ECM ENGINE CONTROL AND MONITORING

AFX3

Programmer's Manual

REV 1.00 1/27/23

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1.00	1/27/2023	Original Release	

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Contents

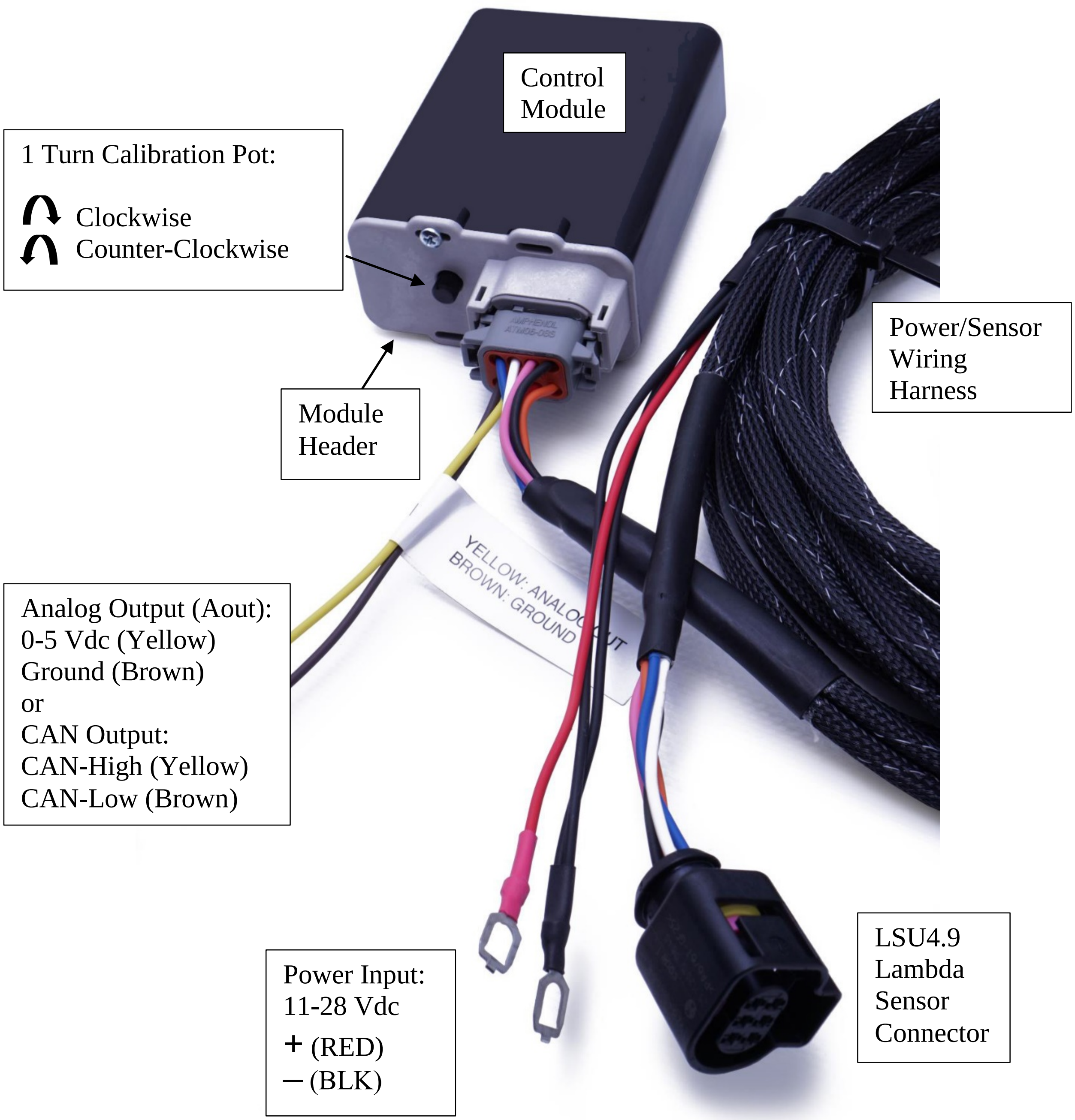
General Notes

1. All numbers are decimal unless preceded by the “0x” suffix which denotes a hexadecimal value: e.g. 0xFF = 255.
2. 1 byte contains 8 bits.
3. One “unsigned character” contains 1 byte (unsigned 8) and has a range of 0x00 – 0xFF (0 – 255).
4. One “string” contains 1 byte (unsigned 8) and has a range of 0x00 – 0xFF (0-255). The number represents an ASCII character.
5. One “unsigned integer” contains 2 bytes (unsigned 16) and has a range of 0x0000 – 0xFFFF (0 – 65535).
6. One “unsigned long” contains 4 bytes (unsigned 32) and has a range of 0x00000000 – 0xFFFFFFFF (0 – 4294967295).
7. One “single float” contains 4 bytes (single float) that represent a decimal number using the IEEE-754 standard.
8. A “lo” byte and “high” byte can be combined as follows to form a 2-byte unsigned integer: e.g. lo byte = 0x10 (16), hi byte = 0x1F (31), 2-byte integer = 0x1F10 = 31*256+16 = 7952
9. “lo” byte can also be referred to as the least significant byte (LSB).
10. “sec” suffix denotes seconds.
11. “m” suffix denotes meters.
12. “us” suffix denotes microseconds.
13. “ms” suffix denotes milliseconds.
14. “mA” suffix denotes milliamperes.
15. “kbit/s” suffix denotes kilobits per second.
16. If a subindex value for an Object Dictionary (OD) is unspecified, it is assumed to be 0x00.
17. Data value boxes that are shown as blank are reserved; do not use these locations.
18. All messages on the CAN bus must have a unique identifier which is referred to as “CANid” in this manual but can also be referred to as “COB ID” (communication object identifier.)
19. All messages with multiple data bytes are transmitted on the CAN bus least significant byte first, i.e. “Intel format.

1.0 Introduction

1.1 Kit Contents

The AFX3 kit is a ceramic sensor-based Lambda, AFR, and O_2, measurement system with a 0-5 Vdc linear Analog Output (Aout) or Controller Area Network (CAN) communication via the CANopen protocol.



2.0 Specifications

Measurable Lambda Range	See Section 3.4
Lambda Measurement Accuracy	Within 0.01 Lambda
Supply Voltage	11 to 28 Vdc
Input Power Requirement	12 W Steady State Up to 40 W During 25 Start-Up
Sensor Tightening Torque	15-20 N·m (11-15 lb·ft)
Maximum Exhaust Gas Temperature	850℃
Operating Temperature Range	-40 to 85℃
Analog Output Range and resolution	0 to 5 Vdc @ 10 bits (4.9 mV/bit)
Analog Output Accuracy	Within 10 mV
Analog Output Impedance when sinking current	0 Ω @ -5 mA MAX
Analog Output Impedance when sourcing current	392 Ω
CAN Output	High Speed with 11-bit identifier
CAN Baud Rates	1 Mbit/s 500 kbit/s (default) 250 kbit/s 125 kbit/s
Selectable CAN termination resistor	120 Ω (1%)
CAN Message Broadcast rate	5 ms to 65535 ms (20 ms default)
Overall Module Dimensions (L x W x H)	4.125" x 2.75" x 1.5"
Module Weight	5 oz

3.0 Connecting the AFX3 module

Power and CAN/Analog Output connections to the module are made using the Power/Sensor wiring harness. The power input requirement is 11 to 28 Vdc at 12 W (steady-state). During the 25 second start-up, there can be a peak power draw of up to 40 W. Do not extend the wires between the sensor and the control module. Use only ECM sensor cables to connect the sensor to the module. You can lengthen the power wires on the cable but use large gauge wire and make sure that the voltage at the module end of the wiring harness (between pins 2 and 8 of the Module Header) is at least 11 V when the sensor is operating.

The AFX3 can be configured to output either a 0-5 Vdc linear analog signal or CAN messages with an 11-bit identifier at the default CAN baud rate of 500 kbit/s. The CAN baud rate can be modified by the user (see Section 8.9). The maximum distance between any two nodes on a CAN bus operating at 500 kbit/s is 100 m. Each end of the CAN bus must have a terminating resistor of 120 Ω. There is a jumper selectable termination resistor on the PCB. Section 3.4 for information on configuring the AFX3 output.

3.1 Analog Output

1. The output resolution of the 0-5 Vdc Analog Output is 10 bit (4.9 mV/bit), updated every 5 ms. The accuracy is +/- 2 bits.
2. The 0-5 Vdc linear Analog Output is NOT floating. The Analog Output ground is connected directly to the –ve terminal of the power input. Furthermore, there is a dedicated ground return wire for the sensor heater in the power cable. **DO NOT COMBINE THESE GROUNDS TOGETHER WHEN EXTENDING THE POWER CABLE.** They must be run separately back to the power supply ground. See the Ground Wiring Diagram in Appendix E.
3. Although the Analog Output can source up to 5 mA without affecting the accuracy of the signal (Aout), it should be connected to a high impedance input of at least 1 MΩ. When the output is sinking current its impedance is 392 Ω. Do not apply a voltage to either the Analog Output signal or ground, this may damage the unit.

3.2 CAN Output

1. Configuration software (ECM Configuration Tool) for the module can be downloaded from the ECM website: http://www.ecm-co.com/product.asp?lcan This software allows the setup, configuration, monitoring, and recording of data via CAN communication using supported CAN adapters (e.g. KVASER Leaf Light HS v2.)
2. The CAN output wires can be lengthened using appropriate twisted pair. Maximum CAN bus length depends on baud rate, line capacitance and the number of nodes. See Section 8.9 for bus length limits.
3. The module broadcasts several messages on the CAN bus using the CANopen protocol. Each message has an 11-bit number known as the CAN identifier (CANid). Since multiple modules can be placed on the same CAN bus, each module on the bus also has an identifying number known as the node identifier (NID). The default NID for the AFX3 is 0x10. The allowable range for the NID is 0x01 to 0x7F. The NID can be modified by the user, see Section 8.3.

4. When connecting other devices on the same CAN bus, ensure that the following CANids are not used. Note that this list applies to EACH AFX3 on the CAN bus:

Message type	CANid (hex)
NMT	0x00
Emergency	0x80 + NID
TPDO1	0x180 + NID
TPDO2	0x280 + NID
TPDO3	0x380 + NID
TPDO4	0x480 + NID
SDO Tx	0x580 + NID
SDO Rx	0x600 + NID
Heartbeat	0x700 + NID
LSS	0x7E4, 0x7E5

3.3 User Configurable Software Features

All user configurable features (TPDO configuration, broadcast rate, averaging alphas etc.) are stored in non-volatile memory (EEPROM) in the module. These values are retained in memory even if power is no longer applied to the module. Writing to an EEPROM location in the microcontroller involves a multi-step (copy-erase-write) procedure that is performed 4 bytes (32 bits) at a time:

1. Compare the new/desired value with the value currently in the memory location.
2. If they are the same, abort the writing process.
3. Otherwise, set the memory location to 0 (“erase”).
4. Then write the new value to the memory location (“write”).

If power to the module is turned OFF during this 4 step process, the EEPROM location may be corrupted. It is very important to wait for any EEPROM write to complete before turning off power to the module. Writing/updating an EEPROM memory location requires more time compared to writing to a RAM location; about 20 ms for a 4-byte EEPROM location versus 2 us for a 4-byte RAM memory location.

Note that a write takes place ONLY if that EEPROM memory location needs to be changed to a DIFFERENT non-zero value. The number of EEPROM write cycles (resulting in a CHANGE in value) is limited to about 300,000 at 25°C. Therefore, any user configurable features should be updated/changed only when necessary. Exceeding the 300,000 write cycle limit will result in that specific location becoming unusable and the value indeterminate. Reading EEPROM locations are NOT affected by the 300,000 cycle limit, only writes to EEPROM locations are. Therefore, the following is recommended to ensure the integrity of the EEPROM data:

When modifying any user configurable features using an OS Command (see Appendix B), perform a SDO Read of the OS status and OS reply to ensure that the command executed correctly. When writing to any location in the ECM CANopen Object Dictionary, read back the value written to determine if the write was successful.

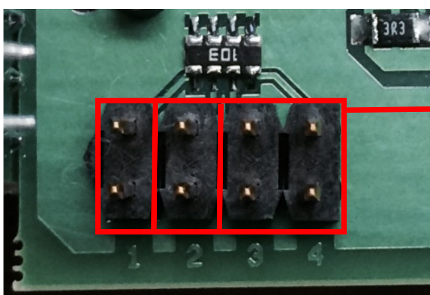
3.4 User Configurable Hardware Features

During start-up the LED display indicates the configuration immediately after the display blank (8.8.8.8.) Below is the default configuration (no jumpers):

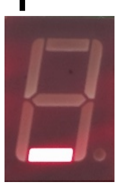
1. Sensor Type: LSU4.2 or Non-cofired NTK
2. Analog Output 0-5 V Range: 9.0-16.0 AFR
3. LED Display units: Gasoline AFR

Sensor Type, LED Display Units and Analog Output Range can be configured as follows:

1. Disconnect AFX3 from power source.
2. Remove the 2 screws located by the connector, slide the board out from enclosure.
3. Locate 8 position header (JP2) as shown below.
4. Insert the appropriate jumper(s), slide board into enclosure and install screws.



3	4	DISPLAY
OPEN	OPEN	GASOLINE AFR
JUMPER	OPEN	METHANOL AFR
OPEN	JUMPER	LAMBDA
JUMPER	JUMPER	METHANE O2(%)



OPEN = STD 0-5 V Aout Range
9.0-16.0 Gasoline AFR
0.610-1.098 Lambda
4.00-7.10 Methanol (CH3OH) AFR
0.00-15.0 Methane (CH4) O_2 (%)

JUMPER = WIDE 0-5 V Aout Range
6.0-20.0 Gasoline AFR
0.411-1.373 Lambda
2.66-8.88 Methanol (CH3OH) AFR
-5.00-25.0 Methane (CH4) O_2 (%)

OPEN = LSU4.2/Non-cofired NTK

JUMPER = LSU4.9

The CAN and Analog Output can be configured as follows:

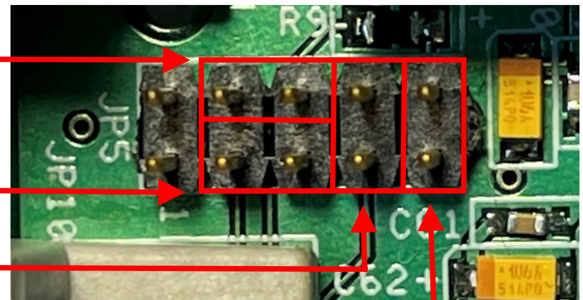
1. Disconnect AFX3 from power source.
2. Remove the 2 screws located by the connector, slide the board out from enclosure.
3. Locate the 10 position header (JP5) as shown below.
4. Insert the appropriate jumper(s), slide board into enclosure and install screws.

To connect the CAN signals to the Module Header (JP10) and enable the CAN Output insert jumpers as shown below:

CAN-High to Pin 3/JP10
(Yellow harness wire)

CAN-Low to Pin 4/JP10
(Brown harness wire)

CAN enable

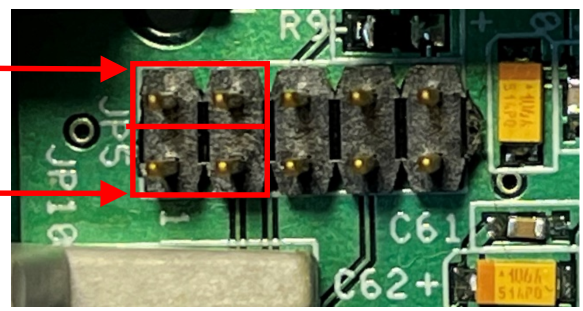


(Optional) 120 Ω CAN bus termination resistor

To connect the Analog Output signals to the Module Header (JP10) insert jumpers as shown below:

0-5 Vdc Analog Output to Pin 3/JP10
(Yellow harness wire)

Ground to Pin 4/JP10
(Brown harness wire)



3.5 Sensor Calibration

To calibrate the Lambda sensor, connect the sensor to the module, hang the sensor in ambient air with the sensor tip pointing down, apply power and wait at least 20 minutes. Turn the 1 Turn Calibration Pot as shown below until the LED Display reads CAL–. The rotation direction shown below is as seen from the Module Header side (see Section 1.1). (e.g. If the LED Display reads AIR_ turn the 1 Turn Calibration Pot clockwise).

4.0 Getting Information from the AFX3 Module

Once power is applied to the AFX3 module with the correct cable and sensor attached, the module will perform the following 25 second start-up sequence:

On the 4 digit LED display:

1. Display check (8.8.8.8.) for 2 seconds.
2. Sensor, Analog Output and LED display configuration for 2 seconds (see Section 3.4)
3. Firmware revision for 2 seconds.
4. Sensor warm-up countdown for 19 seconds.

On the Analog Output:

1. 1.000 V for 10 seconds
2. 4.000 V for 10 seconds
3. 0.000 V for 5 seconds.

CAN output:

1. CAN messages with an 11-bit identifier begin transmitting periodically at the broadcast rate within 1 second after power is applied.
2. Default broadcast rate is every 20 ms. (User configurable, see Section 8.1)
3. Default NID is 0x10. (User configurable, see Section 8.3)
4. Default baud rate is 500 kbit/s. (User configurable, see Section 8.9)
5. The organization and configuration of the CAN messages follows the CANopen protocol.

Once the start-up sequence is finished the data provided by the AFX3 module is ready to be used.

If there is an error, the 4 digit LED display will show "SEn" or "bAt" followed by a symbol (see photo below.) The Error Codes are listed in Appendix A. When an Error Code is present, the Analog Output is set to 0 V and the CAN TPDOs for Lambda, AFR and O_2 are set to 0.

4.1 CANopen Message Types

i) HEARTBEAT (Broadcast rate = 0.5 sec, DLC=1)

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x700+NID	value							

value = NMT STATE (see Appendix C)

ii) ERROR (Broadcast rate = 0.250 sec, DLC=8)

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x80+NID	0x00	0xFF	0x00	Error Code lo	0x00	Aux	0x00	0x00

Error Code lo byte = Error Code (0x01 = Sensor Warm-up, 0x00 = Data valid, see Appendix A)
Aux = Sensor Warm-up countdown in seconds (active during ECM Error Code 0x01)

iii) TRANSMIT PROCESS DATA OBJECT [TPDO] (Broadcast rate = 0.020 sec, DLC=8)

TPDO1 CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x180+NID	Lambda				O_2 (%)			
TPDO2 CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x280+NID	AFR				VOUT (Volts)			
TPDO3 CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x380+NID	VIN (Volts)				IP1 (mA)			
TPDO4 CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x480+NID	RPVS (Ω)				VHCM (Volts)			

The table above shows the default TPDO assignments. Note that all 4 TPDOs can be turned on or off and that the assignments can be changed by the user. See Section 8.5 Enabling TPDOs, Section 8.6 Disabling TPDOs and Section 8.7 TPDO MAPPING.

Furthermore, the NID and TPDO Broadcast rate can be changed by the user. See Section 8.3 Changing the NID and Section 8.4 Changing the TPDO Broadcast Rate for more information.

Each module can transmit up to four TRANSMIT PROCESS DATA OBJECTS (TPDOs) at the programmed TPDO broadcast rate. The default broadcast rate is 20 ms. A TPDO contains two data values; each corresponds to a measured parameter (e.g. Lambda, AFR, O_2, FAR, PHI, etc). Each data value is formatted as a single precision 32-bit floating point number that conforms to the IEEE-754 standard. All TPDO data is transmitted on the CAN bus least significant byte first (Intel format).

Example: The following data was transmitted by the module with NID = 0x10 on TPDO1 and contains 2 PDOs, Lambda and O_2.

TPDO1 CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x190	0x63	0xC6	0x99	0x3F	0xF2	0xFD	0x54	0x40

Lambda = 0x3F99C663 = 1.20137
O_2 = 0x4054FDF2 = 3.32800

Configuring which data values are transmitted in a particular TPDO is also known as TPDO MAPPING and can be set by the user (see Section 8.7).

4.2 Analog Output Calculation

The 0-5 Vdc linear Analog Output voltage (Aout) can be converted to the desired units by using the following formula. See Section 3.4 for the 0 V and 5 V Range values.

Output Value = (Aout/5.0) * (5 V Range – 0 V Range) + 0 V Range

Example: Calculate the output value in Lambda units for an AFX3 module configured for WIDE 0-5V Range and has a Aout voltage of 3.061V.

From Section 3.4 determine the Aout range and units:
WIDE 0 V Range = 0.411 Lambda
WIDE 5 V Range = 1.373 Lambda

Output Value in Lambda = (3.061/5.000) * (1.373-0.411) + 0.411 = 1.000

5.0 Writing to the AFX3 Module (SDO Write)

Configuration of the AFX3 module is performed by writing to the Object Dictionary (OD) and by issuing ECM CANopen OS Commands (OS Command). Both of these actions are implemented using a Service Data Object Expedited Write (SDO Write). The format is as follows:

SDO Write Tx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	Size	OD lo	OD hi	Sub	Data0	Data1	Data2	Data3

Size = 0x2F (1-byte write)
0x2B (2-byte write)
0x23 (4-byte write)

OD lo = low byte of OD address
OD hi = hi byte of OD address
Sub = Subindex of OD address
Data0 always contains the Least Significant Byte (LSB) of the data to be written to the OD.

A SDO Write will generate the following reply:

SDO Write Rx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x580+NID	0x60	OD lo	OD hi	Sub				

Example: Write a 2-byte integer = 0x204 to OD address 0x5017 subindex 0 in the module with NID = 0x10

SDO Write Tx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x610	0x2B	0x17	0x50	0x00	0x04	0x02		

The module will reply as follows:

SDO Write Rx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x590	0x60	0x17	0x50	0x00				

6.0 Reading from the AFX3 Module (SDO Read)

During configuration it may be necessary to read certain locations in the Object Dictionary (OD). The format for a Service Data Object Read (SDO Read) is as follows:

SDO Read Tx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x40	OD lo	OD hi	Sub				

OD lo = low byte of OD address
OD hi = hi byte of OD address
Sub = Subindex of OD address

A SDO Read will generate the following reply:

SDO Read Rx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x580+NID	Size	OD lo	OD hi	Sub	Data0	Data1	Data2	Data3

Size = 0x4F (1-byte response)
0x4B (2-byte response)
0x43 (4-byte response)

OD lo = low byte of OD address
OD hi = hi byte of OD address
Sub = Subindex of OD address
Data0 always contains the Least Significant Byte (LSB) of the data present at the OD address.

Example: Read OD address 0x5008 subindex 0x32 in the module with NID = 0x10

SDO Write Tx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x610	0x40	0x08	0x50	0x32				

The module will reply as follows:

SDO Write Rx CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x590	0x4B	0x08	0x50	0x32	0xBC	0x02		

OD address 0x5008, subindex 0x32 of the module with NID = 0x10 contains the 2-byte value 0x2BC

7.0 Identifying the AFX3 Module

Each AFX3 module can be uniquely identified by reading the following four parameters in the OD:

i) Vendor ID (0x000001C6) located at OD address 0x1018, subindex 0x01 (4-byte integer/unsigned 32)
ii) Product Code (AFX3 = 0x00000015) located at OD address 0x1018 subindex 0x02 (4-byte integer/unsigned 32)
iii) Revision Number located at OD address 0x1018, subindex 0x03 (4-byte integer/unsigned 32)
iv) Serial Number located at OD address 0x1018, subindex 0x04 (4-byte integer/unsigned 32)

Furthermore, the hardware and software revision number can be found at the following locations:

i) Hardware Revision is located at OD address 0x1009, subindex 0x00 (4-byte string)
ii) Software Revision is located at OD address 0x100A, subindex 0x00 (4-byte string)

8.0 User Configuration of the AFX3 Module

There are several features in the AFX3 that can be configured by the user. These settings are non-volatile and are stored in EEPROM unless noted otherwise (see Section 3.3).

8.1 Modifying the Pre-Broadcast Averaging of Data

The Lambda sensor output data (Ip1) is averaged before it is used in any Lambda/AFR/O_2 calculation. Each data point is averaged by the module every 5 ms independent of the TPDO broadcast rate (see Section 8.4). The averaging filter (α) can range from 0.001 (heavy averaging) to 1.000 (no averaging). The averaging filter, also called an Infinite Impulse Response filter (IIR) or digital low-pass filter, is used as follows:

$$AvgData_n = \alpha \times Data_n + (1 - \alpha) \times AvgData_{n-1}$$

Where:
$AvgData_n$ = Current averaged data value calculated by the module.
α = User-programmable averaging filter, also called “alpha”. (Range 0.001 to 1.000)
$Data_n$ = Current data value measured by the module.
$AvgData_{n-1}$ = Previous averaged data value calculated by the module 5 ms ago.

The default α value is 1.000 and is stored in non-volatile memory (EEPROM) in the module. Note that O_2, Lambda, PHI, AFR and FAR are calculated from the Ip1 measurement and therefore are affected by the Ip1 averaging value.

The α value is sent to the module as a scaled (x1000) unsigned 16-bit integer sent least significant byte (LSB) first (Intel format). This value is written to OD address 0x5012 by performing an SDO Write. Averaging values beyond the range specified are limited to the appropriate maximum or minimum.

CANid	byte 0	byte 1	Byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2B	0x12	0x50	0x08	α x 1000 lo byte	α x 1000 hi byte		

α x 1000 = 1-1000 (0x0001 – 0x03E8)

Example: Set the α for Ip1 to 0.256 for the module with NID = 0x05. Multiply 0.256 x 1000 = 256 (0x0100).

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x605	0x2B	0x12	0x50	0x08	0x00	0x01		

8.2 Returning the Pre-Broadcast Averaging to Factory Default

The Ip1 averaging filter (α) can be reset to the factory default value (1.000) by issuing the ECM OS Command 0x15 (see Appendix B).

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	0x23	0x10	0x01	0x15			

8.3 Changing the NID

The Node ID (NID) can be programmed from 0x01 to 0x7F (1 to 127). To change the NID, several messages must be sent to the AFX3 module. This must be followed by a reset of the module.

First place the module(s) into LSS (Layer Select Services) configuration mode. If there is only one CANopen module on the CAN bus this process requires only one message. If there are several CANopen modules on the same CAN bus the specific module must be identified using Product Code, Revision Number and Serial Number, (see Section 7.0). Note that the data is sent LSB first. For example, if the serial number is 0x12345678, then byte1 = 0x78, byte2 = 0x56, byte3 = 0x34, byte 4 = 0x12.

MULTIPLE MODULES ON BUS

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4
0x7E5	0x04	0x00			
0x7E5	0x40	0xC6	0x01	0x00	0x00
0x7E5	0x41	Product Code			
0x7E5	0x42	Revision Number			
0x7E5	0x43	Serial Number			

SINGLE MODULE ON BUS

CAN id	byte 0	byte 1
0x7E5	0x04	0x01

If successful, the module will respond with the following message.

CAN id	byte 0
0x7E4	0x44

The next message sent contains the new NID as an unsigned hexadecimal character.

CAN id	byte 0	byte 1
0x7E5	0x11	new NID

The module will reply with byte 0 = 0x11 and byte 1 = 0x00 on CAN id 0x7E4 indicating a successful NID change.

The last message sent takes the module out of configuration mode.

CAN id	byte 0	byte 1
0x7E5	0x04	0x00

After the NID has been successfully changed, the module enters pre-operational mode and does not broadcast data. The module can be returned to broadcast mode 1 of 3 ways:

i) Power-cycle the module by disconnecting and reconnecting the power.
ii) A second method is to send a command instructing the module to perform a hard reset (similar to power-cycling the module but software controlled).

CAN id	byte 0	byte 1
0x00	0x81	NID

iii) A third method is to send a command instructing the module to reset the CAN interface only.

CAN id	byte 0	byte 1
0x00	0x82	NID

Example: Change the NID for the following module with **multiple modules** on the CAN bus.

CURRENT NID = 0x10 (16)
PRODUCT CODE = 0x02 (2)
REVISION NUMBER = 0x03 (3)
SERIAL NUMBER = 0x192 (402)
NEW NID = 0x1A (26)

MESSAGE SENT

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4
0x00	0x80	0x10			
0x7E5	0x04	0x00			
0x7E5	0x40	0xC6	0x01	0x00	0x00
0x7E5	0x41	0x02	0x00	0x00	0x00
0x7E5	0x42	0x03	0x00	0x00	0x00
0x7E5	0x43	0x92	0x01	0x00	0x00
0x7E5	0x11	0x1A			
0x7E5	0x04	0x00			
0x00	0x82	0x1A			

MODULE REPLY

CAN id	byte 0	byte 1
0x7E4	0x44	
0x7E4	0x11	0x00

Example: Change the NID for the **only module** on the CAN bus with CURRENT NID= 0x10 (16) and NEW NID = 0x1A (26).

MESSAGE SENT

CAN id	byte 0	byte 1
0x00	0x80	0x10
0x7E5	0x40	0x01
0x7E5	0x11	0x1A
0x7E5	0x04	0x00
0x00	0x82	0x1A

MODULE REPLY

CAN id	byte 0	byte 1
0x7E4	0x44	
0x7E4	0x11	0x00

8.4 Changing the TPDO Broadcast Rate

The data broadcast rate can be programmed from 5 ms to 65535 ms and applies to all TPDOs that have been enabled (see Section 8.5). It is an unsigned 16-bit integer (2 bytes) written least significant byte (LSB) first (Intel format) to OD address 0x1800, subindex 0x05. The default broadcast rate is 20 ms. The format of the SDO Write to the AFX3 module is as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	
0x600+NID	0x2B	0x00	0x18	0x05	Broadcast rate lo	Broadcast rate hi		

Example: Set TPDO broadcast rate to 500 ms (0x01F4) for the module with NID = 0x0F (15).

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x60F	0x2B	0x00	0x18	0x05	0xF4	0x01		

There is a minimum broadcast rate that is dependent on the number of modules transmitting on the CAN bus and how many TPDOs have been enabled for each module. If the broadcast rate is too fast the bus master will not be able to identify or configure any of the modules. The formula for calculating the minimum broadcast rate is as follows:

Minimum Broadcast Rate (ms) > Total number of TPDOs for all modules x 0.3125

Example: There are 8 modules on the CAN bus.
NID 0x01 has 3 TPDOs enabled
NID 0x02 has 1 TPDOs enabled
NID 0x03 has 4 TPDOs enabled
NID 0x04 has 2 TPDOs enabled
NID 0x05 has 4 TPDOs enabled
NID 0x06 has 4 TPDOs enabled
NID 0x07 has 4 TPDOs enabled
NID 0x08 has 4 TPDOs enabled

Minimum Broadcast Rate (ms) = (3 + 1 + 4 + 2 + 4 + 4 + 4 + 4) x 0.3125 = 8.125 ms. Since the broadcast rate is valid only in increments of 1ms, round 8.125 ms up to the next integer value, i.e. 9 ms. Therefore, no module can have a TPDO broadcast rate less than 9 ms.

8.5 Enabling Transmit Process Data Objects (TPDO)

There are four TPDOs; each can be individually enabled to transmit the mapped PDO data at the broadcast rate. The following OD addresses are required to enable each TPDO.

TPDO	EnableOD Address	Transmit CANid
TPDO1	0x1800	0x180 + NID

TPDO2	0x1801	0x280 + NID
TPDO3	0x1802	0x380 + NID
TPDO4	0x1803	0x480 + NID

To enable a TPDO, perform a SDO Write to the Enable OD Address for that particular TPDO as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x23	EnableOD Address lo	EnableOD Address hi	0x01	Transmit CANid lo	Transmit CANid hi	0x00	0x40

Example: Enable TPDO4 for the module with NID = 0x20, (EnableOD Address = 0x1803,
Transmit CANid = 0x480 + 0x20 = 0x4A0).

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x620	0x23	0x03	0x18	0x01	0xA0	0x04	0x00	0x40

8.6 Disabling Transmit Process Data Objects (TPDO)

The following OD addresses are required to disable each TPDO.

TPDO	EnableOD Address	Transmit CANid
TPDO1	0x1800	0x180 + NID
TPDO2	0x1801	0x280 + NID
TPDO3	0x1802	0x380 + NID
TPDO4	0x1803	0x480 + NID

To disable a TPDO, perform a SDO Write to the Enable OD Address for that particular TPDO as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x23	EnableOD Address lo	EnableOD Address hi	0x01	Transmit CANid lo	Transmit CANid hi	0x00	0xC0

Example: Disable TPDO1 for the module with NID = 0x10, (EnableOD Address = 0x1800,
Transmit CANid = 0x180 + 0x10 = 0x190).

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x620	0x23	0x00	0x18	0x01	0x90	0x01	0x00	0xC0

8.7 Transmit Process Data Object Mapping (TPDO MAPPING)

Each TPDO transmits two PROCESS DATA OBJECTS (PDOs). Which PDOs are transmitted by the module in a particular TPDO can be configured by the user.

Configuring a TPDO is a 4 step process:

i) Write a 0 to the TPDO Configuration OD Address, subindex 0x00.
ii) Enter the OD address of the 1st PDO.
(see Appendix D PROCESS DATA OBJECTS)
iii) Enter the OD address of the 2nd PDO.
iv) Enter the number of PDOs in the TPDO.

Also, the following information is required to successfully map a TPDO.

TPDO	ConfigOD Address	EnableOD Address	Transmit CANid
TPDO1	0x1A00	0x1800	0x180 + NID
TPDO2	0x1A01	0x1801	0x280 + NID
TPDO3	0x1A02	0x1802	0x380 + NID
TPDO4	0x1A03	0x1803	0x480 + NID

Write a 0 to the TPDO Configuration OD Address, subindex 0x00 by performing a SDO Write as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	ConfigOD Address lo	ConfigOD Address hi	0x00	0x00			

Configure the 1st PDO by performing a SDO Write follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x23	ConfigOD Address lo	ConfigOD Address hi	0x01	0x20	0x00	PDO OD Address lo	PDO OD Address hi

Configure the 2nd PDO by performing a SDO Write follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x23	ConfigOD Address lo	ConfigOD Address hi	0x02	0x20	0x00	PDO OD Address lo	PDO OD Address hi

Enter the number of PDOs in the TPDO by performing a SDO Write as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	ConfigOD Address lo	ConfigOD Address hi	0x00	0x02			

Example: Map the PDO for O_2 and AFR to TPDO2 for the module with
NID = 0x02. (O_2 PDO OD Address = 0x2001, AFR PDO OD Address = 0x2013,
ConfigOD Address for TPDO2 = 0x1A01)

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x602	0x2F	0x01	0x1A	0x00	0x00			
0x602	0x23	0x01	0x1A	0x01	0x20	0x00	0x01	0x20
0x602	0x23	0x01	0x1A	0x02	0x20	0x00	0x13	0x20
0x602	0x2F	0x01	0x1A	0x00	0x02			

8.8 Factory Reset

Parameters that are stored in non-volatile memory (EEPROM) can be reset to a standard configuration by issuing the ECM OS Command 0xDF (see Appendix B).

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	0x23	0x10	0x01	0xDF			

Issuing this command sets configuration and module parameters as follows:

1. Lambda sensor enabled
2. Pre-broadcast averaging values reset to factory default (see Section 8.2)
3. TPDOs are reset to factory default (see Section 4.1.3)
4. TPDO Broadcast rate set to factory default (see Section 8.4)

Note that the following are **NOT** affected by a factory reset:

i) CAN baud rate. To set the CAN baud rate see Section 8.9
ii) Node id (NID). To set the NID see Section 8.3

8.9 Changing the CAN baud rate

To change the CAN baud rate, several messages must be sent to the AFX3 module. This must be followed by a reset of the module. The procedure described below will change the CAN baud rate on ALL modules. If there are multiple modules on the CAN bus during this procedure, all the modules must be communicating at the same baud rate.

First place the module(s) into LSS (Layer Select Services) configuration mode. If there is only one CANopen module on the CAN bus this process requires only one message. If there are several CANopen modules on the same CAN bus the specific module must be identified using Product Code, Revision Number and Serial Number, (see Section 7.0). Note that the data is sent LSB first. For example, if the serial number is 0x12345678, then byte1 = 0x78, byte2 = 0x56, byte3 = 0x34, byte 4 = 0x12.

MULTIPLE MODULES ON BUS

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4
0x7E5	0x04	0x00			
0x7E5	0x40	0xC6	0x01	0x00	0x00
0x7E5	0x41	Product Code			
0x7E5	0x42	Revision Number			
0x7E5	0x43	Serial Number			

SINGLE MODULE ON BUS

CAN id	byte 0	byte 1
0x7E5	0x04	0x01

If successful, the module will respond with the following message.

CAN id	byte 0
0x7E4	0x44

Send the command to configure the baud rate. This will apply to ALL modules that are set to LSS configuration mode.

CAN id	byte 0	byte 1	byte 2
0x7E5	0x13	0x00	Index

Where “Index” corresponds to the following baud rates:
0 = 1 Mbit/s Theoretical maximum bus length: 30m
1 = 800 kbit/s (Not supported. Do not use.)
2 = 500 kbit/s Theoretical maximum bus length: 100m
3 = 250 kbit/s Theoretical maximum bus length: 250m
4 = 125 kbit/s Theoretical maximum bus length: 500m
5 = Reserved
6 = 50 kbit/s
7 = 20 kbit/s (Not supported. Do not use.)
8 = 10 kbit/s (Not supported. Do not use.)

If successful, the module will respond with the following message:

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x7E4	0x13	Error						

If Error = 0, then the baud rate configuration is successful. Otherwise, it has failed.

Send the command to activate the new baud rate.

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x7E5	0x15	Delay (lsb first)						

Where delay is the millisecond time delay before the new baud rate is active. This insures that CAN messages stop transmitting on one baud rate before the new baud rate is active. This value is also sent LSB first. No reply message expected.

At this point, the new baud rate is active, and you will no longer be able to communicate on the old baud rate. Make sure you set your software to communicate on the new baud rate.

Example: Change the baudrate for the **only module** on the CAN bus.

NEW BAUDRATE = 250 kbit/s
DELAY = 2000 ms (0x07D0)

MESSAGE SENT

CAN id	byte 0	byte 1	byte 2
0x00	0x80	0x10	
0x7E5	0x40	0x01	
0x7E5	0x13	0x00	0x03
0x7E5	0x15	0xD0	0x07

MODULE REPLY

CAN id	byte 0	byte 1
0x7E4	0x44	
0x7E4	0x13	0x00

8.10 Sensor ON/OFF

Sensor power can be turned OFF by issuing the following SDO Command (see Appendix B):

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	0x23	0x10	0x01	0x08			

When the sensor power is OFF the Analog Output is set to 0 V, CAN TPDOs for Lambda, AFR and O_2 are set to 0, the Error Code is set to 0x13 and the LED display reads “off” as shown below:

Sensor power can be turned ON by issuing the following SDO Command (see Appendix B):

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	0x23	0x10	0x01	0x07			

Issuing this SDO Command results in a new start-up sequence (See Section 4.0).

8.11 Modifying the LED Display Intensity

The LED Display intensity can be modified from its default value. It is an unsigned 8-bit integer (1 bytes) written to OD address 0x509E, subindex 0x00. The format of the SDO Write to the AFX3 module is as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7

0x600+NID	0x2F	0x9E	0x50	0x00	LED Intensity			

LED Intensity:
0 – Display OFF
1 – Maximum intensity (Default)
10 – Minimum intensity

Any values transmitted in byte 4 that are outside of this range (0-10) defaults to 1 (Maximum intensity.)

Example: Turn the LED Display OFF for a module with NID = 0x0F.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x60F	0x2F	0x9E	0x50	0x00	0x00			

8.12 Analog Output Override

The Analog Output voltage (Aout) can be modified by the user. The allowable range is 0-5 Vdc. To enable this feature, the desired output voltage is written to the module as single precision floating point number in 32-bit IEEE-754 format by performing a SDO Write to OD address 0x509D. The hex value is loaded least significant byte first (Intel format). The OD address uses RAM memory and therefore is volatile. After every power cycle the OD address defaults to -1.0 (i.e. Override OFF).

Writing any number < 0 turns this feature OFF and the Analog Output is set to the voltage calculated by the module.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x23	0x9D	0x50	0x00	desired output voltage (float)			

Example: Set the Analog Output voltage to 2.500 V (0x40200000) for the module with NID = 0x10.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x610	0x23	0x9D	0x50	0x00	0x00	0x00	0x20	0x40

Example: To revert back to the standard Analog Output write -1.000 V (0xBF800000) to OD address 0x509D for the module with NID = 0x10.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x610	0x23	0x9D	0x50	0x00	0x00	0x00	0x80	0xBF

Appendix A: Error Codes

CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x80+NID	0xFF	0x00	0x00	Error Code lo	Error Code hi	Aux		

ERROR CODE	**LED DISPLAY**	**DESCRIPTION OF ERRORS**
0x0000	LAMBDA, AFR, %O2	All OK, (green led constantly on)
0x0001	Sensor Warmup Count-down	Wide-band sensor warm-up period Count-down value in "Aux" byte 5
0x0002	**8.8.8.8.**	Power on reset/ Init hardware
0x0013	**oFF**	Sensor power turned off
0x0014	**SEn1**	Sensor not present/ HTR open
0x0015	**SEn2**	HTR shorted
0x0031	**bAt_**	+Vsw < 11 for > 7sec
0x0032	**bAt¯**	+Vsw > 28V
0x0041	**SEn4**	VS too high
0x0051	**SEn5**	RVS too high
0x0061	**SEn6**	2V > VP+ > 6V
0x00A1	n/a	Invalid software state
0x00B1	n/a	CAN overrun
0x00B2	n/a	CAN passive mode
0x00B3	n/a	CAN heartbeat error
0x00B4	n/a	CAN recover bus off
0x00B5	n/a	CAN Tx CanId collision
0x00B6	n/a	Serial overrun
0x00B7	n/a	Can overrun Lss
0x00B8	n/a	Can overrun Sdo
0x00B9	n/a	Can overrun Rx
0x00BA	n/a	Can overrun ECT5

Note: The Error Code is also available as a TPDO see Appendix D.

Appendix B: ECM CANopen OS Commands

A user-specific CANopen OS Command to the AFX3 module is sent using an SDO expedited write message in the following form. These commands apply only to the AFX3 module and are listed on the following page:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x2F	0x23	0x10	0x01	Command			

Issuing a SDO Read of OD address 0x1023, subindex 0x02 will indicate the status of the command.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x40	0x23	0x10	0x02				

The module will reply as follows:

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x580+NID	0x4F	0x23	0x10	0x02	Status			

The values that may be returned are listed below.

Status	
0x00	Last command completed. No error occurred. No reply.
0x01	Last command completed. No error occurred. The reply can now be read.
0x02	Last command completed. Error occurred. No reply.
0x03	Last command completed. Error occurred. The reply can now be read.
0x04 - FE	Reserved
0xFF	Command is executing.

If there is a reply it can read using an SDO Read of OD address 0x1023, subindex 0x03.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x600+NID	0x40	0x23	0x10	0x03				

The reply value will be located in byte 4 of the response to the SDO Read.

CANid	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x580+NID	0x4F	0x23	0x10	0x03	Reply			

The reply values and what they indicate are listed on the following page.

COMMAND	**VALUE**	**DESCRIPTION**	**REPLY**
SensorOn	0x07	Turn on sensor power	None
SensorOff	0x08	Turn off sensor power	None
ResetAllFilters	0x15	Resets recursive average of Ip1	
		defAlphaOK	0x00
ResetTPDOs	0x1F	Set all TPDOs as delivered from factory.	None
ResetTPDOs	0x1F	Set all TPDOs as delivered from ECM	None
DisableTPDOCOBreset	0x22	TPDO CANids set by user	None
EnableTPDOCOBreset	0x23	TPDO CANids default to CANopen standard	None
FactoryReset	0xDF	Set all EE values to a standard configuration.	None

Appendix C: Heartbeat

A Heartbeat message is transmitted every 0.5 seconds by the module. During normal operation the module is in operational mode (NMT state = 0x05).

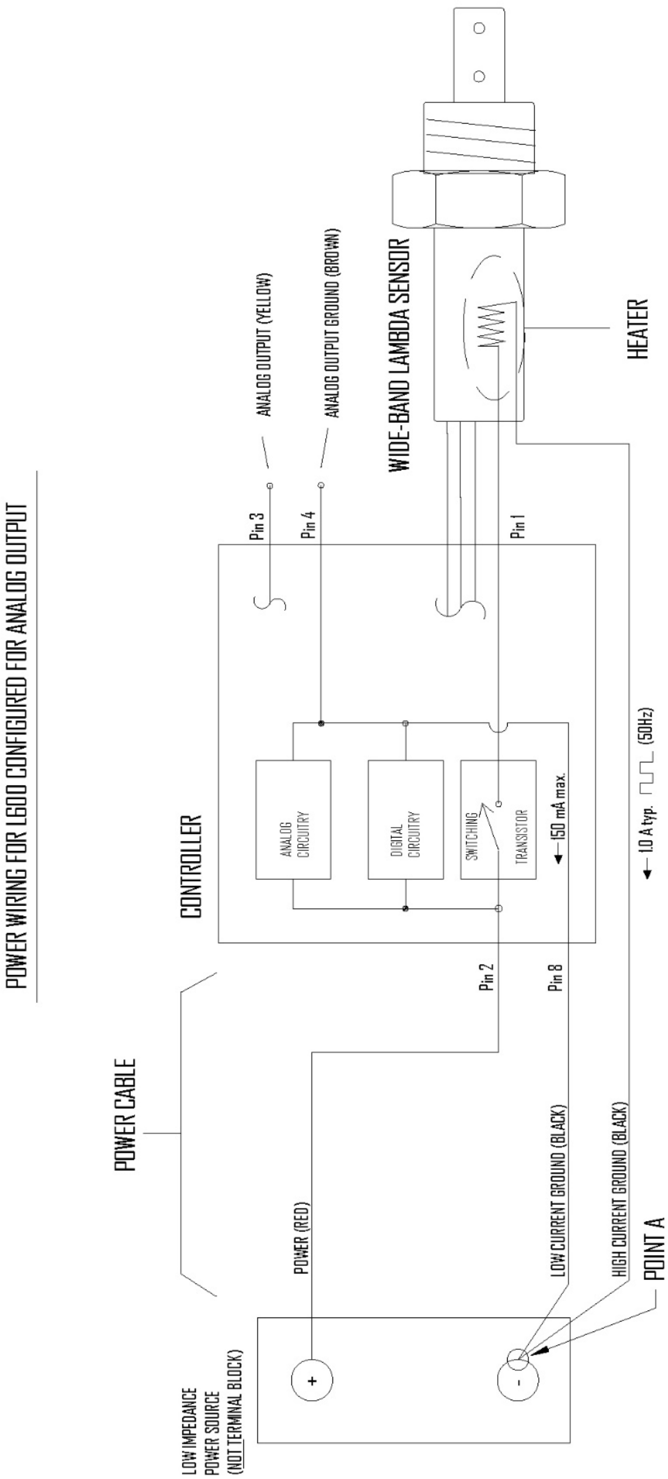
CAN id	byte 0	byte 1	byte 2	byte 3	byte 4	byte 5	byte 6	byte 7
0x700+NID	NMT state							

NMT state	
0x00	Boot-up
0x04	Stopped
0x05	Operational
0x7F	Pre-operational

Appendix D: Process Data Objects

Address	Type	Symbol	Description
0x2000	single float	DUTY	Heater Positive Duty Cycle (%)
0x2001	single float	O2	O_2 (%)
0x2003	single float	AOUT	Analog Output Voltage (V)
0x2004	single float	RPVS	Rpvs (Ω) * 1000
0x2005	single float	VHCM	Commanded Heater Voltage (Vrms) * 1000
0x2006	single float	VS	Vs Voltage (V) * 1000
0x2007	single float	VP1P	Vp1+ (V) * 1000
0x2008	single float	VHOF	Measured Heater Voltage when OFF (Vpk) * 1000
0x2009	single float	VIN	Input Voltage (V) * 1000
0x200A	single float	VHON	Measured Heater Voltage when ON (Vpk) * 1000
0x200B	single float	TPCB	Circuit Board Temperature (deg C) * 100
0x200D	single float	UERF	Diagnostic Bit Flags (dec)
0x200E	single float	UERC	Error Code (dec) see Appendix A
0x2010	single float	O2C	O_2 (%) for AIR_ AIR CAL
0x2012	single float	LAM	Lambda
0x2013	single float	AFR	AFR
0x2014	single float	PHI	PHI
0x2015	single float	FAR	FAR
0x2018	single float	IP1	Ip1 (A)
0x201C	single float	NLO	Diagnostic O_2 (%)

Appendix E: Ground Wiring Diagram



NOTES:

1. TWO GROUND WIRES ARE USED. ONE TO CLOSE THE CURRENT LOOP ON THE SENSOR HEATER AND ONE TO CLOSE THE LOOP ON THE ELECTRONIC CIRCUITRY. IF YOU RUN GROUNDS ON SAME WIRE, YOU WILL GET NOISE IN THE ANALOG OUTPUT.
2. DO NOT REWIRE TO MAKE SINGLE WIRE FROM POINT A TO THE ACTUAL BATTERY/POWER GROUND. IF YOU DO THEN YOU WILL GET A VOLTAGE POTENTIAL BETWEEN THE ANALOG OUTPUT GROUND AND BATTERY/POWER GROUND.
3. IF YOU WIRE AS SHOWN ABOVE, VOLTAGE POTENTIAL BETWEEN ANALOG OUTPUT GROUND AND BATTERY/POWER GROUND WILL BE SMALL (<0.002 VOLTS).
4. IN SOME APPLICATIONS, CUTTING LOW CURRENT GROUND (BLACK) AT THE GROUND TERMINAL AND CLOSING GROUND VIA THE ANALOG OUTPUT GROUND MAY IMPROVE NOISE IMMUNITY OF THE SYSTEM. FOR THIS CASE, THE GROUND OF THE EQUIPMENT ATTACHED TO THE ANALOG OUTPUT MUST ALSO BE CONNECTED TO BATTERY/POWER GROUND.

L600 GND DWG

408-734-3433

Appendix F: Warranty and Disclaimers

WARRANTY

The products described in this manual, with the exception of the lambda and pressure sensors, are warranted to be free from defects in material and workmanship for a period of 365 days from the date of shipment to the buyer. Within the 365 day warranty period, we shall at our option repair such items or reimburse the customer the original price of such items which are returned to us with shipping charges prepaid and which are determined by us to be defective. This warranty does not apply to any item which has been subjected to misuse, negligence or accident; or misapplied; or modified; or improperly installed.

The lambda and pressure sensors are considered an expendable part and as such cannot be covered by a warranty.

This warranty comprises the sole and entire warranty pertaining to the items provided hereunder. Seller makes no other warranty, guarantee, or representation of any kind whatsoever. All other warranties, including but not limited to merchantability and fitness for purpose, whether express, implied, or arising by operation of law, trade usage, or course of dealing are hereby disclaimed.

The warranty is void if the display head is opened.

LIMITATION OF REMEDY

Seller's liability arising from or in any way connected with the items sold and/or services provided shall be limited exclusively to repair or replacement of the items sold or refund of the purchase price paid by buyer, at seller's sole option. In no event shall seller be liable for any incidental, consequential or special damages of any kind or nature whatsoever, including but not limited to lost profits arising from or in any way connected with items sold and/or services provided to buyer, whether alleged to arise from breach of contract, express or implied warranty, or in tort, including without limitation, negligence, failure to warn or strict liability. In no event shall the company's liability to buyer arising out of or relating to the sale of any product or service exceed the purchase price paid by buyer to the company for such product or service.

PRODUCT CHANGES

We reserve the right to discontinue a particular product or to make technical design changes at any time without notice.

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