# 2. SYSTEM DESCRIPTION & OPERATION

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## 2.1 THEORY OF OPERATION

The Gaseous Fuel Injection (GFI) system is a computerized natural gas fuel injection system for spark ignited engines. This system can convert most gasoline powered engines to burn natural gas. There are two types of conversions: 1) Bi-Fuel, vehicles using either gasoline or natural gas. or 2) Mono-Fuel, vehicles using only natural gas. Most after market installations are bi-fuel while original equipment manufacturer (OEM) installations are typically mono-fuel. The instructions in this manual concentrate on bi-fuel installations but are applicable to mono-fuel applications.

### *2.1.1 WHAT IS NATURAL GAS*

Natural Gas (NG) is a mixture of hydrocarbon gases with a high concentration of methane ($CH_4$). the abundant reserves of NG in the United States and Canada allows it to be used as the efficient fuel of the future. NG is a clean burning fuel, making it a highly suitable fuel to meet emission standards.

### *2.1.2 NATURAL GAS VS. GASOLINE*

It is important to recognize that Compressed Natural Gas (CNG) is different from gasoline in several ways. Because most vehicle operators are used to driving gasoline powered vehicles, the operator may mistake the inherent differences in their converted vehicle as a fault of the system. A vehicle exhibiting symptoms of a lean gasoline mixture may in fact be too rich in natural gas. Also, a marginal base vehicle problem may surface only when running on natural gas, because of the different characteristics of the fuels. The major differences between CNG and gasoline are summarized below:

### *2.1.3 GASEOUS VERSUS LIQUID FUELS*

Even under extreme pressures and temperatures, CNG is gaseous. As a result, a series of high flow injectors are required to provide a sufficient mass of CNG that is introduced the engine. By comparison, gasoline is stored and injected as a liquid that is vaporized in the engine before it is burned.

### *2.1.4 FUEL IGNITION AND COMBUSTION*

Gaseous fuels are "dry" fuels that require a higher spark plug firing voltage to ignite the fuel. This puts a higher load on the vehicle ignition system; consequently, a marginally operating secondary ignition system may exhibit problems when running on natural gas, such as backfires or stalling.

Natural Gas burns slower than gasoline under certain operating conditions. To compensate, the GFI system advances the ignition timing over the base gasoline timing, when required, to optimize driveability and emissions of the vehicle. See paragraph 2.4.6 on page 2-9.

### *2.1.5 DILUTED AIR CHARGE*

Because natural gas is injected into the air stream, the fuel displaces approximately 10% of the air intake. This reduces the air charge into the cylinder and reduces the power produced. This power loss is only a restriction on maximum power; there is adequate power available for most driving conditions.

Because GFI is a throttle body injection system, there may be longer crank times in the alternative fuel mode than with gasoline operation; particularly on engines with large intake manifolds..

### *2.1.6 ENERGY DENSITY*

Natural gas is less energy dense than gasoline (i.e. there is less energy available from the same volume of natural gas as there is with gasoline). As a result, the maximum power achievable from a natural gas system is slightly lower (10 to 13% at the top end).

**NOTE:** *This power loss is only a restriction on maximum power; there is adequate power available for most driving conditions.*

### 2.1.7 SYSTEM OPERATIONS OVERVIEW

The Gaseous Fuel Injection (GFI) system design is comprised of a gas regulator, a combined metering valve and computer (compuvalve), gas discharge nozzles, two temperature sensors, and a fuel selector switch (bi-fuel applications only). Incorporated into the compuvalve are absolute pressure sensors (fuel and intake manifold) and a fuel temperature sensor. The system operation may be summarized as follows:

- Fuel from the fuel storage vessels flows to the high pressure regulator.
- The regulator provides a consistent operating fuel pressure (100 psi) for the system.
- The fuel is passed through a special GFI fuel filter to the compuvalve. This compuvalve electronically meters fuel according to demand and controls spark advance for optimum driveability and emissions when running on natural gas. A combination of base vehicle and GFI sensors are used to dynamically monitor the engine and environment to provide closed loop control of fueling. The compuvalve uses speed density calculations for both fuel flow and air flow while adjusting the air to fuel mixture. Adjustments occur for each spark event.
- The fuel is introduced into the air intake system through the discharge nozzles.
- When natural gas is selected, the GFI computer intercepts the base vehicle fuel gauge signal and substitutes an appropriate signal to indicate the volume of natural gas in the fuel storage vessel(s). In gasoline mode, the normal fuel level sensor signal is passed to the gauge.

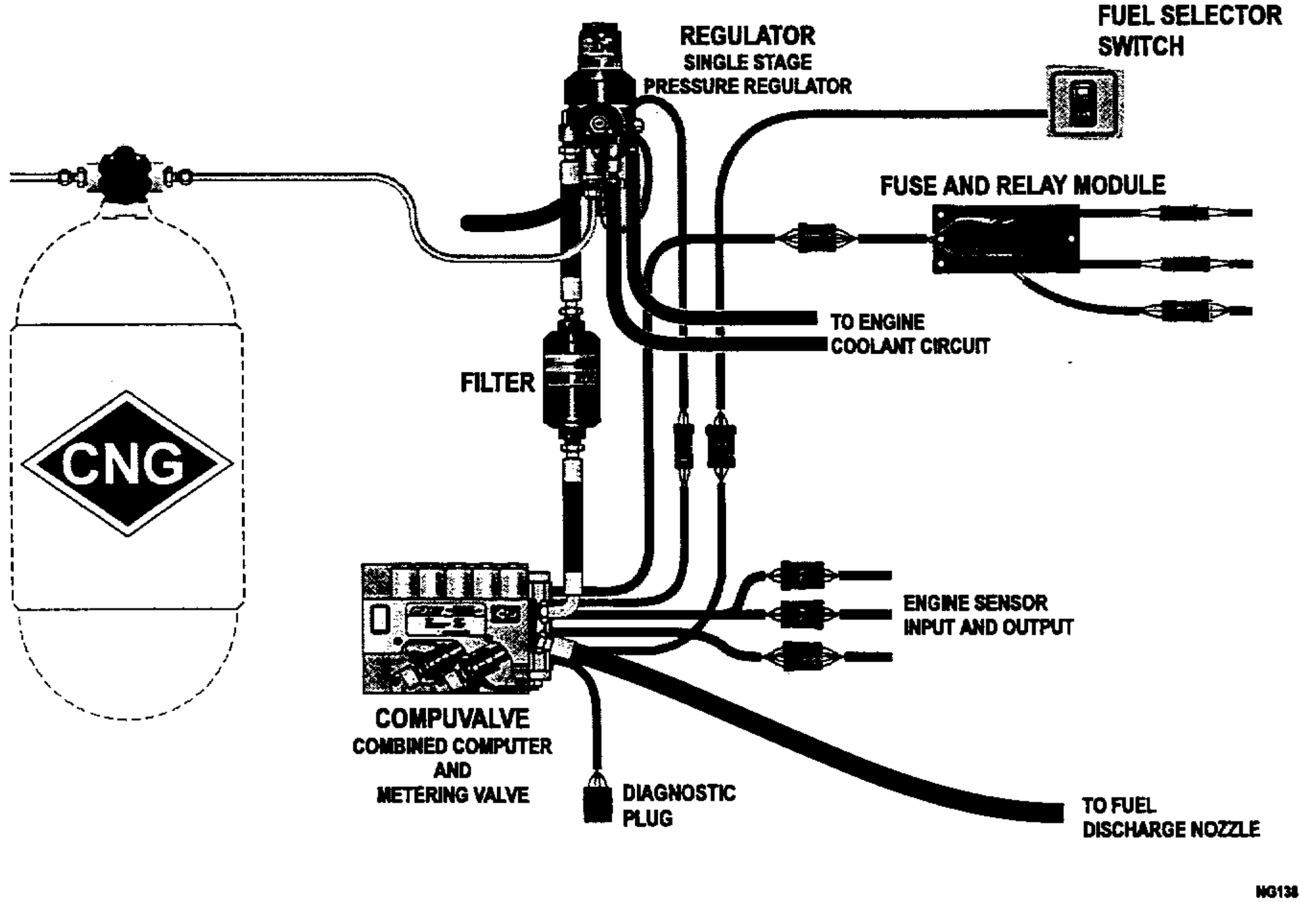


**Figure 2-1. Generalized Schematic of GFI Natural Gas Installation.**

## 2.2 REGULATOR

The GFI system uses a high pressure single stage regulator to control gas pressure. Natural gas enters the regulator at the inlet port (1) and goes through a 40 micron filter (2). This filtered gas proceeds to the high pressure solenoid activated valve (3) that, when activated , passes natural gas to the pressure regulator section and Fuel Storage Pressure (FSP) sensor (4).

The FSP sensor generates a signal that is sent to the *GFI* computer that, in turn, sends a compatible signal to the base vehicle fuel gauge. The fuel gauge responds by giving a natural gas pressure reading as it does for gasoline tank in normal mode operation.

The regulator section uses a conventional spring-diaphragm-pintle mechanism to regulate pressure in the outlet chamber . From the outlet chamber, regulated gas is passed to outlet port (5). The outlet chamber is also connected to a 175 psig pressure relief valve (6); if outlet chamber pressure exceeds 175 psi, the valve opens and vents to relief port (7) or alternate relief port (8).

This regulator uses engine coolant for heat control. Two standard ports (9) and (11) and one alternate port (10) are provided. The coolant is hosed to one port then returned through one of the other ports, no preferred coolant flow direction is required.

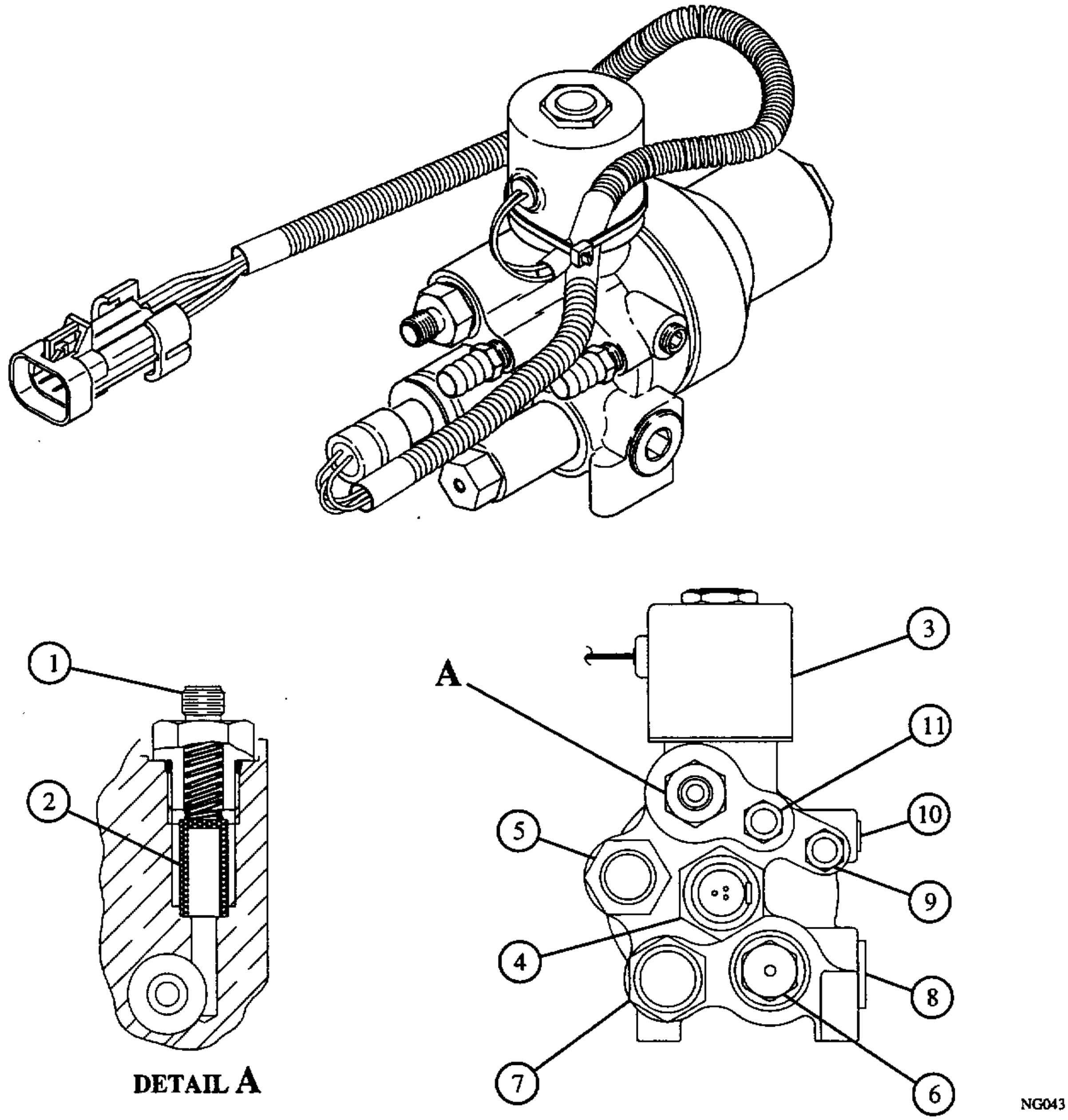


**Figure 2-2. Regulator Component Identification.**

| INDEX | DESCRIPTION | INDEX | DESCRIPTION |
|---|---|---|---|
| 1 | Fuel Inlet Fitting | 7 | Relief Port |
| 2 | 40 Micron Filter | 8 | Alternate Relief Port |
| 3 | High Pressure Solenoid | 9 | Coolant Port |
| 4 | Fuel Storage Pressure (FSP) Sensor | 10 | Alternate Coolant Port |
| 5 | Fuel Outlet Port | 11 | Coolant Port |
| 6 | Relief Valve | | |

## 2.3 COMPUVALVE

The compuvalve forms the intelligent operation of the GFI system. In a single package, it contains the metering valve and computer for the system, as well as, a number of input sensors used for the system.

### *2.3.1 METERING VALVE*

Regulated gas from the regulator enters through the inlet port (1) and flows through an internal fuel rail. The flow is controlled by 7 injectors: 5 high flow injectors (2) that operate in an on/off mode for major step changes; and 2 low flow injectors (3) that are pulse width modulated for flow trimming. These injectors are controlled by the computer. The metered gas flow is released through outlet port (4) to the fuel discharge nozzles.

### *2.3.2 COMPUTER*

The computer system routinely controls the following factors: Fuel Selection, Fuel Flow, Ignition Timing and a fuel vessel level signal to the OEM fuel gauge. The computer section consists of a 2 board computer module inside the electronics cavity of the metering valve. For calibration and adaptive memory, the ECU uses SRAM (Static Random Access Memory). Program memory is stored in ROM (Read Only Memory) . The memory is non-volatile and is neither reset nor lost when battery voltage is removed.

The software is responsible for calculations, based on calibration and sensor input, that result in computer commands that adjust fuel flow and ignition timing. The calibrations are programmable and consist of three parts:

- **Kit Characterization** includes corrections for production variability in: injectors, pressure transducers and temperature sensors. This is loaded at the factory and not accessible in the field.
- **Application Calibration** is responsible for fueling demand characteristics and spark system information. These are calibration files furnished by the factory to the distributor/dealer and are downloaded during installation.
- **Field Calibration** specifies information that is required for the area of operation (e.g. fuel composition and fuel gauge calibration). This information is entered by the installer during installation.

The computer uses speed density calculations for fuel flow and air flow to adjust the air to fuel mixture based on a stoichiometric value* for the fuel composition. Speed density calculations are based on knowing the temperature and pressure of air and fuel. The Manifold Absolute Pressure (MAP), Fuel Absolute Pressure (FAP) and Fuel Rail Temperature (FRT) are sensors located in the metering valve. The Intake Air Temperature (IAT) sensor is mounted in the intake system and the Manifold Skin Temperature (MST) is located on the intake manifold. Adjustments occur for each spark event.

The computer controls the High Pressure Solenoid (HPS). The solenoid is opened when natural gas is selected (bi-fuel applications) and the GFI system is energized for operation.

The signal from the Fuel Storage Pressure (FSP) sensor allows the GFI computer to display the natural gas fuel level on the dashboard fuel gauge when the vehicle is operating on alternative fuel.

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* Stoichiometric value is the optimum fuel to air ratio that will yield complete combustion of fuel and air. For natural gas this ratio is typically 16.4 parts air to 1 part fuel (for gasoline, the ratio is 14.7:1)

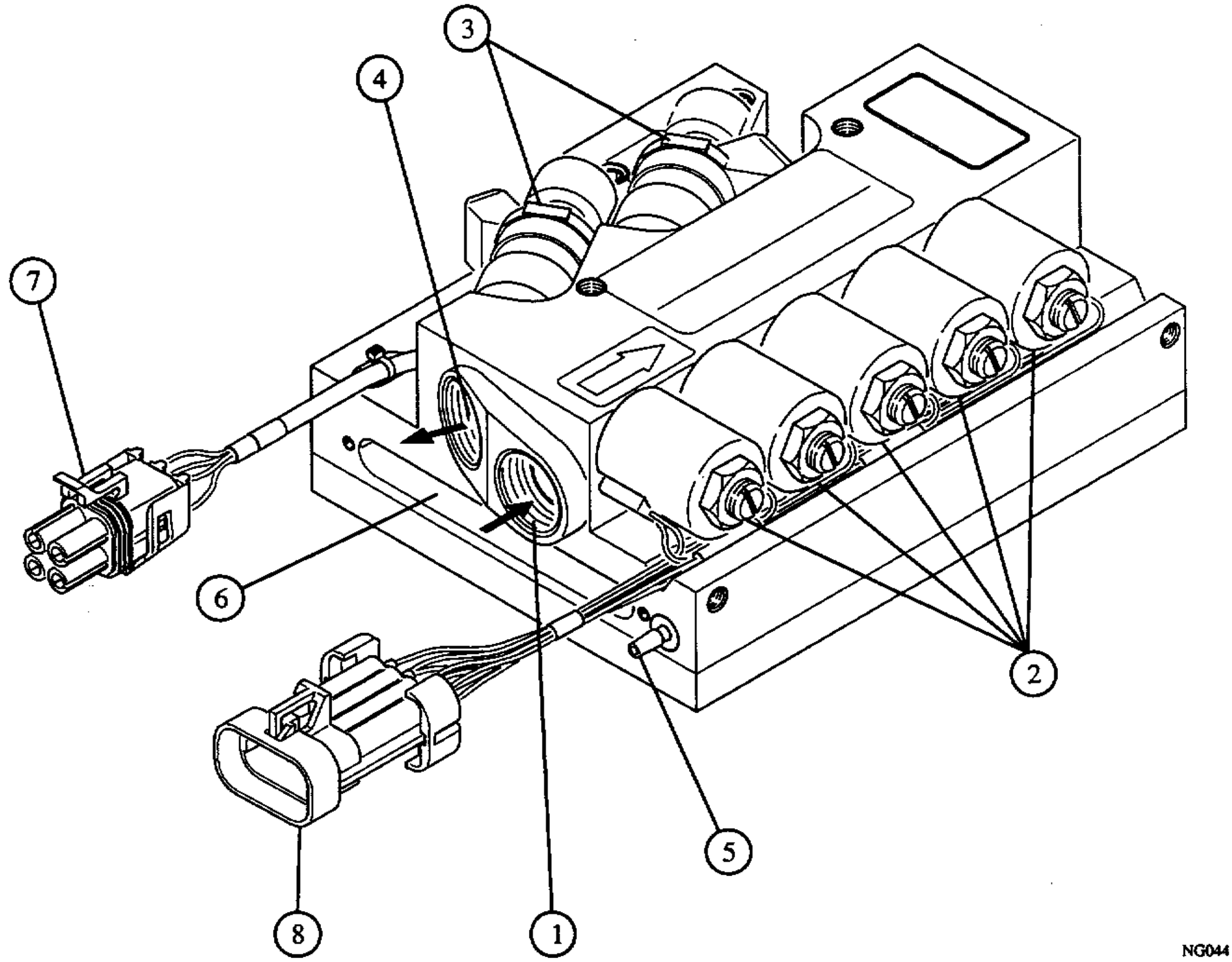


**Figure 2-3. Compuvalve Component Identification.**

| INDEX | DESCRIPTION | INDEX | DESCRIPTION |
|---|---|---|---|
| 1 | Fuel Inlet Port | 5 | MAP Inlet Barb |
| 2 | High Flow Injector Solenoids | 6 | Main Wire Harness Port |
| 3 | Low Flow Injectors | 7 | Low Flow Injector Connector |
| 4 | Fuel Outlet Port | 8 | High Flow Injector Connector |

## 2.4 GFI System Controls

Below the system block diagram shows the inputs and outputs and the fuel flow through the system.

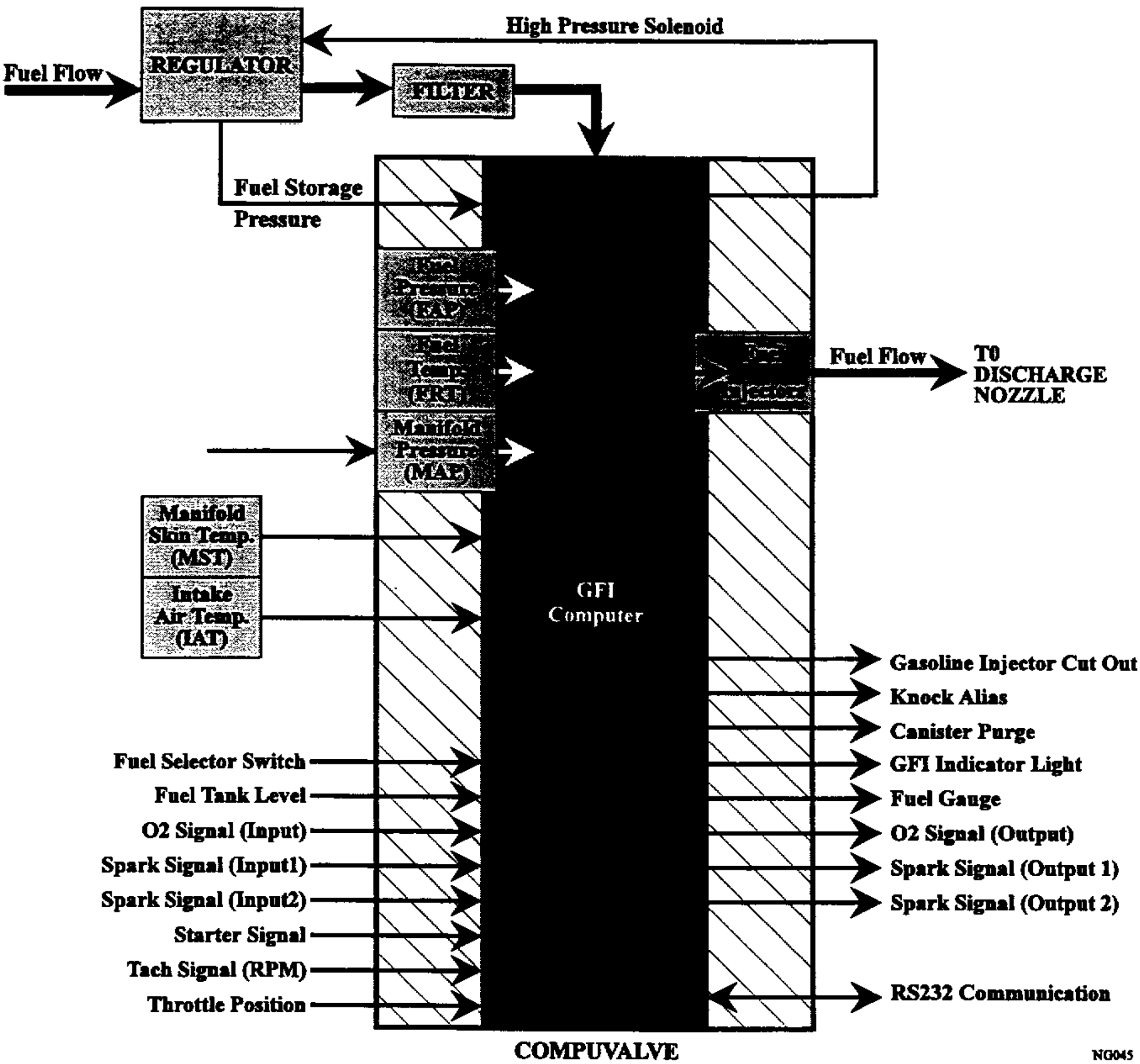


**Figure 2-4. Compuvalve & System Block Diagram.**

### 2.4.1 *Fuel Pressure Regulation*

High pressure CNG enter the single stage regulator. When the high pressure solenoid is open, the regulator delivers a nominal 100 psi to the compuvalve.

**NOTE:** *The regulator requires back pressure to open. If the low pressure line is disconnected or removed downstream, the regulator will not open.*

### 2.4.2 *Fuel Flow Calculation and Control*

The compuvalve uses a speed density calculation and feedback loop to determine the required fuel quantity for the engine's current demand. The computer selects the correct combination of injectors to deliver this flow. The correct mass of CNG is delivered through the metering valve to the discharge nozzle(s). This calculation is typically updated at every spark event.

### 2.4.3 *Fuel Gauge Control*

CNG tank pressure is registered on the fuel gauge while running CNG. Normal gasoline level is registered while running gasoline.

### 2.4.4 *Fuel Switch Over*

The compuvalve controls the automatic switch over from natural gas to gasoline. This event occurs when fuel pressure in the compuvalve falls below a specified level. Ignition timing, injector cut-out, fuel gauge control, and alias bypass must all be coordinated by the compuvalve.

**NOTE:** *Fuel supply cannot be switched when the vehicle is running. The key must be turned to off before fuel selection can be manually selected. This does not affect auto switchover.*

### 2.4.5 *RS-232 Port*

The GFI system computer has an RS-232 port that serves two basic functions: external programming and system monitoring. Refer to the Appendix for software application instructions.

### 2.4.6 *Ignition Timing*

To optimize emissions and power output, the system advances the base vehicle spark timing by 2 to 15 degrees. The system may or may not advance spark during idle, depending on the particular calibration. Spark advance is applied after 10 seconds of engine operation.

**NOTE:** *After 10 seconds, engine must be accelerated to 1000 rpm to initialize the spark advance. After the first application, advance will be applied, as required, down to 100 rpm.*

### 2.4.7 *GFI - Compuvalve Assembly*

To perform these functions, the computer utilizes input from several sensors and controls various devices. This system computer is located in the combined metering valve and computer assembly and is referred to as the compuvalve.

## 2.5 Inputs from GFI Devices

### *2.5.1 Barometric Absolute Pressure (BAP)*
This is a calculated value based on the MAP sensor reading before the engine begins crank. The result is displayed in inches of Mercury (in. Hg.) and does not reset until the engine is shutoff and restarted.

### *2.5.2 Dash Switch*
This is a single pole double throw (SPDT) switch mounted inside the vehicle. It is supplied with battery voltage through the compuvalve and returns voltage on either the ALT/FUEL (natural gas) or GSL (gasoline) selector line. If battery voltage is not returned on the ALT/FUEL line, the system defaults to gasoline mode.

**NOTE:** *The vehicle may not run in natural gas mode even though the switch is in the alternate fuel (GFI) position. The system requires several factors to be set before running alternate fuel, including sufficient pressure from the vaporizer/regulator.*

### *2.5.3 Fuel Absolute Pressure (FAP)*
This is a pressure transducer that converts pressure to voltage through a piezo-resistive element. It is internal to the compuvalve. The fuel pressure is used to adjust the injector combination according to supply pressure.

### *2.5.4 Fuel Rail Temperature (FRT)*
This device is a thermistor mounted in the fuel stream at the output of injector 1. It is supplied with 5 volts from the compuvalve. It is an internal sensor which cannot be serviced. As the temperature of the sensing element increases, its resistance decreases. FRT is used primarily to calculate fuel density.

### *2.5.5 Fuel Storage Level (FSP)*
This pressure transducer functions as a variable resistor. It is given a 5 volt reference, and outputs a voltage between 0.25 and 4.75 volts when exposed to a pressure of 0 to 3000 psi. It provides an indication of fuel vessel pressure to allow the compuvalve to drive the fuel gauge.

### *2.5.6 Intake Air Temperature (IAT)*
This device is a thermistor mounted in the air stream and is supplied with 5 volts from the compuvalve. As the temperature of the sensing element increases, its resistance decreases. IAT is used to calculate air density. A non-functioning sensor will give a constant reading of 47°C.

### *2.5.7 Manifold Absolute Pressure (MAP)*
This is a pressure transducer that converts pressure to voltage through a piezo-resistive element. It is internal to the compuvalve and is attached to the intake manifold via hose with a damper tube that is routed to an external hose barb. MAP is used to monitor the engine operating state. This reading is displayed in inches of mercury (in. Hg.).

**NOTE:** *Unusually high MAP values may be an indication of over fueling or a vacuum leak.*

### *2.5.8 Manifold Skin Temperature (MST)*
This device is a thermistor mounted on the engine and is supplied with 5 volts from the compuvalve. As the temperature of the sensing element increases, the resistance decreases. This sensor does not have the same temperature response as the IAT sensor. MST is used to calculate air/fuel density. A non-functioning sensor will give a constant reading of 77°C.

## 2.6 Inputs from Base Vehicle Sources

### 2.6.1 *Ground*

This is the most important connection in the entire system. It is imperative that these connections are solid and electrically sound. CONNECT GROUND CONNECTIONS BEFORE CONNECTING POWER OR ANY OTHER CONNECTIONS. Connection must be to a solid block or chassis ground - do not attach to body sheet metal.

### 2.6.2 *Battery (B+)*

This is a tap from an UNSWITCHED source of 12 volts. The line that is tapped must be capable of handling an additional 10A for the system. The system requires a nominal 9 volts to operate.

### 2.6.3 *Ignition Switched Battery (SW B+)*

This tap powers relay 1 to connect B+ to the compuvalve. This line MUST remain "hot" during cranking. There is a 200mA draw on this line.

### 2.6.4 *Gasoline Injectors*

The control lines to the base vehicle fuel injectors are fed through normally closed relays, that are open while running alternative fuels.

### 2.6.5 *O2 Sensor*

All zirconia based O2 sensors work on the same principle. A voltage swing is output when the sensor is exposed to near stoichiometric air/fuel mixture. If no oxygen is present (system rich), the output is .8 to .9 volts. If free oxygen is present (system lean) the output is approximately .2 volts. The compuvalve uses this signal to correct for small fueling errors.

A bad sensor may go undetected, as it may produce a voltage high enough to trigger the compuvalve or the standard gasoline system. It is recommended that the O2 sensor be inspected or replaced every 30,000 miles. The sensor may be tested by verifying that the output voltage swings from .2 v to .9 v at least once per second with the engine warm at 2000 rpm.

### 2.6.6 *Starter*

This tap allows the compuvalve to recognize CRANK. The system may provide additional fuel during cranking. This is used only when required by the calibration.

### 2.6.7 *TACH*

This tap provides the compuvalve with a data pulse once per spark event. This is used to determine engine rpm.

### 2.6.8 *TDC*

The compuvalve intercepts the top dead center (TDC) signal and advances the signal in time to optimize power and emissions.

### 2.6.9 *Gasoline Fuel Gauge Sender*

The resistance from the gasoline fuel tank level sender is fed into the compuvalve. This is typically from a variable resistance device mounted in the fuel tank. The signal is then passed through to the fuel gauge when in gasoline mode.

### 2.6.10 *Throttle Position Sensor (TPS)*

The GFI system monitors voltage from the base vehicle TPS as an indication of throttle position and to identify throttle transients. This feature is used only when specified in the specific vehicle supplement.

## 2.7 OUTPUT TO GFI DEVICES

### *2.7.1 HIGH PRESSURE SOLENOID (HPS)*

The solenoid opens to allow fuel into the regulator when the GFI computer applies voltage across the coil.

### *2.7.2 INJECTOR RELAYS*

These are normally closed relays that open the gasoline injector circuits when the GFI computer applies voltage across the coils of the relays.

### *2.7.3 DASH LIGHT (BI-FUEL ONLY)*

The dash light is a 12 volt device, powered when *GFI* is running on an alternative fuel. It is not and should not be connected to the selector switch.

### *2.7.4 COMPUVALVE INJECTORS*

There are two types of injectors used on the compuvalve. The metal cased injectors are "high flow" and deliver the higher volumes of fuel when required during cruise and acceleration. These are strictly on/off devices. The plastic cased injectors provide idle and trimming flow. These are pulsed as required.

## 2.8 OUTPUT TO BASE VEHICLE DEVICES

### *2.8.1 TDC*

The compuvalve outputs either the original signal(s) or a modified TDC signal. The system will only modify this signal while running in natural gas, and may be programmed not to modify the signal at idle or during partial throttle conditions (reference section 2.4.6).

**NOTE:** *The compuvalve must be powered up with B+ and SW B+ for the TDC signal to pass through in either natural gas or gasoline mode.*

### *2.8.2 O2 SENSOR*

The oxygen sensor signal is normally passed through the compuvalve and returned to the EEC computer input. In some cases, an alias signal is sent to the EEC computer when the system computer is programmed to do so.

### *2.8.3 FUEL GAUGE*

In natural gas mode, the GFI computer intercepts the normal base vehicle dashboard fuel gauge signal and substitutes a signal to indicate the volume (pressure) of natural gas in the storage vessel. The substitute signal is based on signals from the FSP sensor located on the regulator.