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Outline

The Driver's Control Center Differential system is system that appropriately controls the differential limiting force of center differential LSD depending on running conditions of a vehicle. The new DCCD system evolved provides controls that follow operations of the driver, while conventional DCCD system provides those based on conditions of the vehicle.

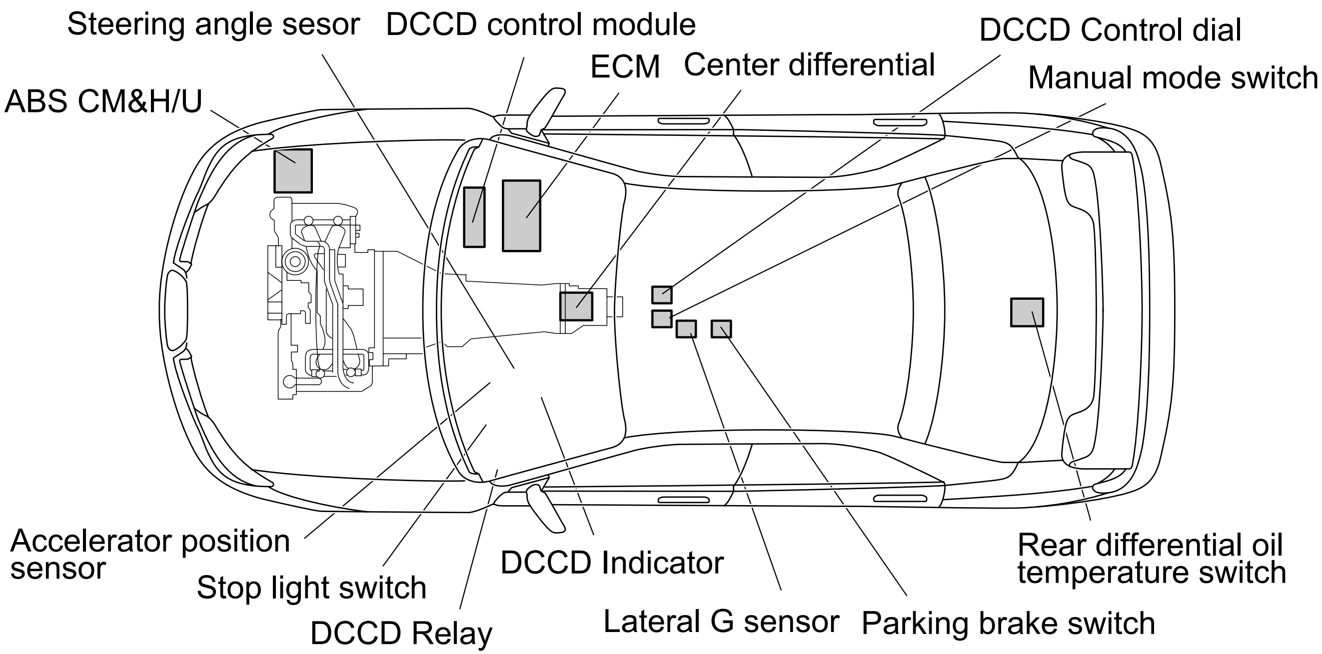
The system consists of a center differential of planetary gear type provided with LSD function, a steering angle sensor, a yaw rate sensor, a lateral G sensor, a DCCD control module and other components.

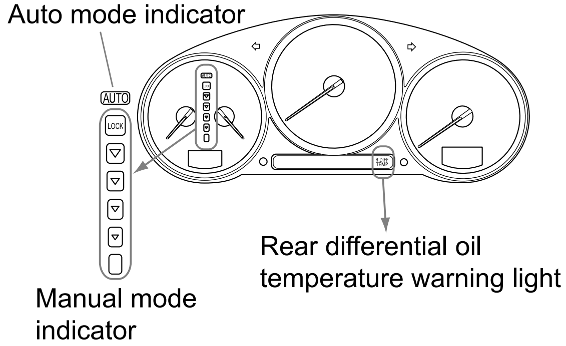
Hybrid LSD mechanism using conventional electromagnetic clutch LSD mechanism added with torque-sensitive mechanical LSD mechanism allows approximate coincidence between the vehicle acceleration/deceleration and LSD clutch differential limiting timings, resulting in linear LSD characteristics acquired through driver's accelerator operation. Thus, the driver can more freely control the vehicle by easily grasping behavior of the vehicle.

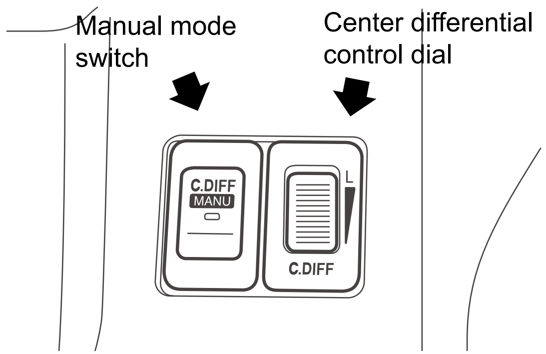
In addition, the steering angle sensor let the DCCD control module know the driver's intension of turning. In combination with the yaw rate and lateral G sensors, it adjusts the electromagnetic clutch LSD differential limiting force based on the running path imaged by the driver and the actual behavior of the vehicle. Thus, cornering in better accordance with the driver's image is enabled, preventing occurrence of understeer and oversteer.

For balancing between the vehicle turning performance and traction during turning in a high order, the center differential driving torque is set to have distribution ratio 41:59.

Parts Location







Manual mode switch/DCCD control dial

In manual mode, the DCCD control can be used to adjust the differential limiting force of the electromagnetic clutch LSD mechanism in the range from free to lock.
Current settings of the control dial are displayed on the indicator in the meter.

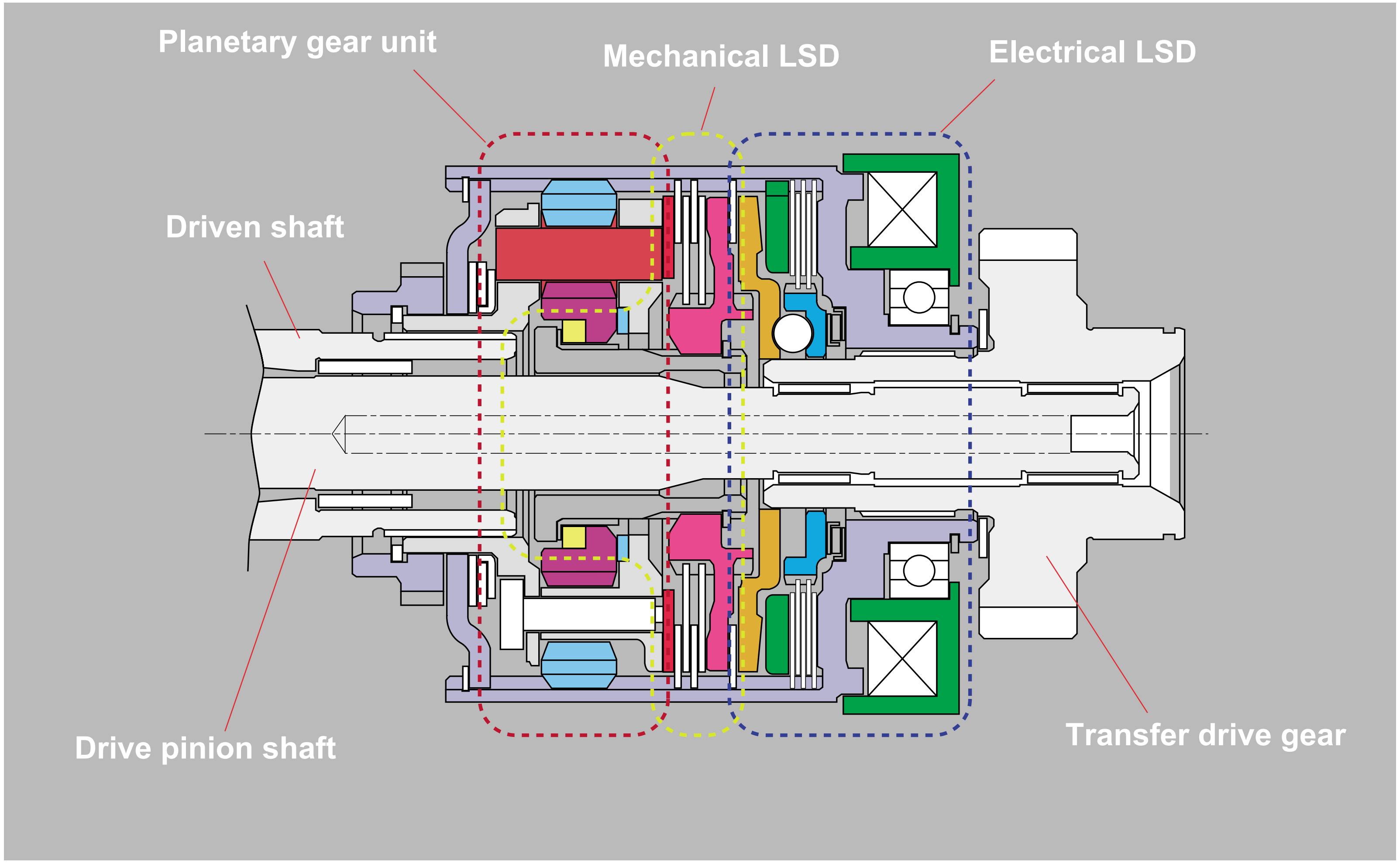
Rear differential oil temperature warning light

When the DCCD system has detected abnormally high temperature of the rear differential oil, it notifies the driver of it through the warning light in the meter and, at the same time, frees the differential limiting force of the electromagnetic clutch LSD mechanism.

Center Differential

The center differential consists of three components: a planetary gear unit differential, a torque-sensitive mechanical LSD mechanism and an electromagnetic clutch LSD mechanism.

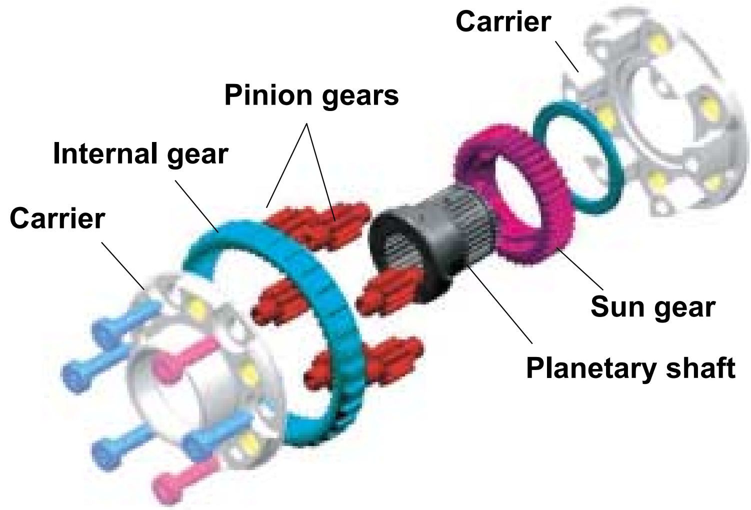
Engine output power input from the transmission driven shaft to the center differential goes through the planetary gear unit and is transmitted to the front wheel side from the drive pinion shaft penetrating through the driven shaft and to the rear wheel side from the transfer drive gear.

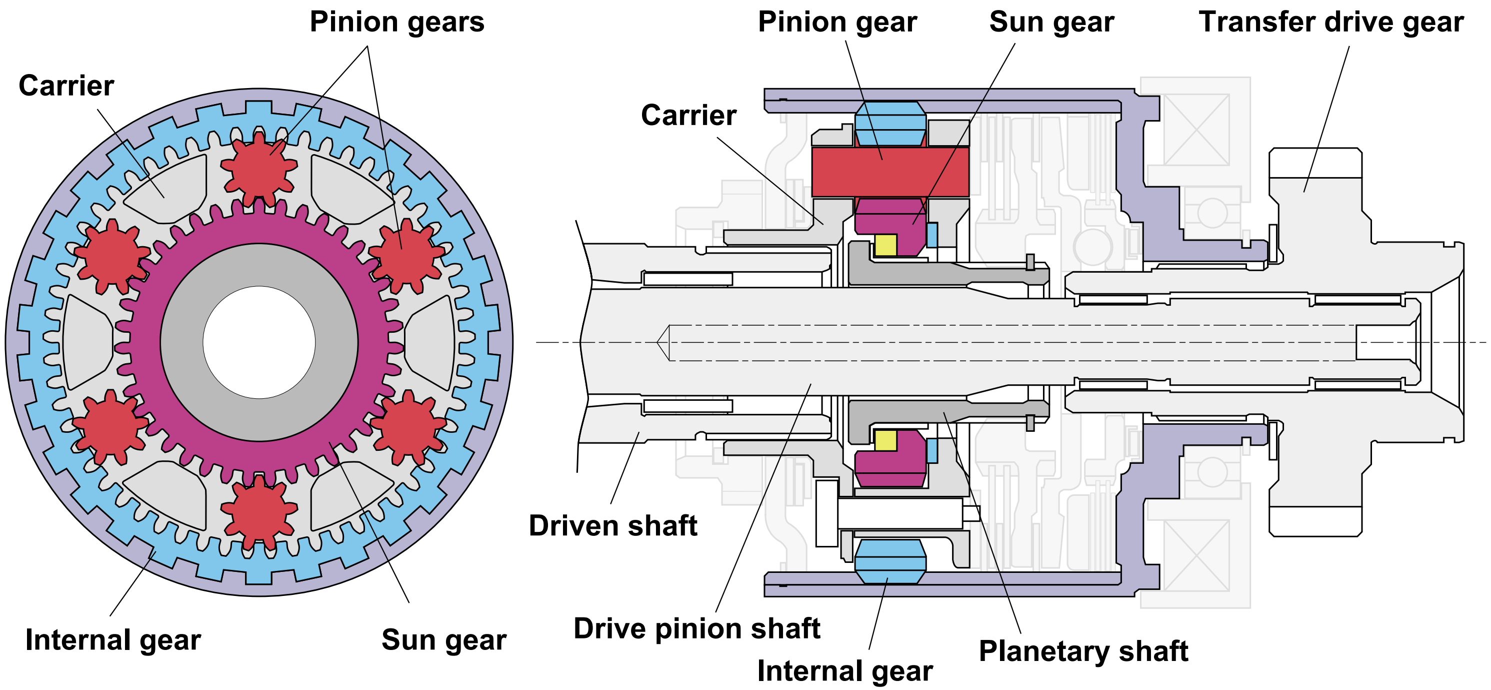


Center Differential Mechanism

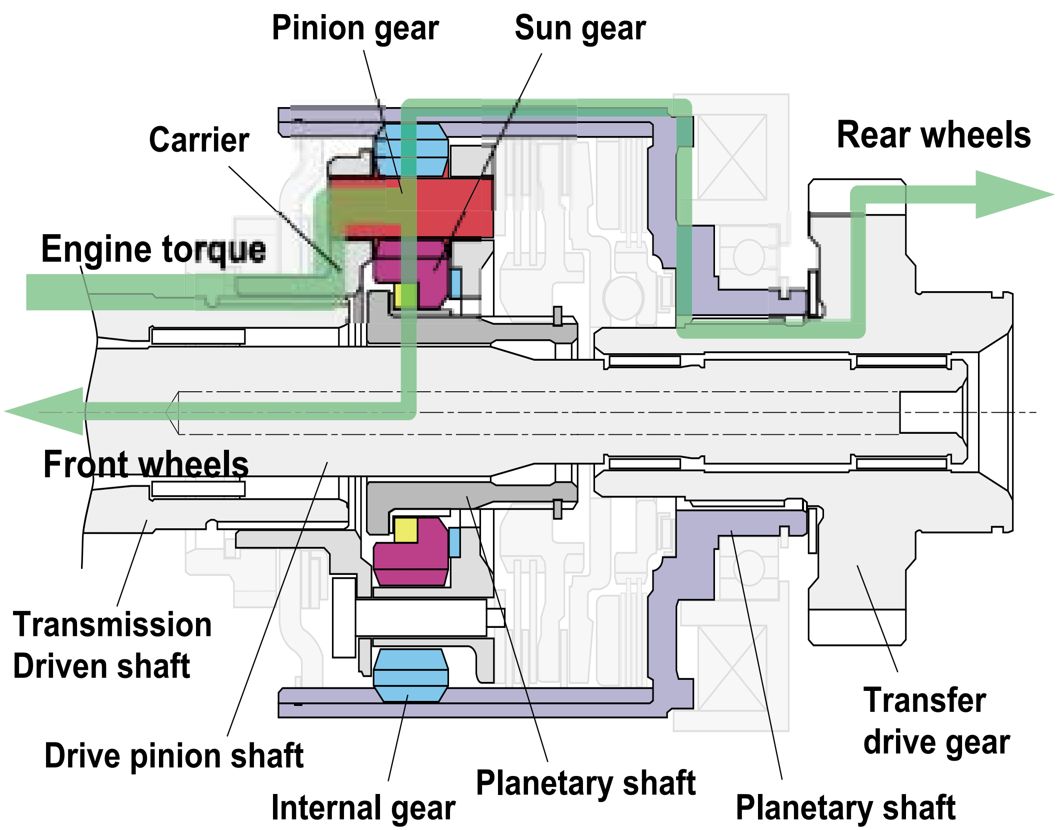
The planetary gear unit differential consists of a carrier containing six pinion gears, an internal gear mounted to inner periphery of the differential case and a sun gear mounted to the planetary shaft outer periphery.

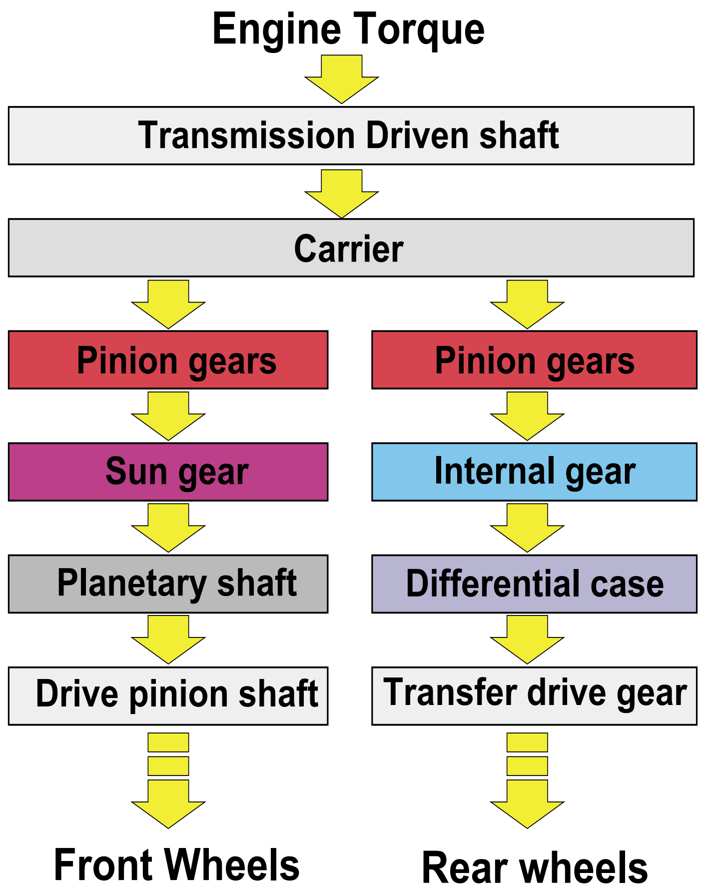
Engine driving force input from the carrier is transmitted to the sun and internal gears engaged with the pinion gears with torque distribution ratio 41:59*. (*Value in the state with no differential limiting carried out by the LSD mechanism)





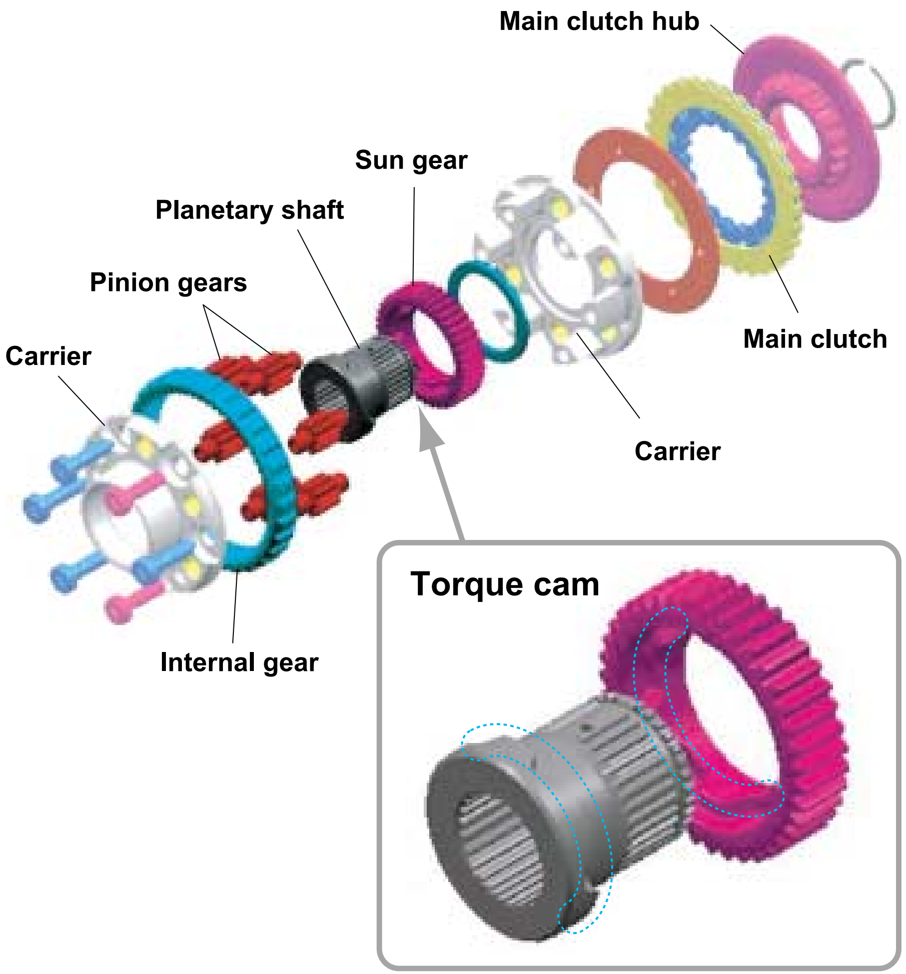
Power flow

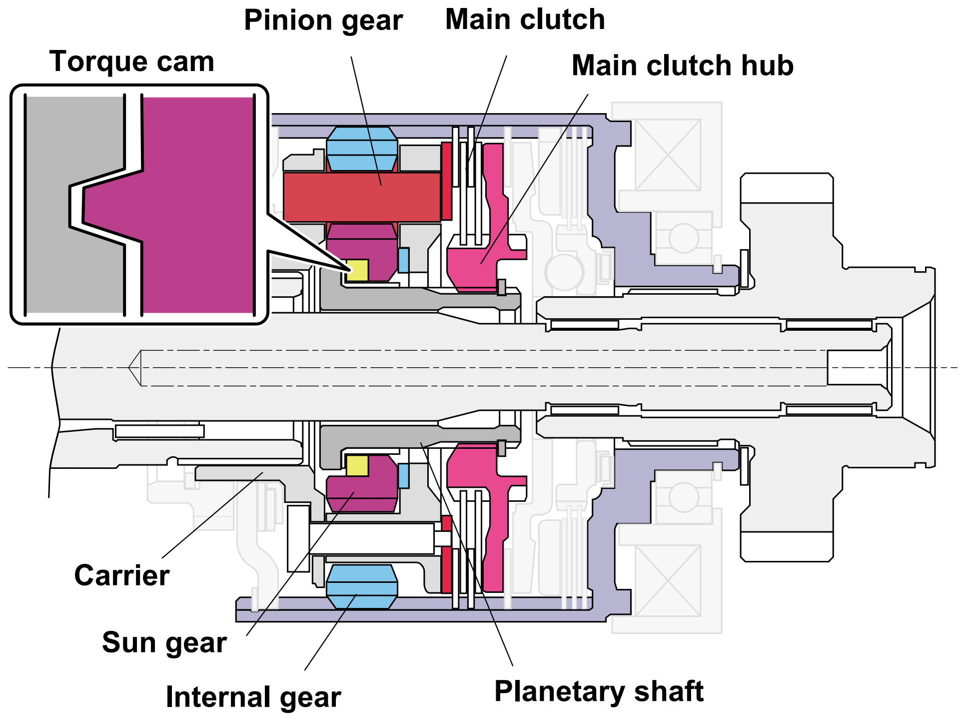

Pinion gear
Sun gear
Carrier
Rear wheels
Engine torque
Front wheels
Transmission Driven shaft
Drive pinion shaft
Internal gear
Planetary shaft
Planetary shaft
Transfer drive gear


Engine Torque
Transmission Driven shaft
Carrier
Pinion gears
Pinion gears
Sun gear
Internal gear
Planetary shaft
Differential case
Drive pinion shaft
Transfer drive gear
Front Wheels
Rear wheels

Mechanical LSD Mechanism

The torque-sensitive mechanical LSD mechanism consists of a torque cam, main clutch and main clutch hub mounted to the sun gear and planetary shaft. The differential limiting function is achieved by restraining free rotation of the planetary gear unit when the main clutch is engaged with the torque cam.





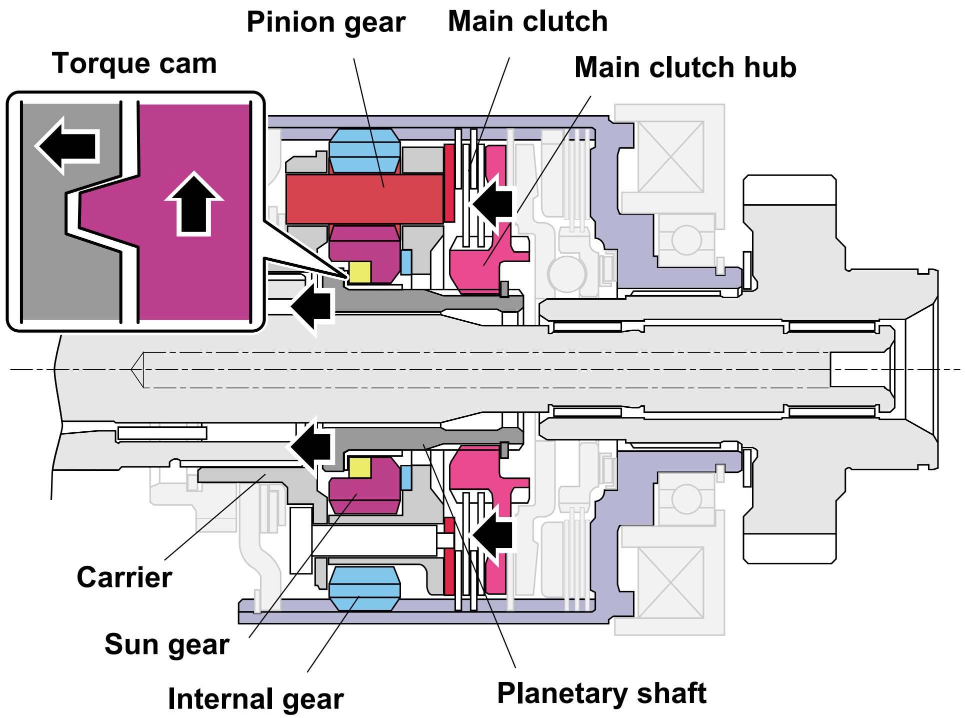
Differential limiting function of torque-sensitive mechanical LSD mechanism

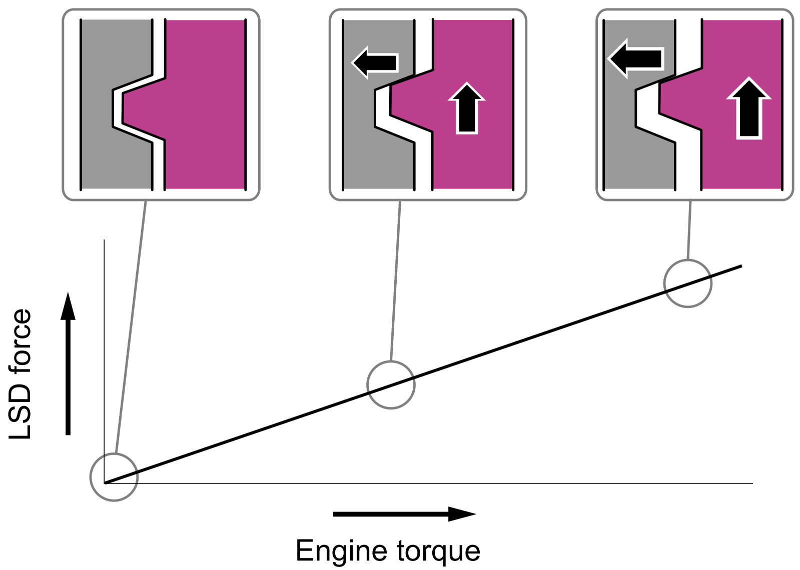
When torque input is to the center differential by acceleration or deceleration, the torque cam transmits the torque from the sun gear to the planetary shaft, generating force that moves the planetary shaft leftward in the figure given below.

This force moves the main clutch hub mounted to the planetary shaft leftward in the figure, causing the main clutch to be engaged.

Because the main clutch outer periphery is connected to rear wheels through the differential case and its inner periphery to front wheels through the main clutch hub and planetary shaft, engagement of the main clutch causes to limit the differential action of the planetary gear unit.

The main clutch engagement force is determined by the leftward force generated by the torque cam; therefore, the differential limiting force generated by the mechanical LSD automatically changes in proportion to the engine driving force (accelerator pedal travel).





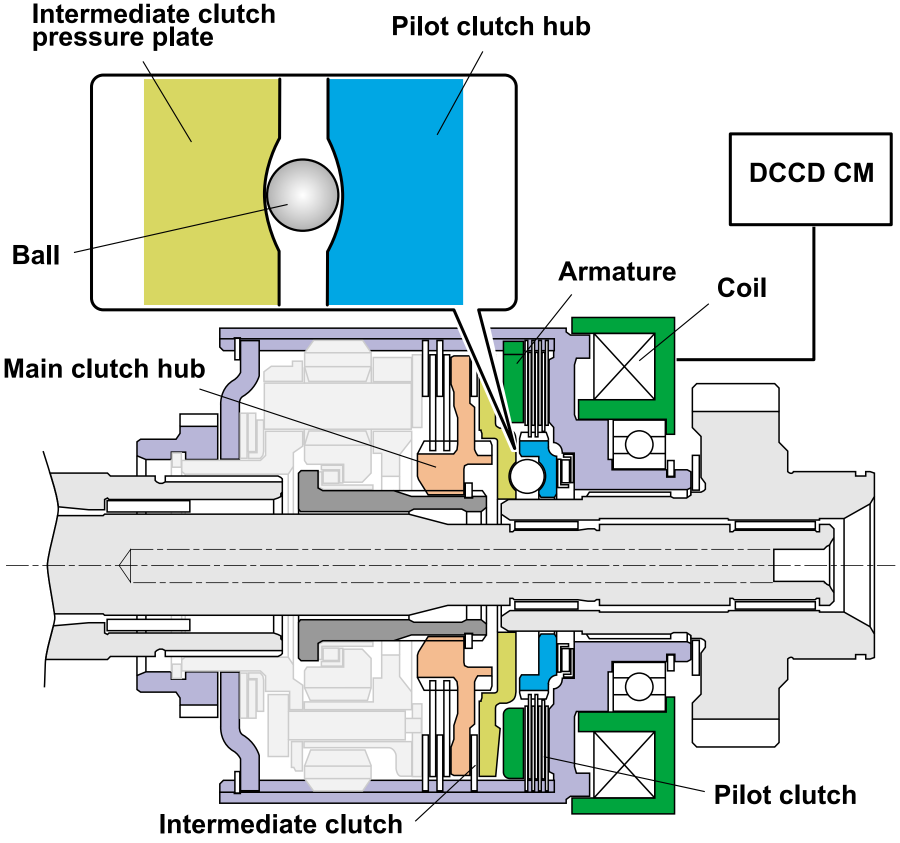
Electromagnet Clutch LSD Mechanism

The electromagnetic clutch LSD mechanism consists of a main clutch, an intermediate clutch, a pilot clutch, an armature, a coil, six balls placed between the pilot clutch hub and intermediate pressure plate and other components.

This LSD mechanism carries out differential limiting by converting braking force of the pilot clutch to main clutch engagement force by the balls and intermediate pressure plate.

When inactive

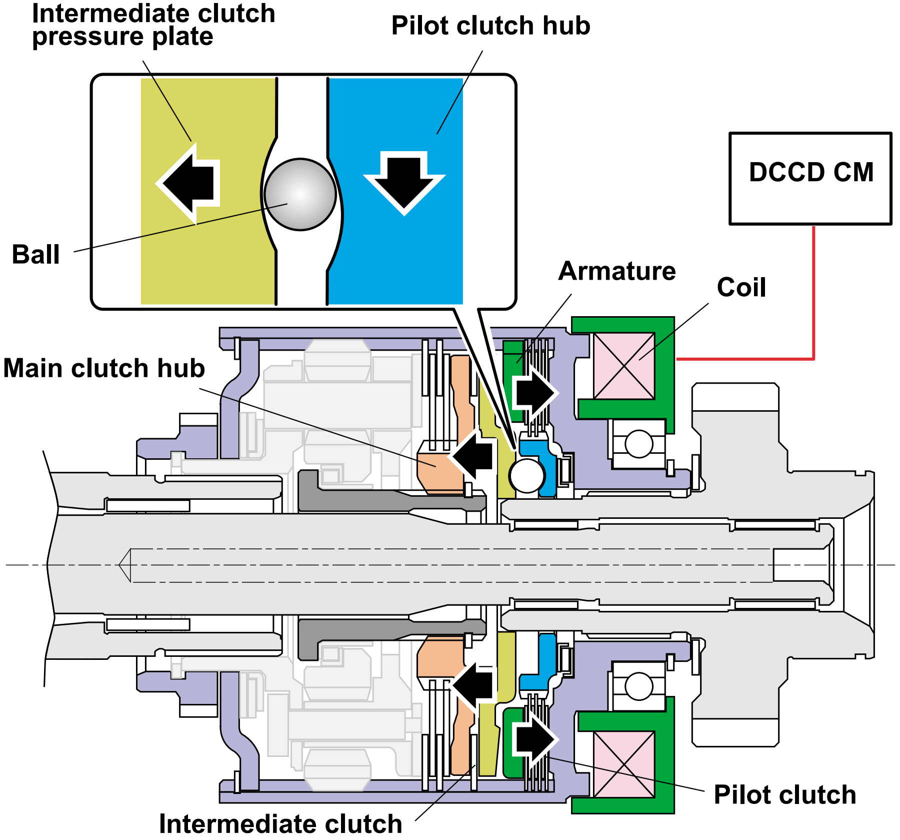
While the coil is deenergized, the pilot clutch is freed, allowing the pilot clutch hub, balls and intermediate pressure plate (connected to the sun gear through the main clutch hub) to turn idle with approximately the same rotational speed as the sun gear. In this state, the electromagnetic clutch LSD makes no differential limiting.



When active

When the coil is energized, its magnetic force attracts the armature to engage the pilot clutch. As the result, the pilot clutch hub is locked onto the differential case. (The pilot clutch engagement force varies by current flowing through the coil.)

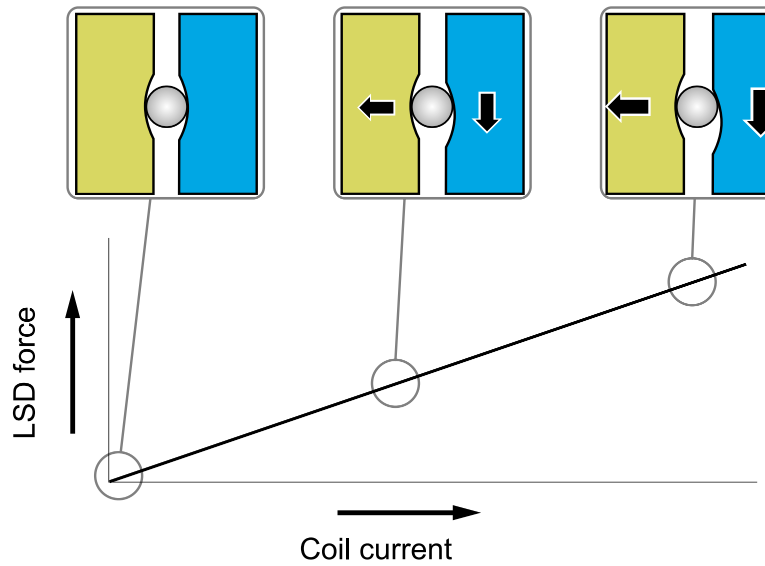
If rotational difference between the sun and internal gears is generated due to a slip in any of tires with the pilot clutch engaged, a phase difference that depends on the pilot clutch engagement force is generated between the intermediate pressure plate connected to the sun gear and the pilot clutch hub (connected to the internal gear through the differential case).



As the result, the balls placed between the intermediate pressure plate and pilot clutch hub are given a force that presses the intermediate pressure plate leftward, causing the intermediate and main clutches to be engaged with each other.

Connection between the intermediate and main clutch limits the differential action between the sun and internal gears.

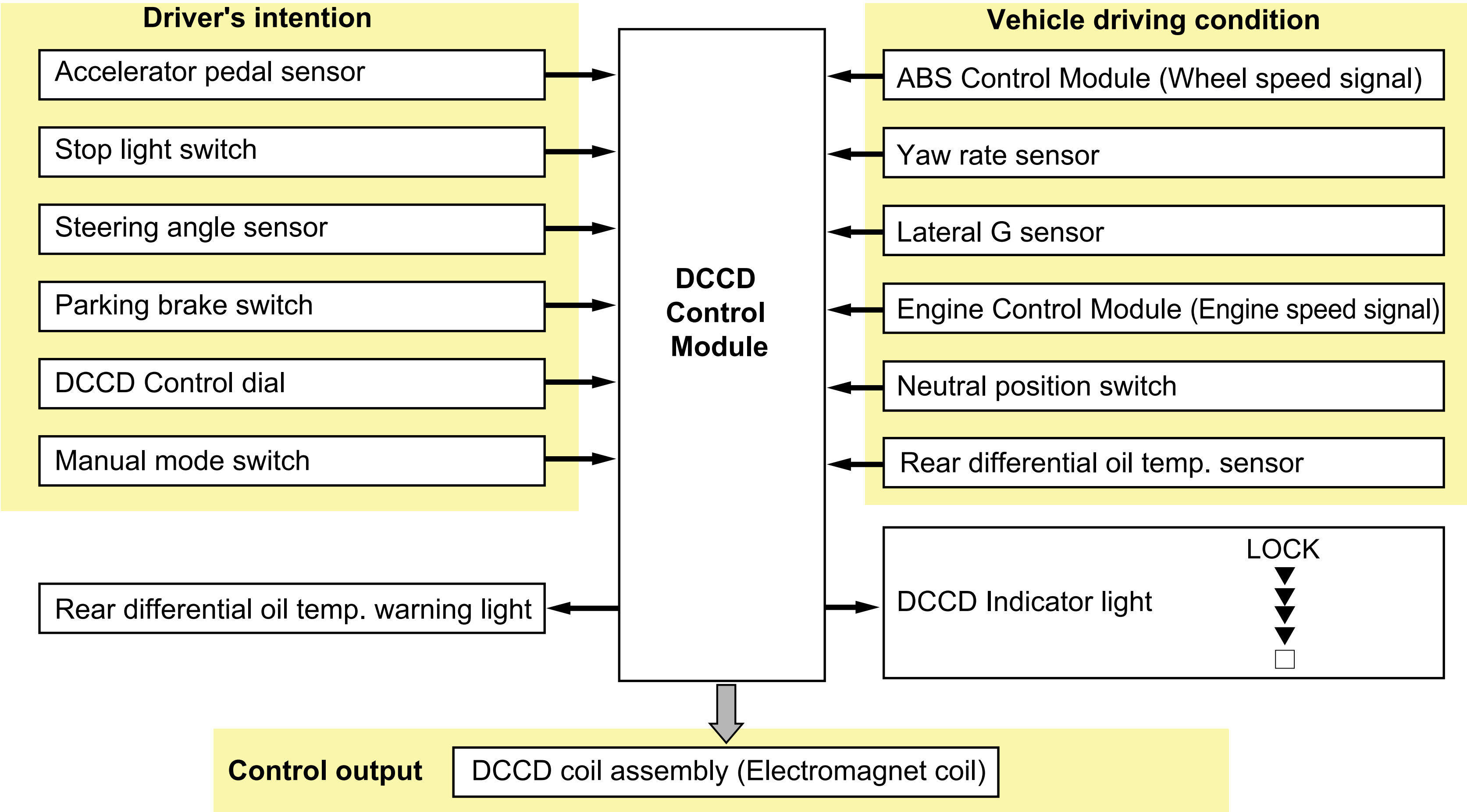
The force given to the balls that presses the intermediate pressure plate leftward is determined by the pilot clutch engagement force. Therefore, the differential limiting force of the electromagnetic clutch LSD can be controlled by adjusting the pilot clutch engagement force with current applied to the coil.



System operation

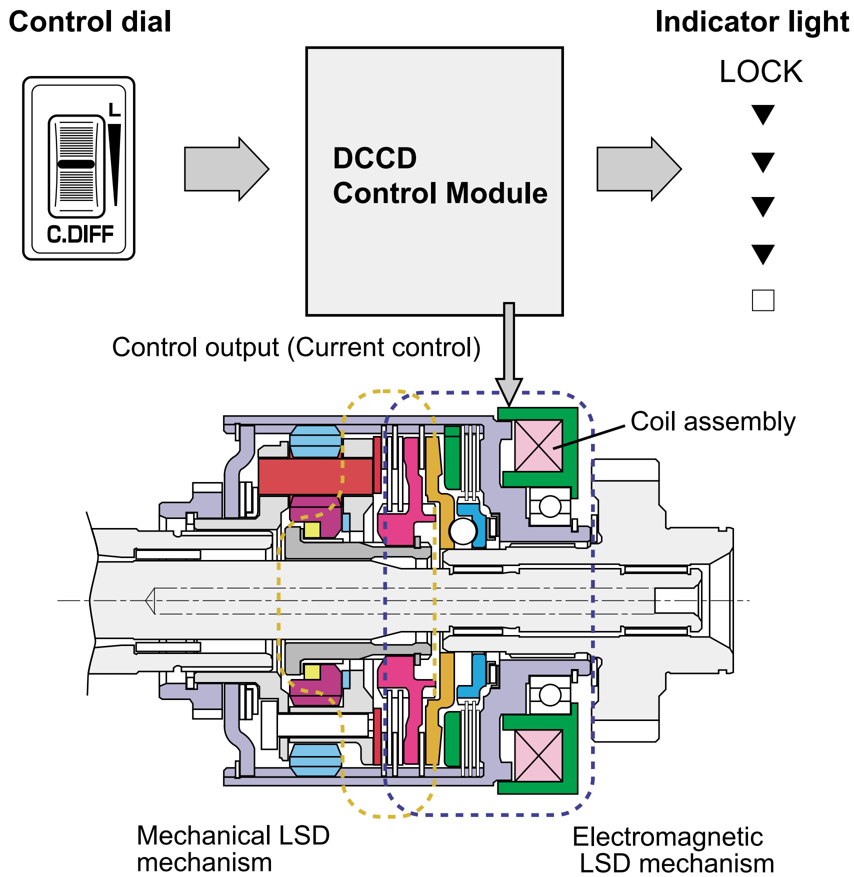
The DCCD system input/output items are shown in the figure below. The system consists of sensors detecting "driver's intention" such as a steering angle sensor, those detecting "vehicle conditions" such as yaw rate and lateral G sensors and DCCD coil that controls engagement force of the electromagnetic clutch LSD.

System control is available in one of two modes: manual and auto. Operations in each mode are as follows:
Manual mode: The system controls the magnetic clutch LSD to acquire the differential limiting force set on the control dial.
Auto mode: Based on information from sensors detecting "driver's intension" and those detecting "vehicle conditions", the system executes electromagnetic clutch LSD control considering the driver's intension.



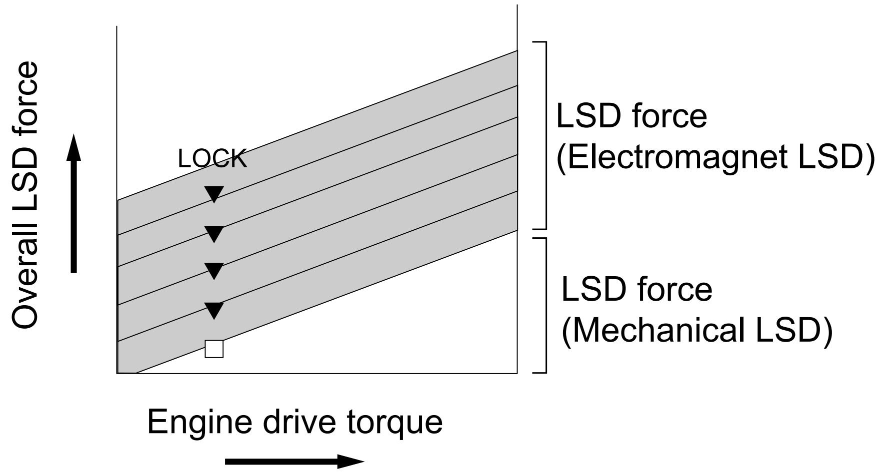
Manual Mode Operation

Pressing the Manual Mode switch causes the DCCD system to be placed in manual mode. In this mode, the control dial can be used to arbitrarily adjust the magnetic clutch LSD limiting force ranging from free to lock.



The DCCD control module gives certain current determined by setting on the control dial to the coil. It causes the magnetic clutch LSD differential limiting force to be fixed to a certain value.

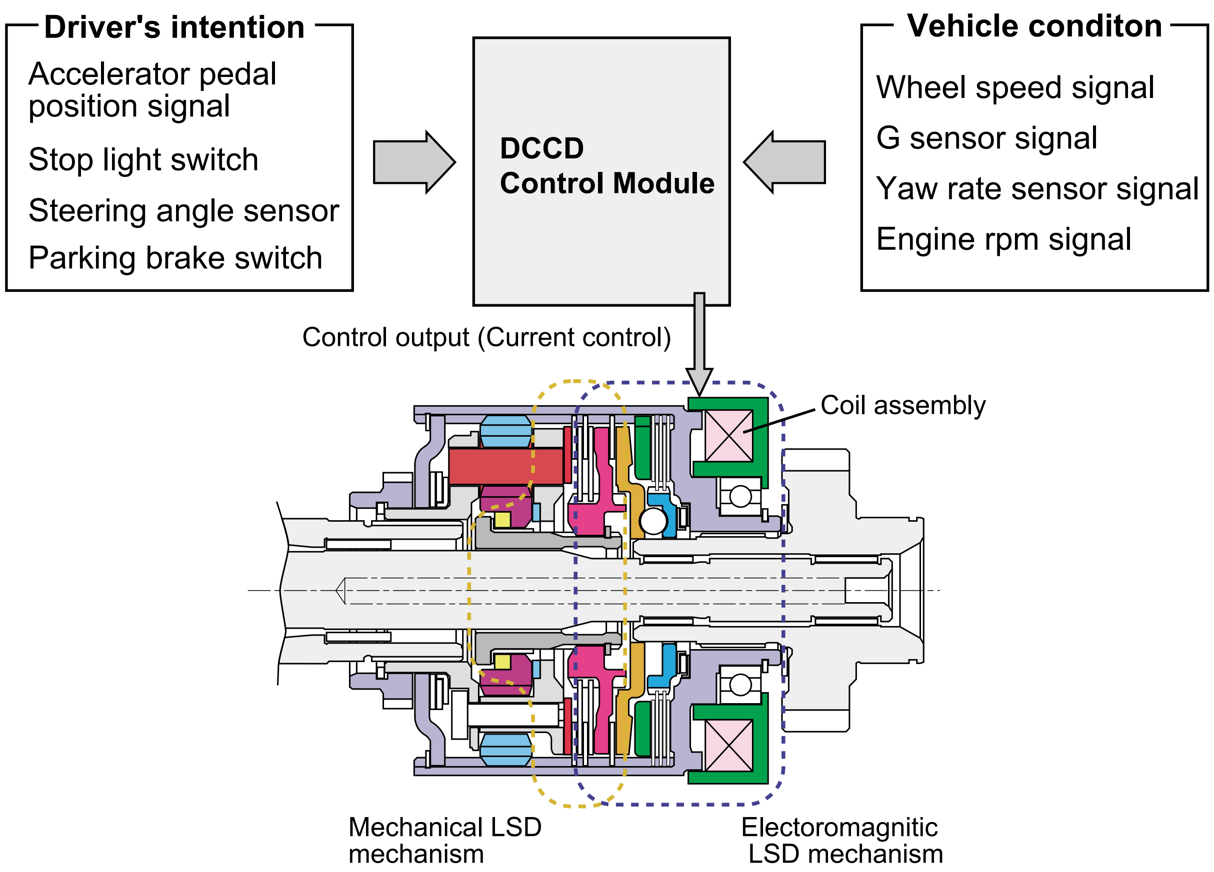
The chart given below shows differential limiting force characteristics of the whole center differential containing the mechanical LSD. When the control dial is set to its lowest position, the coil current is zero and the magnetic clutch LSD is free, with only the mechanical LSD functioning.
When the control dial is set to the LOCK position, the coil current is the maximum, with the highest differential limiting force generated by the magnetic clutch LSD.



Notes:
When the ignition switch is set OFF in manual mode, the DCCD system automatically returns to auto mode.
Because the differential limiting force by the mechanical LSD is active even if it is set free in manual mode, the LSD function of the center differential is not completely freed.

Auto Mode Operation

In auto mode, the differential limiting force of the electromagnetic clutch LSD is automatically adjusted according to the driver's intention and vehicle driving conditions. Of various controls including engine driving force sensitive control and ABS differential signal input control, this section discusses system operations including the vehicle running characteristics, using an example of cornering control.



Controls in auto mode

- Engine driving force sensitive control
Optimum control of the electromagnetic clutch LSD engagement force, estimating the driving force from the throttle travel, engine rotational speed and prospective gear ratio, aiming to compensate the mechanical LSD characteristics.

- ABS differential signal input control
Control of electromagnetic clutch LSD engagement force so that the ABS system performance can be maximized.

- Brake switch signal input control
Control of electromagnetic clutch LSD engagement force so that the brake performance can be maximized.

- Parking brake switch signal input control
Releasing the electromagnetic clutch LSD when the parking brake is applied.

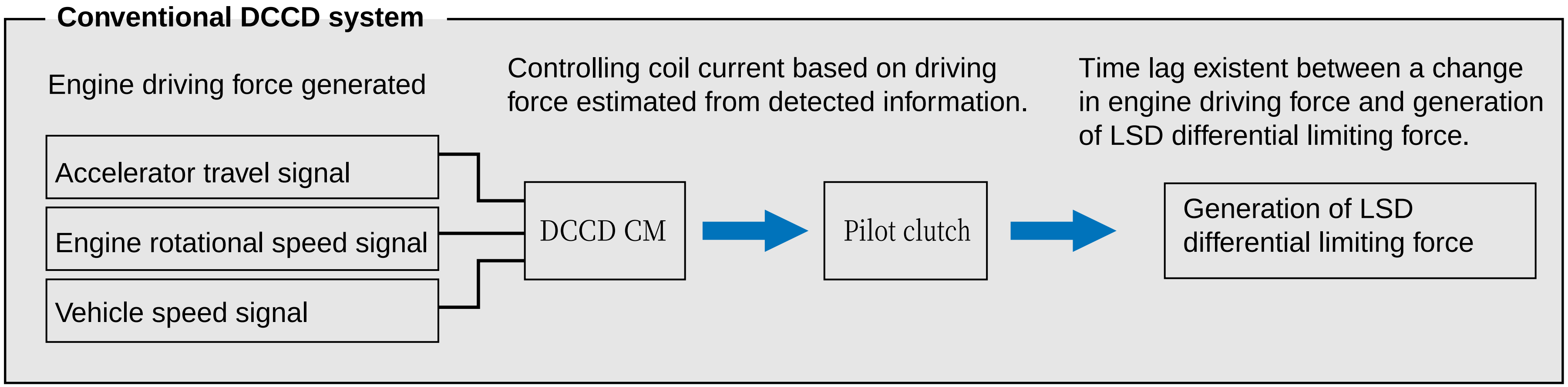
- Tight cornering control
Reducing the electromagnetic clutch LSD engagement force during turning at low speed to prevent occurrence of tight corner braking phenomena.

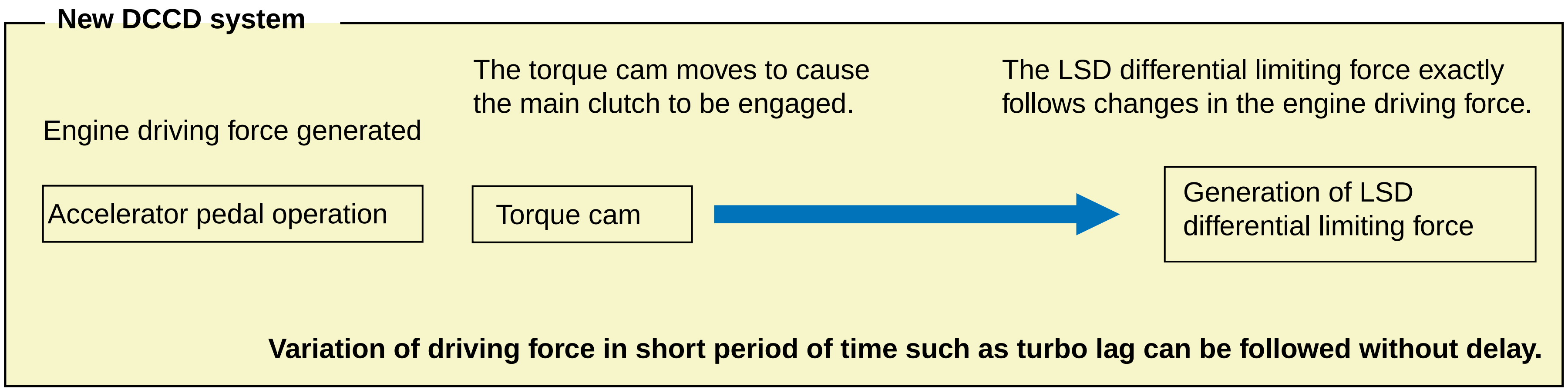
- Slip control
Controlling the electromagnetic clutch LSD engagement force depending on the slippage, if any, detected through four wheel speed signals.

- Cornering control
Control that satisfies both controllability and stability of a turning vehicle. Maintaining the best cornering performance by controlling the pilot clutch engagement force based on the driver's intention and vehicle turning conditions determined from a steering angle, yaw rate and lateral G sensors and vehicle speed.

Advantages of mechanical LSD

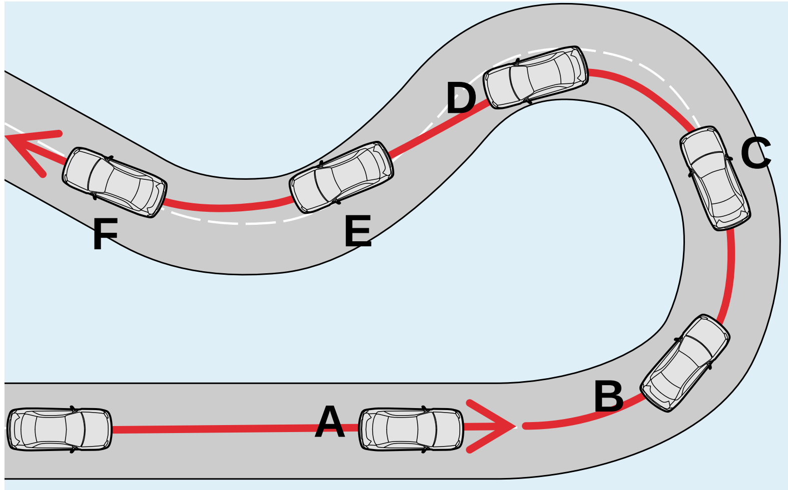
The mechanical LSD mechanism is advantageous in that it has good response of the LSD differential limiting force to the engine driving force and has direct vehicle operational stability allowing the driver to easily grasp changes in the vehicle behavior.
This section discusses these advantages in comparison with conventional DCCD system.

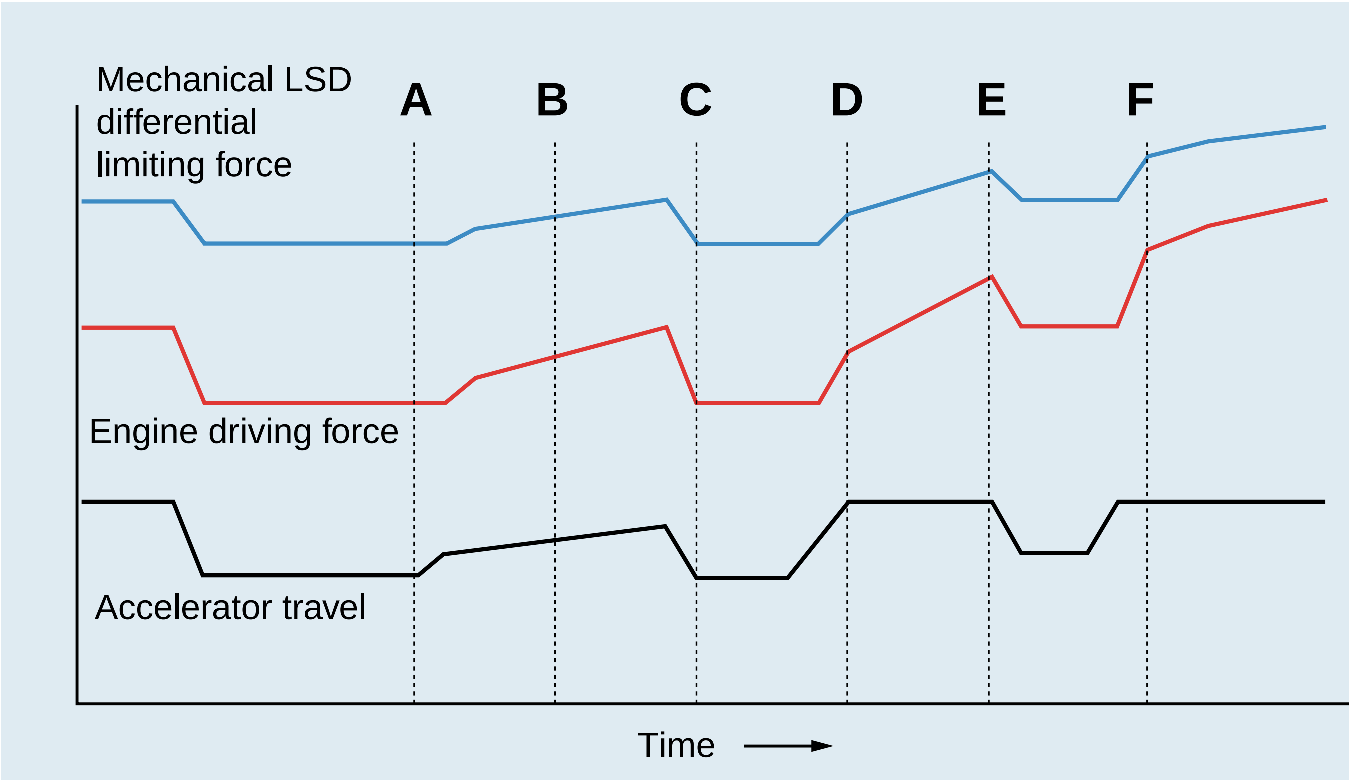


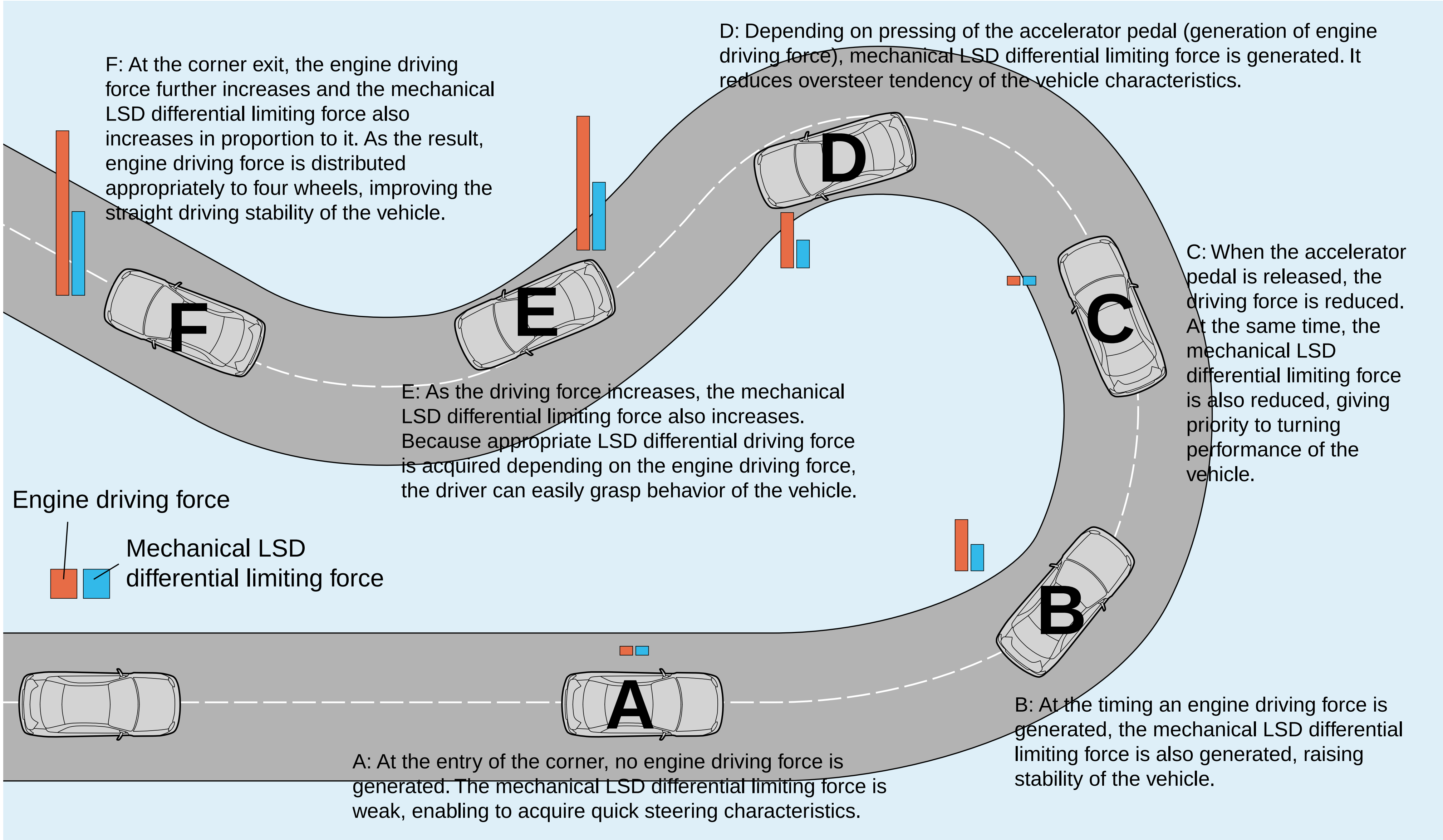


Engine driving force and mechanical LSD differential limiting force during turning

The figure given below shows the engine driving force and mechanical LSD differential limiting force during turning of a vehicle. Consider the relationships between the engine driving force and mechanical LSD differential limiting force and the resulting running characteristics of the vehicle at points A through F.



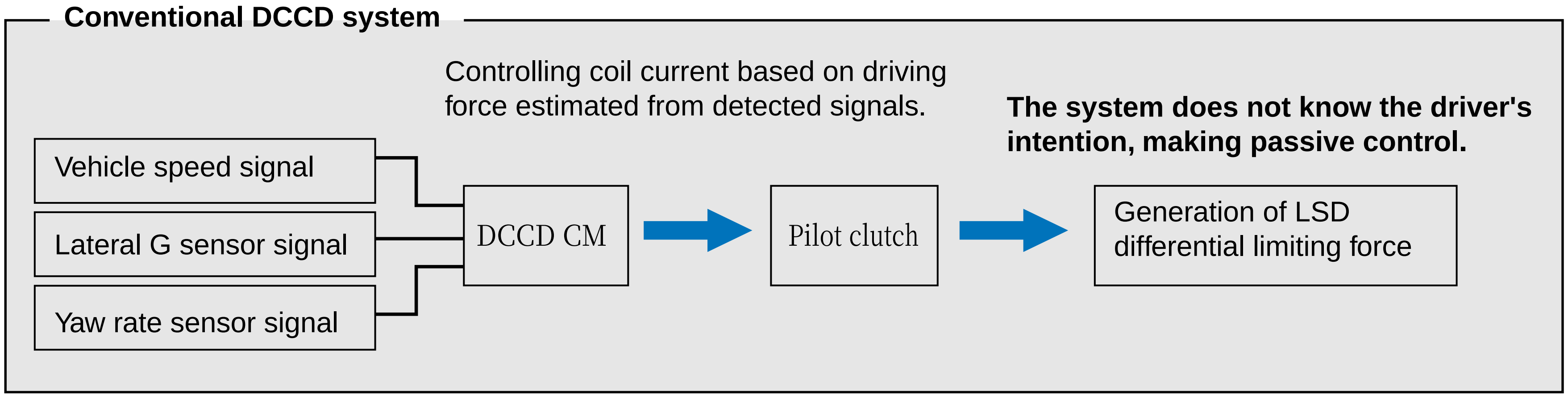


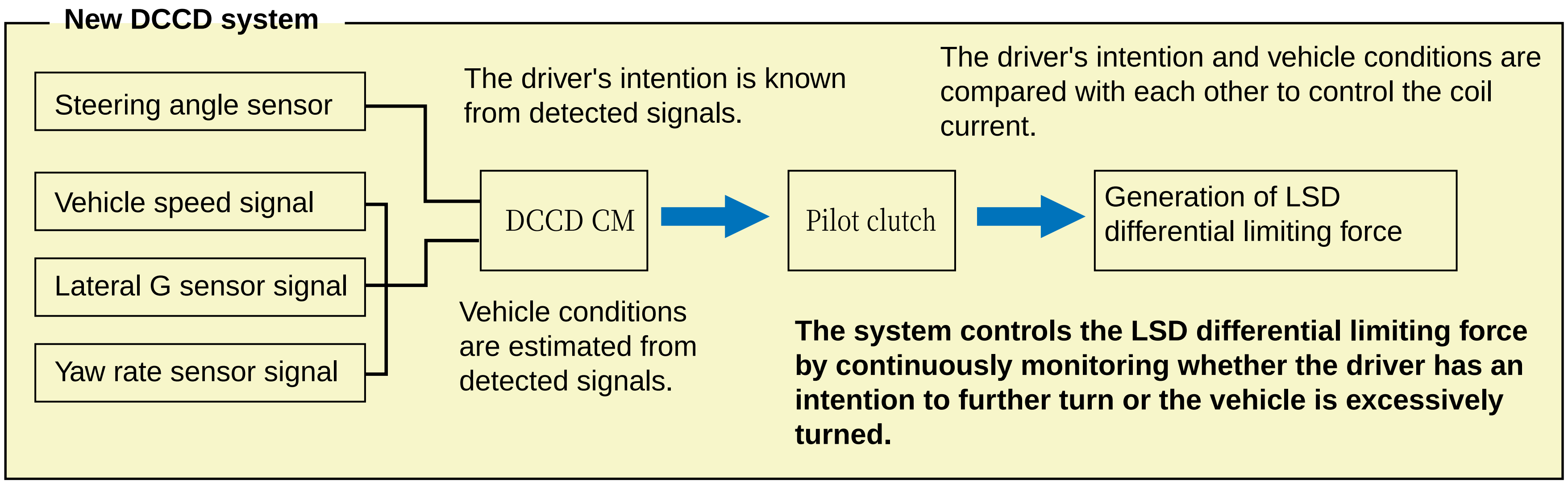


As described above, new DCCD system employing the mechanical LSD mechanism allows the timings of generating LSD differential limiting force to precisely follow the acceleration/deceleration timings of the vehicle. In addition, the differential limiting force is proportional to the engine driving force. Thus, the driver can easily grasp behavior of the vehicle and control the vehicle more freely.

Controls giving priority to driver's intention

DCCD CM can know the driver's intention* to turn from steering angle sensor signal. By reflecting this information to the electromagnetic clutch LSD control, excessive understeer or oversteer during turning can be avoided, allowing cornering as imaged by the driver.
(*The driver's intention can be determined through comparison among steering angle, lateral G and yaw rate sensor signals.)

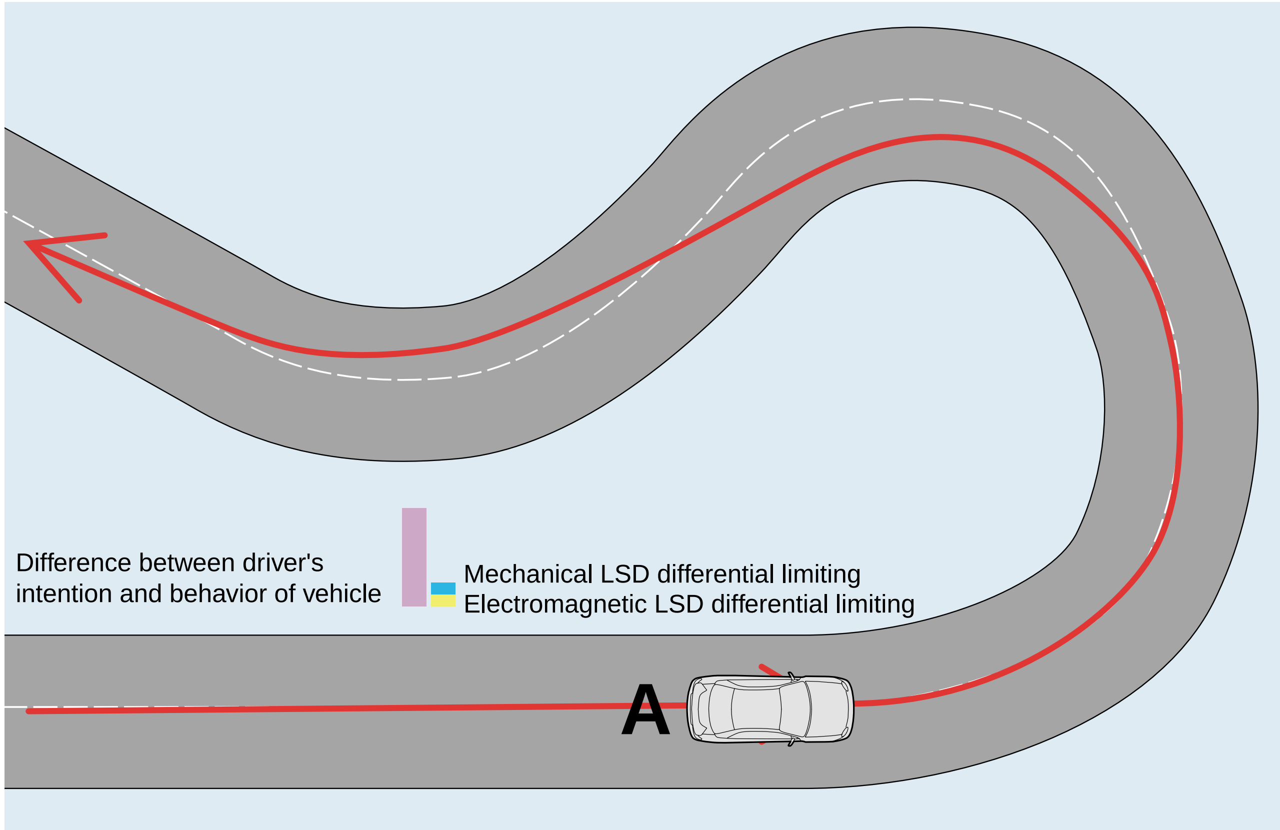


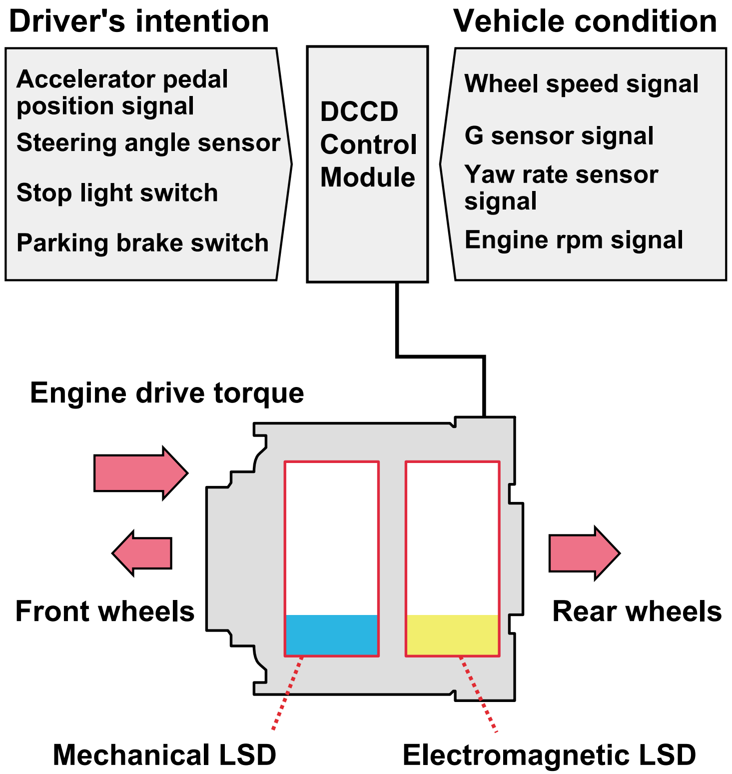


Comprehensive LSD differential limiting force and vehicle operational stability during turning

Consider relationships between the steering operation by the driver and the LSD differential limiting force and the resulting running characteristics of the vehicle.

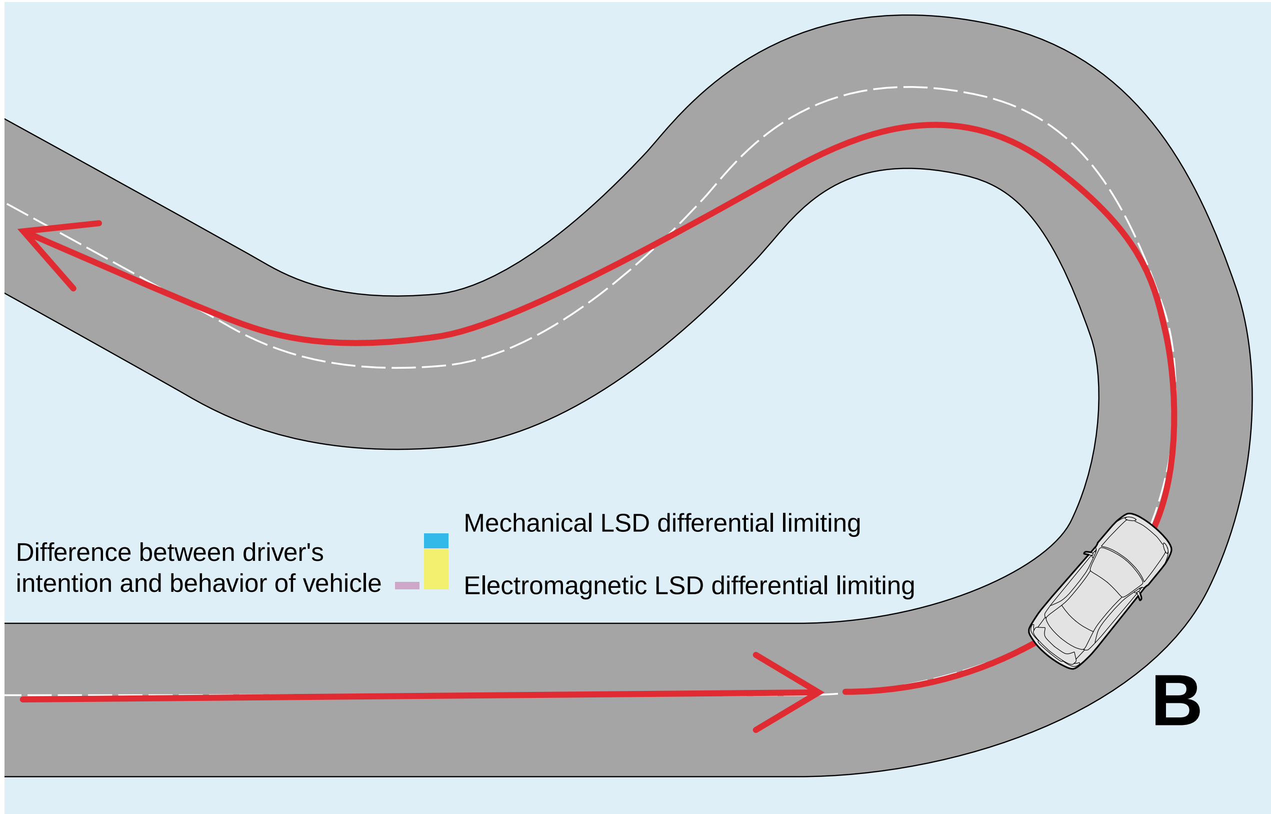
A: Turning the steering wheel at an entry of a corner
Because the yaw rate is lower compared to the steering angle, DCCD CM reduces the electromagnetic clutch LSD differential limiting force, assuming that the driver has an intention to turn. It enables easier differential limiting by the center differential, allowing the driver to easily turn the vehicle.

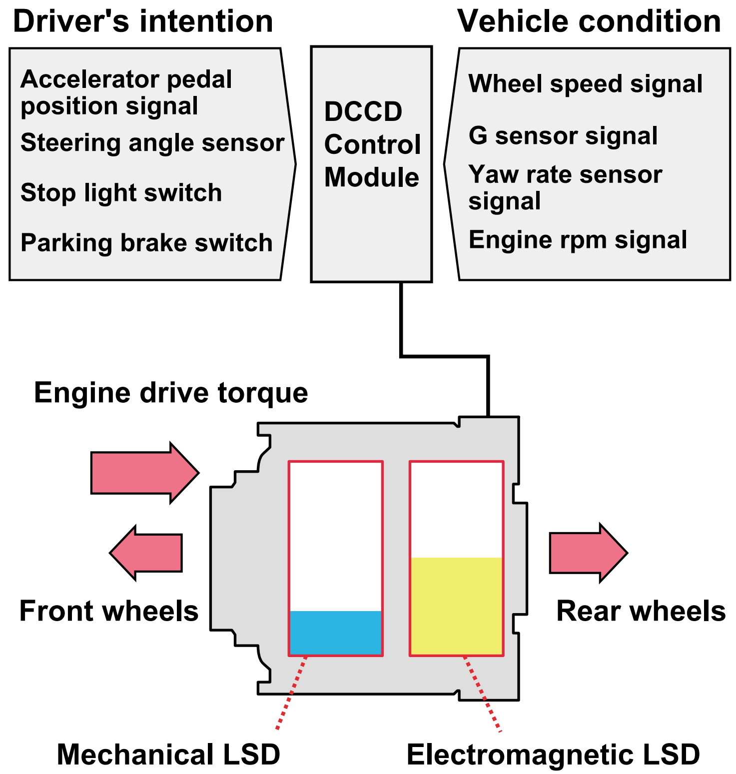




B: Steady turning condition

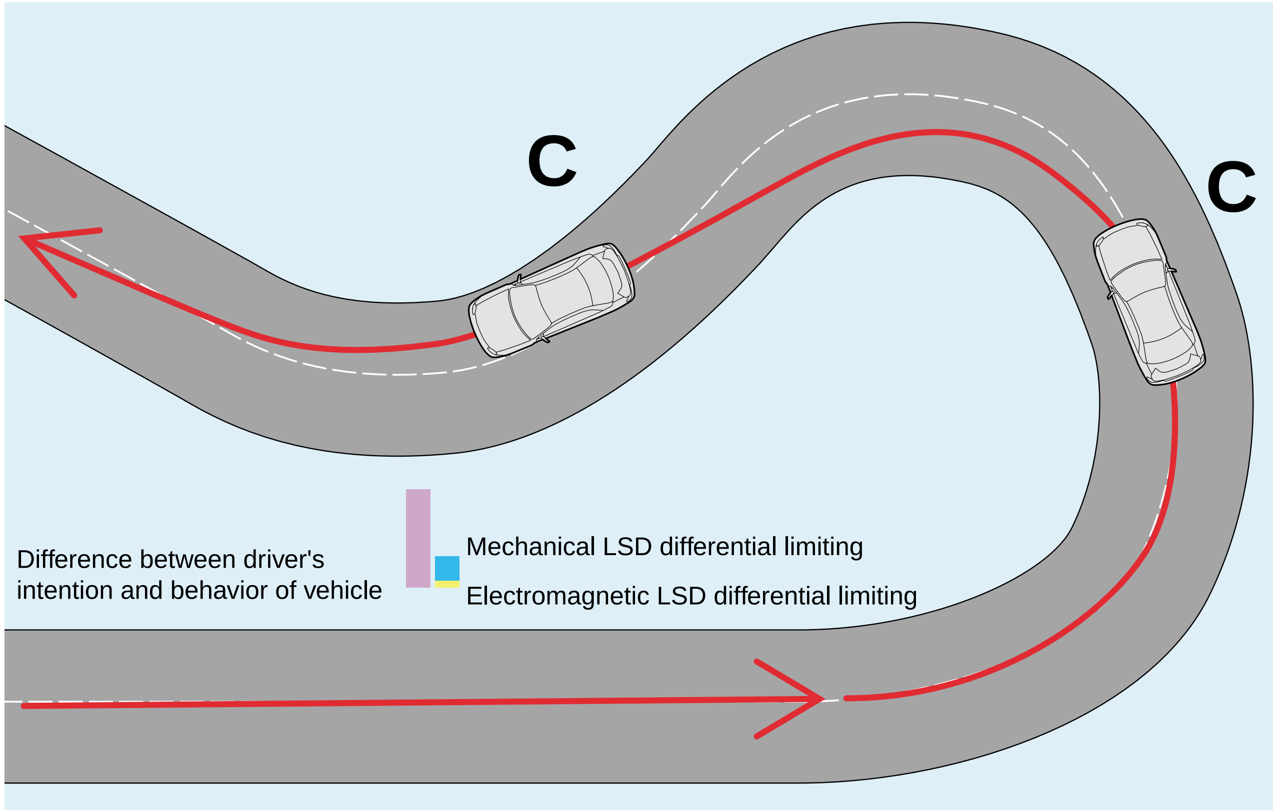
Because the yaw rate matches the steering angle, DCCD CM maintains the electromagnetic clutch LSD differential limiting force at an appropriate level, assuming that the vehicle is turning as intended by the driver.

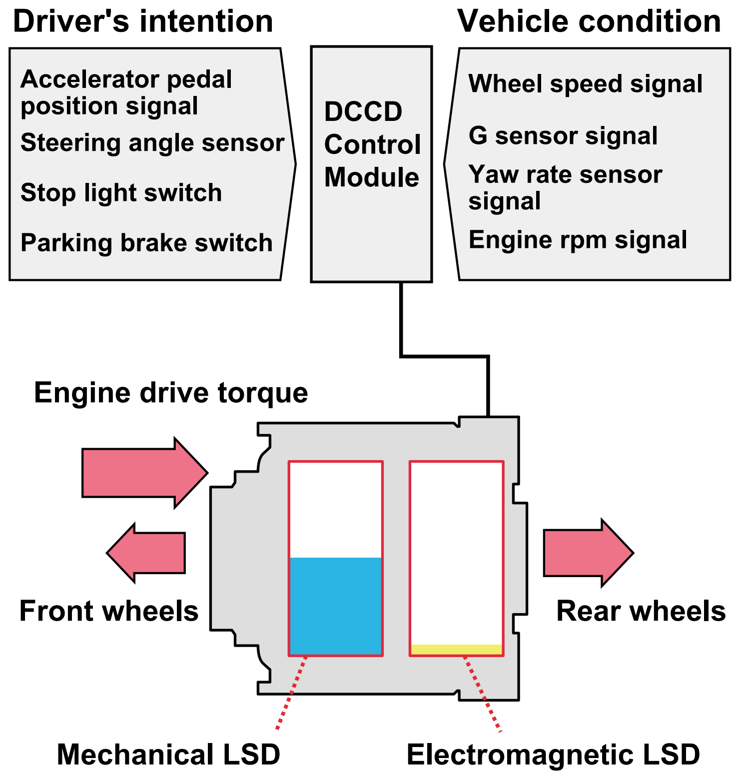




C: Further turning the steering wheel during turning

Because the yaw rate is lower compared to the steering angle, DCCD CM reduces the electromagnetic clutch LSD differential limiting force, assuming that the driver has an intention to further turn. It enables easier differential limiting by the center differential, allowing the driver to easily turn the vehicle.





D: Returning the steering wheel during turning

Because the yaw rate is higher compared to the steering angle, DCCD CM increases the electromagnetic clutch LSD differential limiting force, assuming that the driver has an intention to go straight. It makes tires less slippery, raises the traction and reserves the straight running stability.