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HYPERMOTIVE

ADS-DV SOFTWARE INTERFACE SPECIFICATION

VERSION 3.0

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1. INTRODUCTION

This document lists the signals on the CAN_B bus of the Formula Student ADS-DV demonstrator vehicle that is used for communications between the AI Computer and the Vehicle Control Unit (VCU), and the autonomous driving state machine that complies with the Formula Student Rules. It should be used in combination with the CAN database (adsdv_2021_vcu_ai_interface_v1.dbc). The CAN_B bus uses the CAN 2.0B protocol and runs at a baud rate of 500 kbps.

This CAN interface has been designed to comply with the 2019 Formula Student Rules for driverless vehicles and the supplementary regulations for the 2018 Formula Student Germany (FSG) competition, which provide more detailed guidelines on the data that must be logged for driverless vehicles. Any signals that are only relevant to the FSG data logging rules are highlighted in this document.

1.1. GLOSSARY OF TERMS

ADS-DV	Autonomous Driving System – Dedicated Vehicle
AI Computer	Designation for the autonomous driving computer used in the Formula Student Rules
AMI	Autonomous Mission Indicator
AS	Autonomous System
ASMS	Autonomous System Master Switch
ASSI	Autonomous System Status Indicator
EBS	Emergency Braking System
FSG	Formula Student Germany
MPP	Multi-Purpose Port
RES	Remote Emergency Stop
SDC	Shutdown Circuit
TS	Tractive System
TSMS	Tractive System Master Switch
VCU	Vehicle Control Unit

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1.2. CHANGE LOG

Version	Date	Changes made
0.2	24 Oct 2018	First release
2.0	21 May 2019	CAN DBC database file name added, Drive motor torque interface simplified: axle torque request signals changed to unsigned [0-195 Nm], Minimum axle torque feedback signals removed (FRONT_AXLE_TRQ_MIN_Nm & REAR_AXLE_TRQ_MIN_Nm), List of implausible operating conditions added, 'Manual' option for AMI state removed.
3.0	27 Jan 2021	Friction braking messages (AI2VCU_Brake and VCU2AI_Brake) updated to allow independent variation of brake pressure requests for the front and rear axles, steering angle limits revised to ±24.0°, battery charging procedure and BMS faults added to VCU2AI_Status fault diagnostics, AMI_STATE enumerations updated to include new 'Static inspection A', 'Static inspection B' and 'Autonomous demo' missions for scrutineering, Unused VCU diagnostics messages removed, List of reserved CAN IDs updated.

2. CAN MESSAGES

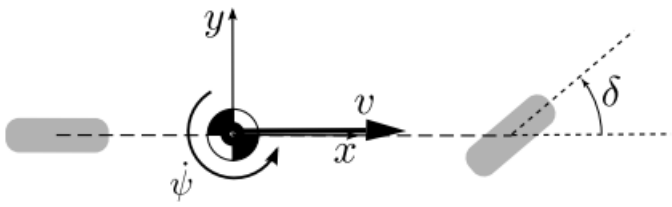
2.1. AI COMPUTER MESSAGES

Message name	AI2LOG_Dynamics2	
CAN ID	501h	
Description	Vehicle dynamics message to comply with Formula Student Germany (FSG) data logging requirements	
Signal	**Type**	**Description**
Accel_longitudinal_ms2	Signed	Longitudinal vehicle acceleration [m/s^2]
Accel_lateral_ms2	Signed	Lateral vehicle acceleration [m/s^2]
Yaw_rate_degps	Signed	Yaw rate [°/s]

Message name	AI2VCU_Status	
CAN ID	510h	
Description	AI Computer status signals for the VCU and some FSG logging signals	
Signal	**Type**	**Description**
HANDSHAKE	Unsigned	Handshake bit to check communications between the AI Computer and VCU
ESTOP_REQUEST	Enum	AI request for a vehicle emergency stop: 0 = no E-stop requested 1 = E-stop requested
MISSION_STATUS	Enum	Autonomous mission status for the VCU to determine which autonomous driving state it should be in: 0 = not selected 1 = mission selected 2 = running 3 = finished
DIRECTION_REQUEST	Enum	Vehicle direction request: 0 = neutral 1 = forward
LAP_COUNTER	Unsigned	Lap counter for the 'Track drive' mission (FSG data logging requirement)
CONES_COUNT_ACTUAL	Unsigned	Number of cones that have currently been detected (FSG data logging requirement)
CONES_COUNT_ALL	Unsigned	Running counter of detected cones (FSG data logging requirement)
VEH_SPEED_ACTUAL_kmh	Unsigned	Actual vehicle speed (FSG data logging requirement)
VEH_SPEED_DEMAND_kmh	Unsigned	Demanded vehicle speed (FSG data logging requirement)

Message name	AI2VCU_Drive_F		
CAN ID	511h		
Description	Requests for the front drive motor		
Signal		Type	Description
FRONT_AXLE_TRQ_REQUEST_Nm		Unsigned	Requested absolute front axle torque (motor torque × gear ratio). Whether torque is positive (driving) or negative (braking) will depend on the setting of the motor speed limit Range: [0, 195]
FRONT_MOTOR_SPEED_MAX_rpm		Unsigned	Maximum motor speed for vehicle speed control Range: [0, 4000]

Message name	AI2VCU_Drive_R		
CAN ID	512h		
Description	Requests for the rear drive motor		
Signal		Type	Description
REAR_AXLE_TRQ_REQUEST_Nm		Unsigned	Requested absolute rear axle torque (motor torque × gear ratio) Range: [0, 195]
REAR_MOTOR_SPEED_MAX_rpm		Unsigned	Maximum motor speed for vehicle speed control Range: [0, 4000]

Message name	AI2VCU_Steer		
CAN ID	513h		
Description	Steer angle request		
Signal		Type	Description
STEER_REQUEST_deg		Signed	Requested steer angle according to the bicycle model for vehicle dynamics. A positive angle turns the front wheels to the left according to the ISO 8855 vehicle co-ordinate system:  Range: [-24.0, 24.0]

Message name	AI2VCU_Brake	
CAN ID	514h	
Description	Hydraulic brake pressure request	
Signal	**Type**	**Description**
HYD_PRESS_F_REQ_pct	Unsigned	Normalised hydraulic pressure request for the front axle friction brakes. Range: [0, 100]
HYD_PRESS_R_REQ_pct	Unsigned	Normalised hydraulic pressure request for the rear axle friction brakes. Range: [0, 100]

2.2. VEHICLE CONTROL UNIT (VCU) MESSAGES

Message name	VCU2LOG_Dynamics1	
CAN ID	500h	
Description	Vehicle dynamics message to comply with Formula Student Germany (FSG) data logging requirements	
Signal	**Type**	**Description**
Speed_actual_kmh	Unsigned	Actual vehicle speed
Speed_target_kmh	Unsigned	Target vehicle speed
Steer_actual_deg	Signed	Actual steer angle (bicycle model)
Steer_target_deg	Signed	Requested steer angle (bicycle model)
Brake_actual_pct	Unsigned	Actual mechanical braking percentage
Brake_target_pct	Unsigned	Requested mechanical braking percentage
Drive_trq_actual_pct	Signed	Sum of actual front and rear axle torque
Drive_trq_target_pct	Signed	Sum of requested front and rear axle torque

Message name	VCU2LOG_Status	
CAN ID	502h	
Description	Vehicle status reporting to comply with Formula Student Germany (FSG) data logging requirements	
Signal	**Type**	**Description**
State_ASSI	Enum	Autonomous System Status Indicator (ASSI) state: 1 = AS_OFF 2 = AS_READY 3 = AS_DRIVING 4 = EMERGENCY_BRAKE 5 = AS_FINISHED
State_EBS	Enum	Emergency Braking System (EBS) state: 1 = unavailable 2 = armed 3 = triggered
AMI_STATE	Enum	Autonomous Mission Indicator (AMI) state: 0 = not selected

		1 = Acceleration 2 = Skidpad 3 = Autocross 4 = Track drive 5 = Static inspection A 6 = Static inspection B 7 = Autonomous demo
State_steering	Enum	Steering system status: 0 = off 1 = active
State_service_brake	Enum	Service brake (mechanical friction brakes) status: 1 = disengaged 2 = engaged 3 = available
Lap_counter	Unsigned	Signal gatewayed from AI2VCU_Status (510h)
Cones_count_actual	Unsigned	Signal gatewayed from AI2VCU_Status (510h)
Cones_count_all	Unsigned	Signal gatewayed from AI2VCU_Status (510h)

Message name	VCU2AI_Status	
CAN ID	520h	
Description	VCU and powertrain status reporting to the AI Computer	
Signal	**Type**	**Description**
HANDSHAKE	Unsigned	Handshake bit to check communications between the VCU and AI Computer
SHUTDOWN_REQUEST	Enum	VCU request for AI Computer to shut down [0 = no shutdown; 1 = shutdown requested]
AS_SWITCH_STATUS	Enum	Status of the autonomous system master switch (ASMS) [0 = off; 1 = on]
TS_SWITCH_STATUS	Enum	Status of the tractive system master switch (TSMS) [0 = off; 1 = on]
GO_SIGNAL	Enum	Remote “Go” signal to allow the vehicle to start driving: 0 = no go 1 = go
STEERING_STATUS	Enum	Steering system status: 0 = off 1 = active
AS_STATE	Enum	Autonomous system state: 1 = AS_OFF 2 = AS_READY 3 = AS_DRIVING 4 = EMERGENCY_BRAKE 5 = AS_FINISHED
AMI_STATE	Enum	Autonomous Mission Indicator (AMI) state: 0 = not selected

		1 = Acceleration 2 = Skidpad 3 = Autocross 4 = Track drive 5 = Static inspection A 6 = Static inspection B 7 = Autonomous demo
FAULT_STATUS	Enum	Flag to indicate the presence of a critical fault: 0 = no faults 1 = fault detected
WARNING_STATUS	Enum	Flag to indicate the presence of a warning. Used for fault diagnosis after a run: 0 = no warning 1 = warning active
WARN_BATT_TEMP_HIGH	Enum	High traction battery temperature warning flag: 0 = no warning 1 = warning active
WARN_BATT_SOC_LOW	Enum	Low traction battery SOC warning flag: 0 = no warning 1 = warning active
AI_ESTOP_REQUEST	Enum	Flag for E-stop request from the AI Computer: 0 = inactive 1 = E-stop requested
HVIL_OPEN_FAULT	Enum	Flag for open-circuit fault in the shutdown circuit / HVIL: 0 = no fault 1 = fault detected
HVIL_SHORT_FAULT	Enum	Flag for short-circuit fault in the shutdown circuit / HVIL: 0 = no fault 1 = fault detected
EBS_FAULT	Enum	Emergency Braking System fault flag: 0 = no fault 1 = fault detected
OFFBOARD_CHARGER_FAULT	Enum	Offboard battery charger fault flag: 0 = no fault 1 = fault detected
AI_COMMS_LOST	Enum	AI-VCU CAN communications fault flag: 0 = no fault 1 = fault detected
AUTONOMOUS_BRAKING_ FAULT	Enum	NEUTRAL direction request made while vehicle is still moving: 0 = no fault 1 = fault detected
MISSION_STATUS_FAULT	Enum	MISSION_STATUS set to ‘FINISHED’ while vehicle is moving: 0 = no fault

		1 = fault detected
CHARGE_PROCEDURE_FAULT	Enum	AS or TS master switches are on when the battery is being charged: 0 = no fault 1 = fault detected
BMS_FAULT	Enum	BMS fault detection flag: 0 = no fault 1 = fault detected
SHUTDOWN_CAUSE	Enum	Enumerated list identifying the fault that caused the VCU to shut down: 0 = no shutdown 1 = AI Computer request 2 = HVIL open-circuit fault 3 = HVIL short-circuit fault 4 = EBS fault 5 = Offboard battery charger fault 6 = AI communications fault 7 = Autonomous braking fault 8 = Mission status fault 9 = Charging procedure fault 10 = BMS fault

Message name	VCU2AI_Drive_F		
CAN ID	521h		
Description	Feedback from the front drive motor		
Signal		Type	Description
FRONT_AXLE_TRQ_Nm		Signed	Actual front axle drive motor torque Range: [-195, 195]
FRONT_AXLE_TRQ_REQUEST_Nm		Unsigned	Requested front axle torque (AI2VCU_Drive_F, FRONT_AXLE_TRQ_REQUEST_Nm)
FRONT_AXLE_TRQ_MAX_Nm		Unsigned	Maximum allowable drive torque at axle Range: [0, 195]

Message name	VCU2AI_Drive_R		
CAN ID	522h		
Description	Feedback from the rear drive motor		
Signal		Type	Description
REAR_AXLE_TRQ_Nm		Signed	Actual rear axle drive motor torque Range: [-195, 195]
REAR_AXLE_TRQ_REQUEST_Nm		Unsigned	Requested rear axle torque (AI2VCU_Drive_R, REAR_AXLE_TRQ_REQUEST_Nm)
REAR_AXLE_TRQ_MAX_Nm		Unsigned	Maximum allowable drive torque at axle Range: [0, 195]

Message name	VCU2AI_Steer	
CAN ID	523h	
Description	Feedback from the steering controller	
Signal	Type	Description
STEER_ANGLE_deg	Signed	Actual steer angle Range: [-24.0, 24.0]
STEER_ANGLE_MAX_deg	Unsigned	Maximum allowable steer angle. Limit is the same for steering left (+) and right (-)
STEER_ANGLE_REQUEST_deg	Signed	Requested steer angle (AI2VCU_Steer, STEER_REQUEST_deg)

Message name	VCU2AI_Brake	
CAN ID	524h	
Description	Feedback from the hydraulic braking system	
Signal	Type	Description
HYD_PRESS_F_pct	Unsigned	Actual normalised front axle hydraulic brake pressure Range: [0, 100]
HYD_PRESS_F_REQ_pct	Unsigned	Requested normalised front axle hydraulic brake pressure (AI2VCU_Brake, HYD_PRESS_F_REQ_pct)
HYD_PRESS_R_pct	Unsigned	Actual normalised rear axle hydraulic brake pressure Range: [0, 100]
HYD_PRESS_R_REQ_pct	Unsigned	Requested normalised rear axle hydraulic brake pressure (AI2VCU_Brake, HYD_PRESS_R_REQ_pct)

Message name	VCU2AI_Wheel_speeds	
CAN ID	525h	
Description	Wheel speed measurements	
Signal	Type	Description
FL_WHEEL_SPEED_rpm	Unsigned	Front left wheel speed
FR_WHEEL_SPEED_rpm	Unsigned	Front right wheel speed
RL_WHEEL_SPEED_rpm	Unsigned	Rear left wheel speed
RR_WHEEL_SPEED_rpm	Unsigned	Rear right wheel speed

Message name	VCU2AI_Wheel_counts
CAN ID	526h
Description	Raw pulse count measurements from the wheel speed sensors

Signal	Type	Description
FL_PULSE_COUNT	Unsigned	Pulse counts from front left wheel speed sensor Range: [0, 65535]
FR_PULSE_COUNT	Unsigned	Pulse counts from front right wheel speed sensor Range: [0, 65535]
RL_PULSE_COUNT	Unsigned	Pulse counts from rear left wheel speed sensor Range: [0, 65535]
RR_PULSE_COUNT	Unsigned	Pulse counts from rear right wheel speed sensor Range: [0, 65535]

2.3. RESERVED CAN ADDRESSES

The AI Computer must not transmit any data using the following CAN IDs:

000h	450h to 470h inclusive
080h to 084h inclusive	4E2h
100h	4FDh to 4FFh inclusive
120h to 124h inclusive	550h
181h to 184h inclusive	581h to 584h inclusive
201h	601h
284h	604h
301h	700h to 705h inclusive
410h to 41Fh inclusive	

2.4. HANDSHAKE

A handshake must be performed between the VCU and the AI Computer when the tractive system is enabled to allow autonomous driving. The handshake bits are located in the first bytes of the AI2VCU_Status (510h) and VCU2AI_Status (520h) messages.

The VCU will alternate the value of the HANDSHAKE bit between 0 (low) and 1 (high). When the VCU sets the HANDSHAKE bit to 1 in the VCU2AI_Status message, it will wait for the AI Computer to set the corresponding HANDSHAKE bit in the AI2VCU_Status message to 1, at which point the VCU will change its HANDSHAKE value to 0 and wait for a value of 0 to be received from the AI Computer. This cycle will then continue throughout the operation of the vehicle (see figure 1) and will be used to measure the response time of the AI Computer as part of the scrutineering of all ADS-DV vehicles.

If the value of the handshake bit received from the AI Computer does not match the value of the transmitted signal within 50ms, the VCU will raise an 'AI_COMMS_LOST' fault. If the vehicle is in the autonomous driving mode and in any state other than AS_OFF when this fault occurs, the vehicle emergency stop procedure will be activated.

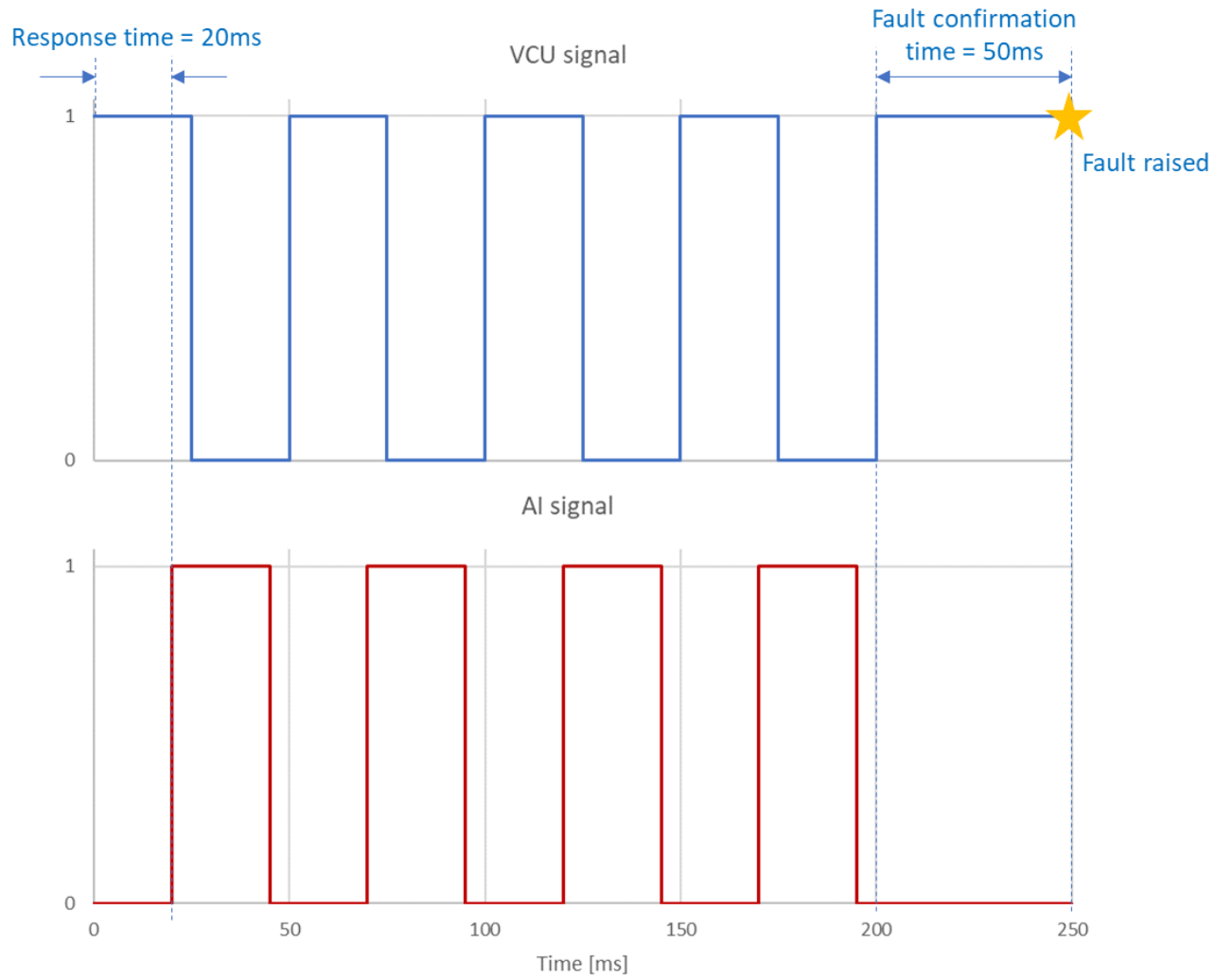


Figure 1: VCU-AI handshake and comms fault detection

3. AUTONOMOUS SYSTEM STATE MACHINE

Figure 2 shows the autonomous driving state machine implemented in the VCU in accordance with the Formula Student Rules. Any numbering on state transitions relates to the order in which the conditions are evaluated.

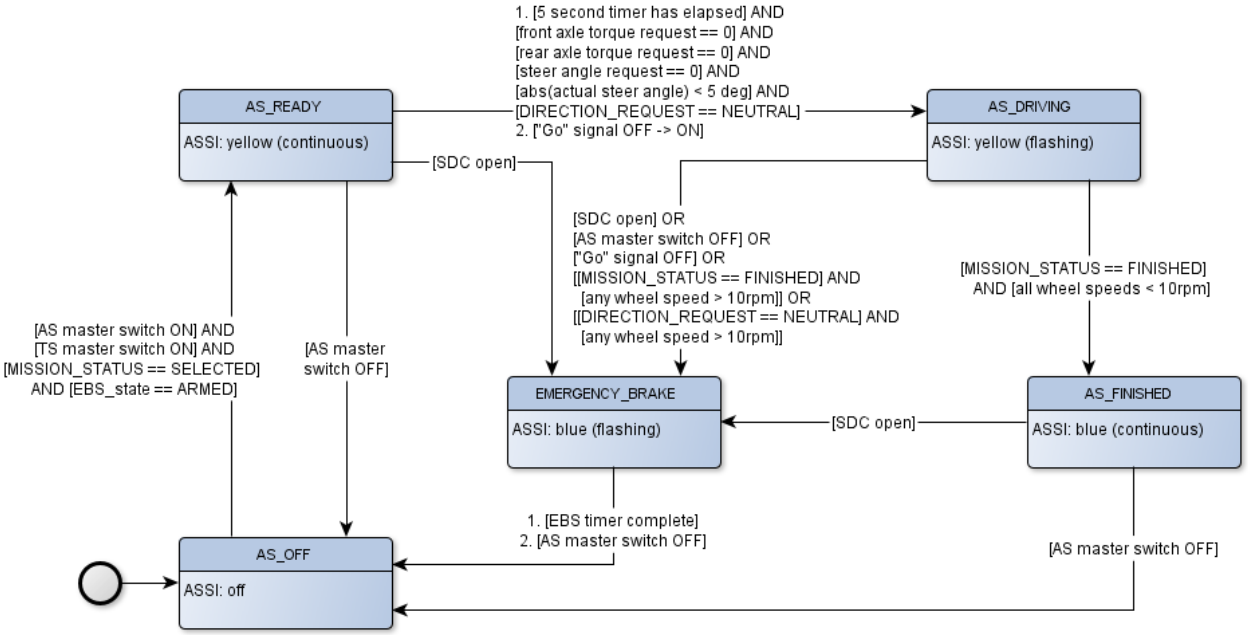


Figure 2: Autonomous driving state machine

3.1. AS_OFF TO AS_READY

The autonomous driving state machine will transition from AS_OFF to AS_READY when all the following conditions are satisfied:

- Tractive System Master Switch (TSMS) is turned on,
- Autonomous System Master Switch (ASMS) is turned on,
- An autonomous mission has been selected using the Autonomous Mission Indicator (touchscreen display),
- The Emergency Braking System (EBS) is in its ARMED state.

The selected autonomous mission will be transmitted from the VCU in the 'AMI_STATE' CAN signal ('VCU2AI_Status' message, 520h). The AI software should then update the 'MISSION_STATUS' signal ('AI2VCU_Status' message, 510h) to the SELECTED state (signal value of 1) to confirm the mission selection.

3.2. AS_READY TO AS_DRIVING

When the AS_READY state is active in the autonomous driving state machine, all powertrain components will have been initialised and be ready to act on the commands received from the AI Computer. At this point the VCU will not respond to drive or steering requests from the AI Computer

to avoid any unintended motion of the vehicle. The transition from AS_READY to AS_DRIVING will be as follows:

1. The VCU will remain in the AS_READY state for a minimum of 5 seconds before checking the exit conditions to move to AS_DRIVING.
2. Requests from the AI Computer must meet the following criteria:
    a. Front and rear drive motor torque requests must be zero,
    b. Requested steering angle must be zero,
    c. 'DIRECTION_REQUEST' signal ('AI2VCU_Status' message, 510h) must be set to NEUTRAL.

    The intention is that the direction request is set to FORWARD when in the AS_DRIVING state. The VCU will also check that the actual steering angle of the front wheels is less than 5° to prevent any sudden steering movements when entering the AS_DRIVING state.
3. Once the above conditions have been satisfied, the VCU will monitor the remote "Go" signal from the GrossFunk RES transmitter to detect a rising edge. If the switch for the "Go" signal is in the 'on' position while in AS_READY, it must be turned off and on again before the VCU will enter the AS_DRIVING state. Once the rising edge has been detected, the CAN signal 'RES_GO_SIGNAL' ('VCU2AI_Status' message, 520h) is set to TRUE and transmitted to the AI Computer. The state machine will then transition to the AS_DRIVING state.

3.3. AS_DRIVING TO AS_FINISHED

1. The AI Computer must inform the VCU when the selected autonomous mission has been completed in accordance with the rules for the driverless dynamic events. The AI software is responsible for bringing the vehicle to a stop at the end of each event by applying the service brake.
2. Once the vehicle has stopped, the AI Computer must set the value of the CAN signal 'MISSION_STATUS' ('AI2VCU_Status' message, 510h) to FINISHED (signal value of 3).
3. When the VCU sees that the autonomous mission has been completed and the vehicle has come to rest, the autonomous driving state changes from AS_DRIVING to AS_FINISHED.
4. Upon entering the AS_FINISHED state, any commands for the drive or steering motors from the AI Computer will be ignored.

3.4. AS_FINISHED TO AS_OFF

The VCU state machine will return to the AS_OFF state when the ASMS is turned off.

3.5. AS_READY TO EMERGENCY_BRAKE

The VCU state machine will enter the EMERGENCY_BRAKE state from AS_READY if the shutdown circuit (SDC) is broken, which could be caused by any of the following:

- The remote E-stop button is pressed,
- The remote E-stop receiver in the vehicle loses contact with the transmitter,
- Either of the E-stop buttons on the vehicle is pressed,

- The inertial crash sensor in the vehicle is activated,
- The VCU detects a critical system fault,
- The BMS detects a critical fault in the traction battery pack,
- The autonomous driving dongle is removed from the vehicle's Multi-Purpose Port (MPP).

3.6. AS_READY TO AS_OFF

The VCU state machine will return to the AS_OFF state if the ASMS is turned off.

3.7. AS_DRIVING TO EMERGENCY_BRAKE

The VCU will enter the EMERGENCY_BRAKE state if any of the following criteria are satisfied:

- The SDC is open (see section 3.5 for possible causes),
- The "Go" signal received from the GrossFunk RES transmitter is turned off,
- The AS master switch is turned off,
- The 'MISSION_STATUS' CAN signal from the AI Computer is set to 'FINISHED' while any of the wheel speeds are greater than 10rpm,
- The 'DIRECTION_REQUEST' CAN signal from the AI Computer is set to 'NEUTRAL' while any of the wheel speeds are greater than 10rpm.

The last condition is in addition to those specified in the Formula Student Rules as in this scenario it is assumed that the AI Computer has lost control of the vehicle by not bringing it to a stop at the end of the driving mission.

3.8. AS_FINISHED TO EMERGENCY_BRAKE

The emergency stop procedure will be activated if HVIL/shutdown circuit is broken while the VCU state machine is in the AS_FINISHED state.

3.9. EMERGENCY_BRAKE TO AS_OFF

Once the 15 second timer for the emergency braking procedure has elapsed, the state machine will return to AS_OFF when the ASMS is turned off. A power cycle of the vehicle will be required to return to a state where the vehicle can be driven again.

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4. IMPLAUSIBLE OPERATING CONDITIONS

The following is a list of operating conditions that are not permissible when the ADS-DV is in its autonomous driving mode. If any of these conditions are met, the VCU will execute an emergency stop to bring the vehicle to a halt.

1. In the AS_DRIVING state, an emergency stop will be initiated if the 'DIRECTION_REQUEST' signal in the AI2VCU_Status message (510h) is changed from 'FORWARD' to 'NEUTRAL' while the vehicle is moving, i.e. any of the wheel speed measurements is greater than 10 rpm.
2. In the AS_DRIVING state, an emergency stop will be initiated if the 'MISSION_STATUS' signal is changed from 'RUNNING' to 'FINISHED' while the vehicle is moving, i.e. any of the wheel speed measurements is greater than 10 rpm.