Hints and Tips:

Stoich – Short for Stoichiometric – a 14.7:1 Air/fuel ratio (AFR) – the desired ratio for normal driving. When measured as AFR it is about 14.7:1 – when measured as Lambda it is 1.0 or “Lambda = 1”. Lambda is another way of expressing the air fuel ratio – Lambda is **Actual AFR / 14.7**. So an AFR of 12.8:1 would be expressed as Lambda “.87”. It doesn’t matter which you use – just as long as you use the same one in all settings and don’t get them confused as you go back and forth between the scanner and the tuner software. I prefer AFR.

*HPTuners likes to display everything in EQ Ratio (Equivalence Ratio) – which is yet another way to reflect the AFR – EQ is the opposite of Lambda as far as the formula goes: **EQ = 14.7/Actual AFR.** So an AFR of 12.8:1 would be expressed as EQ “1.148”. Some people like this because richer mixtures are HIGHER numbers and leaner mixtures are lower numbers – the exact opposite of Lambda. Some think it is just more intuitive this way.*

MAP – Manifold Absolute Pressure – a small sensor near the intake section of your engine measures the pressure inside the manifold. It is very much like a simple barometer. If you open one of the many tables in your tuner software that measures MAP, you will see readings ranging from about .15 to 1.25. It is measured in BAR which is the metric equivalent of the US measurement “inches of mercury”. Basically at sea level on a standard day it would measure exactly 1 bar (1.00). Since we are at 2200 feet MSL here in Vegas, it will never read more than about .91 bar. When you start your engine and let it idle the throttle body is closed and the engine is pulling air in against that restricted throttle body so a vacuum is created. At idle your engine will likely read around .30. As you increase the throttle it will read higher and higher until wide open throttle which will read the same as outside air pressure – about .91 bar. The only way to get an engine to read higher than 1.00 bar is with forced induction (superchargers and turbos). When you see references to a 2 bar or 3 bar custom OS this means the computer has been modified to allow readings higher than 1.00 bar. Your E38 computer can read up to 3 Bar without any mods. MAP is one of the most common axes we use when tuning since it is a direct relation to the throttle and workload of the engine.

MAF – Mass Airflow Sensor – a VERY accurate sensor for measuring the amount of air being drawn into the intake. Basically it is a heated wire. As air flows across that wire it cools the wire. The ECM will try to keep that wire at a set temperature so it will apply more or less voltage to that wire to keep the temperature steady. The more air flowing, the more the wire is cooled down and the more voltage the ECM has to apply to keep it heated. That voltage is converted to a frequency somewhere between 0Hz and 15000Hz. The higher the frequency, the more air is flowing. That frequency is then used to look up the amount of air actually flowing. It is measured as Grams per Second or sometimes as Grams per Cylinder. The MAF sensors in today’s cars are VERY accurate.
E38 Gen IV Corvette – EFI Tuning Class

**IAT Sensor – Intake Air Temperature** – a sensor located very near or in some cases as part of the MAF sensor. It measures the temperature of the air entering the intake. Various tables can then be used to adjust things like timing, mixture, etc. based on the temperature of the air.

**PE = Power Enrichment** – At full throttle best horsepower is obtained by enriching the mixture to about 12.8:1 AFR. There is a PE table in the ECM that sets this. Stock tunes have the table set to about 1.26 at all RPMs – the 1.26 you see in the HP Tuners PE table is EQ Ratio. (Remember, take a standard 14.7:1 AFR and divide by 1.26 to obtain a desired AFR of 11.66:1 - too rich for my taste but the factory likes it that way). If you look at one of Gil’s tunes he will have reset that table to somewhere around 1.13. (14.7/1.13 = 13.00) – but that may vary depending on what he did with your MAF sensor.

**STFT = Short term fuel trims** – oxygen sensors in your exhaust system (before the cats) measure AFR and send a voltage to the ECM. These are part of the CLOSED LOOP system. A voltage of less than .45V (450 mV) means the mixture is lean (greater than 14:7:1 AFR), and a voltage higher than 450mV means the mixture is rich. The ECM uses these voltages to tell the short term fuel trims to either add or subtract fuel as needed to achieve stoich. If you are monitoring the STFT PIDs during a scan and they are constantly reading negative numbers, it means the VE table and or MAF sensor is adjusted too rich and the trims are having to subtract fuel to bring the mixture back to stoich. If the STFTs are reading positive numbers all the time, it means the MAF or VE table is adjusted too lean and the trims are having to ADD fuel to reach stoich.

**LTFT = Long term fuel trims** – Also part of the CLOSED LOOP system. If STFTs are consistently far from 0 for a long period of time (example – they are averaging -7.5 at most throttle settings) the LTFTs will jump to -7.5 and store that value as a new “base” for the STFTs. The STFTs then will track closer to 0.

When you first buy your car the LTFTs are 0. Over time they “learn” what the STFTs are doing and make adjustments to help the STFTs not have to work so hard. Both STFTs and LTFTs are DISABLED during wide open throttle. Only the Power Enrichment table is used during WOT runs.

**WB or WB02 = Wide Band Oxygen Sensor.** You can’t really do any serious tuning without one. I have an older Innovate LM-1. You can get good ones on eBay for between $75 and $200. Most come with an adapter to stick in the exhaust pipe as well as a removable sensor that can be screwed into the bung in your headers. When using the exhaust adapter you can ONLY do full throttle tuning. Part throttle does read correctly on a WBO2 display because too much air is sucked into the end of the tail pipes making the readings extremely lean. For serious tuning you must screw the sensor into the bung in the headers and route the cable up through the hood and into the car.

**PID** – Stands for Proportional, Integral, Derivative. Basically it is a “sensor” in your car. Your car has hundreds of PIDs that can be monitored. MAP sensors, MAF sensors, RPM, Speed, Gear, throttle positions, temperatures of oil, air, water, etc. All these are PIDs and can be monitored in the scanner. When you go out to do a “scanning session” you choose the PIDS you want to monitor before you...
begin the scan. Your ECM can stream a maximum of about 24 PIDS at once – so don’t just select a ton of them and expect to get good readings while scanning – you will bring your ECM to a crawl as it tries to dump all that live data to your computer.

**Open Loop** – This is analogous to the old carburetor days. Your car runs in open loop mode when you first start it in the morning (for about 60 seconds) and when you put your foot to the floor (WOT). All other times it runs in closed loop mode. Open loop is basically a series of tables that have preset injector and VE settings. While running in open loop mode let’s say you press the throttle down half way. The ECM first measures the MAP (manifold absolute pressure) and looks in a table for the amount of air to be expected at that RPM and the amount of fuel to inject for that throttle setting. They are fixed settings in that table, there is no feedback loop of any kind. It may not be exact, but the car will run. The VE tuning you hear about is an open loop tune – no STFTs or LTFTs are used at all in open loop.

**Closed loop** – this is where your car spends most of its time. When you start the car in the morning you are in open loop mode for a minute. The system immediately begins “heating” the O2 sensors in the exhaust. Once the O2 sensors are “heated and ready” and the engine has reached a certain operating temperature, the system goes into “closed loop mode”. This means there is constant feedback happening. You push the throttle, the MAF sensor and VE table are referenced to approximate the amount of air and fuel to mix – the injectors fire - and the combustion happens. A split second later the O2 sensors in your exhaust read the result and send a signal back to the ECM telling it whether it was rich or lean. From there the LTFTs and STFTs adjust the fuel injectors until the O2 sensors are reading a perfect stoich 14.7:1 AFR. This constant feedback loop is happening all the time when you are doing normal driving.
Maps and Histograms—EFILive calls them Maps – HPtuners calls them histograms. These can be created to view a specific parameter across a wide range of throttle settings. For instance we can create a histogram that plots actual AFR (as read by your WBO2 meter) across multiple RPMS and multiple throttle settings. Here is a histogram of AFR plotted against MAP (columns) and RPM (rows).

Putting it all together

Let’s walk through a typical few minutes of your engine’s life. What is happening is actually quite simple once you understand the pieces and parts. The main thing to remember during all of this is that EVERYTHING STARTS WITH THE MEASUREMENT or ESTIMATE OF AIR in the manifold. The computer spends its life dealing with nothing more than AIR, FUEL and SPARK in that order – that is all it does. It looks at the air, adds the proper amount of fuel by firing the injectors and then lights it off with the spark. Over and over and over…. 

You jump in the car and start the engine. A series of fixed tables are used for the CRANKING part of the startup – these tables are typically richer than 14.7:1 depending on the temperature (the colder – the richer). Basically the tables have a fixed estimate of the amount of air being sucked into the cylinders during cranking and the ECM fires the injectors the right amount to achieve startup. Some other tables then set the idle slightly higher than usual for a few moments to make sure the engine stays running as things warm up. You are in OPEN LOOP mode during this stage.

As the seconds tick by the ECM is warming up the oxygen sensors in the exhaust – these O2 sensors have “heaters” built into them to help them get up to temp more quickly. There are some tables you
may see in your tuning software that deal with “delay until closed loop can be enabled”. These tables ensure the heaters get the sensors up to temperature so they read correctly.

Once the O2 sensors are “ready” – the system enters CLOSED LOOP MODE. To achieve a clean running engine – the engine uses **two** different systems to determine how long to fire each injector for every single combustion event. The reason it uses two systems is partly for redundancy and partly for a “cross check” of itself.

Wherever you put the throttle, the following two things happen **SIMULTANEOUSLY** for each cylinder firing event:

- **A)** The ECM receives the signal from the MAF sensor which is telling it **exactly** how much air is entering the intake in grams (remember EVERYTHING STARTS WITH AIR). Then it takes that air measurement and makes some adjustments to it based on RPM, intake temperature, coolant temperature, throttle position, and a few other tables. Using all these factors and multipliers, it knows exactly how long to fire that injector to HOPEFULLY achieve a 14.7:1 ratio (or 12.8:1 if the driver is requesting very high power). BUT IT DOESN’T FIRE THE INJECTOR YET – WE HAVE SOMETHING ELSE HAPPENING IN PARALLEL...

- **B)** At the same time the ECM receives the signal from the MAP sensor. That MAP measurement is compared against the VE table (the volumetric efficiency table is a table that estimates the approximate amount of air in a cylinder based on a given RPM and a given MAP reading). Like the MAF tables, the VE table is setup at the factory based on known variables such as how much the heads flow, cylinder size, cam size, valve sizes, induction system qualities, etc. The resulting value that comes from the VE table is again modified by some other tables like IAT, ECT (coolant temp) and the final value is used to fire that injector just the right amount to HOPEFULLY achieve a 14:7:1 ration (or 12.8:1 if your foot is on the floor).

Assuming the MAF is adjusted correctly and the VE table is adjusted correctly, the resulting values used to fire the injector should be very close to each other. The system will use an average of the two values coming from those two methods to actually fire that injector. The MAF is typically more accurate since it is a true measure of airflow. The VE table is less accurate since it is a fixed table based on known entities when the engine is built, but it won’t know if the air filter is clogged, or a cold air intake has been added, etc. whereas the MAF sensor is actually reading the airflow in the intake and can take all those variables into account. Most E38 computers are set so that only the MAF is used above 4000 RPM – the VE table is ignored.

Now, notice in both the A and the B methods we fire that injector and HOPE for a good combustion event. This is where closed loop comes in. Once the combustion happens the O2 sensor reads the exhaust and determines if it was rich or lean. The fuel trims are then used in **subsequent** combustion events to either shorten or lengthen the amount of time the injector sprays so that the desired AFR can
be reached. Of course this can only really work if the throttle is being held steady. The minute you move the throttle the slightest bit, the table values and MAF readings are all different and the whole process starts over, so fuel trims are really only accurate during steady driving. Out on a road course or an autocross course they are basically useless since the throttle is changing all the time. Remember, the fuel trims (closed loop process) are always a second or so behind since they are adjusting everything “after the fact”. They can only adjust the injector timings for subsequent combustion events at that same throttle setting. This is why it so important to tune the MAF sensor correctly, and tune the VE table correctly. When both systems are tuned correctly, the HOPEFULLY part is greatly reduced and drivers will notice a big difference in “responsiveness” of the throttle since it nails the AFR dead on every time no matter what you do with that throttle. The fuel trims need to do very little work.

**Speed Density vs MAF Tuning** – Some people disable the MAF sensor completely and run only on the VE table. This is called a “Speed Density tune” or “SD Tune”. Others disable the VE table completely and run only on the MAF sensor – this is called a “MAF Only Tune”.

Gil doesn’t touch the VE tables at all, he only adjusts the MAF sensor and PE tables when he tunes your car. Sometimes he messes with spark timing a bit if he sees problems. I have looked at most of Gil’s tunes and he typically will add 2 – 3% to the MAF frequency table. This basically is telling the ECM that MORE air is entering the engine. The ECM will respond by firing the injectors a little longer resulting in a slightly richer mixture. In closed loop mode however the O2 sensors will just tell the trims to subtract fuel to bring it back to stoich. Typically with a Gil tune loaded my short term fuel trims will average -8 to -10 instead of the usual -2 or so. Why does he do this? Since a richer engine tends to make more power, it can make the engine feel more responsive during rapid throttle movements, yet fuel economy is not harmed too badly since the closed loop function will keep the mixture correct while cruising on the freeway regardless of what he does to the MAF. Unfortunately the side effect is that the WOT runs will also show very rich so he will adjust the PE table to bring it back down to 12.8:1 AFR or so.

**VVE Table – Virtual Volumetric Efficiency Table** – All the computers up to about 2007 had standard VE tables. Basically MAP across the top and RPM down the side – like this:
The numbers you see in the cells are the volumetric efficiency numbers, basically as mentioned earlier they express an estimated volume of air measured in kPa in a cylinder for a given MAP and RPM.

Based on that number the ECM can fire the injector just the right amount to HOPEFULLY achieve the proper AFR.

One of the reasons GM decided to move away from VE tables and instead use VVE tables is because a table like the one shown above has “holes” in it. In other words, what if the RPM is at 2130 RPM and the MAP is at 42.1? The table above has values that are close, but the computer would have to either use the closest values (2200 RPM and 43 MAP) or interpolate on the fly. Instead GM decided to build a Virtual VE table based on a very complicated math formula called 2nd order, non-linear, multivariate polynomial. I won’t even pretend to try to explain that, but basically they divide the table above into about 29 zones. Then they use a series of variables that “represent” the numbers in each zone. They can achieve the VE result of literally any possible MAP – RPM combination using these complex variables, but unfortunately HPTuners can no longer tune the VVE tables. HPTuners will show you the variables and zones, but don’t even touch those unless your math abilities are of the caliber of Matt Damon in Good Will Hunting. In HPTuners you can see the variables and polynomials in the Airflow-Speed Density tab under VE Coefficients – but like I said – leave them alone.

EFILive has the ability to edit the VVE tables. Basically it reads the 2nd order, non-linear, multivariate polynomial values and builds an old style table like the one you see above. You can then edit the table just like in the old days, make the values higher if you want more fuel, lower if you want less, and then press a button and it regenerates the new 2nd order, non-linear, multivariate polynomial values for the computer.
E38 Gen IV Corvette – EFI Tuning Class

The good news is that a really smart guy named “ktoonsez” on the HPTuners forum wrote a powerful little Windows application that can do the work for HPTuners. I tried it and it works well. Basically it reads the 2nd order, non-linear, multivariate polynomial variables from your HPTuners tune, and generates that old style VE table like the one shown above. You then turn on the scanner and go driving for about half an hour using a histogram in the scanner that tracks the VE Error. His little app then reads your histogram, makes adjustments on the VE table and then regenerates the 2nd order, non-linear, multivariate polynomial values in your tune which you then upload into the E38. I will demonstrate in the class.

Gotchas!

CAT OVERTEMP PROTECTION - Be careful when you take your car to the dyno and have it tuned. The E38 GEN IV computer has a “cat overtemp protection” system built in. In HPTuners if you go to the COT Lean Cruise tab you will see the temperature thresholds (about 1661 degrees) and max enrichment value (EQ = 1.21). Basically this means if you are at full throttle and the cats hit 1661 degrees F, the system will start enriching the mixture all the way up to EQ = 1.21 (remember, to convert EQ back to AFR divide Commanded AFR/1.21 to get your resulting AFR). Normally the commanded AFR is 14.7 (stoich) but in this case we are at full throttle so the PE table is engaged and we are commanding around 12.8:1. So 12.8/1.21 = 10.58 – the system is commanding REALLY REALLY RICH to cool those cats down! The bad part is that if Gil sees 10:58 on his AFR display, he will start trying to lean that out in the PE table. The danger here is that he makes the PE table really lean to compensate, then you make a full throttle run some day and the Cats are not hot, you are running REALLY LEAN which is dangerous. It is better to adjust this CAT protection table to either not command so rich (I set mine for max enrichment of 1.05 instead of 1.21) or raise the temperature thresholds so the protection doesn’t kick in so soon. Or you can just set the Cat Overtemp Protection to DISABLED. I will tell Gil about this next time I see him so he adjusts and watches for that when he tunes cars.

LOCKED TUNES – both software vendors offer the ability to LOCK your tune – meaning you upload the tune to your car and LOCK it and then no one else can modify that tune. The rule is simple – DON’T USE IT. Never lock a tune – you never know when someone else will need to get to that tune or make changes and you will have killed their ability to do so.

DOD – Displacement on Demand – you will see a lot of tables in HPTuners that specify DOD. The E38 computer is capable of turning off cylinders on certain engines during highway cruise to save fuel. NOT USED on Corvettes so ignore those tables and leave them alone.

Mating your WBO2 meter to your scanning software. All good Wideband readers have either an external voltage output or a serial output so you can take the signal from the WBO2 sensor and feed it into your scanning software so it can be seen along with all the other PIDs you are scanning on your
laptop. My Innovate LM-1 meter has an “Aux Out” jack that puts out a voltage between 0 and 5 volts DC depending on the AFR that it is reading at a given time. This voltage is adjustable using a Windows application that is included with the meter. For instance it can be set to send 1 volt when the AFR is 5:1 and 5 volts when the AFR is 50:1 – or anything in between. The manual that comes with your scanning software will tell you how to set it up. HPTuners wants you to set your WBO2 meter to 1 volt at 10:1 AFR and 5 volts at 20:1 AFR. Once you program that into the meter your HPTuners scanner software will show your WBO2 reading right on the screen of your laptop along with all the other PIDS you are scanning, and what HPTuners is displaying should exactly match the display on the meter. I have found however that they don’t always exactly match. I set mine up per the book and everything from about 14:1 all the way up to 20:1 matched pretty well, but at full throttle the meter would read 12:8:1 but HPTuners would display my wideband as reading 12.3:1. I had to fiddle with the programming of those voltages and fudge things around for a while to get them to really match well at all AFRs – and I never really got it perfect.

Some WBO2 meters have a serial output (mine does). Instead of outputting a voltage that corresponds to an AFR, the serial connection is more like a true computer connection – it sends the actual data as displayed on the meter directly to your laptop computer. The serial cable was included with the meter but since most modern computers don’t have serial connectors anymore I had to buy a $5 Serial to USB adapter. Once I got that connection working it was DEAD ON ACCURATE at all readings right down to the hundredth! I definitely recommend getting a WBO2 meter that has serial output. It is worth it!