## The ECU, Process Center of the Electronic Control System

The ECU is an extremely reliable piece of hardware which has the capability to receive and process information hundreds of times per second. At the heart of the ECU is the microprocessor. It is the processing center of the ECU where input information is interpreted and output commands are issued. The process and output functions of the ECU can be divided into the following six areas:

• Fuel Injection Control

• ESA / VAST Spark Advance Control

• Idle Speed Control

• Self Diagnosis

• Related Engine and Emissions Control

• Failure Management (fail-safe and back-up)

Fuel, spark, and failure management functions will be covered individually in this chapter. Idle Speed Control, related engine systems, emissions control systems, and the self diagnosis system will be the subject of chapters 6, 7, 8, and 9, respectively.
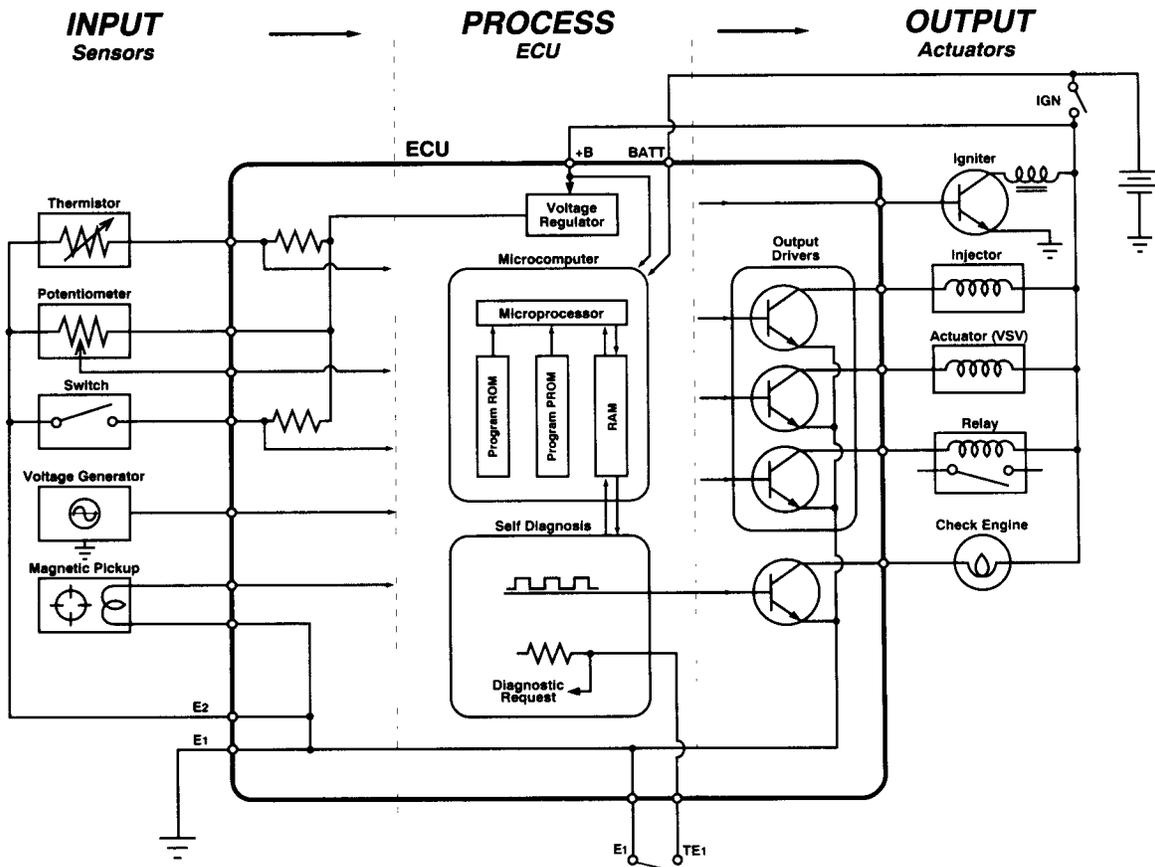
ECU Power Distribution and EFI Main Relay Circuits

POWER DISTRIBUTION CIRCUITS
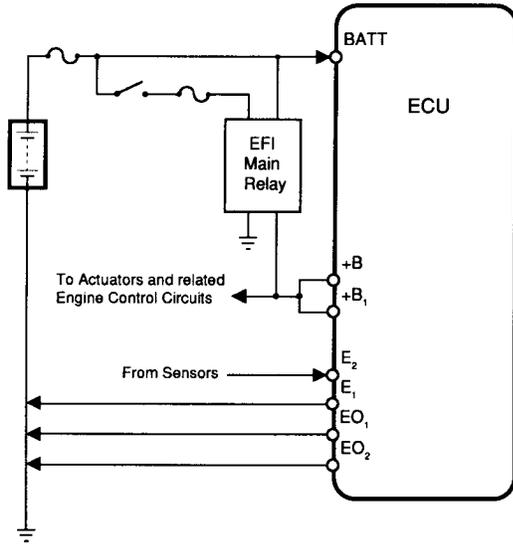
The ECU cannot properly function without dependable power feeds and ground circuits. The power distribution system involves several electrical circuits, protection devices, relays, and grounds.

ECU Power Feeds

The ECU receives its ignition-switched power from the EFI main relay on all of Toyota's EFI systems. In addition to the ignition +B power feed, all P7 and TCCS ECUs have a direct battery feed, identified as BATT, supplied from either the EFI, STOP, or ECU +B fuse. The EFI main relay +B output is the power source which feeds the ECU and related engine control circuits. The direct battery feed (terminal BATT) serves to maintain voltage to the ECU **keep alive memory** when the ignition switch is off. Conventional EFI has no keep alive memory capabilities and, therefore, uses only an ignition switched power feed from the EFI main relay.

Main Relay Circuits

Toyota utilizes several different EFI Main Relay
circuits depending on application. These circuits
can be categorized into four distinct types.
1) Dual contact EFI Main Relay, ignition switch controlled
2) Single contact EFI Main Relay, ignition switch controlled
3) Dual EFI Main Relays, ignition switch or ECU controlled
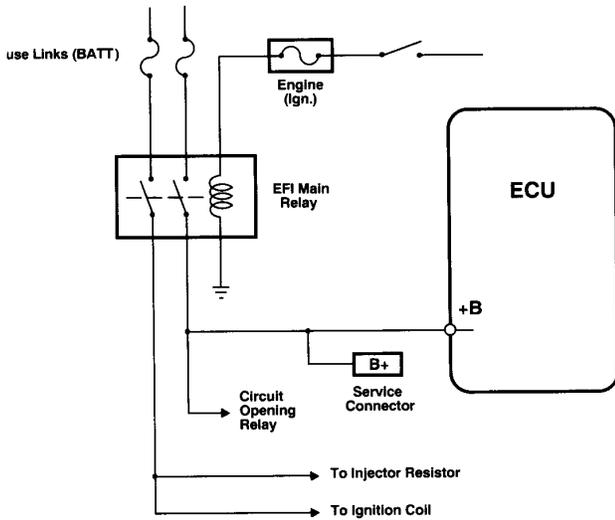4) Single contact EFI Main Relay, ECU controlled

Generally speaking, the EFI Main Relay supplies current to the following major circuits:

• ECU +B and +B1

• Injectors (dual relay or dual contact relay only)

• Circuit opening relay (power contact and pull-in windings)

• Air flow meter VB circuit (when so equipped)

• Output Actuator Vacuum Switching Valves (VSV)

  - Fuel Pressure Up (FPU)

  - Exhaust Gas Recirculation (EGR)

  - Throttle Opener

• ISC motor/solenoid windings

• Check connector +B terminal

Because the EFI Main Relay supplies battery voltage to the +B terminal of the check connector when the ignition switch is in the run position, this is an excellent place to perform a quick check of the relay function.

DUAL CONTACT, IGNITION CONTROLLED CONVENTIONAL EFI (4M-E)

use Links (BATT)

Engine (Ign.)

EFI Main Relay

ECU

B+

Service Connector

Circuit Opening Relay

+B

To Injector Resistor

To Ignition Coil

EFI MAIN RELAY SINGLE CONTACT, IGNITION CONTROLLED

Ignition Switch   Battery

IGN   STOP

BATT

EFI Main Relay

ECU

+B

+B1

To ISC

To VSVs

To Air Flow Sensor VB (Some Models)

To Check Connector +B

To Circuit Opening Relay

Dual Contact (Single Relay), Ignition Switch Controlled

This EFI Main Relay configuration is used on the Conventional EFI system. It uses separate power contacts to supply current to the fuel injector/ignition circuits and the ECU/circuit opening relay circuit. This limits current flow that the ECU power contact must handle.

This configuration improves the reliability of the relay, reduces possible voltage drop, and also isolates any inductive noise from the injectors to the EFI Computer by utilizing the battery as a large capacitor.

When the ignition switch is turned to the "run" or "start" position, current is supplied to the pull-in winding of the relay. Pull-in ground is wired directly to the vehicle chassis. The only power feed to the ECU on this system is the +B circuit.
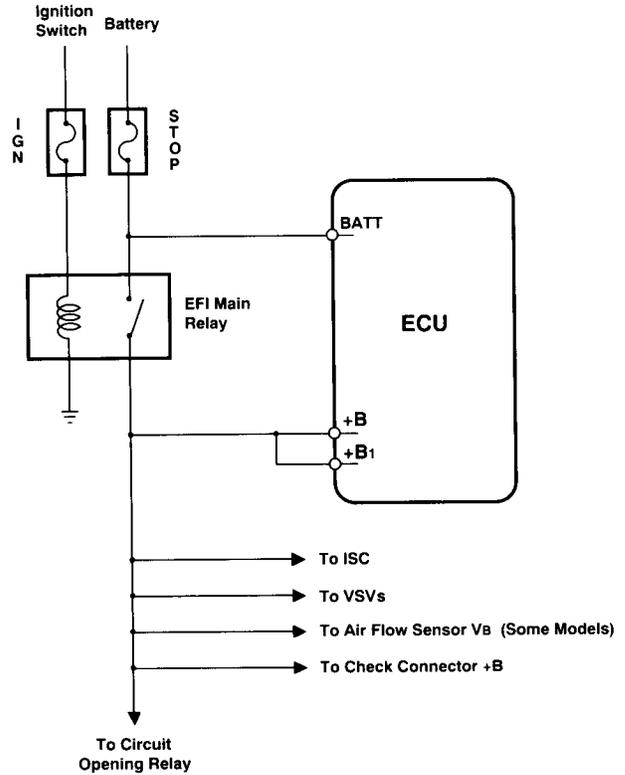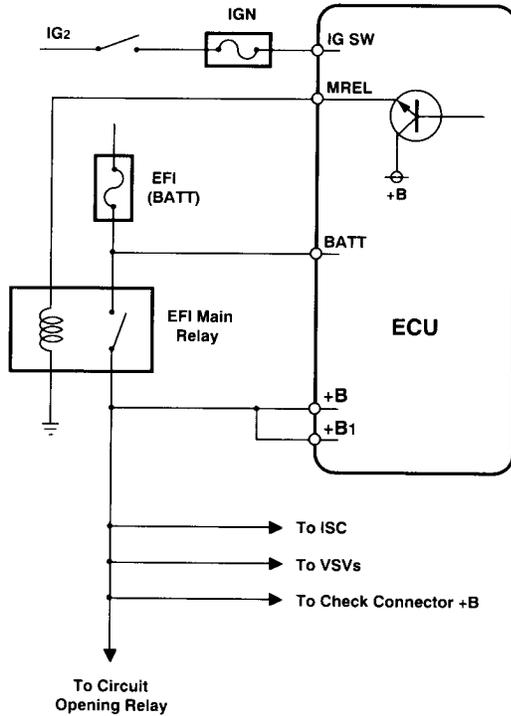
Single Contact, Ignition Switch Controlled

This EFI Main Relay circuit is one of the most popular power distribution schemes used on late model TCCS equipped engines. It is used on most applications without a stepper type Idle Speed Control Valve (ISCV).

When the ignition switch is turned to the "run" or "start" position, current is supplied to the pull-in winding of the relay. Pull-in ground is wired directly to the vehicle chassis. ECU BATT voltage is supplied from the STOP fuse on these applications.
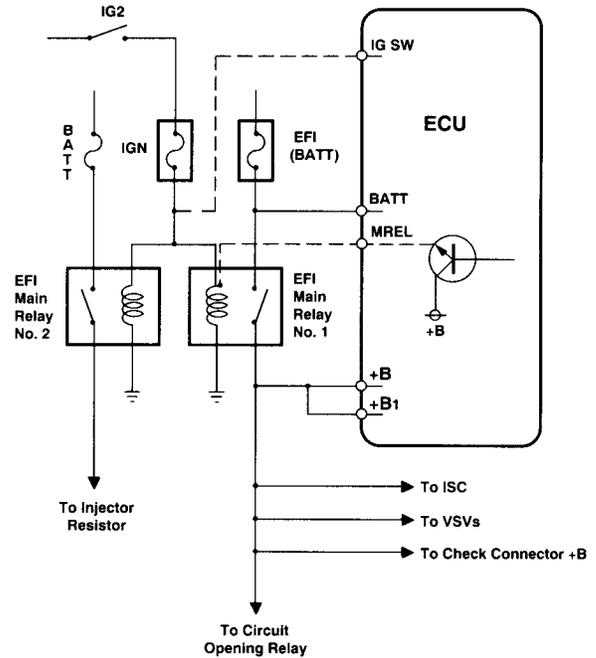
EFI MAIN RELAY
SINGLE CONTACT, ECU CONTROLLED

To Circuit
Opening Relay

When the ignition switch is turned off, the ECU will maintain current flow through the EFI Main Relay pull-in winding for a few seconds after power down to allow time to reset the stepper ISCV.

DUAL EFI MAIN RELAY
IGNITION SWITCH OR ECU CONTROLLED

To Circuit
Opening Relay

Single Contact, ECU Controlled

This EFI Main Relay circuit is used exclusively on applications equipped with the stepper type Idle Speed Control Valve. This relay is powered by the ECU rather than the ignition switch to allow control of the relay for approximately two seconds after the ignition is switched off. This allows the ECU to step the ISCV back to engine restart position after ignition power down.

When the ignition switch is turned on or engine cranked, the ECU receives a voltage signal at the IG SW terminal. This causes the ECU to supply current from the MREL terminal to the EFI Main Relay pull-in winding. The pull-in winding is grounded directly to the vehicle chassis. ECU BATT voltage is supplied from the EFI fuse on these applications.

Dual Relays, Ignition Switch or ECU Controlled

This configuration utilizes two separate relays identified as EFI Main Relay #1 and EFI Main Relay #2. Relay #2 supplies current to the fuel injector circuit. Relay #1 supplies current to the ECU, Circuit Opening Relay, and other circuits depending on application. If a stepper ISCV is used ('85 and '86 5M-GE), the ECU will drive relay #1 so the ISCV can be operated after the ignition is switched off.

ECU GROUND CIRCUITS
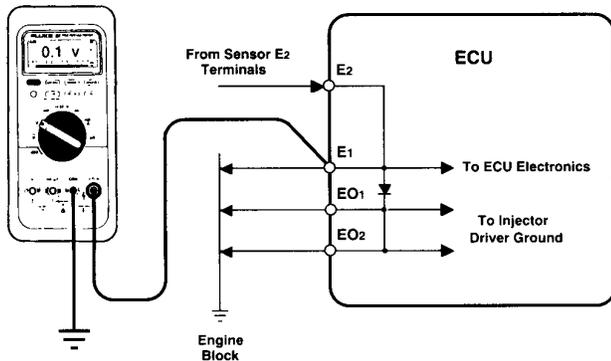
ECU Grounds and Quick Checks

No electrical circuit will function normally without a dependable ground. Toyota EFI systems use a redundant ground system which significantly reduces the chance of ground problems; however, this circuit should never be overlooked when troubleshooting ECU related systems.

The E2 circuit serves as a signal return or sensor ground. Referring to an EWD, you will notice that the throttle position sensor, water and air temperature sensors, and air flow meter all flow current to ground through circuit E2. The ECU supplies a chassis ground through the E1 circuit which typically terminates somewhere on the engine.
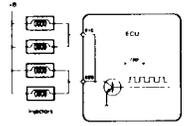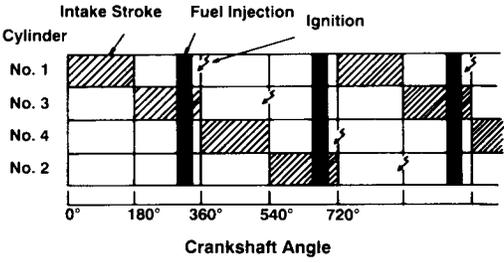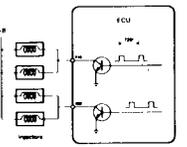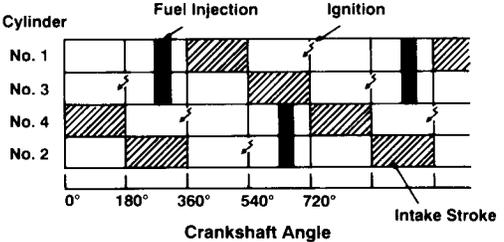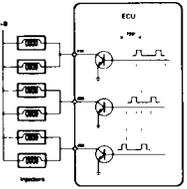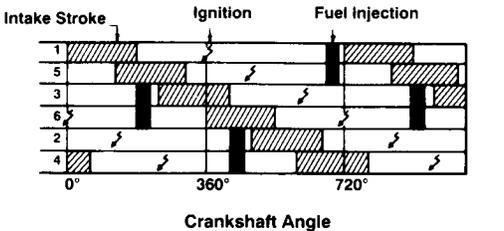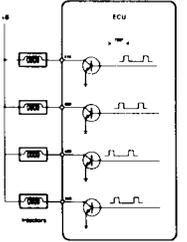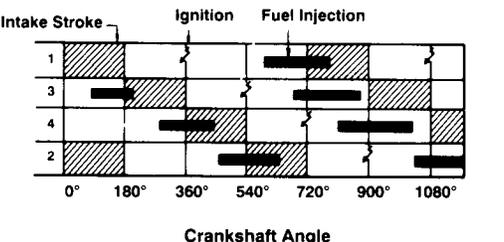
Circuits E01 and E02 serve as grounds for the fuel injector driver circuits. To provide a redundant ground for the ECU, these two grounds are tied to the E1 circuit through a diode. In the event that the E1 wiring to chassis is open circuit, E1 circuit current could flow through the diode to ground. The diode serves to prevent voltage spikes from the injectors from interfering with other ECU circuits.

It is not uncommon for many or even all ECU grounds to terminate at the same point and fasten to the engine with the same fastener. Sometimes a ground fault is due to one fastener being left loose after a service procedure has been performed.

It is a fairly simple task to confirm the integrity of all ECU ground circuits in fairly short order. Two methods can be used to identify and isolate a ground fault; these are the circuit continuity check and the voltage drop check. These procedures along with checks of the power distribution circuits are addressed in exercises 5-1 and 5-2.

Fuel Injection Control

Injection Pattern	Injection Timing	Engines
Simultaneous		**4K-E,** **4A-FE** **2S-E, 3S-FE, 5S-FE (GEN 1)** **4M-E, 5M-E, 5M-GE,** **3Y-E, 4Y-E** **22R-E, 22R-TE** **3VZ-E, 3F-E** **3E-E**
2 Groups		**4A-GE (L type EFI)** **4A-GZE** **5S-FE (GEN 2)** **5E-FE**
3 Groups		**7M-GE** **7M-GTE** **2VZ-FE**
Independent		**3S-GE** **3S-GTE** **3VZ-FE**

Injector Timing

Injection Timing Control

Injection timing control determines when each injector will deliver fuel to its corresponding intake port. There are three different methods of injector timing used on Toyota engines, depending on application. These methods are Simultaneous, Grouped, and Independent injection.

Simultaneous Injection

All injectors are pulsed simultaneously by a common driver circuit. Injection occurs once per crankshaft revolution just prior to the crankshaft reaching TDC cylinder *1. This means that twice per engine cycle one half of the calculated fuel is delivered by the injectors. This is the simplest and most common injection timing method in use.

Grouped Injection

Injectors are grouped into pairs. The pairs consist of two consecutive cylinders in the firing order; each pair is driven by a separate driver circuit. Four cylinder engines use two groups, six cylinder engines three groups, and the 1UZ-FE V8 engine uses four groups of injectors.

Injection is timed to deliver fuel immediately preceding the intake stroke for the leading cylinder in the pair. The entire group is pulsed once per engine cycle, delivering the entire calculated charge of fuel. This timing method ensures that fuel does not linger behind the intake valve, thereby, reducing emissions, improving fuel economy and throttle response.

Independent Injection

Injectors are driven independently and sequentially by separate driver circuits. Injection is timed to deliver the entire fuel charge just prior to each intake valve opening. This timing method provides optimum engine performance, emissions, and fuel economy.
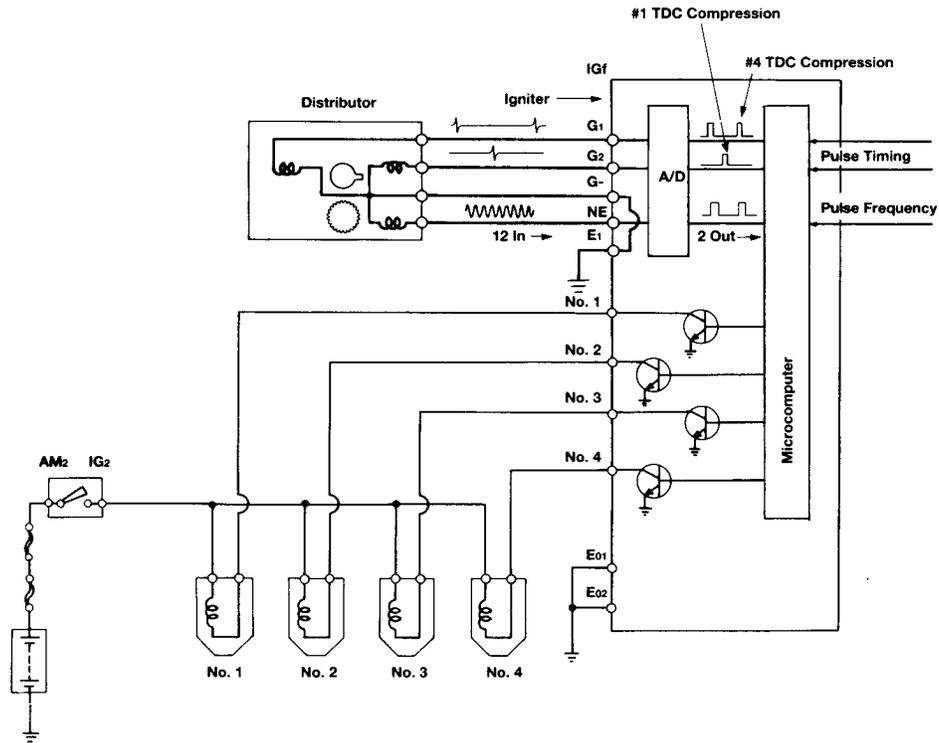
Input Signals Required to Pulse Injectors

There are three signals which are necessary to operate the fuel injectors. These are the Ne, G, and IGf signals. Inside the ECU, the Ne Signal is used to produce an injection chive signal. The G signal is used to determine the timing of the injection signals. The IGf signal is monitored for fuel delivery fail-safe. (With Conventional EFI, the IG signal is used to produce the injection drive signal.)

The ECU cannot pulse the injector without an Ne signal and will not start or run if this signal is not present. If the G signal is not present while cranking the engine, the ECU will not be able to identify when to produce the injection signal. The result will be the same, no injection pulse. If the IGf signal is not present, the ECU will go into fuel fail-safe by stopping injection pulses.

If, however, the ECU loses the G signal with the engine running, the engine will continue to run because the timing of injection signals is locked in once the engine starts.

Signal	Engine Condition When Signal Lost	Effect on Injection and Spark
Ne	Cranking	No spark, no injection pulse, engine will not start
Ne	Running	Engine stalls, no spark, and no injection pulse
G1*	Cranking	Engine will not start, no injection pulse, no spark
G1*	Running	Engine will continue to run, signal only necessary for starting
IGf	Running or Cranking	Engine will not start or run, no injection pulse

* Applications with G2 will default to either G sensor if the other sensor fails.

Injector Operating Modes

There are two injection operating modes used by the ECU, depending on engine operating conditions. These modes are called synchronous and asynchronous.

Synchronous Injection

Synchronous injection simply means that injection events are synchronized with ignition events at specific crankshaft angles. Synchronous injection is used a great majority of the time.

Asynchronous Injection

Asynchronous injection is only used during acceleration, deceleration, and starting. It occurs independently of ignition events based on change in idle contact (IDL) or start switch (STA) status without regard to crankshaft angle.

Crankshaft Rotation

720°

360°

Ne Signal

Ignition Primary Signal (IG)

Pulse Transformation

Synchronous

Injection Signal (4 cylinders) Simultaneous

Asynchronous

Injection Signal (4 cylinders) Simultaneous

IDL Signal — OFF / ON

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                          ┌─────────────────────┐
                          │         ECU         │
                          ├─────────────────────┤
                          │       Step 1        │
┌──────────────────────┐  ├─────────────────────┤
│ Manifold Pressure Sensor│ │Basic Injection Duration Determined│
├──────────────────────┤  └─────────────────────┘
│      Distributor      │            │
└──────────────────────┘  ┌─────────────────────┐
                          │       Step 2        │
                          ├─────────────────────┤
                          │ Corrected Injection Duration│
                          │ Determined          │
                          │ (Basic Injection Duration│
                          │ Correction)         │
┌──────────────────────┐  ├─────────────────────┤
│ Intake Air Temp. Sensor │ │Intake Air Temperature Correction│
├──────────────────────┤  │Warm-up Enrichment   │
│   Water Temp. Sensor  │  │After-Start Enrichment│
├──────────────────────┤  │Power Enrichment     │
│ Throttle Position Sensor│ │Air/Fuel Ratio Feedback Connection│
├──────────────────────┤  └─────────────────────┘
│    Oxygen Sensor      │            │
└──────────────────────┘  ┌─────────────────────┐
                          │       Step 3        │
┌──────────────────────┐  ├─────────────────────┤
│    Battery Voltage    │  │Final Injection Signal Determined│
└──────────────────────┘  │(Voltage Correction) │
                          └─────────────────────┘
                                     │
                             ┌──────────────┐
                             │   Injectors   │
                             └──────────────┘
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ECU Control of Injector Duration

An Overview of Injection Duration Calculations

Determination of final **injection pulse width** is the function of a three-step process.

Step 1, Basic Injection Duration

The first step involves calculation of basic injection duration. Input sensors used in basic duration calculation are:

• Air Flow Meter (Vs or Ks)
• Manifold Pressure Sensor (PIM)
• Engine rpm (Ne)

The ECU calculates basic injection duration based upon engine speed and air flow volume. These two inputs considered together establish an engine load factor. The ECU monitors the Air Flow Meter signal or Manifold Pressure Sensor for intake air volume information and the Ne signal for engine speed information.

• As either of these parameters increase, injection duration is increased.

Step 2, Injection Duration Correction Factors

The second step involves duration corrections. Input sensors used for injection duration corrections are:

• Engine Water Temperature (THW)
• Intake Air Temperature (THA)
• Throttle Angle (VTA or IDL & PSW)
• Exhaust Oxygen Content (OX)

Once basic injection duration is calculated, the ECU must modify the injection duration based on other changing variables. Variables considered in the correction calculation are coolant and intake air temperature, throttle position and exhaust oxygen sensor feedback (when operating in closed loop).

• As engine and intake air temperatures move from cold to warm, injection duration is reduced.

• As the throttle opens (IDL contact break), injection frequency is momentarily increased.

• Fuel injection duration swings back and forth between longer to shorter durations to correct conditions detected by the exhaust oxygen sensor.

Step 3, Battery Voltage Correction

The final step is a battery voltage correction. The input signal used in battery voltage corrections is: 0 Battery Voltage (+B)

There is an operational delay between the time the ECU sends the injection signal to the driver circuit and the actual opening of the injector. This delay changes with the strength of the magnetic field around the injector coil. The delay increases as battery voltage falls.

To determine final injection duration, the ECU corrects for injector opening delay by using a battery voltage **correction coefficient.**

• The battery voltage correction coefficient increases injection duration as sensed battery voltage falls.

ECU Injection Strategy
While Starting
Prime Pulse

Because the rpm and intake air volume signals are erratic at cranking speed, injection duration calculation is done differently while the engine is cranking, compared to all other operating conditions.

• To prime the engine upon initial cranking, all injectors are pulsed in an asynchronous mode one time immediately after a G and Ne signal are received.
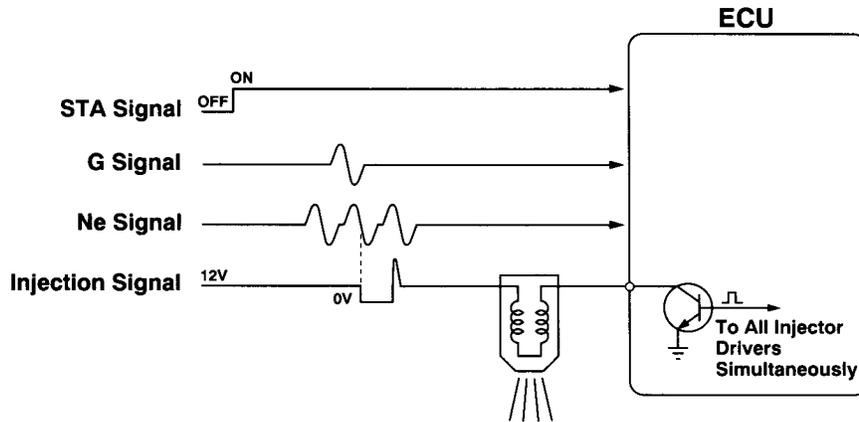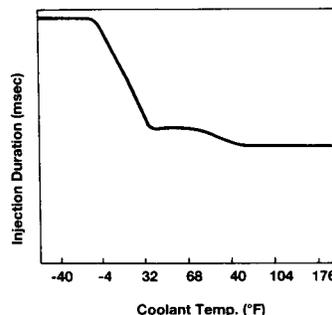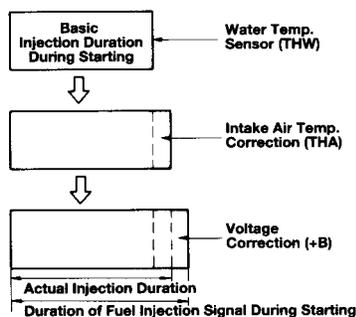

Starting Injection Control

To provide accurate fuel injection duration during cranking periods, the ECU uses a program which determines a basic injection volume based on engine coolant temperature. Once a basic injection duration is calculated, corrections are made for intake air temperature and battery voltage (which is typically low under cranking load).

• Basic injection duration while cranking is increased at low coolant temperatures.

• Injection duration while cranking is corrected for intake air temperature by increasing duration at low intake air temperatures.

• Injection duration while cranking is corrected for battery voltage by increasing injection duration at lower voltage.

The graph represents the basic cranking enrichment strategy used by the ECU. Note that at temperatures below freezing, basic injection duration increases drastically to overcome the poor vaporization characteristics of fuel at these temperatures.

## Engine Running Injection Duration Calculation

After Start-up Enrichment
To stabilize the engine immediately after starting, for a short period of time after starting, the ECU supplies extra fuel to the engine to ensure a smooth transition from cranking to running. The maximum enrichment value is determined by the coolant temperature signal, THW.

Basic Injection Calculation
Once the engine has stabilized, engine rpm information and intake air volume measurements are used to determine basic injection duration.

• As intake air volume increases, injector duration increases.

• As engine rpm increases, injector frequency increases.
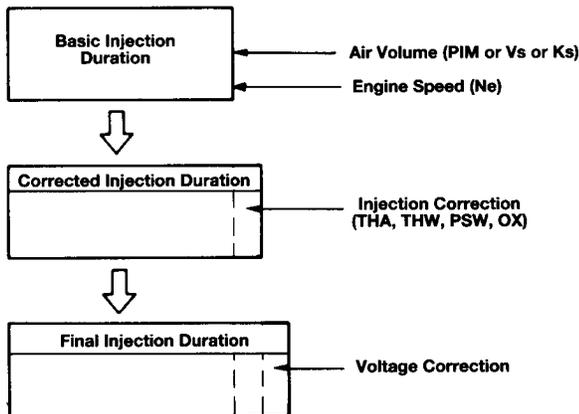
Injection Corrections
A correction coefficient is calculated by determining the values of the various input sensors. This correction coefficient is used to modify the basic injection duration value to achieve a corrected injection duration value.

Correction For Intake Air Temperature
The density of intake air varies with temperature. The colder the air, the denser it becomes. For this reason, a correction coefficient is used for changes in air temperature.
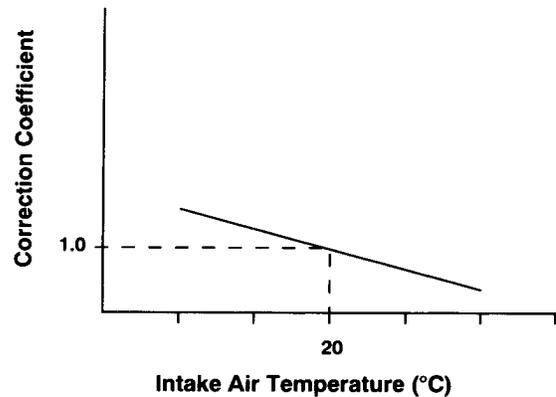

Referring to the coefficient graph, note that a standard air temperature of 68'F (20'C is used. At this temperature, the correction factor is 1.0.

For example, a correction factor of 1.0 means that no correction is made from the basic calculation. A coefficient of 1.1 means that injection duration is being increased by a factor of 10% while a coefficient of 0.9 means that injection duration is being decreased by a factor of 10%.

• As intake air temperature falls below the standard temperature, the correction coefficient increases and injection duration is increased (and vice versa).

Correction For Coolant Temperature (Warm-up Enrichment)

When the engine is cold, fuel vaporization is relatively poor until the intake manifold warms up. To prevent lean driveability problems associated with this condition, the ECU enriches the air/fuel ratio accordingly based on engine coolant temperature.
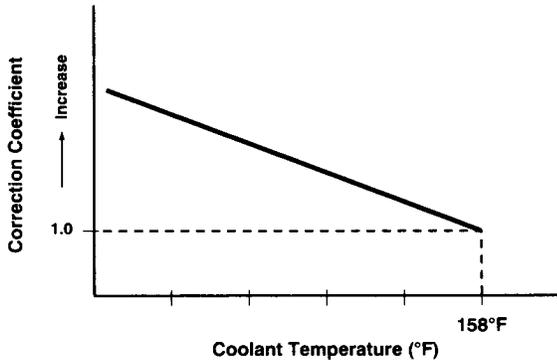

The correction coefficient graph above shows a standard value of 158'F (70'C).

- At temperatures below 158'F, basic injection calculations are increased.

- At extremely cold temperatures, injection duration can be increased to almost double normal warm engine values.

Power Enrichment Correction

When the ECU determines that the engine is being operated under moderate to heavy load, it increases injection duration values by up to 20% to 30%. This power enrichment program is based on information received from the air flow meter or manifold pressure sensor, the throttle position sensor and engine rpm.
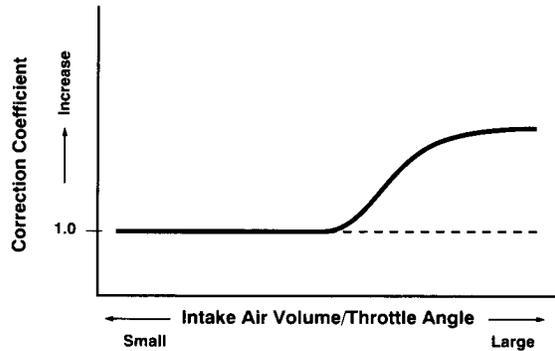

- As engine load increases, injection duration is increased.

- As engine rpm increases, injection frequency increases at the same rate.

Battery Voltage Correction

Because of the injector opening delay which varies with charging system voltage, the ECU must modify the corrected injection duration by a battery voltage correction coefficient to achieve a final injection duration value.

The final injection duration determines the quantity of fuel which is delivered to the engine.
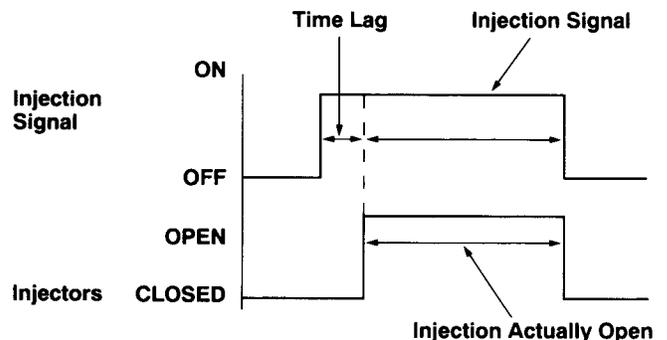
Closed Loop Air/Fuel Ratio Correction

Under certain operating conditions, primarily cruise and idle, the ECU corrects the injection duration value based on signals from the exhaust oxygen sensor. This feedback correction is necessary to promote better vehicle emissions control.
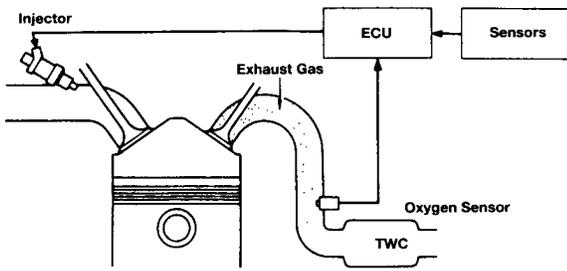

By achieving more accurate fuel metering, the oxygen content of the exhaust stream is held within a very narrow range which supports the most efficient operation of the three-way catalyst (TWC).

Stoichiometry and Catalyst Efficiency

The accompanying graph represents the efficiency of a three-way catalyst system at varying air/fuel ratios. As the graph clearly shows, the catalyst is most efficient in a narrow air/fuel ratio range.

The theoretical or ideal air/fuel ratio at which all tail pipe emissions are best converted is referred to as **stoichiometry**. The stoichiometric air/fuel ratio occurs around 14.7 to 1 (14.7 pounds of air for each pound of fuel).

It is important to note that the primary reason for using a closed loop fuel control system is to satisfy the requirements of the three-way catalyst system.
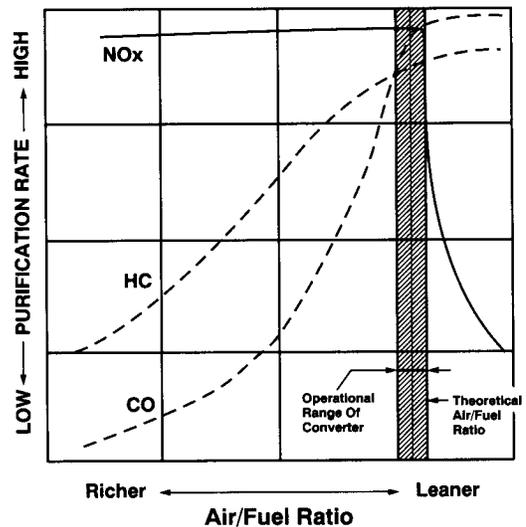
Closed Loop Operation

Closed loop operation simply means that the ECU is making air/fuel ratio corrections based on oxygen sensor information. Although the ECU can calculate injection duration very accurately without using information from the oxygen sensor, closed loop control brings the air/fuel ratio within the extremely narrow operating parameters of the three-way catalyst (TWC).

The oxygen sensor monitors the oxygen concentrations in the exhaust stream and outputs a voltage signal to the ECU. This signal allows the ECU to determine whether the air/fuel ratio is leaner or richer than the theoretical value necessary for the best catalyst conversion efficiency.

• Exhaust oxygen sensor voltage signal above 1/2 volt indicates an air/fuel ratio richer than stoichiometry. 'Me ECU will reduce fuel injection duration to correct this condition.

• Exhaust oxygen sensor voltage signal below 1/2 volt indicates an air/fuel ratio leaner than stoichiometry. The ECU will increase fuel injection duration to correct this condition.

• During normal closed loop operation, the oxygen sensor signal rapidly switches between these two conditions (at a rate of more than eight times in ten seconds at 2500 rpm). Small injection duration corrections take place each time the signal voltage switches from high to low and back again.

The closed loop correction coefficient ranges from 0.8 to 1.2 (that is, +20% from the basic fuel calculation). If the air/fuel ratio goes out of the ECU's range of correction, the ECU will typically set a diagnostic code and return to open loop operation.

In a closed loop control system, the command corrects the condition.

• Oxygen sensor monitors exhaust condition

• ECU commands injectors to correct condition

• Oxygen sensor indicates correction accuracy

• ECU again commands injectors to correct condition
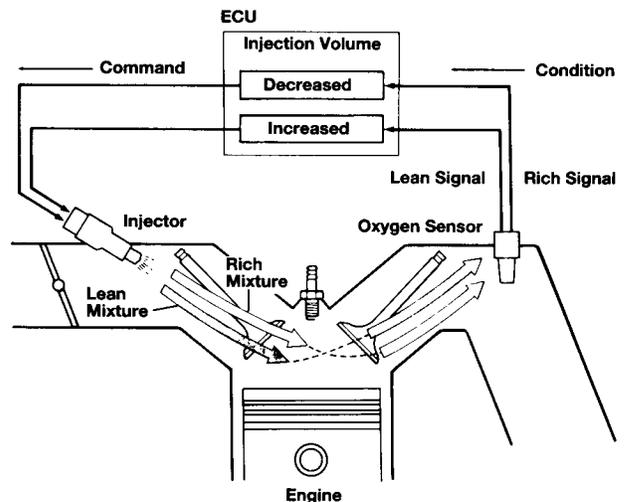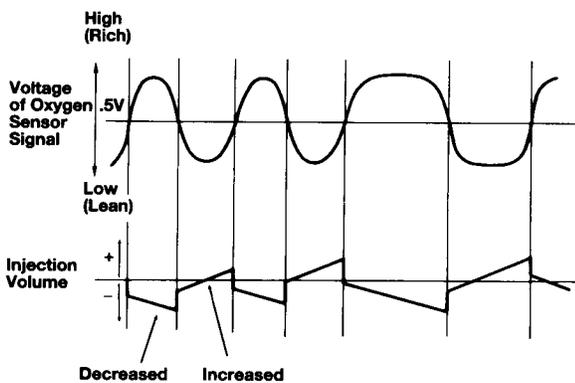
Open Loop Operation

Open loop operation means that the ECU is not correcting the air/fuel ratio based on oxygen sensor information. The ECU ignores exhaust oxygen sensor information even if the sensor is detecting an excessively rich or lean mixture. There are certain operating conditions where it is not desirable to operate the system in closed loop due to risk of catalyst overheating and driveability concerns. These conditions are:

- Engine starting
- Cold engine operation
- Moderate to heavy load operation

In open loop operation, a correction coefficient of 1.0 is used.

Acceleration and Deceleration Corrections

When the engine operating conditions are in transition, either accelerating or decelerating, the injection volume must be increased or decreased slightly to improve engine performance and fuel economy. The input sensor signals used and the enrichment or enleanment strategies used vary with engine application.

Acceleration Enrichment

As the engine is accelerated, a momentary lean condition exists as the throttle begins to open (this is due to the fact that fuel is more dense than air and cannot move into the cylinder as quickly). To prevent a stumble or hesitation, the ECU uses an acceleration enrichment fuel strategy. When the IDL signal goes from on to off, the ECU delivers an acceleration enrichment fuel pulse.
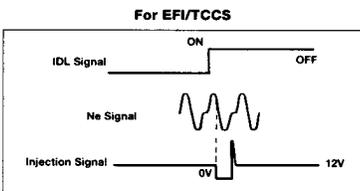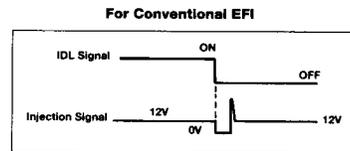

- As the IDL contact opens, the ECU commands all injectors to simultaneously deliver an extra asynchronous injection pulse.

On Conventional EFI engines, this pulse is delivered at the moment the IDL contact breaks. On EFI/TCCS engines, this pulse is delivered synchronous with the Ne signal which follows the IDL contact break.

Deceleration Fuel Cut

During closed throttle deceleration periods from higher engine speeds, fuel delivery is not necessary. In fact, deceleration emissions and fuel economy are adversely affected if fuel is delivered during deceleration.
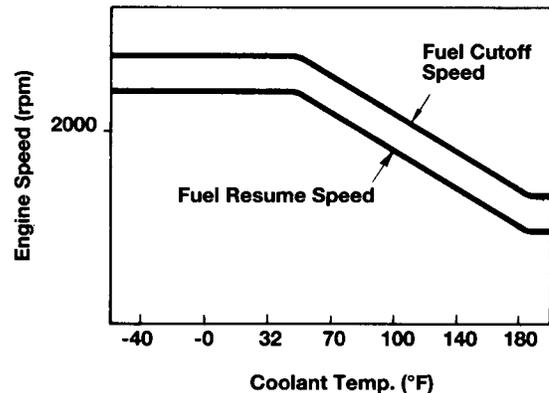

To prevent excessive decel emissions and improve fuel economy, the ECU stops injection pulses completely during certain deceleration conditions.

- When the IDL contacts close with engine rpm above a given speed, the ECU cuts injection operation completely.

- When the engine falls below the threshold rpm, or when the throttle is opened, fuel injection is resumed.

Referring to the graph, fuel cutoff and resumption speeds are variable, depending on coolant temperature, A/C clutch status, and SIT signal.

- With A/C clutch on, fuel cutoff and resumption speeds will be increased.

- With the stop light switch on, fuel cutoff and resumption speeds will be decreased (some applications only).

Large

↑

Fuel
Injection
Volume

↓

Small

Rev Limit RPM

Low ⟶   Engine RPM   ⟶ High
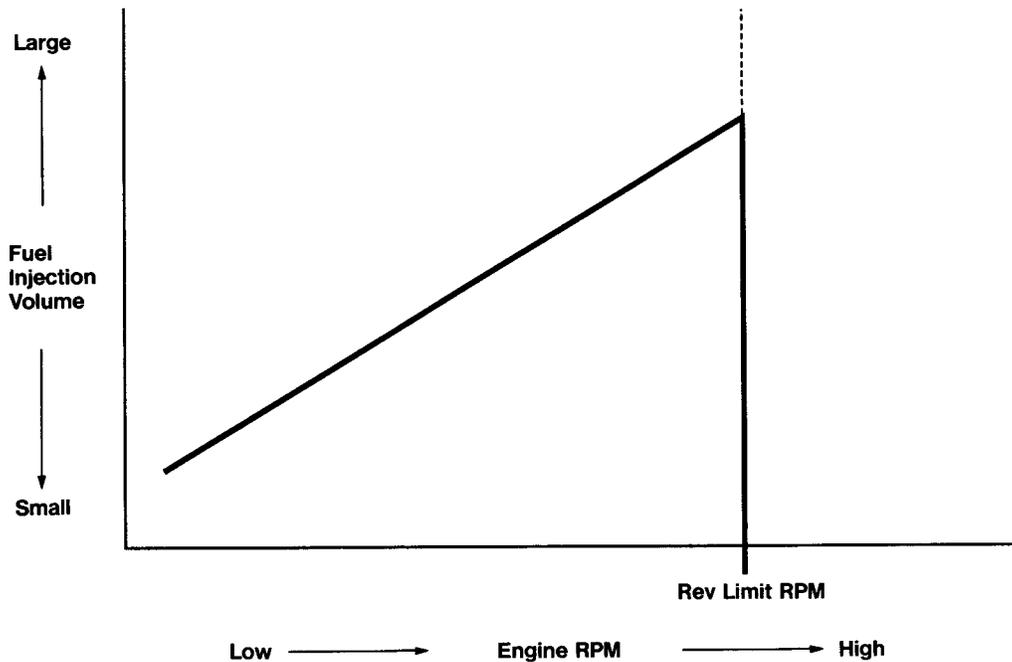
Engine Over-rev Fuel Cutoff

To prevent potential engine damage, a revlimiter is programmed into the ECU. Any time engine rpm exceeds the pre-programmed threshold, the ECU cuts fuel delivery. Once rpm falls below the threshold, fuel delivery is resumed.

Over-rev rpm threshold varies depending on engine design and application but typically runs in the 6500 to 7500 rpm range, usually cutting fuel slightly above the engine's red line rpm.

Vehicle Over-speed Fuel Cutoff

On some vehicles, fuel injection is halted if the vehicle speed exceeds a predetermined threshold programmed into the ECU. Fuel injection resumes after the speed drops below this threshold.

Spark Advance Control

Electronic Spark Advance (ESA)Variable Advance Spark Timing (VAST)

Introduction To ECU
Spark Advance Controls

The Advantage of ECU Controlled Spark Timing
To maximize engine output efficiency, the ignition spark must be delivered at the precise moment which will result in maximum combustion chamber pressure occurring at about 100 ATDC. The amount of ignition spark advance, or lead time required to achieve this, will vary depending on many factors.

For example, because fuel bum time remains relatively constant, spark lead time must be increased as engine rpm increases. Because fuel has a tendency to detonate under heavy load conditions, spark lead time must be decreased as manifold pressure and intake air flow increase.

Engines equipped with Conventional and P7/EFI systems use a mechanical advance distributor to accomplish changes in spark lead time. The centrifugal (governor) advance increases spark lead time as engine rpm increases, and the vacuum advance decreases lead time as manifold pressure increases.

When all of the variables which affect optimum timing are considered, there are many more factors which influence required spark lead time. The coolant temperature, quality of fuel, and many other engine operating conditions can significantly impact ideal ignition time.

ESA/VAST

CONVENTIONAL

Ignition Advance
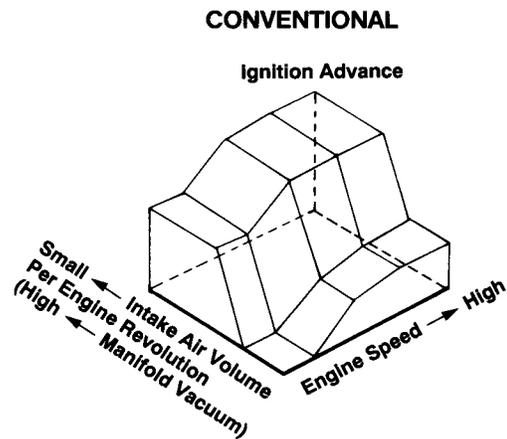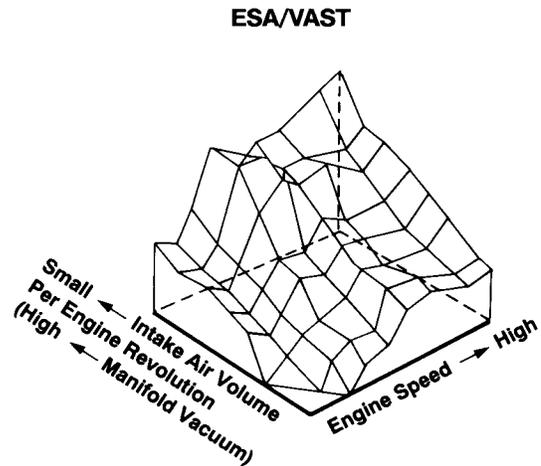
To provide for optimum spark advance under a wide variety of engine operating conditions, a spark advance map is developed and stored in a look up table in the ECU. This map provides for accurate spark timing during any combination of engine speed, load, coolant temperature, and throttle position while using feedback from a knock sensor to adjust for variations in fuel octane.

Prior to strict emissions and fuel economy standards, mechanical control of spark advance was adequate to accomplish reasonable engine performance and emissions control. However, in the automotive environment of the '90s, adequate is not good enough.

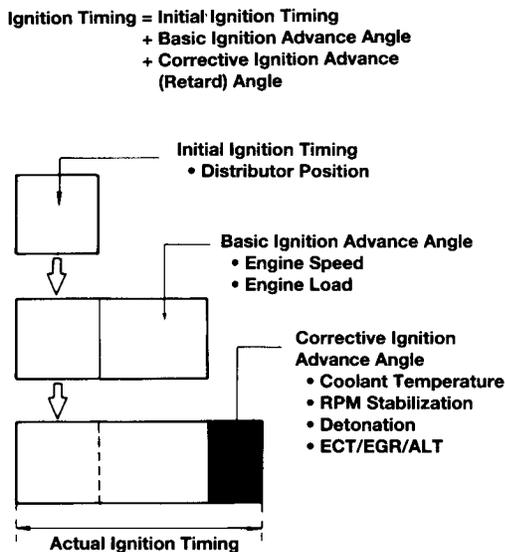## Two ECU Spark Advance Control Systems Used By Toyota

There are two distinctly different ECU controlled ignition systems in use on TCCS equipped engines. These systems are known as Electronic Spark Advance (ESA) and Variable Advance Spark Timing (VAST). Both systems accomplish the same goal; they provide ideal ignition timing under a wide variety of engine operating conditions.

You also learned the mechanics of how the ESA and VAST systems signal the igniter and fire the ignition coil. You have learned the system hardware. The objective of this lesson is to identify the process the ECU uses to calculate optimum spark advance angle under a wide variety of operating conditions. The ECU program which accomplishes this is the system software.

ECU Control Of Spark Advance Angle
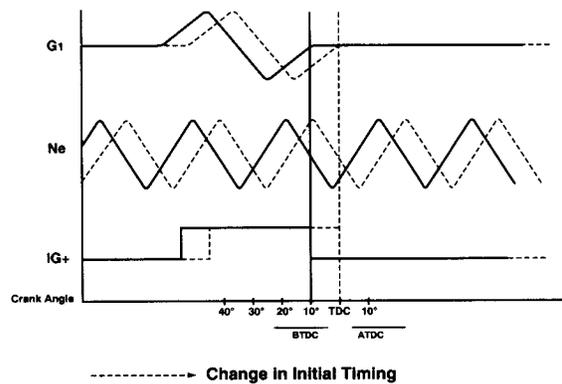
Overview Of Advance Angle Calculation

Determination of optimum spark advance angle is the function of a three-step process.

Ignition Timing = Initial Ignition Timing
+ Basic Ignition Advance Angle
+ Corrective Ignition Advance (Retard) Angle

Initial Ignition Timing
• Distributor Position

Basic Ignition Advance Angle
• Engine Speed
• Engine Load

Corrective Ignition Advance Angle
• Coolant Temperature
• RPM Stabilization
• Detonation
• ECT/EGR/ALT

Actual Ignition Timing

Step 1, Initial Timing Adjustment

The first step involves correct adjustment of initial timing. The input sensor used by the ECU to determine initial timing is: 0 Standard Crankshaft Angle (G1, G2, and Ne)

The initial timing adjustment is critical to proper operation of the ECU controlled spark advance system. Initial timing is a function of the physical position of the distributor in the engine and becomes the base upon which all advance functions are added. Once the initial timing is adjusted properly, it will not change.

G1

Ne

IG+

Crank Angle   40°   30°   20°   10°   TDC   10°
                          BTDC   ATDC

- - - - - - - - -► Change in Initial Timing

- If distributor position in the engine is changed, the relationship between Ne and G signals to TDC changes.

- Any deviation from specified initial timing will cause an equal amount of error in the final spark advance angle.
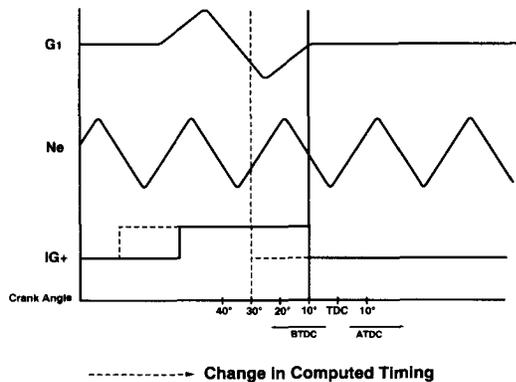
Step 2, Basic Advance Angle

The second step involves calculation of the basic advance angle. Input sensors used in basic advance angle calculation are:

• Intake Air Volume (Vs or Ks)

• Intake Manifold Pressure (PIM)

• Engine rpm (Ne)

The basic advance angle is primarily a function of inputs from the engine rpm and intake air volume sensors. This calculation is equivalent to the combined centrifugal and vacuum advance on a mechanical distributor.

G₁

Ne

IG+

Crank Angle   40° 30° 20° 10° TDC 10°
                          BTDC   ATDC

------→ **Change in Computed Timing**

• As engine rpm increases, spark angle is advanced.

• As intake air volume (engine load factor) increases, spark angle is retarded.

Step 3, Corrective Advance Angle

The final step in determining optimum or final spark advance angle is calculation of corrective advance angle. Input sensors used in corrective advance angle calculations are:

• Starting Signal (STA)

• Engine Water Temperature (THW)

• Throttle Angle (VTA or IDL & PSW)

• Knock Detection (KNK)

• Altitude (HAC)

• Electronically Controlled Transmission (ECT)

The biggest advantage of ECU controlled spark advance is the system's ability to adjust timing for all possible variables in the ideal advance angle equation. The corrective advance angle calculation accomplishes this by fine tuning the advance angle for changes in coolant temperature, engine detonation, transmission shift status, altitude, accessory status, and other variables.

• ECU advances spark angle for cold engine operation and retards for over-temperature conditions.

• ECU retards spark angle when detonation is detected.

• ECU advances spark angle for high altitude operation (models equipped with HAC sensor).

ECU Spark Advance Strategy While Starting

ESA System

Engine starting: During starting, when engine speed is below approximately 500 rpm (or when STA signal is high), spark advance angle (IGt signal) is fixed at initial timing. A Backup IC located in the ECU generates a reference timing signal which is output to the microprocessor and the IGt line to the igniter. The reference signal represents base timing and is calculated based on inputs from the G1 and Ne sensors.
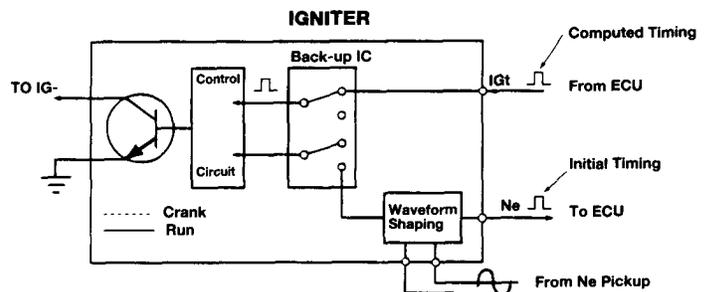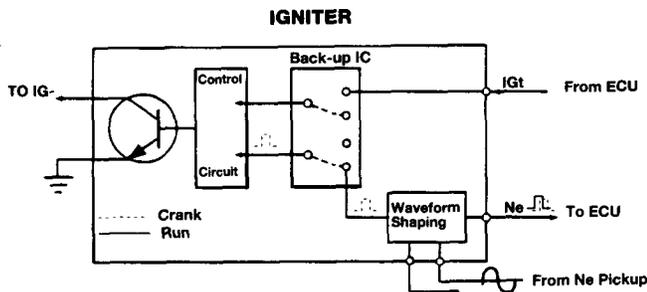
Engine running: Once the engine starts, timing of the IGt signal is controlled by the microprocessor in the ECU. Based on inputs from various sensors, a basic and corrective advance angle are calculated. The final spark advance angle consists of the sum of the initial, basic, and corrective spark advance angles.
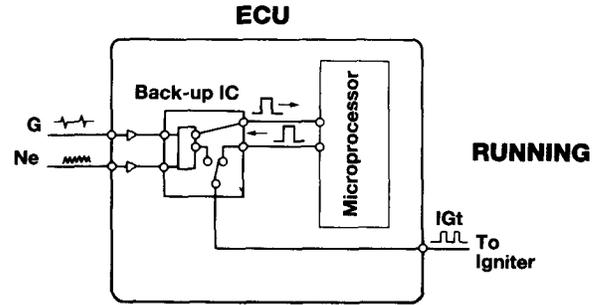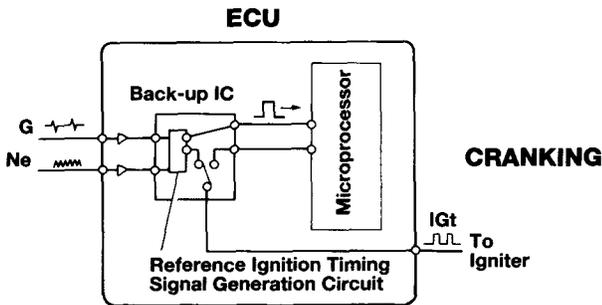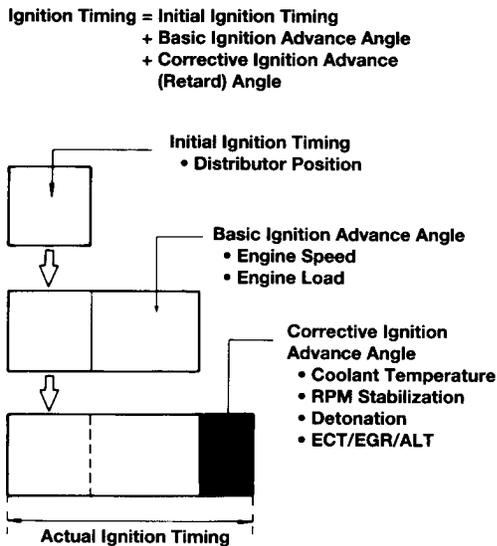

VAST System

Engine starting: During starting, when below a predetermined rpm, no IGt signal is sent from the ECU to the igniter. The ignition coil is driven by the back-up circuit in the igniter at initial timing.

Engine running: Once the engine starts, the ECU sends an IGt signal back to the igniter; the ignition coil is driven by this signal at computed timing.
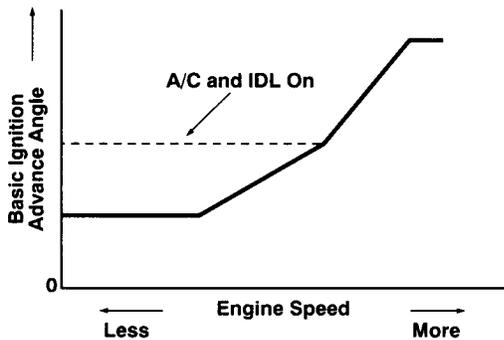
ECU Spark Advance Strategy While Running

Ignition Timing = Initial Ignition Timing
+ Basic Ignition Advance Angle
+ Corrective Ignition Advance
(Retard) Angle

Initial Ignition Timing
• Distributor Position

Basic Ignition Advance Angle
• Engine Speed
• Engine Load

Corrective Ignition
Advance Angle
• Coolant Temperature
• RPM Stabilization
• Detonation
• ECT/EGR/ALT

Actual Ignition Timing

Basic Ignition Advance Angle

The ECU calculates the basic advance angle by evaluating engine rpm and intake air volume signals. These sensors' signals have the most significant effect on basic timing calculation.

ADVANCE FOR ENGINE RPM

A/C and IDL On

Basic Ignition Advance Angle

0

Engine Speed

Less ← → More

ADVANCE FOR ENGINE LOAD

Basic Ignition Advance Angle

0

Engine Load

Less ← → More
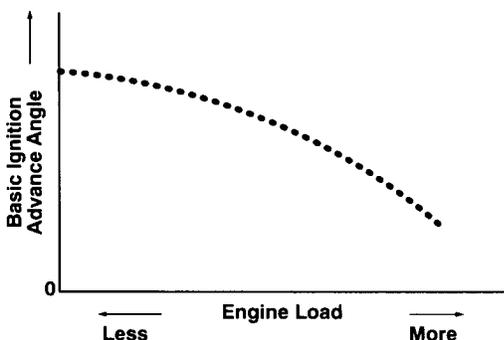
There are other sensor inputs which also affect the basic spark advance angle. The A/C compressor clutch signal advances basic spark angle when the IDL contacts are on (on some engines), and on the 3S-GTE engine, basic advance angle is retarded if the ECU judges that regular fuel is being used, based on signals from the engine knock (KNK) sensor.

Corrective Ignition Advance Angle
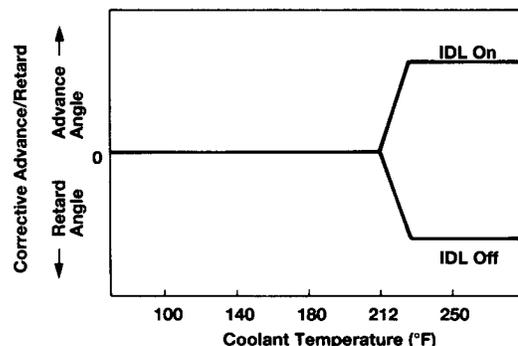
Engine Temperature Corrections

To improve cold driveability, the ECU advances spark angle. The ECU considers intake air volume and the status of the IDL contact to determine how much cold advance to add to the basic spark calculation.

WARM-UP CORRECTION

Corrective Advance

0   -40   0   32   70   100   140   180

Coolant Temperature (°F)
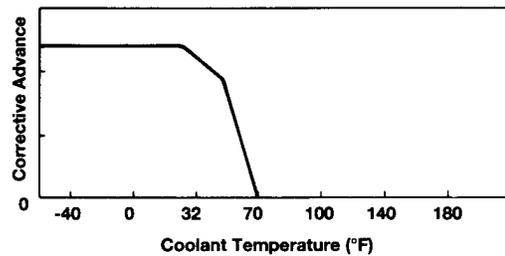
As the engine temperature approaches overtemp, the ECU will advance spark when the IDL contact is on, to prevent overheating. When the IDL contact is off, the ECU will retard spark to prevent detonation. Advance and retard shown on the graph are corrections to the basic advance angle.

OVER TEMPERATURE CORRECTION

Corrective Advance/Retard

Advance Angle

0

Retard Angle

IDL On

IDL Off

100   140   180   212   250

Coolant Temperature (°F)

Fuel Feedback Idle Stabilization Correction

To prevent surging due to closed loop air/fuel ratio swings, when the IDL contacts are on, the ECU advances timing as lean commands are sent to the injectors (fuel injection volume decreased). This very small amount of advance added to the basic advance angle serves to stabilize engine idle quality.
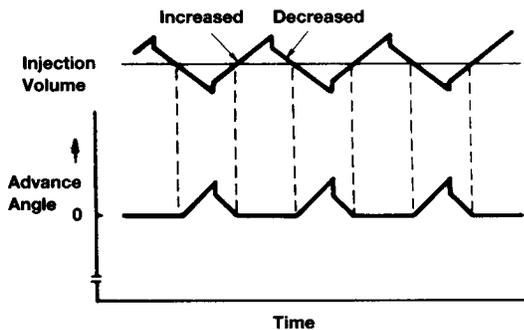
## Engine Load Idle Stabilization Correction

When engine rpm changes at idle due to increased load, the ECU adjusts timing to stabilize idle speed. The ECU constantly monitors and calculates average engine speed. If the average speed is determined to go below a pre-programmed target rpm, the ECU will add advance to the basic spark angle to help re-establish the target idle speed.
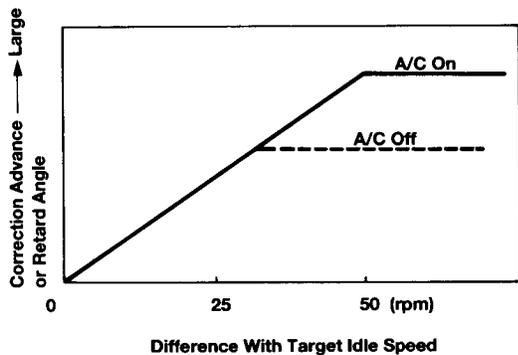

Detonation Correction

The ECU constantly monitors the signal from the knock sensor to determine when detonation occurs. When detonation is sensed, basic advance angle is retarded in varying degrees, depending on the strength of the knock sensor signal. Once detonation stops, the ECU gradually cancels the retard, allowing timing to return to the basic advance angle.

The detonation correction strategy allows the engine to operate at optimum timing regardless of fuel octane, maximizing engine performance when high octane fuel is used. On some engines, this system only operates in a closed loop mode under load (vacuum below approximately 8 inches of mercury). Other engines operate in ignition closed loop under all engine load ranges.
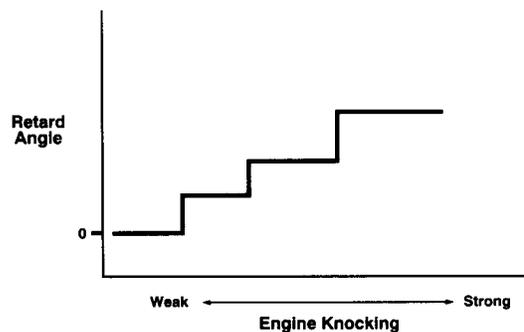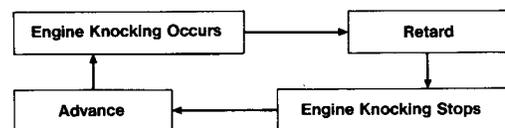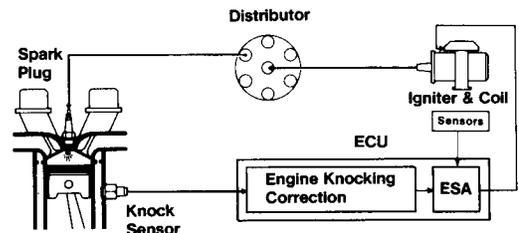
## ECT (Transmission) Shift Correction

On some applications with integrated ECT controls, the Engine and Transmission ECU retards the basic advance angle temporarily during gear shifting. This strategy helps reduce shift shock by reducing engine torque momentarily, just as the transmission shifts. The amount of retard varies depending on the status of engine and ECT sensor inputs.

ECT SHIFT CORRECTION
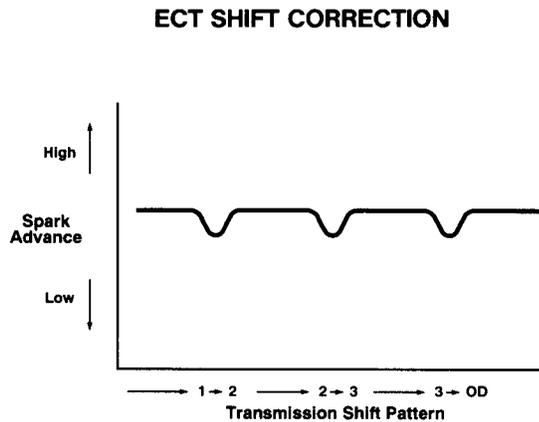
High Altitude Correction

This strategy, which is used only on applications with High Altitude Compensation (HAC) capabilities, improves engine performance and idle quality during high altitude operation by advancing timing over the basic calculated spark angle.
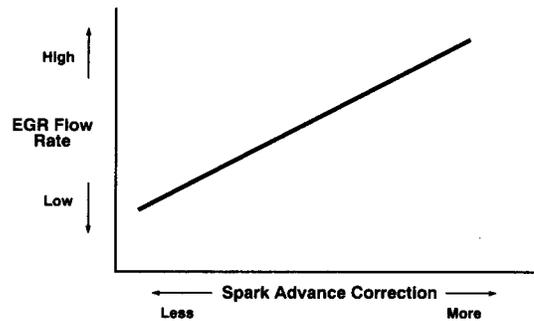
ALTITUDE ADVANCE CORRECTION
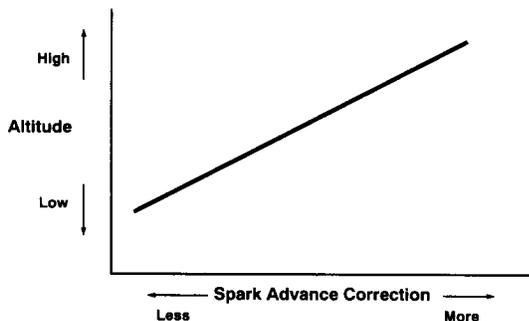
EGR Flow Correction

This strategy advances timing from the basic calculation when the IDL contact is off and the ECU is commanding EGR flow. This correction allows the engine to operate more efficiently because it resists detonation when EGR is introduced into the cylinders.

EGR FLOW CORRECTION

Summary

It is possible that minor calibration faults in key system inputs can have a significant effect on calculated spark advance, resulting in degraded driveability. When performance problems arise which appear to be the result of inaccurate timing advance calculation, do not overlook calibration of all relevant input sensors which influence timing during the affected driving mode. The best way to confirm sensor calibration is by becoming familiar with, and performing, the ECU Standard Voltage Check procedures.