ECM ENGINE CONTROL AND MONITORING

egrCAN

Modular, Multichannel, Exhaust Gas Recirculation (EGR) Ratio and Lambda Measurement System

Instruction Manual

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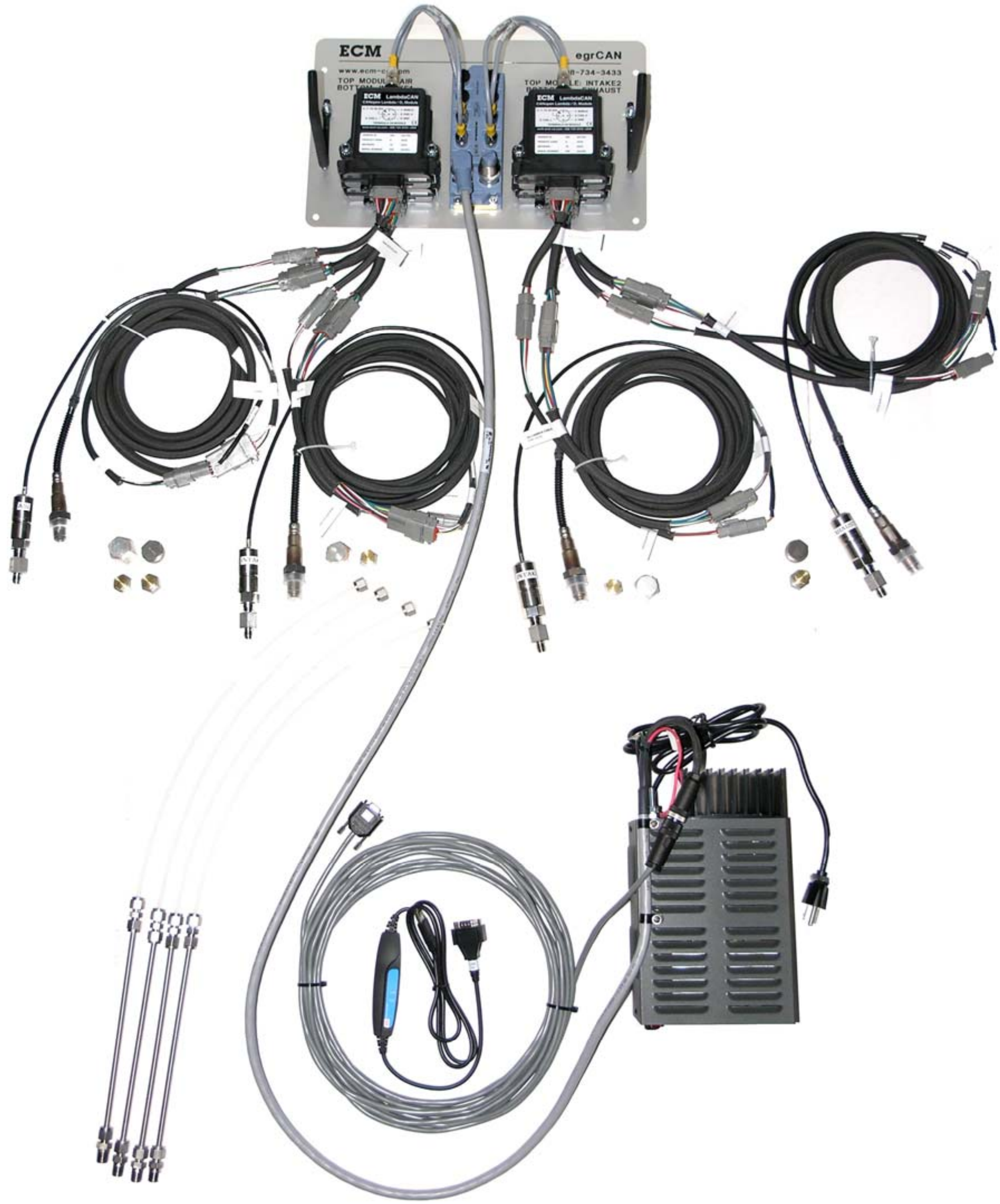


A two-zone egrCAN system with optional module mounting panel and AC/DC Power Supply. %EGR can be determined at two locations in the engine.

Introduction

egrCAN is a modular, multichannel, exhaust gas recirculation (EGR) ratio measurement system. egrCAN is scalar. The basic system (see Figure 1) consists of three modules: one measuring ambient air (the “air module”), one measuring the intake charge (the “intake module”), and one measuring the exhaust of the engine (the “exhaust module”). More intake and exhaust modules can be added to measure EGR in different locations in the intake manifold (to study EGR distribution) or to measure %EGR in multi-stage EGR systems. Additionally, all egrCAN systems report engine %O2[1], Lambda (AFR, FAR, Equivalence Ratio) and absolute pressure at each measurement location.

egrCAN is a CAN-based system. Thus, all communication with the system is via CAN. A supplied PC Configuration Tool is used to configure the modules, observe module outputs, record module outputs, and produce a .dbc file. dashCAN displays can be added to egrCAN systems to display system parameters.

Figure 1 shows a basic egrCAN system. Each module outputs information that is used to calculate %EGRv (volume based %EGR) via the formula:

%EGR = 100 · (O2air - O2int) / (O2air – O2exh) [Equation 1]

where:

O2air = Parameter O2 (%O2) output by the “air” module.
O2int = Parameter O2 (%O2) output by an “intake” module. An egrCAN system can have multiple intake modules. Thus multiple %EGRs can be reported for different locations (for EGR distribution studies) or stages (for multi-stage EGR systems).
O2exh = Parameter O2 (%O2) output by an “exhaust” module.

The %EGR calculated via Equation 1 is numerically equivalent to the commonly used definition of volume-based definition of:

%EGRv = 100 · ve / (va + ve) [Equation 2]

where:

%EGRv = volumetric (molar) exhaust gas recirculation, percent
ve = volume of exhaust gas inducted into the engine
va = volume of air from the atmosphere inducted into the engine

Note that the calculation (Equation 1) of the various %EGRv must be performed by the host’s data acquisition system. egrCAN provides the required O2s (ie. O2air, O2int, O2exh) for the calculations.

egrCAN will make available EGR information at a much higher bandwidth than with classical sampling systems. Averaging of the calculated %EGR information can be performed in the host data acquisition system.

[1] To match the appearance of parameter names, O_2 will be written as O2 (no lower case 2).

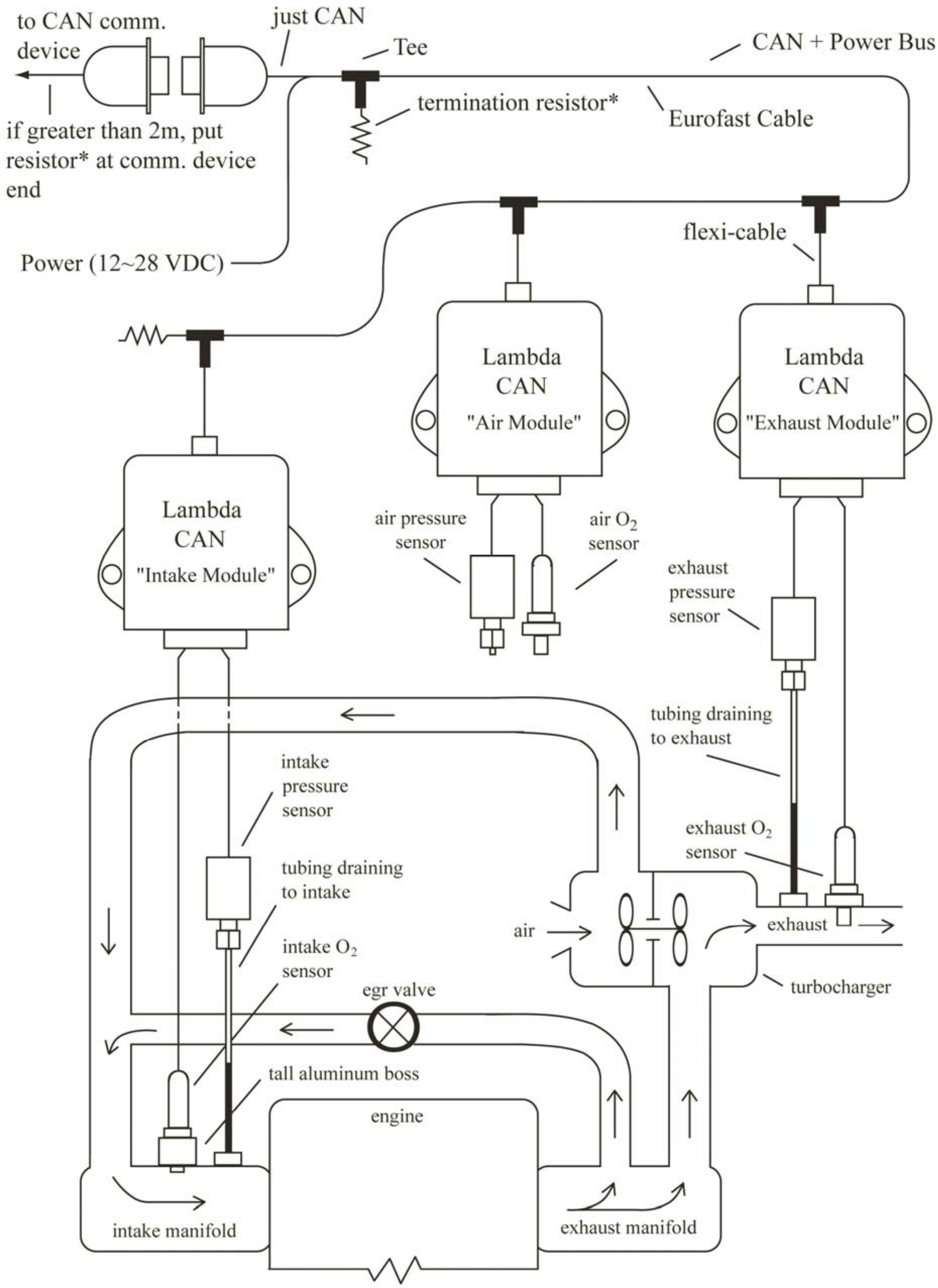


Figure 1: Basic egrCAN System

Setting up egrCAN (Hardware)

There are 2 steps to setting up the egrCAN hardware:

1. Mounting O2 and pressure sensors on the engine
2. Attach the modules to the bus

Mounting O2 and Pressure Sensors

◆ Mounting "Air Module" O2 and Pressure Sensors

The air module's O2 and pressure sensors should be mounted in a quiescent volume containing the air that is to be drawn into the engine. Mounting could be as simple as hanging the sensors by their wires in ambient air. Alternatively, the sensors could be mounted on conditioned-air ducting leading to the intake of the engine.

ECM supplies both steel and aluminum mounting bosses for the air module's O2 sensor and pressure sensor (see Figure 2). However in some cases, user-designed sensor mounting bosses may be more appropriate. It is important to minimize the velocity of air passing over the O2 sensor as excessive cooling will lead to measurement errors. Keep in mind that the O2 sensor gets very hot and will burn whatever it touches.

General rules and information for mounting are as follows:

- O2 sensor thread is 18mm x 1.5mm
- Pressure sensor thread is ¼" NPT
- Pressure sensor must measure pressure within 2" (50mm) of the O2 sensor
- Mount sensors so that no water will collect on either sensor
- Mount sensors where air velocity is as low as possible
- Apply pressure to pressure sensor through a ¼" or 6mm teflon hose if the proposed pressure sensor mounting location is hot or vibrates
- Locate pressure sensor where temperature is between -20 °C and 70 °C.

◆ Mounting "Intake Module" O2 and Pressure Sensors

egrCAN determines the %EGR at the location of the intake module's O2 and pressure sensor. Although this at first might seem obvious, this is different from sampling-type (i.e. pumping) %EGR measurement instruments that tend to average the %EGR measured from a drawn volume surrounding the pump's sample point. Consequently, egrCAN is both better at measuring the distribution of EGR in an intake manifold and less intrusive. egrCAN supports the use of multiple intake modules allowing the simultaneous determination of EGR distribution in an intake manifold. Alternatively, multiple intake modules can be used to determine %EGR for multi-stage EGR systems.

A 1" (25.4mm) tall aluminum mounting boss (P/N 12-04) is provided for the intake O2 sensor. The mounting boss places the tip of the O2 sensor flush with the inner wall of the manifold and thus does not influence intake flow. The aluminum mounting boss can either be welded (to aluminum manifolds) or epoxied (to plastic manifolds).

The pressure sensor is not directly mounted on the intake manifold. An aluminum boss (P/N 12-07 (USA) or 12-14 (Metric)) is to be welded or epoxied to the intake manifold and a stainless steel/teflon line ((P/N 12-08 (USA) or 12-11 (Metric)) runs between the boss and the pressure sensor. The purpose of the stainless steel/teflon line is to isolate the pressure sensor from the heat and vibration of the engine. The stainless steel end of the line attaches to the engine and the teflon end attaches to the pressure sensor. General rules and information for mounting are as follows:

- O2 sensor mounting boss is 18mm x 1.5mm
- Pressure sensor line mounting boss is ¼" NPT (USA) or ¼" ISO (Metric)
- After welding a boss, run a tap through it to remove any thread distortion
- Pressure sensor line is ¼" diameter (USA) or 6mm (Metric)
- Pressure sensor must measure pressure within 2" (50mm) of the O2 sensor
- Mount sensors so that no water will collect on or drain into either sensor
- Do not modify the length or diameter of the pressure line
- Locate pressure sensor where temperature is between -20 °C and 70 °C
- Route cables away from hot, moving, sharp, or high voltage (spark) wires.

◆ Mounting "Exhaust Module" O2 and Pressure Sensors

Mount the exhaust O2 sensor using the short steel 18 mm boss (P/N 12-02) between 300 mm downstream of exhaust valve and ten exhaust diameters upstream of exhaust exit. Preferentially mount downstream of turbocharger and upstream of exhaust catalyst. egrCAN supports the use of multiple exhaust modules.

As with the intake pressure sensor, the exhaust pressure sensor cannot be mounted directly to the engine. A steel mounting boss (P/N 12-05 (USA) or 12-12 (Metric)) is provided which should also be welded to the exhaust system within 2" (50mm) of the O2 sensor boss. The pressure sensor connects to the exhaust through a supplied stainless steel/Teflon line (P/N 12-08 (USA) or 12-11 (Metric)). The purpose of the stainless steel/teflon line is to isolate the pressure sensor from the heat and vibration of the engine. The stainless steel end of the line attaches to the engine and the Teflon end attaches to the pressure sensor. General rules and information for mounting are as follows:

- O2 sensor mounting boss is 18mm x 1.5mm
- Pressure sensor line mounting boss is ¼" NPT (USA) or ¼" ISO (Metric)
- After welding a boss, run a tap through it to remove any thread distortion
- Put antiseize on the threads of the O2 sensor and the thread of the pressure line fitting that screws into the exhaust
- Pressure sensor line is ¼" diameter (USA) or 6mm (Metric)
- Pressure sensor must measure pressure within 2" (50mm) of the O2 sensor
- Mount sensors so that no water will collect on or drain into either sensor
- Do not modify the length or diameter of the pressure line
- Locate pressure sensor where temperature is between -20 °C and 70 °C
- Do not exceed 850 °C gas temperature at location of O2 sensor
- Route cables away from hot, moving, sharp, or high voltage (spark) wires.

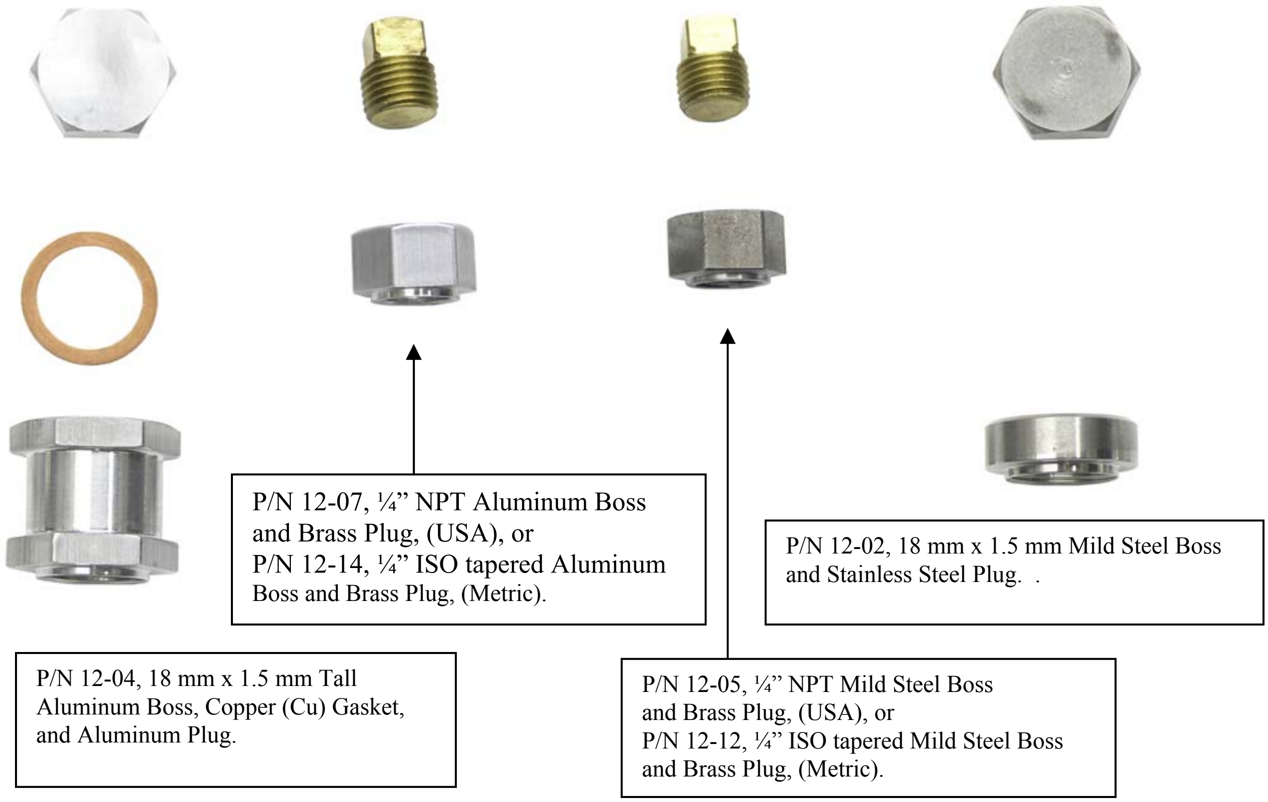


Figure 2: Bosses and Plugs

Attaching the Modules to the Bus

Figure 1 and Appendix A shows a basic (3 module) egrCAN system. egrCAN is a bus-based measurement system. The bus is composed of Eurofast cables (in 2m, 4m, and 10m lengths), Tees, termination resistors, and “flexi-cables”. The Eurofast cables contain both CAN communication wires and power wires for the modules. There is a lot of flexibility in building the bus with the components (cables, tees, termination resistors, flexi-cables). Generally speaking, if it screws together and there is a termination resistor at each end of the bus, it will work.

The bus needs to be powered. Power requirements are 12 to 28V and 2A (steady-state) per module. Power can either be supplied from a battery or a number of AC/DC power supplies offered by ECM. To minimize voltage drops, power the bus close to the modules. The CAN communication is tapped into the bus at the power entry end. This is not a requirement but it is the way the power entry devices are manufactured. If the distance between the termination resistor (see * in Figure 1) and the CAN communication device exceeds 2m, move the termination resistor (120 Ohm) to the CAN communication end of the cable.

In most cases, just LambdaCAN modules are used in egrCAN systems. In some diesel engine applications, it may be possible to replace the exhaust LambdaCAN module(s) with NOxCANg modules. When egrCAN systems leave ECM, the modules are labeled “AIR”, “INTAKEn”, “EXHAUSTm” (where “n” and “m” are numbers for modules of non-basic systems. ex. where there is more than one intake module). Additionally, the programmed node id (NID) appears on each module.

Setting up egrCAN (Software)[1]

There are 3 steps to setting up the egrCAN software:

1. Configuring the modules using ECM's Configuration Software[1]
2. Producing a .dbc file for the host data acquisition system
3. Processing data in host data acquisition system (i.e. calculating %EGR)

Configuring the Modules

Modules are configured using a CAN adapter and the supplied configuration software ("Configuration Tool"). The software runs on a PC and requires one of the following CAN adapters:

1. Kvaser USB-to-CAN adapter
2. ETAS USB-to-CAN adapter
3. VectorCAN CAN PCMCIA adapter card.

Although available from ECM, a CAN adapter is not normally supplied with egrCAN.

Before using the Configuration Tool, the CAN adapter software and Configuration Tool software should be installed on the PC, all modules should be hooded up to the bus (with proper termination), the bus should be powered, and the CAN adapter should be connected to the bus and the PC. Double click on the ECM icon and the window shown in Figure 3 will appear.

Click on the "Modules" tab, then the "START" button. Within seconds, the modules on the bus will be identified. If they are not, there is a possibility that two or more modules share the same node id. To resolve this, hook one module up at a time to check/change its node id. This is performed by opening the "Task" menu and clicking on "Change Node ID".

Once the Configuration Tool has found all the modules, select the module and configure it by opening the Task bar (see Figure 4). See Table 1 for the recommended task settings. See Table 2 for the list of available tasks. Don't click on the EIB or Stand-Alone buttons. The modules need to be left in Stand-Alone mode.

At the bottom of the configuration screen, the parameters to be transmitted by the module are selected. Parameters are selected in pairs; called TPDOs. Click the TPDO to activate its transmission and select the two parameters assigned to that parameter. See Table 1 for the recommended TPDOs. Tables 3 and 4 show the lists of available parameters. "O2" must be selected from each module to enable the calculation of %EGR.

[1] Alternatively, the egrCAN can be operated by direct CAN messaging to and from a user-program. For information on how to do this, refer to the LambdaCAN Module Instruction Manual (on CD).

There is a limit to the amount of information being passed on the CAN bus. Assuming that nothing but egrCAN modules on the bus, the following formula calculates the minimum programmable broadcast rate (used by all modules) given a total number of TPDOs transmitted (total for all modules)

Minimum broadcast rate (ms) = total number of TPDOs for all modules x 0.3125

In addition, the Configuration Tool displays the bus loading.

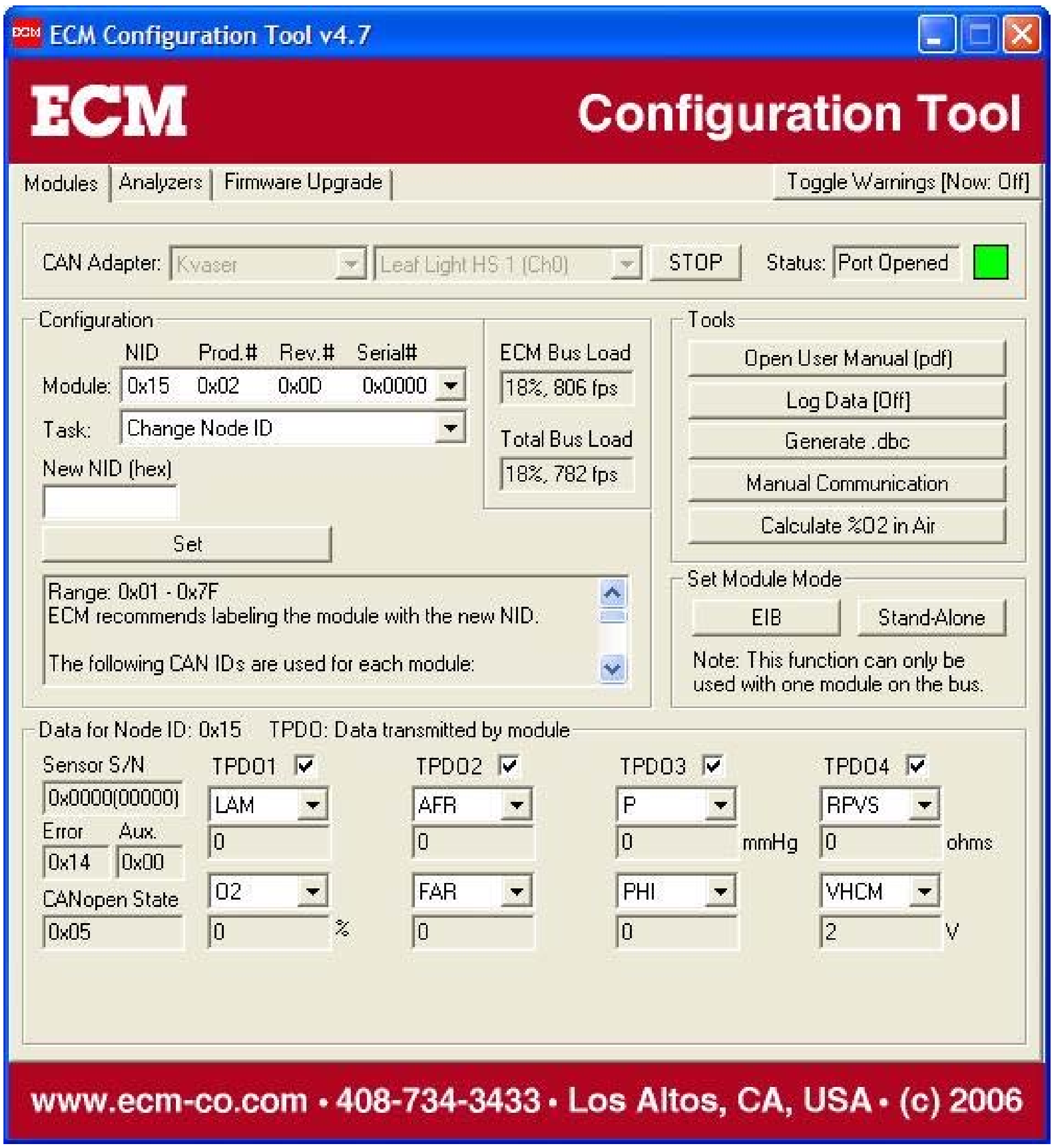


Figure 3: Configuration Tool Software Opening Window

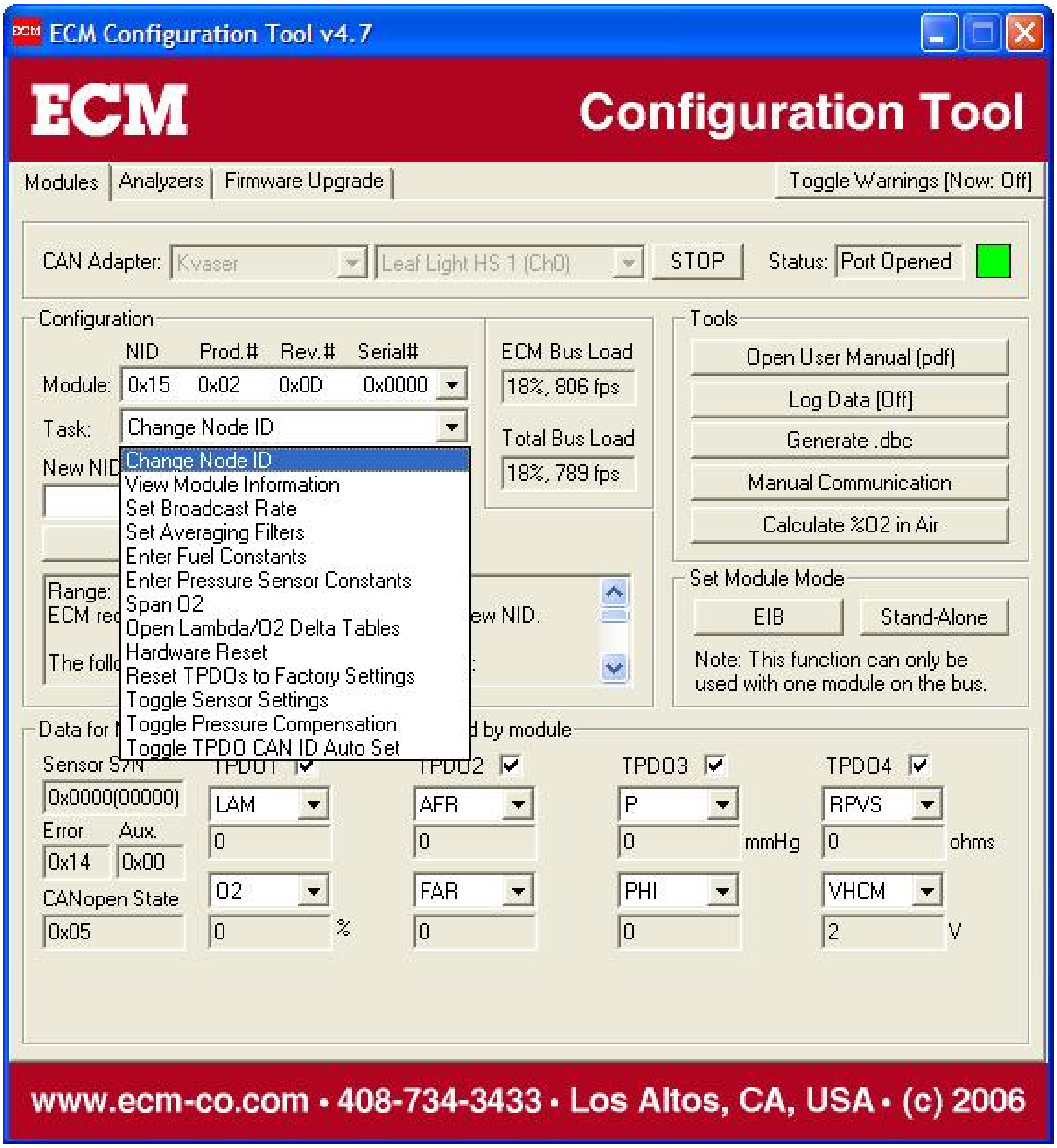


Figure 4: Configuration Tool Tasks

Broadcast Rate: 5 ms for all modules
Alpha Lambda: 0.025 for all modules
Alpha P (pressure): 0.005 for “Air” and “Intake” Modules, 1.000 for “Exhaust” Modules
Fuel Constants: Actual or Default of H:C=1.85, O:C=0.0, N:C=0.0
Pressure Sensor Constants: Enter sensor-specific “N” and “C” values
(written on sensor cable) for each module
TPDOs (“Air” Module): O2, PKPA, RPVS, VH, IP1, TEMP
(“Intake” Module): O2, PKPA, RPVS, VH, IP1, VSM
(“Exhaust” Module): O2, PKPA, RPVS, VH, IP1, Lambda

Table 1: Recommended Task Values and TPDOs for egrCAN Systems

Change Node ID: Allowable range 0x01 to 0x7F (hex). When you assign a Node ID (NID), the following CAN IDs **cannot be used** by any other devices on the bus: 0x00, 0x80 + NID, 0x180 + NID, 0x280 + NID, 0x380 + NID, 0x480 + NID, 0x580 + NID, 0x600 + NID, 0x700 + NID, 0x7E4, 0x7E5.

View Module Information: Manufacturer's Name, Hardware Version, Software Version

Set Broadcast Rate: All activated TPDOs are transmitted every "n" milliseconds. "n" can be programmed. 5 ms is the minimum. Data is sent at a baud rate of 500 kbps. Minimum broadcast rate (ms) = total number of TPDOs for all modules x 0.3125

Set Averaging Filters: Lambda (i.e. O2R, IP1, IP1R, LAMR, AFR, PHI, FAR, LAM, O2, IP1X), NOx (i.e. NOx, IP2, IP2R), and Pressure (i.e. PR16, PR10, PCF, P) data are averaged prior to broadcast. There are three averaging filters (alpha numbers): One for Lambda (all of: O2R, IP1, IP1R, LAMR, AFR, PHI, FAR, LAM, O2, IP1X are acted upon by this same filter), one for NOx (all of: NOx, IP2, IP2R are acted upon by this same filter), and one for Pressure (all of: PR16, PR10, PCF, P are acted upon by this same filter). Data is averaged every 5 ms independent of the broadcast rate using the alpha number according to the formula: $AvgData_n$ = alpha x $Data_n$ + (1-alpha) x $AvgData_{n-1}$. If an alpha is set to 1.000, there is no averaging and hence the instantaneous measured data is sent.

Enter Fuel Constants: H:C, O:C, and N:C ratios or if the fuel is H2. Defaults: H:C = 1.85, O:C = 0, N:C = 0

Enter Pressure Sensor Constants: N and C are the gain and offset of the pressure sensor. N and C are written on a label attached to the pressure sensor. P (psia) = N x (V - C). V = voltage from sensor. See Appendix C.

Span O2: User enters displayed %O2 (TPDO data) and the actual %O2 of the span gas. This is how you calibrate the Lambda sensor and the O2 (and Lambda) measurement function of the NOx sensor. See Appendix C.

Zero NOx (NOxCAN(g) only): User enters displayed NOx value (TPDO data) and the actual NOx value of the "zero" gas. Zero gas does not necessarily have to be exactly zero. A non-zero value can be entered. See Appendix C.

Span NOx (NOxCAN(g) only): User enters displayed NOx value (TPDO data) and the actual NOx value of the gas. See Appendix C.

Open Lambda/O2 Delta Tables: There are two tables. The first, the Delta O2 Table, allows modification of calculated %O2 via a user-entered look-up table. Delta O2 Table entries will not influence Lambda, AFR, FAR or PHI values. The second, the Delta Lambda Table, allows modification of calculated Lambda (and hence AFR, FAR, and PHI) via a user-entered look-up table. The Delta Lambda table will not influence O2 values. See Appendix C.

Select NOx Curve (NOxCANg only): Match engine (wet) data or model gas data.

Set NOx Gamma/Beta (NOxCANg only): User enters parameters for O2 compensation.

Hardware Reset: Equivalent to powering the module down then up again.

Reset TPDOs to Factory Settings: These are the parameters displayed and transmitted. TPDO stands for Transmit Process Data Object.

Toggle Sensor Settings: Allows power to ceramic sensor to be turned on and off (Default: On) and enables rapid sensor warm-up scheduling (Default: On (fast)).

Toggle Pressure Compensation: Enable and disable pressure compensation of O2 (Lambda, AFR, FAR, PHI) data. Default: On.

Toggle TPDO CAN ID Auto Set: Enable and disable TPDO CAN ID Auto Set.

Table 2: Task List for LambdaCAN, NOxCAN, and NOxCANg Modules

Parameter Name Displayed	Full Parameter Name	Parameter Description
O2R	%O2real (%)	%O2 before addition of Delta O2 Table
IP1	Ip1 (A)	Pressure-compensated Lambda sensor pumping current
RPVS	RPVS (Ohms)	Lambda sensor internal VS cell resistance
VHCM	VH Commanded (V)	Desired heater voltage commanded by the module
VS	VS (V)	Lambda sensor internal VS cell voltage
VP1P	VP+ (V)	Lambda sensor pumping voltage
VSW	Vsw (V)	Supply voltage measured at the module
VH	VH Measured (V)	Actual heater voltage at the module
TEMP	Circuit Board Temp (°C)	Temperature of the module circuit board
IP1R	Ip1raw (bits)	Lambda sensor pumping current (unsigned integer format)
PR16	Praw16 (bits)	16 bit Pressure sensor output voltage (unsigned integer format)
ERFL	Error bit flags (bits)	Module error flags (unsigned long format)
ERCd	ECM CANOpen Error Code	ECM CANOpen Error Code
PR10	Praw10 (bits)	10 bit Pressure sensor output voltage (unsigned integer format)
PCF	Pressure Correction Factor	Lambda sensor pressure compensation correction factor / 10^3
PCFE		ECM diagnostic parameter
O2E		ECM diagnostic parameter
IP1E		ECM diagnostic parameter
PE		ECM diagnostic parameter
P	P (mmHg)	Pressure sensor measured pressure (absolute) in mmHg
LAMR	LAMBDA real	Lambda before addition of Delta Lambda Table
AFR	Air-Fuel Ratio	Air-Fuel ratio calculated using LAMBDA
PHI	PHI	PHI = 1/LAMBDA
FAR	FAR*10000	FAR = (1/AFR) * 10000
LAM	LAMBDA	Lambda after addition of Delta Lambda Table
O2	O2 (%)	%O2 after addition of Delta O2 Table
IP1X	Ip1 non Pcomp (A)	Non-pressure compensated Lambda sensor pumping current
PVLP	P (V)	Raw volts from pressure sensor
PKPA	P (kPa)	Pressure sensor measured pressure (absolute) in kPa
PBAR	P (bar)	Pressure sensor measured pressure (absolute) in bar
PPSI	P (psi)	Pressure sensor measured pressure (absolute) in psi

Table 3: LambdaCAN Parameter List

Parameter Name Displayed	Full Parameter Name	Parameter Description
NOx	NOx (ppm)	NOx
O2R	%O2real (%)	%O2 before addition of Delta O2 Table
IP1	Ip1 (A)	Pressure-compensated Ip1 sensor pumping current
IP2	Ip2 (A)	Ip2 sensor pumping current
RPVS	RPVS (Ohms)	NOx sensor internal VS cell resistance
VHCM	VH Commanded (V)	Desired heater voltage commanded by the module
VS	VS (V)	NOx sensor internal VS cell voltage
VP1P	VP1+ (V)	NOx sensor Ip1 pumping voltage
VP2	VP2 (V)	NOx sensor Ip2 pumping voltage
VSW	Vsw (V), not used for NOxg	Supply voltage measured at the module, not used for NOxg
VH	VH Measured (V)	Actual heater voltage at the module
TEMP	Circuit Board Temp (°C)	Temperature of the module circuit board
IP1R	Ip1raw (bits)	NOx sensor Ip1 pumping current (unsigned integer format)
IP2R	Ip2raw (bits)	NOx sensor Ip2 pumping current (unsigned integer format)
ERFL	Error bit flags (bits)	Module error flags (unsigned long format)
ERCd	ECM CANOpen Error Code	ECM CANOpen Error Code
PR10	Praw10 (bits)	10 bit Pressure sensor output voltage (unsigned integer format)
PCF	Pressure Correction Factor	NOx sensor Ip1 pressure compensation correction factor/10^3
PCFE		ECM diagnostic parameter
O2E		ECM diagnostic parameter
IP1E		ECM diagnostic parameter
PE		ECM diagnostic parameter
P	P (mmHg)	Pressure sensor measured pressure (absolute) in mmHg
LAMR	LAMBDAreal	Lambda before addition of Delta Lambda Table
AFR	Air-Fuel Ratio	Air-Fuel ratio calculated using LAMBDA
PHI	PHI	PHI = 1/LAMBDA
FAR	FAR*10000	FAR = (1/AFR) * 10000
LAM	LAMBDA	Lambda after addition of Delta Lambda Table
O2	O2 (%)	%O2 after addition of Delta O2 Table
IP1X	Ip1 non Pcomp (A)	Non-pressure compensated NOx sensor Ip1 pumping current
PVLP	P (V)	Raw volts from pressure sensor
PKPA	P (kPa)	Pressure sensor measured pressure (absolute) in kPa
PBAR	P (bar)	Pressure sensor measured pressure (absolute) in bar
PPSI	P (psi)	Pressure sensor measured pressure (absolute) in psi
IP3	Ip3 (□A) (NOxCANg only)	NOx sensor Ip3 pumping current

Table 4: NOxCAN(g) Parameter List

Producing a .dbc File

A .dbc file describes to the device receiving data from one or more LambdaCAN and/or NOxCAN(g) modules what is in the data packages. For each module, the packages will contain data for the parameters selected in the activated TPDOs and an error code. The Configuration Software has a tool called "Generate .dbc…" that will generate a .dbc file for all the LambdaCAN and NOxCAN(g) modules on a CAN bus. Make sure that each module is configured as desired and that all modules are on the bus before the "Generate .dbc…" button is pushed. Data package information from all the modules is stored in the one .dbc file produced.

Programs importing the .dbc file and applying it to the CAN data transmitted by the modules will see data, etc identified as follows:

Data: **name_nid[units]**

where: name = parameter name. See Table 3 for LambdaCAN, Table 4 for NOxCAN(g)
nid = node id of module in hex
units = units of parameter

for example: O2_0X01[%] which is the %O2 measured by module with nid 0X01

Error code: **ECM_Error_Code_nid**

where nid = node id of module hex
error code is in hex and given in Table 5

for example: ECM_Error_Code_0x11

Auxiliary: **ECM_Auxiliary _time[sec]**

where: time = decrementing countdown to module activation in hex

for example: ECM_Auxiliary_0X12[sec]

ECM ERROR CODE	**LED ACTION**	**DESCRIPTION OF ERRORS**
0x0000	Grn ON	All OK, (green led constantly on)
0x0001	Flash Grn 10Hz	Sensor warm-up period
0x0002	Grn/Both/Red 2s	Power on reset/ Init hardware
0x0011	Pulse Red 1x/2s	16b ADC failed to init
0x0012	Pulse Red 1x/2s	+Vsw shorted
0x0013	Red ON	Sensor turned off (red led constantly on)
0x0014	Pulse Red 1x/2s	HTR open
0x0015	Pulse Red 1x/2s	HTR shorted
0x0021	Pulse Red 2x/2s	1wire bus shorted
0x0022	Pulse Red 2x/2s	No 1wire present
0x0023	Pulse Red 2x/2s	CRC16 error
0x0024	Pulse Red 2x/2s	Invalid 1wire parameter (sensor type)
0x0025	Pulse Red 2x/2s	1-wire data format not compatible (old rev)
0x0031	Pulse Red 3x/2s	+Vsw < 9 for > 7sec
0x0032	Pulse Red 3x/2s	+Vsw > 30V
0x0041	Pulse Red 4x/2s	VS too high
0x0051	Pulse Red 5x/2s	RVS too high
0x0052	Pulse Red 5x/2s	(VHcommanded - VHactual) > 0.5V for > 10sec
0x0061	Pulse Red 6x/2s	VP+ > 6V
0x0062	Pulse Red 6x/2s	VP+ < 2V
0x0063	Pulse Red 6x/2s	VP2 out of range (NOxCAN only)
0x0064	Pulse Red 6x/2s	0.15V > VS+ > 0.75V
0x0065	Pulse Red 6x/2s	User data (span) in 1wire corrupted (user must set new span)
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
0x00FF	Both ON	Module powering down within 500ms
ECM AUX	N/A	Sensor Warm-up count down in seconds (active during ECM Error Code 0x0001)

Table 5: LambdaCAN and NOxCAN(g) Error Codes List

Selecting what Data is to be Sent (TPDOs)

Data send from LambdaCAN and NOxCAN(g) modules is packaged as TPDOs (Transmit Process Data Object). Each TPDO contains two pieces of data and each module can send up to four TPDOs. All selected TPDOs will be sent at the broadcast rate. For example, if the broadcast rate is 5 ms and four TPDOs were selected to be sent, then eight pieces of data would be transmitted every 5 ms. To avoid slowing down the effective data rate on the CAN bus, select the number of TPDOs to be sent and the broadcast rate sparingly. For the case of multiple modules sending multiple TPDOs on the same CAN bus, the minimum (i.e. fastest) broadcast rate is given by:

Minimum Broadcast rate (ms) = The total number of TPDOs for all modules x 0.3125

For example, if there are eight modules, each sending two TPDOs, the minimum broadcast rate is 5 ms.

The data transmitted is selected in the “Data” area of the Configuration Tool. Activate the number of TPDOs to be used by clicking in its box to put in a check mark. Select the data contained in each TPDO using the pull-down windows. The list of available parameters for the LambdaCAN module is given in Table 3. The list of available parameters for the NOxCAN(g) module is given in Table 4.

Note that in the parameter list, there are two Lambdas: LAMR (Lambda Real) and LAM (Lambda).

LAMR is the Lambda value calculated by the module.

LAM is the Lambda value calculated by the module and modified by the Delta Lambda Table according to the relationship:

LAM = LAMR + Delta Lambda Table value (interpolated from table)

The modified LAM (Lambda) will also influence AFR, FAR, and PHI.

Similarly for O2R and O2:

O2 = O2R + Delta O2 Table value (interpolated from table)*

* except when O2R > 18 for which O2 = O2R, regardless of table data.

Processing Data in Host Data Acquisition System

The egrCAN system will output the following parameters at the programmed broadcast rate:

1. The %O2 in air, the %O2 in the intake manifold, the %O2 in the exhaust
2. Lambda operating point of the engine
3. The barometric pressure, intake pressure, and exhaust pressure.

%EGR can be calculated via the following formula in the host data acquisition system:

$$\%EGR = 100 \cdot (O2air - O2int) / (O2air - O2exh) \qquad \text{[Equation 1]}$$

where:

O2air = Parameter O2 (%O2) output by the "air" module.
O2int = Parameter O2 (%O2) output by an "intake" module. An egrCAN system can have multiple intake modules. Thus multiple %EGRs can be reported for different locations (for EGR distribution studies) or stages (for multi-stage EGR systems).
O2exh = Parameter O2 (%O2) output by an "exhaust" module.

Sometimes it is useful to average the calculated %EGR. The following recursive averaging filter is easy to perform in real-time:

$$\mathbf{Averaged\%EGR_t = \alpha \times \%EGR_t + (1 - \alpha) \times Averaged\%EGR_{t-1}}$$

where:

$Averaged\%EGR_t$ = the updated average %EGR value

α = The user-programmable averaging.
Range: 0.001 (heavy averaging) to 1.000 (no averaging).
Recommended: 0.293

$\%EGR_t$ = the latest %EGR value calculated via Equation 1

$Averaged\%EGR_{t-1}$ = the previous average %EGR value

Setting up egrCAN (Calibration)

Ceramic sensors (i.e. O2 (Lambda) and NOx sensors) operate on a diffusion mechanism. Gases diffuse through a passage into the sensor where oxidation, oxygen liberating, and oxygen pumping occurs. The diffusion passage is like a filter and like a filter it can get clogged. In fact, it is impossible for the passage not to get clogged when the sensor is being used. This clogging of the diffusion passage is the main mechanism by which a sensor "ages" resulting in a calibration shift.

The sensors shipped with LambdaCAN and NOxCAN(g) modules have been calibrated (i.e. zeroed and spanned) before leaving the factory. It is recommended that they be calibrated periodically during use. How often can only be determined by your experimentation. Alternatively, the sensors can be sent to ECM for recalibration.

Calibration information (both factory calibration and user calibration) for the O2 and NOx sensors is stored in a memory chip in the sensor's connector. Therefore, the sensor does not have to be used with the module it was calibrated with. Once calibrated, the sensor can be sent to another site to be used. After use, the sensor can be returned to the calibration center for recalibration thus compensating for any sensor aging. Centralization of calibration in this way improves measurement consistency and extends useful sensor life.

Calibration of the O2 (Lambda) Sensor and the Delta Tables

The "Span O2" task is used to calibrate the O2 sensor. This task calibrates both the %O2 and Lambda (AFR, FAR, PHI) measurements from the sensor. To perform an O2 span:

1. The sensor should on for at least 20 minutes. Most of the time, you only need to wait 2 minutes but some sensors, due to condensed material on them or other reasons, take longer to stabilize.
2. Put the sensor and the pressure sensor in ambient, stationary air.
3. Calculate the %O2 in the air. The %O2 in air with no humidity is 20.945. This percentage decreases with increasing humidity. To calculate the %O2 in non-zero humidity air, use the "Calculate %O2 in Air" tool in the Configuration Software. 20.7 is a common number.
4. Make sure O2 is a TPDO parameter.
5. Select the Task "Span O2". Enter the displayed (as the TPDO) O2 and the actual %O2 (as calculated in 3 above), then click on "Span".

◆ **Special Note Re. Calibration of "Intake" O2 Sensor**

Sometimes after calibration of the "Intake" O2 sensor in air, the sensor will read a higher (i.e. 0.2 to 0.8 higher) %O2 when installed in the intake of a running engine with zero EGR. This is due to a thermal effect of the O2 sensor.

To compensate for this effect, perform the following in-situ SPAN of the intake O2 sensor:
Mount the intake O2 and pressure sensors to the intake manifold, bring the engine to operating temperature with zero EGR, shut off the fuel, motor the engine for 5 seconds (to fill the intake manifold with air), stop the engine, and perform the "Span O2" task.

◆ **Delta O2 Table and Delta Lambda Table**

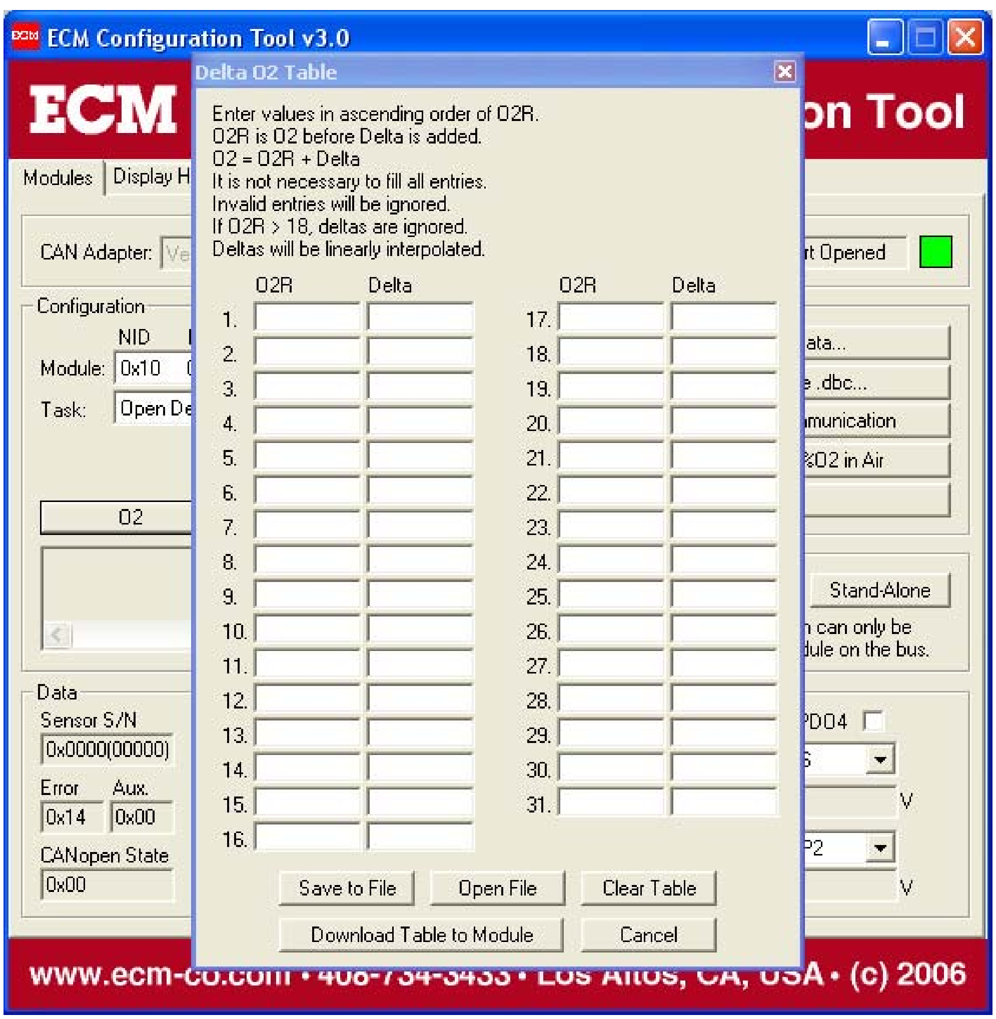
The %O2 calculated by LambdaCAN and NOxCAN(g) modules is denoted as "O2R" and is a wet (i.e. water taken into consideration in %O2 calculation), at chemical-equilibrium (i.e. not frozen-equilibrium) %O2 measurement (see Appendix C). The Lambda (AFR, FAR, PHI) calculated by the LambdaCAN and NOxCAN(g) modules is denoted as "LAMR" and matches that calculated by mass flowrates of air and fuel entering the engine.

Sometimes users would like dry %O2 readings, or frozen-equilibrium %O2 readings, or dry frozen-equilibrium readings, or readings that match another instrument. For this purpose, the Delta O2 Table is used. The Delta O2 Table (found in the task "Open Delta Tables") allows the user to add a number (a "delta") to the "O2R" calculated by the LambdaCAN and NOxCAN(g) modules giving the "O2" parameter:

O2 = O2R + Delta O2 Table value (interpolated from table)*

* except when O2R > 18 for which O2 = O2R, regardless of table data.

A Delta O2 Table can be created, edited, and saved as a text file (.txt) on your PC. The file must be downloaded into the LambdaCAN or NOxCAN(g) module for it to be used. Unlike the sensor calibration information (i.e. zero, span) which is stored in a memory chip in the sensor's connector, the Delta O2 Table is stored in the module.



Similarly, sometimes users would like Lambda (AFR, FAR, PHI) readings to match other instruments such as gas-bench analyzer calculated values (ex. via Spindt or Brettschneider) or company "heritage" Lambda measurement techniques. The Delta Lambda Table (found in the task "Open Delta Tables") allows to user to add a number (a "delta") to "LAMR" calculated by the LambdaCAN and NOxCAN(g) modules giving the "LAM" parameter:

LAM = LAMR + Delta Lambda Table value (interpolated from table)

AFR, FAR, and PHI are calculated from "LAM". A Delta Lambda Table can be created, edited, and saved as a text file (.txt) on your PC. The file must be downloaded into the LambdaCAN or NOxCAN(g) module where it is used. File LA42.TXT (for LSU4.2 sensor) or file LA49.TXT (for LSU4.9 sensor) can be downloaded to make LambdaCAN and NOxCAN(g) modules match default ETAS LA4 data (see Appendix C). Unlike the sensor calibration information (i.e. zero, span) which is stored in a memory chip in the sensor's connector, the Delta Lambda Table is stored in the module.

Calibration of NTK NOx Sensor and the Delta Tables (NOxCAN Only)

The NOxCAN kit (not the NOxCANg kit) uses the NGK Spark Plugs (NTK) NOx sensor. This sensor has an 18mm thread. The following applies to the calibration of the NOxCAN kit only. For the NOxCANg kit, refer to the next section.

There are two parts of the NOx sensor: the O2 (Lambda, AFR, FAR, PHI) measuring part and the NOx measuring part. The O2 (Lambda, AFR, FAR, PHI) measuring part should be calibrated in a similar manner as it is for the Lambda sensor (i.e. using "O2 Span"). It is important to realize that when in the exhaust of a running engine, the NOx sensor is seeing water vapor. Therefore it will report "wet" %O2 and ppm NOx numbers. Classical gas analysis equipment (ex. NOx Chemiluminescent Analyzer (CLA)) typically have the water removed from the gases before they reach the analyzer. Thus classical gas analysis equipment will report "dry" numbers. When comparing "wet" to "dry" numbers make sure to compensate for the removed water.

The calibration of the NOx measuring portion of the NTK NOx sensor is more complex than the O2 part. First some characteristics of the NTK NOx sensor must be understood:

The NTK NOx sensor was designed to be used in a hot exhaust pipe. If it is mounted in a cold sample tube, the NOx measurement response will be very slow (i.e. hundreds of seconds). Also, the zero and gain of the NOx measurement is sensitive to changes in the exhaust pipe's temperature. To reduce this sensitivity, ECM offers a heated NOx sensor mount (the BTU200). With or without the BTU200, for best accuracy the NOx sensor should be calibrated in a mounting pipe and pipe temperature similar to that it will be used at.

The gases the NOx sensor is measuring must contain water. Since the combustion of hydrocarbon fuels produces 5 to 15% water (depending on fuel type and Lambda), this is not a problem unless the sensor is placed after a water separator. Also, for best accuracy, the NOx sensor should be calibrated in gases with approximately the same amount of water vapor as is in the exhaust it will be measuring.

When the NOx sensor is off (i.e. cold) and is stored for a period longer than a few days, the sensor may adsorb water vapor. This results in a NOx measurement error until the water is boiled off the sensor. When the sensor is used in an engine, this will occur quickly. However, if the sensor is held in air or is mounted in a cold pipe with slow moving gases, it may take up to eight hours for the water to boil off.

To minimize above-described effects, it is strongly recommended that the NOx zero and span be performed with the NOx sensor mounted in the exhaust of a running engine and in comparison to a CLA (chemiluminescence) NOx analyzer. It is not recommended that the NOx sensor be calibrated using the CLA's zero and span gases (i.e. "model gases") because the NOx sensor will be mounted in a cold tube during this calibration and water vapor will not be present in suitable quantities in the calibration gases.

Therefore, the recommended calibration procedure for the NTK NOx sensor is:

1. Hold the powered NOx sensor and pressure sensor (if so equipped) in air for eight hours. This is to remove any adsorbed water. Pressure information is required if the calibration is to be pressure compensated.
2. "Span O2" the sensor in a manner similar to the Lambda sensor.
3. "Zero NOx" the sensor in a running engine and in comparison to a NOx CLA. The NOx level doesn't have to be exactly zero for the zero process. For example, if it is 12 ppm, the Configuration Software will allow this.
4. "Span NOx" the sensor in a running engine and in comparison to a CLA. Span at the upper range of NOx to be measured.

If a CLA is not available, the back-up calibration procedure for the NTK NOx sensor is:

1. Hold the powered sensor in air for eight hours. This is to remove any adsorbed water.
2. "Span O2" the sensor in a manner similar to the Lambda sensor.
3. "Zero NOx" the sensor while it is attached to a BTU200 or in a tube heated to the temperature of the exhaust pipe the sensor will be used in. For general-purpose use, zero the sensor in gases containing approximately 20% O2 (balance N2). **IMPORTANT NOTE**: Do not zero in pure N2 or N2 bubbled through water! This damages the sensor.
4. "SPAN NOx" the sensor in the same heated condition as the "Zero NOx" using a NOx + O2 + N2 span gas that has been bubbled through water. Correct the span NOx ppm content of the gas using the formula:

NOx (corrected) = NOx (in tank) x ((%O2 in air)/20.945)

where: "%O2 in air" is determined using the "Calculate %O2 in Air" tool with Rh=100%, the pressure in the bubbler, and the water temperature in the bubbler.

The following conditions may result in inaccurate NOx readings:

1. If the sensor is not held in air for eight hours (while powered) prior to calibration.
2. If the pipe the sensor is mounted in during calibration is not heated.
3. If the calibration model gases are not bubbled through water.

4. If the calibration model gases change composition while flowing from the tanks to the sensor.
5. If the NOx sensor is subsequently used in an unheated sample line.
6. If the NOx sensor subsequently measures exhaust gases after these gases have passed through a water separator.

IMPORTANT NOTE: ECM has found it very difficult to accurately calibrate the NTK NOx sensor using model gases. Calibrate in an engine and in comparison to a NOx CLA if possible.

The NOxCAN module supports the Delta O2 Table and Delta Lambda Table features as described in the lambda sensor calibration section. There is no Delta NOx Table feature.

Calibration of NGK NOx Sensor and the Delta Tables (NOxCANg Only)

The NOxCANg kit (not the NOxCAN kit) uses the NGK Insulators (NGK) NOx sensor. This sensor has a 20mm thread. The following applies to the calibration of the NOxCANg kit only. For the NOxCAN kit, refer to the previous section.

There are two parts of the NOx sensor: the O2 (Lambda, AFR, FAR, PHI) measuring part and the NOx measuring part. The O2 (Lambda, AFR, FAR, PHI) measuring part should be calibrated in a similar manner as it is for the Lambda sensor (i.e. using "O2 Span"). It is important to realize that when in the exhaust of a running engine, the NOx sensor is seeing water vapor. Therefore it will report "wet" %O2 and ppm NOx numbers. Classical gas analysis equipment (ex. NOx Chemiluminescent Analyzer (CLA)) typically have the water removed from the gases before they reach the analyzer. Thus classical gas analysis equipment will report "dry" numbers. When comparing "wet" to "dry" numbers make sure to compensate for the removed water.

The NOxCANg kit requires that the user select whether he is using the NOx sensor in the exhaust of an engine or in model gases (bubbled NOx + O2 + N2). This is selected by the "Select NOx Curve" task. This selection modifies the calculated NOx. Additionally there are four O2 compensation parameters (two gammas, and two betas) that affect the calculated NOx. One set of gamma, beta is used for the engine NOx calculation and the other for the model gas NOx calculation. These numbers are factory-set to nominal values, stored in the sensor's memory chip, and should not be changed without contacting ECM. Unlike the NOxCAN kit, use of a heated NOx sensor mount (the BTU200) is not necessary with the NOxCANg kit.

The calibration of the NOx measuring portion of the NGK NOx sensor can be performed either in the exhaust of an engine or using model gases. Model gases are mixtures of NOx, O2, and N2 that have been bubbled through water before reaching the sensor.

When calibrating the NGK NOx sensor using engine gases, the recommended procedure is:

1. Hold the powered NOx sensor and pressure sensor in air for 20 minutes. Pressure information is required if the calibration is to be pressure compensated.
2. Select "Engine" in the task "Select NOx Curve".

3. “Span O2” the sensor in a manner similar to the Lambda sensor.
4. “Zero NOx” the sensor in a running engine and in comparison to a CLA. The NOx level doesn’t have to be exactly zero for the zero process. For example, if it is 12 ppm, the Configuration Software will allow this. Since water is in the gases that the NOx sensor is seeing, it is best to use a “wet” NOx number from the CLA. If you do not do this, you are putting an error into the measurement since %H2O, and hence the difference between a “wet” and “dry” measurement, changes with stoichiometry.
5. “Span NOx” the sensor in a running engine and in comparison to a CLA. Span at the upper range of NOx to be measured. Again, it is best to use a “wet” NOx number from the CLA.

When calibrating the NGK NOx sensor using model gases, the recommended procedure is:

1. Hold the powered NOx sensor and pressure sensor in air for 20 minutes. Pressure information is required if the calibration is to be pressure compensated.
2. Select “Model Gas” in the task “Select NOx Curve”.
3. “Span O2” the sensor in a manner similar to the Lambda sensor.
4. “Zero NOx” the sensor in ambient, stationary air (i.e. same condition as “Span O2”). **IMPORTANT NOTE**: Do not zero in pure N2 or N2 that has been bubbled through water! This will damage the sensor.
5. Mount the sensor in a vessel and pass bubbled model gases of the composition NO + O2 (approximately 20%) + N2 (balance) past the sensor. The ppm NO should be close to the ppm that will be measured in use**.** **IMPORTANT NOTE**: Do not span in a mixture that contains less than 1% O2! Use approximately 20% O2 for best calibration.
6. Correct the span NOx ppm content of the gas for water vapor using the formula:

NOx (corrected) = NOx (in tank) x ((%O2 in air)/20.945)

where: “%O2 in air” is determined using the “Calculate %O2 in Air” tool with Rh=100%, the pressure in the bubbler, and the water temperature in the bubbler.

IMPORTANT NOTE: We have found that the best calibration is performed based on measured NOx data from a NOx CLA sampling from the vessel holding the NOx sensor (i.e. not using the above formula). We believe that this is because of reactions that occur in the lines from the tanks to the sensor.

7. “Span NOx” when the displayed NOx is stable.
8. Select “Engine” in the task “Select NOx Curve” before using the NOx sensor in an engine.

The NOxCANg module supports the Delta O2 Table and Delta Lambda Table features as described in the lambda sensor calibration section. There is no Delta NOx Table feature.

Using the dashCAN Display

The dashCAN display (see below) is a small (105 mm x 63 mm x 63 mm), two-channel remote display for CAN networks containing LambdaCAN and NOxCAN(g) modules. dashCAN comes with a two meter cable and a "T" (P/N 09-05). Simply attach dashCAN to the CAN bus and any two parameters being transmitted from LambdaCAN and NOxCAN(g) modules can be displayed. dashCAN can display parameters from the same module or two different modules. Multiple dashCAN displays can be attached to the CAN bus.

dashCAN has two modes of operation: RUN (when measurements are displayed) and SYS (where dashCAN is set-up). The SYS key toggles between the modes.

While in RUN mode:

1. If the ↑ button is pressed, the displays will show the serial numbers of the modules assigned to the displays.
2. If the ↓ button is pressed, the displays will show the parameter names assigned to the displays. See Tables 2 and 3.
3. If the ENT button is pressed, the displays will show the units of the parameters.
4. "PCTG" is %. "dIM" means dimensionless (ex. for AFR, FAR, PHI, Lambda).

In RUN mode, four things other than data can be displayed:

1. "ERR" and "####" where "###" is an error code. See Table 5.
2. "…." which means that a module has not been assigned to that display.
3. "----" which means that dashCAN has an internal problem.
4. "XXXX" which means that dashCAN is not receiving any data from the module assigned to that display.

When first entering SYS mode, either "MOd" will be on the upper display or "LOCK" will be on the lower display. If "MOd" is displayed, the ↑ and ↓ keys will roll through the setup options (see Table 6). First the options for the upper channel are shown on the upper display, followed by identical options for the lower channel on the lower display, ending with the global CONF (Configuration) setup. Pressing the ENT key will select the displayed setup option and allow its programming.

If "LOCK" is displayed, the dashCAN has been locked and its setup cannot be changed until it is unlocked. Appendix E describes how to LOCK and unlock dashCAN.

Setup Option	Level 1	Function
MOd		Select module s/n. Default is NONE.
RATE		Set parameter averaging rate. Range 0.001 to 1.000 Default is 1.000
dISP		Select parameter. Note: Parameters available are those programmed using Configuration Software.
CONF	LEdS LOCK	Set display intensity. Default is 3333. Lock and Unlock Display for Programming

MOd, RATE, and dISP appear on the upper display for the upper channel and on the lower display for the lower channel. CONF just appears on the lower display and is for global dashCAN setup. All entries must be followed by pressing the ENT key.

Table 6: Menu Tree for dashCAN

MOd (Module) Setup Option

In MOd setup, the serial number of the module assigned to the upper or lower channel is entered. The serial number is written on a label on the module. The module assigned to the upper channel will send information to the upper display and the module assigned to the lower channel will send information to the lower display. The same module can be assigned to both channels or different modules can be assigned to each channel.

After entering MOd (i.e. press ENT when "MOd" is displayed), the serial numbers of the available modules will be displayed. Select using ↑ and ↓ followed by the ENT key.

RATE Setup Option

Data is transmitted from modules at the broadcast rate and the programmed averaging that was programmed using the Configuration Software. This transmitted data can then be further averaged before being displayed on the displays. Separate averaging can be programmed for the upper display and the lower display.

The averaging is programmed with values from 0.001 (heavy averaging) to 1.000 (no averaging). The default is 1.000. The averaging is performed as follows:

$$\mathbf{DisplayedValue_t = \alpha \times Parameter_t + (1 - \alpha) \times DisplayedValue_{t-1}}$$

where:

$DisplayedValue_t$ = the new displayed value

α = The user-programmable averaging.
Range: 0.001 (heavy averaging) to 1.000 (no averaging).

$Parameter_t$ = the latest value transmitted by the module

$DisplayedValue_{t-1}$ = the previous displayed value

The selected display averaging does not affect the module's CAN transmission rate or averaging.

dISP (Display) Setup Option

In dISP setup, the parameters to be displayed are selected. Only parameters selected to be transmitted by the Configuration Software can be displayed.

Here is an example of setting the parameter to be displayed on the upper display:

1. Press the SYS key until “MOd” is displayed.
2. Press the ↓ key until “dISP” is on the top display. Then press the ENT key.
3. Press the ↓ key until desired parameter name is displayed. See Tables 3 and 4. Then press the ENT key.
4. Press SYS to return to RUN mode.

CONF (Configure) Setup Option

CONF setup appears at the end of the setup list on the lower display. To enter CONF, press the SYS key until “MOd” appears on the upper display, press the ↓ key until “CONF” appears on the bottom display, and then press the ENT key. CONF is for global dashCAN setup.

◆ **LEdS**

The display intensity is programmable. Press the ENT key when “LEdS” appears on the lower display, press the ↑ or ↓ keys until the display intensity is suitable, press ENT, and press SYS to return to RUN mode.

◆ **LOCK**

“LOCK” locks the MOd, RATE, dISP, and LEdS setup. This stops unauthorized modification of the display. Refer to Appendix E for more information.

Specifications and Limits

Measurements and Accuracies

Parameter	Range	Response Time	Accuracy
$\%O_2$	-25 to 25%[1]	< 150 ms [4]	±0.2
Lambda (λ)	0.4 to 25	< 150 ms [4]	±0.005 (at λ=1) ±0.008 (0.8<λ<1.2) ±0.009 (elsewhere)
AFR	6 to 364[2]	< 150 ms [4]	±0.1 (at 14.6 AFR) ±0.2 (12<AFR<18) ±0.5 (elsewhere)
Equivalence Ratio (Φ)	0.04 to 2.5	< 150 ms [4]	±0.005 (at Φ =1) ±0.008 (0.8< Φ <1.2) ±0.009 (elsewhere)
FAR	27 to 1667[2,3]	< 150 ms [4]	±5 (at 687 FAR) ±14 (555<FAR<833)
Pressure	0 to 517 kPa/75 Psia	< 50ms [5]	±0.2 Psia ±1.4 kPa

[1] For stoichiometries leaner than Lambda=1, negative $\%O_2$s are displayed. This novel convention is sometimes used with lean-burn engines.
[2] AFR and FAR range given for a fuel with an H:C ratio of 1.85.
[3] FAR x 10000 is displayed. This is the most commonly used way to express FAR. For example, with an H:C=1.85 fuel, Lambda=1 is FAR=686.8.
[4] The response times are affected by averaging filter "alpha lambda" (for Ip1, $\%O_2$, λ, AFR, Φ, FAR).
[5] The response times are affected by averaging filter "alpha P" (for P, PVLP, PKPA, PBAR, PPSI).

Sensor Limits and Specifications

◆ **O_2 Sensor**

Gas Temperature Range: 0 - 850 °C, 32 - 1562 °F

Maximum Temperature: 950 °C, 1742 °F

Maximum Rate of Temperature Change: 50 °C/s, 122 °F/s

Fuel Composition:

H:C ratio range: 1.00 - 10.00, or Hydrogen (H_2)
O:C ratio range: 0.00 - 10.00
N:C ratio range: 0.00 - 1.00

gasoline: 1.70 < H:C < 2.10, O:C=0.0, N:C=0.0, (1.75 or 1.85 are commonly used)
methanol: H:C=4.0, O:C=1.0, N:C=0.0
ethanol: H:C=3.0, O:C=0.5, N:C=0.0
propane: H:C=2.67, O:C=0.0, N:C=0.0
methane: H:C=4.0, O:C=0.0, N:C=0.0

Maximum allowable levels of fuel "Impurities":

Lead: 0.012 gm/gal., 0.003 gm/ltr.
Phosphorous: 0.0008 gm/gal., 0.00027 gm/ltr.
Sulfur: 0.035% by weight

Do not use the O_2 sensor in a heavily-sooting or crankcase-oil-burning engine because these conditions will shorten the life of the sensor.

Thread Size: 18mm x 1.5 mm. Lightly coat with non-lead containing antiseize compound. The O_2 sensor's thread size is identical to that of the exhaust gas oxygen (EGO) sensors used in current production automobiles with 3-way exhaust catalysts.

Hex Size: 22 mm

Tightening Torque: 40 ±4 Nm, 30 ±3 ft-lbf for exhaust O_2,
4 ±1 Nm, 3 ±1 ft-lbf for intake O_2

◆ **Pressure Sensor**

Note: Must attach to engine via pressure sensor tubing only!
Do not directly attach to the engine or pressure sensor damage will result.

Diaphragm Material: Stainless steel

Maximum Pressure: 200 Psia, 1379 kPa (absolute)

Operating Temperature Range: -40 to 105 °C

Thread on Pressure Sensor: ¼” NPT

Fitting on Pressure Sensor: Swagelok SS-400-7-4 to mate with ¼” tube (USA) or
Swagelok SS-6MO-7-4 to mate with 6 mm tube (Metric)

◆ **Pressure Sensor Tubing**

Note: Stainless steel end of tubing towards engine. Teflon end towards pressure sensor.

Mating Thread with Engine: ¼” NPT (USA) or ¼” ISO tapered (Metric)

Tubing Assembled Length: 19” (USA) or 483 mm (Metric)

Tubing Diameter: ¼” (USA) or 6mm (Metric)

Nut, Front Ferrule, Back Ferrule at Pressure Sensor end of Tubing:
Swagelok SS-402-1, SS-403-1, SS-404-1 (USA) or
Swagelok SS-6M3-1, SS-6M4-1, SS-6M2-1 (Metric)

Union between Stainless Steel and Teflon Tubing: Swagelok SS-400-6 (USA) or
Swagelok SS-6MO-6 (Metric)

Fitting on Engine End of Tubing: Swagelok SS-400-1-4, ¼” tube to ¼” NPT (USA) or
Swagelok SS-6MO-1-4RT, 6 mm tube to ¼” ISO tapered (Metric)

Output Specifications

◆ **CAN**

Protocol: Broadcast

Speed: 500 kHz

Isolation: Electrically isolated from power supply ground

General Specifications

◆ **Power**

DC: 11 to 28 VDC

Current Draw: 2A steady-state (per module and sensors),
On start-up, O_2 sensor and module may draw as much as 4A for 30 s.

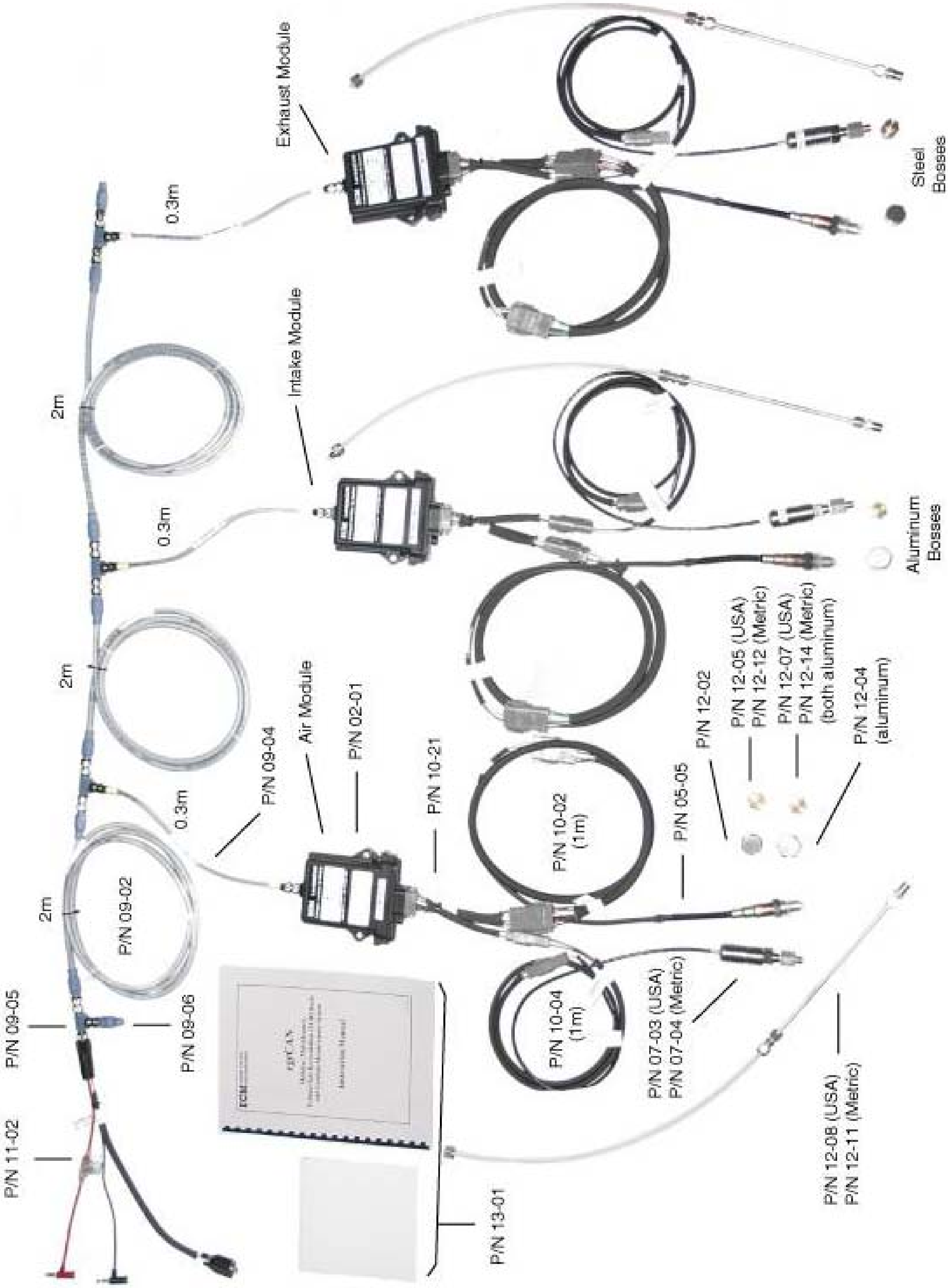
◆ **Environment**

Module: IP67, -55 to 125 °C, 100% humidity, module is sealed

◆ **Dimensions and Weight**

Module: 120 mm x 37 mm x 143 mm, 4 ¾” x 1 ½” x 5 ¾”, (W x H x D)
244 gm, 8.7 oz

Appendix A: egrCAN Kit Contents (Basic System)



The Basic egrCAN Kit consists of:

	Description	P/N	Quantity
1.	LambdaCAN Control Module	02-01	3
2.	O2 Sensor	05-05 (LSU4.2, Type P)	3
3.	Pressure Sensor, 0-75 psia, 517 kPa	07-01 (USA) or 07-02 (metric)	3
4.	Pressure Sensor Tubing	12-08 (USA) or 12-11 (metric)	3
5.	Module Y Cable	10-21	3
6.	Lambda Extension Cable	10-02 (1m)	3
7.	Pressure Extension Cable	10-04 (1m)	3
8.	2m Eurofast 12mm Cable	09-02	3
9.	Flexi-Eurofast Cable	09-04 (0.3m)	3
10.	Eurofast "T"	09-05	4
11.	Eurofast Terminating Resistor	09-06	2
12.	DC Power Cable, DB9F, Banana	11-02	1
13.	18mm x 1.5mm MS Boss and SS Plug	12-02	2
14.	18mm x 1.5mm Tall Aluminum Boss, Gasket, Plug	12-04	2
15.	¼" Tapered MS Boss and Brass Plug	12-05 (USA) or 12-12 (Metric)	2
16.	¼" Tapered Aluminum Boss and Brass Plug	12-07 (USA) or 12-14 (Metric)	2
17.	Manuals and Configuration software CD	13-01	1

Appendix B: Module Stand-alone Mode and EIB Mode

CAN data from LambdaCAN and NOxCAN(g) modules can either be taken directly from the modules themselves or from the CAN port of display heads connected to the modules. When data is taken directly from one or more modules, each module must in Stand-alone mode. When data is taken from one or more display heads of an EGR 5210, Lambda 5220, or EGR 5230 analyzer, each module must be in EIB mode.

Therefore, the module must be properly configured in Stand-alone mode or EIB mode depending on how it will be used. When LambdaCAN and NOxCAN(g) modules are sold alone, they are delivered in Stand-alone mode. When LambdaCAN and NOxCAN(g) modules are sold as part of a NOx 5210, Lambda 5220, or EGR 5230 analyzer, they are delivered in EIB mode.

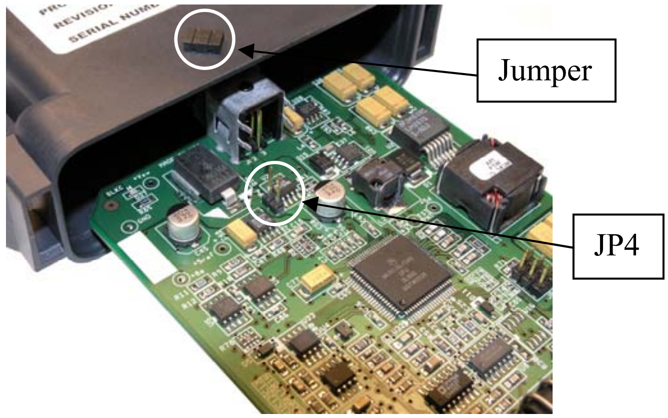
To convert from one mode to the other requires software reprogramming of the module followed by the installation (to set to Stand-alone) or removal (to set to EIB) of a jumper inside the module.

◆ **To convert a module from EIB to Stand-alone Mode**

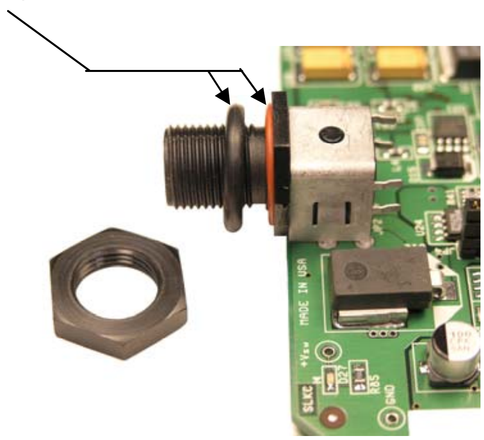
1. Take the nut off the end of the module. Use an 18mm socket without the wrench.

2. Release the two tangs at each side of the module.

3. Slide the PCB out. Install a jumper on JP4.



5. Make sure both O-rings are on the threaded connector.



6. Slide the PCB into the enclosure until the two tangs “click”.

7. Put the nut on and tighten ONLY ½ turn from where it is seated. If this nut is tightened too much, the connector will crack and the enclosure will not be sealed.

8. Connect the module to a power supply and a PC (via a CAN communication adapter) using the cabling shown. A sensor does not have to be connected to the module. Note that only one module is connected and a display head is not involved.

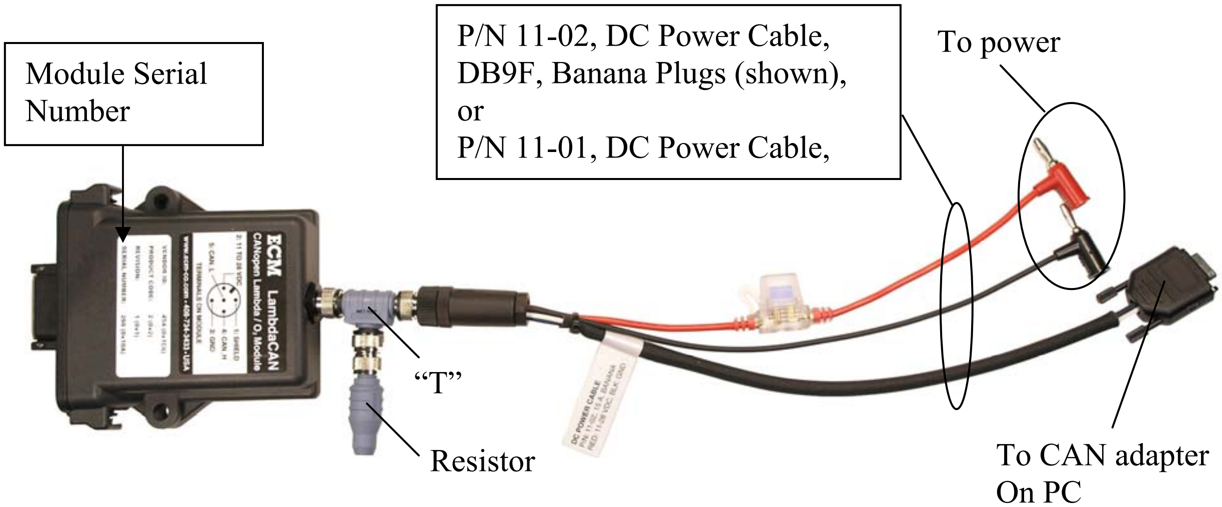
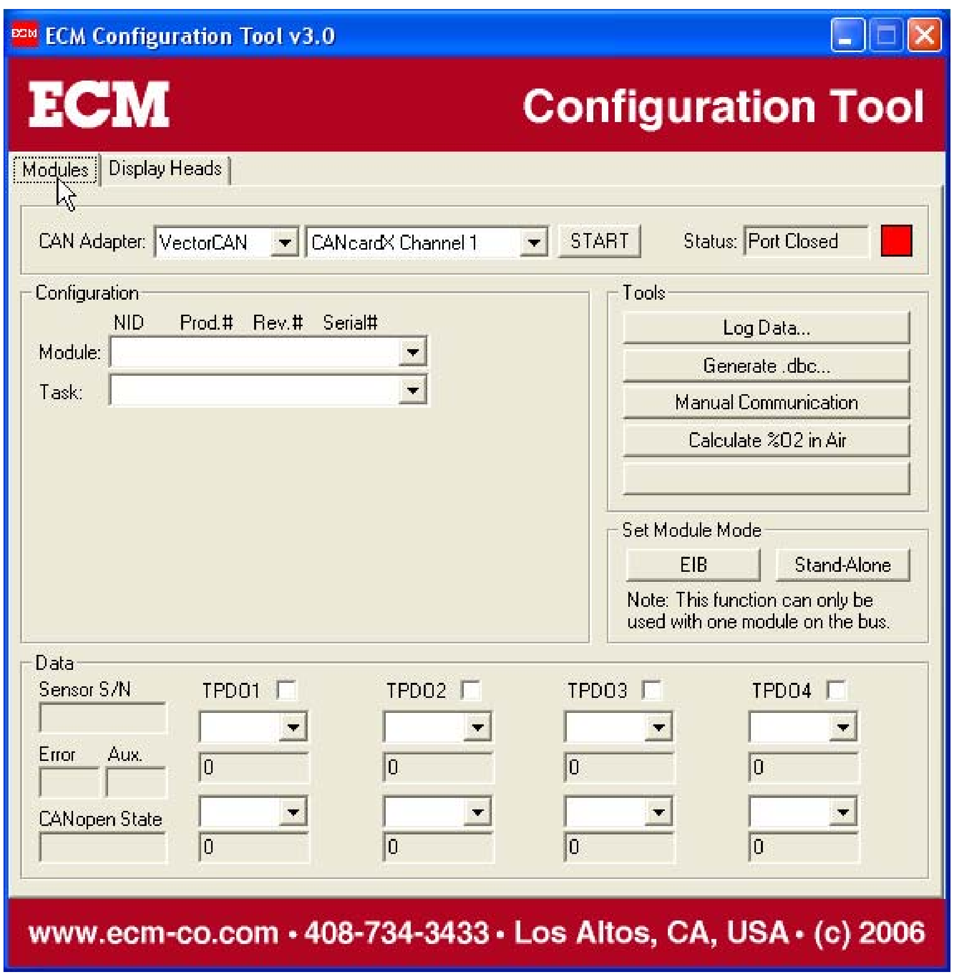


Figure A1: Module prepared for Reprogramming

9. Start the Configuration Tool (software). Click on the "Module" tab. Select the CAN adapter being used. Then start the communication.



10. Click on the “Set to Stand-Alone Mode”. Wait for “Done” Message.
    Stop communication and exit program. The module is in Stand-alone mode.

◆ **To convert a module from Stand-alone Mode to EIB Mode**

1. Use the Configuration Tool (software) to “Set to EIB Mode”.
2. Remove the jumper on JP4 in the lambda module.

Appendix C: Interpreting Data from LambdaCAN and NOxCAN(g) Modules

◆ Comparing to Spindt and Brettschneider Calculations

LambdaCAN and NOxCAN(g) calculate Lambda, AFR, FAR, and PHI numbers comparable to those determined by mass flowrates of air and fuel into the engine. Lambda calculations based on gas-bench analyzer data (i.e. measurements of CO, CO2, etc) do not always give these same values. This fact is well documented in the literature.

However, some organizations prefer to call their specific (and often unique) Spindt or Brettschneider calculations of Lambda the "true" values. To satisfy such needs, ECM has provided the Delta Lambda Table and Delta O2 Table features.

◆ Before and After Catalyst Measurements

The Lambda and NOx sensors operate on a diffusion mechanism. Molecules leaving the combustion chamber (O2, CO, CO2, H2O, H2, HC, NOx, N2, etc) diffuse into the sensor where oxidation, oxygen liberating, and oxygen pumping occurs. O2, Lambda, AFR, FAR, and PHI are determined from the oxygen pumping rate and assumptions about the combustion products entering the sensor. One such assumption is that the exhaust exists in a certain chemical composition. Exhaust gases entering and exiting a catalytic converter have different chemical compositions. LambdaCAN and NOxCAN(g) assume that the gases are engine-out (not catalyst-out). Therefore measurements made at the exit of a catalyst will require a Delta O2 Table and a Delta Lambda Table correction to be accurate. This is sometimes called "H2 Correction".

◆ Wet versus Dry Measurements

Percentages of components in the exhaust of an engine are expressed as percentages (molecule count or volume) or ppm. The numerator used to calculate these percentages and ppm contains the molecule-of-interest count and the denominator contains the total number of molecules in the sample containing the "count". One of the molecules produced by the process of combustion, and in significant quantities (ex. 15%), is H20.

Percentages and ppm calculated by LambdaCAN and NOxCAN(g) consider the water molecules in the denominator and are called "wet" percentages (or ppm). This only makes sense since the sensors are directly in the exhaust where the H2O is present. In contrast to this, classical gas-bench analyzers almost always remove the water before the gas sample reaches the analyzers. This is because the analyzers cannot tolerate condensed water. Therefore, gas-bench analyzers will report O2 percentages and NOx ppms as "dry" percentages (or ppm) (i.e. without H2O molecules counted in the denominator).

Therefore, when comparing "wet" (or "true") O2 and NOx data from LambdaCAN and NOxCAN(g) to "dry" O2 and NOx data from gas-bench analyzers, realize that the dry percentages and ppm will be 5% to 10% higher than the wet (or true) readings. The wet to dry conversion for %O2 is a function of %O2 (or Lambda) and can be performed by using a

Delta O2 Table. The wet versus dry reporting of NOx is best resolved by how the NOxCAN(g) is zeroed and spanned. If you want wet numbers, calibrate using wet (i.e. water-compensated) CLA data. If you want dry numbers, calibrate using dry CLA data.

◆ **Equilibrium versus Non-Equilibrium O2**

Gases exiting the combustion chamber of an Otto or Diesel cycle engine are not at chemical equilibrium. As the exhaust valve opens, the gas temperature and pressure drop so quickly that many chemical reactions still occurring are slowed down or "frozen" at non-equilibrium values (for the specific temperature and pressure they are at). This degree of chemical non-equilibrium is affected by exhaust valve timing and ignition timing. The Lambda and NOx sensors are hot and highly catalytic and will bring the exhaust they sample closer to chemical equilibrium. The result of this is that the %O2 measured by the Lambda and NOx sensor will be close to equilibrium levels (typically 0.5% lower than actual engine-out). For example, at Lambda = 1 conditions, the %O2 reported by the Lambda and NOx sensor will be 0 (the chemical equilibrium %O2 value) as opposed to the actual frozen equilibrium %O2 value of approximately 0.5%. Keep this in mind when comparing gas-bench measured %O2 with Lambda and NOx sensor-measured O2. This difference can be corrected for by a Delta O2 Table.

◆ **Lambda Sensor-Measured O2 versus NOx Sensor-Measured O2**

Both the Lambda sensor and the NOx sensor will report %O2. However, the NOx sensor will not measure %O2 (and hence Lambda, AFR, FAR, and PHI) as accurately as the Lambda sensor. This is because in the Lambda sensor, the electrodes measuring %O2 are pure platinum. Pure platinum electrodes give best %O2 measuring performance. In the NOx sensor, the %O2 measuring electrodes have some gold in them which keeps the electrodes from destroying the NOx in the exhaust. NOx is measured in a second set of electrodes downstream of the %O2 measuring electrodes. If the first set of electrodes were pure platinum, the NOx would not reach the second set.

◆ **Pressure**

The main source of error influencing O2 (Lambda, AFR, FAR, PHI) measurements is exhaust pressure. This error is more significant the further from Lambda = 1 the exhaust stoichiometry gets. Pressure compensation (P-comp) data is stored in the memory chip of every Lambda and NOx sensor. All that is required is the addition of a calibrated pressure sensor to the module and the entering of the correct pressure sensor constants to activate the pressure compensation. It is highly recommended that pressure compensation be used with any lean burn, HCCI, or diesel engine.

◆ Comparing to an ETAS LA4 Meter

Many ETAS meters with new sensors will not correctly show the %O2 when the sensor is held in air. The actual %O2 in air depends on the humidity and will be almost always less than 20.945%. Since the measurement of %O2 is the fundamental mechanism by which the wideband sensor determines Lambda, the effect that this error has on meter accuracy is obvious. This %O2 measurement error will have a negligible effect at Lambda=1 but the effect on Lambda will increase the further Lambda gets from Lambda=1.

All lambda meters should read the correct %O2 when the sensor is held in air. Due to sensor aging and changes in ambient pressure (due to weather and altitude changes), this may not be the case. However, LambdaCAN and NOxCAN(g)'s "Span O2" feature allows to user to restore the system's accuracy.

The O2 span is performed by holding the sensor in air and entering the actual %O2 in air. However, if you are comparing a LambdaCAN or NOxCAN(g) to an ETAS meter and you want the LambdaCAN or NOxCAN(g) to match the ETAS meter, then you must span the LambdaCAN or NOxCAN(g) to whatever the ETAS meter says the %O2 is in air – even if it is wrong.

Therefore, if you want a LambdaCAN or NOxCAN(g) to match an ETAS meter, whether or not the ETAS meter reads the correct %O2 in air, do the following:

1. Make certain that the "LA42.TXT" (for the LSU4.2 sensor) or "LA49.TXT" (for the LSU4.9 sensor) curve is downloaded to the LambdaCAN or NOxCAN(g) module as the "Delta Lambda Table". This is for the case of matching the "Default Curve" in the ETAS meter. Other curves are available and the user can create his own curve.

2. Turn on the ETAS meter and hold the sensor in air. Read the %O2 on the ETAS meter. This value should be 20.945 or less since 20.945 is pure air with no humidity. We have seen values of over 22%.

3. O2 span the LambdaCAN or NOxCAN(g) to the %O2 given on the ETAS meter even if it is wrong.

This procedure is to be used only if you want the LambdaCAN or NOxCAN(g) to match a specific ETAS meter and sensor combination. Normally, the LambdaCAN and NOxCAN(g) are spanned to the correct %O2 in air.

Appendix D: Setting Up ETAS INCA for ECM Modules

Hardware Setup: Using ETAS ES591.1

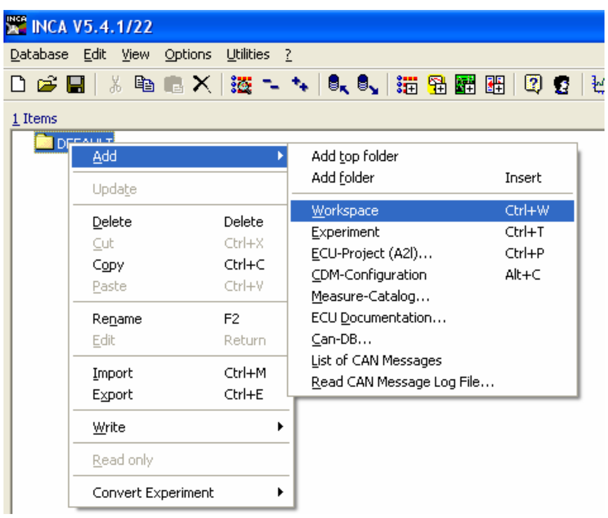
1. Connect the power port to a power source between 6V and 32V.
2. Connect the Ethernet port directly to the Ethernet port on your PC. This port does not use an internet/intranet connection like a router.
3. Connect either the CAN1 or CAN2 port to a CAN network (i.e. ECM modules or display heads).

Software Setup: Using ETAS INCA V5.4.1, Hotfix 22, GM Install

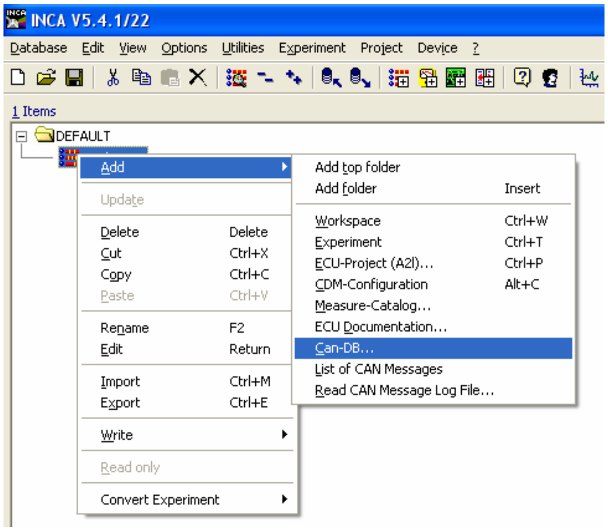
1. Double click the INCA V5.4 icon to open the software.

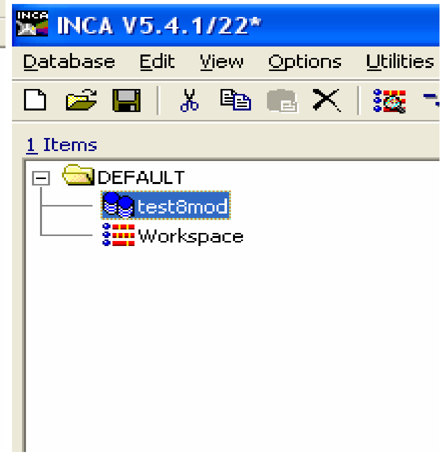
2. **Create a new Database**. In the Database menu, select New. Give your database a name (i.e. a folder name). In INCA, a Database means the current working directory. Each project is created in a unique directory. When INCA is opened, it will default to the last Database that was used.

3. **Add a new Workspace**. Right click on the "DEFAULT" folder icon, select Add > Workspace. You can rename it to whatever you want.

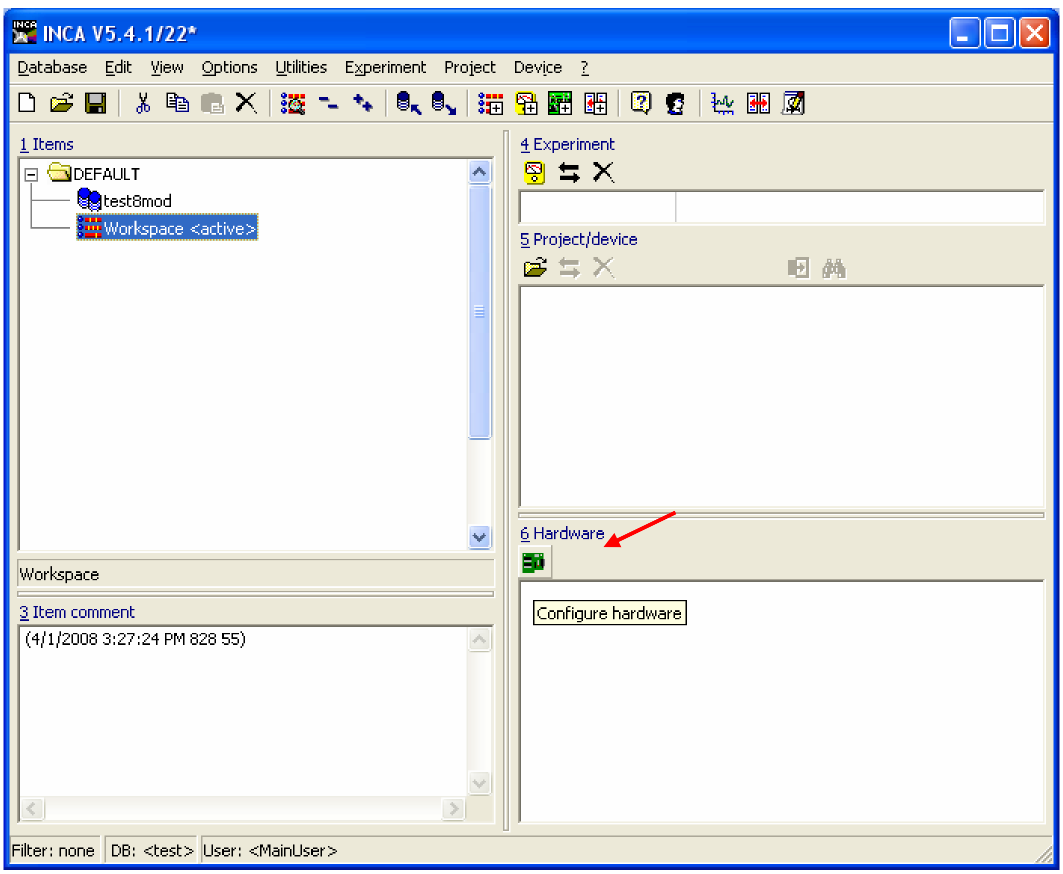


4. **Add a new dbc file for your project.** Right click on the workspace you created in step 3, select Add > Can-DB. Browse to your dbc file and click open. In this example, we are using a file named test8mod.dbc. An INCA log window will pop up. You can ignore this.

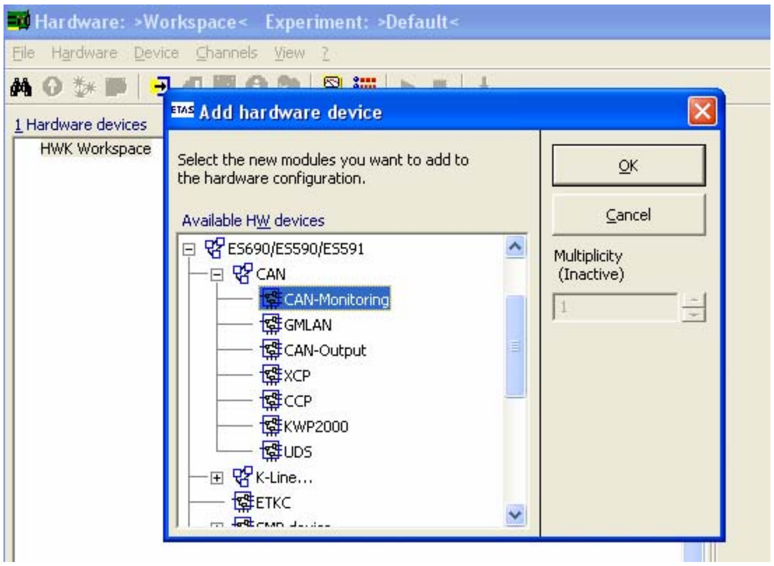




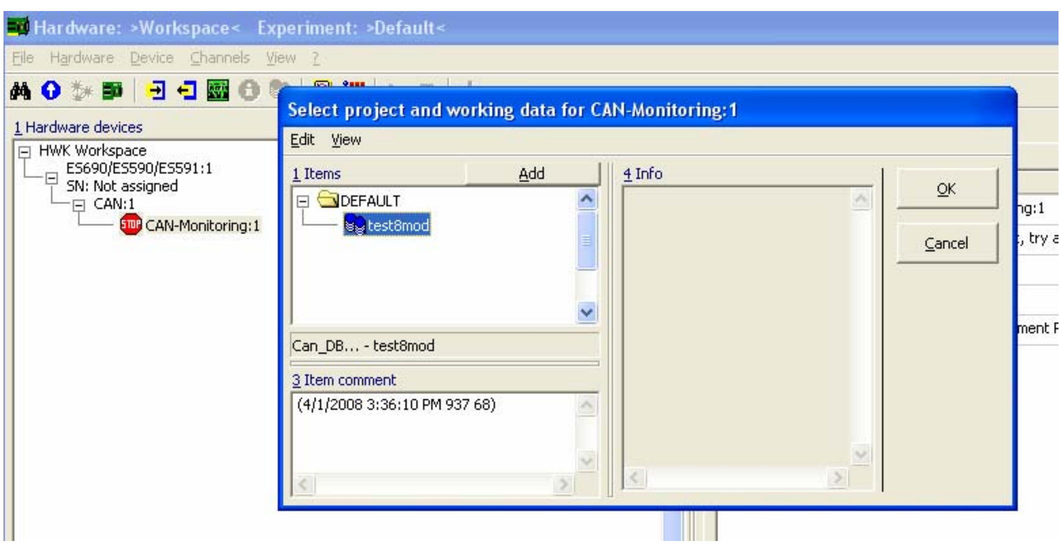
5. **Configure the hardware.** Click on the icon for the workspace you created in step 3. Open the Hardware Configuration icon under the section text “6. Hardware”. A hardware configuration window will open.



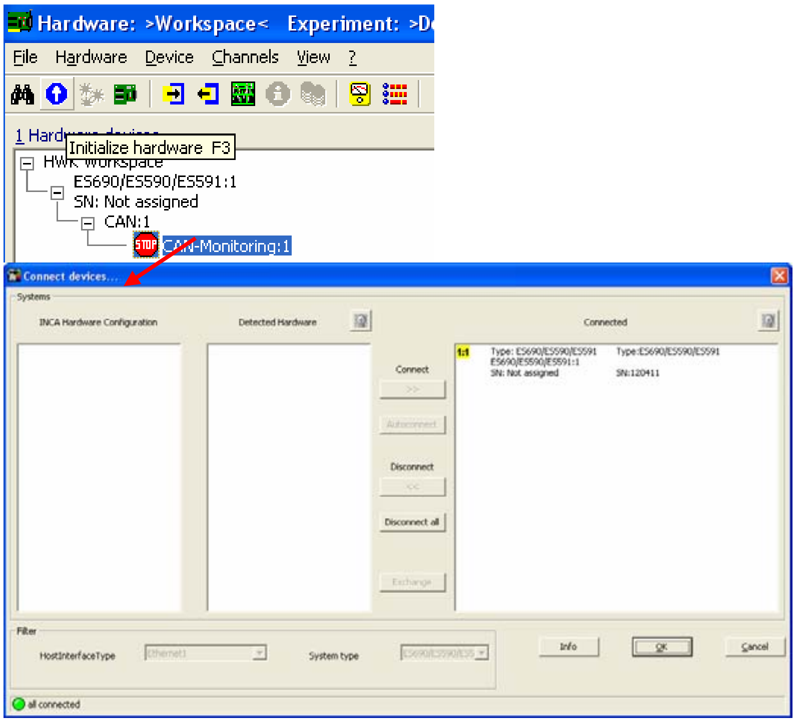
6. **Select the hardware.** In the hardware configuration window, right click the "HWK Workspace" listed under the section text "1. Hardware Devices", and select Insert. Select the ETAS device you wish to use. In this example, we are using an ETAS ES591.1. Expand the selection tree by clicking the "+" next to the hardware device model. Expand the CAN selection and select CAN-Monitoring. Click OK.



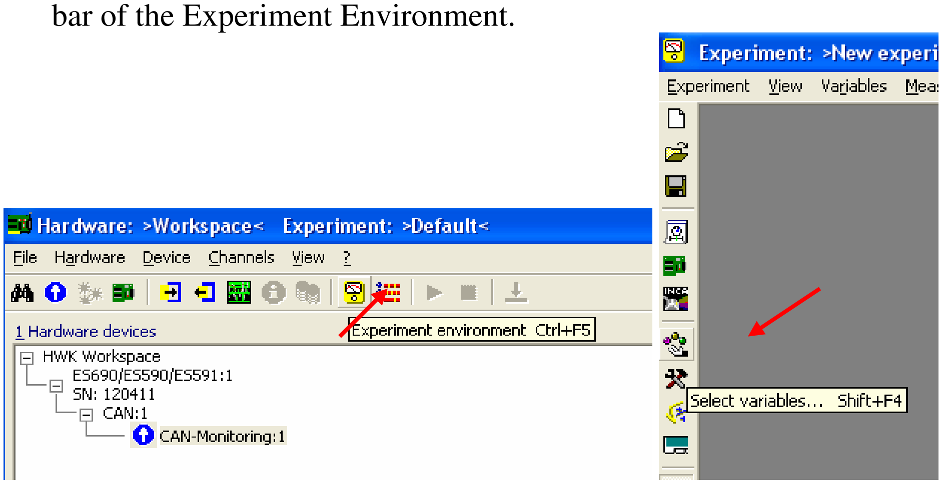
7. **Associate the dbc.** When you clicked OK in the last step, another window will pop up that will allow you to select a dbc that you have added to your workspace from step 4. Expand the selection tree, select your dbc file, and click OK.



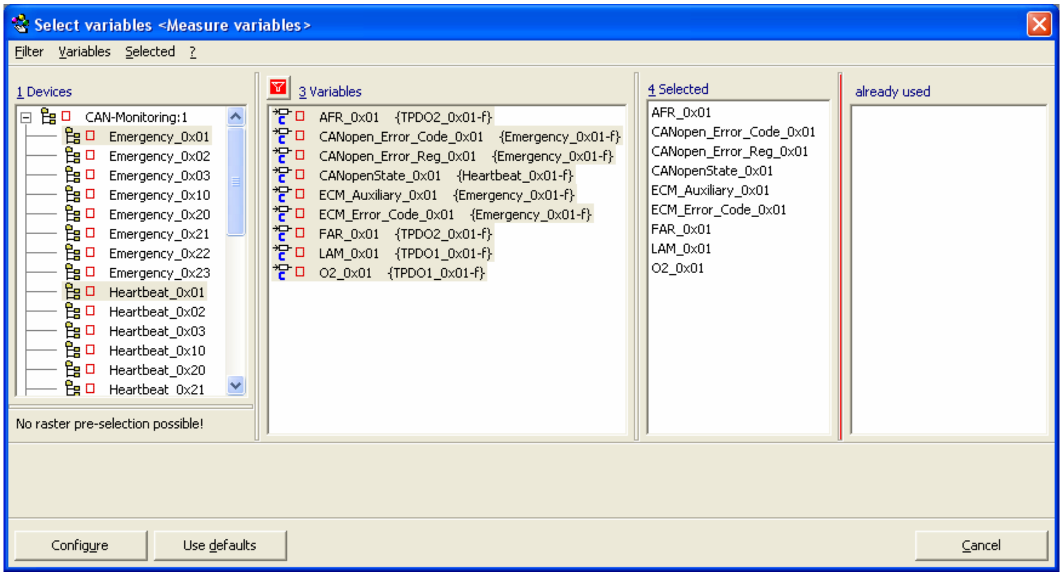
8. **Initialize hardware.** The hardware is currently stopped, as indicated by the red stop sign icon next to the selected hardware. You must initialize it before you can use it to collect data. Click on the Initialize Hardware button on the upper tool bar and wait for the hardware to complete its initialization. Another window will pop up to confirm the device to connect to. Click OK.



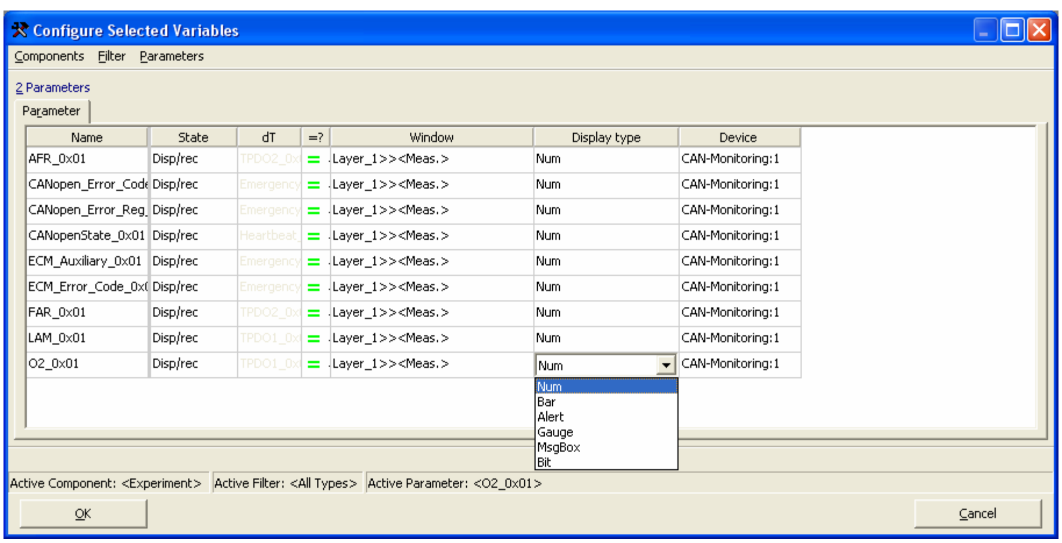
9. **Open an Experiment Environment.** Click on the Experiment Environment button on the upper tool bar to open an Experiment Environment. The Experiment Environment is where you can setup the monitoring of the CAN bus. By default, the Experiment Environment will be blank. You must select the variables from the dbc file that you wish to monitor. Click on the Select Variables icon in the left hand tool bar of the Experiment Environment.



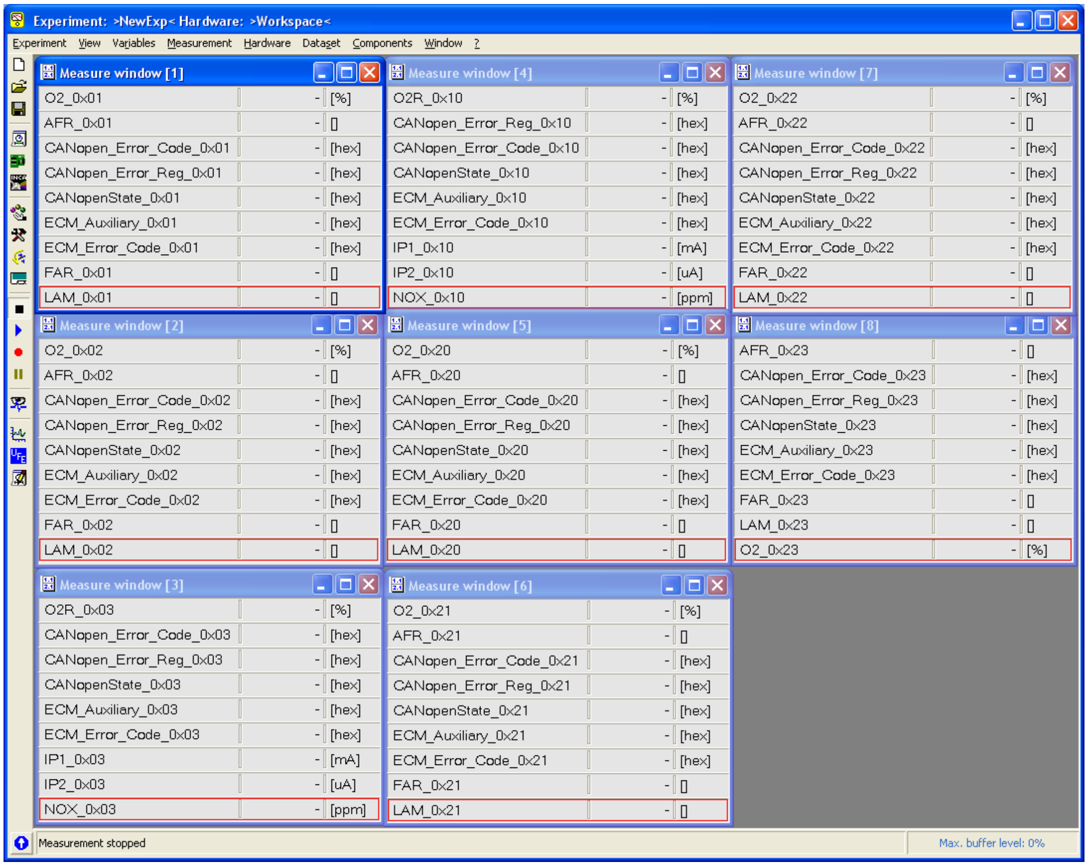
10. **Select and Configure Variables.** Select the variables that you wish to monitor in the Experiment Environment. These variables names are based on the data found in the dbc file. Click Configure.



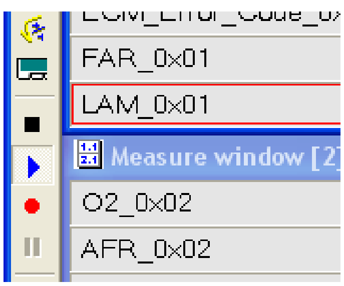
11. Another window will pop up to configure each selected variable. You can configure, for each variable, whether to record or simply display the data, how the data will be displayed (graphs, charts, gauges, numeric, etc.). When complete, click OK. We have left all configurations at default for this example.



12. A new sub-window will be added to the Experiment Environment. You do not need to select all the variables you want to monitor all at once. You can click on the Select Variables icon again at a later time to add more variables. Each set of variables you add will be placed in a new sub-window unless it is configured to join an existing sub-window. In this example, we have created a sub-window for each of the eight modules in the dbc file.



13. **Start CAN monitoring.** Right now there is no data displayed. That is because the CAN monitoring is stopped. To begin CAN monitoring, click on the Start Visualization icon (blue triangle) on the left hand tool bar. To stop CAN monitoring, click the Stop Measuring icon (black square) on the left hand tool bar. To begin recording the data, click on the Start Recording icon (red circle) on the left hand tool bar.



Appendix E: LOCKing and unLOCKing dashCAN

When dashCAN is locked, its setup cannot be modified.

◆ **To LOCK dashCAN**

1. Press SYS until "MOd" is displayed.
2. Press ↓ until "CONF" is displayed. Then press ENT.
3. Press ↓ until "LOCK" is displayed. Then press ENT.
4. "50" will be displayed. Press ↑ until "60" is displayed. Then press ENT. dashCAN is now LOCKed.

◆ **To unLOCK dashCAN**

1. Press SYS until "LOCK" is displayed. Then press ENT.
2. "50" will be displayed. Press ↑ until "60" is displayed. Then press ENT. dashCAN is now unLOCKed.

If an unauthorized person learns that 60 is the key number, contact ECM.

Safety Warnings

In installation and use of this product, comply with the National Electrical Code and any other applicable Federal, State, or local safety codes.

The O2 sensor is heated, gets hot, and can burn you.

Always wear eye protection when working near engines, vehicles, or machinery.

During installation, turn off the power and take all other necessary precautions to prevent injury, property loss, and equipment damage. Do not apply power until all wiring is completed.

Never work on a running engine.

When installing the egrCAN's cabling and sensor(s) on a stopped engine, it is best to think-out your moves before you make them.

Route and cable-tie all cables away from hot, moving, sharp, or high voltage (spark) objects.

Take into consideration the movement of the engine, chassis, and wind buffeting when instrumenting the engine.

Clear tools away from the engine before starting.

Operate the engine only in a well ventilated area and never when you or one of your co-workers is tired.

When operating the egrCAN in a moving vehicle, the operator should keep his or her eyes on the road.

One measure of professionalism is how much you and your co-workers can accomplish without an injury. Always be at your professional best. Think and act with safety in mind.

Warranty and Disclaimers

WARRANTY

The products described in this manual, with the exception of the O2 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 O2 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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EC DECLARATION OF CONFORMITY

We declare under our sole responsibility that the products:

AFM1540 Lambda Module
AFM1600 Lambda and O_2 Analyzer
DIS1000 Display head
EGR 4830 Analyzer
NOx 5210 NOx Analyzer
Lambda 5220 Lambda Analyzer
EGR 5230 EGR Analyzer
LambdaCAN Lambda Module
LambdaCANc Lambda Module
NOxCAN NOx Module
NOxCANg NOx Module
NOx1000 NOx Module
appsCAN Module
gpioCAN Module
dashCAN
DashCANc
SIM300
SIM400
BTU200

To which this declaration relates are in conformity with the essential requirements of the following standards:
EN61326: 1997/A2: 2001 (Class A & Annex A)
EN61010-1: 2001 (Electrical Safety)

And therefore conform to the requirements of the following directives:
89/336/EEC Electromagnetic Compatibility (EMC)
72/23/EEC Low Voltage Directive (LVD)

Ronald S. Patrick
Vice President Sales
October 23, 2009

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