..., 5.xx to void the angular measurement results when the sensor fusion was enabled but temporarily not being used due to a sensor saturation or other sensor malfunction.

2.2.4.4 Practical Recommendations

In the beginning, the user defines an inclinometer position on the machine, direction of the measurement angle or two angles in orthogonal directions, and the angular ranges.

It is important to understand that the inclinometer calculates angles based on the gravity acceleration and the angles are measured between the inclinometer unit frame or machine frame and the Earth absolute reference frame (X_E, Y_E, Z_E) where the gravity acceleration vector is uniquely defined.

The inclinometer can measure only pitch θ and roll ϕ angles. It cannot measure the yaw angle ψ , since the yaw angle is in the plane perpendicular to the gravity acceleration in the Earth absolute reference frame (X_E, Y_E, Z_E) and therefore cannot be detected by an accelerometer.

The user starts with aligning the inclinometer unit frame with the Earth absolute reference frame at the inclinometer expected position on the machine. This is done by pointing the unit frame Z-axis down, making it coincident with the gravity acceleration vector, and then aligning the unit pitch θ and roll ϕ angles with the required measurement angles.

The user can do this alignment either by mechanically rotating the inclinometer housing on the machine or by changing the unit frame orientation using inclinometer configuration parameters.

After the inclinometer position and the unit frame orientation are defined, the user should choose the type of the angles, since both: tilt and rotation angles have their pros and cons for angular measurements.

Table 1. Tilt and Rotation Angles

Inclination Angles	Advantages	Disadvantages
Tilt, $\pm 90^\circ$ Range	<ul style="list-style-type: none"> Numerically stable in the whole angular range. Smooth angular transition inside the measurement range. 	<ul style="list-style-type: none"> $\pm 90^\circ$ range for pitch and roll angles. No roll-over detection.
Tilt, $\pm 180^\circ$ Range	<ul style="list-style-type: none"> Numerically stable in the whole angular range. 	<ul style="list-style-type: none"> Abrupt angular transition inside the measurement range in roll-over points.

Inclination Angles	Advantages	Disadvantages
	<ul style="list-style-type: none"> • $\pm 180^\circ$ range for pitch and roll angles. • Roll-over detection. 	
Unit Rotation Angles	<ul style="list-style-type: none"> • Smooth angular transition inside the measurement range, except for the gimbal lock points. • $\pm 180^\circ$ range for pitch and roll angles. • Roll-over detection. 	<ul style="list-style-type: none"> • Numerically unstable pitch and roll angles in gimbal lock points.
Euler Angles	<ul style="list-style-type: none"> • Smooth angular transition inside the measurement range, except for the roll angle in gimbal lock points. • $\pm 180^\circ$ range for the roll angle; • Roll-over detection. • Uniquely define the unit angular position in space. 	<ul style="list-style-type: none"> • $\pm 90^\circ$ range for pitch angle to avoid ambiguity in angular rotations. • Numerically unstable roll angle in gimbal lock points.

For single and dual-axis measurements, when the measurement range is not above $\pm 90^\circ$, the tilt angles in the $\pm 90^\circ$ range are recommended, see Figure 7 and Figure 8. They are numerically stable and have a smooth angular transition inside the measurement range. If necessary, the roll-over can be monitored by the gravity angle.

For single-axis measurements, when the measurement range is above $\pm 90^\circ$, the rotation angles are recommended. For unit rotation angles, either pitch or roll angle can be used depending on the position of the unit on the machine. For Euler angles, the roll angle can be used, since it covers the entire $\pm 180^\circ$ range.

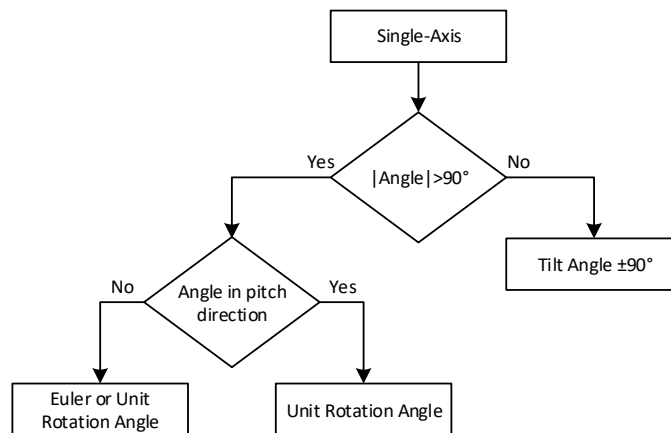


Figure 7. Single-Axis Measurements

For dual-axis measurements with the measurement range above $\pm 90^\circ$, both: tilt angles in the $\pm 180^\circ$ range or rotation angles can be used, see Figure 8. If a smooth angular transition inside the measurement range is not necessary, the tilt angles in the $\pm 180^\circ$ range are recommended due to their numerical stability in the whole measurement range.

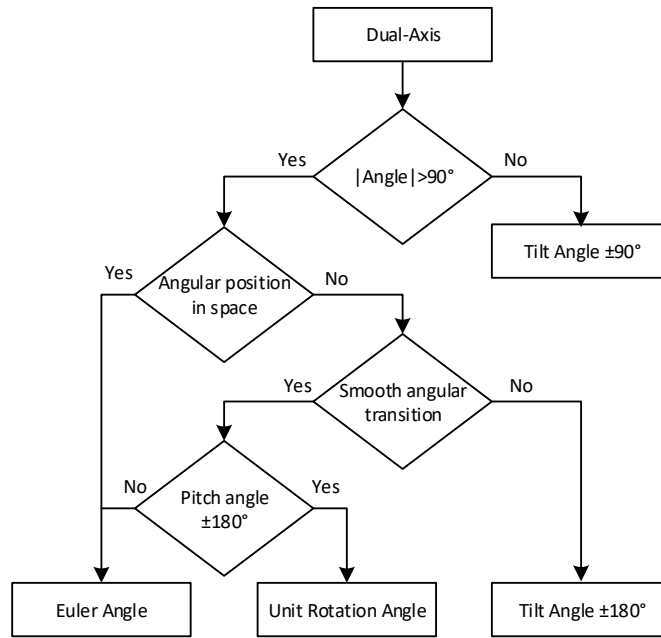


Figure 8. Dual-Axis Measurements

In case it is necessary to get the $\pm 180^\circ$ range for both: pitch and roll angles with a smooth angular transition, the unit rotation angles should be used. Otherwise, the Euler angles are preferred, since they have a gimbal lock only for the roll angle, the pitch angle is numerically stable in the whole measurement range.

The Euler angles are the angles of choice when it is necessary to define the unit angular position in space. The yaw angle is then determined by an external magnetic or GPS sensor.

Even when the Euler angles are not used to calculate the pitch and roll angles, they are still used internally to compensate the unit initial installation angles.

2.2.4.5 Default Settings

Both: AX060900 and AX060910 inclinometers measure tilt angles in the $\pm 90^\circ$ range by default.

2.3 Hardware Block Diagram

The inclinometers, depending on configuration, contain one or two three-axis MEMS accelerometers, and three single-axis MEMS gyroscopes, see Figure 9.

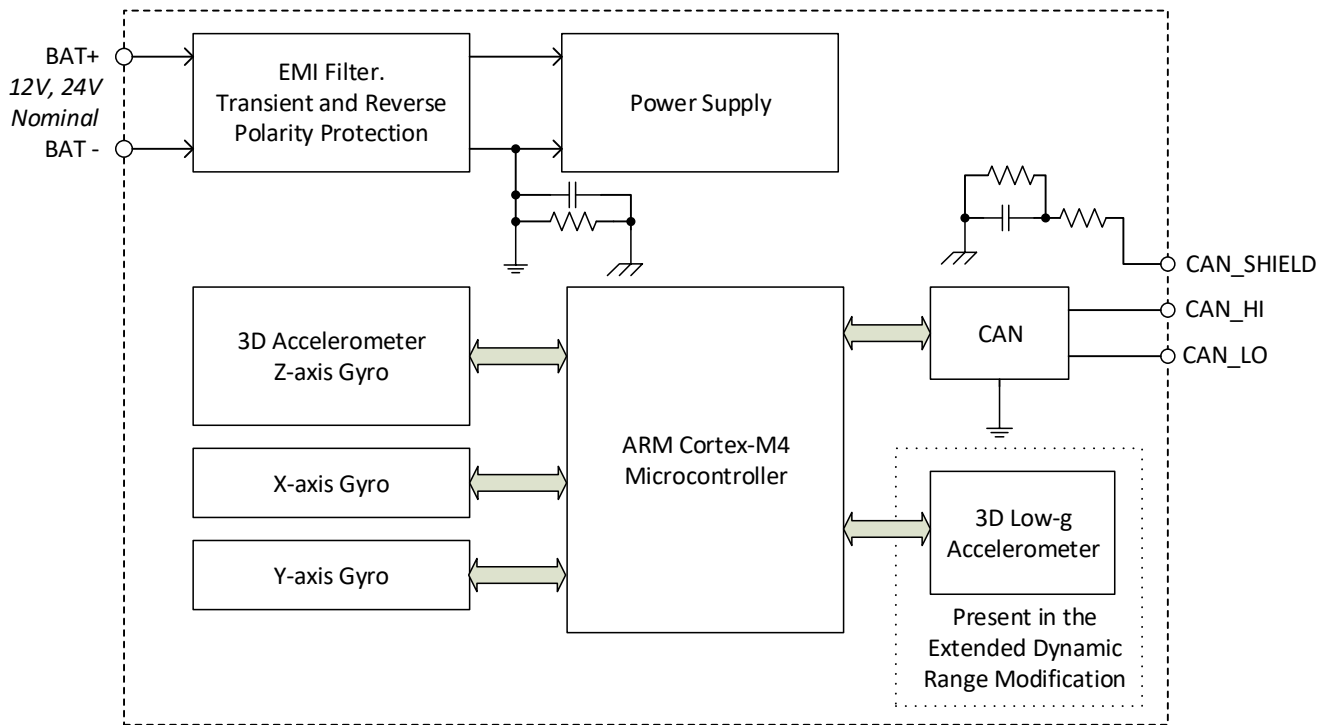


Figure 9. Simplified Inclinometer Hardware Block Diagram

The extended dynamic range inclinometer (AX060910) has a dedicated 3D low-g accelerometer to accurately measure inclination angles in a static condition.

The outputs of MEMS accelerometers and gyroscopes are processed by a 32-bit microcontroller to calculate the unit accelerations, angular rates, and inclination angles. The inclination angles are then output to CAN bus together with all other necessary additional information.

The inclinometers have a wide range of protection features including a transient and reverse polarity protection, see [Technical Specifications](#) section.

2.4 Software Organization

2.4.1 Angular Measurements

The inclinometer software block diagram for measuring angles, accelerations, and angular rates is presented in Figure 10.

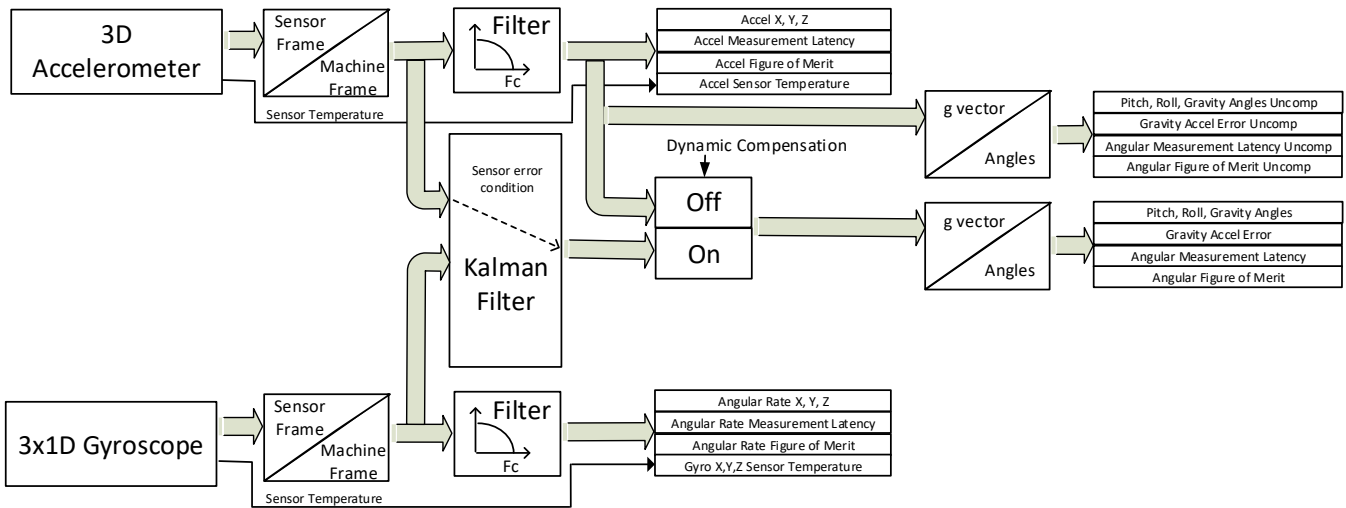


Figure 10. Software Block Diagram for Angular Measurements

A separate 3D low-g accelerometer is used in the extended dynamic range inclinometer (AX060910). A signal of this low-g accelerometer is combined with a regular 3D accelerometer to improve the accuracy of static angular measurements, see Figure 11.

The unit accelerations and angular rates from accelerometers and gyroscopes are first converted to the machine frame. Then the acceleration and angular rate signals go through the low pass filters and are output separately in two sets of data, one representing acceleration and the other one – the angular rate of the unit.

The unit angles are measured with or without dynamic compensation. When the dynamic compensation is on, the Kalman Filter is used to combine accelerations with the angular rates to estimate the gravity vector used for angular calculations. When the dynamic compensation is off, the filtered accelerometer signals define the gravity vector and are used to calculate the unit angles.

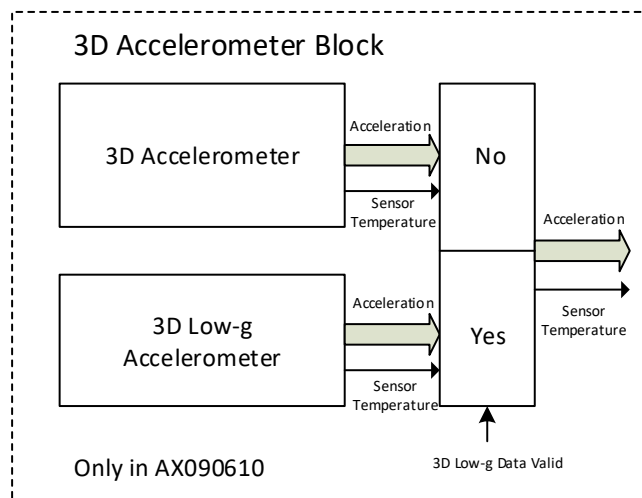


Figure 11. Acceleration Data Collection with Low-g Accelerometer

Even when the dynamic compensation is on, the Kalman Filter might be temporarily disabled due to the sensor saturation or other malfunction. In this case, the unfiltered accelerometer signals are used for angular calculations until the Kalman Filter is ready to take over the gravity vector calculations to define the unit angles.

An auxiliary set of uncompensated angular measurements, calculated on the base of the filtered accelerometer signals, is provided to evaluate the efficiency of the Kalman Filter in real time. When the dynamic compensation is off, the uncompensated angular measurements are the same as the regular angular measurements.

2.4.2 Configurable Internal Architecture

The inclinometer belongs to a family of Axiomatic smart controllers with configurable internal architecture. This architecture allows building a controlling algorithm using a set of internal configurable function blocks without the need of a custom software.

The inclinometer data acquisition and angular measurement internal software structure, shown in Figure 10, is presented in [Accelerometer](#), [Gyroscope](#), and [Angle Measurement](#) function blocks.

The user can modify the inclinometer functionality using PC-based Axiomatic Electronic Assistant (EA) software through the CAN interface, without disconnecting the inclinometer from the user's system.

The inclinometer application firmware can be also updated in the field using the Axiomatic EA, see the [Flashing New Firmware](#) section.

2.5 CAN Interface

The inclinometer CAN interface is compliant with Bosch CAN protocol specification, Rev.2.0, Part B, and the following J1939 standards:

Table 2. J1939 Standard Support

ISO/OSI Network Model Layer	J1939 Standard
Physical	J1939/11 – Physical Layer, 250K bit/s, Twisted Shielded Pair. Rev. SEP 2006. J1939/15 - Reduced Physical Layer, 250K bits/sec, Un-Shielded Twisted Pair (UTP). Rev. AUG 2008. J1939/14 - Physical Layer, 500 Kbps. Rev. OCT 2011. J1939/16 – Automatic Baud Rate Detection Process. Rev. NOV 2018.
Data Link	J1939/21 – Data Link Layer. Rev. DEC 2006 The inclinometer supports Transport Protocol for: Commanded Address messages (PGN 65240), ECU identification messages -ECUID (PGN 64965), and software identification messages -SOFT (PGN 65242). It also supports responses on PGN Requests (PGN 59904). Please note that the Proprietary A PGN (PGN 61184) is taken by Axiomatic Simple Proprietary Protocol and is not available for the user.
Network	J1939, Appendix B – Address and Identity Assignments. Rev. FEB 2010. J1939/81 – Network Management. Rev. MAR2017.

ISO/OSI Network Model Layer	J1939 Standard
	The inclinometer is an Arbitrary Address Capable ECU. It can dynamically change its network address in real time to resolve an address conflict with other ECUs. The inclinometer supports: Address Claimed Messages (PGN 60928), Requests for Address Claimed Messages (PGN 59904) and Commanded Address Messages (PGN 65240).
Transport	N/A in J1939.
Session	N/A in J1939.
Presentation	N/A in J1939.
Application	J1939/71 – Vehicle Application Layer. Rev. SEP 2013
	The inclinometer can receive application-specific PGNs with input signals and transmit application specific PGNs with up to ten output signals. All application specific PGNs are user programmable.
	J1939/73 – Application Layer – Diagnostics. Rev. FEB 2010
	Memory access protocol (MAP) support. DM14, DM15, DM16 messages used by the Axiomatic EA to program configuration parameters.

2.5.1 CAN Baud Rate

The inclinometer can operate at J1939 standard 250 kbit/s and 500 kbit/s baud rates. It can also run at 667kbit/s and at 1Mbit/s – the maximum baud rate supported by the CAN inclinometer hardware.¹

¹ *Inclinometers with firmware V1.xx...4.xx could operate only at 250kbit/s baud rate, and with firmware V5.xx...6.xx – at 250, 500, and 1000 kbit/s (1Mbit/s) baud rates.*

The baud rate selection is performed automatically upon connection to the CAN network using passive and active automatic baud rate detection process described in J1939/16. Once detected, the baud rate is stored in non-volatile memory and used on the next inclinometer power-up.

The baud rate detection can be disabled for permanently installed units to maintain the desired baud rate on the CAN network.

2.5.2 J1939 Name and Address

Before sending and receiving any application data, the inclinometer claims its network address with a unique J1939 Name. The Name fields are presented in the table below:

Table 3. J1939 Name Fields

Field Name	Field Length	Field Value	Configurable
Arbitrary Address Capable	1 bit	1 (Capable)	No
Industry Group	3 bit	3 (Construction Equipment)	No
Vehicle System Instance	4 bit	0 (First Instance)	No
Vehicle System	7 bit	0 (Nonspecific System)	No
Reserved	1 bit	0	No
Function	8 bit	136 (Slope Sensor)	No
Function Instance	5 bit	6 (AX06090x, Tri-Axial Gyro Inclinometer, SAE J1939, Axiomatic proprietary value)	No

Field Name	Field Length	Field Value	Configurable
ECU Instance	3 bit	0 (First Instance)	Yes
Manufacturer Code	11 bit	162 (Axiomatic Technologies Corp.)	No
Identity Number	21 bit	Calculated on the base of the microcontroller unique ID	No

The user can change the inclinometer *ECU Instance* using the Axiomatic EA to accommodate multiple units on the same CAN network.

The inclinometer takes its network *ECU Address* from a pool of addresses assigned to self-configurable ECUs. The default address can be changed during an arbitration process or upon receiving a commanded address message. The new address value will be stored in a non-volatile memory and used next time for claiming the network address. The *ECU Address* can also be changed in the Axiomatic EA, see [J1939 Network](#) function block.

2.5.3 Slew Rate Control

The inclinometer has an ability to adjust the CAN transceiver slew rate for better performance on the CAN physical network, see [J1939 Network](#) function block for further details.

2.5.4 Network Bus Terminating Resistors

The inclinometers do not have an embedded 120 Ohm CAN bus terminating resistor.

The terminating resistors should be installed externally on both ends of the CAN twisted pair cable according to the J1939/11(15) standards to avoid communication errors.

Even if the length of the CAN network is short and the signal reflection from both ends of the cable can be ignored, at least one 120 Ohm resistor is required for the majority of CAN transceivers to operate properly.

2.6 Default Settings

The inclinometer is shipped with the following preconfigured settings to transmit angular and angular rate data on the CAN bus.

2.6.1 CAN Interface

By default, the inclinometer angular and angular rate data is transmitted in a standard PGN:

- *PGN 61481, Slope Sensor Information 2, SSI2.*

The inclinometer is also preconfigured the way that it can send data in:

- *PGN 61459, Slope Sensor Information, SSI.*
- *PGN 61482, Angular Rate Information, ARI;*
- *PGN 65256, Vehicle Direction/Speed, VDS;*
- *PGN 64905, Vehicle Direction/Speed 2, VDS2.*

The user should use the Axiomatic EA to activate sending the appropriate preconfigured PGNs by changing the *Transmission Enable* configuration parameter from *No* to *Yes*, see [CAN Output Message](#) function block. Any other user-defined PGNs can be configured by the EA as well.

2.6.1.1 PGN 61459, Slope Sensor Information, SSI

This PGN provides measurements of the vehicle pitch and roll angles, and a measurement of the vehicle pitch rate. It has the following parameters:

Transmission Repetition Rate: 10 ms
 Data Length: 8
 Default Priority: 3
 Parameter Group Number: 61459

Start Position	Length	Parameter Name	SPN
1-2	2 bytes	Pitch Angle	3318
3-4	2 bytes	Roll Angle	3319
5-6	2 bytes	Pitch Rate	3322
7.1	2 bits	Pitch Angle Figure of Merit	3323
7.3	2 bits	Roll Angle Figure of Merit	3324
7.5	2 bits	Pitch Rate Figure of Merit	3325
7.7	2 bits	Pitch and Roll Compensated	3326
8	1 byte	Roll and Pitch Measurement Latency	3327

Parameter Name: Pitch Angle
 Data Length: 2 bytes
 Resolution: 0.002 deg/bit, -64 offset
 Data Range: -64 to 64.51 deg Operational Range: same as data range
 Type: Measured

Parameter Name: Roll Angle
 Data Length: 2 bytes
 Resolution: 0.002 deg/bit, -64 offset
 Data Range: -64 to 64.51 deg Operational Range: same as data range
 Type: Measured

Parameter Name: Pitch Rate
 Data Length: 2 bytes
 Resolution: 0.002 deg/sec per bit, -64 offset
 Data Range: -64 to 64.51 deg/sec Operational Range: same as data range
 Type: Measured

Parameter Name: Pitch Angle Figure of Merit
 Data Length: 2 bits

Bit 2	Bit 1	Description
0	0	Pitch angle fully functional. Data is within sensor specification.
0	1	Pitch angle degraded. Data is suspect due to environmental conditions.
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Roll Angle Figure of Merit
 Data Length: 2 bits

Bit 2	Bit 1	Description
0	0	Roll angle fully functional. Data is within sensor specification.

0 1 Roll angle degraded. Data is suspect due to environmental conditions.
 1 0 Error
 1 1 Not available
 Type: Status

Parameter Name: Pitch Rate Figure of Merit
 Data Length: 2 bits
 Bit 2 Bit 1
 0 0 Pitch rate fully functional. Data is within sensor specification.
 0 1 Pitch rate degraded. Data is suspect due to environmental conditions.
 1 0 Error
 1 1 Not available
 Type: Status

Parameter Name: Pitch and Roll Compensated
 Data Length: 2 bits
 Bit 2 Bit 1
 0 0 Compensation Off
 0 1 Compensation On
 1 0 Error
 1 1 Not available
 Type: Status

Parameter Name: Roll and Pitch Measurement Latency
 Data Length: 1 byte
 Resolution: 0.5 ms/bit, 0 offset
 Data Range: 0 to 125 ms Operational Range: same as data range
 Type: Measured

2.6.1.2 PGN 61481, Slope Sensor Information 2, SSI2

This PGN provides measurements of the vehicle extended pitch and roll angle. It has the following parameters:

Transmission Repetition Rate: 10 ms
 Data Length: 8
 Default Priority: 3
 Parameter Group Number: 61481

Start Position	Length	Parameter Name	SPN
1-3	3 bytes	Pitch Angle Extended Range	4976
4-6	3 bytes	Roll Angle Extended Range	4977
7.1	2 bits	Pitch Angle Extended Range Compensation	4978
7.3	2 bits	Pitch Angle Extended Range Figure of Merit	4979
7.5	2 bits	Roll Angle Extended Range Compensation	4980
7.7	2 bits	Roll Angle Extended Range Figure of Merit	4981
8	1 byte	Roll and Pitch Extended Range Measurement Latency	4982

Parameter Name: Pitch Angle Extended Range
 Data Length: 3 bytes
 Resolution: 1/32768 deg/bit, -250 deg offset

Data Range: -250 to 250.9999 deg Operational Range: same as data range
Type: Measured

Parameter Name: Roll Angle Extended Range
Data Length: 3 bytes
Resolution: 1/32768 deg/bit, -250 deg offset
Data Range: -250 to 250.9999 deg Operational Range: same as data range
Type: Measured

Parameter Name: Pitch Angle Extended Range Compensation
Data Length: 2 bits

Bit 2	Bit 1	
0	0	On
0	1	Off
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Pitch Angle Extended Range Figure of Merit
Data Length: 2 bits

Bit 2	Bit 1	
0	0	Pitch angle fully functional. Data is within sensor specification.
0	1	Pitch angle degraded. Data is suspect due to environmental conditions.
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Roll Angle Extended Range Compensation
Data Length: 2 bits

Bit 2	Bit 1	
0	0	On
0	1	Off
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Roll Angle Extended Range Figure of Merit
Data Length: 2 bits

Bit 2	Bit 1	
0	0	Roll angle fully functional. Data is within sensor specification.
0	1	Roll angle degraded. Data is suspect due to environmental conditions.
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Roll and Pitch Extended Range Measurement Latency
Data Length: 1 byte
Resolution: 0.5 ms/bit, 0 offset
Data Range: 0 to 125 ms Operational Range: same as data range
Type: Measured

Type: Measured

2.6.1.3 PGN 61482, Angular Rate Information, ARI

This PGN provides measurements of the vehicle pitch, roll, and yaw rate. It has the following parameters:

Transmission Repetition Rate: 10 ms
Data Length: 8
Default Priority: 3
Parameter Group Number: 61482

Start Position	Length	Parameter Name	SPN
1-2	2 bytes	Pitch Rate Extended Range	4983
3-4	2 bytes	Roll Rate Extended Range	4984
5-6	2 bytes	Yaw Rate Extended Range	4985
7.1	2 bits	Pitch Rate Extended Range Figure of Merit	4986
7.3	2 bits	Roll Rate Extended Range Figure of Merit	4987
7.5	2 bits	Yaw Rate Extended Range Figure of Merit	4988
8	1 byte	Angular Rate Measurement Latency	4989

Parameter Name: Pitch Rate Extended Range
Data Length: 2 bytes
Resolution: 1/128 deg/sec per bit
Offset: -250 deg/sec
Type: Measured

Parameter Name: Roll Rate Extended Range
Data Length: 2 bytes
Resolution: 1/128 deg/sec per bit
Offset: -250 deg/sec
Type: Measured

Parameter Name: Yaw Rate Extended Range
Data Length: 2 bytes
Resolution: 1/128 deg/sec per bit
Offset: -250 deg/sec
Type: Measured

Parameter Name: Pitch Rate Extended Range Figure of Merit
Data Length: 2 bits

Bit 2	Bit 1	
0	0	Pitch rate fully functional. Data is within sensor specification.
0	1	Pitch rate degraded. Data is suspect due to environmental conditions.
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Roll Rate Extended Range Figure of Merit
Data Length: 2 bits

Bit 2	Bit 1
-------	-------

0	0	Roll rate fully functional. Data is within sensor specification.
0	1	Roll rate degraded. Data is suspect due to environmental conditions.
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Yaw Rate Extended Range Figure of Merit

Data Length: 2 bits

Bit 2	Bit 1	
-------	-------	--

0	0	Yaw rate fully functional. Data is within sensor specification.
0	1	Yaw rate degraded. Data is suspect due to environmental conditions.
1	0	Error
1	1	Not available

Type: Status

Parameter Name: Angular Rate Measurement Latency

Data Length: 1 byte

Resolution: 0.5 ms/bit

Offset: 0 ms

Type: Measured

2.6.1.4 PGN 65256, Vehicle Direction/Speed, VDS

Transmission Repetition Rate: On request

Data Length: 8

Default Priority: 6

Parameter Group Number: 65256

Start Position	Length	Parameter Name	SPN
1-2	2 bytes	Compass Bearing	165
3-4	2 bytes	Navigation-Based Vehicle Speed	517
5-6	2 bytes	Pitch	583
7-8	2 bytes	Altitude	580

Parameter Name: Compass Bearing. (Not used by the inclinometer. Populated with 0xFFFF)

Data Length: 2 bytes

Resolution: 1/128 deg/bit, 0 offset

Data Range: 0 to 501.99 deg Operational Range: same as data range

Type: Measured

Parameter Name: Navigation-Based Vehicle Speed (Not used by the inclinometer. Populated with 0xFFFF)

Data Length: 2 bytes

Resolution: 1/256 km/h per bit, 0 offset

Data Range: 0 to 250.996 km/h Operational Range: same as data range

Type: Measured

Parameter Name: Pitch

Data Length: 2 bytes

Resolution: 1/128 deg/bit, -200 deg offset

Data Range: -200 to 301.99 deg Operational Range: -200 deg (DECENT)

to +301.992 deg (ASCENT)

Type: Measured

Parameter Name: Altitude (Not used by the inclinometer. Populated with 0xFFFF)

Data Length: 2 bytes

Resolution: 0.125 m/bit, -2500 m offset

Data Range: -2500 to 5531.875 m

Operational Range: same as data range

Type: Measured

2.6.1.5 PGN 64905, Vehicle Direction/Speed 2, VDS2

Transmission Repetition Rate: On request

Data Length: 8

Default Priority: 6

Parameter Group Number: 64905

Start Position	Length	Parameter Name	SPN
1-2	2 bytes	Vehicle Roll	3623

Parameter Name: Vehicle Roll

Data Length: 2 bytes

Resolution: 1/128 deg/bit, -200 deg offset

Data Range: -200 to 301.99 deg

Operational Range: -90 to 90 degrees

Type: Measured

3 INCLINOMETER LOGICAL STRUCTURE

The inclinometer is internally organized as a set of function blocks, which can be individually configured and arbitrarily connected together to achieve the required inclinometer functionality, see Figure 12.

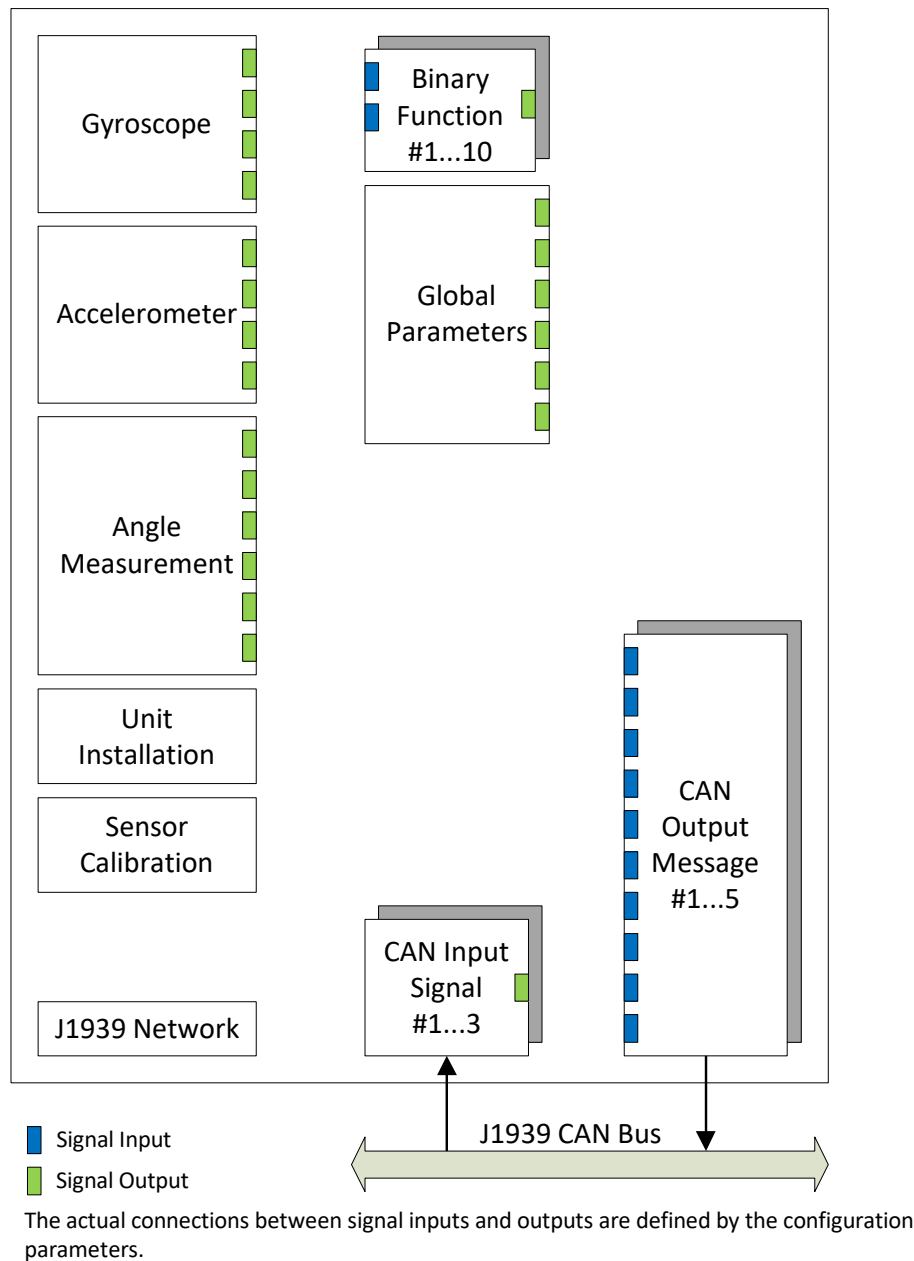


Figure 12. The Inclinometer Logical Block Diagram

Each function block is absolutely independent and has its own set of configuration parameters, or setpoints. The configuration parameters can be viewed and changed through CAN bus using Axiomatic Electronic Assistant (EA) software.

The gyroscope and accelerometer sensors are presented by *Gyroscope* and *Accelerometer* function blocks, respectively. *Angle Measurement* function block controls measurements of the inclination angles. *Unit Installation* function block is used to compensate installation angles after

the unit is mounted at a customer's site. *Sensor Calibration* is an auxiliary function block representing the inclinometer calibration parameters.

The J1939 CAN interface is represented by the *CAN Input Signal*, *CAN Output Message* and *J1939 Network* function blocks. The *CAN Input Signal* function blocks are used to receive CAN signals transmitted on the CAN bus. They have one signal output, which is updated once the signal is received. The *CAN Output Message* function blocks are used to transmit CAN signals on the CAN bus. Each CAN message can contain up to ten individual CAN output signals, which receive data from their individual signal inputs.

In case the inclinometer data need to be processed before been output, the unit has ten *Binary Function* blocks to do simple data conversion operations.

The inclinometer also has a *Global Parameters* function block containing four constant output signals and other auxiliary output signals.

3.1 Function Block Signals

The inclinometer function blocks can contain signal inputs and outputs to communicate with each other. Each signal input can be connected to any signal output using an appropriate configuration parameter. There is no limitation on the number of signal inputs connected to a signal output.

When a signal input is connected to a signal output, data from the signal output of one function block is available on the signal input of another function block.

The function block signal data can have the following signal types: {*Undefined*, *Discrete* or *Continuous*}.

3.1.1 Undefined Signal

The *Undefined* signal type is used to present a no-signal condition in signal data or to specify that the signal input is not connected (not used).

3.1.2 Discrete Signal

The *Discrete* signal type is used to present a discrete signal that has a finite number of states in signal data or to specify that the signal input or output is communicating this type of signals.

The discrete signals are stored in four-byte unsigned integer variables that can present any state value in the $0 \dots 0xFFFFFFFF$ range.

3.1.3 Continuous Signal

The *Continuous* signal type presents continuous signals, usually physical parameters, in signal data or as a signal input or output type.

The continuous signals are stored in floating point variables. They are not normalized and present data in the appropriate physical units. The user can do simple scaling of the continuous signal data by changing *Scale (Resolution)* and *Offset* configuration parameters in the appropriate function blocks.

3.1.4 Signal Type Conversion

Discrete and *Continuous* signals are automatically converted into each other when a signal input of one signal type is connected to a signal output of a different signal type.

3.1.4.1 Discrete to Continuous Conversion

A *Discrete* signal is converted into a positive *Continuous* signal of the same value.

3.1.4.2 Continuous to Discrete Conversion

A positive *Continuous* signal is converted into the same value *Discrete* signal. A fractional part of the *Continuous* signal is truncated. If the *Continuous* signal value is above the maximum *Discrete* signal value, the resulted *Discrete* signal value will saturate to the maximum *Discrete* signal value: `0xFFFFFFFF`.

All negative *Continuous* signals are converted into zero value *Discrete* signals.

3.1.4.3 Undefined Signal Conversion

An *Undefined* signal is not converted into a specific discrete or continuous signal value. It presents a no-signal condition on both: *Discrete* and *Continuous* signal inputs and outputs. The value of an undefined signal is not defined unless a default signal value configuration parameter is used in a function block. In this case, the configuration parameter value is used as a signal value when the signal is not defined, see [Binary Function](#) blocks.

3.2 Gyroscope

The *Gyroscope* function block presents all three gyroscope MEMS sensors sensing inclinometer angular rate in three orthogonal directions (3D).

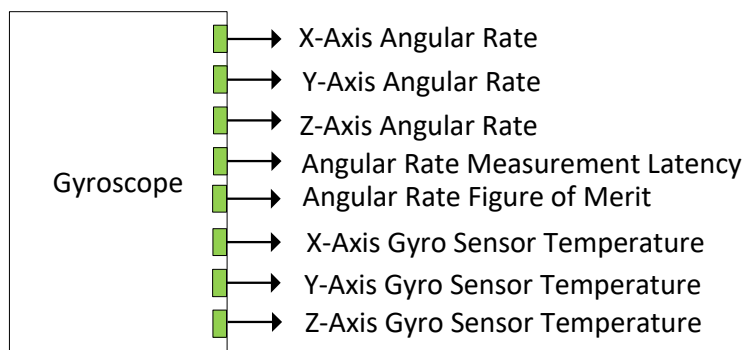


Figure 13. Gyroscope Function Block

This function block has 8 signal outputs. The *X, Y, Z - Axis Angular Rate* continuous signals represent the gyroscope angular rates about the appropriate axis in the machine frame in [deg/s]. The machine frame is coincident with the unit frame by default when the initial pitch and roll angles are zero in the [Unit Installation](#) function block.

The *Angular Rate Measurement Latency* continuous signal defines the angular rate measurement latency in [ms].

The *Angular Rate Figure of Merit* discrete signal defines whether the gyroscope angular rate data can be trusted. It has the following set of states:

Table 4. Gyroscope Angular Rate Figure of Merit

State	Description
0	All gyroscopes are fully functional. Data is within the sensor specification.
1	Data is suspect due to environmental conditions. Set when any of the gyroscope sensor temperatures is less than -40°C or greater than +125°C.
2	Error condition has been detected.

The *X,Y,Z – Axis Gyro Sensor Temperature* continuous signals represent the internal temperatures for each individual gyroscope sensor in [°C].

The *Gyroscope* function block configuration parameters are defined below.

Table 5. Gyroscope Function Block Configuration Parameters

Name	Default Value	Range	Units	Description
Input Filter	On	{Off, On}	–	Low-pass input filter.
Input Filter Cut-Off Frequency	5	[1...35]	Hz	Cut-Off Frequency when <i>Input Filter</i> is <i>On</i> .

3.3 Accelerometer

The *Accelerometer* function block represents the 3D accelerometer sensor.

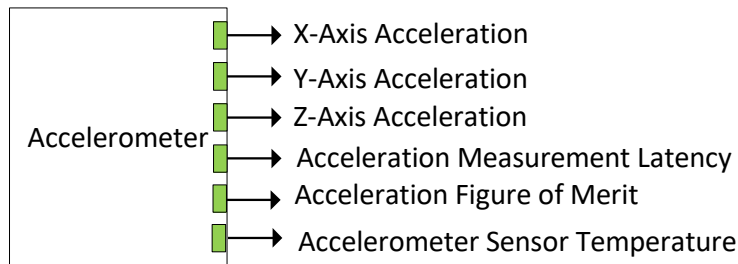


Figure 14. Accelerometer Function Block

The *Accelerometer* function block has 6 signal outputs. The unit accelerations: *X,Y,Z - Axis Acceleration* are presented in gravity units [g] in the machine frame. The machine frame is coincident with the unit frame by default when the initial pitch and roll angles are zero in the [Unit Installation](#) function block.

The *Acceleration Measurement Latency* continuous signal defines the acceleration measurement latency in [ms].

The *Acceleration Rate Figure of Merit* discrete signal defines whether the acceleration data can be trusted. It has the following set of states:

Table 6. Gyroscope Angular Rate Figure of Merit

State	Description
0	Accelerometer is fully functional. Data is within the sensor specification.

State	Description
1	Data is suspect due to environmental conditions. Set when the accelerometer sensor temperature is less than -40°C or greater than +125°C.
2	Error condition has been detected.

The *Accelerometer Sensor Temperature* output represents the 3D accelerometer sensor temperature in [°C].

The *Accelerometer* function block configuration parameters are defined below.

Table 7. *Accelerometer Function Block Configuration Parameters*

Name	Default Value	Range	Units	Description
Input Filter	On	{Off, On}	–	Low-pass input filter.
Input Filter Cut-Off Frequency	5	[1...35]	Hz	Cut-Off Frequency when <i>Input Filter</i> is <i>On</i> .

3.4 Angle Measurement

The *Angle Measurement* function block calculates pitch, roll and gravity angles in the machine frame, see Figure 15. The machine frame is coincident with the unit frame by default when the initial pitch and roll angles are zero in the [Unit Installation](#) function block.

The angles can be calculated with or without a sensor fusion algorithm. The angle outputs calculated without the sensor fusion algorithm are named as *Uncompensated*.

For example, *Pitch Angle Uncompensated* output is a version of a regular *Pitch Angle* output calculated without using the sensor fusion algorithm. This allows to evaluate the performance of a sensor fusion algorithm in real time to make a knowledgeable decision whether using the gyroscope-compensated inclinometer provides a noticeable advantage in the customer's application.

The sensor fusion algorithm can be enabled or disabled by the *Dynamic Angle Compensation* configuration parameter. When the sensor fusion is disabled, there is no difference between the uncompensated and regular outputs; they both output the same data.

By default, the *Dynamic Angle Compensation* is *On* and the sensor fusion algorithm is enabled.

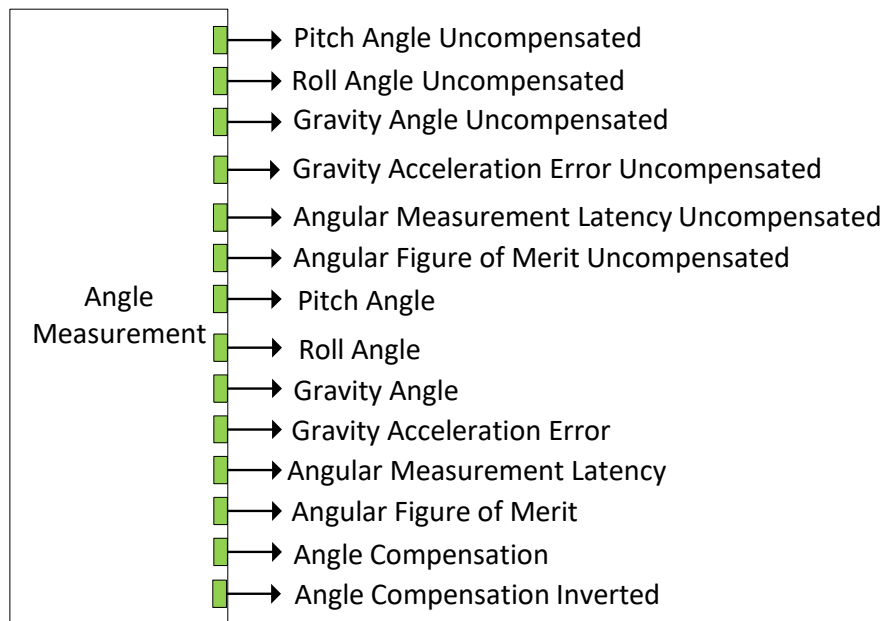


Figure 15. Angle Measurement Function Block

The *Pitch Angle* and *Pitch Angle Uncompensated* are continuous signals that output the unit pitch angle θ in [deg]. They have ± 90 [deg] range for Euler angles and ± 180 [deg] for unit rotation angles. For tilt angles, they can be either ± 90 or ± 180 [deg] depending on the *Tilt Angle Range* configuration parameter.

The *Roll Angle* and *Roll Angle Uncompensated* are continuous signals that output the roll angle ϕ in [deg]. They have a full ± 180 [deg] range for Euler and unit rotation angles. For tilt angles, they can be either ± 90 or ± 180 [deg] depending on the *Tilt Angle Range* configuration parameter.

The *Gravity Angle* and *Gravity Angle Uncompensated* are continuous signals that output the gravity angle ρ in [deg]. They have 0...180 [deg] range.

The *Gravity Acceleration Error* and *Gravity Acceleration Error Uncompensated* continuous signals output the gravity acceleration error δ_g in [g].

The *Angular Measurement Latency* and *Angular Measurement Latency Uncompensated* continuous signals output the angular measurement latency in [ms].

The *Angular Figure of Merit* and *Angular Figure of Merit Uncompensated* are discrete signals that define whether the angular output data can be trusted. They have the following set of states:

Table 8. Angular Figure of Merit

State	Description
0	Angular data is fully functional. Data is within the sensor specification.
1	Angular data is suspect due to environmental conditions. <i>Dynamic Angle Compensation:</i> On – The accelerometer sensor temperature or one of the gyroscope sensor temperatures is less than -40°C or greater than $+125^{\circ}\text{C}$. Off - Accelerometer sensor temperature is less than -40°C or greater than $+125^{\circ}\text{C}$.
2	Error condition has been detected.

State	Description
	<p><i>Dynamic Angle Compensation:</i></p> <p>On –The accelerometer sensor or one of the gyroscope sensors is saturated or is malfunctioning or the sensor fusion algorithm is temporarily disabled (due to a sensor error or while recovering from an error condition) ¹.</p> <p>Off – The accelerometer sensor is saturated or is malfunctioning or the gravity acceleration error has exceeded the maximum configured value.</p>

¹The Gravity Acceleration Error was used to determine an error condition for the Angular Figure of Merit when the sensor fusion algorithm was temporarily disabled in firmware versions 1.xx, ..., 5.xx.

The *Angle Compensation* and *Angle Compensation Inverted* are discrete output signals that define whether the sensor fusion algorithm is being used. They have the following set of states:

Table 9. *Angle Compensation*

State	Description
0	Angle Compensation is Off. The sensor fusion algorithm is disabled.
1	Angle Compensation is On. The sensor fusion algorithm is enabled and being used.
2	Error State. The sensor fusion algorithm is enabled but not being used (temporarily disabled).

Table 10. *Angle Compensation Inverted*

State	Description
0	Angle Compensation is On. The sensor fusion algorithm is enabled and being used.
1	Angle Compensation is Off. The sensor fusion algorithm is disabled.
2	Error State. The sensor fusion algorithm is enabled but not being used (temporarily disabled).

The *Angle Measurement* function block configuration parameters are presented below:

Table 11. *Angle Measurement Function Block Configuration Parameters*

Name	Default Value	Range	Units	Description
Pitch and Roll Angle Type	Tilt Angle	{Euler Angle, Tilt Angle, Unit Rotation Angle}	–	Type of the pitch and roll angle.
Tilt Angle Range	±90	{±90, ±180}	deg	Tilt angle measurement range.
Maximum Gravity Acceleration Error	0.2	[0.05...0.5]	g	Maximum gravity acceleration error acceptable for the angular calculations.
Dynamic Angle Compensation	On	{Off, On}	–	<p>Kalman filter On/Off. Defines whether the inclinometer angles are calculated using the sensor fusion algorithm.</p> <p>Even when the <i>Dynamic Angle Compensation</i> is On, the sensor fusion algorithm can be temporarily disabled due to a sensor saturation or other sensor malfunction.</p>

Name	Default Value	Range	Units	Description
Accelerometer Noise Density	0.12 ¹ 0.037 ²	[0...1]	mg/sqrt(Hz)	Accelerometer white-noise Kalman filter parameter.
Gyro Noise Density	0.008 ¹ 0.007 ²	[0...1]	deg/s/sqrt(Hz)	Gyroscope white-noise Kalman filter parameter.
Gyro Rate Random Walk	0.0005	[0...1]	deg/s ² /sqrt(Hz)	Gyroscope rate random walk Kalman filter parameter.

¹For AX060900. ²For AX060910.

3.5 Unit Installation

The *Unit Installation* function block is used to compensate initial installation angles after the unit is mounted on a machine at a customer's site.

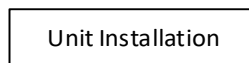


Figure 16. Unit Installation Function Block

The function block has no signal inputs and outputs. Its configuration parameters are presented below.

Table 12. Unit Installation Function Block Configuration Parameters

Name	Default Value	Range	Units	Description
Coordinate Rotation Yaw Angle	0	[-180...180]	deg	Initial unit frame rotation yaw angle.
Coordinate Rotation Pitch Angle	0	[-180...180]	deg	Initial unit frame rotation pitch angle.
Coordinate Rotation Roll Angle	0	[-180...180]	deg	Initial unit frame rotation roll angle.
Initial Pitch Angle	0	[-90...90]	deg	Initial installation pitch angle.
Initial Roll Angle	0	[-180...180]	deg	Initial installation roll angle.
Auto-Null Command	No ²	{No, Yes}	–	Auto-Null Command. Set <i>Yes</i> to automatically update the <i>Initial Pitch Angle</i> and <i>Initial Roll Angle</i> .

¹The *Coordinate Rotation Yaw, Pitch, and Roll Angles* were added in V4.0 firmware.

²The *Auto-Null Command* is not a real configuration parameter. It always returns *No* value when being read.

The *Coordinate Rotation Yaw, Pitch and Roll Angles* (ψ, θ, ϕ) are used to change the original orientation of the unit frame. The original orientation is shown on the inclinometer label. The coordinate rotation angles are Euler angles applied in the standard yaw-pitch-roll order to the unit frame.

Normally, the coordinate rotation angles are taken in 90-degree increments: 0, ± 90 , ± 180 , but theoretically they can be assigned any value in the [-180...+180] degree range.

After the coordinate system is rotated, the user can install the inclinometer on the machine and set the initial installation pitch and roll angles.

The initial installation pitch and roll angles are Euler angles used to transform the unit accelerations from the unit frame to the machine frame. They can be written manually or set up automatically when *Auto-Null Command* is set to *Yes*.

To set up the initial installation angles automatically, the user issues the *Auto-Null Command* when the machine is in the initial null-angle position, leveled on the operation area. The machine frame is coincident with the Earth reference frame in this position, see [Unit Reference Frames](#).

The user should avoid the gimbal lock condition when issuing the *Auto-Null Command* since in this case the *Initial Roll Angle* cannot be accurately defined, and the resulting machine frame orientation can be random, see [Gimbal Lock](#).

3.5.1 Unit Frame Orientation Examples

The user can change the unit frame orientation by applying the *Coordinate Rotation Yaw, Pitch and Roll Angles* (ψ, θ, ϕ) to the original default orientation of the unit frame.

For example, let us assume that the unit in the original null-angle position is placed vertically on the machine, long side up, and the angle of interest will be measured as the unit pitch angle, see Figure 17. Remember, that the measured angle cannot be yaw angle, only pitch or roll angle, see [Practical Recommendations](#).

This assumption will require a new unit frame orientation presented in Figure 17. In the new orientation, the Z-axis points down to be coincident with the gravity vector, the X and Y axes are rotated the way that the Y-axis points towards the viewer, X-axis points right, and rotation about the Y-axis gives the required pitch angle according to the right-hand rule, see [Unit Coordinate System](#).

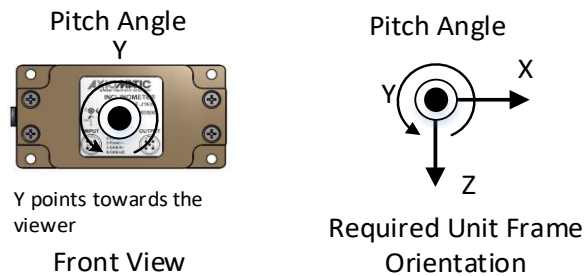


Figure 17. Unit Frame Orientation Example. New Unit Frame Orientation

To convert the original unit frame orientation into the required one, perform (0,0,-90°) coordinate system rotation, see Figure 18.

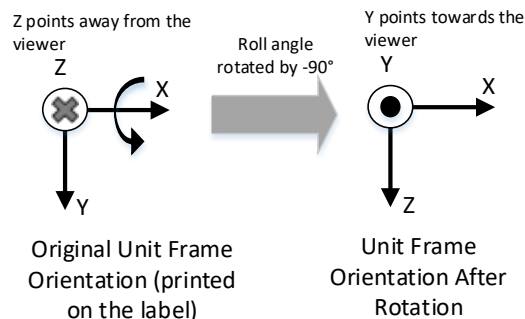


Figure 18. Unit Frame Orientation Example. Coordinate System Rotation

In user applications, to avoid errors, it is recommended checking the new unit frame orientation on the bench before installing the inclinometer on the machine. The Axiomatic CAN Assistant – Visual, P/N: AX070501VIS can be used to verify angular directions and ranges after performing the unit frame coordinate rotation.

3.6 Sensor Calibration

The *Sensor Calibration* function block represents internal calibration read-only parameters. It does not have any signal inputs and outputs.



Figure 19. Sensor Calibration

The calibration parameters can be inspected in the field by a qualified technician. They are also written by the Axiomatic EA in a setpoint file together with other configuration parameters.

3.7 Binary Functions

There are ten *Binary Function* blocks available to the user for performing simple data conversions. Each *Binary Function* block has two continuous signal inputs and one continuous signal output.

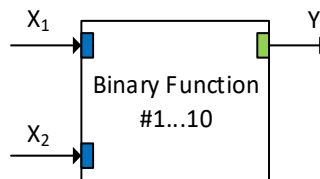


Figure 20. Binary Function Block

The *Binary Function* block performs the following data conversion:

$$Y = A \cdot F[a_1 \cdot f_1(X_1) + b_1; a_2 \cdot f_2(X_2) + b_2] + B, \quad n = 1,2; \quad (11)$$

- where:
- X_n – Input signal;
 - $f_n(X_n)$ – Unary function;
 - a_n – Scale;
 - b_n – Offset;
 - $F[x; y]$ – Binary Function;
 - A – Output Scale;
 - B – Output Offset.

The function block input signals can be undefined. The user can specify a default signal value that will be used when the signal is not defined. If the default signal value is not specified, the output signal of the function block will become undefined too.

The following unary functions can be used to process the input signals.

Table 13. Unary Functions

Function Name	Description	Comment
Undefined	$f(x) = x$	Signal is not processed

Function Name	Description	Comment
! Logical Not	$f(x) = !x$	x is converted into 4-byte unsigned integer before function is applied
~ Bitwise Not	$f(x) = \sim x$	x is converted into 4-byte unsigned integer before function is applied
abs(x) Absolute	$f(x) = x, \text{ if } x \geq 0$ $f(x) = -x, \text{ if } x < 0$	

The following binary functions are defined in the function block:

Table 14. Binary Functions

Function Name	Description	Comment
Undefined	$F[x;y] = \text{Undefined}$	Output signal is undefined
+ Addition	$F[x;y] = x + y$	
- Subtraction	$F[x;y] = x - y$	
* Multiplication	$F[x;y] = x * y$	
/ Division	$F[x;y] = x / y$	Division by 0 gives 0
% Modulus	$F[x;y] = x \% y$	x and y are converted into 4-byte unsigned integers before function is applied
max(x,y) Maximum	$F[x;y] = x, \text{ if } x \geq y$ $F[x;y] = y, \text{ if } x < y$	
min(x,y) Minimum	$F[x;y] = x, \text{ if } x \leq y$ $F[x;y] = y, \text{ if } x > y$	
== Equal	$F[x;y] = 1, \text{ if } x = y$ $F[x;y] = 0, \text{ if } x \neq y$	
!= Not Equal	$F[x;y] = 1, \text{ if } x \neq y$ $F[x;y] = 0, \text{ if } x = y$	
> Great	$F[x;y] = 1, \text{ if } x > y$ $F[x;y] = 0, \text{ if } x \leq y$	
>= Great Equal	$F[x;y] = 1, \text{ if } x \geq y$ $F[x;y] = 0, \text{ if } x < y$	
< Less	$F[x;y] = 1, \text{ if } x < y$ $F[x;y] = 0, \text{ if } x \geq y$	
<= Less Equal	$F[x;y] = 1, \text{ if } x \leq y$ $F[x;y] = 0, \text{ if } x > y$	
Logical OR	$F[x;y] = x \vee y$	x and y are converted into 4-byte unsigned integers before function is applied
&& Logical AND	$F[x;y] = x \wedge y$	x and y are converted into 4-byte unsigned integers before function is applied
Bitwise OR	$F[x;y] = x y$	x and y are converted into 4-byte unsigned integers before function is applied
& Bitwise AND	$F[x;y] = x \& y$	x and y are converted into 4-byte unsigned integers before function is applied
^ Bitwise XOR	$F[x;y] = x \wedge y$	x and y are converted into 4-byte unsigned integers before function is applied
<< Left Shift	$F[x;y] = x \ll y$	x and y are converted into 4-byte unsigned integers before function is applied
>> Right Shift	$F[x;y] = x \gg y$	x and y are converted into 4-byte unsigned integers before function is applied

The *Binary Function* has the following set of configuration parameters:

Table 15. Binary Function Block Configuration Parameters

Name	Default Value	Range	Units	Description
Binary Function	Undefined	See Binary Function table	–	$F[x;y]$ – Binary function
Output Scale	1	Any value	–	A – Output Scale
Output Offset	0	Any value	–	B – Output Offset
Input #1 Signal Source	Not Connected	Any signal output of any function block or “Not Connected”	–	X_1 – Input Signal #1
Input #1 Signal Default	No	{No, Yes}	–	Defines whether the default signal value for X_1 is defined.
Input #1 Signal Default Value	0	Any value	–	X_1 default value, if <i>Input #1 Signal Default</i> is <i>Yes</i> .
Unary Function #1	Undefined	See Unary Function table	–	$f_1(x)$ – Unary function #1
Scale #1	1	Any value	–	a_1 – Scale #1
Offset #1	0	Any value	–	b_1 – Offset #1
Input #2 Signal Source	Not Connected	Any signal output of any function block or “Not Connected”	–	X_2 – Input Signal #2
Input #2 Signal Default	Yes	{No, Yes}	–	Defines whether the default signal value for X_2 is defined.
Input #2 Signal Default Value	1	Any value	–	X_2 default value, if <i>Input #2 Signal Default</i> is <i>Yes</i> .
Unary Function #2	Undefined	See Unary Function table	–	$f_2(x)$ – Unary function #2
Scale #2	1	Any value	–	a_2 – Scale #2
Offset #2	0	Any value	–	b_2 – Offset #2

3.8 Global Parameters

The *Global Parameters* functional block gives the user access to a set of global constants, unit supply voltage and the microcontroller internal temperature.

The function block has one configurable *Global Discrete Constant Signal* output, one configurable *Global Continuous Constant Signal* output and two continuous pre-set constant signal outputs: *Global Const. Signal = 0.0* and *Global Const. Signal = 1.0*.

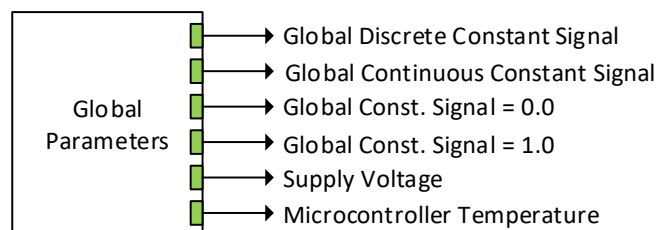


Figure 21. Global Parameters Function Block

The function block also contains *Supply Voltage* continuous signal output presenting the inclinometer supply voltage in [V]. Please note, that this voltage is not the voltage on the

inclinometer power supply connector pins. It is an internal voltage measured after the EMI filter, reverse polarity, and transient protection circuit. It is always less than the actual power supply voltage by approximately 0.7...0.95 V.

The microcontroller internal temperature is presented on the *Microcontroller Temperature* continuous signal output in [°C].

The *Global Parameters* function block has the following configuration parameters.

Table 16. *Global Parameters Function Block Configuration Parameters*

Name	Default Value	Range	Units	Description
Global Continuous Constant Signal	0	Any value	–	Output signal value of the <i>Global Continuous Constant Signal</i> .
Global Discrete Constant Signal	0	[0... 4294967295 (0xFFFFFFFF)]	–	Output signal value of the <i>Global Discrete Constant Signal</i> .

3.9 J1939 Network

The *J1939 Network* function block defines the global J1939 CAN bus settings. It does not have signal inputs and outputs.

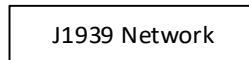


Figure 22. *J1939 Network Function Block*

Configuration parameters of the *J1939 Network* function block are presented below. They contain *ECU Network* and *CAN Network Parameters*.

Table 17. *J1939 Network Function Block Configuration Parameters*

Name	Default Value	Range	Units	Description
ECU Instance Number	0	[0...7]	–	ECU Instance field of the J1939 ECU Name.
ECU Address	226	[0...253]	–	J1939 ECU address.
Baud Rate ¹	–	{250, 500, 667, 1000} ³	kbit/s	Current baud rate on the CAN network.
Automatic Baud Rate Detection ²	Yes	{No, Yes}	–	Set to <i>No</i> once ECU is permanently installed on the CAN network.
Slew Rate	Low	{Low, High}	–	Slew rate control of the CAN transceiver.

¹ Read-only parameter. Not available in firmware V1.xx...4.xx.

² Not available in firmware V1.xx...4.xx.

³ Range is {250, 500, 1000} in firmware V5.xx...6.xx.

3.9.1 ECU Network Parameters

The user can change the *ECU Instance Number* and *ECU Address* to adjust the unit on the CAN network.

Changing the *ECU Instance Number* is necessary to accommodate multiple inclinometers on the same CAN network. The list of available ECU instances is shown in the *ECU Instance Number Setup* dialog window in the Axiomatic EA. The user should select the required ECU instance

number and then press OK or, starting from Axiomatic EA 5.14.103.0, double-click the selected instance number.

The *ECU Address* is automatically adjusted as the result of an address arbitration process on the J1939 CAN network. It can also be changed by a commanded address message. The user can also manually change the ECU address using the *ECU Address* configuration parameter.

The user selects the new ECU address from the list of available ECU addresses in the *ECU Address Setup* dialog window similar to the ECU instance number setup dialog. After the required ECU address is selected, the user should press OK button or, starting from Axiomatic EA 5.14.103.0, double-click the selected address.

3.9.2 CAN Network Parameters

The *Baud Rate* read-only configuration parameter shows the current baud rate on the CAN network.

The *Automatic Baud Rate Detection* parameter defines whether the ECU will try to detect the CAN baud rate in case of communication errors. The baud rate is detected from the list of supported CAN baud rates.

To avoid an arbitrary selection of the CAN baud rate by ECUs involved in the automatic baud rate detection process, it is necessary to disable the automatic baud rate detection in ECUs that are already permanently installed on the CAN network.

The *Slew Rate* configuration parameter defines the slew rate of the CAN transceiver the following way:

Table 18. Slew Rates

Slew Rate Value	Transceiver Slew Rate	Note
Fast	19 V/ μ s	Available for all baud rates.
Slow	4 V/ μ s	Only available for 250kbit/s baud rate.

The user can select the *Slew Rate* only when the inclinometer operates at 250 kbit/s baud rate. For baud rates higher than 250 kbit/s, the *Slew Rate* is always set to *Fast* independently of the *Slew Rate* configuration parameter.

The *Slow* slew rate is preferable at 250 kbit/s baud rate in the majority of applications due to the reduced EMI of the CAN transceiver. The *Fast* slew rate, in this case, is used when the distance between CAN nodes substantially exceeds 40 m – the maximum value defined by the J1939/11(15) standard.

3.10 CAN Input Signal

There are three *CAN Input Signal* function blocks available to the user. Each function block represents one CAN input signal that can be received from the CAN bus. The function block has one signal output with a user-defined signal type.

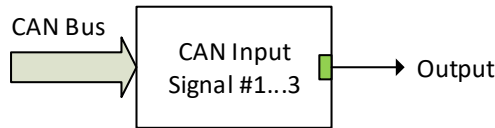


Figure 23. CAN Input Signal Function Block

The *CAN Input Signal* function block reads single-frame application specific CAN messages and extracts CAN signal data presented in a user-defined data format. Different *CAN Input Signal* function blocks can read and process the same CAN message to extract different CAN signal data.

The CAN messages transmitted by the unit itself are also processed by *CAN Input Signal* function blocks. The only difference in processing of the internal messages is that they are not sampled from the CAN bus and therefore their processing does not depend on the state of the bus.

Configuration parameters of the *CAN Input Signal* function block are presented below:

Table 19. CAN Input Signal Function Block Configuration Parameters

Name	Default Value	Range	Units	Description
Signal Type	Undefined	{Undefined, Discrete, Continuous}	–	CAN input signal type
PGN	65535	Any J1939 PGN ¹ value	–	Signal message PGN value.
PGN From Selected Address	No	{No, Yes}	–	Only CAN messages from the selected address will be accepted, if Yes.
Selected Address	0	[0; 253]	–	Address of the ECU transmitting CAN messages if <i>PGN From Selected Address</i> is set to Yes.
Data Position Byte	1	[1; 8]	–	Start byte of the CAN input signal in the CAN message data frame.
Data Position Bit	1	[1; 8]	–	Start bit of the CAN input signal in the <i>Data Position Byte</i> .
Size	1	[1...32]	bit	CAN input signal size.
Resolution	1	Any value	signal units / bit	CAN input signal resolution for continuous input signals.
Offset	0	Any value	signal units	CAN input signal offset for continuous input signals.
Autoreset Time	500	[0; 10000]	ms	Function block signal output auto-reset time. If <i>Autoreset Time</i> is 0, the auto-reset is disabled.

¹Proprietary A PGN (61184) is excluded. It is taken by Axiomatic Simple Proprietary Protocol and therefore cannot be used in function blocks.

The CAN input signal position is defined within the CAN message data frame by the *Data Position Byte* and *Data Position Bit* configuration parameters the same way as in the J1939 standard. The start and stop bits of the CAN signal in the 64-bit CAN message data frame are calculated using the formulas:

$$StartBit = (DataPositionByte - 1) \cdot 8 + (DataPositionBit - 1), \tag{12}$$

$$StopBit = StartBit + Size - 1, \text{ where: } StartBit, StopBit \in [0 \dots 63].$$

Resolution and *Offset* configuration parameters are set for continuous CAN input signals. They are not used with discrete CAN signals.

The following rules apply when converting the CAN signal data to the function block output signal:

- It is assumed that the CAN signal code with all bits set to 1 represents an undefined signal. The undefined signal is ignored by the function block;
- Discrete signals can take any value except the one reserved for the undefined signal (all bits set to 1);
- Continuous signals can take only values from the range reserved for continuous signals in the J1939 standard. If the CAN signal code is outside of the range reserved for the continuous signal, the signal is ignored.

When the *Autoreset Time* is not equal to 0, the function block will auto-reset the output signal to the undefined state if the output signal has not been updated within the auto-reset time frame by the new CAN message data.

3.11 CAN Output Message

There are five *CAN Output Message* function blocks available to the user. Each function block represents one single frame CAN output message that can be sent on the CAN bus. The message can contain up to ten CAN output signals. Each CAN output signal is presented by its own signal input in the function block.

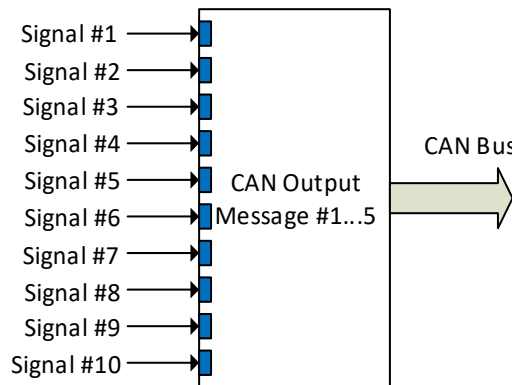


Figure 24. CAN Output Message Function Block

Configuration parameters of the *CAN Output Message* function block are presented below:

Table 20. CAN Output Message Function Block Configuration Parameters

Name	Default Value ¹	Range	Units	Description
PGN	61459	Any J1939 PGN value ²	–	CAN message PGN.
Transmission Enable	No	{Yes, No}	–	Enables the CAN output message transmission.

Name	Default Value ¹	Range	Units	Description
Transmission Rate	10	[0;10000]	ms	CAN output message transmission rate. If 0 – transmission is upon request.
Destination Address	255	[0; 255]	–	Destination address of the PDU1 PGN messages.
Length	8	[0...8]	byte	CAN message data frame length.
Priority	3	[0...7]	–	CAN message priority.
Signal #1 Type	Continuous	{Undefined, Discrete, Continuous}	–	Type of the 1-st CAN output signal.
Signal #1 Source	Pitch Angle	Any signal output of any function block or <i>Not Connected</i>	–	Input signal source of the 1-st CAN output signal.
Signal #1 Byte Position	1	[1...8]	–	Byte position of the 1-st CAN output signal.
Signal #1 Bit Position	1	[1...8]	–	Bit position of the 1-st CAN output signal.
Signal #1 Size	16	[1...32]	bit	Size of the 1-st CAN output signal.
Signal #1 Resolution	0.002	Any value	signal units / bit	Resolution of the 1-st CAN continuous output signal.
Signal #1Offset	-64	Any value	signal units	Offset of the 1-st CAN continuous output signal.
Signal #2 Type	Continuous	{Undefined, Discrete, Continuous}	–	Type of the 2-nd CAN output signal.
Signal #2 Source	Roll Angle	Any signal output of any function block or <i>Not Connected</i>	–	Input signal source of the 2-nd CAN output signal.
Signal #2 Byte Position	3	[1...8]	–	Byte position of the 2-nd CAN output signal.
Signal #2 Bit Position	1	[1...8]	–	Bit position of the 2-nd CAN output signal.
Signal #2 Size	16	[1...32]	bit	Size of the 2-nd CAN output signal.
Signal #2 Resolution	0.002	Any value	signal units / bit	Resolution of the 2-nd CAN continuous output signal.
Signal #2Offset	-64	Any value	signal units	Offset of the 2-nd CAN continuous output signal.
...
Signal #10 Type	Undefined	{Undefined, Discrete, Continuous}	–	Type of the 10-th CAN output signal.
Signal #10 Source	Not Connected	Any signal output of any function block or <i>Not Connected</i>	–	Input signal source of the 10-th CAN output signal.
Signal #10 Byte Position	1	[1...8]	–	Byte position of the 10-th CAN output signal.
Signal #10 Bit Position	1	[1...8]	–	Bit position of the 10-th CAN output signal.

Name	Default Value ¹	Range	Units	Description
Signal #10 Size	1	[1...32]	bit	Size of the 10-th CAN output signal.
Signal #10 Resolution	1	Any value	signal units / bit	Resolution of the 10-th CAN continuous output signal.
Signal #10 Offset	0	Any value	signal units	Offset of the 10-th CAN continuous output signal.

¹ For CAN Output Message #1.

² Proprietary A PGN (61184) is excluded. It is taken by Axiomatic Simple Proprietary Protocol and therefore cannot be used in function blocks.

Configuration parameters: *Signal #1...10 Byte Position* and *Signal #1...10 Bit Position*, together with the *Signal #1...10 Size* have the same meaning as in the *CAN Input Signal* function block. The user should be careful not to overlap the output signals.

The following rules apply when converting function block signal data to the CAN output signal code:

- Undefined signals are presented in the signal code with all bits set to 1.
- Discrete signals are directly assigned to the signal code without any conversion.
- Continuous signals are converted to the signal code based on the *Signal #1...10 Resolution* and *Signal #1...10 Offset* configuration parameters. They are saturated to the continuous signal code range defined in the J1939 standard when they go out of range.

4 CONFIGURATION PARAMETERS

The inclinometer configuration parameters can be viewed and changed using the standard J1939 memory access protocol through the CAN bus using the PC-based Axiomatic Electronic Assistant (EA) software.

4.1 Electronic Assistant Software

Axiomatic provides PC-based Electronic Assistant (EA) software to communicate with a wide range of Axiomatic products, including this inclinometer. The software can be downloaded from Axiomatic website www.axiomatic.com.

The Axiomatic EA uses the Axiomatic USB-CAN converter P/N AX070501 to connect to the CAN network. The converter with cables can be ordered as an Axiomatic EA KIT, P/Ns: AX070502 or AX070506K.

Please, refer to the user manual UMAX07050X for description of the EA and associated products, and for the CAN network connection troubleshooting.

The Axiomatic EA software version number supporting all inclinometer configuration parameters is shown on the user manual front page. For example, the user should use Axiomatic EA 5.15.108.0 or higher with the inclinometer application firmware version 7.xx described in this user manual. The most recent Axiomatic EA software version can be downloaded from Axiomatic website.

Before connecting to the CAN network, the user should ensure that the EA baud rate is the same as the baud rate used by ECUs on the network. The EA baud rate is displayed in the bottom-right corner of the EA screen and can be changed in the *Options* menu.

If the inclinometer is the only one ECU on a temporary network set for configuring the unit, the EA baud rate should be set to the baud rate of the CAN network where the inclinometer is planned to be deployed. This baud rate will be stored in the ECU non-volatile memory and used by the unit on the next power-up.

Upon connection, the EA will show the inclinometer on the list of ECUs that are present on the J1939 CAN network. If the inclinometer is the only one ECU on the network, the following screen will appear, see Figure 25.

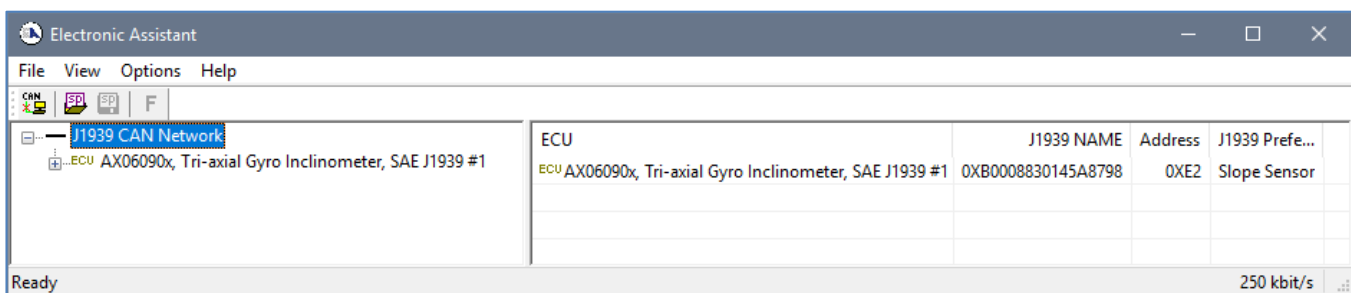


Figure 25. Inclinometer in the Axiomatic EA

The user can then browse through the ECU parameters, read *General ECU Information* and *Bootloader Information* groups, view and modify configuration parameters, see Figure 26.

The configuration parameters are grouped by function blocks. Please, refer to the appropriate section of this manual describing the required function block.

In the *General ECU Information* group, the user will see the version number of the application firmware. Please, make sure that the user manual version number matches the most significant part of the application firmware version number. Otherwise, a different user manual is required to work with this inclinometer.

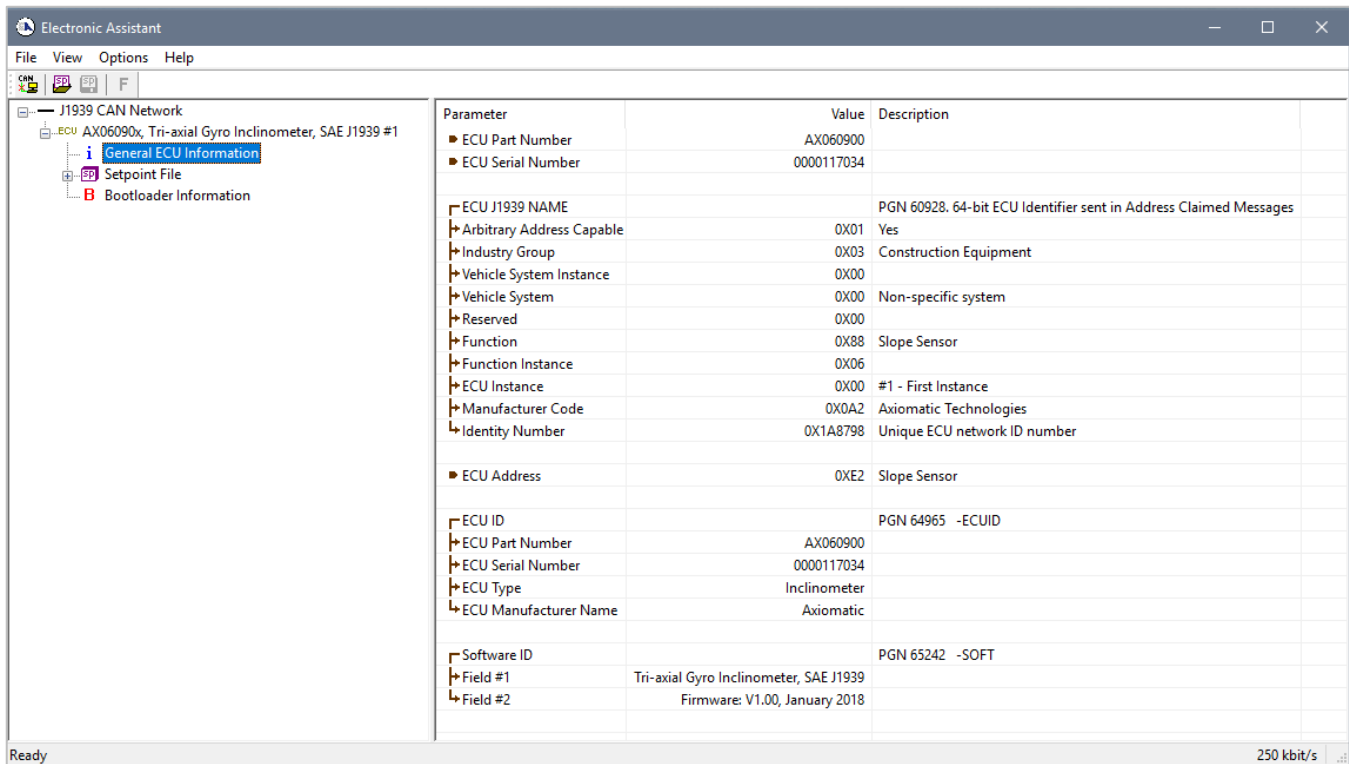


Figure 26. General ECU Information Screen

4.2 Function blocks in the Axiomatic EA

Each inclinometer function block is presented by its own setpoint group in the *Setpoint File* main group. Individual configuration parameters (setpoints) of a function block can be accessed through the function block setpoint group, see Figure 27.

The user can view and, when necessary, change configuration parameters by double-clicking on the appropriate setpoint name. A pop-up dialog window will appear, see Figure 28.

If the user changes the configuration parameter, the new value will be stored in a non-volatile memory and used immediately by the inclinometer.

The inclinometer will perform an internal reset of all function blocks after each change of the configuration parameters. If the new configuration parameter affects the CAN network identification, the unit will reclaim its network address with a new network identification message.

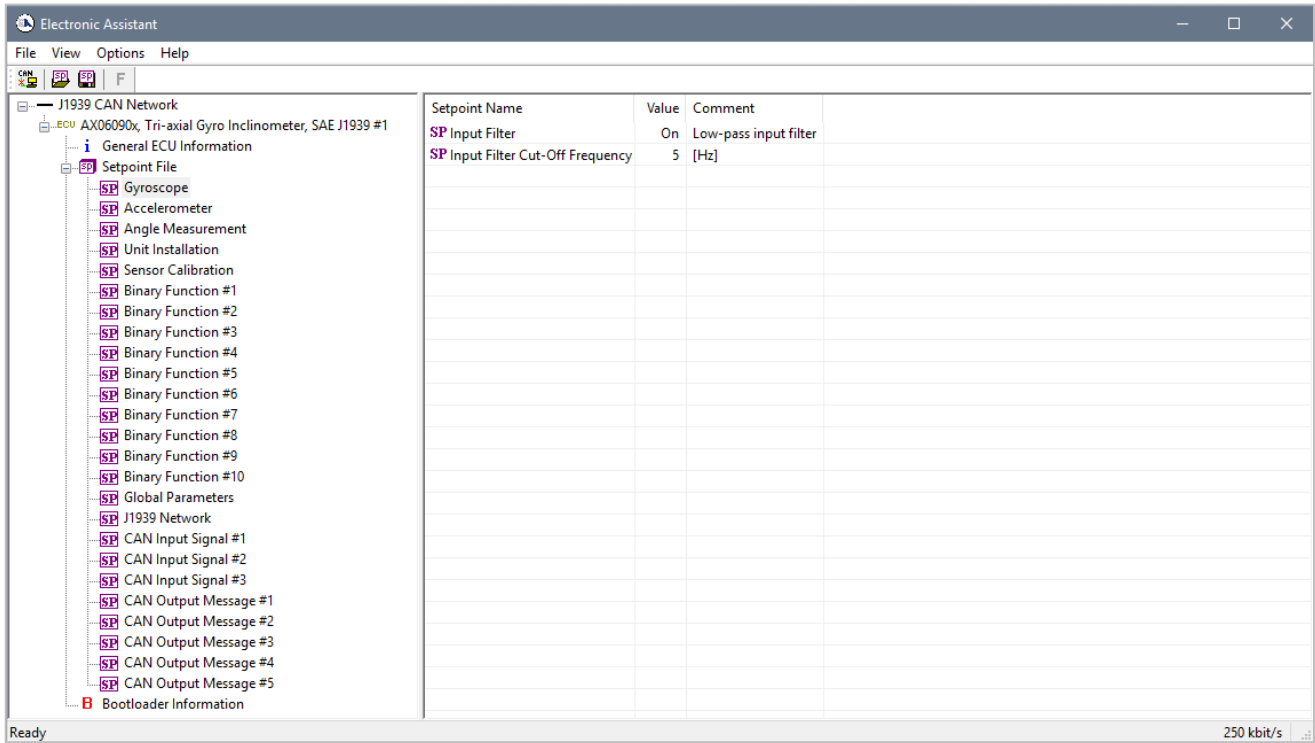


Figure 27. Accelerometer Function Block in the Axiomatic EA

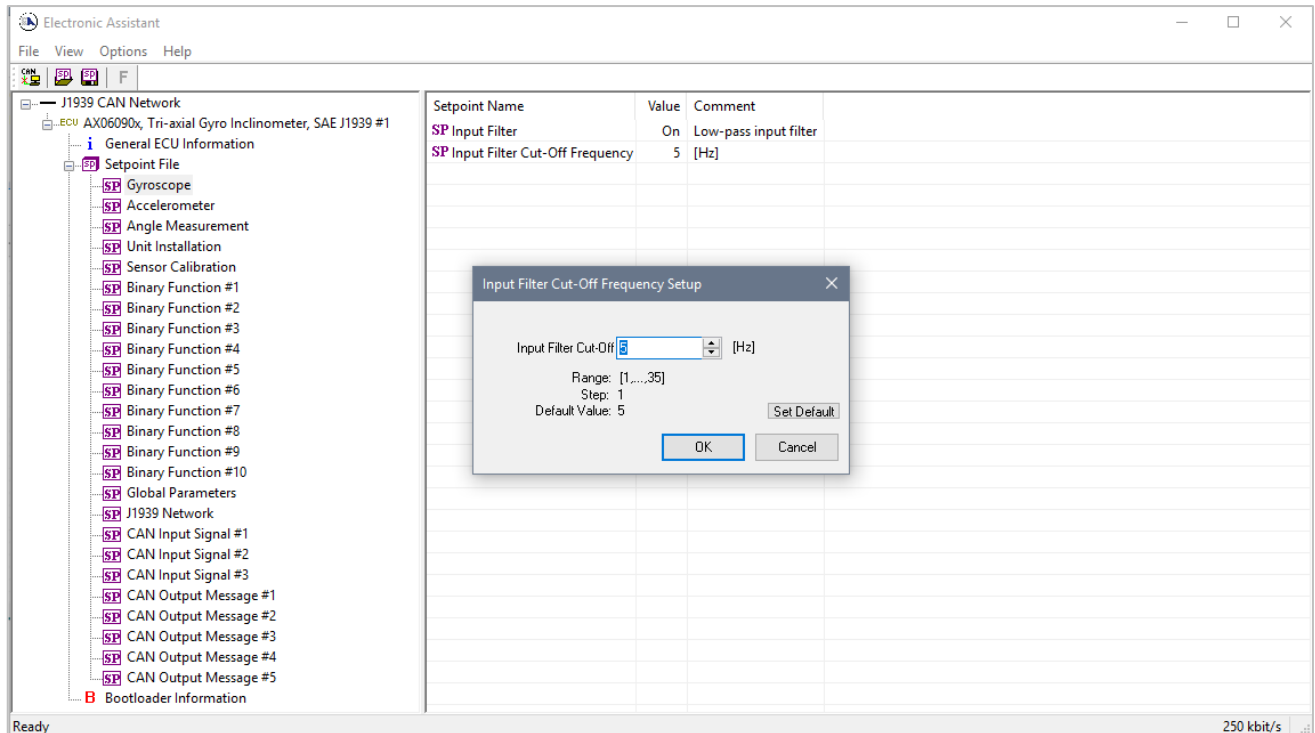


Figure 28. Changing a Configuration Parameter in the Axiomatic EA

4.3 Setpoint File

The Axiomatic EA can store all inclinometer configuration parameters in one setpoint file and then flash them into the unit in one operation.

The setpoint file is created and stored on disk using a command *Save Setpoint File* from the EA menu or toolbar. The user then can open the setpoint file, view or print it, and also flash the setpoint file into the inclinometer, see Figure 29.

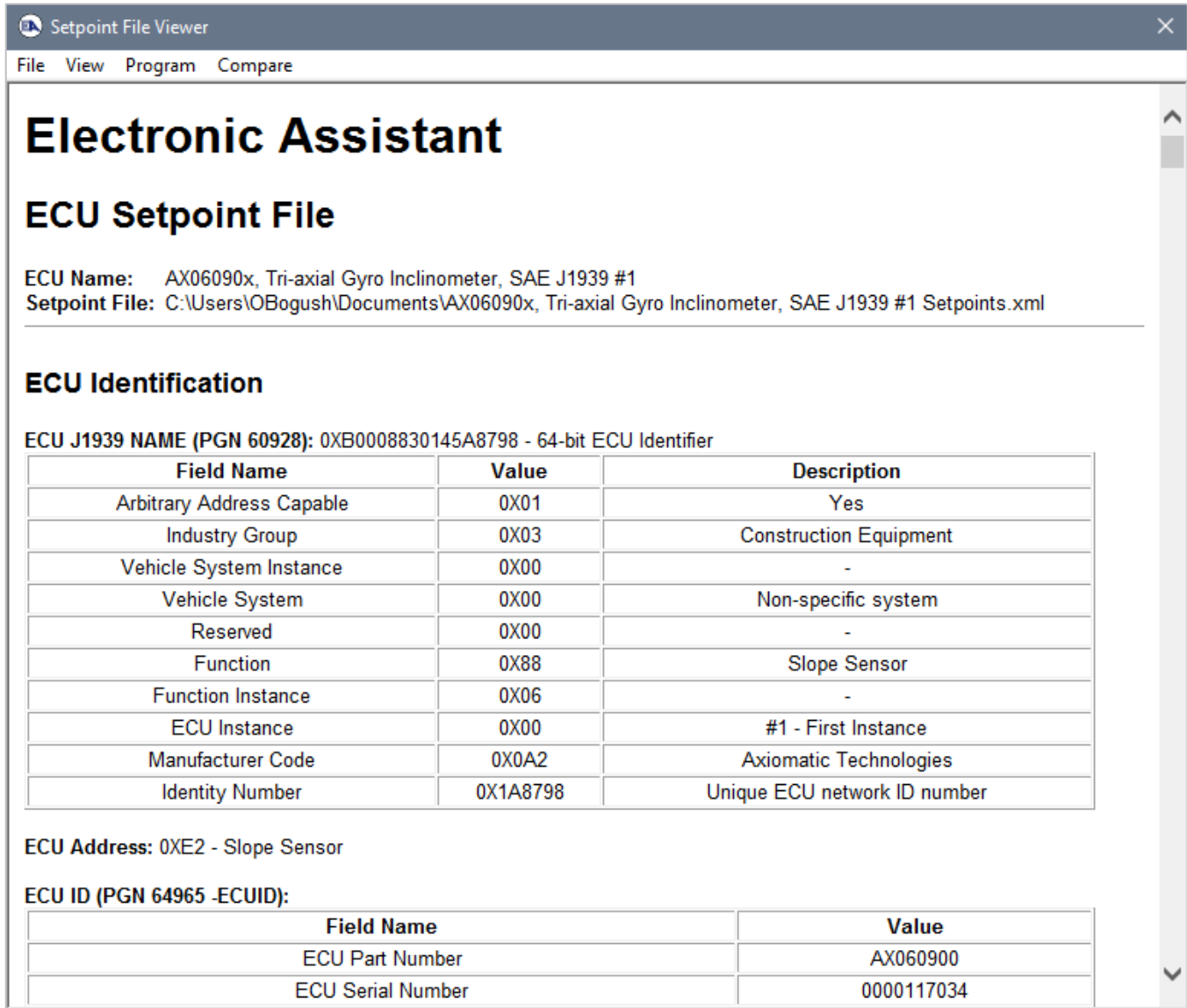


Figure 29. An Axiomatic EA Setpoint File

The CAN network identification and “read-only” configuration parameters are not transferrable using this operation. Also, the inclinometer will perform one or several internal resets of all function blocks during the setpoint flashing operation to ensure that all updates have been applied and the inclinometer is running a new set of configuration parameters at the end of the flashing operation.

There can be small differences in configuration parameters between different versions of the application firmware. It is recommended that the user manually inspect all configuration parameters after flashing if the setpoint file was created by a different version of the application firmware.

A setpoint file containing default configuration parameters for the current firmware version is available upon request.

4.4 Configuration Example

The user can change the default inclinometer functionality using the configuration parameters. A detailed description of the unit configuration process is presented below, as an example.

4.4.1 User Requirements

Let us assume that the user requires to generate a proprietary PGN message with a signal flag alarming the user that a platform is tilted more than 30 degrees from its original 0-degree position. The proprietary PGN message parameters are the following:

Transmission Repetition Rate: 100 ms
 Data Length: 1
 Default Priority: 6
 Parameter Group Number: 65280 (PDU2 Proprietary)

Start Position	Length	Parameter Name	SPN
1.1	2 bits	User Alarm Flag	N/A

Parameter Name: User Alarm Flag
 Data Length: 2 bits

Bit 2	Bit 1	
0	0	Off – Platform is not tilted
0	1	On – Platform is tilted
1	0	Error
1	1	Not available

Type: Status

4.4.2 Configuration Steps

As a first step, we need to create a block diagram of the required unit configuration using the function blocks, see Figure 30. Limit our block diagram to the function blocks affected by the new user requirements.

Then configure each individual function block. Start with *Binary Function #1*.

Connect the X_1 input of the *Binary Function #1* to the *Gravity Angle* output of the *Angle Measurement* function block, set X_2 default value to *30 degrees*, and set the *Binary Function F[x,y]* to \geq (*Great Equal*), see Figure 31.

Then configure *CAN Output Message #5* function block to send the proprietary PGN message with the *User Alarm Flag* signal in *Signal #1*.

First, configure the PGN message. Set *PGN* to *65280*, *Transmission Enable* to *Yes*, *Transmission Rate* to *100 ms*, *Length* to *1 Byte*, and *Priority* to *6*.

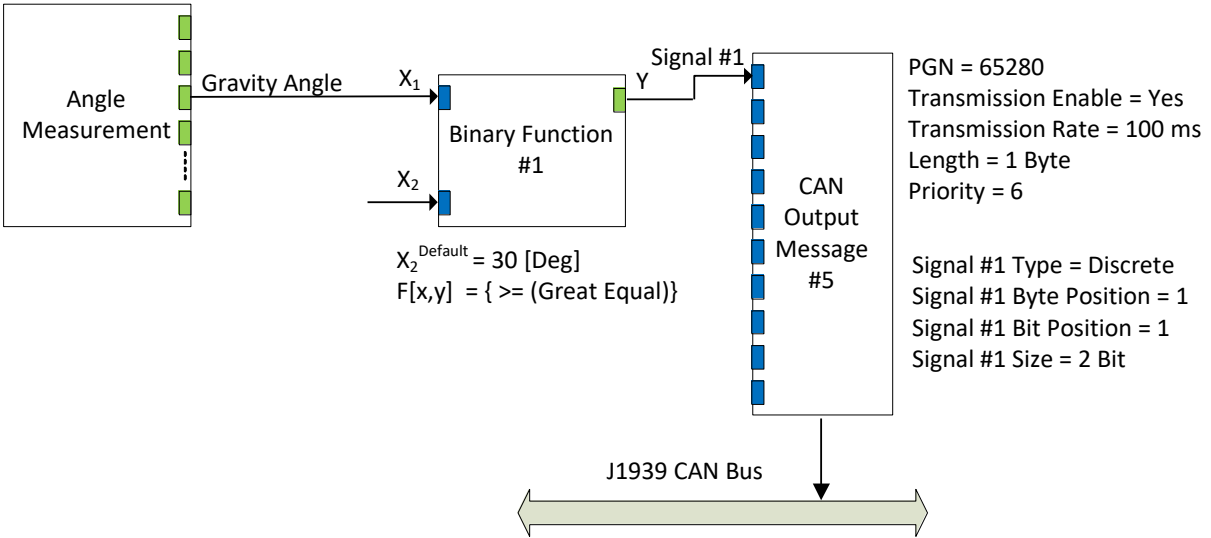


Figure 30. Block Diagram of the Example Configuration

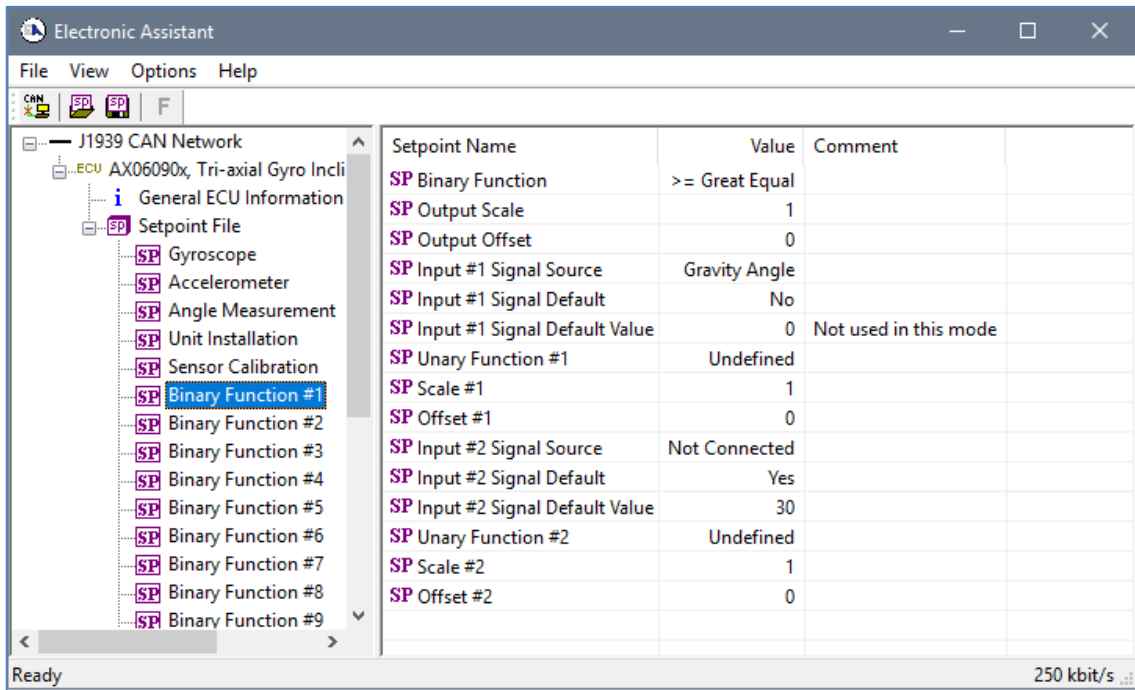


Figure 31. Binary Function #1 Example Configuration

Then, configure CAN Signal #1. Set Signal #1 Type to Discrete, Signal #1 Source to Binary Function #1, Signal #1 Byte Position to 1, Signal #1 Bit Position to 1, and Signal #1 Size to 2 bits, see Figure 32.

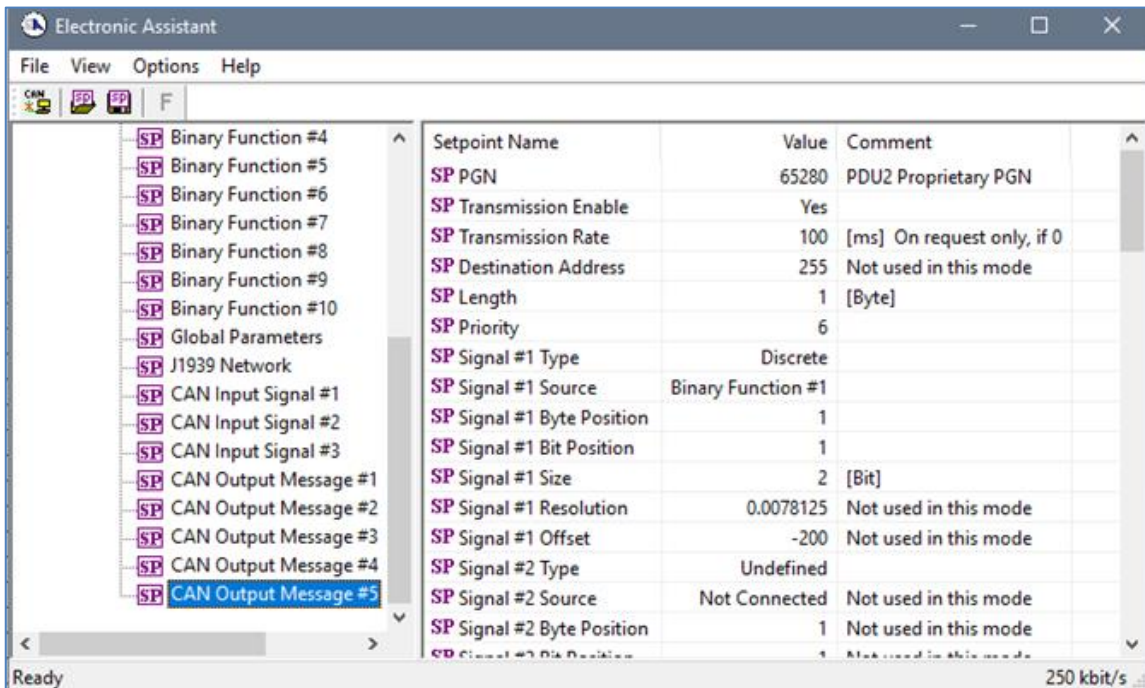


Figure 32. CAN Output Message #5 Example Configuration

As the last step, if the default functionality is not required, the user can disable sending SS/2 CAN messages in the *CAN Output Message #2* function block by setting the *Transmission Enable* configuration parameter to *No*.

The inclinometer configuration is finished. Now the unit operates according to the new user requirements. The configuration parameters are all set and are already written to the non-volatile unit memory. The users can write them to a setpoint file for the future use, if necessary.

The setpoint file for this example is available upon request.

5 FLASHING NEW FIRMWARE

When the new firmware becomes available, the user can replace the inclinometer firmware in the field using the unit embedded bootloader. The firmware file can be received from Axiomatic on request.

To flash the new firmware, the user should activate the embedded bootloader. To do so, start the Axiomatic EA and in the *Bootloader Information* group screen click on the *Force Bootloader to Load on Reset* parameter. The following dialog will appear, see Figure 33¹.

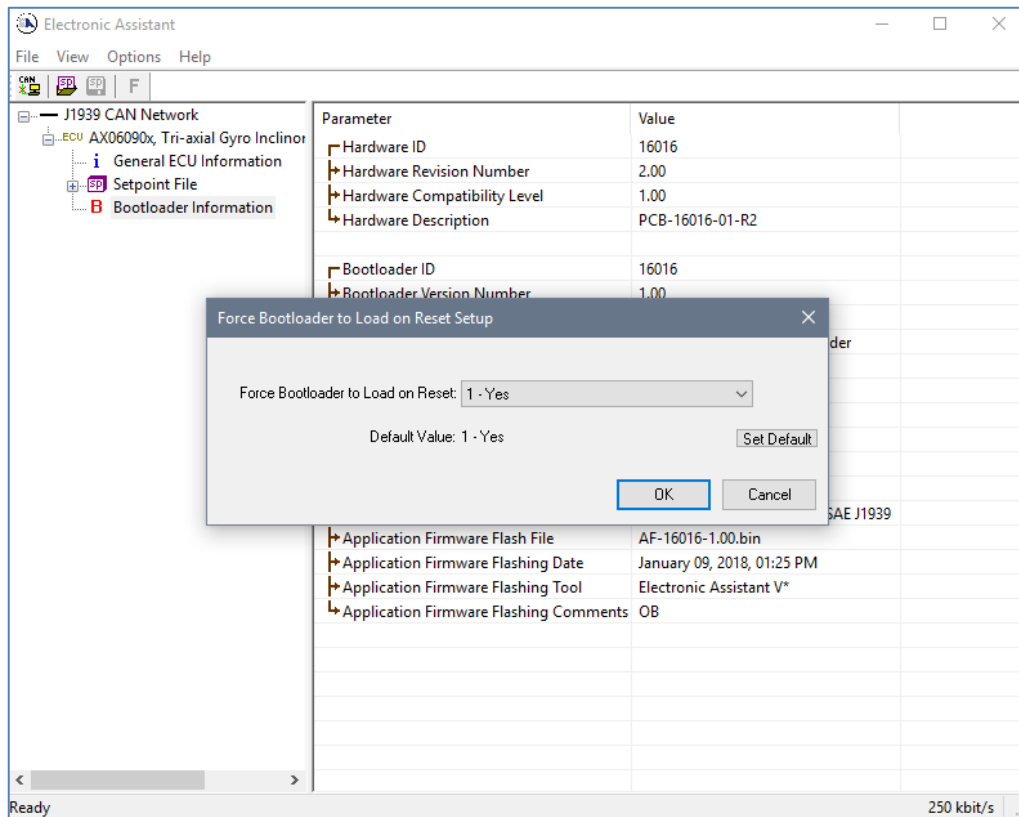


Figure 33. Bootloader Activation. First Step

¹ For bootloader versions 1.xx...3.xx, and 4.xx, originally shipped with older versions of the application firmware, the user should request a special application firmware file compatible with the installed bootloader version to upgrade the inclinometer firmware. The bootloader version can be found on the *Bootloader Information* group screen.

The Axiomatic EA will prompt the user to change the *Force Bootloader to Load on Reset* parameter flag to Yes. This will automatically activate the bootloader on the next ECU reset. After accepting the change, the next screen will ask the user if the reset is actually required, see Figure 34. Select Yes.

After automatic reset, instead of *AX0609xx, Tri-Axial Gyro Inclinometer, SAE J1939*, the user will see *J1939 Bootloader* ECU in the *J1939 CAN Network* top-level group in the Axiomatic EA. This means that the bootloader is activated and is ready to accept the new firmware.

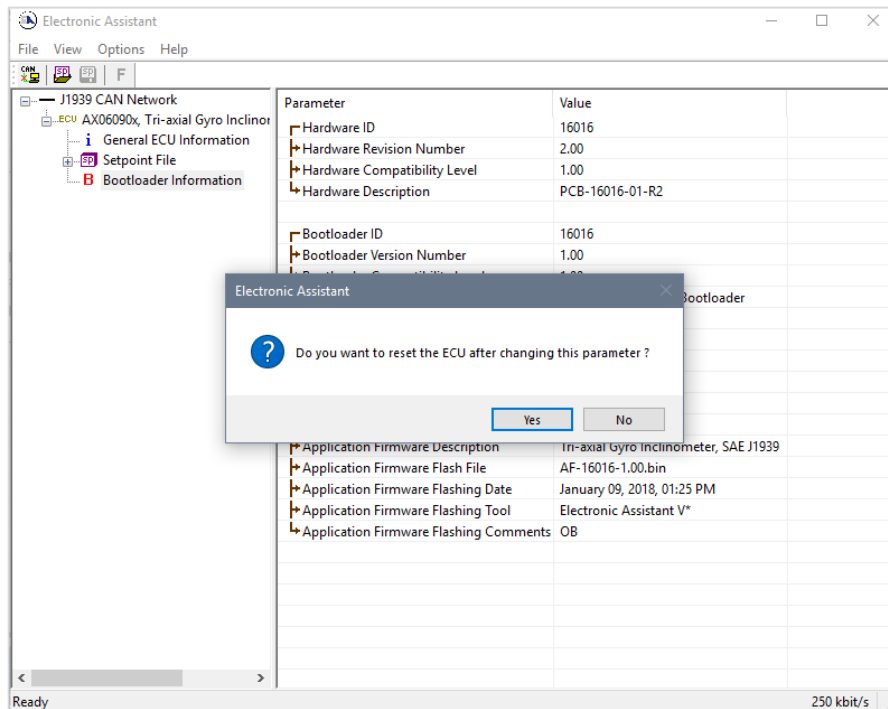


Figure 34. Bootloader Activation. Final Reset

All the bootloader specific information: controller hardware, bootloader details, and the currently installed application firmware remains the same in the bootloader mode and the user can read it in the *Bootloader Information* group screen, see Figure 35. The information can be slightly different for different versions of the bootloader.

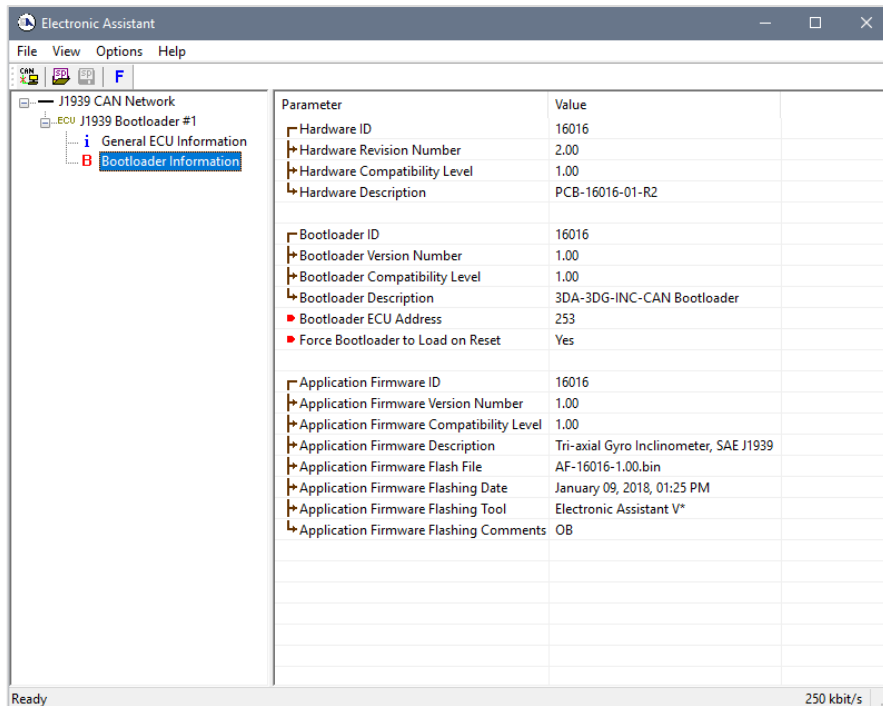


Figure 35. Bootloader Information Screen

At this point, the user can return to the installed controller firmware by changing the *Force Bootloader to Load on Reset* flag back to *No* and resetting the ECU.

To flash the new firmware, the user should click on **F** toolbar icon or from the *File* menu select the *Open Flash File* command. The *Open Application Firmware Flash File* dialog will appear. Pick up the flash file with the new inclinometer firmware and confirm the selection by pressing the *Open* button. The *Flash Application Firmware* dialog window will appear¹, see Figure 36.

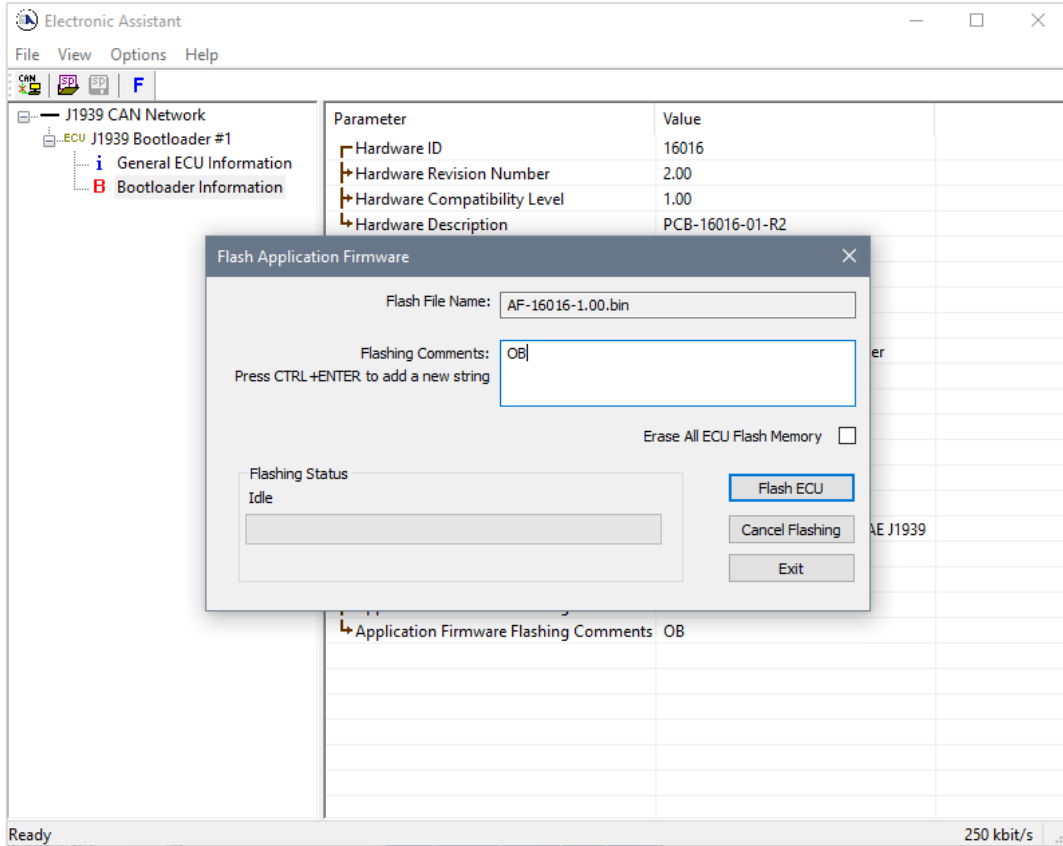


Figure 36. Flashing New Firmware. Preparation

¹ In this example, instead of the new firmware, the old firmware V1.00 is being simply re-flashed.

Now the user can add any comments to the flashing operation in the *Flashing Comments* field. They will be stored in the *Bootloader Information* group after flashing.

The user can also check the *Erase All ECU Flash Memory* flag to erase all inclinometer flash memory. This operation, used in other products to reset configuration parameters kept in the flash memory to their default values, has no effect in this product. This is because the configuration parameters of the inclinometer are stored in a separate EEPROM memory.

The flashing operation will not normally change the configuration parameters. The default values will be set only to the new configuration parameters introduced by the new firmware. The old configuration parameters will keep their original values unless otherwise is stated in the user manual.

Select the *Flash ECU* button to start flashing. A reminder that the old application firmware will be destroyed by the flashing operation will appear. Press *Ok* to continue and watch the dynamics of

the flashing operation in the *Flashing Status* field. When flashing is done, the following screen will appear prompting the user to reset the ECU, see Figure 37.

Select *Yes* and see the ECU running the new firmware, see Figure 38. This will indicate that the flashing operation has been performed successfully.

For more information, refer to the *J1939 Bootloader* section of the Axiomatic EA user manual.

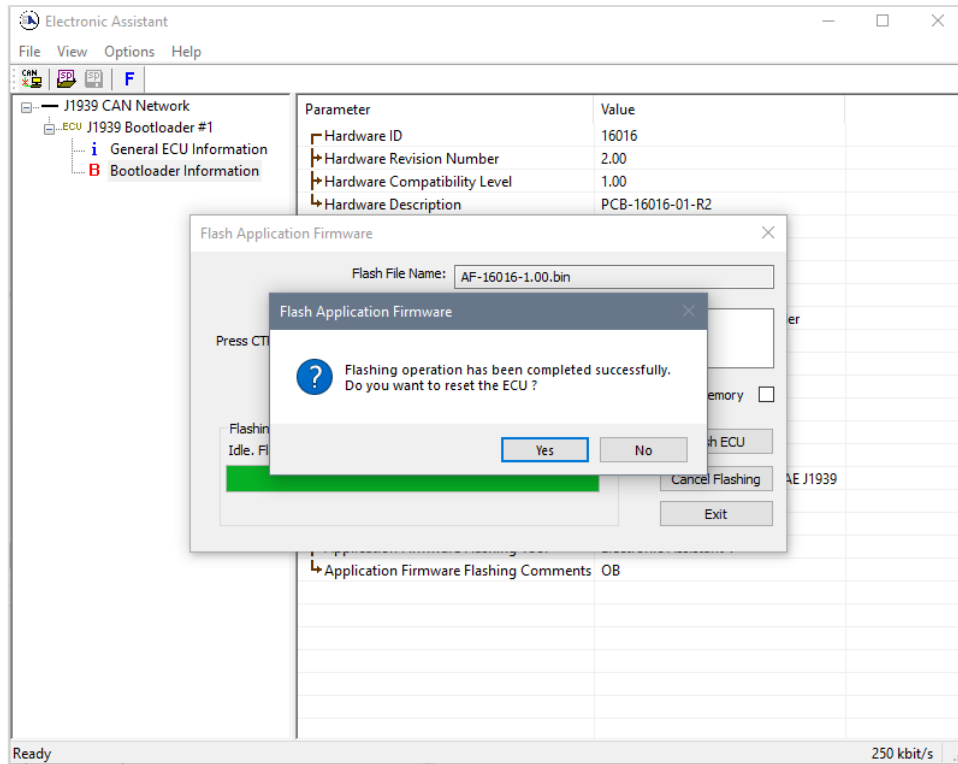


Figure 37. Flashing New Firmware. Final Reset

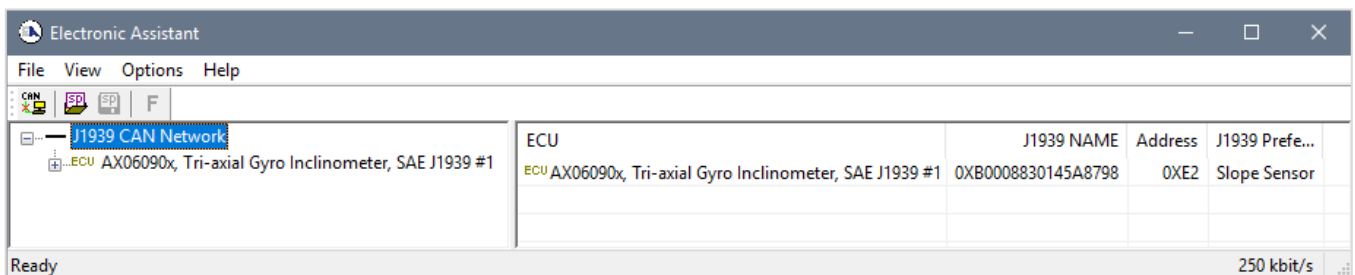


Figure 38. Firmware has been Updated. New Firmware Screen

6 TECHNICAL SPECIFICATIONS

Specifications are indicative and subject to change. Actual performance will vary depending on the application and operating conditions. Users should satisfy themselves that the product is suitable for use in the intended application. All our products carry a limited warranty against defects in material and workmanship. Please refer to our Warranty, Application Approvals/Limitations and Return Materials Process as described on <https://www.axiomatic.com/service/>.

6.1 Performance Parameters

Stated at 25°C unless otherwise specified.

6.1.1 Angular Measurements

Inclinometers AX060900, AX060910 are designed to measure pitch, roll, and gravity inclination angles with the gyro compensation enabled by default.

6.1.1.1 AX060900

Table 21. AX060900 Angular Measurement Parameters

Parameter	Value	Remarks
Measurement Range	±180° – Pitch & Roll 0...180° – Gravity	±90° Pitch & Roll in default configuration
Resolution	0.07°	Effective Resolution (3.46*NoiseRMS). Typical with gyro compensation. Typical without gyro compensation at Cut-Off Frequency Fc=5Hz.
Initial Accuracy	±1.5°	Maximum
Temperature Drift	±1.3°	Maximum, in the full temperature range: -40...85°C
Nonlinearity	±0.15%	Typical
Cross-Axis Sensitivity	±0.5%	Maximum
Cut-off frequency, Fc	1...35 Hz, 5 Hz default; 8 Hz with gyro compensation	User selectable (except for the gyro compensation)
Maximum Dynamic Acceleration	±2g	Maximum short-term linear acceleration per axis with gyro compensation

6.1.1.2 AX060910

Table 22. AX060910 Angular Measurement Parameters

Parameter	Value	Remarks
Measurement Range	±180° – Pitch & Roll 0...180° – Gravity	±90° Pitch & Roll in default configuration
Resolution	0.06°	Effective Resolution (3.46*NoiseRMS). Maximum with gyro compensation. Maximum without gyro compensation at Cut-Off Frequency Fc=5Hz
Initial Accuracy	±2.0°	Maximum
Temperature Drift	±3.0°	Maximum, in the full temperature range: -40...85°C
Nonlinearity	±0.1%	Maximum
Cross-Axis Sensitivity	±1.0%	Maximum
Cut-off frequency, Fc	1...35 Hz, 5 Hz default; 8 Hz with gyro compensation	User selectable (except for the gyro compensation)
Maximum Dynamic Acceleration	±6g	Maximum short-term linear acceleration per axis with gyro compensation

6.1.2 Angular Rate Measurements

6.1.2.1 AX060900

Table 23. AX060900 Angular Rate Measurement Parameters

Parameter	Value	Remarks
Measurement Range	$\pm 125^\circ/\text{s}$	
Resolution	$0.08^\circ/\text{s}$	Effective Resolution ($3.46 \cdot \text{NoiseRMS}$). Typical at Cut-Off Frequency $F_c=5\text{Hz}$
Offset Error	$\pm 1^\circ/\text{s}$	Maximum
Offset Temperature Drift	$\pm 0.8^\circ/\text{s}$	Maximum, in the full temperature range: $-40 \dots 85^\circ\text{C}$
Sensitivity Error	$\pm 2.5\%$	Maximum, in the full temperature range: $-40 \dots 85^\circ\text{C}$
Nonlinearity	$\pm 0.5^\circ/\text{s}$	Typical
Cross-Axis Sensitivity	$\pm 1.5\%$	Maximum
Cut-off frequency, F_c	$1 \dots 35\text{ Hz}$, 5 Hz default	User selectable

6.1.2.2 AX060910

Table 24. AX060910 Angular Rate Measurement Parameters

Parameter	Value	Remarks
Measurement Range	$\pm 300^\circ/\text{s}$	
Resolution	$0.2^\circ/\text{s}$	Effective Resolution ($3.46 \cdot \text{NoiseRMS}$). Maximum at Cut-Off Frequency $F_c=5\text{Hz}$
Offset Error	$\pm 1.3^\circ/\text{s}$	Maximum
Offset Temperature Drift	$\pm 0.6^\circ/\text{s}$	Maximum, in the full temperature range: $-40 \dots 85^\circ\text{C}$
Sensitivity Error	$\pm 3\%$	Maximum, in the full temperature range: $-40 \dots 85^\circ\text{C}$
Nonlinearity	$\pm 0.5^\circ/\text{s}$	Maximum, in the full temperature range: $-40 \dots 85^\circ\text{C}$
Cross-Axis Sensitivity	$\pm 1.7\%$	Maximum
Cut-off frequency, F_c	$1 \dots 35\text{ Hz}$, 5 Hz default	User selectable

6.2 Power Supply Input

Table 25. Power Supply

Parameter	Value	Remarks
Supply Voltage	$9 \dots 36\text{ VDC}$	12V , 24V – nominal.
Supply Current ¹	40 mA 75 mA	Maximum at 24V . Maximum at 12V .
Protection	Reverse polarity, Transients	

¹ CAN bus is connected.

6.3 CAN Output

Table 26. CAN Parameters

Parameter	Value	Remarks
Number of ports	1 CAN Port	To output data and change the internal configuration of the inclinometer

Parameter	Value	Remarks
Communication standards	SAE J1939	Full support for a J1939 ECU is provided. By default, the inclinometer transmits angular information on the CAN network in PGN 61481, <i>Slope Sensor Information 2</i> . User configurable PGNs are also available.
	Baud Rate	250 kbit/s, 500 kbit/s, 667 kbit/s, 1 Mbit/s. Automatic Baud Rate Detection. ¹
	ISO 11898	120Ohm terminated twisted pair, baud rate up to 1Mbit/s. External 120Ohm termination is required.
	Bosch CAN protocol specification 2.0, Part A, B.	For the internal CAN controller.
Protection	Short circuit to ground	
	Connection to the power supply	Only for 12V systems, 24V max.

¹ *Inclinometers with firmware V1.xx...4.xx could operate only at 250kbit/s baud rate, and with firmware V5.xx...5.xx – at 250, 500, and 1000 kbit/s (1Mbit/s) baud rates.*

6.4 General Specifications

Table 27. General Specifications

Parameter	Value	Remarks
Sensor Type	MEMS	
Internal Logic	User Configurable	Axiomatic Electronic Assistant, P/Ns: AX070502 or AX070506K.
Operating Temperature	-40...+85 °C	Industrial temperature range.
Environmental Protection	IP67	IEC 60529 with mated connectors.
Vibration	Sinusoidal. 10G Peak, 10Hz-2000Hz-10Hz, 20 Minutes, 8hrs/axis.	MIL-STD-202G, method 204D, test condition C.
	Random. 7.68 Grms, 10Hz to 2000Hz, 8hrs/axis.	Custom, meets or exceeds: MIL-STD-202G, method 214A, test condition I/B.
Shock	Half-Sine. 50G Peak, 9ms, 8pulses/axis.	Custom, based on: MIL-STD-202G, method 213B, test condition A.
Size	4.41 x 2.25 x 1.32 in (112 x 57 x 34 mm)	See dimensional drawing.
Weight	0.80 lb (0.36 kg)	

6.5 Enclosure

All inclinometers use the same cast aluminum enclosure with two 5-pin M12 A-coded round connectors, see *AX060900 Dimensional Drawing*, in Figure 39.

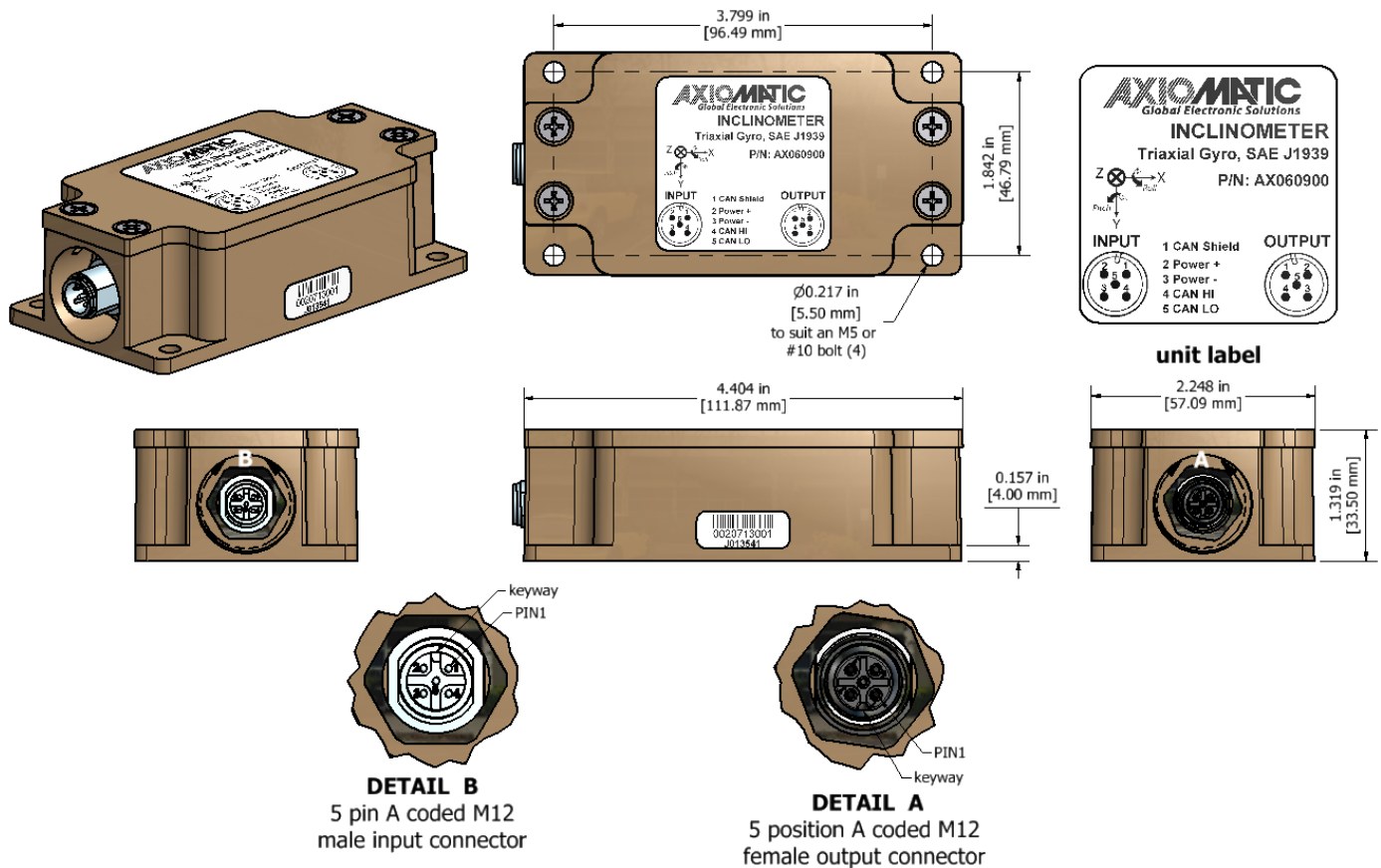


Figure 39. AX060900 Dimensional Drawing

The connector pinout for all inclinometers is the same, see Figure 40. Use mating connectors compliant with IEC 61076-2-101:2012.

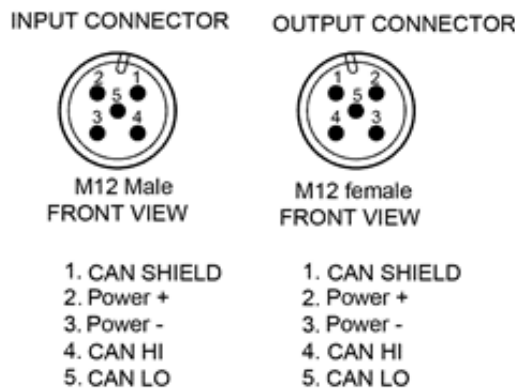


Figure 40. Connector Pinouts

If only one connector is used, an M12 sealing cap with IP67 rating should be installed on the unused connector. PROT-M12 FB – 155538 from PHOENIX CONTACT is recommended for the unused output M12 connector, Axiomatic P/N AX070140.

There is only one CAN port supported by the unit. Both CAN connectors are electrically connected together to facilitate cable routing in the user system. A mating plug with CAN termination, P/N: AX070114, can be ordered for applications requiring a termination of the CAN network.

6.6 Unit Orientation

The unit coordinates, together with the Pitch and Roll directions are shown on the inclinometer label, see Figure 41.

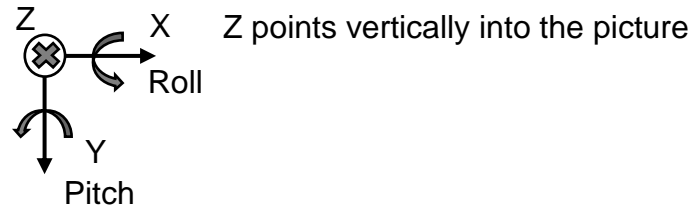


Figure 41. Unit Orientation

6.7 Installation

See mechanical installation information on the dimensional drawing.

The CAN wiring is considered intrinsically safe. All field wiring should be suitable for the operating temperature range of the unit. CAN wiring may be shielded using a shielded twisted conductor pair and the shield must be connected to the CAN_SHIELD pin.

7 THIRD PARTY SOFTWARE LICENSE NOTICES

This section contains Third Party Software License Notices and/or Additional Terms and Conditions for licensed third-party software components included in the Tri-Axial Gyro Inclinometer firmware.

Table 28. Third Party Software License Notices

Third Party Software	License Notice/Terms
<p>STMicroelectronics microcontroller support software</p>	<p>COPYRIGHT(c) 2017 STMicroelectronics Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met: Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer. Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution. Neither the name of STMicroelectronics nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission. THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT HOLDER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.</p> <p>Licensed under MCD-ST Liberty SW License Agreement V2, (the "License"); You may not use this file except in compliance with the License. You may obtain a copy of the License at: http://www.st.com/software_license_agreement_liberty_v2 Unless required by applicable law or agreed to in writing, software distributed under the License is distributed on an "AS IS" BASIS, WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied. See the License for the specific language governing permissions and limitations under the License.</p>
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8 VERSION HISTORY

User Manual Version	Firmware version	Axiomatic Electronic Assistant (EA) version	Date	Author	Modifications
7E	7.xx	5.15.108.0 or higher	Nov 28, 2023	Olek Bogush	<ul style="list-style-type: none"> Removed single-axis versions: p/n AX062008, AX062018.
7D	7.xx	5.15.108.0 or higher	Sep 14, 2023	Kiril Mojsov	<ul style="list-style-type: none"> Performed Legacy Updates
7C	7.xx	5.15.108.0 or higher	Nov 27, 2020	Olek Bogush	<ul style="list-style-type: none"> Corrected microcontroller type on the <i>Simplified Inclinometer Hardware Block Diagram</i>.
7B	7.xx	5.15.108.0 or higher	Sep 14, 2020	Olek Bogush	<ul style="list-style-type: none"> Added notes excluding Proprietary A PGN (61184) from customer's use in function blocks. Updated <i>J1939 Standard Support</i> table, <i>CAN Input Signal</i> and <i>CAN Output Message</i> function blocks.
7A	7.xx	5.15.108.0 or higher	Feb 3, 2020	Olek Bogush	<ul style="list-style-type: none"> Added vibration and shock data to <i>General Specifications</i>.
7	7.xx	5.15.108.0 or higher	Dec 20, 2019	Olek Bogush	<ul style="list-style-type: none"> Added 667kbit/s baud rate. Updated relevant sections of the UM.
6	6.xx	5.14.105.0 or higher	October 29, 2019	Olek Bogush	<ul style="list-style-type: none"> Updated <i>Angular Figure of Merit</i>, clarified <i>Angle Compensation</i> and <i>Angle Compensation Inverted</i> signals in <i>Angle Measurement</i> function block. Updated <i>Figure 10. Software Block Diagram for Angular Measurements</i>. Updated <i>Maximum Gravity Acceleration Error</i> sub-section. Corrected <i>Enclosure, Dimensional Drawing</i> inclinometer part number.
5A	5.xx	5.14.105.0 or higher	Sept 3, 2019	Olek Bogush	<ul style="list-style-type: none"> Added unit weight in <i>Technical Specifications</i> section.
5	5.xx	5.14.105.0 or higher	August 12, 2019	Olek Bogush	<ul style="list-style-type: none"> Added automatic baud rate detection from the list of 250kbit/s, 500kbit/s, 1Mbit/s baud rates. Updated relevant sections of the UM. Updated <i>J1939 Network</i> sub-section. Added <i>Baud Rate and Automatic Baud Rate Detection</i> configuration parameters. Updated <i>Slew Rate</i> configuration parameter description.
4A	4.xx	5.13.100.0 or higher	June 18, 2019	Olek Bogush	<ul style="list-style-type: none"> Updated <i>J1939 Network</i> sub-section.
4	4.xx	5.13.100.0 or higher	January 8, 2019	Olek Bogush	<ul style="list-style-type: none"> Added configurable unit frame orientation. Added <i>Coordinate Rotation Yaw, Pitch and Roll Angles</i> in <i>Unit Installation</i> function block. Updated <i>Gimbal Lock, Practical Recommendations, Unit Installation, CAN Output</i>.

User Manual Version	Firmware version	Axiomatic Electronic Assistant (EA) version	Date	Author	Modifications
3A	3.xx	5.13.99.0 or higher	Nov 16, 2018	Olek Bogush	<ul style="list-style-type: none"> • Clarified <i>Resolution</i> remarks, added <i>Maximum Dynamic Acceleration</i> parameter in <i>Angular Measurement Parameters</i> table. • Clarified <i>Gimbal Lock</i> in <i>Angle Measurements</i>. • Corrected <i>Unit Installation</i> for single-axis modifications.
3	3.xx	5.13.99.0 or higher	Nov 5, 2018	Olek Bogush	<ul style="list-style-type: none"> • Added new modifications: <ul style="list-style-type: none"> ○ AX062008, Tri-Axial Gyro Inclinator, Vertical Mount; ○ AX062018, Tri-Axial Gyro Inclinator with Extended Dynamic Range, Vertical Mount. • Updated different parts of the manual. • Removed angular resolution with gyro compensation in <i>Angular Measurements. Technical Specification</i>. • Corrected <i>Figure 7. Single-Axis Measurements</i>. • Changed the user manual name from UMAX0609xx to UMAX0609XX_20XX.
2	2.xx	5.13.98.0 or higher	August 17, 2018	Olek Bogush	<ul style="list-style-type: none"> • Added AX060910, Tri-Axial Gyro Inclinator with Extended Dynamic Range. • Updated <i>Hardware Block Diagram</i>, <i>Software Organization</i>, <i>Angle Measurement</i> sub-sections. • Updated <i>Technical Specifications</i> section. Removed <i>Settling Time</i>. • Corrected default PGN in <i>CAN Output</i>. • Changed the user manual name from UMAX06090x to UMAX0609xx.
1A	1.xx	5.13.95.0 or higher	June 25, 2018	Olek Bogush	<ul style="list-style-type: none"> • Updated <i>Technical Specifications</i> section. • Corrected <i>Configuration Example</i> sub-section. • Updated Finnish office phone number on the front page.
1	1.xx	5.13.95.0 or higher	February 26, 2018	Olek Bogush	<ul style="list-style-type: none"> • Initial release.

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Gateways, CAN/Modbus, RS-232
Gyroscopes, Inclinometers
Hydraulic Valve Controllers
Inclinometers, Triaxial
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