ECM ENGINE CONTROL AND MONITORING

AFRecorder 2400G

Four Function Engine Diagnostic System

Instruction Manual

6/03 Part Number 2400G-11

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Introduction

The AFRecorder 2400G

The AFRecorder 2400G is a portable, microcomputer-based engine development tool that is suitable for use either in a laboratory or on a test track. The AFRecorder integrates the features of several separate instruments into a single, compact, easy-to-use package. The AFRecorder measures, displays, and records the key parameters influencing the performance of a spark ignition engine:

- Air-to-Fuel Ratio (6.00 - 150.00 AFR)
- Spark Timing (60 deg. BTDC - 30 deg. ATDC)
- Engine Speed (100 - 9,999 RPM)
- Manifold Pressure (0 - 35 Psia).

Its features include:

- Easy-to-read, selectable 4 line or large (0.72") character backlit display
- Measured parameters can be displayed in all commonly used engineering units
- Measures Air-to-Fuel Ratio for all 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 outputs for each measured parameter
- 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 2400G package:

Item No.	Description	Part Number
1.	AFRecorder 2400G	2400G
2.	Air-to-Fuel Ratio (AFR) Sensor	2400E-1
3.	AFR Sensor Cable, 20 ft.	2400E-2
4.	Spark Timing Pickup/Cable, 20 ft.	2400A-3
5.	Engine Speed Pickup	2400A-4
6.	Engine Speed Pickup Cable, 20 ft.	2400A-5
7.	Pressure/Vacuum Hose, 5/32", 20 ft.	2400A-6
8.	120 VAC U.S. Power Cord, 6 ft.	2400G-38
9.	12 VDC Power Cord, 20 ft.	2400E-7
10a. (or b.)	Spare Power Fuses, 1 A (b: 0.5A), Slow Blow, for 120 VAC (b: for 230 VAC) (Quantity 2)	2400G-39(b)
11.	Spare Power Fuse, 6.3 A, Slow Blow, for 12 VDC	2400A-8
12.	DB9M Outputs Connector	2400G-9
13.	AFRemote Software	2400G-10
14.	AFRecorder Instruction Manual	2400G-11
15.	AFRecorder Carrying Case	2400A-12
16.	Case Ground Cable, Braided, 3 ft.	2400A-17
17.	Ground Cable, Insulated, 20 ft.	2400A-40
18.	Adjustment Screwdriver	2400E-35

Important Operation Notes

Please read and follow all of the cautions contained in the **Safety Warnings** section on page 55 of this manual.

Air-to-Fuel Ratio Sensor

Read the **AFR Measurement Calibration ("AIR CAL")** section on page 25.

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 26), 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 37.)

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.

Spark Timing and Engine Speed Inputs

Do not directly wire an ignition coil's primary or secondary terminal to the "RPM" or "SPARK" input of the AFRecorder. Due to the high voltages at the coil, filter circuitry or the Spark Timing Pickup/Cable (Part No. 2400A-3 provided with the AFRecorder) must be used.

Use only the probes and cables provided with the AFRecorder or those approved by ECM.

Route the spark timing and engine speed cables away from hot or moving objects.

Manifold Pressure Input

Route the hose so as to avoid the draining of condensed water or fuel into the pressure sensor located inside the AFRecorder. Also, route and cable-tie the hose away from hot or moving objects and ignition wires (the pressure/vacuum hose is conductive).

Physical Features and Hook-up

Front Panel

Once the power, sensors, cables, 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 display.

The display has a 4-line by 20-character format. Upon command (see **Setup - Display - Size** on page 17), the display can enlarge the measurements of a selected parameter so that they fill the display. In addition to displaying the measurements of parameters, the display can show the statistics of a recorded session or menu information for AFRecorder setup. 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 19) of a selected parameter 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 on the same values and may be used separately or together (see **Setup - Options - Alarms** on page 21).

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, a 18 mm spark plug (ex. Champion D15Y) can be used to plug the hole.

Engine Speed Hook-up

The magnetic engine speed pickup was designed to use "factory timing marker" type provisions installed on many automobile engines since the mid-1970s. Figure 1 shows a typical installation. Once the hook-up for engine speed has been completed, details about the engine speed signal must be input into the AFRecorder (see **Setup - Constants - RPM/SPK** on page 22).

"Factory timing marker" provisions consist of a pickup support (typically a cylindrical tube with a 5/16" or larger i.d. and 3/8" to 1 1/2" in length) mounted on the engine close to the harmonic balancer or one of the pulleys. The balancer or pulley must have between one (1) and twelve (12) **evenly-spaced notches**. As the balancer or pulley rotates, the notch(es) align with the center of the cylindrical tube. It is preferable to use notches on the pulley because pulleys are most often mounted solidly to the crankshaft unlike balancers which often have rubber between their hub and inertia ring. For best signal strength, the notch width should be approximately 1/16" wide, 1/16" deep, and sharp edged. Except for the notches, the balancer or pulley should present a smooth surface to the cylindrical tube.

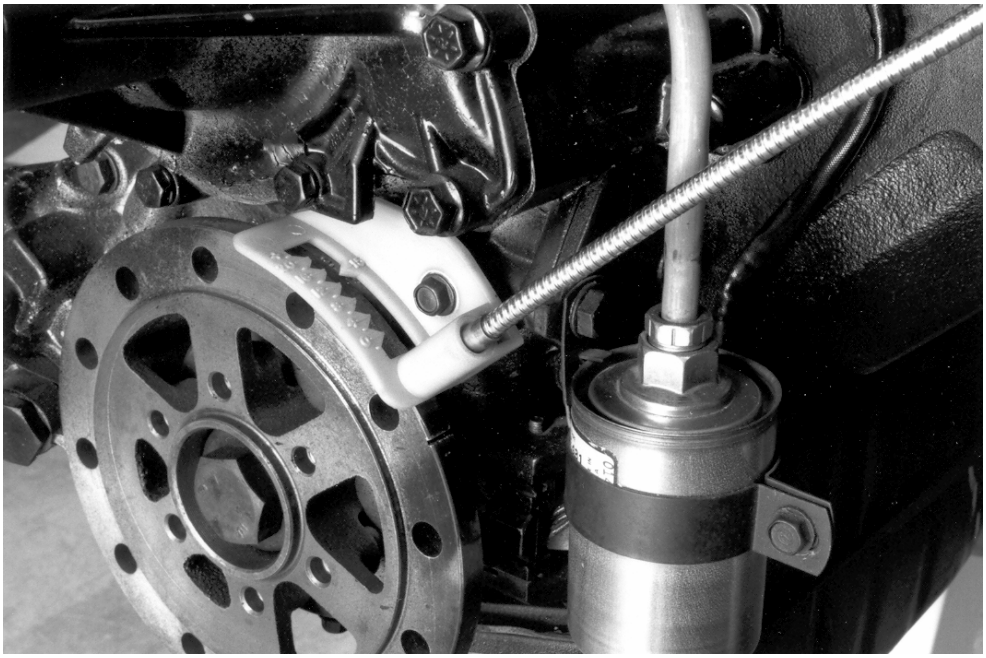

Figure 1: Installed Magnetic Engine Speed Pickup

To install the pickup, slide its sensing end into the support (cylindrical tube) until it rests against the balancer or pulley (see Figure 1). If the notches are wider than the diameter of the pickup (5/16"), then the pickup must be securely held away from the rotating surface to avoid pickup damage. The movable sleeve provided with the pickup allows it to fit three different support hole diameters. The pickup will make some noise if it rubs against the rotating part. Contact with the balancer or pulley is acceptable and is often required in order to get a good signal from an out-of-round balancer or pulley. If the rotating part is trued (and for the case of a balancer, re-balanced if trued), the pickup can be withdrawn approximately 0.005" for silent operation.

Attach the CPC end of the engine speed pickup cable to the pickup and route the cable to the BNC engine speed input ("RPM") connector on the back of the AFRecorder. Use cable ties to keep the pickup and cable away from hot or moving objects and ignition wires.

The “factory timing marker” provides a quick and easy way to detect engine speed but sometimes, a more robust setup may be desired. In these cases, it is recommended that a larger magnetic pickup with a sturdy mount and a matching target wheel be used. The goal is to get a signal of at least 4V (peak-to-peak) at the lowest engine speed. The voltage output of magnetic pickups is a function of the target’s surface speed (i.e. of the notch in the steel target wheel), so before a pickup can be chosen, the target wheel diameter must be chosen. A 6’’ diameter wheel with a width equal (or greater) to the diameter of the pole of the magnetic pickup is often most practical. At a minimum engine speed of 500 RPM, a 6” wheel has a surface speed of 157 i.p.s. (inches per second). The magnetic pickup can then be selected based on: having at least a 4 V peak-to-peak output at 157 i.p.s., fitting the application, and being available. The wheel must be made out of steel and centered on the crankshaft. The notches should have the same width and depth as the diameter of the pole of the magnetic pickup, be evenly spaced on the wheel, and ideally “n/2” in number (“n” is the number of cylinders in the engine). The pickup-to-wheel spacing should be ½ (or less) the diameter of the pole of the magnetic pickup. If possible, view the pickup’s output on an oscilloscope before attaching it to the AFRecorder. The “pulses” in the signal should be evenly spaced (at constant engine speed), always be greater than 4V (peak-to-peak), and well above the noise floor. Observe the signal as it crosses zero to see if it is falling or rising. This information and the “RPM Pulses/2 Rev” (“n” if as described above and a 4-stroke engine) are required for AFRecorder setup. The magnetic pickup signal should feed, via shielded cable, the “RPM” input of the AFRecorder. Adjustment of the RPM “ADJ” potentiometer may be required. Specific applications can be discussed with ECM.

The spark timing pickup can also be used to measure engine speed. In this case, the spark timing pickup is installed as described in the **Spark Timing Hook-Up** section on page 9 (i.e. connected to the "SPARK" input). If possible, clamp the spark timing pickup around the coil wire (as opposed to a cylinder's spark plug wire) when measuring engine speed from spark information. This measurement is not as accurate as that obtained from the engine speed pickup due to variations in spark timing. See **Setup - Options - Sensors** (page 20) and **Engine Speed and Spark Timing Sensing** (page 46) for more information.

RPM measurement may also be possible with other types of sensor signals and by tapping existing engine control system signals. Contact ECM for details on these other engine speed measurement techniques.

To the right of the RPM input connector is its signal adjustment potentiometer ("ADJ"). This potentiometer is factory-set for use with the supplied magnetic engine speed pickup (see the **Intermittent Engine Speed and/or Spark Timing Measurements** section on page 51 for

more information). With other types of sensors and signals, the potentiometer typically needs to be turned clockwise.

Spark Timing Hook-up

Spark timing can be measured for engines with conventional ignition systems (distributor), or with distributorless ignition systems (D.I.S.). To measure spark timing, engine speed must also be measured. Once the hook-up for spark timing has been completed, details about the spark timing signal must be input into the AFRecorder (see **Setup - Constants - RPM/SPK** on page 22).

To hook-up for spark timing, clamp the inductive spark pickup around #1 cylinder's spark plug wire. The pickup's braided ground wire should be connected to the engine block. If the AFRecorder is being AC powered (i.e. not powered by the vehicle's battery), the supplied insulated ground cable should be connected between the AFRecorder's case ground terminal and the engine block. For all conventional and most D.I.S. systems, the "SPARK PLUG SIDE" of the pickup should face #1 cylinder's spark plug. For D.I.S. systems in which #1 cylinder fires with a positive polarity, the pickup should be reversed with its "SPARK PLUG SIDE" towards #1 cylinder's coil pack. Route the cable to the BNC spark timing input ("SPARK") on the back of the AFRecorder. Use cable ties to keep the pickup and cable away from hot or moving objects and other ignition wires. **When using the inductive spark timing input, the "SPARK PICKUP" switch must be set to "IND" (inductive).**

Spark timing measurement may also be possible with other types of sensor signals and by tapping existing engine control system signals. This includes directly wiring to the ignition coil's primary side; however, not without suitable signal filtering before feeding the signal to the AFRecorder! When these "direct" spark timing inputs are used, the "Spark Pickup" switch is set to "DIR". Contact ECM for details on "direct" spark timing measurement techniques.

To the right of the SPARK input connector is its signal adjustment potentiometer ("ADJ"). This potentiometer is factory-set for use with the supplied inductive spark pickup (see the **Intermittent Engine Speed and/or Spark Timing Measurements** section on page 51 for more information). When "direct" spark timing measurement techniques are used, the potentiometer typically needs to be turned clockwise.

Manifold Pressure Hook-up

The AFRecorder uses an internal piezoresistive pressure transducer. The transducer measures absolute pressure. To measure intake manifold pressure (or any other pressure within the transducer's range), connect the fitting on the back of the AFRecorder to a similar barbed fitting on the engine's intake manifold using the supplied 5/32" hose. Keep the AFRecorder above the level of the engine's intake manifold to avoid the draining of condensed water or fuel into the transducer. Use cable ties to keep the hose away from hot or moving objects and ignition wires (the pressure/vacuum hose is conductive). After use, drain the hose of liquids that may have collected in it during its use.

Analog Outputs and Simulated EGO Sensor Output

Linearized and programmable 0 to 5 VDC outputs are available for each measured parameter. 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 18 and **Setup - Outputs - Sim EGO** on page 19 for information on programming these outputs and **Output Specifications and Limits** on page 41 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 26), 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), Spark Timing (SPK), Engine Speed (RPM) and Manifold Pressure (Pman). Depending on prior programming (see **Setup - Display** on page 16 and **Setup - Options - Sensors** on page 20), the AFRecorder may show just one or a combination of the measured parameters. Figure 2 shows the AFRecorder's display during measurement.

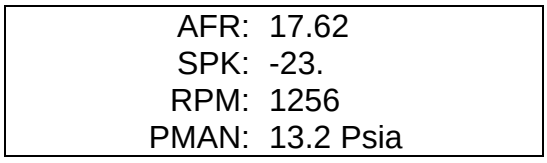

Figure 2: AFRecorder Display During Measurement

Information other than the measured AFR 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 25)
xxxx	AFR measurement function error (see **Troubleshooting** on page 51)
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 26)

When the $\%O_2$ in the exhaust exceeds 19.5%, 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.

Spark timing is given relative to top-dead-center (TDC). If the spark timing is before TDC (BTDC), it is negative, If the spark timing is after TDC (ATDC), it is positive. Thus a SPK (spark timing) of -23 means 23 degrees BTDC.

A SPK measurement of "- - - -" is displayed if the AFRecorder is not receiving sufficient information from the spark timing or engine speed inputs to calculate a spark timing and "31" is displayed if the spark timing is out of range.

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 14. Pressing "SYS" at any time will suspend the current operation and display the main menu shown in Figure 3.

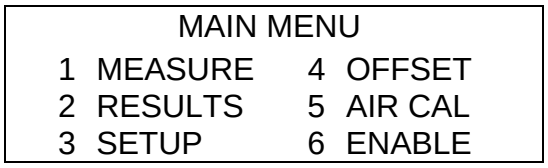

Figure 3: Main Menu (accessed by pressing "SYS")

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 "OFFSET", "AIR CAL", or "ENABLE"). Figure 4 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	1	AFR	Recorded data statistics
				2	SPK	
				3	RPM	
				4	Pman	
		3	POINT			Display one recorded point (+: advance, -: back up)
3	SETUP	1	DISPLAY	1	SIZE	One or four line display
				2	AFR UNITS	AFR, ϕ, λ, or $\%O_2$
				3	Pman UNITS	Psia, Atm, inHg or kPa
				4	RATE	Slow/medium/fast update
		2	RECORD	1	DURATION	Sample duration
				2	INTERVAL	Sample interval
		3	OUTPUTS	1	ANALOG	Program output ranges
				2	SIM EGO	Program EGO AFR switch point
				3	ALARMS	Alarm source & limits
				4	CAL D/A	Calibrate analog outputs
		4	OPTIONS	1	SENSORS	Select sensors
				2	ICC	Activate ICC
				3	ALARMS	Arm lights & buzzers
				4	SOUND	Activate key beeping
		5	CONSTS	1	ENGINE	ICC factors
				2	AFR SENSOR	Calibration specifications
				3	RPM/SPK	Input signal specifications
				4	FUEL	H:C, O:C, and N:C ratios
				5	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 4: Menu Tree for the AFRecorder

Recording

Recording is started by pressing the "REC" (Record) key while the AFRecorder is displaying its measured parameter(s). During recording, the display will appear as shown in Figure 5.

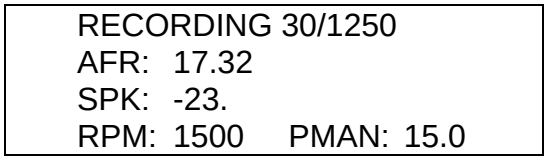

Figure 5: AFRecorder Display During Recording

In the four-line configuration, 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 5, 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 for each parameter in this case.

In the large character display configuration, a small "R" is shown near the decimal point during recording. Even though only one parameter is shown with the large display, the AFRecorder may be measuring and recording up to four parameters.

During recording if the AFRecorder detects an AFR outside of its measurement range (ϕ less than 0.1 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. If the engine speed or manifold pressure is outside of the AFRecorder's measurement range, then the closest limit value will be displayed, recorded, and used to calculate the statistics. If the AFRecorder does not detect a spark or calculates an out of range spark, it will display "- - - -" or "31" but will record and use 31 (deg. ATDC) to calculate the statistics. The value of 31 (deg. ATDC) is outside of the AFRecorder's measurement range for spark timing.

The number of parameters to measure (and hence record), the recording duration, and the sample interval (time between recorded samples) are all programmable (see **Setup - Options - Sensors** on page 20 and **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 6). The maximum processing time is approximately 25 seconds. The results menu can also be accessed from the main menu (see Figure 3). 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.

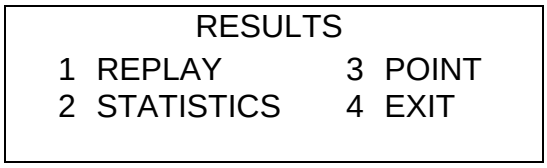

Figure 6: The Results Menu

Results - Replay

If "REPLAY" is selected from the results menu, the display replays the recorded data in slow-motion (see Figure 7). The display is updated with the measured parameters' values at each sample time. The visual and audible limit alarms are disabled during replay.

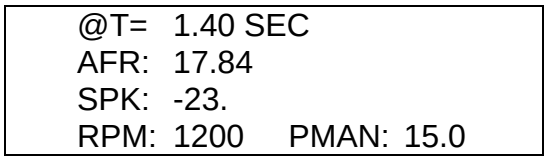

Figure 7: AFRecorder Display During Replay

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 8).

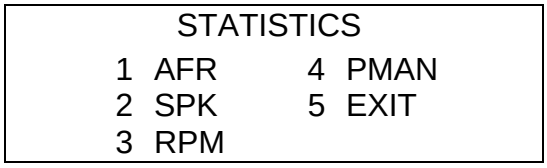

Figure 8: The Statistics Menu

Selection of "AFR", "SPK", "RPM", or "PMAN" will begin the display (see the two screens in Figure 9) of the statistics of that parameter during the recorded session. 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 statistics menu.

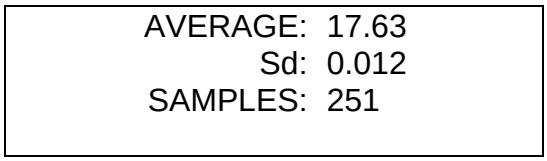

Figure 9a: Example of Statistical Results Screen 1

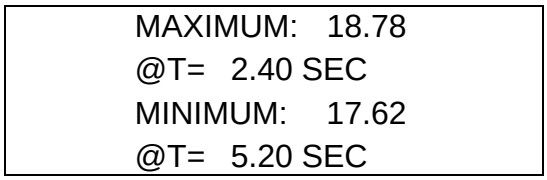

Figure 9b: Example of Statistical Results Screen 2

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 recorded values of the measured parameters 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 10. 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.

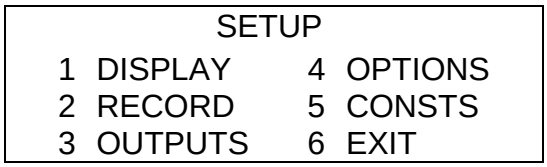

Figure 10: The Setup Menu

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 11). "EXIT" returns the AFRecorder to the setup menu.

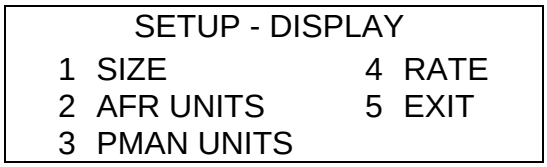

Figure 11: Setup - Display Menu

◆ **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 the number of measured parameters recorded during a recording session.

◆ **Setup - Display - AFR Units or Pman Units**

The choice of "AFR UNITS" or "PMAN UNITS" from the setup - display menu allows the selection of the engineering units in which AFR or Pman (manifold pressure) are 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.

The choices for Pman units are: Psia, atm, inHg, and kPa.

◆ **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.

Rate	Display Update Interval	Measurement Averaging
SLOW	1.00 sec.	100 measurements
MEDIUM	0.50 sec.	25 measurements
FAST	0.24 sec.	12 measurements

Table 1: Display Rate Options

The table also shows the number of measurements which are averaged to generate the information displayed for a given update interval. The averaging is performed on data sampled at 0.02 sec. intervals. Note that during recording, measurements are stored "raw" (not averaged) at the selected sample interval (see **Setup - Record Menu** on page 18).

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 - 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 0.02 seconds. For more information, see the **Specifications and Limits** section on page 36.

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 12). "EXIT" returns the AFRecorder to the setup menu.

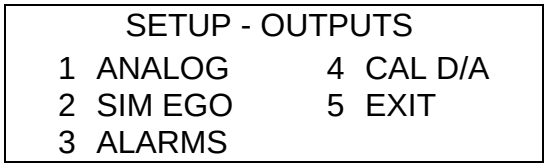

Figure 12: Setup - Outputs Menu

◆ 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 Offset** on page 24), spark timing, engine speed, and manifold pressure 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) was 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. It is important to note that if the displayed units were then changed from AFR to ϕ, then the analog output would be linearized in ϕ (the new displayed units) instead of AFR (the old displayed units) and the analog output would change even though the same AFR was being measured (except at the 0 V AFR and the 5 V AFR). The reason for the difference is that a linear change in ϕ is not a linear change in AFR because one is inversely proportional to the other. **If the H:C, O:C, or N:C ratio of the fuel is changed, the analog output levels must be reprogrammed.**

The analog outputs are updated every 0.02 seconds. See the **Output Specifications and Limits** section on page 41 for more information.

◆ **Setup - Outputs - Sim EGO**

The choice of "SIM EGO" allows the setting of the AFR at 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 0.02 seconds. **If the H:C, O:C, or N:C ratio of the fuel is changed, the simulated EGO output must be reprogrammed.** See the **Output Specifications and Limits** section on page 41 for more information.

◆ **Setup - Outputs - Alarms**

The choice of "ALARMS" allows the setting of the measured values which trigger the alarm lights and the modulated buzzer. The alarms (lights and buzzer) are triggered by measurements (averaged at the display rate, see Table 1) of one selected parameter. To set the alarms requires: the choice of the parameter that will trigger the alarms (see Figure 13), and the values of this parameter ("HIGH LIMIT" and "LOW LIMIT") that, once transgressed, will trigger the alarms. 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.

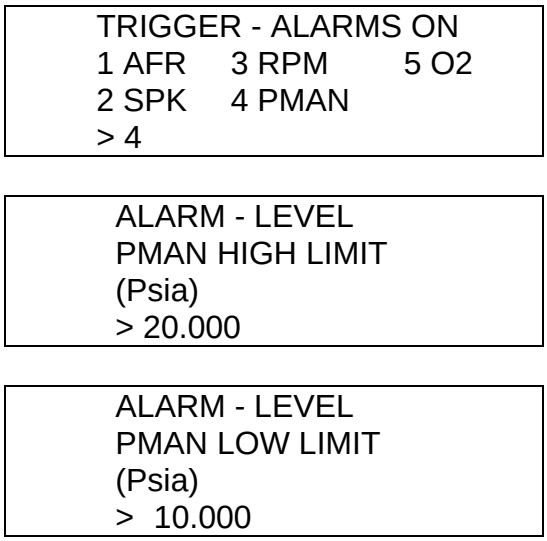

Figure 13: Menus to Enter Values that Trigger the Alarms
(example given for Pman as selected parameter)

Once the parameter and values have been entered, the alarms can be independently armed (see **Setup - Options - Alarms** on page 21).

◆ **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 selection of functions of the AFRecorder (see Figure 14). Selecting "EXIT" from this menu will return the AFRecorder to the setup menu.

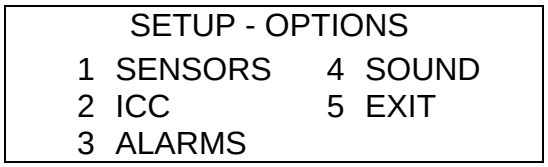

Figure 14: The Setup - Options Menu

◆ **Setup - Options - Sensors**

The "SENSORS" option contains displays in which the air-to-fuel ratio, spark timing, engine speed, and manifold pressure measurements may be selected for display and recording. Note that these choices influence both the display's appearance during measurement and the parameters to be recorded. Because information from both the spark timing sensor and the engine speed sensor must be used to determine spark timing, spark timing alone cannot be selected.

The "SENSORS" option also allows the use of the spark timing pickup instead of the engine speed pickup to determine engine speed. If the response to "RPM from SPK" is "YES", then information from the spark timing pickup will be used to determine engine speed. For "RPM from SPK", the spark timing pickup remains hooked up to the "SPK" input and "RPM PULSES/2 REV" and "ACTIVE EDGE OF RPM" (choose "RISING") must be set to that delivered by the spark timing pickup (see **Setup - Constants - RPM/SPK** on page 22).

If all of the sensors are accidentally turned off, the AFRecorder will override this choice and use AFR as the only selection.

◆ **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 21). 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. **If the H:C, O:C, or N:C ratio of the fuel is changed then the AFR alarms must be reprogrammed.** See **Setup - Outputs - Alarms** on page 19 for more information.

◆ **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, sensors, and fuel are input into the AFRecorder (see Figure 15). Selecting "EXIT" from this menu will return the AFRecorder to the setup menu.

SETUP - CONSTANTS	
1 ENGINE	4 FUEL
2 AFR SENSOR	5 AIR
3 RPM/SPK	6 EXIT

Figure 15: 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 25). 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 - RPM/SPK

Constants required to determine engine speed and spark timing are entered after selecting "RPM/SPK" in the setup - constants menu. Five subsequent displays allow the entry of these constants. Figure 16 shows these displays.

```
RPM/SPK CONSTANTS
RPM PULSES/2 REV

> 2
```

```
RPM/SPK CONSTANTS
ACTIVE EDGE OF RPM
1 RISING   2 FALLING
> 2
```

```
RPM/SPK CONSTANTS
ANGLE OF RPM EDGE
(-180 TO 180)
> 9.5
```

```
RPM/SPK CONSTANTS
SPK PULSES/2 REV

> 1
```

```
RPM/SPK CONSTANTS
ACTIVE EDGE OF SPK
1 RISING   2 FALLING
> 1
```

Figure 16: Displays Prompting RPM/SPK Sensor Information

The first display requests the number of RPM pulses per 2 crankshaft revolutions or 720 degrees ("RPM PULSES/2 REV"). An integer between 1 and 12 must be entered here. When the engine speed pickup is used, this is the number of times the notch(es) on the balancer/pulley align with the pickup in two crankshaft revolutions. This is two times the number of notches on the pulley. Most engines have one notch; for those engines, two (2) should be entered. In all cases, the notches must be evenly spaced and number between one (1) and twelve (12). If the spark timing pickup is being used to determine engine speed (see

"RPM from SPK" in **Setup - Options - Sensors** on page 20) then the number of spark pulses per 2 crankshaft revolutions should be entered here. If the spark timing pickup is clamped around a cylinder's spark plug wire, one (1) should be entered for a 4-stroke engine and two (2) for a 2-stroke engine.

The second display requests the active edge of the RPM pulses ("ACTIVE EDGE OF RPM"). "FALLING" should be chosen if the engine speed pickup is being used. "RISING" should be chosen if the spark timing pickup is being used to determine engine speed.

The third display requests the angle of the active RPM edge. ("ANGLE OF RPM EDGE, -180 TO 180 deg."). A number between -180 (180 deg. BTDC) and 180 (180 deg. ATDC) must be entered here. Note that a negative number means "degrees before top-dead-center". If only engine speed is being measured, then any number within the allowable range may be entered. If the engine has a provision for the engine speed pickup, the engine manufacturer's documentation should be referenced for the "mag. probe offset" and this value entered. This number is the engine's crankangle when the notch in the balancer/pulley aligns with the pickup. Table 2 contains common values used by vehicle manufacturers. If there is more than one notch on the balancer/pulley (but less than nine), the crankangle of any notch location may be used.

General Motors	9.5
Ford	0
Chrysler	10

Table 2: Common Values for “ANGLE OF RPM EDGE (-180 TO 180 deg.)” when using the Magnetic Engine Speed Pickup

If the "mag. probe offset" cannot be found in the engine manufacturer's documentation, then its value should first be estimated by a rough measurement and entered. A timing light can then be used to determine the spark timing at idle and this measurement and the AFRecorder's measurement can be used to calculate the correct value to enter using the formula:

Correct "ANGLE OF RPM EDGE" = Rough "ANGLE OF RPM EDGE" +
((Timing Light Measurement) - (AFRecorder Measurement)).

For example, if a "rough" value of 135 deg. is entered and at idle, the timing light reads -17 and the AFRecorder reads -10, then a new value of 128 (135 + (-17 - (-10)) = 128) should be entered.

The fourth display requests the number of spark pulses per 2 crankshaft revolutions or 720 degrees ("SPK PULSES/2 REV"). An integer between 1 and 8 must be entered here. If the inductive spark timing pickup is clamped around #1 cylinder's spark plug wire, one (1) should be entered for a 4-stroke engine and two (2) for a 2-stroke engine.

The fifth display requests the active edge of the spark pulses ("ACTIVE EDGE OF SPK"). "RISING" should be chosen if the spark input is being driven by the inductive spark timing pickup.

If the answer to the first display ("RPM PULSES/2 REV") is greater than eight (8), then the measurable range of spark timing of the AFRecorder will be reduced from 90 deg. (ie. -60 to 30) to 60 deg., and a sixth display will appear asking “MAX SPARK ADVANCE (-60 TO -30)”. The reason for this is that to determine spark timing, the AFRecorder must use the engine speed input as a crankangle reference. If more than one crankangle reference pulse occurs within the measurable spark timing range, the AFRecorder will not know what crankangle reference pulse to use. For example, if “RPM PULSES/2 REV” is equal to twelve (12), there will be two crankangle reference pulses in 60 deg of crankangle rotation. In this case, the measurable range of spark timing must be reduced to 60 deg to avoid an ambiguity. So if -50 (ie. 50 deg. BTDC) was entered for “MAX SPARK ADVANCE”, the measurable spark timing range would be -50 to 10 (ie. 50 deg. BTDC to 10 deg. ATDC).

◆ **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). **If the H:C, O:C, or N:C ratio of the fuel is changed then the analog output for AFR, the simulated EGO output, and the AFR alarms must be reprogrammed.** The **Input Specifications and Limits** section on page 37 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:

$$\%O_2 = 20.9\% \times (P_b - P_w) / P_b.$$

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 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. The offset AFR is 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 - Air** 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. Do not "AIR CAL" the AFR sensor if it is smoking. Smoking is caused by gasoline or some other liquid evaporating off of the sensor and does not present the sensor with a proper field-calibration atmosphere. If the AFR sensor is smoking, operate it in an engine for a few minutes to burn off the liquid.

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: ##.#" (where ##.# is the $\%O_2$ in air) 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** 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 21 and **Unit-Specific Information** on page 51), 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. This is an effective thing to do if the AFR sensor is accidently "AIR CAL"ed in an atmosphere other than air (ie. an exhaust of an engine that was just stopped).

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") and "ENABLE/DISABLE" functions, the "CAL D/A" option, the display of "%O2", "xxxx", "V LO", 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 supplied software program AFRemote. AFRemote will run as a stand-alone DOS program or from a 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.

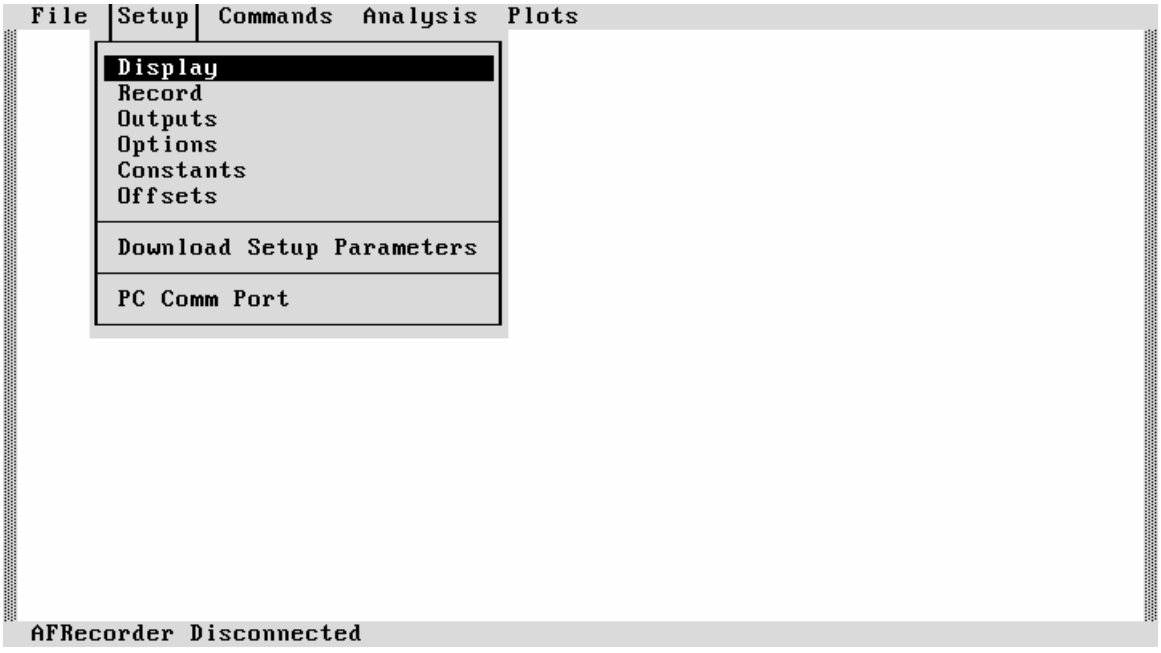

Figure 17: An AFRemote Pull-Down Menu Screen

Figure 17 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's 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 10).

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

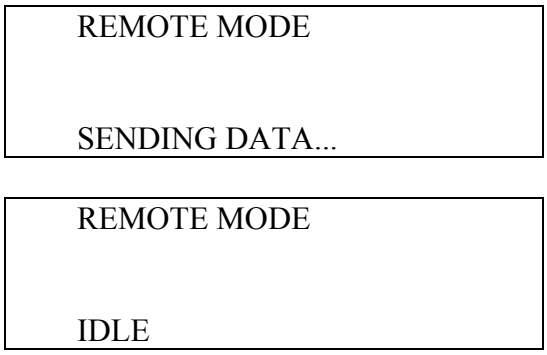

Figure 18: AFRecorder Display During Software Connection

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.

Figure 19: PC Screen During Software Connection

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 parameters and their units are those selected in setup (see **Setup - Display Menu** on page 16 and **Setup - Options - Sensors** on page 20). The update interval and the measurement averaging are at the "FAST" rate and are not adjustable (see Table 1 on page 17). During real-time display and real-time plotting, the AFRecorder also displays the measured parameters.

Real-Time Display

Real-time display duplicates the four-line display format of the AFRecorder on the PC's screen.

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 (see Figure 20).

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.

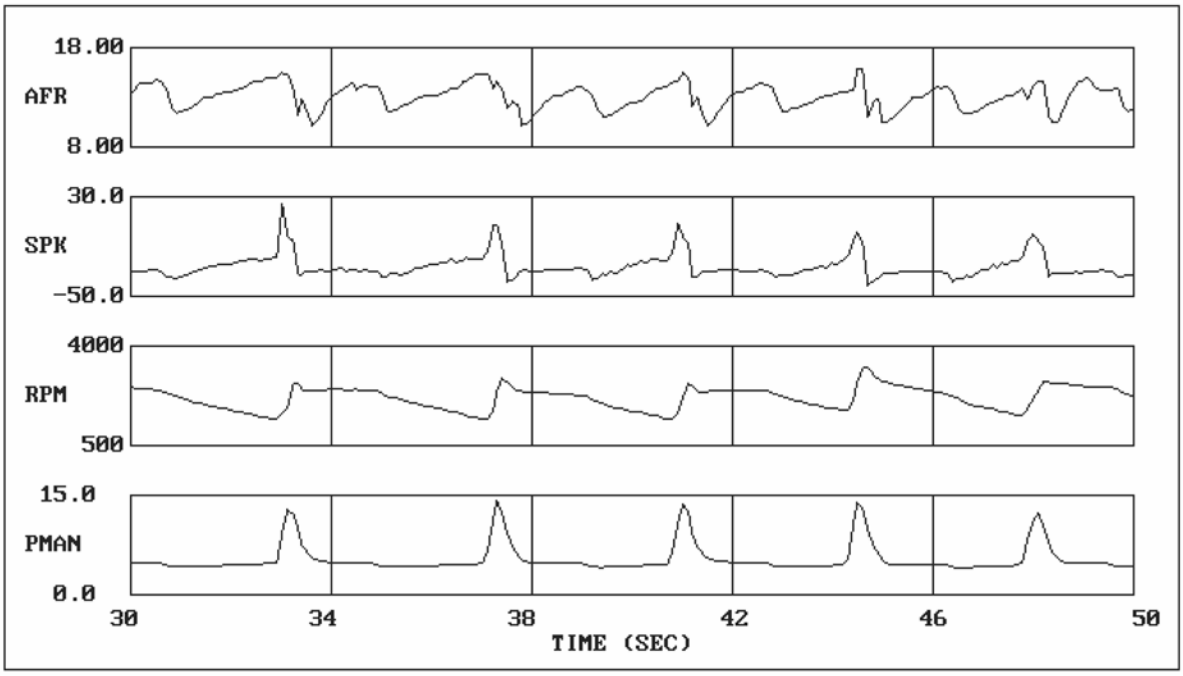

Figure 20: AFRemote Four Parameter Plot

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 21 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, air-to-fuel ratio, spark timing, engine speed, and manifold pressure. The data is separated by tabs.

Each row contains the measured values at the time given in the first column. Note that data begins at time zero (0). Exported files always contain five columns; even if one parameter was not selected (see **Setup - Options - Sensors** on page 20). If a sensor was not selected, its limit value (see the section entitled **Recording** on page 14) will appear in that parameter's column.

```
0.000    15.125    -14.419    1459.416    5.025
0.100    15.239    -14.761    1456.617    5.279
0.200    15.466    -17.073    1449.614    5.449
0.300    15.693    -14.965    1450.455    5.110
0.400    15.352    -14.247    1453.019    5.025
0.500    15.012    -14.815    1459.558    5.110
0.600    15.125    -17.848    1468.920    5.533
0.700    15.806    -18.978    1507.297    5.703
0.800    16.260    -20.195    1576.484    6.381
0.900    16.407    -22.971    1634.636    6.720
1.000    15.466    -24.458    1722.681    6.550
1.100    13.874    -27.499    1773.655    6.550
1.200    13.375    -28.864    1814.253    6.381
1.300    13.519    -30.097    1871.287    6.211
1.400    13.925    -30.587    1918.312    6.296
1.500    14.077    -34.361    1959.983    6.381
  .         .         .          .          .
  .         .         .          .          .
  .         .         .          .          .
```

Figure 21: An Exported Data File

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 31) 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 the measured parameters 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 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 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 21) except that a not-selected parameter (see **Setup - Options - Sensors** on page 20) will have zeros in its column.

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 (from DOS 5.0) 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 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 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]	< 150 ms	±0.1 (stoichiometric) ±0.2 (12<AFR<18) ±0.5 (elsewhere)
	ϕ	0.10-2.5	< 150 ms	±0.006 (stoich.) ±0.008 (0.8<ϕ<1.2) ±0.009 (elsewhere)
	λ	0.4-10.0	< 150 ms	±0.006 (stoich.) ±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)
Spark Timing	deg.	60 BTDC- 30 ATDC[3]	inst.	±1.0 deg.[2]
Engine Speed	RPM	100-9,999	inst.	±0.1%
Manifold Pressure	Psia atm in.Hg kPa	0-35.0 0-2.38 0-70.0 0-241	1.0ms	±1% FSO

[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.

[2] At constant engine speed. When engine speed is rapidly changing, accuracy is reduced.

[3] If "RPM PULSES/2 REV" is greater than eight (8), then this range is reduced to 60 deg. with a programmable "Maximum Spark Advance" input.

Recording Specifications

Sample Selection: Choose 1, 2, 3, or 4 parameters to record. If a sensor is not selected, a zero (0) is stored for its value.
Sample Size: Up to 5000 measurements.
Recording Duration: 1.0 second to memory limit (programmable).
Sample Interval (time between samples): 0.02 seconds to 30.0 minutes (programmable in increments of 0.02 seconds).
Data Retention: Up to 10 years.

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

Sample Selection: All parameters are stored. If a sensor is not selected, its limit value is stored.
Sample Size: 100 to 100,000 measurements of each parameter.
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 36.

- AFR measurement calibration information is provided in the sections entitled **AFR Measurement Calibration ("AIR CAL")** on page 25 and **Unit-Specific Information** on page 51.

- 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 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 -

Spark Timing and Engine Speed:

- Measurement Range, Response Time, Accuracy: See the section entitled **Measurements and Accuracy** on page 36.

- The "SPARK PICKUP" switch must be set to "IND" (inductive) when the inductive spark timing pickup (Part Number 2400A-3) is used.

- RPM and SPK (with "SPARK PICKUP" switch set to "DIR" (direct)) inputs must be between 0 V (battery ground) and 15 V.

- The AFRecorder may be damaged if the RPM or SPARK input is connected directly (i.e. without pre-filtering and clamping circuitry) to either an ignition coil's primary or secondary side because of the large voltages that can occur at these points.

- Information about the spark timing and engine speed signals must be input into the AFRecorder to complete the setup. Refer to the sections entitled **Setup - Constants - RPM/SPK** on page 22 and **Engine Speed and Spark Timing Sensing** on page 46 for additional information.

- While using the magnetic engine speed pickup (Part Number 2400A-4) set "ACTIVE EDGE OF RPM" to "FALLING".

- While using the inductive spark timing pickup (Part Number 2400A-3) set "ACTIVE EDGE OF SPK" to "RISING".

- The RPM and SPARK signal adjustment potentiometers ("ADJ") on the back of the AFRecorder may be used to reduce the occurrence of intermittent engine speed and/or spark timing measurements. See the section entitled **Intermittent Engine Speed and/or Spark Timing Measurements** on page 51 for more information.

- Connectors: Male BNC. Outside ring of “RPM” BNC is signal ground and is connected internally to the AFRecorder's power. Outside ring of “SPARK” BNC is signal ground and is connected internally to the AFRecorder’s power supply ground only when the “SPARK PICKUP” switch is set to “DIR”.

Manifold Pressure:

- Measurement Range, Response Time, Accuracy: See the section entitled **Measurements and Accuracy** on page 36.
- Proof Pressure: 60 Psia (damage will occur at higher pressures).
- Sensor Material: All wetted surfaces are stainless steel.
- Connector: 1/8" barbed brass male hose fitting.
- Hose: 5/32" vacuum hose.

Output Specifications and Limits

Analog Outputs:

- Programmable Ranges for: Air-to-Fuel Ratio (AFR, ϕ, λ, or $\%O_2$), Spark Timing, Engine Speed, and Manifold Pressure.

- Minimum Programmable Ranges (value at 5 V minus the value at 0 V):
  5 AFR, 0.5 ϕ, 0.5 λ, 5 $\%0_2$
  20 degrees spark
  500 RPM
  5 Psi, 0.35 atm, 10 inHg, 35 kPa

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

- Bits Resolution: 12 bits.

- Update Rate: 0.02 seconds.

- Connector: Female DB9.

  Pin 1: Air-to-Fuel Ratio (in AFR, ϕ, λ, or $\%O_2$)
  Pin 2: Engine Speed (RPM)
  Pin 3: Spark Timing (SPK)
  Pin 4: Manifold Pressure (Pman)
  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 or ϕ 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 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 .05 seconds.
- Update Rate: 0.02 seconds.
- Connector: See Analog Outputs 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 parameter's value is greater than the programmed value.

- "LOW" Indication: Low light (green) and low buzzer (slow repetition rate).

- "LOW" Activation: Occurs when chosen parameter'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 22.

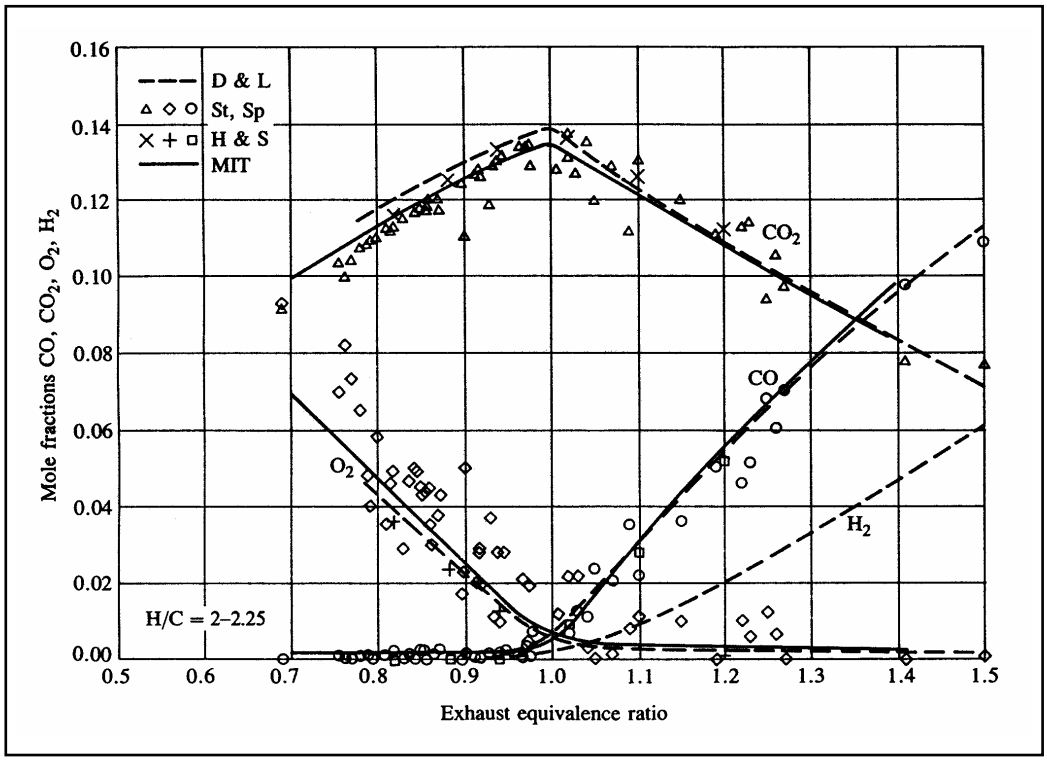

Figure 22: Exhaust Constituents as a Function of Air-to-Fuel Ratio[1]

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,

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

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 21). ICC factors should be increased for engines with conditions conducive to lesser than typical production-engine amounts of combustion completeness.

Engine Speed and Spark Timing Sensing

Engine speed and spark timing are determined by measuring the time elapsed between transitions (edges) of their signals. Figure 23 shows engine speed and spark timing signals after signal conditioning inside the AFRecorder. In this figure, the active edges contain the arrowheads.

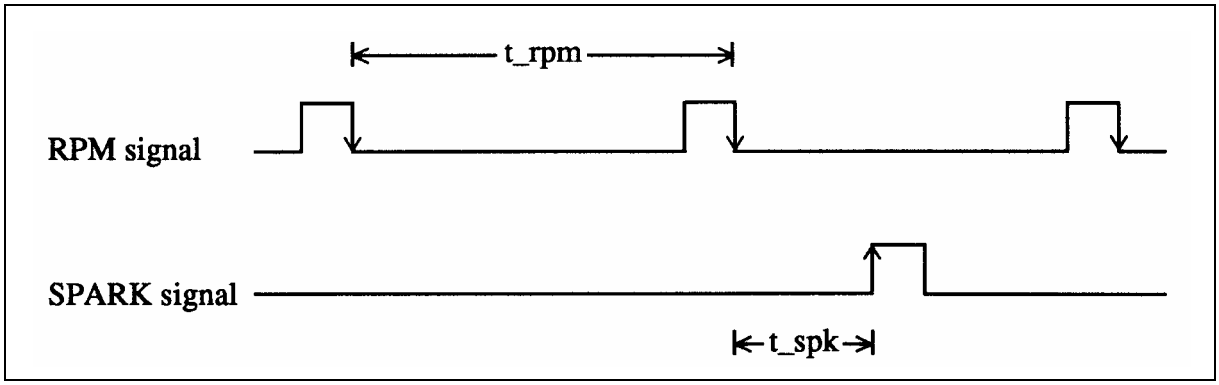

Figure 23: Engine Speed and Spark Timing Signals

Engine speed (RPM) is determined by measuring the time (t_rpm) between successive active edges of the engine speed signal. The calculation uses the number of pulses in the engine speed signal per two crankshaft revolutions (RPM PULSES/2 REV) entered in the setup constants menu. The equation for engine speed is:

$$RPM = 120/(t\_rpm \times (RPM\ PULSES/2\ REV))$$

Engine speed is determined from the spark signal using a similar calculation. Note that variations in spark timing will result in variations in the calculated engine speed.

Spark timing (SPK) is determined by measuring the time (t_spk) between the active edge of the spark signal and the previous active edge of the engine speed signal. If multiple active edges in the spark timing signal are present, the AFRecorder uses the first one to occur after the active edge of the engine speed signal. The spark calculation uses the crankangle location of the active edge of the engine speed signal (ANGLE OF RPM EDGE) and the number of pulses in the engine speed signal per two crankshaft revolutions (RPM PULSES/2 REV).

The raw value of spark timing (SPKraw) is calculated from:

$$SPKraw = (ANGLE\ OF\ RPM\ EDGE) + (t\_spk/t\_rpm) \times (720/(RPM\ PULSES/2\ REV))$$

Note that the engine speed (i.e. t_rpm) is required to calculate the raw spark timing. The setup input for the number of pulses in the spark timing signal per two crankshaft revolutions (SPK PULSES/2 REV) is used by the AFRecorder to detect missing spark pulses.

The raw spark timing value is modified to take into account the effect of engine speed variations on the measurement technique. The resulting modified spark timing is scaled to range from -60 (60 deg. BTDC) to 30 (30 deg. ATDC) and it is this scaled value that is displayed and recorded as spark timing (SPK). The exception to this occurs when "RPM PULSES/2 REV" is greater than eight (8). In this case, the spark timing has a range of 60 deg. with a programmable beginning of range.

Manifold Pressure Sensing

Pressure is measured by the AFRecorder using an integrated circuit piezoresistive pressure sensor. The sensor has a silicon diaphragm in which resistors are implanted in a wheatstone bridge arrangement. One side of the diaphragm is sealed with an internal vacuum reference and the other is acted on by the external pressure source. The internal vacuum reference allows the unit to measure absolute pressure.

Signal processing electronics convert the output of the wheatstone bridge to a voltage proportional to the absolute pressure. Manifold pressure sensing is factory-calibrated.

Measurement, Display, Recording, Storage, and Statistics

Measurement

Figure 24 shows the timing of the capture of air-to-fuel ratio (AFR), manifold pressure (Pman), engine speed (RPM), and spark timing (SPK) information by the AFRecorder. At 0.02 sec. (20 ms) intervals, the AFRecorder takes the values of the four parameters. Air-to-fuel ratio and manifold pressure information are available on a continuous basis to the AFRecorder. However, because engine speed and spark timing are calculated after the reception of active edges, updates in their values occur in steps (versus continuously).

For example, at times 1 and 2 (see Figure 24), different values of air-to-fuel ratio and manifold pressure are measured, while engine speed and spark timing remain the same. The measurement of air-to-fuel ratio and manifold pressure occur within 100 microseconds of each-other. At time 3, the engine speed value calculated changes and at time 4, the spark timing value calculated changes.

Display, Recording, and Storage

The values taken at the 0.02 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 0.02 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 fourth measurement time in Figure 24 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 0.1 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. If engine speed or manifold pressure is outside of the AFRecorder's measurement range, then the closest limit value will be displayed, recorded, and stored real-time to disk. If the AFRecorder does not detect a spark or calculates an out of range spark, it will display "- - - -" or "31" but will record and store real-time to disk "31". The value of 31 (deg. ATDC) is outside of the AFRecorder's measurement range for spark timing.

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 a parameter's value is beyond the AFRecorder's measurement range.

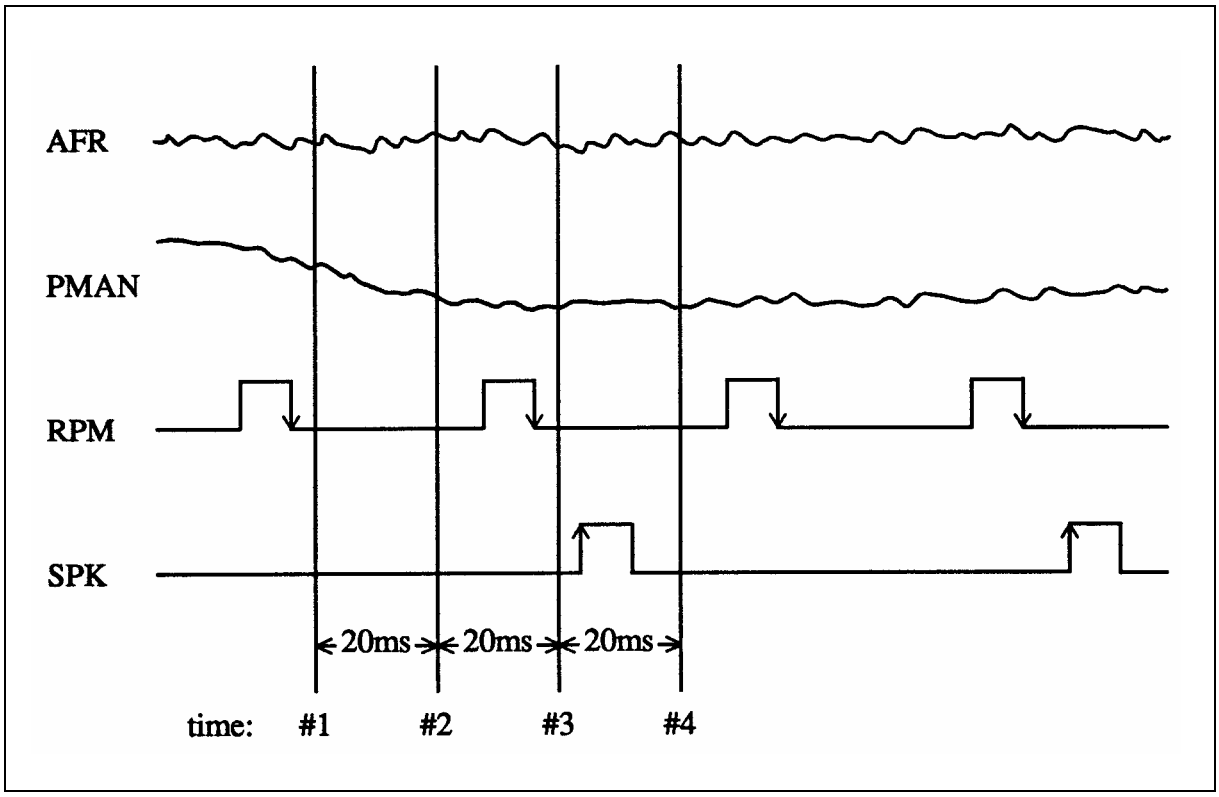

Figure 24: Measurement of Parameters by the AFRecorder

Maintenance

Unit-Specific Information

AFRecorder 2400G Serial No.: _____

AFR Sensor Serial No.: _____

Io_2: _____
Ico: _____
Ih_2: _____
I_1: _____
I_2: _____
I_3: _____
I_4: _____
I_5: _____
I_6: _____
I_7: _____
I_8: _____
I_9: _____
I_{10}: _____
I_{11}: _____

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 when the AFR sensor is in stationary air.

Intermittent Engine Speed and/or Spark Timing Measurements

The magnetic engine speed pickup and the inductive spark timing pickup were designed to provide reliable signals to the AFRecorder. However in some applications, overly strong or weak signals will be generated resulting in intermittently high or low engine speed and/or intermittent spark timing measurements. Should this occur, adjustment potentiometers ("ADJ") accessible on the back of the AFRecorder can be used to decrease or increase the AFRecorder's sensitivity to these signals (see the sections entitled **Engine Speed Hook-up** on page 7 and **Spark Timing Hook-up** on page 9. The adjustment potentiometers are

factory-set and before attempting to remedy improper measurements by their adjustment, the pickups should be checked for proper hook-up. The adjustment potentiometers have a fifteen-turn range and should not be rotated beyond their limits.

If only the spark timing measurements are intermittent then only the SPARK signal potentiometer should be adjusted. If both the engine speed and spark timing measurements are intermittent, then the RPM signal adjustment must be performed first. Adjustments should be made one-half turn at a time. During adjustment, the AFRecorder's recording statistics function or AFRemote's real-time plot to disk feature can be used to detect intermittent measurements.

If the engine speed measurements are intermittently less (or greater) than they should be, the RPM signal potentiometer should be turned counter-clockwise (or clockwise) to increase (decrease) the AFRecorder's sensitivity. If the "RPM from SPARK" option is enabled (see **Setup - Options - Sensors** on page 20), "RPM" in the previous sentence should be replaced by "SPK".

If the spark signal is not detected by the AFRecorder, "- - - -" will be displayed. In this case, the SPARK signal potentiometer should be turned counter-clockwise to increase the AFRecorder's sensitivity. The AFRecorder will display "31" if it calculates a spark timing outside of the range 60 deg. BTDC to 30 deg. ATDC (or the programmed range if "RPM PULSES/2 REV" is greater than eight (8)). This is usually caused by spark "noise" triggering the AFRecorder. In this case, the SPARK signal potentiometer should be turned clockwise to decrease the AFRecorder's sensitivity. With distributorless ignition systems, it may be necessary to decrease the AFRecorder's sensitivity (i.e. turn the potentiometer clockwise) to avoid the interference caused by the "waste" spark.

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 (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.

3. Excessive engine speed or spark timing pickup pulses.

Simple experimentation (ex. ground the AFRecorder's case, move the AFRecorder away from the engine, relocate the cabling, disconnect the engine speed or spark timing sensors, 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 sensors on a stopped engine it is best to think-out your moves before you make them.

Route and cable-tie all sensors, cables, and hoses 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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