Warning!

Use this system with EXTREME Caution! The AEM EFI System allows for extreme flexibility in engine tuning.
Misuse of this product can destroy your engine!
Read this User's Manual thoroughly before using this product.

Technical Help

NEED ASSISTANCE?

If you need technical or installation assistance with your AEM EMS System,

DO NOT RETURN THIS SYSTEM TO YOUR VENDOR.

Please contact our technical help department. Our technicians will be able to solve most problems over the telephone.

Only AEM can authorize the return of this system after having discussed your problem over the phone.

Call 800-423-0046 for technical assistance.

AEM is continuously adding features or making improvements to the AEM EFI system. For the latest updates check www.aempower.com.

NOTE: AEM holds no responsibility for any engine damage that results from the misuse of this product!

This product is legal in California for racing vehicles only and should NEVER be used on public highways.

2205 126th Street, Unit A
Hawthorne, CA. 90250
Tel: (310) 484-2322
Fax: (310) 484-0152

AEM EFI Basics

Version 1.3

Congratulations! You have just purchased the AEM Programmable Engine Management System (AEM PEMS), the finest programmable engine management system on the market. The following information details the features and operations of the AEM PEMS, as well as the engine requirements necessary to successfully operate the AEM PEMS. To ensure proper use of this system and to prevent risk of damage to your vehicle, you must read these instructions and understand them thoroughly before attempting to program this unit.

The AEM PEMS

The AEM Programmable Engine Management System (AEM PEMS) is a Windows™-based, user-programmable Electronic Control Unit (ECU) that uses a powerful 16/32 Motorola bit3 microprocessor and has 1Mb memory for data storage. On most applications, the AEM PEMS is a "plug and play" (PNP) installation, eliminating the need for time-consuming, expensive custom wiring harnesses. Additionally, the AEM PEMS uses the vehicle manufacturer's Original Equipment (OE) sensors, eliminating the need to adapt sensors from another vehicle.

Functions and Controls

The AEM PEMS controls the fuel delivery, ignition timing, transmission shift points, and all ancillary engine controls. The ancillary controls can be boost controllers, VTEC solenoids, staged inlet manifolds, Nitrous Oxide systems, two-step rev limiters, and/or any other type of additional system that requires a logic control. The AEM PEMS has 1 Mb of internal memory for data acquisition that records all input and output channels at high speed for comprehensive data analysis and tuning ease. This data is displayed in our AEMLog software in both easy-to-use text and graphical format. This is essential to the proper tuning of the engine. ***Data acquision stores important engine data to help determine the running condition of the engine. This data allows the tuner to make changes to the engine calibration for maximum power and reliability. Just a few of the items displayed are air fuel ratio (AFR), Ignition timing, knock information or any parameter that relates to the operation of the vehicle. Even non-engine parameters can be displayed such as vehicle speed through wheel speed sensors, drive shaft speed, or accelerometer information.*** The data acquisition system also displays oscilloscope patterns for input signals for various magnetic, Hall effect or infrared sensors on the vehicle. This feature aids in the diagnosis of potential noise or synchronization problems.

In addition to comprehensive data acquisition, the system is capable of aiding in engine diagnosis by allowing the tuner to perform cylinder balance testing by shutting off one injector or spark plug at a time and recording the RPM change between cylinders.

AEM PEMS Operating System

The AEM PEMS is Windows™-based and therefore uses this familiar format for copying, moving, viewing, and manipulating data. User-defined templates are configurable and enable the tuner to establish a "quick key" to organized, useful information during the tuning process. Up to 12 template buttons can be made to cover virtually any tuning parameter at the click of a button.

The major advantage of Windows™-based software is that the user can utilize a mouse for quick data entry; as opposed to the slow, cumbersome key entry method of a DOS based system. The software is infinitely adjustable so that virtually any combination of engine control, power adder(s), and ancillary device(s) can be programmed to maximize the potential of the vehicle. Furthermore, the AEM PEMS is capable of accurately delivering the proper amount of fuel and correct ignition timing for **any** boost level or possible operating condition.

Required Tools for Operation

A PC (preferably a notebook computer) equipped with Windows 95, 98, 2000, NT, or Me edition-operating program with at least a Pentium 100 processor and 16 Mb memory is required to run the AEM PEMS software. The computer connects to the AEM ECU via a standard serial cable that can be purchased through AEM or a local computer supply store. **There are no special connectors or cables to buy.** If you purchased the AEM Racing PEMS, a wire harness kit and sensor terminations will have to be purchased from AEM. If any sensors other than OE sensors are used it will be necessary to purchase the appropriate sensor terminations through AEM. These sensors can also be purchased from an electronic fuel injection (EFI) system component supplier.

The user of the AEM PEMS **MUST** have an excellent understanding of internal combustion engine in both theory and operation. This includes not only the mechanical aspect of the engine, but it's requirements in terms of air/fuel ratio, ignition requirements, and mechanical limits. AEM provides conservative guidelines for base ignition timing and recommended air/fuel ratios. We recommend that the ignition timing be set 5° retarded from stock on a naturally aspirated engine and 10° retarded on turbo or nitrous oxide engines. It is very beneficial to have a fast response air/fuel measurement system to get the best performance from your engine. If a wide-band oxygen sensing system or UEGO system is not used, we recommend starting even richer than the guidelines suggest.

Installation Requirements

The AEM PEMS will **ONLY** perform correctly on an engine that is in proper working order. It cannot compensate for engine problems such as an improperly timed camshaft, poor compression or any other mechanical problem. Please ensure that the engine is in good working order before installing this ECU.

The AEM PEMS must be located in a water-safe part of the car. It is important to place it where it will not encounter temperatures in excess of 160° C. The preferred mounting location is in the interior of the car. In the case where a PNP unit is used, the stock location is ideal. **NEVER** run the ignition wires, or any high power wire in close proximity to the ECU as this may cause RFI or EMI problems. Only ignition wires with a carbon core or "spiral wound" core should be used. **Do NOT use metallic conductor wires. ANY DEVIATION FROM THIS WILL RESULT IN IMPROPER OPERATION OF THE AEM PEMS.**

Fuel Delivery System Requirements

Adequate fuel delivery is generally the greatest problem that we have encountered when tuning and calibrating EFI systems. We cannot stress enough how important it is to have adequate, consistent fuel pressure, **and** volume to the injectors. The use of a properly sized fuel line from the tank, fuel rail and return hose is imperative. Measures must be taken to eliminate excessive pulsations in the fuel rail so the injectors get even fuel flow. These instructions will review the entire fuel delivery system in the following section to help you design your own comprehensive fuel delivery system. On vehicles using the PNP version of the AEM PEMS, all of the essential elements for adequate fuel delivery are designed into the stock fuel system. If you are using a PNP system on a vehicle that is heavily modified (forced induction, nitrous oxide, etc.) pay close attention to the following information regarding fuel delivery, as the OE fuel delivery system may not be capable of supplying an adequate amount of fuel.

Fuel Tank or Fuel Cell

In most cases the stock fuel tank is acceptable for street use. Most OE fuel tanks have internal baffles to reduce fuel slosh in the tank, which reduce the chances of intermittent fuel delivery.

Fuel cells are the best means of fuel storage because they eliminate the chance of fuel slosh by using a foam liner that dampens the fuel travel. Fuel cells also have the fuel pick up placed in a position that is at the lowest portion of the tank—or in the case of a drag racing car—in the rear of the tank where the fuel shifts to during acceleration.

In either case, the tank must be vented to provide air for displaced fuel as the engine consumes it. The tank must also have provisions for fuel return. It is important that the fuel return be placed as far away from the pick up as possible to prevent foaming or bubbles at the inlet.

Fuel Pump Sizing

To achieve proper fuel delivery, you must select the right fuel pump for your vehicle. In most cases, where the engine has been modified only with "bolt on" performance items, there is rarely need for a larger fuel pump or larger injectors. Vehicle manufacturers typically design a "safety factor" into the fuel pump to accommodate the deterioration of the fuel system over time. This safety factor is intended to compensate for a fuel filter that is nearing the end its life, or for deposits in the injector orifice. Our research has revealed that generally there is about a 15%-20% oversize in most factory fuel pumps.
If the engine is enhanced via forced induction or nitrous oxide, the stock fuel pump is inadequate. **If the engine's power is increased more than 15-20% fuel delivery must increase as a factor of the power gain.**

The way to determine the proper-size fuel pump is based on the desired brake specific fuel consumption (BSFC) of the engine. This term refers to how much fuel in pounds per hour (pph) the engine consumes per horsepower and is a measure of the efficiency of the engine. It is a useful term in determining the total fuel requirement of the engine.

On vehicles equipped with forced induction or nitrous oxide, higher BSFC's are required as an added measure of safety to prevent detonation or high combustion chamber temperatures. Below is a guide of BSFC's with standard CR that AEM uses for various engines that run on gasoline:

- Naturally Aspirated engines have a BSFC of .48 to .50
- Forced Induction engines have a BSFC of .65 to .68

Methanol (alcohol) powered engines require twice the amount of fuel so the BSFC's are doubled.

Calculating the total fuel requirement of an engine requires simple equations that we outline in the following section. You must know how much power the engine is anticipated to make and we recommend that you guess on the high end. The fuel requirement will be determined in pounds per hour of fuel flow. Since most pumps are rated in gallons/hour you must know the weight of your fuel/gallon. (The vast majority of gasoline based fuels run at 7.25 lbs./gallon.)

The equations to determine your fuel requirement is as follows:

- **(Power x BSFC) x (1 + Safety Margin) = pounds/hour**
- **Pounds/hour / 7.25 = gallons/hour.**

An example of this equation is:

- 500 hp gasoline engine using moderate boost with a 30% safety margin
- (500 x .625) x 1.30 = 406.25 lbs./hr.
- 406lbs/7.25 = 56 gallons/hour.
- If the pump that is being considered is rated in liters per hour, use the conversion factor of 3.785l/gallon. The pump described above would be rated at 56 gallons **x** 3.785 liters = 211.96 liters/hour.

In the fuel pump sizing, always use a safety margin greater than 20%.

Fuel Pump Location

The fuel pump should be located at a level that corresponds the lowest part of the fuel tank. This does **NOT** mean that the pump should be in a vulnerable position such as hanging below the tank. The pump should also be positioned so that it is protected from the road hazards (speed bumps, curbs, road debris etc.). In the event of an accident, the vehicle structure around the fuel pump should not deform to a point where the pump and its electrical connections are compromised.

The wiring for the fuel pump **MUST** be rated for the amperage of the pump. As with all high current wiring, a fuse rated for the amperage of the pump should be used. It is always better to err on the large side for the wire size. The ground for the pump must be the same size as the power lead and be mounted to a location that is clean and clear of any undercoating or paint.

Fuel Injectors

The AEM PEMS requires the use of "saturated" or high-impedance fuel injectors. **If "Peak and Hold" or low impedance injectors are to be used, an injector resistor must be used or you will damage the ECU.** Resistors can be purchased from AEM. The PNP version of the AEM PEMS is configured for the stock injectors and no additional parts are required.

To determine the size of the injectors, the total engine power must be estimated or known. The fuel pump calculations and BSFC information mentioned in the previous section provides a good understanding of the fuel requirements for an engine. The following equation will allow you to determine the requirements of your injectors:

Using the same engine as above:

- **((Power x BSFC) x (1 + Safety Margin))/Number of Injectors = pounds/hour**
-

An example of this equation is:

- 6 CYL. engine rated at 500 hp on gasoline using moderate boost with a 15% safety margin on the injector
- 500 x .625 = 313 lbs/6 = 52 lbs/hr/ injector. 52 x 1.15=60lbs/hr/ injector

If we take the flow of the injector (60 lbs/hr) and multiply it by the number of cylinders (6), we arrive at a total of 360 lbs/hr of flow. As you can see, the fuel pump described above has enough capacity to feed the engine with a little room to spare.

It is a good idea to know the maximum operating pressure of the fuel injectors. In some cases the fuel injector will not open if the fuel pressure exceeds the design limit of the injector. Also, at the higher pressures the injector fuel flow may become non-linear and cause inconsistent fuel delivery, usually creating a lean condition. Most injectors can withstand up to 70 psi. Many of the pintle style injectors can withstand higher pressure.

In the fuel injector sizing, always use a safety margin between 15-20%.

Fuel Hoses & Routing

Even with proper injector and fuel pump sizing, a fuel system will not flow adequately unless the hoses that deliver the fuel to the fuel rail are of sufficient size and are routed properly. On systems that use the PNP version of the AEM PEMS, there is no need to replace the fuel delivery hoses unless the engine is heavily modified.

NEVER route fuel hoses through the interior of a car. Put bluntly, this is a **dangerous** thing to do. Whenever possible, use a delivery tube to make the connection from the pump discharge to the filter in the front of the car. The lines should be rated to withstand at least twice the maximum pressure of the EFI system.

Using the above parameters of our sample engine with moderate boost, we expect to see pressures in the 65-70 psi range. This will require a line with at least 140-psi rating (most AN hoses exceed this by a large margin). When routing fuel lines, it is imperative that they are protected from road hazards and the exhaust system. The fuel line should **NEVER** be routed near battery cables. Use clamps to secure AN hose every 15 inches, or 24 inches if a rigid tube is used.

The following table will help you determine which hose size is correct for your application: These sizes are based on a nominal fuel pressure of 40 psi.

Fuel Delivery Hose Sizes

Gasoline Powered Engines

Up to 499 HP	.344” hose	-6AN
500 - 799 HP	.437” hose	-8 AN
900 – 1100 HP	.562” hose	-10 AN

Methanol Engines

Up to 499 HP	.437” hose	-8 AN
500 - 799 HP	.562” hose	-10 AN
900 – 1100 HP	.687” hose	-12 AN

The above table should be used for typical passenger car applications. However, for custom applications the hose run length will affect fuel delivery. If you have a long hose run, then the actual flow will have to be determined by running the fuel pump into a graduated cylinder, then measuring the flow vs. time and calculating the flow in gallons per hour (g/h). Also note that if fuel banjos are used in the system be sure they have adequate fuel flow capability.

The fuel return hoses should be one size smaller than the delivery hose. For the sample engine described above, we would use a .437” (-8) delivery hose and a .344” (-6) return hose.

Fuel Filter and Fuel Rail

Often overlooked in EFI installations, the fuel filter must have the capacity, filtering efficiency and burst strength to withstand the pressures of an EFI system. It must be able to flow the amount of fuel that matches the maximum fuel pump output. The filter is always located after the fuel pump, however it does not matter if it is positioned in the front or rear of the vehicle (we prefer to put it toward the front for easy serviceability). AEM carries fuel filters for high-powered engines, which use an easy to find, high volume, replaceable element.

It is imperative that a pre-filter be mounted to the fuel pick up in the tank. These filters are very high volume and create very little pressure drop. The use of a pre-filter ensures long fuel pump life and can eliminate low flow conditions caused by debris entering the pump inlet.

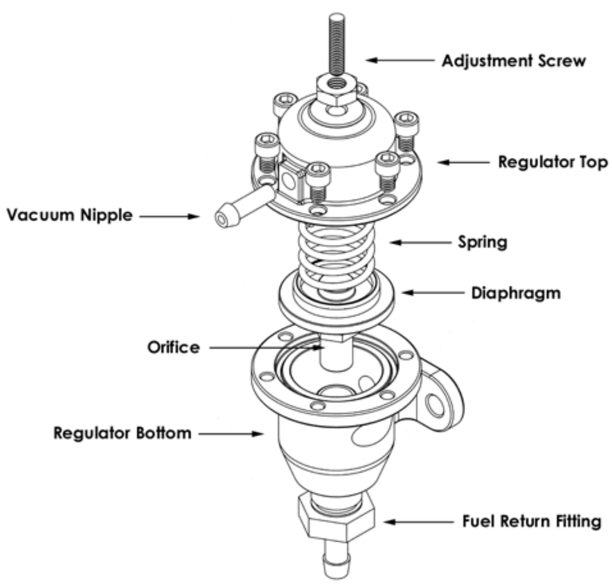
The final link in the fuel delivery system is the fuel rail. The fuel rail should be consistent with, or larger than, the hose size. The additional capacity of a large-diameter fuel rail helps to dampen the pulsations created by the fuel injectors and ensures even fuel delivery under all conditions.

Fuel Pressure Regulator and Pulse Dampener

The fuel pressure regulator maintains a constant pressure across the fuel injector. The inlet manifold pressure varies with throttle angle, and engine speed. Small throttle angles and high engine speed produce low manifold pressure (high vacuum). While high throttle angles and low rpm give high manifold pressure. In addition to these conditions, low manifold pressure is associated with idle and high manifold pressure is at full throttle. It is the fuel pressure regulators job to keep a constant fuel pressure across the injector(s) regardless of manifold pressure.

Currently, there are several types of fuel pressure regulators in use. Many late model cars use a return-less system where the fuel pressure regulator is mounted in the fuel tank adjacent to the fuel pump (and therefore requires no return line back to the fuel tank). In most naturally aspirated applications these types of systems are adequate. With forced induction or heavily modified engines, an adjustable fuel pressure regulator with manifold vacuum reference must be fitted.

The two common types of fuel pressure regulators used are non-adjustable and adjustable. As the name implies, a non-adjustable regulator is set at a fixed value and is manifold-vacuum referenced (whenever a regulator is said to be vacuum referenced, this means that the inlet manifold vacuum/pressure is ported into the chamber above the regulator diaphragm).



As manifold pressure increases, the pressure in the top chamber of the pressure regulator increases along with it, allowing the regulator to compensate for the increased demand of the fuel delivery system.

Keep in mind that at idle or low throttle openings with high rpm, there is very low manifold pressure (vacuum). This tends to literally draw fuel from the injector. As manifold pressure increases (as the throttle is opened), this vacuum dissipates and it is harder for the fuel to discharge from the injector. The regulator reacts to the differences in manifold pressure to maintain constant fuel pressure across the injector. There is a spring in the vacuum (top) chamber of the fuel pressure regulator. The spring's pressure on the diaphragm determines the fuel system's static pressure. The system's static pressure is the amount of pressure measured with the vacuum hose disconnected or with the engine turned off. The fuel system's static pressure is higher than the fuel pressure at idle or under high vacuum conditions.

When the engine is running, the engine vacuum acts against the spring and the effect of the vacuum diminishes as the throttle is opened. At idle, there is a high amount of fuel returned to the tank because the vacuum is pulling the diaphragm seat off of the fuel return orifice, reducing fuel pressure. As the throttle is opened, the diaphragm seat starts to close off the orifice, restricting the amount of fuel flow through the return line.

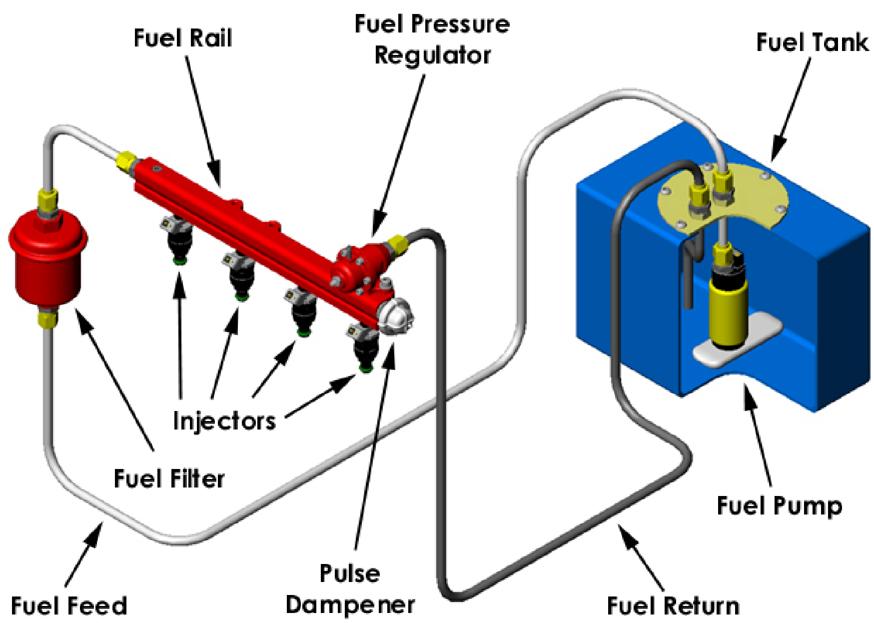
An adjustable regulator allows the static pressure to be raised or lowered via an adjusting screw that acts on the diaphragm spring. On most adjustable regulators, when the screw is turned **in** pressure raises and when it is turned **out** pressure is reduced. Although we highly recommend installing a proper fuel delivery system, raising or lowering fuel pressure *can* compensate for fuel injectors that may not be properly sized for an application.

Most aftermarket fuel pressure regulators (and OE regulators) use a 1:1 ratio of fuel to boost pressure for increasing fuel pressure in applications where forced induction is used. This means that for every psi of boost, fuel pressure is increased one psi. This ensures adequate fuel delivery under boosted conditions.

Many vehicle manufacturers use a pulse dampener to reduce the pulsations in the fuel rail caused by the opening and closing of the injectors (a dampener also reduces the noise of the injectors). In applications where a new fuel system must be installed, a fuel pressure dampener is integral to ensuring consistent fuel flow to the injectors. AEM fuel rails have a provision for a pulse dampener. The dampener assembly part numbers are:

Honda PN:	16680-PE7-661	Dampener
Honda PN:	16705-PD1-003	Inner Gasket
Honda PN:	90428-PD6-003	Outer Gasket
AEM PN:	2-602	Fitting for Rail

Before the fuel system is assemble in the vehicle inspect for debris and damages. Before the fuel system is checked make sure to have a fire extinguisher near by in case of fire. After the fuel system is installed you must inspect the integrity of the entire system. Begin by purging the lines. To do this, run the fuel pump with the hose that connects to the fuel rail placed in a grounded container. This will eliminate any debris left in hose during its manufacturing process. Inspect the fuel rail for cleanliness before starting the engine. Make sure that the fuel pressure is set correctly for your application. Then, reattach all of the hoses and run the fuel pump by switching the ignition to the "ON" position (**DO NOT** turn over the engine at this time), and visually inspect all of the connections for fuel seepage or leaks. If any seepage or leaks are present in the system, repair them before proceeding.



Ignition System

There are several different types of ignition systems in use on modern cars.
They are:

- Distributed spark using a single coil and a distributor for all cylinders.
- Wasted spark using one coil for two cylinders.
- Direct Fire using one coil on plug of each cylinder.

Distributed Spark

Distributed spark systems have been around the longest. As the name implies, the spark is distributed to the plugs via a coil output to a rotor, then through the distributor cap to the appropriate plug via a high-tension (HT) lead. This is the most complex system because of the relationship that has to be maintained between the firing point, rotor to cap terminal angle, and engine position. Distributed spark systems also rely on a mechanical link between the engine and ignition output, which adds another dimension of unreliability-and to a minor extent-inaccuracy in timing. In addition to these problems, distributed spark systems typically produce the least intense spark of all ignition systems. The time to achieve full charge diminishes as engine speed increases; therefore the coil charge is reduced as a function of RPM. In spite of the potential problems with distributed spark systems, they have been used successfully for many years on high-performance engines. Distributed spark ignition systems respond well to spark amplification within their design limits.

Wasted Spark

Wasted spark systems employ one coil for two cylinders. The term “wasted spark” comes from the fact that each plug fires every engine revolution. On a 4-cycle engine, the piston is at Top Dead Center (TDC) two times for every cycle; once for firing and again during the overlap phase. The wasted spark coil fires one plug Before Top Dead center (BTDC) and another plug just before the overlap phase (at the latest part of the exhaust stroke before the exhaust valve closes). Wasted spark systems have a higher potential for spark intensity because the duty of charging and discharging is split between the coils, which allows for more charge time per coil. Additionally, wasted spark systems build up less heat in the coil, making it more reliable. Wasted spark systems have been in use since the mid 80’s on GM cars and on motorcycles for considerably longer than that. There are no moving parts, no complicated relationships with a cap and rotor to maintain, and they deliver very accurate spark timing. Furthermore, multi-channel spark amplification systems to enhance spark duration or intensity are available for wasted spark ignition systems.

Direct Fire

Direct fire systems employ one coil on each spark plug and is the most reliable system used today, (this type of system is used on most modern cars). Each coil fires sequentially in the cylinder firing order. The charge time for each coil is twice as long as those of a wasted spark system, which allows direct-fire, coil manufacturers to build compact, lightweight coils that retain sufficient spark energy. There are no moving parts to wear out and no HT leads that will deteriorate. The lack of HT leads in direct fire systems is a major advantage for an EFI-equipped car because there is a very low incidence of noise due to leaking or improperly routed wires. There have been incidences of the terminal from a direct-fire coil (that attaches to the spark plug) cracking and subsequently causing Radio Frequency Interference (RFI) or “noise” to the ECU. This will cause engine operation problems, but it should be noted that these cases are extremely rare.

Amplifying Spark Energy

There are several ways to amplify the spark. This can be accomplished either by making the spark duration longer or by increasing the intensity of the spark. Firing the plugs multiple times on each cycle increases Spark duration. Spark intensity is increased by shortening the duration of the spark and increasing voltage at the plug. It is necessary to amplify the spark on engines with high cylinder pressures, such as forced-induction or nitrous oxide applications. On engines that utilize bolt-on modifications with no internal engine modifications, an enhanced ignition system is rarely needed. The AEM system is compatible with most stock and aftermarket ignition systems.

We have found that in many instances where there is some type of misfire associated with high RPM, the ignition system is at fault. The total ignition system must be in perfect working order to fire at the high cylinder pressures commonly used in high performance or racing engines. The reference to “total” ignition system refers to the point of signal generation to the ECU to the spark discharge at the spark plug.

Engine Position and Ignition Sequence

Each cylinder of a four-cycle engine undergoes four phases for every “engine cycle”: intake, compression, power, and exhaust. This cycle takes two revolutions of the crankshaft to complete. **(For an outstanding demonstration on the four-cycles of an engine please go to:** http://www.howstuffworks.com/engine.html). The piston is at Top Dead Center (TDC) two times during the cycle (once between the compression/power cycle and once between the exhaust/intake cycles). When the piston in a cylinder is at TDC between the compression/power cycles, both the intake and exhaust valves are closed to contain the rapidly expanding gas caused by the combustion of the mixture. When the piston is at TDC between the exhaust/intake cycle there is no combustion being performed and both the intake and exhaust valves are slightly open. This is the “overlap” phase of the engine cycle (there are several reasons for the overlap phase of engine operation but it is beyond the scope of this instruction manual to discuss them). In the following discussion keep in mind that the cam angle sensor determines “engine position” and tells the ECU what the cam angle is in relation to the TDC firing (between compression/power cycles) position.

1. Signal generation to the ECU
    a. The ECU must receive an electronic signal at the proper time to process information on crank angle (degrees before or after TDC) and output a signal to fire the ignition coil at the proper time in relation to crank angle (ignition timing) and firing position of the engine (TDC firing position). This signal is generated from a mechanical link between the engine and the computer. Usually a sensor is placed on the engine block adjacent to a “trigger wheel” on the crankshaft. The trigger wheel has multiple teeth that are a factor of the number of cylinders of the engine. For example, if our six-cylinder engine that we

mentioned previously has a trigger wheel with 24 teeth, which means the engine will fire every eighth tooth (1,9 & 17). Remember, - the crank goes around two times for every CYCLE (720 degrees of rotation), therefore our 6 cylinder engine fires every 120 degrees of rotation (120 degree firing interval X 6 cylinders = 720 degrees/cycle).

b. Sometimes the crank angle sensor is mounted to the camshaft. This is possible because of the mechanical link between the cam(s) and crank. Using our six cylinder engine as an example, if the cam turns at ½ the engine speed, then on the same 24-tooth wheel mounted to the cam there would be a firing event every 4th tooth (1,5,9,13,17 & 21). A complete cycle for the cam is one revolution (two crank revolutions), so the number of degrees for every firing event is halved.

c. A cam angle sensor is used to determine when the engine is at the TDC firing position. This is accomplished via a sensor mounted adjacent to the camshaft with a single tooth trigger mounted to the camshaft. The angle between the cam in the firing position and the sensor trigger position determines the sequencing of the injectors for sequential operation. On distributed spark or direct fire systems, it determines how to initiate the ignition firing order.

2. Signal Processing in the ECU

   a. Once the ECU receives the signals from the crank and cam angle sensors, it processes the data through predetermined tables in the ECU program. Based on the timing map and any modifications to timing due to various other input information it receives, the ECU sends a signal to the appropriate coil or igniter, depending on what type of ignition system is used. Because time is required to process the signals being received by the ECU and to deliver the output signal to the ignition, the cam and crank angle sensor pulse relative to TDC is well in advance of the actual event of TDC. The calculation of TDC is mathematically derived from a value entered by a programmer.
   b. Modifications to the timing output signal may include a reduction in timing due to high engine temperature or inlet air charge. These modifiers are usually some factor of the base timing map that are corrected for a specific engine operating condition such as engine temperature or excessive knocking.
   c. On distributed systems, the order in which the HT leads are positioned on the distributor cap determines the firing sequence of the plugs. With this type of system, the output signal from the ECU usually is not strong enough to trigger the coil directly; therefore an igniter is used to amplify the signal from the ECU to the coil(s). The sequencing of the coil discharge in wasted spark or direct fire systems is controlled in the software of the ECU.

Noise

Misfire caused by “noise,” (commonly referred to as radio frequency interference {RFI}, or electro magnetic interference {EMI}), is usually due to routing the input signal leads in close proximity of the HT leads. Typically, spark plug wires cause RFI or primary ignition wires arcing to an engine component, which causes a frequency that interferes with the ECU. Routing two wires that carry high current parallel to each other cause EMI. The strength of current necessary to incur “noise” is dependent on the sensitivity of the device the wires are connected to. A common preventative measure for eliminating “noise” is to twist the wires together to minimize the electromagnetic field near the wires.

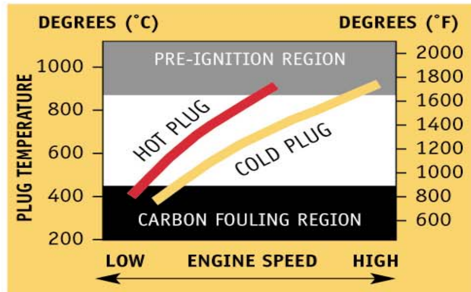
On any EFI system, resistive spark plug leads are REQUIRED to suppress noise!

Common resistive spark plug leads include those with a carbon impregnated fiberglass core or spiral wound filament around a carbon core wire.

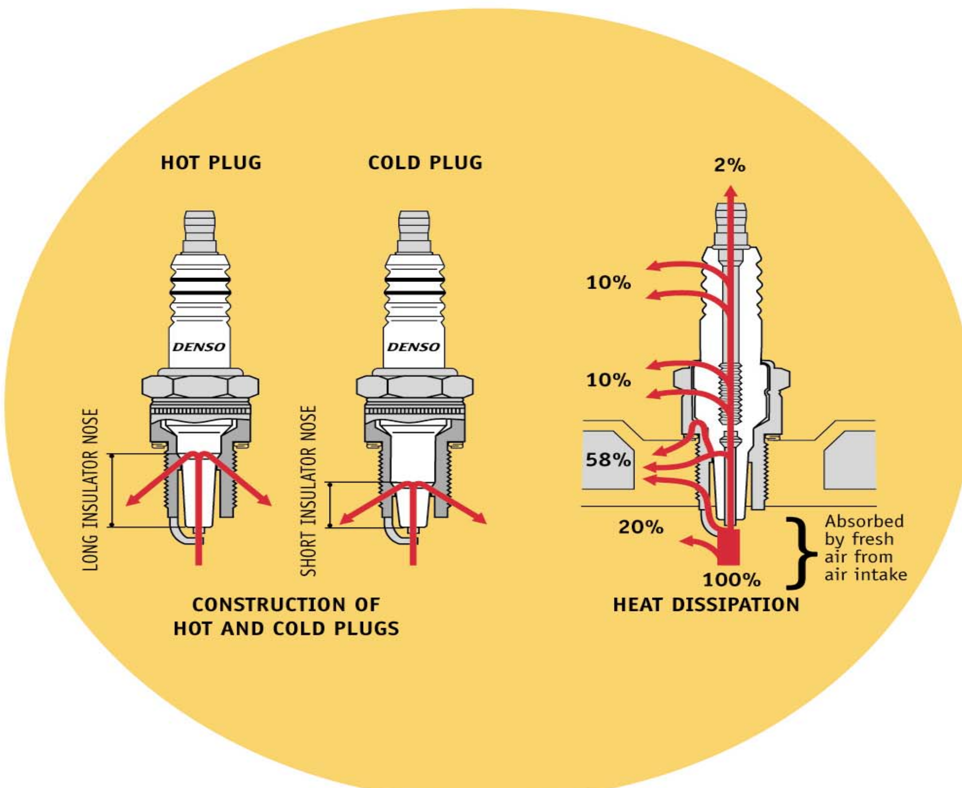
Another source of noise that can cause a misfire is an electrical “leak” in a plug wire or boot. Even a very small pinhole in a spark plug insulator or boot will allow electricity to arc to the cylinder head and interfere with the ECU signal.

Spark Plugs

Spark plug selection affects engine performance. On forced induction engines, it is critical that the proper heat range and gap is used. Heat range refers to the ability of the spark plug to conduct heat away from the electrode to the engine. A plug that has high thermal conductivity has a short insulator that comes in contact with a large portion of the metallic plug shell. This large area allows the combustion heat to be carried through the plug shell to the cooling jacket of the cylinder head. In the case of a hot plug, the insulator is recessed deeply into the plug shell with minimal contact to the shell. The plug has low thermal conductivity due to the lack of contact with the shell. The nose of the insulator should operate at between 400 – 850 degrees C. Temperatures above 400 degrees C are desirable because at higher temperatures deposits from carbon, lead or soot are burnt off. Temperatures of 850 degrees C and over should not be exceeded because this is typically the point where detonation or auto ignition can occur. Lower heat range plugs have a higher resistance to auto ignition while higher heat range plugs have less tendency to foul.



TEMPERATURE CURVES OF HOT AND COLD PLUGS



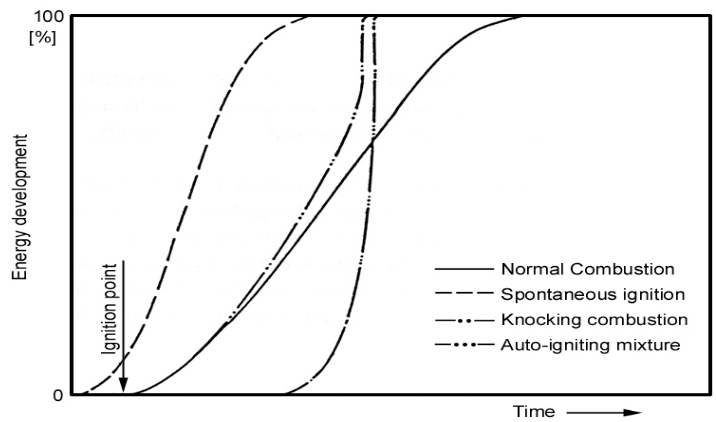
The spark plug gap on forced induction engines should be reduced REGARDLESS of the type of ignition system. We have read many instruction manuals for aftermarket ignition systems that recommend that the plug gap be opened up for better flame propagation. Although this recommendation may have had some merit when vehicles had carburetors, it does not apply to modern engines with electronic engine management systems. The smaller gap on forced-induction engines requires less spark energy to arc across the ground and the electrode and has a lesser tendency to misfire under the extreme pressures of a racing engine combustion chamber. Also there are spark plugs made with exotic fine wire highly conductive center electrodes that require less energy to fire such as the Denso Iridium that are well suited to racing conditions. The following is a chart of gap sizes for various engines on gasoline:

Naturally Aspirated up to 11.0:1 CR	1.1mm (.044")
Naturally Aspirated 11.0:1 to 14.0:	1.8mm (.032")
Forced Induction to 20-PSI	.7mm (.028")
Forced Induction to 40-PSI	.6mm (.022")

The color or condition of the spark plug is a general indicator of how rich or lean the engine is running and also if the engine is exhibiting signs of detonation if it is not audible. This is a plug color chart (supplied courtesy of Denso) of plug conditions.

Engine Knock (Detonation) and Preignition

It is important to understand the mechanisms that cause knocking and preignition to set up an ignition map that is suitable for the engine. Auto ignition, also known as knocking, pinging, or detonation, is generally caused by improper combustion in an engine. An internal combustion engine runs properly when the spark-initiated combustion wave expands rapidly but smoothly throughout the combustion chamber. Combustion knock is caused by spontaneous ignition in the hot unburned portion of the fuel mixture (typically referred to as end gas) in the combustion chamber. The remaining charge portion is compressed first by the upward piston movement and then by the moving flame front. Knocking is the almost instantaneous ignition of part of the remaining mixture. This mixture auto ignites because the rapidly rising pressure and temperature caused by the piston movement and the expanding gas from the flame front are sufficient to ignite the remaining gasses. To illustrate the loads imposed on the engine components by knocking, note that normal combustion speeds are about 12-25 $m.s^{-1}$ while knocking combustion speeds may be as high as 250-300 $m.s^{-1}$. The next illustration depicts the difference between a normal and abnormal combustion process.



If the gasoline-air mixture auto-ignites somewhere in the cylinder (other than at the spark plug) just after spark ignition, the auto-ignition combustion wave can collide with the spark-initiated combustion wave, causing the vibration we hear as a knock or ping. Depending on its intensity, knocking combustion may range from barley audible “pinging” to a rather violent thumping. The point at which the knocking becomes damaging to the engine is dependent on the components used in the engine. If sustained knocking occurs, then the pistons may be damaged. When knocking reaches a violent thump, engine operation should be ceased or at minimum the load and temperature reduced to prevent engine damage. Light knocking that happens during acceleration is less harmful and may not damage the engine. Knocking tendency is increased by the following design or operational characteristics:

- High Engine loads encountered while towing a vehicle.
- Using low octane gasoline in a high-compression engine.
- Too much timing advance for the type of fuel being used.
- Higher air density, (this can be caused by starting a calibration at high altitude and then traveling to a lower one, or the addition of forced induction).
- Increased temperatures and pressure in the combustion chamber due to inadequate engine cooling.
- Excessive inlet air temperature.
- Spark plugs with an improperly high heat range.
- A non-central spark plug location in the combustion chamber.
- An elongated combustion chamber design.
- Too lean of an air/fuel mixture.

The following tuning adjustments can be performed on an engine to reduce or eliminate knocking:

- Reduce ignition timing.
- Verify that the air/fuel mixture is adequate for your engine set up.
- Verify that the spark plugs are of proper heat range.

Preignition

Preignition is the ignition of the charge in the combustion chamber before the spark occurs. This type of ignition is caused by a very hot, or even incandescent surface in the combustion chamber. These “hot spots” can be an overheated spark plug, a glowing remnant of carbon in the chamber or even a hot exhaust valve edge. The preignition condition flame front rapidly expands while the piston is still on its way up the bore. Due to the very high pressure generated by the expanding flame front and the piston approaching TDC, the combustion chamber pressure rises rapidly causing audible knocking. Detonation and preignition typically have a cause and effect relationship; when detonation is prolonged and overheats the spark plug to the point where the tip glows, preignition occurs. Preventative measures can be taken to avoid preignition by using spark plugs with the correct heat range, avoiding detonation by using fuel with the correct octane rating for your application, and when building an engine, ensuring that there are no machined components with sharp corners in the combustion chamber. Also, the cooling system must be in good working condition to effectively cool the combustion chamber. Sustained operation of an engine in either of these conditions can result in severe engine damage.

Auxiliary engine controls

In addition to controlling ignition timing and fuel delivery for an engine, the AEM PEMS is capable of performing numerous auxiliary functions. These functions include but are not limited to:

- Variable valve control for any make of engine
- Staged injectors (sequential on 4 & 6 cyl. engines, batch on 8 cylinder engines.)
- Idle speed control motor with either a stepper motor or a duty cycled solenoid
- Dual RPM control
- Nitrous Oxide control
- Waste Gate control
- Thermostatic fan control
- Transmission control
- Ignition gear cut control
- Traction control

These are only a few items that the AEM PEMS can operate. Virtually any device that needs to be switched on or off in accordance with a given set of vehicle parameters is controllable with the AEM PEMS. Additionally, any device that requires a pulse-width-modulated output can be used with the AEM PEMS.

In the event that all of the injector drives are not utilized, the remaining ones can be employed to perform duty-cycled functions. Refer to Appendix A for a full list of features of the AEM PEMS.

Electronic Wiring Conventions

Noise can be a serious problem and can cause intermittent misfiring of the engine. Every precaution should be taken to prevent interference to the ECU's operation. Resistive plug leads are REQUIRED, and shielded cables from the crank and cam angle sensor inputs are highly recommended. All racing AEM PEMS wire harnesses come with properly shielded cables and are color coded for easy identification of circuits. They are also shrink wrapped for abrasion protection. The crank and cam angle sensor wire has a bare wire running down the length of it. It is **NOT** terminated at the sensor end of the cable because we ground it at the plug end of the harness. DO NOT GROUND THIS WIRE! This will cause a condition called ground looping and will remove any noise protection the cable has.

To eliminate or reduce the chance of EMI, wires that carry high current must run in twisted pairs. An example of this would be the power leads from a multiple spark ignition system. These ignition systems can carry up to 100 amps for a couple milliseconds at the time of discharge, which induces a strong magnetic field in close proximity of the wires.

The routing of the wire loom is critical to EFI system performance and safety. The following safety considerations should be made when installing the wire loom:

- Heat protection: the loom should be placed away from or insulated from sources of heat. The obvious item(s) that should be avoided are the exhaust manifolds, EGR delivery tubes, and turbochargers. If it is absolutely necessary to route a wire in close proximity to any of these items, then a suitable insulator must be used.

- Noise suppression: do not route wires near the HT leads. For coil- on-plug ignition systems this is not as critical.
- Moving component protection: route wires away from moving components such as fans, the blower belt, or the throttle linkage. Also, make sure the wires are not under any strain when the engine is at full deflection on the motor mounts (we have seen map sensor wires disconnect while under full acceleration because the motor mounts were bad).
- Never have the wires in exposed bundles throughout the engine compartment. A professional harness has shrink tube over it to resist abrasion and chemical damage to the wire loom.

Grounding

The ECU must have an electrically secure ground connection, which means that the battery negative must be properly grounded to the chassis AND engine. The ground wire, weather it is from the battery or to the chassis and engine, must have perfect electrical conductivity. This means that there must not be any paint or rust under the wire terminal. Make sure that when you install the ground wire there is bare metal exposed where the wire contacts the vehicle component. To prevent rust build up, we recommend applying a protective layer of dielectric grease, such as Standard Ignition SL-4, to the bare metal surface. The ground wire must be **at least** the same gauge as the power lead to the ECU. We also recommend that the ground wire be as short as possible.

Power Requirements of the AEM PEMS

The AEM PEMS requires a minimum of 10V of electrical current to run. We recommend that the ECU be supplied with 13.8V nominal operating voltage. Ensure that the vehicle's charging system is in perfect operating condition prior to installing the AEM PEMS.

The AEM PEMS must have two sources of 12V power. One power source is continuous to the ECU; the other is switched 12V power. The AEM PEMS wire harness comes with a relay that is activated by the ignition switch to power up the ECU. The wire size for the lead to the relay is 14 gauge. In the event that the ECU must be removed from the vehicle, the memory for the microprocessor will NOT be lost. The reason for a continuous 12V supply of electricity to the ECU is to retain logged data until it is downloaded from the ECU. Should you choose to cut power off to the ECU completely, the same relay that is used to power up the ECU from the ignition switch can be used by connecting the ECU 12V continuous power lead to terminal 87 of the relay.

Use of Relays to Control Ancillary Devices

Relays are remote switching devices that are used to isolate a device from the ECU's circuitry to reduce noise and power constraints on the ECU. Typical devices that are powered by a relay are:

- Fuel Pump
- Variable Valve Control
- Oxygen Sensor Heater
- ECU power
- Nitrous Oxide solenoids

Noise can be caused by the electric motor in a fuel pump, which if connected directly to the ECU, may feed back into the circuit board ground plane. In the case of a fuel pump, the typical amperage required to run the pump is 10A or more depending on its size. The driver in the ECU that sends the command to run the fuel pump is only capable of supplying 1.5A, and clearly this type of load on the driver would cause it to burn out. There are drivers that can handle larger currents but cost, size, heat dissipation, and noise problems prevent their use.

- Typical relays in use today are capable of carrying 40A. A relay has an electromagnet inside it that is used as a switch. This electromagnet, or switch, is used to position a contact within the relay that is capable of carrying high current. There are typically four or five terminals on the base of a relay. These terminals can be wired in several ways to achieve different results. Refer to the appendix for common wiring schemes used with relays.

Wire Terminations and Solder Joints

A proper wiring job includes proper termination of the wire at the sensor. The wire terminal end must be moisture tight where it plugs into the sensor and it must have strong, electrically sound terminals. The preferred method of securing a wire to a terminal is to use a crimp terminal with NO solder. It is important to use the proper crimping tool for sound terminal construction.

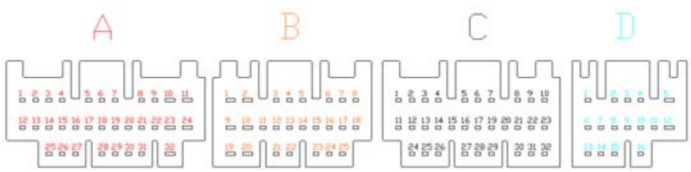
Plastic terminal plugs must have moisture tight seals. Inspect each plug to make sure the seals are in place. Also, before the plug is installed on the sensor, apply a dab of di-electric grease in the terminal slots to further aid in corrosion resistance.

If a splice into a wire must be made and no solder-less terminals are available, then you must properly solder the splice.

It is extremely important to make sure that all wires are in their proper locations. Easy-to-read schematic for easy identification of wire assignments. If you are not sure of how a wire set is assigned for a given terminal, do NOT guess. Damage may occur to the ECU if any wires are crossed.

Wire Harness for AEM PEMS Race ECU

AEM makes a prefabricated wire harness kit for custom installations or vehicles that require a universal harness. This harness is made of O.E. quality components and is labeled for every wire lead. All of the connectors for the components used with the EFI system are labeled in a similar manner to avoid any confusion of wire terminations.



Pin Assignments
as Viewed from Wire Side of Plug

Electronic Components used with the AEM PEMS

The AEM PEMS is capable of receiving many input signals that influence the calibrations for ignition or fuel, determine which device to activate, or warn the vehicle operator of any problems with the drive train. The group of sensors that the ECU uses for calibration purposes is listed below.

Throttle Position Sensor (TPS)

The TPS determines the position of the throttle blade in the throttle body. This input is used to determine rate of throttle angle change (both positive and negative), idle position, and discrete throttle opening for TPS-based calibrations. The TPS typically is a potentiometer bolted to the end of the throttle shaft. Rotating the throttle varies the resistance, and consequently, the voltage returned to the ECU is a function of that resistance. The rate of change is measured to determine whether a vehicle is accelerating or decelerating. Based on this rate of change, the proper amount of fuel is either added or subtracted from the base calibration to achieve the proper amount of fuel for the operating condition.

The TPS is also used to determine if the vehicle is idling. When the throttle is at rest, the vehicle is considered to be either idling or under heavy deceleration, and the fuel and ignition calibrations are adjusted for optimum idle characteristics. The TPS can be used as a calibration input if the AEM PEMS is set up to be a throttle position vs. RPM based mapping scheme. This type of mapping allows the tuner to set up the fuel map based on the throttle angle from 0 to 100% on the Y-axis of the map, with the X-axis being RPMs. This type of mapping is usually best for naturally aspirated racing engines with individual runner inlet manifolds and no plenum chamber or very aggressive cams.

The TPS has three leads: 5V+ into the TPS, a return to the ECU based upon the resistance of the TPS, and a ground. You will have to scale the TPS the first time you start your engine with the AEM PEMS installed. This is done by turning the ignition on and going to the *Options* screen. There will be two selections in the dropdown box called *TPS Min* and *TPS Max*. Select the *TPS Min* box and WITHOUT touching the throttle, simply hit the enter key on your computer. Next select the *TPS Max* box, push the throttle all the way to the floor and hit enter. The TPS is now calibrated for its full range of motion.

While on the subject of throttle opening we must caution you to make sure that full throttle is achieved by having someone verify that the throttle blade is opening fully and up against the stop on the throttle body while you depress the throttle. Also, make sure that nothing interferes with the full range of the throttle opening, such as a floor mat.

Manifold Absolute Pressure Sensor (MAP)

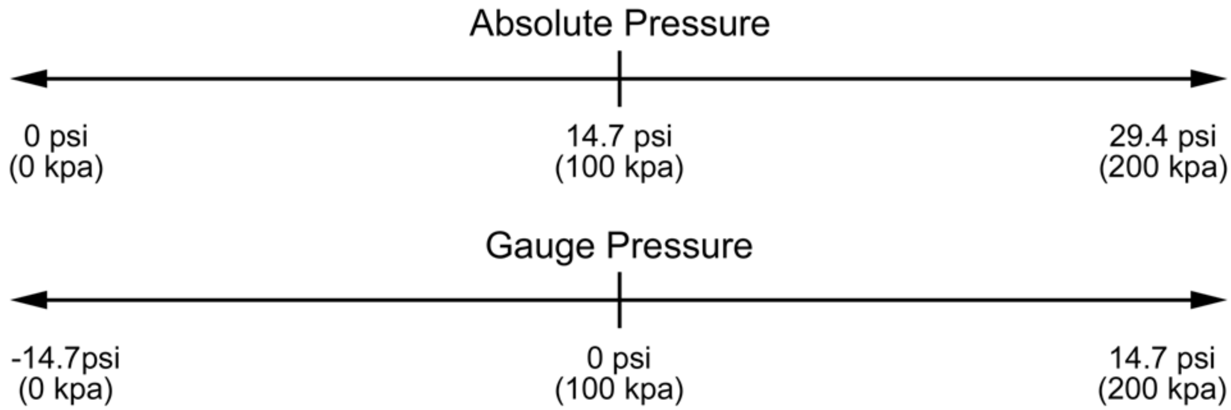
Before any discussion is held of what a MAP sensor is, it is necessary to understand what manifold pressure is. The definition of pressure is the force per unit area, thus it is an intensive quantity formed as a ratio force and area. So if a 100-pound force is exerted on a piston that has a total area of 100 in^2 the pressure acting on each square inch is 100lb/100 in^2 or 1 PSI. If the same force were to be applied to a piston with an area of only 1 in^2 the pressure exerted on the piston would be 100 lb/ 1 in^2 or 100 PSI. Now consider if a 100-pound person stepped on a nail that has a tip that is only .010” diameter. This would yield a pressure of 10,000 pounds. (100 lb / .010 in^2 = 10,000 pressure)

Realistically, there is no such thing as “manifold vacuum,” just low manifold pressure. The average air pressure exerted on Earth under standard conditions is 14.7 psi or 101.325 kilopascals (kpa). An engine ingests air by creating a differential of pressure across the engine via the movement of the pistons in their bores. When a piston moves down the bore, pressure in the bore is reduced. When the inlet valve opens, the awaiting relative higher-pressure air above the inlet valve enters the chamber and fills the void caused by the motion of the piston in the bore. On an engine without a means of forcing air into the engine, the most this pressure can be is whatever the atmospheric pressure of the day is. At sea level the average pressure is 14.7 psi.

It is common to refer to low manifold pressure as vacuum, which is how we will refer to low pressure for the purposes of this discussion. Pressure is measured in two ways: one is absolute pressure, and the other is gauge pressure. The difference between these is where the zero point of each scale starts. With absolute pressure, zero is a complete void of all pressure. With the more common gauge pressure, zero is at standard atmospheric pressure (14.7 psi). Anything below 14.7 psi is referred to as vacuum and anything above that is referred to as boost or positive pressure.

Closed or very small throttle angles are associated with low manifold pressure (a vacuum on the gauge measuring style), and large throttle angles or full throttle is considered high manifold pressure (0 on the gauge measuring style).

> Typical boost or vacuum gauges used in automotive applications use the gauge type of readout. In automotive engineering, the absolute method of measuring pressure is used. To illustrate the different ways to read manifold pressure refer to the accompanying chart.



We find it easiest to work with the accepted standard of kilopascals (kpa) of absolute pressure. It is important to know the relationships of the various nomenclatures of pressure. The units of pressure in use today are;

- 1 bar (b) = 100 kilopascals (kpa) = 14.5 psi = 29.529” Hg.
- 1 atm. = 101.325 kpa = 14.7 psi = 29.92” Hg = 1.01325 b

Pressure Conversion Table

PSI Absolute	Kpa	Inches Hg	Bar	Pressure Gauge
1.00	6.89	2.04	0.07	-27.89 in Hg ↓
2.00	13.79	4.07	0.14	-25.86
3.00	20.68	6.11	0.21	-23.82
4.00	27.58	8.14	0.28	-21.79
5.00	34.47	10.18	0.34	-19.75
6.00	41.37	12.22	0.41	-17.71
7.00	48.26	14.25	0.48	-15.68
8.00	55.16	16.29	0.55	-13.64
9.00	62.05	18.32	0.62	-11.61
10.00	68.95	20.36	0.69	-9.57
11.00	75.84	22.40	0.76	-7.53
12.00	82.74	24.43	0.83	-5.50
13.00	89.63	26.47	0.90	-3.46
14.00	96.53	28.50	0.97	-1.43
14.70	**101.35**	**29.93**	**1.01**	**0**
15.00	103.42	30.54	1.03	0.3 psi ↓
16.00	110.32	32.58	1.10	1
17.00	117.21	34.61	1.17	2
18.00	124.11	36.65	1.24	3
19.00	131.00	38.68	1.31	4
20.00	137.90	40.72	1.38	5
21.00	144.79	42.76	1.45	6
22.00	151.68	44.79	1.52	7
23.00	158.58	46.83	1.59	8
24.00	165.47	48.86	1.65	9
25.00	172.37	50.90	1.72	10
26.00	179.26	52.94	1.79	11
27.00	186.16	54.97	1.86	12
28.00	193.05	57.01	1.93	13
29.00	199.95	59.04	2.00	14
30.00	206.84	61.08	2.07	15
31.00	213.74	63.12	2.14	16
32.00	220.63	65.15	2.21	17
33.00	227.53	67.19	2.28	18
34.00	234.42	69.22	2.34	19
35.00	241.32	71.26	2.41	20
36.00	248.21	73.30	2.48	21

Bold type is standard atmosphere

Vacuum in Hg"
Standard ATM
Pressure in PSI

The MAP sensor provides manifold pressure information to the ECU for calibration based on MAP vs. RPM. The MAP information is used in both the fuel and ignition Y-axis of their respective maps. On racing engines that use individual runner manifolds, a TPS based fuel map can be used while the ignition can be MAP based. This is desirable because the ignition should always be load based to provide knock free operation.

A MAP sensor reads in absolute pressure, just like the name implies. The amount of pressure indicated by the sensor depends on the amount of voltage feedback delivered to the ECU. As the throttle is opened and closed, or boost is built up in the manifold, the sensor reacts to the changing pressure and outputs a voltage signal to the ECU based on the given pressure.

The MAP sensor has three leads: 5V+ into the MAP sensor, a return to the ECU based upon the resistance of the MAP sensor, and a ground. A MAP sensor MUST have a hose routed to it from the inlet manifold in order to read manifold pressure and it MUST receive a constant pressure signal to it at all times. If the pressure signal fluctuates, the calibration will be adversely affected because the fuel and ignition values will cycle with the MAP signal.

To avoid varying MAP signals, the pressure line must be connected to the intake plenum. In the case of individual runner manifolds, TPS-based mapping is best.

If a MAP sensor is used for boost compensation or load sensitive ignition timing, an accumulator must be used. An accumulator is a common closed container that has a hose from each runner routed to it. An accumulator dampens the pulsing commonly found in this type of manifold set up, which will aid in the delivery of a steady MAP signal (A fuel pressure regulator can have its pressure source routed to an accumulator for the same reasons).

The AEM PEMS has a variety of MAP sensor ranges to suit everything from naturally aspirated engines, to forced induction engines up to whatever boost can be generated by the turbo or supercharger(s).

Mass Air Flow Sensor (MAF)

A Mass Air Flow Sensor (MAF) is used to measure the mass flow of inlet air into the engine using a form of direct measurement. A MAF can be in the form of a gate-style sensor with a door that reacts to airflow, a hot wire that uses a proportional amount of current to keep a filament at a predetermined temperature above ambient, or a vortex generator that uses microwaves to measure vortices shed from an aerodynamic probe in the air stream. All of these devices deliver a signal to the ECU that is proportionate to intake airflow volume. The most common type of MAF is a hot wire, or a variant of a hot wire system. The amount of current required to keep the filament 300 degrees above ambient is directly proportional to the air mass flowing into the engine. Humidity in the air helps cool the wire even further, and the sensor accounts for the effect of moisture. The only drawback to an MAF is that it presents a physical air path restriction in the inlet manifold. Fortunately, the AEM PEMS can be calibrated to accommodate larger mass MAF sensors and allows for the use of different sensors as needed. Like TPS and MAP based systems, an MAF system can be set up to perform the fuel calibration by defining the mass flow as the Y-axis of the fuel map.

O_2 (Oxygen) Sensors

There are many types of O2 sensors that are employed by vehicle manufacturers, and it is well beyond the scope of this manual to describe all of them. An O2 sensor provides a reading of the air/fuel ratio (AFR) to the ECU so that it can make the necessary fuel calibration corrections to achieve a desired Air Fuel Ratio (AFR).

An O2 sensor works by sensing whether there is an abundance or lack of oxygen in the exhaust gases, depending on whether the gas mixture is too rich or too lean. If there is excess oxygen and the mixture is too lean, output voltage from the O2 sensor to the ECU will be high. The ECU may then compensate by adding fuel. The converse is true of rich mixtures.

Common O2 sensors include 3-, 4-, and 5-wire heated or wide-band sensors. Three- and 4-wire sensors are ideal for determining whether a vehicle's AFR is at the optimum stoichiometric ratio. Stoichiometric ratio refers to the ideal mixture of fuel and air by mass to completely consume both reactants (gas and air) with nothing left over. Based on the properties of most pump gasoline used today this ratio is typically a 14.64:1 air/fuel ratio. Although this ratio provides the best combustion characteristics with the least emissions output and optimum catalytic converter performance, it is NOT the best AFR for maximum power at full throttle or under boost. This mixture is too lean and may cause engine damage.

The typical working voltage for most O2 sensors is 200mv to 850mv. The AEM PEMS has a menu of the most common O2 sensors used and it requires that you enter the type of O2 sensor used for your engine. Keep in mind that because 3- and 4-wire O2 sensors respond primarily to stoichiometric AFR, they are less accurate than UEGO sensors for calibration purposes. If this is the only sensor available to you, we recommend that the calibration be done using a lab-type AFR meter, such as the Horiba Mexa 700. Once the calibration is completed, a narrow band O2 sensor can be used to regulate the AFR at idle and part throttle.

There are wide-band, four-wire O2 sensors that have the capability of accurately measuring AFRs. The most common one is used on the Porsche Carrera 4 and is a Bosch unit (part number 0.258.104.002). This sensor is compatible with the AEM PEMS and can be used for calibration purposes.

The most desirable O2 sensor for calibration use is the NTK Universal Exhaust Gas Oxygen (UEGO) sensor. It is a very accurate, fast responding sensor that reads well beyond each side of the stoichiometric ratio. It is a 7-wire sensor that uses a resistor to calibrate its output and has 5 or 6 wires returning to the ECU. The additional wire in the case of a 6-wire unit is a redundant ground wire. The AEM PEMS is also compatible with this type of sensor and it is required for the "auto map" mode of AFR tuning. The Horiba Mexa 700 uses this type of sensor because of its wide response range.

The following is a chart of typical AFRs. **Note that every engine is different and this may not be the optimum set up for your particular vehicle**. The AFRs on this chart are very conservative to minimize the potential for engine damage. These AFRs depend on the condition that ignition timing and fuel octane are adequate enough to prevent knocking. The very low loads found in the lower right corner occur during deceleration, and because there is no "work" being done by the engine, AFRs during deceleration can be very lean. We have seen AFRs of 20.0:1 during deceleration runs.

Naturally Aspirated Piston Engines W/ Pent roof Combustion Chamber

Air/Fuel Ratio

L	**100**	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	12.8:1	12.8:1
O	**90**	13.5:1	13.5:1	13.5:1	13.5:1	13.5:1	13.5:1	13.5:1	13.5:1
A	**80**	14.0:1	14.0:1	14.0:1	14.0:1	14.0:1	14.0:1	14.0:1	14.0:1
D	**70**	14.0:1	14.2:1	14.2:1	14.2:1	14.2:1	14.2:1	14.2:1	14.2:1
	60	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1
I	**50**	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1
N	**40**	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1
	30	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1
K	**20**	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	15:1	15:1	15:1
P	**10**	14.0:1	14.7:1	14.7:1	15:1	15:1	15:1	15:1	15:1
A		**Idle**							**Maximum**

RPM

Turbocharged Piston Engines W/ Pent roof Combustion Chamber

Air/Fuel Ratio

LOAD IN KPA								
300	13.0:1	12.5:1	12.2:1	12.2:1	12.2:1	12.2:1	12.2:1	12.2:1
275	13.0:1	12.8:1	12.5:1	12.5:1	12.2:1	12.2:1	12.2:1	12.2:1
250	13.0:1	12.8:1	12.5:1	12.5:1	12.2:1	12.2:1	12.2:1	12.2:1
225	13.0:1	12.8:1	12.8:1	12.8:1	12.5:1	12.5:1	12.5:1	12.5:1
200	13.0:1	12.8:1	12.8:1	12.8:1	12.5:1	12.5:1	12.5:1	12.5:1
175	13.0:1	13.0:1	13.0:1	12.8:1	12.8:1	12.8:1	12.8:1	12.8:1
150	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	12.8:1	12.8:1
125	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	12.8:1	12.8:1
100	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	13.0:1	12.8:1	12.8:1
75	14.0:1	14.2:1	14.2:1	14.2:1	14.2:1	14.2:1	14.2:1	14.2:1
50	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1
25	14.0:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1	14.7:1
	Idle							**Maximum**

RPM

The AFR is often referred to as a Lambda (λ) number. A Lambda of 1.00 is equal to the stoichiometric ratio for the reactants in a system. For our purposes, the stoichiometric ratio is the ratio for the amount of ANY fuel used in an internal combustion engine. With Lambda measurement, any number higher than 1.00 is considered lean (more air than necessary to react with the fuel) and any number lower than 1.00 is considered rich.

Although Lambda is the term most often used when working with O2 sensors, we will use AFR in this manual because it is the most common term used when referring to internal combustion engines. The following is a chart for converting Lambda values to AFRs.

Lambda to AFR conversion chart

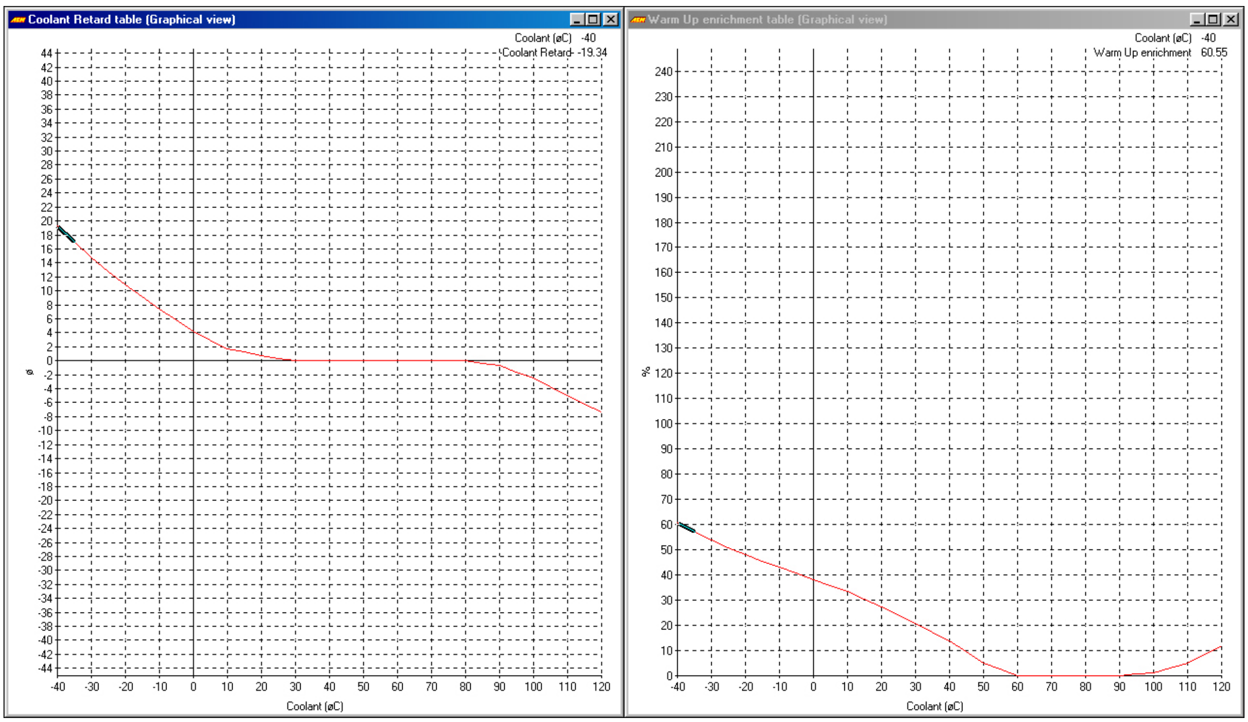
Lambda	AFR	Lambda	AFR	Lambda	AFR	Lambda	AFR
1.3	19.03	1.14	16.69	0.98	14.35	0.82	12.00
1.29	18.89	1.13	16.54	0.97	14.20	0.81	11.86
1.28	18.74	1.12	16.40	0.96	14.05	0.8	11.71
1.27	18.59	1.11	16.25	0.95	13.91	0.79	11.57
1.26	18.45	1.1	16.10	0.94	13.76	0.78	11.42
1.25	18.30	1.09	15.96	0.93	13.62	0.77	11.27
1.24	18.15	1.08	15.81	0.92	13.47	0.76	11.13
1.23	18.01	1.07	15.66	0.91	13.32	0.75	10.98
1.22	17.86	1.06	15.52	0.9	13.18	0.74	10.83
1.21	17.71	1.05	15.37	0.89	13.03	0.73	10.69
1.2	17.57	1.04	15.23	0.88	12.88	0.72	10.54
1.19	17.42	1.03	15.08	0.87	12.74	0.71	10.39
1.18	17.28	1.02	14.93	0.86	12.59	0.7	10.25
1.17	17.13	1.01	14.79	0.85	12.44	0.69	10.10
1.16	16.98	1	14.64	0.84	12.30	0.68	9.96
1.15	16.84	0.99	14.49	0.83	12.15	0.67	9.81

Coolant Temp Sensor (CLT)

The coolant temperature sensor (CLT) is a variable resistance thermistor (thermal resistor) that sends a return voltage back to the ECU based on the temperature of the engine coolant. This sensor can also be used for virtually any other type of automotive fluid if it is located in that liquid's respective reservoir. Unlike other types of sensors that emit voltage signals to the ECU, with CLTs the ECU outputs a +5V signal to the CLT and the sensor's resistance determines the return voltage. The AEM PEMS is compatible with virtually all CLT sensors.

The CLT provides the ECU with engine temp information. The AEM PEMS modifies the base fuel calibration during start and warm up based on the CLT input. In addition to adding fuel, a CLT can signal to the ECU to modify ignition timing at varying engine temps for optimum performance. On racecars, ignition timing is typically advanced during warm up to heat the engine faster. Racecars use an ignition based warm up because usually idle speed motors are not used. On streetcars, where clean emissions are important, we reduce timing based on CLT input to light the catalytic converter(s) off sooner.

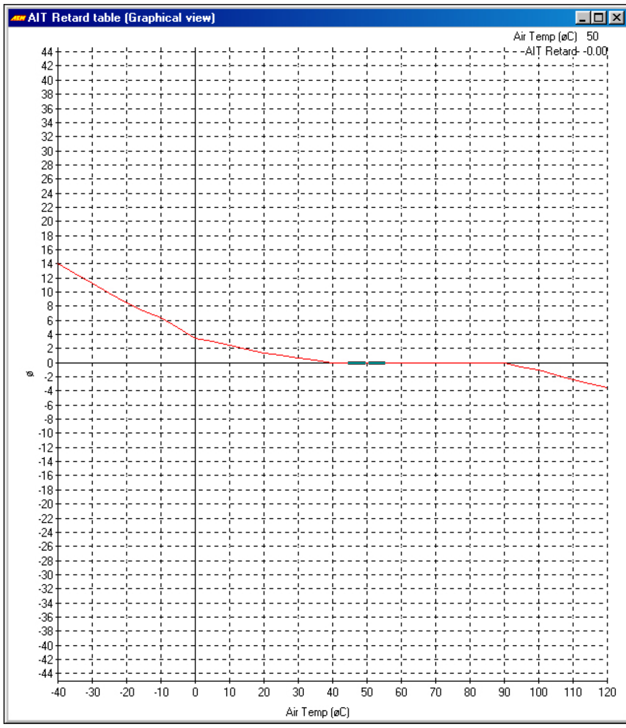
Another use for CLT sensor input is to increase fuel delivery to the engine if the coolant temperature exceeds a limit defined by the tuner. The additional fuel in many cases can help cool the engine.

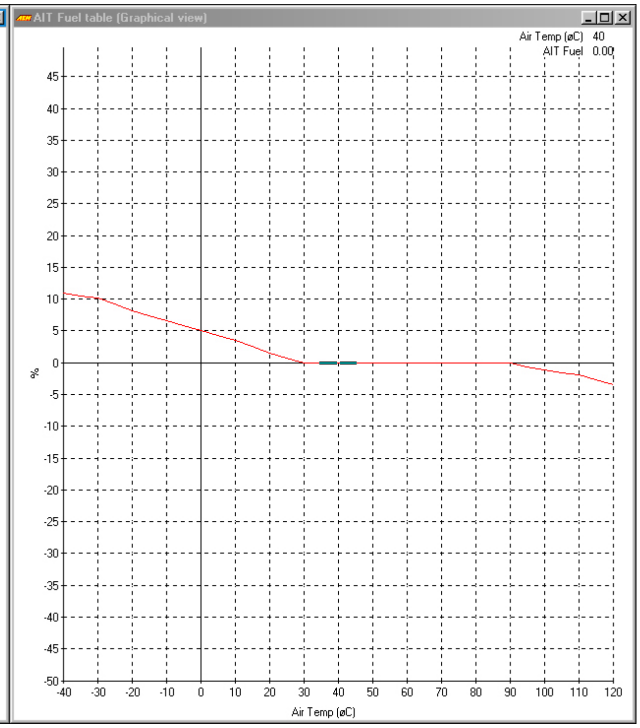


Manifold Air Temp Sensor (MAT) &Inlet Air Temp Sensor (IAT)

Manifold Air Temp Sensors (MAT) and Inlet Air Temp Sensors (IAT) are variable resistance thermistors that send a return voltage signal back to the ECU based on the inlet air temp either in the inlet manifold or in the inlet duct to the throttle body (The ECU outputs a +5V power to the sensor and the return voltage is based on the resistance of the sensor). These sensors can also be used as auxiliary temp sensors for any air temp measurement, such as intercooler inlet and outlet temps.

The AEM PEMS is compatible with virtually all MAT & IAT sensors. Based on the inlet air temp readings provided by an MAT or IAT, an ECU can add or subtract fuel or ignition timing depending the given conditions. For example, a typical use for an MAT sensor is to change the ignition timing and fueling of an engine based on inlet air temp. This is particularly useful on forced induction engines where inlet air temps can increase dramatically. Typical ECU programs reduce timing as inlet air temp increases to help reduce the chance of knocking.





Knock Sensor (KNK)

The knock sensor is like a microphone mounted to the engine block that is used to detect combustion knock. Every engine is different with respect to the amount of noise it generates. In most production engines, the sensitivity of the knock sensor is based on an average noise profile generated during dyno testing. A knock sensor that has a slightly lower threshold of sensitivity to knock is used to compensate for variances in engine noise.   When the engine makes noise in frequencies and amplitude higher than the baseline noise profile, the sensor senses knock and the ECU reduces ignition timing until the noise (knock) is suppressed. Engines that have knock sensors on them from the factory need to have the baseline noise profile recorded when setting up the AEM PEMS.

Tuning and Set Up Parameters for the AEM PEMS/Vehicle Usage

The intended use of the vehicle must be defined before calibration work begins. The type of service the vehicle will see determines the calibration parameters for ignition timing, fuel delivery, and idle quality. For example, an ignition map for a vehicle that is heavy, or used to tow, is going to be less aggressive than an ignition map for a light racing vehicle that uses high-octane racing gasoline. The fuel curve for racing vehicles is based upon maximum performance, which is sometimes too lean for a road car. It is extremely important to carefully consider the intended use of the vehicle and plan on performing calibrations that suit the use of the car.

With the AEM PEMS however, it is possible to have two calibrations for the same car. A typical example is a forced-induction engine that uses a low boost setting for street and daily driving and on weekends is raced with a high boost setting and unleaded race fuel. With the AEM PEMS, a tuner can make calibrations to suit both of these conditions that can be easily loaded into the ECU at a legal off-road racing venue.

FUEL USAGE

The type of fuel used determines the degree of timing that can be run in an engine and how lean a tuner can allow a car to run to achieve maximum power. On ALL cars that use an O2 sensor, unleaded fuel MUST be used. If a vehicle uses leaded racing fuel, then an O2 sensor should be used for tuning only and must be removed as soon as possible as it will be contaminated by the lead oxide in the exhaust gas.

There are several unleaded race fuels that have octane levels necessary to perform calibration work. We use an ELF product called TR-4 that is unleaded and supports over 30-psi of boost. Unocal also makes a very good unleaded race fuel that can support high boost.

When performing calibration work, especially on a dyno under boosted conditions or when using nitrous oxide, high-octane racing gas is required. The use of high-octane fuel helps prevent serious engine damage from severe knocking under heavy load. Because the loading on an engine while performing dyno testing is usually higher than in actual use, lower-octane fuel MAY be used for normal driving. The exception to this is in racing applications because of the severe heat and loads imposed on the engine.

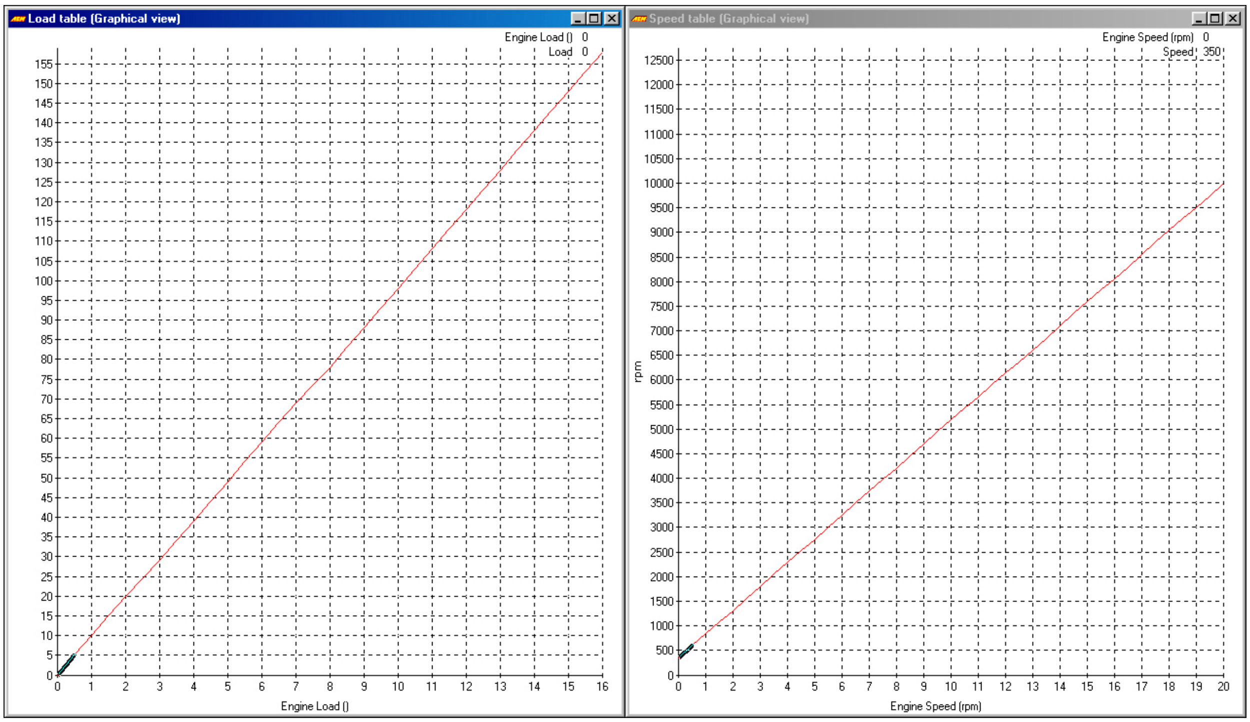
ENGINE MODIFICATIONS

Before calibration work is to be performed on any engine, find out as much as possible about the engine's critical parameters. These include the engine's compression ratio, the strength of the internal components, the history of the engine, etc. You may also extend or reduce the engine's rpm limit depending on its condition. An engine set up may include power enhancers such as Nitrous Oxide, Forced Induction, racing cams and/or extensive internal modifications. Tuning parameters will be different for each of these modifications. With racing engines, in many cases the type of calibration setup will be dictated by the manifold and throttle body design employed by the tuner. For example, an engine that uses an individual runner (IR) manifold would likely use a TPS-based fuel map with a load-based ignition map, or a TPS-based ignition map with load compensation. This mapping combination for IR manifolds is very responsive and we highly recommend it. This combination, however, would not work on a forced-induction engine because of the lack of boost compensation with respect to fuel delivery. We have set up turbocharged drag racing cars with TPS-based fuel and ignition mapping and boost compensation for both, however on a road car this is not desirable because the vehicle will encounter various terrain changes that are better suited to load- based mapping.

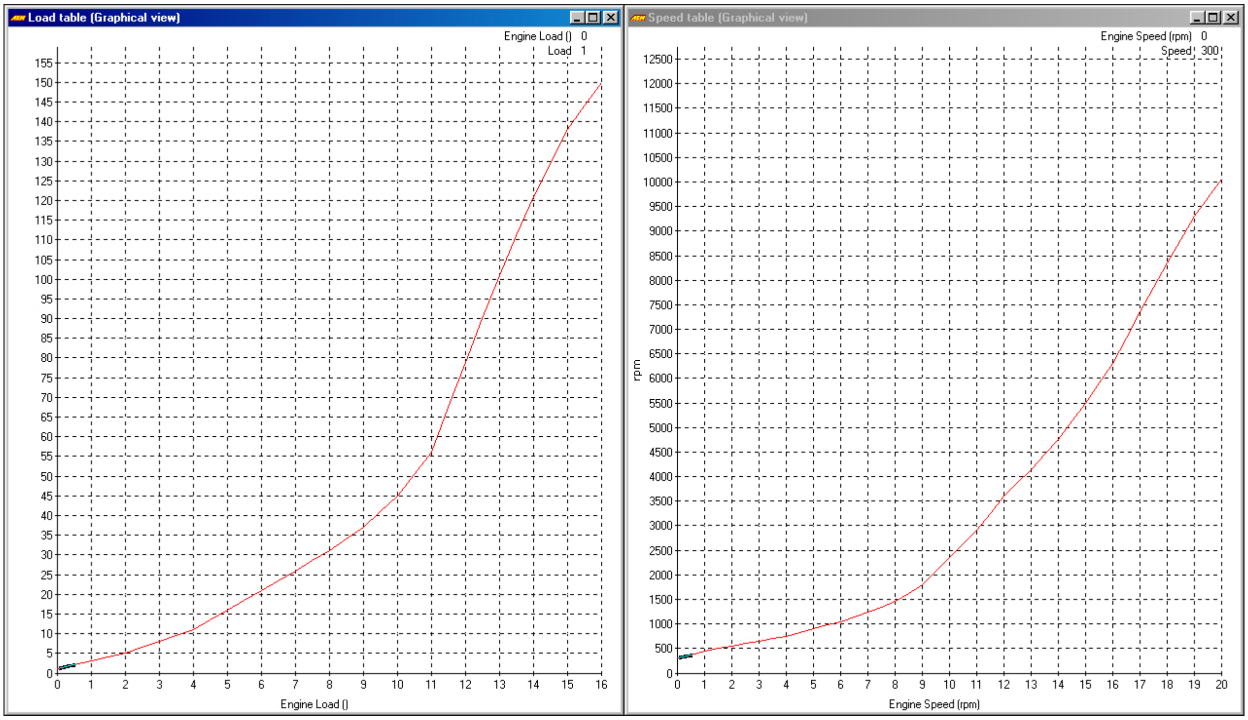
Courtesy of TWM Induction

Set up RPM and Load axes

The RPM (X) and Load (Y) axes of the 3D maps must be set up before any calibration work is to be done. The matrix for all 3D maps except the idle fuel and idle ignition maps is 23 (X) by 17 (Y). The set points may be linear or non linear. Most road cars with relatively mild tuning characteristics use linear X & Y axes. On engines that are modified with narrow power bands the non-linear set up is often used. The reason a non-linear set up is good for highly tuned engines is because the airflow through them is very non linear. The set up of the X & Y axes allows the tuner to accommodate the non-linear characteristics of the engine by placing the set points for RPM and Load closer together in the region where drivability is critical.



Linear Load and RPM Setup



Non-Linear Load and RPM Setup

Verifying Input Signals from Crank and Cam Angle Sensors

Once the AEM PEMS is installed, (either PNP or Race) the input signals from the crank and cam angle sensors must be verified. This is performed using a dual trace oscilloscope or the AEM PEMS. The input signals can be monitored by choosing the "input signals" template button at the top of the screen. A window with a parameter screen will appear. This will have fields the various input signals that must be working correctly for the ECU to work. The monitored signals are; "Sync tooth", "Ref tooth" and "Sync Errors". When cranking the engine, a pattern will appear in the middle column of the "Sync tooth" and "Ref tooth" fields. The middle column of the "Sync error" field will have a numerical value, which should be three or less. Verify that the pattern is symmetrical and even. There should be no Sync Errors except one when discontinuing cranking. If the signals are OK then proceed to the next step. If not, then there may be a broken wire for the input if there is no signal or noise may be present if there are numerous "Sync Errors". If noise is suspected, then a load resistor may have to be added to the input line. These are available from AEM and are easily installed on the input wire.

Verifying Ignition Sequence

Once the input signals are verified, the ignition sequence (firing order) must be verified. If the engine uses a distributor, the order of the HT leads on the cap must be in the proper order. This MUST be verified by the following procedure.

1. Remove all of the spark plugs from the engine.
2. Remove the distributor cap. Have someone rotate the engine in its proper rotation. Note the direction of the rotation of the rotor.
3. After noting the rotor rotation, place a finger, or a push-in type of compression gauge, over the spark plug hole.
4. When there is a high positive pressure (compression) at the hole, stop rotating the engine. (You will feel the air pressure trying to push your finger or the gauge out of the hole.)

Slowly turn the engine until the TDC mark appears adjacent to the pointer. If possible, look into the spark plug hole to verify that the valves are closed and the piston is at TDC. This is easily done on 4 valve/cyl. and hemi engines. On Wedge-type combustion chambers the visual inspection is more difficult, but possible using a small mirror and flashlight.

Remove the distributor cap and note the position of the rotor relative to the cap #1 terminal. If the rotor is adjacent to the #1 terminal, then verify the order in which the HT leads are installed onto the cap. They should follow the firing order in the direction of rotation of the rotor.

For wasted spark systems, this procedure is much easier. The coil assignment for each plug is in the order in which the coil fires.

The AEM Race PEMS is capable of firing up to five coils in wasted spark configuration for running up to 10 cylinders. The ECU fires the coils in the sequence of a designated firing order. To determine which HT leads to assign to each coil, write down the number of coils and give them a letter designation. As an example, we will use an inline six-cylinder engine with a firing order of 153624. There should be three coils labeled A, B and C to fire the plugs. If the coils are fired in an ascending A, B, C sequence, follow the firing order on the coils.

Common Firing Orders and Coil Assignments

Coil A	Coil B	Coil C
1	5	3
6	2	4

Wasted Spark Plug wire configuration

Inline Four (I-4) Cylinder Engines:	Coil A	Coil B	Coil C	Coil D
1 – 3 – 4 – 2 Most modern four-cylinder engines 1 & 4	2 & 3			
1 – 2 – 4 – 3 Ford 1.6L & Cosworth BDA	1 & 3	2 & 4		
Horizontal Four Engines				
1 – 4 – 3 – 2 VW	1 & 3	2 & 4		
1 – 3 – 2 – 4 Subaru	1 & 2	3 & 4		
Inline Six (I-6) Engines				
1 – 5 – 3 – 6 – 2 – 4	1 & 6	2 & 5	3 & 4	
V-8 Engines				
Chevrolet and Chrysler SB, & BB				
1 – 8 – 4 – 3 – 6 – 5 – 7 – 2	1 & 6	5 & 8	4 & 7	2 & 3
Ford SB & FE				
1 – 5 – 4 – 2 – 6 – 3 – 7 – 8	1 & 6	3 & 5	4 & 7	2 & 8

The AEM PEMS is also capable of running up to 5-cylinder, direct-fire ignition systems. The sequencing of these is straightforward; simply install the coils, or leads from the coils, in order to the plugs. The software in the ECU will fire the coils in the firing order entered by the tuner.

Verifying Fuel Delivery System and Injector Capabilities

Check that the fuel pressure is set to the value you intend to run the EFI system on. Most systems start at 40 PSI with the manifold vacuum pressure hose disconnected from the top of the regulator.

Verify that there are no leaks in the system. If there is any sign of leakage you MUST correct it before starting the calibration. This is not only for obvious safety reasons, but also because the calibration may be incorrect due to improper fuel delivery.

Have someone crank the engine over and listen to the injectors using a mechanics stethoscope. Depending on the type of injector, the sound they make when opening and closing may be audible without a stethoscope. Never use a DVOM to check the injector circuit. There is a tool available called a “noid” that plugs into the injector harness and verifies that current is reaching the injector from the ECU by pulsing an LED light.

Verifying TPS Setting

The throttle position sensor must be calibrated for its full range of motion. Using the AEMPro software go to the configure menu at the top of the screen and follow the instructions to configure the TPS.

Verifying Engine Set Up in Software

The engine input signals must be set up for the engine to run. Verifying the engine input signals requires knowledge of the number of teeth on the crank angle sensor and whether the sensor is crank driven or cam driven. Other procedures that must be completed to verify the engine’s software program include:

- The firing order for the ignition must be entered
- The MAP sensor value must be selected
- The RPM set points for the fuel and ignition maps (X-axis) must be entered
- The load points for the Y-axis must be entered.
- The RPM limiter should be set to a safe value for the engine
- All auxiliary controls must be set up. This includes variable valve controls, nitrous oxide or any other ECU controlled device
- On PNP systems, most of these are set up. The only exception to this will be if an auxiliary device has been added to the vehicle
-

It is a good idea to make a checklist of every option the engine has and go through the set up software step by step to verify operation of each item.

Before Starting the engine

On Plug and Play systems, there are base calibrations available on the software CD supplied with the ECU or on the AEM web page. These calibrations are set up to start and run the engines for which they are intended. These calibrations are NOT set up to be run at full load especially in the case where forced induction or nitrous oxide is used. The calibration MUST be verified before running the engine at maximum load.

Starting the Engine

If the above sections are completed correctly, the engine should start with minimal cranking. On PNP systems, the supplied baseline calibration can be loaded into the system and the engine should fire with minimal cranking. On race systems, the start fuel, warm up parameters and base fuel map may have to be adjusted to get the engine to fire. If the race system has been installed on a vehicle with catalytic converter(s) we strongly recommend that they are removed before starting the engine to prevent damaging them. After the calibration is complete, the catalytic converter(s) should be reinstalled.

The fuel parameters required to start the engine on a racecar can easily be adjusted. However, determining how rich or lean to make the fuel delivery at start up is a delicate process. We recommend that small steps be taken when performing start-up and warm-up calibrations. One of the most common fuelling problems at start up is that too much fuel will foul the spark plugs making the engine difficult, if not impossible, to start. If your engine will not start although it is cranking, remove the spark plugs and inspect their condition. Do not crank the engine excessively. If there is a no start condition, determine if the spark plugs are firing and the injectors are working. If both are operating correctly, then the ignition timing must be checked to ensure that the ignition is firing at the correct timing value.

Setting Ignition Timing

Synchronizing your vehicle's ignition timing is critical to engine performance. The ECU and the engine must read the same timing value in order to perform a valid calibration. To verify ignition timing, put a timing light on the number 1 plug wire and start the engine. Establish communication with the ECU and go to the ignition monitor. Observe the ignition timing with the timing light and check the monitor to verify that the ECU readings correspond with the timing light. If the readings do not correspond, they must be synchronized. Since the light reads ignition timing at the engine, the ECU should be calibrated to the timing light reading. This is done by going to the ignition setup menu and adjusting the timing to agree with the engine. Because the timing light is the link between the engine and the real firing position, its value is the one to use for setting purposes. **In other words, believe the timing light above all else.**

Vehicles that use a wasted spark system must be timed with a distributor less ignition system adaptor. This is available from Snap On tools part number MT-255. Without this device the engine timing cannot accurately be established and the calibration is invalid.

Engine Calibration

Proceed with this section ONLY if the ignition timing has been verified.

It is essential that extreme caution be exercised in the initial set up of the fuel and ignition tables for the first use. We recommend very conservative settings for fuel and ignition. This means that a rich mixture is used for initial tuning and the ignition timing is at least 5° retarded from the factory ignition timing. In the case of turbocharged, supercharged of Nitrous Oxide systems, you should start with 10° retarded from the stock timing.

Engine Fuel Requirements

Determining an optimum AFR for each load point of an engine is dependent on the overall operating condition of the engine. An example of this is at wide open throttle the requirement is for high power, while during a low-throttle, steady-state condition the AFR requirement is for minimal emissions and fuel consumption.

In the case of high power, the mixture value is somewhat below stoichiometric ($\lambda \approx 0.9$ to 0.95). For best catalytic converter performance and fuel economy, the mixture is at stoichiometric or higher ($\lambda \approx 1.0$ to 1.1). During idling, the optimum AFR is the one where the least amount of fuel is consumed provided the engine fires steadily and reliably. Running the engine at or near the stoichiometric ratio at idle increases the potential for misfire. Consequently, a typical AFR at idle is usually around 1.2 to 1.5 times stoichiometric.

Operational conditions that influence the AFR include engine temperature, variable valve timing, or an acceleration/deceleration period. The AEM PEMS is able to address all of the factors that influence the engine's ability to run by applying enrichment factors to the base calibration. The 3D fuel and ignition mapping software supplied with the AEM PEMS allows for precise calibration of all operational points of the engine. The addition of modifiers (discussed below) to the base calibration compensates for the varied operational conditions of an engine.

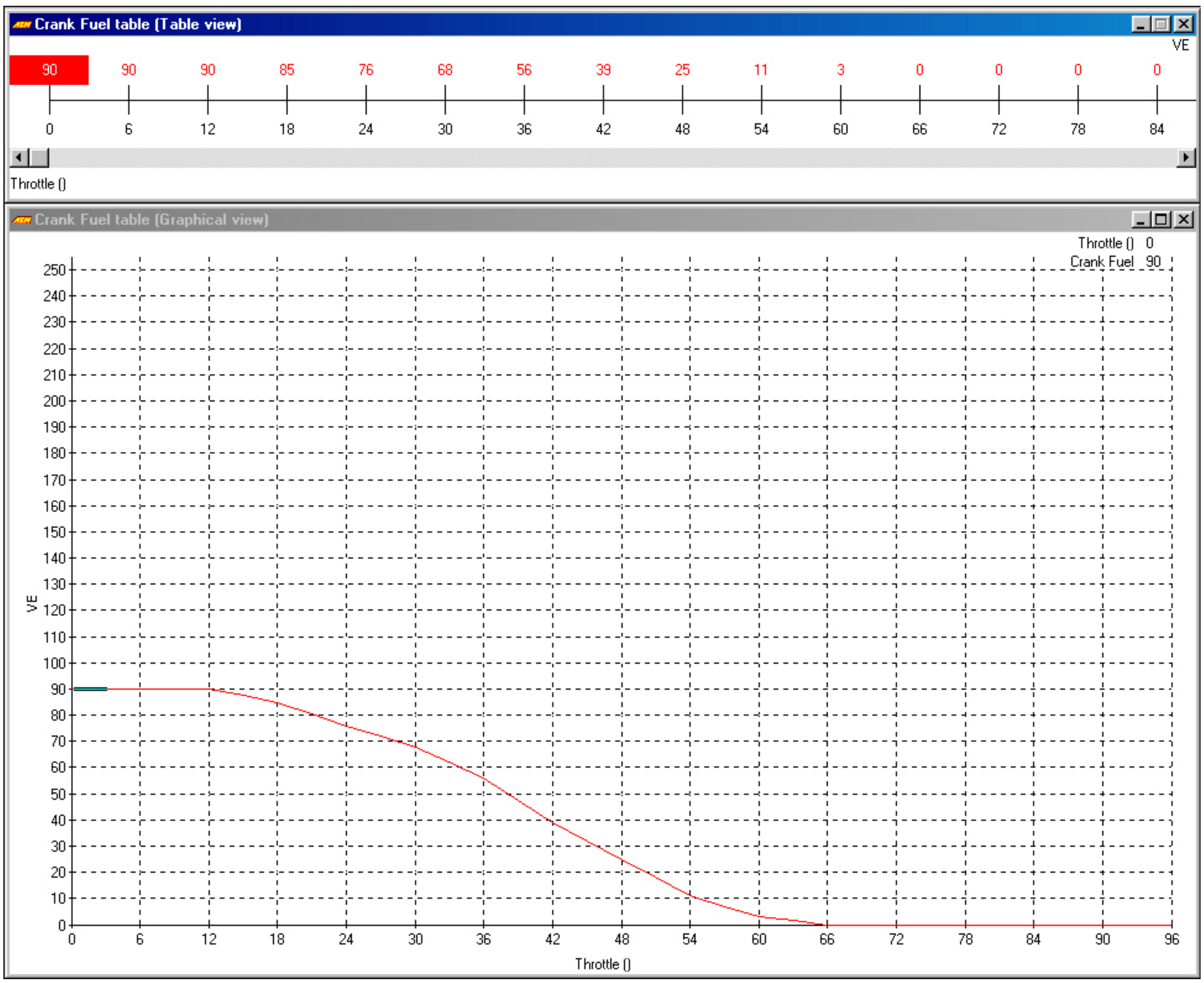
Modifying the Fuel Curve for Start Up

There is a brief period of run time during initial engine cranking when the engine requires additional fuel for a quick and smooth start up. When the engine is cold, the fuel requirement at start up will be higher than at normal operating temperatures. One reason for the extra fuel required during start up is that during the cranking cycle, fuel flow through the inlet port is low and the fuel injected into the valve area has a tendency to be deposited on the port wall and the valve head. Since fuel in droplet form causes a leaner mixture due to a lack of atomization, additional fuel is required.

The additional fuel required for both cold and warm start up is addressed in the "*start/warm up*" menu. There are four parameters that can be adjusted: "*Crank Fuel*", "*Crank Pulse*", "*Start Extra*" and "*Start Decay*". These parameters are discussed in detail below.

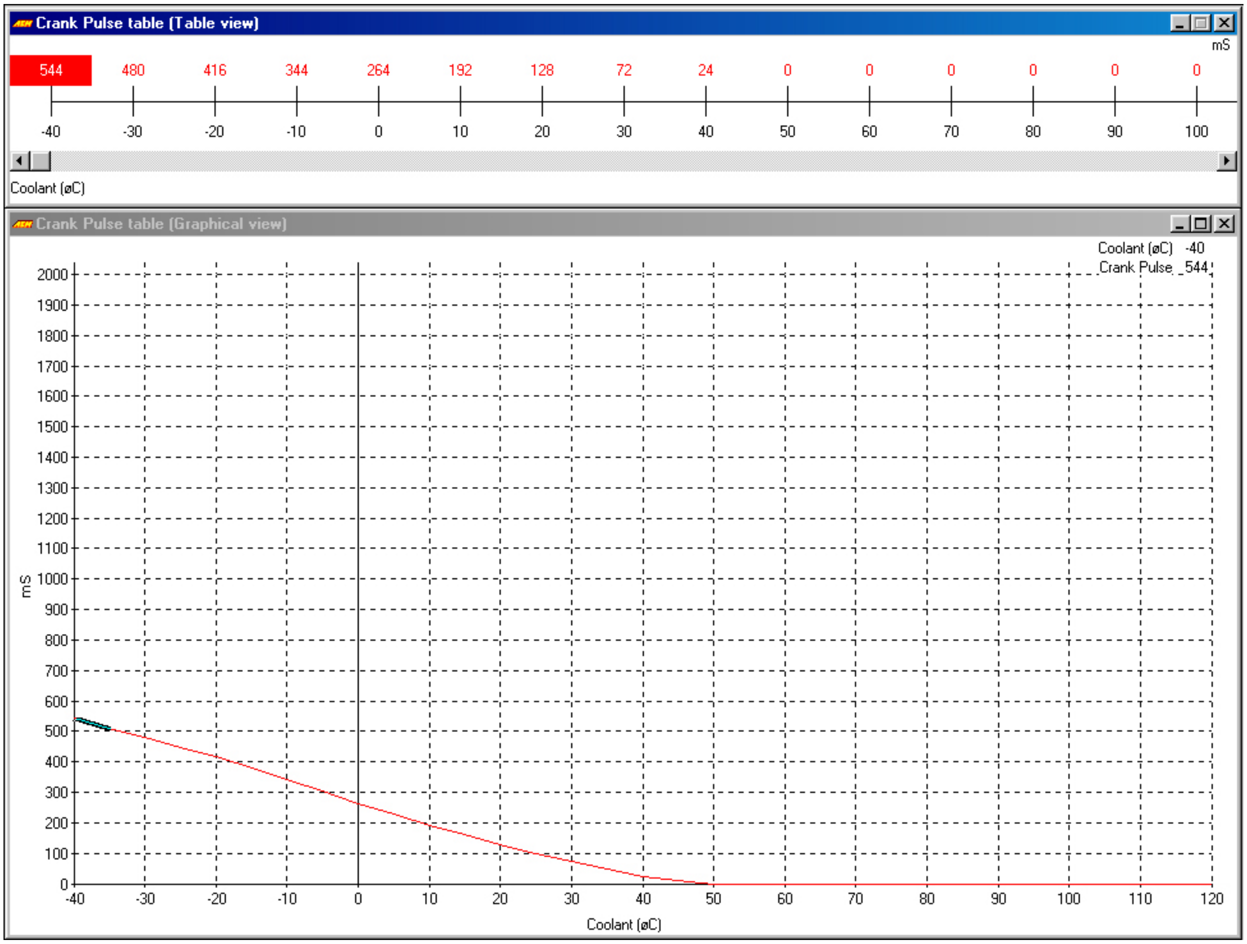
Crank Fuel

Crank Fuel is a fixed amount of fuel used during cranking that is injected into the engine. This is a throttle position vs. VE value that does NOT come from the main fuel map. Rather, it is an assigned raw fuel value used only during cranking. Once the engine exceeds the minimum cranking speed, the value jumps to the main fuel map.



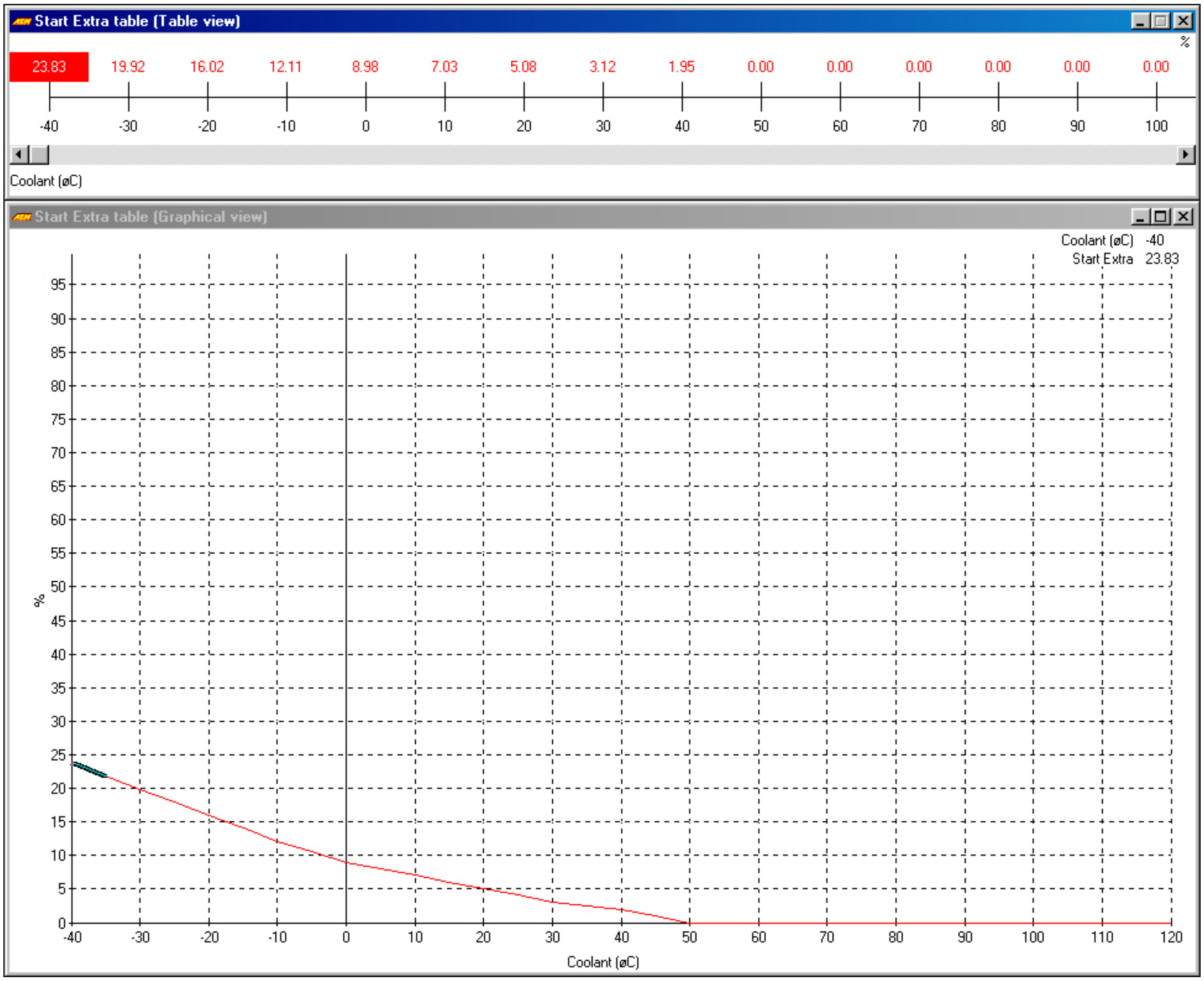
Crank Pulse

Crank Pulse is a small amount of fuel that is injected into the cylinder chambers by all of the injectors as the key is turned on. It is determined by a temperature dependent parameter vs. injection time, in microseconds. The crank pulse is essentially a small fuel prime that makes start up quicker. Usually there is very little fuel used in this parameter once the engine is up to operating temperature.



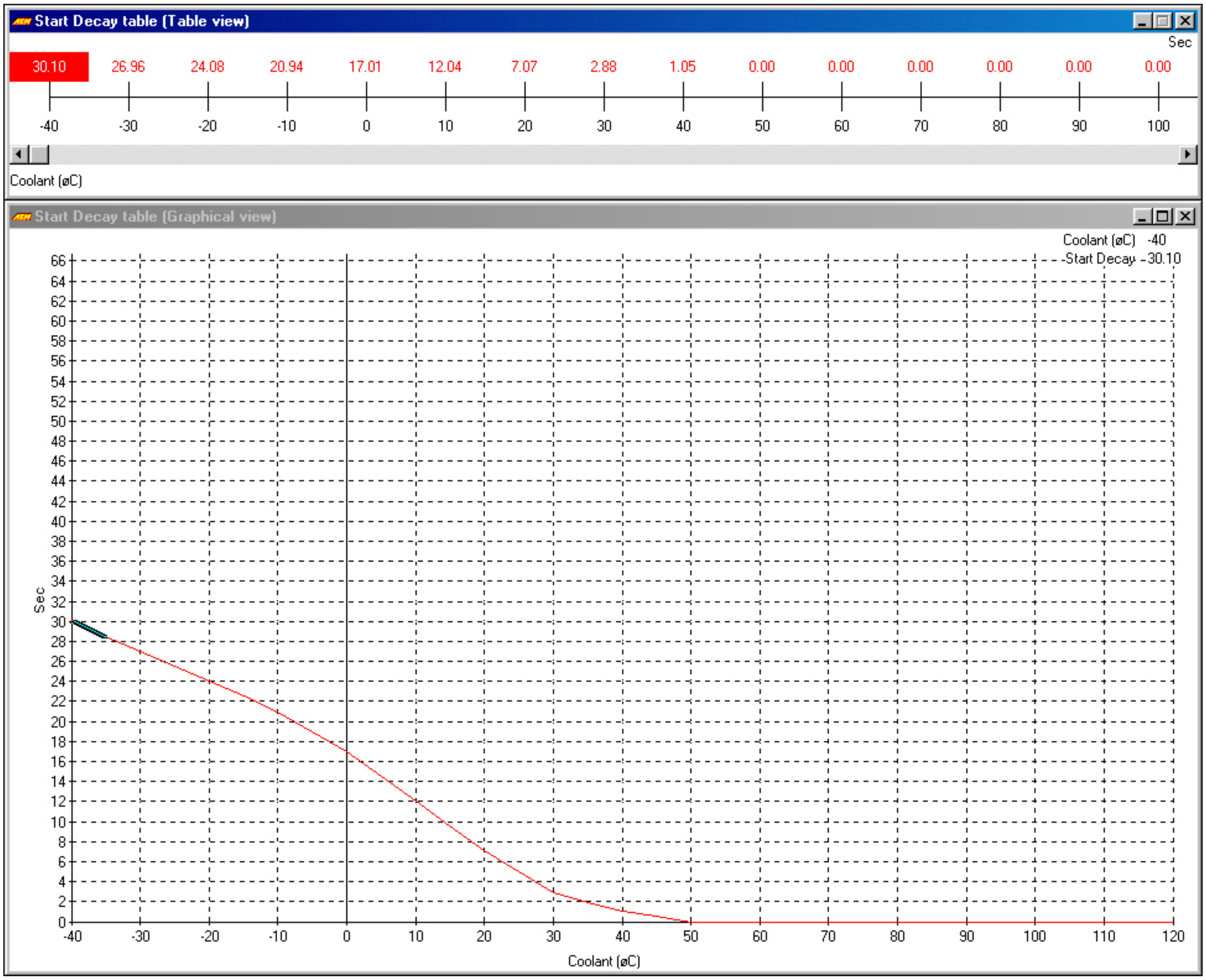
Start Extra

Start Extra is an additional amount of fuel that is delivered to the engine based on a percent vs. engine temperature value. Once the engine speed exceeds minimum cranking speed, a given amount of fuel determined by the Start Extra value is added for the amount of time programmed into the “Start Decay” parameter.



Start Decay

Start Decay is a time vs. temperature parameter that reduces the Start Extra fuel curve. After the Start Extra fuel cycle is initiated, the decay timer starts reducing the amount of start extra fuel delivered to the engine. The time required to shut off the "Start Extra" fuel delivery curve is dependent on engine temperature.



Modifiers to Fuel Curve for Engine and Air Temperature

When an engine is cold the following conditions occur:

- Increased quenching of the flame front on the cold combustion chamber walls
- Unfavorable mixture distribution due to high wall film deposits caused by the cold port walls and valve face
- Reduced fuel vaporization due to cold inlet air temperatures

These factors have to be counterbalanced by having a richer than normal mixture during the warm up phase of engine operation.

There are two parameters in the AEM PEMS software used to maintain smooth operation during the warm up phase: "*Warm Up*" and "*Air Comp Table".* Both of these parameters are temperature vs.

enrichment in percent modifiers. The engine temp. vs. enrichment parameter serves as a means of adding fuel for various operating temperatures.

One often-overlooked strategy of using engine temp vs. enrichment is to introduce additional fuel when the engine exceeds a high operating temperature. This will help cool the engine down and possibly prevent damage due to overheating. *The Air Comp Table* can also add OR subtract fuel from the calibration based on inlet air temp. When inlet air is very cold there is a possibility of poor vaporization, and it may be desirable to enrich the mixture even if the engine is at operating temperature. However, this is dependent on the amount of heat that is added to the air stream after the air inlet. *The Air Comp Table* is also used to lean the engine out if inlet air temp is very high since the reduced charge density from the high inlet temp requires less fuel to combust.

Acceleration/Deceleration Modifiers for Engine Fueling

When the throttle is rapidly opened or closed the demand for fuel increases or decreases. If at a low-throttle-angle, steady-state running condition the throttle is opened rapidly, manifold pressure increases. In this situation, the sudden demand for air (hence power) requires a temporary enrichment of the mixture to maintain a reasonable AFR. Because the rapid opening of the throttle is consistent with the need for high-power AFR during acceleration, it is equivalent to the value needed for full power.

The amount of enrichment required is largely dependent on the design of the inlet tract and placement of the injectors. Enrichment for systems where the injectors are placed far from the inlet valves will have to be higher than if the injectors are placed near the inlet valves. This is because when the injectors are far from the inlet valves, such as on throttle body systems, there is considerable manifold wall wetting.

At low manifold pressures (commonly high manifold vacuum), fuel tends to stay in the air stream in a vapor-like state and has relatively low wetting characteristics. The reason the wetting is lower at high vacuum is because the pressure in the inlet manifold is closer to the vapor pressure of the fuel, allowing the fuel to evaporate more readily (This is the same phenomenon that makes water boil at a lower temperature at higher altitudes than at sea level).

As the throttle opens, manifold pressure increases (vacuum decreases), which increases the pressure on the fuel vapor driving it to a more liquid state. This causes droplets of fuel to deposit on the manifold walls and come out of the air stream. When the air speed in the inlet manifold increases to a point where the liquid fuel on the manifold walls is reintroduced into the air stream, there is no need for additional fueling and acceleration fuel is shut off.

With most modern road cars the injectors are placed near the inlet valves so that manifold wall wetting is virtually eliminated. With the elimination of wetting comes the drastic reduction of acceleration fuel requirement. This configuration of fuel injector needs short duration and a small amount of fuel for acceleration enrichment.

The prime input for acceleration data for the ECU is the throttle position sensor (TPS). A secondary input for acceleration data is the MAP sensor. The TPS indicates the rate of change of the throttle plate to the ECU so that it can calculate the amount of fuel in both volume (additional pulse width) and time (duration of additional pulse width). Very rapid throttle movements usually require a short duration of a large amount of fuel, while slow throttle changes use minimal amounts of additional fuel over a longer period. On cars that employ forced induction, a MAP-based acceleration fuel scheme is recommended. This is usually done with heavy vehicles or vehicles that experience very high loads. The rate of MAP change and MAP value can be used to provide additional fuel if necessary. An example of this type of acceleration fueling is a turbocharged engine that is used to pull a heavy load. A small opening of the throttle will cause a significant boost increase if the turbocharger is small. The TPS, because of the small throttle angle increase, does not provide accurate airflow information to the ECU. If there is a MAP-based acceleration parameter in the calibration, then the additional air supplied by the turbo can be accommodated.

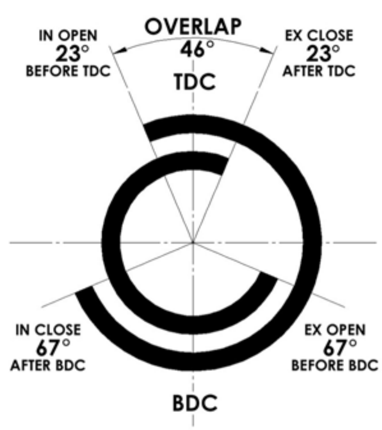
When the throttle is closed rapidly the need for fuel is reduced sharply. Just as the TPS and MAP sensors provide information on increasing TPS or MAP values, they also provide information on decreasing values. Under deceleration manifold pressure is very low (high vacuum). Any fuel that was on the manifold walls, port walls, or valve head is re-introduced into the air stream due to the rapid decrease in manifold pressure resulting in a temporarily rich mixture. The main fuel MAP values are usually very low when experiencing low manifold pressure, so minimal fuel is being injected into the engine. However, the mixture will still be rich due to the re vaporization of the wetted fuel.

The AEM PEMS can be programmed to turn off or nearly turn off the fuel injectors during periods of deceleration. This eliminates after burning in the exhaust manifold, and reduces hydrocarbon emissions. There is a range of RPM and manifold pressure that must be defined by the programmer to turn off the fuel. The RPM defined usually has a lower limit of idle speed plus 300 RPM. The manifold pressure is usually idle pressure minus 15 kpa. There is the possibility that a load value of idle – 15 kpa can be achieved during sustained running, but the throttle angle decrease must be sensed by the ECU to activate deceleration fuel cut. (Click here to see accel and decel fuel parameters set).

Fuel Injector Timing

The activation of the fuel injector should coincide with the flow of air into the cylinder. The advantages to injecting the fuel during this phase of the combustion cycle include a reduction in hydrocarbon (Hc) emissions, better atomization of the fuel, less fuel consumption, and higher power for the fuel consumed (lower BSFC). If the injector sprays fuel while the valve is closed, there is a higher incidence of fuel wetting the back of the inlet valve, which causes poor atomization, and higher Hc emissions.

In most automotive engines the **inlet** valve opens (IO) slightly before TDC (BTDC) and closes (IC) after BDC (ABDC). The **exhaust** valve opens (EO) before BDC (BBDC) and closes (EC) after TDC (ATDC). It is a good idea to have information on the valve train operation of your engine. If this information is not available, keep in mind that most engines have an IO in the range of 25-5 degrees and an IC of 40-60 degrees ABDC. The typical exhaust timing would be EC at 5-25 degrees ATDC and EO of 60-40 BBDC. For our discussion on injector timing we will use an inlet valve-opening event of 10 degrees BTDC and an exhaust closing event of 10 ATDC.



During the initial inlet valve opening, the exhaust valve remains slightly open while the exhaust cycle is completed. This valve sequence is referred to as “valve overlap.” During the overlap period the inlet valve remains at high pressure until the exhaust valve closes, creating a momentary backflow into the inlet port. Backflow is more prevalent under low manifold pressure (vacuum) conditions because of the significantly lower pressure in the manifold, compared to the positive pressure created by the end of the exhaust stroke. As throttle is opened, backflow decreases because the differential of pressure is reduced and the higher-velocity inlet air mitigates the backflow to a large extent.

Once the exhaust valve closes, airflow at the inlet port reverses direction and increases in velocity and flow as the inlet valve opens and the piston travels down the bore. It is at this point that fuel should be injected into the combustion chamber.

The AEM PEMS calculates the injector timing relative to the TDC SPARK EVENT, which is 180 degrees + timing prior to the TDC overlap event. Because of this relationship, you MUST ADD 180 to the desired injection firing time.

Lets use our example cam timing from above:

1. EC is at 10° ATDC, which leaves 170° of crank angle to BDC
2. Add 180° for the injector timing event relative to TDC SPARK to arrive at an injector timing number of 350°

In equation format this is:

- (180-EC) + 180 = injection timing.

From the example:

- (180-10)+180=350.

We must emphasize that there are many variables that influence backflow at the inlet valve. The method of calculating the injector firing event described here is an excellent starting point, but we recommend that performance testing is performed for optimal injector timing. The parameters to observe are: Hc count, power, and BSFC. Of course, the lowest Hc and BSFC with the highest power is the most desirable combination.

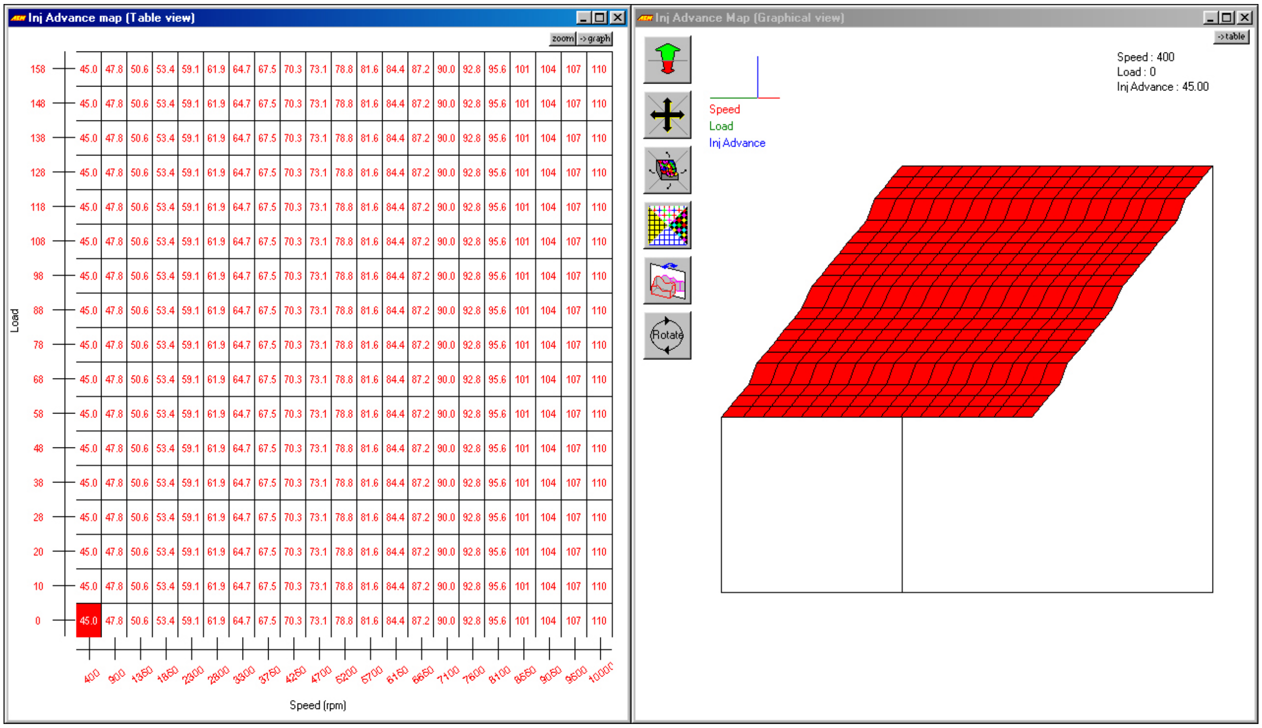
As engine speed increases, there is less time to inject the fuel into the engine. This is especially true for high throttle angles, because of the respective high injector duty cycles that accompanies full throttle operation.

High injector duty cycle referrers to the amount of time required to inject sufficient fuel into the engine relative to engine speed. Consider that at 6000 RPM an engine has 10 milliseconds (Ms) to complete a revolution (360° rotation) and 20 Ms to complete one cycle (2 complete revolutions). This means that the injector cannot be open more than 20 Ms at 6000 RPM. If the injector needs to be open 20 Ms to provide adequate fuel to the engine, then the duty cycle in this example would be 100%. This condition is known as having the injector go static, which means that it remains fully open with no closing time between injections. At this point there is no appreciable fuel control via the ECU, and the amount of fuel quantity delivered is controlled by the fuel pressure and static flow of the injector.

RPM	Revolutions/second	Ms/revolution	Ms/ CYCLE	RPM	Revolutions/second	Ms/revolution	Ms/ CYCLE
250	4.2	240.00	480.00	**7750**	129.2	7.74	15.48
500	8.3	120.00	240.00	**8000**	133.3	7.50	15.00
750	12.5	80.00	160.00	**8250**	137.5	7.27	14.55
1000	16.7	60.00	120.00	**8500**	141.7	7.06	14.12
1250	20.8	48.00	96.00	**8750**	145.8	6.86	13.71
1500	25.0	40.00	80.00	**9000**	150.0	6.67	13.33
1750	29.2	34.29	68.57	**9250**	154.2	6.49	12.97
2000	33.3	30.00	60.00	**9500**	158.3	6.32	12.63
2250	37.5	26.67	53.33	**9750**	162.5	6.15	12.31
2500	41.7	24.00	48.00	**10000**	166.7	6.00	12.00
2750	45.8	21.82	43.64	**10250**	170.8	5.85	11.71
3000	50.0	20.00	40.00	**10500**	175.0	5.71	11.43
3250	54.2	18.46	36.92	**10750**	179.2	5.58	11.16
3500	58.3	17.14	34.29	**11000**	183.3	5.45	10.91
3750	62.5	16.00	32.00	**11250**	187.5	5.33	10.67
4000	66.7	15.00	30.00	**11500**	191.7	5.22	10.43
4250	70.8	14.12	28.24	**11750**	195.8	5.11	10.21
4500	75.0	13.33	26.67	**12000**	200.0	5.00	10.00
4750	79.2	12.63	25.26	**12250**	204.2	4.90	9.80
5000	83.3	12.00	24.00	**12500**	208.3	4.80	9.60
5250	87.5	11.43	22.86	**12750**	212.5	4.71	9.41
5500	91.7	10.91	21.82	**13000**	216.7	4.62	9.23
5750	95.8	10.43	20.87	**13250**	220.8	4.53	9.06
6000	100.0	10.00	20.00	**13500**	225.0	4.44	8.89
6250	104.2	9.60	19.20	**13750**	229.2	4.36	8.73
6500	108.3	9.23	18.46	**14000**	233.3	4.29	8.57
6750	112.5	8.89	17.78	**14250**	237.5	4.21	8.42
7000	116.7	8.57	17.14	**14500**	241.7	4.14	8.28
7250	120.8	8.28	16.55	**14750**	245.8	4.07	8.14
7500	125.0	8.00	16.00	**15000**	250.0	4.00	8.00

Getting back to fuel injector timing and delivery, if the cam has 270° duration on the inlet lobe, then it takes 7.5 Ms for the valve to open and close at 6000 RPM. As we stated earlier, the time to inject fuel diminishes as engine speed increases. This means that we have to start the fuel injection event sooner as engine speed increases, and eventually there is not going to be enough time to fully inject the fuel into the combustion chamber. At this point the injector will begin to deposit fuel on the backside of the inlet valve, which will be consumed on the next cycle for the given cylinder. The air speed at this point is great enough that there is shearing action on the wetted surface of the valve seat/head, and with the high flow of air fuel atomization occurs.

On our example engine, with the throttle angle and engine speed low, we would start with an injector opening around 10° BTDC. Although this may seem like an early time to activate the injector when compared to the EC event, when you consider the distance to the valve head, the time it takes the injector to react to the ECU command and the time necessary for the ECU to output the opening signal, the exhaust valve is closed. As engine speed increases with larger throttle angles and higher flow rates, fuel injection timing must occur earlier. If injection timing is too late during high flow rates, the charge of fuel will travel through the open valves during the overlap event and be sent out the exhaust valves and wasted. This condition wastes fuel and contributes to hydrocarbon emissions. Elevated BSFC numbers indicates late injection timing.

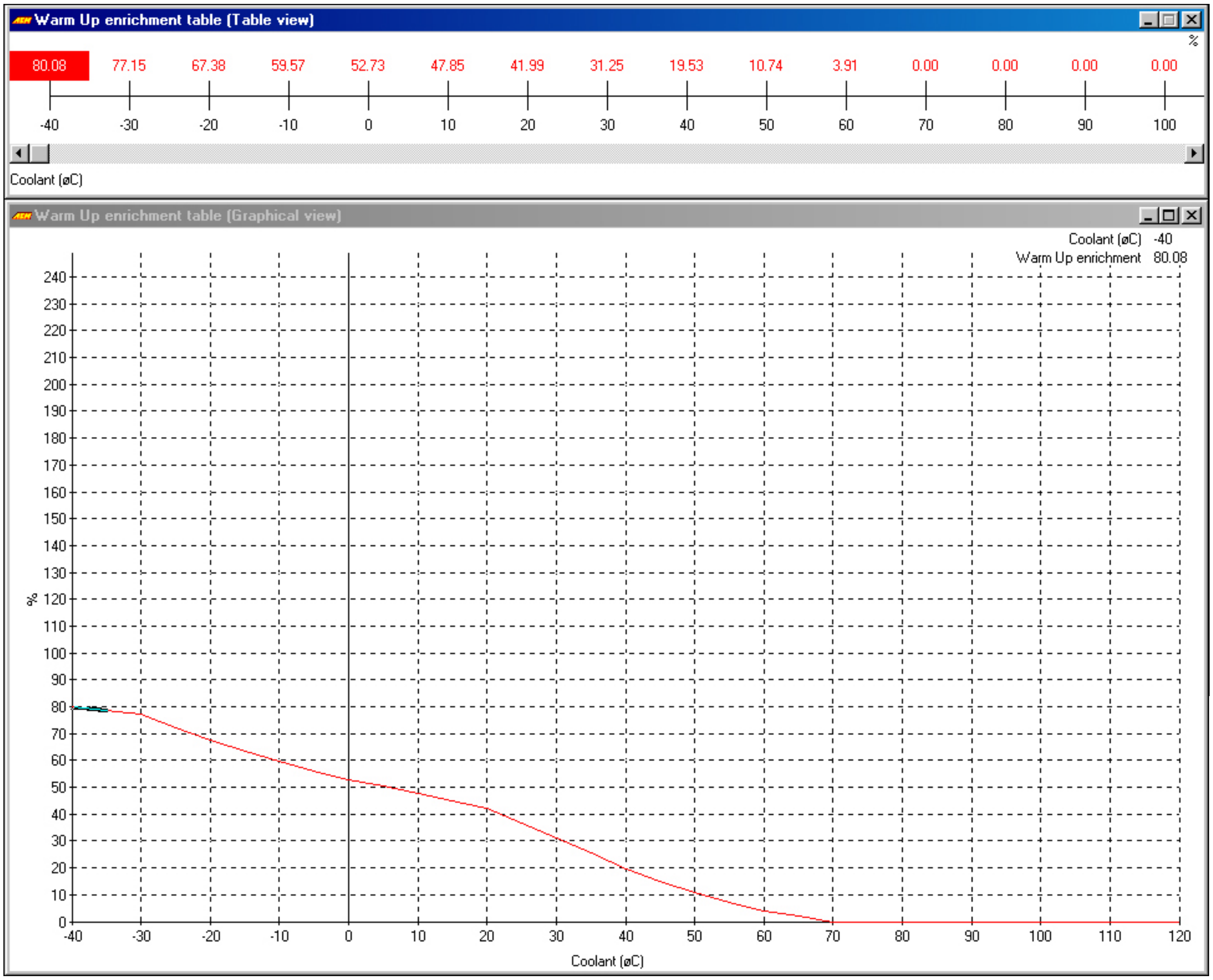


Load	400	900	1350	1850	2300	2800	3300	3750	4250	4700	5200	5700	6150	6650	7100	7600	8100	8550	9050	9500	10000
158	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
148	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
138	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
128	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
118	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
108	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
98	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
88	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
78	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
68	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
58	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
48	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
38	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
28	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
20	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
10	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110
0	45.0	47.8	50.6	53.4	59.1	61.9	64.7	67.5	70.3	73.1	78.8	81.6	84.4	87.2	90.0	92.8	95.6	101	104	107	110

Main Fuel Map

The main fuel map is a 3D map that is RPM and Load (or TPS) based for the amount of fuel that is to be injected into the engine. This map is the basis for all of the fuel delivery to the engine. All modifiers to the fuel requirement of the engine are applied to the cell value that the ECU determines at a given time of engine operation.

As an example, if the engine is at 3000 RPM at 50 Kpa manifold pressure, and the injection pulse width is at 4.6Ms on a warmed up engine at a steady state, then no modifiers would be in use.



If we had a fuel modifier of 50% due to engine temperature, the pulse width (not the cell value) would be 4.6Ms + 50% additional fuel for a total of 6.9Ms of fuel pulse width.

The main fuel map can be viewed as a 3D graph and as a table of values. The table can be displayed in duty cycle, pulse width, or raw numbers. The manipulation of data in the fuel map is very easy. To modify the main fuel map, simply highlight the area that needs to be manipulated and then right click for a drop down menu of data manipulation choices. Then, choose the appropriate choice for the task that needs to be accomplished. Because the AEM PEMS is a Windows® based system, you can even copy values of different maps and paste them onto other programs.

Boost Compensation

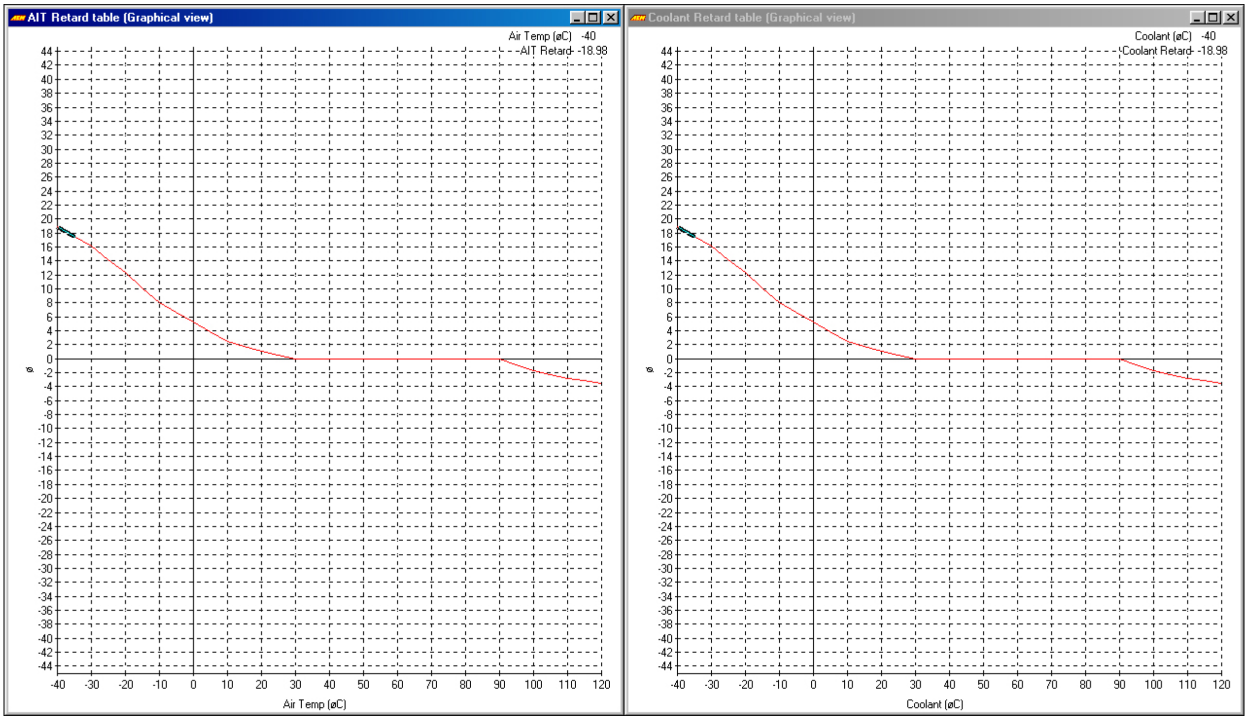
Engine Ignition Timing Requirements

Once the fuel/air charge has made its way into the combustion chamber, it must be ignited accurately for complete combustion. A vehicle's ignition timing should be optimized to produce maximum torque without the chance of abnormal combustion, such as knocking, for all operational conditions. Operational conditions include warm up, acceleration/deceleration, steady state, and full load.

When setting up the ignition map, the compression ratio, fuel type, vehicle type and vehicle weight must be considered. If you are unfamiliar with setting up the ignition map, please refer to the discussion on these factors and their implications on ignition timing in the previous section.

Ignition Timing Temperature Compensations

The AEM PEMS includes two-dimensional timing vs. engine coolant temperature and timing vs. inlet air temperature maps. This allows the tuner to make ignition-timing corrections based upon engine or inlet air temperature. The ignition modifier is simply a map that adds or subtracts timing based on engine coolant or inlet air temperature.



Engine Coolant Temperature vs. Timing Map

This modifier is useful for making warm up easier on racecars not equipped with idle speed controls. The addition of timing when the engine is cold helps stabilize idle speed during warm up and heat the combustion chamber to get the coolant temp up to operating level quickly. The only caution that should be heeded when using this type of set up is not to use full power until the engine is fully warmed up, especially engines that utilize forced induction or nitrous oxide.

On cars that have to meet emission standards, the opposite scheme can be used to light off the catalytic converter(s) quickly. Retarded ignition timing has late burning characteristics and provides more heat to the exhaust stream. This can be used to light off the cat(s) when the engine is cold.

Inlet Air Compensation

This ignition modifier is used to change the ignition timing based on inlet air temperature readings. It is especially useful on forced induction engines where inlet air temperatures can rise dramatically in a short period of time. Since elevated inlet air temperatures contribute to autoignition, when inlet air temperatures reach high levels, ignition timing can be retarded to avoid pinging or knocking. For severe cold weather, the IAT ignition compensation can also aid in warming up cars with no idle speed control.

Idle Speed Stabilization

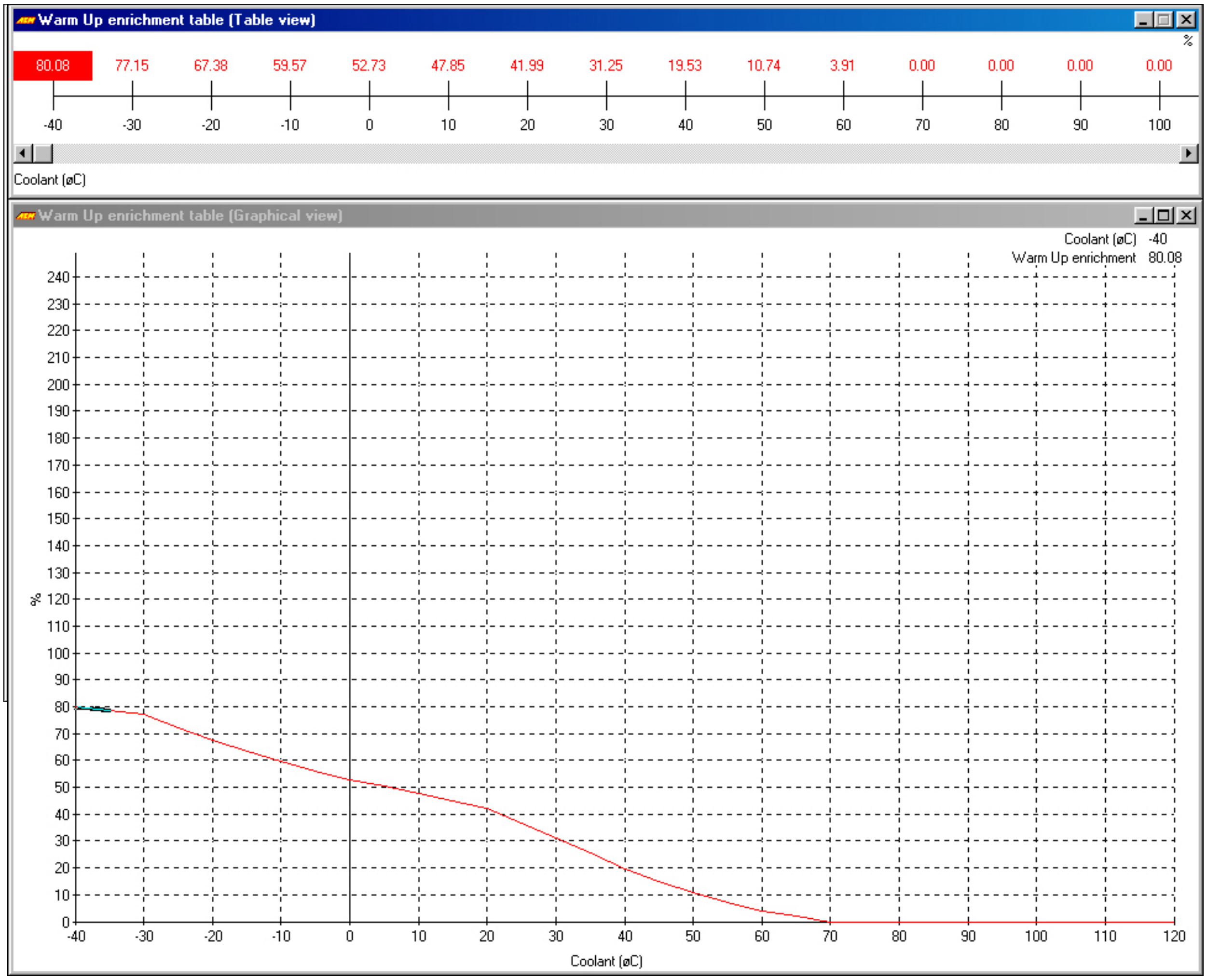
The idle speed stabilization modifier can stabilize idle speed by advancing or retarding the timing slightly while idling. The map adds timing when idle speed is too low and subtracts timing when idle sped is too high. Idle speed will respond differently depending on the engine, inlet manifold, and cam timing. We recommend experimenting with this timing modifier to obtain best results.

Ignition Acceleration

The AEM PEMS includes a function called ignition acceleration, in which ignition timing can be used to enhance light throttle drive off. This function includes a 2D map for ignition advance vs. time in seconds and a TPS setting that can be enabled for initial drive off or left on all of the time. The 2D map constrains timing to a maximum of 10° timing increase for a maximum of 5 seconds. The value can be added at drive off (tip in of the throttle) by selecting the TPS voltage range to activate the ignition advance, or by selecting "continuous" ignition accel. If either of these functions are enabled, timing will be altered every time the TPS's rate of change value is met or exceeded (The rate of change is a volts/second of travel selected by the tuner). The higher the voltage number, the LESS sensitive the TPS will be for this function.

Main Ignition MAP

The main ignition map is a 3D map that is RPM and Load based for the ignition value. **This map is the basis for all of the ignition timing of the engine.** All modifiers to ignition timing are applied to the cell value that main ignition map determines for the engine at a given time. For example, if the engine is at 3000 RPM at 50 Kpa manifold pressure, the ignition timing for that cell is at 36° BTDC if there were no modifications being done to the timing curve at that point.



If we had a timing modification of +5° advance due to engine temperature, the timing value (not the cell value) would be 36° + 5° additional timing for a total of 41° of timing.

At low manifold pressure the flame front is slower due to the low density of mixture in the combustion chamber. Because peak manifold pressure is optimal at 15-20 degrees ATDC and the burn rate is slower at very low manifold pressure, the ignition point must be started earlier. The main ignition map typically has high ignition timing values during times of low manifold pressure and high RPM, which gradually decreases at load increases.

As the throttle is opened, the density of the mixture increases and the flame propagation increases in speed. The timing must be reduced as load and RPM increase to keep the peak pressure at approximately the same point and reduce the chances of knocking.

With forced induction engines, the burn rate increases as charge density is increased. In this example, timing must be reduced because of the faster burn rate, and to further reduce the chances of knocking. On forced induction engines, the inlet charge temperature is elevated because of the heat generated by compressing the air. Utilizing an intercooler or after-cooling system usually helps reduce the inlet charge temperature. But in many cases this still will not bring the inlet charge down to ambient temperature, making the engine more susceptible to knocking.

Remove the spark plugs each time the timing is increased to a higher value and check for signs of detonation. The spark plug is the best indicator of what is happening in the engine because it is such an integral part of the combustion chamber. If you see small flecks of black deposits, or very small shiny beads on the porcelain of the plug, there is a good chance that the engine is knocking. Retard the timing to eliminate the knocking, enrich the mixture, or use a higher octane of fuel.

The combustion chamber plays an important role in the amount of ignition timing that can be used for the various operational phases of an engine. The most common type of combustion chamber design used in contemporary engines is a four-valve/cylinder, pent roof chamber. There are many other types of combustion chambers, such as a wedge, hemispherical, and canted valve, to name a few. Ideally, it is best to initiate flame propagation at the geometric center of the chamber. However, this is typically impossible to do because the spark plug is usually located at the top or edge of the combustion chamber. The reason it is desirable to have the flame front start at the geometric center of the combustion chamber is because there is less chance of autoignition of the mixture.

A pent roof combustion chamber places the spark plug near the center of the combustion chamber. Wedge combustion chambers are the most sensitive to spark knock because of the distance the flame front must travel within the bore prior to the power stroke.

When ignition occurs, a flame kernel starts at the spark plug electrode and expands across the combustion chamber. As the front progresses across the chamber, the hot expanding gas compresses and heats the end gasses and mixture at the opposite end of the chamber. If the pressure, and consequently temperature, inside the chamber increases beyond the flash point of the end gas, autoignition occurs. Because the pent roof type of chamber has a spark plug that is nearer to the geometric center of the chamber, the flame travels more evenly across the combustion chamber, leaving very little end gas that can be compressed or ignited by the advancing flame front. Thanks to the short distance the flame front has to travel in pent roof type chambers, ignition timing usually does not have to be as advanced as much as a wedge type chamber, to achieve maximum torque. We find that there is usually about five to eight degrees less timing required for pent roof combustion chambers than for wedge types.

Charge motion, which is comprised of intake swirl and squish; increase combustion speed when compared to a standard combustion chamber. The combination of these factors increases the mean effective pressure (MEP), lowers fuel consumption, and delivers smaller cycle-to-cycle variations at full throttle operation.

In addition to the performance benefit of effective charge motion, the resulting factors reduce Hc emissions, with a slightly increased NOx component. At partial load the benefits of charge motion vs. a standard combustion chamber are similar, but due to the decrease in density of the intake charge, not very.

The combination of swirl and squish is greater than either squish or swirl alone. Swirl improves mixture preparation and is mostly responsible for reducing ignition delay and cycle-to-cycle variations. Swirl is accomplished through the inlet port design or by using shrouded valves in the combustion chamber. As engine speed increases, the swirl motion increases along with it. Cycle-to-cycle variations decrease with increasing swirl action.

Squish is accomplished via a small gap between the head deck and the piston top. The decrease of this gap drives the inlet charge toward the spark plug electrode. An additional benefit of having this small gap is the reduction of end gas volume at the extreme edges of the cylinder. This reduces the tendency for spark knock and leads to a reduction of Hc emissions.

Cycle-to-cycle variation refers to a situation where an engine operates on the threshold of knocking or detonation throughout the engine cycles and is based on the average peak pressure of all of the cycles. The cycles with lower peak pressures may not be prone to detonation, while those with higher peak pressures may detonate with increasing intensity as peak pressure increases. Increasing this cyclic variation will increase the number of cycles that detonate, and decreasing the number leads to less cycles that detonate.

Ignition Delay is the point at which perceptible inflammation of the mixture and a pressure rise in the combustion chamber occurs. The time between when spark occurs at the spark plug and when inflammation of the mixture occurs is the delay time. This delay is caused by the chemical reactions that take place when the rate of reaction after the delay accelerates to an extent that noticeable combustion and a rise in cylinder pressure and temperature occurs. The chemical reaction within and on the surface of the initial flame kernel causes energy to be released during the ignition delay period. When the flame front is at this initial stage of propagation there are energy losses via conduction, radiation, and convection of heat. If too much of this energy is lost, the mixture will fail to propagate and a misfire will result.

As compression ratio increases the requirement for charge motion in the chamber is reduced. Engines that have high compression ratios generally require reduced ignition timing requirements due to the increased flame speed. The design of the combustion chamber in a high compression engine is necessarily small. The compactness of the chamber imparts its own charge motion and squish into the mixture.

We have included some sample ignition timing maps for gasoline engines that are typical for use on a street car. These examples include a naturally aspirated engine, forced-induction engine, and a high-compression engine. **These are conservative samples that should be used as a starting point only.** The tuner of the engine must use good judgment when selecting the appropriate timing map for the engine.

Typical Ignition Timing Figures for Initial Setup

Naturally Aspirated Piston Engines W/ Pent roof Combustion Chamber

Ignition Timing

LOAD IN KPA									
L	**100**	15	22	32	33	33	33	33	33
O	**90**	15	22	33	34	34	34	34	34
A	**80**	15	22	33	35	35	35	35	35
D	**70**	15	23	35	35	35	35	36	36
	60	15	24	35	35	36	36	37	37
I	**50**	15	24	35	35	36	36	37	37
N	**40**	15	24	37	37	38	39	40	40
	30	15	24	37	37	38	39	40	40
K	**20**	15	25	40	45	45	45	45	45
P	**10**	15	25	40	45	45	45	45	45
A		**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**

RPM

Turbocharged Piston Engines W/ Pent roof Combustion Chamber

Ignition Timing

LOAD IN KPA									
L	**300**	11	14	23	23	24	24	24	24
O	**275**	11	15	24	24	25	25	25	25
A	**250**	11	15	24	24	26	26	26	26
D	**225**	11	16	24	26	27	27	27	27
	200	12	17	26	27	27	27	27	27
	175	12	19	28	29	29	29	29	29
I	**150**	12	20	29	30	30	30	30	30
N	**125**	12	20	30	30	31	31	31	31
	100	15	22	32	33	33	33	33	33
K	**75**	15	23	35	35	35	35	36	36
P	**50**	15	24	35	35	36	36	37	37
A	**25**	15	25	40	45	45	45	45	45
		1000	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**

RPM

Naturally Aspirated Piston Engines W/Wedge Combustion Chamber

		Ignition Timing							
L	**100**	15	22	32	35	35	35	35	35
O	**90**	15	22	33	35	35	35	35	35
A	**80**	15	22	34	35	35	35	35	35
D	**70**	15	23	34	35	36	36	37	37
	60	15	24	35	35	36	36	37	37
I	**50**	15	24	35	35	36	36	37	37
N	**40**	15	24	37	37	38	39	40	40
	30	15	24	37	39	39	39	40	40
K	**20**	15	25	40	47	47	47	47	47
P	**10**	15	25	40	47	47	47	47	47
A		**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**
					RPM				

Turbocharged Piston Engines W/Wedge Combustion Chamber

		Ignition Timing							
L	**300**	11	14	23	23	24	24	24	24
O	**275**	11	15	24	24	25	25	25	25
A	**250**	11	15	24	24	26	26	26	26
D	**225**	11	16	24	26	27	27	27	27
	200	12	17	26	27	27	27	27	27
	175	12	19	29	30	30	30	30	30
I	**150**	12	20	30	31	31	31	31	31
N	**125**	12	20	32	32	33	33	33	33
	100	15	22	34	35	35	35	35	35
K	**75**	15	23	34	35	36	36	37	37
P	**50**	15	25	40	47	47	47	47	47
A	**25**	15	25	40	47	47	47	47	47
		1000	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**
					RPM				

Effect of Mixture (λ) on Ignition Timing

Generally speaking, air/fuel mixtures that are lower than stoichiometric (λ<1) require less ignition timing due to their higher burning speed and, consequently, shorter ignition delay time. The converse is true of leaner mixtures.

Engine Mechanical Limitations and use of the RPM Limiter

The AEM PEMS has an engine speed limiter that can be used to limit engine speed or as a “two step” limiter. This function limits engine speed based on the RPM selected by the tuner.

Depending on the preferences of the engine tuner or builder, there are several ways to limit engine speed. These include fuel cut, ignition cut, or fuel and ignition cut. With this function, a two-step limiting strategy can be used for drag racing applications. This set up uses a clutch-activated switch to detect when the clutch pedal is depressed and limits the engine to a secondary RPM that is defined by the user. At the starting line, the engine is held to that RPM until the clutch is released. Upon release of the clutch, the primary RPM setting is used for the RPM limit function.

The engine speed limiter ONLY works under acceleration. The limiter electronically keeps the engine from over revving. The AEM PEMS, or any other PEMS for that matter, will not protect the engine on a missed downshift. If while driving the operator of the vehicle accidentally shifts from 5th to 2nd gear, the mechanical link between the engine and the drive wheels will over speed the engine. The ECU can do nothing about limiting the engine during periods of engine over speed coupled with a deceleration condition.

Boost Control

On turbocharged engines, a means of controlling the boost into the engine is absolutely necessary. The AEM PEMS has a sophisticated, yet easy to use, boost control function. It utilizes a Delco boost control solenoid to control the waste gate on the engine. The engine's boost levels can be controlled at all operational phases of the engine.

Idle Speed Control

On street cars, consistent idle speed control is necessary to maintain smooth idle characteristics. This is accomplished by using an idle speed control device that is usually a stepper motor or duty-cycled solenoid. In either case, the job of the idle speed control is to bypass air around the throttle body directly into the inlet manifold to maintain idle speed. This does NOT mean that the engine receives all of its idle air from the idle speed device. The idle speed control is meant only to provide supplemental air during periods of higher load while at idle, such as when the air conditioning is used.

Setting engine idle speed is accomplished by programming the fuel mixture and ignition timing to obtain the leanest, smoothest idle characteristics with NO idle controls activated. The idle controls can either be controlled with ignition timing or driven by an idle speed control device. The only incoming air used to sustain idle must come through the throttle body for this step. The throttle body set screw, or an air bypass screw controls this.

Once smooth idle is achieved, reset the TPS. Activate the ignition idle speed control via the options menu. Turn on the headlights and check the idle speed. Adjust the ignition timing idle speed to compensate for any RPM fluctuation that occurs with the headlights on. The reason we set the idle speed with the headlights on is because the load at idle with them on is minimal, and timing correction usually does the job of keeping the idle speed consistent.

Next, activate the idle speed device. Turn on the air conditioner, and if the car has an automatic transmission, put it in gear **(BE SURE TO SET THE PARKING BRAKE BEFORE YOU PUT THE CAR IN GEAR)!** Adjust the idle speed device to compensate for any fluctuations in idle speed.

Appendix 1
AEM Fuel Injection features

Outputs
- 10 Injector outputs
- 5 Ignition outputs
- 1 Fuel pump outputs
- 4 +12v user defined drivers (VTEC, EGR, etc) outputs
- 2 O2 heater ground controls
- 2 Temperature controlled outputs (radiator fan)
- 6 user defined (-) switched outputs (NOS, a/c, purge, etc..)
- 1 Check Engine / Shift light
- 1 Tachometer output
- 2 PWM outputs (may also be run as switched outputs) boost control, IAC motor, staged nitrous, etc)
- 2 Stepper motor drives (may also drive 4 wire antagonistic pair outputs)

Inputs
- 2 Knock channels with control
- 2 O2 channels with control
- 4 Thermo Couple inputs
- 6 Gear position inputs
- 5 Speed sensor inputs
- 1 Spare temperature input
- Throttle Position
- Manifold Pressure / Mass air input
- Barometric pressure sensor
- 2 Spare 0-5v input (pressure sensor, or position sensor)
- Coolant Sensor
- Air inlet Temperature
- Battery voltage sensing
- Clutch or neutral input (may be used for 2-step rev control)
- Crank position (timed)
- Cam position (timed)
- Extra TDC or air flow (Vortex) input
- Speed sensor input (for gear selection, traction control, etc)
- All ECU inputs are filtered for RFI & EMI protection

Memory
- 512 Megabyte internal logging memory
- Flash ROM
- Fault logging

Communication
- RS-232 pc com link