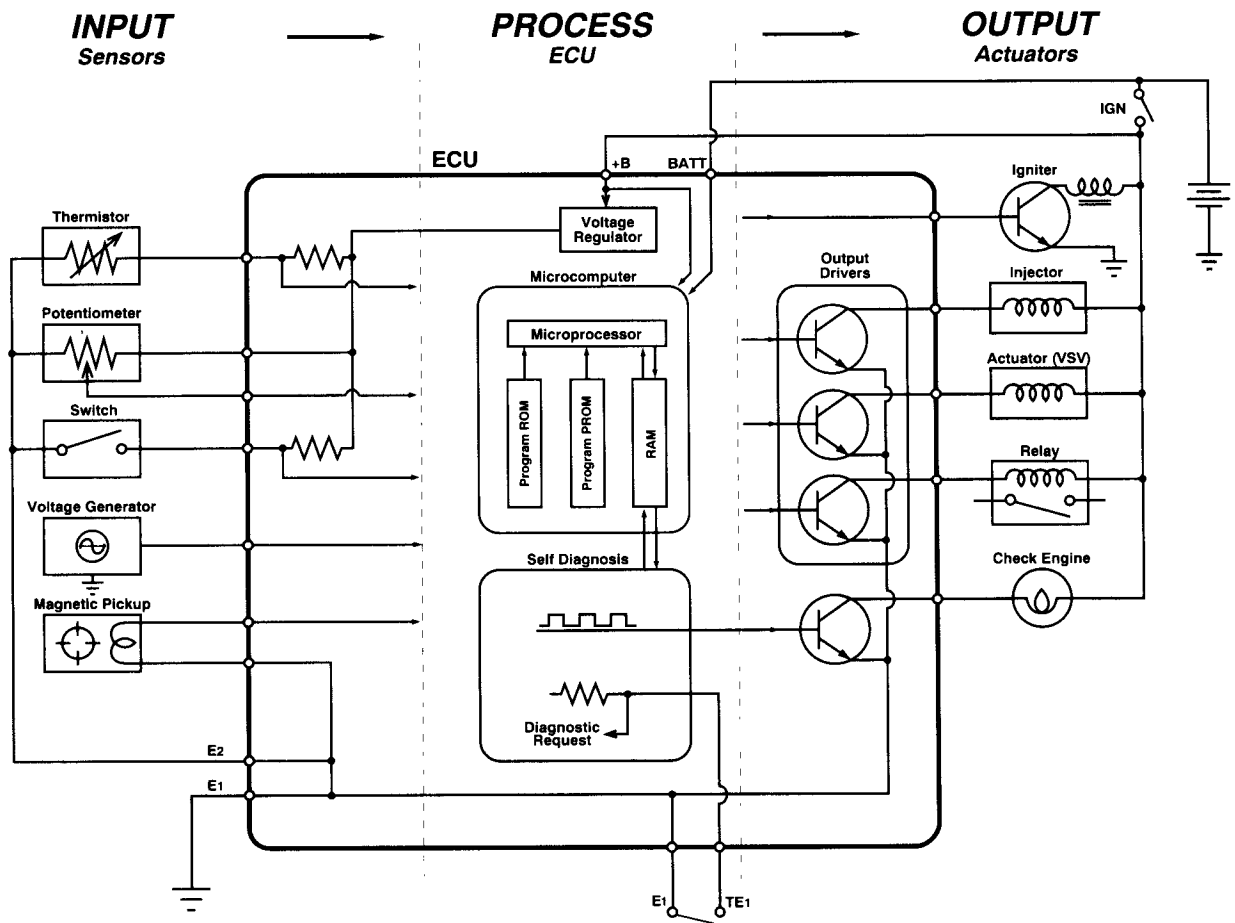


Overview

The EFI/TCCS system is an electronic control system which provides Toyota engines with the means to properly meter the fuel and control spark advance angle. The system can be divided into three distinct elements with three operational phases.

The three system elements are:

- Input Sensors
- Electronic Control Unit (A Microcomputer)
- Output Actuators



The electronic control system is responsible for monitoring and managing engine functions which were previously performed by mechanical devices like carburetors, vacuum, and centrifugal advance units. In an electronic control system, these functions are managed in three phases.

- The input phase of electronic control allow the Electronic Control Unit (ECU) to monitor engine operating conditions, utilizing information from the input sensors.
- The process phase of electronic control requires the ECU to use this input information to make operating decisions about the fuel and spark advance systems.
- The output phase of electronic control requires the ECU to control the output actuators, the fuel injectors, and igniter to achieve the desired fuel metering and spark timing.

In this chapter, we will explore the details of the electronic control system hardware and software. The chapter starts with a thorough examination of the system's input sensor circuits and the ECU power distribution system. It concludes with a closer look at the ECU process functions and the control strategy use(for optimum fuel metering and spark advance angle control.

The Microcomputer

The heart of the TCCS system is a **microcomputer**. A microcomputer is a device which receives information, processes it, and makes decisions based on a set of **program instructions**. The microcomputer exercises control over the output actuators to carry out these instructions.

The use of microcomputers has taken the science of engine management into the space age by increasing the speed with

which information can be processed and allowing the electronic control system to manage more engine functions. With the ability to process information so rapidly, the modern ECU is capable of carrying out its programmed instructions with extreme accuracy. Engine management can address virtually every condition the engine will encounter so that for any engine condition, the ECU will deliver optimum fuel and spark.

Evolution of Toyota's Electronic Fuel Injection Systems

Early Conventional EFI computers were first configured from analog circuits, and they controlled only fuel delivery and injection. The modern Electronic Control Units (ECU) utilize digital circuits and microprocessors which have served to improve EFI system capabilities.

Modern TCCS engine controls, introduced to the U.S.A. market in 1983, are capable of managing fuel delivery, idle speed control (ISC), electronic spark advance (ESA), and emissions systems with extraordinary speed and accuracy.

In the evolution of Toyota's fuel injection, three levels of electronic control refinements have taken place.

- Conventional EFI
- P7/EFI
- EFI/TCCS

The main difference between these systems is the capability of the ECU. These capabilities have grown from simple fuel control to the addition of self-diagnostics to the control of ignition spark advance and more. The following chart summarizes basic capabilities by system and can be used as a guide in identification and troubleshooting.

Evolution of Toyota EFI Systems

	Fuel Control (EFI)	Spark Control (ESA)	Self Diagnosis	Fail Safe Strategy	Idle Speed Control (ISC)
Conventional EFI	YES	NO	NO	NO	NO
P7/EFI	YES	NO	YES	NO	NO
EFI/TCCS	YES	YES	YES	YES	YES

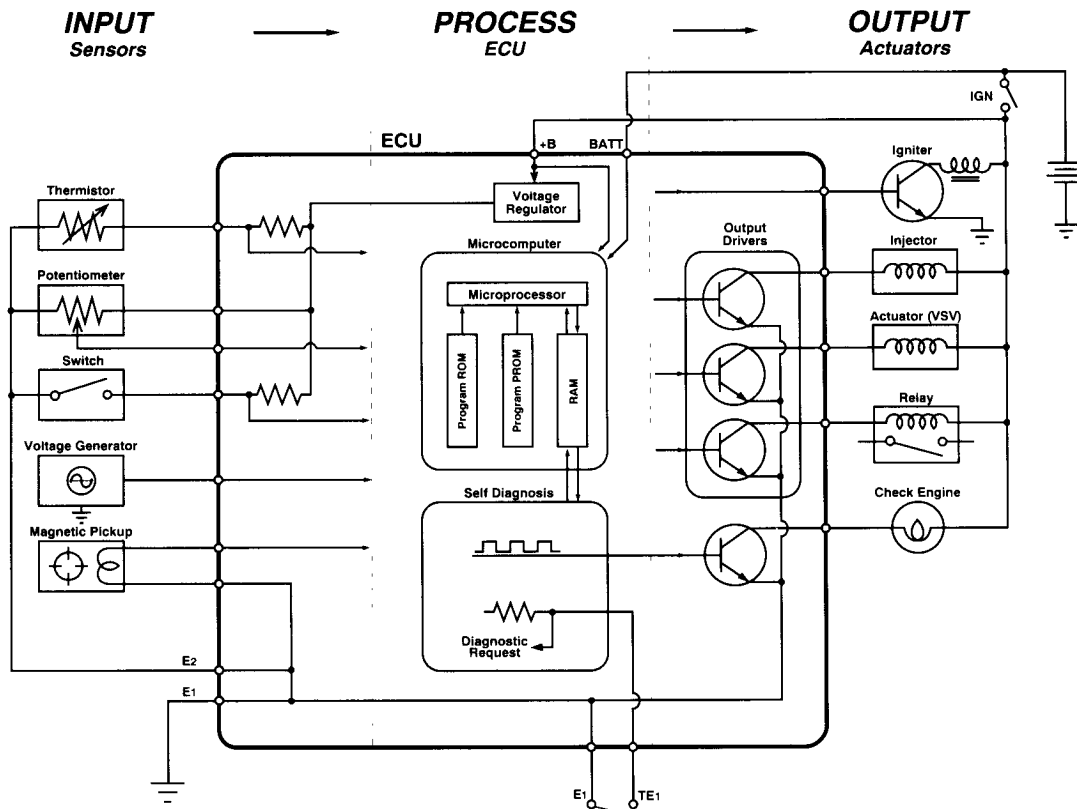
System identification is relatively simple.

- The Conventional EFI system has no check engine light.
- The P7/EFI system has a check engine light but has a mechanical advance distributor.
- The EFI/TCCS system has a check engine light and an electronic advance distributor.

The Input Sensors, Information Source for the ECU

In an electronic control system, the ECU uses its sensors in much the same manner as we use our five senses. Our sense of touch tells us when things are hot or cold; our sense of hearing allows us to distinguish one sound from another; our sense of smell tells us when fresh coffee is brewing somewhere nearby. Sensors give the ECU similar abilities: the ability to feel the temperature of the engine coolant, to listen for the sound of detonation, and to smell the exhaust stream for the presence of sufficient oxygen.

This lesson on input sensors will address how each major ECU input sensor circuit works. Each sensor circuit will be broken down so you can see its individual components: the sensor, electrical wiring, and the ECU.

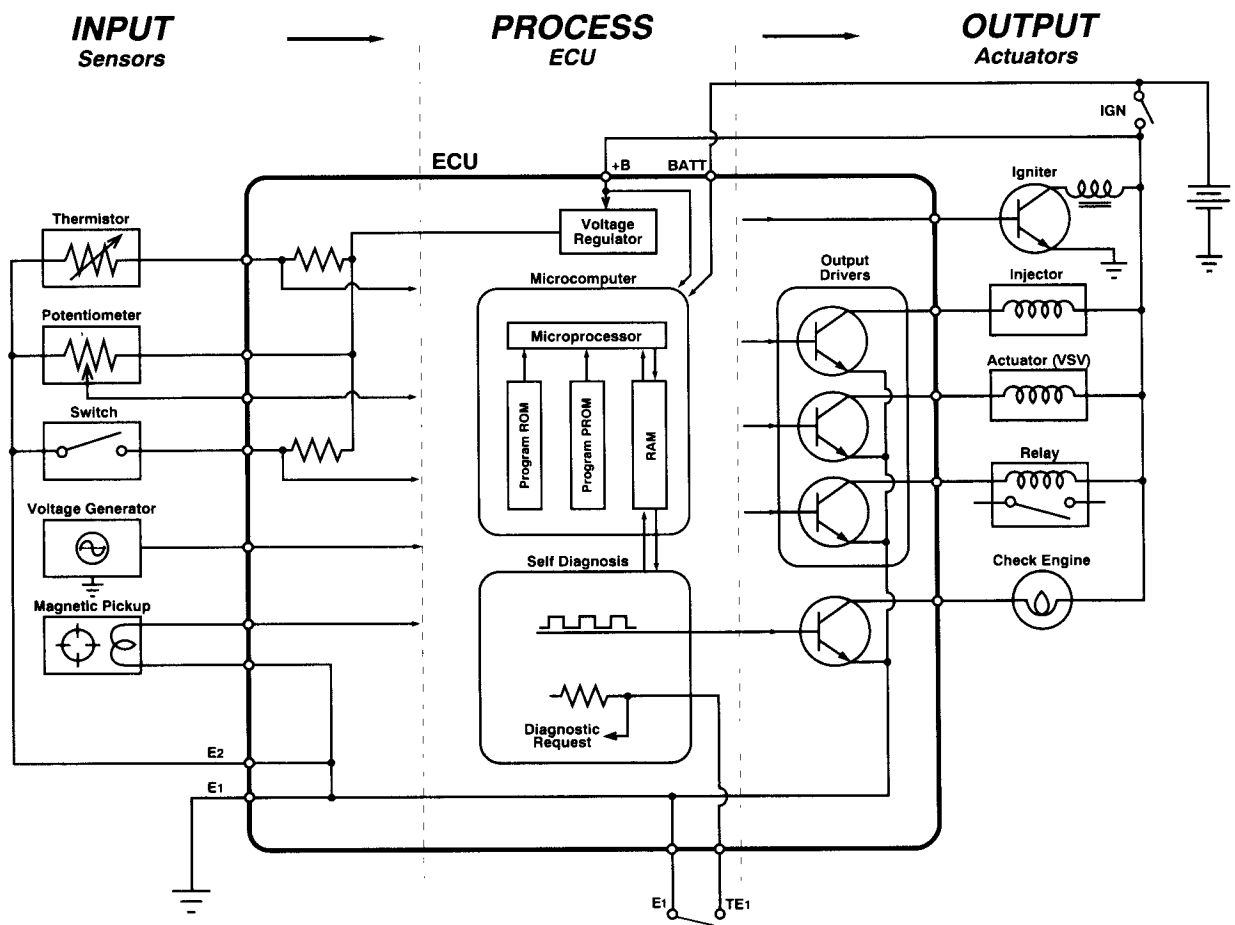


Overview

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Input Sensors Used in Basic Injection and Spark Calculation

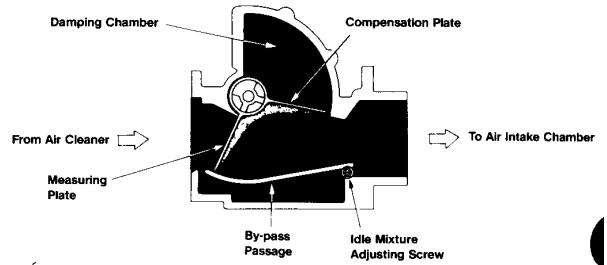
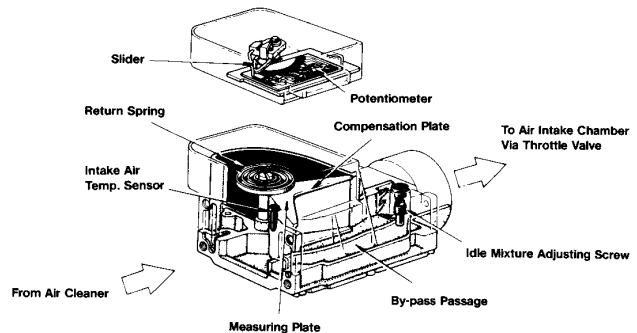
Engine Air Flow Sensing

Vane Type Air Flow Meters (Vs, General Information)

The vane type air flow meter is located in the air induction system inlet pipe between the air cleaner and the throttle body. It is composed of the measuring plate, compensation plate, return spring, potentiometer, and by-pass passage. The sensor also incorporates the idle mixture adjusting screw (factory sealed), the fuel pump switch, and the intake air temperature sensor (which will be addressed later in this lesson). Because intake air volume is a direct measure of the load placed on an engine, the vane type air flow meter provides the most important input to the ECU for fuel and spark calculations.

When air passes through the air flow meter, it forces the measuring plate open to a point where it balances with the force of the return spring. The damping chamber and compensation plate prevent vibration of the measuring plate during periods of sudden intake air volume changes.

The potentiometer, which is connected to the measuring plate and rotates on the same axis, converts the mechanical movement of the measuring plate into a variable voltage signal. Movement of the measuring plate and the analog voltage signal produced by this sensor are proportional to the volume of air entering the intake manifold.



Vane Air Flow Meter Electrical Circuit

The sensor movable contact is attached to the measuring plate and rides on a fixed resistor wired between the reference voltage input and the ground. As the volume of air entering the engine increases, the movable contact moves across the fixed resistor, causing a change in signal output voltage.

There are two designs of vane air flow meters used on Toyota L type EFI systems. The first design generates a signal which varies from low voltage at low air volumes to high voltage at high air volumes. The second design sensor has opposite signal characteristics. These sensors also operate on different reference voltages. Both sensor designs integrate an intake air temperature sensor into the air flow meter.

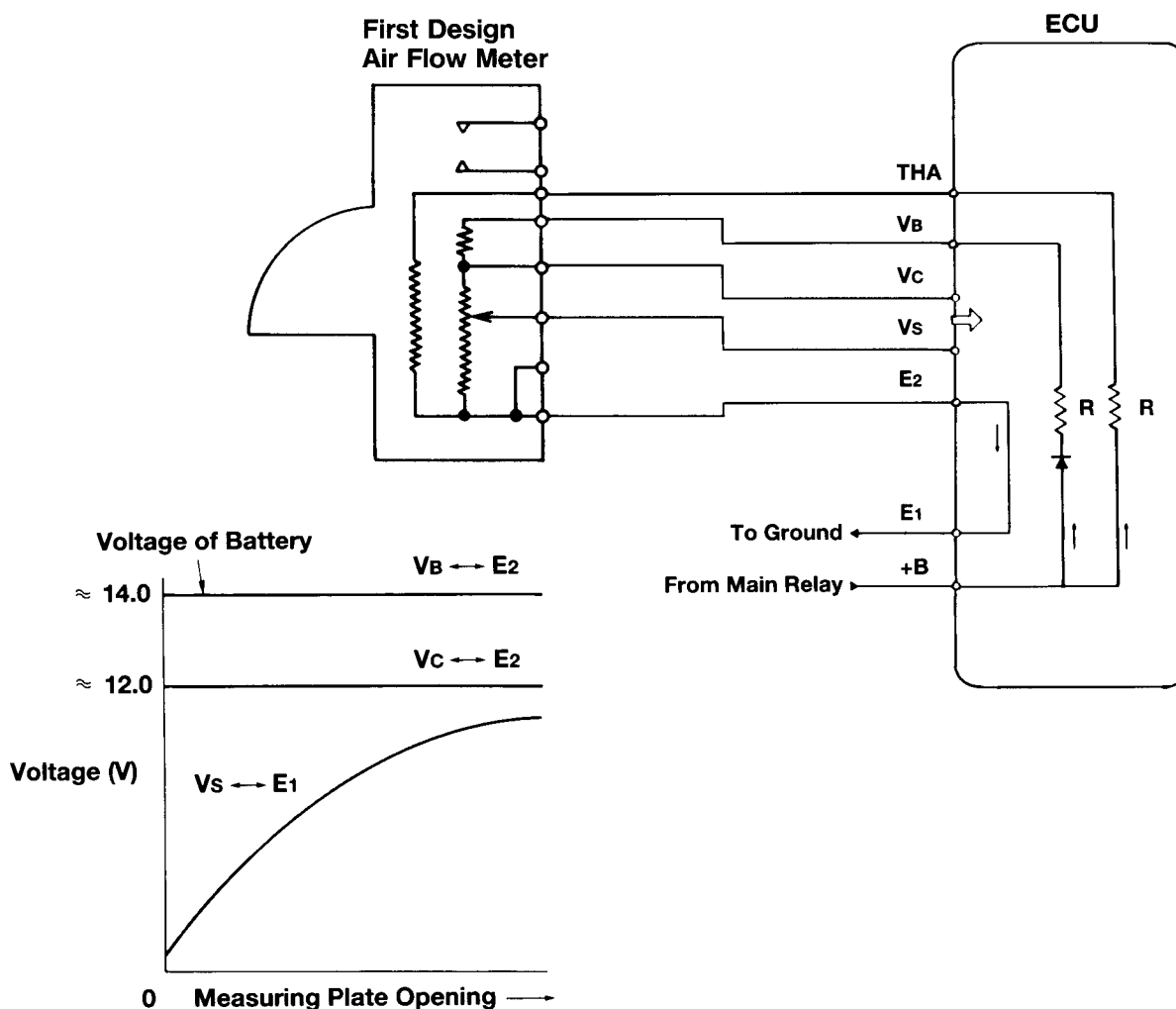
First Design Vane Air Flow Meter

The first design air flow meter is found on all Conventional EFI engines and many later model TCCS equipped engines. This sensor has an electrical connector with seven terminals, four of which are used for air flow measurement.

Air Flow Sensor Terminal Identification (First Design Sensor)

V _B	Voltage Battery	Battery voltage supply to sensor
V _C	Voltage Constant	ECU constant reference voltage
V _S	Voltage Signal	Signal voltage representing air flow
E ₂	Earth Ground	Sensor ground return path

The air flow meter and ECU are wired as shown in the diagram. Signal characteristics are depicted by the accompanying graph. The use of battery voltage, V_B, as a sensor input necessitates the use of the V_C terminal as a constant reference signal for the ECU. This is because battery voltage may change with variances in electrical load and ambient temperatures. Without the use of a constant reference voltage, these changes would cause a change in the V_S signal value recognized by the ECU.



Second Design Air How Meter

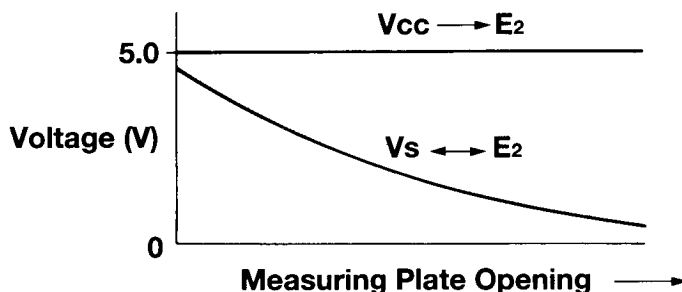
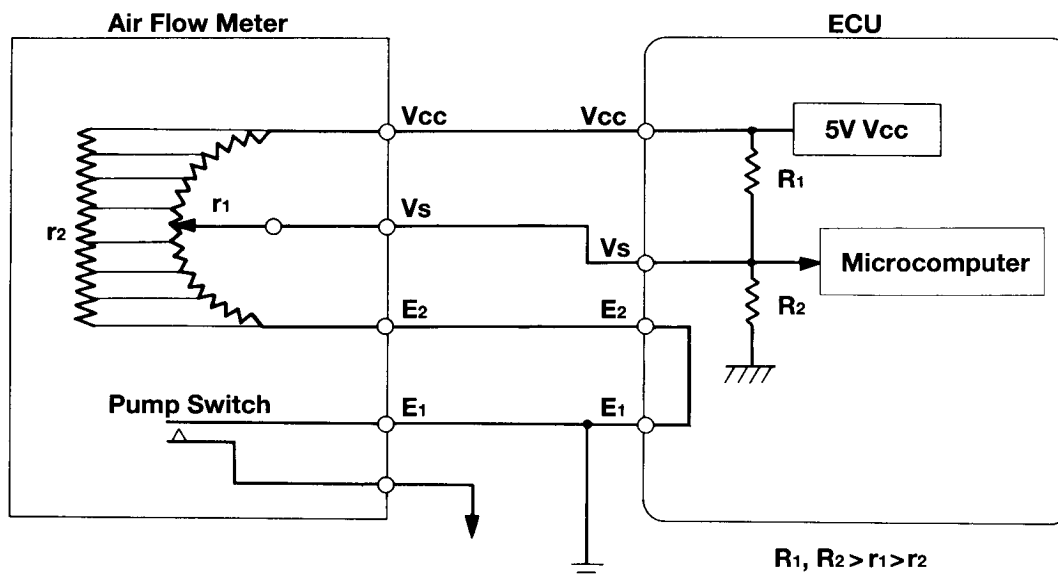
The second design air flow meter was introduced on the '85 5M-GE engine, and its use expanded with many late model TCCS equipped engines. This sensor has an electrical connector with seven terminals, three of which are used for air flow measurement.

The air flow meter and ECU are wired as shown in the diagram; signal characteristics are depicted by the accompanying graph. The use of a regulated 5 volt reference eliminates the need for the VB terminal with this sensor circuit.

Air Flow Sensor Terminal Identification (Second Design Sensor)

Vcc	Voltage Constant Control	Regulated 5 volt reference
Vs	Voltage Signal	Signal voltage representing air flow
E2	Earth Ground	Sensor ground return

Resistors R1 and R2 provide self diagnostic capabilities and allow for a fail-safe voltage at the ECU in the event of an open circuit. These two resistors have a very high resistance value (relative to r1 and r2) and essentially have no electrical effect on the circuit under normal operating conditions. They will, however, affect the open circuit voltage measured on the Vs wire at the ECU.



Karman Vortex Air Flow Meter (Ks)

The Karman vortex air flow meter is currently used on the 7M-GTE Toyota engine and the 2JZ-GE and 1UZ-FE Lexus engines. It is located in the air induction system inlet pipe between the air cleaner and the throttle body. The sensor is composed of a **photocoupler** and mirror, a vortex generator, and an integrated circuit (IC) which together, measure the frequency of the vortices generated by air entering the intake system.

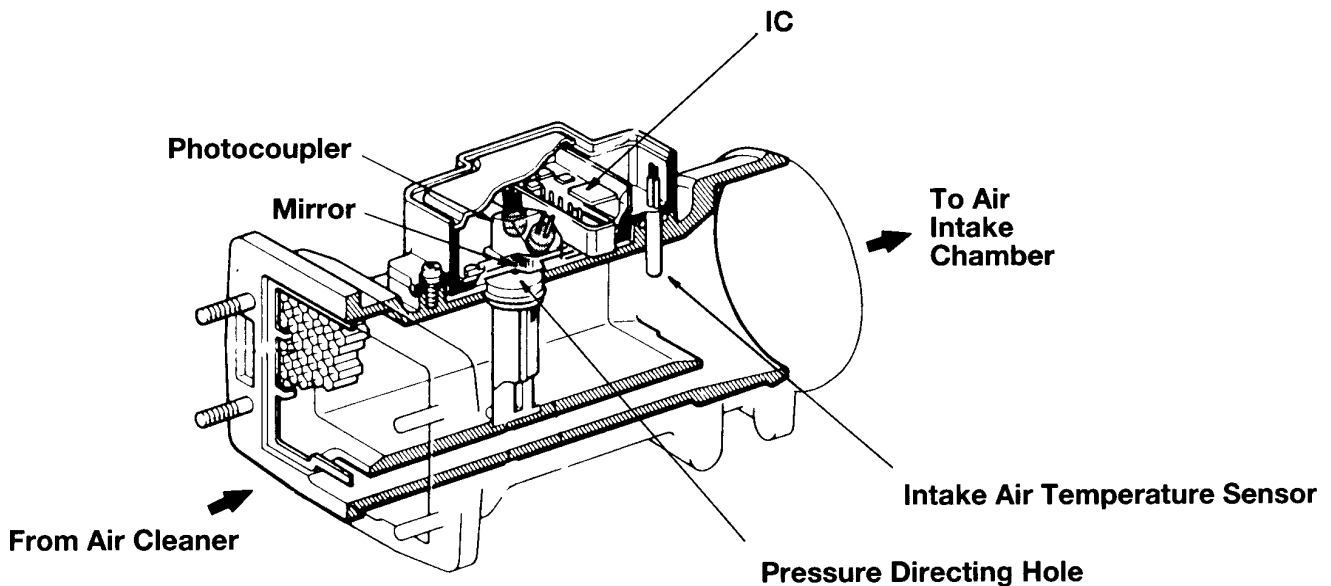
When compared with the vane type air flow meter, the Karman vortex meter is smaller, lighter, and offers less restriction to incoming air. Similar to the vane type air meter, the

Karman vortex meter integrates the intake air temperature sensor into the meter assembly.

The sensor has an electrical connector with five terminals, three of which are used for air flow measurement.

Karman Vortex Air Flow Meter Terminal Identification

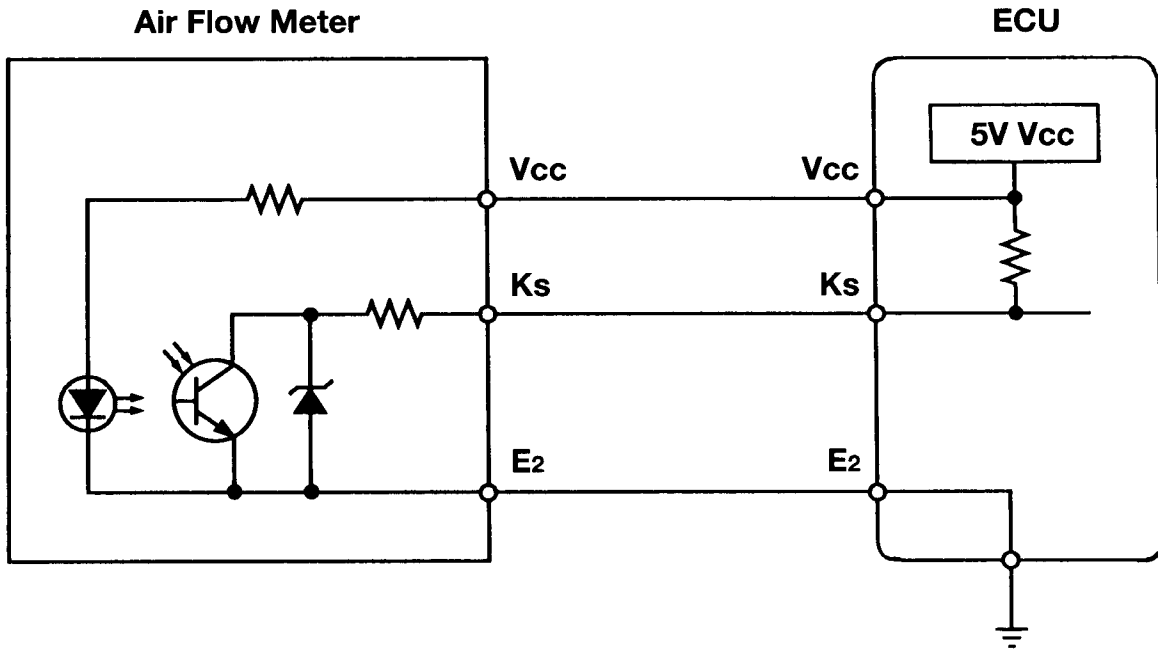
Vcc	Voltage Constant Control	Regulated 5 volt reference
Ks	Karman Signal	Digital frequency signal representing air flow
E2	Earth Ground	Sensor ground return



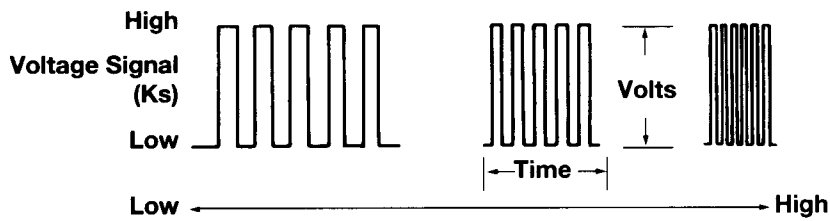
ENGINE CONTROLS - INPUT SENSORS

The Karman vortex air flow meter and ECU are wired as shown in the diagram. Signal characteristics are represented by the illustration of the variable frequency square wave. Because of the pull-up resistor wired between the Vcc and Ks circuit, the Ks signal will go to 5 volts if the circuit is opened.

When air passes through the air flow meter, the vortex generator creates a swirling of the air downstream. This swirling effect is referred to as a "Karman vortex." The frequency of this Karman vortex varies with the velocity of the air entering the air flow meter and other variables. The photocoupler and metal foil mirror are used to detect changes in these vortices.



Frequency Increases Proportionally With Air Flow



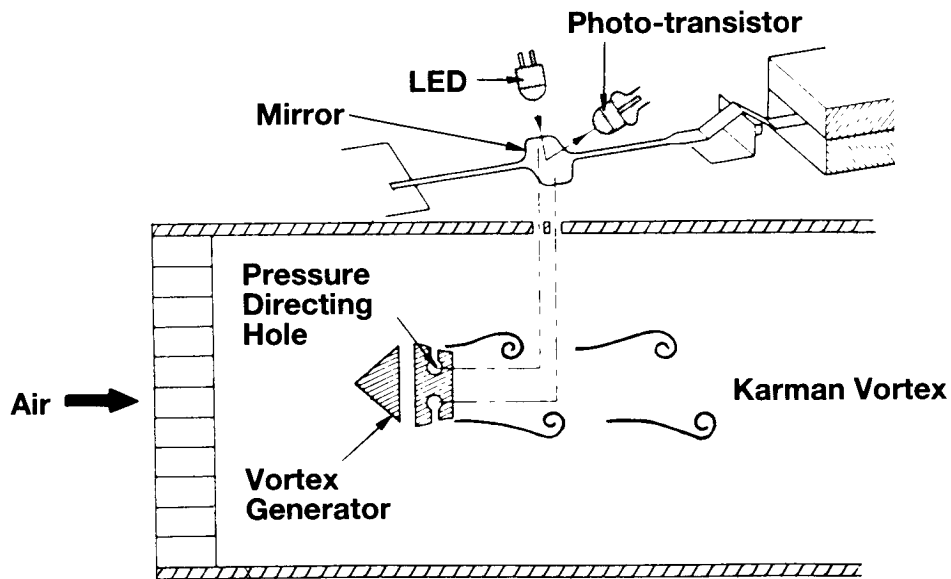
Intake Air Volume

- ≈ 30 Hz @ 700 rpm
- ≈ 90 Hz @ 2500 rpm
- ≈ 170 Hz @ 4000 rpm

ENGINE CONTROLS - INPUT SENSORS

The metal foil mirror is used to reflect light from the LED to the photo transistor. The foil is positioned directly above a pressure directing hole which causes it to oscillate with the changes in vortex frequency. As the mirror

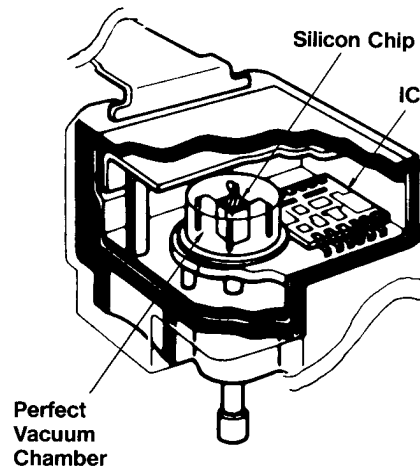
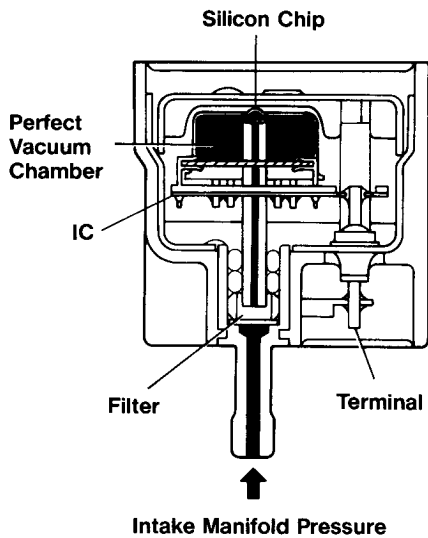
oscillates, the 5 volt Vcc reference is switched to ground by a photo transistor within the sensor. The resulting digital signal is a 5 volt square wave which increases in frequency in proportion to increases in intake air flow.



Manifold Absolute Pressure Sensor

The manifold absolute pressure sensor (sometimes referred to as vacuum sensor) is used on engines equipped with D type EFI. It is typically located somewhere on the bulkhead with a vacuum line leading directly to the intake manifold. It measures intake air volume by monitoring changes in manifold absolute pressure, a function of engine load.

The sensor consists of a piezoresistive silicon chip and an Integrated Circuit (IC). A perfect vacuum is applied to one side of the silicon chip and manifold pressure applied to the other side. When pressure in the intake manifold changes, the silicon chip flexes, causing a change in its resistance. The varying resistance of the sensor causes a change in signal voltage at the PIM (Pressure Intake Manifold) terminal.



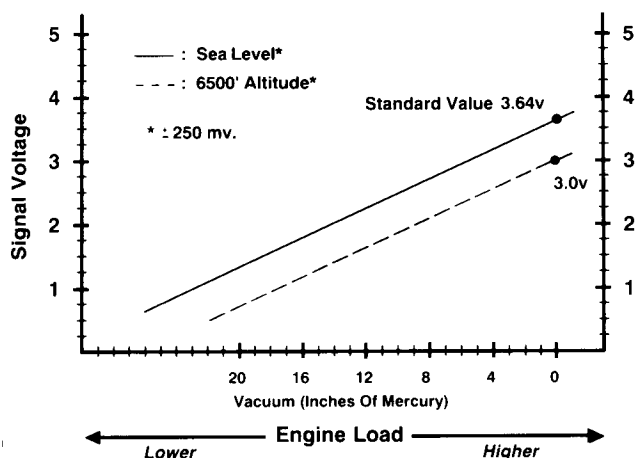
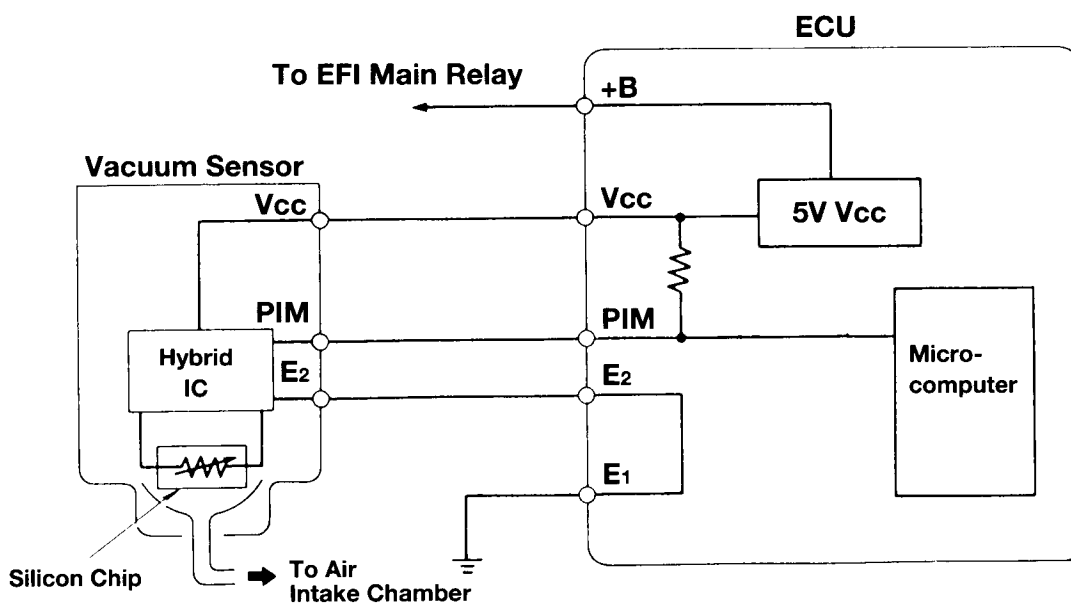
The manifold absolute pressure sensor has an electrical connector with three terminals.

Manifold Absolute Pressure Sensor Terminal Identification

Vcc	Voltage Constant Control	Regulated 5 volt reference
PIM	Pressure Intake Manifold	Signal voltage representing manifold pressure
E2	Earth Ground	Sensor ground return path

The sensor and ECU are wired as shown in the diagram. As manifold pressure increases (approaches atmospheric pressure) there is a proportionate increase in PIM signal voltage. This analog signal characteristic is depicted in the accompanying graph.

TO check sensor calibration, signal voltage should be checked against the standards shown on the graph, and a voltage drop check should be performed over the entire operating range of the sensor.



Voltage Drop

Applied Vacuum kPa (mm Hg) (in. Hg)	13.3 (100) (3.94)	26.7 (200) (7.87)	40.0 (300) (11.81)	53.5 (400) (15.75)	66.7 (500) (19.69)
Voltage drop V	0.3 - 0.5	0.7 - 0.9	1.1 - 1.3	1.5 - 1.7	1.9 - 2.1

Engine Speed and Crankshaft Angle Sensing

On TCCS equipped engines, the Ne and G1 signals inform the ECU of engine rpm and crankshaft angle. This information, along with information from the air flow or manifold pressure sensor, allows the ECU to calculate the engine's basic operating load. Based on measured load, basic injection and spark advance angle can be accurately calculated.

Ne Signal (Number of Engine Revolutions)

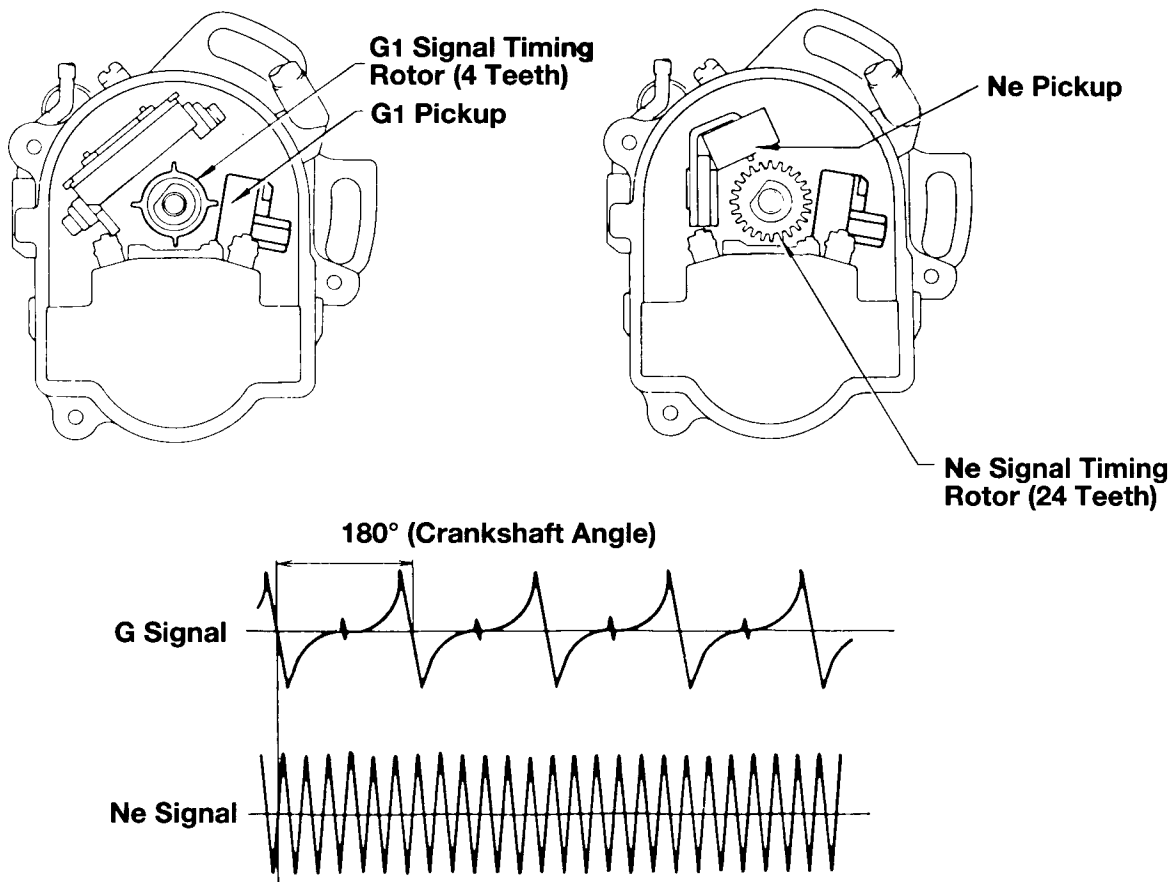
The Ne signal generator consists of a pickup coil and toothed timing rotor. The number of teeth on the signal timing rotor is determined by the system used. The Ne sensor produces an alternating current waveform

signal and is of critical importance to the ECU. If this signal fails to reach the ECU, the engine will not run.

G or G1 Signal (Group #1)

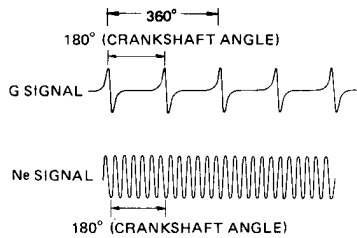
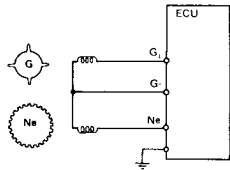
The G signal generator is very similar to the Ne signal generator. The G1 signal represents the standard crankshaft angle and is used by the ECU to determine ignition and injection timing in relation to TDC.

Depending on engine, there are different variations of Ne and G1 signal generators. The following illustrations show the relationship between the Ne and G1 signals and the different variations of signal generators.

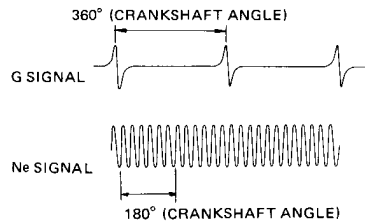
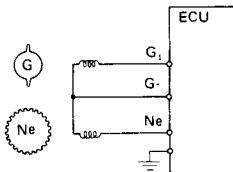


Ne AND G SIGNAL VARIATIONS

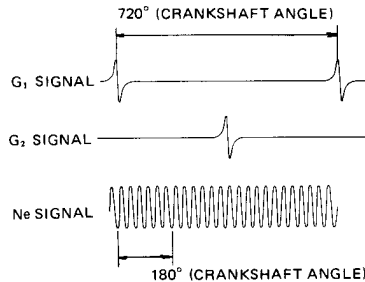
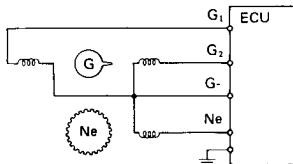
G signal (1 pickup coil, 4 teeth)
Ne signal (1 pickup coil, 24 teeth)



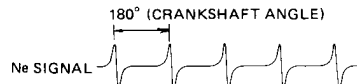
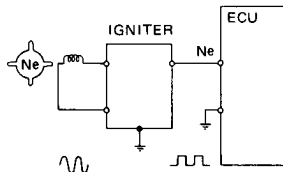
G signal (1 pickup coil, 2 teeth)
Ne signal (1 pickup coil, 24 teeth)



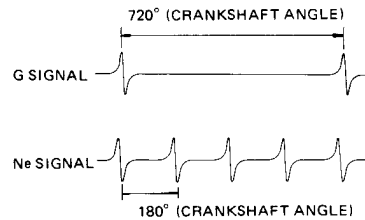
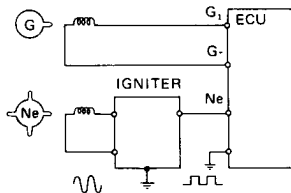
G₁ and G₂ signal (2 pickup coils, 1 tooth)
Ne signal (1 pickup coil, 24 teeth)



Ne signal (1 pickup coil, 4 teeth)



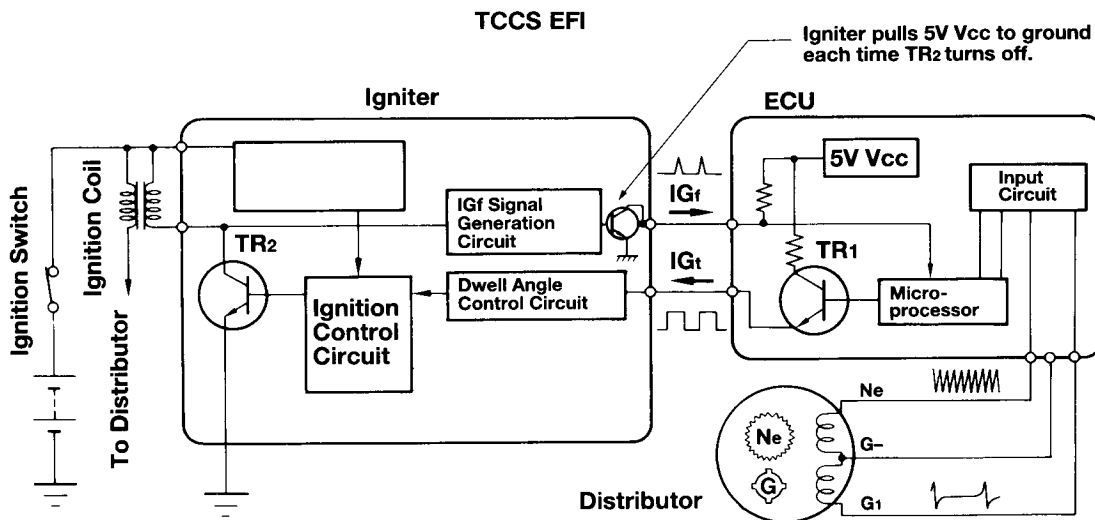
G signal (1 pickup coil, 1 tooth)
Ne signal (1 pickup coil, 24 teeth)



IGf Signal

The IGf signal is generated by the igniter on EFI/TCCS systems. The ECU supplies a 5 volt reference through a pull-up resistor to the IGf signal generation circuit in the igniter. When a spark plug fires, the IGf signal generation circuit pulls the five volts to ground, causing a pulse to be sensed at the ECU. One pulse is generated by the igniter for each ignition event which is carried out.

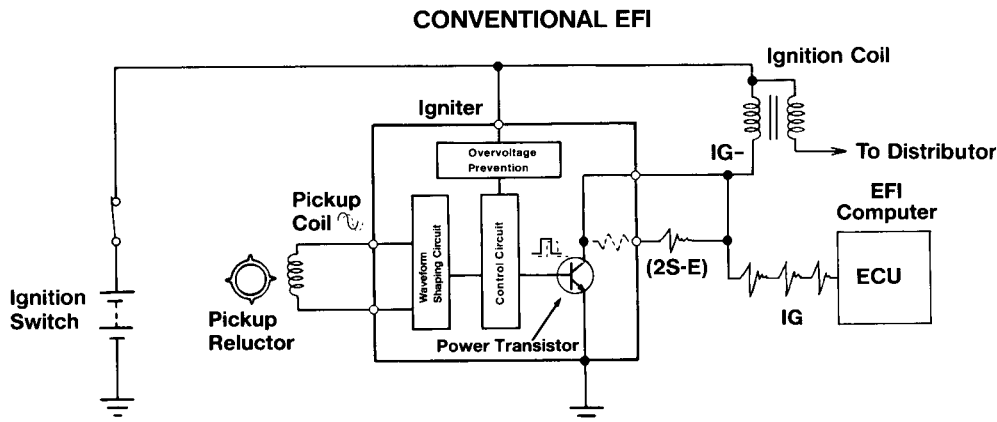
The IGf signal confirms that ignition has actually occurred. In the event of a failure to trigger an ignition event, the ECU will shut down injector pulses to protect the catalyst from flooding with raw fuel. Typically this fail-safe shutdown occurs within eight to eleven IGt signals after the IGf signal is lost. This condition can occur with any primary ignition system fault, an igniter failure, a problem with the IGf circuit wiring, or with a faulty ECU.



IG Signal

On Conventional EFI engines, the IG signal is used to inform the ECU of engine rpm. This signal is generated directly from the coil negative terminal or from an electrically equivalent point inside the igniter on the early

P-7 2S-E engine. Conventional EFI engines do not use an Ne or G sensor and do not use an IGf signal. The IG signal is also used by the ECU to trigger injection pulses; therefore, if this signal is lost, the engine will stall for lack of injection pulse.



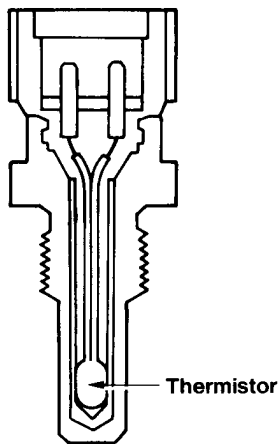
Input Sensors Used For Injection and Spark Corrections

Water Temperature Sensor (THW)

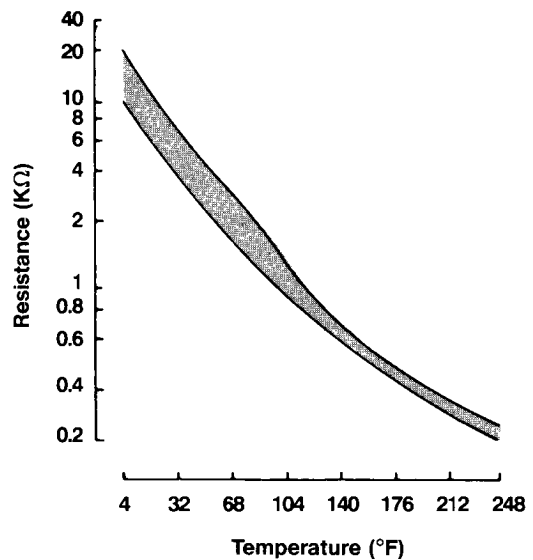
The water temperature sensor is typically located near the cylinder head water outlet. It monitors engine coolant temperature by means of an internally mounted thermistor. The thermistor has a negative temperature coefficient (NTC), so its resistance value decreases as coolant temperature rises. The accompanying resistance graph demonstrates this relationship.

The water temperature sensor is required because fuel vaporization is less efficient when the engine is cold. Internal engine friction is also higher during cold operation, increasing operating load. The THW signal is used by the ECU to determine how much fuel enrichment correction is necessary to provide good cold engine performance. In addition to fuel calculations, the THW signal plays a major role in almost every other function that the ECU serves.

THW SENSOR



THW RESISTANCE

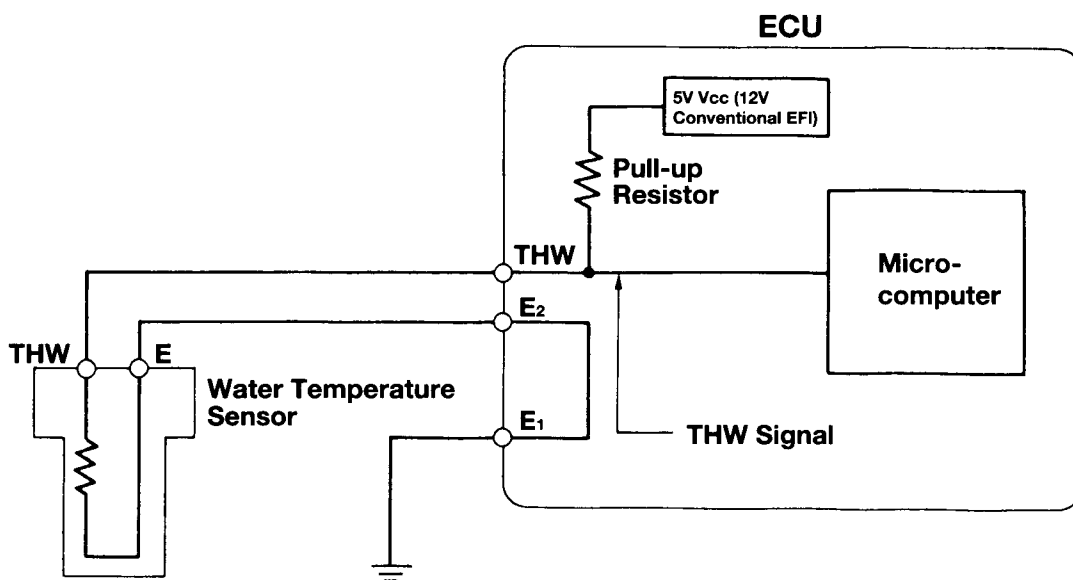


The water temperature sensor has a two terminal electrical connector attached to either end of the thermistor element.

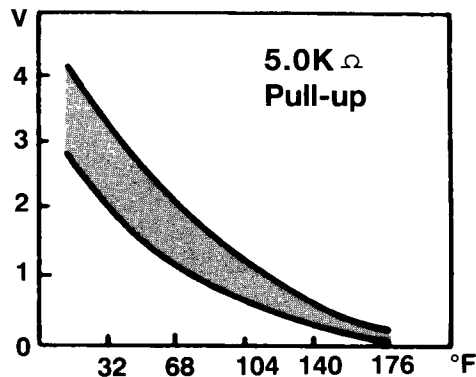
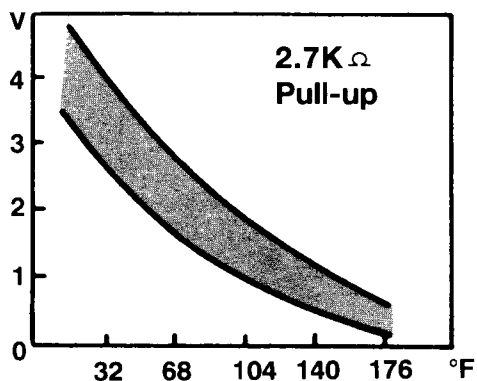
The sensor and ECU are wired as shown in the diagram. Signal voltage characteristics are determined by the value of the **pull-up resistor**, located inside the ECU, either 2.7 K Ω or 5 M. The graphs accompanying the diagram give approximate voltage specifications. To determine which pull-up resistor a particular ECU uses, refer to the technical reference charts in Appendix B of this book.

Water Temperature Sensor Terminal Identification

THW	Thermo Water Sensor	Analog signal representing engine coolant temperature
E2	Earth Ground	Sensor ground return path

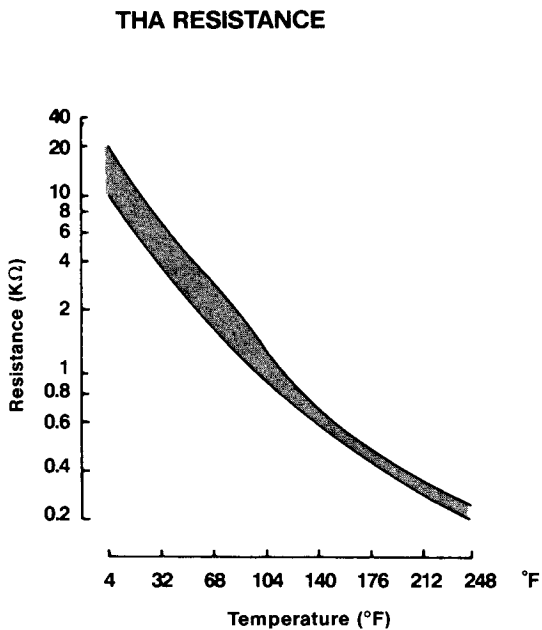
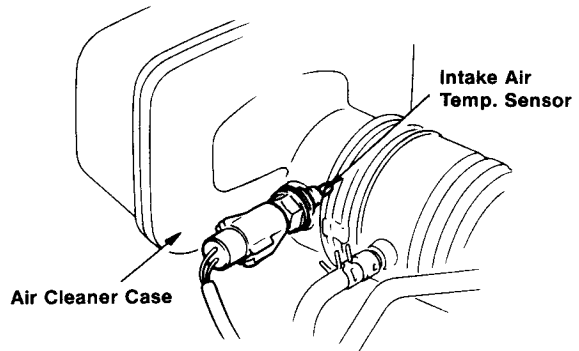
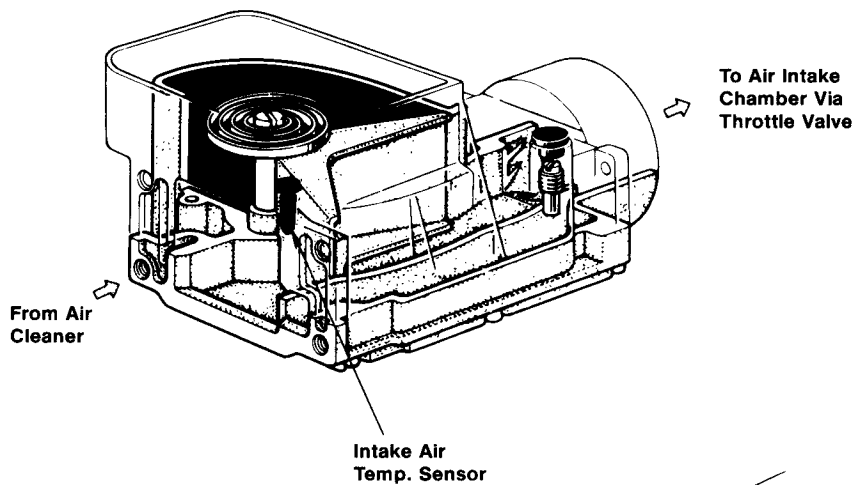


THW SIGNAL VOLTAGE



Air Temperature Sensor (THA)

The air temperature sensor monitors the temperature of air entering the intake manifold by means of a thermistor. This thermistor is integrated within the air flow meter on L type systems and located in the intake air hose just downstream of the air cleaner on D type systems. It has the same resistance characteristics as the water temperature sensor.



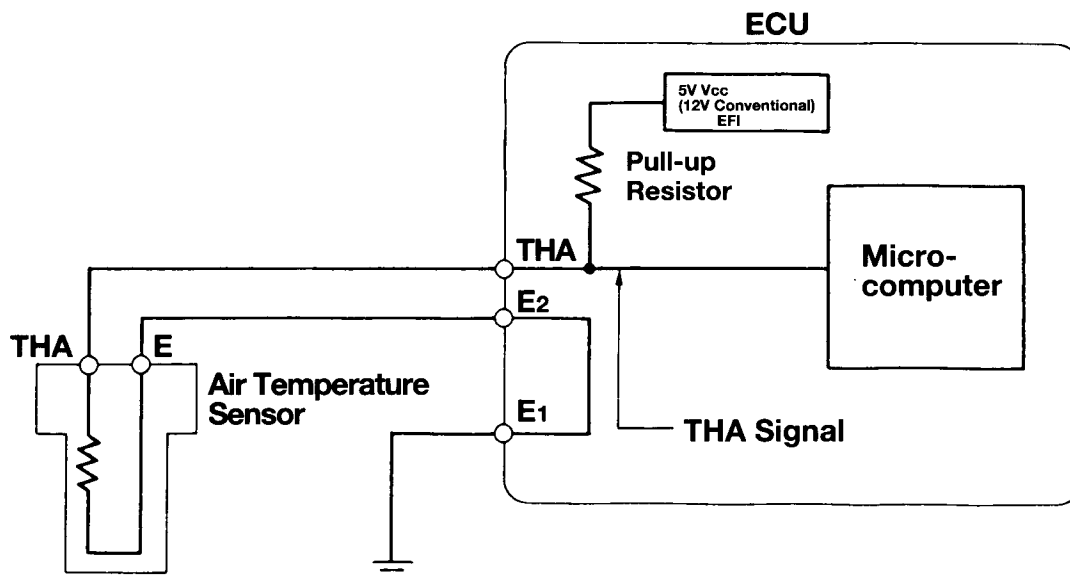
This sensor has a two-terminal electrical connector attached to either end of the thermistor element.

The air temperature sensor and ECU are wired as shown in the diagram. Resistance and voltage signal characteristics are represented by the accompanying graphs.

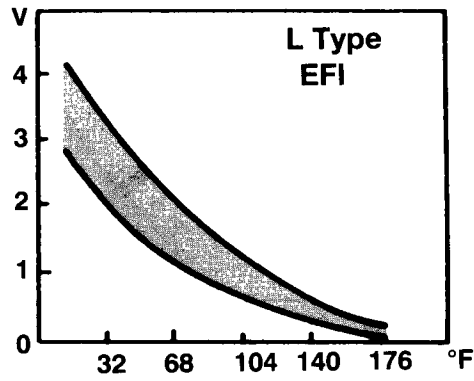
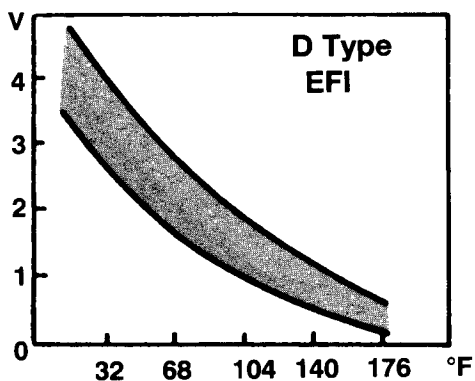
Air Temperature Sensor Terminal Identification

THA	Thermo Air Sensor	Analog signal representing intake air temperature
E2	Earth Ground	Sensor ground return path

An intake air temperature monitor is necessary in the EFI system because the pressure and density of air changes with temperature. Because air is more dense when cold, the ECU factors intake air temperature into the fuel correction program.



THA SIGNAL VOLTAGE



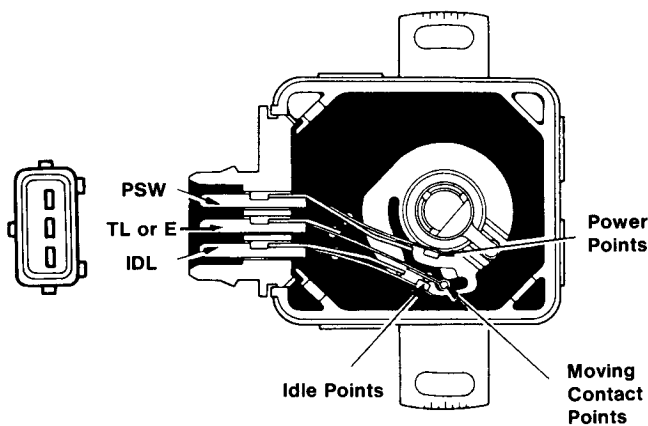
Throttle Angle and Closed Throttle Sensing

Throttle position sensors typically mount on the throttle body, directly to the end of the throttle shaft. Depending on engine and model year, Toyota EFI equipped engines use one of two different types of throttle position sensors. These sensors are categorized as on-off type and linear type. The linear type sensor is typically used on most late model Electronically Controlled Transmission (ECT) equipped vehicles.

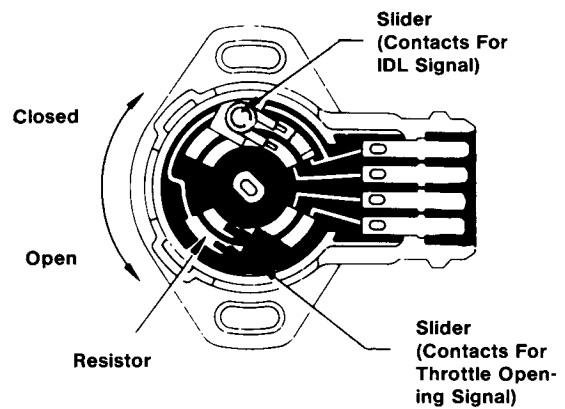
The on-off type sensor circuits can be further broken down into first and second design. This sensor is typically used on manual or non-ECT transmission equipped applications.

All throttle sensors, regardless of design, supply the ECU with vital information about idle status and driver demand. This information is used by the ECU to make judgments about power enrichment, deceleration fuel cut-off, idle stability, and spark advance angle corrections.

ON-OFF THROTTLE POSITION SENSOR



LINEAR THROTTLE POSITION SENSOR



On-Off Type Throttle Position Sensors (IDL & PSW)

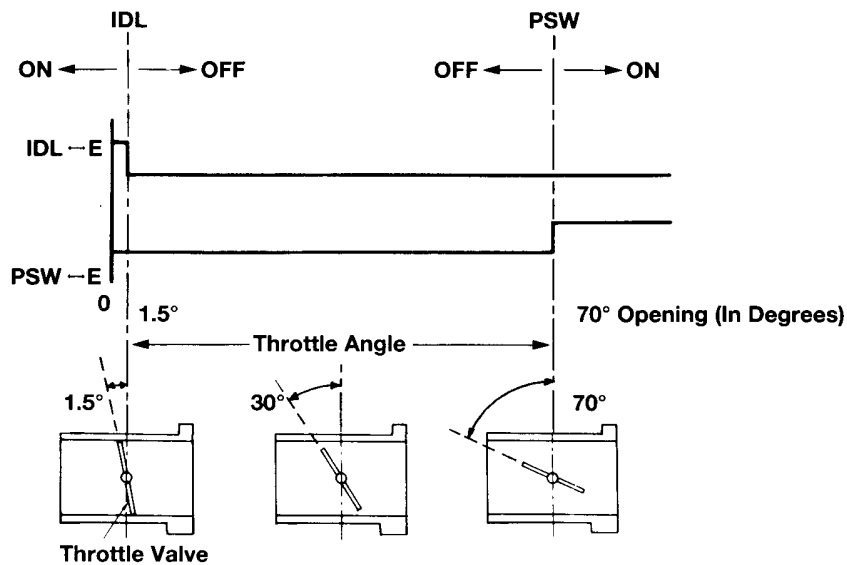
The on-off type throttle position sensor is a simple switch device which, depending on application, either pulls a reference voltage to ground or sends a battery voltage signal to the ECU. The on-off throttle position sensors are electrically wired to the ECU as shown in the accompanying diagrams.

First Design On-Off Type Sensor

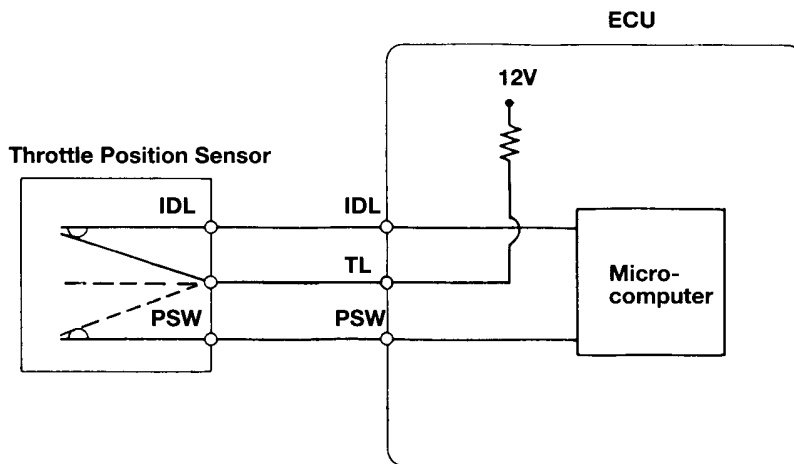
The first design sensor is used on Conventional EFI engines. It utilizes a dual

position contact which switches a battery voltage signal to either the IDL or PSW inputs at the ECU. This switching action causes the voltage signal at the ECU to go high whenever the switch contacts are closed.

Referring to the voltage graph, IDL signal voltage is high when the throttle is closed and goes low when the throttle exceeds a 1.5° opening. PSW voltage is low until the throttle exceeds about a 70° opening; then it goes high.



1ST DESIGN THROTTLE SENSOR



Second Design On-Off Type Sensor

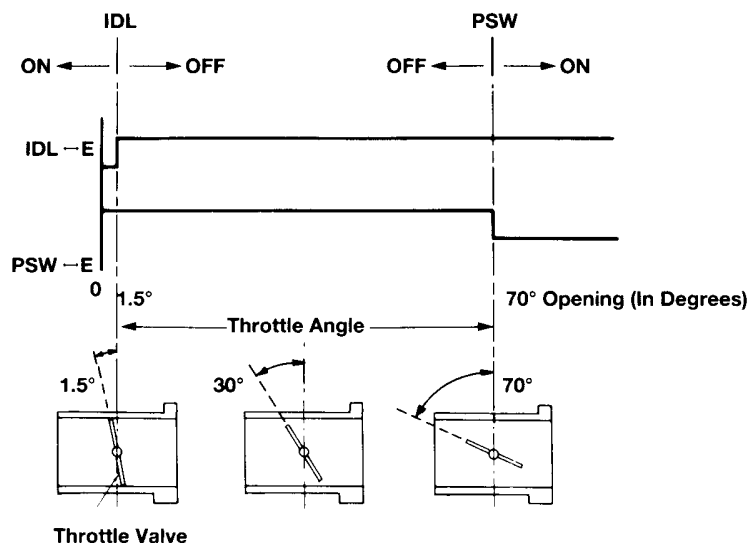
The second design sensor, which is used on many late model TCCS equipped engines, utilizes a dual position contact to switch an ECU reference voltage to ground. This switching action causes the signal at the ECU to go low whenever the switch contacts are closed.

Referring to the voltage graph, IDL signal voltage is low when the throttle is closed and goes high when the throttle exceeds a 1.5' opening. PSW voltage is high until the throttle opens to about 70'; then it goes low.

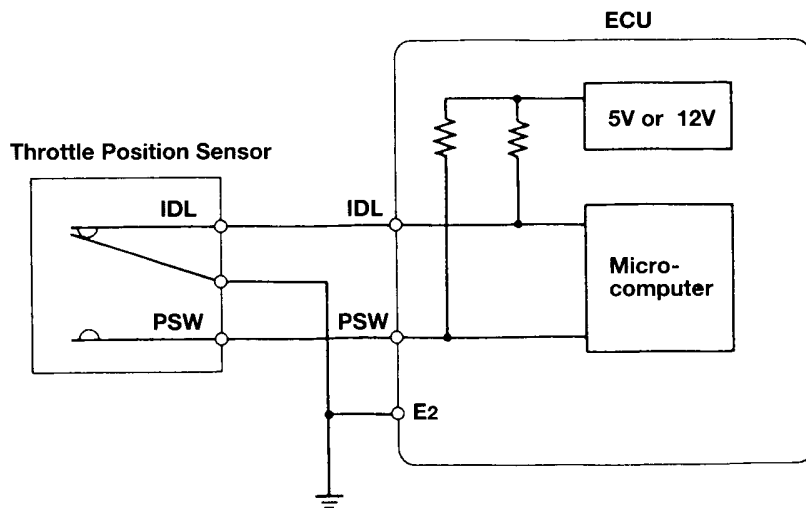
The three wire electrical connector terminals are identified as follows.

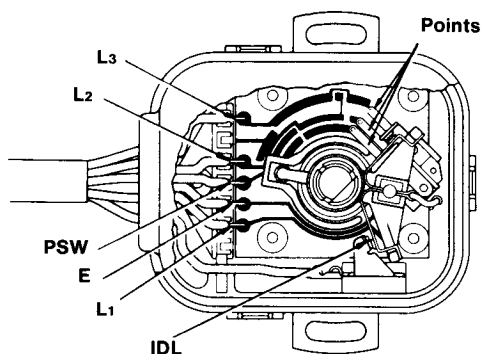
1st and 2nd Design On-Off Throttle Position Sensor Terminal Identification

IDL	Idle Switch	Digital signal representing closed throttle status
PSW	Power Switch	Digital signal representing near wide open throttle demand
TL 1st design	Throttle Position	Power supply for throttle position sensor (from ECU)
E2 2nd design	Earth Ground	Sensor ground return path



2ND DESIGN THROTTLE SENSOR

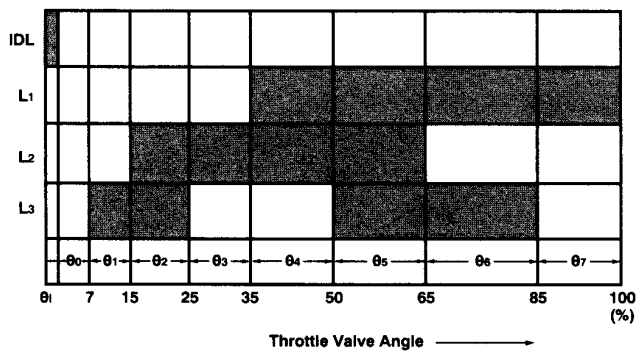
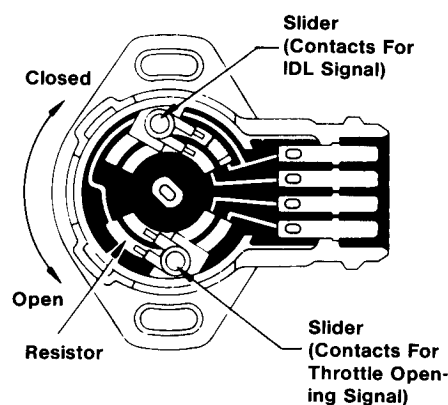




Linear Throttle Position Sensor (VTA)

The linear throttle position sensor is mounted to the throttle body. It is composed of two movable contacts, a fixed resistor, and four electrical terminals. The two movable contacts move along the same axis as the throttle valve. One is used for the throttle opening angle signal (VTA) and the other for the closed throttle signal (IDL).

On '83 and '84 Cressidas/Supras and '83 through '86 Camrys equipped with an Electronically Controlled Transmission (ECT), a modified sensor, which incorporates three additional signal wires designated L1, L2, and L3, is used. These signals represent throttle opening angles in between the 1.5' IDL and 70' PSW signals. The L1, L2, and L3 signals are used by the ECT system and are generated in a similar manner as the IDL and PSW signals on the 2nd design sensor. The TCCS ECU only uses the IDL and PSW signals from this sensor.



As the throttle opens, a potentiometer circuit converts the mechanical movement of the throttle valve into a variable voltage signal. The voltage produced by this sensor is proportional to the throttle valve opening angle.

The Linear Throttle Position Sensor has an electrical connector with four terminals.

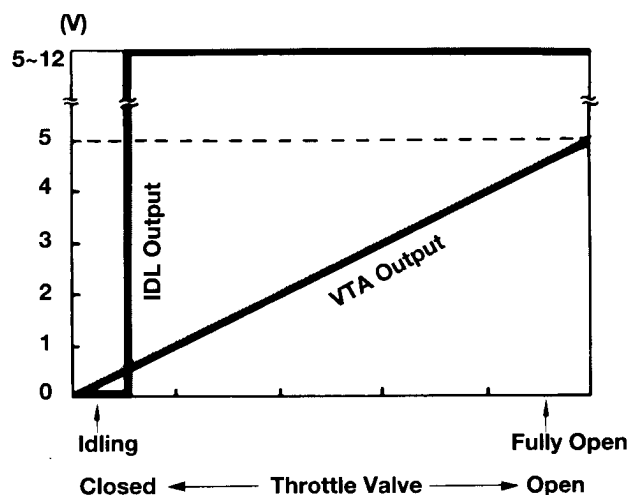
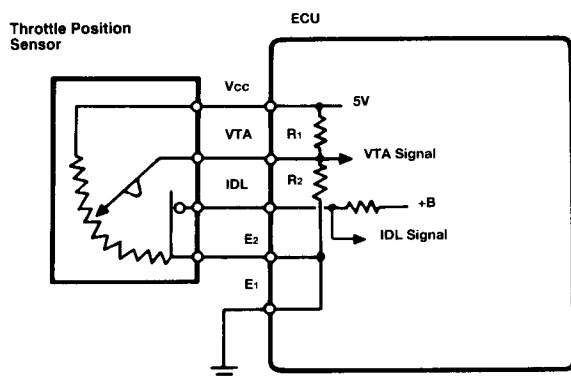
Linear Throttle Position Sensor Terminal Identification

Vcc	Voltage Constant Control	Regulated 5 volt reference
VTA	Voltage Throttle Angle	Analog signal voltage representing throttle angle
IDL	Idle Switch	Digital signal voltage representing closed throttle position
E2	Earth Ground	Sensor ground return path

The sensor and ECU are wired as shown in the diagram. As the throttle valve opens, the sensor VTA contact moves closer to the voltage source, causing a signal voltage increase.

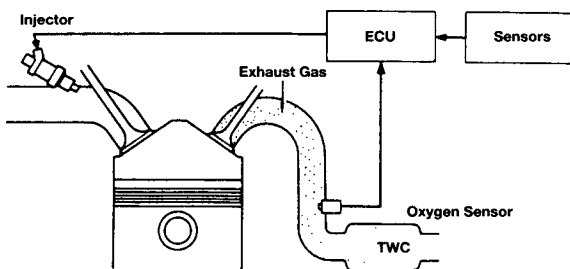
At closed throttle, the IDL contact is held closed. This pulls the IDL signal circuit to ground. As the throttle opens, the IDL contact breaks, causing the digital IDL signal voltage to go from low to high. These signal characteristics are depicted in the accompanying graph.

Resistors R1 and R2 provide self diagnostic capabilities and allow for a fail-safe voltage at the ECU in the event of an open circuit. These two resistors have a very high resistance value and essentially have no electrical effect on the circuit under normal operating conditions. They will, however, affect the open circuit voltage measured on the VTA wire at the ECU.



Exhaust Oxygen Content Sensing (OX1)

Exhaust oxygen sensors are used on Toyota EFI and EFI/TCCS equipped engines to provide air/fuel ratio feedback information to the ECU. This information is used to constantly adjust the air/fuel ratio to stoichiometry during warm idle and cruise operating conditions. The **stoichiometric** air/fuel ratio delivers one pound of fuel for each 14.7 pounds of air entering the intake manifold and results in the most efficient combustion and catalyst operation. When the electronic control system is using information from the oxygen sensor to adjust air/fuel ratio, the system is said to be operating in **closed loop**.



Exhaust oxygen sensor efficiency is dependent upon its operating temperature. The sensor will only generate an accurate signal when it has reached its minimum operating temperature of 750°F. Therefore, the oxygen sensor is typically located in the exhaust stream at the manifold collector. This location is close enough to the exhaust valves to maintain adequate operating temperature under most driving conditions and allows a representative exhaust sample from all cylinders.

Open and Closed Loop Operation

In addition to promoting efficient combustion and catalyst operation, a stoichiometric air/fuel ratio also promotes excellent fuel economy. This relatively lean mixture is desirable during cruise and idle operation; however, other operating conditions often require a richer air/fuel ratio. When the electronic control system ignores signals from the oxygen sensor and does not correct the air/fuel ratio to 14.7:1, the system is said to be operating in open loop.

In order to prevent overheating of the catalyst and ensure good driveability, open loop operation is required under the following conditions:

- During engine starting
- During cold engine operation
- During moderate to heavy load operation
- During acceleration and deceleration

During open loop operation, the ECU ignores information from the exhaust oxygen sensor and bases fuel injection duration calculations exclusively on the other input sensors.

Exhaust Oxygen Sensors

Toyota engines utilize two different types of oxygen sensors. The zirconium dioxide sensor is used on all engines except the '90 and later 4A-GE Federal and 3VZ-E California 2WD truck engines. These two engines use a titania oxide sensor.

To bring the system to closed loop operation more rapidly, many engines use a heated exhaust oxygen sensor. The heated sensor provides more accurate exhaust sampling during idle and low speed operation when exhaust temperatures are relatively low. Use of a heated sensor allows closed loop operation earlier during engine warm-up cycles and also allows more flexibility in oxygen sensor location. These factors help in meeting strict exhaust emissions control standards.

Engines produced for sale in California also incorporate a Sub-Oxygen Sensor which helps improve the efficiency of the catalyst system. This sensor is located after the catalyst and is used to fine tune the air/fuel ratio delivered by the injectors, helping to optimize catalyst efficiency.

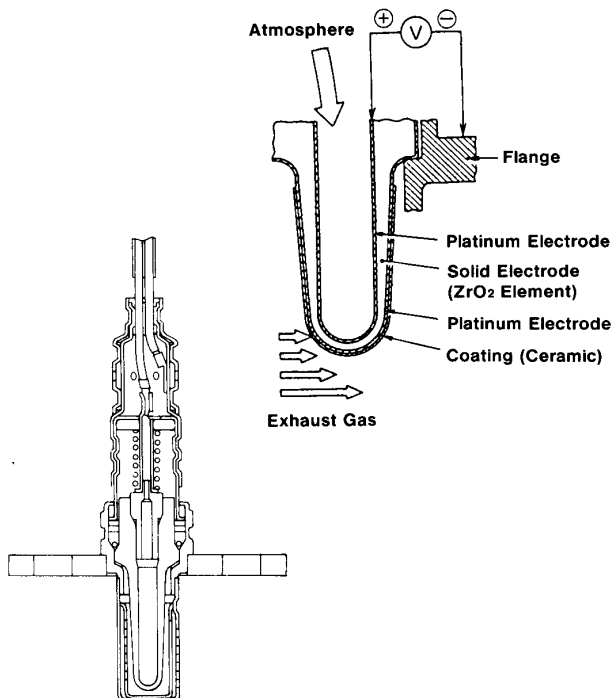
Zirconium Dioxide Sensor The zirconium dioxide oxygen sensor is an electro-chemical device which compares the oxygen content of the exhaust stream with the oxygen in an ambient air sample. It consists of a zirconium dioxide (ZrO_2) element sandwiched between two platinum electrodes.

This sensor behaves very similar to a single cell battery. The electrodes act as the positive (+) and negative (-) plates, and the zirconium dioxide element acts as the electrolyte.

Rich air/fuel ratio: If the oxygen concentration on the inside plate differs greatly from that on the outside plate, as it would with a rich air/fuel ratio, electrons will flow through the ZrO_2 element to the plate exposed to the high oxygen concentration. During rich operating conditions, the inside, or positive plate, is exposed to a much higher concentration of oxygen than the outside, or negative plate. This creates a difference in electrical potential, or voltage, which is measured by a **comparator circuit** in the ECU.

Lean air/fuel ratio: When the air/fuel ratio becomes lean, the oxygen content of the exhaust gas increases significantly. Because both plates are now exposed to a relatively high concentration of oxygen, electrons balance equally between the two plates. This eliminates the electrical potential between the plates.

ZIRCONIUM DIOXIDE OXYGEN SENSOR



Zirconium Dioxide Oxygen Sensor Operating Characteristics

Air/Fuel Ratio	Exhaust Oxygen Concentration	Ambient Oxygen Concentration	Electron Concentration	Signal Voltage
Rich	Low	High	Positive plate	High
Lean	High	High	Positive and Negative plates	Low

ENGINE CONTROLS - INPUT SENSORS

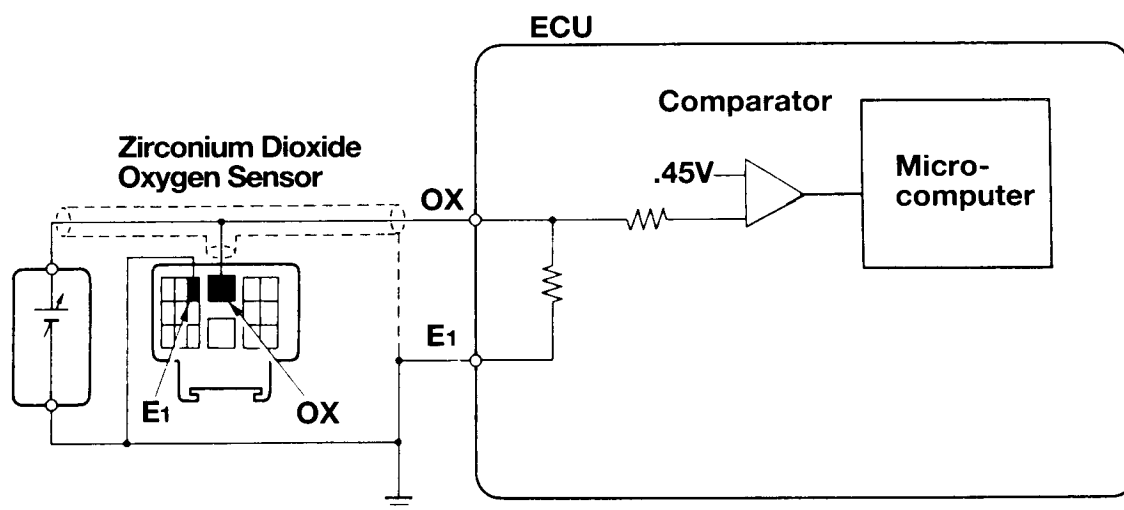
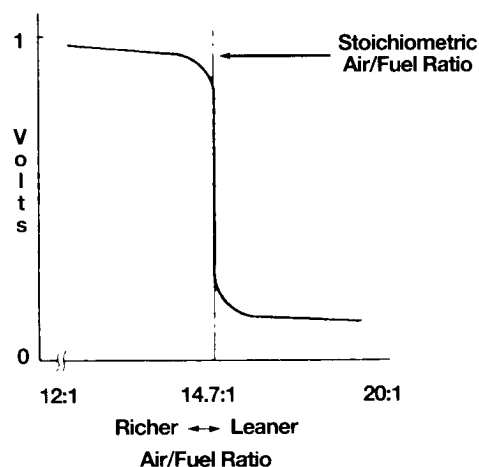
ZrO₂ sensor voltage signal and ECU processing: The voltage signal produced by the oxygen sensor is relatively small. During the richest operating conditions, this signal approaches 1000 millivolts (1 volt).

The ZrO₂ oxygen sensor is wired as shown in the diagram. Voltage characteristics are depicted in the accompanying graph.

As the voltage graph illustrates, the output of the ZrO₂ sensor acts almost like a switch. As the air/fuel ratio passes through the stoichiometric range, voltage rapidly switches from high to low.

The ECU comparator circuit is designed to monitor the voltage from the sensor and send a digital signal to the microprocessor. If sensor voltage is above the comparator switch point, $\approx 1/2$ volt, the comparator output will be high. If the sensor voltage is below the comparator switch point, the comparator output will be low. The microcomputer monitors the output of the comparator to determine how much oxygen remains in the exhaust stream after combustion occurs.

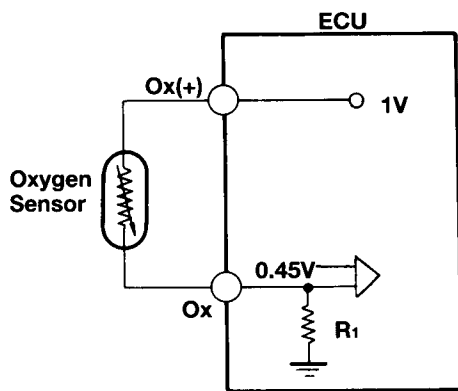
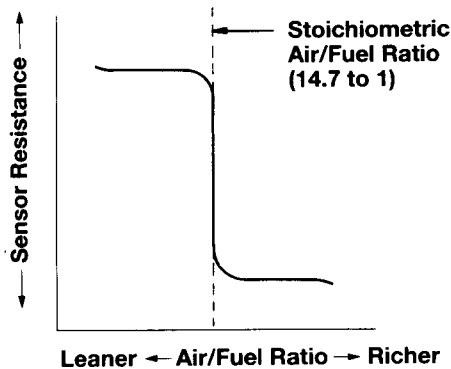
**ZIRCONIUM DIOXIDE SENSOR SIGNAL
VOLTAGE CHARACTERISTICS**



Titania Oxide Sensor This four-terminal device is a variable resistance sensor with heater. It is connected in series between the OX+ reference and a fixed resistance located inside the ECU. This circuit operates similarly to a thermistor circuit.

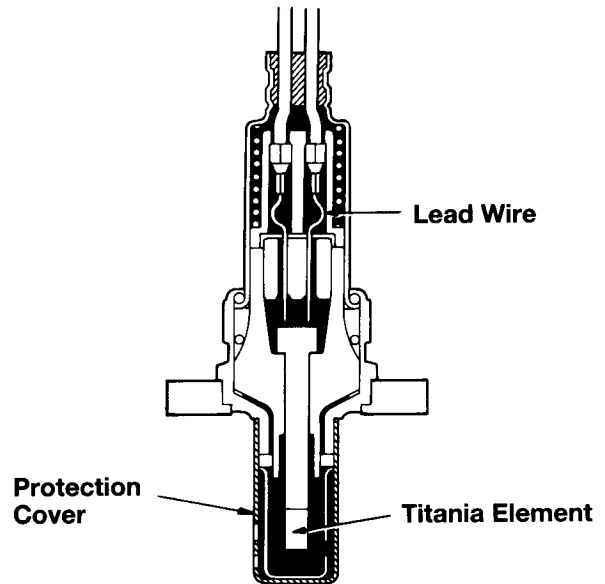
The properties of the thick film titania element are such that as oxygen concentration of the exhaust gas changes, the resistance of the sensor changes. As the sensor resistance changes, the signal voltage at the ECU also changes.

TITANIA OXIDE SENSOR RESISTANCE CHARACTERISTICS



The titania sensor and ECU are wired as shown in the diagram. A one-volt potential is supplied at all times to the OX+ terminal of the sensor. The resistance value of the sensor changes abruptly as the stoichiometric boundary is crossed. The accompanying voltage and resistance graphs depict these characteristics and their influence on OX signal voltage.

TITANIA OXIDE OXYGEN SENSOR



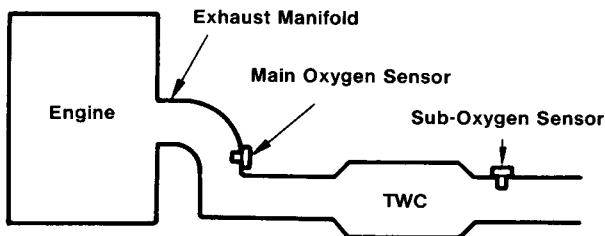
The ECU comparator circuit is designed to monitor the voltage drop across R1. As the voltage drop across the sensor increases, the drop across R1 decreases and vice versa. This gives the OX signal voltage the same characteristic as the ZrO₂ sensor.

If sensor voltage drop is low, as it would be with a rich mixture, OX signal voltage will be above the comparator switch point, 450 millivolts, and the comparator output will be high. If the sensor voltage drop is high, OX signal voltage will be below the comparator switch point and the comparator output will be low.

Sub-Oxygen Sensor (OX2)

The sub-oxygen sensor is used on California and some Federal engines. It is used to monitor the exhaust stream after the catalyst to determine if the air/fuel mixture is within the range for efficient converter operation.

The sub-oxygen sensor is identical to the ZrO₂ main oxygen sensor located ahead of the catalyst. Information from this sensor is used by the ECU to fine tune the air/fuel ratio and improve emissions.



Oxygen Sensor Terminal Identification

OX ₁	Main Oxygen Sensor	Analog signal representing pre-catalyst exhaust oxygen content
OX ₂	Sub-Oxygen Sensor	Analog signal representing post-catalyst exhaust oxygen content
OX	Oxygen Sensor Signal	Titania Oxygen Sensor Analog Signal
OX+	Oxygen Sensor Reference	Titania Oxygen Sensor Reference Voltage
HT	Oxygen Sensor Heater	Sensor heater current path
E1	Earth Ground	Sensor ground return path

Oxygen Sensor Heater Circuits (HT)

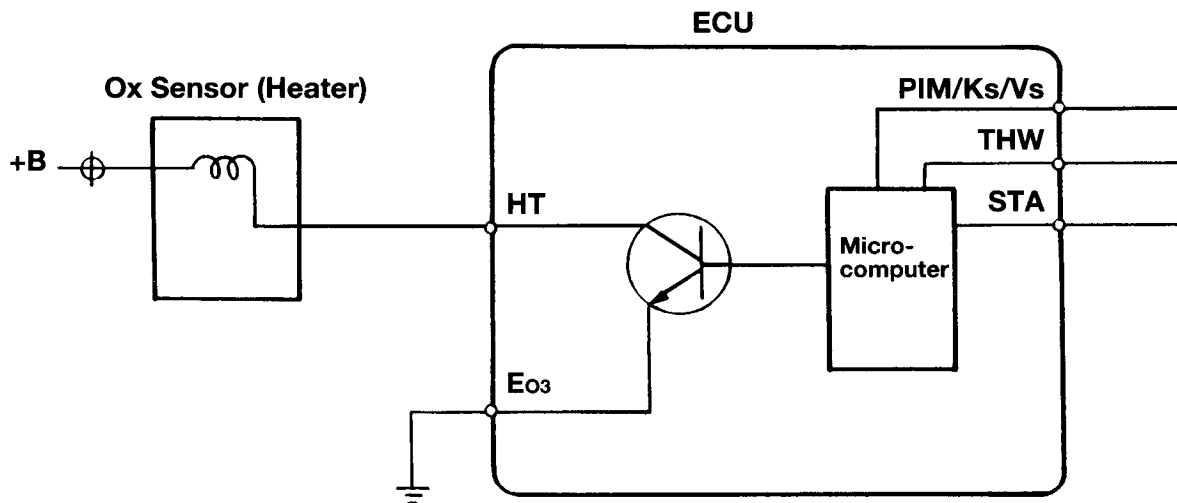
Oxygen sensors work very efficiently when the sensing element temperature is above 750°F (400°C). At warm cruise, it is not difficult to maintain oxygen sensor temperatures at or above this point. However, when the engine is first started or when idling or when driving under very light load, the oxygen sensor can cool down, forcing the fuel system to return to open loop operation.

The oxygen sensor heater control system maintains sensor accuracy by turning on the heater element whenever intake air volume is low (exhaust temperatures are low under these conditions). By heating the sensor electrically, sensor detection performance is enhanced.

This allows feedback operation under conditions which might otherwise require open loop fuel control. The ECU monitors the following parameters and cycles the oxygen sensor heater on:

- When intake air flow is below a given point.
- and
- coolant temperature is above approximately 32°F (0°C).
- specified time has elapsed after starting.

The oxygen sensor heater and ECU are wired as shown in the diagram. Whenever the above mentioned conditions are met, the ECU turns on the driver transistor to supply a ground path for heater current.

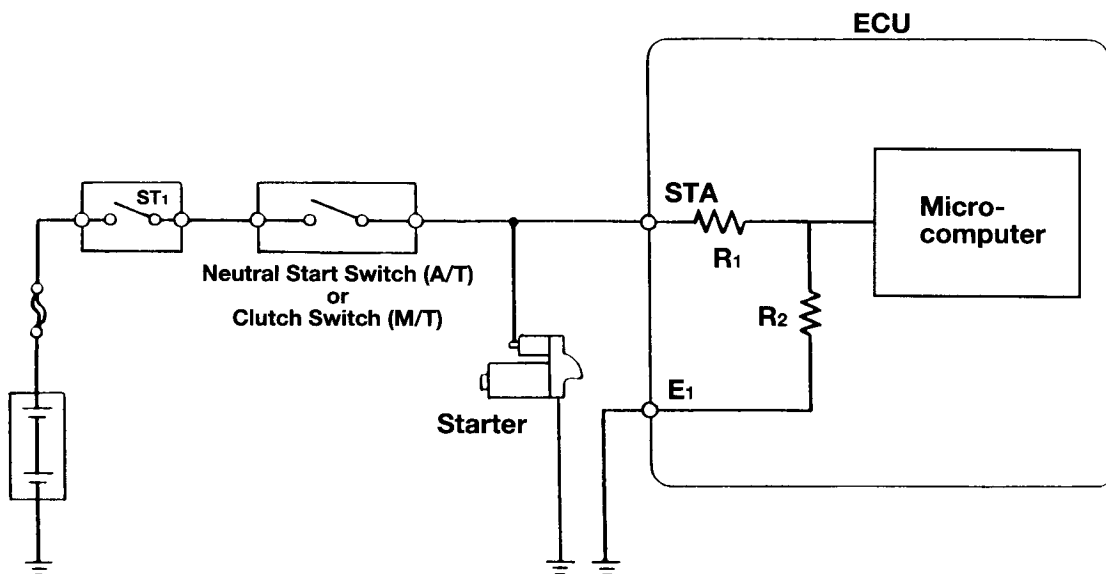


Other Inputs Affecting Injection and Spark Correction

Engine Cranking Signal (STA)

STA is a digital signal which is used by the ECU to determine if the engine is being cranked. The signal is generated at the ST1 terminal of the ignition switch and is used by the ECU primarily to increase fuel injection volume during cranking.

The STA circuit is wired to the ECU as shown in the diagram. The ECU will sense cranking voltage at the STA terminal whenever the ignition is switched to the "start" position as long as the neutral or clutch switch is closed.



Engine Detonation (Knock) Signal (KNK)

Knock Sensor

The knock sensor is a **piezoelectric** device mounted to the cylinder block which generates a voltage whenever it is exposed to vibration. When engine detonation occurs, vibration of the cylinder block causes the sensor to generate a voltage signal. The sensor signal varies in **amplitude** depending on the intensity of knock.

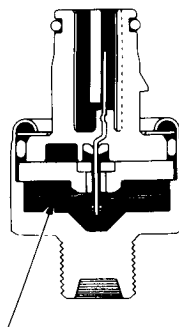
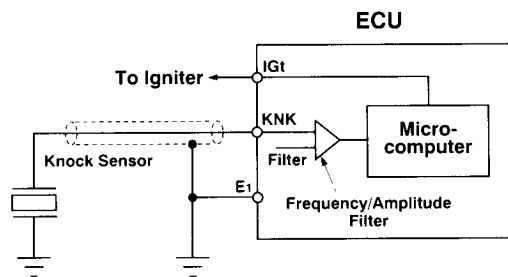
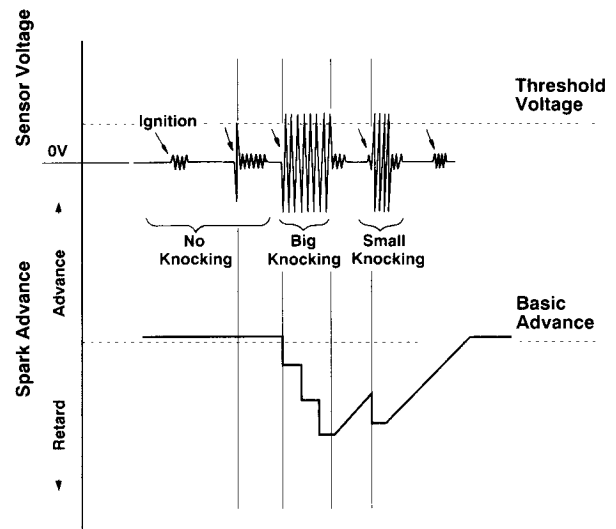
Typically, detonation vibration occurs in the 7KHz range (7 thousand cycles per second). Knock sensor and ECU designs take advantage of this fact.

There are two different types of knock sensors used on Toyota engines. The mass type sensor produces a voltage output over a wide input frequency range; however, its signal output is greatest at a vibration frequency of approximately 7KHz. With this type of sensor, the ECU uses a filter circuit to distinguish between background noise and actual engine knock.

The resonance type sensor is tuned into a very narrow frequency band and only produces a significant signal voltage when exposed to vibrations in the 7KHz range. The ECU requires less complicated filter circuitry with this type of sensor.

ECU Detonation Control

The ECU and knock sensor are wired as shown in the diagram. When engine detonation occurs, the ECU monitors knock sensor signal feedback to determine the degree of detonation taking place. This is accomplished by filtering out sensor signal voltage which does not go above preprogrammed amplitude parameters. Because other background noise and vibration cause some signal output from the knock sensor, the ECU is also programmed to filter out any signal which does not fall within certain frequency ranges.



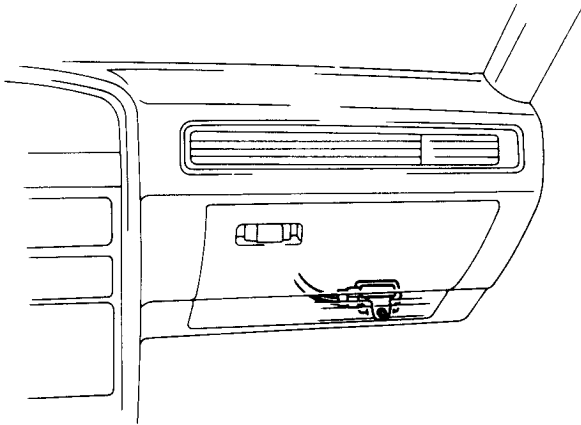
Piezoelectric Element

When the ECU judges that detonation is taking place, it retards ignition timing until the knocking stops. Timing is then advanced back to calculated value or, if detonation again begins, retarded again until detonation is stopped. In this manner, the ignition system can be operated at maximum efficiency, on the borderline of detonation, while avoiding an audible "ping." In the event that the ECU continues to sense detonation, timing retard is limited based on a clamp value stored in memory. If the ECU determines that the knock retard is not functional, it will enter a fail-safe mode and fix the retard angle to prevent engine damage.

Altitude Sensing (HAC)

Some TCCS equipped engines like the 3F-E, 3VZ-E (Cab and Chassis), and the 7M-GTE incorporate an altitude sensor in the TCCS system to shorten injection duration when the vehicle is operated at higher altitudes.

'87 - '88 SUPRA (7M-GTE)



Because the density of oxygen in the atmosphere is lower at high altitudes, the air volume measured by the air flow meter will not accurately represent actual oxygen entering the engine. This would result in a mixture which is excessively rich, causing emissions and driveability concerns.

The HAC sensor is integrated with the ECU on the 3-FE, 3VZ-E, and 1989 and later 7M-GTE engines. It is remotely mounted behind the glove box on the '87 and '88 7M-GTE Supra. The remotely mounted HAC sensor is wired to the ECU exactly the same as the manifold pressure sensor is wired on D type EFI. In fact, the HAC sensor circuit is electrically the same as a manifold pressure sensor circuit. The HAC sensor simply measures atmospheric pressure rather than intake manifold pressure.

The signal from the HAC circuit in the ECU is used to determine the fuel correction coefficient to be used after basic injection has been calculated. The accompanying graph represents how this correction factor affects final injection duration.

Stop Light Switch (STP)

The stop light switch input to the ECU is used to modify the deceleration fuel cut program when the vehicle is braking. Whenever the STIR signal is high (brake pedal is depressed), fuel cutoff and resumption rpm is reduced to improve driveability characteristics of the vehicle.

In the event the STP signal is lost, fuel cut will take place at the standard deceleration speed, causing an objectionable feel when fuel is canceled.

The STP signal at the ECU will be low as long as the brake pedal is not applied. When the pedal is depressed, current flows through the normally open stop light switch to the stop lamps and the ECU, causing the STP voltage to go high.

