M221 Technical Specification
29T-068696TK-03

Release 2.9.0 (r2020-1)

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Chapter 1. Technical specification

This document is the technical specification for OpenECU part *01T-068696-000 Issue 1*. Within this document, that part is referred to as the *M221-000 ECU*.

> **Note**
>
> For a list of issues and possible work arounds for this ECU, found after publication of this document, please refer to the hardware errata for this ECU (named *29T-068696 M221 Technical Spec Errata*).

Specific option control may exist for this part. In that case, parts of this document will be overridden by an option control specific technical specification. Please refer to the option control technical specification for more information.

1.1. Overview

This technical specification relates to the following ECU variant:

- M221D-000 — for development and testing, including full interactive calibration tool integration.

Table 1.1. Specification

Specification	Variant
	M221D-000
Status	Prototype [a]
Processor	MPC5534
Rate	80MHz
Code space	up to 768KiB [b]
RAM space	up to 832KiB [b]
Calibration space	up to 256KiB [b]
Calibratable	Y
Reprogrammable	Y
Power control relays	-
Actuator supplies	-
Sensor supplies	1
Inputs	23
Outputs	15
CAN buses	2
LIN buses	-
RS232 links	-
Connectors	1x46
Weight	- [c]

Specification	Variant
	M221D-000
Vibration	- [c]
Shock capability	- [c]
Enclosure	IP69K [d]
EMC	- [c]
Partial operating voltage	6 to 24V
Full operating voltage	9 to 16V [e]
Standby current (typical)	(pending) at 12V
Operating current (typical)	(pending) at 12V
Operating temperature range	-40 to +105°C
Storage temperature range (installation)	-40 to +105°C
Storage temperature range (shipping)	-40 to +85°C

[a] Target ECU at a prototype stage, available in limited quantities.
[b] See list of possible memory configurations in the appendix of the User Guide
[c] Please contact Pi for details.
[d] Designed for chassis mounted applications.
[e] Designed for 12V systems.

1.2. Function reference

Various input and output functionality is supported where some pins may be capable of more than one function. Some functions require a combination of pins but not all pin combinations are possible.

Table 1.2. Function reference

I/O type	External	Internal	Pins
Power			
ECU supply	1	-	A2
ECU ground	1	-	A31
Sensor supply	1	-	A25
Module control, status			
Module control FEPS	1	-	A27
Communication			
CAN buses	2	-	A23+A24, A28+A43
Inputs — time based			
Analogue	13	31	A4, A5, A12, A13, A14, A15, A18, A19, A20, A21, A22, A26, A44
Digital	16	22	A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A26, A27, A29, A41, A42, A44
Frequency	16	-	A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A26, A27, A29, A41, A42, A44
PWM	16	-	A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A26, A27, A29, A41, A42, A44

I/O type	External	Internal	Pins
Quadrature	16	-	A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A26, A27, A29, A41, A42, A44
Outputs — time based			
Analogue output	1	-	A3
Digital	14	5	A1, A16, A17, A30, A32, A33, A34, A35, A36, A37, A38, A39, A45, A46
PWM	14	2	A1, A16, A17, A30, A32, A33, A34, A35, A36, A37, A38, A39, A45, A46
Inputs — angle based			
Crank-shaft primary	1	-	A29
Cam-shaft	15	-	A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A26, A27, A41, A42, A44
Analogue	13	62	A4, A5, A12, A13, A14, A15, A18, A19, A20, A21, A22, A26, A44
Analogue injector duration	-	10	
Outputs — angle based			
Injector saturating	10	-	A16, A32, A33, A34, A35, A36, A37, A38, A39, A45
Ignition	10	-	A16, A32, A33, A34, A35, A36, A37, A38, A39, A45

Chapter 2. Connector pinout

The M221-000 variants have one ECU connector (pocket) named A, which has a pinout as given in the following table. Currents listed are RMS unless otherwise stated.

The following abbreviations are used in the pinout tables below:

C	Communication
I	Input
M	Monitor
O	Output
P	Power
CT	Current trip
GND	Ground
PWR	Power
SB	Short to battery
SG	Short to ground
TT	Temperature trip

2.1. Pocket A

Connector packs can be ordered from Pi. Individual connector components can be ordered from Pi or from various manufacturers.

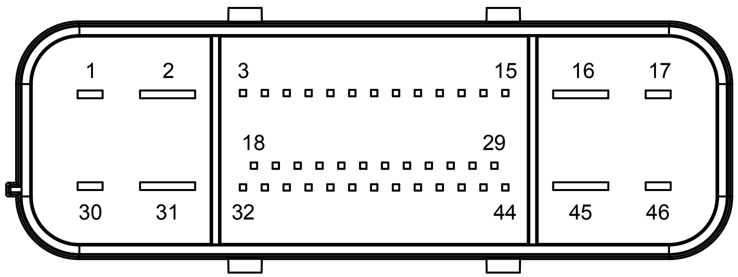


Table 2.1. Part numbers of the mating connector

Supplier	Part number	Part
TE	1326110-1	Cable mount connector (right handed)
	1326341-1	Cable mount connector (left handed)
	1326113-1	Cover

Table 2.2. Part numbers for the 6.3 mm pin

Supplier	Part number	Colour	Part
Yazaki	7116-4142-02	Tin	Female crimp contact
	7158-3081-50	Red	Seal (for wire 1.40 mm - 2.10 mm)
	7158-3082-90	Blue	Seal (for wire 2.18 mm - 3.00 mm)
	7158-3083	Black	
	7158-3080-60	Green	Plug for unused position
Pins A2 and A31			

Table 2.3. Part numbers for the 2.8 mm pin

Supplier	Part number	Colour	Part
TE	1326032-4	Tin	Female crimp contact
Yazaki	7158-3111-60	Green	Seal (for wire 1.19 mm - 1.90 mm)
	7158-3112-70	Yellow	Seal (for wire 1.88 mm - 2.10 mm)
	7158-3113-40	White	Seal (for wire 2.18 mm - 3.00 mm)
	7158-3114-90	Blue	Plug for unused position
Pins A1, A17, A30 and A46			

Table 2.4. Part numbers for the 0.64 mm pin

Supplier	Part number	Colour	Part
TE	0638551-1	Tin	Female crimp contact

Supplier	Part number	Colour	Part
Deutsch	0413-204-2005	Red	Plug for unused position
Pins A3, A4, A5, A12, A14, A18, A19, A20, A21, A22, A23, A24, A25, A28, A29, A32, A33, A34, A35, A36, A37, A38, A39, A40, A41, A42 and A43			

Table 2.5. Part numbers of the pin crimp tools

Supplier	Tool assembly part number	Die assembly part number	Part
TE	91338-1	91338-2	Crimp tool for the 0.64 mm female terminal, PRO-CRIMPER III Hand Tool
Diamond Die and Mold Company	088BR	-	Crimp tool for the 2.8 mm female terminal
	088BR-1		Crimp tool for the 6.3 mm female terminal

Table 2.6. Connector pinout — Pocket A

Main connector — Pocket A								
Pin	**P**	**Function**	**I/O**	**M**	**Loading**	**Filter**	**Range**	**Notes**
A1		Digital	O	Y	Low side		1.5A	Related to internal channels Monitor (tt) and Monitor (v).
A2		V_{PWR}	P				16 A	Related to internal channels AIN VPWR and DOT hold-PSU.
A3		Variable Resistance	O	Y	to V_{GND}		3.9 Ohm to 200.1 Ohm	Controlled by SPI. Related to internal channels DOT fault-clear and Monitor (ct).
A4		Analogue	I		51k to V_{GND} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.
A5		Analogue	I		51k to V_{GND} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.
A6		Digital	I		51k to V_{GND} plus 47k series	72Hz	0V to V_{PWR}	High-speed digital input associated with output pin A32. Active low.
A7		Digital	I		51k to V_{GND} plus 47k series	72 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A33. Active low.

Main connector — Pocket A								
Pin	**P**	**Function**	**I/O**	**M**	**Loading**	**Filter**	**Range**	**Notes**
A8		Digital	I		51k to V_{GND} plus 47k series	72 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A34. Active low.
A9		Digital	I		51 to V_{GND} plus 47k series	72 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A35. Active low.
A10		Digital	I		4k7 to V_{PWR} plus 47k series	72 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A36. Active low.
A11		Digital	I		4k7 to V_{PWR} plus 47k series	72 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A37. Active low.
A12		Digital	I		51k to V_{GND} plus 20k series	530 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A38. Active low.
		Analogue					0V to 5V	General purpose analogue input.
A13		Digital	I		15k to V_{PSU1} plus 20k series	530 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A39. Active low.
		Analogue					0V to 5V	General purpose analog input.
A14		Digital	I		51k to V_{GND} plus 20k series	530 Hz	0V to V_{PWR}	High-speed digital input associated with output pin A16. Active low.
		Analogue					0V to 5V	General purpose analogue input.
A15		Digital	I		200 ohm to V_{PSU1} plus 20k series	530Hz	0V to V_{PSU1}	High-speed digital input associated with output pin A45. Active low.
		Analogue					0V to 5V	General purpose analogue input.
A16		Digital	O	Y	Low side		4A peak / 1A hold	Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A17		Digital	O	Y	Low side		1.5A	Related to internal channels Monitor (tt) and Monitor (v).
A18		Analogue	I		15k to V_{PSU1} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.
A19		Analogue	I		15k to V_{PSU1} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.

Main connector — Pocket A

Pin	P	Function	I/O	M	Loading	Filter	Range	Notes
A20		Analogue	I		51k to V_{GND} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.
A21		Analogue	I		51k to V_{GND} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.
A22		Analogue	I		1k to V_{PSU1} plus 20k series	530 Hz	0V to 5V	General purpose analogue input.
A23		CAN+ (high)			No termination resistor			CAN bus 1 high (+ve), see also: A24. Related to internal channel DOT disable-CAN.
A24		CAN- (low)			No termination resistor			CAN bus 1 low (-ve), see also: A23. Related to internal channel DOT disable-CAN.
A25		Sensor Supply	P	Y			5V, 250mA	Sensor supply 1. ±6% worst-case voltage tolerance. Related to internal channels DOT enable-EXT-PSU1 and Monitor (v).
A26		Digital	I		51k to V_{GND} plus 47k series	72Hz	0V to V_{PWR}	General purpose digital input / key position (ignition sense) input.
		Analogue					0V to 5V	General purpose analog input.
A27		FEPS	I		33k effective to V_{GND}	72Hz	-41V to +42V	Module flash programming control. General purpose digital input. Related to internal channel AIN FEPS.
		Digital			51k to V_{GND} plus 47k series		0V to V_{PWR}	General purpose digital input. Related to internal channel AIN FEPS.
A28		CAN+ (high)			No termination resistor			CAN bus 0 high (+ve), see also: A43. Related to internal channel DOT disable-CAN.
A29		Digital	I		4k7 to V_{PWR} plus 47k series	72Hz	0V to V_{PWR}	General purpose digital input.
A30		Digital	O	Y	Low side		1.5A	Related to internal channels Monitor (tt) and Monitor (v).
A31		V_{GND}	P				16 A	
A32		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A6. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).

Main connector — Pocket A								
Pin	**P**	**Function**	**I/O**	**M**	**Loading**	**Filter**	**Range**	**Notes**
A33		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A7. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A34		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A8. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A35		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A9. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A36		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A10. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A37		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A11. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A38		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A12. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A39		Digital	O	Y	Low side		4A peak / 1A hold	Controlled directly by pin A13. Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A40		Sensor ground	P				1 A	A40 and A31 connected together internally.
A41		Digital	I		4k7 to V_{PWR} plus 47k series	72Hz	0V to V_{PWR}	General purpose digital input.
A42		Digital	I		4k7 to V_{PWR} plus 47k series	72Hz	0V to V_{PWR}	General purpose digital input.
A43		CAN- (low)			No termination resistor			CAN bus 0 low (-ve), see also: A28. Related to internal channel DOT disable-CAN.

Main connector — Pocket A								
Pin	**P**	**Function**	**I/O**	**M**	**Loading**	**Filter**	**Range**	**Notes**
A44		Digital	I		4k7 to V_{PWR} plus 47k series	50Hz	0V to V_{PWR}	General purpose digital input.
		Analogue					0V to 5V	General purpose analog input.
A45		Digital	O	Y	Low side		4A peak / 1A hold	Related to internal channels DIN injector-batt-fault, DOT injector-clock, Monitor (d), Monitor (sb) and Monitor (v).
A46		Digital	O	Y	Low side		1.5A	Related to internal channels Monitor (tt) and Monitor (v).

Chapter 3. Internal signals

Table 3.1. Internal signals

Signal	I/O	Signal type	Range	Notes
Analogue				
AIN 3.3V	I	Analogue	0V to 5V	Internal 3.3V supply monitor. 12-bit unsigned conversion.
AIN 5VD	I	Analogue	0V to 5V	5VD Reference voltage measurement. 12-bit unsigned conversion.
AIN FEPS (pin A27)	I	Analogue	-41.000V to +42.273V	Scaling from measured volts (V_m) to actual volts (V_a) is V_a = $(1832*V_m-4510)/110$.
AIN internal-ecu-temp	I	Analogue	-55 °C to 150 °C	Internal temperature monitor. 12-bit unsigned conversion. Transfer function is nonlinear and must be determined by lookup table.
AIN PSU+2.5VD	I	Analogue	0V to 5V	Internal 2.5V precision reference. 12-bit unsigned conversion.
AIN VPWR (pin A2)	I	Analogue	0V to 40V	Switched power supply voltage monitor. 12-bit unsigned conversion. To convert measured voltage (V_m) to actual voltage (V_a) use the equation, $V_a=V_m*8$.
AIN VREF	I	Analogue	0V to 5V	Analogue input reference voltage measurement. 12-bit unsigned conversion.
AIN VRH	I	Analogue	0V to 5V	5V reference for analogue input conversions. 12-bit unsigned conversion.
AIN VRH-VRL 25%	I	Analogue	0V to 5V	1.25V reference for analogue input conversions. 12-bit unsigned conversion.
AIN VRH-VRL 50%	I	Analogue	0V to 5V	2.5V reference for analogue input conversions. Will read as 2.48V due to 20mV offset in processor implementation. 12-bit unsigned conversion.
AIN VRH-VRL 75%	I	Analogue	0V to 5V	3.75V reference for analogue input conversions. 12-bit unsigned conversion.

Signal	I/O	Signal type	Range	Notes
AIN VRL	I	Analogue	0V to 5V	0V reference for analogue input conversions. 12-bit unsigned conversion.
Current trip monitor				
Monitor (ct) (pin A3)	I	Digital	0 or 1	Active high.
Digital				
DIN injector-batt-fault (pin A16, A32, A33, A34, A35, A36, A37, A38, A39 and A45)	I	Digital	0 or 1	Batch fault indicator for injector outputs. Set to 1 when a short to battery fault occurs on any output.
DOT disable-CAN (pin A23 and A24)	O	Digital	0 or 1	Set to 0 to enable the CAN-1 transceiver, set to 1 to disable.
DOT disable-CAN (pin A28 and A43)	O	Digital	0 or 1	Set to 0 to enable the CAN-0 transceiver, set to 1 to disable. Implements Wake-On-CAN.
DOT enable-EXT-PSU1 (pin A25)	O	Digital	0 or 1	Sensor supply switch. Set to 1 to enable supply.
DOT fault-clear (pin A3)	O	Digital	0 or 1	A transition from 0 to 1 clears the current trip fault on the variable resistance output.
DOT hold-PSU (pin A2)	O	Digital	0 or 1	Control power supply to the ECU.
DOT injector-clock (pin A16, A32, A33, A34, A35, A36, A37, A38, A39 and A45)	O	Digital	0 or 1	PWM clock signal for all injectors.
Digital monitor				
Monitor (d) (pin A16)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A32)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A33)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A34)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A35)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A36)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A37)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A38)	I	Digital	0 or 1	Digital diagnostic monitor.

Signal	I/O	Signal type	Range	Notes
Monitor (d) (pin A39)	I	Digital	0 or 1	Digital diagnostic monitor.
Monitor (d) (pin A45)	I	Digital	0 or 1	Digital diagnostic monitor.
Fault Monitor				
Monitor (sb) (pin A16)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A32)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A33)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A34)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A35)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A36)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A37)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A38)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A39)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Monitor (sb) (pin A45)	I	Digital	0 or 1	Short to Battery fault monitor. Serial input.
Memory check				
Monitor (counter eTPU background task)	I	Digital data	0 to 65535	Cyclic counter providing number of times the eTPU background task runs. Its rate of increase can be used to determine the rate of the background task.
Monitor (fc SDM-checksum)	I	Digital data	0 to 65535	Saturating counter providing number of times the eTPU module's data memory failed a checksum test.
Thermal trip monitor				
Monitor (tt) (pin A1)	I	Analogue	0V to 5V	Digital output thermal trip monitor.
Monitor (tt) (pin A17)	I	Analogue	0V to 5V	Digital output thermal trip monitor.
Monitor (tt) (pin A30)	I	Analogue	0V to 5V	Digital output thermal trip monitor.
Monitor (tt) (pin A46)	I	Analogue	0V to 5V	Digital output thermal trip monitor.
Voltage monitor				
Monitor (v) (pin A1)	I	Analogue	0V to 36.915V	Digital output voltage monitor. 12-bit unsigned conversion.

Signal	I/O	Signal type	Range	Notes
Monitor (v) (pin A16)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A17)	I	Analogue	0V to 36.915V	Digital output voltage monitor. 12-bit unsigned conversion.
Monitor (v) (pin A25)	I	Analogue	0V to 5.712V	Switched sensor supply voltage monitor. 12-bit unsigned conversion. To convert measured voltage (V_m) to actual voltage (V_a) use the equation, V_a=V_m*37.7/33.
Monitor (v) (pin A30)	I	Analogue	0V to 36.915V	Digital output voltage monitor. 12-bit unsigned conversion.
Monitor (v) (pin A32)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A33)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A34)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A35)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A36)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A37)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A38)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A39)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A45)	I	Analogue	0V to 7.5V	Injector diagnostic feedback voltage.
Monitor (v) (pin A46)	I	Analogue	0V to 36.915V	Digital output voltage monitor. 12-bit unsigned conversion.

Chapter 4. Operational details

4.1. ECU power

The power supply pin (V_{PWR} A2) and the ground pin (V_{GND} A31) are both rated to (pending).

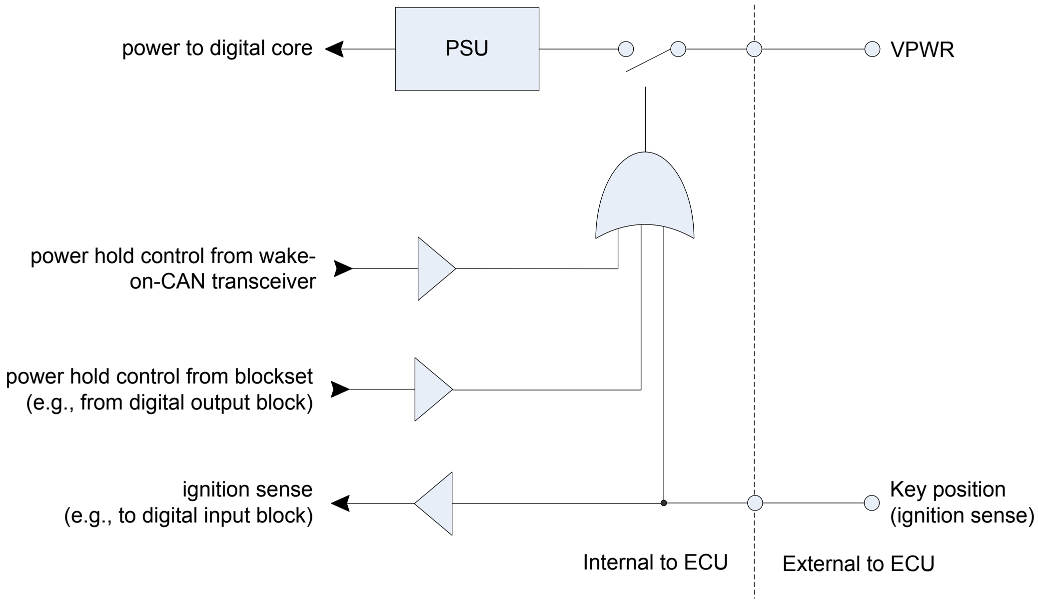
The ECU V_{GND} (pin A31) and sensor ground (pins A40) are directly connected together via a ground plane in the ECU PCB. The ECU case is capacitively coupled to V_{GND}.

The ECU is designed for 12V or 24V vehicles, with various modes of operation based on the voltage (see Table 1.1, “Specification”). The ECU is protected against reverse supply connection. All inputs and outputs are protected against short-to-V_{PWR} or short-to-V_{GND} over normal operating range.

4.2. ECU power — control

The ECU power arrangement is shown in Figure 4.1, “Switching arrangement for main power supply”.

Figure 4.1. Switching arrangement for main power supply



In order to power the ECU from a sleep state, the power supply pin (V_{PWR} A2) must be powered and at least one of the following must occur:

- Key position (ignition sense) input (pin A26 is driven high)
- A dominant bit is detected on CAN bus A28 and A43

The ECU will remain powered as long as the power supply pin (V_{PWR} A2) is connected to a power supply and any one of the following signals are asserted:

- key position (ignition sense) input (pin A26)
- the internal power hold signal (DOT hold-PSU)
- the CAN transceiver on pins A28 and A43 has detected CAN traffic

> **Note**
>
> In order for the ECU to enter a shutdown state, all three signals must be non-asserted.

In order to shut the ECU down, the CAN transceiver on pins A28 and A43 must be placed into its shutdown state. To place the transceiver into its shutdown state, the DOT disable-CAN must be toggled at a frequency of 1 Hz and a duty cycle of 50%.

> **Note**
>
> If there is any CAN traffic on this CAN bus, however, the ECU will not be able to enter a shutdown state.

The application software must monitor the CAN bus and determine if it is appropriate to shut the ECU down by disabling the CAN transceiver.

The internal power hold signal allows for the ECU application software to hold the ECU on after the external key position input is opened, allowing, for example, non-volatile memory processing to occur. For the ECU to hold power the internal DOT hold-PSU channel needs to be asserted. Setting this internal channel high will hold power when the key position input is opened, setting it low will allow the ECU to power off when the key position input is opened.

> **Note**
>
> When using the *power hold* functionality, it is best to set the internal DOT hold-PSU channel high *as soon as* the external key position input (pin A26) is closed and only set low once all required shutdown tasks have completed.

> **Note**
>
> When the ECU is first connected to a power supply, the ECU will power itself up regardless of the state of the external key position input even if there is no CAN traffic due to the initialization behavior of the wake-on-CAN device.
>
> If there is no application software, the boot code will place the ECU into a shutdown state after 10 seconds of inactivity on the CAN bus.

4.3. ECU power — sensor supplies

The ECU provides one external sensor power supply (pin A25). The sensor supply can be switched off using DOT enable-EXT-PSU1 to allow the application software to perform intrusive diagnostics on sensors.

The power supply is monitored by an analogue input which can be used to check for short circuits and measure the exact output voltage for use with ratiometric sensors.

Table 4.1. PSU 1 monitor voltages

Voltage [a]	Meaning
4.73V - 5.00V	Output short to battery
4.04V - 4.73V	Normal operation
0.00V - 4.04V	Output over current or short to ground

[a] These voltages are based on absolute A/D counts (referenced to the ECU's internal 5V supply).

4.4. Analogue inputs

The analogue inputs (pins A4, A5, A15, A18, A19, A20, A21 and A22) sample voltage with varying resolution and range. See the pin information for more details.

> **Note**
>
> If any of the pins A16, A32, A33, A34, A35, A36, A37, A38, A39 and A45 are not being used as digital outputs then it is possible for them to be used as analogue inputs with a range of 0V to 7.5V, a loading of TBC to ground and a filter of 1Hz.
>
> If any of the pins A1, A17, A30 and A46 are not being used as digital outputs then it is possible for them to be used as analogue inputs with a range of 0V to 36.915V, a loading of 47K to ground and a filter of 78Hz.
>
> Providing the output transistor is switched off, the pin can be driven by an external source and the pin's voltage monitor will reflect the actual voltage on the pin.

4.5. Analogue inputs — ratiometric measurement

Ratiometric sensors are read in as a ratio between the sensor and reference voltages (V_{sens}/ V_{ref}). Correction is only required on channels for which an absolute voltage measurement is required. Correction is not required for sensors supplied from the 5V sensor supply and which produce an output that is ratiometric to the supply.

To read a variable sensor which is an absolute referenced sensor (V_{sens},abs) the V_{ref} for the ADC requires correction:

$$V_{ABSOLUTE} = \frac{V_{MEASURED} \times V_{REF}}{V_{2.5} \times 2}$$

Where $V_{MEASURED}$ is the A/D conversion for an external pin, V_{REF} is the A/D conversion for internal channel AIN VRH, $V_{2.5}$ is the A/D conversion for internal channel AIN PSU+2.5VD, and *2* is a constant.

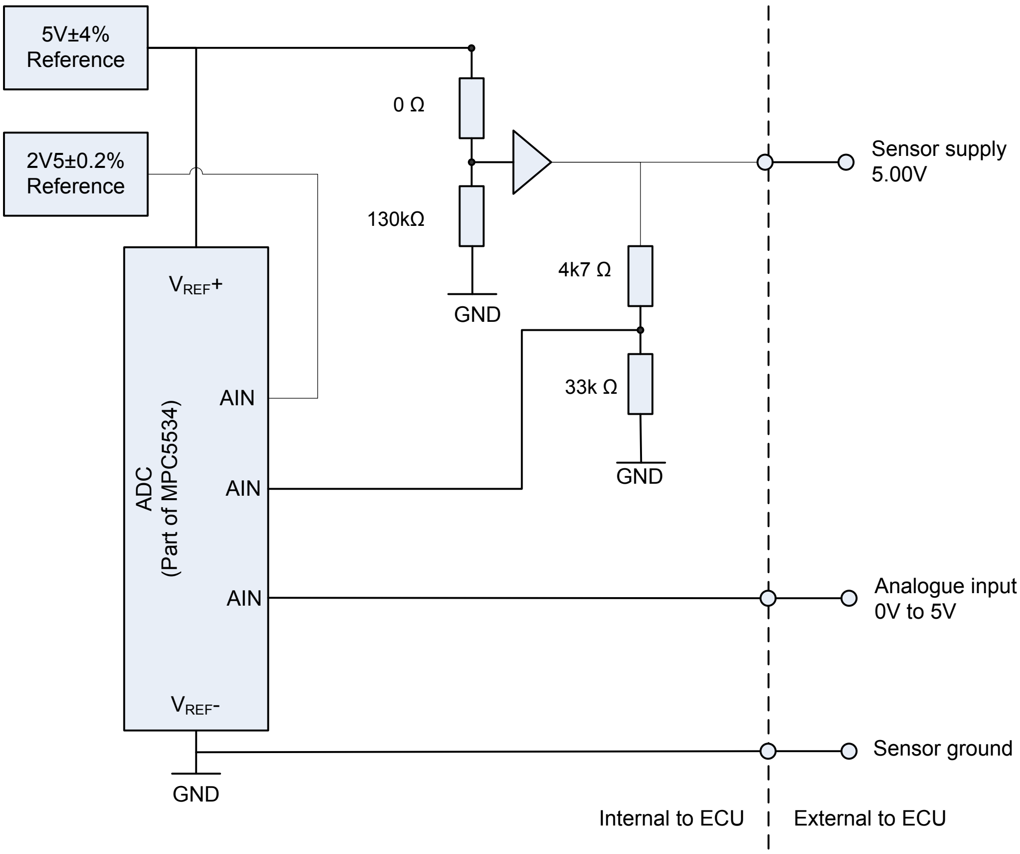
4.6. Analogue inputs — internal temperature input

The M221 family has provision for an internal temperature sensor measured by AIN internal-ecu-temp. This temperature sensor is unpopulated by default, so measurements of this signal will report 0 V.

4.7. Analogue inputs — relationship between V_{REF}, sensor supplies and inputs

The ECU power arrangement is shown in Figure 4.2, “VREF arrangement”. The figure shows the relationship between the internal 5V V_{REF} and ground, the external sensor supply and ground, and the analogue inputs.

Figure 4.2. V_{REF} arrangement



The internal low precision 5V reference supplies the reference pin on the ADC. The exact voltage being produced can be read on a scaled ADC channel, Vext_psu = (Vadc * 37.7)/33. The sensor ground is a nominal 0V, but may be slightly above this due to voltage drop across the protection device.

The exact voltage on the analogue input pin can be read on a direct (unscaled) ADC channel. Standard 0-5V inputs are passed directly to the ADC with no scaling.

Some analogue input pins are internally pulled up to the sensor power supply (pin A25). If the sensor supply is not enabled, floating inputs will fluctuate when read by the ADC. The sensor supply must be enabled for voltage measurements made on any of these channels.

4.8. Digital inputs

The digital inputs (pins A6, A7, A8, A9, A10, A11, A12, A13, A14, A15, A26, A27, A29, A41, A42 and A44) sense the binary state based on the pin voltage and a threshold.

Not inverted

For pins A12, A13, A14, A26, A29, A41, A42 and A44, see Table 4.2, "Digital input thresholds" for input voltages corresponding to the measured digital state.

Table 4.2. Digital input thresholds

Pin voltage	Digital state
<= 1.69 V	0

Pin voltage	Digital state
>= 3.36 V	1

Inverted

The M221 injector trigger inputs A6, A7, A8, A9, A10, A11, A12, A13, A14 and A15 inputs are inverted digital inputs. See Table 4.3, “Injector trigger input thresholds” for the voltage thresholds on these inputs.

Table 4.3. Injector trigger input thresholds

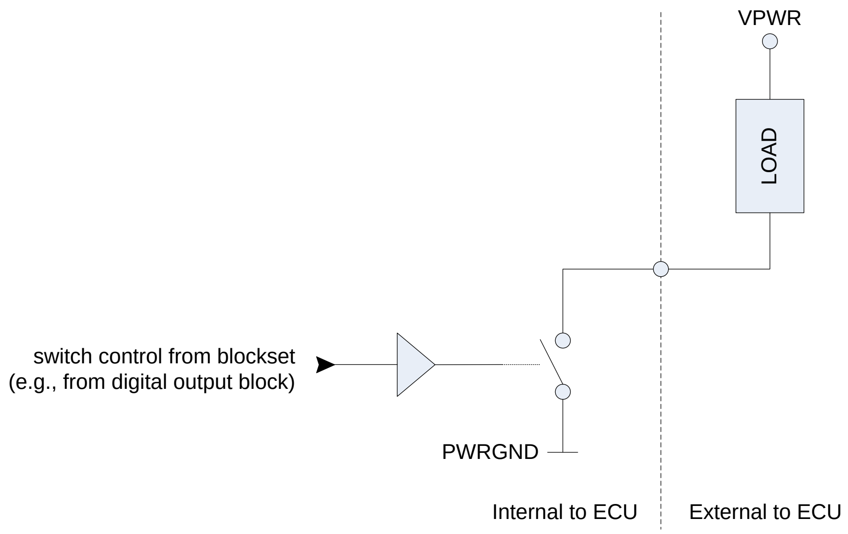
Pin voltage	Digital state
> 3.68 V	0
< 1.22 V	1

> **Note**
>
> All external signals are low pass filtered to prevent signals of excessive frequency from tying up the target processor. See the pin information for more details.

4.9. Digital outputs

Pins A1, A17, A30 and A46 are configured as low-side — the ECU switches the output pin to ground, the load is connected to the output pin and the battery.

Figure 4.3. Low-side switching arrangement for digital outputs



These low-side digital outputs contain internal monitoring circuitry that provides diagnostic information. However, as a consequence a small leakage current will flow through the actuator when the low-side output driver is turned off. Refer to Table 4.4, “Low-side digital output leakage current” for typical leakage currents at specified operating voltages.

Table 4.4. Low-side digital output leakage current

Supply Voltage (V)	Typical Leakage Current (mA)
13	0.030

Supply Voltage (V)	Typical Leakage Current (mA)
25	0.075

4.10. Digital output — state monitoring

The voltage of the digital output pins A1, A17, A30 and A46 can be monitored using a corresponding internal *Monitor (v)* channel. The analogue monitor channel measures the actual voltage at the pin after scaling according to the equation

measured voltage (Vm, 0 to 5V) to actual voltage (Va, 0 to 36.9V): Va = Vm*347/47

When the pin is used as a PWM, there are two possible uses for such a feedback:

- Before starting a PWM, by reading the voltage on the pin and checking for open or short circuits.
- By reading the average voltage on a PWM output and comparing it with the demanded PWM width and the battery voltage reading, you can perform a consistency check that the PWM output is performing as expected. This method can be applied if the PWM frequency is higher than the filter cut off frequency for that output.

When the pin is used as a plain digital output, feedback is used as follows:

- Read the voltage on the pin and check for open or short circuits.

4.11. Digital output — low-side driver protection and diagnostics

The digital outputs A1, A17, A30 and A46 are self protected by a thermal shutdown circuit. This protection is based only on output driver chip temperature and is independent of operating voltage.

Over-temperature shutoff occurs in the range 150 to 190 ºC (170 ºC typical). The device automatically restarts when temperature falls approximately 15 ºC below cutoff temperature.

An application can monitor these outputs for thermal shutdown via the *Monitor (tt)* analogue input channels for the corresponding outputs. See Table 4.5, “Low-side digital output thermal trip” for threshold values.

Table 4.5. Low-side digital output thermal trip

Monitor (tt) voltage	Output Status
<= 1 V	Device in thermal shutdown
>= 4.7 V	Normal operation

> **Note**
>
> The low-side output thermal monitors are non-latching; in order to guarantee detection of a fault, the application must balance the rate at which it samples the monitor inputs against the cooldown rate of the hardware in a fault condition. This rate will depend on the particular installation and usage profile of the ECU, but in general higher sample rates are required for cooler environmental conditions.

4.12. Injector outputs — operation

The injector outputs (pins A16, A32, A33, A34, A35, A36, A37, A38, A39 and A45) are peak and hold injectors controlled by the associated injector trigger inputs A6, A7, A8, A9, A10, A11, A12, A13, A14 and A15 and the injector clock controlled by PWM output DOT injector-clock.

The application must set the DOT injector-clock output to the desired dither frequency and 50% duty cycle for proper operation.

When a trigger input pin for an injector transitions from high to low, the associated injector output will be turned on. The output current will be allowed to rise to the peak current of 4A, then will immediately be limited to the hold current of 1A. See Figure 4.4, "Normal injector operation" for the normal operation waveform. See Table 4.6, "Injector current thresholds" for the range of peak and hold currents.

> **Note**
>
> If an injector output is short-to-battery, the current waveform will essentially be the same as the normal operation waveform.

Figure 4.4. Normal injector operation

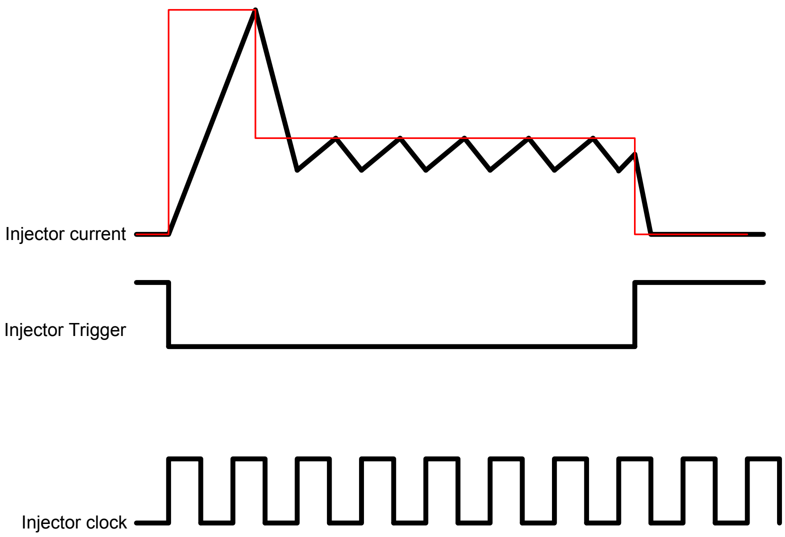
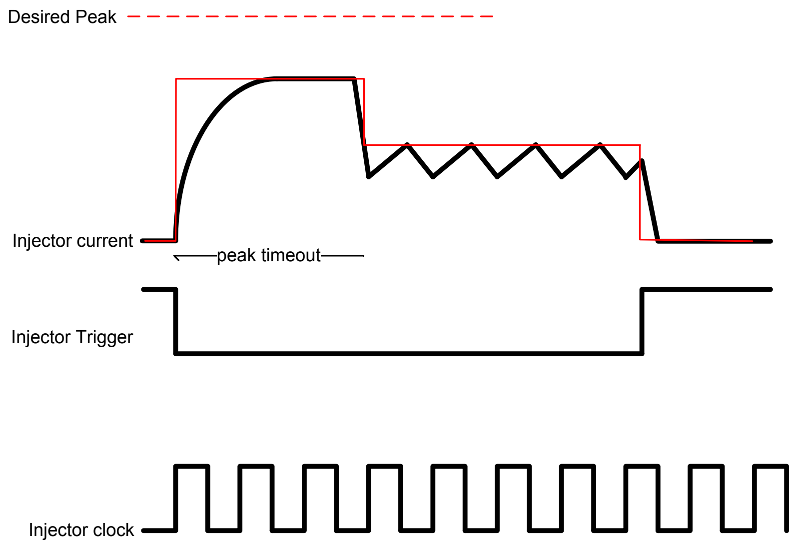


Table 4.6. Injector current thresholds

Injection Stage	Min (A)	Max (A)
Peak	3.74	4.63
Hold	0.89	1.25

> **Note**
>
> If the current does not reach the peak current within nominal 7 ms (due to, for instance, low supply voltage), the output will switch to the 1A hold level. This timeout may be different under option control; consult option control documentation if applicable. See Figure 4.5, "Injector operation under timeout"

Figure 4.5. Injector operation under timeout



The injector trigger input must be high for at least (pending) ms to re-enable the peak current threshold after an output is switched off.

4.13. Injector outputs — open circuit and short-to-ground diagnostics

The injector outputs (A16, A32, A33, A34, A35, A36, A37, A38, A39 and A45) include output state and short-to-battery monitors.

The digital and analogue state monitors *Monitor (d), Monitor (v)*, respectively, for the injector output pins reflect the state of the output pin. A short to ground or open-circuit condition is indicated if the Monitor (d) remains zero or the Monitor (v) remains below a threshold. See Table 4.7, "Injector Diagnostic Monitor(v) thresholds" for threshold levels.

Table 4.7. Injector Diagnostic Monitor(v) thresholds

Monitor (v) voltage	Output Status
>= 3.41 V	Normal
<= 2.42 V	Open or shorted to ground

4.14. Injector outputs — short-to-battery diagnostics

The M221 injector output hardware monitors the outputs for short to battery operation. This detection requires an injector to be activated, and the hardware latches the first detected fault until the application reads the fault flag status. The faults are made available by reading the *Monitor (sb)* digital inputs (see Table 4.8, "Injector Diagnostic Monitor(sb) levels"). The platform will set the DIN injector-batt-fault digital input to 1 when a new injector short-to-battery fault has been detected.

An application should read the *Monitor (sb)* digital inputs at a fast rate to ensure that it detects all occurrences of faults on each injector. If a short-to-battery fault is detected on one injector, no other injectors can register a fault until that first fault is read by the application.

Reading the *Monitor (sb)* input for an injector will reset the fault flag for that output as well as the DIN injector-batt-fault fault flag.

> **Note**
>
> Reading a *Monitor (sb)* flag to clear the DIN injector-batt-fault has a delay of one model iteration; if the application reads a short to battery monitor in one iteration and the DIN injector-batt-fault is asserted at the beginning of the next iteration, a new injector fault has been detected.

The injector short to battery protection acts as a current limit; the output will still be active as long as the input trigger pin is low but the current will be limited to the hold current of 1A.

Table 4.8. Injector Diagnostic Monitor(sb) levels

Monitor (sb) value	Output Status
1	Normal
0	Short to battery

4.15. Variable resistance output — operation

The M221 provides a variable resistance output on A3.

The resistance is controlled by using a SPI based digital potentiometer. The output of the digital potentiometer is controlled from software by commanding it to a percentage of its total range. The digital potentiometer resistance is calculated according to the following transfer function:

Digital potentiometer resistance = (50000 Ohm * commanded percentage) + wiper resistance

Where the wiper resistance is between 50 and 100 Ohm.

The overall circuit resistance is then calculated according to the following equation:

resistance = (50300 / (Digital potentiometer resistance)) * 3.9 Ohm + 3.9 Ohm.

4.16. Variable resistance output — over current protection

The output is protected for over-current. If the current through the effective resistance exceeds approximately 1A, the hardware will assert the Monitor (ct) digital input and set the input to its maximum resistance.

If the current trip is asserted, the application should reduce the digital poteniometer resistance to its minimum (highest circuit resistance), then set the DOT fault-clear to one to re-enable the output.

> **Note**
>
> The DOT fault-clear signal is edge-based; the fault condition is cleared on a transition of this signal from 0 to 1. If the short condition is persistent, however, the Monitor (ct) will immediately set again, and an application must set the fault clear flag to zero again before attempting to reset the output.

4.17. CAN communication busses

The CAN busses (pins A23+A24 and A28+A43) are implemented using high-speed CAN transceivers. Neither CAN bus has terminating resistors.

CAN bus 0 (pins A28+A43) will wake the ECU from shutdown mode if traffic is detected on that bus.

4.18. Memory — non-volatile storage and lifetime

The ECU supports non-volatile memory storage in Flash. Battery backed RAM is not supported.

The processor's Flash memory is split into small and large memory blocks. The application and calibration are stored in large blocks, whilst DTC information, freeze frames and so on are stored in small blocks.

The largest Flash block can take up to approximately 7.5 seconds to erase. This occurs in an environment where the Flash has been erased and programmed many times at its temperature extreme. The typical erase time is smaller, especially at ambient temperatures. Reprogramming an ECU (where many large blocks would be erased), or storing DTC information across power cycles, can therefore take some time. Users and applications should take this into consideration.

The minimum number of erase cycles is approximately 1,000 for large Flash blocks and 100,000 for small Flash blocks. This occurs in an environment where the Flash has been erased and programmed many times at its temperature extreme. The typical number of erase cycles is larger, especially at ambient temperatures.

The minimum data retention is approximately 5 years for blocks which have been erased less than 100,000 times, and approximately 20 years for blocks which have been erased less than 1,000 times.

The information about the Flash has been taken from Freescale's MPC5534 Microcontroller Data Sheet document, revision 4 (dated Mar 2008).

4.19. System modes

The ECU can run in one of two system modes: reprogramming mode and application mode. In *reprogramming* mode, the ECU can be reprogrammed with application software from a calibration tool. In *application* mode, the ECU runs the programmed application software. The ECU selects which mode to enter when it is powered up by measuring the voltage on the A27 pin.

Table 4.9. System mode selection

Voltage	System mode
> +36V	Enter reprogramming mode. If valid application software has previously been programmed, then use the CCP settings from that application, otherwise use the default CCP settings.
< -16V	Enter reprogramming mode. Use the default CCP settings.
Otherwise	Enter application mode if valid application software has previously been programmed, otherwise enter reprogramming mode.

4.20. Floating point capabilities

The ECU closely adheres to the IEEE-754 for floating point numbers.

When using Simulink, floating point Simulink models are supported — all calculations are performed using single-precision (even if the model uses double-precision, the ECU performs calculations using single-precision).

When using the C-API, floating point applications are supported — all calculations are performed using single or double precision, as determined by the application code (although double precision will incur some software overhead — see the compiler reference manual for further details).

The rounding mode is set to *round-to-nearest*. In some conditions, the ECU will not adhere to the IEEE-754 standard:

Table 4.10. Floating point conditions

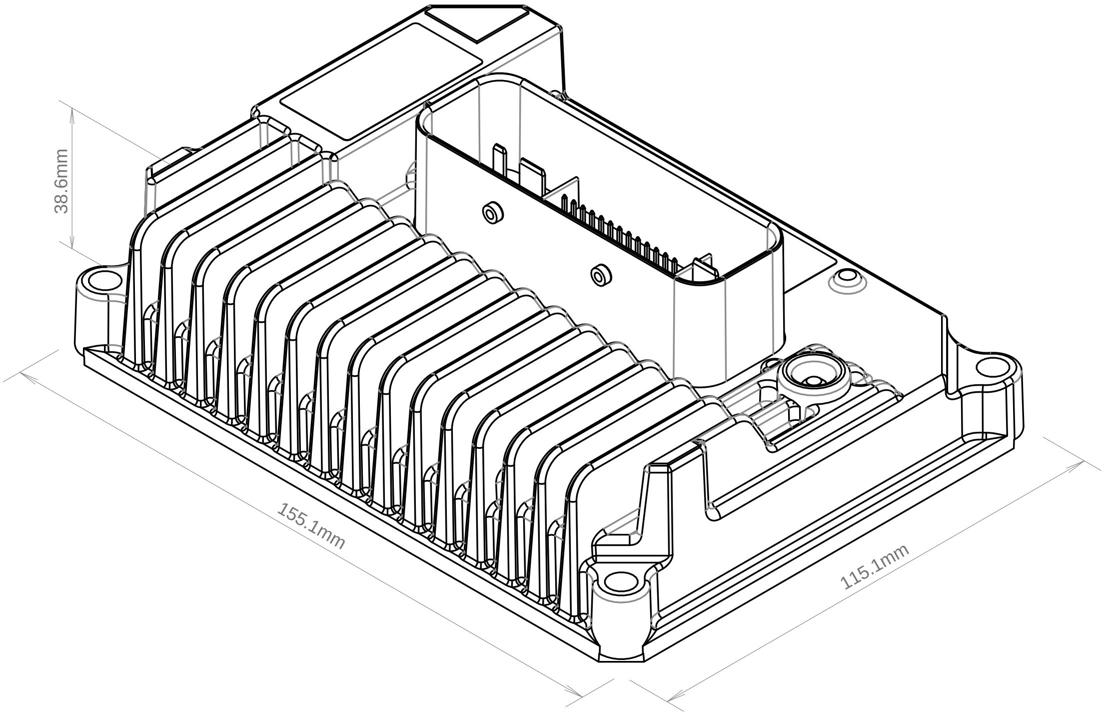
<table>
<tr><th>Condition</th><th>Result</th></tr>
<tr><td>Underflow</td><td>The result of a calculation underflow is ±0. The sign is based on the signs of the operands.</td></tr>
<tr><td>Overflow</td><td rowspan="2">The result of a calculation overflow is ±max where max is approximately 3.4×10^{38}. The sign is based on the signs of the operands.</td></tr>
<tr><td>Divide by zero</td></tr>
</table>

The ECU does not generate ±*Inf*, *NaN* or a denormalised number as the result of a calculation.

Chapter 5. Dimensions

The ECU has the following dimensions:

Figure 5.1. Outline of physical dimensions



Appendix A. Contact information

If you have questions, or are experiencing issues with OpenECU please see the FAQ website:

website
    Support.OpenECU.com [http://Support.OpenECU.com]

If you still have questions after searching through the FAQ, or want to discuss sales or proposals, you can contact main office:

Tel
    +1 734 656 0140

Fax
    +1 734 656 0141

during normal working hours (Mon to Fri, 0930 to 1700 EST).