

Theory of Operation

Fullscreen



Electronic Air Suspension (Vehicles built before April 11, 2016)

Last updated: October 20, 2023

Overview

EAS is the Electronic Air Suspension system available as an option to Coil Suspension on the Model S from SOP 2012 through to April 2016. The possible configuration values for Electronic Air Suspension are the following: Standard or Plus.

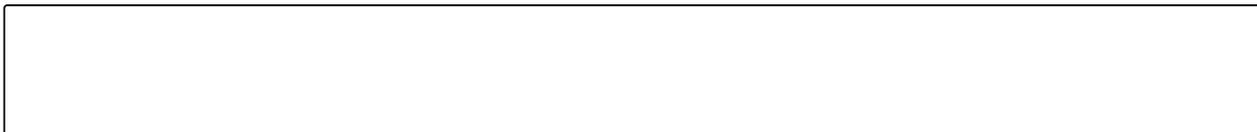
EAS is a Nitrogen closed system, air is only drawn into the system when air mass in the reservoir/system is low. This is drawn by the Compressor and is passed through the air filter to remove any impurities.

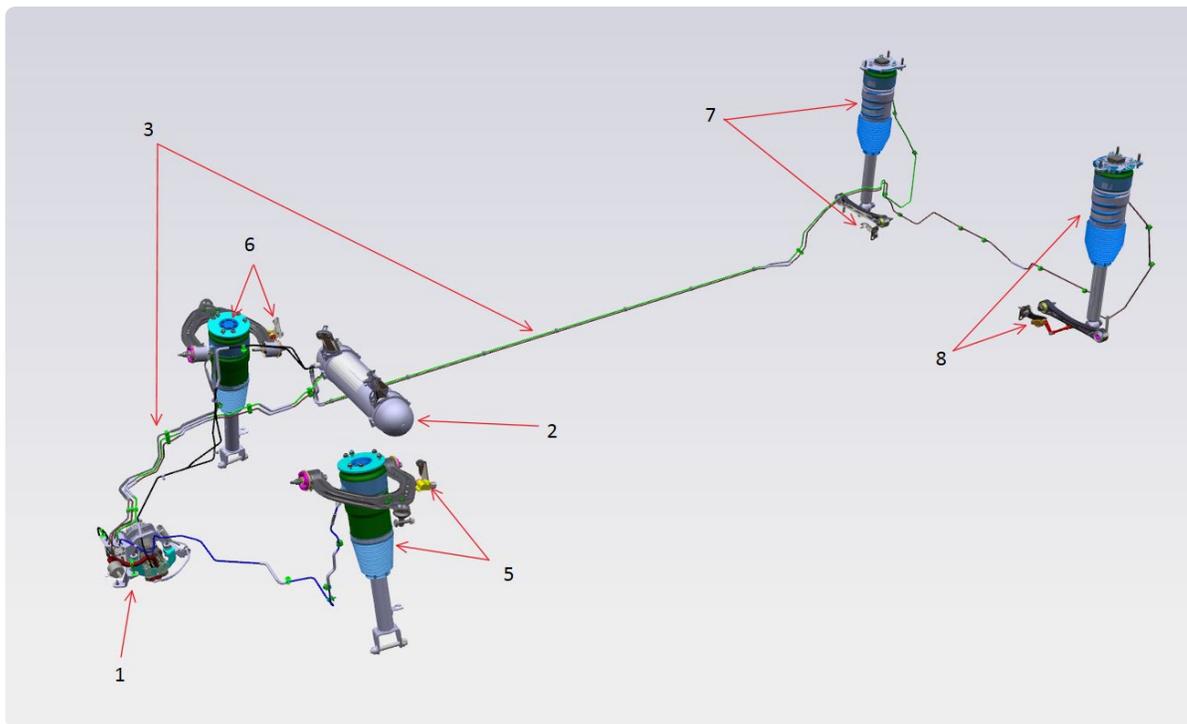
This compressed air is then fed via the solenoid valve block to individual suspension modules and/or the reservoir, this is determined by the ECU.

EAS architecture uses the Compressor to pump air between the Suspension Modules and the Reservoir to maintain a Closed Loop System.

The ECU monitors the vehicle's axle height via the four height sensors and adjusts the vehicle height based parameters such as road speed and driver requested height level setting.

This process maintains vehicle suspension at the correct height for all conditions. The ECU also monitors system pressure and switches the compressor on or off to maintain that pressure.



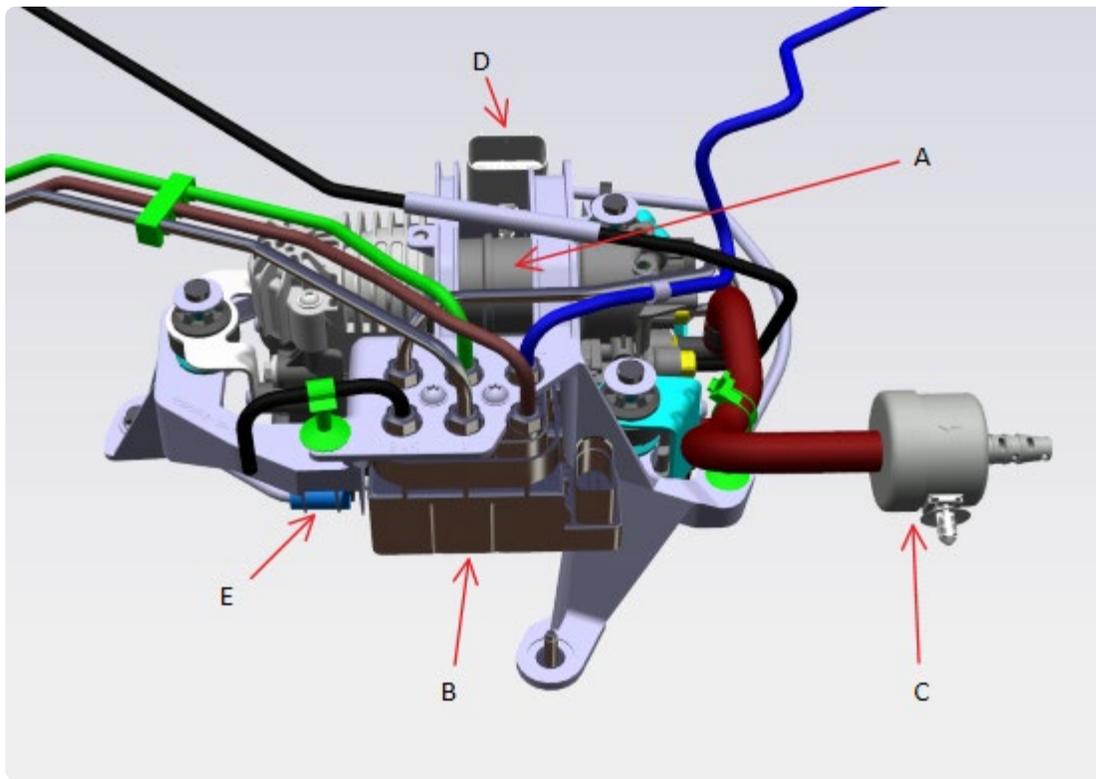


1. Air Compressor Assembly (inc Solenoid Valve Block, Air Filter and Ambient Temperature Sensor)
2. Reservoir & Fill Valve
3. Air supply pipes
4. Air suspension Electronic Control Unit (not shown)
5. LH Front Suspension Module and Height Sensor
6. RH Front Suspension Module and Height Sensor
7. RH Rear Suspension Module and Height Sensor
8. LH Rear Suspension Module and Height Sensor

Component Descriptions

Air Compressor Assembly

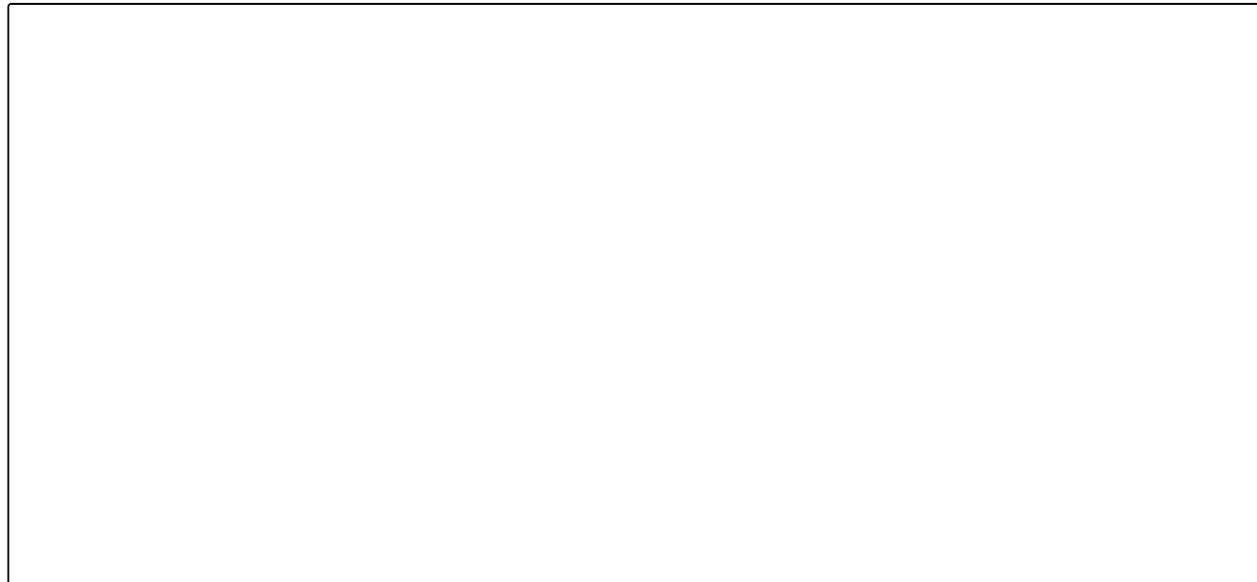


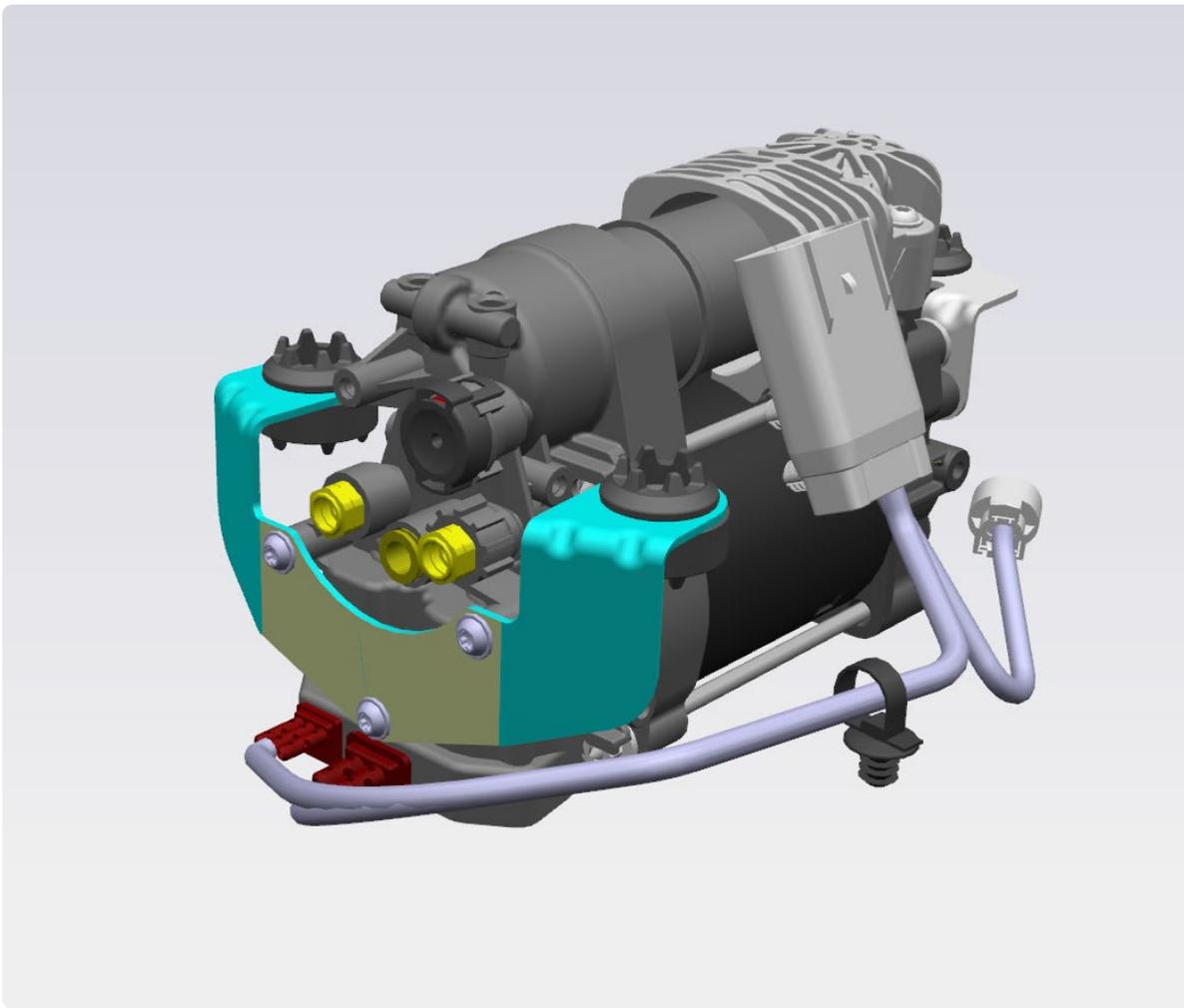


- A - Air compressor
- B - Solenoid Valve Block
- C - Air Filter
- D - Electrical connector
- E - Ambient air temperature sensor

In depth look into Air Compressor Assembly Components

Compressor





Compressor

The maintenance-free oil-free piston compressor is driven by an electric motor. The ECU controls the compressor run time. The unit is rubber mounted to the bracket to isolate mechanical vibration.

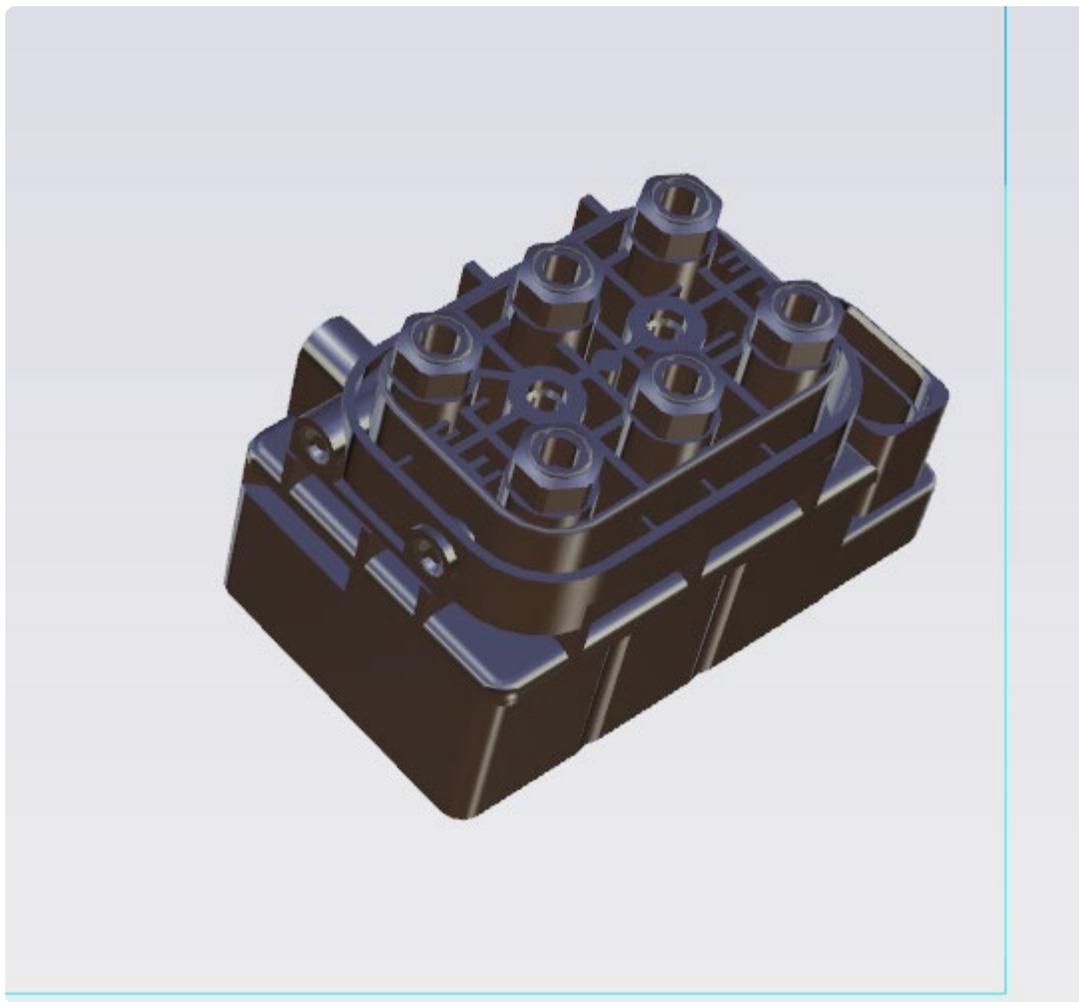
The Air Compressor also contains the following:

- **Reversing Solenoid Valves** - The reversing solenoid valves are energized by the ECU to draw excess air from the air suspension bellows, back through the compressor, and into the reservoir.
- **Pressure Retention Valve** - The relief valve opens pneumatically and limits the maximum system pressure at 18 to 24 bar
- **Air Dryer** - The dryer absorbs humidity from the intake air. The dryer is regenerated when air is vented from the system and released to the environment along with humidity.
- **Throttle/Check Valve** - The throttle/check valve regulates the pressure being returned to the reservoir.

Specification	Value
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Voltage range	9 to 15 volts
Maximum permanent current	40 Amps
Operating temperature range	-40°C to 80°C, Max. 100°C for 3 minutes
Operating pressure range	0 to 16 bar (232 psi)

Solenoid Valve Block

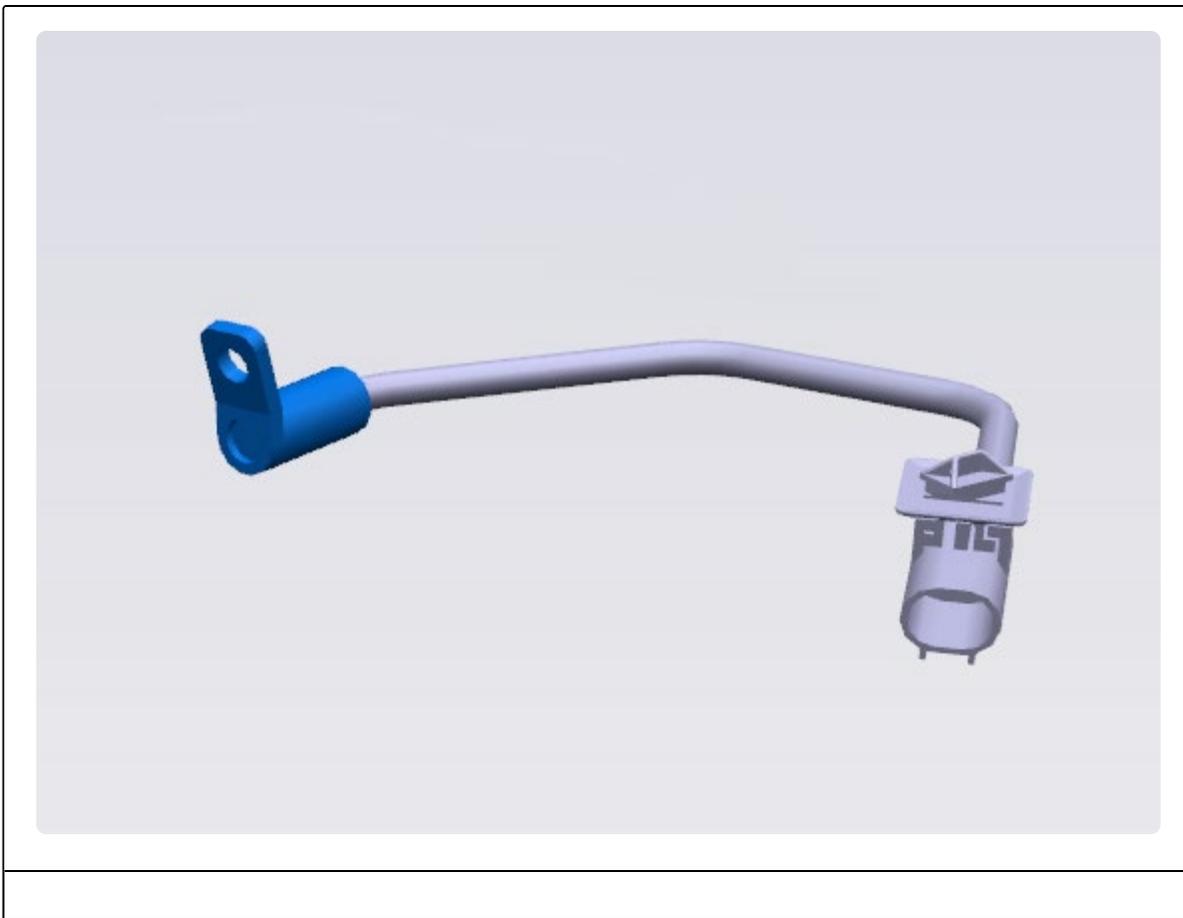


The Solenoid Valve Block is designed to control air flow to and from the Air Suspension Modules, Reservoir and vent to atmosphere this is controlled by commands from the ECU. The Block also features a colour key to assist in assembly to identify the correct Air Supply Pipes.

Integrated also into this Block are the following:

- **Pressure Sensor** - The pressure sensor measures the air spring module and reservoir pressures and keeps the system air mass constant
- **Solenoid Valves** - The 4 solenoid valves are held closed by system air pressure and are operated open by the ECU to maintain the correct pressure in all parts of the system, according to information received from sensors or driver commands. This ensures that the vehicle is always at the correct height. These valves also control limp home modes.
- **Environment Valve** - The environment valve vents excess air pressure in the system to atmosphere.

Ambient Air Temperature Sensor



The ambient air temperature sensor is mounted on top of the compressor. It provides ambient air temperature data to the ECU to maintain system performance in different ambient conditions.

The resistance of the sensor changes in function of ambient temperature. The higher the ambient temperature the lower the resistance of the sensor.

The Air Suspension ECU reads the voltage drop over the sensor. There are a few thresholds that are important for the

operation of the air suspension system. Below table shows the voltage thresholds and the corresponding sensor resistance values.

Sensor Voltage	0.089	0.14	0.297	0.666	1.425	2.431	3.07
Sensor Temp	130	110	80	50	20	-10	-40

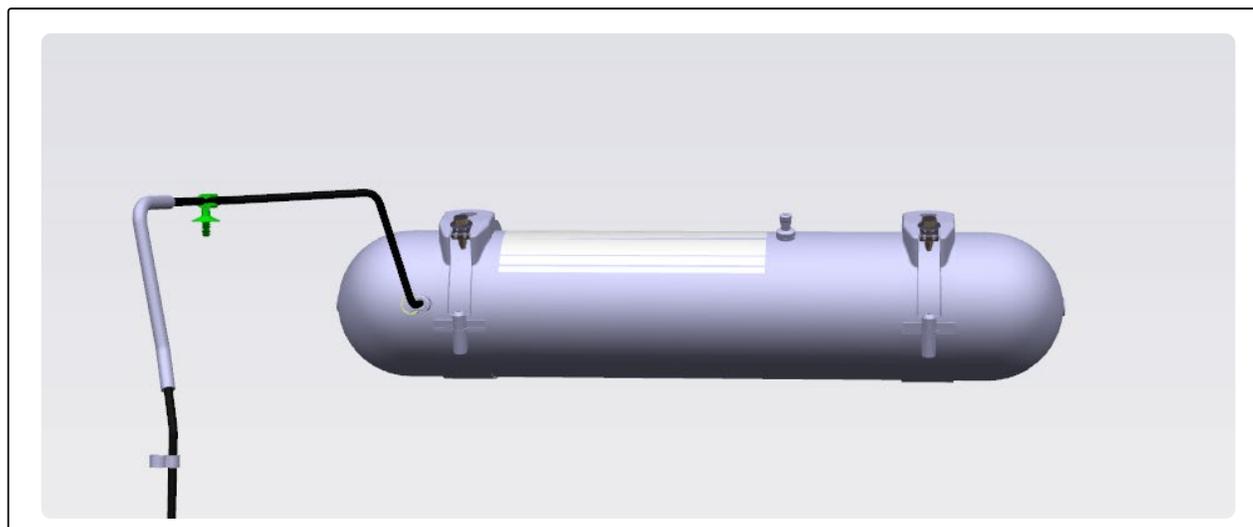
Voltage thresholds and corresponding resistance values that are used in the EAS firmware

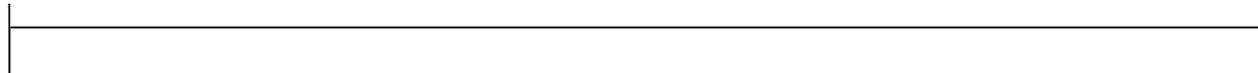
- **0.14 V (110 degC)** - DTC DTC - temperature signal shorted to ground in wiring harness is set when the voltage drops below this threshold.
- **0.297 V (80 degC)** - The voltage that corresponds to the maximum operating temperature of the EAS system. Air suspension leveling will no longer work when the voltage drops below this threshold. This voltage level is also the reset condition for DTC DTC - temperature signal shorted to ground in wiring harness. So the DTC is only reset when the voltage level exceeds this value again.
- **3.07 V (-40 degC)** - The voltage that corresponds to the minimum operating temperature of the EAS system. Air suspension leveling will no longer work at temperatures below this value.

Note

In the unlikely situation where the ambient temperature sensor reads a voltage between 0.297V (80 degC) and 0.14V (110 degC), leveling is disabled but DTC is not set. Obviously, these ambient temperatures are not realistic, but in the rare case where either the sensor malfunctions or there is a wiring issue, this situation can cause confusion because the air suspension system does not level but the ECU also does not set a DTC.

Reservoir & Fill Valve





The Reservoir is designed to provide an instant Compressed Air Supply pressure when the ECU requests Air Suspension Module fill (raising the vehicle) and if required as a storage reservoir when Air Suspension Module are deflating (lowering the vehicle)

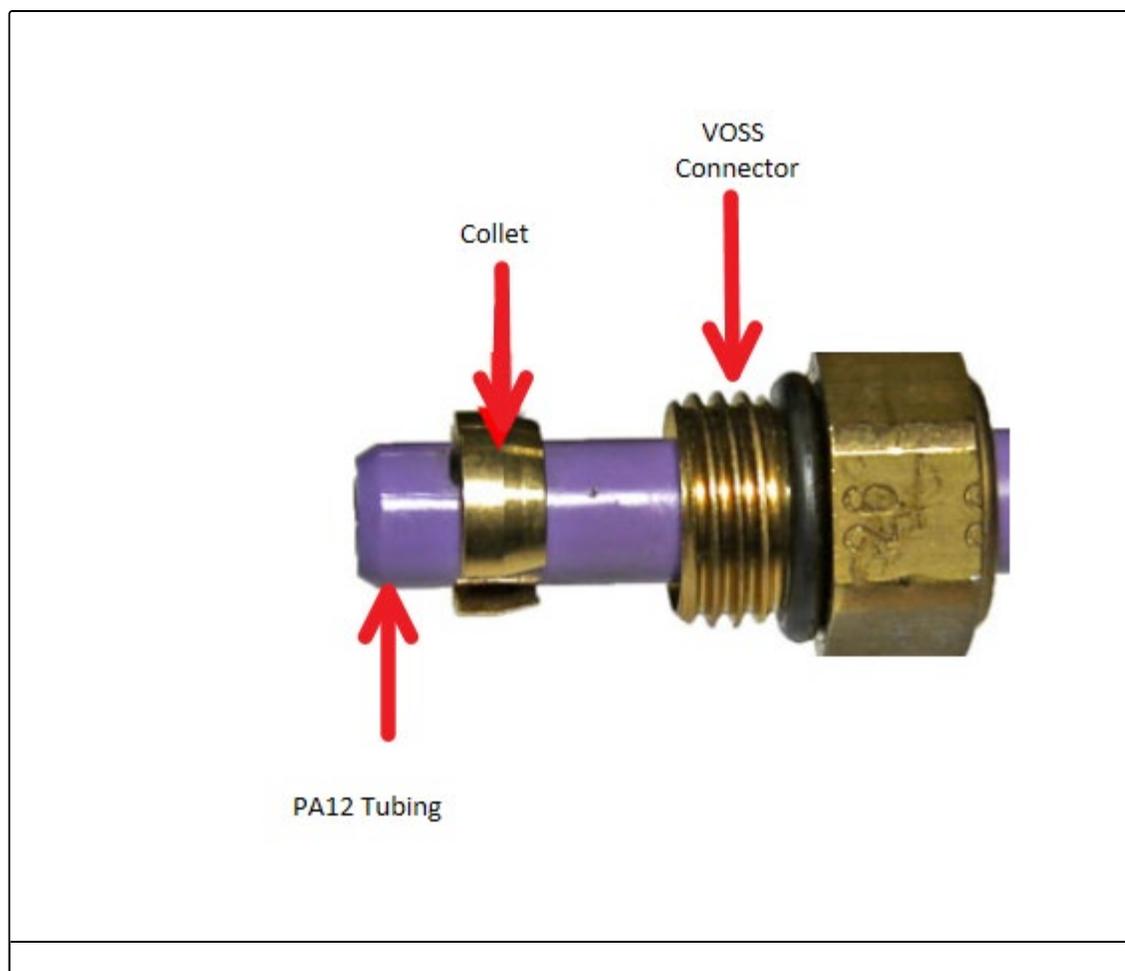
The reservoir has a volume capacity of 5.2 Litres (317.32 cubic inch) and a regular operation pressure of 15 bar (217.55 psi) absolute.

The system filling valve is used if the air suspension system is required to be filled from an external supply. (See Online Manual)

Note

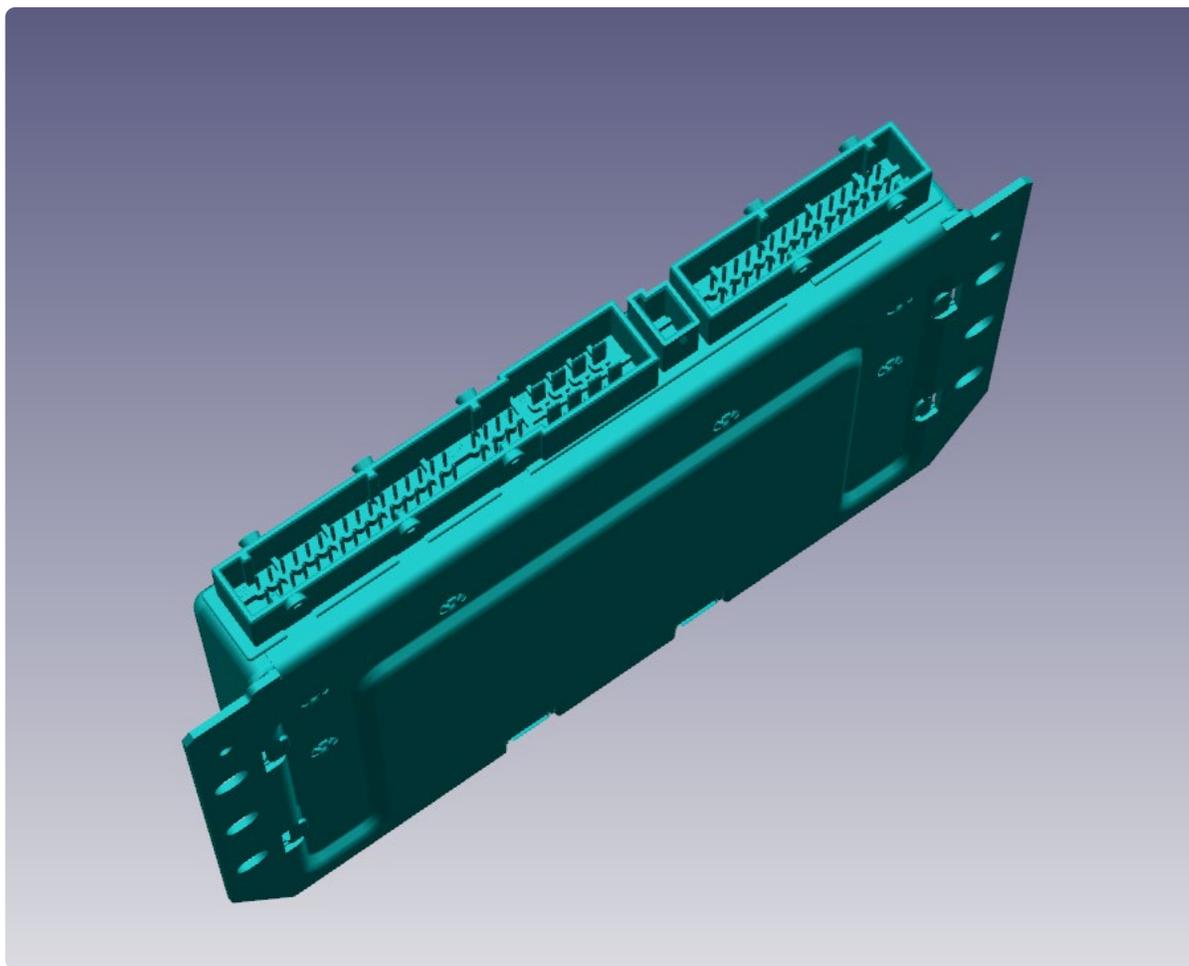
Vehicles built before Oct 30th 2013 have a fill valve in the air line from the Valve Block to the Reservoir, vehicles built after Oct 30th 2013 has the fill valve integrated into the tank wall (as above illustration)

Air Supply Pipes



Polyamide Tubing (PA12) forms the pipe work to distribute Air Pressure from/to the Suspension components. These are secured to the said components using VOSS type connections.

Air Suspension ECU



Air Suspension Electronic Control Unit (ECU)

The ECU is located inside the vehicle below the instrument panel, forward of the center console. (see Service Manual for removal guides)

This ECU controls the height of the vehicle by managing the air pressure inside the suspension system, using the Compressor and Valve Body. It calculates the height of each axle separately by averaging the height signals it receives from the height sensors located on each corner of the vehicle, located on the Suspension assembly. Using the touchscreen, the driver can manually choose between four different vehicle height levels. When the vehicle is being driven, height levels can also change automatically, depending on the vehicle's speed/user settings. When the vehicle

is parked, height levels can also change automatically after loading and unloading passengers, once all doors are closed. To prevent headlights from blinding oncoming traffic during height changes, the ECU keeps the rear axle higher than the front axle.

ECU Operation:

The ECU receives the following signals from sensors and other vehicle systems via the CAN network.

ECU Inputs:

- Rail On
- Chassis CAN Signals
- Solenoid Valve Block Pressure Sensor
- Ambient Air Temperature Sensor
- Height Sensors
- Door State
- User Interface - Touchscreen

ECU Outputs:

- Solenoid Valve Block (Suspension Module Valves, Reverse Valves & Environmental Valve)
- Air Compressor (via the Relay)

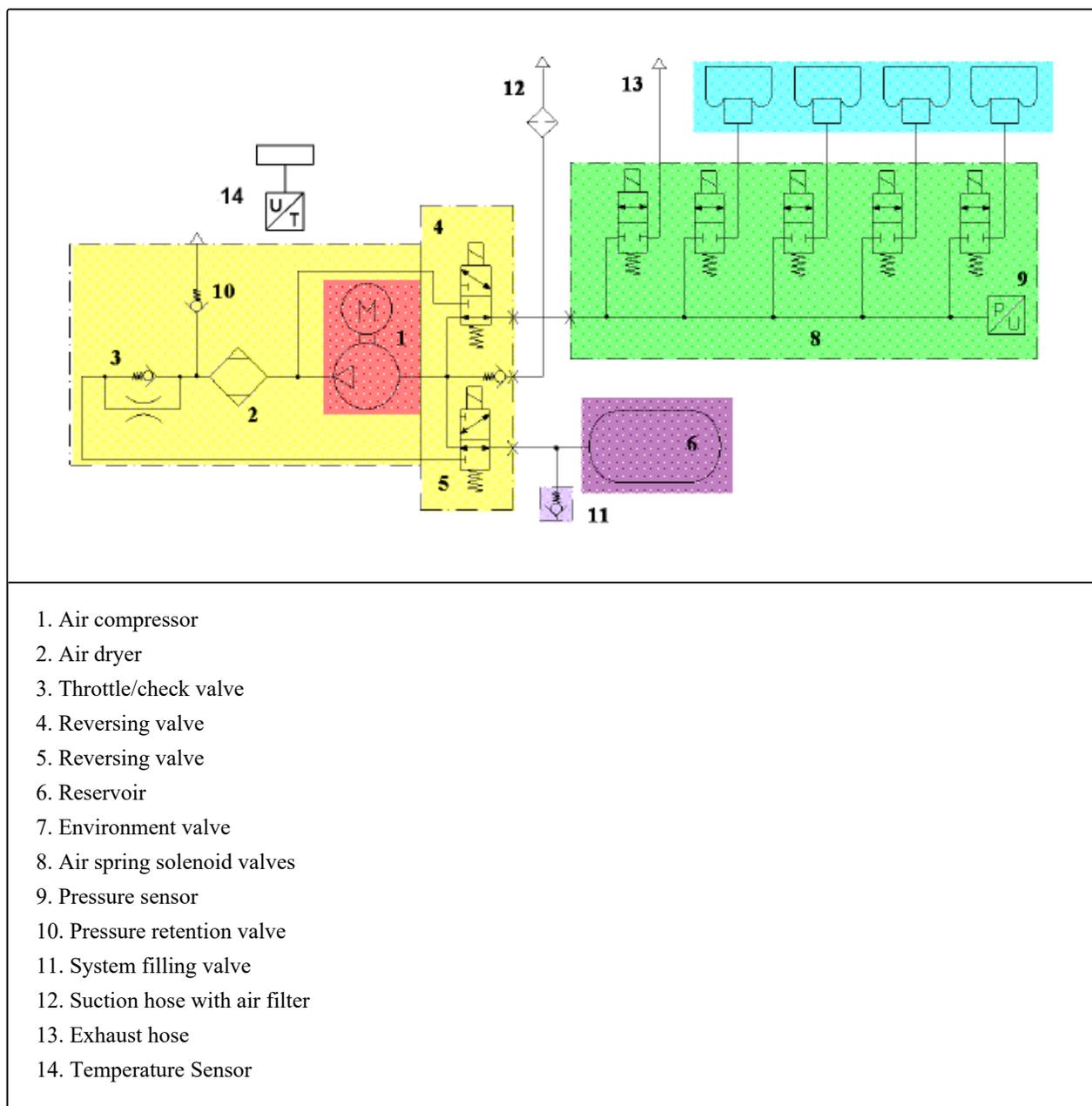
When the ECU deems it necessary to fill the suspension modules or through a user input to raise the height of the vehicle on the touchscreen, the ECU operates the Air Compressor via a Relay located in the Front Fuse/Relay Box. The ECU also energizes the Reversing Solenoid Valves and the Suspension Module Valves in the Solenoid Valve Block to allow compressed air from the Reservoir into the Spring Bellows of the required Suspension Modules.

To deflate the Suspension Modules, the ECU energizes the Reversing Solenoid Valves and Suspension Module Valves in the Solenoid Valve Block, allowing the Air Compressor to pump compressed air from the Spring Bellows of the required Suspension Modules back to the Reservoir.

During maintenance, complete filling and deflating of the Air Suspension System is performed using an External Filling Station and Toolbox (see the Online Manual)

The Air Dryer in the Compressor absorbs the humidity of the intake air and is regenerated when the air is vented from the system. The venting air decompresses in the Dryer by means of a Throttle/Check valve. The Dryer releases stored humidity through the Reversing Solenoid Valves and the Environmental Valve in the Solenoid Valve Block, then through the exhaust hose to atmosphere.

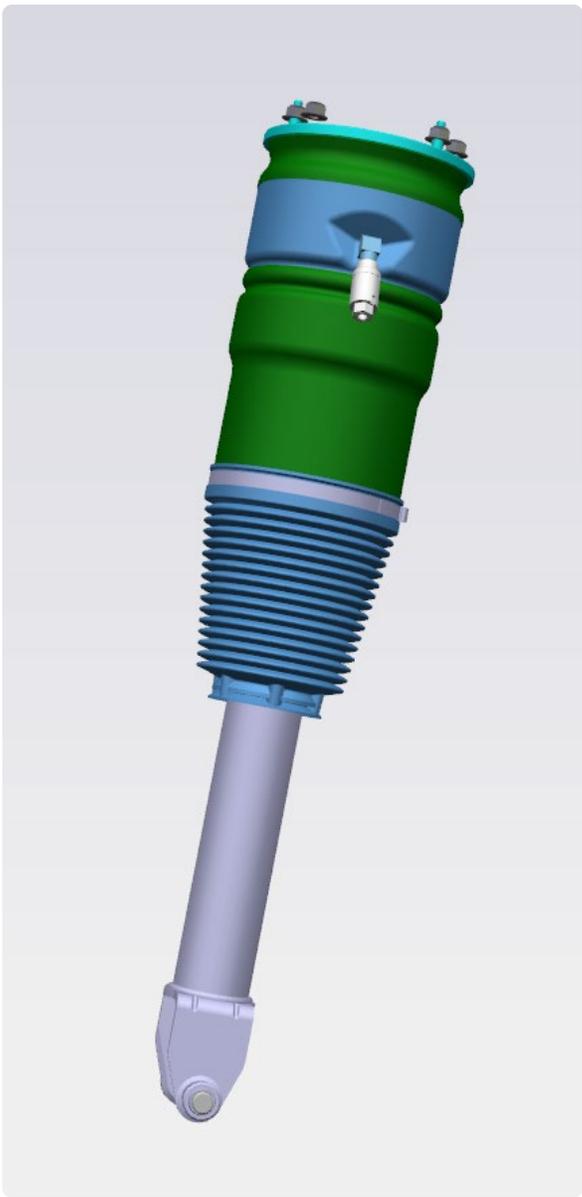
The ECU is also pre-programmed with various user operating modes and additional service/maintenance modes. For Instance when the driver selects a height level from the touchscreen, the requested level is transmitted to the ECU via CAN signals. (see User-Selectable Height Settings)



Suspension Module & Height Sensor

Air Suspension Module (ASM)

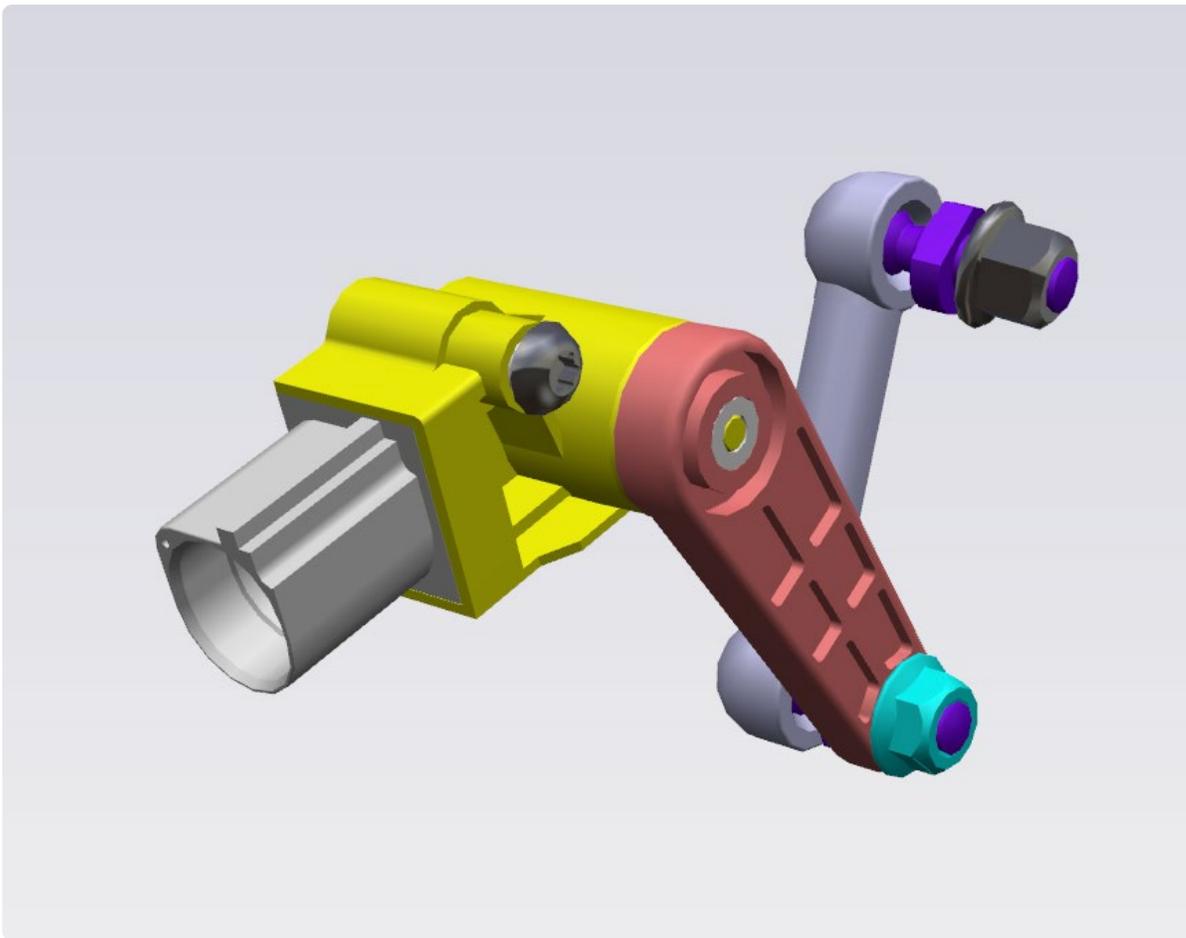




Each suspension module contains a Comfort Air Spring that is inflated with compressed air as deemed required by the system ECU, it also incorporates a Pressure Retaining Valve, Protection Boot and Damper Mount

(Image shown is a Front Suspension Module of a Single Motor Model S, Rear and Dual Motor models are similar in construction)





Ride Height Sensor

The contact-less Hall effect sensors fitted at each corner of the vehicle and are the mechanical to electrical interface to measure/monitor the change in vehicle level. They are supplied with 5 volts DC and send a Pulse Width Modulation (PWM) output signal to the ECU

Instrument Cluster Indicator Lights

Depending on the severity of a fault, either a yellow or red indicator light displays in the instrument cluster to inform the driver of a fault. A yellow indicator light indicates a temporary fault, or one that does not require immediate servicing of the vehicle. A red indicator light indicates that the fault that needs immediate attention. When a fault occurs, the vehicle enters a limp home mode. See System Faults for more information.

Driver Operation - Level Selecting

The air spring operates in conjunction with the solenoid valves to maintain system pressure and vehicle stability.

The driver can select from four height levels using the touchscreen. Click on the ****Controls > Suspension > ****

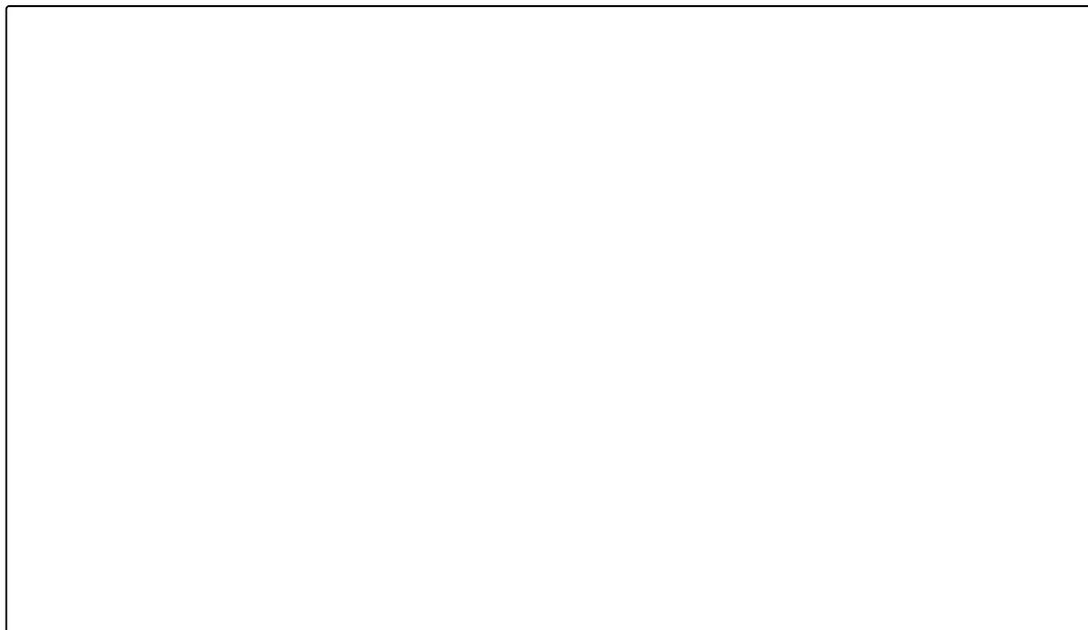
This request will not be accepted in the following conditions:

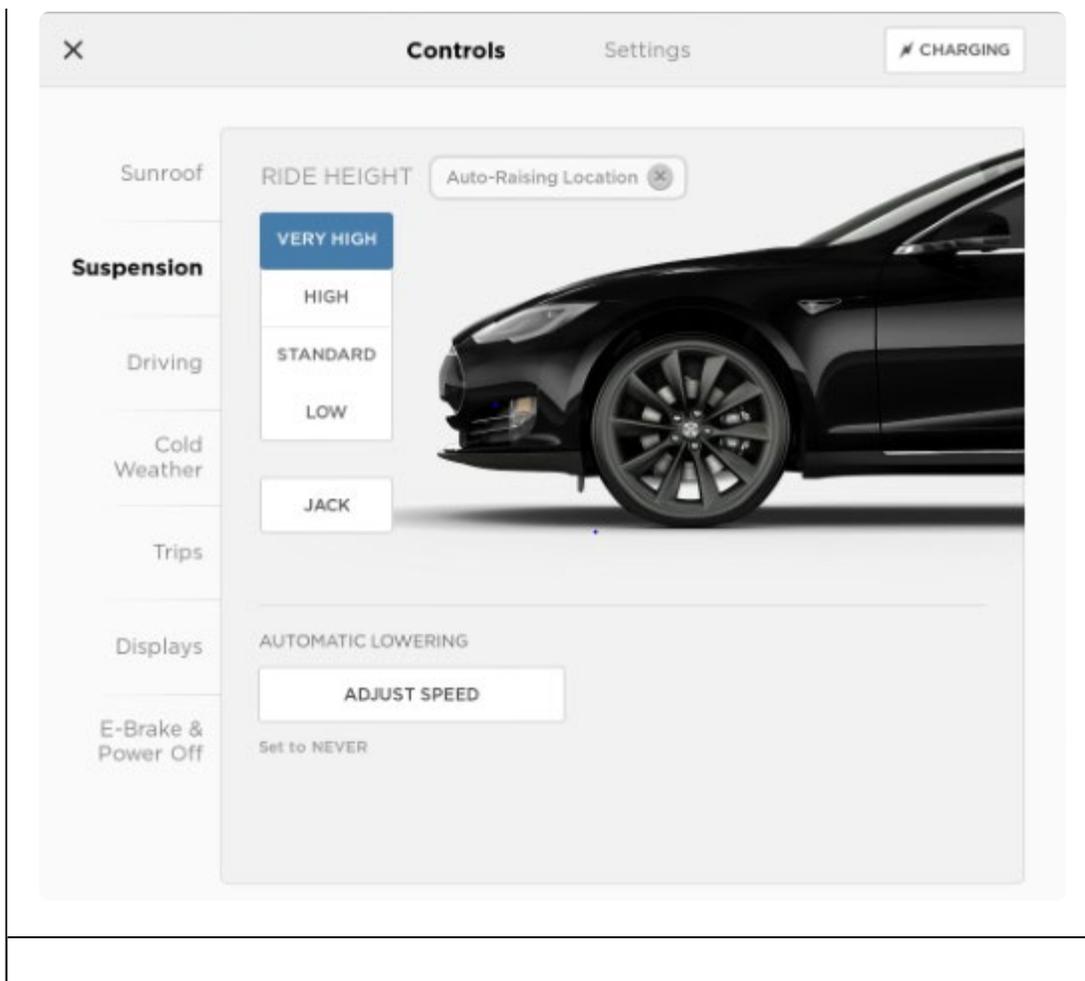
- Vehicle Speed higher than allowed height
- Jack Mode Active
- Yellow or Red Fault Lamp illuminated in Instrument Cluster
- Service Mode Active
- One or more Vehicle Doors are open (Level Down Only)
- Drive is not ready or Signal Invalid
- VBatt low

This will also activate an Instrument Cluster message of "Leveling Not Possible" or Leveling Not Allowed" dependent on the condition

Very High

- Can only be selected at speeds below 22 mph (35 km/h).
- Sets suspension at 1.3 inches (33 mm) higher than Standard.
- Used to gain extra ground clearance in unusual situations.
- If selected and vehicle speed exceeds 22 mph (35 km/h), the vehicle automatically lowers to High

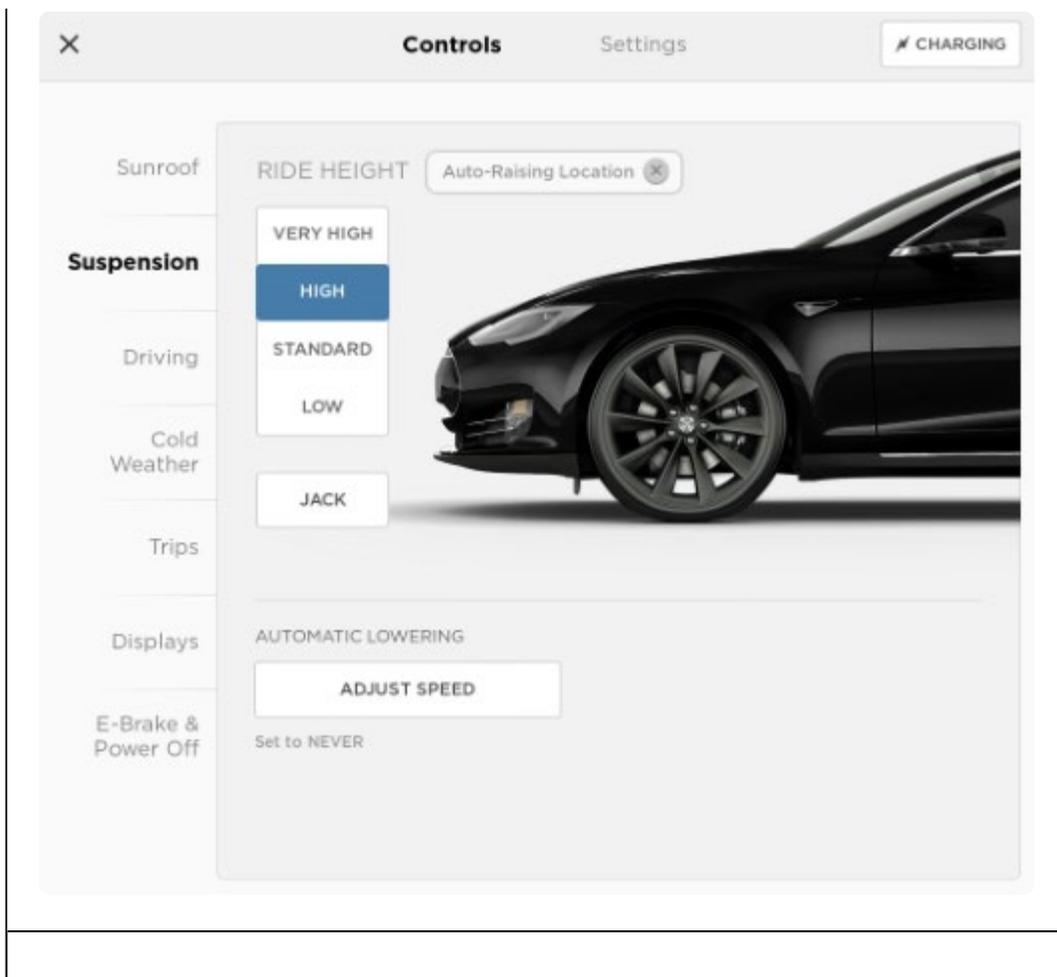




High

- Can only be selected at speeds below 34 mph (55 km/h).
- Sets suspension 1 inch (23 mm) higher than Standard.
- Used to gain extra ground clearance in parking lots, parking garage ramps, large speed bumps, etc.
- If selected and vehicle speed exceeds 34 mph (55 km/h), the vehicle automatically lowers to Standard.

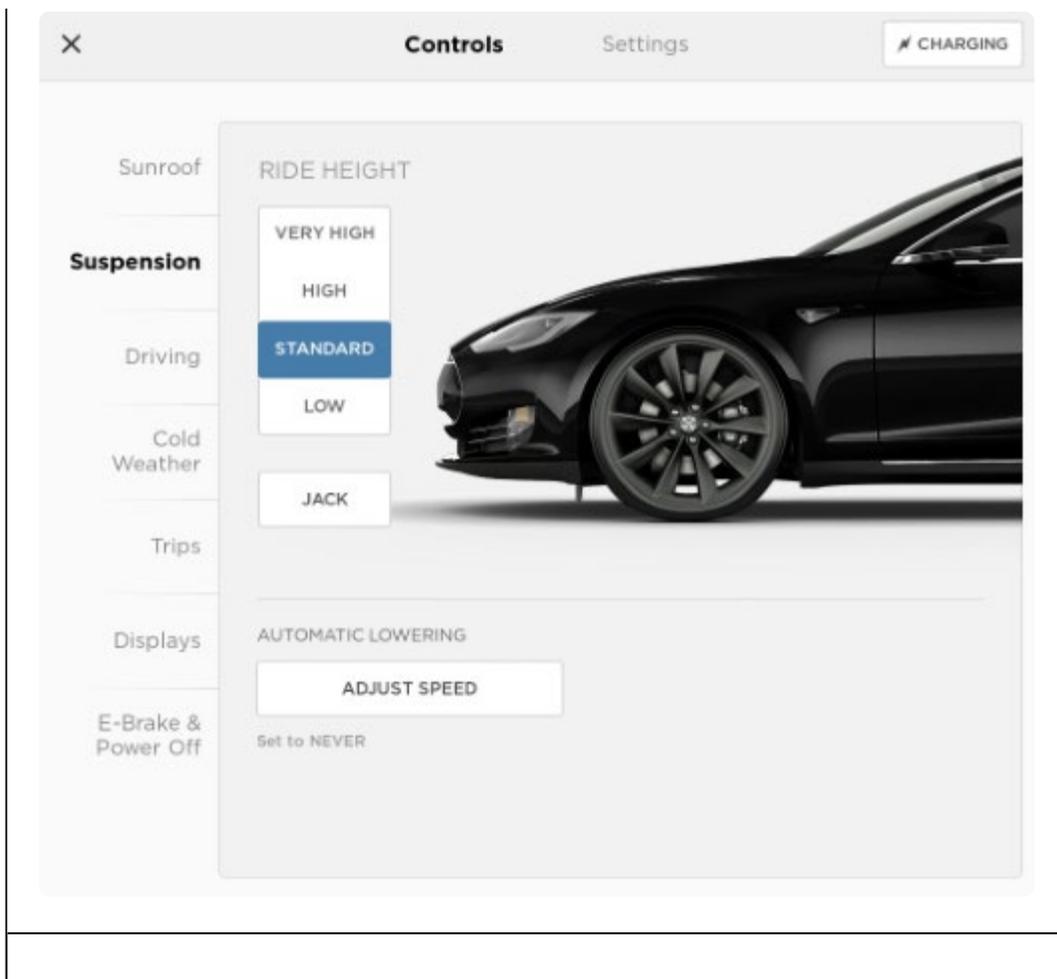




Standard

- The vehicle automatically levels to the Standard ride height, unless Automatic Lowering has been set to "Always Low" to ensure optimum comfort and handling under all loading conditions (extra passengers, heavy luggage, etc.).
- This also ensures that the vehicle has the proper ride height under all loading conditions (the rear of the vehicle does not sag down when heavily loaded).

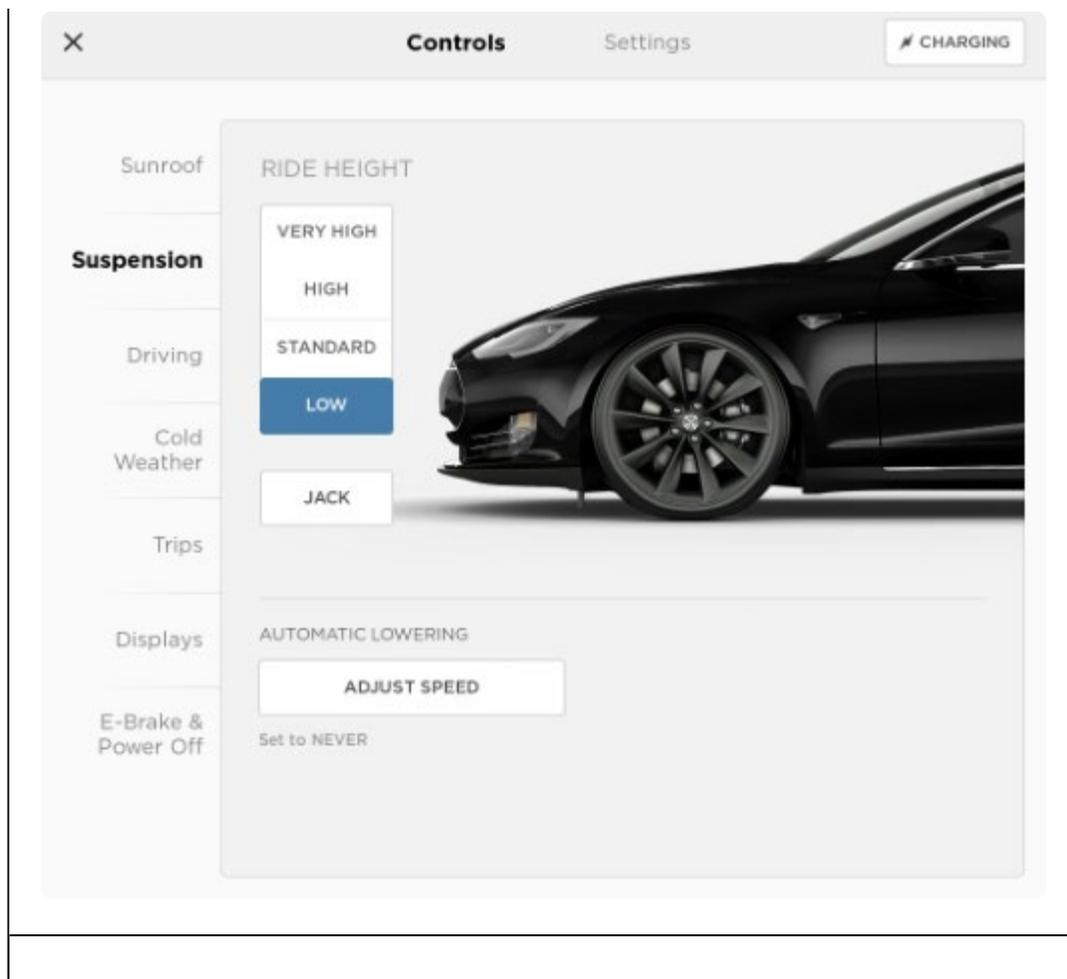




Low

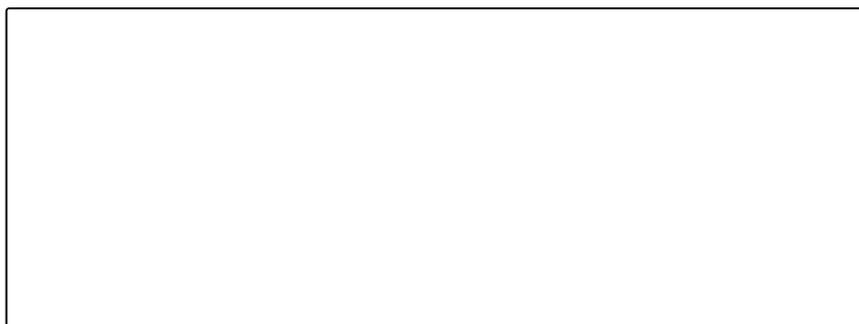
- Automatically lowers the vehicle by 0.75 inch (19 mm)
- Can be selected from the touchscreen when parked, for easier loading/unloading of passengers and cargo.

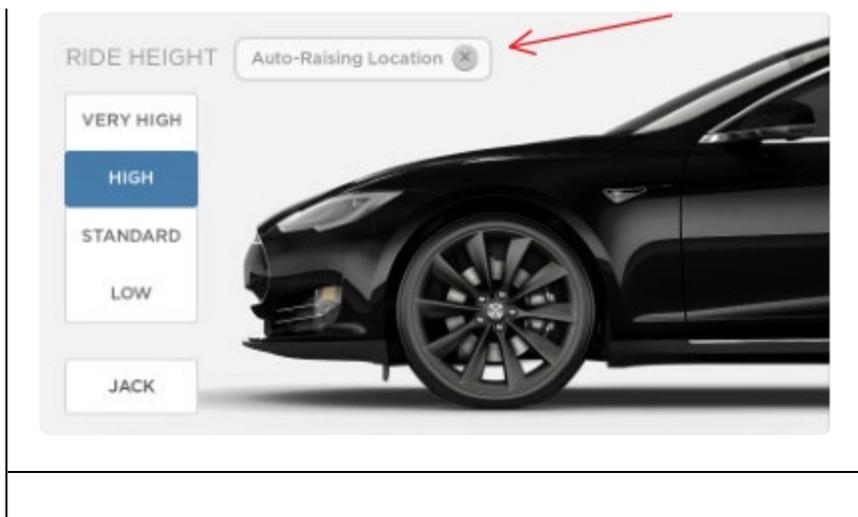




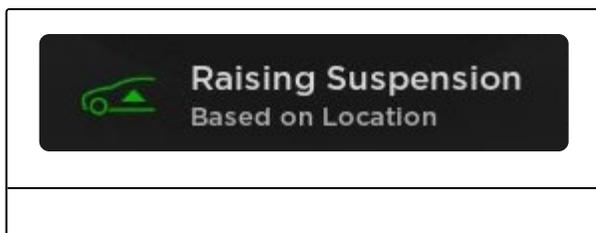
Location-Based Suspension Height

- Location-Based Suspension setting saves the driver from continually adjusting the suspension in the same location, for example a steep driveway or speed bumps.
- Whenever the Suspension has been commanded by user input to High or Very High the Vehicle saves the GPS location
- An icon is present on the display "Auto-Raising Location" (see arrowed below)
- This can be cancelled by clicking the X, this removes the Auto-Raise Location data for that location.





- When returning to the same location the Suspension returns to the pre-selected ride height and the Instrument Cluster Displays "Raising Suspension - Based on Location"
- This only takes affect if Vehicle speed is below the threshold speed of that Suspension height



Automatic Lowering Speed

Adjusting Suspension to be set to transition to Low at pre-selected speeds. Click **Controls > Suspension > Automatic Lowering**.

Note

- This can also be saved to a Drivers Profiles
- Can only be selected with Vehicle is Stationary and in Park



X Automatic Lowering Speed

Select a speed at which the ride height will automatically transition to LOW. Vehicle will remain LOW above this speed.

ALWAYS **NEVER**

ALWAYS will maintain LOW at all speeds.
NEVER will disable automatic transition to LOW.

X Automatic Lowering Speed

Select a speed at which the ride height will automatically transition to LOW. Vehicle will remain LOW above this speed.

ALWAYS NEVER

ALWAYS will maintain LOW at all speeds.
NEVER will disable automatic transition to LOW.

X Automatic Lowering Speed

Select a speed at which the ride height will automatically transition to LOW. Vehicle will remain LOW above this speed.

ALWAYS **75+ mph** NEVER

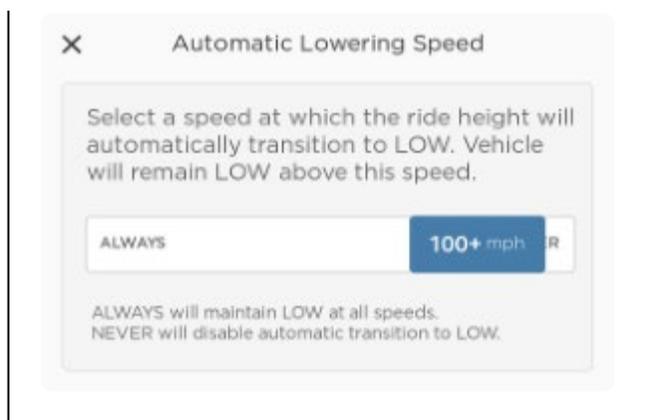
ALWAYS will maintain LOW at all speeds.
NEVER will disable automatic transition to LOW.

X Automatic Lowering Speed

Select a speed at which the ride height will automatically transition to LOW. Vehicle will remain LOW above this speed.

50+ mph NEVER

ALWAYS will maintain LOW at all speeds.
NEVER will disable automatic transition to LOW.

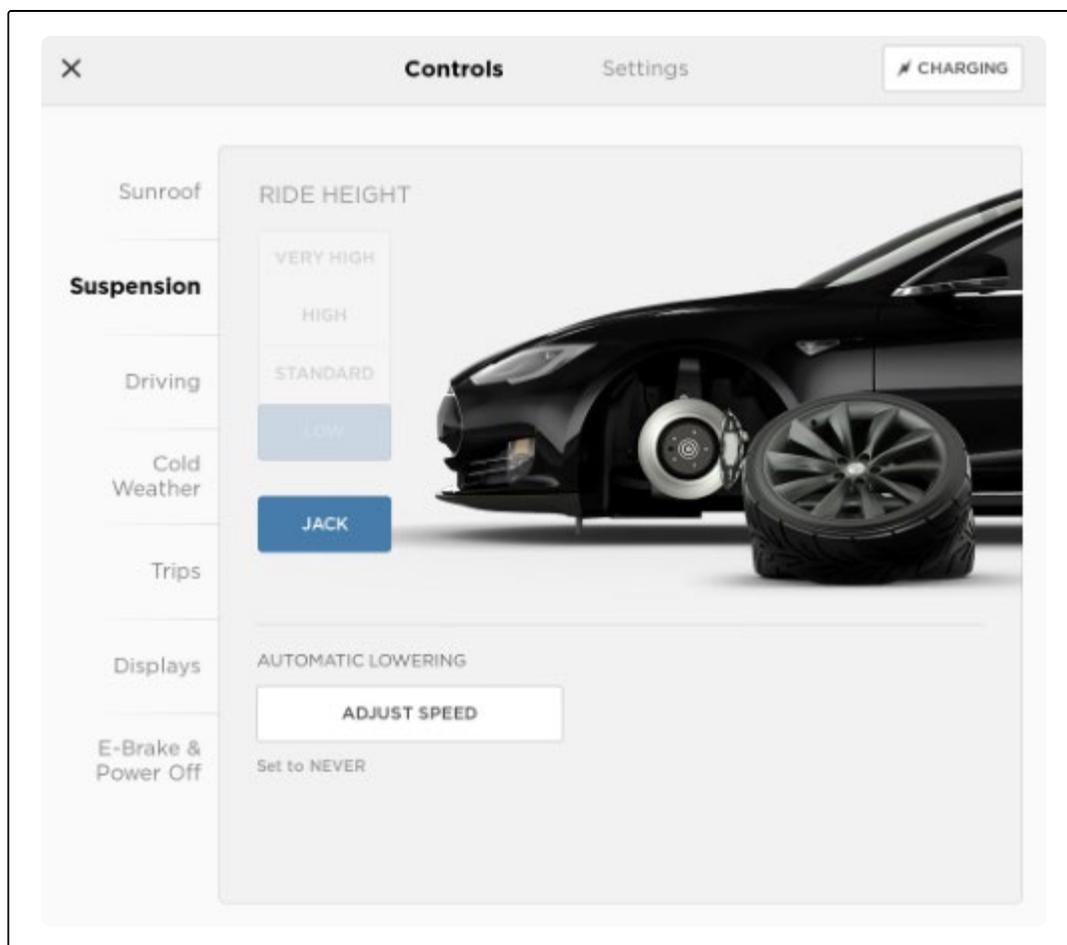


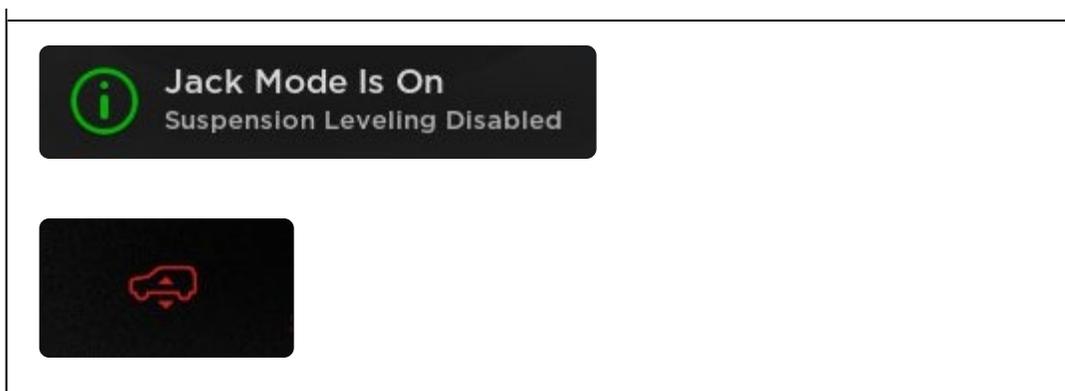
Jack Mode

Before jacking the vehicle to change a wheel or lifting the vehicle on a hoist, jack mode must be selected on the touchscreen. Click **Controls > Suspension > Jack**

Note

Selecting jack mode can only be done when the vehicle is stationary and in Park





- Jack mode also illuminates the RED Air Suspension Warning Lamp and an icon in the lower part in the Instrument Panel
- Jack mode turns the Electronic Air Suspension system off, which allows the user to safely jack up the vehicle without the vehicle trying to adjust its height.
- Once the jacking procedure is complete, Jack mode can be switched off using the touchscreen.
- The vehicle automatically exits Jack mode when driven above 4 mph (7 km/h)

Note

Jack Mode is also activated automatically if the ECU detects that the vehicle is unable to lower to its target/selected height or that it is being supported

Operating Modes

Standstill

- Stationary Drive Rail ON every control action to maintain level is allowed with all doors CLOSED, with any OPEN doors, only up-levelling is allowed.

Drive

- Control actions enabled to maintain selected level unless restricted by cornering (prevents unnecessary levelling actions)

Post-Run

- This mode occurs when the Drive Rails are switched to OFF after a Drive Cycle but the Level Control Map in the ECU is still active for a short time

- Vehicle re-levelling is allowed to counter Passengers/Loads if removed or the effects of temperature
- The ECU commands the Air Compressor Assembly to operate according to the inputs received.
- Only levelling up is allowed if any of the Vehicle Doors are detected open via CAN Signals (or faults of this circuit cannot verify Door Status)

Sleep & Wake Up

- Sleep mode duration time is determined by parameters set from firmware in the ECU, up to 9 hours.
- During sleep mode, a timer wakes the ECU up to three times, to command the Air Compressor Assembly to enable any height adjustments. These height adjustment periods are known as a wake-up mode.
- As the vehicle cools (or heats up) after driving, the pressure in the Suspension Modules can fluctuate slightly, resulting in the vehicle not being level.
- The wake-up mode ensures that the vehicle is levelled after the vehicle temperature has stabilized and before it is driven again.
- After 9 hours the mode changes to Off Mode

Off Mode

- The system enters the off mode after the vehicle has been in sleep mode for more than 9 hours
- Level control is completely deactivated.
- ECU has a low energy consumption

Deactivation of Level Control

- Level Control will be deactivated or terminated in the following conditions
- Limp Home
- Slope Detection
- Curve Detection
- Lift Platform
- Open Door Detected (lowering control)
- VBatt Low
- Service Mode Activated

Slope and Curve Detection

- Lateral and Longitudinal Accelerations are monitored during Standstill and Drive
- These are used to calculate Slope and Curve Detection
- When Signal via CAN exceeds the threshold set in the ECU the Level Control will be interrupted and Self-Leveling will be prohibited
- Dependent on the Set Level and Vehicle Speed dictates ECU threshold
- Level Control allowed when these values are within the thresholds/parameters
- Vehicle Speed and Steering Angle are used for additional Curve detection algorithm
- Using these signal from CAN it can calculate Lateral Acceleration
- If one or both of these signals are invalid this detection is disabled

Serviceability

Service mode functions are all performed using Toolbox. Only perform service mode functions on a stationary vehicle. If the vehicle speed is above 20 mph (30 km/h), the system automatically exits service mode.

The disassembly of pressurized parts (reservoir, compressor, and air spring damper) requires deflation of the system components using Toolbox, BEFORE parts are removed

The ECU supports the following service mode functions:

- Selecting Level using Toolbox/Touch Screen
- System filling (see Service Manual)
- Height sensor calibration
- Deflating Suspension Module into reservoir
- Deflating components to atmosphere
- Actuator test by selecting height levels
- Measure pressure in individual component
- Measure pressure in all components
- Finish Service

Selecting Level using Toolbox/Touch Screen

The ECU performs the required Height Level depending on selection using Toolbox/Touch Screen

Warning

Door latch signal are ignored in this mode so the Vehicle will lower if requested by Toolbox/Touch Screen even if the door is open.

Height Sensor Calibration

Calibration of the vehicle height must be performed at Standard Ride Height on a Wheel Alignment Lift (See Online Manual)

Perform a Ride Height Calibration when any of the following is relevant:

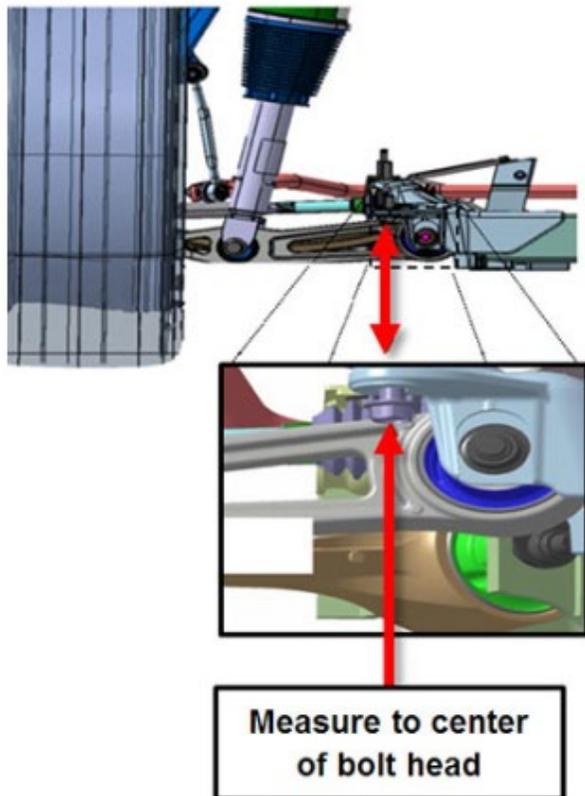
- Removing or Replacing Height Sensors
- Changing TAS ECU
- Performing repairs on any of the Suspension System
- Wheel Alignment

If equipped with Autopilot the Front Radar Sensor will also need calibration AFTER Ride Height Calibration

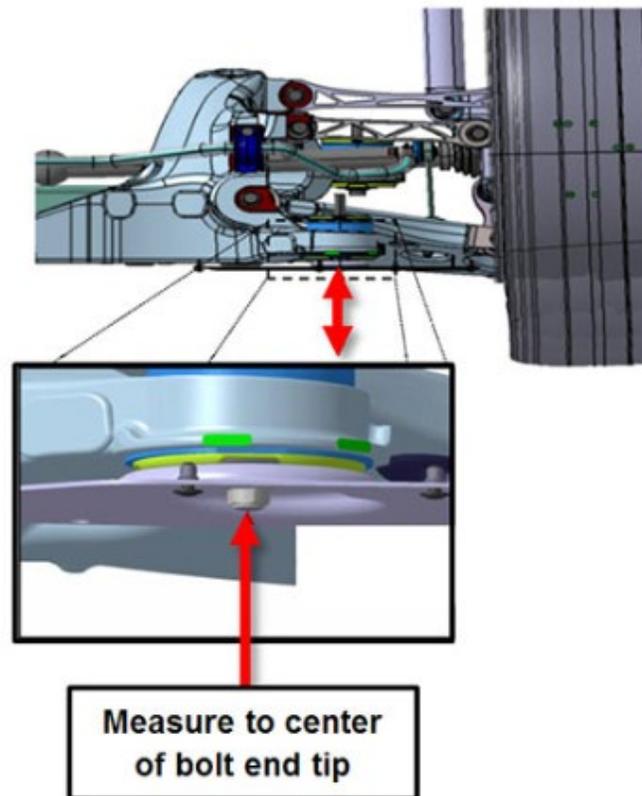
When re-calibrating the following is also required:

- Wheel Type Configuration
- Correct Tyre Pressures
- No additional weights in the vehicle (People or Loads)
- During the calibration process using Toolbox, a correction value for the four sensors is calculated and stored permanently in the ECU's EEPROM (Electrically Erasable Programmable Read Only Memory)
- Reference height values that represent the actual height for the front and rear axles are stored in the ECU.
- The vehicle's height level is measured between the ground and the bottom of the chassis at pre-selected points
- Check Online Manual for up to date Specification

Front Suspension
Rearmost subframe bolt
Rear view, left side



Rear Suspension
Front subframe bolt
Front view, left side



Service Filling

- See Service Manual for up to date information

Deflating Suspension Module into Reservoir

- Precondition: The vehicle must be on a 2 post lifting platform.
- Commanded via Toolbox the ECU deflates a single Suspension Module or an Axle into the Reservoir.
- A single Suspension Module or an Axle can be selected to deflated for a fixed short time or a predefined pressure

Deflating Components to Atmosphere

- Precondition: The vehicle must be on a 2 post lifting platform.
- Commanded via Toolbox the ECU can deflate a single Suspension Module, Axle or Reservoir into the atmosphere

- The selected component can be selected to deflate for a Fixed Short Time or a Predefined Pressure.
- If Deflating Reservoir into Ambient for a Fixed Short Time is selected, reverse valves 1 and 2 are switched on. This causes a slow deflation for the benefit regeneration of the air dryer.
- If Deflating Reservoir into Ambient to a Predefined Pressure is selected, reverse valves 1 and 2 are switched on for the first deflating step. This causes a slow deflation for the benefit of regeneration of the air dryer. This is followed by deflating steps with only reverse valve 1 switched on. This causes a fast deflation without regeneration of the air dryer.

Actuator Test by Selecting Set Levels

- The main hose is filled up for a short time by opening the reservoir. The pressure is then measured and stored.
- The environment valve is opened for a specified time to deflate the main hose. After deflating, the pressure in the main hose is measured again and the pressure difference is evaluated.

Measure Pressure in Individual Component

- With the vehicle on the ground, the system performs a pressure check on the selected component.

Measure Pressure in All Components

- With the vehicle on the ground, the system performs a pressure check on all components in sequence

Finish Service

- When the finish service function is selected, the service mode exits and the ECU switches to normal mode.

System Fault States/Modes

System Faults

Faults in the air suspension system do not result in restriction of steering angle, nor contact between the tire and the vehicle body in any driving conditions. However, vehicle dynamics could be severely affected. Depending on the type of fault, a warning is sent to the instrument cluster via CAN signal.

There are three limp home modes, depending on the level of system fault. Mode 1 is the lowest priority and mode 3 is highest priority. A limp home mode with a high priority replaces a limp home mode with a lower priority.

Limp Home Mode 1

- Height increases are disabled.
- Only height decreases (via axle leveling) are possible until Standard Level is reached.

- Height decreases are possible only when vehicle speed exceeds 10 mph.
- Height decreases are achieved using the environment valve.
- Level changes using the touchscreen are disabled.

Limp Home Mode 2

- Level control is disabled.
- Level changes using the touchscreen are disabled.
- The air mass in the reservoir can be measured.

Limp Home Mode 3

- Level control actuators are switched off.
- The air mass in the reservoir cannot be measured.

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