GDI Strategy Overview

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Status:	Confidential	**Issue Date:**	**01July2014**

Email: info@openecu.com
Telephone: Tel: +1 (734) 656 0140
Address: OpenECU LLC
47023 W. Five Mile Road, Plymouth, MI 48170-3765, USA
Incorporated in Delaware 20-5693756

Revision History see version control tool

Abstract

This document describes the functionality contained in the gasoline direct injection engine control strategies and answers common questions customers have about them.

Contents

1. Introduction and Scope

This document serves as a software strategy product description, at a level of detail more specific than what is shown in marketing fliers. However, this is not an engineering requirements document. Such detailed requirements, design, and Pi process documents for engine control are Pi intellectual property, which can be made available to customers according to specific business agreements.

2. Software Environment

The Gasoline and GDI strategies are developed in Matlab Simulink. C language versions of the strategies are not available. The strategies are appropriate for use on OpenECU, as well as other 3rd party ECUs. Use on 3rd party ECUs may require some software manipulation to meet the destination ECUs operating system needs.

These strategies use floating point arithmetic and native Simulink blocks in the core of the application. No proprietary OpenECU blocks are used in the core of the application, thus the strategy can be more easily ported to a 3rd party ECU.

3. GDI Engine Components

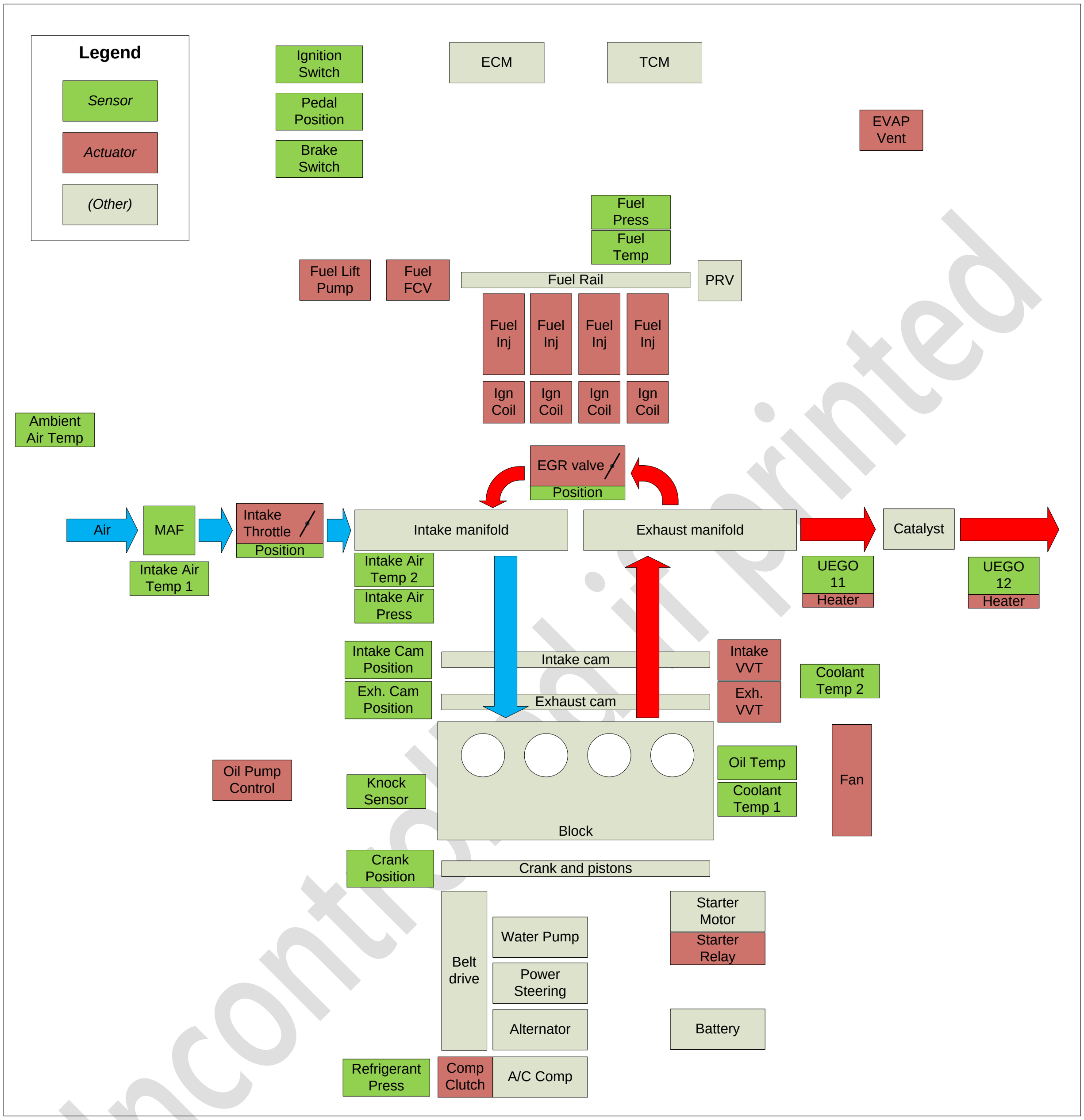

Figure 1: GDI Engine Components

The OpenECU GDI strategies are capable of controlling engine components, such as those shown in Figure 1, which describes a common-rail gasoline direct injection engine.

Why GDI strategies are different

The GDI strategies are an extension of the OpenECU Gasoline strategy, with the following notable differences:

- Fuel pressure controls, for the electronically-variable mechanical high pressure GDI fuel pump.
- Facility for multiple injections per firing.

The GDI fuel pump is unique, compared to port-fuel-injected gasoline, because it is driven by a set of lobes on the camshaft, and its flow control valve must be actuated synchronously with the camshaft position. This results in fast response of the pump to achieve the target fuel pressure, allowing the user to vary the fuel pressure widely over the different engine operating conditions (typically from 25 to 150 bar fuel pressure.) With GDI, fuel pressure therefore becomes an additional tool that calibrators can use to achieve conflicting performance goals, such as light-load fuel dose accuracy, or peak output fuel dose quantity.

4. GDI Control Architecture

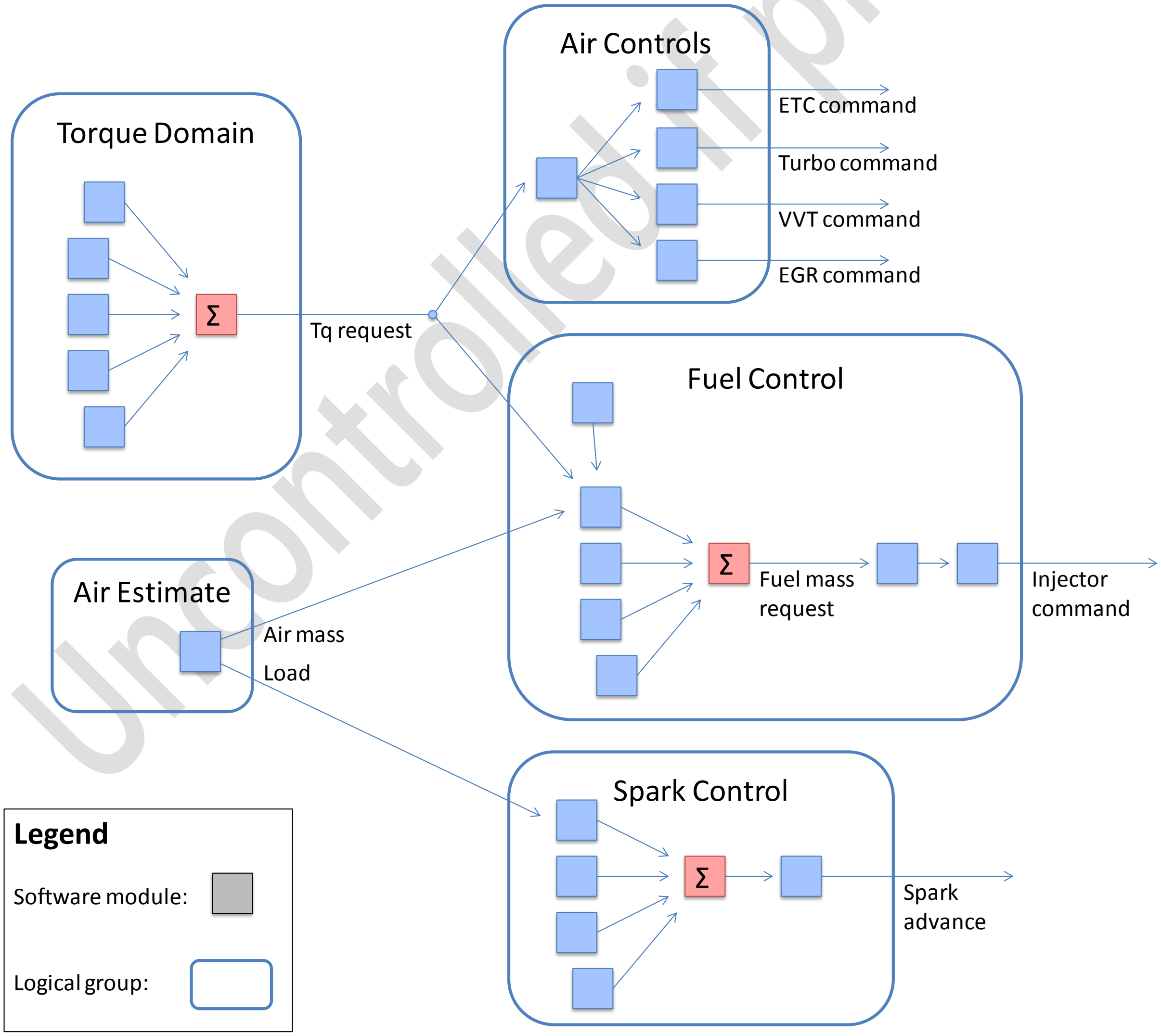

Figure 2: GDI Control Architecture

The OpenECU GDI strategies utilize the control architecture depicted in Figure 2 above. This approach neatly distributes the different control responsibilities into groups of logic, and allows the user to focus on specific areas of development, according to their goals (basic engine running, startup, transient, emissions, etc.)

5. GDI Functional Behavior

The "software modules" shown in Figure 2 are described in further detail below, according to their logical group.

5.1 Torque Domain

5.1.1 Idle Speed Control

The idle control feature starts by determining what state of idle the engine is operating.

- Closed loop idle
- Engine cranking
- Return to idle
- Drivability

The idle control logic works by adjusting both spark timing and (IACV or ETC) to regulate the desired idle speed and torque.

The desired idle speed for closed loop idle is determined by engine temperature, time since engine start, alternator load, and air conditioning compressor load.

A feed-forward and feedback control scheme using a PID is used to regulate the idle speed of the engine. Feed-forward tables for the various idle states are developed to set the IACV or ETC air position. Spark control is only used in closed loop idle speed control.

For the case of IACV-based systems, provisions for ensuring the stepper position limits are not reached are included, as well as learning the stepper position.

5.1.2 Engine Speed Limiter

The Engine Speed Limiter provides rev-limit functionality by reducing Torque. The amount of the intervention can be specified on a per-gear basis, for improved feel. Additionally, total fuel or spark shut-off can be specified, to create a "hard limit."

5.1.3 Driver Request

The accelerator pedal position is validated and processed to indicate the overall driver requested Torque. This can be customized such that the throttle response is configured based on vehicle speed, gear, temperature, or for other drivability reasons.

5.1.4 CAN Torque Requests

Requests from other vehicle systems (ACC, ESC, TCM) are also incorporated by the Torque Domain. These requests (typically originating from CAN messages) can be configured such that they are only able to reduce torque (ESC), or can have authority to increase torque (ACC).

5.1.5 Engine Loads Model

An Engine Loads Model is used to estimate the amount of torque the various loads on the engine are consuming (aside from the transmission.) This includes an engine friction model, and accounts for engine temperature and loads from the auxiliary devices, such as the alternator, coolant pump, steering pump, air conditioning compressor, and any other accessories.

Using the Engine Loads Model in the Torque Domain provides improved drivability, and more consistent behavior and performance across different driving cycles.

The end result of the Torque Domain logic is a total requested indicated torque. Here, “indicated torque” represents the total (average) torque produced by the combustion chambers. Note that some of this torque is lost to friction, or taken up by accessory loads, so therefore the “brake torque” sent to the dyno (or transmission) will be less than the indicated torque.

5.2 Air Charge Estimate

The strategy allows the user to select from direct MAF measurement (if available), or a speed-density model, to determine the air mass in the cylinder. When using speed-density, gas law equations based on inlet manifold pressure & temperature and lookup tables for volumetric efficiency are used to estimate the amount of inlet manifold gas mix which is trapped within the cylinders. The MAF sensor will indicate the amount of fresh air drawn into the engine under steady state conditions. This is combined with a filtered version of the manifold model to estimate the fraction of fresh air versus EGR gas in the manifold. An EGR flow model can be used to deal with transient air mixing effects in the inlet manifold. The result is an estimate of the air mass currently in the cylinder (mg fresh air, per cylinder, per firing.)

5.3 Air Controls

5.3.1 Air Demand

The Air Demand model is used to estimate how much air (mg fresh air, per cylinder, per firing) is suitable to create the Torque request. Then, within this model, requests are created for the various air-controlling devices (throttle, turbo, VVT, et cetera.) In this way, the strategy determines the overall configuration of the air-controlling devices that is best suited to the current operating condition.

5.3.2 Electronic Throttle Control

The throttle valve position is varied according to Air Demand. The throttle demand is further controlled through rate limiting functions to provide smooth operation. The throttle demand is then processed through a series of feedforward and feedback control loops to determine a duty cycle for the H-bridge output.

5.4 Fuel Controls

5.4.1 Target Air Fuel Ratio

This feature determines the desired air fuel ratio for the engine based on operating state and sensor inputs. The target air fuel ratio (AFR) can be modified for cold start, hot soak, and high load operation. Ideally the engine will operate at a stoichiometric mixture for optimum behavior, however under these three conditions additional enrichment or enleanment may be required.

High load operation provides a multiplier to the base fuel amount via a lookup table based on speed and load.

Hot soak operation provides a multiplier to the base fuel amount via a lookup table. This amount will be ramped out based on coolant temperature and the duration the engine has been stopped.

Cold start operation provides a multiplier to the base fuel amount based on coolant temperature which can be decayed to zero based on engine speed and load. Base Fuel

The target AFR is used with the milligrams of air per cylinder to determine the desired fuel mass.

This fuel mass is the base fuel that will be subject to additional modifications described elsewhere in the document.

5.4.2 Closed Loop

This feature reads the HEGO sensor feedback and makes adjustments to the delivered fuel to ensure the target AFR value is achieved. Logic exists to limit the enablement of close loop fuel control by considering DFSO, injector faults, engine run time, and coolant temperature. The logic monitors the switching of the sensor between rich and lean and determines a fuel multiplier.

5.4.3 Transient Fuel

Transient fuel provides enrichment during changes in engine speed and load. Transient fuel can be enabled for tip-in and tip-out events. Once enabled, the transient fueling logic allows for tuning of fast and slow transient fuel compensations.

5.4.4 Deceleration Fuel Shut Off

This feature provides the ability to linearly ramp out, and ramp in fuel, as well as retard spark, and provide DFSO enrichment during exit events. The logic monitors the driver request throttle, engine speed, and engine runtime to enable DFSO.

5.4.5 Adaptive Fuel

The adaptive fuel feature stores a scalar gain and offset which is used to compensate for errors in the base fuel delivery. The logic is enabled by a range of inputs ensuring the value to be stored is in fact stable and reliable. The logic then stores in NVM the offset and gain values and uses these values on subsequent drive cycles.

5.4.6 Catalyst Protection

The catalyst protection feature estimates the exhaust gas temperature by a simple model that considers speed, load, AFR, and spark advance. The exhaust gas temperature is used to estimate the catalyst exotherm and compensate for heat loss in the exhaust. The final catalyst temperature estimate is used to determine if catalyst protection should be enabled.

Once enabled the catalyst protection feature will adjust the fuel mixture and the spark timing to reduce the exhaust gas temperature, and thus cool the catalyst.

5.4.7 Final Fuel

The final fuel feature combines all of the fuel correction sources with the base fuel to determine the final fuel quantity, and determines the specific injection timing for each individual injector. The feature sums up the base fuel and nine other correction factors to determine a final fuel correction. The factors are:

- Base Fuel
- RPM Limiter Correction
- DFSO Correction
- Catalyst Protection Correction
- Closed Loop Fuel Correction
- Injector Fault Correction
- Transient Fuel Correction
- Adaptive Fuel Correction

The final fuel logic also has a feature to disable all fuel injectors should the possibility of over-enrichment during engine cranking occur. This is otherwise known as anti-flood control.

The final fuel logic also determines the fuel injector timing, in addition to the fuel injector duration. The timing logic compensates for the start of injection (SOI) to ensure injection always occurs on a closed intake valve.

5.5 Spark Controls

5.5.1 Base Spark

The base spark is determined by a lookup table of engine speed and load.

5.5.2 Spark Modifiers

The base spark value is modified by the following parameters:

- Charge air temperature
- Knock spark offset
- Drivability/Transient spark

The drivability/transient spark provides the ability to retard the spark briefly during a transient engine event to avoid spark knock.

5.5.3 Spark Arbitration

The spark arbitration feature takes the base spark value and the various modifiers and arbitrates a final spark advance, as well as managing the dwell period for the coils.

The arbitration looks at inputs from:

- Cranking spark
- Running spark
- Catalyst spark offset

The spark arbitration manages the dwell control for the coils and compensates for battery voltage. The final output of the spark arbitration are the coil on-angle and the coil off-angle.

5.6 Miscellaneous Controls

5.6.1 Engine Running Mode

Stateflow based logic to process an enumeration to determine if the engine is:

- Stopped
- Cranking
- Running

This feature also provides an output of the time since engine start which is used elsewhere in the software to control start and post-start behavior.

5.6.2 Evaporative Emissions Controls

Canister purge controls the evaporative emissions container and recovering fuel vapor by introducing it to the intake manifold. The logic contains enable logic to govern when purge can be active, as well as logic to control the amount of purge demand requested by the ECU. The purge logic calculates the purge flow based on the closed loop fuel adjustment that resulted from the purge event.

5.6.3 Air Conditioning Control

The air conditioning feature manages the control of the air conditioning compressor and the cooling fans. The air conditioner logic allows for the compressor to be turned off during WOT or high RPM operation to provide additional driving torque to the vehicle. Additionally the logic supports the idle speed control logic in anticipating the load from the air conditioning compressor, and compensating for compressor cycling.

5.6.4 Cooling Fan Control

This logic monitors the engine coolant temperature and operates the low speed and high speed cooling fans. This logic also monitors battery voltage to ensure sufficient voltage is present to operate the fans. Additionally the cooling fan control conducts diagnostic tests of the fans to ensure they are operating normally.

5.6.5 Manual Calibration Override

All features have the ability to take manual calibration override to help the process of engine calibration and tuning.

5.6.6 CAN Communications

Some basic CAN messaging is built into the strategies currently. The strategies will output engine speed, vehicle speed, MIL state, odometer, fuel quantity, and ambient temperature. Additional CAN outputs can be easily configured using OpenECU CAN transmit blocks, as needed.

No CAN inputs are currently used in the strategies.

5.6.7 Diagnostics

5.6.7.1 Out of Range

All analog inputs are checked for out of range (OOR) low, high, and open circuit.

Fuel injectors are diagnosed for output drive monitor faults

Canister purge is diagnosed for output drive monitor faults

5.6.7.2 Rationality

All analog inputs are checked for slew rate.

Certain sensors have additional rationality checks:

- MAP vs. TPS rationality
- Accelerator pedal1 vs. Accelerator pedal2
- TPS1 vs. TPS2

6. Frequently Asked Questions

6.1 Are the strategies production-ready?

Depends on what market or industry is being targeted. For modern production automotive applications the strategies are a great place to start but the diagnostic and OBD features required of modern automotive control systems would need to be added. The strategies are intended to jump start the development of production strategies and get a development team up and running quickly.

6.2 What emissions level can they achieve?

The gasoline strategies are capable of meeting Euro3 emissions in their current configuration. Typically, for more stringent emissions levels, a system approach is desired looking at the combined interaction between engine system hardware, aftertreatment, and the control strategies. OpenECU engineering has worked as part of an OEM team implementing a system to meet Euro 6 level emissions requirements.

6.3 Do they have diagnostics?

The strategies have some basic diagnostics for sensor faults as well as some rationality checks. These diagnostics do not include any OBD major monitor diagnostics. The gasoline strategies have approximately 80-90% of the comprehensive component diagnostics and 0% of the major monitor diagnostics required to meet US or European OBD legislation.

6.4 Do you support OBD?

OpenECU offers an OBD infrastructure handler separate from the gasoline strategies. The OBD infrastructure handler can be integrated with the strategies to provide all of the service tool support and communications.

6.5 Can the strategies be used in other ECUs?

Yes. The strategies are built from pure Simulink and can thus be easily ported to other ECUs that support model based development.

6.6 What engines can they be used on?

The gasoline strategies can be used on engines matching the following configuration:

Number of cylinders:	1 to 8		
Injectors per cylinder	8cyl: 1	6cyl: 1	4cyl: 2
Injector type:	Strategy independent, hardware dependant		
Coil type:	Smart coil only		
Coil quantity	1 to 8		

Crank wheel configuration	12 – 60 teeth with 1, 2, or 3 missing teeth
Cam wheel configuration	1 – 8 teeth
Number of cam wheels	1

6.7 How are the strategies sold or licensed?

The gasoline strategies can be licensed with our without source code. Users can receive a pre-flashed ECU that can be calibrated and tuned via CCP, or they can receive raw source code.

7. Terms and Abbreviations

AFR	Air Fuel Ratio
DFSO	Deceleration Fuel Shut Off
EGR	Exhaust Gas Recirculation
ETC	Electronic Throttle Control
IAC	Idle Air Control
IAT	Intake (manifold) Air Temperature
MAP	Manifold Absolute Pressure
OBD	On-board Diagnostics
OOC	Out of correlation
OOR	Out of range
RS	Recommended section
TPS	Throttle Position Sensor