ECM ENGINE CONTROL AND MONITORING

AFRecorder 2000A

Fast Air-to-Fuel Ratio Analyzer

Instruction Manual

6/03 Part Number 2000A-11

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Introduction

The AFRecorder 2000A

The AFRecorder 2000A is a portable, UEGO (universal exhaust gas oxygen) sensor-based, air-to-fuel ratio (AFR) analyzer. The UEGO sensor is mounted directly in the engine's exhaust giving the instrument the ability to make fast, accurate AFR measurements with ease. The AFRecorder can be powered either by AC or DC (vehicle battery) power making it suitable for dynamometer or in-vehicle use. The AFRecorder has a wide range of operation:

- Air-to-Fuel Ratio (AFR: 6.00 - 150.00)
- Lambda (λ: 0.4 - 10.0)
- Equivalence Ratio (ϕ: 0.10 - 2.5)
- Oxygen ($\%O_2$: 0 - 22%).

Its features include:

- Air-to-Fuel Ratio can be displayed in AFR, Lambda (λ), and Equivalence Ratio (ϕ) units. $\%O_2$ can also be displayed.
- Measures Air-to-Fuel Ratio for a wide variety of fuel types.
- Large (5,000 point) non-volatile memory for recording.
- Slow-motion or select-time playback with statistics.
- Linearized and programmable 0 to 5 VDC analog output.
- Simulated EGO (exhaust gas oxygen) sensor output with a programmable switch point.
- Programmable visual and audible limit alarms.
- RS-232 communication interface.
- 100-240 VAC and 11-16 VDC operation.

The AFRecorder can be operated in two modes: "stand-alone" or "remote". In stand-alone mode, commands are entered into the AFRecorder using the front panel's keypad and the measurements, recordings, and operational menus are viewed on the front panel's display. In remote mode, commands are entered and measurements, recordings, and operational menus are viewed using an IBM-compatible PC. In either mode, the alarms (lights and buzzer) come from the AFRecorder.

The AFRemote software package is used to operate the AFRecorder in remote mode. In addition to measurement, recording, and setup functions, AFRemote provides:

- Real-time plotting
- File handling facilities
- Keyboard and mouse control.

AFRecorder Components List

The following items are included with the AFRecorder 2000A package:

Item No.	Description	Part Number
1.	AFRecorder 2000A	2000A
2.	Air-to-Fuel Ratio (AFR) Sensor	2400E-1
3.	AFR Sensor Cable, 20 ft.	2400E-2
4.	120 VAC U.S. Power Cord, 6 ft.	2400G-38
5.	12 VDC Power Cord, 20 ft.	2400E-7
6.	Case Ground Cable, Braided, 3 ft.	2400A-17
7a.	Spare Power Fuses, 1 A, Slow Blow, for 120 VAC (Quantity 2)	2400G-39
	or	
7b.	Spare Power Fuses, 0.5 A, Slow Blow, for 230 VAC (Quantity 2)	2400G-39b
8.	Spare Power Fuse, 6.3 A, Slow Blow, for 12 VDC	2400A-8
9.	DB9M Outputs Connector	2400G-9
10.	AFRemote Software	2000A-10
11.	AFRecorder Instruction Manual	2000A-11

Important Operation Notes

Please read and follow all of the cautions contained in the **Safety Warnings** section on page 41 of this manual.

Air-to-Fuel Ratio Sensor

Read the **AFR Measurement Calibration (AIR CAL)** section on page 19.

Do not use the air-to-fuel ratio (AFR) sensor with leaded fuel or in a heavily-sooting or crankcase-oil-burning engine because these conditions can shorten the life of the sensor.

Do not operate an engine for more than three minutes with the AFR sensor installed in the exhaust if the AFRecorder is off, or if the AFR measurement function is disabled (see **AFR Measurement Enable/Disable** on page 20) or if the DC supply voltage is less than 11 VDC.

Only connect or disconnect the AFR sensor from the AFRecorder when the AFRecorder is off or if the AFR measurement function is disabled.

Do not mount the AFR sensor where liquid fuel or condensed water will collect on the sensor's tip.

To minimize thermal shock to the AFR sensor caused by condensed water, operate the engine for approximately one minute before turning on the AFRecorder and leave the AFRecorder on for approximately two minutes after stopping the engine. If leaded fuel is used (which is not recommended), then the AFRecorder should be on before the engine is started.

Do not use the AFR sensor where gas temperatures or pressures exceed the specified ranges (See the **Input Specifications and Limits** section on page 30).

Do not allow the AFR sensor's sealing rubber (where the wires come out of the sensor) to exceed 200 deg. C.

Do not drop the AFR sensor onto a hard surface.

The AFR sensor is self-heated. Do not touch or expose it to flammable substances when the AFRecorder is on.

Before installing the AFR sensor, apply a small amount of non-lead containing antiseize compound to its threads. Do not get the compound on the sensor's tip.

Route and cable-tie the AFR sensor’s cable away from hot or moving objects and ignition wires.

Physical Features and Hook-up

Front Panel

Once the power, AFR sensor and cable, and outputs have been hooked-up, all user interactions (in stand-alone mode) with the AFRecorder are made through the front panel. To enter or operate in remote mode, the front panel is not used although the statue of this mode is indicated on the LCD display.

Measurements are shown in a large format that fills the display. When AFR units other than AFR (i.e. λ and ϕ) or $\%O_2$ are selected, the units are shown to the left of the measurement. During the review of a recording, the display will operate in 4-line mode, showing the measurement and the time of the measurement on the display at the same time. In addition to displaying AFR, the display shows menu information for AFRecorder set-up. The display contrast adjustment is located on the back panel of the unit.

The "HIGH" and "LOW" warning lights are tested for a short time when the AFRecorder is turned on and stay on when programmed values (see **Setup - Outputs - Alarms** on page 16) are transgressed. The internal modulated buzzer is tested on power-up and can also indicate high and low values (fast buzzer repetition rate with "HIGH", slow buzzer repetition rate with "LOW"). The lights and buzzer act may be enabled separately or together (see **Setup - Options - Alarms** on page 17).

The keypad is labeled with numerics and three "hot keys" (SYS, REC, ENT). "SYS" stands for SYSTEM and pressing it halts the current operation and brings the AFRecorder to the main menu. "REC" stands for RECORD and pressing it while the AFRecorder is measuring starts a recording session. "ENT" stands for ENTER and pressing it designates the acceptance by the user of an entered selection. The "-" key serves both as a minus sign and a backspace key for the cursor. Thus the "-" key is used to delete an incorrect entry.

Rear Panel and Power Hook-up

The AFRecorder can be powered either by AC line power (100-240 VAC) or by a 12 VDC battery. Do not operate the unit with both AC line power and DC power attached at the same time.

AC power enters the AFRecorder through the AC line input module on the rear panel. The input module integrates the power cord entry, the on-off switch, the AC line voltage selection, and the AC line fuses into one assembly. The AC line input module must be correctly programmed and fused for the AC voltage being fed into the unit or damage to the AFRecorder may result. There are two AC line voltage selections: 100-120 VAC and 220-240 VAC. To program the module for a different AC line input voltage or to change the AC line fuses (2), open the module by putting a screwdriver in the slot on the top of the module and carefully pulling the module door open. After the module's door is open, pull out the red fuse holder. The AC line voltage is programmed by putting the red fuse holder in the module so that either "115V" (for 100-120 VAC) or "230V" (for 220-240 VAC) on the fuse holder is

seen from the back of the AFRecorder when the AC line input module's door is closed. 1 A Slow Blow fuses are required for 100-120 VAC power and 0.5 A Slow Blow fuses are required for 220-240 VAC power. All fuses must be rated for 250 VAC.

DC power enters the AFRecorder through the smaller of the two keyed circular plastic connectors (CPCs) on the rear panel. The input voltage must be between 11 VDC and 16 VDC. A 6.3 A Slow Blow fuse for the DC power is located below the connector. Only the supplied 12 VDC power cord should be used. One end of the cable mates with the smaller CPC on the rear panel and the other end should be connected directly to a 12 VDC automotive battery so as to provide the cleanest possible power to the AFRecorder. The red clip is positive and the black is negative. Use cable ties to keep the cable away from hot or moving objects and ignition wires. For the case of a vehicle with two twelve volt batteries connected in series, the ground of the AFRecorder power cable (black clip) must be connected to the negative terminal of the battery that is connected to the vehicle's chassis. The red clip of the cable must be connected to the positive terminal of that same battery.

A case ground terminal is provided to electrically connect the AFRecorder's case to the vehicle's chassis, the engine block, or the negative terminal of the battery. This may provide improved noise rejection in some environments. A braided cable is supplied for this purpose.

Air-to-Fuel Ratio Hook-up

The AFR sensor is mounted in the engine's exhaust by threading it into a M18X1.5 mm boss that is welded or brazed to the engine's exhaust pipe. This thread size is identical to that of the exhaust oxygen sensors used in current production automobiles with 3-way exhaust catalysts. Mounting bosses can be easily made by threading a length of 1 1/4" diameter steel bar with a M18X1.5 mm tap and cutting off 5/16" wide pieces as they are needed. Alternatively, a M18X1.5 mm jam nut can be used if its thickness is reduced to 5/16".

To mount the boss, first drill a 1/2" diameter hole in the desired AFR sensing location. If a individual cylinder's AFR is to be measured, drill approximately 12" from that cylinder's exhaust valve. If an engine's AFR is to be measured, drill approximately 12" from where the exhaust pipes join. These recommended locations are based on trade-offs between sensor response time, sensor temperature, exhaust mixing, and engine/exhaust packaging.

Long distances between the engine and the AFR sensor should be avoided because such installations result in increased condensed water being sprayed on the sensor during engine start-up. Liquid water striking the AFR sensor thermally shocks it and can lead to sensor failure.

Many engines have air pumped into the exhaust as part of their emission control strategy. The AFR sensor must be mounted upstream of where the air enters the exhaust system or else the measured AFR will be leaner than actual.

Before drilling, take into account the length of the sensor, any engine or chassis movement, the routing of the cable, and avoiding the collection of liquid fuel or condensed water on the sensor. After drilling the hole, clamp the boss over the hole and weld or braze it to the exhaust pipe. After the boss is attached to the exhaust, tap the threads to clean them and file the top of the boss to provide a flat surface for sealing.

Install the sensor by lightly coating its threads with a non-lead containing antiseize compound and tightening to 30 ±3 ft-lbf (40 ±4 Nm). Attach one end of the cable to the sensor and route the cable to the AFR sensor input on the back of the AFRecorder (the larger of the two keyed plastic connectors (CPCs)). Use cable ties to keep the cable away from hot or moving objects and ignition wires. Do not modify the cable as this may affect the AFRecorder's operation.

During AFR sensor use, observe the conditions outlined in the **Important Operation Notes** section on page 3. When the AFR sensor is not being used, an 18 mm spark plug (ex. Champion D15Y) can be used to plug the hole.

Analog Output and Simulated EGO Sensor Output

A linearized and programmable 0 to 5 VDC output is available for AFR or $\%O_2$. Also available is a simulated EGO (exhaust gas oxygen) sensor output with a programmable switch point. These outputs are taken from the female DB9 connector on the back of the AFRecorder. See **Setup - Outputs - Analog** on page 16 and **Setup - Outputs - Sim EGO** on page 16 for information on programming these outputs and **Output Specifications and Limits** on page 32 for the DB9 connector pin assignments.

RS-232 Communication Hook-up

The AFRecorder communicates with an IBM-compatible PC via a serial port cable connected between the units. The serial port connector on the back of the AFRecorder is a male DB9. The serial port connector on the back of IBM-compatible PCs is either a male DB9 (9 pins) or a male DB25 (25 pins). A simple "straight through-type" serial port cable with mating ends and of the desired length is all that is needed for the hook-up. If a custom length cable is being made then only pins 2 (Tx from AFRecorder), 3 (Rx to AFRecorder), and 5 (case ground and signal ground) of the DB9 connector on the back of the AFRecorder need to be used.

At the PC end of the cable, if the connector is a DB9 then pin 2 is Rx (from AFRecorder), pin 3 is Tx (to AFRecorder), and pin 5 is case ground and signal ground. At the PC end of the cable, if the connector is a DB25 then pin 2 is Tx (to AFRecorder), pin 3 is Rx (from AFRecorder), pin 1 is case ground, and pin 7 is signal ground.

Stand-Alone Operation

Measurement and the SYS Key

Upon power-up, the AFRecorder executes the following sequence:

1. System initialization is done. The display shows "Initializing" and the "HIGH" and "LOW" alarm lights and internal buzzer are tested.

2. If the AFR measurement function is enabled (see **AFR Measurement Enable/Disable** on page 20), a 45 second countdown is performed to allow the AFR sensor to reach operating temperature. If the "SYS" key is pressed during the countdown, the main menu is displayed.

3. The AFRecorder begins the measurement and display of air-to-fuel ratio (AFR) or $\%O_2$.

Information other than the measured AFR or $\%O_2$ is shown depending on certain conditions:

Display	Meaning
++++	Exhaust AFR beyond sensor's lean limit
- - - -	Exhaust AFR beyond sensor's rich limit
%02: 20.9	AFR measurement function properly calibrated in air (see **AFR Measurement Calibration (AIR CAL)** on page 19)
xxxx	AFR measurement function error (see **Troubleshooting** on page 39)
V LO	Supply voltage to AFRecorder is less than 11 VDC or AFR sensor disconnected
OFF	AFR measurement function disabled (see **AFR Measurement Enable/Disable** on page 20)

When the $\%O_2$ in the exhaust exceeds 18%, the AFRecorder will automatically change from displaying AFR to $\%O_2$. This allows for the fast visual checking of the AFR measurement calibration when the engine is stopped and the exhaust contains **pure air**. When the engine is restarted, the AFRecorder will automatically change back to displaying AFR in the programmed units.

Once the AFRecorder has begun displaying the measured parameters, only two keys will alter its operation: "SYS" (System) and "REC" (Record). The outcome of pressing "REC" will be discussed in the section entitled **Recording** on page 12. Pressing "SYS" at any time will suspend the current operation and display the main menu shown in Figure 1.

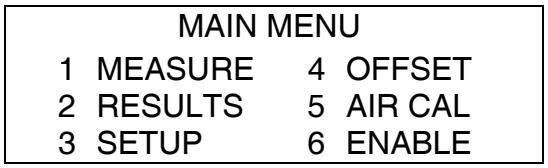

Figure 1: Main Menu (accessed by pressing "SYS")

From the main menu, the user can command the continuation of the measurement and display of AFR (select "1 MEASURE" by pressing "1" on the keypad), the review of a recorded session (select "RESULTS"), the modification of the AFRecorder's configuration (select "SETUP"), or the modification of the AFR measurement function (select "OFFSET", "AIR CAL", or "ENABLE"). Figure 2 shows the "tree" of sub-menus below the main menu. Using the keypad, the user can move within the tree and make selections.

Main Menu		Level 1		Level 2		Function
1	MEASURE					Measure & display
2	RESULTS	1	REPLAY			Slow motion playback
		2	STATISTICS			Recorded data statistics
		3	POINT			Display one recorded point (+: advance, -: back up)
3	SETUP	1	DISPLAY	1	UNITS	AFR, ϕ, λ, or $\%O_2$
				2	RATE	Slow/medium/fast update
				3	SIZE	Display size during recording
		2	RECORD	1	DURATION	Sample duration
				2	INTERVAL	Sample interval
		3	OUTPUTS	1	ANALOG	Program output range
				2	SIM EGO	Program simulated EGO sensor AFR switch point
				3	ALARMS	Alarm source & limits
				4	CAL D/A	Calibrate analog output
		4	OPTIONS	1	ICC	Activate ICC
				2	ALARMS	Arm lights & buzzer
				3	SOUND	Activate key beeping
		5	CONSTS	1	ENGINE	ICC factors
				2	AFR SENSOR	Calibration specifications
				3	FUEL	H:C, O:C, and N:C ratios
				4	AIR	Enter $\%O_2$ in air
4	OFFSET					Set AFR measurement offset
5	AIR CAL					Calibrate AFR measurement function in air
6	ENABLE					Toggle AFR sensor power on/off for sensor removal

Figure 2: Menu Tree for the AFRecorder

Recording

Recording is started by pressing the "REC" (Record) key while the AFRecorder is displaying AFR. During recording, the display will either show a small “R” near the decimal point of the measurement (if setup in large format) or will appear as shown in Figure 3 (if setup in small format).

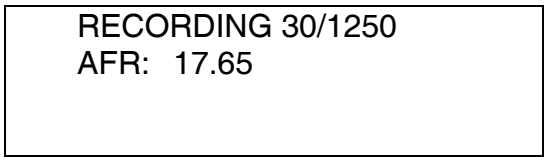

Figure 3: AFRecorder Display During Recording (small format)

In small font, the upper row of the display shows the number of samples recorded and the total number of samples to be taken. In the example of Figure 3, sample number 30 of 1250 has been taken. An additional "hidden" sample is taken at t=0 giving an actual total of 1250+1 samples.

During recording if the AFRecorder detects an AFR outside of its measurement range (ϕ less than 0.10 or ϕ greater than 2.5), it will display "++++" (for too lean) or "----" (for too rich). The value recorded will be the lean or rich limit and the limit value will be used to calculate the statistics.

The recording duration and the sample interval (time between recorded samples) are all programmable (see **Setup - Record Menu** on page 15). To abort a recording before it is finished, press "SYS", "REC", "+" or "-". If a recording session is aborted before its programmed duration, data from the previous session and the partially completed new session will be lost. If the recording session is allowed to complete, the recorded data will be retained by the AFRecorder even if the AFRecorder's power is disconnected.

Results Menu

After the recording session is completed, the AFRecorder will process the recorded data and present the results menu (see Figure 4). The maximum processing time is approximately 25 seconds. The results menu can also be accessed from the main menu (see Figure 1). By selecting "EXIT" in the results menu, the AFRecorder is returned to the main menu. However, the recorded data remains stored in the AFRecorder for analysis or uploading to an IBM-compatible PC.

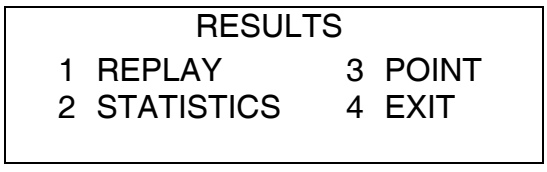

Figure 4: The Results Menu

Results - Replay

If "REPLAY" is selected from the results menu, the display replays the recorded data in slow-motion (see Figure 5). The display is updated with the data at each sample time. The visual and audible limit alarms are disabled during replay.

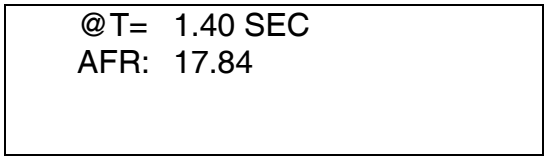

Figure 5: AFRecorder Display During Replay

The replay can be halted by pressing "+", or "-". After halting the replay, pressing "+" will update the display with the data from the next sample time. Pressing "-" will update the display with the data from the previous sample time. Pressing "ENT" will continue the replay. At the end of the replay, the AFRecorder returns to the results menu. Pressing "SYS" will abort the replay and the AFRecorder will present the main menu.

Results - Statistics

If "STATISTICS" is selected, the statistics of the last recording will be displayed (see Figure 6a).

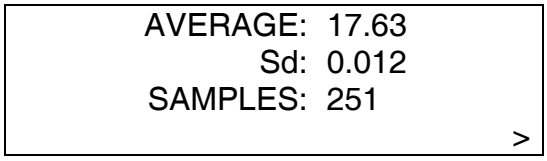

Figure 6a: Example of Statistical Results Screen 1

The first screen contains the average, standard deviation (Sd), and the number of samples. Note that the "hidden" sample at t=0 is used for the calculations. The second display containing the maximum, the minimum, and the times of the maximum and minimum is accessed by pressing any key other than "SYS". Pressing any key (other than "SYS") once more will return the AFRecorder to the results menu.

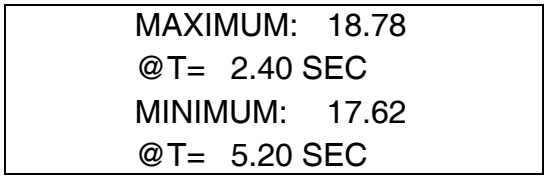

Figure 6b: Example of Statistical Results Screen 2

Results - Point

Selecting "POINT" from the results menu allows the examination of the recorded data at a given time (point) in the recording. To examine the data, the keypad is used to enter the time followed by the "ENT" (enter) key. Then, "+", and "-" can be used to step through the recording. Pressing "ENT" again returns the AFRecorder to the results menu.

Setup Menu

"SETUP" is the third selection in the main menu and the gateway to configuring the AFRecorder. The setup menu is shown in Figure 7. During setup, the defaults or previous selections are displayed for acceptance (using the "ENT" (enter) key) or for modification. Any improper or out-of-range entries are rejected by the AFRecorder and the "-" key is used as a backspace to erase an entry. The entry of any setup parameter must be completed by the pressing of the "ENT" key. The "EXIT" option returns the AFRecorder to the main menu.

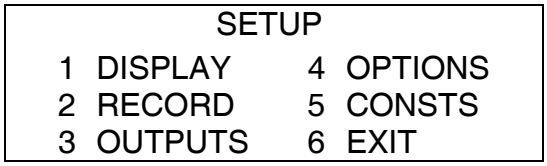

Figure 7: The Setup Menu

Setup - Display Menu

The selection of "DISPLAY" from the setup menu allows the configuration of the manner in which AFR is displayed (see Figure 8). "EXIT" returns the AFRecorder to the setup menu.

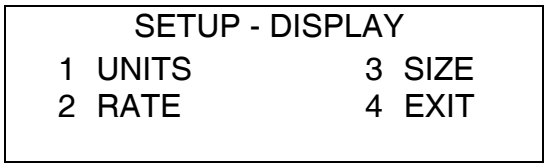

Figure 8: Setup - Display Menu

•Setup - Display - Units

The choice of "UNITS" from the setup - display menu allows the selection of the engineering units in which AFR are shown and recorded.

The choices for AFR units are: AFR, ϕ, λ, or %O2. The units of AFR are a mass ratio of air divided by fuel going into the engine. ϕ (equivalence ratio) is dimensionless and is defined as the stoichiometric AFR divided by the measured AFR. λ (lambda) is the numerical inverse of ϕ. A ϕ of greater than one and a λ of less than one denotes a rich mixture. Conversely, a ϕ of less than one and a λ of greater than one denotes a lean mixture.

Note that the units in which AFR is displayed, the units in which the analog output range is defined, the units in which the simulated EGO sensor switch point is selected, and the units in which the alarm triggers are all programmable and are all independent.

- **Setup - Display - Rate**

"RATE" determines how often AFR on the display is updated. Each choice (SLOW, MEDIUM, and FAST) has a specific update interval associated with it as shown in Table 1.

The table also shows the number of measurements which are averaged to generate the AFR displayed for a given update interval. The averaging is performed on data sampled at 0.01 second intervals. Note that during recording, measurements are stored "raw" (not averaged) at the selected sample interval (see **Setup - Record Menu** on page 15).

Rate	Display Update Interval	Measurement Averaging
SLOW	1.00 sec.	200 measurements
MEDIUM	0.50 sec.	50 measurements
FAST	0.25 sec.	25 measurements

Table 1: Display Rate Options

Selecting a display rate also determines the duration of the alarms (lights and buzzer). The alarms, when triggered, will be on for the duration of the display update interval.

- **Setup - Display - Size**

The choice of "SIZE" from the setup - display menu allows the selection of either the large or small display format during recording. If the large format is chosen, a small “R” beside the decimal point of the AFR will be shown during a recording. If the small format is chosen, the measurement and the sample counter will be shown during the recording.

Setup - Record Menu

The "RECORD" selection from the setup menu allows the setting of the recording duration (in minutes and seconds) and the sample interval (time between samples). A maximum of 5000 measurements may be made during a recording session. The minimum sample interval is 0.01 seconds. For more information, see the **Specifications and Limits** section on page 29.

Setup - Outputs Menu

The choice of "OUTPUTS" in the setup menu allows the programming of the analog, simulated EGO (exhaust gas oxygen) sensor, and alarms outputs (see Figure 9). "EXIT" returns the AFRecorder to the setup menu.

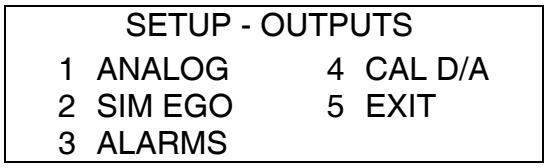

Figure 9: Setup - Outputs Menu

- **Setup - Outputs - Analog**

The choice of "ANALOG" from the setup - outputs menu allows the selection of the units (ie. AFR, ϕ, λ, or $\%O_2$) and their 0 V and 5 V values. The analog output is a linear function of the selected units between their values entered for 0 V and 5 V.

The analog outputs are updated every 0.01 seconds. See the **Output Specifications and Limits** section on page 32 for more information.

- **Setup - Outputs - Sim EGO**

The choice of "SIM EGO" allows the selection of the units (i.e. AFR, ϕ, or λ) and its value in which the simulated exhaust gas oxygen (EGO) sensor output transitions from its low (approximately 0.02 V) state to its high (approximately 0.8 V) state (or vice versa). A low output means that the AFR is leaner than its programmed value and a high output means that the AFR is richer than its programmed value. The simulated EGO sensor output is updated every 0.01 seconds. See the **Output Specifications and Limits** section on page 32 for more information.

- **Setup - Outputs - Alarms**

The choice of "ALARMS" allows the selection of the units (AFR, ϕ, λ, or $\%O_2$) and average values which trigger the alarm lights and the modulated buzzer. The averaging is done at the display rate (see Table 1). The "HIGH LIMIT" alarm is the red light and the fast repetition rate buzzer. The "LOW LIMIT" alarm is the green light and the slow repetition rate buzzer.

Once the units and values have been entered, the alarms can be independently armed (see **Setup - Options - Alarms** on page 18).

- **Setup - Outputs - Cal D/A**

The choice of "CAL D/A" allows the calibration and the verification of the accuracy of the D/A (digital to analog) conversion process of the AFRecorder. If this option is selected, the AFRecorder will calibrate its analog outputs with respect to its internal voltage reference and will hold the analog outputs at 1 V and 4 V so that they may be verified externally. The simulated EGO sensor output will also be held at its two values during this process.

Setup - Options Menu

The choice of "OPTIONS" from the setup menu allows the enabling of functions of the AFRecorder (see Figure 10). Selecting "EXIT" from this menu will return the AFRecorder to the setup menu.

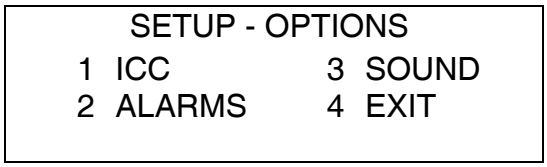

Figure 10: The Setup - Options Menu

- **Setup - Options - ICC**

"ICC" stands for "Incomplete Combustion Compensation". The activation of this option takes into account engine characteristics which, if ignored, would reduce the accuracy of the AFR measurement. The degree of ICC can be programmed (see **Setup - Constants - Engine** on page 18). It is recommended that this option be turned off when using fuels containing oxygen (i.e. methanol).

- **Setup - Options - Alarms**

The "ALARMS" option in the setup-options menu allows the visual limit alarms and the buzzer limit alarms to be independently armed.

- **Setup - Options - Sound**

The "SOUND" option allows the turning on or off of the "beep" that accompanies the pressing of keys on the keypad.

Setup - Constants Menu

The "CONSTANTS" menu is where calibration information about the engine, AFR sensor, fuel, and air are input into the AFRecorder (see Figure 11). Selecting "EXIT" from this menu will return the AFRecorder to the setup menu.

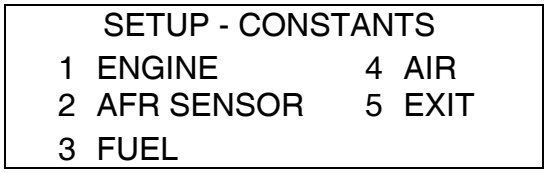

Figure 11: The Setup - Constants Menu

- **Setup - Constants - Engine**

Information pertaining to the engine's degree of combustion efficiency is entered after selecting "ENGINE" from the setup - constants menu. The three displays following this selection allow the entry of ICC (incomplete combustion compensation) factors for lean (ICC LEAN), stoichiometric (ICC STOICHIOMETRIC), and rich (ICC RICH) air-to-fuel ratios for the engine being tested. This information is used to improve the accuracy of the AFR measurement. ICC values from 0.0 to 10.0 may be entered with 5.0 (for each ICC) the recommended settings for typical production engines. In general, the following engine conditions require an increase in the ICC factors:

1. High degree of valve overlap
2. Low compression ratio
3. Cold engine operation
4. Spark timing advanced from MBT (minimum timing for best torque).

- **Setup - Constants - AFR Sensor**

The AFR sensor's calibration constants are entered after selecting "AFR SENSOR" from the setup - constants menu. Fourteen displays following this selection allow the entry of Io_2, Ico, Ih_2, and I_1 to I_{11} values. These constants describe the AFR sensor's sensitivity to oxygen (Io_2), carbon monoxide (Ico), and hydrogen (Ih_2). These constants are factory determined and provided with every sensor. If any AFR sensor parameter is entered (including reentering the same number), the AFRecorder assumes that a new sensor is being used and resets the "AGE FACTOR" to 1.00 (see **AFR Measurement Calibration (AIR CAL**) on page 19). The effect of this is to negate all AFR sensor field calibration and to return the AFRecorder to the factory-delivered AFR sensor calibration.

- **Setup - Constants - Fuel**

Information about the chemical composition (atom ratios) of the fuel is required to determine the AFR. This information is entered into the AFRecorder after selecting "FUEL" in the setup - constants menu.

The information requested is "H:C RATIO" (the hydrogen to carbon atom ratio of the fuel), "O:C RATIO" (the oxygen to carbon atom ratio of the fuel), and "N:C RATIO" (the nitrogen to carbon ratio of the fuel). The **Input Specifications and Limits** section on page 30 contains values for common fuels.

- **Setup - Constants - Air**

Information about the $\%O_2$ in air is used during the "AIR CAL" of the AFR sensor. The oxygen concentration in dry air (zero humidity) is 20.9% and decreases with increasing humidity. The $\%O_2$ in air can be calculated from the barometric pressure (P_b), and the water vapor pressure (P_w) using the formula:

$$\%O_2 = 20.95\% \times (P_b - P_w) / P_b$$

A psychrometric chart is used to determine the water vapor pressure (P_w).

AFR Measurement Offset

The main menu selection of "OFFSET" allows the user to bias the displayed, recorded, and output (analog, simulated EGO output, and alarms) AFR by an entered amount. The entered offset acts across the entire range of measured AFRs. The offset must be entered in "AFR" units (limited to ±2 AFR) but it will act on the reported AFR in AFR, ϕ, and λ units. The AFR offset does not act on $\%O_2$. For example, if the measured AFR is 14.6 and the offset is -0.5, the displayed AFR will be 14.1.

AFR Measurement Calibration ("AIR CAL")

The selection of "AIR CAL" from the main menu field-calibrates the AFR measurement function with air as the calibration gas. "AIR CAL" requires that the user enter the $\%O_2$ in air in **Setup - Constants - Air** (on page 19) and only needs to be performed if the AFRecorder does not display this entered value when the AFR sensor is held in stationary air. AFR measurement calibration will be needed when the AFR sensor degrades and/or when atmospheric pressure conditions change due to weather and altitude changes.

The procedure for air calibration is:

1. Put the AFR sensor in stationary air.
2. After 20 minutes:
    a. If the AFRecorder shows "%O2: ##.#" for AFR (where ##.# is the $\%O_2$ in air) then the AFR measurement function does not require calibration.

b. If the AFRecorder does not show "%O2: ##.#" then select "AIR CAL" from the main menu and initiate calibration. Note that the correct $\%O_2$ in air must be entered in **Setup - Constants - Air** (on page 19) before initiating "AIR CAL".

The "AIR CAL" procedure takes approximately 10 seconds. Upon completion, the "AGE FACTOR" will be displayed. The age factor of a new AFR sensor at the same atmospheric conditions under which it was factory calibrated is 1.00. This will change with sensor degradation and/or changes in atmospheric conditions. "AIR CAL" will correct for sensor degradation and/or changes in atmospheric pressure (those resulting from weather and altitude changes). The "AGE FACTOR" will decrease as the sensor ages.

If any AFR sensor parameter (Io_2, Ico, Ih_2, I_1 to I_{11}) is entered (including reentering the same number) (see **Setup - Constants - AFR Sensor** on page 18), the AFRecorder assumes that a new sensor is being used and resets the "AGE FACTOR" to 1.00. The effect of this is to negate all AFR sensor field calibration and to return the AFRecorder to the factory-delivered AFR sensor calibration.

The AFRecorder will abort "AIR CAL" if the AFR sensor's output in air is unreasonable or if its output is unsteady. Both conditions could be the result of a faulty sensor or an improper calibration environment (i.e. not pure air).

AFR Measurement Enable/Disable

Selecting "ENABLE" from the main menu allows the AFR sensor to be powered down ("DISABLED") and up ("ENABLED") for sensor removal. To avoid AFR sensor damage, the sensor should only be removed or attached when the sensor is disabled or when the AFRecorder is off. After enabling the AFR measurement function, the AFR sensor requires 45 seconds to reach its operating temperature.

Remote Operation (using AFRemote Software)

Software Operation

Remote mode allows the following categories of AFRecorder operation, which are available in stand-alone mode, to be directed from an IBM-compatible PC: measurement, recording/results, setup, and offset. In addition, real-time display, plotting, and file handling capabilities are provided. The AFR measurement calibration ("AIR CAL"), the "ENABLE/DISABLE" function, the "CAL D/A" option, the display of $\%O_2$, "xxxx", "V LO", "OFF" (see **Measurement and the "SYS" Key** on page 9), and the automatic display of $\%O_2$ are not available in remote mode. Remote mode uses the supplied software program AFRemote. AFRemote will run as a stand-alone DOS program or from an MS-DOS prompt within Windows. AFRemote will work on floppy disk, hard disk, or RAM disk. Simply copy the file AFREMOTE.EXE to the desired target disk.

The commands used by AFRemote to interact with the AFRecorder may be used in a user-written program. Contact ECM for information on communicating with the AFRecorder.

AFRemote is a menu-driven program. Thus, operation of the AFRecorder in remote mode is not unlike its operation in stand-alone mode in that the user is prompted for entries. AFRemote however, uses a fancier menu structure with pull-down menus and "exploding" dialog boxes, and can be operated using the PC's keyboard and a mouse.

To start AFRemote, type "AFREMOTE" (without quotes) while in the directory containing AFREMOTE.EXE.

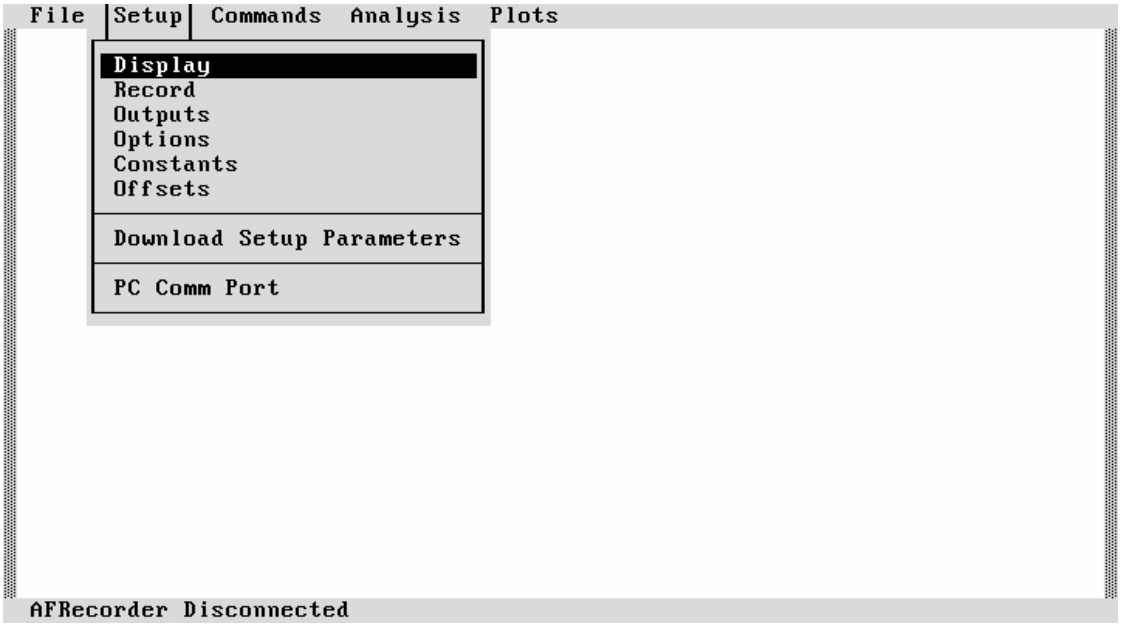

Figure 12: An AFRemote Pull-Down Menu Screen

Figure 12 shows an example of the PC's main menu screen after starting AFRemote and selecting one of the pull-down menus. Along the top of the screen are the main menu's choices: "File", "Setup", "Commands", "Analysis", and "Plots". The bottom line of the screen is a status line which indicates "AFRecorder Disconnected" or AFRecorder Connected" during program operation. The status line displays a copyright notice when AFRemote is first started. The rest of the screen is used for other menus, dialog boxes, and measured or recorded data.

A selection from the main menu is made either by typing the first letter of the selection (ex. "F" for File) or by clicking (press and release) the mouse left button with its cursor on the selection's name. After making a selection, the menu will unfold showing further choices related to that selection.

The cursors (arrow keys) or mouse are used to highlight a selection which can be chosen by pressing the "Enter" key or clicking the mouse's left button. Pressing the escape key ("Esc") or the left mouse button (while not on a selection) will exit from a menu. To exit AFRemote, select "File" followed by "Exit".

In some cases, a dialog box will appear in the center of the screen. Dialog boxes request the entry of alphanumeric data (which must be followed by the pressing of the "Enter" key) or indicate that an error has been made. The mouse will not operate while in a dialog box.

Entering and Leaving Remote Mode

- **To enter remote mode:**

1. Turn off the AFRecorder and the PC.

2. Make the hardware connection between the AFRecorder and the PC by connecting the RS-232 communication cable between the AFRecorder and any one of two serial ports (Com1, Com2) on the back of the PC (see the section entitled **RS-232 Communication Hook-up** on page 7).

3. Turn on the AFRecorder and the PC.

4. Start AFRemote by typing "AFREMOTE" and pressing the "Enter" key while in the PC's directory containing the file AFREMOTE.EXE.

5. Indicate the serial communication port on the PC that is being used by selecting the option "Setup", followed by "PC Comm Port", and the communication port ("Com1" or "Com2"). Com1 is the default and if Com2 is used, it must be selected each time AFRemote is started.

6. Make the software connection between the AFRecorder and the PC by selecting "Commands" followed by "Connect to AFRecorder".

During software connection, setup data from the AFRecorder is sent to the PC. The AFRecorder's display will briefly indicate this by the first display in Figure 13 followed by the second display indicating that the connection is complete. The PC's screen will show a similar progression in the connection (i.e. acknowledgment, uploading setup data, connected) as shown in Figure 14. When the connection is complete, the status "AFRecorder Connected" is shown in the bottom, left corner of the screen.

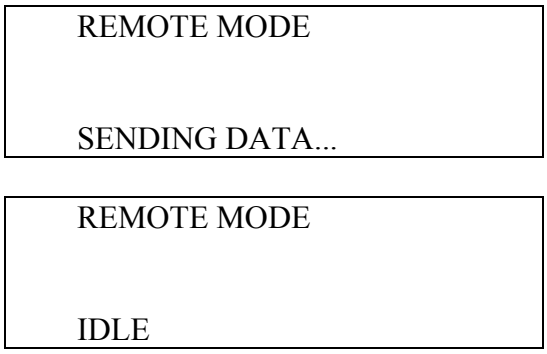

Figure 13: AFRecorder Display During Software Connection

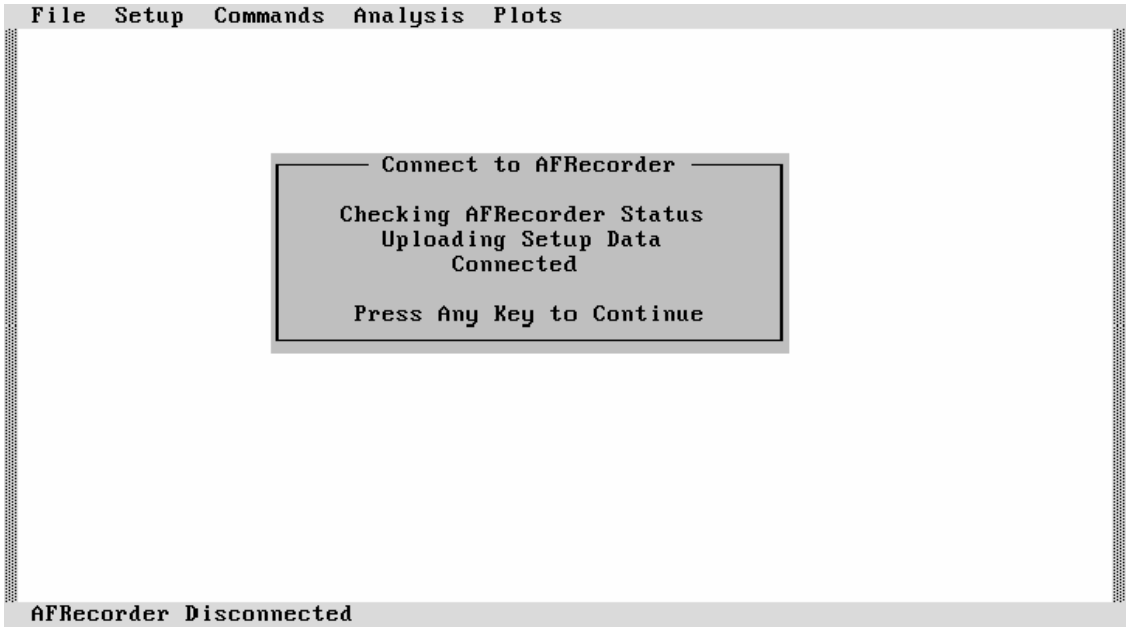

Figure 14: PC Screen During Software Connection

After the software connection has been completed, operation of the AFRecorder can be controlled from the PC.

- **To leave remote mode:**

Remote mode is terminated by selecting "Commands" followed by "Disconnect AFRecorder" on the PC, or by pressing the "SYS" key twice on the AFRecorder.

Measurement

AFR can be viewed on the PC's screen in two forms: real-time display or real-time plotting. The update interval and the measurement averaging are at the "FAST" rate and are not adjustable (see Table 1 on page 15). During real-time display and real-time plotting, the AFRecorder also displays the AFR.

Real-Time Display

Real-time display is started by selecting "Commands" followed by "Real-Time Display On". The command "Real-Time Display Off" ends the display. "xxxx", "V LO", "OFF", are not available with AFRemote. In real-time display, the display will not automatically change to $\%O_2$ when the $\%O_2$ in the exhaust exceeds 18%.

Real-Time Plotting

Real-time plotting turns the PC into an oscilloscope showing the values of AFR as a function of time.

Real-time plotting is started by selecting "Plots" followed by "Draw Real-Time Plot". Pressing any key on the PC's keyboard or the mouse's left button will suspend the plotting. Pressing any key (except for "Esc") or the left button again will continue the plotting. Pressing "Esc" twice will stop the plotting and return to the main menu.

Modifications in the scaling the plots are made using the "Plots" menu and the "Set Plot Scales" selection.

Measurement with Direct Storage to Disk

Real-Time to Disk

Data can be directly stored on a floppy disk, a hard disk, or a RAM disk while being viewed on the PC's screen by selecting "Commands" followed by "Real-Time to Disk". This option allows the storage of very large amounts of data.

On selection of this option, AFRemote requests the sample interval (allowable values: 0.1 to 60 sec.), the sample size (allowable values: 100 to 100000), and the filename. It is recommended that the filename extension .AFR be used.

During real-time to disk operation, the PC's display is updated with every fifth data point for sample intervals less than 0.13 seconds, with every other data point for sample intervals between 0.13 seconds and 0.25 seconds, and with every data point for sample intervals greater than 0.25 seconds. Note that this data is not averaged as it is for the options "Real-Time Display" or "Draw Real-Time Plot". The AFRecorder's display will not show data for sample intervals less than 0.30 seconds.

Should the "Esc" key be pressed during real-time to disk operation, the process is terminated and the file is closed with the data collected up to the time when the "Esc" key was pressed.

The data is stored in a compact format ("AFRemote format") suitable for re-input and analysis by AFRemote. If the data is to be input into another data analysis program, it must be stored in ASCII format by selecting "File" followed by "Create Export File". A filename will be requested and it is recommended that the filename extension .EXP be used for these files. Note that ASCII files cannot be loaded into AFRemote for plotting and analysis, only files stored in the compact format. It takes much longer to store data in ASCII format than it does in AFRemote format.

Figure 15 is an example of an "exported" file. The time and recorded measurements are always stored as two columns. The left column is time and the right column is AFR. The data is separated by tabs. Note that data begins at time zero (0).

```
0.000    15.125
0.100    15.239
0.200    15.466
0.300    15.693
0.400    15.352
0.500    15.012
0.600    15.125
0.700    15.806
0.800    16.260
0.900    16.407
1.000    15.466
1.100    13.874
1.200    13.375
1.300    13.519
1.400    13.925
1.500    14.077
   .        .
   .        .
   .        .
```

Figure 15: An Exported Data File (on PC's screen)

Real-Time Plot to Disk

Data can be directly stored on a floppy disk, a hard disk, or a RAM disk while being plotted on the PC's screen by selecting "Plots" followed by "Real-Time Plot to Disk".

Activation of this option is very similar to "Real-Time to Disk" (see **Real-Time to Disk** on page 24) except that the data is plotted while being stored to disk.

Recording

Recording is initiated by selecting "Commands", followed by "Start Recording". At this command, the PC will trigger the recording by the AFRecorder. The "Reset" command may be used to stop a recording session in progress.

Note that recording is different from real-time to disk or real-time plot to disk data storage in that recorded data is stored in the AFRecorder before being uploaded and stored in the PC.

Uploading and Storage of Recorded Data

After the recording session is completed, the recorded data can be uploaded to the PC for analysis and storage. Data is uploaded by selecting "Commands" followed by "Upload Recorded Data". The maximum time to upload recorded data is approximately two minutes for 5000 measurements. This time varies with the type of PC used.

The uploaded data can be stored in the PC either in a compact format ("AFRemote format") suitable for re-input and analysis by AFRemote, or in ASCII format suitable for input into other data analysis programs. "File" followed by "Save Recorded Data" stores data in AFRemote format. A filename will be requested for the recorded data. It is recommended that a filename with the extension .AFR be used for these files. These files may be recalled from disk later using the command "Load PC File Data".

"Create Export File" stores recorded data in ASCII format. A filename will be requested for the recorded data. It is recommended that a filename with the extension .EXP be used for these files. It takes much longer to store data in ASCII format than it does in AFRemote format.

An "exported" recorded file is similar in appearance to an "exported" real-time to disk file (see Figure 15).

Results and Plot Configuration

Analysis of Data

AFRemote allows real-time to disk data, real-time plot to disk data, recorded data (via "Upload Recorded Data"), or loaded data (via "Load PC File Data") to be analyzed by statistics or static plotting. Statistics are accessed by selecting "Analysis" followed by “Air-Fuel Ratio”.

Plot Modification

"Plots" followed by "Draw Static Plot" plots the data currently within AFRemote. The static plot is drawn using data at each sample interval (not averaged). The plot scaling is modified by "Set Plot Scales".

Hardcopy of Plots

To print hardcopies of static plots on the PC's screen using DOS, a screen-dump utility such as GRAPHICS (from DOS 5.0 or greater) must be executed prior to entering AFRemote. The GRAPHICS command consists of "GRAPHICS" (without quotes) followed by the printer type. Refer to a DOS 5.0 (or greater) manual for more information. Once GRAPHICS has been executed, hardcopies of the screen can be made by pressing the "Shift" and "Print Screen" keys at the same time. Attempting to screen-dump during a real-time operation (ex. real-time plotting) will interrupt the procedure and result in a system timeout.

If AFRemote is run from a MS-DOS prompt within Windows, use the Windows clipboard to capture the plot.

Setup

The setup of the AFRecorder in remote mode is very similar to its setup in stand-alone mode. One difference is that in remote mode, the **modified setup parameters must be downloaded to the AFRecorder for setup changes to take effect**. Select the AFRemote "Setup" menu to specify the setup parameters. Then select "Setup" followed by "Download Setup Parameters" to download the setup parameters to the AFRecorder. Refer to the section entitled **Setup Menu** on page 14 for more information.

AFR Measurement Offset

An AFR measurement offset may be entered to bias the measured AFR by selecting "Setup" followed by "AFR Offset". The entered offset acts across the entire range of measured AFRs. The offset must be entered in "AFR" units (limited to ±2 AFR) but it will act on the reported AFR in AFR, ϕ, and λ units. The AFR offset does not act on $\%O_2$. For example, if the measured AFR is 14.6 and the offset is -0.5, the displayed AFR will be 14.1. The offset AFR is used for display, recording, and outputs. **The AFR offset must be downloaded to the AFRecorder for it to take effect.**

Specifications and Limits

Measurements and Accuracy

Parameter Measured	Units	Range	Response Time	Accuracy
Air-to-Fuel Ratio	AFR	6.0 - 150.0[1]	< 150ms	±0.1 (stoichiometric) ±0.2 (12<AFR<18) ±0.5 (elsewhere)
	ϕ	0.10 - 2.5	< 150ms	±0.006 (stoichiometric) ±0.008 (0.8<ϕ<1.2) ±0.009 (elsewhere)
	λ	0.4 - 10.0	< 150ms	±0.006 (stoichiometric) ±0.008 (0.8<λ<1.2) ±0.009 (elsewhere)
$\%O_2$	%	0 - 22%	< 150ms	±0.2% (0<$\%O_2$<2) ±0.4% (elsewhere)

[1] AFR range given for gasoline with an H:C ratio of 1.85. For other fuels, AFR range depends on the composition (i.e. H:C ratio, O:C ratio, N:C ratio) of the fuel.

Recording Specifications

Data Recorded: AFR in displayed units or $\%O_2$.
Sample Size: Up to 5000 measurements.
Recording Duration: 1.0 second to memory limit (programmable).
Sample Interval (time between samples): 0.01 second to 30.0 minutes (programmable).
Programmable in increments of 0.01 second.
Data Retention: Up to 10 years.

Real-Time to Disk and Real-Time Plot to Disk Specifications

Data Recorded: AFR in displayed units or $\%O_2$.
Sample Size: 100 to 100,000 measurements of each parameter.
Sample Interval (time between samples): 0.1 to 60 seconds.

Input Specifications and Limits

Air-to-Fuel Ratio:

- Measurement Range, Response Time, Accuracy: See the section entitled **Measurements and Accuracy** on page 29.

- AFR measurement calibration information is provided in the sections entitled **AFR Measurement Calibration (AIR CAL)** on page 19.

- Fuel Composition:

  H:C ratio range: 1.00 - 10.00
  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)

  Do not use the AFR sensor with leaded fuel or in a heavily-sooting or crankcase-oil-burning engine because these conditions will severely shorten the life of the sensor.

- Maximum allowable levels of fuel "impurities":

  Lead: 0.012 gm/gal.
  Phosphorous: 0.0008 gm/gal.
  Sulfur: 0.035 % by weight

- Exhaust Gas Temperature Range: 0 - 850 deg. C, 32 - 1562 deg. F.
  Maximum Exhaust Temperature: 950 deg. C, 1742 deg. F.
  Maximum Rate of Temperature Change: 50 deg. C/sec, 122 deg. F/sec.

- Exhaust Gas Pressure Range: 0.8 - 1.3 atm.

- Installation:

  Thread Size: M18X1.5 mm. Lightly coat with non-lead containing antiseize compound.
  Hex Size: 22 mm.
  Tightening Torque: 30 ±3 ft-lbf, 40 ±4 Nm.

  The AFR 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.

  Use of an AFR sensor cable other than that supplied may affect accuracy and life of the AFR sensor.

- Connector on AFR sensor: AMP Series 1, Arrangement 13-9 (Standard Duty Connector)

Pin 1: Heater +	Pin 6: Ip, Vs cell -
Pin 2: Heater -	Pin 7: Not connected
Pin 3: Ip cell +	Pin 8: Cal resistor
Pin 4: Not connected	Pin 9: Cal resistor
Pin 5: Vs cell +	

- Connector on AFR sensor: W.W. Fischer S105A062-60/5.2S (Severe Duty Connector)

Pins 1, 9: Heater +	Pin 5: Vs cell +
Pins 2, 10: Heater -	Pin 6: Ip, Vs cell -
Pin 3: Ip cell +	Pin 7: Cal resistor
Pin 4: Not connected	Pin 8: Cal resistor

- Connector on AFR sensor: Sanwa SNW-1608-ACM-5 (Optional Connector)

Pin 1: Heater +	Pin 5: Ip -, Vs cell -
Pin 2: Heater -	Pin 6: Vs cell +
Pin 3: Ip cell +	Pin 7: Cal resistor
Pin 4: Cal Resistor	Pin 8: Ip-, Vs cell -

Output Specifications and Limits

Analog Output:

- Programmable Ranges for: Air-to-Fuel Ratio (AFR, ϕ, λ) or $\%O_2$
- Minimum Programmable Ranges (value at 5 V minus the value at 0 V):
  5 AFR, 0.5 ϕ, 0.5 λ, 5 $\%0_2$
- Output Range (linearized in displayed units): 0 - 5 VDC. 20 mA max.
- Bits Resolution: 12 bits.
- Update Rate: 0.01 sec.
- Connector: Female DB9.

  Pin 1: Air-to-Fuel Ratio (AFR, ϕ, λ) or $\%O_2$
  Pin 2: Not connected
  Pin 3: Not connected
  Pin 4: Not connected
  Pin 5: Signal Ground
  Pin 6: Simulated EGO Sensor
  Pin 7: Not connected
  Pins 8, 9: Signal Ground

All outputs must be measured relative to the signal ground pin(s) on the connector. In the case where the AFRecorder and an external data acquisition system are both powered by the same 12 VDC battery, then the inputs of the data acquisition system receiving the output(s) from the AFRecorder must be set up in differential mode. If differential mode is not available and single-ended mode is used, be aware that an approximately 10 mV potential exists between the 12 VDC battery ground (measured at the battery) and the signal ground (measured at the outputs connector of the AFRecorder). Single-ended inputs of some data acquisition systems will tie the signal ground to the power supply ground. This will not cause any problems with the AFRecorder but its effect on the data acquisition system must be considered.

To compensate for differences in voltage references and ground potentials between the AFRecorder and a data acquisition system receiving its outputs, use Equation A:

$$AFR = \left(AFR_5 - AFR_0\right) \times {}^{V}\!/_{5} + AFR_0 \qquad \text{[Equation A]}$$

where: AFR is the compensated AFR value.
AFR_0 is the programmed AFR for 0 Volts.
AFR_5 is the programmed AFR for 5 Volts.
V is the voltage calculated from Equation B.

Note that the "AFR" in Equation A is replaced by λ, ϕ, or $\%O_2$ for the chosen analog output units.

$$V = \frac{3V_{ad}}{V_{ad4} - V_{ad1}} + \frac{V_{ad4} - 4V_{ad1}}{V_{ad4} - V_{ad1}} \qquad \text{[Equation B]}$$

where: V is the value calculated and used in Equation A.

V_{ad} is the voltage reported by the data acquisition system when collecting data.

V_{ad1} is the voltage reported by the data acquisition system when the AFRecorder is outputting "1" Volt.

V_{ad4} is the voltage reported by the data acquisition system when the AFRecorder is outputting "4" Volts.

Note that V_{ad1} and V_{ad4} must be measured when the data acquisition system is fully hooked-up and the AFRecorder is fully hooked-up and the AFR sensor is "on".

Simulated Exhaust Gas Oxygen (EGO) Sensor Output:

- Programmable transition Air-to-Fuel Ratio (AFR, ϕ, or λ).
- "High" Output Level (for richer than programmed transition AFR): Approximately 0.8 V., 20 mA max.
- "Low" Output Level (for leaner than programmed transition AFR): Approximately 0.02 V.
- Transition Time (10% to 90% complete): Approximately 50 ms.
- Update Rate: 0.01 sec.
- Connector: See Analog Output Connector (pin 6).

Limit Alarms (front panel lights and internal modulated buzzer):

- "HIGH" Indication: High light (red) and high buzzer (fast repetition rate).
- "HIGH" Activation: Occurs when chosen unit's (AFR, ϕ, λ, or $\%O_2$) value is greater than the programmed value.
- "LOW" Indication: Low light (green) and low buzzer (slow repetition rate).
- "LOW" Activation: Occurs when chosen unit's value is less than the programmed value.

RS-232 Communication:

- Data Format: Bi-directional, 4800,8,N,1.
- Connector: Male DB9.

  Pin 2: Tx from AFRecorder
  Pin 3: Rx to AFRecorder
  Pin 5: Shield ground and signal ground
  All other pins: Not connected

- Cable: Use straight-through DB9 cable to computer.
- Software: AFRemote software for IBM PC-compatible computer provided on 720 Kb (3 1/2") media.

General Information

Power (AC): 100-120 VAC, 0.35 A (continuous)

- Fuses (2): 1.0 A, Slow Blow, 250 VAC, Type 3AG.

Power (AC): 220-240 VAC, 0.17 A (continuous)

- Fuses (2): 0.5 A, Slow Blow, 250 VAC, Type 3AG.

Power (DC): 11-16 VDC, 6 A (surge), 2.5 A (continuous)

- Connector: AMP Series 1, Arrangement 11-4.

  Pin 1: +12 VDC
  Pin 2: +12 VDC
  Pin 3: Battery ground (low current)
  Pin 4: Battery ground (high current)

- Fuse: 6.3A, Slow Blow, 250 VAC, Type 3AG.

Case Ground:

Electrically connecting the AFRecorder's case to the vehicle's chassis, the engine block, or the negative terminal of the battery using braided cable may provide improved noise rejection in some environments. Inside the AFRecorder, there is a 2.2K resistor connecting the case ground and the power ground.

Dimensions: 10.2" x 4.6" x 13.3",
25.9 cm x 11.7 cm x 33.8 cm (W x H x D)

Weight: 10 lbs., 4.5 kg.

Theory of Operation

Air-to-Fuel Ratio Sensing

The AFRecorder determines an engine's air-to-fuel ratio (AFR) by measuring the concentrations of O_2 (oxygen), CO (carbon monoxide), and H_2 (hydrogen) in the engine's exhaust. The concentrations of O_2, CO, and H_2 in an engine's exhaust change as a function of AFR, as shown in Figure 16.

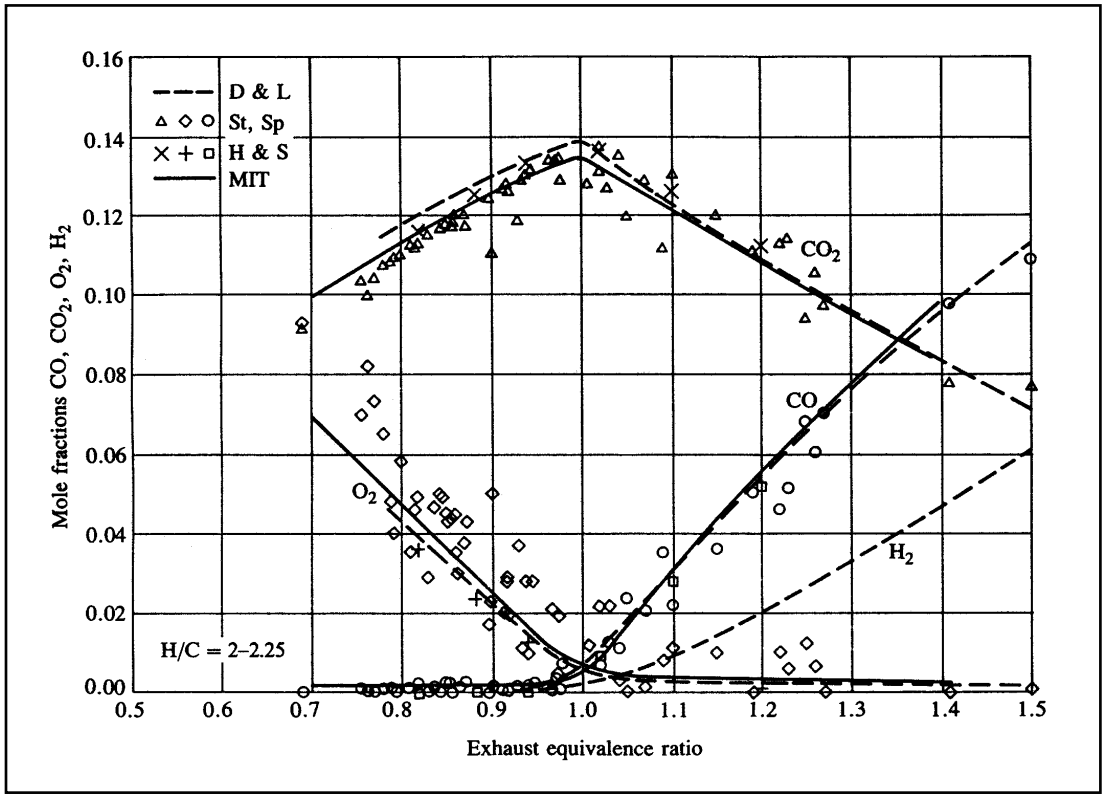

Figure 16: Exhaust Constituents as a Function of Air-to-Fuel Ratio[1]

The basic relationships between the concentrations of exhaust constituents (O_2, CO, H_2) and the engine's AFR can be calculated using chemical equilibrium relations and atom balances. However, the degree to which an engine exactly matches these calculations is dependent on the degree to which the combustion has approached equilibrium (or "completeness"). This degree of completeness is engine-dependent and a function of parameters such as valve timing, compression ratio, and cylinder wall temperature. The accuracy of AFR calculations based on measurements of concentrations of O_2, CO, and H_2 are improved with information as to an engine's degree of combustion completeness.

[1] From *Internal Combustion Engine Fundamentals* by J.B. Heywood, McGraw Hill, 1988.

The AFR sensor's (sometimes called a "UEGO" or "Universal Exhaust Gas Oxygen" sensor) sensitivities to concentrations of O_2, CO, and H_2 in an engine's exhaust are defined as Io_2, Ico, and Ih_2 respectively. These sensitivities are factory-determined and provided with each AFR sensor.

The degree to which an engine's exhaust approaches chemical equilibrium is defined as ICCl, ICCs, and ICCr. ICC stands for "incomplete combustion" and the suffixes "l", "s", and "r" stand for "lean", "stoichiometric", and "rich". The ICC factors are factory-set for typical production engines and can be modified (see **Setup - Constants - Engine** on page 18). ICC factors should be increased for engines with conditions conducive to lesser than typical production-engine amounts of combustion completeness.

Display, Recording, Storage, and Statistics

Display, Recording, and Storage

The values taken at the 0.01 sec. intervals are available for use by the AFRecorder and the software program AFRemote.

The AFRecorder's display is updated with an average of these values. The averaging and the display update interval are selectable (see Table 1 on page 17).

AFRemote's real-time display and real-time plotting options use data processed at the "Fast" setting in Table 1.

Recorded data is available at the selected sample interval of between 0.01 sec. and 30 min. and is not averaged. For example, if the sample interval was selected to be 0.08 sec., during recording, information from every eighth measurement time would be recorded.

Real-time to disk and real-time plotting to disk data is available at the selected sample interval of between 0.1 and 60 sec. and are also not averaged.

Should the AFRecorder detect an AFR outside of its measurement range (ϕ less than 0.25 or ϕ greater than 2.5), it will display "++++" (for too lean) or "----" (for too rich). The value recorded or stored real-time to disk will be the lean or rich limit.

Statistics

Real-time to disk data, real-time plotting to disk data, recorded data (via "Upload Recorded Data"), or loaded data (via "Load PC File Data") may have its statistics calculated (average, standard deviation, maximum, minimum).

The previously described limit values are used to calculate the statistics if the AFR's value is beyond the AFRecorder's measurement range.

Maintenance

Troubleshooting

Air-to-Fuel Ratio Measurement Failure

The AFR sensing function has failed if the AFRecorder displays "xxxx", "----", "V LO", or an oscillating $\%O_2$ reading when the AFR sensor is in stationary air and enabled (see **AFR Measurement Enable/Disable** on page 22).

Errors Reported on the AFRecorder's Display

There are two ways that the AFRecorder reports errors: as "ERROR # ..." (where # is a number) or as "EEPROM Errors Found ...".

"ERROR # ..." is most often caused by the entry of an unrealistic setup parameter or combination of parameters, or an incorrect “AIR CAL”. Should this occur, all setup parameters should be verified and at least one sensor constant reentered (even if already correct) followed by an “AIR CAL”. If an incorrect setup parameter cannot be found and normal operation cannot be restored, contact ECM with the error number and the entered setup parameters.

"EEPROM Errors Found ..." indicates that one or more of the setup parameters stored in the EEPROM has been corrupted. Usually, this is the result of a severe powerline or signal surge. If this occurs, the AFRecorder replaces the corrupted setup parameters(s) with default values. Should this occur, all setup parameters should be verified as the default values may not be as desired.

Auto-Resetting of the AFRecorder

The AFRecorder contains self-monitoring circuitry ("watchdog") that will reset the AFRecorder when abnormal operation is detected. After being reset, the AFRecorder will act as if it was just turned on. Conditions that will cause the AFRecorder to reset itself are:

1. Unreliable or "noisy" power. The power can be corrupted if a timing light is powered by the same power supply.

2. Excessive spark noise. Spark noise can enter the AFRecorder via the AFR cable if it is placed too close to the spark plug wire.

Simple experimentation (ex. ground the AFRecorder's case, move the AFRecorder away from the engine, relocate the cabling, or use a separate battery) will usually isolate the cause and suggest a cure.

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.

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 AFRecorder's power and AFR sensor on a stopped engine it is best to think-out your moves before you make them.

Route and cable-tie all wires away from hot, moving, sharp, high energy (spark), and caustic 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 coworkers is tired.

When operating the AFRecorder 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 coworkers 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 AFR sensor, 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 replace 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.

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.

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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