Section 6

Automatic Temperature Control

Introduction to Automatic A/C

The heating, ventilation and air conditioning (HVAC) system in a house contains a wall-mounted thermostat to control outlet temperatures, distribution and fan speed. Changes are rarely made to the system other than to reprogram the ON and OFF times and to switch the system ON and OFF. In a vehicle, not all drivers wish to individually adjust all the functions while driving. For this reason, Automatic A/C systems were developed.

Automatic A/C Temperature Control

Automatic A/C is also referred to as “climate control.” Automatic A/C systems function like conventional manual HVAC systems, but also offer these functions:

- Ability to **maintain a specific interior temperature** selected by the driver under a variety of temperature and solar conditions
- **Automatic fan speed** selection based on the heating or cooling need
- **Automatic air distribution** pattern based on the HVAC mode
- **Automatic air intake control**

In an Automatic A/C system, the refrigerant circuit, electronic controls and safety systems are basically the same as a manual A/C system. Toyota Automatic A/C systems add additional sensors and controls to the basic system.

Here are some functions of the Automatic A/C controls on a late model Toyota:

Outlet Air Temperature Control	In response to the temperature control setting, the outlet air temperature, evaporator temperature sensor and engine coolant temperature sensor compensations are used by the air mix control damper control to calculate a target damper opening angle.
	The temperature setting for driver and front passenger is controlled independently in order to provide a separate air temperature for the right and left sides.
Blower Control	This function controls the operation of the blower motor according to the signals from the engine coolant temperature sensor, evaporator temperature sensor and the solar sensor. In addition, it protects the blower motor controller from the current surges when the blower motor is first activated.
Air Outlet Control	When the AUTO switch is ON, automatic control causes the air mix control servo-motor to rotate to a desired position for the correct outlet air temperature. During operation, the potentiometer in the servo-motor detects the actual damper opening so the system can match the actual opening to the desired damper opening.
	To prevent the front windshield from fogging up when the outside air temperature is low, the system automatically switches the blower outlet to the FOOT/DEF mode. Sensor inputs from engine coolant temperature, outside air temperature, amount of sunlight, required blower outlet temperature and vehicle speed.
Air Inlet Control	Drives the servo-motor (for air inlet) according to the operation of the air inlet control switch and fixes the dampers in the FRESH and RECIRC position.
	When selecting RECIRC mode under manual operation, if the outside air temp. is low and refrigerant pressure has a malfunction, the A/C ECU automatically switches the air inlet mode to the FRESH mode. However, if the outside air temperature is much lower than the specified temperature, in spite of the malfunction of the refrigerant pressure, the A/C ECU automatically switches the air inlet mode to the FRESH mode.
	When selecting RECIRC mode under manual operation, if the compressor switches OFF, the A/C ECU automatically switches the air inlet mode to the FRESH mode.
Compressor Control	The control switches the magnetic clutch OFF when the blower motor is switched OFF, when the engine coolant temperature is below a predetermined value, an abnormal refrigerant pressure has been input or the discharge temperature of the evaporator is below a predetermined value.
	When the DEF mode switch is ON, the magnetic clutch relay activates automatically to engage the compressor. In addition, when the blower is switched OFF and the front defroster switch is switched ON, the blower will activate in the automatic control condition.
Seat Heater Control	The HI, LO and OFF settings of the seat heater can be switched by pressing the seat heater switch (driver and front passenger). Based on signals from the seat heater temperature sensor, the A/C ECU switches the seat heater relay ON/OFF to regulate the set temperature. Switching the ignition to OFF switches the seat heater OFF.

Rear Window Defogger Control	When the rear window defogger is ON, the rear window defogger and outside rearview mirror heater operates. After 15 minutes, the system switches OFF.
Outer Temperature Indication Control	Based on signals from the ambient temperature sensor, this control calculates the outside temperature which is then corrected in the A/C ECU and displayed in the A/C control panel.
Self-Diagnosis	Checks the sensor according to the operation of the A/C switches. The heater control panel then displays a portion of the Diagnostic Trouble Code (DTC) indicating a malfunction or a sensor check function.
	Drives the actuators through a preset sequence according to the operation of the A/C switches (actuator check function).

Automatic A/C Components

An Automatic A/C system contains the following components:

Component	Function
A/C Electronic Control Unit (ECU)	Logic system to control system components based on sensor inputs
Heater Relay (blower fan relay)	Confirms blower fan is ON
Temperature Sensors (thermistors): Ambient Temperature Sensor Humidity Sensor Room Temperature Sensor Evaporative Temperature Sensor Engine Coolant Temperature Sensor Duct Sensor	Temperature-sensitive resistors: – Measures outside air temperature – Measures humidity level inside car – Measures cabin air temperature – Measures evaporator temperature to prevent freezing – Measures engine coolant temperature – Measures dash outlet temperature
Pressure Switches (high and low)	Ensures system pressure is within safe operation conditions
Belt Protection Sensor	Detects compressor speed
Solar Sensor	Detects sunlight for greater system control
Engine RPM Sensor	Determines engine speed for idle up mode
Speed Sensor	Determines vehicle speed

Customization Features

Certain A/C modes can be "customized" or deselected using the hand-held tester. For more information, refer to the diagnostics section in the *Vehicle Repair Manual.*

Air Conditioner

DISPLAY (ITEM)	DEFAULT	CONTENTS	SETTING
SET TEMP SHIFT (Air Inlet Mode)	NORMAL	To control with the shifted temperature against the display temperature.	+2/+1C/NORMAL –1C/–2C
AIR INLET MODE (Air Inlet Mode)	AUTO	In case of turning the A/C ON when you desire to make the compartment cool down quickly, this is the function to change the mode automatically to RECIRCULATED mode.	MANUAL/AUTO
COMPRESSOR MODE (Compressor Mode)	AUTO	Function to turn the A/C ON automatically by pressing the AUTO button when the blower is ON and the A/C is OFF.	MANUAL/AUTO
COMPRS/DEF OPER (Compressor/Air inlet DEF operation)	LINK	Function to turn the A/C ON automatically linking with the FRONT DEF button when the A/C is OFF.	NORMAL/LINK
FOOT/DEF MODE (Foot/DEF auto mode)	ON	Function to turn the air flow from FOOT/DEF to ON automatically when AUTO MODE is ON.	OFF/ON
AUTO BLOW UP (Foot/DEF automatic blow up function)	ON	Function to switch the blower level automatically when the defroster is ON.	OFF/ON
FOOT AIR LEAK (Foot air leak)	ON	Function to cut off the airstream felt underfoot while the vehicle is moving.	OFF/ON
AMBIENT TMP SFT (Ambient Temperature Shift)	NORMAL	To control with the shifted ambient temperature against the display ambient temperature.	+3C/+2C/+1C NORMAL/–1C/–2C/–3C

A/C Amplifier

The ECU of a Toyota Automatic A/C system not only controls compressor clutch and engine idle-up operation, it also controls outlet temperature, airflow distribution and fan speed based on a determination of interior, ambient temperature and humidity with a compensation for solar load.

Microcomputer-Controlled Auto A/C System

Auto A/C system sensors and components.

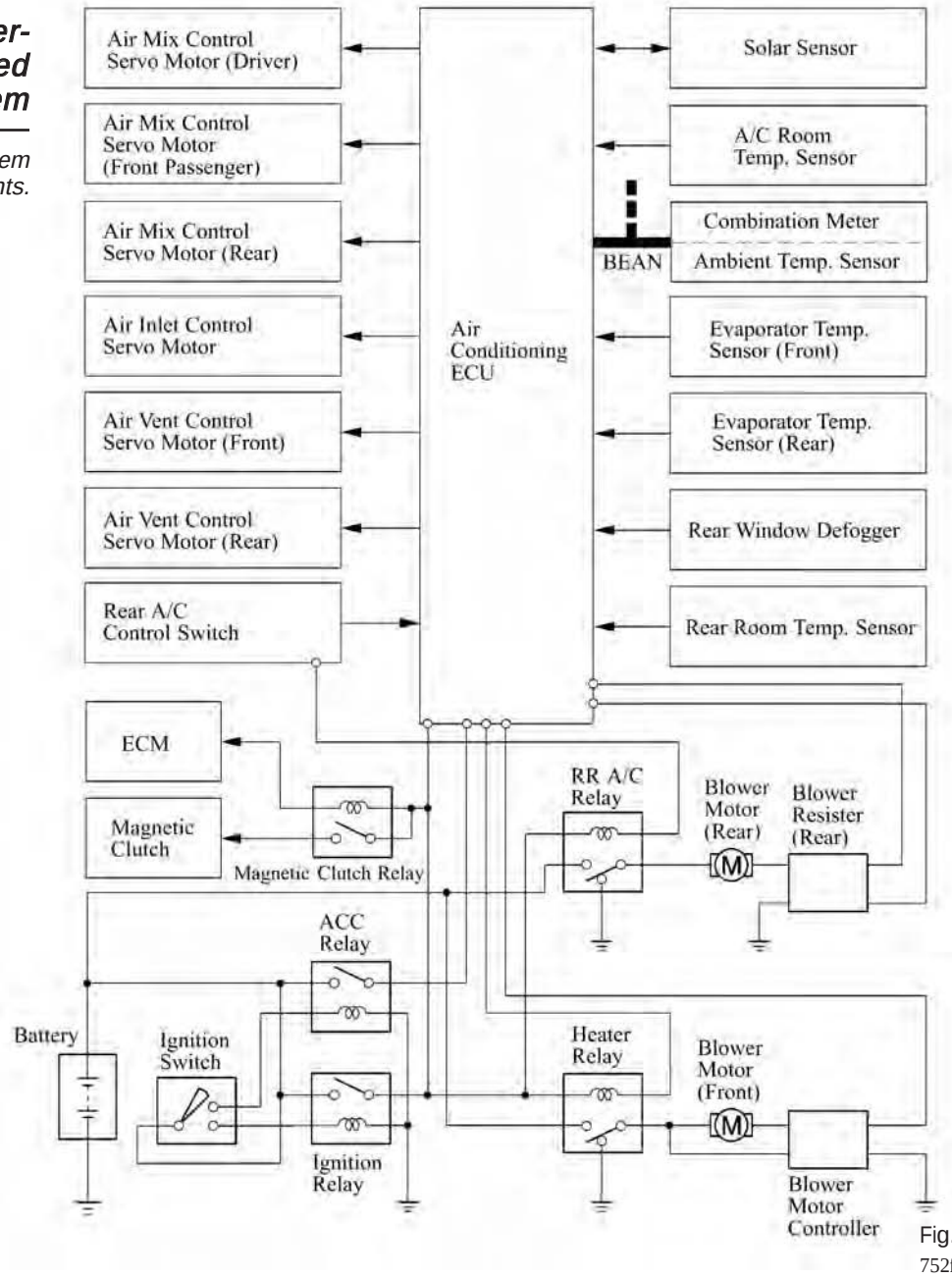

Fig. 6-1
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In addition, the A/C ECU monitors refrigerant pressure by controlling the compressor clutch and provides signals to the **ECM (engine control module)** for idle stabilization. In some vehicles, the compressor clutch relay is not controlled directly by the A/C ECU but instead by the powertrain control module that receives a signal from the A/C ECU.

The primary control unit for the compressor clutch circuit is the A/C ECU. The ECU is a device that has an output current greater than the input signals. The amplifier section of the ECU processes low current signals from a number of sources to control a relay. The relay supplies power to energize the compressor clutch. The relay also adds a further level of amplification to the circuit since the power side of a relay can pass more current than is needed to activate the control side.

The amplifier cycles the compressor clutch ON and OFF in order to provide the most efficient transfer of heat at the evaporator while preventing the evaporator from icing. The amplifier's output signal also activates the condenser fans at low speed and raises the engine idle speed (via the engine and transmission ECU) to avoid stalling the engine whenever the compressor switches ON.

Compressor Clutch Circuit

Main components:

- *Prevents overcooling or lock up.*
- *Prevents excessive pressure.*

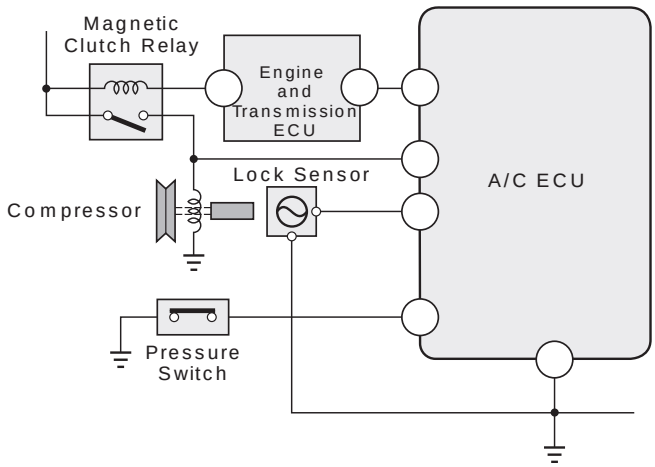

Fig. 6-2
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Input Sensor Signals to the A/C Amplifier (A/C ECU)

Input Signal	Function
Temperature Selector	Selects desired cabin (interior) temperature
A/C Switch	Allows driver to switch compressor ON or OFF
Heater Relay (blower fan relay)	Confirms blower fan is ON
Thermistors: Ambient Temperature Sensor Room Temperature Sensor Evaporative Temperature Sensor Engine Coolant Temperature Sensor	Electrical temperature sensor: – Measures outside air temperature – Measures cabin air temperature – Measures evaporator temperature to prevent freezing – Measures engine coolant temperature
Pressure Switches (high and low)	Ensures system pressure is within safe operating condition
Belt Protection Sensor	Detects drive-belt speed
Solar Sensor	Detects sunlight for greater system control
Engine RPM Sensor	Determines engine speed for idle up mode
Speed Sensor	Determines vehicle speed
Humidity Sensor	Determines humidity of cabin air

Automatic A/C Control Panel

Compared to a manual system, an automatic A/C system features a temperature control display marked with degrees and one or two additional buttons on the control panel labeled AUTO to select automatic fan speed and/or air distribution (almost like your home's HVAC system).

When automatic A/C is desired, the driver selects the temperature in one of three ways:

1. Slide lever
2. Rotating knob
3. Push button

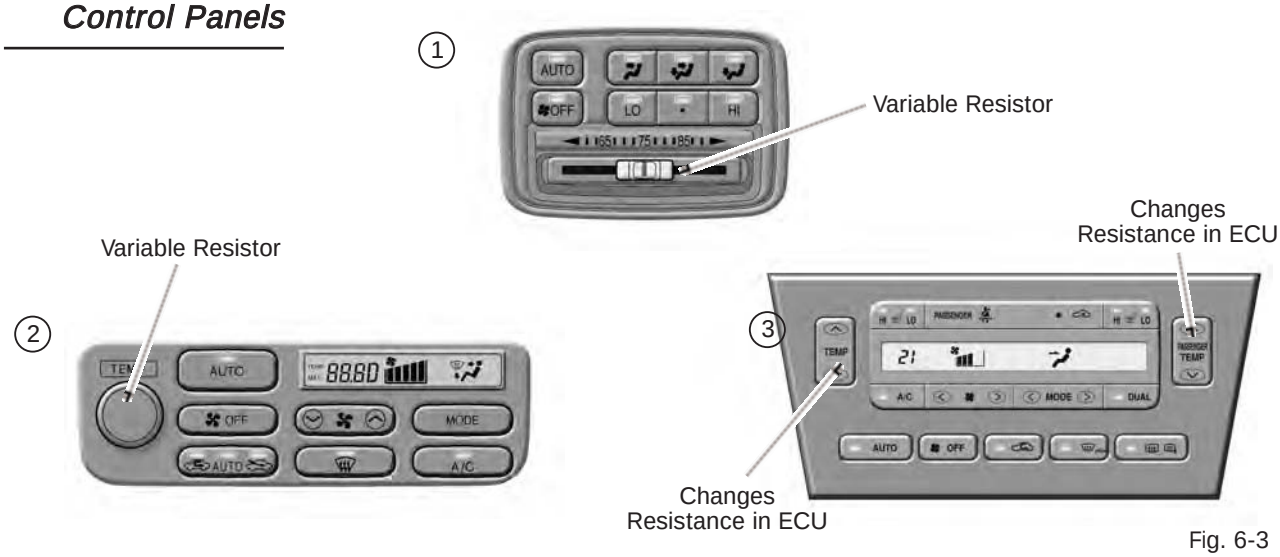

Fig. 6-3
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Each type of control causes a transistor circuit in the ECU to send a variable voltage signal to the microprocessor. Changing the temperature selector (or display) changes the signal value.

The primary input signal to the amplifier is a variable voltage from the temperature selector that represents the desired interior temperature. This potentiometer provides a variable resistance as it moves from cold to hot (except at the extremes). In the chart on the following page, notice the **MAX COOL** position (lower than 70° F) the resistance rises to infinity ($\infty\ \Omega$). In the **MAX HEAT** position (over 85° F), the resistance goes to 0 ohms.

Temperature Selector Resistance Chart

- *Variable resistor.*
- *Higher temperature setting has lower resistance (Ω)*

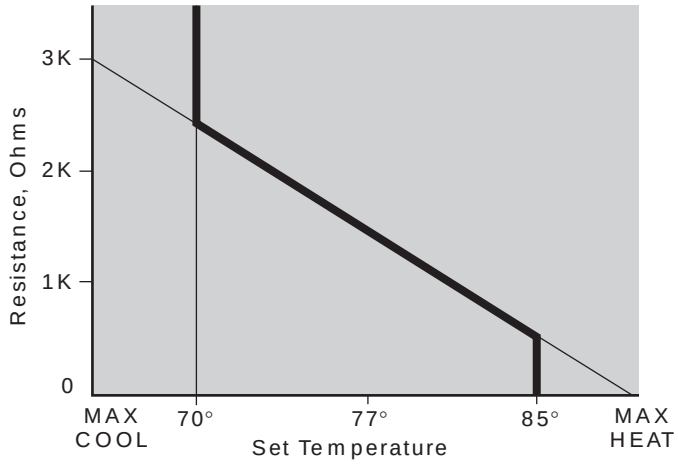

Fig. 6-4
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Temperature Sensor Circuits

The objective of the Automatic A/C system is to reach an output temperature based on a preset temperature. Toyota uses the terms **"TSET"** to represent the preset temperature and **"TAO"** to represent the desired output temperature. To be effective, the HVAC system must be able to deal with variables such as the number of passengers in the vehicle, relative outside temperature and the solar load in the vehicle. For maximum comfort, the system anticipates conditions that will affect the interior temperature before the temperature rises. Here are the various inputs to the A/C ECU to determine TAO. It is only important to be aware of the variables that determine TAO.

TAO (output temperature) = A x TSET – B x TR – C x TAM – D x TS + E

Temperature	Description
A	Set temperature coefficient
B	Room air temperature coefficient
C	Ambient air temperature coefficient
D	Solar radiation coefficient
E	Correct constant
TSET	Set temperature
TR	In-car temperature
TAM	Ambient air temperature
TS	Solar radiation

Servo-Motor Control

On current vehicles, servo-motors control the damper doors. A servo-motor is an electric motor that contains a potentiometer (variable resistor) or a multiple-position contact switch. This device acts like a position sensor to provide feedback to the amplifier to confirm and to control the position of the damper.

The Automatic A/C system uses the air mix (“blend door”) system for rapid and accurate temperature adjustment; the blend (air mix) door is moved by the ECU-controlled servo-motor instead of a cable from the temperature selector. Current water control valves are also operated by a cable (via a servo-motor).

Distribution Control (Servo-Motor Controls)

- *Electrically controlled.*
- *Mover air mix or blend doors.*

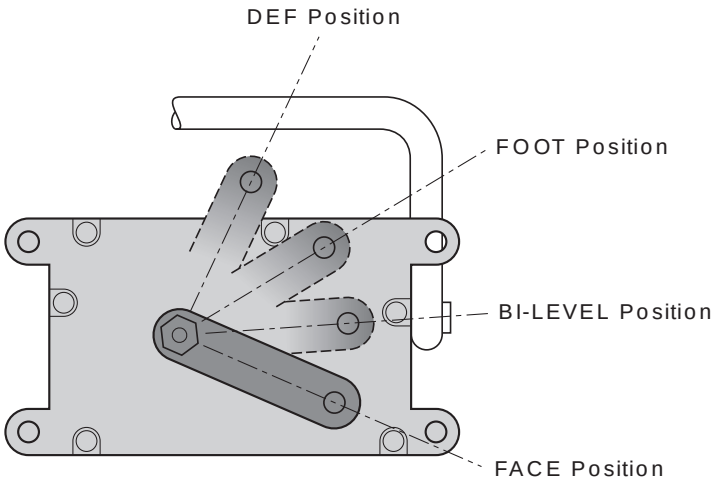

Fig. 6-5
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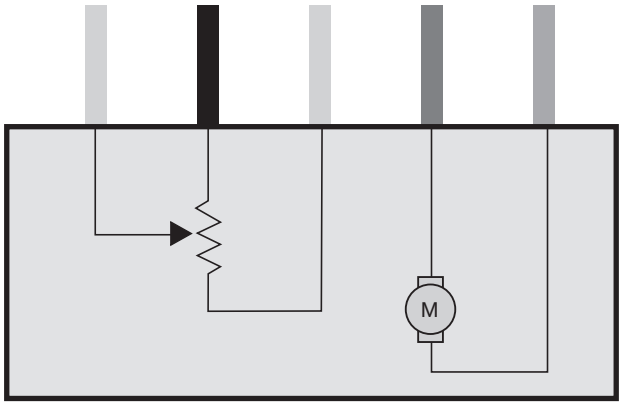
Servo-Motor Internal Circuit

Moving contacts provide feedback on actual door movement.



Servo-Motor

Fig. 6-6
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Temperature sensor signals from various locations in the vehicle are amplified inside the A/C ECU to produce a temperature value. This value is then compared with the preset temperature (from the A/C control panel) to determine the relative **balance** of the system. When all of the amplified input signals meet the preset air temperature, the system is said to be in balance; that is, the air mix servo-motor damper door remains in position and the fan speed is kept low. Once the system is in balance, there is no current flow to the air mix servo-motor.

When heat or solar load conditions create an imbalance, the ECU amplifies the difference to operate one of two **switching amplifiers** according to whether the interior must be warmer or cooler. The switching amplifiers contain pairs of transistors and can conduct in either polarity to produce a signal which controls the air mix servo.

Control of Blend Air Damper

Since the servo-motor is an electric DC motor, changing the polarity (+ and –) of the supply and ground causes the motor to rotate in different directions, just like a power window motor. When there is a temperature difference, one switching amplifier produces a positive voltage; the other amplifier supplies a ground to move the air mix servo-motor in the direction of cooler or warmer air delivery.

Depending on temperature requirements, the ECU selects a “target” damper door position and measures the actual position with a potentiometer (variable resistor) within the servo-motor. The ECU also monitors the resulting change in temperature to verify the servo-motor(s) responds appropriately.

Servo-Motor Control Circuit

Switching amplifiers control polarity to air mix servo-motor.

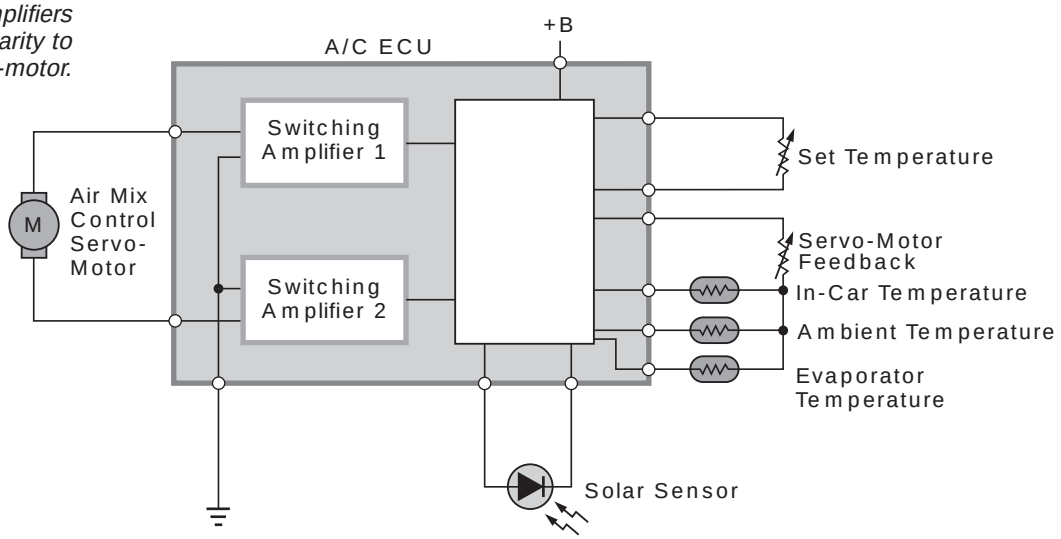

Fig. 6-7
752f607

The A/C ECU will continue to output a control current to the servo until the system is in “balance” as follows:

- Initially, this happens when the potentiometer in the servo-motor indicates movement of the servo to a position which offsets the temperature change.
- Later, the temperature in the vehicle will change to match the desired temperature. Thus, the ECU will stop current flow to the servo-motor.

This system allows the temperature to “overshoot,” to rapidly adjust the temperature in response to a temperature change. This is followed by readjusting to the desired temperature setting.

Servo-Motor Circuit

Moving contacts provide feedback on door movement.

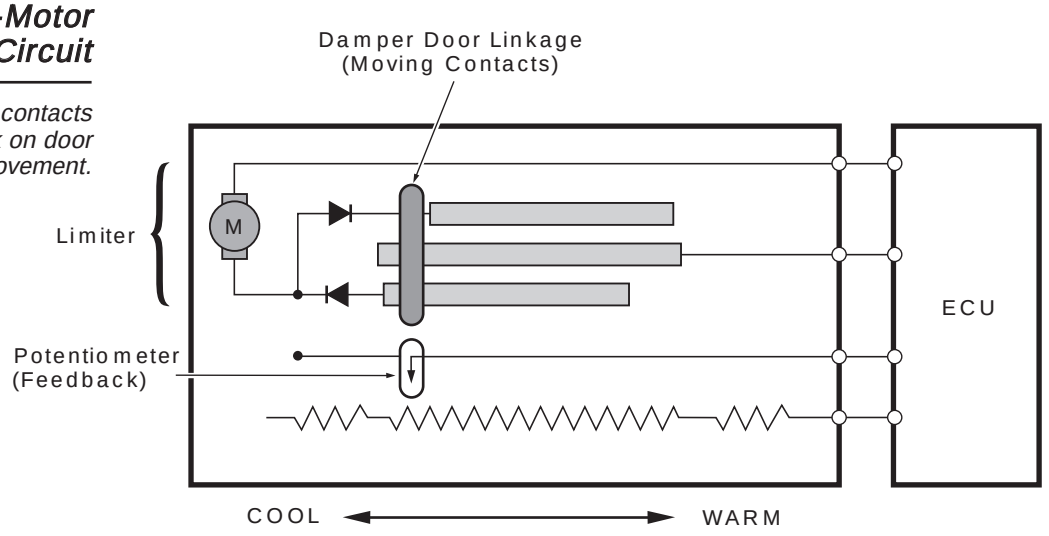

Fig. 6-8
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Pulse Pattern Type Servo Motor

The pulse pattern type servo motor contains a printed circuit board instead of a potentiometer to provide position feedback. The printed circuit board has three contact points and transmits two ON-OFF signals to the A/C ECU to identify the pulse phase. Using this signal, a smart connector detects the damper position and its direction of movement.

Pulse Pattern Type Servo Motor

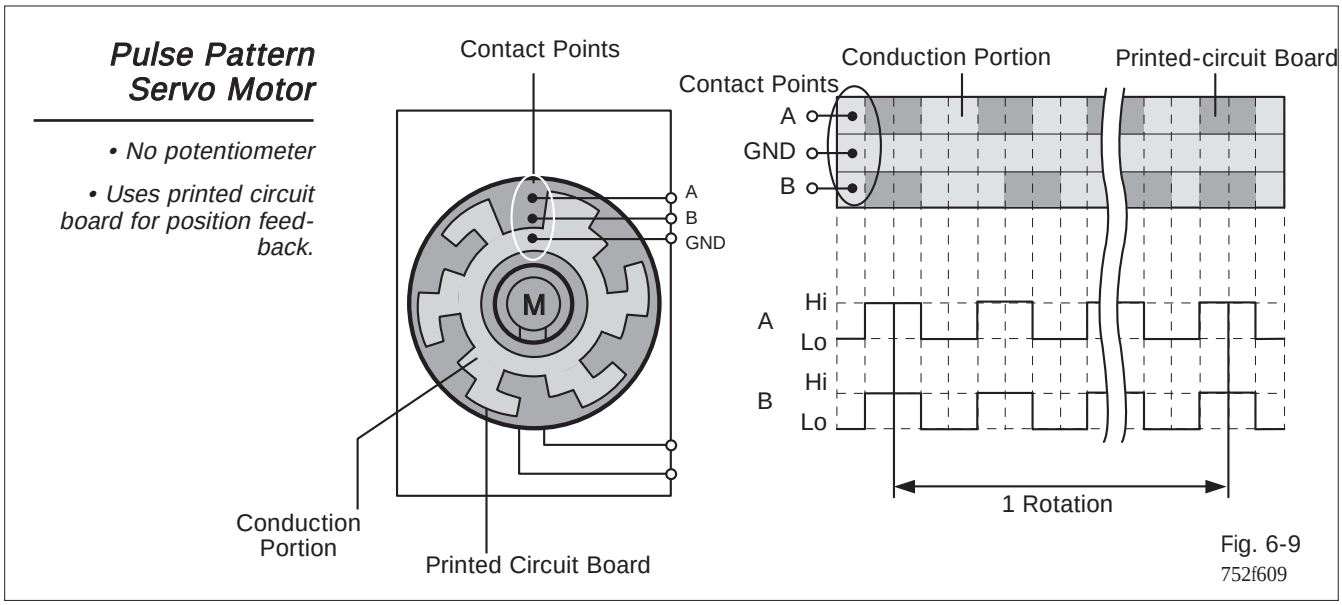

Fig. 6-9
752f609

Pressure Switches

Pressure switches can sense high or low pressures or both. These can be separate switches or a single switch that senses multiple pressures (dual or triple pressure switch). Pressure switches are normally closed and are located in the high-pressure side of the system. When the switch opens due to excessively high or low system pressure, the amplifier will disable the compressor clutch to prevent component damage. For additional information, refer to Multipressure Switch in Section 3.

Pressure Sensor

Functions like the pressure switches to monitor excessively high or low pressures for compressor control.

Thermistor

A thermistor is a temperature-sensitive resistor. Most electrical components have a higher electrical resistance as the temperature increases. This is called a positive temperature coefficient. Special thermistors with a **Negative Temperature Coefficient (NTC)** provide accurate temperature sensing for A/C and fuel injection systems. As the temperature increases, the electrical resistance decreases. The A/C ECU reads the resultant voltage to interpret the temperature.

Resistance vs. Temperature of Thermistor

- *A/C temperature sensors are thermistors.*
- *Resistance decreases and temperature increases.*

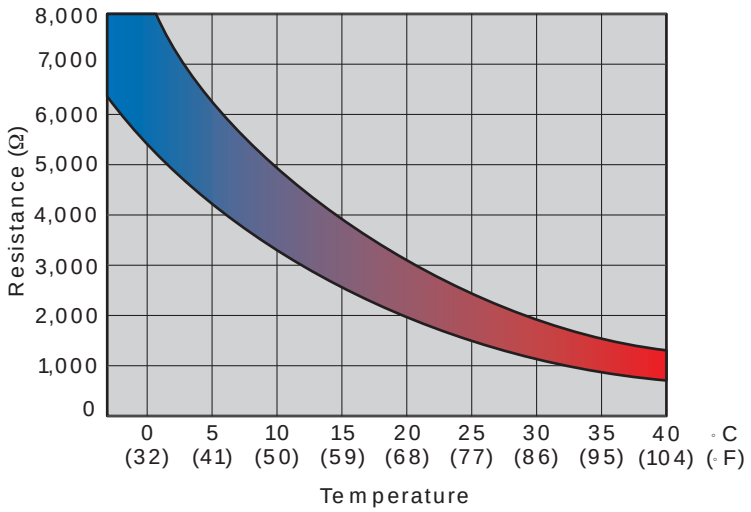

Fig. 6-10
752f610

The A/C ECU supplies a fixed voltage to the sensor, then measures the voltage drop across the thermistor. As the resistance changes, so does the voltage drop. In this way, the amount of voltage drop created by the thermistor is used by the amplifier as an input signal.

Sensor (Thermistor)

On some Toyota vehicles, sensors are placed in the air distibution ducts to monitor air temperature and humidity. The A/C ECU adjusts the air distribution system to change the airflow and air temperature accordingly.

Ambient Temperature Sensor (Thermistor)

Outside temperature is measured by the ambient sensor so the system can anticipate changes in cooling demand as the ambient temperature changes. It is located in front of the radiator and condenser, but out of the air stream.

Ambient Temperature Sensor

- *Located at front grille.*
- *Senses outside air temperature.*
- *Also controls temperature gauge.*

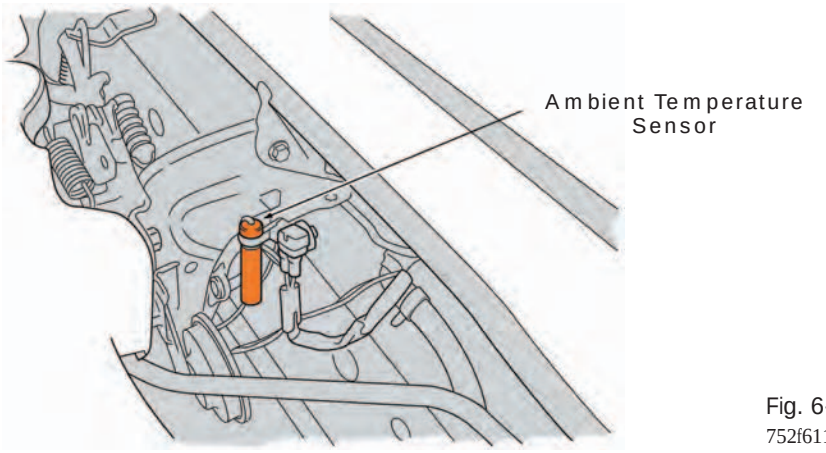

Fig. 6-11
752f611

In-Car Sensor (Thermistor)

The in-car sensor measures the air temperature inside the vehicle. In-car sensors are usually located in the dash or center console. The actual sensing element is very small, about 1/8″ (2 mm) diameter so it can respond quickly to temperature changes.

To avoid being affected by solar radiation or hot car surfaces, it is shaded from direct light but located in the air stream. Some models use an aspirator powered by the air pressure in the blower case to draw interior air past the sensor.

In-Car or Interior Temperature Sensor

- *Thermistor measures interior air temperature.*
- *Aspirator creates air movement over sensor.*

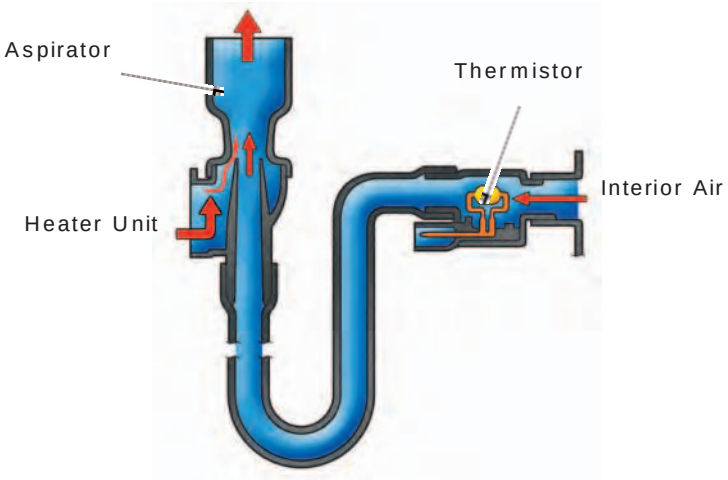

Fig. 6-12
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Sensor Location

Thermistor sends "air temperature" signal to the A/C control unit.

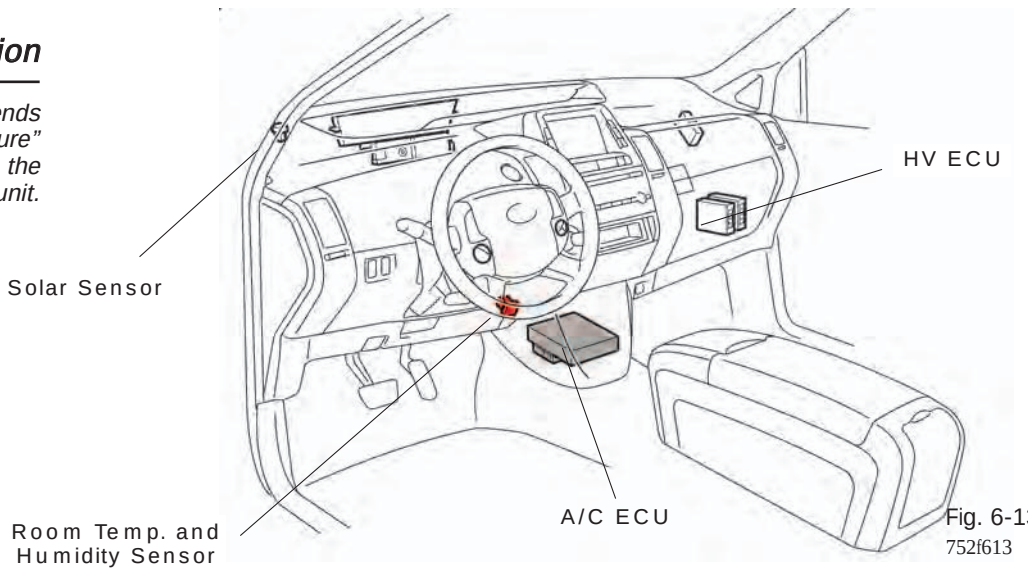

Fig. 6-13
752f613

Room Temperature and Humidity Sensor

The latest hybrid HVAC systems use a humidity sensor function combined with the room temperature sensor. Detecting humidity in the vehicle interior optimizes the amount of dehumidification during A/C operation. This results in the A/C compressor consuming less power and creates an ideal humidity level inside the vehicle.

A resistance film inside the sensor absorbs and releases air in the interior. During the absorption and release process, the humidity-sensing film expands (during humidity absorption) and contracts (during drying). As the resistance film expands and contracts, the clearance between the carbon particles in the resistance film changes which increases or decreases its electrical resistance. The A/C ECU then determines the amount of humidity by measuring the resistance between the electrodes.

Humidity Sensor

Combined with temperature sensor to regulate interior humidity levels.

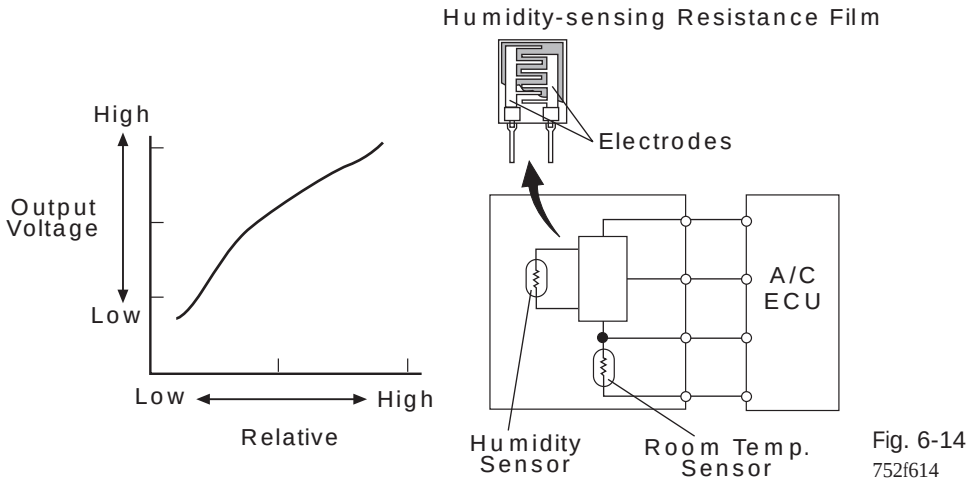

Fig. 6-14
752f614

Solar Sensor

Sixty percent of the heat entering a vehicle comes from solar radiation. Since the air in the car does not heat up immediately in bright sun, the desired interior temperature can be maintained by **anticipating** the effect of solar heat load. The solar sensor is usually located on top of the instrument panel.

The solar sensor is a photo-diode rather than a thermistor. It normally blocks the flow of current in both directions (it has a resistance of near ∞Ω except in the presence of light. When exposed to light, the photo-diode biases the junction of the diode so that its resistance in one polarity falls to near 0. It then gradually begins to conduct in one direction.

Solar Sensor

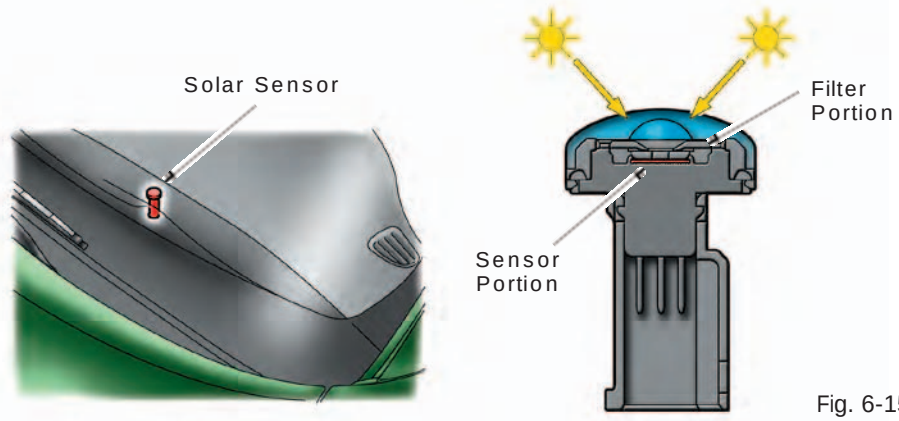

Fig. 6-15
752f615

Like a temperature sensor, the solar sensor is supplied with a fixed voltage so the A/C ECU can read the voltage drop to and sense the solar heat entering the vehicle. The amplifier (or A/C ECU) can adjust the outlet air temperature based on changes in sunlight before the interior temperature changes. Some Toyota vehicles use a solar sensor that measures sunlight falling from two angles to provide additional control over both driver and passenger seating areas.

On current models, the A/C control unit controls blower speeds through several steps according to various sensor inputs — the following chart tracks blower air volume according to the amount of sunlight.

Stepless Fan Speeds

Sunlight on solar sensor changes fan speed.

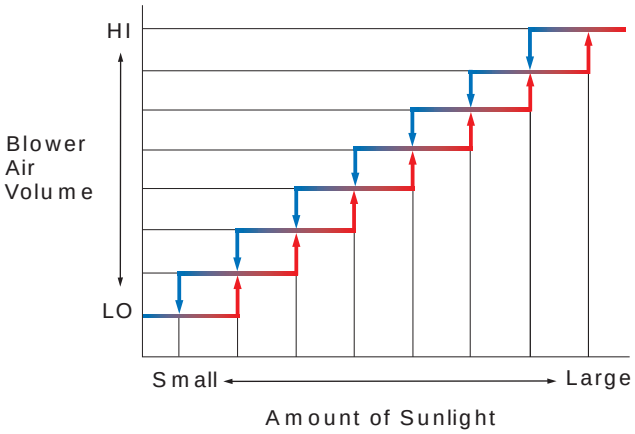

Fig. 6-16
752f616

Maximum Cool Damper

On vehicles with automatic temperature control, a **MAX COOL Damper Door** can open (**MAX COOL** mode and **FACE** air-distribution modes) to deliver additional cool air from the plenum to the dash vent outlets.

The damper is located after the evaporator. When energized, the damper moves to allow cool air to bypass the heater core to deliver the lowest possible air temperature to the outlet air vents.

Maximum Cool Damper

Adds flow on MAX COOL.

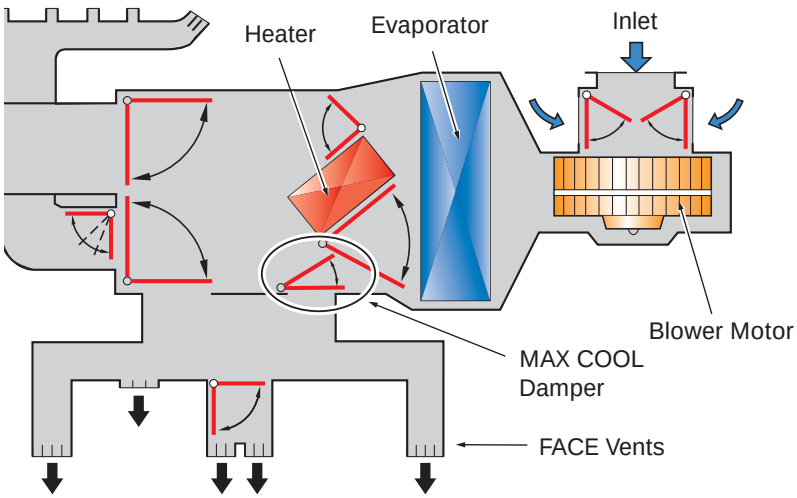

Fig. 6-17
752f617

Multimode

When the max cool damper is open, air resistance through the system decreases. This allows more air to enter the vehicle through the system without increasing fan speed or noise.

This feature blows air from all the vents during warm-up immediately after the engine starts in cold weather. This prevents the windows from fogging and helps to warm up the upper body.

Rear A/C Unit

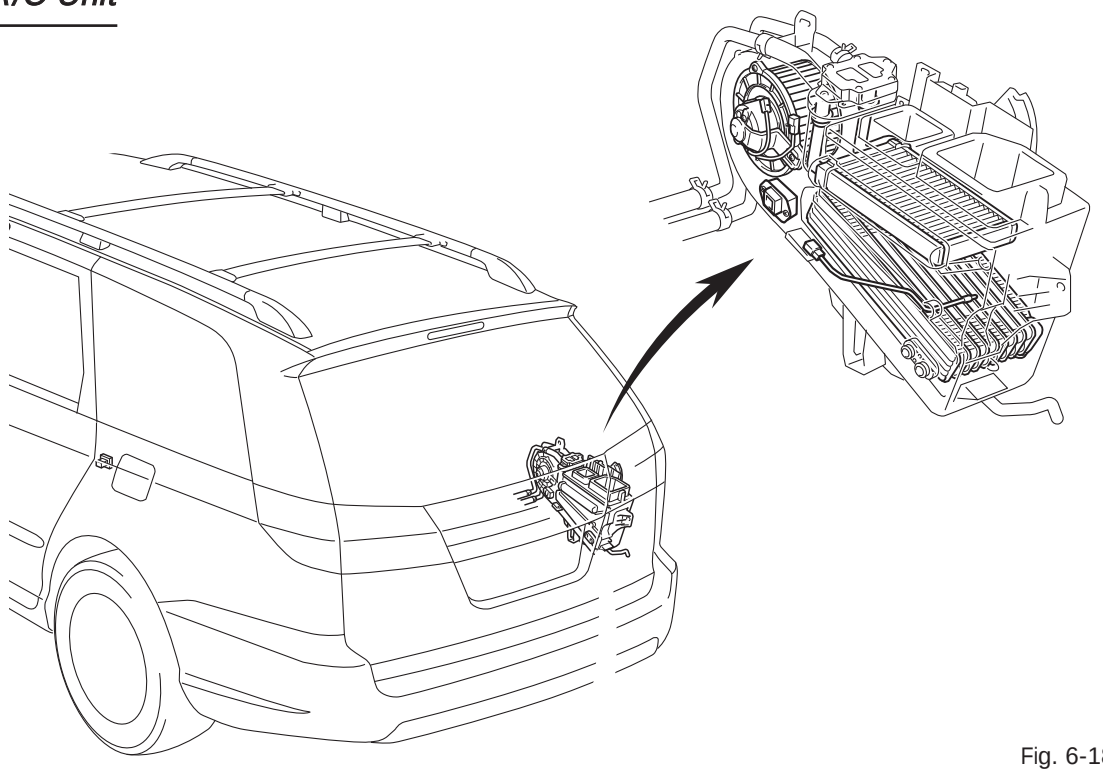

Fig. 6-18
752f618

Rear Air Conditioning

Some Toyota vehicles contain a separate rear air-conditioning system to provide additional temperature control for rear passengers. The A/C compressor supplies refrigerant to a separate A/C assembly mounted behind the rear seat area.

The A/C compressor provides refrigerant for both the front and rear systems. Some vehicles may or may not have a magnetic solenoid valve to control refrigerant flow to the rear unit. If equipped, the magnetic valve is part of the rear expansion valve.