USER MANUAL

Dual Output CAN Controller
1 – Universal Input, 2 – 3A Outputs
1 – +5V Reference, CAN (SAE J1939)

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VERSION HISTORY

User Manual Version	Firmware version	Axiomatic Electronic Assistant (EA) version	Date	Author	Modifications
1	1.xx	3.0.23.0 or later	Feb. 2, 2009	Olek Bogush	Initial release – draft version.
2	2.xx	3.0.23.1 or later	Feb. 12, 2009	Olek Bogush	• Digital Input Level setpoint and associated with this setpoint comments were removed from the Universal Input functional block. • One of the anti-windup conditions was changed in the PID Control functional block. • The default ECU Address was corrected to 152 in the Network Setpoint Group paragraph table.
2a	2.xx	3.0.23.1 or later	March 12, 2009	Olek Bogush	• In the Introduction and the Controller Architecture some paragraphs were clarified. • In the Conversion Function, PID Control and Multi-Input Function functional blocks descriptions of the algorithms were corrected.
2b	2.xx	3.0.23.1 or later	June 24, 2009	Olek Bogush	• Added clarification of the message destination address in the CAN Output Message functional block
2b	2.xx	3.023.1 or later	July 16, 2009	A. Wilkins	• Added pinout and dimensions
3	3.xx	3.027.1 or later	August 7, 2009	Olek Bogush	• Changed a default value from 0 to 1 for CAN signal resolution setpoints in CAN Output Message and CAN Input Signal functional blocks. • In CAN Input Signal functional block Autoreset Time description has been changed.
3a	3.xx	3.027.1 or later	August 18, 2009	Olek Bogush	• Dither Amplitude setpoint in the PWM Output functional block has been clarified.
3b	3.xx	3.027.1 or later	Oct 19, 2009	Olek Bogush	• In the Multi-Input Function functional block the range of scale values was changed from [-1;1] to “Any value” for Axiomatic EA versions 3.0.29.0 or later.
3c	3.xx	3.027.1 or later	Oct. 23, 2009	A. Wilkins	• Modified pinout to identify Output 1 and 2 GND
3d	3.xx	3.027.1 or later	Dec 14, 2009	Olek Bogush	• In the “Controller Architecture” section changed name of the Fig.1. • Added block-diagram symbols for all functional blocks. • Added detailed description of the data source states other than “Valid Data”. • Added rules for conversion of the logical signals and CAN signal codes into each other. • Added Default Setpoint Settings subsection.
4	4.xx	3.027.1 or later	June 17, 2010	Olek Bogush	• In the PID Control functional block, the anti-windup algorithm was changed from simply clamping the integral part to stopping the

					integration process when the output of the functional block saturates and the control error contributes to its further saturation. • Added the number of the functional blocks available in the controller inside the graphical presentation of the functional blocks. • The inversion function formula Inv(...) was removed from all logical inputs of all functional blocks for simplicity. It was mentioned instead that the inputs can be inverted. • Clarified description on the Fig. 1,2. • Footnotes were changed. Now they contain a document name and a version number. • Corrected Inverted Signal Value in a table describing signal inversion. • Added description of the input modes for the Universal Input functional block. Frequency and PWM input mode at extreme frequencies was corrected and clarified. • Changed some functional block drawings. • Clarified descriptions of the Conversion Function. • Clarified descriptions of the Multi-Input Function. • Clarified the Disable Input in the PWM Output functional block. • J1939 standard document revisions were updated in the Network Support section. • Added hyperlinks to functional block names.
--	--	--	June 21, 2010	A. Wilkins	• Added technical specifications
4a	4.xx	3.027.1 or later	Oct 14, 2010	Olek Bogush	• Explained discrete logical inputs in the Controller Architecture section. • Clarified the Reset Input of the PID Control functional block.
4b	4.xx	--	January 31, 2013	A. Wilkins	• Changed Power input range per ECN12-0166.
4c	4.xx	--	June 23, 2015	A. Wilkins	• Added CE marking information.
5	5.xx	5.12.83.0 or later	June 7, 2016	Gustavo Del Valle	• Added section for re-flashing over CAN with bootloader support via the Axiomatic Electronic Assistant
5	5.xx	--	Nov. 7, 2016	A. Wilkins	• Added updated dimensional drawing
5a	5.xx	--	August 9, 2023	Kiril Mojsov	• Performed Legacy Updates

ACRONYMS

CAN	Controller Area Network
CANopen®	CAN-based higher layer protocol supported by CAN in Automation (CiA) Note: CANopen® is a registered community trademark of CAN in Automation e.V.
DM	Diagnostic message. Defined in J1939/73 standard
EA	The Axiomatic Electronic Assistant. The Axiomatic EA is a PC application software from Axiomatic, primarily designed to view and program Axiomatic control setpoints through CAN bus using J1939 Memory Access Protocol
ECU	Electronic control unit
EMI	Electromagnetic Interference
LSB	Less Significant Byte
PC	Personal Computer
PGN	Parameter Group Number. Defined in J1939/73 standard
PID	Proportional–integral–derivative (regulator)
PWM	Pulse-width modulation
RS232	PC serial port interface
SAE J1939	CAN-based higher level protocol designed and supported by Society of automobile Engineers (SAE)
USB	Universal Serial Bus
UTP	Un-shielded twisted pair

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1 INTRODUCTION

The following User Manual describes architecture, functionality, and application programming of a dual output CAN controller with: one universal input, two 3A PWM outputs, and one low power +5V voltage reference output.

The controller is designed to independently control two proportional or on/off solenoid valves using PWM control from a variety of input sources. It accepts: voltage, current, resistance, frequency, PWM, and discrete levels from its universal input. Signals transmitted on the CAN bus can also be used as input sources.

A programmable internal architecture provides users with an ultimate flexibility, allowing them to build their own custom controls from a set of predefined internal functional blocks using PC-based Axiomatic EA software. All application programming is performed through CAN interface, without disconnecting the controller from the user's system.

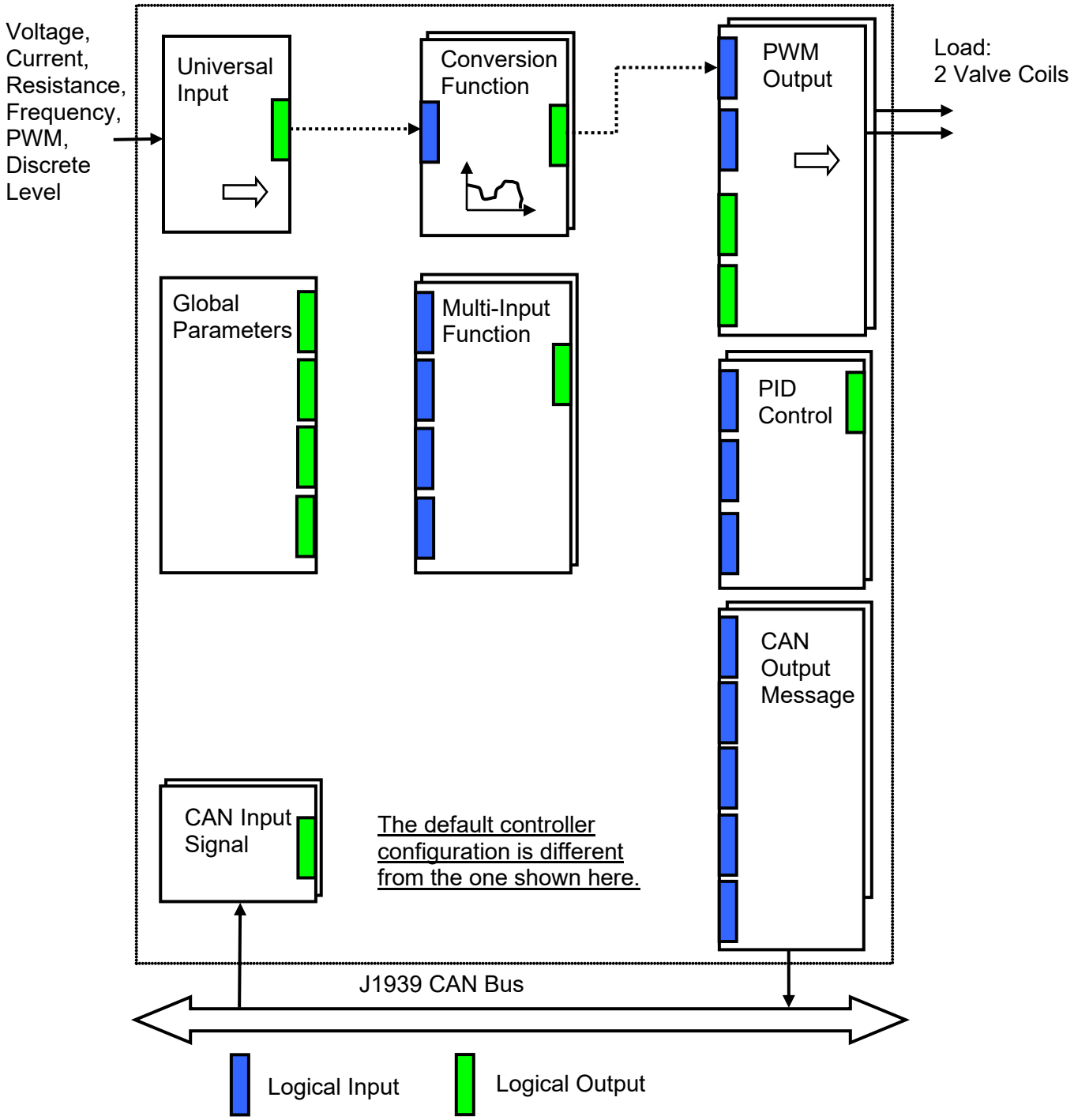
Besides reading signals transmitted on the CAN bus, the controller can also transmit CAN messages carrying signals internally generated by the controller. They include: values acquired from the universal input, output currents, output fault conditions, etc.

Due to high versatility of the controller, it can be used, with some minor restrictions, to control non-inductive loads, for example: automotive lamps. It can also act as a signal to CAN converter, converting: voltage, current, etc. from the universal input to CAN messages.

The controller supports 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. Support for CANopen® and other high-level CAN protocols can be available on request.

2 CONTROLLER ARCHITECTURE

The controller consists of a set of internal functional blocks, which can be individually programmed and arbitrarily connected together to achieve the required system functionality, see Figure 1.



As an example, the Universal Input is connected to a Conversion Function block and the Conversion Function block is connected to a PWM Output block, providing a path for the input signal from input to output through the Conversion Function.

Figure 1. The Controller Internal Structure

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

There are two types of the controller functional blocks. One type represents the controller hardware resources, for example: the universal input or PWM outputs. The other type is purely logical – these functional blocks are included to program the user defined functionality of the controller. The number and functional diversity of these functional blocks are only limited by the system resources of the internal microcontroller. They can be added or modified on the customer's request to accommodate user-specific requirements.

The user can build virtually any type of a custom control by logically connecting inputs and outputs of the functional blocks. This approach gives the user an absolute freedom of customization and an ability to fully utilize the controller hardware resources in a user's application.

Depending on the block functionality, a functional block can have: logical inputs, logical outputs or any combinations of them. The connection between logical inputs and outputs is defined by logical input setpoints. The following rules apply:

- A logical input can be connected to any logical output using a logical input setpoint.
- Two or more logical inputs can be connected to one logical output.
- Logical outputs do not have their own setpoints controlling their connectivity. They can only be chosen as signal sources by logical inputs.

To provide data flow between logical inputs and outputs, all logical output signals are normalized to [0;1] data range using the following equation:

$$Yn = (Y - Ymin) / (Ymax - Ymin),$$

where: Yn – normalized output value,
Y – original output value,
Ymax – maximum output value,
Ymin – minimum output value.

The original output values are restored, if necessary, at the logical inputs using the following reverse linear transformation:

$$X = Xn \bullet (Xmax - Xmin) + Xmin,$$

where: X – original restored input value,
Xn – normalized input value, Xn=Yn,
Xmax – maximum input value, Xmax=Ymax,
Xmin – minimum input value, Xmin=Ymin.

All functional blocks have (Xmax, Xmin) and (Ymax, Ymin) setpoint pairs controlling the normalization process. They will be called "normalization parameters" further in the setpoint descriptions.

For discrete logical inputs and outputs the normalization parameters are not required, since the discrete signals can take only two values: {0,1}. When a regular logical output of a functional block is connected to a discrete logical input, it is assumed that the input values below 0.5 represent state 0 and above 0.5 – state 1:

Discrete Logical Input	Logical State
< 0.5	0
≥ 0.5	1

For additional flexibility, in a majority of functional blocks, logical input signals can be inverted using the following inversion function:

Inv(Xn,I), I∈ {Yes,No},

Inv(Xn,I)={1-Xn, if I=Yes; Xn, if I=No}

In addition to signal values in the range of [0;1], the logical inputs and outputs also carry information on the state of the data source. This information can show that the source is not available or there is an error in data, or the data source is in a special state.

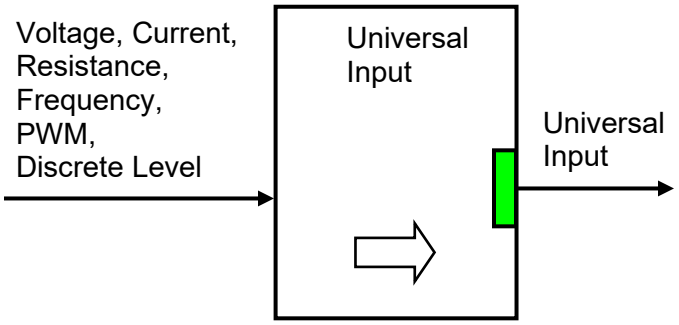
When the data source does not carry a valid data, the output signal value is always set to 0 and the inversion operation on the signal in suppressed. In this case, instead of the signal value, the logical signal carries a signal state code, associated with its signal state, see the table below:

Signal State	Signal Value, Xn	Signal State Code	Inverted Signal Value	
			Xn'=Inv(Xn,Yes)	Xn'=Inv(Xn,No)
Valid Data	[0;1]	0	1-Xn	Xn
Special	0	0…4294967295 (0…0xFFFFFFFF) – Special State Code	0	0
Error	0	0…4294967295 (0…0xFFFFFFFF) – Error Code	0	0
Not Available	0	0	0	0

The states of the data source other than the "Valid Data" are primary used by CAN functional blocks to report that a CAN input signal is absent on the bus, is out of range, etc. Other functional blocks usually use only the "Error" state to show an error condition.

2.1 Universal Input

The Universal Input functional block has one logical output providing a normalized input signal from the physical input to other functional blocks of the controller.



The functional block setpoints are presented in the following table:

Name	Default Value	Range	Units	Description
Input Parameter	Voltage	{Input Disabled, Voltage, Current, Resistance, Discrete Voltage Level, Frequency, PWM Duty Cycle}	–	Type of the universal input electrical parameter to be measured
Voltage Range	0…5V	{0…10V, 0…5V, 0…2.5V, 0…1V}	–	Signal range for Voltage measurements[1]
Current Range	0…20mA	{0…20mA, 4…20mA}	–	Signal range for Current measurements[1]
Frequency Range	10Hz…1kHz	{10Hz…1kHz, 100Hz…10kHz}	–	Signal frequency range for Frequency and PWM Duty Cycle measurements[1,2]
Pull-Up/Pull-Down Resistor	Disabled	{Disabled, 10kOhm Pull-Up, 10kOhm Pull-Down}	–	Connection of the pull-up/pull-down resistor for: Discrete Voltage Level, Frequency and PWM Duty Cycle measurements
Analog Input Filter	Both: 50Hz and 60Hz noise rejection	{Disabled, 50Hz noise rejection, 60Hz noise rejection, Both: 50Hz and 60Hz noise rejection}	–	Input filter for: Voltage, Current and Resistance measurements
Debounce Input Filter	1.78µs	{Disabled, 111ns, 1.78µs, 14.22µs}	–	Debounce input digital filter for Frequency and PWM Duty Cycle measurements
Digital Input Polarity	Active High	{Active High, Active Low}	–	Input polarity for Discrete Voltage Level and PWM Duty Cycle measurements
Vmax – Maximum Input Voltage	5.0	[0…10], but Vmax>Vmin	V	Normalization parameters for Voltage measurements
Vmin – Minimum Input Voltage	0.0	[0…10], but Vmin<Vmax	V	
Imax – Maximum Input Current	20.0	[0…20], but Imax>Imin	mA	Normalization parameters for Current measurements
Imin – Minimum Input Current	0.0	[0…20], but Imin<Imax	mA	
Rmax – Maximum Input Resistance	250.0	[0…250], but Rmax>Rmin	kOhm	Normalization parameters for Resistance measurements
Rmin – Minimum Input Resistance	0.0[3]	[0…250], but Rmin<Rmax	kOhm	
Fmax – Maximum Input Frequency	1000.0	[0…10000], but Fmax>Fmin	Hz	Normalization parameters for Frequency measurements
Fmin – Minimum Input Frequency	0.0[4]	[0…10000], but Fmin<Fmax	Hz	
Dmax – Maximum Duty Cycle	100.0	[0…100], but Dmax>Dmin	%	Normalization parameters for PWM Duty Cycle measurements
Dmin – Minimum Duty Cycle	0.0	[0…100], but Dmin<Dmax	%	

[1] Signal range should comply with normalization parameters. Setting, for example, voltage range to 0…1V and Vmin=5V, Vmax=10V will result in the logical output being equal to 0.0 independently of the input voltage.
[2] Normalization parameters for Frequency measurements do not apply to PWM duty cycle measurements and do not affect choosing the Frequency Range in this mode.
[3] Resistance bellow 20 Ohm is measured as 0 Ohm.
[4] Frequencies bellow 9.5Hz for 10Hz…1kHz range (95Hz for 100Hz…10kHz range) are measured as 0 Hz.

2.1.1 Voltage Input

To acquire a voltage signal, the user should set up: Input Parameter – to Voltage, Voltage Range – to the expected signal range, Vmin and Vmax – to the minimum and maximum voltage acquired by the functional block.

Usually, Vmin and Vmax are set to cover the entire signal range. For example, for Voltage Range equal to 0…5V: Vmin=0 [V] and Vmax=5 [V]. For some applications, however, they can be set inside the signal range. For example, if there is a +5V potentiometer input, setting Vmin=0.1[V] and Vmax=4.9 [V] will ensure that the minimum and maximum potentiometer positions will be clearly identified.

The voltage signal, as well as all other analog signals, is sampled every 1.1(1) ms. By default, it is filtered by the running average filter, which is set up using the Analog Input Filter setpoint. The parameters of the filter are provided below:

Analog Input Filter	Number of points	Averaging Period [ms]
Disabled	-	-
50Hz noise rejection	18	20
60Hz noise rejection	15	16.6(6)
Both: 50Hz and 60Hz noise rejection	90	100

2.1.2 Current Input

The current signal is acquired the same way as a voltage signal. The user should set up: Input Parameter – to Current, Current Range – to the expected current signal range, Imin and Imax – to the minimum and maximum current that will be output as a logical signal by the functional block.

The user should also define the filter parameter using the Analog Input Filter setpoint.

Please, remember that the unit acquires current by measuring a voltage drop on an internal reference resistor. The value of this resistor provided in the Technical Specification should be within an acceptable range for the current source.

2.1.3 Resistance Input

The Universal Input functional block can be set up to measure resistance by setting the Input Parameter setpoint to Resistance, and Rmin, Rmax normalization parameters to the required resistance range.

Analog input filter is also used for resistance measurements. It is recommended that the Analog Input Filter setpoint be set to the value rejecting both: 50Hz and 60Hz industrial noise.

A special algorithm is used to maintain monotonicity of the conversion function during switching between resistance ranges. The actual resistance range used for measuring resistance can be found in the following table:

Range	Resistance
0…150 Ohm	<100 Ohm
0…2 kOhm	100 Ohm …1.1 kOhm
0…20 kOhm	1.1 kOhm …11.1 kOhm
0…250 kOhm	>11.1 kOhm

2.1.4 Frequency and PWM Input

The user can set up the Universal Input to measure frequency or PWM input signal using the Input Parameter setpoint. The user should define the frequency range of the input signal by the Frequency Range setpoint and set up the Fmin, Fmax or Dmin, Dmax normalization parameters.

The polarity of the input signal is set up by the Digital Input Polarity setpoint. The user can also apply a pull-up or pull-down resistor by the Pull-Up/Pull-Down Resistor setpoint and change the debounce input filter settings using the Debounce Input Filter setpoint to filter out parasitic spikes that can be present in the noisy input signal.

Be aware, that the debounce filter settings can affect accuracy of the frequency and PWM signal acquisition at the high frequency. For example, for the 10 kHz PWM signal, setting the Debounce Input Filter to 14.22µs will result in the 14.22% additional error in the output data.

For the Frequency and PWM Duty Cycle input modes the Universal Input functional block will output an error code if the frequency of the input signal is beyond the selected frequency range. The signal value, in this case, will be 0.

Frequency Range	Input Frequency	Error Code
10Hz…1kHz	< 9.155 Hz	0
	≥ 1.2 kHz	1
100Hz…10kHz	< 91.55 Hz	0
	≥ 12 kHz	1

This error code can be acquired through the CAN bus when the logical output of the Universal Input is connected to the CAN Output Message functional block.

For the Duty Cycle measurements, a special algorithm will identify a loss of the PWM frequency carrier as 0% or 100% valid PWM signal depending on the Digital Input Polarity setpoint and the actual digital state of the input.

2.1.5 Discrete Voltage Level Input

The discrete voltage level input mode is the simplest mode of the Universal Input functional block. It is intended to input control signals mainly from switches and buttons.

To activate this mode the user should set the Input Parameter setpoint to the Discrete Voltage Level and define the polarity of the input signal by the Digital Input Polarity setpoint.

The user can also apply a pull-up or pull-down resistor by the Pull-Up/Pull-Down Resistor setpoint.

The debouncing time for the input signal in this mode is fixed and set to 100ms.

2.2 Conversion Function

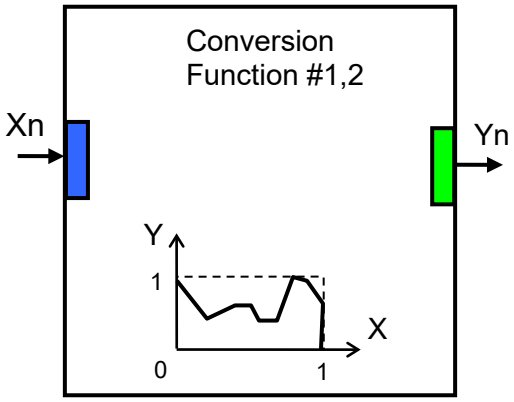
A Conversion Function functional block allows the user to perform a linearization of an input signal, apply a user-defined control profile, and to do a hotshot control, if necessary. There are two Conversion Function blocks available in the current version of the controller.

The function block has one logical input, one output and implements a function:

$$Yn = F(Xn),$$

where:

Xn – normalized input signal (can be inverted by the inversion function),
Yn – normalized output signal.



The function F(x) is defined using a piecewise linear approximation in up to 11 points. Each point is presented by three parameters:

$$P_i = (State_i, Xn_i, Yn_i),\ i = 0\ldots 10,$$

where: P_i – i-th point of the function F,
$State_i$ – state of the i-th point. $State_i \in \{Off, On\}$,
Xn_i – normalized input value at the i-th point.
Yn_i – normalized output value at the i-th point.
If the $State_i$=Off, the point is not active and is not used in the function approximation.

The function values between active points (with $State_i$=On) are defined the following way:

$$Yn = A_j \bullet Xn + B_j,\ j = 0\ldots N,\ N \le 10,$$

$$A_j = (Yn_j - Yn_{(j+1)}) / (Xn_j - Xn_{(j+1)}),$$

$$B_j = (Yn_{(j+1)} \bullet Xn_j - Yn_j \bullet Xn_{(j+1)}) / (Xn_j - Xn_{(j+1)}),$$

$$Xn \in [Xn_j ; Xn_{(j+1)}[,\ State_j=On,\ State_{(j+1)}=On.$$

where: A_j, B_j – linear approximation coefficients between j and (j+1) active points.
N – number of active points.

The Conversion Function functional block is also capable to implement a hotshot control. For this purpose the user can specify two values for the last, 10-th, function point. The first value is a normalized output value at the 10-th point and the second one is the value that will be assigned to the output if the input remains Xn =1.0 for a hotshot time.

The Conversion Functional block has the following set of setpoints:

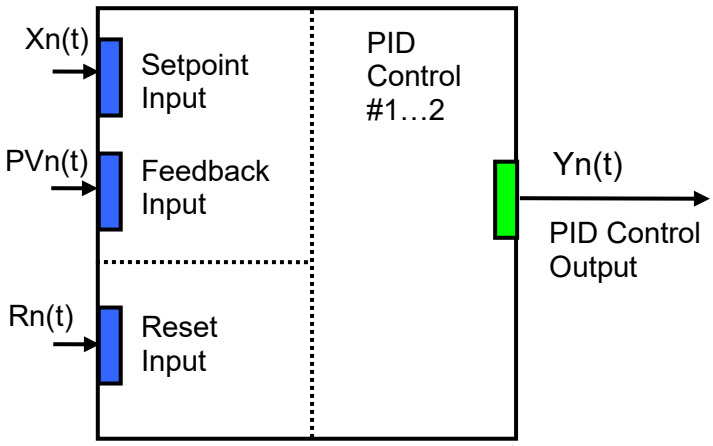
Name	Default Value	Range	Units	Description
Input Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Defines a source of the input signal Xn
Input Inversion	No	{Yes, No}	–	Specifies, whether the input signal Xn is inverted
Point 0 State	On	–	–	$State_0$. Read only parameter
Point 0 X	0	–	–	Xn_0. Read only parameter
Point 0 Y	0	[0;1]	–	Yn_0
Point 1 State	Off	{Off, On}	–	$State_1$
Point 1 X	0.1	[Xn_0; Xn_2]	–	Xn_1
Point 1 Y	0	[0;1]	–	Yn_1
Point 2 State	Off	{Off, On}	–	$State_2$
Point 2 X	0.2	[Xn_1; Xn_3]	–	Xn_2
Point 2 Y	0	[0;1]	–	Yn_2
Point 3 State	Off	{Off, On}	–	$State_3$
Point 3 X	0.3	[Xn_2; Xn_4]	–	Xn_3
Point 3 Y	0	[0;1]	–	Yn_3
Point 4 State	Off	{Off, On}	–	$State_4$
Point 4 X	0.4	[Xn_3; Xn_5]	–	Xn_4
Point 4 Y	0	[0;1]	–	Yn_4
Point 5 State	Off	{Off, On}	–	$State_5$
Point 5 X	0.5	[Xn_4; Xn_6]	–	Xn_5
Point 5 Y	0	[0;1]	–	Yn_5
Point 6 State	Off	{Off, On}	–	$State_6$
Point 6 X	0.6	[Xn_5; Xn_7]	–	Xn_6
Point 6 Y	0	[0;1]	–	Yn_6
Point 7 State	Off	{Off, On}	–	$State_7$
Point 7 X	0.7	[Xn_6; Xn_8]	–	Xn_7
Point 7 Y	0	[0;1]	–	Yn_7
Point 8 State	Off	{Off, On}	–	$State_8$
Point 8 X	0.8	[Xn_7; Xn_9]	–	Xn_8
Point 8 Y	0	[0;1]	–	Yn_8
Point 9 State	Off	{Off, On}	–	$State_9$
Point 9 X	0.9	[Xn_8; Xn_{10}]	–	Xn_9

Name	Default Value	Range	Units	Description
Point 9 Y	0	[0;1]	–	Yn_9
Point 10 State	On	–	–	$State_{10}$. Read only parameter
Point 10 X	1	–	–	Xn_{10}. Read only parameter
Point 10 Y	0	[0;1]	–	Yn_{10}
Hotshot Delay	0	0…10000	ms	Undefined if 0
Hotshot Y	0	[0;1]	–	Yn_{10}, if Xn=1.0 for Time>Hotshot Delay, and Hotshot Delay ≠ 0

2.3 PID Control

To provide the user with means to build generic closed loop PID regulators, two PID Control functional blocks were added to the controller.

A PID Control functional block has: setpoint and feedback inputs, manual control mode and a reset input to bring the regulator into its initial state. The user can also adjust the time resolution for fast or slow responding closed loop systems.



The normalized output of the PID Control functional block Yn(t), as a function of time, can be described by the following formula:

$$Yn(t)=Clip(Y(t)),$$

$$Y(t) = P\bullet[\ e(t) + 1/T_I\bullet\int e(t)dt - T_D\bullet dPVn(t)/dt\ ],$$

where:

Clip(Y(t))={Y(t), if $0\le Y(t)\le 1$; 0, if $Y(t)<0$; 1, if $Y(t)>1$} – clipping function;
e(t) = Xn(t) – PVn(t) – error function, where
Xn(t) – normalized setpoint variable, set by the Setpoint Input,
PVn(t) – normalized process variable, set by the Feedback Input,
P – proportional gain,
T_I – integral time,
T_D – derivative time.

All PID Control logical inputs can be inverted.

To avoid saturation of the output due to the integral term of the PID regulator, an anti-windup algorithm is implemented. The integrator is stopped when the output saturates and the error function moves the output to further saturation:

$Y(t)>1$ and $e(t)>0$ or $Y(t)<0$ and $e(t)<0$.

When the Reset Input is activated, the integral part of the PID regulator is reset to zero and the output of the PID Control functional block is brought to zero, too:

$$\int e(t)dt=0,\ Y(t) = 0, \quad \text{when } Rn(t)\geq 0.5,$$

where:

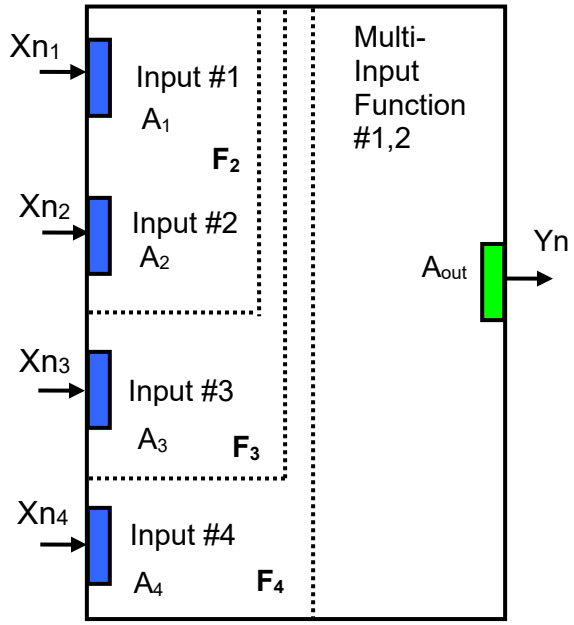
$Rn(t)$ – normalized reset variable, set by the Reset Input.

Setpoints of the PID Control functional block are presented in the following table:

Name	Default Value	Range	Units	Description
Setpoint Input Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of a setpoint input signal
Setpoint Input Inversion	No	{Yes, No}	–	Specifies, whether to invert the setpoint signal
Feedback Input Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of a feedback input signal
Feedback Input Inversion	No	{Yes, No}	–	Specifies, whether to invert the feedback signal
Reset Input Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of a reset input signal. The signal brings the regulator into its initial state.
Reset Input Inversion	No	{Yes, No}	–	Specifies, whether to invert the reset signal
Manual Control	No	{Yes, No}	–	Put the PID control in a manual control mode. In this mode the PID regulator is off and the PID output is equal to the value of the “Manual Control Output” setpoint
Manual Control Output	0.5	[0;1]	–	Output of the PID control in the manual control mode
Proportional Gain	1.0	[0;100000]	–	Proportional PID parameter
Integral Time Constant	0.1	[0;100000]	s	Integral PID parameter
Derivative Time Constant	0.01	[0;100000]	s	Derivative PID parameter. Derivation from the process variable is used.
Time Resolution	0.001	[0.001;10]	s	Time interval between PID control cycles

2.4 Multi-Input Function

There are two Multi-Input Function functional blocks added to the controller to increase its flexibility to support different user-defined control algorithms. A Multi-Input Function functional block takes up to four input signals, scales them, and performs consequent arithmetic or logical operations. Then it outputs the result, which can be scaled as well.



The normalized output signal Yn of the Multi-Input Function functional block can be presented by the following formula:

$$Yn=Clip(Y),$$

$$Y = A_{out} \bullet F_4[F_3[F_2[A_1 \bullet Xn_1, A_2 \bullet Xn_2], A_3 \bullet Xn_3], A_4 \bullet Xn_4],$$

where:

$Clip(Y)=\{Y, \text{ if } 0 \le Y \le 1; 0, \text{ if } Y<0; 1, \text{ if } Y>1\}$ – clipping function;
Xn_i, i=1,…,4 – normalized signal value of the i-th input source (can be inverted);
A_i, i=1,…,4 – scale coefficient of the i-th input signal;
A_{out} – scale coefficient of the output signal;
$F_i[x, y]$, i=2,…,4 – binary function of the i-th input signal. The function takes two arguments: x and y, where x is a result of the previous F_{i-1} binary function or a scaled 1-st input signal value and y is a scaled i-th input signal value. The function does not exist for the 1-st input signal.

If any of the input sources are not connected, the formula is truncated to perform operations with only connected input sources. For example:

$Y= A_{out} \bullet F_2[A_1 \bullet Xn_1, A_2 \bullet Xn_2]$, if the 3-rd input source is ”Not Connected”

$Y=A_{out} \bullet F_3[F_2[A_1 \bullet Xn_1, A_2 \bullet Xn_2], A_3 \bullet Xn_3]$, if the 4-th input source is ”Not Connected”

In case the 1-st or the 2-nd input source is not connected, the output signal of the functional block is not available and its signal value is set to Yn=0.

The Multi-Input Function functional block has the following set of setpoints:

Name	Default Value	Range	Units	Description
Input #1 Source	Not Connected	Any logical output of any functional block or "Not Connected"	–	Source of the input #1 signal
Input #1 Inversion	No	{Yes, No}	–	Specifies, whether to invert the input #1 signal
Input #1 Scale	1.0	[-1…1] or Any value*	–	Input #1 signal scale coefficient
Input #2 Source	Not Connected	Any logical output of any functional block or "Not Connected"	–	Source of the input #2 signal
Input #2 Inversion	No	{Yes, No}	–	Specifies, whether to invert the input #2 signal
Input #2 Scale	1.0	[-1…1] or Any value*	–	Input #2 signal scale coefficient
Input #2 Function	+	{+, ∗,÷, Max, Min, OR, AND, XOR, <, ≤, =, >, ≥}	–	Binary function of the input #1 scaled signal and the input #2 scaled signal
Input #3 Source	Not Connected	Any logical output of any functional block or "Not Connected"	–	Source of the input #3 signal
Input #3 Inversion	No	{Yes, No}	–	Specifies, whether to invert the input #3 signal
Input #3 Scale	1.0	[-1…1] or Any value*	–	Input #3 signal scale coefficient
Input #3 Function	+	{+, ∗,÷, Max, Min, OR, AND, XOR, <, ≤, =, >, ≥}	–	Binary function of the Input #2 function result and the input #3 scaled signal
Input #4 Source	Not Connected	Any logical output of any functional block or "Not Connected"	–	Source of the input #4 signal
Input #4 Inversion	No	{Yes, No}	–	Specifies, whether to invert the input #4 signal
Input #4 Scale	1.0	[-1…1] or Any value*	–	Input #4 signal scale coefficient
Input #4 Function	+	{+, ∗,÷, Max, Min, OR, AND, XOR, <, ≤, =, >, ≥}	–	Binary function of the Input #3 function result and the input #4 scaled signal
Output Scale	1.0	[-1…1] or Any value*	–	Output signal scale coefficient

*Any scale value can be programmed using Axiomatic EA version 3.0.29.0 or later.

The binary functions $F_i[x,y]$ have the following implementation specifics.

In the division function, to avoid ambiguity in dividing by 0, the dividend and the divisor are not allowed to be less than δ:

$$F_i^{(\div)}[x,y] = \max(x,\delta)/\max(y,\delta), \qquad i=2,\ldots,4$$

where: δ =1.0E-6 is a specially introduced computational constant.

For logical functions {OR, AND, XOR} values $X_i \geq 0.5$ (i=1,…,4) are treated as 1 (true) and $X_i < 0.5$ – as 0 (false).

To minimize influence of computational errors during normalization, comparison functions {≤, =, ≥ } are defined the following way:

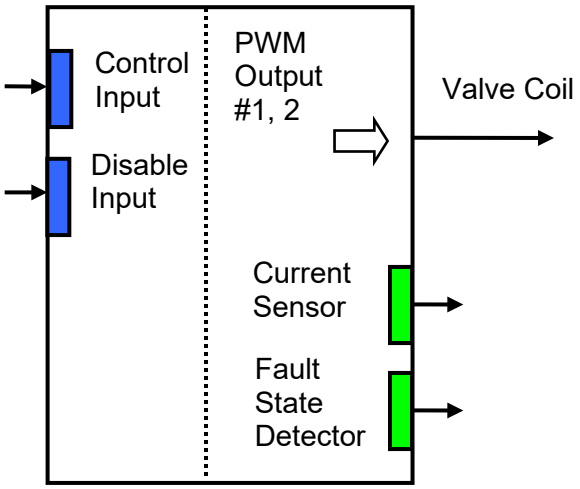
$F_i^{(\leq)}[x,y] = \{1, \text{if } x \leq y+\delta;\ 0, \text{if } x > y+\delta\}$,

$F_i^{(=)}[x,y] = \{1, \text{if } |x-y| \leq \delta;\ 0, \text{if } |x-y| > \delta\}$,

$F_i^{(\geq)}[x,y] = \{1, \text{if } x \geq y-\delta;\ 0, \text{if } x < y-\delta\}$.

2.5 PWM Output

Two PWM Output functional blocks represent hardware PWM output stages of the controller. Each block has a control and a disable inputs to control the load, and two logical outputs: one providing data from the current sensor connected to the load, and the other – from the fault state detector:



The user can select: the output mode, minimum and maximum output values, dither parameters, and ramps. Also, PID coefficients can be set to control the output current in the “Output Current” mode. For the current sensor, the user can define an averaging time to minimize effect of the output dither on the sensor readings.

Each PWM Output functional block has the following set of setpoints:

Name	Default Value	Range	Units	Description
Output Mode	Output Current	{Output Disable, Discrete On/Off, Output Current, Output Voltage, Output PWM Duty Cycle}	–	Specifies a control mode of the controller PWM output stage
Reverse Action	No	{Yes, No}	–	Defines a reverse control (increasing the input signal will decrease the output value: from Imax to Imin, etc.)

Name	Default Value	Range	Units	Description
Control Input Source	Universal Input	Any logical output of any functional block or “Not Connected”	–	Defines a source of the control input signal. This signal controls the PWM output
Control Input Inversion	No	{Yes, No}	–	Specifies, whether the control input signal is inverted
Disable Input Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Defines a source of the disable input signal. This signal immediately brings the output to its original “Disabled” state[5].
Disable Input Inversion	No	{Yes, No}	–	Specifies, whether the disable input signal is inverted
Imax – Max Output Current	1.0	[0; 3], but Imax>Imin	A	Normalization parameters for Output Current mode. Imax is limited, if DithAmp is high[1].
Imin – Min Output Current	0	[0;3], but Imin<Imax	A	
Vmax – Max Output Voltage	24.0	[0; 60], but Vmax>Vmin	V	Normalization parameters for Output Voltage mode.
Vmin – Min Output Voltage	0.0	[0; 60], but Vmin<Vmax	V	
Dmax – Max PWM Duty Cycle	100.0	[0; 100], but Dmax<Dmin	%	Normalization parameters for Output PWM Duty Cycle mode.
Dmin – Min PWM Duty Cycle	0.0	[0; 100], but Dmin<Dmax	%	
RampUp – Ramp Up Time	10.0	[0; 100000]	ms	Time, during which the output ramps from its minimum to maximum value.
RampDown – Ramp Down Time	10.0	[0; 100000]	ms	Time, during which the output ramps from its maximum to minimum value.
DithFreq – Dither Frequency	100.0	[20; 400]	Hz	Frequency of the superimposed dither[2]
DithAmp – Dither Amplitude	5.0	[0; 40]	%	Point-to-point amplitude of the superimposed dither. Defined in % of the maximum output value[4]. Limited in the Output Current mode, if Imax is high[1].
Proportional Gain	0.8	[0; 1000]	–	Proportional PID parameter. Password Protected[3].
Integral Time Constant	0.03	[0; 10]	s	Integral PID parameter. Password Protected[3].
Derivative Time Constant	0.001	[0; 10]	s	Derivative PID parameter Password Protected[3].
Current Sensor Averaging Time	100	[0; 1000]	ms	Current sensor output will be updated every specified averaging period of time with an average value calculated on the previous averaging time interval.

Name	Default Value	Range	Units	Description
Current Sensor Max	3.0	–	A	Normalization parameters for the current sensor output. Read only.
Current Sensor Min	0	–	A	

[1]Due to a limited dynamic range of the current control circuit, Imax and DithAmp values should satisfy the following equation:

$$Imax \cdot (1 + DithAmp/100) \leq 3.15,$$

where: 3.15 – internal control constant.
[2]A global parameter for all PWM outputs.
[3]To avoid accidental changing of the PID parameters, they are password protected. The password is: PIDSetupNow, case sensitive. PID control loop is only used in the Output Current mode.
[4]The maximum output value is defined by the Output Mode. It is equal to: Imax in the Output Current mode, Vmax – in the Output Voltage mode and Dmax – in the Output PWM Duty Cycle mode.
[5]This state corresponds to the zero output, if Reverse Action is not activated (default). If the Reverse Action is activated, the output will be set to the maximum value, which is the value of the output when the control signal is equal to zero in this mode.

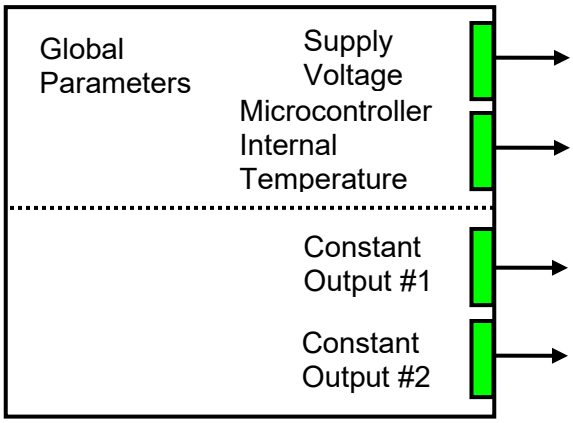
2.5.1 Fault State Detector

A fault-state detector changes its state from 0 to 1, when the PWM output is connected to ground or to the battery terminal. In case the PWM output is shorted to ground, it may be necessary to drive the output with some control signal to detect the fault condition.

The fault-state detector does not come on in the overvoltage/undervoltage condition when the supply voltage goes beyond the specified power supply voltage range (6…60 VDC), resulting the PWM outputs to be temporary shut down as a protective measure.

2.6 Global Parameters

The Global Parameters functional block gives the user access to the controller supply voltage and the microcontroller internal temperature as well as to a set of two constant logical outputs:



These outputs can be used by other functional blocks as constant input sources. For example, they can be used to set up threshold values for Multi-Input Functions.

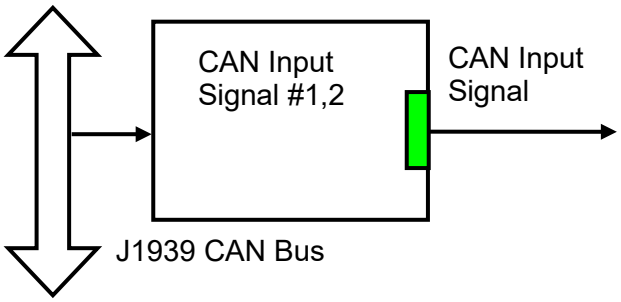
The setpoints for this functional block are presented in the following table:

Name	Default Value	Range	Units	Description
Constant Output #1	0.0	[0…1]	–	Logical output with a constant

Name	Default Value	Range	Units	Description
				value.
Constant Output #2	0.0	[0…1]	–	Logical output with a constant value.
Vsmax – Max Supply Voltage	70	–	V	Normalization parameters for the controller supply voltage. Read only parameters.
Vsmin – Min Supply Voltage	0	–	V	
Tmax – Max Microcontroller Temperature	150	–	°C	Normalization parameters for the microcontroller embedded temperature sensor. Read only parameters.
Tmin – Min Microcontroller Temperature	-50	–	°C	

2.7 CAN Input Signals

There are two CAN Input Signal functional blocks supported by the controller. Each functional block provides the controller with a logical interface to CAN application specific signals transmitted on the CAN bus. It can be programmed to read a single-frame CAN messages with virtually any CAN signal data format and then output the signal data to its logical output for processing by other functional blocks of the controller.



The functional block has an ability to filter out signals transmitted only from a selected address. This way, it can be bound to a specific ECU on the CAN network. It can also automatically reset the input signal in case the signal has been absent on the network for more than a specific period of time. CAN application specific signals transmitted by the controller itself are also processed by this functional block.

The setpoints of a CAN Input Signal functional block are presented in the following table:

Name	Default Value	Range	Units	Description
Signal Type	Undefined	{Undefined, 1-Bit Discrete, 2-Bit Discrete, 4-Bit Discrete, 1-Byte Continuous, 2-Byte Continuous, 4-Byte Continuous}	–	Type of the CAN input signal
PGN	65280	Any J1939 PGN value	–	PGN of the single frame CAN messages carrying the CAN

Name	Default Value	Range	Units	Description
				input signal
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 carrying the CAN input signal
Data Position Byte	1	[1; 8]	–	Input signal data position byte within the CAN message data frame. LSB for continuous input signals
Data Position Bit	1	[1; 8]	–	Less significant input signal data position bit within the “Data Position Byte” for discrete input signals[1]
Resolution	1	Any value	Signal Units / Bit	CAN continuous signal resolution
Offset	0	Any value	Signal Units	CAN continuous signal offset
Signal Max Value	1	Any value, but: Signal Max Value > Signal Min Value	Signal Units	Normalization parameters for the CAN input signal. Valid only for continuous signals
Signal Min Value	0	Any value, but: Signal Min Value < Signal Max Value	Signal Units	
Autoreset Time	500	[0; 10000]	ms	Time interval, after which the output signal will be automatically reset to “Not Available”, if a new CAN message, carrying the signal, has not arrived. If 0 – autoreset is disabled.

[1]Discrete input signals should be within the “Data Position Byte” borders, not split between the adjacent bytes.

According to the J1939/71 standard, CAN signals can carry not only signal values, but also special indicators, including: error indicator, “signal not available” indicator, etc. CAN signal types, supported by the controller, have the following CAN signal code mapping to the controller logical signals:

CAN Signal Type	CAN Signal Code	Logical Signal		
		State	Value	Signal State Code
1-Bit Discrete*	0…1	Valid Data	0…1 (=CANSignalCode)	0
2-Bit Discrete	0…1	Valid Data	0…1 (=CANSignalCode)	0
	2	Error	0	0
	3	Not Available	0	0
4-Bit Discrete*	0…1	Valid Data	0…1	0

CAN Signal Type	CAN Signal Code	Logical Signal		
		State	Value	Signal State Code
			(=CANSignalCode)	
	2…13 (0x02…0x0D)	Special	0	0…11 =CANSignalCode-2
	14 (0x0E)	Error	0	0
	15 (0x0F)	Not Available	0	0
1-Byte Continuous	0…250 (0…0xFA)	Valid Data	[0;1] - normalized signal code	0
	251…253 (0xFB…0xFD)	Special	0	0…2 =CANSignalCode-251
	254 (0xFE)	Error	0	0
	255 (0xFF)	Not Available	0	0
2-Byte Continuous	0…64255 (0…0xFAFF)	Valid Data	[0;1] - normalized signal code	0
	64256…65023 (0xFB00…0xFDFF)	Special	0	0…267 =CANSignalCode-64256
	65024…65279 (0xFExx)	Error	0	0…255 =CANSignalCode-65024
	65280…65535 (0xFFxx)	Not Available	0	0
4-Byte Continuous	0…4211081215 (0… 0xFAFFFFFF)	Valid Data	[0;1] - normalized signal code	0
	4211081216… 4261412863 (0xFB000000… 0xFDFFFFFF)	Special	0	0…50331647 =CANSignalCode-4211081216
	4261412864… 4278190079 (0xFExxxxxx)	Error	0	0…16777215 =CANSignalCode-4261412864
	4278190080… 4294967295 (0xFFxxxxxx)	Not Available	0	0

*CAN signal code mapping for these types is specific to this control.

This mapping closely follows the J1939/71 standard for the 2-bit Discrete and all continuous CAN signal types, dividing the CAN code in similar ranges to represent different states of the signal. For the 1-bit and 4-bit Discrete signal types there are no generic rules specified by the J1939/71 standard to encode special indicators. The control uses its own mapping scheme for these types.

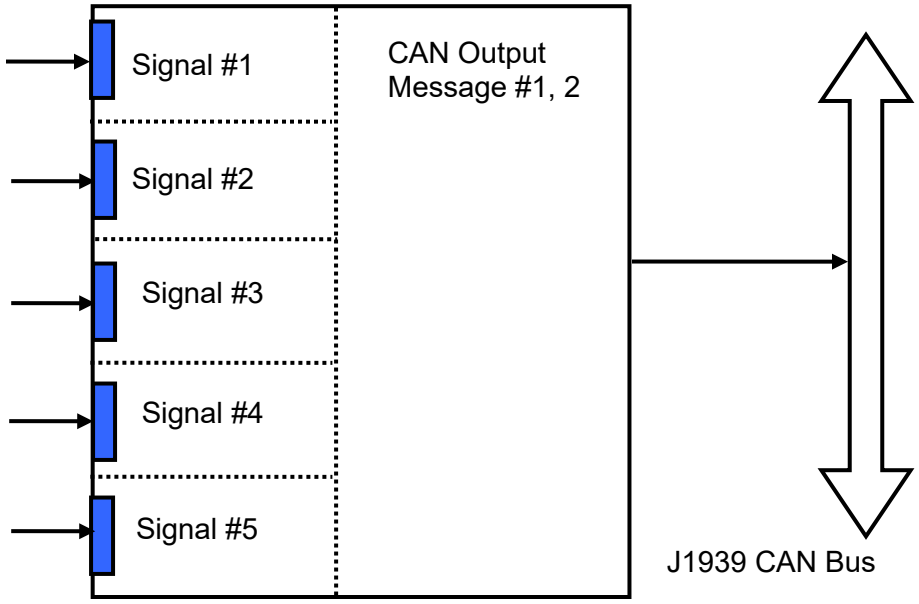
The J1939 standard does not specify how to encode the error codes and parameter specific indicators within the special indicator ranges. The control uses its own simple way of encoding, converting parameter specific and error indicators into absolute signal state codes. This allows to receive and transmit the same codes using different CAN signal types in a consistent way.

For example, if the logical signal is in the “Error” state with the error code equal to 1, the CAN signal code carrying this error will be 650251 (0xFE01) for the “2-Byte Continuous” CAN signal type or 4261412865 (0xFE00 0001) – for the “4-Byte Continuous” CAN signal type. See also the CAN Output Messages for reverse conversion of the logical signals into the CAN signal codes.

2.8 CAN Output Messages

There are two CAN Output Message functional blocks, which allow the controller to send two independent single frame application specific CAN messages to the CAN bus.

The messages can be sent continuously or upon request. Each message contains up to five user defined CAN signals:



The CAN output messages do not have a specific destination address. In case the PGN of the message is presented in the PDU1 format, the message is sent to the global address (0xFF).

The setpoints of a CAN Output Message functional block are presented in the following table:

Name	Default Value	Range	Units	Description
PGN	65281(Out1), 65282(Out2)	Any J1939 PGN value	–	CAN output message PGN
Transmission Enable	No	{Yes, No}		Enables the CAN output message transmission
Transmission Rate	0	[0;10000]		CAN output message transmission rate. If 0 – transmission is upon request
Signal #1 Type	Undefined	{Undefined, 1-Bit Discrete, 2-Bit Discrete, 4-Bit Discrete, 1-Byte Continuous, 2-Byte Continuous, 4-Byte Continuous}	–	Type of the CAN output signal #1
Signal #1 Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of the CAN output signal #1
Signal #1 Inversion	No	{Yes, No}	–	Specifies, whether to invert the output signal #1

Name	Default Value	Range	Units	Description
Signal #1 Data Position Byte	1	[1; 8]	–	Signal #1 data position byte within the CAN message data frame. LSB for continuous output signals
Signal #1 Data Position Bit	1	[1; 8]	–	Less significant signal #1 data position bit within the “Signal #1 Data Position Byte” for discrete output signals[1]
Signal #1 Resolution	1	Any value, except 0	Signal Units / Bit	CAN output signal #1 resolution. Valid only for continuous signals
Signal #1 Offset	0	Any value	Signal Units	CAN output signal #1 offset. Valid only for continuous signals
Signal #1 Max Value	1	Any value, but: Signal #1 Max Value > Signal #1 Min Value	Signal Units	Normalization parameters for the CAN output signal #1. Valid only for continuous signals
Signal #1 Min Value	0	Any value, but: Signal #1 Min Value < Signal #1 Max Value	Signal Units	
Signal #2 Type	Undefined	{Undefined, 1-Bit Discrete, 2-Bit Discrete, 4-Bit Discrete, 1-Byte Continuous, 2-Byte Continuous, 4-Byte Continuous}	–	Type of the CAN output signal #2
Signal #2 Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of the CAN output signal #2
Signal #2 Inversion	No	{Yes, No}	–	Specifies, whether to invert the output signal #2
Signal #2 Data Position Byte	1	[1; 8]	–	Signal #2 data position byte within the CAN message data frame. LSB for continuous output signals
Signal #2 Data Position Bit	1	[1; 8]	–	Less significant signal #2 data position bit within the “Signal #2 Data Position Byte” for discrete output signals[1]
Signal #2 Resolution	1	Any value, except 0	Signal Units / Bit	CAN output signal #2 resolution. Valid only for continuous signals
Signal #2 Offset	0	Any value	Signal Units	CAN output signal #2 offset. Valid only for continuous signals
Signal #2 Max Value	1	Any value, but: Signal #2 Max Value > Signal #2 Min Value	Signal Units	Normalization parameters for the CAN output signal #2. Valid only for continuous

Name	Default Value	Range	Units	Description
Signal #2 Min Value	0	Any value, but: Signal #2 Min Value < Signal #2 Max Value	Signal Units	signals
Signal #3 Type	Undefined	{Undefined, 1-Bit Discrete, 2-Bit Discrete, 4-Bit Discrete, 1-Byte Continuous, 2-Byte Continuous, 4-Byte Continuous}	–	Type of the CAN output signal #3
Signal #3 Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of the CAN output signal #3
Signal #3 Inversion	No	{Yes, No}	–	Specifies, whether to invert the output signal #3
Signal #3 Data Position Byte	1	[1; 8]	–	Signal #3 data position byte within the CAN message data frame. LSB for continuous output signals
Signal #3 Data Position Bit	1	[1; 8]	–	Less significant signal #3 data position bit within the “Signal #3 Data Position Byte” for discrete output signals[1]
Signal #3 Resolution	1	Any value, except 0	Signal Units / Bit	CAN output signal #3 resolution. Valid only for continuous signals
Signal #3 Offset	0	Any value	Signal Units	CAN output signal #3 offset. Valid only for continuous signals
Signal #3 Max Value	1	Any value, but: Signal #3 Max Value > Signal #3 Min Value	Signal Units	Normalization parameters for the CAN output signal #3. Valid only for continuous signals
Signal #3 Min Value	0	Any value, but: Signal #3 Min Value < Signal #3 Max Value	Signal Units	
Signal #4 Type	Undefined	{Undefined, 1-Bit Discrete, 2-Bit Discrete, 4-Bit Discrete, 1-Byte Continuous, 2-Byte Continuous, 4-Byte Continuous}	–	Type of the CAN output signal #4
Signal #4 Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of the CAN output signal #4
Signal #4 Inversion	No	{Yes, No}	–	Specifies, whether to invert the output signal #4
Signal #4 Data Position Byte	1	[1; 8]	–	Signal #4 data position byte within the CAN message data frame. LSB for continuous output signals

Name	Default Value	Range	Units	Description
Signal #4 Data Position Bit	1	[1; 8]	–	Less significant signal #4 data position bit within the Signal #4 Data Position Byte for discrete output signals[1]
Signal #4 Resolution	1	Any value, except 0	Signal Units / Bit	CAN output signal #4 resolution. Valid only for continuous signals
Signal #4 Offset	0	Any value	Signal Units	CAN output signal #4 offset. Valid only for continuous signals
Signal #4 Max Value	1	Any value, but: Signal #4 Max Value > Signal #4 Min Value	Signal Units	Normalization parameter for the CAN output signal #4. Valid only for continuous signals
Signal #4 Min Value	0	Any value, but: Signal #4 Min Value < Signal #4 Max Value	Signal Units	
Signal #5 Type	Undefined	{Undefined, 1-Bit Discrete, 2-Bit Discrete, 4-Bit Discrete, 1-Byte Continuous, 2-Byte Continuous, 4-Byte Continuous}	–	Type of the CAN output signal #5
Signal #5 Source	Not Connected	Any logical output of any functional block or “Not Connected”	–	Source of the CAN output signal #5
Signal #5 Inversion	No	{Yes, No}	–	Specifies, whether to invert the output signal #5
Signal #5 Data Position Byte	1	[1; 8]	–	Signal #5 data position byte within the CAN message data frame. LSB for continuous output signals
Signal #5 Data Position Bit	1	[1; 8]	–	Less significant signal #5 data position bit within the “Signal #5 Data Position Byte” for discrete output signals[1]
Signal #5 Resolution	1	Any value, except 0	Signal Units / Bit	CAN output signal #5 resolution. Valid only for continuous signals
Signal #5 Offset	0	Any value	Signal Units	CAN output signal #5 offset. Valid only for continuous signals
Signal #5 Max Value	1	Any value, but: Signal #5 Max Value > Signal #5 Min Value	Signal Units	Normalization parameter for the CAN output signal #5. Valid only for continuous signals.
Signal #5 Min Value	0	Any value, but: Signal #5 Min Value < Signal #5 Max Value	Signal Units	

[1]CAN discrete signals should be within the “Data Position Byte” borders, not split between the adjacent bytes.

The logical signals can carry not only signal values but also error and special codes reflecting different states of the logical signal. The logical signals are converted into CAN signal codes the same way as in the CAN Input Signal functional block, closely following the J1939/71 standard when possible. See the table below:

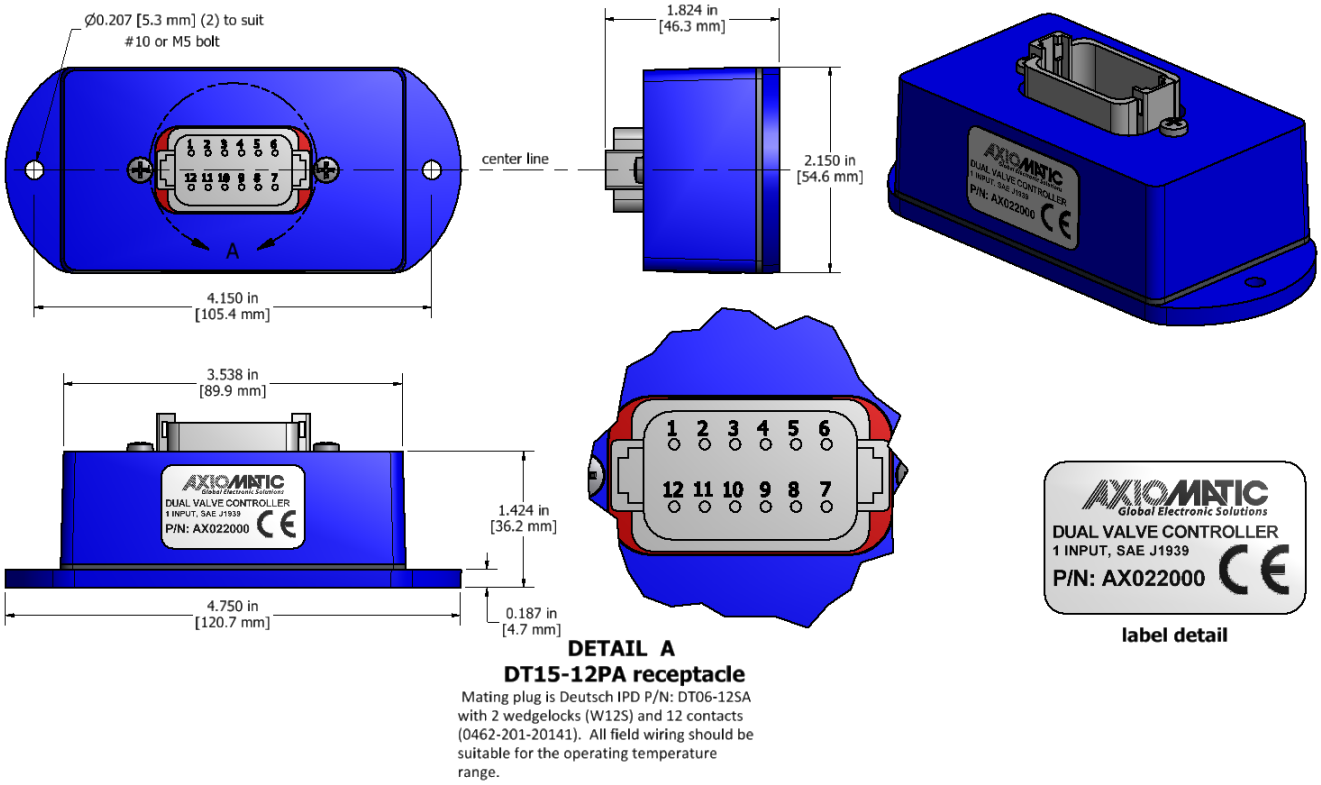
CAN Signal Type	Logical Signal			CAN Signal Code
	State	Value	Signal State Code	
1-Bit Discrete	Valid Data	[0;1]	0	0, if Value<0.5 1, if Value≥0.5
	Special*	0	0…4294967295 (0…0xFFFFFFFF)	1
	Error*	0	0…4294967295 (0…0xFFFFFFFF)	1
	Not Available*	0	0	1
2-Bit Discrete	Valid Data	[0;1]	0	0, if Value<0.5 1, if Value≥0.5
	Special*	0	0…4294967295 (0…0xFFFFFFFF)	3 (Same as “Not Available”)
	Error	0	0…4294967295 (0…0xFFFFFFFF)	2
	Not Available	0	0	3
4-Bit Discrete*	Valid Data	[0;1]	0	0, if Value<0.5 1, if Value≥0.5
	Special	0	0…4294967295 (0…0xFFFFFFFF)	2…13 (0x02…0x0D) =SignalStateCode+2, if SignalStateCode<12 =13, if SignalStateCode ≥12
	Error	0	0…4294967295 (0…0xFFFFFFFF)	14 (0x0E)
	Not Available	0	0	15 (0x0F)
1-Byte Continuous	Valid Data	[0;1]	0	0…250 (0…0xFA) – calculated from the Value using normalization parameters
	Special	0	0…4294967295 (0…0xFFFFFFFF)	251…253 (0xFB…0xFD) = SignalStateCode+251, if SignalStateCode<3, =253, if SignalStateCode ≥3
	Error	0	0…4294967295 (0…0xFFFFFFFF)	254 (0xFE)
	Not Available	0	0	255 (0xFF)
2-Byte Continuous	Valid Data	[0;1]	0	0…64255 (0…0xFAFF) – calculated from the Value using normalization parameters
	Special	0	0…4294967295 (0…0xFFFFFFFF)	64256…65023 (0xFB00…0xFDFF) = SignalStateCode+64256, if SignalStateCode<768, =65023, if SignalStateCode ≥768
	Error	0	0…4294967295 (0…0xFFFFFFFF)	65024…65279 (0xFExx) = SignalStateCode+65024, if SignalStateCode<256, =65279, if SignalStateCode ≥256

CAN Signal Type	Logical Signal			CAN Signal Code
	State	Value	Signal State Code	
	Not Available	0	0	65535 (0xFFFF)
4-Byte Continuous	Valid Data	[0;1]	0	0…4211081215 (0… 0xFAFFFFFF) – calculated from the Value using normalization parameters
	Special	0	0…4294967295 (0…0xFFFFFFFF)	4211081216… 4261412863 (0xFB000000… 0xFDFFFFFF) =SignalStateCode+4211081216, if SignalStateCode<50331648, =4261412863, if SignalStateCode ≥50331648
	Error	0	0…4294967295 (0…0xFFFFFFFF)	4261412864… 4278190079 (0xFExxxxxx) =SignalStateCode+4261412864, if SignalStateCode<16777216, =4278190079, if SignalStateCode ≥16777216
	Not Available	0	0	4294967295 (0xFFFFFFFF)

*Conversion rules are specific to this control. They are not defined by the J1939/71 standard.

3 INSTALLATION INSTRUCTIONS

Network Termination	It is necessary to terminate the network with external termination resistors. The resistors are 120 Ohm, 0.25W minimum, metal film or similar type. They should be placed between CAN_H and CAN_L terminals at both ends of the network.
Operating Conditions	-40 to 85 °C (-40 to 185 °F)
Packaging	Aluminum enclosure, integral connector (TE Deutsch equivalent), Encapsulated Refer to the dimensional drawing.
Protection	IP67 rating for the product assembly NOTE: TE Deutsch connectors are rated at IP67 for submersion (3 ft., 0.9 m).
Weight	0.70 lbs. (0.32 kg)



DETAIL A
DT15-12PA receptacle
Mating plug is Deutsch IPD P/N: DT06-12SA with 2 wedgelocks (W12S) and 12 contacts (0462-201-20141). All field wiring should be suitable for the operating temperature range.

label detail

Electrical Connections	12-pin integral connector (equivalent TE Deutsch P/N: DT15-12PA) A mating plug kit is available as Axiomatic P/N: **AX070105**.

CAN and I/O Connector	
Pin #	**Description**
1	Output 1
2	Output 1 GND
3	Power +
4	CAN Shield
5	CAN_LO
6	CAN_Hi
7	+5V reference
8	Input GND
9	Universal Input 1
10	Power GND
11	Output 2 GND
12	Output 2

Installation	Mounting holes sized for #10 or M4.5 bolts. The bolt length will be determined by the end-user's mounting plate thickness. The mounting flange of the controller is 0.19 inches (4.75 mm) thick. If the module is mounted without an enclosure, it should be mounted to reduce the likelihood of moisture entry. Install the unit with appropriate space available for servicing and for adequate wire harness access (6 inches or 15 cm) and strain relief (12 inches or 30 cm). The CAN wiring is considered intrinsically safe. The power wires are not considered intrinsically safe and so in hazardous locations, they need to be located in conduit or conduit trays at all times. The module must be mounted in an enclosure in hazardous locations for this purpose. All field wiring should be suitable for the operating temperature range of the module. All chassis grounding should go to a single ground point designated for the machine and all related equipment.

4 NETWORK SUPPORT

The controller is designed to work on the J1939 CAN network. When connected to the network or upon power up, it automatically recognizes the network connection, claims a network address, and then starts a network communication.

The network part of the controller is compliant with Bosch CAN protocol specification, Rev.2.0, Part B, and the following J1939 standards:

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.
Data Link	J1939/21 – Data Link Layer. Rev. DEC 2006
	The controller supports Transport Protocol for Commanded Address messages (PGN 65240) and software identification -SOFT messages (PGN 65242). It also supports responses on PGN Requests (PGN 59904).
Network	J1939, Appendix B – Address and Identity Assignments. Rev. FEB 2010. J1939/81 – Network Management. Rev. 2003-05.
	The controller 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 controller 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. FEB 2010
	The controller can receive application specific PGNs with input signals and transmit application specific PGNs with up to five 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 setpoints.

4.1 J1939 Name and Address

Upon connecting to the network, before sending and receiving any application data, the controller claims its network address with the unique J1939 Name. The Name fields are presented in the table bellow:

Field Name	Field Length	Field Value	User Programmable
Arbitrary Address Capable	1 bit	1 (Capable)	No

Field Name	Field Length	Field Value	User Programmable
Industry Group	3 bit	0 (Global)	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	66 (I/O Controller)	No
Function Instance	5 bit	16 (Seventeenth Instance)	No
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 Unit Serial Number	No[1]

[1]Programmed through the RS232 service interface in production

The user can change the controller ECU instance using the Axiomatic EA to accommodate multiple controllers on the same CAN network.

The controller takes its network address from a pool of addresses assigned to self configurable ECUs. The address is preset to 152, but the controller can change it during an arbitration process or upon receiving a commanded address message. The new address value is then stored in a non-volatile memory and is used during the next address claim procedure. The user can also change the controller network address using the Axiomatic EA, if necessary.

4.2 Slew Rate Control

To adjust the controller CAN output to the parameters of the physical network, the controller has a setpoint controlling the CAN transceiver slew rate. It can be set to “Fast” or “Slow” slew rate according to the following table:

Setpoint Value	Slew Rate
Fast	19 V/µs
Slow	4 V/ µs

For the majority of J1939 CAN applications the slow slew rate is preferable due to the reduced EMI of the transceiver.

4.3 Network Bus Terminating Resistors

The controller does not have an embedded 120Ohm CAN bus terminating resistor. The appropriate resistors should be installed externally on both ends of the CAN twisted pair cable according to the J1939/11 or J1939/15 standards.

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 120Ohm resistor is required for the majority of CAN transceivers to operate properly.

4.4 Network Setpoint Group

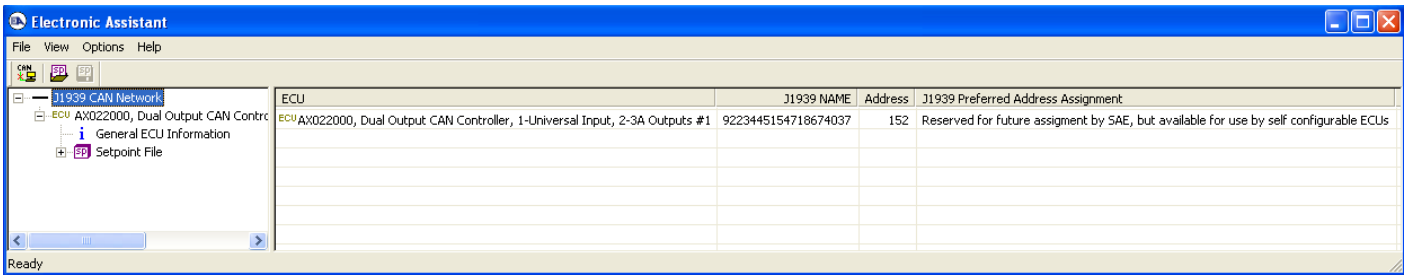
The following table summarizes the Axiomatic EA programmable setpoints controlling the controller CAN network functionality:

Name	Default Value	Range	Units	Description
ECU Instance Number	0	[0…7]	–	ECU Instance field of the J1939 ECU Name.
ECU Address	152	[0…253]		ECU Address
Slew Rate	Slow	{Slow, Fast}	–	Slew rate control of the CAN transceiver

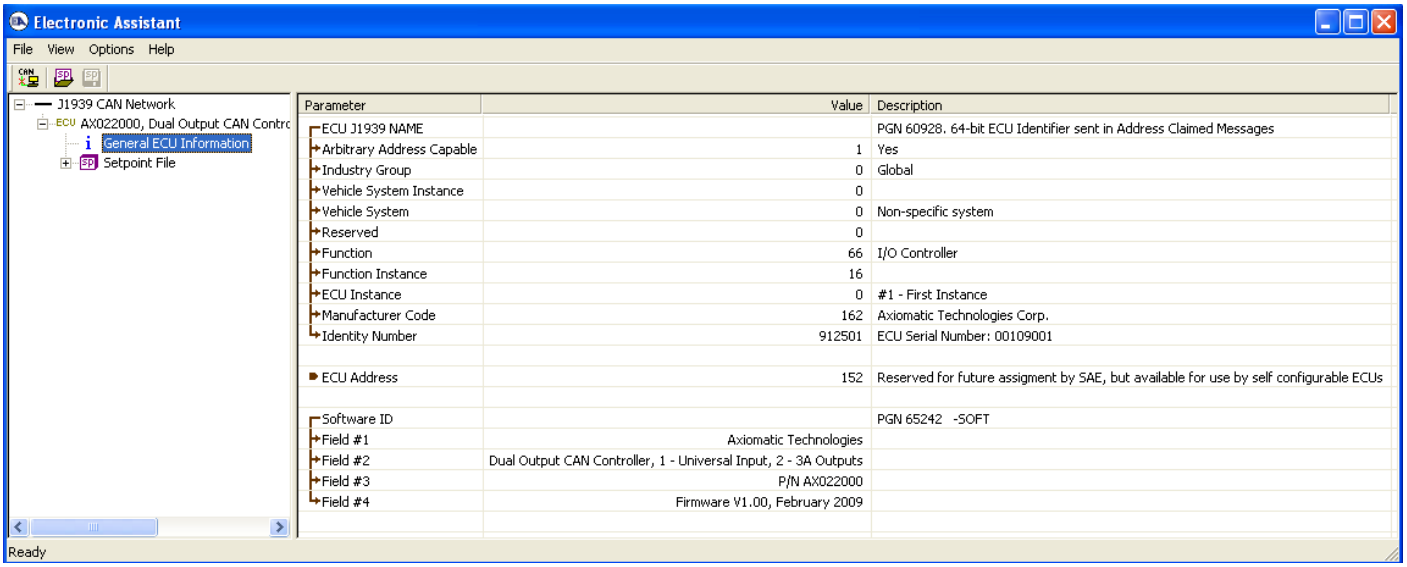
5 SETPOINT PROGRAMMING

The controller setpoints can be viewed and programmed using the standard J1939 memory access protocol through the CAN bus. Axiomatic provides PC-based Electronic Assistant (EA) software, together with USB-CAN converter, to accommodate this task.

After successful connection to the controller, the Axiomatic EA will show the following screen:



The user can then browse through the ECU parameters, read general ECU information, view and modify setpoints:



The setpoints are grouped on the base of their functionality. Please, refer to the appropriate sections of this manual describing the required functional block or a setpoint group.

Please also refer to the Axiomatic EA user manual for the description of the Axiomatic EA functionality and for the network connection troubleshooting.

5.1 Default Setpoint Settings

The controller is preprogrammed by the manufacturer with default setpoint values. These values can be found for each internal functional block in the Controller Architecture section of this manual.

In the default configuration, both PWM Output functional blocks are set to output current and are connected to the Universal Input. The Universal Input is programmed to accept voltages in the 0…5 voltage range, see the block diagram on Figure 2.

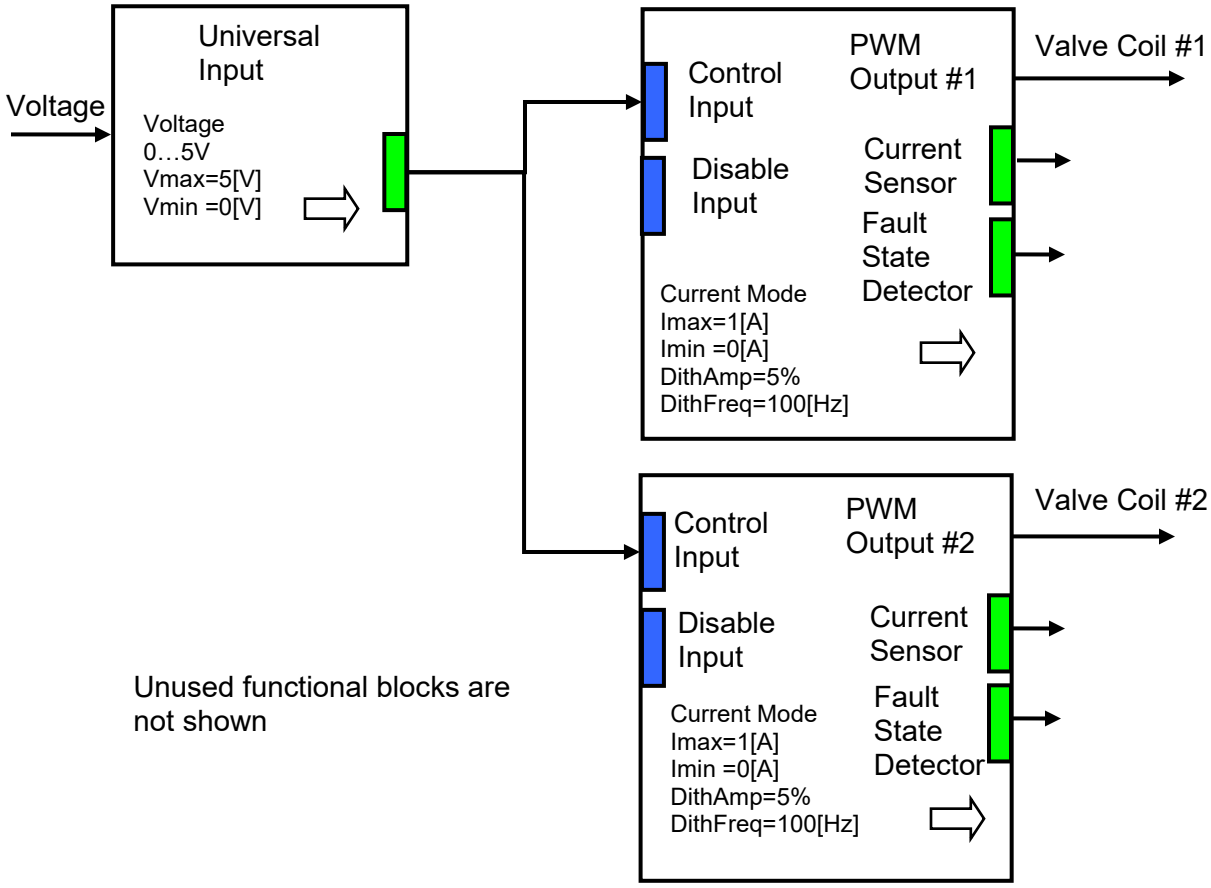


Figure 2. Default Controller Configuration

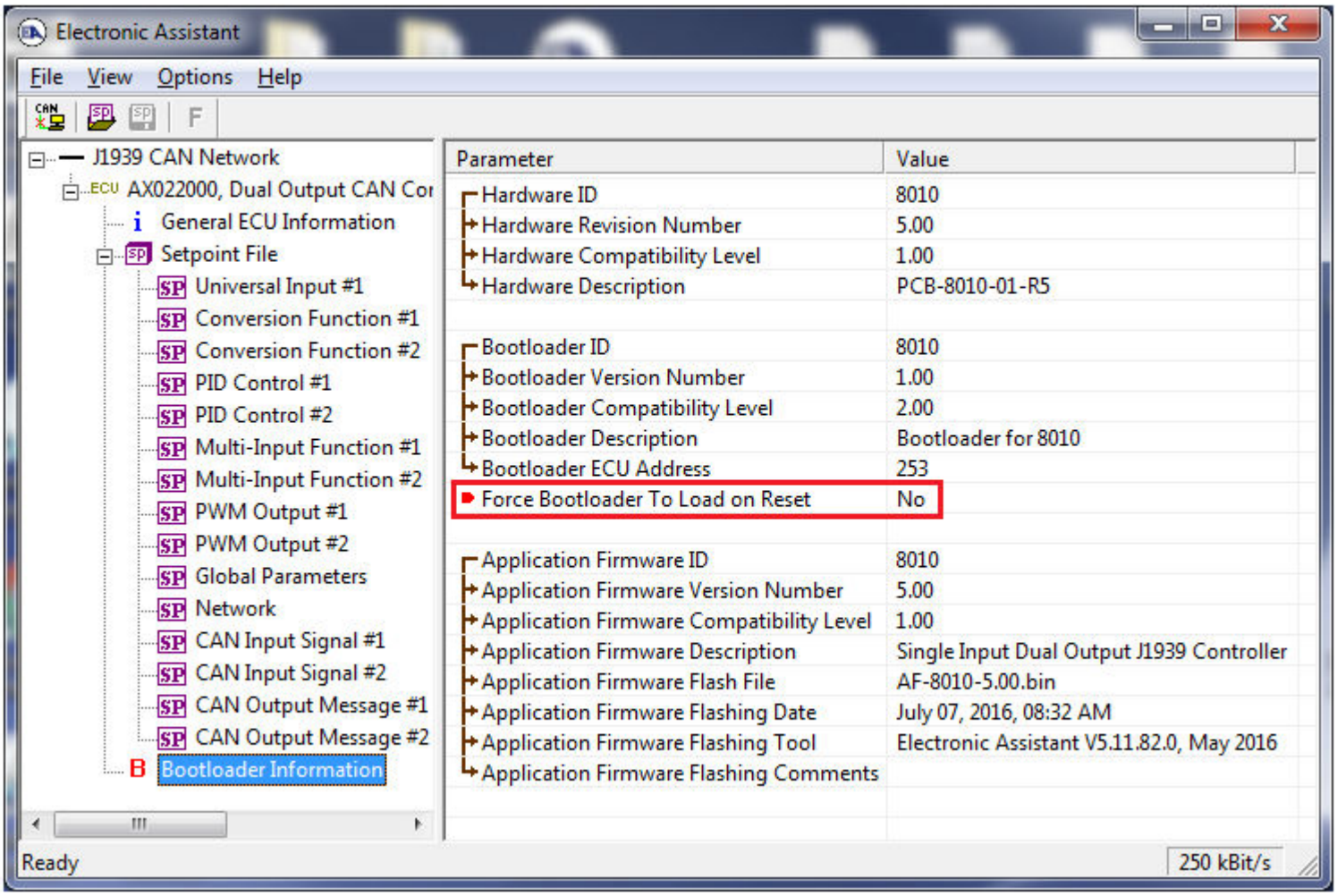
As the result, this simple configuration outputs currents from 0 to 1A, when voltage is changes from 0 to 5V.

This default controller configuration is set only as an example. The user should use the Axiomatic EA to program a user-specific controller configuration on the base of the required controller functionality.

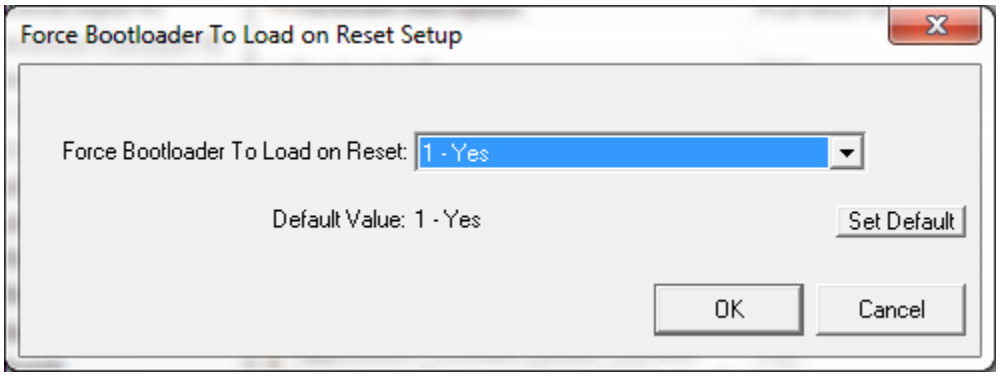
6 REFLASHING OVER CAN WITH THE AXIOMATIC EA BOOTLOADER

The AX022000 can be upgraded with new application firmware using the **Bootloader Information** section. This section details the simple step-by-step instructions to upload new firmware provided by Axiomatic onto the unit via CAN, without requiring it to be disconnected from the J1939 network.

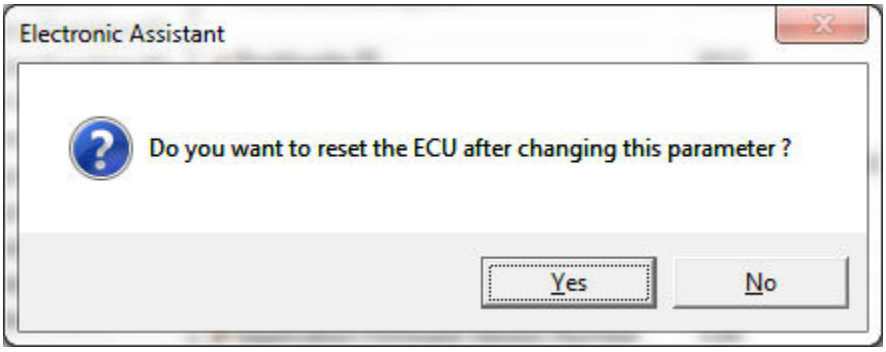
1. When the Axiomatic EA first connects to the ECU, the **Bootloader Information** section will display the following information.



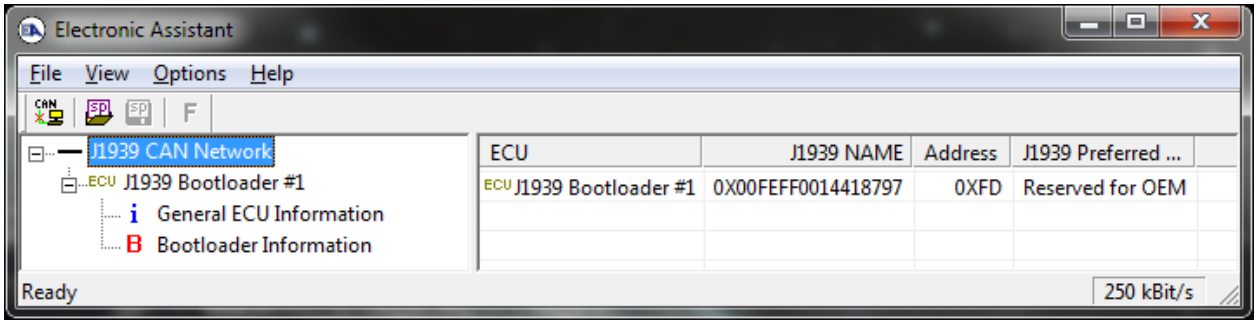
2. To use the bootloader to upgrade the firmware running on the ECU, change the variable **"Force Bootloader To Load on Reset**" to *Yes.*

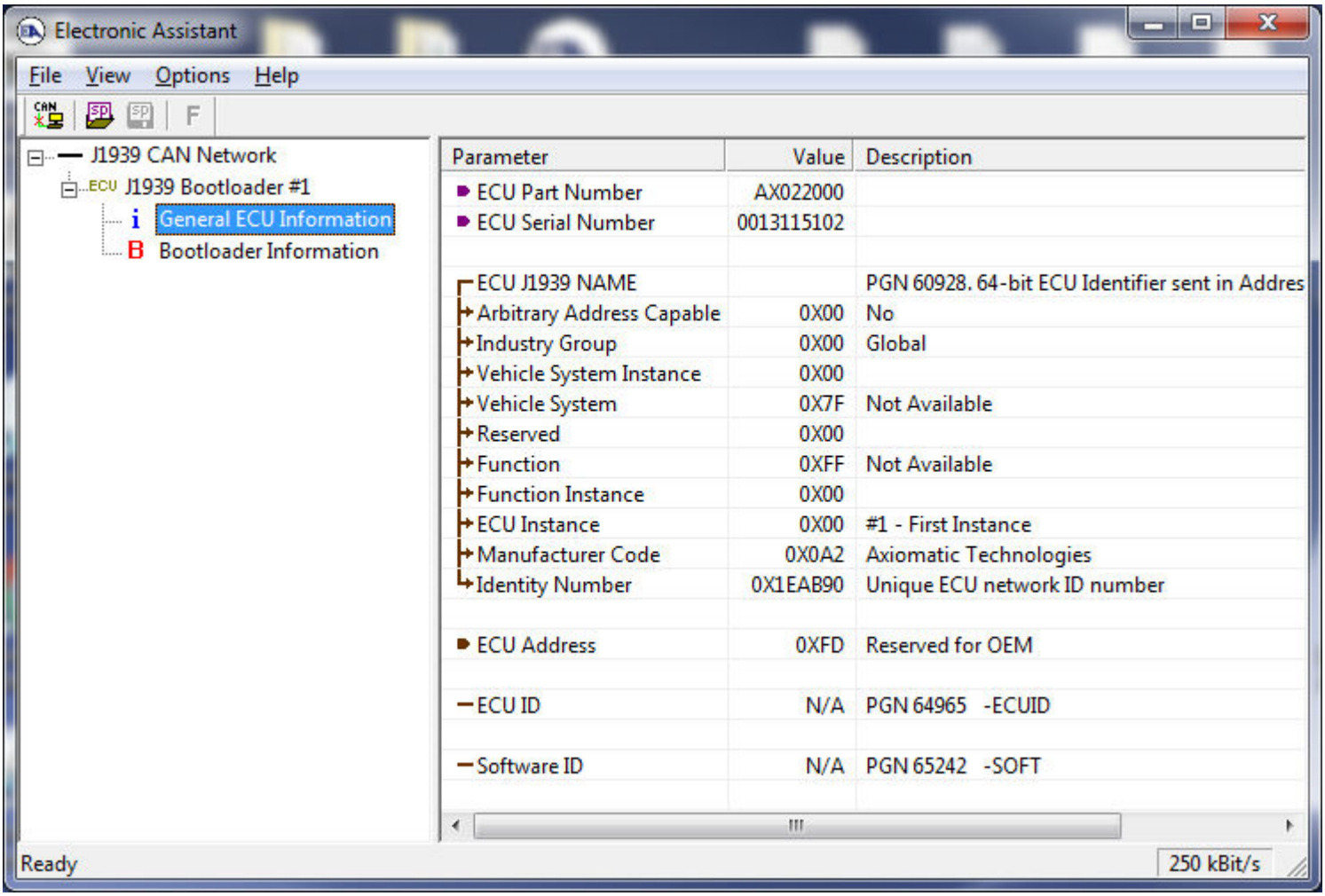


3. When the prompt box asks if you want to reset the ECU, select *Yes*.



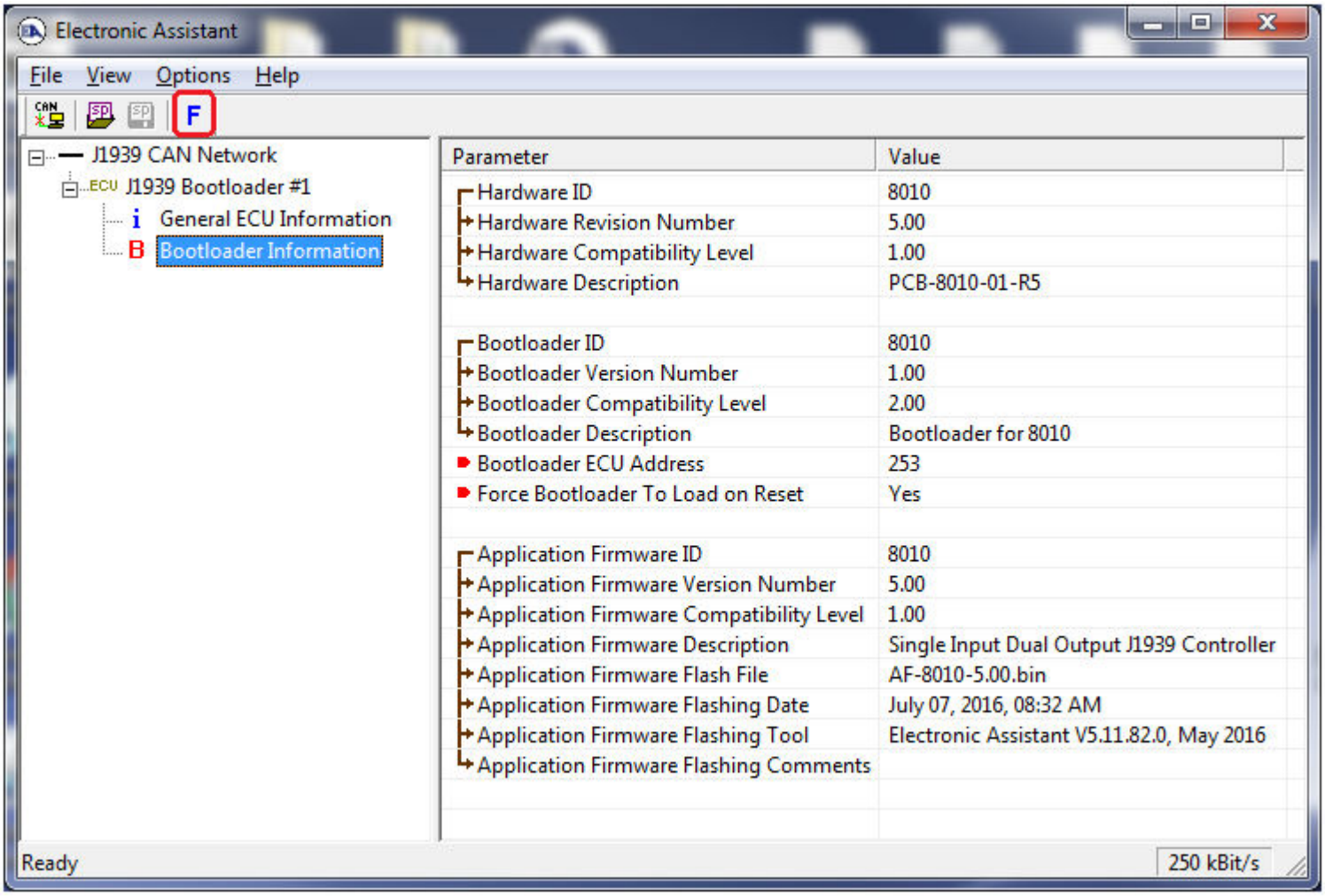
4. Upon reset, the ECU will no longer show up on the J1939 network as an AX022000 but rather as **J1939 Bootloader #1**.





Note that the bootloader is NOT Arbitrary Address Capable. This means that if you want to have multiple bootloaders running simultaneously (not recommended) you would have to manually change the address for each one before activating the next, or there will be address conflicts, and only one ECU would show up as the bootloader. Once the 'active' bootloader returns to regular functionality, the other ECU(s) would have to be power cycled to re-activate the bootloader feature.

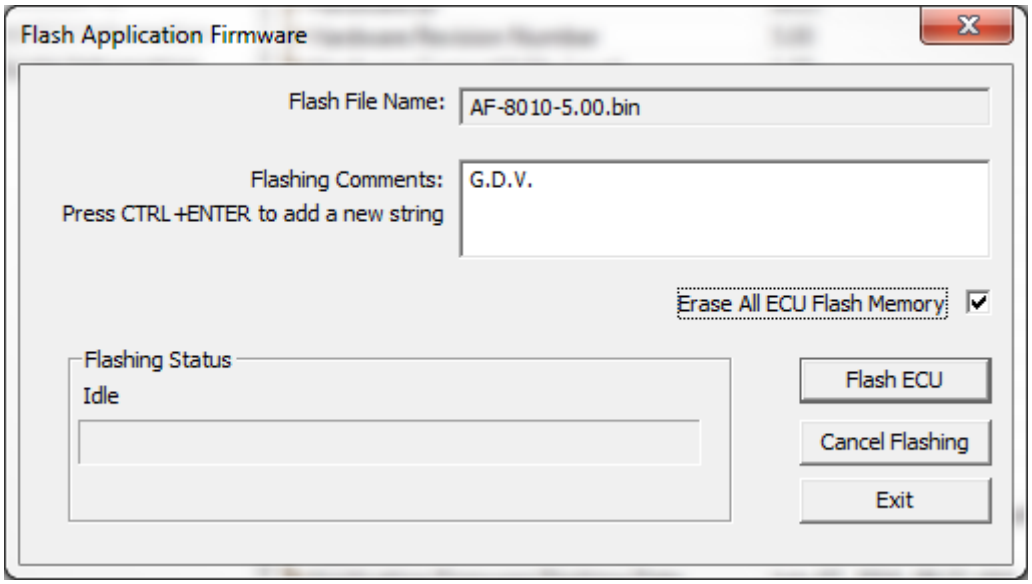
5. When the **Bootloader Information** section is selected, the same information is shown as when it was running the AX022000 firmware, but in this case the **F**lashing feature has been enabled.



6. Select the **F**lashing button and navigate to where you had saved the **AF-08010-x.yy.bin** file sent from Axiomatic. (Note: only binary (.bin) files can be flashed using the Axiomatic EA tool)

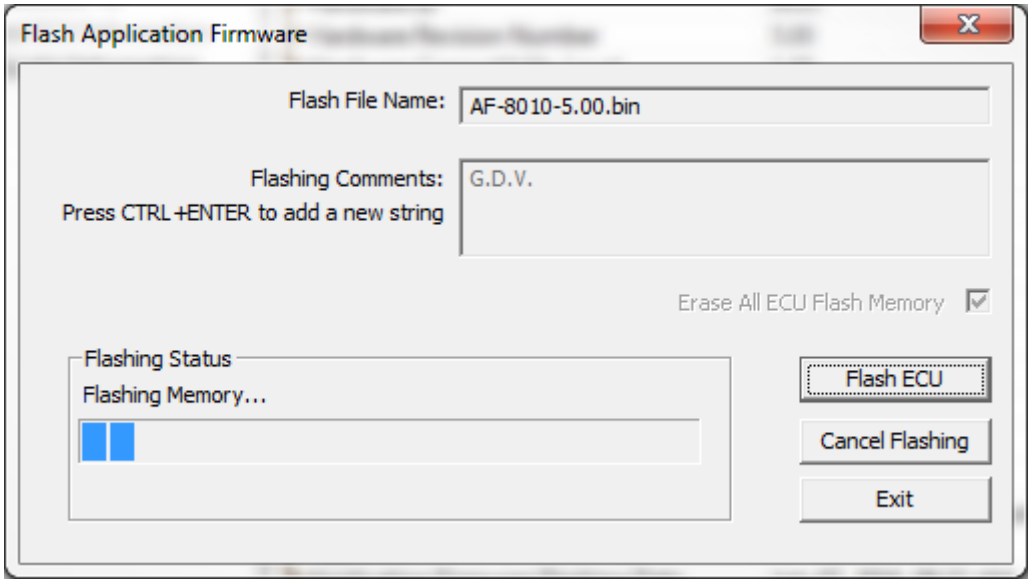
7. Once the Flash Application Firmware window opens, you can enter comments such as “Firmware upgraded by [Name]” if you so desire. This is not required, and you can leave the field blank if you do not want to use it.

   Note: You do not have to date-stamp or timestamp the file, as this is all done automatically by the Axiomatic EA tool when you upload the new firmware.

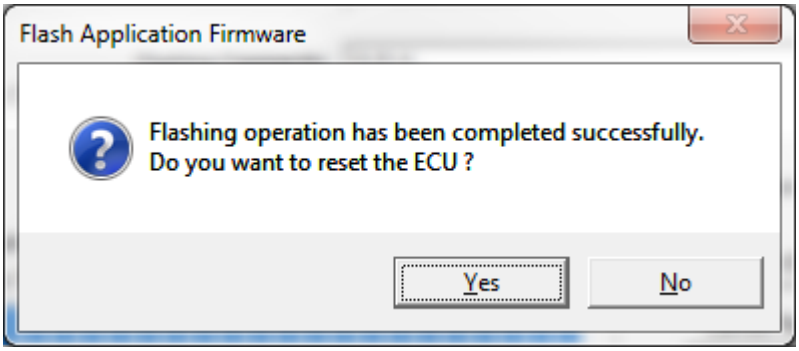


WARNING: Do not check the “Erase All ECU Flash Memory” box unless instructed to do so by your Axiomatic contact. Selecting this will erased ALL data stored in non-volatile flash. It will also erase any configuration of the setpoints that might have been done to the ECU and reset all setpoints to their factory defaults. By leaving this box unchecked, none of the setpoints will be changed when the new firmware is uploaded.

8. A progress bar will show how much of the firmware has been sent as the upload progresses. The more traffic there is on the J1939 network, the longer the upload process will take.



9. Once the firmware has finished uploading, a message will popup indicating the successful operation. If you select to reset the ECU, the new version of the AX022000 application will start running, and the ECU will be identified as such by the Axiomatic EA. Otherwise, the next time the ECU is power-cycled, the AX022000 application will run rather than the bootloader function.



Note: If at any time during the upload the process is interrupted, the data is corrupted (bad checksum) or for any other reason the new firmware is not correct, i.e. bootloader detects that the file loaded was not designed to run on the hardware platform, the bad or corrupted application will not run. Rather, when the ECU is reset or power-cycled the **J1939 Bootloader** will continue to be the default application until valid firmware has been successfully uploaded into the unit.

7 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/.

Inputs

Power Supply Input	12V, 24Vdc nominal (8…36 Vdc power supply range)
Protection	Reverse polarity protection is provided. Overvoltage protection up to 38V is provided. Overvoltage (undervoltage) shutdown of the output load is provided.
CAN	SAE J1939 Command
Universal Signal Input	Refer to Table 1.0. The input is user selectable.

Table 1.0 – **Input – User Selectable Options**

Analog Input Functions	Voltage Input, Current Input or Resistive Input
Voltage Input	0-1V (Impedance 1 MOhm) 0-2.5V (Impedance 1 MOhm) 0-5V (Impedance 200 KOhm) 0-10V (Impedance 133 KOhm for 0-5V, 133 to 20 KOhm for 5-10V))
Current Input	0-20 mA (Impedance 124 Ohm) 4-20 mA (Impedance 124 Ohm)
Resistive Input	25Ω to 250 kΩ
Digital Input Functions	Discrete Input, PWM Input, Frequency Input
Digital Input Level	5V CMOS
PWM Input	0 to 100% 10 Hz to 1kHz 100 Hz to 10 kHz
Frequency Input	10 Hz to 1kHz 100 Hz to 10 kHz
Digital Input	Active High, Active Low
Input Impedance	1 MOhm high impedance, 10KOhm pull down, 10KOhm pull up to +5V
Input Accuracy	≤ 1%
Input Resolution	12-bit

Outputs

CAN	SAE J1939 Messages
Output	2 Proportional or On/Off Outputs (Up to 3A) High Side Switch, Current Sensing, Grounded Load The user can select the following options for output using the Axiomatic EA. • Output Disable • Discrete Output • Output Current (PID loop*, with current sensing) • Output Voltage • Output PWM Duty Cycle *Parameters are password protected.
Output Accuracy	Output Current mode ≤2% Output Voltage mode ≤3% Output PWM Duty Cycle mode ≤ 3%
Voltage Reference	+5V, 10 mA, 0.5% Short circuit protected (current limited to 22-24 mA) Protected from connection to the power supply rail.
Protection for Output + Terminal	Fully protected against short circuit to ground and short circuit to power supply rail. Unit will fail safe in the case of a short circuit condition, self-recovering when the short is removed.

General Specifications

Microprocessor	32-bit, 128 KByte flash program memory
Control Logic	User programmable functionality using the Axiomatic Electronic Assistant (Application-specific control logic or factory programmed setpoints are available on request.)
Communications	1 CAN port (SAE J1939)
User Interface	User configuration and diagnostics are provided with the Axiomatic Electronic Assistant KIT, P/Ns: AX070502 or AX070506K. The Axiomatic Service Tool is a *Windows*-based graphical user interface that allows easy configuration of the controller's setpoints.
Operating Conditions	-40 to 85 °C (-40 to 185 °F)
Packaging	Aluminum enclosure, integral connector (TE Deutsch equivalent) Encapsulated Refer to the dimensional drawing found in Installation Instructions.
EMC Compliance	CE marking
Protection	IP67 rating for the product assembly NOTE: TE Deutsch connectors are rated for submersion (3 ft., 0.9 m).
Weight	0.70 lb. (0.32 kg)

OUR PRODUCTS

AC/DC Power Supplies

Actuator Controls/Interfaces

Automotive Ethernet Interfaces

Battery Chargers

CAN Controls, Routers, Repeaters

CAN/WiFi, CAN/Bluetooth, Routers

Current/Voltage/PWM Converters

DC/DC Power Converters

Engine Temperature Scanners

Ethernet/CAN Converters, Gateways, Switches

Fan Drive Controllers

Gateways, CAN/Modbus, RS-232

Gyroscopes, Inclinometers

Hydraulic Valve Controllers

Inclinometers, Triaxial

I/O Controls

LVDT Signal Converters

Machine Controls

Modbus, RS-422, RS-485 Controls

Motor Controls, Inverters

Power Supplies, DC/DC, AC/DC

PWM Signal Converters/Isolators

Resolver Signal Conditioners

Service Tools

Signal Conditioners, Converters

Strain Gauge CAN Controls

Surge Suppressors

OUR COMPANY

Axiomatic provides electronic machine control components to the off-highway, commercial vehicle, electric vehicle, power generator set, material handling, renewable energy and industrial OEM markets. ***We innovate with engineered and off-the-shelf machine controls that add value for our customers.***

QUALITY DESIGN AND MANUFACTURING

We have an ISO9001:2015 registered design/manufacturing facility in Canada.

WARRANTY, APPLICATION APPROVALS/LIMITATIONS

Axiomatic Technologies Corporation reserves the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. 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 at https://www.axiomatic.com/service/.

COMPLIANCE

Product compliance details can be found in the product literature and/or on axiomatic.com. Any inquiries should be sent to sales@axiomatic.com.

SAFE USE

All products should be serviced by Axiomatic. Do not open the product and perform the service yourself.

This product can expose you to chemicals which are known in the State of California, USA to cause cancer and reproductive harm. For more information go to www.P65Warnings.ca.gov.

SERVICE

All products to be returned to Axiomatic require a Return Materials Authorization Number (RMA#) from sales@axiomatic.com. Please provide the following information when requesting an RMA number:

- Serial number, part number
- Runtime hours, description of problem
- Wiring set up diagram, application and other comments as needed

DISPOSAL

Axiomatic products are electronic waste. Please follow your local environmental waste and recycling laws, regulations and policies for safe disposal or recycling of electronic waste.

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