ECM ENGINE CONTROL AND MONITORING

AFRecorder 4800™

Dual-Channel
Fast Air-Fuel Ratio Analyzer

Instruction Manual

6/03 Part Number 4800-11

Printed in the United States of America.

Table of Contents

Introduction

The AFRecorder 4800

The AFRecorder 4800 is a dual-channel, UEGO (universal exhaust gas oxygen) sensor-based, air-to-fuel ratio (AFR) analyzer. The AFRecorder 4800 comes in two forms: a Model R (rack mount) and a Model P (portable). Both AFRecorders report an engine's AFR in four ways:

- Air-to-Fuel Ratio: AFR_L, AFR_R (left and right sensor)
- Average Deviation of AFR: DEV_L, DEV_R (left and right sensor)
- Left Minus Right AFR: L - R
- Average AFR: AVG.

Its features include:

- Air-to-Fuel Ratio can be displayed in AFR, λ, or ϕ units. $\%O_2$ can also be displayed.
- Measures Air-to-Fuel Ratio for a wide variety of fuel types
- Selectable 4 line or large (0.72") character backlit displays
- 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 outputs
- Simulated EGO (exhaust gas oxygen) sensor outputs with programmable switch points
- RS-232 communication interface
- 100-240 VAC (Models R and P) and 11-16 VDC (Model P) operation.

The AFRecorder can be operated in two modes: "stand-alone" or "remote". In stand-alone mode, commands to the AFRecorder are entered using the keypad on the front panel and the measurements, recordings, and operational menus are viewed on the front panel displays. In remote mode, commands are entered and measurements, recordings, and operational menus are viewed using an IBM-compatible PC.

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 4800R (rack mount) package.
For pictures, visit www.ecm-co.com.

Item No.	Description	Part Number
1.	AFRecorder 4800R	4800R
2a. (standard)	Air-to-Fuel Ratio (AFR) Sensors (Quantity 2)	2400E-1
or		
2b. (optional)	Air-to-Fuel Ratio (AFR) Sensors (Quantity 2) with Severe Duty Connectors	2400E-1S
3a. (standard) [1]	AFR Sensor Cables, 30 ft. (Quantity 2)	2400E-32
or		
3b. (optional) [2,3]	Severe Duty Panel-Mount Cable Kit	4800R-21
4.	120 VAC U.S. Power Cable, 6 ft. (replaced with appropriate power cable for export)	2400G-38
5a.	Spare Power Fuses, 2 A, Slow Blow, Type 3AG, for 120 VAC (Quantity 2)	4800R-18
or		
5b.	Spare Power Fuses, 1 A, Slow Blow, Type 3AG, for 250 VAC (Quantity 2)	4800R-18b
6.	DB15M Outputs Connector	2400E-9
7.	AFRemote Software	4800A-10
8.	AFRecorder Instruction Manual	4800-11

See Notes on next page.

Notes:

[1] The AFR cabling can be modified to suit customer needs.

[2] When the Severe Duty Panel-Mount Cable Kit (Part No. 4800R-21) is supplied, the AFR sensors are equipped with matching severe duty connectors. An AFR sensor with a severe duty connector is Part No. 2400E-1S. AFRecorder to back-of-panel AFR cabling is not supplied as part of kit unless requested.

[3] The Severe Duty Panel-Mount Cable Kit consists of:

1. Quantity 2 of AMP CPC Connector/Plug/Clamp Terminal Kit (Part No. 4800R-19). Each kit includes the following:

   a. Connector Plug — AMP 206708-1
   b. Cable Clamp — AMP 206966-1
   c. Terminals for 24-20 AWG Wire (Quantity 6) — AMP 66105-4
   d. Terminals for 18-14 AWG Wire (Quantity 2) — AMP 66360-4

2. Quantity 1 of Fischer Panel-Mount Connector/ID Ring/Sealing Cap Kit, Left Channel/Black (Part No. 4800R-20L). Each kit includes the following:

   a. Panel-mount Connector — Fischer D105A062
   b. Black connector ID Ring — Fischer 105.2282
   c. Connector Sealing Cap — Fischer 105.2132

3. Quantity 1 of Fischer Panel-Mount Connector/ID Ring/Sealing Cap Kit, Right Channel/White (Part No. 4800R-20R). Each kit includes the following:

   a. Panel-mount Connector — Fischer D105A062
   b. White connector ID Ring — Fischer 105.2281
   c. Connector Sealing Cap — Fischer 105.2132

4. 15’ Severe Duty AFR Cable Extension, Left/Black Channel (Part No. 2400E-30L).

5. 15’ Severe Duty AFR Cable Extension, Right/White Channel (Part No. 2400E-30R).

The following items are included with the AFRecorder 4800P (portable) package.
For pictures, visit www.ecm-co.com.

Item No.	Description	Part Number
1.	AFRecorder 4800P	4800P
2.	Air-to-Fuel Ratio (AFR) Sensors (Quantity 2)	2400E-1
3.[1]	AFR Sensor Cable, 20 ft. (Quantity 2)	2400E-2
4.	120 VAC U.S. Power Cable, 6 ft. (replaced with appropriate power cable for export)	2400G-38
5.	12 VDC U.S. Power Cable, 20 ft.	2400E-7
6a.	Spare Power Fuses, 2 A, Slow Blow, Type 3AG, for 120 VAC (Quantity 2)	4800R-18
or		
6b.	Spare Power Fuses, 1 A, Slow Blow, Type 3AG, for 230 VAC (Quantity 2)	4800R-18b
7.	Spare Power Fuse, 10A, Slow Blow, Type 3AG, for 12 VDC	4800A-8
8.	Case Ground Cable, Braided, 3 ft.	2400A-17
9.	DB9M Outputs Connector	2400G-9
10.	AFRemote Software	4800A-10
11.	AFRecorder Instruction Manual	4800-11

Notes:

[1] The AFR cabling can be modified to suit customer needs.

Important Operation Notes

Please read and follow all of the cautions contained in the **Safety Warnings** section on page 45 of this manual.

Air-to-Fuel Ratio Sensors

Read the **AFR Measurement Calibration ("AIR CAL")** section on page 22.

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

Do not operate an engine for more than three minutes with the AFR sensors installed in the exhaust if the AFRecorder is off, or if the AFR measurement function is disabled (see **AFR Measurement Enable/Disable** on page 23), or if the supply voltage is less than 11 VDC (Model 4800P only).

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

Do not mount the AFR sensors where liquid fuel or condensed water will collect on the sensors' tips.

To minimize thermal shock to the AFR sensors 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. This suggestion can be ignored for cold-start studies. 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 sensors where exhaust gas temperatures or pressures exceed the specified ranges. (See the **Input Specifications and Limits** section on page 34.)

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

Do not drop the AFR sensors onto a hard surface.

The AFR sensors are self-heated. Do not touch or expose them to flammable substances when the AFRecorder is on.

Before installing the AFR sensors, apply a small amount of non-lead containing antiseize compound to their threads. Do not get the compound on the sensors' tips.

Route and cable-tie the AFR sensors' cables away from hot or moving objects and ignition wires.

Physical Features and Hook-up

Front Panel

Once the power, sensors, 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 status of this mode is indicated on the LCD displays.

The front panel holds two 4-line by 20-character format, backlit LCD displays. The contrast (Models 4800R and 4800P) and intensity (Model 4800R only) of each display can be adjusted via potentiometers accessible from the back of the instrument. The left display reports the measurements of the left AFR sensor and the right display reports the measurements of the right AFR sensor. Upon command (see **Setup - Display - Size** on page 17), the AFRecorder can enlarge the measurements of two parameters (i.e. two of: AFR_L, AFR_R, DEV_L, DEV_R, L-R, AVG) so that they each fill a display. In addition to displaying measurements, the displays can show the statistics of a recorded session or menu information for AFRecorder set-up.

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 to delete an incorrect entry.

Rear Panel and Power Hook-up

The AFRecorder Model 4800R is powered by AC line power (100-240 VAC). The AFRecorder Model 4800P can be powered by either AC line power (100-240 VAC) or by a 12 VDC battery. Do not operate the instrument with both the 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 instrument 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 fuses), 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 "230" (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. 2 A Slow Blow fuses are required for 100-120 VAC power and 1 A Slow Blow fuses are required for 220-240 VAC power. All fuses must be rated for 250 VAC.

DC power enters the AFRecorder Model 4800P through the smaller of the three keyed circular plastic connectors (CPCs) on the rear panel. The input voltage must be between 11 VDC and 16 VDC. A 10 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 supply 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 12 VDC 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 the same battery.

A terminal block is provided to electrically connect the AFRecorder's case to the vehicle's chassis, the engine block, the negative terminal of the battery, or a "ground mecca". This may provide improved noise rejection in some environments. A braided cable should be used for this purpose. The AFRecorder Model 4800R joins the AFR sensor cable shields to the case outside the instrument using a removable jumper. This gives the Model 4800R the maximum flexibility for integration into specific installations. The AFRecorder Model 4800P joins the AFR sensor cable shields to the case inside the instrument.

Air-to-Fuel Ratio Hook-up

The AFR sensors are mounted in the engine's exhaust by threading them into M18X1.5 mm bosses that are 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 1¼" diameter steel bar with a M18X1.5 mm tap and cutting off 5/16" wide pieces as they are needed.

To mount a boss, first drill a ¾" diameter hole in the desired AFR sensing location. If an individual cylinder's AFR is to be measured, drill approximately 12" from that cylinder's exhaust valve. If two or more cylinders' AFR is to be measured using one sensor, drill approximately 12" from where the cylinders' exhaust pipes join. These recommended locations are based on trade-offs between sensor response time, sensor temperature, exhaust mixing, and typical engine/exhaust packaging.

Long distances between the engine and the AFR sensors should be avoided because such installations result in increased condensed water being sprayed on the sensors during engine start-up. Liquid water striking an 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 sensors must be mounted upstream of where the air enters the exhaust system or else the measured AFR value 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 sensors by lightly coating their threads with a non-lead containing antiseize compound and tightening to 30 ±3 ft-lbf (40 ±4 Nm). Attach one end of each AFR cable to each sensor and route the cables to the AFR sensor inputs on the back of the AFRecorder. Use cable ties to keep the cables away from hot or moving objects and ignition wires. Do not modify the cables as this may affect the AFRecorder's operation.

During AFR sensor use, observe the conditions outlined in the **Important Operation Notes** section on page 5. When an AFR sensor is not being used, an 18 mm spark plug (ex. Champion D15Y) can be used to plug the hole.

Analog Outputs and Simulated EGO Sensor Outputs

Linearized and programmable 0 to 5 VDC outputs are available for each AFR measurement. These outputs can be fed into an external data acquisition system. Also available are simulated EGO (exhaust gas oxygen) sensor outputs with programmable switch points. See **Setup - Outputs - Analog** on page 19 and **Setup - Outputs - Sim EGO** on page 19 for information on programming these outputs and **Output Specifications and Limits** on page 36 for the DB15F (Model 4800R) or DB9F (Model 4800P) 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 female DB25 (Model 4800R) or a male DB9 (Model 4800P). The serial port connector on the back of IBM-compatible PCs is either a male DB-25 (25 pins) or a male DB-9 (9 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 the shield ground (use pin 1 on DB25 or pin 5 on DB9), Rx to AFRecorder (use pin 2 on DB25 or pin 3 on DB9), Tx from AFRecorder (use pin 3 on DB25 or pin 2 on DB9), and signal ground (use pin 7 on DB25 or 5 on DB9) need to be used.

Stand-Alone Operation

Measurement and the SYS Key

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

1. System initialization is performed. The displays show "Initializing" and the internal buzzer is tested.

2. If the AFR measurement function is enabled (see **AFR Measurement Enable/Disable** on page 23), the left display begins a 40 second countdown to allow the AFR sensors to reach operating temperature. If the "SYS" key is pressed during the countdown, the main menu is displayed.

   During countdown, the right display shows the sensors' status (i.e. enabled or disabled) and programmed AFR offsets (see **AFR Measurement Offsets**, page 22).

3. After the countdown has completed, the AFRecorder begins the measurement and display of Air-to-Fuel Ratio (AFR), Average Deviation of AFR (DEV), Left minus Right Sensor AFR (L-R), and Average AFR of both sensors (AVG). The left AFR sensor's values are displayed on the left display and the right AFR sensor's values are displayed on the right display. Depending on prior programming (see **Setup - Display** on page 17), the AFRecorder may enlarge one of these parameters on each display. Figure 1 shows the AFRecorder's displays during measurement.

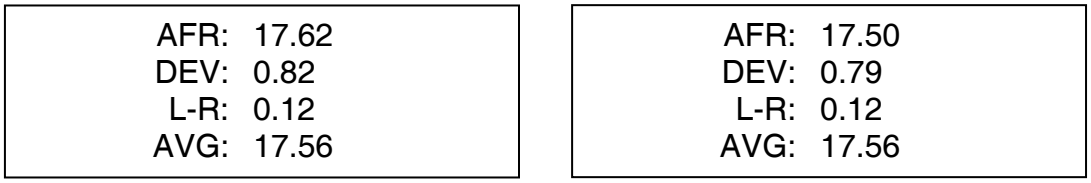

Figure 1: AFRecorder Displays During Measurement

Information other than the measured AFR is shown depending on certain conditions:

Display	Meaning
%O2: 20.7	AFR measurement function properly calibrated in air. See **AFR Measurement Calibration ("AIR CAL")** on page 22.
xxxx	AFR measurement function error. See **Troubleshooting** on page 43.
V LO	Supply voltage to AFRecorder is less than 11 VDC (4800P) or AFR sensor is disconnected.
OFF	AFR measurement function disabled. See **AFR Measurement Enable/Disable** on page 23.

When the $\%O_2$ in the exhaust surrounding a sensor exceeds 19.5%, the AFRecorder will automatically change from displaying that sensor's 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.

The Average Deviation of AFR (DEV) is the average percentage change in the measured AFR in 0.01 seconds. It is defined as:

$$DEV = \frac{\sum_{i=1}^{n} \left| AFR_i - AFR_{i-1} \right|}{\sum_{i=1}^{n} AFR_i} \times 100$$

where AFR_i is the current AFR, AFR_{i-1} is that sensor's AFR 0.01 seconds earlier, and n is the number of measurements. The greater "DEV" gets, the "rougher" the measured AFR is.

Once the AFRecorder has begun displaying the AFR measurements, 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 14. Pressing "SYS" presents the main menu on the left display (see Figure 2). Subsequent menu-related displays appear on the left display.

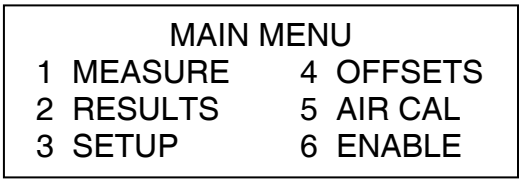

Figure 2: Main Menu (accessed by pressing "SYS")

From the main menu, the user can command the continuation of the measurement and display of parameters (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 "OFFSETS", "AIR CAL", or "ENABLE"). Figure 3 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
				1	AFR_L	Left AFR sensor
				2	AFR_R	Right AFR sensor
				3	L-R	Left minus Right AFR
				4	AVG	Average AFR
		3	POINT			Display one recorded point (+: advance, -: back up)
3	SETUP	1	DISPLAY	1	SIZE LEFT	One or four line display
				2	SIZE RIGHT	One or four line display
				3	AFR UNITS	AFR, ϕ, λ, or $\%O_2$
				4	RATE	Slow/medium/fast update
		2	RECORD	1	DURATION	Sample duration
				2	INTERVAL	Sample interval
				3	SENSORS	Select AFR sensors to record
		3	OUTPUTS	1	ANALOG	Program output ranges
				2	SIM EGO	Program simulated EGO AFR switch points
				3	CAL D/A	Calibrate analog outputs
		4	OPTIONS	1	ICC	Activate ICCs
				2	SOUND	Activate key beeping
				3	DEFAULTS	Sets all setup values including sensor constants to default values
		5	CONSTS	1	SENSOR_L	Calibration specifications for left AFR sensor
				2	SENSOR_R	Calibration specifications for right AFR sensor
				3	FUEL & AIR	H:C, O:C, and N:C ratios of fuel and $\%O_2$ of air
				4	ICC_L	ICC factors for left sensor
				5	ICC_R	ICC factors for right sensor
4	OFFSETS					Set AFR measurement offsets
5	AIR CAL					Calibrate AFR measurement functions in air
6	ENABLE					Toggle AFR sensor power on/off for sensor removal

Figure 3: Menu Tree for the AFRecorder

Pressing "SYS" at any time will suspend the current operation and present the user with the main menu.

Recording

Recording is started by pressing the "REC" (Record) key while the AFRecorder is displaying its measured AFRs. During recording, the displays will appear as shown in Figure 4.

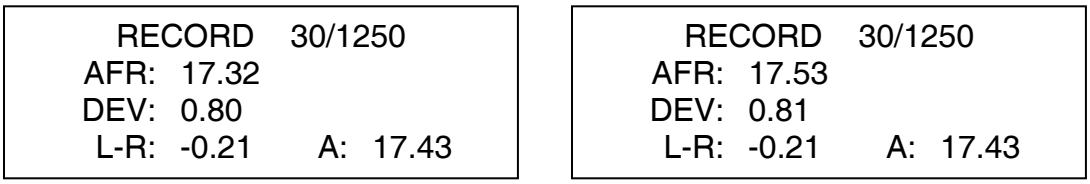

Figure 4: AFRecorder Displays During Recording

In the four-line configuration, the upper row of each display shows the number of samples recorded and the total number of samples to be taken. In the example of Figure 4, 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 of each AFR in this case. Up to 5,000 samples (total for both AFR sensors) may be recorded.

In the large character display configuration, a small "R" is shown near the decimal point during recording.

During recording, if the AFRecorder detects an AFR outside of its measurement range (λ less than 0.40 or λ greater than 10.0), the value recorded will be the rich or lean limit and the limit value will be used to calculate the statistics.

The recording duration, the sample interval (time between recorded samples), and the AFR sensor(s) to record are all programmable (see **Setup - Record Menu** on page 18). 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 5). The results menu can also be accessed from the main menu (see Figure 2). 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.

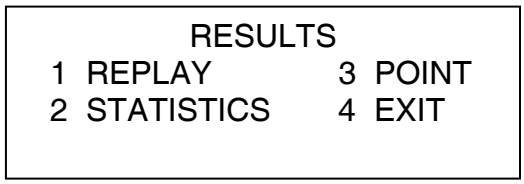

Figure 5: The Results Menu

Results - Replay

If "REPLAY" is selected from the results menu, the display replays the recorded data in slow-motion (see Figure 6). "AFR_L" is the AFR of the left sensor, "AFR_R" is the AFR of the right sensor, "L-R" is the left sensor's AFR minus the right sensor's AFR, and "A" is the average AFR of both sensors. The display is updated with the measured parameters' values at each sample time. "DEV" is not shown during replay.

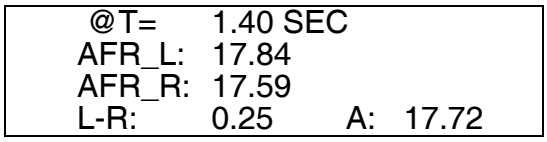

Figure 6: AFRecorder Display During Replay

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 menu will appear (see Figure 7).

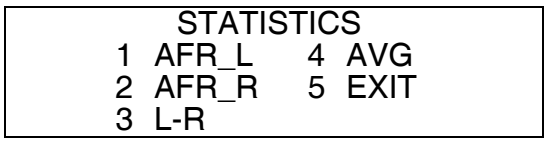

Figure 7: The Statistics Menu

Selection of "AFR_L", "AFR_R", "L-R", or "AVG" will begin the display (see the two screens in Figure 8) of the statistics of that parameter during the recorded session. The first screen contains the average, standard deviation (Sd), and the number of samples. The standard deviation of AFR is calculated as:

$$Sd = \sqrt{\frac{\sum_{i=1}^{n} (AFR_i - AFR_{avg})^2}{n}}$$

using data from the entire recording. As with the Average Deviation of AFR (DEV), the greater Sd gets, the "rougher" the recorded AFR is. Sd is different from the real-time parameter DEV. DEV is calculated from a computationally simpler formula more suited for real-time calculation and display.

The "hidden" sample at t=0 is used for the statistical 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 statistics menu.

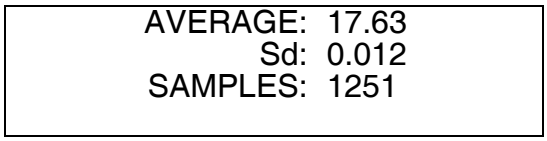

Figure 8a: Example of Statistical Results Screen 1

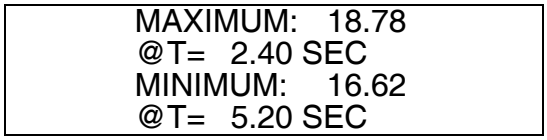

Figure 8b: Example of Statistical Results Screen 2

Choosing "EXIT" from the statistics menu will return the AFRecorder to the results menu.

Results - Point

Selecting "POINT" from the results menu allows the examination of the AFRs 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 is used to configure the AFRecorder. The setup menu is shown in Figure 9. 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.

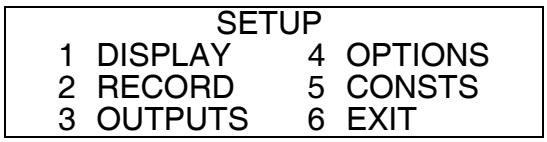

Figure 9: The Setup Menu

Setup - Display Menu

The selection of "DISPLAY" from the setup menu allows the configuration of the manner in which the measured parameters are displayed (see Figure 10). "EXIT" returns the AFRecorder to the setup menu.

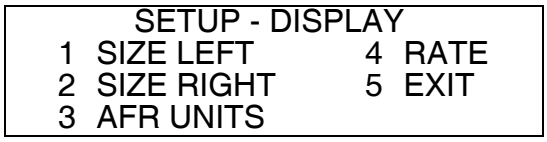

Figure 10: Setup - Display Menu

- **Setup - Display - Size**

The choice of "SIZE" from the setup - display menu allows the configuration of the display as a four-line display ("SMALL") or a single line large character display ("LARGE").

If "LARGE" is selected, the AFRecorder will request the selection of the measured parameter to enlarge.

The choice of display size does not influence whether one or both AFR sensors are recorded during a recording session.

- **Setup - Display - AFR Units**

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

The choices for AFR units are: AFR, ϕ, λ, or $\%O_2$. 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 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.

- **Setup - Display - Rate**

"RATE" determines how often the measurement information 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 recursively averaged to generate the information displayed for a given update interval. The averaging is performed on data sampled at 0.01 second intervals. For example, the displayed data at the "Fast" display rate is the result of 34 measurements at 0.01 second intervals with the averaging formula of (New Average) = 1/8*(New Value) + 7/8*(Old Average).

Rate	Display Update Interval	Measurement Averaging
SLOW	1.20 sec.	32 measurements
MEDIUM	0.60 sec.	16 measurements
FAST	0.34 sec.	8 measurements

Table 1: Display Rate Options

Setup - Record Menu

The "RECORD" selection from the setup menu allows the setting of the recording duration (in minutes and seconds), the sample interval (time between samples), and which (one or both) of the AFR sensors to record. A maximum of 5,000 measurements may be taken during a recording session (i.e. 2,500 for each sensor or 5,000 for one sensor). The minimum sample interval is 0.01 seconds. For more information, see the **Specifications and Limits** section on page 33.

Setup - Outputs Menu

The choice of "OUTPUTS" from the setup menu allows the programming of the analog and simulated EGO (exhaust gas oxygen) sensor outputs (see Figure 11). "EXIT" returns the AFRecorder to the setup menu.

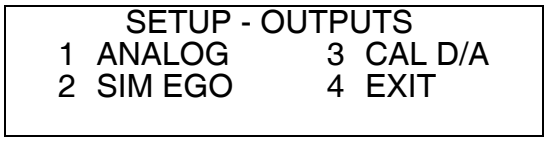

Figure 11: Setup - Outputs Menu

- **Setup - Outputs - Analog**

The choice of "ANALOG" from the setup - outputs menu allows the setting of the analog voltages output by the AFRecorder for the values of air-to-fuel ratio (including the offset, see **AFR Measurement Offsets** on page 22) measured.

The analog outputs are a linear function of the measurements in their displayed units between the values entered for 0 V and 5 V. For example, if the 0 VDC output for AFR (in AFR units) were programmed as 10 and the 5 VDC output as 15 then a voltage output of 1 Volt would result from a measured AFR of 11 if the displayed units were AFR. The analog outputs are updated every 0.01 seconds. See the **Output Specifications and Limits** section on page 36 for more information.

- **Setup - Outputs - Sim EGO**

The choice of "SIM EGO" allows the setting of the AFRs at which the simulated exhaust gas oxygen (EGO) sensor outputs transition from their low (approximately 0.02 V) states to their high (approximately 0.8 V) states (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 outputs are updated every 0.01 seconds. Separate simulated EGO switch threshold values are maintained for each of the AFR units choices (AFR, ϕ or λ).

- **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.

Setup - Options Menu

The choice of "OPTIONS" from the setup menu allows the activation of AFRecorder functions (see Figure 12). Selecting "EXIT" from this menu will return the AFRecorder to the setup menu.

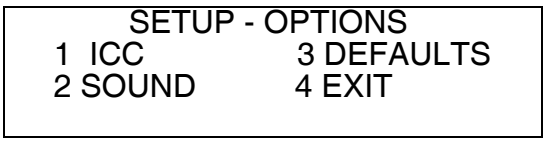

Figure 12: The Setup - Options Menu

- **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 - ICC_L, ICC_R** on page 21). It is recommended that this option be turned off when using fuels containing oxygen (i.e. methanol). ICC can be independently activated for each AFR sensor.

- **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 - Options - Defaults**

The "Defaults" option resets all setup parameters including sensor constants to default values.

Setup - Constants Menu

The "CONSTANTS" menu is where calibration information about the sensors, fuel, air, and engine is input into the AFRecorder (see Figure 13). Selecting "EXIT" from this menu will return the AFRecorder to the setup menu.

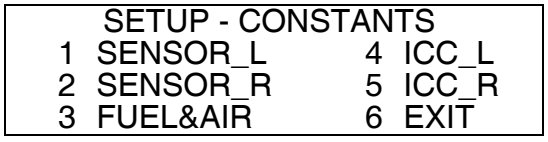

Figure 13: The Setup - Constants Menu

- **Setup - Constants - Sensor_L, Sensor_R**

The AFR sensors' calibration constants are entered after selecting "SENSOR_L" (for the left AFR sensor) or "SENSOR_R" (for the right AFR sensor) from the setup - constants menu. Fourteen displays following this selection allow the entry of Io_2, Ico, Ih_2, I_1 and I_2 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 22). 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 & Air**

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 & AIR" 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 atom ratio of the fuel). The **Input Specifications and Limits** section on page 34 contains values for common fuels.

Information about the $\%O_2$ in air is used during the "AIR CAL" of the AFR sensors. The oxygen concentration in dry air (zero humidity) is 20.95% 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).

- **Setup - Constants - ICC_L, ICC_R**

Information pertaining to the engine's degree of combustion efficiency is entered after selecting "ICC_L" (for the left AFR sensor) or "ICC_R" (for the right AFR sensor) 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 -10.0 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)

The ICCs must be activated (see **Setup - Options - ICC** on page 20) for them to influence the reported AFR(s).

AFR Measurement Offsets

The main menu selection of "OFFSETS" allows the user to bias the displayed, recorded, and output AFRs for each AFR sensor by an entered amount. The entered offset acts across the entire range of measured AFRs. Separate offset values are maintained for each of the AFR units choices (AFR, ϕ, λ or $\%O_2$). For example, if the measured AFR is 14.6 and the offset is -0.1, the displayed AFR will be 14.5. The offset AFRs are used for display, recording, and outputs.

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 - Fuel & Air** (on page 21) 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 altitude and weather 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, followed by the AFR sensor to calibrate (left or right), and initiate calibration. Note that the correct $\%O_2$ in air must be entered in **Setup - Constants - Fuel & Air** (on page 21).

      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 1.0. 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 or I_2) is entered (including reentering the same number) (see **Setup - Constants - AFR Sensor_L, Sensor_R** on page 20 **and Unit-Specific Information** on page 43), 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 the "AIR CAL" if the AFR sensor's output in air is unreasonable or if its output is not steady. An aborted "AIR CAL" can be caused by 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 sensors to be powered down ("DISABLED") and up ("ENABLED") for sensor removal. To avoid AFR sensor damage, a sensor should only be removed or attached when the sensors are disabled or when the AFRecorder is off. After enabling the AFR measurement function, the AFR sensors require 40 seconds to reach 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 offsets. In addition, real-time plotting and file handling capabilities are provided. The AFR measurement calibration ("AIR CAL") and "ENABLE/DISABLE" functions, the "CAL D/A" option, the display of "%O2", "xxxx", "VLO", and "OFF" (see **Measurement and the "SYS" Key** on page 11), and the large character display are not available in remote mode. Remote mode uses the 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.

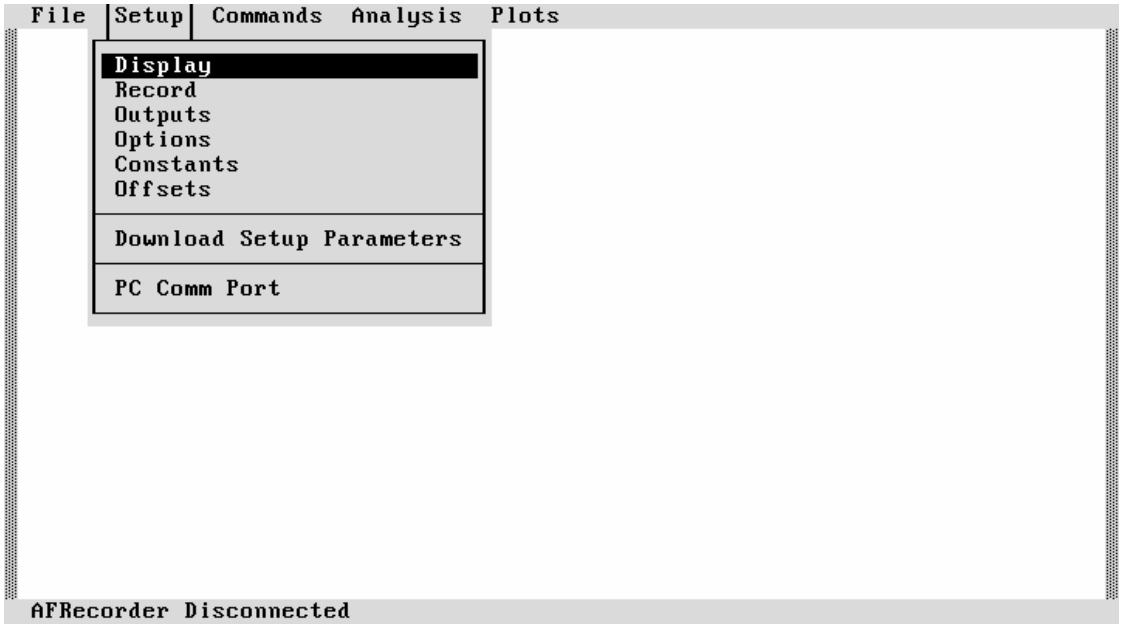

Figure 14: An AFRemote Pull-Down Menu Screen

Figure 14 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 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".

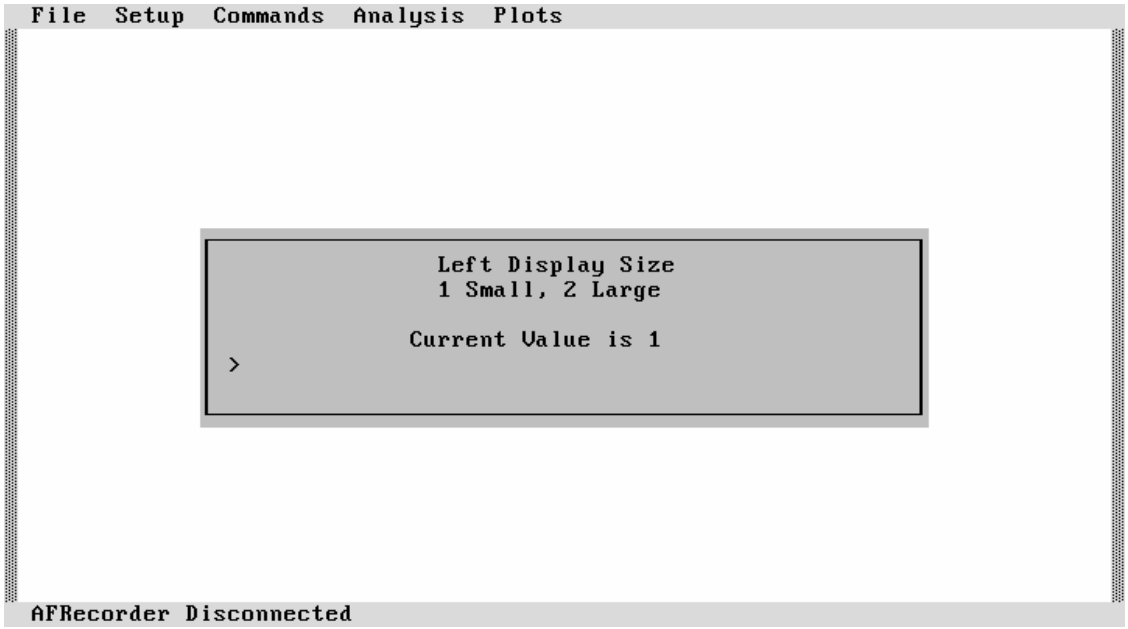

Figure 15: A Dialog Box

In some cases, a dialog box will appear in the center of the screen (see Figure 15). 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 9).

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 16 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 17. When the connection is complete, the status "AFRecorder Connected" is shown in the bottom, left corner of the screen.

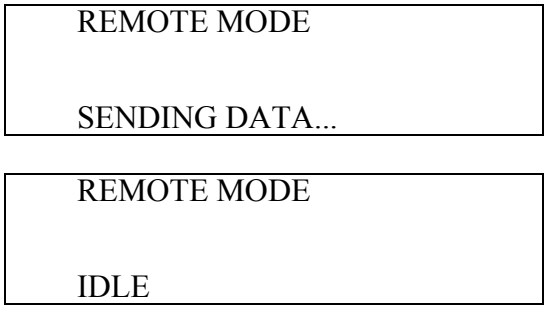

Figure 16: AFRecorder Display During Software Connection

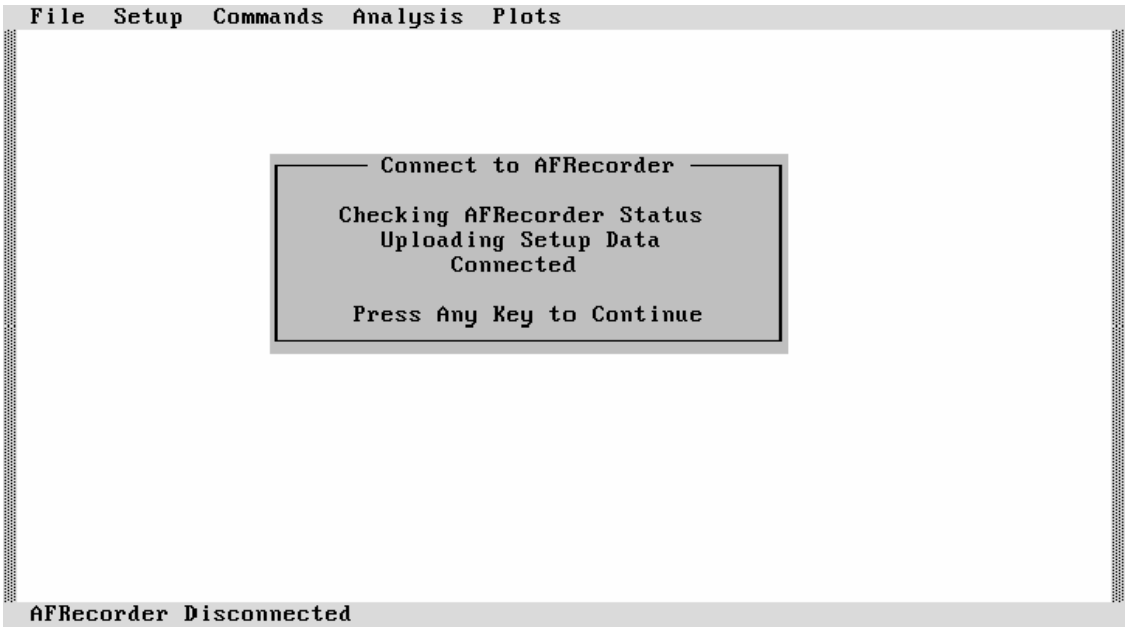

Figure 17: PC Screen During Software Connection

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

Measured parameters can be viewed on the PC's screen in two forms: real-time display or real-time plotting. With both forms, the AFR units are those selected in setup (see **Setup - Display Menu** on page 17). The update interval and the measurement averaging are at the "FAST" rate and are not adjustable (see Table 1 on page 18). During real-time display and real-time plotting, the AFRecorder also displays the measured parameters.

Real-Time Display

Real-time display duplicates the display format of the AFRecorder on the PC's screen (see Figure 18).

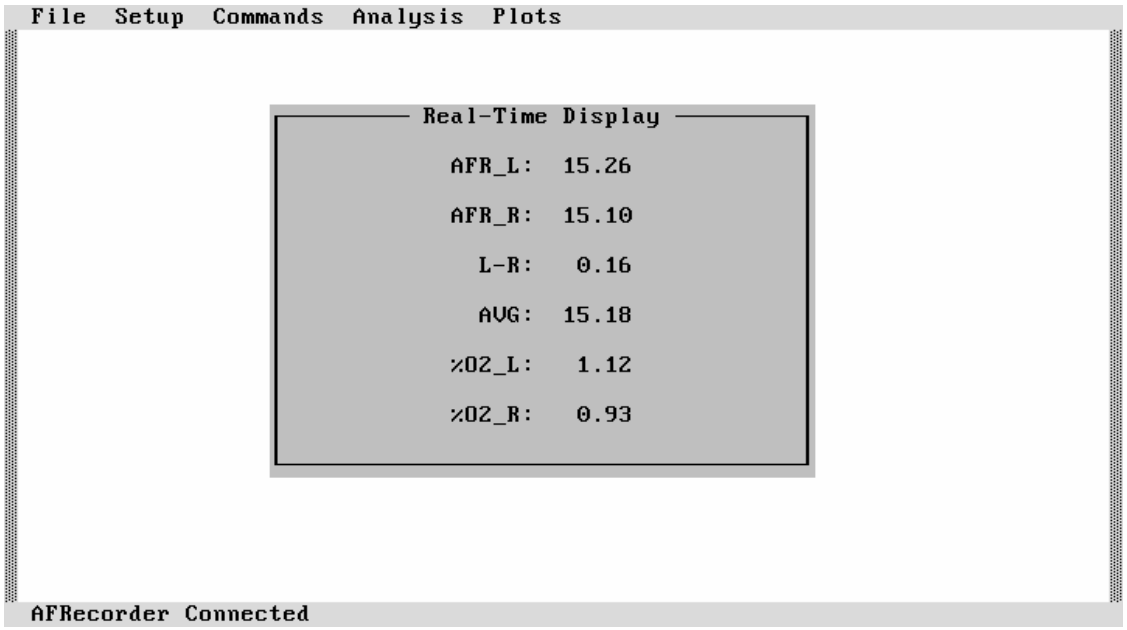

Figure 18: Real-Time Text Display

Real-time display is started by selecting "Commands" followed by "Real-Time Display On". The command "Real-Time Display Off" ends the display. "%O2", "xxxx", "V LO", "OFF", and the large character display are not available with AFRemote.

Real-Time Plotting

Real-time plotting turns the PC into an oscilloscope showing the values of the measured parameters 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 appearance of the plots (i.e. type and scaling) are made using the "Plots" menu and the "Set Plot Type" or "Set Plot Scales" selections.

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 0.34 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 19 is an example of an "exported" file. The time and recorded measurements are always stored as five columns. The columns contain, from left to right: time, AFR_L, AFR_R, L-R, and AVG. The data is separated by tabs.

0.000	15.125	14.419	0.706	14.772
0.100	15.239	14.761	0.478	15.000
0.200	15.466	14.073	1.393	14.770
0.300	15.693	14.965	0.728	15.329
0.400	15.352	14.247	1.105	14.800
0.500	15.012	14.815	0.197	14.914
0.600	15.125	14.848	0.277	14.987
0.700	15.806	14.978	0.828	15.392
0.800	16.260	14.195	2.065	15.228
0.900	16.407	14.971	1.436	15.689
1.000	15.466	14.458	1.008	14.962
1.100	13.874	14.499	-0.625	14.187
1.200	13.375	14.864	-1.489	14.120
1.300	13.519	14.097	-0.578	13.808
1.400	13.925	14.587	-0.662	14.256
1.500	14.077	14.061	0.016	14.069
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

Figure 19: An Exported Data File

Each row contains the measured values at the time given in the first column. Note that data begins at time zero (0). All parameter values are stored, even if one AFR sensor was not used. If an AFR sensor was not used then its rich or lean limit will appear in that parameter's column.

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 Plotting to Disk".

Activation of this option is very similar to "Real-Time to Disk" (see **Real-Time to Disk** on page 29) 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 of AFR 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 to the PC.

Uploading and Filing 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 four minutes (for 10,000 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 19) except that if an AFR sensor is not selected for recording (see **Setup - Record** on page 18) then there will be zeros in the columns for that sensor, "L-R", and "AVG".

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 the measured parameter.

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 type and scales can be modified by "Set Plot Type" and "Set Plot Scales".

Hardcopy of Plots

To print hardcopies of static plots on the PC's screen, a screen-dump utility such as GRAPHICS (distributed with DOS) must be executed prior to entering AFRemote. The GRAPHICS command consists of "GRAPHICS" (without quotes) followed by the printer type. Refer to a DOS 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 16 for more information.

AFR Measurement Offsets

AFR measurement offsets may be entered to bias the measured AFRs for each AFR sensor by selecting "Setup" followed by "Offsets". The entered offset acts across the entire range of measured AFRs. Separate offset values are maintained for each of the AFR units choices (AFR, ϕ, λ or $\%O_2$). For example, if the measured AFR is 14.6 and the offset is -0.1, the displayed AFR will be 14.5. 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]	< 150 ms	±0.1 (stoichiometric) ±0.2 (12<AFR<18) ±0.5 (elsewhere)
	ϕ	0.10 - 2.5	< 150 ms	±0.006 (stoichiometric) ±0.008 (0.8<ϕ<1.2) ±0.009 (elsewhere)
	λ	0.4 - 10.0	< 150 ms	±0.006 (stoichiometric) ±0.008 (0.8<λ<1.2) ±0.009 (elsewhere)
$\%O_2$	%	0 - 22%	< 150 ms	±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

Sample Selection: Choose one or both AFRs to record. If an AFR sensor is not selected, a zero (0) is stored for its value, L-R, and AVG.
Sample Size: Up to 5,000 measurements.
Recording Duration: 1.0 second to memory limit (programmable).
Sample Interval (time between samples): 0.01 seconds to 30.0 minutes (programmable).[2]
Data Retention: Up to 10 years.

[2] The recorded sample interval is programmable in increments of 0.01 seconds.

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

Sample Selection: Both AFRs are stored. If an AFR sensor is not used, its limit value is stored.
Sample Size: 100 to 100,000 measurements for each AFR sensor.
Sample Interval: 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 33.

- AFR measurement calibration information is provided in the sections entitled **AFR Measurement Calibration ("AIR CAL")** on page 22 and **Unit-Specific Information** on page 43.

- Fuel Composition:

  H:C ratio range: 0.00 - 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 sensors with leaded fuel or in a heavily sooting or crankcase oil burning engine because these conditions will severely shorten the life of the sensors.

- 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 antiseize compound.
  Hex Size: 22 mm.
  Tightening Torque: 30 ±3 ft-lbf, 40 ±4 Nm.

  The AFR sensors' thread size is identical to that of the exhaust oxygen (EGO) sensors used in current production automobiles with 3-way exhaust catalysts.

  Use of AFR sensor cables other than that supplied may affect the accuracy and life of the AFR sensors.

- 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 Outputs:

- Programmable Ranges for: Air-to-Fuel Ratio (in AFR, ϕ, λ) or $\%O_2$ of each AFR sensor.

- Output Range (linearized in displayed units): 0 - 5 VDC. 20 mA max.

- Bits Resolution: 12 bits.

- Update Rate: 0.01 seconds.

- Connector: Female DB15 (Model 4800R only).

  Pin 1: Left Air-to-Fuel Ratio (in AFR, ϕ, λ, or $\%O_2$)
  Pin 2: Right Air-to-Fuel Ratio (in AFR, ϕ, λ, or $\%O_2$)
  Pin 3: Signal Ground
  Pin 4: Left Simulated EGO Sensor
  Pin 5: Signal Ground
  Pins 6, 7, 8, 9, 10: Not connected
  Pin 11: Right Simulated EGO Sensor
  Pins 12, 13: Signal Ground
  Pins 14, 15: Not connected

- Connector: Female DB9 (Model 4800P only).

  Pin 1: Left Air-to-Fuel Ratio (in AFR, ϕ, λ, or $\%O_2$)
  Pins 2, 4: Not Used
  Pin 3: Right Air-to-Fuel Ratio (in AFR, ϕ, λ, or $\%O_2$)
  Pin 5: Signal Ground
  Pin 6: Right Simulated EGO Sensor
  Pin 7: Left Simulated EGO Sensor
  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 (Model 4800P only), then the inputs of the data acquisition system 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 power source ground (measured at the battery) and the signal ground (measured at the outputs connector). 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 $\%O_2$ if those are the chosen AFR 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 sensors are "on".

Simulated Exhaust Gas Oxygen (EGO) Sensor Outputs:

- Programmable transition Air-to-Fuel Ratio (in AFR, ϕ, or λ) for each AFR sensor.
- "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 .05 seconds.
- Update Rate: 0.01 seconds.
- Connector: See Analog Outputs Connector on page 36.

RS-232 Communication:

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

- Connector: Female DB25 (Model 4800R only).

  Pin 1: Shield ground
  Pin 2: Rx to AFRecorder
  Pin 3: Tx from AFRecorder
  Pin 7: Signal ground
  All other pins: Not connected

- Connector: Male DB9 (Model 4800P only).

  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 cable to computer.

- Software: AFRemote software for IBM PC-compatible computer provided on 1.44MB (3 1/2") media.

General Information

Power (AC): 100-120 VAC, 0.70 A (continuous)

- Fuses (2): 2.0 A, Slow Blow, 250 VAC, Type 3AG

Power (AC): 220-240 VAC, 0.34 A (continuous)

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

Power (DC, Model 4800P only): 11-16 VDC, 12 A (surge), 5.0 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: 10 A, Slow Blow, 250 VAC, Type 3AG

Case Ground:

Electrically connecting the AFRecorder's case to the vehicle's chassis, the engine block, the negative terminal of the battery, or a “ground mecca” may provide improved noise rejection in some environments. A braided cable should be used for this purpose.

The AFRecorder Model 4800R externally connects the case ground to the AFR sensor cable grounds using a removable jumper. This gives the Model 4800R the maximum flexibility for integration into specific installations. Neither ground is connected to the signal ground.

The AFRecorder Model 4800P internally connects the case ground to the AFR sensor cable grounds. The signal ground is connected to these grounds through a 2.2K resistor located inside the instrument.

Dimensions:

- Model 4800R

  19.0” x 3.5” x 14” (fits standard 19” rack)
  48.3 cm. x 8.9 cm. x 35.6 cm. (W x H x D).

- Model 4800P

  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:

- Model 4800R

  14.3 lbs., 6.5 kg.

- Model 4800P

  12 lbs., 5.4 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 20.

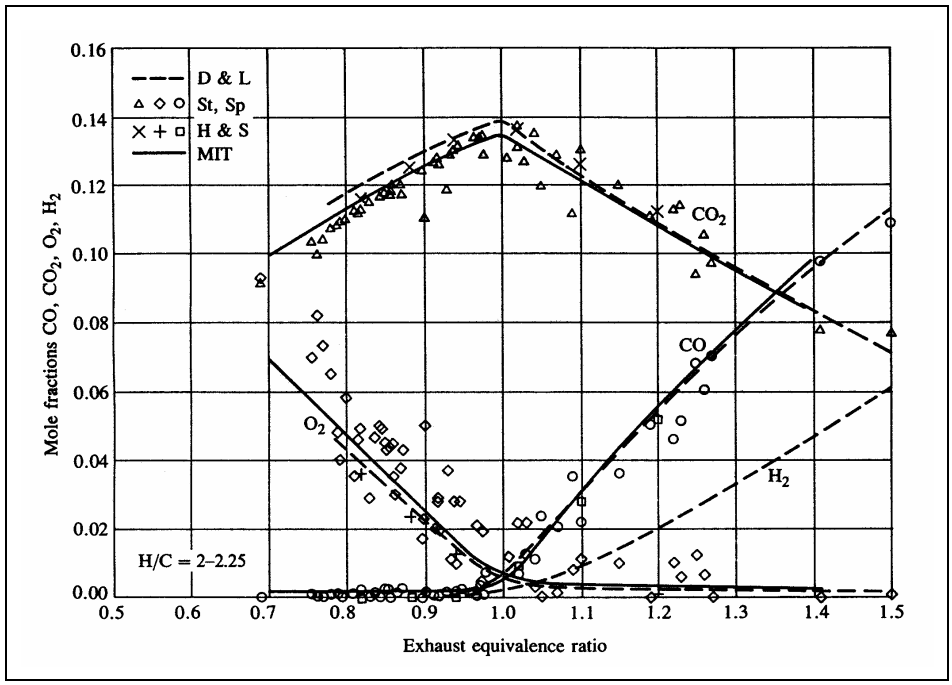

Figure 20: Exhaust Constituents as a Function of Air-to-Fuel Ratio[1]

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.

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.

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

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 - ICC_L, ICC_R** on page 21. ICC factors should be increased for engines with conditions conducive to lesser than typical production-engine amounts of combustion completeness.

Maintenance

Unit-Specific Information

AFRecorder 4800 Serial No.: _____

AFR Sensor Serial No.: _____ AFR Sensor Serial No.: _____

Io_2: _____	Io_2: _____
Ico: _____	Ico: _____
Ih_2: _____	Ih_2: _____
I_1: _____	I_1: _____
I_2: _____	I_2: _____

ICCl (lean):	5.0 (for typical production engines)
ICCs (stoichiometric):	5.0 (for typical production engines)
ICCr (rich):	5.0 (for typical production engines)

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 for AFR when the AFR sensor is enabled and in stationary air.

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 parameter constant be reentered (even if it is already correct). 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.

2. Excessive spark noise.

Simple experimentation (ex. ground the AFRecorder's case, move the AFRecorder or cabling away from the engine, or use a separate battery (Model 4800P only)) 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 sensors on a stopped engine it is best to think-out your moves before you make them.

Route and cable-tie all sensors and cables 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 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 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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