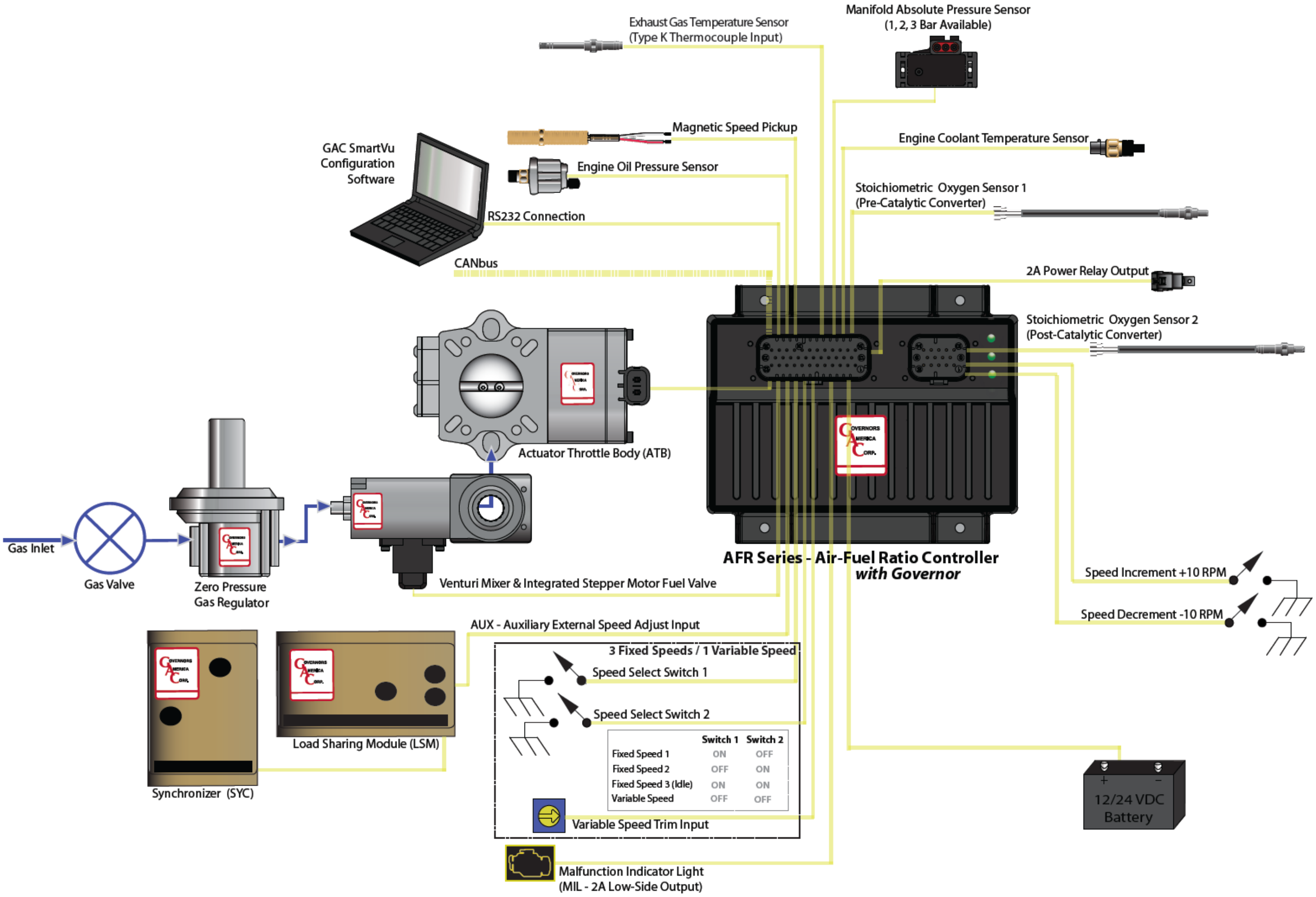
ENGINE
GOVERNING
SYSTEMS

AFR200 Series

Air Fuel Ratio Controller

GOVERNORS AMERICA CORP.®

PRODUCT USER GUIDE



	Switch 1	Switch 2
Fixed Speed 1	ON	OFF
Fixed Speed 2	OFF	ON
Fixed Speed 3 (Idle)	ON	ON
Variable Speed	OFF	OFF

EGSA Electrical Generating Systems Association

Governors America Corp., 720 Silver Street, Agawam, MA 01001
Tel: 413.786.5600, Fax: 413.789.7736
info@governors-america.com
www.governors-america.com

ISO 9001 CERTIFIED

GREEN
SOLUTIONS
for less green....

Table of Contents

1 Introduction

The Air Fuel Ratio (AFR) 200 series controller provides a comprehensive fuel management system for gaseous-fueled, spark-ignited engines which incorporates:

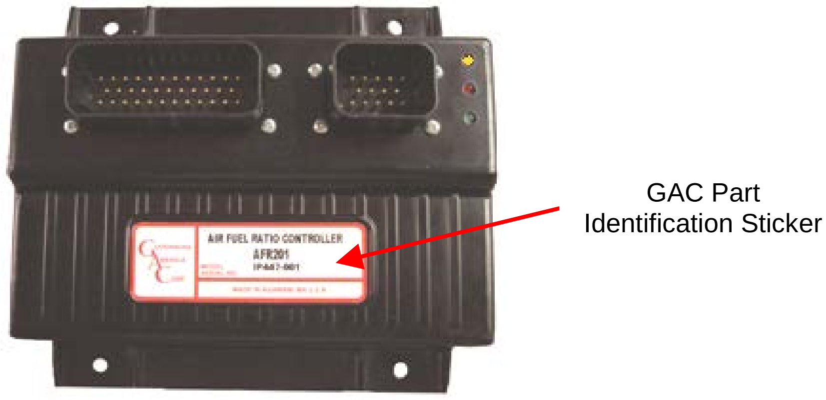
- Optimal closed loop air-fuel ratio and delivery control
- Actuator throttle body control
- A built-in engine speed governor
- Diagnostic capability
- Engine sensor and data monitoring
- CAN / serial communication
- Many optional sensor and binary inputs
- Easy configuration and customization using GAC's SmartVU software

The system is applicable to a wide range of gaseous fueled engines ranging from 1L to 13L+. The AFR200 series controllers when used in conjunction with the ICM200 (Ignition Control Module) series offers a complete Fuel and Ignition Management Solution (FIMS) referred to as the FIMS500 system. Each of these controllers has the ability to work independently of the other in the event of a failure.

The AFR200 series controller is ruggedly designed to be used in a wide variety of engine environments. The connector, harness and cast aluminum case are all environmentally sealed to IP-67. The AFR is designed to be highly reliable and includes protection against reverse battery voltage, transient voltages, short circuits and a loss of engine speed sensor signal or battery supply.

A representation of the AFR controller is shown in the following figure. The AFR has one 35-pin connector and one 14-pin connector although in some variations of the controller the 14-pin connector will be removed. This information is covered in greater detail in the following sections.

AFR200 Series Controller Identification



1.1 Certifications

The AFR system is capable of supporting the strict emission regulations of both the US and Europe; standards which most of the world follow. Once a system has been calibrated for optimal emissions results, the calibration can be loaded into subsequent engine packages with favorable repeatability.

2 Product Variations

There are a variety of different models of the AFR 200 series depending on the features desired as shown in the following table. Note that only the unique features are shown in the below table since the controllers share common standard inputs and features which are covered in greater detail in follow sections.

Product Selection Table

Model	Unique Features
AFR200	1 Oxygen Sensor Input
AFR201	2 Oxygen Sensor Inputs
AFR210	1 Oxygen Sensor Input 1 Exhaust Gas Temperature Input; Type K Thermocouple
AFR211	2 Oxygen Sensor Inputs 1 Exhaust Gas Temperature Input; Type K Thermocouple

2.1 AFR Product Selection Clarification

- Number of Oxygen Sensors: The number of oxygen sensors is either selected as one for pre-catalytic converter (or no converter) or two (pre- and post-catalytic) if additional diagnostic capability is desired for the catalytic converter itself.

- Exhaust Temperature Input: The AFR has the ability to protect the engine in the event of an over-temperature condition using a type K thermocouple sensor placed in the exhaust stream.

2.2 Standard Features

- Optimal Closed Loop Air-Fuel Ratio and Delivery Control:

    - Actuator Throttle Body or Universal Actuator Control
    - Proprietary, Fast Responding, Non-Linear, Air/Fuel Ratio Control
    - Variable O2 Lambda Control Strategy; Engine Speed vs. Load Mapping
    - Fail-safe Open Loop Control for Initial Tuning Values and Troubleshooting
    - Industrial, Highly Accurate Stepper Motor Integrated with Venturi Mixer
    - Programmable Stepper Motor Start Position

- Built-in Engine Speed Governor:

    - Multi PID Governing EDG™ Designed to Control Engine Speed with Precise Response to Transient Load Changes
    - Three Fixed Speeds & One Variable Speed
    - Overspeed Shutdown Protection
    - Speed Ramping from Idle to Operation Speed
    - Starting Fuel Control for Lower Engine Exhaust Emissions
    - Full PID Adjustment Capability

- Engine Sensor Data Monitoring and Diagnostic Capability:

  - Pre- and Post-Catalytic Converter Oxygen Sensor
  - Manifold Absolute Pressure (MAP) Sensor 1, 2, or 3 Bar (14.5, 29, 43.5 PSI)
  - Magnetic Speed Pickup
  - Exhaust Gas Temperature Sensor; Type K Thermocouple
  - Oil Pressure Sensor
  - Coolant Temperature Sensor

- Inputs and Outputs:

  - Power Relay Output (2A)
  - Malfunction Indicator Lamp (MIL) Output & Status LEDs
  - Speed Increment / Decrement +/- 10 RPM Binary Inputs
  - Auxiliary Speed Trim Input

- CAN / Serial RS232 Communication:

  - Diagnostic Trouble Code (DTC) Support
  - J1939 Data Broadcast

- GAC's SmartVU Software:

  - Data Monitoring / Graphing Functionality
  - Easy Configuration and Customization
  - Import / Export Calibration Capability
  - Advanced Troubleshooting Data
  - Diagnostic Timers and Logging Windows

- 12 and 24VDC Compatible

- High Reliability

3 Operational Description

3.1 Overview

The AFR's fuel control algorithm maintains a stoichiometric air-fuel ratio for optimized emissions and engine performance. Engine speed can be governed in either isochronous or droop modes using GAC's proprietary Electronic Digital Governor (EDG) algorithm.

The AFR control operates the closed loop fuel system with five major components:

- Digital precise stepper motor fuel control valve to adjust the flow of fuel into the system
- Static venturi mixer to combine fuel and air to the appropriate mixture
- Electrically controlled throttle body valve or universal actuator to control the amount of air mixture that enters the engines intake manifold based on engine speed input
- Oxygen sensor to monitor exhaust to determine whether the engine is running lean or rich
- Manifold Air Pressure (MAP) sensor to measure intake manifold pressure (or vacuum)

For added control and engine protection, the AFR can also sense the following optional sensors:

- Second (post-catalytic) oxygen sensor
- Engine Oil Pressure (EOP) sensor
- Engine Coolant Temperature (ECT) sensor
- Exhaust Gas Temperature (EGT) sensor; Type K thermocouple

3.2 Air Fuel Ratio (AFR) Controller Feedback Inputs

The following sensors are mandatory and used by the AFR for closed-loop control of the air fuel ratio and engine speed governing.

3.2.1 Pre-Catalytic Converter Oxygen (O2) Sensor

The AFR uses a narrow-band oxygen sensor, located after the merge point in the exhaust manifold / plumbing and before any exhaust conditioners. This sensor output is between 0 and 1V based on the oxygen concentration in the exhaust gas. The closed loop feedback is accomplished by varying fueling based on engine speed and load in addition to the oxygen sensor output.

When no signal is received from the O2 sensor, the sensor fails, or the sensor is not at operating temperature (must be greater than 600°F) as is the case when a cold engine is first started, the AFR orders a fixed (unchanging) rich fuel mixture. This is referred to as "open loop" operation because no input is used from the O2 sensor to regulate the fuel mixture.

Adaptation is further carried out by a feedback / predictive algorithm which uses customizable PIDs. The predefined table values are then changed real-time to ensure the desired oxygen sensor voltage set point (lambda value) is constantly maintained. The air fuel mixture is constantly adjusted which results in a switching from lean to rich and vice versa in order to operate at peak efficiency and minimize emissions.

Voltages near 0.9V indicate that the fuel mixture is rich and there is little unburned oxygen in the exhaust whereas voltages closer to 0.1V indicate the mixture is lean. At 0.5V the engine is operating at stoichiometry.

3.2.2 Manifold Absolute Pressure (MAP) sensor

A pressure sensitive electronic circuit inside the MAP sensor monitors the movement of the internal diaphragm and generates a voltage signal that changes in proportion to intake manifold pressure. This produces an analog voltage signal that typically ranges from 0.5 to 4.5 volts. The output voltage usually increases when the throttle is opened and vacuum drops. The Manifold Absolute Pressure (MAP) sensor is a key sensor because it is used to determine engine load. It is optional if none of the multi-PID functionality is desired.

3.2.3 Engine Speed Sensor

Engine speed information for the speed governing algorithm is usually received from a magnetic speed sensor. The speed sensor is typically mounted in close proximity to an engine driven ferrous gear, usually the engine flywheel ring gear. As the teeth of the gear pass the magnetic sensor, a signal is generated which is proportional to engine speed.

Other speed sensing devices may be used, provided the generated frequency is proportional to the engine speed and meets the voltage and frequency range specification. The AFR will begin to govern the engine once the RPM reaches the crank termination set point.

3.3 Speed Control and Protection

The proprietary multiple PID governor control system provides fast and accurate control (+/- 0.25%) of the engines speed to any dynamic load changes in isochronous or droop operation. When connected to a throttle body actuator and supplied with a magnetic speed sensor signal the governor portion will direct the engine to the desired speed setting.

The governor has several built in configurable features: three fixed and variable speed with correlating droop settings; engine overspeed shutdown protection; speed ramping from idle to operation speed; and starting fuel control for lower engine exhaust emissions. The three fixed governed speeds and one variable governed speed are all selectable through two discrete inputs. An additional accessory input is available for connecting to GAC load sharing modules (generator set option).

The AFR will protect the engine by shutting it down in the event of an engine overspeed, low oil pressure, high coolant temperature, or high exhaust temperature. These thresholds are all customizable using SmartVU. Additionally the controller is designed to withstand reverse polarity connections, transient voltage spikes, and engine speed data loss in the event of a failure.

3.3.1 Auxiliary (AUX) Speed Trim Input

The auxiliary input signal is intended to provide a speed trim input for the engine to synchronize with another power source / generator. The aux input range is 0-10 volts with a nominal value of 5 VDC. When enabled, the input tells the governor what speed to set the engine to.

The AFR is configured for a negative slope meaning that a value of 10V will be the lowest engine speed and 0V will be the highest engine speed. The default window for engine speed adjustment is + / - 10% from the fixed speed setting.

3.4 Fueling States

During the engine cranking cycle, starting fuel can be adjusted from an almost closed, to a nearly full fuel position. Once the engine has started, the speed control point is determined by the idle speed set point and the speed ramping algorithm. The speed ramping functions adjust the engines speed acceleration and deceleration and is fully customizable by SmartVU.

After engine speed ramping has been completed, the engine will be at its governed operating speed. When at the desired governed engine speed, the actuator will be energized with sufficient current to maintain the desired engine speed in a closed loop speed control, independent of engine load (isochronous operation).

3.5 Communication & Configuration

The controller has both RS232 and CANbus communication capability. Communication with SmartVU is done over RS232 using a serial port or USB to serial converter. The CANbus is typically used to communicate with other devices such as J1939 capable display devices, and data readers.

3.5.1 SmartVU Configuration Software

The AFR is programmed and calibrated using GAC's SmartVU configuration software. The SmartVU interface allows the user the ability to customize engine performance real-time, monitor data, view diagnostic information, and store configurations. This information is covered in greater detail in later sections.

3.5.2 Diagnostics

The AFR has the ability to diagnose and indicate numerous failure conditions as well as store an extensive fault history. This information is readily indicated by the Malfunction Indicator Lamp (MIL) output or by the status indication LEDs on the AFR itself. For more detailed diagnostics the SmartVU diagnostic interface provides a host of information including engine data, speed vs. load mapping and OBDII P-codes and GAC G-codes. This information is covered in greater detail in later sections.

3.6 Optional Sensors

The following section covers the optional sensors which are available for interface with the AFR. Note that the post-catalytic oxygen and the exhaust gas temperature sensor capability are only available with certain variations of the AFR whereas the engine oil pressure and coolant temperature sensor inputs are available with all variations.

3.6.1 Post-Catalytic Oxygen (O2) Sensor

An additional narrow-band stoichiometric oxygen sensor can be mounted in or behind the catalytic converter to monitor converter efficiency. These are referred to as the downstream O2 sensors. A downstream oxygen sensor works exactly the same as an upstream O2 sensor in the exhaust manifold. If the converter is doing its job and is reducing the pollutants in the exhaust, the downstream oxygen sensor should show little activity (few lean-to-rich transitions, which are also called "cross-counts"). The sensor's voltage reading should also be fairly steady (not changing up or down), and average 0.45 volts or higher. If the signal from the downstream oxygen sensor starts to mirror that from the upstream oxygen sensor(s), it means converter efficiency has dropped off and the converter isn't cleaning up the pollutants in the exhaust.

3.6.2 Engine Oil Pressure (EOP) Sensor

The engine oil pressure sensor is used by the AFR in order to diagnose and determine whether or not a low oil pressure condition exists during engine operation. The setpoint is entered via SmartVU and the AFR will then shutdown the engine in the event of a failure.

3.6.3 Engine Coolant Temperature (ECT) Sensor

The engine coolant temperature sensor is used by the AFR to gauge engine temperature and alert the operator or shutdown the engine in the event of an over temperature condition. The GAC offered coolant temperature sensor is a thermistor where the sensors resistance varies inversely to temperature changes. This number can be displayed on a scan tool, and may also be used by the instrument panel cluster or driver information center to display the temperature reading of the coolant.

3.6.4 Exhaust Gas Temperature (EGT) Sensor

The AFR has the ability to monitor a type K thermocouple to determine engine exhaust gas temperature. If the high temperature threshold is exceeded during operation, the AFR will impose a de-rate in throttle % and will allow the system to recover once the temperature has returned to the normal operating region. If the temperature does not decrease over a set time interval the AFR will shut the engine down. These limits and thresholds can be calibrated within the AFR controller using SmartVU.

3.7 Binary Inputs / Outputs

The following section covers the various low-side (close to ground) outputs and inputs the AFR includes.

3.7.1 Power Relay Output

The AFR includes a 2A low-side binary output for control of the power relay. The power relay is used to provide power to the oxygen sensor heaters as well as control the shutdown of the engine. This information is detailed greater in following sections.

3.7.2 Malfunction Indicator Lamp (MIL) Output

The AFR provides an optional Malfunction Indicator Lamp (MIL) output which can be wired to an external fault lamp or buzzer in order to indicate engine, sensor, or controller malfunctions. This output is triggered to match the Fault LED on the AFR itself. The max current is 2A and the output is a 12V or 24V high side output. The blink patterns and fault indication is covered in greater detail in the diagnostics section.

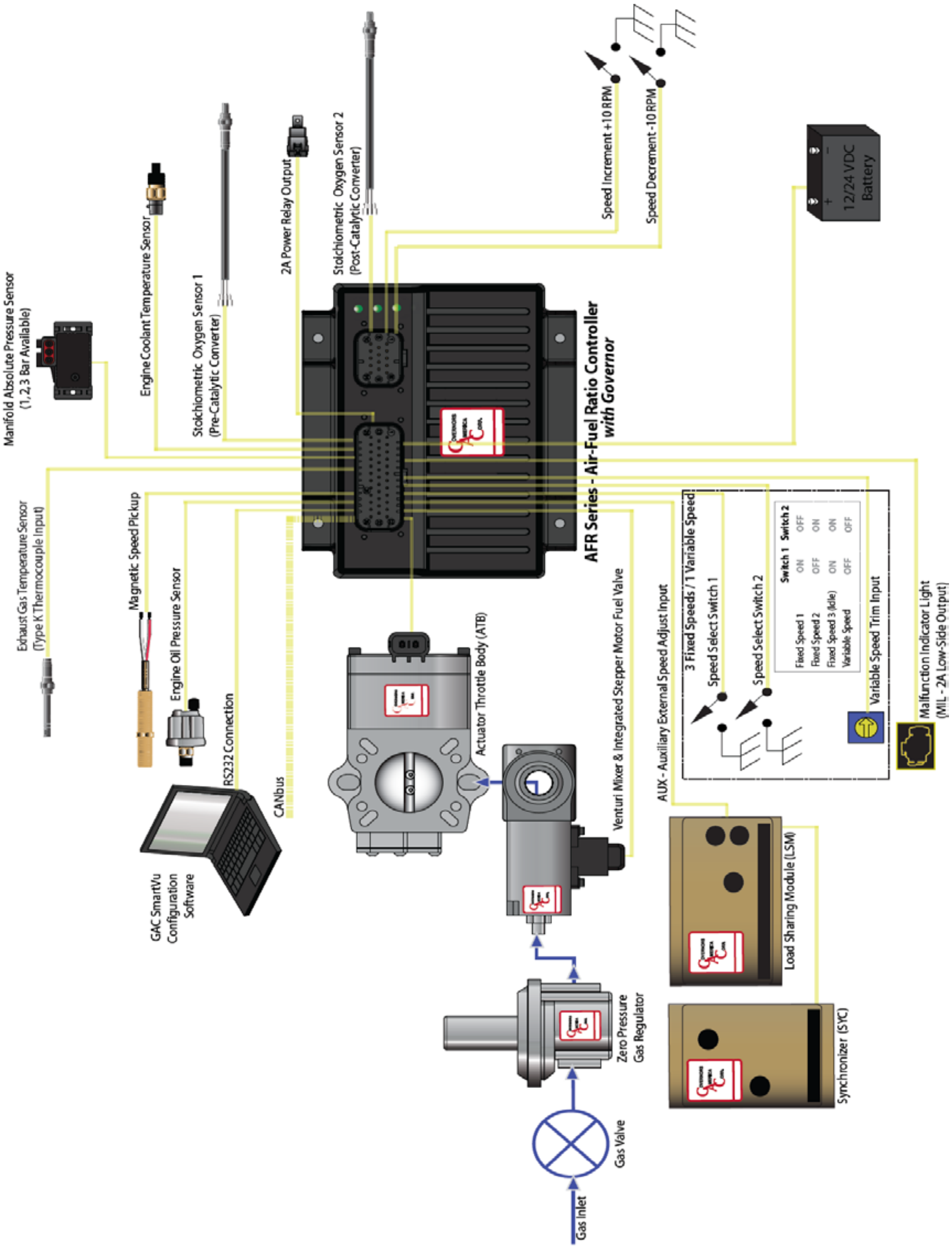
3.7.3 Engine Speed Increment / Decrement

The AFR has two active low binary inputs used to control variable speed increment and decrement. When tied to ground momentarily each of these inputs will either increment or decrement engine speed by 10 RPM while in variable speed mode.

⚠ **WARNING**

Take extreme caution when using this feature since it will allow adjustment through the full range of engine RPM up to the overspeed setpoint if the limits have not been calibrated.

4 System Interconnect Diagram



	Switch 1	Switch 2
Fixed Speed 1	ON	OFF
Fixed Speed 2	OFF	ON
Fixed Speed 3 (Idle)	ON	ON
Variable Speed	OFF	OFF

5 AFR Components and Optional Equipment

5.1 AFR & Related GAC Components Table

Component	GAC Part Number	Description
Air Fuel Ratio Controller (AFR)	AFR200	1 x O_2 Sensor Capable
	AFR201	2 x O_2 Sensor Capable
	AFR210	1 x O_2 Sensor, EGT Capable
	AFR211	2 x O_2 Sensor, EGT Capable
AFR Mating Connectors	EC1501	Connector J1 (35 - PIN)
	EC1502	Connector J2 (14 – PIN) *Note this connector is not used on the AFR200 and 210.
	CH1519	AFR200 Series Harness Kit, 35-Terminal
	CH1520	AFR200 Series Harness Kit, 14-Terminal
Actuator Throttle Bodies (ATBs)	Numerous	See information provided in following section. Connector Included
Air-Fuel Mixer / Control Valves	MXSB20,22,24,26, 28,30-STM	Size 20,22,24,26,28,30 w/ integrated stepper motor control valve (T1)
	MXMB40,42,44,46, 48,50 –STM, MXLB75,85-STM	Size 40,42,44,46,48,50 w/ integrated stepper motor control valve (T2)
Stepper Motor Mating Connector	EC1507	4-pin Delphi Mating Connector for Fuel Control Valve Stepper Motor (T3)
Zero Pressure Gas Regulators	RPR102	With 3/4" NPT Fittings, R500Z
	RPR103	With 1" NPT Fittings, R600Z
	RPR104	With 1” NPT Fittings, R600Z
Oxygen Sensors	SOX102	Heated Narrow-Band 02 Sensor; 12V
	SOX103	Narrow-Band, O2 Sensor, 24V
Oxygen Sensor Mating Connector	EC1508	4-pin O2 Sensor Mating Connector; SOX102
	EC1520	2-pin O2 Sensor Mating Connector; SOX103
Manifold Absolute Pressure (MAP) Sensors	SPM200-1B	MAP - 1 Bar (14.5 PSI)
	SPM201-2B	MAP - 2 Bar (29 PSI)
	SPM202-3B	MAP - 3 Bar (43.5 PSI)
Manifold Absolute Pressure (MAP) Mating Connector	EC1509	Mating Connector MAP - 1 Bar
	EC1510	Mating Connector MAP - 2 Bar
	EC1511	Mating Connector MAP - 3 Bar
Engine Oil Pressure Sensor (EOP)	SPO100	10 Bar (150 PSI) w/ Knurled Nut, Ring #10 Posts, 1/8-27 NPTF
Engine Coolant Temperature Sensor (ETC)	STC101	250°F (120°C) w/ Two Male 1/4” Quick Connect Terminals, 3/8-18 NPT
Exhaust Gas Temperature Sensor (EGT)	STE101	Type K Thermocouple w/ Mini-TC Connector & Mate, 1/4 NPT
Magnetic Speed Sensors	Numerous	See information provided under Engine Sensor Installation & Information

Speed Trim Potentiometers	Numerous	See information provided under Component Selection Information
Power Control Relay	RLY02-1009	Power Relay Kit, 12V only, 1-pole, N.O.
	RLY02-1011	Power Relay Kit, 24V only, 1-pole, N.O.
	EC1506	Relay Mating Connector
RS232 PC Interface	EC1516	DB-9 Female Connector & Backshell
	EAM204	USB to RS232 Adapter
Fuse Mating Connector Kit	EC1505	Fuse Holder Assembly – ATC

5.2 Component Selection Information

The following sections provide detail on sizing or choosing the various components offered from GAC for the AFR200 series controller.

5.2.1 GAC Actuator Throttle Bodies

GAC has developed a matrix to help identify the correct bore size for a throttle body. The information needed to determine the sizing is the engine displacement as well as the operating RPM. When selecting the bore size ensure that the choice made offers some leeway both upward and downward to provide margin.

For GAC provided actuator throttle bodies refer to the following link to the ATB Application Matrix to select the correct bore size:

- http://www.governors-america.com/public_file/file/86/Application_Matrix.jpg?1243535515
    - Since this information is based on ideal situations the bore selection may need to be changed once tested in actual application.

For GAC actuator throttle body variations refer to the following link for product information:

- http://www.governors-america.com/throttle_body_actuators.html
    - The AFR is only capable of driving a universal actuator or GAC actuator throttle body up to 6A of continuous current draw. This limits the selection to the T1 and T2 actuator throttle body families which are available in the following bore sizes:
        - T1: 25, 30, 35, 40mm
        - T2: 45, 55, 65mm
        - T3: 75, 85mm
        - T4: 85mm and more (future)
    - AFR installations DO NOT require the feedback version of the ATB which incorporates a position sensor for accurate control.
    - Due to high intake manifold pressure certain applications require internal sealing as well as high temperature capability.
    - GAC offers both 12V and 24V versions of the ATBs so ensure the correct version is selected.

5.2.2 Air-Fuel Mixer / Control Valve Assembly

The following table is used to determine the appropriate air-fuel mixer selection (MX) as cross-referenced to the ATB bore size for optimal engine performance.

MXSB & T1 ATB / Mixer Compatibility Matrix*

Mixer Type			T1 ATB Size			
Mixer P/N	**Throat Size (inch)**	**Throat Size (mm)**	**25mm**	**30mm**	**35mm**	**40mm**
MXSB20	0.625	15.88	X			
MXSB22	0.6875	17.46	**X**			
MXSB24	0.75	19.05	X	X		
MXSB26	0.8125	20.64		**X**	X	
MXSB28	0.875	22.23		X	**X**	X
MXSB30	0.9375	23.81			X	**X**

T2 ATB / Mixer Compatibility Matrix*

Mixer Type			T2 ATB Size		
Mixer P/N	**Throat Size (inch)**	**Throat Size (mm)**	**45mm**	**55mm**	**65mm**
MXMB40	1.25	31.75	**X**		
MXMB42	1.3125	33.34	X	X	
MXMB44	1.375	34.93	X	X	
MXMB46	1.4375	36.51		**X**	X
MXMB48	1.5	38.10		X	X
MXMB50	1.5625	39.69			**X**

T3 ATB / Mixer Compatibility Matrix

Mixer Type			T3 ATB Size	
Mixer P/N	**Throat Size (inch)**	**Throat Size (mm)**	**75mm**	**85mm**
MXLB75	2.41”	61.22”	**X**	
MXLB85	2.60”	66.00”		**X**

Important Note: The information provided is the recommended pairings of ATB’s and air-fuel mixers with the most common combination emphasized in bold. The actual application may dictate a different pairing. In some cases, there are more than one possible choice of mixer for a given throttle body. Contact your GAC representative for confirmation on mixer sizing prior to ordering.

5.2.2.1 Mixer Nomenclature Clarification

The mixer part numbers are provided as MXSB##, MXMB## and MXLB## with the SB designating Small-Bore MB designating Medium-Bore and LB designating Large-Bore.

- The MXSB series bolts directly to the T1 GAC ATB family (available up to 40mm)
- The MXMB series bolts directly to the T2 GAC ATB family (available up to 65mm)
- The MXLB series bolts directly to the T3 GAC ATB family (available up to 85mm) or T4 (85mm and above)

Important Note: The ## is provided in 32nds of an inch at the venturi mixer throat. For example, the MXSB20 is 20/32 in. throat diameter.

5.2.3 Zero Pressure Gas Regulator

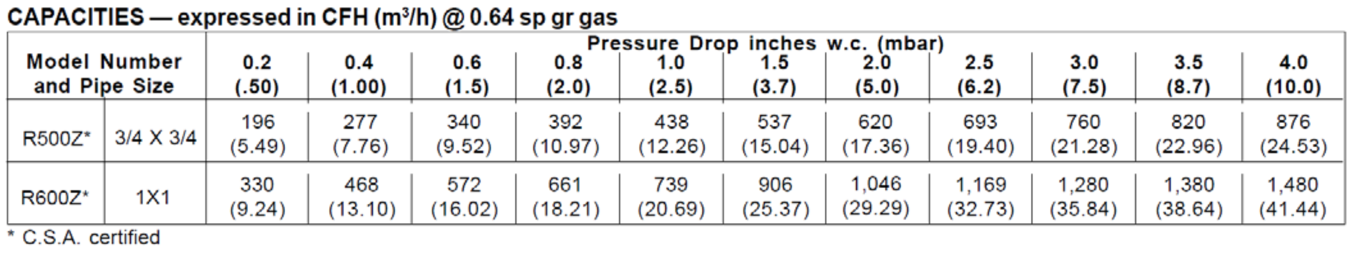
There are two varieties of Maxitrol Zero Pressure Gas Regulators offered by GAC. These are:

- RPR102 – Maxitrol R500Z – 3/4” NPT Fitting
- RPR103 - Maxitrol R600Z – 1” NPT Fitting

In most cases you can simply select the correct version of the regulator by choosing the size fitting you prefer and ensuring that the pressure drop is within the allowable range using the provided data**.**

Important Note: The venturi mixer & fuel control valve assembly may have a different size fitting, select interconnect plumbing accordingly.

Zero Pressure Gas Regulator Capacities



CAPACITIES — expressed in CFH (m³/h) @ 0.64 sp gr gas

Model Number and Pipe Size		Pressure Drop inches w.c. (mbar)										
		0.2 (.50)	0.4 (1.00)	0.6 (1.5)	0.8 (2.0)	1.0 (2.5)	1.5 (3.7)	2.0 (5.0)	2.5 (6.2)	3.0 (7.5)	3.5 (8.7)	4.0 (10.0)
R500Z*	3/4 X 3/4	196 (5.49)	277 (7.76)	340 (9.52)	392 (10.97)	438 (12.26)	537 (15.04)	620 (17.36)	693 (19.40)	760 (21.28)	820 (22.96)	876 (24.53)
R600Z*	1X1	330 (9.24)	468 (13.10)	572 (16.02)	661 (18.21)	739 (20.69)	906 (25.37)	1,046 (29.29)	1,169 (32.73)	1,280 (35.84)	1,380 (38.64)	1,480 (41.44)

* C.S.A. certified

5.2.4 Electronic Gas Lockout Valve

This is a non-GAC provided item. Refer to the application / installation information in the Component Information and Installation section for further information on selecting the correct electronic gas lockout valve.

5.2.5 Air Filtration

This is a non-GAC provided item. Refer to the application / installation information in the Component Information and Installation section for further information on selecting the correct air filtration system.

5.2.6 Engine Sensors

Although each of the sensors offered by GAC has been fully validated and approved for use with the AFR system there is always the option of using an alternate supplier as long as the sensor is equivalent in electrical characteristics. The application and installation information provided in following sections provide greater detail on selecting the appropriate sensors.

5.2.7 Speed Trim Potentiometers

The following information details the various variable speed trim potentiometers available for purchase from GAC. The following table shows the various part numbers and a brief description of these components. Note that the greater the resistance and the higher number of turns will provide the greatest precision over speed control.

Speed Trim Potentiometers

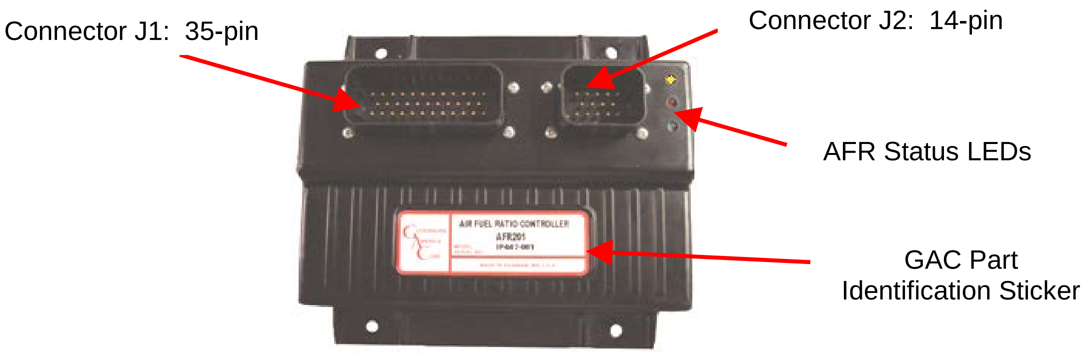
GAC Part Number	Turns	Resistance (Ω)	Features
TP510	10	1k	--
TP501	1	5k	Knob Included
TP502	10	5k	Knob Included
TP503	10	5k	Locking Shaft
TP511	10	10k	--
TP509	10	20k	Knob Included
TP508	10	20k	Locking Shaft

6 Component Information & Installation

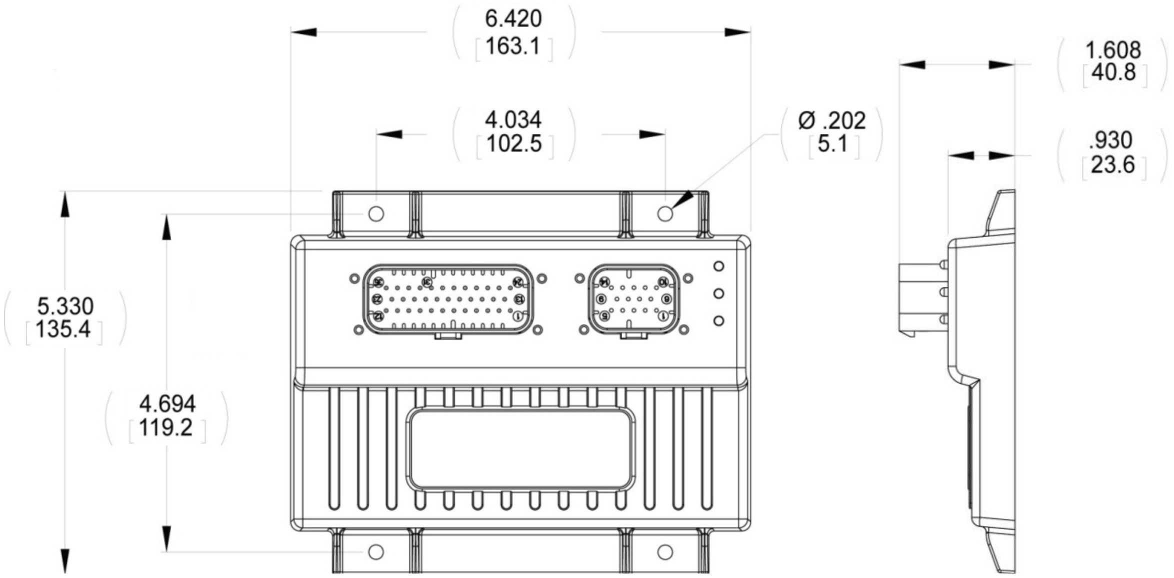
6.1 AFR 200 Series Controller

The AFR 200 is environmentally sealed and has a wide operating temperature range allowing it to be mounted directly to the engine on a flat plate in an area that does not exceed the unit's environmental specifications. A picture of the controller is provided in the following figure**.** The AFR200 and 210 will only have the 35-pin connector (J1) where as the other variations will have both connectors.

AFR200 Series Controller Identification



AFR Dimensions
Dimensions shown as in. [mm]



6.1.1 Application Considerations

- Do not select a mounting location on or near areas of high temperature components such as exhaust systems and turbochargers.
    - The max ambient operating temperature of the controller is 185° F [85° C].
- If the AFR is not mounted to a bulkhead ensure the mounting bracket is designed to withstand vibration using vibration isolators, dampers, standoffs or multi-point mounting as needed.
    - The AFR has been tested to 7G's @ 20 – 2000 Hz but excessive vibration can cause damage to harnessing due to chafing and other factors.
    - Select a bracket material and geometry that supports the AFR securely without flexing due to vibration.
- Allow a minimum of 3 in. [76.2mm] in front of the controller to for harness connection and serviceability.
- When selecting a mounting location ensure the AFR status indication LEDs are clearly visible for diagnostic and troubleshooting purposes.
- Mount the AFR so that the connectors are not facing upward in order to avoid possible water intrusion.
- Select a flat surface or bracket for mounting the AFR to avoid flexing the controller packaging during installation.
- Mount the AFR in a location clear from walkways and steps so that the controller will not be damaged during routine maintenance and operation.
- Choose mounting hardware using the dimensions shown (i.e. Diameter < 0.202 in. [5.1mm]).

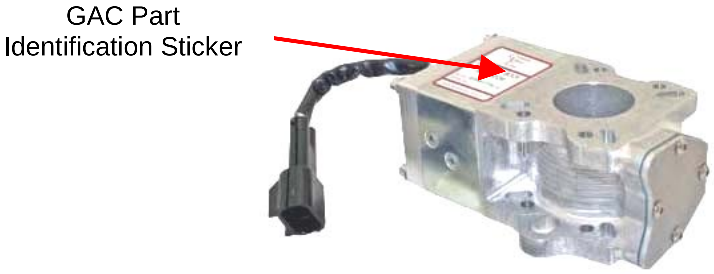
6.1.2 Installation Instructions

1. Clean the mounting area from any debris prior to mounting the AFR.
2. Mount the AFR to the selected location using a bracket or a direct to bulkhead mounting scheme using the dimensions and application information provided.
    - If stand-offs or vibration isolators are required, make sure these are in place prior to proceeding.
3. Insert the mounting hardware selected into the four holes on the AFR.
    - Pre-drill and tap the locations as required prior to installation.
4. Using standard values, torque the selected mounting hardware down to a maximum of 3-6 lb. in. [0.34-0.68 N•m] without applying excessive force to avoid damaging the mounting tabs or flexing the controller.
    - Ensure that each of the mounting bolts / screws is torqued evenly and gradually.

6.2 GAC Actuator Throttle Body (ATB)

A representation of the GAC Actuator Throttle Body (ATB) is shown in the following figure. The GAC part identification sticker is located on the top of the assembly for reference. The ATB is selected using the ATB Application Matrix which utilizes the displacement of the engine and the desired operating RPM detailed previously.

ATB Representation
T1 model shown



For GAC actuator throttle body (ATB) dimensions and mounting patterns for the ATBs refer to the following link for product information: http://www.governors-america.com/throttle_body_actuators.html

6.2.1 Application Considerations

- The throttle plate shaft of the ATB should be parallel with the engine crankshaft so that air flow is equally distributed to all cylinders.
- Ensure there is adequate clearance above and around the ATB for installation of the required air intake components and the air fuel mixer / valve assembly using the provided dimensions**.**
- Select the mounting bolts using the dimensions provided to ensure the length and diameter are appropriate.
- Turbo-charged applications require internal seals due to the high intake manifold pressure and depending on the mounting location a High-Temperature variation will also be required.
    - When selecting an installation location for the ATB in turbo-charged applications the preferred location is as close to the intake manifold as possible and after any charge air cooler to ensure proper operation.

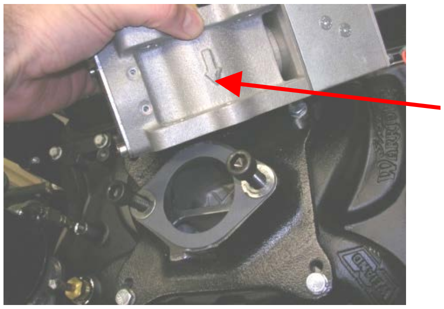
6.2.2 Installation Procedure

The following information is divided between naturally aspirated engines and turbo-charged applications due to the differences in mounting locations. Once again, this information refers to GAC ATBs only.

6.2.2.1 Naturally Aspirated Engines

1. Clean the mounting area to the intake manifold from debris including old gaskets or previously applied sealants.
2. Install the GAC supplied or standard gasket for the throttle body actuator assembly to the intake manifold or use an approved sealant.
3. Place the actuator assembly over the intake manifold with the intake flow indication arrow pointing toward the engine (downward) as shown in the following figure.

Airflow indication



4. Torque the mounting bolts down to 9-14 lb. in. [1-1.6 N•m]. Take caution not to over-torque any components based on the selected hardware.

6.2.2.2 Turbocharged Engines

1. Clean the mounting areas on either side of the ATB from debris including old gaskets or previously applied sealants; ideally this location is as close to the intake manifold as possible and after the charge air cooler.

2. Install standard or GAC supplied or gaskets for the throttle body actuator assembly to the intake manifold connecting location or use an approved sealant.

3. When installing the actuator assembly ensure the flow indication arrow is pointing toward the engine intake as indicated in the following figure.

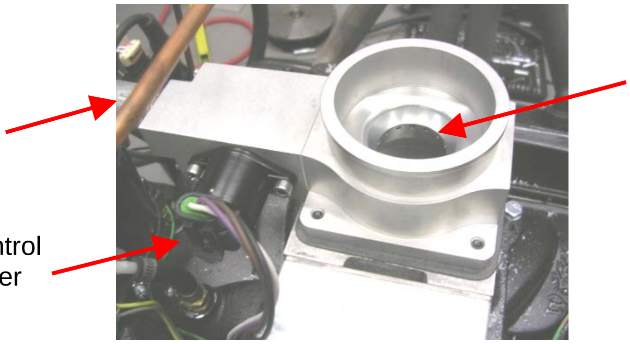
4. Torque the mounting bolts down to 9-14 lb. in. [1-1.6 N•m]. Take caution not to over-torque any components based on the selected hardware.

5. Repeat a similar procedure for the alternate end of the ATB interface with the intercooler output.

6.3 Air-Fuel Mixer & Control Valve Assembly

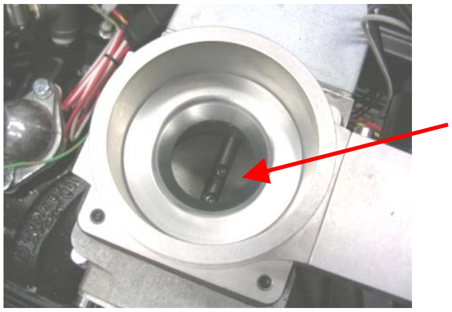
The air-fuel mixer and control valve assembly is used to adjust the air to fuel ratio to the engine in order to regulate how lean or rich the engine will run. The mixer and control valve comes as one combined assembly from GAC for a simplified installation. A picture of a mixer / valve assembly mounted on top of an ATB is shown in the following figure. The control valve stepper motor, fuel inlet, and fuel mixer holes have been called out for clarity as well.

Example Medium Bore Mixer / Valve mounted on ATB



The following figure shows a top view of the air-fuel mixer. Take note of the butterfly valve of the ATB as indicated by the callout.

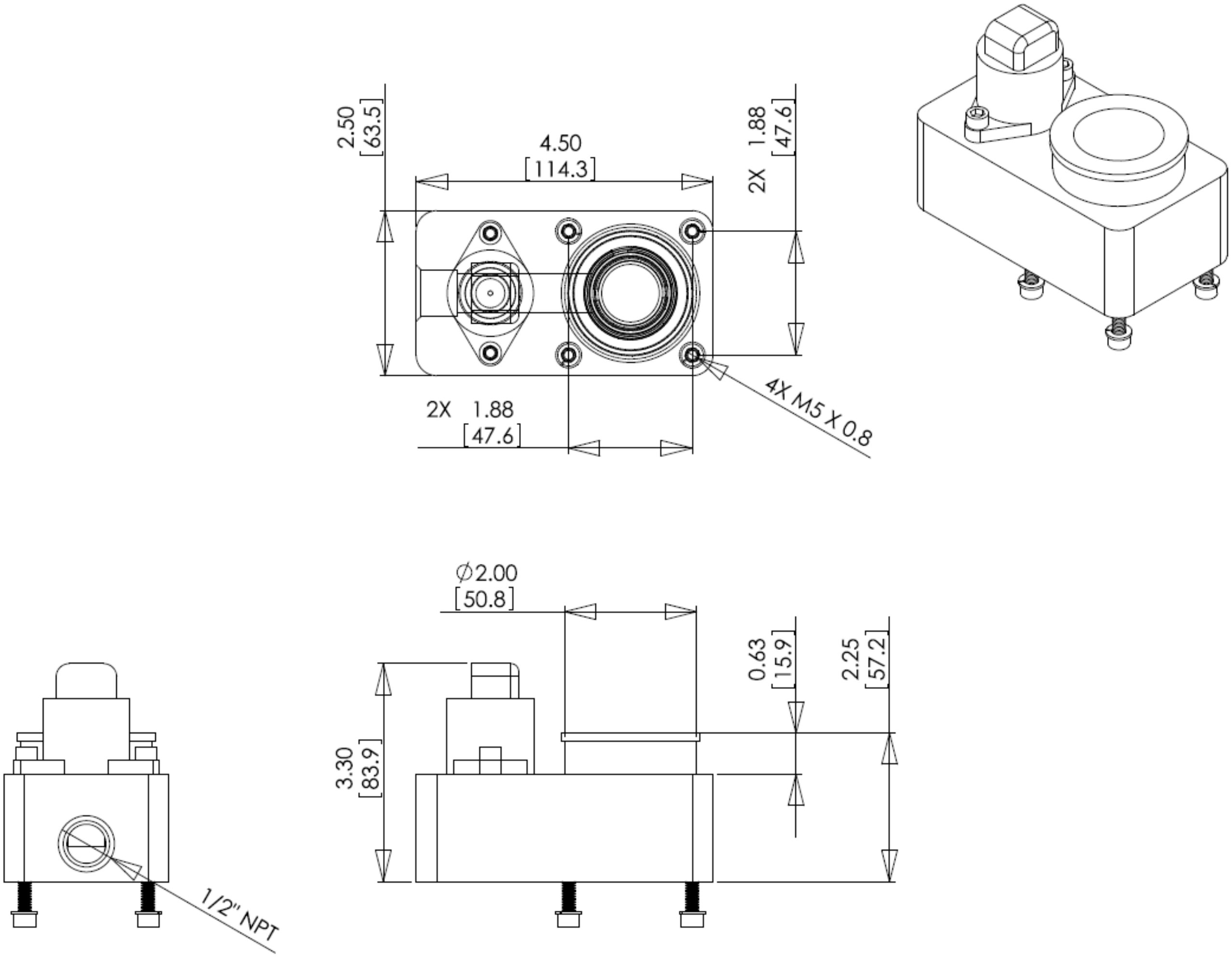
Top View of Medium Bore Mixer



ATB Butterfly Valve

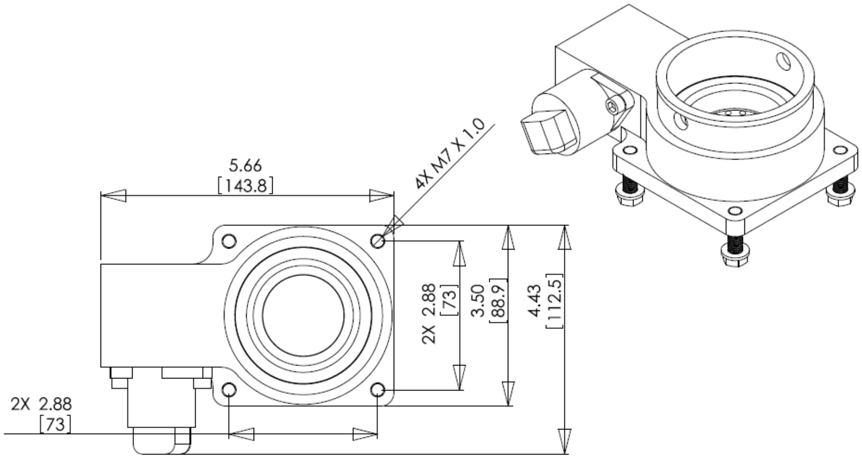
The dimensions of the various mixers available for GAC ATB's are shown in the following figures**.** Refer to the mixer selection guide to determine which mixer / control valve was selected.

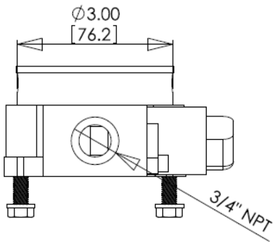
MXSB – Small-Bore Mixer / Air-Fuel Control Valve Dimensions (Size 20 thru 30) – T1 ATBs
Dimensions shown as in. [mm]

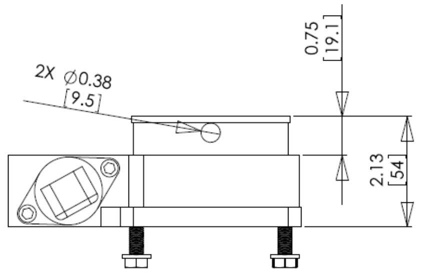


MXMB – Medium-Bore Mixer / Air-Fuel Control Valve Dimensions (Size 40 - 50) – T2 ATBs

Dimensions shown as in. [mm]

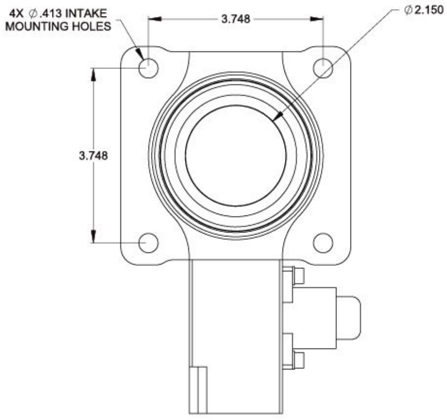


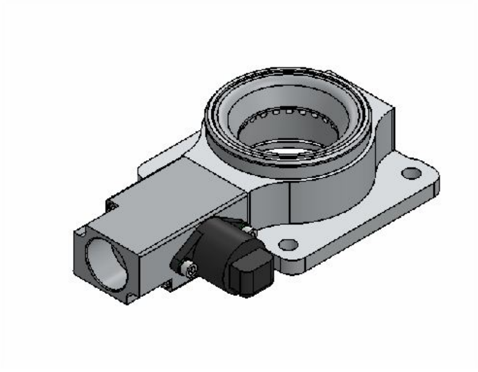


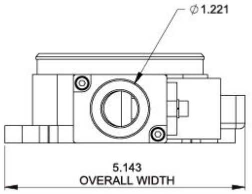


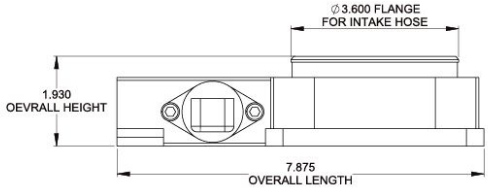
MXLB – Large-Bore Mixer / Air-Fuel Control Valve Dimensions (Size 75, 85) – T3 ATBs

Dimensions shown as in. [mm]









6.3.1 Application Considerations

- The mounting surface for the mixer / valve assembly should ensure that the fuel inlet is horizontally aligned in order to eliminate any effects of gravity on the flow of fuel.

- Ensure there is adequate clearance above and around the mixer / valve assembly using the provided dimensions to allow for the installation of the required air intake components and filters.

- Select the mounting bolts using the dimensions provided to ensure the length and diameter are appropriate or use the GAC provided installation kit.

- Turbo-charged applications require special flanges which allow the mixer / valve to be installed directly after the air filter and before the turbocharger inlet. This implies it is installed separately from the ATB.

6.3.2 Installation Instructions

The following information is divided between normally aspirated engines and turbo-charged applications due to the differences in mounting locations.

6.3.2.1 Naturally Aspirated Engines

1. Clean the mounting area to the ATB from debris including old gaskets or previously applied sealants if present.

2. Install the integral mixer / valve assembly on top of the ATB (with or without adapter plate) using the supplied o-ring or an approved sealant.

   - Ensure the mixer assembly is aligned to the desired orientation prior to seating it on top of the ATB.

3. Insert the four bolts into the mixer / valve assembly, install the nuts, and torque them down to 1-1.8 lb.ft. [1.36-2.44 N•m].

   - Ensure the assembly is not over-torqued and that the torque is applied evenly and gradually.

4. Connection of the fuel supply from the zero pressure gas regulator to the mixer / valve assembly is covered in following sections.

6.3.2.2 Turbocharged Engines

1. Clean the mounting area to the flange of the turbocharger inlet (or adapter) as well as the air filter connection from debris including old gaskets or previously applied sealants if present.

2. Install the integral fuel mixer/control valve assembly (with adapter plate) using the supplied o-ring or approved sealant.

   - Ensure the mixer assembly is aligned to the desired orientation prior to seating it to the flange and that the fuel inlet is horizontal.

3. Insert the four bolts into the mixer / valve assembly, install the nuts, and torque them down to 1-1.8 lb. ft. [1.36-2.44 N•m].

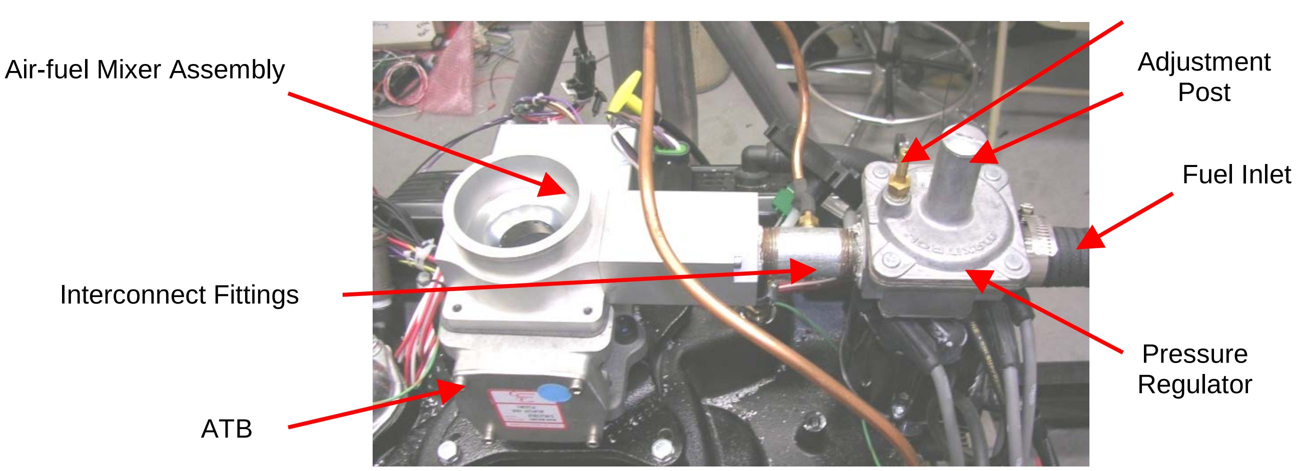
   - Ensure the assembly is not over-torqued and that the torque is applied evenly and gradually.

4. Connection of the fuel supply from the zero pressure gas regulator to the mixer / valve assembly is covered in following sections.

6.4 Gas Pressure Regulator (Zero Pressure)

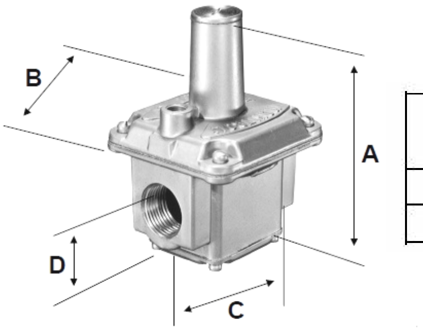
A Zero Pressure Gas Regulator is attached to the fuel inlet port on the mixer / fuel control valve assembly to regulate the pressure / flow to the assembly. The regulator has a reference / feedback port on top of the unit in order to regulate pressure. A representation of a regulator connected to the mixer / control valve on top of an ATB for a naturally aspirated engine is shown in the following figure.

Mixer on ATB with Regulator Installed
Naturally-Aspirated Application Shown



The following figure shows the dimensions of the gas pressure regulator for the purpose of determining a suitable mounting or placement location. Refer to the component selection section to determine the regulator choice if you purchased one from GAC.

Zero Pressure Gas Regulator Dimensions
Dimensions shown as in. [mm]



Model Number	Swing Radius	Call-Outs			
		A	B	C	D
RPR102	3.56 [90]	4.69 [119]	3.13 [79]	3.00 [76]	1.19 [30]
RPR103	4.32 [109.7]	5.68 [144.3]	3.88 [98.3]	4.03 [102.4]	1.46 [37.1]

6.4.1 Application Considerations

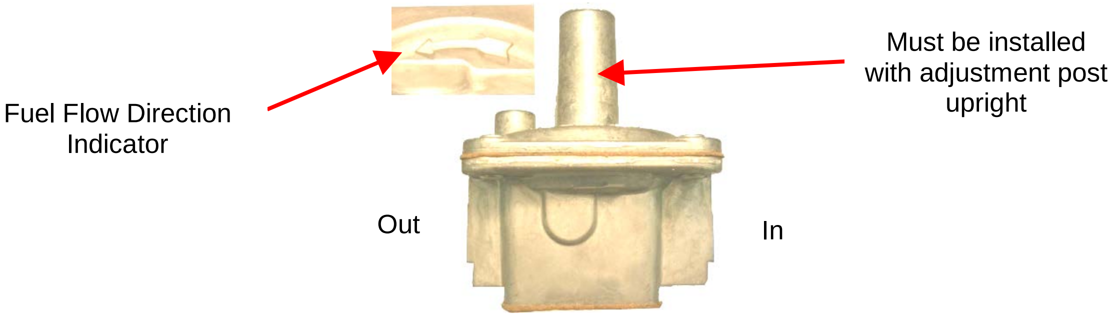
- The installation must comply with all local and government regulations and safety codes.
- The gas regulator MUST be installed with the adjustment post pointing upward and the regulator body extended horizontally in order to guarantee consistent operation.
- It is recommended that the regulator is installed as close to the air-fuel control valve / mixer as the installation will allow. This helps the regulator to provide the best performance in governing the inlet gas supply pressure and fuel volume.
    - Regulator feedback will automatically adjust supply pressure and volume based upon restrictions in the intake tract such as a clogged air filter.
    - Use the dimensions provided in the following figure to determine a suitable location that will not be obstructed or prone to damage by other components.

- The regulator has the following required fittings as identified on the previous figure:
    - RPR 102 Input / Output = 3/4 in. NPT Fitting
    - RPR 103 Input / Output = 1 in. NPT Fitting
    - Feedback / Reference Port = 1/8 in. NPT Fitting
        - Use this information provided in the component selection section to select the appropriate hardware required between the air-fuel mixer assembly and the fuel supply piping if you are using GAC provided parts.
- The maximum inlet pressure to the zero pressure gas regulator is 1 PSI [27.7 in. or 70.3 cm. of Water Column].

6.4.2 Installation Instructions

1. Ensure that the fuel supply is shutoff or disconnected whenever working fuel system plumbing.
2. Install the selected interconnect between the mixer assembly and the pressure regulator using pipe unions or barbed fittings into the fuel inlet port for the air-fuel mixer assembly.
    - Use an approved pipe thread sealant to ensure the connection is leak proof.
    - If barbed fittings are used, ensure that properly-sized, high-quality, hose clamps are installed in pairs.
3. The zero pressure gas regulator is directional. Refer to the following figure for identification of the fuel flow direction indicator and ensure the fuel flow direction is toward the mixer / air-fuel control valve assembly during installation.

Zero Pressure Gas Regulator



4. Install the zero pressure gas regulator outlet port to the interconnect from the air-fuel control and mixer assembly in Step 1 using the appropriate pipe unions or barbed fittings.
    - Ensure the pressure regulator is installed in the correct orientation as detailed in the following figure and the application considerations section.
    - An approved pipe thread sealant can be used to ensure the connection is leak proof.
    - If using barbed fittings use properly sized, high-quality hose clamps in pairs.

5. Connect a hose (or equivalent) to the feedback port that is long enough to reach the air cleaner or air filtration system connection point. This information is covered in greater detail in the section labeled 'Air Filtration.'
    - The reference pressure is taken between the air filtration system and the venturi inlet.
6. Once all the plumbing is complete, enable the fuel supply, and ensure the inlet pressure to the regulator is positive but within the guidelines shown in the application considerations.
7. Remove the slotted cap on the regulator adjustment post to reveal the pressure adjustment screw.
8. Ensure the outlet pressure is slightly positive at full output.
    - This needs to be adjusted once the fuel has been turned on and is the most common reason why an engine will not start or will not run correctly on initial key up. After the SmartVU configuration procedure is complete, the fuel system needs to be enabled.
    - If the engine is being under-fueled at startup, then increase fuel regulator flow. If the engine is over-fueled at startup, then decrease flow. In most cases it is best to decrease the flow of the regulator to its minimum and increase the flow while cranking until the engine starts.

6.5 Electronic Gas Lockout Valve

This electronic gas lockout valve gives the fuel control system electronic authority of gas flow into the regulator increasing over-all safety and performance. Generally when the control system is disabled the gas lockout valve prohibits gas flow.

Typical Electronic Gas Lockout Valve

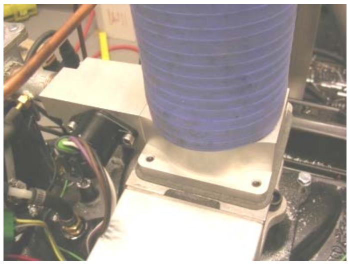
6.5.1 Application Considerations

- GAC recommends the installation of an electronic gas lockout (shutoff) valve for added safety.
- The installation must comply with all local and government regulations and safety codes.
- Refer to the manufacturer's recommendations for the shutoff valve selected.
- If the desire is for the AFR controller and electronic gas lockout valve to wake / shutdown at the same time, wiring information can be found in later sections.

6.6 Air Filtration

The air filtration is used to avoid accidental or unintentional pollutants and debris into the air intake system. The available configurations for plumbing the air filtration range from a simple hose connection at the inlet of the fuel valve assembly or a direct connection of the air filter unit to the mixer assembly.

Hose Connection to Filter



Direct Filter Connection to Mixer Intake

6.6.1 Application Considerations

- Running an engine without an air filter is not recommended due to contamination of the mixture or / and engine back fire.
- Select a filter that is sized accordingly for the application.
- Ensure a location is selected in order to plumb the reference pressure input from the zero pressure gas regulator.
- Refer to the manufacturer's guidelines for installation and application information.

7 Engine Sensor Information & Installation

7.1 Magnetic Engine Speed Pickup

The Magnetic Speed Sensor detects when ring gear teeth, or other ferrous projections, pass the tip of the sensor. The output signal is an AC sine wave whose frequency is converted to crankshaft revolutions per minute (RPM) via the input flywheel teeth value within the AFR.

For information on selecting and adjusting the magnetic pickup see: GAC Document: *PTI3000, Magnetic Speed Sensors* which can be found at the following location:

- http://www.governors-america.com/magnetic_speed_sensors.html

GAC offers various lengths, electrical connections, and both US and metric threads for the speed sensors. The following is a picture of a typical variable reluctance magnetic engine speed pickup offered by GAC.

Magnetic Speed Pickup

7.1.1 Application Considerations

- Some industrial engines have pre existing threaded holes for speed pickup installation. If this is the case determine the appropriate thread (dimension, US or metric) and length sensor required.
    - If there is no pre-drilled hole exists, then drilling and tapping a hole or fabricating a bracket to position the magnetic pickup over the flywheel teeth may be necessary.
- The threaded hole for the speed sensor should be perpendicular to the centerline of the crankshaft and centered over the ring gear teeth.
    - The magnetic pickup should be mounted parallel to the flywheel clutch surface and normal to the crankshaft axis of rotation.
    - Any ferrous gear can be used as long as the frequency and amplitude of the resulting signal meet the speed control specifications.
- The wire leads should be twisted the entire length (14 turns per foot) and may also require shielding if the run is longer than 10 ft. [3 m] or if external interference is present.
    - The shield should never be connected to either of the leads from the speed sensor. They are typically connected to a large ground point near the controller-end only (e.g. engine block).

7.1.2 Installation Instructions

1. Ensure the engine is not running and the ignition switch is turned to the OFF position.
2. Install the magnetic pickup in the engine bell housing, ring gear case, or fabricated bracket.
3. Screw the speed sensor in until it touches a gear tooth and then back it out 3/4 of a turn.

  - Adjust the pickup such that there is a nominal .015”-.030” gap clearance between the teeth and sensor.

4. Secure the speed sensor using the supplied locknut.

5. An AC voltage meter can be used to verify proper magnetic pickup installation. During cranking, sensor output should be greater than 0.5 VAC.

  - If the multi-meter is capable of measuring frequency, the pickup sensor output frequency should measure at (RPM*flywheel tooth count)/60 = X Hz.

7.2 Manifold Absolute Pressure Sensor (MAP)

The Manifold Absolute Pressure sensor from GAC is available in three different pressure ranges (1, 2, or 3 Bar; 14.5, 29, or 43.5 PSI) supporting up to 30 psig of boost as detailed in the parts list section. Typically, naturally aspirated engines use the 1 bar model. All three variations have the same mounting footprint and instructions. A representation of the Manifold Absolute Pressure sensor (MAP) is shown in the following figure.

Manifold Absolute Pressure Sensor Identification

7.2.1 Application Considerations

- The MAP sensor is not required in the event that the multiple-PID functionality is not needed. This implies that the Governor PID, Fuel PI, Valve Position, and O2 Sensor sensors will be solely based on engine speed rather than calculated load. If the MAP sensor is not used, it is good practice to tie the input signal at the AFR to sensor ground to avoid unwanted interaction.

- The MAP sensor has a 6.4mm [0.25 in.] plastic hose barb fitting which can be plumbed directly into the intake manifold using a port or by using a vacuum hose in between the fitting and the sensor.

  - If you are installing the sensor directly to the intake manifold the sensor nozzle must not be angled greater than 60 degrees from vertical to avoid water intake into the nozzle.

  - If you are remotely installing the Manifold Absolute Pressure sensor away from the intake manifold ensure the selected location is higher than the vacuum connection point.

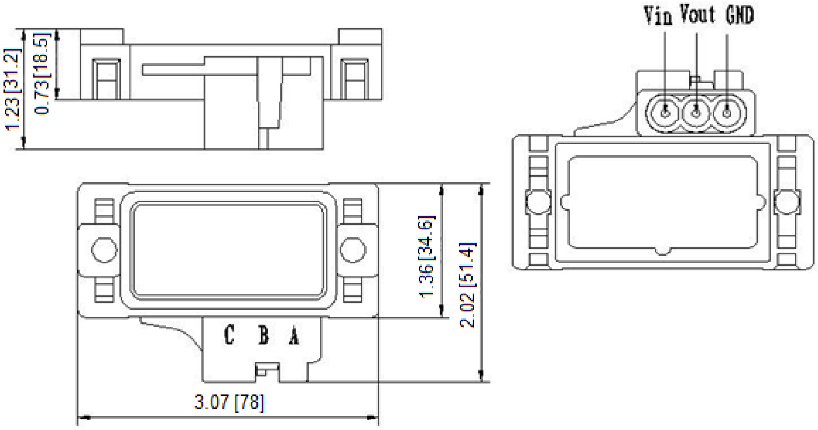
  - Ensure the port is the correct size to ensure a good o-ring seal.

- The recommendation is to mount the sensor with the barb pointing downward to avoid moisture buildup in the sensor orifice which may lead to incorrect readings.

- The MAP sensor has a two bolt mounting pattern and dimensions as shown in the following figure. Use this template when determining the appropriate mounting location / pattern and bolt selection.

Manifold Absolute Pressure Sensor Dimensions

Dimensions shown as in. [mm]



7.2.2 Installation Instructions

1. Lubricate the o-ring seal on the MAP sensor to ensure it is not damaged during installation.
2. Thread the MAP sensor into the appropriate location on or near the intake manifold using the 5mm thru-holes and the selected mounting hardware.
    - Do not over torque the assembly down and ensure that the barb fitting is not damaged during installation and is free from obstruction.
3. If the sensor is remote mounted, install the barb fitting on the intake manifold which should a 6.4mm [0.25 in] barb fitting.
    - Install a section of hose from the intake manifold to the MAP sensor.
    - Ensure the vacuum hose is positioned and cut to the appropriate length to avoid kinks or low points in the line.
    - Avoid routing the vacuum hose next to high temperature components such as turbo-chargers and exhaust systems.

7.3 Exhaust Oxygen Sensor

The engine exhaust oxygen level sensor is used to determine whether or not the engine is running lean or rich and to facilitate the closed loop feedback from the control system. A stoichiometric oxygen sensor (narrow-band) with an output signal of 0 to 1V is used with the AFR.

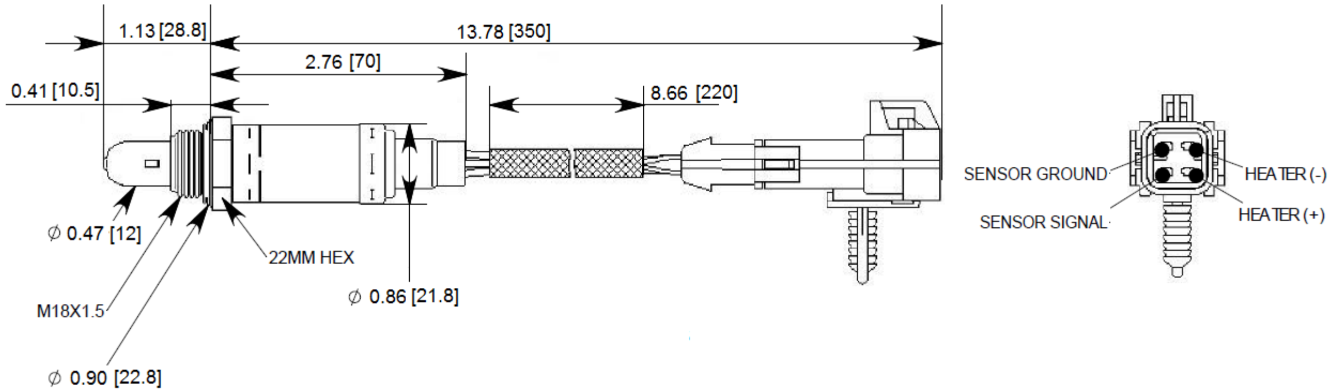
An internal heater element (12V only) allows the sensor to reach its activation temperature quickly for accurate measurements. Depending on the configuration selected you will have one (pre-catalytic converter) or two (pre- and post-catalytic converter) sensors. A representation of the GAC narrow-band oxygen sensors are shown in the following figure**.**

Typical Stoichiometric O_2 Sensors

7.3.1 Application Considerations

- The oxygen sensors both have M18x1.5 thread as shown in the following figure. When selecting the mating connection location ensure the fittings are correct.

Heated 12V Oxygen Sensor Dimensions – SOX102
Dimensions shown as in. [mm]



24V Oxygen Sensor Dimensions – SOX 103

Dimension	Value
Overall Length	1.2 in. [30.5mm]
Wire Quantity	2
Thread Size	M18 x 1.5
Length; Sealing Surface To End of Connector	12.60 in. [320mm]
Wire Length	13.80 in. [350.5mm]

- For the primary oxygen sensor, the sensor should be located in the engine exhaust outlet as close to the merge of all cylinders as possible but prior to the catalytic converter (if equipped).
    - In some cases on multiple bank engines (V-block engines) it's possible to obtain acceptable performance using exhaust gas from only a single bank although the preference if possible is at the merge of both banks.
- For the post-catalytic oxygen level sensor ensure the selected mounting location is mounted near the catalytic converter in order to provide accurate data.
- In turbo-charged applications the sensor must be installed no closer than 18 in. [457 mm] away after the turbocharger outlet.
- The SOX102 sensor heater circuit is 12-14V capable only.
    - The SOX102 sensor is provided with a 1/4” barbed fender plug in order to secure the electrical connection point**.**

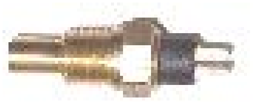
7.3.2 Installation Instructions

1. Install the oxygen sensor into the appropriate location by threading into the location determined from the application considerations section finger tight.
    - Ensure the threads are not galled during this operation.
    - Use a 22mm wrench to tighten the oxygen sensor into place by 1/2 to 3/4 of a turn max. Take caution not to over-torque the sensor and damage it.

7.4 Engine Coolant Temperature Sensor (ECT)

The engine coolant temperature sensor is an optional sensor provided from GAC. The coolant temperature sensor is monitored by the AFR for engine protection in the event of an engine over temperature situation. These limits can be calibrated within the AFR controller using SmartVU. A representation of the engine coolant temperature sensor is shown in the following figure.

Engine Coolant Temperature Sensor



7.4.1 Application Considerations

- The coolant temperature sensor should be located in the engine cooling water jacket prior to the thermostat. The sensor is ideally installed in a coolant passage on the engine block since this location represents engine temperature most accurately.
- The sensor is mounted via a 3/8-18 NPT fitting.
- The sensor is 0.35 in. [9mm] in diameter at the tip and 1.54 in. [29 mm] long from the tip up to the retaining nut (end of threads).
- In some installations require a tee fitting due to the lack of an available port on the engine block.
    - If this is the case, choose a coolant hose that has constant flow under all operating conditions. Do not choose a hose that has flow dependant on whether or not the thermostat is open or closed.
    - Select a hose that is representative of the engine temperature and not a return line from the heater, radiator, or CNG regulator for example.
    - Select a line that has a large amount of flow so that it is not susceptible to rapid fluctuations in temperature due to wind and cold environmental conditions prior to the sensor readout.
- If sourcing an alternate sensor the following specification must be met:
    - The sensor is of the Negative Temperature Coefficient (NTC) thermistor design. This implies that resistance of the sensor varies inversely to temperature.
    - Choose a sensor that is electrically equivalent to VDO p/n 323 479 which has a range up to 250°F [120°C] and is intended for single station applications with a floating ground (two terminals).

7.4.2 Installation Instructions

1. Apply thread sealant to the tee-fittings if applicable but not the sensor threads.

2. Thread the sensor finger tight into the drilled/tapped location from the application considerations.

   - The sensor is easily damaged so take caution when installing the sensor.

3. Using the appropriate wrench, torque the sensor to 30 N•m into the designated location. Take care not to over-torque since the sensor can be damaged.

4. If the sensor is installed by teeing in to a coolant line ensure that the fittings are all torqued down correctly and the coolant temperature is securely mounted.

5. The required electrical connections to the sensor are a pair of 1/4” female insulated quick connect terminals. Connect the signal and ground terminals accordingly.

6. Refill the engine cooling system for any lost coolant. Once the engine is started make sure to top off the cooling system and check for any coolant leaks.

7.5 Engine Oil Pressure Sensor (EOP)

The engine oil pressure sensor is an optional sensor available from GAC. The engine oil pressure sensor is monitored by the AFR for engine protection in the event of a low oil pressure condition during operation. These limits can be calibrated within the AFR controller using SmartVU. A representation of the engine oil pressure sensor is shown in the following figure.

Engine Oil Pressure Sensor

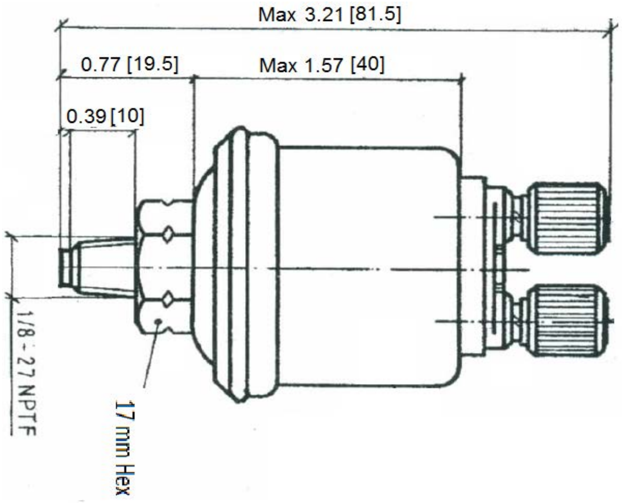
7.5.1 Application Considerations

- The oil pressure sensor should be located in a pressurized oil galley or a location representative of the actual engine oil pressure (not conditioned or restricted by some device).

- The sensor is mounted via a 1/8-27 NPTF fitting as shown in the following figure**.**

Oil Pressure Sensor Dimensions

Dimensions shown as in. [mm]



- If sourcing an alternate sensor the following specifications must be met:
  - The sensor must have a range of 0 – 150 PSIG (0 to 10 Bar).
  - The sensor resistance range must be 10 – 180Ω based on the above limits respectively.
  - The sensor must be electrically equivalent to VDO p/n 360 430.

7.5.2 Installation Instructions

1. Apply thread sealant to the sensor.
2. Thread the sensor finger tight into the location from the application considerations.
   - The sensor is easily damaged so take caution when installing the sensor.
3. Once complete, torque the sensor to a maximum of 30 N•m using a 17mm wrench.
4. The electrical connection points are M4 knurled nuts and the electrical connectors required are #10 insulated ring terminals.

7.6 Exhaust Gas Temperature Sensor (EGT)

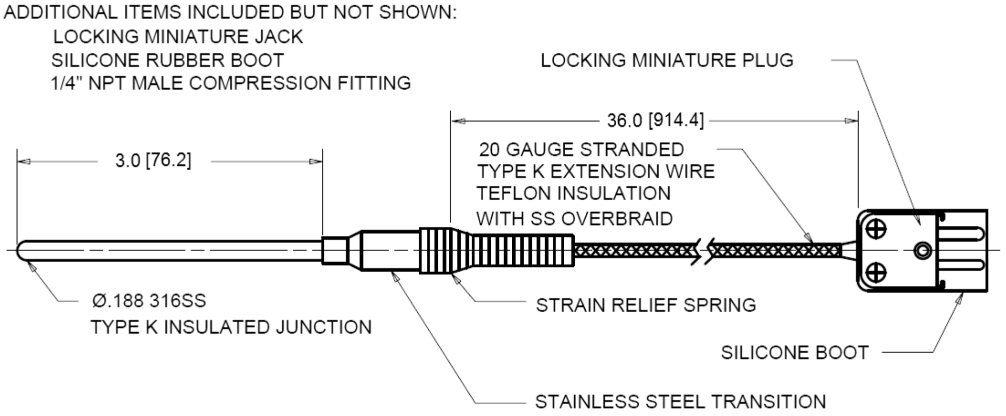
The exhaust gas temperature sensor is an optional sensor available from GAC. The engine exhaust temperature sensor is monitored by the AFR for engine protection in the event of a high exhaust temperature condition during operation. This threshold will cause a de-rate in throttle % and will allow the system to recover once the temperature has returned to the normal operating region. If the temperature does not decrease over a set time interval the AFR will shut the engine down. These limits and thresholds can be calibrated within the AFR controller using SmartVU. A representation of a typical thermocouple is shown in the following figure.

Typical Exhaust Gas Temperature Sensor (Type-K thermocouple)

7.6.1 Application Considerations

- The exhaust temperature probe is located in the engine exhaust outlet as near as possible to the point where all of the cylinders merge.
  - Alternatively the sensor can be placed in the manifold outlet pipe.
- A weld bung or tapped hole must be used and care should be taken such that the tip of the probe is well within the outlet exhaust flow.
- The sensor is mounted via a 1/8 in. NPT fitting as shown in the following figure. Drill and tap the determined mounting location using the provided dimensions.

Exhaust Temperature Sensor Dimensions
Dimensions shown as in. [mm]



- If sourcing an alternate sensor the following specifications must be met:
  - The sensor must be a type-K thermocouple,
  - Must be ungrounded
  - Temperature Range to 650°C [1200°F],
  - Transition Junction / Cable to 480°C [900°F].

7.6.2 Installation Instructions

1. Apply thread sealant to the sensor.
2. Thread the sensor finger tight into the drilled / tapped location from the application considerations.
   - The sensor is easily damaged so take caution when installing the sensor.
3. Once complete, turn the sensor 2 full turns past finger tight.

8 Electrical Connections

8.1 AFR Connector Definitions

AFR Connector J1 Pinout (35-Pin)

#	Description	Comment	Gauge
1	GAC ATB Low	Low Side of the GAC ATB Output	16 AWG
2	RS232 Receive	RS232 Communication Port	20 AWG
3	Oil Pressure	Oil Pressure Resistive Analog Input	20 AWG
4	Coolant Temperature	Coolant Temperature Resistive Analog Input	20 AWG
5	MAP Signal	Manifold Absolute Pressure 0-5V Analog Input	20 AWG
6	MAP Power	Manifold Absolute Pressure Sensor +5V Power	20 AWG
7	MAP Ground	Manifold Absolute Pressure Sensor Ground	20 AWG
8	Stepper Motor 1	Stepper Motor Control Output 1	20 AWG
9	Stepper Motor 2	Stepper Motor Control Output 2	20 AWG
10	Main Power Relay	Main Power Relay Enable Signal	16 AWG
11	O2 Sensor 1 Ground	Oxygen Sensor 1 Ground	18 AWG
12	Mag Pickup Ground	Magnetic Speed Pickup Sensor Ground	18 AWG
13	RS232 Transmit	RS232 Communication Port	20 AWG
14	*Not Used*	*Not Used*	*N/A*
15	*Not Used*	*Not Used*	*N/A*
16	*Not Used*	*Not Used*	*N/A*
17	*Not Used*	*Not Used*	*N/A*
18	MIL	Malfunction Indicator Lamp Output - 2A	16 AWG
19	EGT +	Exhaust Gas Temperature Input +	20 AWG
20	O2 Sensor 1	Oxygen Sensor 1, 0-1V Analog Input	18 AWG
21	Stepper Motor 3	Stepper Motor Control Output 3	20 AWG
22	Stepper Motor 4	Stepper Motor Control Output 4	20 AWG
23	RS232 Ground	RS232 Communication Port Ground	20 AWG
24	GAC ATB High	High Side of the GAC ATB Output	16 AWG
25	EGT -	Exhaust Gas Temperature Input -	20 AWG
26	Auxiliary Speed Trim	Auxiliary Speed Trim	20 AWG
27	Mag Pickup	Magnetic Speed Pickup Input	18 AWG
28	Speed Select 1	Speed Select Switch 1 Input	20 AWG
29	Speed Select 2	Speed Select Switch 2 Input	20 AWG
30	Variable Speed	Variable Speed Resistive Input	20 AWG
31	CAN High	CANbus High Signal	20 AWG
32	CAN Low	CANbus Communication Low Signal	20 AWG
33	CAN Termination	CANbus Termination Resistor (when tied to CAN Low)	20 AWG
34	Battery Ground	Battery Ground	16 AWG
35	Battery	12/24 Volt DC Battery Power	16 AWG

AFR Connector J2 Pinout (14-Pin)

Connector J2 is available on all variations of the AFR except the AFR200 and AFR210

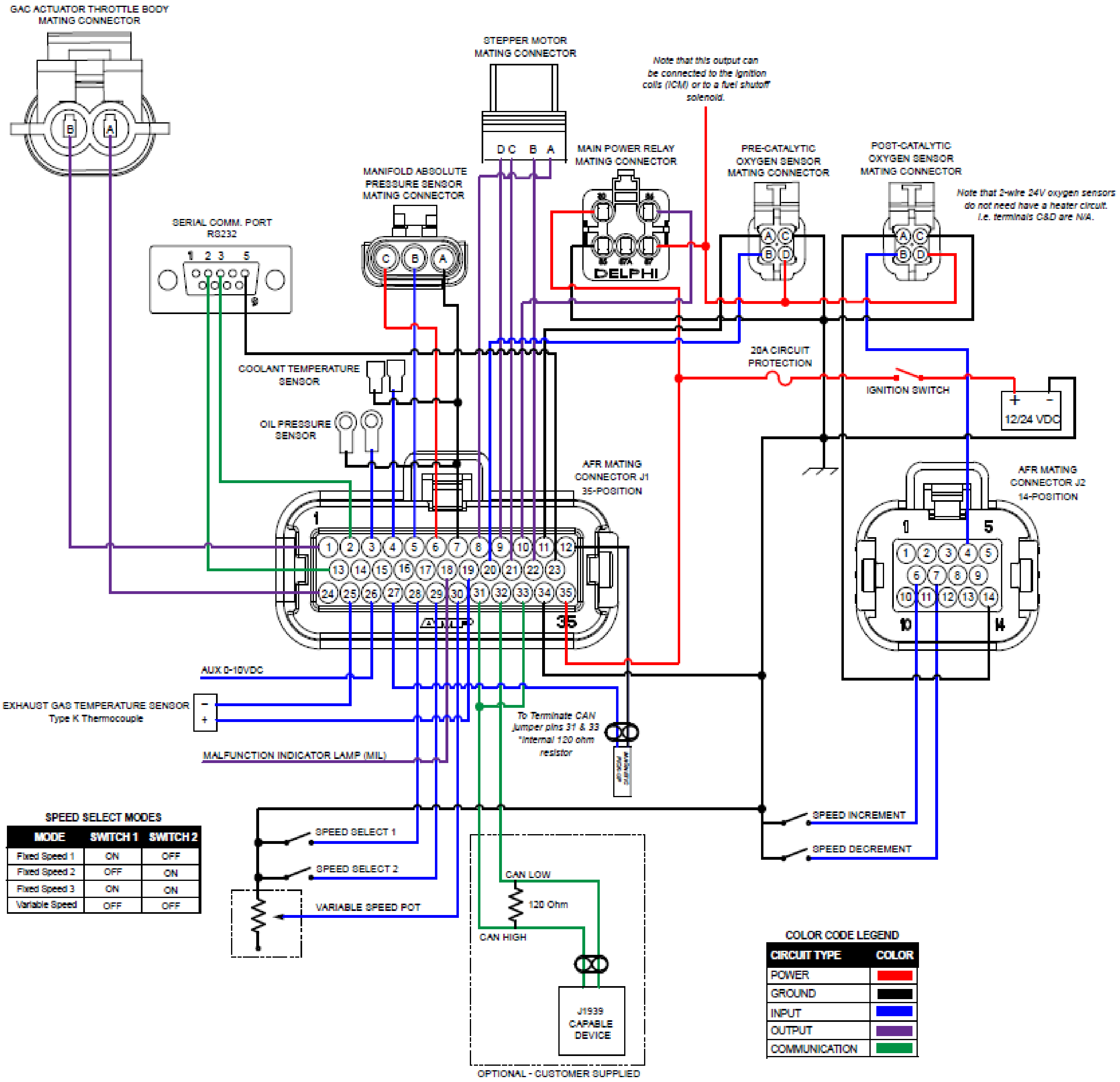
#	Description	Comment	Gauge
1	*Not Used*	*Not Used*	*N/A*
2	*Not Used*	*Not Used*	*N/A*
3	*Not Used*	*Not Used*	*N/A*
4	O2 Sensor 2	Oxygen Sensor 2, 0-1V Analog Input	18 AWG
5	*Not Used*	*Not Used*	*N/A*
6	Speed Increment	Speed Increment +10RPM	18 AWG
7	Speed Decrement	Speed Increment -10RPM	18 AWG
8	*Not Used*	*Not Used*	*N/A*
9	*Not Used*	*Not Used*	*N/A*
10	*Not Used*	*Not Used*	*N/A*
11	*Not Used*	*Not Used*	*N/A*
12	*Not Used*	*Not Used*	*N/A*
13	*Not Used*	*Not Used*	*N/A*
14	O2 Sensor 2 Ground	Oxygen Sensor 2 Ground	18 AWG

8.2 AFR Wiring Diagram

The following figure is a system wiring diagram which details the basic system schematic and mating connector representations for a typical application of the AFR.

AFR211 Wiring Diagram

(Note that your application may not employ all of the circuits shown since the AFR211 is the full-featured version of the AFR controller and uses both connectors J1 and J2)



SPEED SELECT MODES

MODE	SWITCH 1	SWITCH 2
Fixed Speed 1	ON	OFF
Fixed Speed 2	OFF	ON
Fixed Speed 3	ON	ON
Variable Speed	OFF	OFF

COLOR CODE LEGEND

CIRCUIT TYPE	COLOR
POWER	🟥
GROUND	⬛
INPUT	🟦
OUTPUT	🟪
COMMUNICATION	🟩

System Interface Information

The following sections provide greater detail on the basic system wiring information for the AFR series controllers and some additional detail not covered in previous sections.

8.2.1 System Power

The AFR should be wired through a switched (On / Off Switch) DC power source of 5 to 32VDC and circuit protected with a 20 Amp fuse or circuit breaker.

8.2.2 Power Relay (2A) Low Side Output (LSO)

The AFR has the ability to control a power relay when the system is enabled and use this for controlled shutdowns of the engine. The output of this relay is tied to the ignition coil outputs (if an ICM is installed), the oxygen sensor heater circuits, and the fuel shut-off solenoid (if applicable). This allows the AFR to control the air/fuel, ignition, and fuel shut-off solenoids in the event of a controlled shutdown due to a high-temperature, low oil pressure, overspeed, or due to an emergency shutdown using SmartVU.

8.2.3 Speed Selection Inputs

The AFR has two inputs which in various combinations allow the user to select between the 3 fixed speed settings or the variable speed setting. This is accomplished by tying the inputs to ground or leaving them open. The variable speed setting requires an additional potentiometer which can be OEM supplied or purchased from GAC using the information provided previously.

There is a potentiometer calibration within SmartVU that characterizes the selected potentiometer. The following table details the speed selector input combinations and the associated settings.

Speed Selection Table

Desired Selection	Speed Select Switch Input 1	Speed Select Switch Input 2
Variable Speed	Open	Open
Fixed Speed Setting #1	Ground	Open
Fixed Speed Setting #2	Open	Ground
Fixed Speed Setting #3 (Idle)	Ground	Ground

None of these selections are required and that the default setting (both open) is variable speed. The variable speed setpoint can be set identically (i.e. same RPM) to act as an additional (or primary) fixed speed setting.

8.2.4 Communications

Two communications ports are available on the AFR: RS232 / Modbus and CAN / J1939.

8.2.4.1 RS232 / Modbus

The RS232 inputs are used to configure the AFR using GAC's SmartVU software. A DB9-F is the standard mating connector for diagnostic information for GAC products.

8.2.4.2 CAN / J1939

- Data Output: The CAN output supports J1939 protocol for basic engine sensor information and Diagnostic Trouble Codes (DTCs). For J1939 data readers, the current implementation provides engine speed, oil pressure, and coolant temperature information. Information regarding the Diagnostic Trouble Codes (DTCs) is covered under the *System Diagnostics* section.

- CANbus Termination: The AFR is not designed to be the end of line device on the CANbus. If the AFR is located at the end of the CANbus trunk ensure that a 120Ω termination resistor is placed across CAN H and CAN L (pins 18 and 19). As with all CANbus applications there needs to be a matching 120Ω resistor at the other end of the trunk for a total parallel resistance of 60Ω.

8.2.5 Fuel Valve (Stepper Motor) Control Output

The fuel valve used by the AFR is a high-resolution bipolar stepper motor. The following table provides the stepper motor specifications.

Stepper Motor Specification Table

Parameter	Value
Rated Operating Voltage	12V
Resistance, Inductance, Current per Phase	53Ω +/- 10%, 33.5mH, 200mA
Total Steps	240
Travel per Step	0.0164 in. [0.0417mm]
Maximum Travel	0.4 in. [10mm]
Operating Temperature	-40° to 257°F [-40° to 125°C]

The stepper motor has two separate coils (A & B) which when provided the correct signal in the correct orientation will modulate the stepper motor clockwise (extend) or counter-clockwise (retract). The following table details the stepper motor input combinations for operation.

Stepper Motor Control Logic

Extend ↓

Phase	A Pin A	/A Pin B	B Pin C	/B Pin D
1	+	-	+	-
2	+	-	-	+
3	-	+	-	+
4	-	+	+	-

Retract ↑

9 AFR Configuration & Calibration Procedure

This information is contained in the SmartVU Product User Guide available on www.governors-america.com. The guide will cover the basics of connecting to the controller and the required first time setup instructions. In addition, it covers diagnostic and troubleshooting information as well as advanced feature functionality.

10 System Diagnostics

10.1 AFR Indication LEDs

The AFR has 3 LEDs for determining the status of the unit. The following figure identifies the three LEDs as; the top red LED is the fault indicator, the middle red LED is the status indicator, and the bottom green LED is the power indicator.

AFR LEDs

LED	Definition
1	Fault LED
2	Status LED
3	Power LED

AFR LED Definition

LED	Mode	Description
Power	OFF	Unit is not powered on.
Power	ON	Unit is powered on.
Status	OFF	Unit is operating in closed loop mode.
Status	ON	Unit is operating in open loop mode.
Status	Blinking	Unit is changing the position of the fuel valve.
Fault	OFF	While engine running, this indicates there are no new entries in the alarm / warning history.
Fault	ON	A warning or shutdown is active. The light will turn off when the condition goes away and the unit has been power cycled.

10.2 Fault / Warning Blink Codes

The AFR has a simplified blink code system, to examine the history log, in the event a computer is not available. To display the history of blink codes:

- Power off the AFR.
- Power on the AFR, without the engine running.
- The fault LED will blink through the entire fault history in reverse chronological order (newest code first, oldest last).
- Once the AFR has reached the end of the list, it will stop flashing the fault codes.

The fault history log can be cleared on SmartVU's diagnostic screen. The following table provides the list of valid blink codes.

AFR Fault Indication Blink Codes

Count	Alarm/Warning
1	O2 Sensor Circuit No Activity Detected
2	Engine Speed Input Circuit No Signal
3	Engine Overspeed Condition
4	Engine High Temperature Condition
5	Engine Oil Pressure Too Low
6	*Not Used*
7	Post O2 Circuit or Sensor Failure
8	MAP Circuit Low Input
9	Not Used
10	Exhaust Gas Temperature Too High

10.3 Diagnostic Information

The AFR diagnostics features both run timers and fault code(s) readout.

10.3.1 Timers

The Timers window logs total run time of the engine and the AFR control device as well as maintenance timers for the engine and the applicable sensors. Further information is provided in the SmartVU product user guide.

10.3.2 AFR Diagnostic Trouble Code Information

The AFR stores a chronological list of accumulated trouble codes. The AFR communicates malfunctions through this part of the interface with OBDII P-codes and GAC G-codes. The P-codes relay engine and sensor malfunctions as well as decreases in system performance. These issues may cause poor fuel consumption and excessive emissions output as well as potential engine failure. The AFR will also flag the Check Engine warning flag or Engine Shutdown indicator in the event a GAC J1939 display device (JDR) is used.

The G-codes pertain to exceeded safety parameters and general setting changes which log the calibration and run history of the engine and control unit. Codes can be scanned real time while the engine is running. Further information regarding the diagnostics screen is available in the SmartVU product user guide.
The following tables provide the Diagnostic Trouble Codes (DTC) / P-codes that the AFR supports:

AFR supported P-Codes

P-Code	Description	Potential Failure Cause
P0108	MAP Circuit Failure	• Open or short circuit in wiring or connector • Poor connection • Defective sensor
P0118	Coolant Temperature Sensor Failure	• Open or short circuit in wiring or connector • Poor connection • Defective sensor
P0133	Pre-O2 Sensor Circuit Slow Response (Bank 1, Sensor 1)	• Short circuit in wiring or connector • Poor connection • Defective heater circuit or sensor • Sensor beyond maintenance interval replacement period
P0134	Pre-O2 Sensor Circuit No Activity (Bank 1, Sensor 1)	• Open or short circuit in wiring or connector • Poor connection • Defective sensor
P0153	Post-O2 Sensor Circuit Slow Response (Bank 2, Sensor1)	• Short circuit in wiring or connector • Poor connection • Defective heater circuit or sensor • Sensor beyond maintenance interval replacement period
P0154	Post-O2 Sensor Circuit No Activity (Bank 2, Sensor 1)	• Open or short circuit in wiring or connector • Poor connection • Defective sensor
P0171	System too Lean (Bank 1)	• Low gas pressure, poor fuel quality • Pressure regulator misadjustment • Fuel valve assembly not responding or sticking closed
P0172	System too Rich (Bank 1)	• High gas pressure • Pressure regulator misadjustment • Fuel valve assembly not responding or sticking open
P0217	High Coolant Temperature	• Engine coolant temperature has exceeded operational limit defined in calibration • Defective sensor
P0219	Engine Overspeed	• Engine magnetic speed pickup signal has exceeded operational limit defined in calibration • Defective sensor
P0521	Low Oil Pressure	• Engine oil pressure has fallen below minimum operational limit defined in calibration while the engine was running • Defective sensor
P0523	Engine Oil Pressure Sensor Failure	• Open or short circuit in wiring or connector • Poor connection • Defective sensor
P0725	Engine Speed Input Circuit Failure	• Open or short circuit in wiring or connector • Poor connection • Defective sensor
P-None	High EGT (Appears on JDR)	• Engine exhaust gas temperature has exceeded the operational limit defined in calibration • Defective sensor
P-None	Very High EGT (Appears on JDR)	• Engine exhaust gas temperature has exceeded the critical maximum limit defined in calibration and the engine was shut down • Defective sensor

The following table provides the GAC supported G-codes which are available for troubleshooting while using SmartVU. These G-codes are GAC specific fault codes available for view with SmartVU.

AFR supported G-Codes

G-Code	Description	Description
G9002	User Emergency Shutdown	User has commanded shutdown in SmartVu (Stop button)
G9004	Reload System Defaults	User has reloaded the calibration / configuration defaults in SmartVu
G9005	Diagnostic Timer Reset	User has reset the diagnostic timer in SmartVu
G9006	Diagnostic Logging has been cleared	User has reset / cleared the diagnostic fault code log
G9021	EGT Maximum Temperature Shutdown	The exhaust gas temperature maximum limit has been reached and the engine was commanded to shut down
G9022	EGT Maximum Value Reached	The exhaust gas temperature operational limit was reached and the engine was derated to reduce temperature
G9023	Reset Shutdown	The engine speed input was inaccurate, erratic, or lost For 24V applications the "Rolling Average Speed Calculation" should always be enabled in the governor advanced settings menu

J-1939 Fault Codes

JDR Text	SPN	FMI	Fault	Action	Potential Failure Cause
ENGINE OIL PRESSURE	100	2	Open Circuit		• Open circuit on harness or connector • Failed sensor
ENGINE OIL PRESSURE	100	4	Short to Ground		• Short circuit to ground in harness or connector • Failed sensor
ENGINE OIL PRESSURE	100	1	Low Reading	Shutdown	• Engine oil pressure has fallen below minimum operational limit defined in calibration while the engine was running • Defective sensor
ENGINE COOLANT TEMPERATURE	110	4	Short to Ground		• Short circuit in harness or connector • Failed sensor
ENGINE COOLANT TEMPERATURE	110	0	High Reading	Shutdown	• Engine coolant temperature has exceeded operational limit defined in calibration • Defective sensor
ENGINE EXHAUST GAS TEMPERATURE	173	2	Open Circuit		• Open circuit on harness or connector • Failed sensor
ENGINE EXHAUST GAS TEMPERATURE	173	4	Short to Ground		• Short circuit to ground in harness or connector • Failed sensor
ENGINE EXHAUST GAS TEMPERATURE	173	3	Short to Power		• Short circuit to battery or sensor supply in harness or connector • Failed sensor

JDR Text	SPN	FMI	Fault	Action	Potential Failure Cause
ENGINE EXHAUST GAS TEMPERATURE	173	10	Data Erratic		• Exhaust gas temperature sensor data erratic • Intermittent or incorrect poor connection • Defective sensor
ENGINE EXHAUST GAS TEMPERATURE	173	16	High Reading	De-rate	• Engine exhaust gas temperature has exceeded the operational limit defined in calibration • Defective sensor
ENGINE EXHAUST GAS TEMPERATURE	173	0	Severe High	Shutdown	• Engine exhaust gas temperature has exceeded the critical maximum limit defined in calibration and the engine was shut down • Defective sensor
ENGINE INTAKE MANIFOLD 1 PRESSURE	102	4	Short to Ground		• Short circuit to ground in harness or connector • Failed sensor
ENGINE SPEED	190	2	Open Circuit	Shutdown	• Open circuit on harness or connector • Failed sensor
ENGINE SPEED	190	0	Over speed	Shutdown	• Engine magnetic speed pickup signal has exceeded operational limit defined in calibration • Defective sensor
3217	3217	4	O2-1 Short to Ground		• Short circuit to ground in harness or connector • Failed sensor
3217	3217	10	O2-1 Insufficient Activity		• Open circuit on harness or connector • Failed sensor
3227	3227	4	O2-2 Short to Ground		• Short circuit to ground in harness or connector • Failed sensor
3227	3227	10	O2-2 Insufficient Activity		• Open circuit on harness or connector • Failed sensor

11 Symptom Troubleshooting

Problem	Actions / Possible Solutions
Engine does not start (disable fuel supply before troubleshooting)	1. Verify power to the AFR controller a. Check for green power LED indicator b. Check for adequate battery voltage c. Check power cable and supply 2. Verify engine speed is reporting a. Verify proper settings in SmartVU b. Check magnetic pickup clearance c. Check wiring to magnetic pickup 3. Verify proper actuator operation a. Verify proper settings in SmartVU b. Verify actuator duty cycle in SmartVU c. Measure voltage to actuator d. Check connections and wiring to actuator 4. Verify proper fuel valve operation a. Verify proper settings in SmartVU b. Cycle unit power and verify fuel valve calibration c. Check wiring to fuel valve 5. Verify the ignition system is accurately providing spark to the cylinders

⚠ **IMPORTANT**

Only after all of these items have been checked, including any troubleshooting related to SmartVU connection issues; fuel needs to be enabled to verify the fuel supply and flow to the fuel delivery components. If the engine is being under-fueled at startup, then increase fuel regulator flow. If the engine is over-fueled at startup, then decrease flow. In most cases it is best to decrease the flow of the regulator to its minimum and increase the flow while cranking until the engine starts.

6. Specifications

PERFORMANCE	
Isochronous Operation / Steady- State Stability	+/- 0.25%
Speed Range / Governor	400-10kHz (Mag Pickup)
Speed Drift with Temperature	<+/- 1% Max
Idle Adjust	Full Range
Adjustable Droop Range	1-17% Regulation
Speed Trim Range	+/- 5% of Rated Speed

ENVIRONMENTAL	
Ambient Operating Temperature Range	-40° to + 85° C [-40° to + 185° F]
Relative Humidity	Up to 95%

RELIABILITY	
Shock	20G Peak Acceleration
Vibration	7G @ 20-2000Hz
Testing	100% Functionally Tested

INPUT / OUTPUT PARAMETERS	
Supply	12-24 VDC Battery Systems (6.5 to 33VDC)
Polarity	Negative Ground (Case Isolated)
Power Consumption	100mA Max. Continuous plus Actuator, Stepper, Heater, and MIL
Speed Sensor Signal	0.5-120 VRMS
Actuator Current	Up to 6 Amps Continuous
Auxiliary (Load Share/Synchronizer) Input	0-10 VDC
Manifold Absolute Pressure (MAP) Sensor Input	0-5 VDC
Coolant Temperature Input	Resistive 0-450 Ohm
Oil Pressure Input	Resistive 0-250 Ohm
Oxygen Sensor	0-1 VDC
Oxygen Sensor Heater, MIL	0-2 Amps High Side Sourced

CONFIGURATION PARAMETERS	
Flywheel Teeth	50-250
Gain/Stability Multiplier	1-100%
Fixed Speed Settings*	0-maxRPM
Variable Speed Settings*	0-maxRPM
Overspeed Settings*	0-maxRPM
Starting Fuel	0-maxFuel
Oxygen Setpoint	0-999mV
Fuel (Gain / Stability Multiplier)	0-100
Full Value Setpoint	0-240 Steps (0-100%)
Manifold Absolute Pressure (MAP) Sensor	1,2 or 3 Bar

*Maximum RPM is based on the Flywheel Teeth. RPM = Frequency x 60 / Flywheel Teeth. Maximum Frequency is 10,000 Hz.