Technical Note

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Title	Secondary Injection		
Approved By			
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1.0	10/06/11	MM	

Scope

This document describes the process for setting up Secondary Injectors, also known as "Hi/Lo" or "Staged" Injectors.

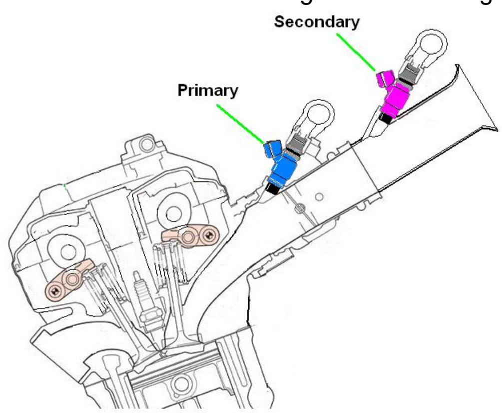
The information is based on the M84, M400, M600, M800 and M880 ECUs although some of the information will be relevant to the M4, M48 and M8 ECUs.

Secondary Injection

Secondary Injection is an engine tuning method where the normal set of fuel injectors is supplemented by a second set of injector. The secondary set of injectors can sometimes be made up of multiple injectors wired to work together. The two sets of injectors are 'staged'.

Two typical scenarios where Secondary Injection is used are:

1. A naturally aspirated engine with multiple throttle bodies. One set of injectors is used in a location close to the cylinder head and fired at low RPM/throttle. The secondary set of injectors is located further away from the cylinder head and only used at high RPM/throttle. The ECU will change from using one set of injectors to the other or possibly phase neatly between the two. This setup can broaden the torque curve of a naturally aspirated engine.
2. A turbo engine with small capacity but high horse power output. With no boost the engine does not require a lot of fuel so using one set of very large injectors can lead to tuning and driveability issues. If a small set of injectors is used so that light load/off boost driveability and tuning is good then a secondary set can be used to make sure there is enough fuel for the high boost running.



WIRING

The Secondary Injection function will use double to number of injector outputs normally used with the specific engine setup. If the engine is a four cylinder **and** sequentially injected the ECU will need four injector outputs for the primary set of injectors and an additional four injector outputs for the Secondary Injection, i.e. an M400 is not suitable. It is possible to use Semi-Sequential injection with Secondary Injection, for example a four cylinder with a Semi Sequential setup (setup as a 2 cylinder, 2 stroke) will only require two injector outputs for the Primary four injectors and two injector outputs for the Secondary four injectors, two injectors from each set will be wired to one output.

The Primary Injectors are the injectors wired to the first injector drives,

E.g. in the case of a 4 cylinder, Injector drives 1- 4 = Primary (Low) injectors and Injector drives 5 – 8 are the Secondary (High) Injectors. Assume a firing order of 1, 3, 4, 2.

Injector Output 1	Injector Output 2	Injector Output 3	Injector Output 4	Injector Output 5	Injector Output 6	Injector Output 7	Injector Output 8
Cylinder 1 Primary	Cylinder 3 Primary	Cylinder 4 Primary	Cylinder 2 Primary	Cylinder 1 Secondary	Cylinder 3 Secondary	Cylinder 4 Secondary	Cylinder 2 Secondary

For sequentially injected engines with up to 5 or 6 cylinders an M800 can be used (Not applicable to the M400 or M600). An M800 can use four ignition outputs as injector outputs for a total of 12 injector outputs. No upgrades are needed if the ignition outputs are used for injectors and it is for a Secondary injection setup.

It must be noted that any injectors connected to an ignition output pin must be a high resistance type (8-16ohms) as the ignition outputs cannot do Peak and Hold injector driving. The injectors for a six cylinder with Secondary injection must be wired as per the table below. Assume a firing order of 1, 5, 3, 6, 2, 4. Note that the primary injectors wire in firing order start from Ignition output 3.

Inj 1	Inj 2	Inj 3	Inj 4	Inj 5	Inj 6	Inj 7	Inj 8	Ign 3	Ign 4	Ign 5	Ign 6
Cyl 2 Prim	Cyl 4 Prim	Cyl 1 Sec	Cyl 5 Sec	Cyl 3 Sec	Cyl 6 Sec	Cyl 2 Sec	Cyl 4 Sec	Cyl 1 Prim	Cyl 5 Prim	Cyl 3 Prim	Cyl 6 Prim

This setup with six cylinders will obviously only leave 2 Ignition outputs left to control the ignition system, an Ignition Expander may be required.

An eight cylinder engine which requires Secondary injection must be configured as semi sequential as there is no provision for 16 injector outputs on an M800.

NOTE: There is **no** provision in any MoTeC ECU to split the number of outputs used by the Primary and Secondary injector sets, i.e. four Primary and two Secondary injectors.

SET UP

The setup for the Secondary Injection is located in ***Adjust – General Setup – Fuel – Secondary Setup.***

Secondary Injection Ratio

This is the flow ratio between the Primary and Secondary Injectors, expressed as a ratio of Secondary: Primary.

Example 1: If the Secondary injector flows 300 cc per minute and the Primary injector flows 150cc then the ratio would be 300/150 = 2:1 = 2.

Example 2: If there are two Secondary injectors wired together and are 300cc/min and the primary is 150cc/min the ratio will be (300 + 300)/150 = 4.

NOTE: The flow rate of the injectors should be properly measured at the fuel pressure that will be use in the car. Many injectors actual flow figures will vary from the advertised flow.

Secondary Injector Current

This is the same parameter as per the normal fuel setup but is specific to the Secondary injectors. When the Secondary Injection function is used the Primary and Secondary injector sets are treated independently.

Secondary Peak Hold Ratio

This is the same parameter as per the normal fuel setup but is specific to the Secondary injectors. This value is only used for Peak and Hold (low resistance) injectors and should remain as 4.0.

Secondary Enrich

Extra fuel can be injected by the Secondary injectors when the Secondary injectors start operating. The extra fuel uses the decay characteristics from the main fuel enrichment. Units: % IJPU

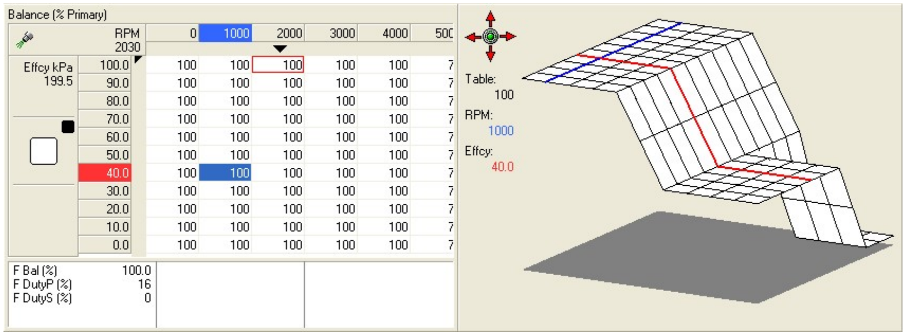
The diagram below shows the extra fuel pulse (circled) width being added to the normal calculated fuel volume for the Secondary Injectors when they are started. This fuel enrichment is used to avoid any lean running during changing of the injector stages.

Secondary Enleanment

This is the fuel removed from the Primary injectors when Secondary injectors stop operating. The reduced fuel uses the decay characteristics from the main fuel enrichment. Units: % IJPU

Secondary Balance Table

Located in ***Adjust – Fuel – Secondary Injection – Secondary Balance Table***.



The Secondary Balance Table determines the balance of fuel volume between the Primary and Secondary Injectors for various RPM and Efficiency Points. In the M84, M400, M600 and M800 the value is a percentage of the Primary Injector flow rate, i.e. 100% = all fuel from the Main Fuel table and all Compensations is delivered by the Primary Injectors. 50% = 50% of all fuel is delivered by the Primary Injectors and 50% is delivered by the Secondary Injectors. 0% = All fuel is delivered by the Secondary Injectors. This has nothing to do with the maximum flow of the injector it is purely indicating what percentage of the tuned fuel (Main Fuel Table plus all Compensations) is delivered by the Primary injectors, the remained is delivered by the Secondary injectors.

It must be understood that the ECU will do the balance based on the volume of fuel the tuner requires in the Main Fuel table and all fuel Compensations and adjust the pulse widths of each injector based on the Secondary Injection Ratio. If the Secondary Injection Ratio is set to 1 (equal flow injectors Primary and Secondary), the Pulse width from each injector will be the same. If the Secondary Injection Ratio is set to 2 (double the flow from the Secondary injectors compared to Primary injectors) the Primary Injector Pulse Width will be double that of the Secondary Injector Pulse Width as it needs more time to flow the same amount of fuel.

As a test and engine could be tuned on the Primary set of injectors, this can be a medium RPM and Load and assuming the Balance Table setting is 100% at this point (all fuel from the Primary Injectors). The tuner should then be able to change the balance table to a lower number, i.e. 50% and the Lambda sensor reading should remain the same. If the Lambda reading changes significantly then the Secondary Injection Ratio is wrong. Incorrect Battery Compensations could have an effect on the Lambda reading as well but these would be minor or not noticeable.

The pulse width is calculated by the ECU using the Secondary Injector Flow Ratio number. The calculation is as follows.

Primary Pulse Width = ((Fuel Table PW + Total Compensation PW) x Secondary Balance table setting) + Battery Compensation PW

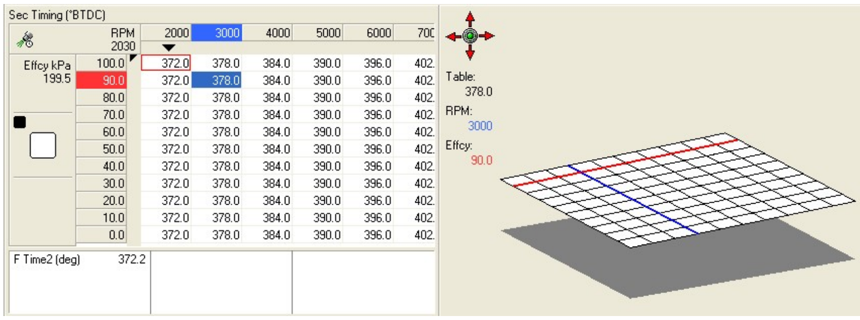
Secondary Pulse Width = (((Fuel Table PW + Total Compensation PW) x (100 – Secondary Balance Table setting)) / Secondary Inj Flow Ratio) + Secondary Battery Compensation PW

Secondary Injection Timing

Located in ***Adjust – Fuel – Secondary Injection Timing***

The Secondary Injection Timing table is the same as the normal Injection timing table but is specific to the secondary injectors. The normal Injection Timing table (***Adjust – Fuel – Injection Timing***) will only affect the Primary Injectors only.

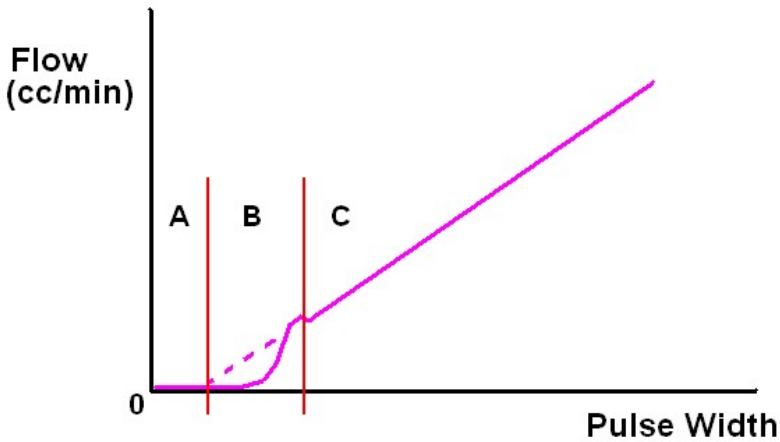
The Secondary Injection Timing table is independent of the normal Injection Timing table. Both tables are in degrees before Top Dead Centre.



RPM 2030 / Effcy kPa 199.5	2000	3000	4000	5000	6000	700
100.0	372.0	378.0	384.0	390.0	396.0	402.
90.0	372.0	378.0	384.0	390.0	396.0	402.
80.0	372.0	378.0	384.0	390.0	396.0	402.
70.0	372.0	378.0	384.0	390.0	396.0	402.
60.0	372.0	378.0	384.0	390.0	396.0	402.
50.0	372.0	378.0	384.0	390.0	396.0	402.
40.0	372.0	378.0	384.0	390.0	396.0	402.
30.0	372.0	378.0	384.0	390.0	396.0	402.
20.0	372.0	378.0	384.0	390.0	396.0	402.
10.0	372.0	378.0	384.0	390.0	396.0	402.
0.0	372.0	378.0	384.0	390.0	396.0	402.

Balance On/Off

Because an injector does not necessarily open from very low pulse widths in a convenient, linear manner (see diagram below) some consideration must be made to account for this.



A. The injector is in the "Dead Time" period where it does not open at all, this can be likened to opening a door, the door does not open the instant someone start to push on it. This period is automatically accounted for in the Battery Compensation table.
B. The injector is in the "Non-Linear" period (sometimes called the "high slope") so injector flow does not follow the logical linear (dotted) flow for pulse widths in this area.
C. The injector flow is linear so a set increase in

It is necessary to have software that makes sure the two sets of injectors switch on/off at a high enough pulse width that the tuner can be sure there is no loss of fuel during the transition.

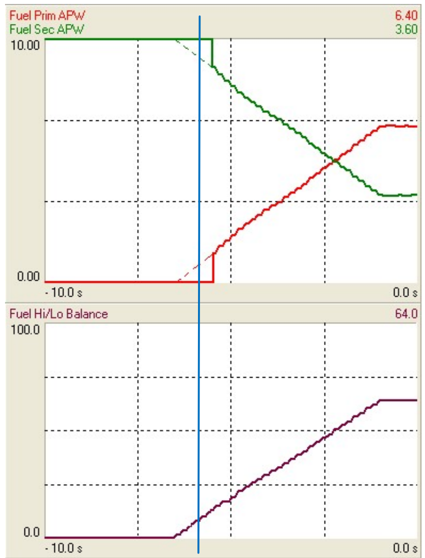
Also having injectors switching on/off at one discrete point would be problematic if the driver was hovering at that point, e.g. if the switching point was at a particular throttle position and the drive was trying to hold this position but there were constantly small movements of the throttle the injectors may be switching constantly. Some Hysteresis is needed to give a different on switching point to the off switching point of the two sets of injectors.

Primary Balance On

The primary injectors will be switched on only when the balance table is above this value.

For example, assume the Primary Balance On was set to 0% and the balance table was set based on throttle position with 0% Balance (all fuel from the secondary injectors) at 100% throttle and 100% Balance (all fuel from the primary injectors) at 0% throttle. If the driver was at 100% throttle and then started to lift the throttle the Balance table would start to change – 100.0%, 99%, 98%, etc. (actual ECU Balance table resolution is 0.1%) which would require the primaries to open – 1%, 2%, etc. The primaries would be trying to open in the 'B' area of the diagram above possibly leading to the engine leaning out.

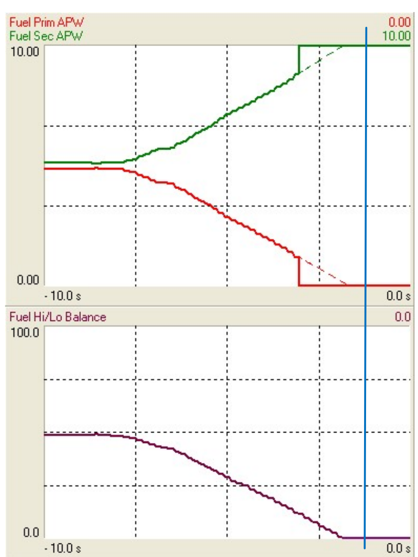
If the Primary Balance on was set to 5% the ECU table would keep supplying 100% of the fuel from the Secondary injectors until the driver lifted the throttle to a point where the Balance table was requesting 95% Balance and then the Primary injectors would switch on in the 'C' area of the injectors flow from the diagram above.



In the diagram above it shows what the ECU is doing with each set of injectors based on the example mentioned in the text. A fuel pulse width of 10msecs has been used in this example. It can be seen that with a Primary Balance Off setting of 5% as the driver lifts the throttle the ECU continues to deliver 100% of the fuel (10msecs) through the secondary injectors. As the driver gets to a throttle position which asks for 5% of fuel from the primary injectors the ECU switches the primaries on and the secondaries drop to 95%. The dotted line shows what would be happening if the Primary Balance On was set to "0".

Primary Balance Off

The Primary Balance Off works in a similar manner to the Primary Balance On but this time it is when the Primary Injectors are already working. If the Balance table is approaching 0% and to avoid the 'B' area of the injector flow it is advisable to turn the Primary injectors off early.



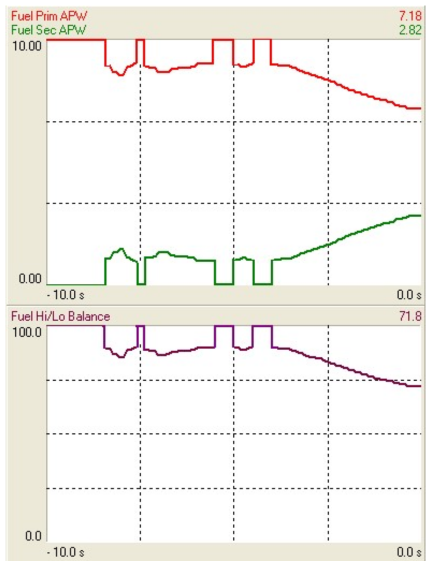
NOTE: The Primary Balance Off must be less than the Primary Balance On.

Hysteresis Explanation

The basic explanation of Hysteresis is when an "on" condition is different to an "off" condition for the same device. An example would be the MoTeC Thermo Fan control, the Fan can be turned on at 90 degrees of water temp but turned off when the temp is reduced to 85 degrees, there is a 5 degree Hysteresis. For Secondary Injection the Hysteresis would involve making sure there was difference between the Primary Balance On to the Primary Balance Off settings.

If the settings for Primary Balance On and Primary Balance Off were the same or very close, e.g. PBOn 10% and PBOff 10% also and the driver was trying to hold the throttle steady at this point (assuming the Balance table has Throttle Position as an axis), any slight movement of the throttle by the driver could have the injector stagewes changing back and forth causing some driveability issues.

It can be seen in the diagram below that the driver is "hovering" near the Balance On/Off parameters. When the Balance On/Off parameters are set to close the balance table with switch between the two for any slight movement of the throttle pedal.



With this example in mind it is best to always have some separation between the Balance On and Balance Off settings, e.g. 5%.

Secondary Balance On/Off

The Secondary Balance On and Secondary Balance Off parameters work the same way as the Primary Balance On and Primary Balance Off but with respect to the Secondary Injectors. Hysteresis effects should also be considered the same.

Secondary Injector Battery Compensation

This battery compensation table uses the same theory as the normal battery compensation under ***Adjust – General Setup – Fuel –Battery Compensation*** but is specific to the secondary injectors only. The two battery compensation tables are independent of each other and should both be set for the specific injecotrs used in the Primary stage and Secondary stage.

Primary and Secondary Duty Cycle and Pulse Width

Now that Staged injection is being used the tuner will need to pay attention to some more parameters for the injectors. The normal Duty Cycle, Effective Pulse Width and Actual Pulse Width are no longer used, these are replaced by:

- Fuel Prim APW (primary injector actual pulse width)
- Fuel Sec APW (secondary injector actual pulse width)

- Fuel Prim EPW (primary injector effective pulse width)
- Fuel Sec EPW (secondary injector effective pulse width)
- Fuel Inj Duty Prim (primary injector duty cycle)
- Fuel Inj Duty Sec (secondary injector duty cycle)

It must be understood that the Duty cycle of the Primary and Secondary injectors are not directly related to the Balance Table number:

Example 1

Secondary Balance Ratio: 1.00

Engine RPM: 3000

Main Fuel Table + Compensations Pulse Width: 10msecs

Balance Table: 100% (all fuel from primary injectors)

Duty Cycle for Primary Injectors = **25%**

Duty Cycle for Secondary Injectors = **0%**

Example 2

Secondary Balance Ratio: 1.00

Engine RPM: 3000

Main Fuel Table + Compensations Pulse Width: 10msecs

Balance Table: 50% (half fuel from primary injectors and half from the secondary injectors)

Duty Cycle for Primary Injectors = **12.5%**

Duty Cycle for Secondary Injectors = **12.5%**

Example 3

Secondary Balance Ratio: 1.00

Engine RPM: 6000

Main Fuel Table + Compensations Pulse Width: 10msecs

Balance Table: 50% (half fuel from primary injectors and half from the secondary injectors)

Duty Cycle for Primary Injectors = **25%**

Duty Cycle for Secondary Injectors = **25%**

As a guide the tuner will be able to leave the Balance Table at 100% everywhere and start to tune the engine, once the Fuel Inj Duty Prim get high (80-90%) that is all the fuel that the Primary Injectors can safely flow. To Reduce the Duty Cycle on the Primary injectors the tuner will need to decrease the Balance Table number, i.e. Example 1 to Example 2. The Lambda reading will remain the same because the total amount of fuel delivered is the same.