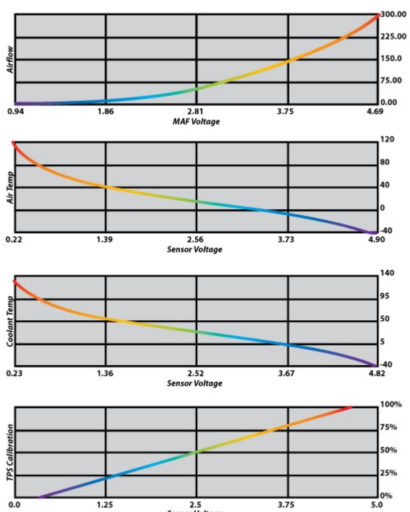
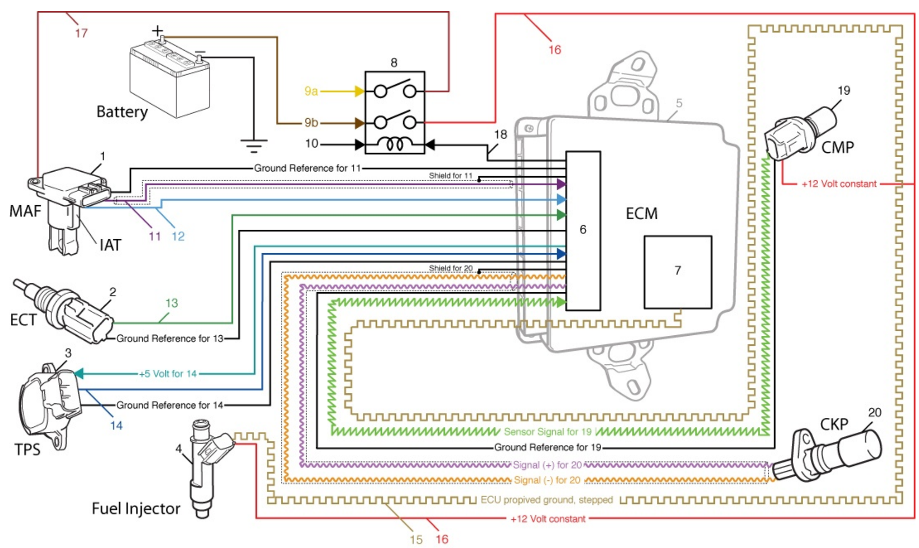
How ECUs Use Closed-Loop Controls to Make Fueling Corrections v1.02

This document has been created to explain how the factory Engine Control Unit (ECU) uses its closed-loop control systems to make fueling corrections for aftermarket intake systems. This document will also go into specific details to explain the consequences of operating your vehicle with these aftermarket intake systems. These consequences are based on operating your vehicle without proper ECU calibrations or while running a stock calibrations with these aftermarket intake systems. We will first explain what goals have be programmed in the ECU code, what components are used in the closed-loop control system, and what authority the ECU has to make corrections and report system failures.

For an introduction, we feel it would be best to review how the fuel system operates. This information has been taken from COBB Tuning's EFI 102 class material. We also offer a Free online EFI 101 class that can be found on this link.



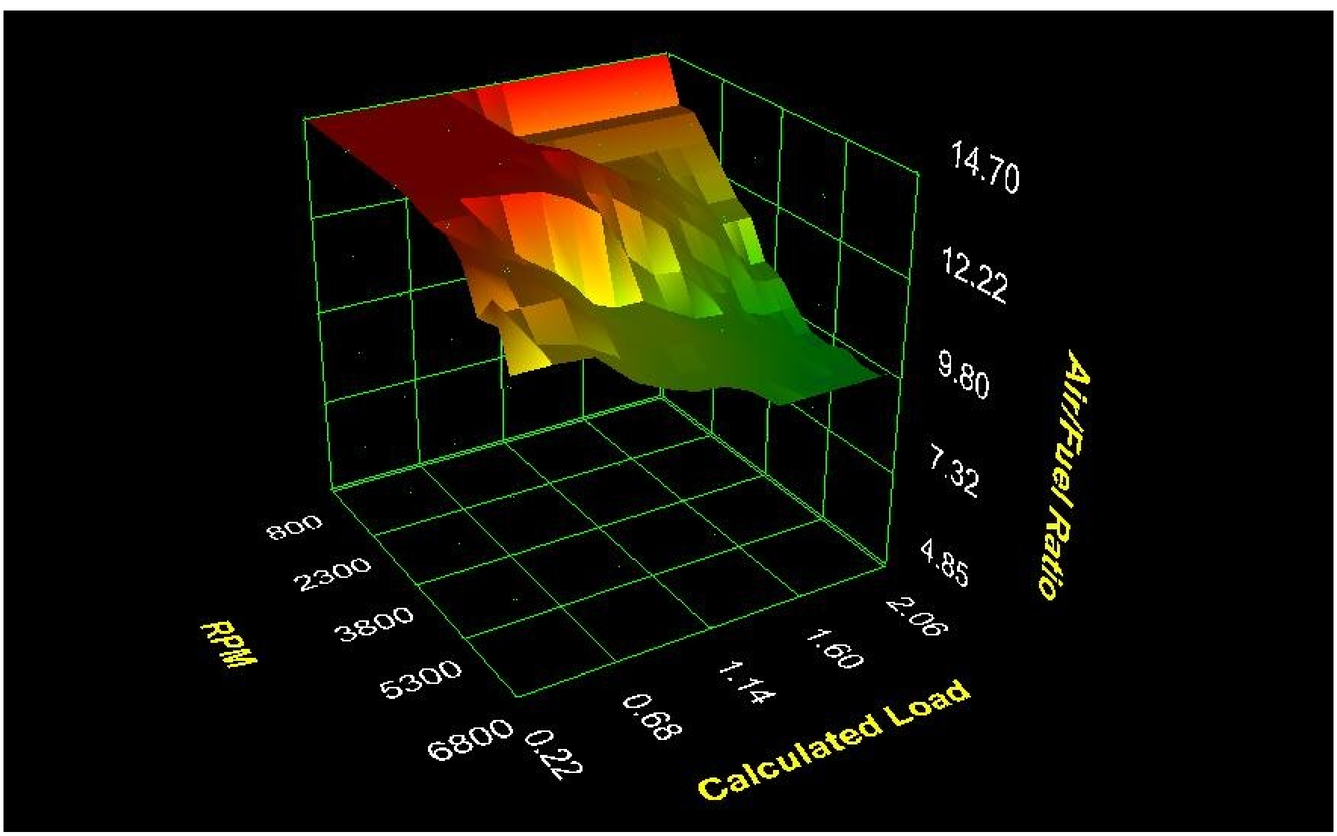


1. Mass Air Flow w/ IAT Sensor (MAF)	8. Main or EFI relay	14. Throttle Position Sensor (TPS) sensor signal
2. Engine Coolant Temp (ECT) Sensor	9a. From "EFI or Main" fuse +5v	15. Drive Signals for fuel injector(s), ECU provides ground path
3. Throttle Position Sensor(s) (TPS)	9b. From "EFI or Main" SBF fuse +12v	16. Power Supply for fuel injector(s) and CMP sensor, +12v switched
4. Fuel Injector(s)	10. From Main relay	17. Power Supply MAF and IAT, +5v switched
5. Engine Control Module (ECM)	11. Mass Air Flow (MAF) sensor signal	18. Control signal for Main or EFI relay
6. Central Prossing Unit (CPU)	12. Intake Air Temp (IAT) sensor signal	19. Camshaft Position (CMP) sensor
7. Drive circuit for Fuel Injectors	13. Engine Coolant Temp (ECT) sensor signal	20. Crankshaft Position (CKP) sensor

The input triggers for most modern EFI fuel systems usually come from the Camshaft Position Sensor (CMP) and Crankshaft Position Sensor (CKP). These input triggers are set-up to let the ECU know when it should open and close the fuel injectors for each cylinder. Inputs from the Main Load Sensor (Mass Air Flow or MAF) are used by the ECU to generate an initial output for the fuel injector pulse width and Camshaft Driven Fuel Pump (CDFP) duty cycles, this output us usually measured in milliseconds. The ECM will then make compensatory adjustments based on additional sensor inputs including: Engine Coolant Temperature (ECT), Throttle Position Sensor (TPS), Knock (KNK), System Voltage, Torque Demand, Heated Exhaust Gas Oxygen (HEGO), etc. The ECU will modify the fuel injector pulse width and CDFP duty cycles based on the look-up values in these compensatory tables then final adjustments are made according to learned information stored inside the ECM; Short Term Fuel Trim (STFT) and Long Term Fuel Trims (LTFT). These final adjustments are usually made by the ECU in order to achieve emissions targets.

All ECUs are simply programmed to understand the engine hardware it is trying to control and the sensors that are being used to control the engine. The hardware being controlled includes the engine long-block, turbochargers, CDFP, electronic throttle bodies, various control solenoids, and engine sensors including the critical MAF sensor. In order to meet ideal emission standards, the ECU is programmed to achieve 1 Lambda (or an Air/Fuel ratio of 14.68:1 for petrol fuel) during idle and light cruising conditions. To achieve this, OEM calibration engineers will spend extensive time working with sensor manufacturers, testing, and analyzing data in order to establish proper ECU calibrations. A major component of these calibrations includes the calibration for the MAF sensor. The MAF calibration is programmed to correlate the ratio of the MASS of fuel being injected in the engine with the MASS of air entering the engine. This information is then used by the ECU to achieve the fuel targets dictated in the fuel table(s). Once the ECU has been properly calibrated, it will then be able to calculate accurate Lambda (or Air/Fuel) values.

The ECU will use the MAF sensor readings to make initial fueling calculations. The ECU will then use the HEGO sensor, which is located in the sealed exhaust system, to measure the actual Lambda (or Air/Fuel ratio) achieved by the engine. This sensor's measurements are then used to make corrections to the fueling of the engine in order for the engine to achieve it's fueling and emissions goals. An example of a modern fuel look-up table can be seen below. This table is only accurate if all other components used for making fueling calculations have been properly calibrated within the ECU.



The ECU is programmed to make more than one correction for fueling, it can actually make several STFT and LTFT corrections across the MAF sensor range. Some ECUs can learn corrections for idle, part throttle, medium throttle, and Wide Open Throttle (WOT) conditions, and some simply apply corrections over various MAF ranges. How the ECU applies LTFT corrections depends on how it has been programmed. The objective of applying these corrections is to allow the ECU to make accurate fueling calculations for the varying fuel mixtures (100% petrol, E10, E15, etc.) that are available at the petrol pump, to account for minor intake system leaks, and to compensate for mechanical variances that may occur from vehicle to vehicle or due to engine component wear. **Ideally, LTFT that are within a +/- 6% range, across the entire MAF, are acceptable.**

If an aftermarket intake system is installed that does not closely duplicate the performance of the stock intake system, then the ECU will immediately start to make STFT corrections. If the ECU constantly measures that a STFT is being made, then it will move that correction to the LTFT so it can apply this correction on a constant basis. If an aftermarket intake system allows for a 10% additional MASS of airflow into the engine without the MAF sensor being properly calibrated, then the ECU will eventually measure and save a +10% LTFT that is applied for fueling calculations. If an aftermarket intake system allows for a 10% less MASS of airflow into the engine without the MAF sensor being properly calibrated, then the ECU will eventually measure and save a -10% LTFT that is applied for fueling calculations. The objective of the closed-loop fueling system is to allow for accurate fuel calculations.

An ECU will usually have the authority to make STFT corrections of +/- 25% and LTFT corrections of +/-35% (these limits vary by vehicle make and model). If the ECU has to make fueling corrections that are beyond these allowable corrections, then the ECU will find that something is wrong with the vehicle and it will illuminate the Malfunction Indicator Lamp (MIL, or Check Engine Light) to inform the driver that the system is either running too lean (P0171) or too rich (P0172). The sophistication of modern ECU closed-loop control systems allows for many different hardware items (intake, headers, exhausts, turbochargers, etc.) to be installed, and the engines can be driven. Although, changing ANY efficiency characteristic of an engine requires that a proper ECU calibration be developed in order to fully utilize this new hardware. Operating an engine that has ANY efficiency-changing hardware installed without a proper calibrations can lead to premature engine failure, poor gas mileage, increased emissions, and poor driving quality.

What this means to you:

- One of the most important things you will want to do after you install a properly designed aftermarket intake system is to reset the ECU and drive at very light loads for extended periods of time after the installation. Resetting the ECU will erase any STFT and LTFT values which will allow the ECU to start making compensatory corrections to the fueling calculations.
- Immediately after starting your vehicle, the fuel trims are usually not active. The ECU must heat the HEGO sensor and make sure various sensors complete system checks before the system is activated.
- The accuracy of all input triggers is critical. Using piggy-back devices that skew these triggers does not allow the ECU to calculate the proper timing of fuel injection or ignition operations. <u>This is critical when trying to calculate fuel injection windows and ignition timing on a DISI engine!</u>
- Using a MAP clamp actually throws off the load calculations and the car will not properly fuel itself, it will be too lean.
- Using a MAP clamp actually throws off the torque calculations and the car will not properly control

the other sub-systems of the engine properly.

- Most ECUs will store LTFT corrections under heavy load conditions and will eventually apply them to WOT conditions under the assumption that these conditions will continue under WOT conditions.
- Engine longevity can be compromised if proper calibrations are not established for any hardware that has changed engine efficiency.
- Reflashing a calibration intended for hardware other other than what is installed on your vehicle may compromise the performance, driving quality, or longevity of the engine.
- Reflashing a calibration that is a “one size fits all” tune may compromise the performance, driving quality, or longevity of the engine.