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TTC 2300 Family

TTC 2300 Family System Manual

Product version 01.00

Original instructions

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1 Introduction

1.1 General

This is the System Manual for the TTC 2300 Family. This document provides detailed information about the products, including applicable safety standards and guidelines, instructions for safe operation, connectors and parts, the I/O features, and other hardware-related topics.

The TTC 2300 Family, which is part of the TTC 2000 Series, includes the following variants:

- TTC 2310 [14]
- TTC 2380 [16]
- TTC 2385 [18]
- TTC 2390 [20]

This System Manual is intended for use by qualified technicians and system integrators.

1.2 Further documentation

This System Manual is one of many user documents for the TTC 2300 Family. Please see your release package for additional user documentation, including:

- Software Manual [12]
- I/O Driver Manual for each variant:
  - TTC 2310 I/O Driver Manual [15]
  - TTC 2380 I/O Driver Manual [17]
  - TTC 2385 I/O Driver Manual [19]
  - TTC 2390 I/O Driver Manual [21]
- Mounting Requirements Document [8]
- Product Drawing [9]
- Quick Start Guide [7]
- Safety Manual [11]

1.3 Notation

In the context of this document, the terms *TTC 2300* and *TTC 2300 Family* refer to the *all* products in the TTC 2300 Family.

NOTE The information given in this System Manual is valid for *all* variants in the TTC 2300 Family, unless otherwise stated.

1.4 Support

The Release Note [10] contains known issues.

Further information, including the latest software releases and most recent documents, can be found on the TTControl Service Area at https://www.ttcontrol.com/service-area/.

For technical assistance and support regarding TTControl GmbH products, create a support ticket via https://ttcontrol.4me.com/.

2 Product overview

The TTC 2000 Series is a series of robust and powerful mid-sized ECUs which can be used for various applications in which sensor values must be captured and evaluated. Hydraulic and electric actuators can be controlled with several of the high-side or low-side outputs. The interaction with other ECUs in the overall system is achieved via various communication interfaces such as 100BASE-T1, 100BASE-TX, CAN, or LIN.

The TTC 2300 Family has been designed for sensor/actuator management for both safety and non-safety applications.

2.1 Features

Overview of features for variants in the TTC 2300 Family. For variant-specific information, see section 2.2.

2.1.1 Communication interfaces

- 4x CAN FD
  - 1x Wake-up capable
  - 1x CAN ISOBUS compliant
- Optional 2x 100BASE-T1, or 100BASE-TX (10/100 Mbit/s) (variant dependant, see Table 1)
- 1x LIN Master
- Supported 4x SENT inputs with SPC [1] functionality

2.1.2 Safety features

- 2x Internal secondary shut-off paths for HS outputs
- I/O Diagnostic measures
- Watchdog
- Voltage monitor for internal supply rails

2.1.3 Additional features

- 2x Emergency shut-off inputs (software configurable)

2.1.4 Power supply

- Supply voltage: 8 to 32 V
- Separate supply pins for CPU subsystem and I/O subsystem
- Load dump protection
- 2x fixed sensor supplies with an output voltage of 5 V
  - SSUP_0
  - SSUP_1
- 1x variable sensor supply, configurable via software for output voltages between 5 V and 12 V (max. 12.75 V) in 50 mV steps
  - SSUP_2

1. upcoming feature

- Each sensor supply can deliver up to 750 mA load current continuously
- Each sensor supply has a capacitive load of up to 100 µF
- All sensor supplies have identical hardware designs
- Sensor supply and battery monitoring

2.1.5 Physical specifications

- Dimensions: 170.6 x 232 x 42 mm
- Weight: 1.2 kg
- Operating ambient temperature: - 40 to + 85 °C
- Storage temperature: - 40 to + 85 °C
- Housing IP6k7- and IP6k9k-rated die-cast aluminum housing
- 2x 48 pin connector
- 1x 2-slot HSD connector (variant dependant)
- Pressure equalization with water barrier
- Operating altitude 0 to 4000 m

Other device dimensions, including tolerances, weight and other physical specifications for the TTC 2300 Family can be found in the Product Drawing (PD) [9]. Additional physical specifications, including thermal requirements, can be found in the Mounting Requirements Document (MRD) [8].

2.1.6 Inputs and outputs

- 60x I/Os: 40x out, 20x in, including:
  - 18x PWM HS with current measurement (variant dependant)
  - 12x digital out LS with current measurement
  - 4x SENT inputs with SPC [1] functionality
- Option to configure up to 4x H-Bridge mode for motor control (SW feature)
- 3x status LEDs

All inputs and outputs of each TTC 2300 variants are protected against electrical surges and short circuits. In addition, internal safety measures allow the detection of open load, overload and short circuit conditions at the outputs. Proportional hydraulic components can be directly connected to the current-controlled PWM outputs. The TTC 2300 Family is designed to support a variety of analog and digital sensor types. Many software-configurable input options can be selected to adapt to different sensor types. A group of individually configurable analog inputs with a precision voltage range from 0 to 5 V. Those analog inputs can be set to different voltage ranges by software in order to achieve the best analog accuracy and resolution. The analog inputs can also be configured as a current input or for resistive measurements.

2.1.7 Core

- Infineon Aurix 32-bit super-scalar TriCore CPU
- Serial flash with file system (optional)
- Internal FEE (Flash Emulated EEPROM)

2.1.8 Software

- C-programming API
- PXROS RTOS with mixed-criticality support
- CODESYS 3.x
- UDS Bootloader compatible
- CAN ISOBUS compliant

Programming options

The unit may be programmed in C or CODESYS 3.x. CODESYS is one of the most common IEC 61131-3 [1] programming systems running under Microsoft Windows. CODESYS supports several editors, including the Instruction List Editor, Sequential Function Chart Editor, and Function Block Diagram Editor. CODESYS produces native machine code for the main processor of the TTC 2300.

2.2 TTC 2300 Family variants

The following TTC 2300 Family variants are described in this System Manual:

- TTC 2310 [14]
- TTC 2380 [16]
- TTC 2385 [18]
- TTC 2390 [20]

Detailed overviews of each variant, including the latest ECU block diagrams, can be found in the variant-specific ECU Datasheets.

Feature	TTC 2310	TTC 2380	TTC 2385	TTC 2390
CPU				
32-bit TC 377	Yes	Yes	Yes	-
32-bit TC 379	-	-	-	Yes
Int. FLASH	6 MB	6 MB	6 MB	16 MB
Int. SRAM	992 kB	992 kB	992 kB	6.47 MB
Int. FEE	256 kB	256 kB	256 kB	1 MB
Memory				
Ext. Serial FLASH	16 MB	16 MB	16 MB	32 MB
Ext. EEPROM				
Ext. FRAM	8 kB	-	-	-
Interface				
CAN FD	4	4	4	4
CAN3 is ISOBUS compliant	Yes	Yes	Yes	Yes
CAN termination	1	1	1	1
100BASE-T1	0	2	0	0
100BASE-TX	0	0	2	2
LIN	1	1	1	1
Outputs				
Digital high-side 4 A	18	10	10	10
Digital low-side 4 A	0	4	4	4
PWM high-side 4 A	8	16	16	16
PWM high-side 8 A	2	2	2	2
PWM low-side 4 A	8	8	8	8
Status LED	3	3	3	3
Inputs				
Analog IN 4-mode (V/I/R)	8	8	8	8
Analog IN 2-mode(V)	4	0	0	0
Timer IN/SENT	4	4	4	4
Timer IN/CL	8	8	8	8
Power				
Sensor supply fixed (5 V)	2	2	2	2
Sensor supply variable (5 to 12.5 V)	1	1	1	1
Sensor GND	4	4	4	4
Terminal 15	1	1	1	1
Wake-up	1	1	1	1
Emergency shut-off path				
External shut-off interfaces	2	2	2	2

Table 1: *TTC2300 Family variants*

3 Instructions for safe operation

3.1 General

- Carefully read, understand, and follow the instructions and specifications listed in this document before operating the device.
  Failure to comply with these instructions or operation of the device outside the intended field of operation may result in serious damage to machinery and may seriously affect the safety of users. TTControl cannot be held liable for any personal injury or property damage resulting from improper installation or use of the device, non-compliance with the instructions in this document, or non-compliance with the intended field of operation. Non- compliance will result in the exclusion of any liability and warranty.
- The regulations and standards which apply are highly dependent on the specfic user applications of the overall system that the TTC 2300 device is built into. Therefore, it needs to be ensured that these regulations and standards are fulfilled by the TTC 2300 by comparing Declaration of Conformity, ECE regulation certificate and Summary of Test Reports (see 4 and 5 for further details).
- Always operate the product within the electrical and environmental specifications and follow the mounting instructions provided by TTControl. Usage of the product outside the specifications may be hazardous to persons or property.
- Only skilled and trained personnel are allowed to operate this device.
- The device must be stored, handled and installed carefully while being mounted and operated using the types of connectors specified in this document.
  Particular care must be taken to ensure that the pressure equalization membrane is not damanged. See [8] for further details.
- The label on the housing contains important information. The label must not be destroyed or made unreadable.
- The TTC 2300 System Manual is written for a specific product version. Ensure that the *Product Version* on the title page of this document matches the version on the ECU label.
- All firmware, bootloaders, or runtime environments (e.g., CODESYS) used with the device must be authorized by TTControl. Any modifications made to the firmware, bootloader, or runtime environment must be authorized by TTControl.
- The device hardware does not require maintenance activities.
- Do not open and/or modify the device.
- Do not operate a prototype device outside laboratory conditions (e.g., in series products, ...).
- Check the TTControl Service Area regularly to see if updated versions of this document or additions to it are available.

3.2 Intended use

The TTC 2300 Family products are programmable electronic control units for sensor/actuator management and designed for use in safety-related applications.

These electronic control units are specifically designed for operation in vehicles and mobile machinery for applications in the following industrial sectors:

- construction
- snow groomers
- fire engines

- agricultural
- municipal sectors
- automotive

Further target applications are subsystems in stationary machinery provided by HYDAC.

3.3 Improper use

- Operation of the device in an environment that violates the specified range is not permissible.
- Use in explosive areas is not permissible.
- Any use of the product other than as described in section 3.2 is considered to be improper.
- TTControl is not liable for damages resulting from improper use.

3.4 Checks to be done before commissioning the device

- Check the supply voltage before connecting the device.
- Check that the device connector and the cable harness are free of defects.
- Check the correct dimensioning of the wires in the cable harness.
- Always disconnect the power supply before conducting any maintenance or repair work to the machine where the device is mounted (for example, welding or maintenance of the battery system).
- Choose a mounting location for the device so that the operating temperature of the device does not exceed the maximum allowed operating temperature.
- Choose a mounting location for the device which prevents any ergonomic hazard to the user/operator.
- A protective fuse must be installed between the vehicle's battery and the power supply input (BAT+) of the device.
- The device is water-resistant according to IP67 and IP6K9K. Ingress protection is given only when all connectors are plugged in, or all unused pins are sealed.
- Refer to the MRD [8] for further guidelines and instructions.

3.5 Disposal

Disposal of the device must be performed in accordance with prevailing national environmental regulations.

4 Standards and guidelines

The TTC 2300 Family was developed to comply with several international standards and guidelines. See section 1 *Referenced norms and standards* for further details.

See the Summary of Test Reports (STR) [13] for details including information about ingress protection, and the electrical, mechanical and chemical capabilities of the devices.

4.1 Safety certification

Applicable functional safety standards:

- ISO 26262:2018, ASIL C
- ISO 25119:2018, AgPL d
- EN ISO 13849:2015, PL d
- IEC 61508:2010, SIL 2
- ISO 19014:2018, MPL d
- ISO 13850:2015, Category 0 and 1

See section 1 *Referenced norms and standards* for further details.

5 Compliance

The TTC 2300 Family conforms to the following directives and regulations:

- Machinery Directive 2006/42/EC
- EMC Directive 2014/30/EU
- RoHS Directive 2011/65/EU
- ECE Regulation No. 10
- FCC Regulation Part 15

5.1 Regulatory information

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

NOTE

> Changes or modifications made to this equipment not expressly approved by TTControl may void the FCC authorization to operate this equipment.

6 Mounting and Label

6.1 Mounting requirements

Any requirements for mounting, temperature and air flow conditions are defined in the Mounting Requirements Document (MRD) [8]. Furthermore, product dimensions and tolerances are defined in the Product Drawing [9].

6.2 Label information

Any information about the label and its content is defined in the Product Drawing [9].

7 Internal structure

7.1 Safety Concept

If TTC 2300 is used in safety-critical applications, you must follow the requirements specified in the Safety Manual[11].

7.1.1 Overview Safety Concept

The following picture describes all possible (application-controlled) enable/disable paths for the TTC 2300 power stages.

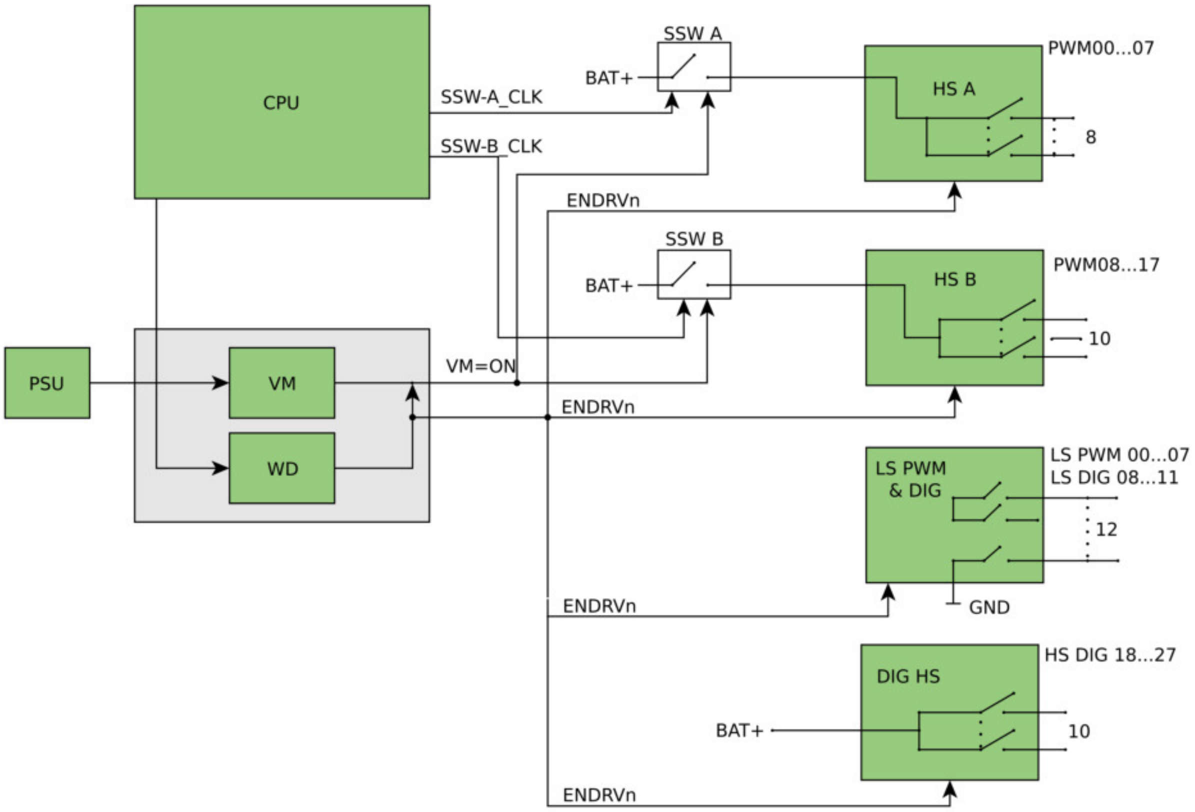


Figure 1: *Safety concept*

7.2 System CPU

CPU MPU

- Composed of the ***Code Access*** *Task MPU* and the ***Data Access*** *Task MPU*
- Applies to SW tasks
- 18 data and 10 code/program ranges, organized in sets; switched via PSW
- Dynamic re-configuration possible
- Scope: whole address space

Bus MPU

- Monitors SRAM accesses via SRI BUS
- Static or dynamic configuration
- Scope: Local SRAM address space

7.2.1 Memory

		TC377	TC397
Cache per CPU	Program	32 kB	32 kB
	Data	16 MB	16 MB
SRAM per CPU	PSPR	64 kB	64 kB
	DSPR	240 kB (core 0/1)	240 kB (core 0/1)
		96 kB (core 2)	96 kB (core 2-5)
	DLMU	64 kB	64 kB
SRAM global	LMU	n/a	768 kB
	DAM	32 kB	128 kB
EMEM	TCM & XCM	2+1 MB	2+2 MB
	XTM	16 kB	16 kB
Program Flash		PF0-PF1: 3 MB (each)	PF0-PF4: 3 MB (each) PF5: 1 MB
	Total	6 MB	16 MB
Data Flash	DF0	256 kB	1 MB
	DF1	128 kB	128 kB

Table 2: *System CPU memory specifications*

7.2.2 CPU access – stall cycles

		Local CPU	Local SRI	Remote SRI
Instruction fetch from PSPR		0	7	10
Data read from PFlash		5+PWS[1]	10+PWS[1]	13+PWS[1]
Instruction fetch from PFlash	buffer miss	2+PWS[1]	9+PWS[1]	12+PWS[1]
	buffer hit	3	6	9
Data read from LMU		n/a	7	10
Data write to LMU		n/a	5 (or 3)[2]	5 (or 4)[2]
Instruction fetch from LMU		n/a	7	10
Data read from DFlash[3]		n/a	5+3*(3+DCWS)[4]	8+3*(3+DCWS)[4]
Data read access from EMEM		n/a	n/a	14 (or 15) [5]
Data write access to EMEM		n/a	n/a	9
Data read access from DAM		n/a	10	13
Data write access to DAM		n/a	7	7

Table 3: *System CPU access – stall cycles*

[1]PWS: Configured PFlash Wait States (Includes cycles for PFlash access cycles only). ECC correction latency is only incurred when the incoming data requires ECC correction.
[2]With pipelining
[3]DFlash runs on FSI clock. $f_{CPU} = 3*f_{FSI}$.
[4]DCWS: Configured DFlash Corrected Wait States (Includes cycles for DFlash access cycles and ECC correction latency).
[5]The EMEM works on f_{BBB} clock which is lower than the f_{SRI} there could be one additional synchronisation cycle for the request to be acknowledged by the EMEM.

7.2.3 3 Core/TC 377

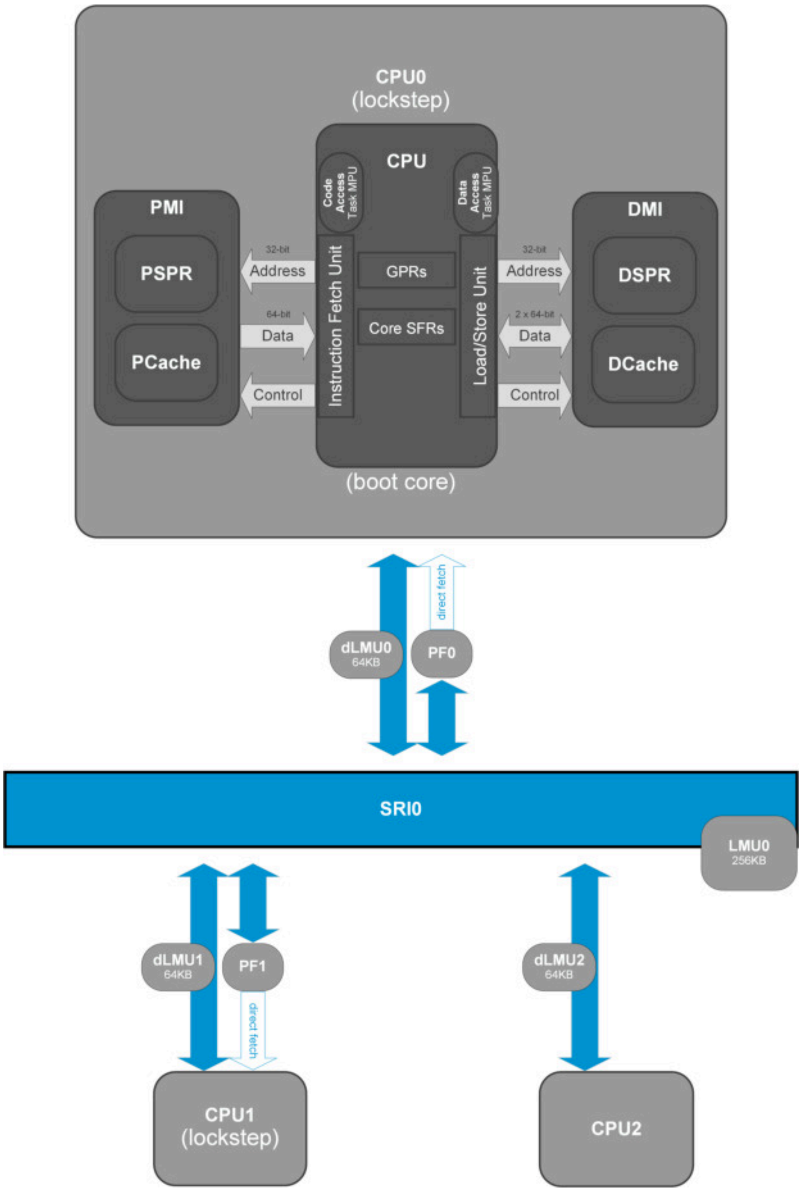


Figure 2: *Detailed block diagram for 3 core (TC 377)*

7.2.4 6 Core/TC 397

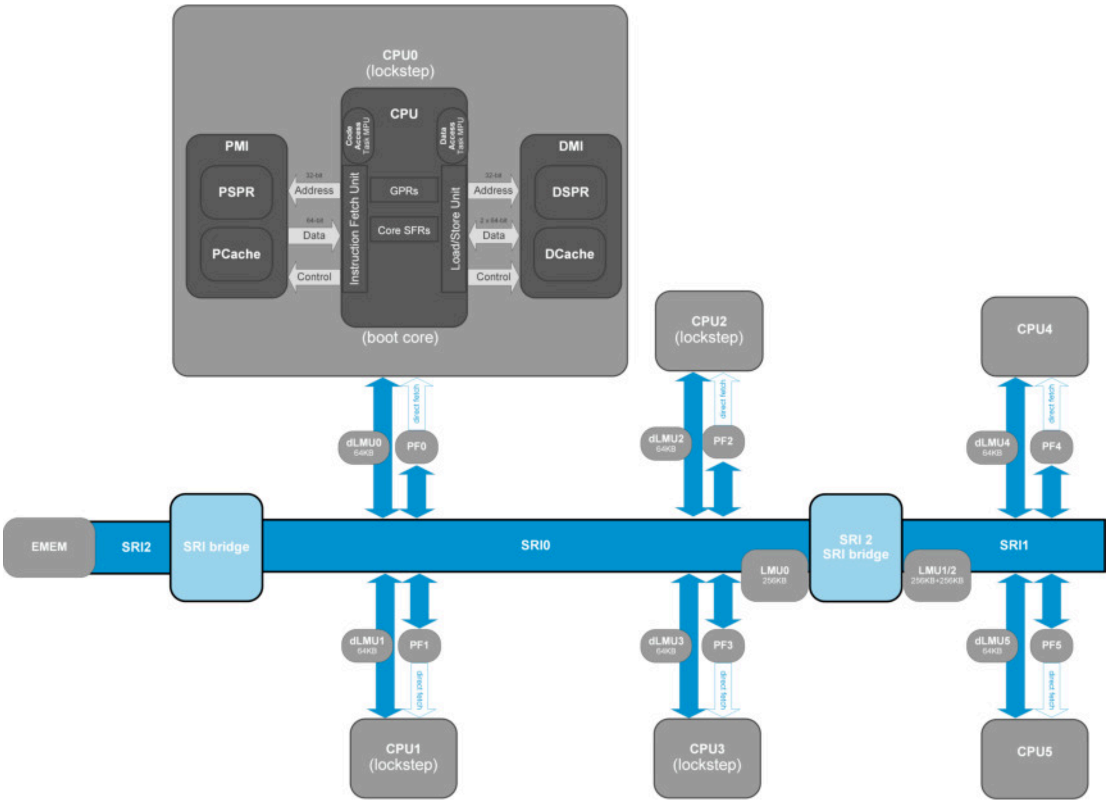


Figure 3: *Detailed block diagram for 6 core (TC 397)*

7.3 Thermal Management

7.3.1 Board Temperature Sensor

Functional description

To measure the temperature within the housing (T_{ECU}), there is a temperature sensor located on the printed circuit board. This sensor allows monitoring of the internal board temperature for diagnostic purposes and monitoring of safety features.

Depending on the T_{ECU} board temperature, the maximum current limit for high- and low-side output stages is adjusted, see e.g.11.10.1. This is a strategy to allow higher current consumption at lower temperatures and to bring the ECU immediately to a safe state and switch off loads if over temperature is detected. See 7.3.1 for temperature limits triggering the safe state.

All input/output tolerance characteristics stated in this System Manual are worst case tolerances and are respected to the internal worst ECU temperature T_{ECU}. At lower T_{ECU}/$T_{ambient}$ temperature and/or lower loads, the tolerances are better.

The (internal) ECU temperature T_{ECU} is close to ambient temperature, when there is no load driven by the power stages at all. The ECU temperature may rise by 40 K above ambient temperature, when there is significant output load (many outputs activated with high load current at the same time) and no airflow supports cooling of the housing. Many applications tend to be somewhere in the middle. Reading out the ECU temperature during system development is a useful feature to analyze the application-specific thermal load and mounting situation.

For further information, please contact TTControl.

Characteristics

Symbol	Parameter	Min	Max	Unit
T_{ECU}	ECU operating temperature	- 40	+ 125	°C
T	Temperature measurement range	- 50	+ 150	°C
T_{tol-m}	Temperature tolerance between - 5 °C and + 125 °C	-5	+ 5	K
$T_{safe\ state}$	Temperature [1]	- 40	+ 125	°C

Table 4: *Board temperature sensor – characteristics*

[1] A temperature (including measurement tolerance) below or above the specified limits immediately triggers the safe state.

8 Connector

Figure 4 shows the main and HSD connectors for the TTC 2385 device. The main connectors, A and B, consist of 96 pins divided into 2x 48 pin connectors. The HSD connectors, C and D, are variant dependent (see section 2.2 for further details).

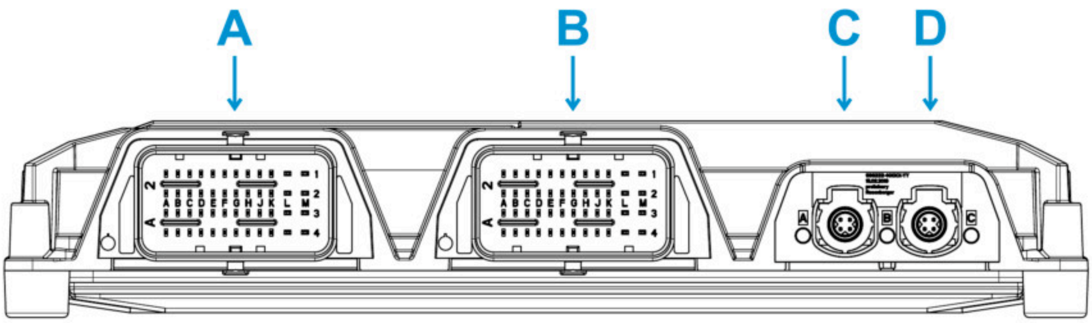


Figure 4: *Connector view (prototype)*

8.1 Mating connector and crimp contacts

This section lists recommended plug housings for *mating* connectors, cables, crimping contacts, and blind plugs.

For detailed specifications, please contact the supplier or refer to the supplier's website.

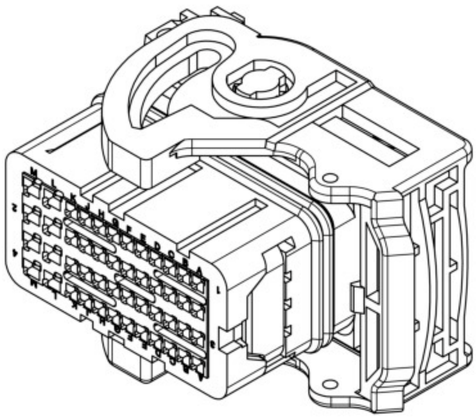
8.1.1 Mating Connector

TTControl recommends the following plug housings for mating connectors:

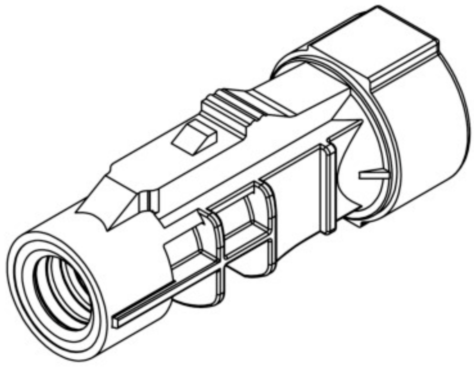
Connector	Description	Part no.	Supplier
A	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, black coding, mat sealed	64320-1311	Molex
B	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, gray coding, mat sealed	64320-1318	Molex
A, B	CMC wire cap for 48 circuits and 28 circuits, CMC receptacle, mat sealed	64320-1301	Molex
C, D	Waterproof housing, A coding [1]	D4K14A-1D5A5-A	Rosenberger
D	Right wire output	064320-3311 (Black) 064320-3318 (Grey)	Molex

Table 5: *Recommended plug housings for mating connectors*

[1] Part number for non-waterproof housing for HSD connector C and D: D4K10A-1D5A5-A



(a) ***Main connector A and B***



(b) ***HSD connector C and D, blind plug***

Figure 5: *Plug housings*

NOTE These images are given for illustrative purposes only. Please refer to the orginal supplier documentation for detailed images.

8.1.2 Crimping contacts

TTControl recommends the following crimping contacts for mating connectors A and B:

Connector	Description	Part no.	Supplier
A, B	1.50 mm CMC CP female terminal, tin plated, for tab dimensions 1.5 mm x 0.8 mm, wire size 0.5 mm^2 - 1.0 mm^2	64323-1029	Molex
A, B	1.50 mm CMC CP female terminal, tin plated, for tab dimensions 1.5 mm x 0.8 mm, wire size > 1.0 mm^2 - 2.0 mm^2	64323-1039	Molex
A, B	0.635 mm CMC CP female terminal, tin plated, for square 0.635 mm x 0.635 mm, wire size 0.5 mm^2	64322-1039	Molex
A, B	0.635 mm CMC CP female terminal, tin plated, for square 0.635 mm x 0.635 mm, wire size 0.75 mm^2	64322-1029	Molex

Table 6: *Recommended crimping contacts for mating connectors*

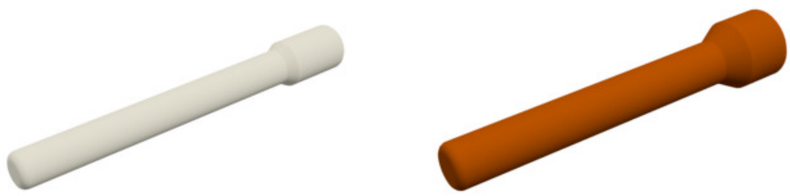
NOTE The table above provides a reduced selection of crimping contacts that can be used with your device. Please contact your supplier for further options.

8.1.3 Terminal cavity

TTControl recommends the following terminal cavity for mating connectors A and B, used to plug unused terminals in the connector to ensure tightness.

Connector	Description	Part no.	Supplier
A, B	0.60 mm terminal cavity (White)	064325-1010	Molex
A, B	1.50 mm terminal cavity (Orange)	064325-1023	Molex

Table 7: *Recommended terminal cavities for mating connectors*



(a) ***Terminal cavity 64325-1010*** (b) ***Terminal cavity 64325-1023***

Figure 6: *Terminal cavities*

8.1.4 Blind plugs

TTControl recommends the following blind plug for the HSD connector:

Connector	Description	Part no.	Supplier
C, D	Blind plug	D4Z023-002A	Rosenberger

Table 8: *Recommended blind plug for the HSD connector*

Figure 5b is also the model for the HSD blind plug.

Connectors and/or blind plugs must be installed to ensure that ingress protection is given. See [13] for further information.

8.1.5 Tools

TTControl recommends the following tools for mating connectors A and B:

Connector	Description	Part no.	Supplier
A, B	Power pin extraction tool	63813-2300	Molex
A, B	Power pin hand crimp tool wire size 0.5 mm^2 - 1.0 mm^2	63811-8900	Molex
A, B	Power pin hand crimp tool wire size 1.0 mm^2 - 2.0 mm^2	63811-9000	Molex
A, B	I/O pin extraction tool	63811-2400	Molex

A, B	I/O pin hand crimp tool wire size 0.35 mm^2	63811-9100	Molex
A, B	I/O pin hand crimp tool wire size 0.5 mm^2 - 0.75 mm^2	63811-9200	Molex

Table 9: *Recommended tools for mating connectors A and B*

8.1.6 Cables

TTControl recommends the following cables for mating connectors:

Connector	Description	Function	Recommendation
A, B	2.0 mm^2	BAT+Power BAT+CPU GND HS OUT (8 A)	Automotive standard
A, B	Twisted stranded wire pair, FLRY 2x0.5 mm^2	CAN	Automotive standard
A, B	0.75 mm^2	all other functions	Automotive standard
C, D	unshielded twisted pair (-T1 with one pair) (-TX with two pairs)	100BASE-T1 100BASE-TX	RosenbergerHSD LD5-105-xxxx-A-x

Table 10: *Recommended cables for mating connectors*

FLRY type cable

FLRY type is an ISO 6722 standardized PVC Automotive Cable with thinned PVC insulation used for automotive batteries and harnesses. Thinner insulation causes that rated voltage of these cables is 60 V and the current-carrying capacity depends on the wire cross-section.

A regularly stranded FLRY-A construction of the cables makes the cable more stiff. Irregularly stranded FLRY-B made out of thinner singular wires make the cables more flexible and the minimum bending radius shorter.

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9 TTC 2300 Family pinning

The pins on the TTC 2300 Family devices with the same underlying hardware, and therefore the same functional properties (e.g., supported I/O functionalities) have been grouped together into *pin groups*. These pin groups can be categorized as either: *multifunctional*, which can be assigned to multiple functions or *fixed*, which can be assigned to only one function (with some exceptions).

Details about these pin groups and information needed to identify every pin in a given pin group can be found in section 11.

A full overview of all 96 pins, including a complete group-by-group overview, can be found in the Software Manual [11]. Instructions on how to use the pins/pin groups is given in the variant-specific I/O Driver Manual [15, 17, 19, 21]. For pin groups that are categorised as *safety-critical*, see the Safety Manual [11] for further details.

NOTE Every pin can be identified by the connector, pin number, and pin name in this System Manual e.g., connector B, pin E4, AD4_IN_00. In the Software Manual, this pin is denoted by its software pin name, e.g., TT_PIN_BE4. Generally, the mapping is given as TT_PIN_<connector><pin#>.

10 Supply

10.1 Positive power supply of internal electronics (BAT+ CPU)

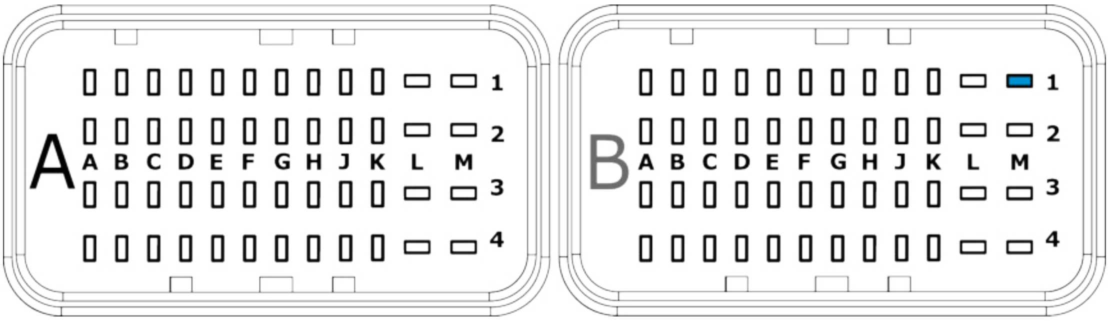

Figure 7: *BAT+ CPU pinout*

Connector	Pin	Pin name
B	M1	BAT+CPU

Table 11: *BAT+ CPU pin group*

Functional description

Supply pin for positive power supply of internal electronics, sensor supply and PVG/V_{OUT} output stages.

As the output voltage of the PVG/V_{OUT} outputs is defined as a percentage value in relation to the battery voltage, the voltage drop on the wire to this pin has a direct influence on the accuracy of the PVG output voltage.

BAT+ CPU pin is equipped with inverse polarity protection.

TTControl recommends using this pin in parallel, with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

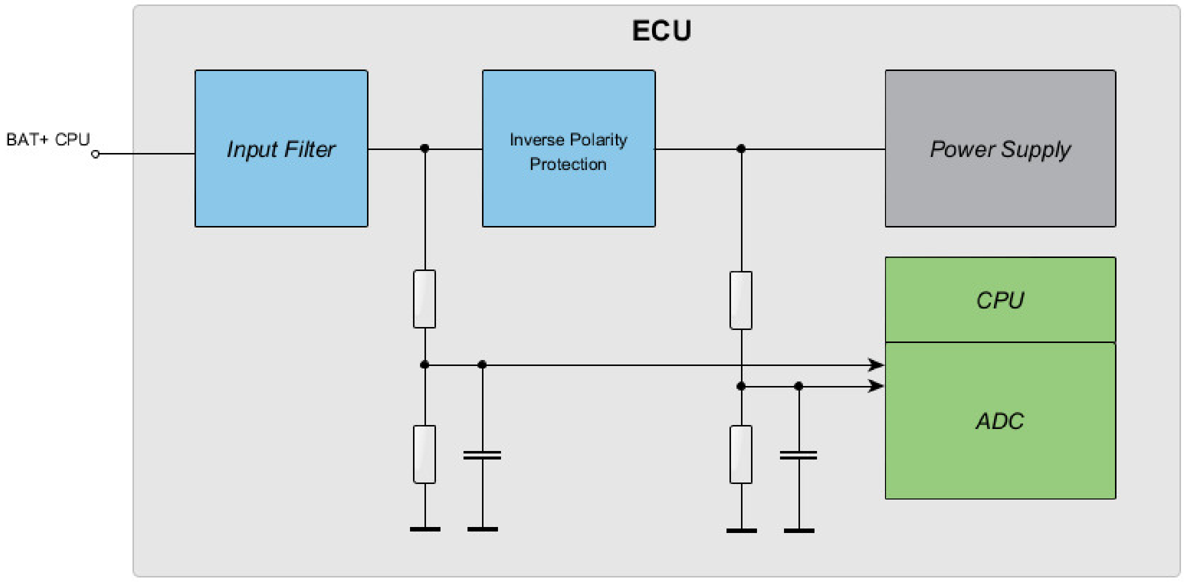

Figure 8: *Supply pin for the internal ECU logic for BAT+ CPU*

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$V_{in\text{-}max}$	Permanent non-destructive supply voltage [1]	-32	32	V
$V_{in\text{-}lim}$	Peak non-destructive supply clamping voltage < 1 ms [1] [2]	-40	42	V
$I_{in\text{-}lim}$	Peak non-destructive supply clamping current < 1 ms [1] [2]	-10	100	A
T_d	Load dump protection according to ISO 7637-2, Pulse 5, Level IV (superimposed 174 V, R_i = 2 Ω) [1]		350	ms
$I_{BAT+\ max}$	Permanent input current at V_{BAT+} = 8 V, 25 °C		3	A

Table 12: *BAT+ CPU maximum ratings*

[1] The control unit is protected by a transient suppressor, specified by clamp voltage, current and duration of voltage transient.

[2] 1 ms pulse width, non-repetitive. The pulse width is defined as the point at which the peak current decreases to 50 % of the maximum value.

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	264		µF
V_{BAT+}	Supply voltage for start up [1]	8	32	V
V_{BAT+}	Supply voltage for full operation [2]	4.5	32	V
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 8 V [1]		210	mA
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 12 V		140	mA
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 24 V		80	mA
$I_{BAT+\ STBY}$	Standby supply current (Terminal 15 and wake up off) [3]		100	µA
$I_{BAT+\ STBY}$	Standby supply current [3] (CAN Wake-up configured)		500	µA

Table 13: *BAT+ CPU characteristics*

[1] 8 V is the initial voltage for start-up at the beginning of the drive cycle.
[2] See section 10.1.1.
[3] T_{ECU} = -40 to +85 °C

10.1.1 Low-voltage operation

The TTC 2300 core system is designed for full operation after start-up between 4.5 V and 32 V, including supply voltage ranges for 12 V and 24 V battery operation, and cold-start cranking according to ISO 16750-2 [4]. The initial minimum supply voltage at the beginning of the ECU operational cycle is 8 V. After start-up, the CPU will remain operational down to 4.5 V, e.g., during cold-start cranking.

The minimum supply voltage during cold-start cranking is defined by ISO 16750-2:2012 [4] (see Table 14, and Table 15). The TTC 2300 core system complies with ISO 16750-2:2012, level I, II (functional status C), III and IV for 12-V systems and level I, II (functional status A) and III (functional status B) for 24-V systems, see ”SO 16750 functional status”.

Restrictions during cold-start cranking also apply to sensor supplies. For further information, see sections 11.4 and 11.5.

For TTC 2300 ISO 16750 code specification, see section 4.

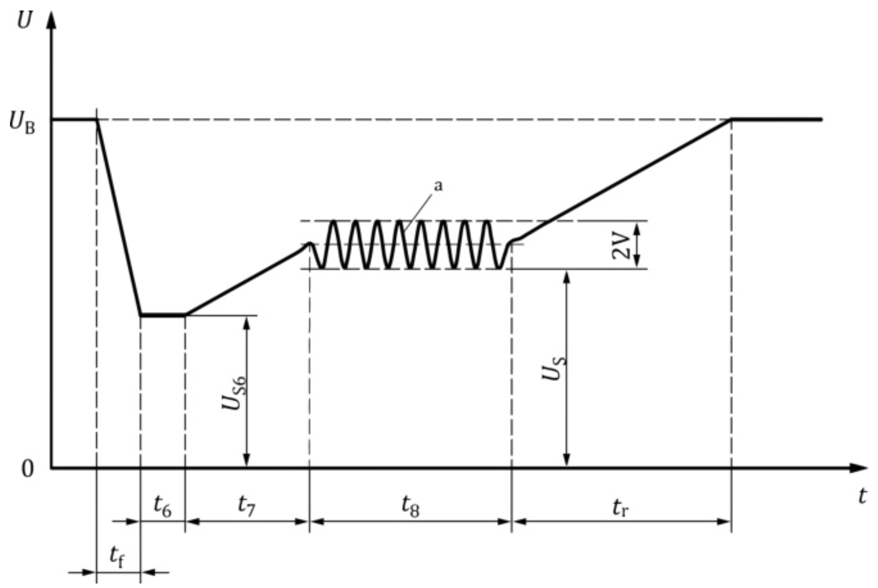

Figure 9: *ISO 16750-2 – Starting profile*

Key t: time
U: test voltage
t_f: falling slope
t_r: rising slope
t_6, t_7, t_8: duration parameters(in accordance with Table 3 and Table 4 of ISO 16750-2)
U_B: supply voltage for generator notin operation (see ISO 16750-1 [3])
U_S: supply voltage
U_{S6}: supply voltage at t_6
a: f = 2 Hz/

ISO 16750 functional status

Starting profile – functional status for 12 V system nominal voltage:

	Functional status		
	A	B	C
Level I	x		
Level II		x	
Level III			x
Level IV		x	

Table 14: *ISO 16750 functional status (12 V)*

Starting profile – functional status for 24 V system nominal voltage:

	Functional status		
	A	B	C
Level I	x		
Level II	x		
Level III		x (after start-up)	

Table 15: *ISO 16750 functional status (24 V)*

Voltage monitoring

The battery voltage on pin BAT+ CPU is connected to an ADC input. Battery voltage measurement can be used for diagnostic purposes.

Symbol	Parameter	Min	Max	Unit
τ_{in}	First order low pass filter	1.5	2.5	ms
V_{nom}	Nominal battery supply range [1]	0	33	V
$V_{tol\text{-}0}$	Zero reading error [2]	-67	67	mV
$V_{tol\text{-}0}$	Zero reading error	-80	80	mV
$V_{tol\text{-}p}$	Proportional error [2]	-3	3	%
$V_{tol\text{-}p}$	Proportional error	-4	4	%
LSB	Nominal value of 1 LSB		13.4	mV

Table 16: *BAT+ CPU voltage monitoring*

[1] The nominal battery supply range is only a value to calculate the actual voltage.
[2] T_{ECU} = -40 to +85 °C

10.2 Positive power supply of power stages (BAT+ power)

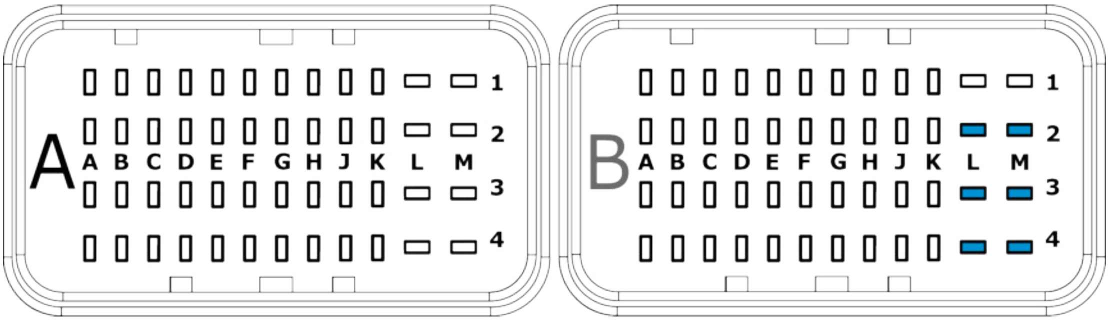

Figure 10: *BAT+ POWER pinout*

Connector	Pin	Pin name
B	L2	BAT+ Power
B	L3	BAT+ Power
B	L4	BAT+ Power
B	M2	BAT+ Power
B	M3	BAT+ Power
B	M4	BAT+ Power

Table 17: *BAT+ POWER pin group*

Functional description

Supply pins for the positive power stage supply of power stages.

The nominal supply voltage for full operation is between 8 and 32 V, including supply voltage ranges for 12 and 24 V battery operation. In this voltage range, all the I/Os work as described in this System Manual. BAT+ Power pins are equipped with inverse polarity protection.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

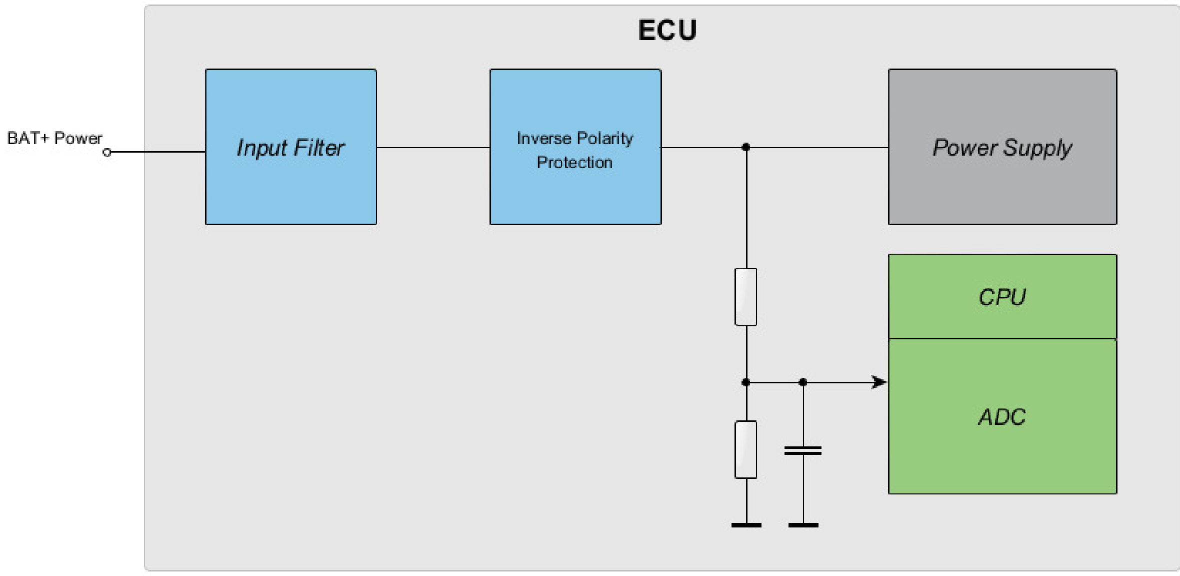

Figure 11: *Supply pin for the internal ECU logic for BAT+ Power*

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$V_{BAT+\ max}$	Permanent non-destructive supply voltage [1]	-32	32	V
$V_{BAT+\ lim}$	Peak non-destructive supply clamping voltage < 1 ms [1] [2]	-45	42	V
$I_{BAT+\ lim}$	Peak non-destructive supply clamping current < 1 ms [1] [2]	-10	100	A
T_d	Load dump protection according to ISO 7637-2, Pulse 5, Level IV (superimposed 174 V, R_i = 2 Ω) [1]		350	ms
$I_{in\text{-}max}$	Permanent battery supply current (all 6 pins in parallel with symmetrical wire connection) [3]		45	A
$I_{in\text{-}max}$	Permanent battery supply current per pin [3]		8	A
$I_{in\text{-}total}$	Total load current, 12 V and 24 V battery operation [4]		34	A
$I_{in\text{-}total}$	Total load current, 12 V and 24 V battery operation [4] [5]		45	A

Table 18: *BAT+ power maximum ratings*

[1] The control unit is protected by a transient suppressor, specified by clamp voltage, current and duration of voltage transient.

[2] 1 ms pulse width, non-repetitive. The pulse width is defined as the point at which the peak current decreases to 50 % of the maximum value.

[3] This battery supply current is related to the total load current of all high-side power-stages. At worst, all outputs are in non-PWM mode or with maximum duty cycle operated, the battery current equals the total load current. With typical PWM-operation the battery supply current is significant lower than the total load current.

[4] Variant dependant

[5] T_{ECU} = -40 to +85 °C

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	176	264	µF
V_{BAT+}	Supply voltage for full operation	6	32	V

Table 19: *BAT+ power characteristics*

10.3 Negative power supply (BAT-)

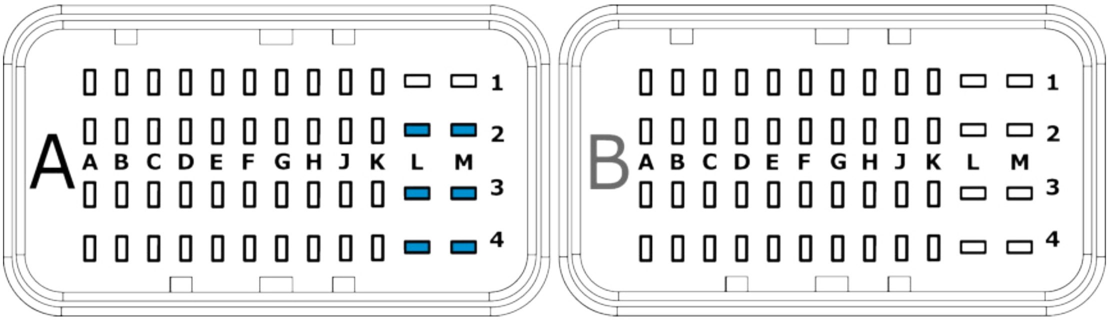

Figure 12: *BAT- pinout*

Connector	Pin	Pin name
A	L2	GND
A	L3	GND
A	L4	GND
A	M2	GND
A	M3	GND
A	M4	GND

Table 20: *BAT- pin group*

Functional description

Supply pins for negative power supply.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$I_{out\text{-}max}$	Permanent current per pin		8	A
$I_{out\text{-}max}$	Permanent current all pins		45	A

Table 21: *BAT- maximum ratings*

10.4 Fuses

> WARNING
>
> The bridging of contacts in the connector housing is not allowed, as it can impair the safety of persons and the machine.

To protect the cable harness, TTControl recommends protecting each power supply path with its own dedicated fuse. Please ensure that the selected fuse type matches the current capability of the cable harness.

Symbol	Parameter	Min	Max	Unit
$I_{BAT+\ CPU}$	Fuse trip current [1] 10.2		3	A
$I_{BAT+\ Power}$	Fuse trip current 10.1		50	A

Table 23: *Recommended fuses for power supply path protection*

[1] The used fuse trip current is dependent on the application. The maximum current load must be considered, see section 10.2

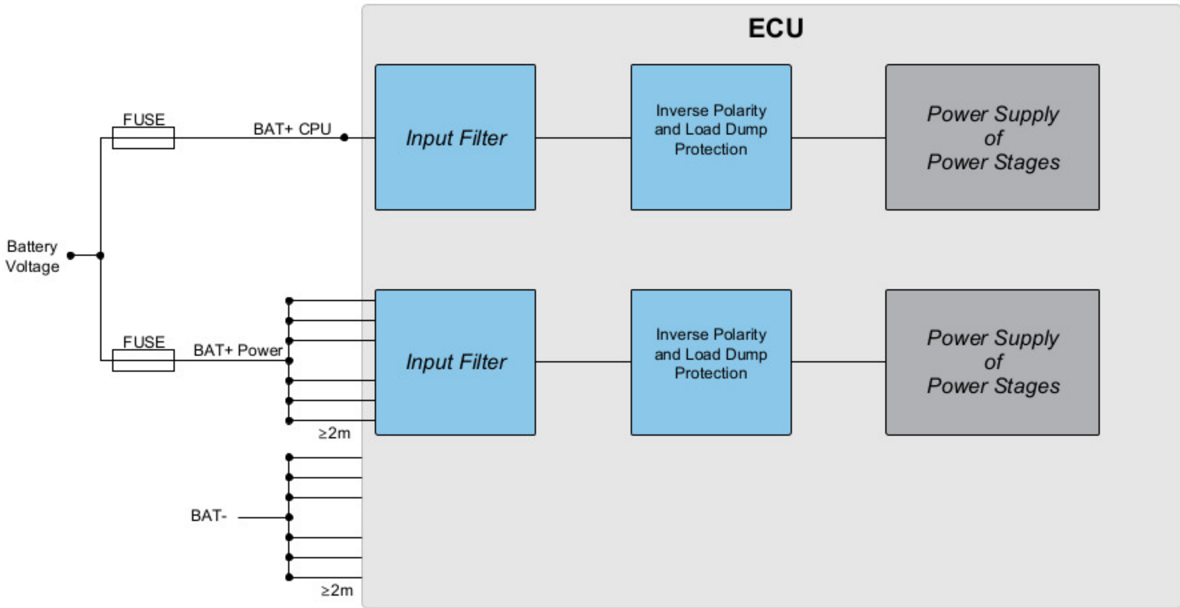

Figure 13: *Battery supply – Fuse*

NOTE It is necessary to use six wires with the same total cross sectional area instead of one thick cable. The same principle should be used with the GND wires. All wires must have the same length (≥2m) and diameter. In this case, an even current distribution can be achieved, even with slightly different contact resistances.

11 Specification of inputs and outputs

The following section gives detailed information about the available pin groups, including which main and alternative functions are supported by each pin/pin group, which variants these functions are available for, their electrical characteristics and ratings, and other relevant information.

The main function is designed to be the primary use of the pin. The technical specifications must be closely observed when using the alternative functions. See the tables in this section for limits, restrictions, and further information.

Varying terminology is used to describe the pin groups, including a generic long name (e.g., Timer IN-/SENT) and a short name (e.g., TIN/SENT). In some cases, the generic long name is given to a section describing multiple pin groups (e.g., PWM high-side outputs), in which each individual pin group is given by its short name (e.g., PWM HS 4A+CM+FM, PWM HS 4A+CM+FM variant-dependant, and PWM HS 8A+CM+FM). Acronyms can be found in the glossary 1.

NOTE All values given in the tables below are valid for the ECU operating temperature range: -40 to +125 °C, unless stated otherwise.

11.1 Sensor GND

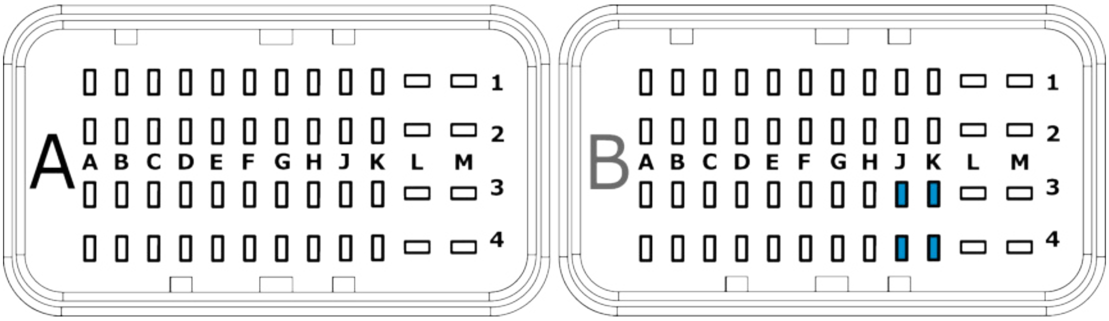

Figure 14: *Sensor GND pinout*

Connector	Pin	Pin name
B	J3	SNS_GND
B	J4	SNS_GND
B	K3	SNS_GND
B	K4	SNS_GND

Table 24: *Sensor GND pin group*

Functional description

Supply pins for analog sensor GND connection.

These pins can also be used as GND connection for digital sensors. They are internally connected to BAT-, and should not be connected to the chassis externally to avoid ground loops.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$I_{out\text{-}max}$	Permanent current per pin [1]		1	A

Table 25: *Sensor GND maximum ratings*

[1] It is recommended to use all sensor ground pins simultaneously to ensure load distribution and minimize voltage drop on the external wiring.

11.2 Terminal 15

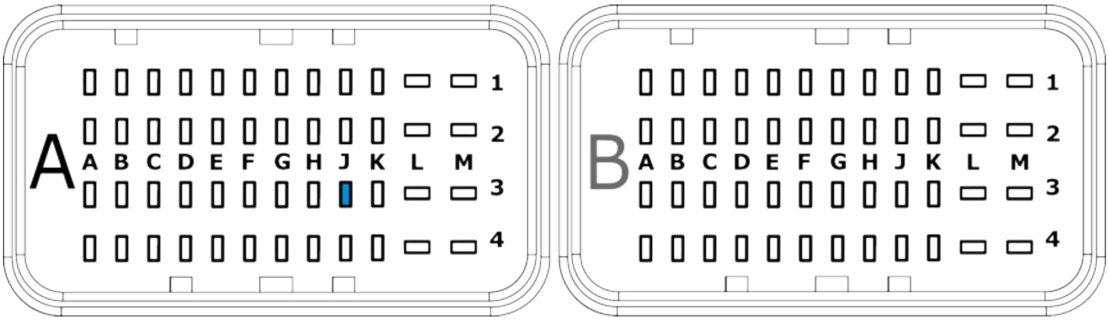

Figure 15: *T15 pinout*

Connector	Pin	Pin name
A	J3	T15

Table 26: *T15 pin group*

Functional description

Pin for Terminal 15 connection. This is the power control input for permanently supplied systems.

When switched to positive supply, this input gives the command to power-up the ECU, regardless of the `Wake-Up` pin status. When switched off, the ECU activates its keep-alive functionality[2] (if keep-alive functionality is enabled by the software) and is switched off by software after a user-defined period of time.

This input is monitored by the CPU via an ADC input.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Permanent (DC) input voltage	-33	33	V
V_{in}	Transient peak input voltage 500 ms	-50	50	V
V_{in}	Transient peak input voltage 1 ms	-100	100	V

Table 27: *T15 maximum ratings*

2. The keep-alive functionality is activated by default.

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{pd}	Pull-down resistor	6.5	11.5	kΩ
I_{in}	Input current at 16 V input voltage	2	2.5	mA
I_{in}	Input current at 32 V input voltage	4	4.5	mA
V_{il}	Input voltage for low level		2.2	V
V_{ih}	Input voltage for high level [1]	3.6	32	V
τ_{in}	Input low pass filter	167.2	212.8	µs

Table 28: *T15 characteristics*

[1] 8 V is the start up voltage at the beginning of the drive cycle

11.3 Wake-up

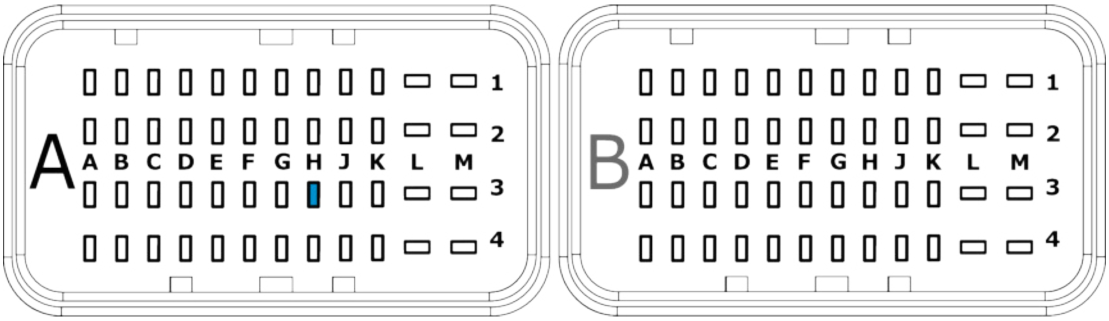

Figure 16: *Wake-up pinout*

Connector	Pin	Pin name
A	H3	WAKE_UP

Table 29: *Wake-up pin group*

Functional description

Pin for Wake-up connection. This is the `Wake-Up` input for permanently supplied systems.

When switched to positive supply (rising edge triggered), this input gives the command to power up the ECU, regardless of the `Terminal 15` pin status. When switched off, the ECU activates its keep-alive functionality (provided that keep-alive functionality is enabled by software) and will switch off by software after a user-defined period of time.

The application software can command the ECU to switch off even if the `Wake-Up` pin is high, but only if `Terminal 15` is off.

This input is monitored by the CPU via an ADC input.

Use case pre-boot sequence

For example, it is possible to start the boot sequence of the ECU by opening the vehicle door by connecting the `Wake-Up` pin with the vehicle door contact. When the driver enters the vehicle and turns the ignition key on (`Terminal 15` to high), the ECU boot process is already finished. With this feature the ECU is ready for operation without any delay.

If the `Wake-Up` pin is in a continuous high state (e.g., vehicle door is left open) and `Terminal 15` pin is not switched on, the application software shall power down the ECU after an application dependent timeout.

After forcing the ECU shutdown via application software, it is necessary to externally toggle the `Wake-Up` pin or activate `Terminal 15` pin to restart the ECU.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Permanent (DC) input voltage	-33	33	V
V_{in}	Transient peak input voltage 500 ms	-50	50	V
V_{in}	Transient peak input voltage 1 ms	-100	100	V

Table 30: *Wake-up maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{pd}	Pull-down resistor	6.5	11.5	kΩ
I_{in}	Input current at 16 V input voltage	2	2.5	mA
I_{in}	Input current at 32 V input voltage	4	4.5	mA
V_{il}	Input voltage for low level		2.2	V
V_{ih}	Input voltage for high level [1]	3.6	32	V
τ_{in}	Input low pass filter [2]	9.3	10.7	µs

Table 31: *Wake-up characteristics*

[1] 8 V is the start-up voltage at the beginning of the drive cycle
[2] There is an additional 50 µs delay in the digital circuitry of wake-up handling.

11.4 Sensor supply 5 V

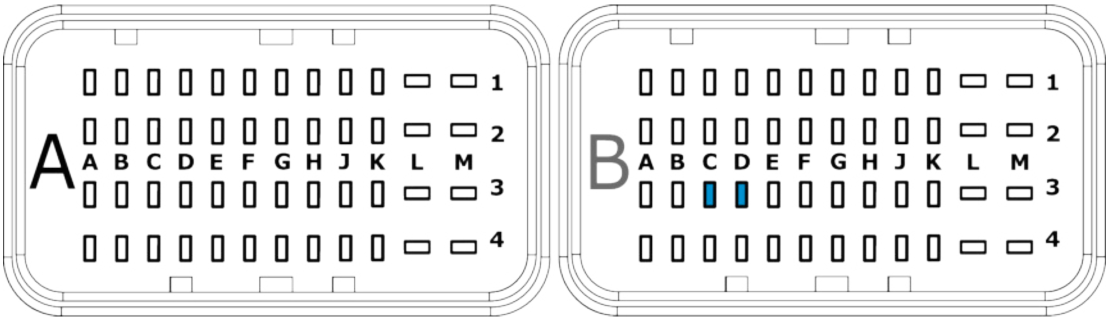

Figure 17: *Sensor supply 5 V pinout*

Connector	Pin	Pin name
B	C3	SSUP_0
B	D3	SSUP_1

Table 32: *Sensor supply 5 V pin group*

Supported functions

- SSP_5V **(main)**

Functional description

Two independent 5 V sensor supplies for 3-wire sensors (e.g., potentiometers, pressure sensors etc.).

For fully redundant sensors with 2 sensor-supply connections, both sensors must be connected to different sensor supplies.

If the input voltage on the BAT+ CPU pin is lower than the typical 6 V (at 5 mA sensor supply load current), the sensor supply output voltage will be out of specification. One example of such low input voltage situations may be cold-start cranking in 12/24 V systems where the supply voltage can drop below 6 V. If the sensor supply output voltage drops below 4.7 V, the application software will be informed about this error situation after glitch filtering.

These pins must not be used in parallel.

TTControl recommends using this pin with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

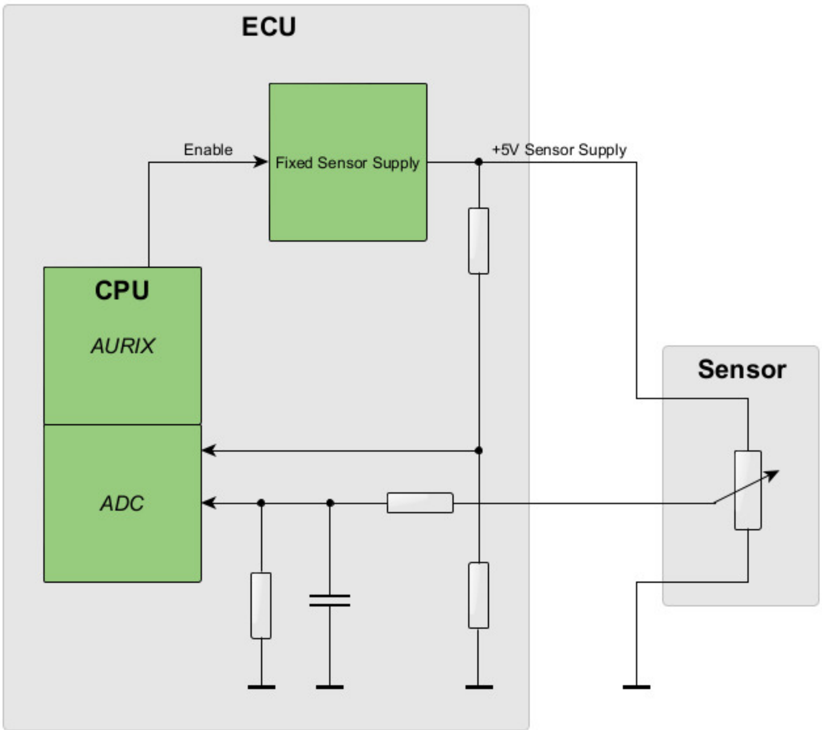

Figure 18: *Sensor supply 5 V*

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Output voltage under overload conditions (e.g., short circuit to supply voltage)	-1	33	V

Table 33: *Sensor supply 5 V maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin output capacitance	37	45	µF
V_{OUT}	Output voltage, at I_{load}	4.9	5.1	V
I_{load}	Load current	0	750	mA

Table 34: *Sensor supply 5 V characteristics*

11.5 Sensor supply variable

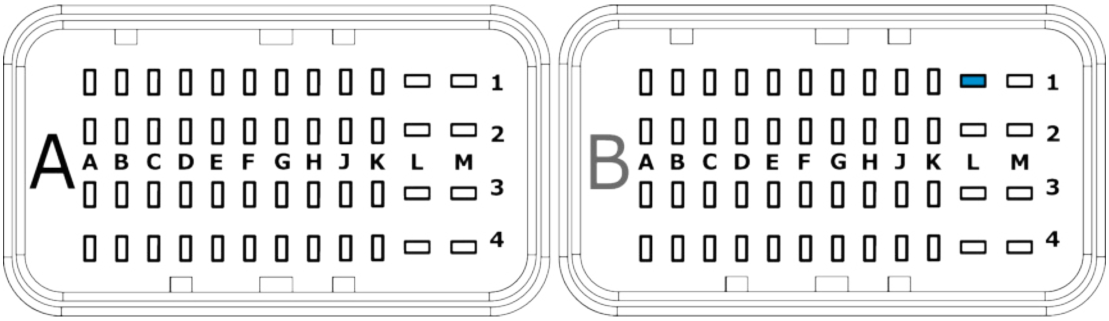

Figure 19: *Sensor supply variable pinout*

Connector	Pin	Pin name
B	L1	SSUP_2

Table 35: *Sensor supply variable pin group*

Supported functions

- SSP_VAR **(main)**

Functional description

One sensor supply with variable output voltage, configurable in 50 mV steps, is provided for 3-wire sensors (e.g., potentiometers, pressure sensors etc.).

As described in section 11.4, the BAT+ CPU pin voltage must be at least 1 V higher than the required sensor supply output voltage V_{SSUP} . If the BAT+ CPU pin voltage is lower than V_{SSUP} -1 V, the sensor supply output voltage will be out of specification.

The variable sensor supply is also used to supply a stable voltage for PVG/V_{OUT} stages in V_{OUT} mode, see section 11.13 for further information.

TTControl recommends using this pin with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Output voltage under overload conditions (e.g., short circuit to supply voltages)	-1	33	V

Table 36: *Sensor supply variable maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin output capacitance	37	45	µF
V_{res}	Programming resolution		50	mV
V_{OUT}	Output voltage, setting range	5	12.75	V
	Output voltage tolerance	-2	2	%
I_{load}	Load current		750	mA

Table 37: *Sensor supply variable characteristics*

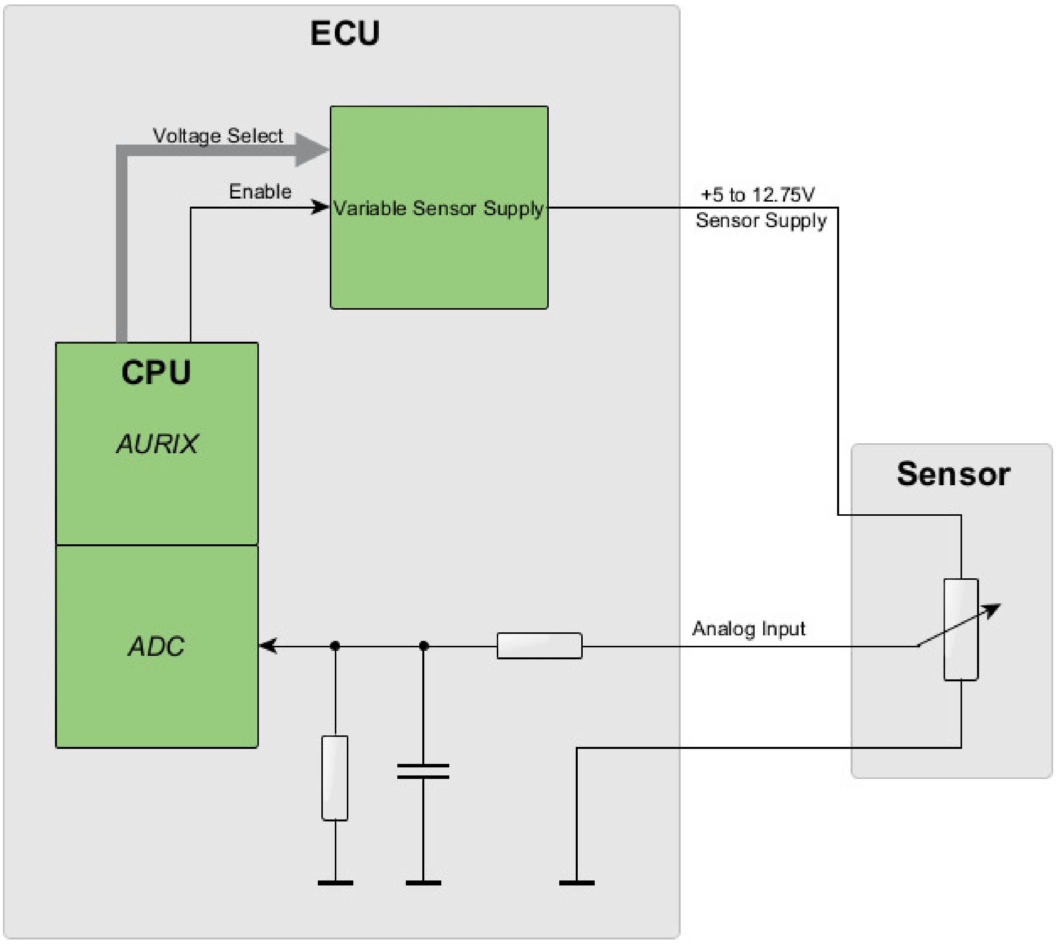

Figure 20: *Sensor supply variable*

11.6 Analog input 4-mode

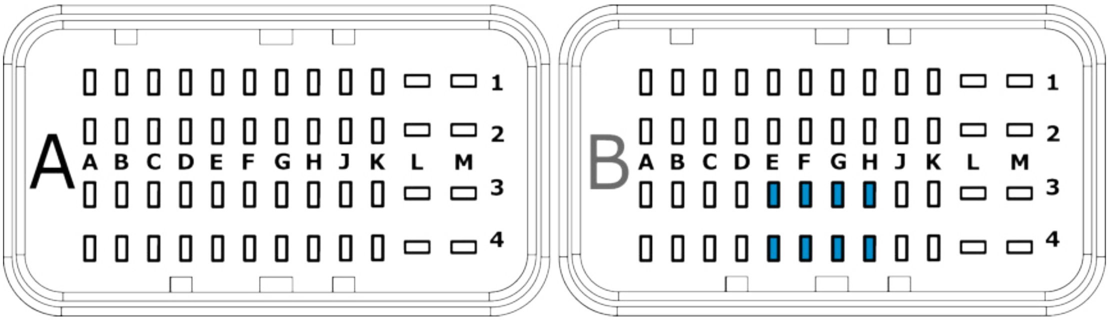

Figure 21: *Analog input 4-mode pinout*

Connector	Pin	Pin name	Function
B	E4	AD4_IN_00	ADC_RIN_100K_HP
B	E3	AD4_IN_01	ADC_RIN_100K_HP
B	F4	AD4_IN_02	ADC_RIN_100K
B	F3	AD4_IN_03	ADC_RIN_100K
B	G4	AD4_IN_04	ADC_RIN_100K_HP
B	G3	AD4_IN_05	ADC_RIN_100K_HP
B	H4	AD4_IN_06	ADC_RIN_100K
B	H3	AD4_IN_07	ADC_RIN_100K

Table 38: *Analog input 4-mode pin group*

Supported functions

- ADC_RAT_5V **(main)**
- ADC_VIN_5V **(main)**
- ADC_CIN_25mA **(main)**
- ADC_RIN_100K **(main)**
  - available for 4 out of 8 pins, see table 38
- ADC_RIN_100K_HP **(main)**
  - available for 4 out of 8 pins, see table 38
- DIN_5V

Functional description

8x multipurpose analog inputs with 12-bit resolution.

All inputs are short-circuit protected, independent of application software (included in low-level driver software). Each input is provided with a first-order low-pass filter with 3 ms time constant, allowing 2 ms sample rate.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input voltage under overload conditions [1]	-1	33	V

Table 39: *Analog input 4-mode maximum ratings*

[1] Due to thermal reasons only one of the 8 inputs may be shorted to 33 V at the same time. A connection to any supply voltage higher than 5 V is not allowed for normal operation.

11.6.1 Analog voltage input

Selected via functions ADC_RAT_5V and ADC_VIN_5V.

Absolute vs. ratiometric voltage measurement
Many sensor types are available in absolute or ratiometric measurement variant:

Ratiometric (ADC_RAT_5V)

A pressure sensor provides a ratiometric output voltage signal with 10 to 90 % of the supply voltage (e.g., 0.5 to 4.5 V) corresponding to a pressure range of 0 to 10 bar. Hence, a pressure of 5 bar will always correspond to 50 % of the sensor supply voltage.
If the sensor supply voltage decreases by about 2 % (e.g., due to thermal effects), so will the reference voltage in the ADC of the ECU, and the corresponding output signal for a pressure of 5 bar will also decrease by 2 % to 2.45 V. Applying ratiometric measurement for the ADC, the measured value of 2.45 V will be postprocessed by applying a compensation factor (equal to the ideal reference voltage divided by the measured real reference voltage) leading again to a final measurement value of 2.5 V. After scaling (from 0.5 to 4.5 V) from 0 to 10 bar in the application software, the result will be a pressure value of 5 bar.

Absolute (ADC_VIN_5V)

A pressure sensor provides an absolute output signal with a range of 0.5 to 4.5 V corresponding to a pressure range of 0 to 10 bar. Hence, an output voltage of 2.5 V ideally corresponds to a pressure of 5 bar. If the internal reference voltage of the sensor decreases by a certain percentage (for example, due to thermal effects) the corresponding output signal for a pressure of 5 bar will change to—for example—2.45 V. Applying absolute voltage measurement for the ADC and additional scaling (from range 0.5 – 4.5 V to range 0 – 10 bar) in the application software will result in a pressure value of 4.875 bar.

An increase of the internal reference of the ECU by temperature drift also has the effect of a reduced voltage reading.

Due to the described behavior, use of ratiometric sensors is recommended.

Absolute or ratiometric function selection is done by software for each input pin.

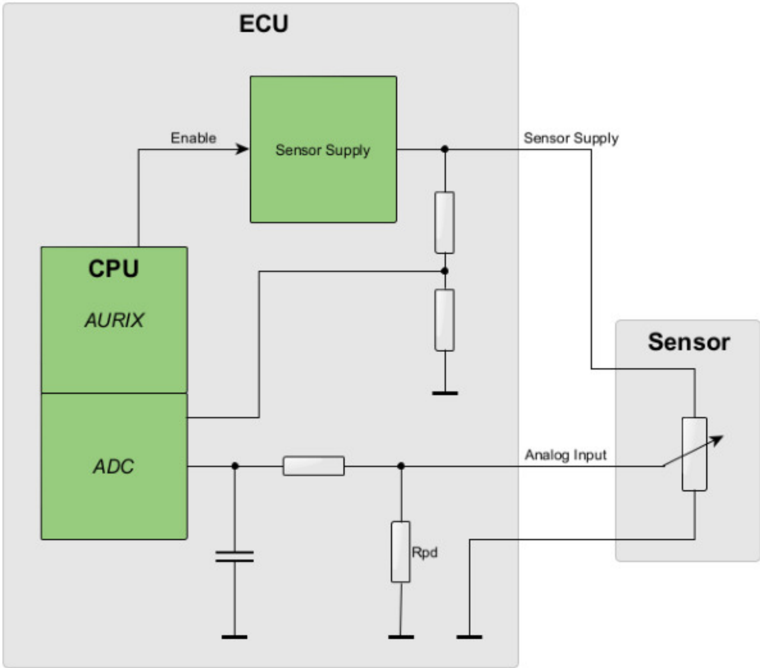

Figure 22: *Analog voltage input (ratiometric)*

Characteristics of 5 V analog input (ratiometric)

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{pd}	Pull-down resistor	98	107	kΩ
τ_{in}	Input low pass filter	2.2	3.8	ms
V_{nom}	Nominal input voltage range	0	5	V
V_{in}	Input voltage range [1]	0.2	4.8	V
V_{tol-0}	Zero reading error [2] [3] [4]	-7	7	mV
V_{tol-0}	Zero reading error [3] [4]	-12	12	mV
V_{tol-p}	Proportional error [2] [3] [4]	-0.2	0.2	%
V_{tol-p}	Proportional error [3] [4]	-0.2	0.2	%
LSB	Nominal value of 1 LSB		1.22	mV

Table 40: *5 V Analog input (ratiometric) – characteristics*

[1] For full accuracy.
[2] T_{ECU} = -40 to +85 °C.
[3] This includes the conversion error of the TTC 2300 and the sensor supply error. The total measurement error is the sum of the error of TTC 2300 and the error of the ratiometric sensor (measurement tolerance).
[4] The total measurement error is the sum of zero reading error and the proportional error.

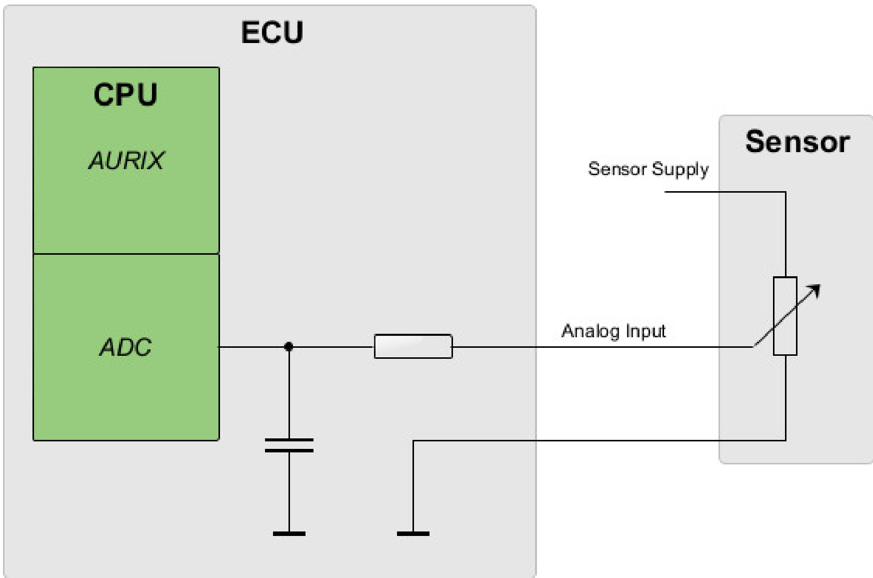

Figure 23: *Analog voltage input (absolute)*

Characteristics of 5 V analog input (absolute)

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{pd}	Pull-down resistor	98	107	kΩ
τ_{in}	Input low pass filter	2.2	3.8	ms
V_{nom}	Nominal input voltage range	0	5	V
V_{in}	Input voltage range [1]	0.2	4.8	V
$V_{tol\text{-}0}$	Zero reading error [2] [3] [4]	-7	7	mV
$V_{tol\text{-}0}$	Zero reading error [3] [4]	-12	12	mV
$V_{tol\text{-}p}$	Proportional error [2] [3] [4]	-0.4	0.4	%
$V_{tol\text{-}p}$	Proportional error [3] [4]	-0.6	0.6	%
LSB	Nominal value of 1 LSB		1.22	mV

Table 41: *5 V Analog input (absolute) – characteristics*

[1] For full accuracy.
[2] T_{ECU} = -40 to +85 °C.
[3] This includes the conversion error of the TTC 2300 only. The total measurement error is the sum the error of TTC 2300 and the absolute sensor error (measurement tolerance plus tolerance of external sensor reference).
[4] The total measurement error is the sum of zero reading error and the proportional error.

11.6.2 Analog current input

Selected via function ADC_CIN_25mA.

Analog input for 0 to 25 mA sensor measurement.

Due to the wider measurement range of the input compared to the output range of popular sensors with 4 to 20 mA, short to GND, short to BAT+ and cable defects can be easily detected.

In case of an overload, the pin is automatically switched to a high impedance state. The protection mechanism tries re-enabling the output 10 times per operational cycle.

During power down (`Terminal 15` off), the ECU does not disconnect the current sensor input. To prevent battery discharge, do not supply the sensors permanently.

TTControl recommends one of the following 2 options:

1. Using a digital output for supplying the sensor. When the device is switched off, the ECU can perform an application-controlled shutdown, e. g., in order to operate a cooling fan to cool down an engine until the temperature is low enough or to store data in the non-volatile memory of the ECU. If the application controlled shut-down is finished, the ECU switches off and consumes less than 1 mA of battery current (including sensors).
2. Using `Terminal 15` to supply the current loop sensor directly.

NOTE `Terminal 15` is often used to switch relays or other inductive loads directly. This may cause transients in excess of ±50 V, for which the sensor must be specified.

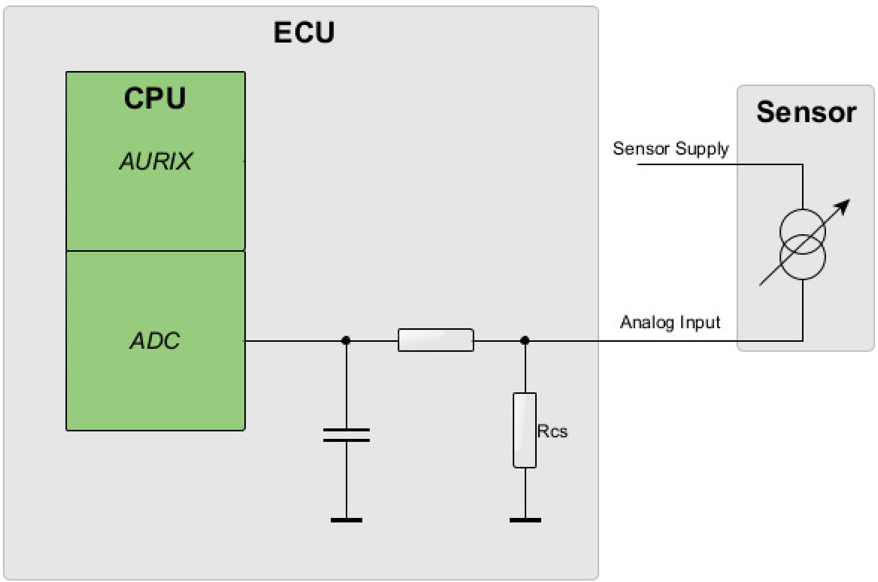

Figure 24: *Analog current input*

Characteristics of analog current input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{CS}	Current sense resistor [1]	109	111	Ω
τ_{in}	Input low pass filter	2.2	3.8	ms
I_{in}	Input current range	0	25	mA
I_{tol-0}	Zero reading error [2] [3]	-100	100	µA
I_{tol-0}	Zero reading error [3]	-150	150	µA
I_{tol-p}	Proportional error [2] [3]	-0.7	0.7	%
I_{tol-p}	Proportional error [3]	-1	1	%
LSB	Nominal value of 1 LSB		12.21	µA

Table 42: *Analog current input – characteristics*

[1] This is the load resistor value for the current loop sensor.
[2] T_{ECU} = -40 to +85 °C
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.6.3 Analog resistance input

Selected via functions ADC_RIN_100K and ADC_RIN_100K_HP (see table 38 for applicable pins).

Input for 0 to 100 kΩ resistance sensor measurement.

Resistive sensors are for example NTC or PTC resistors for temperature measurement.

The actual resistor value of the sensor is computed from the measured input voltage together with the known reference resistor value. Be aware that this measurement setup has the highest accuracy and resolution if the sensors resistance is in the magnitude of the reference resistors value.

The resistance mode may also be used as digital input with switches connected to ground, see figure 27. The use of switches to BAT+ is not allowed.

To enhance the diagnostic coverage, use switches of type Namur. With a Namur-type switch sensor, short to ground, short to BAT+ and cable defects can be easily detected.

Characteristics of analog resistance input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{ref}	Reference resistor	4753	4847	Ω
τ_{in}	Input low pass filter	2.2	3.8	ms
R_{ext_range}	Resistance measurement range	0	100	kΩ

Table 43: *Analog resistance input – characteristics*

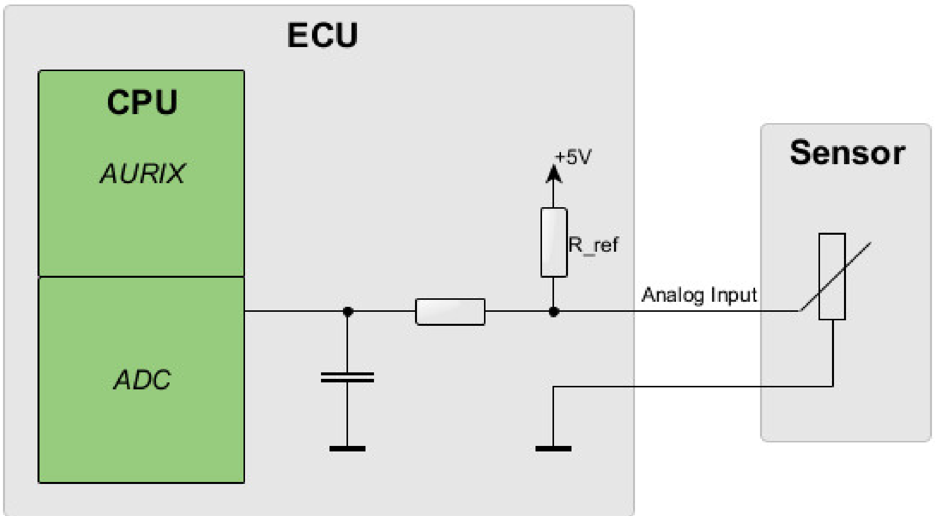

Figure 25: *Analog resistance input*

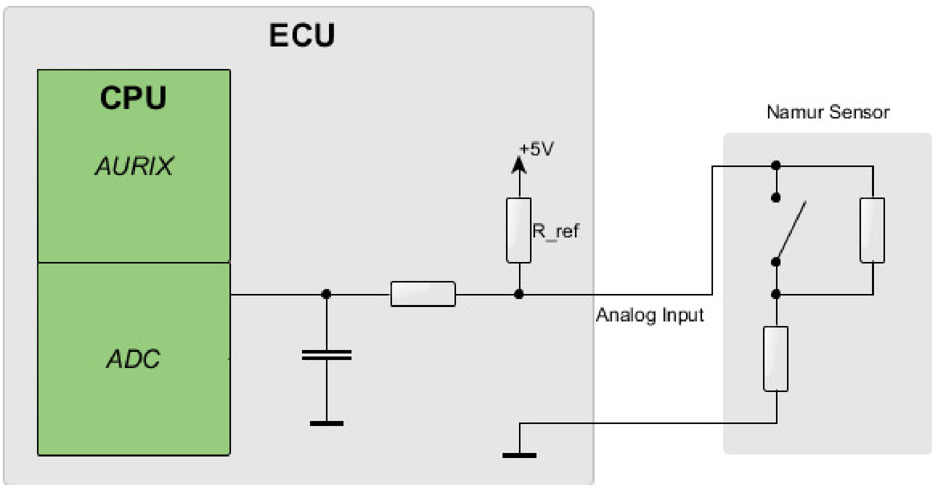

Figure 26: *Namur type sensor (only for switches to ground)*

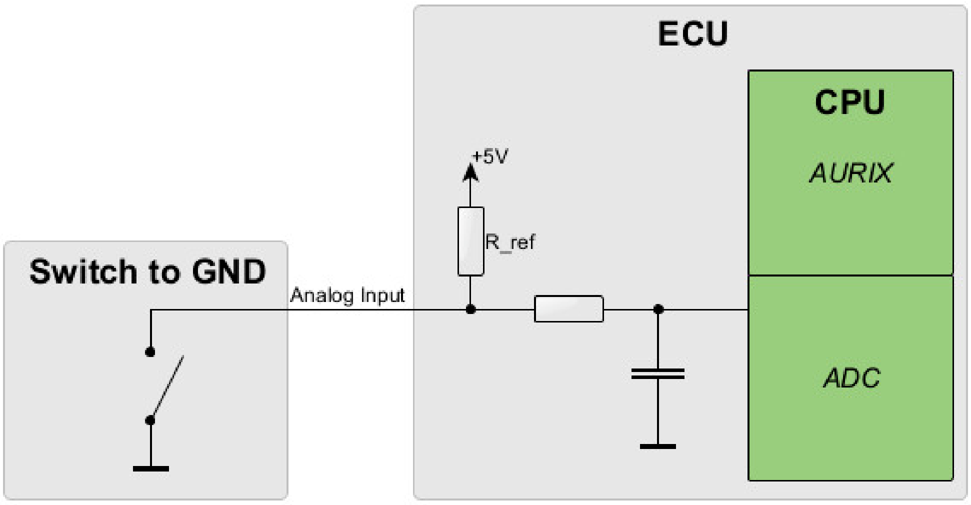

Figure 27: *Switch input (only for switches to ground)*

Tolerance of analog resistance input measurements (standard)

Tolerance at T_{ECU} = -40 to +85 °C:

Symbol	Parameter	Min	Max	Unit
R_{tol-m}	Measurement tolerance for 0 to 99 Ω	-7	7	Ω
R_{tol-m}	Measurement tolerance for 100 Ω	-5	5	%
R_{tol-m}	Measurement tolerance for 200 Ω	-4	4	%
R_{tol-m}	Measurement tolerance for 500 Ω	-2.5	2.5	%
R_{tol-m}	Measurement tolerance for 1 kΩ to 20 kΩ	-2	2	%
R_{tol-m}	Measurement tolerance for 50 kΩ	-3.5	3.5	%
R_{tol-m}	Measurement tolerance for 100 kΩ	-5	5	%

Table 44: *Tolerance at T_{ECU} = -40 to +85 °C*

Tolerance at T_{ECU} = -40 to +125 °C:

Symbol	Parameter	Min	Max	Unit
R_{tol-m}	Measurement tolerance for 0 to 99 Ω	-10	10	Ω
R_{tol-m}	Measurement tolerance for 100 Ω	-10	10	%
R_{tol-m}	Measurement tolerance for 200 Ω	-6	6	%
R_{tol-m}	Measurement tolerance for 500 Ω	-3	3	%
R_{tol-m}	Measurement tolerance for 1 kΩ to 20 kΩ	-3	3	%
R_{tol-m}	Measurement tolerance for 50 kΩ	-5	5	%
R_{tol-m}	Measurement tolerance for 100 kΩ	-7	7	%

Table 45: *Tolerance at T_{ECU} = -40 to +125 °C*

Tolerance of analog resistance input measurements (high precision)

Tolerance at T_{ECU} = -40 to +85 °C:

Symbol	Parameter	Min	Max	Unit
R_{tol-m}	Measurement tolerance for 0 to 99 Ω	-3	3	Ω
R_{tol-m}	Measurement tolerance for 100 Ω	-3	3	%
R_{tol-m}	Measurement tolerance for 200 Ω	-2	2	%
R_{tol-m}	Measurement tolerance for 500 Ω	-1	1	%
R_{tol-m}	Measurement tolerance for 1 kΩ to 10 kΩ	-1	1	%
R_{tol-m}	Measurement tolerance for 20 kΩ	-1	1	%
R_{tol-m}	Measurement tolerance for 50 kΩ	-2	2	%
R_{tol-m}	Measurement tolerance for 100 kΩ	-4	4	%

Table 46: *Tolerance at T_{ECU} = -40 to +85 °C (high precision)*

Tolerance at T_{ECU} = -40 to +125 °C:

Symbol	Parameter	Min	Max	Unit
R_{tol-m}	Measurement tolerance for 0 to 99 Ω	-7	7	Ω
R_{tol-m}	Measurement tolerance for 100 Ω	-7	7	%
R_{tol-m}	Measurement tolerance for 200 Ω	-4	4	%
R_{tol-m}	Measurement tolerance for 500 Ω	-2.5	2.5	%
R_{tol-m}	Measurement tolerance for 1 kΩ to 10 kΩ	-1.5	1.5	%
R_{tol-m}	Measurement tolerance for 20 kΩ	-2.5	2.5	%
R_{tol-m}	Measurement tolerance for 50 kΩ	-4	4	%
R_{tol-m}	Measurement tolerance for 100 kΩ	-6	6	%

Table 47: *Tolerance at T_{ECU} = -40 to +125 °C (high precision)*

NOTE The resistance measurement tolerance is given at specific sensor resistance values. Any values in between need to be linearly interpolated.

11.6.4 Digital input 5 V

Selected via function DIN_5V.

Characteristics of 5 V digital input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{pd}	Pull-down resistor	107	112	Ω
τ_{in}	Input low pass filter	2.2	3.8	ms
V_{il}	Input voltage for low level [1]		<x>	V
V_{ih}	Input voltage for high level [1]	<x>		V
LSB	Nominal value of 1 LSB		1.22	mV

Table 48: *5 V digital input – characteristics*

[1] Values <x> are configured by the application software.

11.7 Analog input 2-mode

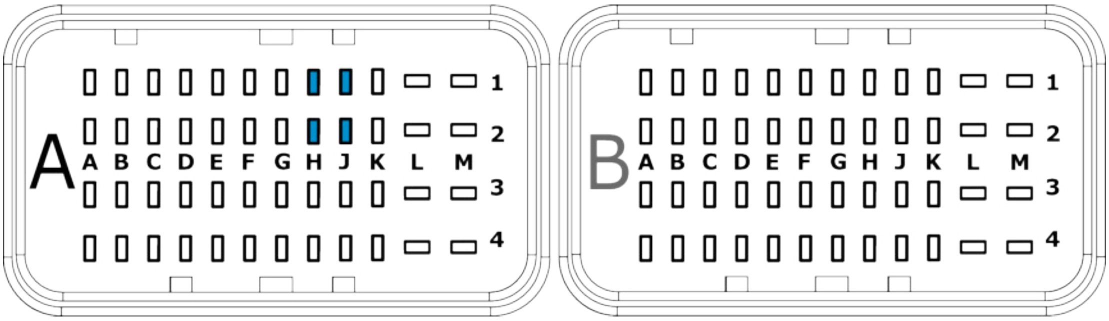

Figure 28: *Analog input 2-mode pinout*

Connector	Pin	Pin name	Variant
A	H1	LS_08	TTC 2310
A	H2	LS_09	TTC 2310
A	J1	LS_10	TTC 2310
A	J2	LS_11	TTC 2310

Table 49: *Analog input 2-mode pin group*

Supported functions

- ADC_RAT_5V **(main)**
- ADC_VIN_5V **(main)**
- ADC_VIN_32V **(main)**
- DIN_5V
- DIN_32V

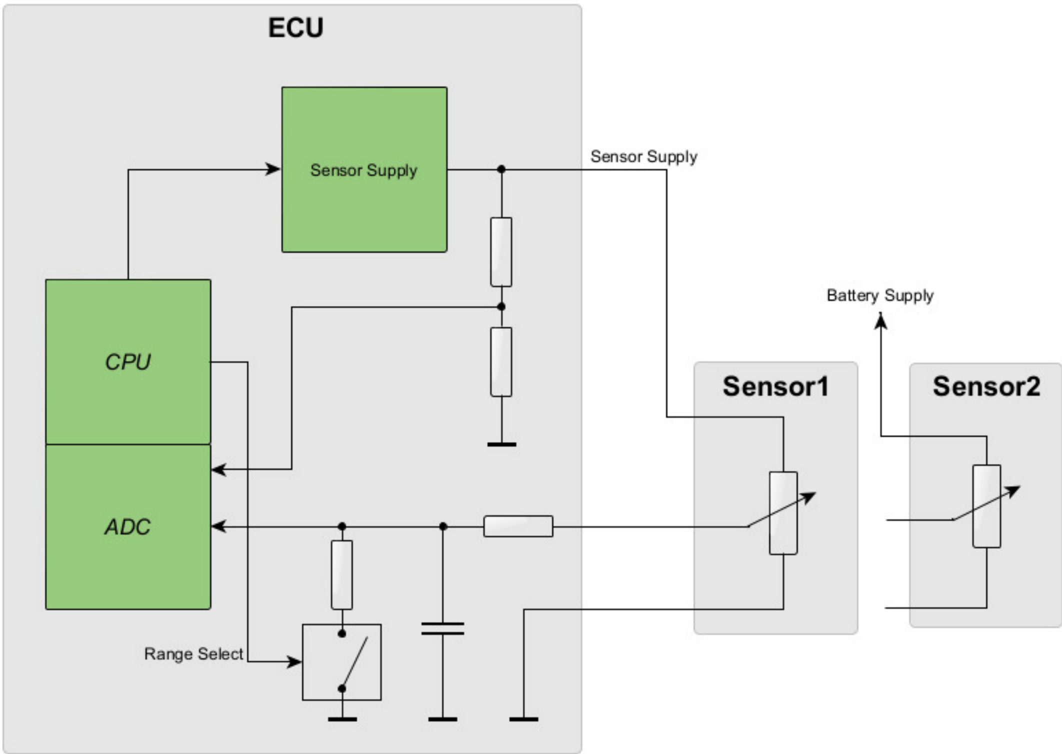

Figure 29: *Analog resistance input 5 V vs 32 V sensor configuration*

Functional description

4x multipurpose analog inputs with 12-bit resolution.
The inputs can be set to 2 different operation modes individually by software:

- Analog Voltage Input: 4 x 0 to 5 V ratiometric or with absolute reference.
- Analog Voltage Input: 4 x 0 to 32 V, with absolute reference.

All inputs are short-circuit protected and independent of application software (included in low-level driver software). Each input is provided with a first-order low pass filter with 3 ms time constant, and converted with a 2 ms sample rate.

11.7.1 Analog inputs

Selected via functions ADC_RAT_5V, ADC_VIN_5V and ADC_VIN_32V.

11.7.2 Digital inputs

Selected via functions DIN_5V and DIN_32V.

11.8 Timer input/SENT

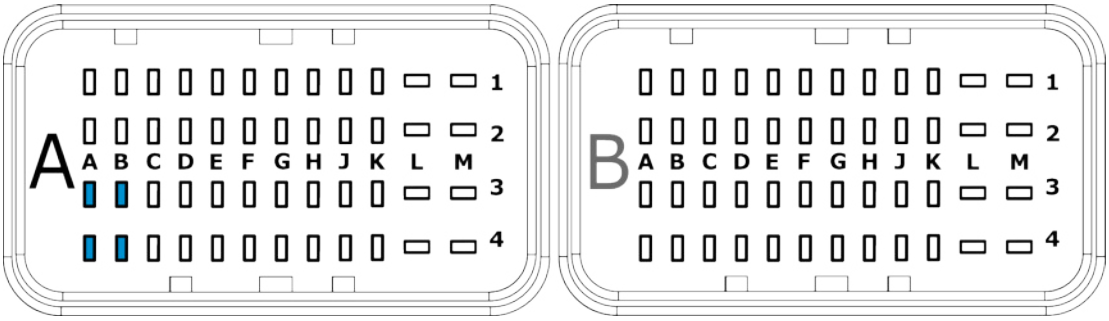

Figure 30: *TIN/SENT pinout*

Connector	Pin	Pin name
A	A4	Timer_SENT_00
A	A3	Timer_SENT_01
A	B4	Timer_SENT_02
A	B3	Timer_SENT_03

Table 50: *TIN/SENT pin group*

SPC functionality is planned for future use, and is currently not supported.

Supported functions

- SENT/SPC **(main)**
- TIN_PWD
- TIN_INC
- TIN_CNT
- ADC_VIN_32V
- DIN_32V

Functional description

4x digital inputs with timer function to process input signals such as frequency (rotational speed), pulse count and quadrature decoding (incremental length measurement), PWM etc.

SENT (Single Edge Nibble Transmission) is a serial interface that transmits 4 bits with 16 discrete pulse periods. The SAE J2716 defines both the physical interface and the protocol. It is intended to allow for the transmission of high resolution data with a low system cost. A SENT sensor usually provides three wires: a signal line, a supply voltage line and a ground line. PWM is used to encode the data.

The inputs can be individually configured via software with a pull-up resistor to adapt them to different sensor types.

The timer input can be used as an analog voltage input as well. For diagnosis, it is possible to measure the analog voltage and frequency at the same channel at the same time.

The SPC[3] is a proprietary Infineon standard which allows the AURIX™to communicate to communicate with a SENT sensor.

The SENT based communication is bidirectional.

It provides the ability to multiplex up to 4 sensors on a single SENT input while each sensor can be individually addressed with an address ID encoded in the SPC pulse from AURIX™.

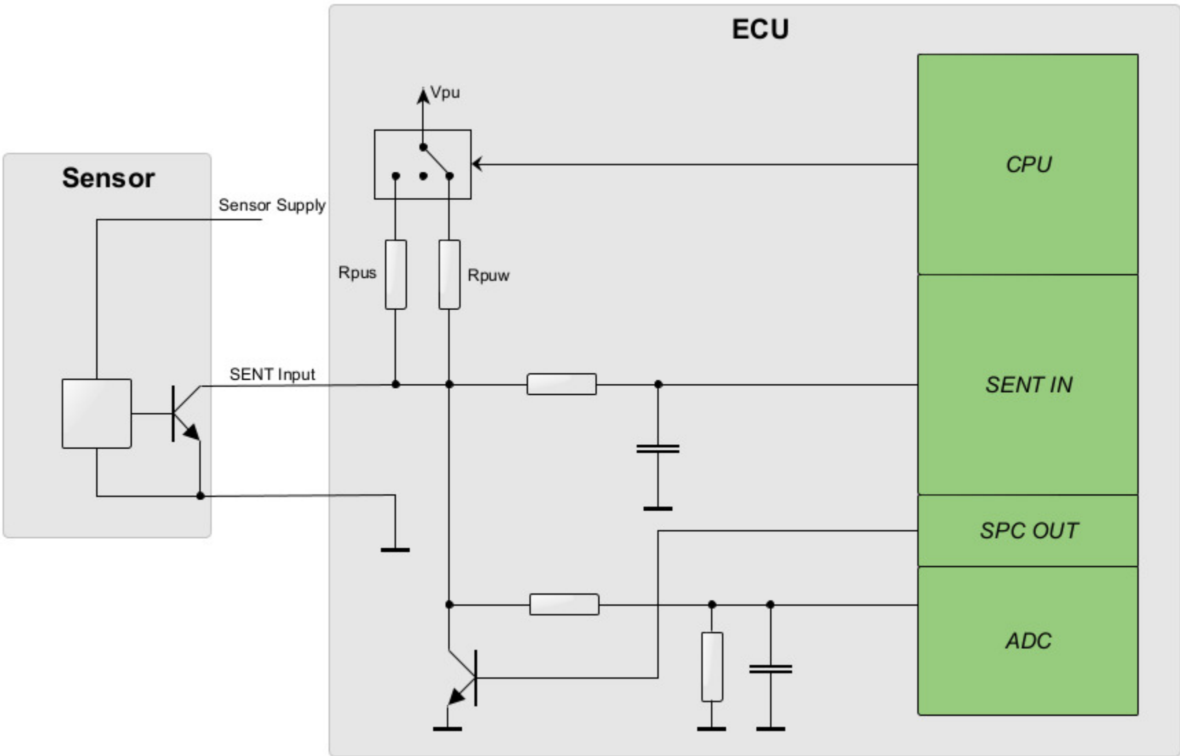

Figure 31: *Digital input for frequency/timing measurement with NPN-type 2-pole sensor*

3. Short PWM Code

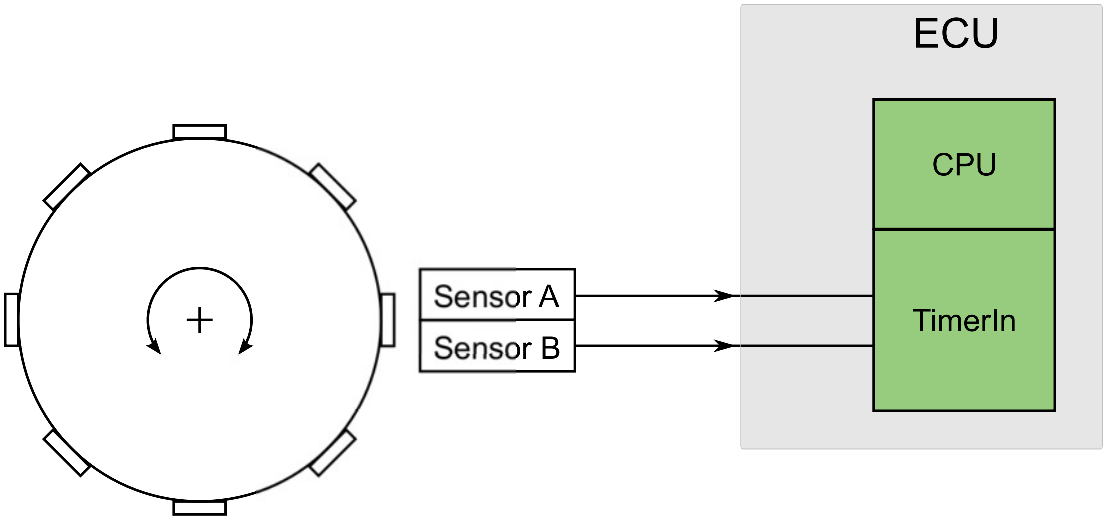

Figure 32: *Digital input pair for encoder and direction*

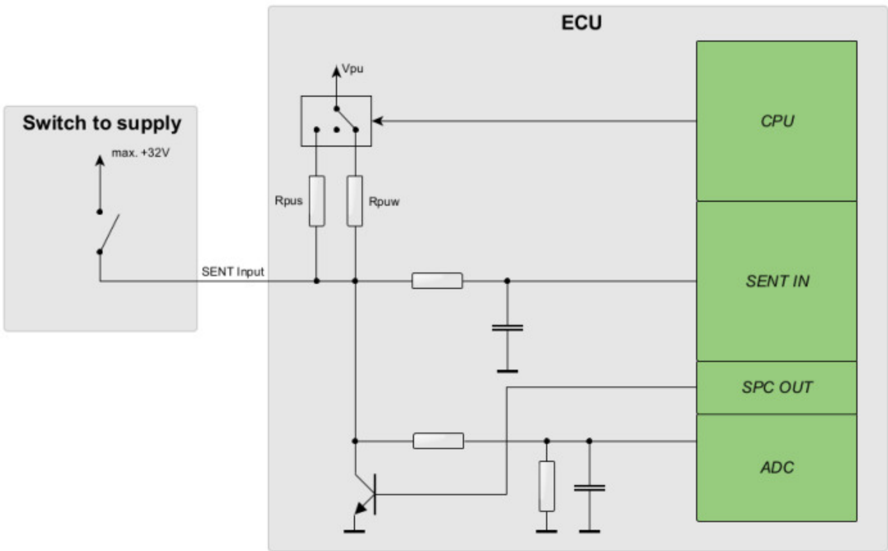

Figure 33: *Digital input for switch connected to (battery) supply voltage*

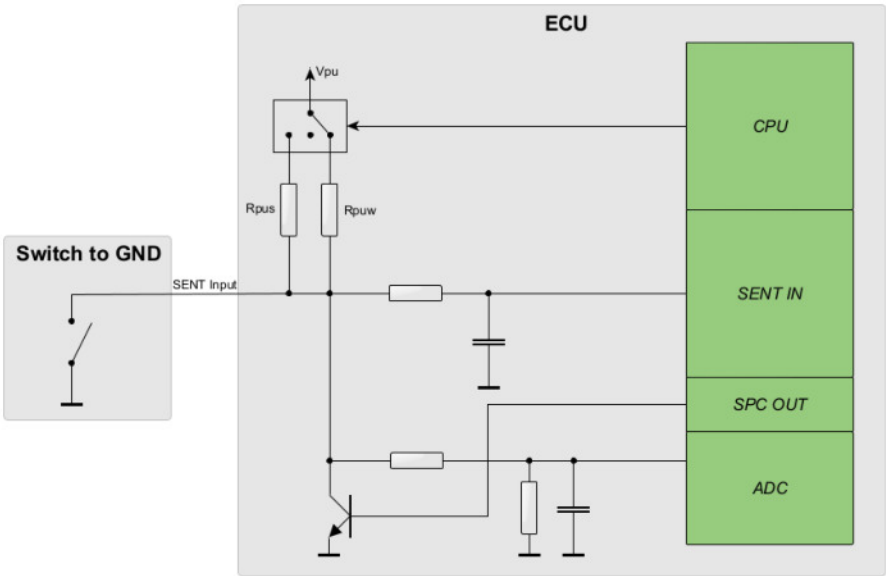

Figure 34: *Digital input for switch connected to ground*

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input voltage under overload conditions	-1	33	V

Table 51: *TIN/SENT maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
R_{pu}	Weak pull-up resistor	12	12.4	kΩ
R_{pu}	Strong pull-up resistor	2.16	2.24	kΩ
V_{pu}	Pull-up voltage (open load) [1]	4.4	4.7	V
τ_{in}	Input low pass filter	2.2	3.8	µs
F_{max}	Maximum input frequency range		20	kHz
F_{min}	Minimum input frequency	0.1		Hz
τ_{min}	Minimum on/off time to be measured	20		µs
V_{il}	Input voltage for low level	0	2	V
V_{ih}	Input voltage for high level	3.2	32	V
t_{res}	Timer resolution	0.2	1	µs

Table 52: *TIN/SENT characteristics*

[1] This is the input voltage with pull-up setting, without the sensor connected.

11.8.1 Analog input

Selected via function ADC_VIN_32V.

11.8.2 Digital input

Selected via function DIN_32V.

11.9 Timer input/current loop

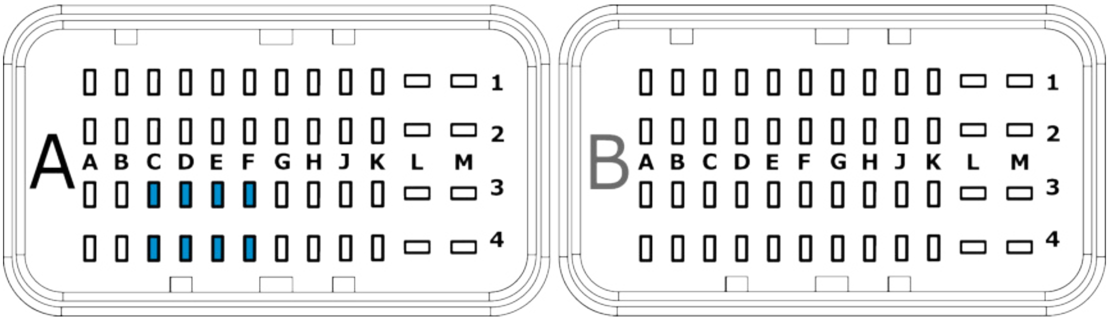

Figure 35: *TIN/CL pinout*

Connector	Pin	Pin name
A	C4	Timer_CL_00
A	C3	Timer_CL_01
A	D4	Timer_CL_02
A	D3	Timer_CL_03
A	E4	Timer_CL_04
A	E3	Timer_CL_05
A	F4	Timer_CL_06
A	F3	Timer_CL_07

Table 53: *TIN/CL pin group*

Supported functions

- TIM_PWD_CL **(main)**
- TIN_INC
- TIN_CNT
- ADC_VIN_32V
- ADC_CIN_CL_25mA
- DIN_32V

Functional description

8x timer inputs can be used as digital (7/14 mA) current loop sensor inputs. See figure 36.

During power down (`Terminal 15` off), the ECU does not disconnect the timer and current loop sensor inputs. It is not recommended to supply the sensors permanently in order to prevent battery discharge.

TTControl recommends one of the following 2 options:

1. Use a digital output for supplying the sensor. When the device is switched off, the ECU can perform an application-controlled shutdown, e. g., in order to operate a cooling fan to cool down an engine

until the temperature is low enough or to store data in the non-volatile memory of the ECU. If the application controlled shut-down is finished, the ECU switches off and consumes less than 1 mA of battery current (including sensors).

2. `Terminal 15` is used to supply the current loop sensor directly.
   Note that `Terminal 15` is often used to switch relays or other inductive loads directly. This may cause transients in excess of ±50 V, for which the sensor must be specified.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input voltage under overload conditions	-1	33	V

Table 54: *TIN/CL maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
R_{pdc}	Pull-down resistor (current loop configuration) [1]	89	98	Ω
τ_{in}	Input low pass filter	1.6	1.8	µs
F_{max}	Maximum input frequency range		20	kHz
F_{min}	Minimum input frequency	0.1		Hz
τ_{min}	Minimum on/off time to be measured	20		µs
I_{il}	Input current for low level (current loop configuration)	4	8.5	mA
I_{ih}	Input current for high level (current loop configuration)	11	20	mA
$I_{il\ SRC}$	Input current (7/14 mA) sensor SRC too low (current loop configuration) [2]		4	mA
$I_{ih\ SRC}$	Input current (7/14 mA) sensor SRC too high (current loop configuration) [3]	20		mA
t_{res}	Timer resolution	0.2	1	µs

Table 55: *TIN/CL characteristics*

[1] With software setting for digital (7/14 mA) current loop sensor inputs (ABS-type sensors).
[2] Fault detection window for defect digital (7/14 mA) current loop sensor inputs with too low current.
[3] Fault detection window for defect digital (7/14 mA) current loop sensor inputs with too high current. If the current exceeds the maximum input current, then overload protection gets active.

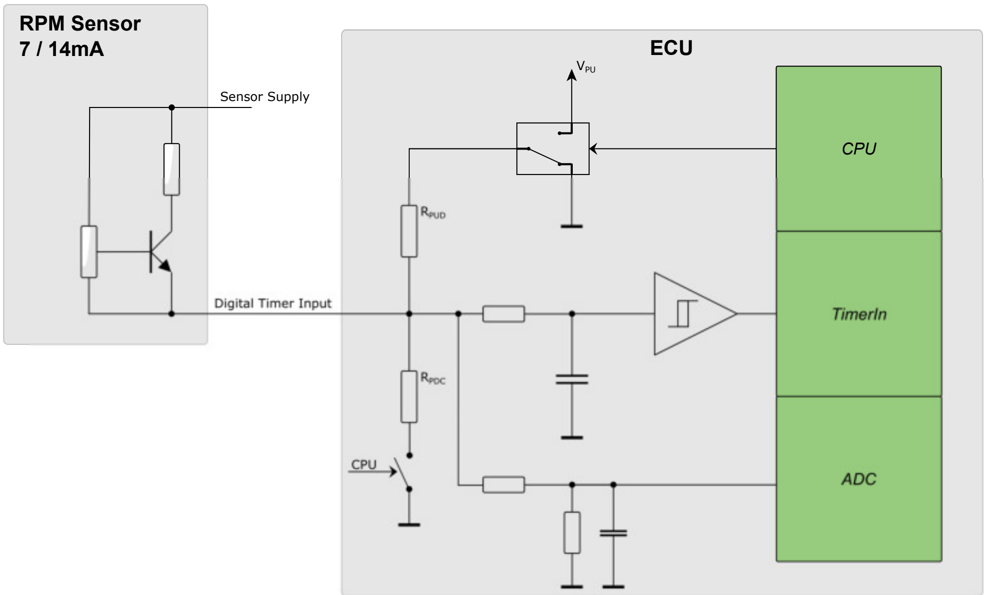

Figure 36: *Digital input for frequency measurement with ABS-type 7/14 mA, 2 pole sensor*

11.9.1 Analog inputs

Selected via functions ADC_VIN_32V, or ADC_CIN_CL_25mA for current mode.

Characteristics of analog voltage input

Symbol	Parameter	Min	Max	Unit
	Resolution		12	bit
R_{pud}	Pull-up/pull-down resistor	7.5	10	kΩ
V_{pu}	Pull-up voltage (open load) [2]	4.25	4.8	V
V_{in}	Input voltage range	0	32	V
τ_{in}	Input low pass filter (analog path)	8	12	ms
V_{tol-0}	Zero reading error [1] [3]	-50	50	mV
V_{tol-0}	Zero reading error [3]	-80	80	mV
V_{tol-p}	Proportional error [1] [3]	-3	3	%
V_{tol-p}	Proportional error [3]	-4	4	%
LSB	Nominal value of 1 LSB		8	mV

Table 56: *TIN/CL – characteristics of analog voltage input*

Characteristics of analog current input

Symbol	Parameter	Min	Max	Unit
R_{pud}	Pull-up/pull-down resistor	89	98	Ω
I_{in}	Input current range	0	25	mA
τ_{in}	Input low pass filter (analog path)	8	12	ms
I_{tol-0}	Zero reading error [1] [3]	-100	100	µA
I_{tol-0}	Zero reading error [3]	-150	150	µA
I_{tol-p}	Proportional error [1] [3]	-2	2	%
I_{tol-p}	Proportional error [3]	-2.6	2.6	%
LSB	Nominal value of 1 LSB		13.4	µA

Table 57: *TIN/CL – characteristics of analog current input*

[1] T_{ECU} = -40 to +85 °C
[2] This is the input voltage with pull-up setting, without the sensor connected.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.9.2 Digital input

Selected via function DIN_32V.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
R_{pud}	Pull-up/pull-down resistor	7.5	10	kΩ
V_{pu}	Pull-up voltage (open load) [1]	4.25	4.8	V
V_{in}	Input voltage range	0	32	V
τ_{in}	Input low pass filter	1.6	1.8	µs
V_{il}	Input voltage for low level	0	2	V
V_{ih}	Input voltage for high level	3	32	V

Table 58: *TIN/CL – characteristics of digital input*

[1] This is the input voltage with pull-up setting, without the sensor connected.

11.10 High-side PWM output

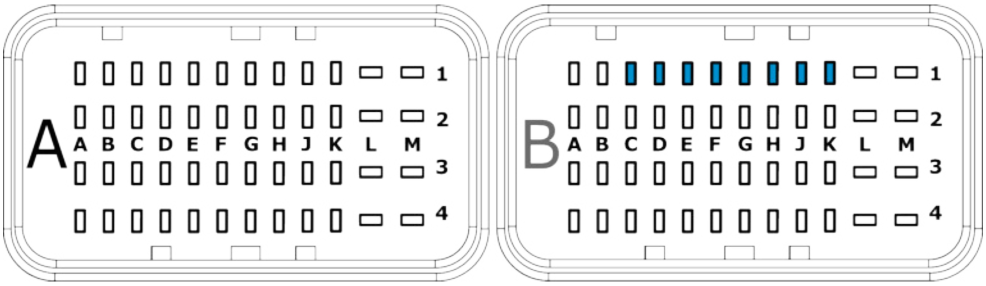

Figure 37: *PWM HS 4A+CM+FM pinout for TTC 2310*

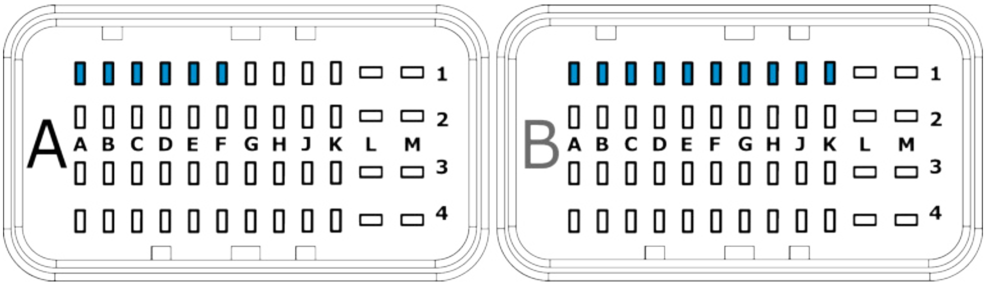

Figure 38: *PWM HS 4A+CM+FM pinout for TTC 2380, TTC 2385 and TTC 2390*

Connector	Pin	Pin name	Variant
B	C1	HS_OUT_00	All
B	D1	HS_OUT_01	All
B	E1	HS_OUT_02	All
B	F1	HS_OUT_03	All
B	G1	HS_OUT_04	All
B	H1	HS_OUT_05	All
B	J1	HS_OUT_06	All
B	K1	HS_OUT_07	All
B	A1	HS_OUT_08	TTC 2380, TTC 2385, TTC 2390
B	B1	HS_OUT_09	TTC 2380, TTC 2385, TTC 2390
A	A1	HS_OUT_10	TTC 2380, TTC 2385, TTC 2390
A	B1	HS_OUT_11	TTC 2380, TTC 2385, TTC 2390
A	C1	HS_OUT_12	TTC 2380, TTC 2385, TTC 2390
A	D1	HS_OUT_13	TTC 2380, TTC 2385, TTC 2390
A	E1	HS_OUT_14	TTC 2380, TTC 2385, TTC 2390
A	F1	HS_OUT_15	TTC 2380, TTC 2385, TTC 2390

Table 59: *PWM HS 4A+CM+FM pin groups*

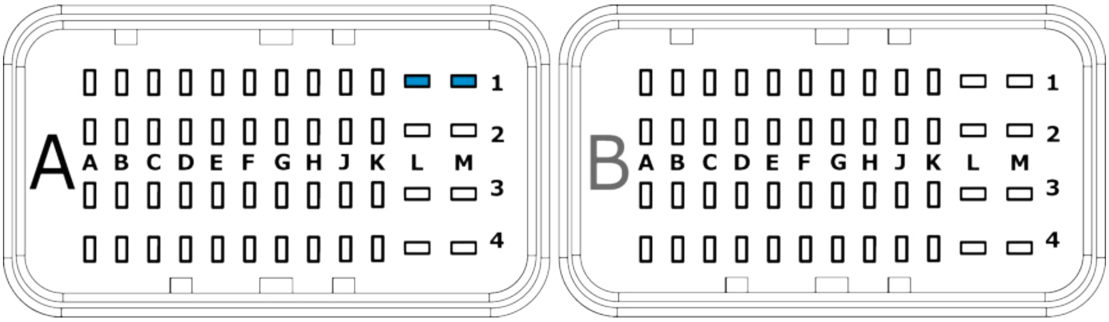

Figure 39: *PWM HS 8A+CM+FM pinout*

Connector	Pin	Pin name
A	L1	HS_OUT_16
A	M1	HS_OUT_17

Table 60: *PWM HS 8A+CM+FM pin group*

Supported functions

- PWM_HS_4A **(main)**
  - available for PWM HS 4A+CM+FM pin groups only, see table 59
- PWM_HS_8A **(main)**
  - available for PWM HS 8A+CM+FM pin group only, see table 60
- ADC_VIN_32V
- DIN_32V
- TIN_PWD

Functional description

Power output stages with freewheeling diodes for inductive loads with low-side connection. The load current is controlled with PWM. For better accuracy and diagnostics, a current measurement/feedback loop is provided.

If an error is detected in a safety-critical system, the watchdog or the main CPU can disable the output stage (off state), triggered by the application software.

For diagnostic and safety reasons, the actual PWM output signal is looped back to a timer input internally on the CPU, and the measured value is compared to the set value. For safety-critical applications, fast error detection is necessary. For this reason, a permanent PWM output is available, setting a minimum on/off time to 100/200 µs instead of 0 or 100 % duty cycle. This ensures a reliable periodical state change of the output, allowing permanent load monitoring that is independent of the operation point. Even when the load is switched off, a short on the load can be detected.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop, and prevent the crimp contact from overheating in case of maximum load current.

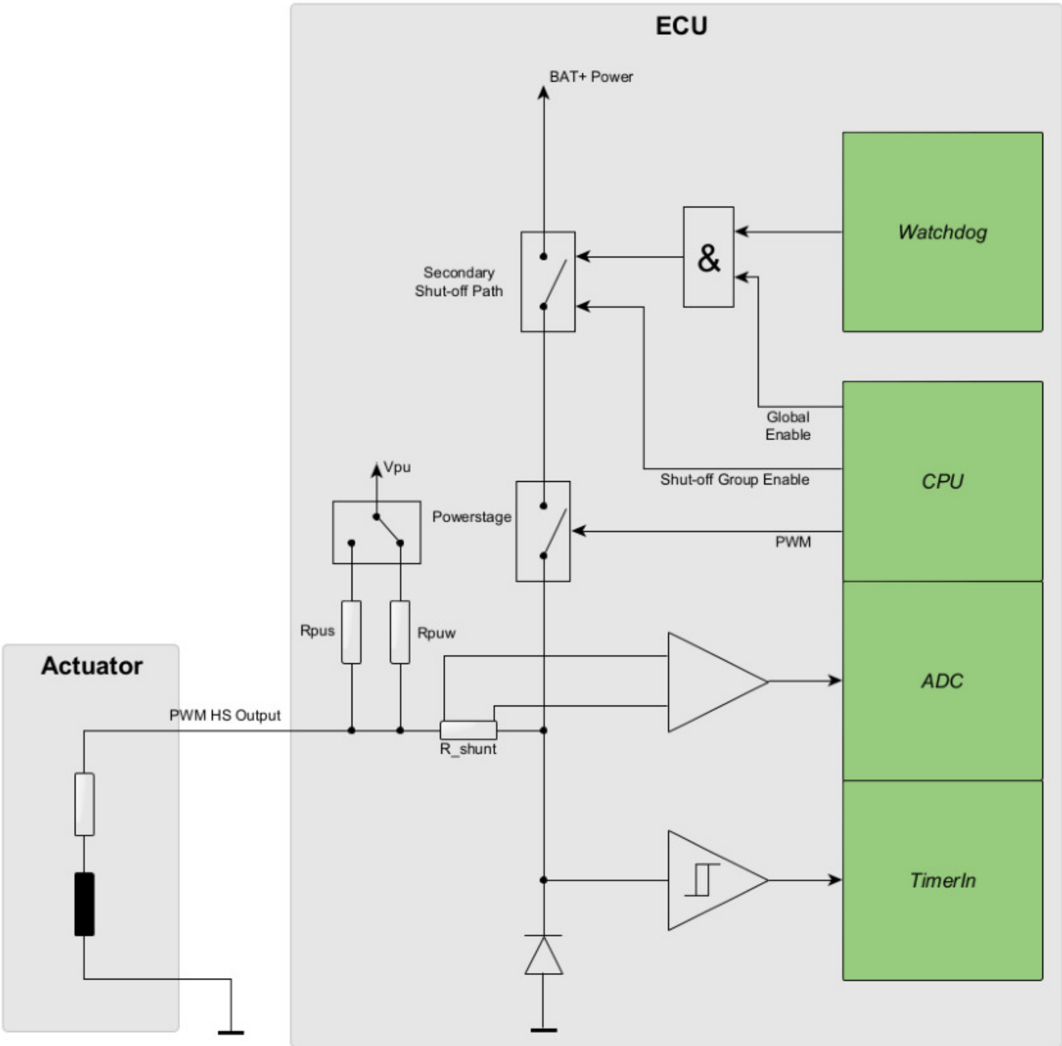

Figure 40: *High-side output stage with PWM functionality*

Power stage pairing

If outputs are used in parallel, always combine two channels from the same double-channel power stage and use the digital output mode. See pinouts 37, 38 and 39 to use the right power stage outputs in parallel.

Due to thermal limits, the resulting total load current of this output pair has to be de-rated by a factor of 0.85 (e.g., combining two 3 A outputs would result in a total load current of 3 A x 2 x 0.85 = 5.1 A). The application software must ensure that both outputs are switched on at the same point in time, otherwise the over-current protection may trip.

For balanced current distribution through each of the pin pairs, the cable routing must be symmetrical if pin-pairs or multiple pins are wired parallel to support higher load currents.

Mutually exclusive mode

The TTC 2300 uses double-channel high-side power stages. For load levelling, it is recommended that loads which are switched on mutually exclusive (which means either load A, or load B is on, but not A and

B at the same time), are connected to the same double-channel power stage. This reduces the thermal stress of the components. The power stage pairing is given in section 11.10.

For high-side PWM output stage operating in 444 to 1000 Hz mode, the current limit is increased to 1 A if used in mutual exclusive mode. For further information, see sections 11.10.1 and 11.10.1.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input voltage under overload conditions [1]	-0.5	32	V
V_{in}	Input voltage under overload conditions [1]	-0.5	$V_{BAT+power}$ +0.5	V

Table 61: *High-side PWM output maximum ratings*

[1] The input voltage may go up to 32 V, but must never exceed battery supply voltage.

11.10.1 High-side PWM outputs 4 A/8 A

Selected via functions PWM_HS_4A and PWM_HS_8A (see tables 59 and 60, respectively, for applicable pins).

Characteristics of high-side PWM output 4 A

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	15	25	nF
R_{pu}	Pull-up resistor	4.6	4.8	kΩ
V_{pu}	Pull-up voltage (open load)	4.2	4.6	V
f_{PWM}	PWM frequency [1]	50	1000	Hz
T_{min-on}	Minimum on time [2]	100		μs
$T_{min-off}$	Minimum off time [2]	200		μs
R_{on}	On-resistance		150	mΩ
I_{max}	Maximum load current (f = 50…250 Hz)		3	A
I_{max}	Maximum load current (f = 50…250 Hz) [3]		4	A
I_{max}	Maximum load current (f = 266…1000 Hz)		1	A
I_{max}	Maximum load current (f = 266…1000 Hz) [4]		2	A
I_{peak}	Peak load current limit [5]		6	A
R_{load_min}	Minimum coil resistance (12 V) [6]	2		Ω
R_{load_min}	Minimum coil resistance (24 V) [6]	4		Ω
R_{load_max}	Maximum load resistance [7]		1	kΩ
C_{load_max}	Maximum load capacitance [8]		200	μF
I_{tol-0}	Zero reading error [3] [9] [10]	-40	40	mA
I_{tol-0}	Zero reading error [9] [10]	-60	60	mA
I_{tol-p}	Proportional error [3] [10]	-2	2	%
I_{tol-p}	Proportional error [9] [10]	-2.6	2.6	%
LSB	Nominal value of 1 LSB		2.5	mA
f_{g_LP}	Cut-off frequency of 3rd low pass filter [11]	60	86	Hz

Table 62: *High-side PWM output 4 A – characteristics*

[1] Not all values for PWM frequency are possible, refer to the I/O Driver Manuals [15, 17, 19, 21] for supported frequency values.
[2] When the output is configured as safety-critical (instead of zero).
[3] T_{ECU} = -40 to +85 °C
[4] For 12 V systems
[5] For t < 180 ms
[6] In addition to the maximum load current limit, there is also a minimum load resistance limit, depending on the battery supply voltage.
[7] Exceeding this value will trigger open load detection.
[8] A current controller is switched on in order to deal with higher capacitive loads using a very low PWM duty cycle. A measured current of below e.g., 100mA can be used.
[9] The measured value is clipped in software if below zero. In some devices, a small output current is necessary to get ADC-values greater than zero.
[10] The total error (I_{tol}) is the sum of proportional error and zero reading error: $I_{tol} = \pm(I_{tol-p} \cdot I_{load} + I_{tol-0})$
[11] An active low pass filter (3rd order) is provided to reduce current ripple from the ADC input. Further digital filtering is applied to eliminate the current ripple completely and provide a stable measurement value for the application.

Characteristics of high-side PWM output 8 A

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	15	25	nF
R_{pu}	Pull-up resistor	4.6	4.8	kΩ
V_{pu}	Pull-up voltage (open load)	4.2	4.6	V
f_{PWM}	PWM frequency [1]	50	1000	Hz
$T_{min\text{-}on}$	Minimum on time [2]	100		µs
$T_{min\text{-}off}$	Minimum off time [2]	200		µs
R_{on}	On-resistance		75	mΩ
I_{max}	Maximum load current (f = 50…250 Hz)		6	A
I_{max}	Maximum load current (f = 50…250 Hz) [3]		8	A
I_{max}	Maximum load current (f = 266…1000 Hz)		2	A
I_{max}	Maximum load current (f = 266…1000 Hz) [4]		4	A
I_{peak}	Peak load current limit [5]		12	A
R_{load_min}	Minimum coil resistance (12 V) [6]	1		Ω
R_{load_min}	Minimum coil resistance (24 V) [6]	2		Ω
R_{load_max}	Maximum load resistance [7]		1	kΩ
$I_{tol\text{-}0}$	Zero reading error [3 8 9]	-20	20	mA
$I_{tol\text{-}0}$	Zero reading error [8 9]	-30	30	mA
$I_{tol\text{-}p}$	Proportional error [3 9]	-2	2	%
$I_{tol\text{-}p}$	Proportional error [8 9]	-2.6	2.6	%
LSB	Nominal value of 1 LSB		5	mA
f_{g_LP}	Cut-off frequency of 3rd low pass filter [10]	60	86	Hz

Table 63: *High-side PWM output 8 A – characteristics*

[1] Not all values for PWM frequency are possible, see section PWM - Pulse Width Modulation driver of the variant I/O Driver Manual [15, 17, 19, 21] for supported frequency values.
[2] When the output is configured as safety-critical (instead of zero).
[3] T_{ECU} = -40 to +85 °C
[4] For 12 V systems
[5] For t < 180 ms
[6] Additionally to observing the maximum load current limit, there is also a minimum load resistance limit, depending on the battery supply voltage.
[7] Exceeding this value will trigger open load detection.
[8] The measured value is clipped in software if below zero. In some devices, a small output current is necessary to get ADC-values greater than zero.
[9] The total error (I_{tol}) is the sum of proportional error and zero reading error: $I_{tol} = \pm(I_{tol-p} \cdot I_{load} + I_{tol-0})$
[10] An active low pass filter (3rd order) is provided to reduce current ripple from the ADC input. Further digital filtering is applied to eliminate the current ripple completely and provide a stable measurement value for the application.

Diagnostic functions

Load monitoring is the detection of overloads, external short circuits of the load output to positive or negative supply (BAT+ Power/BAT-), or any other power output, and the detection of load loss.

The diagnostic functions are different between PWM and digital operation:

- **PWM-operated high-side output (duty cycle 0 % < X < 100 %)**:
Under normal load conditions, the feedback signals to the timer unit, and the ADC follow the corresponding PWM output. In case of a disconnected load (open load), the output is pulled to 5 V by an internal resistor. If there is a short circuit to ground, the feedback signals are constantly low. A short circuit to BAT+ implies that the feedback signals are pulled to 5 V, which also results in a constantly high level. By merging the measurement results from the timer and the ADC unit, it is possible to differentiate the diagnostic functions, as shown in the table below.

Output signal	Status signal			
	Normal	Open load	Short to GND	Short to U_{BAT}
0 % < X < 100 %	◯	◯	◯	◯

Table 64: *PWM-operated high-side output*

- **Digitally operated high-side output (true duty cycle of 0 or 100 %, without min. and max. pulses)**:
When the power stage is switched off, the monitoring interface will read back low level if the load is properly connected or if there is a short circuit to ground. In case of open load or short circuit to BAT+ the monitoring interface will read back high level.
When the power stage is switched on, a high level will be read back in case of normal operation. In case of excessive overload or short circuit to ground, the output switches off to protect the output stage. In this case, the monitoring interface will read back a low level. The possible diagnostic functions of the digital operation are shown in the table below.

Output signal	Status signal			
	Normal	Open load	Short to GND	Short to U_{BAT}
on	◯	◯	◯	◯
off	◯	◯	x	◯

Table 65: *Digitally operated high-side output*

◯ = detected
x = not detected

11.10.2 Analog input

Selected via function ADC_VIN_32V.

11.10.3 Digital input

Selected via function DIN_32V.

If a high-side output is not needed for the given pin groups, the loop-back path of these output stages can be used as a digital input.

External switches which are directly switching to battery voltage must not be used with alternative inputs.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	15	25	nF
τ_{in}	Input low pass filter	2	2.4	µs
R_{pu}	Pull-up resistor	4.6	4.8	kΩ
V_{pu}	Pull-up voltage	4.2	4.6	V
V_{il}	Input voltage for low level	0	2.5	V
V_{ih}	Input voltage for high level [1]	3.75	32	V
V_{in}	Input voltage range [1]	-0.5	$V_{BAT+power}$ +0.5	V

Table 66: *High-side PWM output – characteristics of digital input*

[1] The input voltage may go up to 32 V, but must never exceed battery supply voltage.

11.10.4 Timer input

Selected via function TIN_PWD.

If a high-side output is not needed for the given pin groups, the loop-back path of these output stages can be used as a timer (frequency) input.

External switches which are directly switching to battery voltage must not be used with alternative inputs.

Characteristics of timer input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
τ_{in}	Input low pass filter	2	2.4	µs
R_{pu}	Pull-up resistor	4.6	4.8	kΩ
V_{pu}	Pull-up voltage	4.2	4.6	V
f_{max}	Maximum input frequency [1]		1.5	kHz
f_{max}	Maximum input frequency [2]		20	kHz
f_{min}	Minimum input frequency [3]	0.1		Hz
t_{res}	Timer resolution	0.2	1	µs
t_{min}	Minimum on/off time to be measured by timer input	20		µs
V_{il}	Input voltage for low level	0	2.5	V
V_{ih}	Input voltage for high level [4]	3.75	32	V
V_{in}	Input voltage range [4]	-0.5	$V_{BAT+power}$ +0.5	V

Table 67: *High-side PWM output – characteristics of timer input*

[1] With open collector sensor output
[2] With push-pull sensor output stage
[3] Due to the dynamic range of the timer, there is a minimum frequency when a timer overflow occurs. Even at a lower frequency the output value will be read as 0 Hz.
[4] The input voltage may go up to 32 V but must never exceed battery supply voltage.

11.11 Low-side PWM output

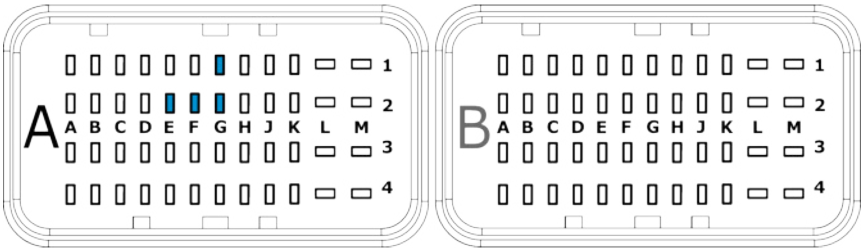

Figure 41: *PWM LS 4A+CM pinout*

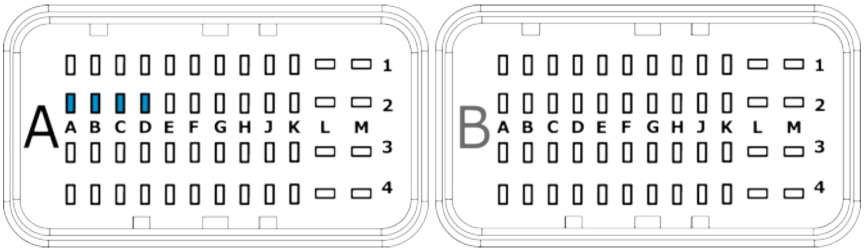

Figure 42: *PWM LS 4A+CM+FM pinout*

Connector	Pin	Pin name	Function
A	A2	LS_00	TIN_PWD
A	B2	LS_01	TIN_PWD
A	C2	LS_02	TIN_PWD
A	D2	LS_03	TIN_PWD
A	E2	LS_04	
A	F2	LS_05	
A	G1	LS_06	
A	G2	LS_07	

Table 68: *PWM LS 4A+CM and PWM LS 4A+CM+FM pin groups*

Supported functions

- PWM_LS_4A **(main)**
- ADC_RAT_5V
- ADC_VIN_5V
- ADC_VIN_32V
- DIN_5V
- DIN_32V
- TIN_PWD
  - available for pins in the (PWM LS 4A+CM+FM) pin group only.

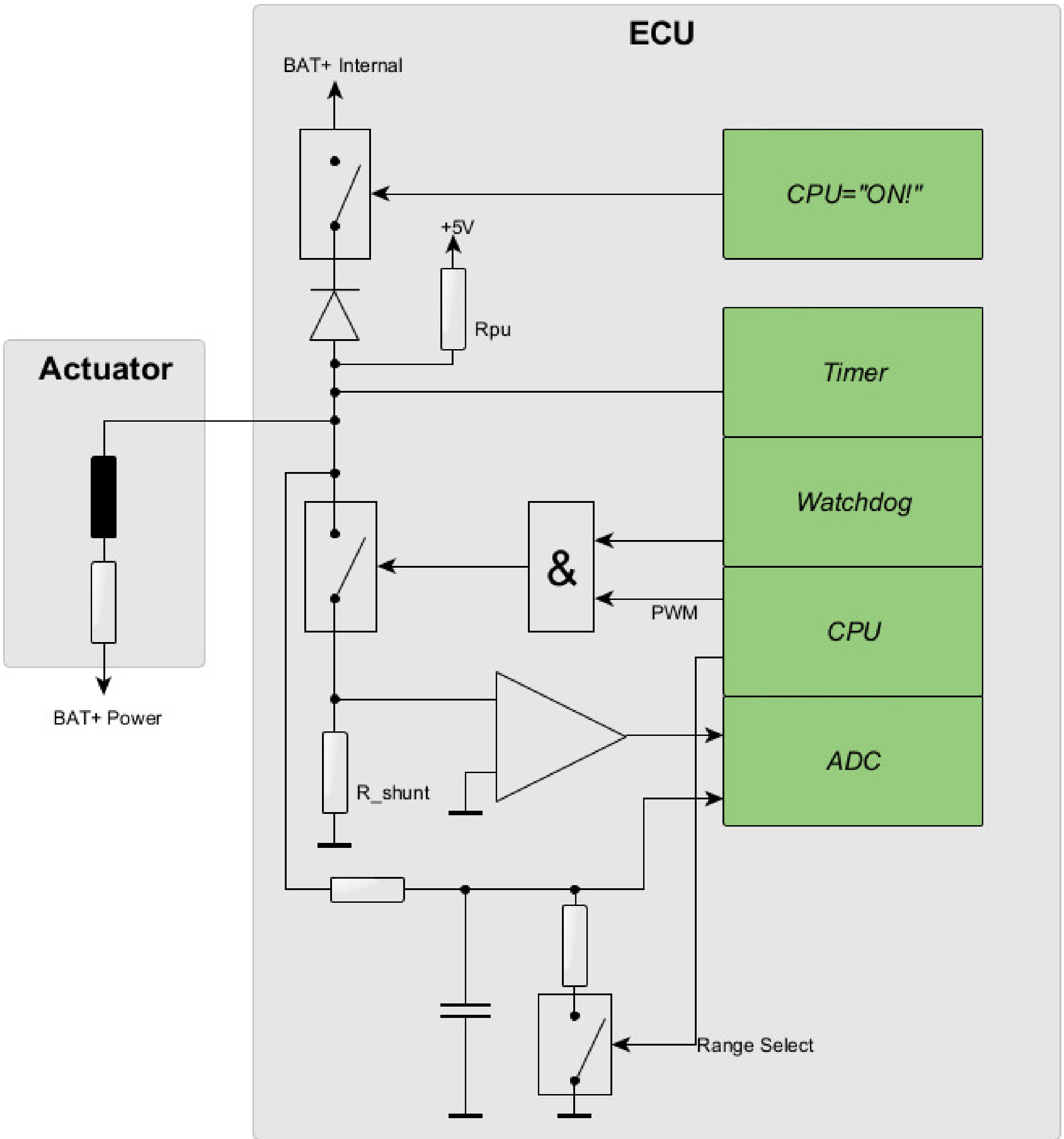

Figure 43: *Low-side output stage with PWM functionality*

Functional description

Low-side power output stages with reverse polarity protected freewheeling diodes to BAT+ for inductive and resistive loads with a high-side connection. The freewheeling diodes are switched off if the CPU is off to prevent a BAT+ phantom supply.

The load can only be set using PWM, not controlled.

A current measurement loop is provided but cannot be used for current control application. The intended use is a plausibility check of the High-side PWM current measurement when it is combined with the Low-side PWM in digital output mode to be able to shut off in case of a short circuit of the load to the battery.

The current that flows through the low-side switch is monitored and triggers the opening in case of over-current. Short-circuit and overload protection is included in the driver software. Before a tripped channel can be re-enabled, the overload situation has to be removed.

For diagnostic and safety reasons, the actual PWM output signal for LS_00 to LS_03 is looped back to a timer input, and the measured value is compared to the set value.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input/output voltage under overload conditions	-0.5	$V_{BAT+power}$ +0.5	V
V_{OUT}	Output voltage under overload conditions [1]		33	V

Table 69: *Low-side PWM output maximum ratings*

[1] Inductive load transients will be clamped internally to BAT+ via free wheeling diode.

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	kΩ
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
R_{pu}	Pull-up resistor (32 V mode)	6.1	6.34	kΩ
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
R_{on}	On-resistance		50	mΩ
I_{load}	Nominal load current		3	A

I_{max}	Maximum load current [1]		4	A
I_{peak}	Peak load current [2]		6	A
$I_{tol\text{-}0}$	Zero reading error [1] [3]	-95	95	mA
$I_{tol\text{-}0}$	Zero reading error [3]	-125	125	mA
$I_{tol\text{-}p}$	Proportional error [1] [3]	-3.4	3.4	%
$I_{tol\text{-}p}$	Proportional error [3]	-4.3	4.3	%
f_{PWM}	PWM frequency [4]	-4.3	4.3	%
f_{PWM}	short time PWM frequency [4] [5]	-4.3	4.3	%

Table 70: *Low-side PWM output characteristics*

[1] T_{ECU} = -40 to +85 °C
[2] Peak current for maximal 100 ms. Exceeding this value will trigger overload protection and switch off the power stage. Steady state operation goes only up to 3 A/4 A depending on temperature.
[3] The total measurement error is the sum of zero reading error and the proportional error.
[4] Not all values for PWM frequency are possible, refer to the I/O Driver Manuals [15, 17, 19, 21] for supported frequency values.
[5] 4A is allowed for a maximum of 10s continuous operation.

11.11.1 Analog inputs

Selected via functions ADC_RAT_5V, ADC_VIN_5V and ADC_VIN_32V.

11.11.2 Digital inputs

Selected via functions DIN_5V and DIN_32V.

11.11.3 Timer input

Selected via function TIN_PWD.

11.12 High-side digital output

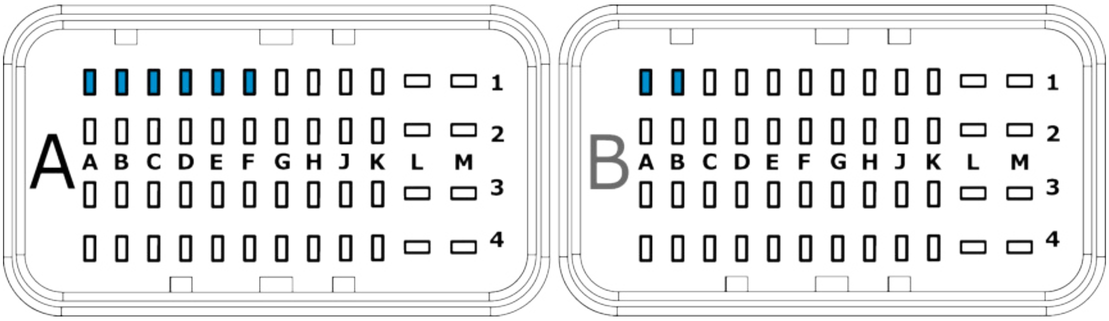

Figure 44: *DOP HS 4A+CS+FM pinout*

Connector	Pin	Pin name	Variant
B	A1	HS_OUT_08	TTC 2310
B	B1	HS_OUT_09	TTC 2310
A	A1	HS_OUT_10	TTC 2310
A	B1	HS_OUT_11	TTC 2310
A	C1	HS_OUT_12	TTC 2310
A	D1	HS_OUT_13	TTC 2310
A	E1	HS_OUT_14	TTC 2310
A	F1	HS_OUT_15	TTC 2310

Table 71: *DOP HS 4A+CS+FM pin group*

Supported functions

- DOP_HS_4A **(main)**
- ADC_VIN_32V
- DIN_32V
- TIN_PWD

Functional description

8x power output stages with freewheeling diodes for inductive and resistive loads with low-side connection.

The load current is controlled with PWM. For better accuracy and diagnostics, a current measurement/feedback loop is provided.

Suitable loads are lamps, valves, relays etc.

If an error is detected in a safety-critical resource, the watchdog or the main CPU will disable the output stage (off state).

For diagnostic reasons, the output signal is looped back to the CPU, and the value measured is compared with the value set. When the output is not used, the loop-back signal can be used as an analog input or as a digital input.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

Power stage pairing

If outputs are used in parallel, always combine two channels from the same double-channel power stage and use the digital output mode. See pinout at 44 for using the right power stage outputs in parallel.

Due to thermal limits, the resulting total load current of this output pair has to be de-rated by a factor of 0.85 (e.g., combining two 3 A outputs would result in a total load current of 3 A x 2 x 0.85 = 5.1 A). The application software has to make sure that both outputs are switched on at the same point in time, otherwise the over-current protection may trip.

For balanced current distribution through each of the pin pairs, the cable routing must be symmetrical if pin-pairs or multiple pins are be wired parallel to support higher load currents.

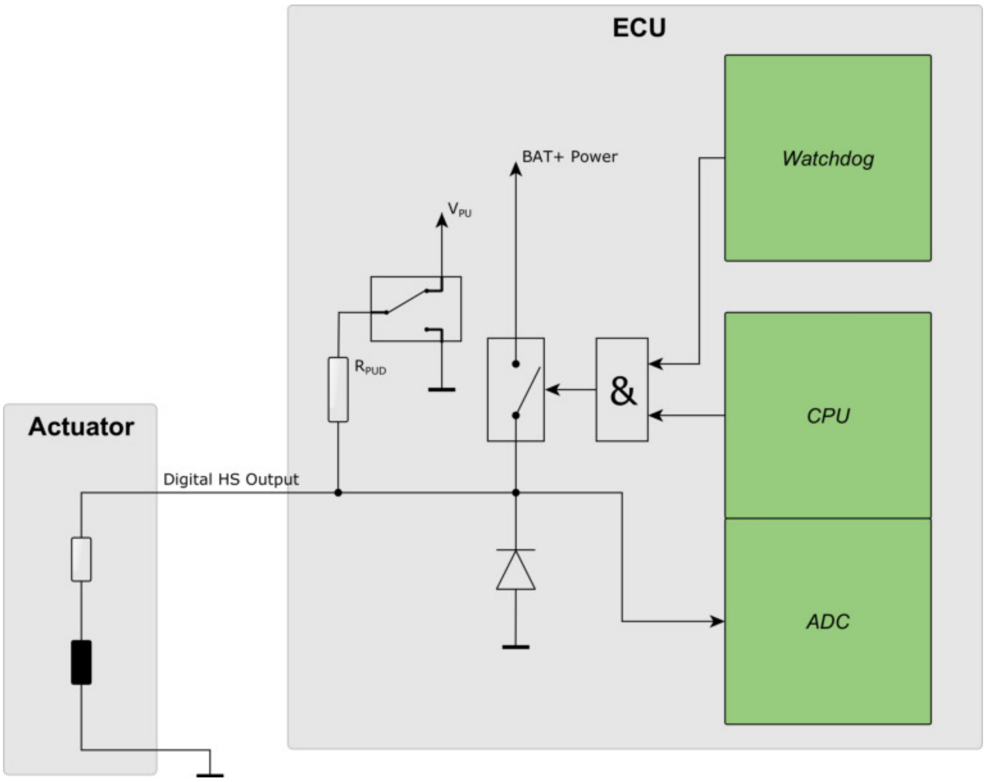

Figure 45: *Digital high-side power stage*

Mutually exclusive mode

The TTC 2300 uses double-channel high-side power stages. For load levelling, it is recommended that loads which are switched on mutually exclusive (which means either load A, or load B is on, but not A and B at the same time), are connected to the same double-channel power stage. This reduces the thermal stress of the components. The power stage pairing is given in section 11.12.

Diagnostic functions

Load monitoring is the detection of overloads, external short circuits of the load output to positive or negative supply (BAT+/BAT-) or any other power output and detection of load loss.

Output signal	Status signal			
	Normal	Open load	Short to GND	Short to U_{BAT}
on	◯	x	◯	x
off	◯	◯	x	◯

◯ = detected
x = not detected

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input/output voltage under overload conditions	-0.5	BAT+ Power +0.5	V

Table 73: *High-side digital output maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	432	528	nF
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	kΩ
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
R_{on}	On-resistance		150	mΩ
I_{load}	Nominal load current		3	A
I_{max}	Maximum load current [1]		4	A
I_{peak}	Peak load current [2]		6	A
I_{tol-0}	Zero reading error [1] [3]	-50	50	mA
I_{tol-0}	Zero reading error [3]	-80	80	mA
I_{tol-p}	Proportional error [1] [3]	-10	10	%
I_{tol-p}	Proportional error [3]	-14	14	%

Table 74: *High-side digital output characteristics*

[1] T_{ECU} = -40 to +85 °C
[2] Peak current for maximal 100 ms. Exceeding this value will trigger overload protection and switch off the power stage. Steady state operation goes only up to 3 A/4 A depending on temperature.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.12.1 Analog voltage inputs

Selected via function ADC_VIN_32V.

External switches which are directly switching to battery voltage must not be used with alternative inputs.

Characteristics of analog voltage input

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	15	25	nF
R_{pu}	Pull-up resistor	4.6	4.8	kΩ
V_{pu}	Pull-up voltage (open load)	4.2	4.6	V
τ_{in}	Input low pass filter	9.5	12	ms
	Resolution		12	bit
$V_{tol\text{-}0}$	Zero reading error [1] [3]	-50	50	mV
$V_{tol\text{-}0}$	Zero reading error [3]	-80	80	mV
$V_{tol\text{-}p}$	Proportional error [1] [3]	-3	3	%
$V_{tol\text{-}p}$	Proportional error [3]	-4	4	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range [2]	0	32	V
V_{in}	Input voltage range [2]	-0.5	BAT+ Power +0.5	V

Table 75: *High-side digital output – characteristics of analog voltage input*

4

[1] T_{ECU} = -40 to +85 °C
[2] The input voltage may go up to 32 V but must never exceed battery supply voltage.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.12.2 Digital inputs

Selected via function DIN_32V.

External switches which are directly switching to battery voltage must not be used with alternative inputs.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
τ_{in}	Input low pass filter	9.5	12	ms
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	kΩ
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
	Resolution		12	bit
$V_{tol\text{-}0}$	Zero reading error [1] [2]	-50	50	mV
$V_{tol\text{-}0}$	Zero reading error [2]	-80	80	mV
V_{il}	Input voltage for low level [3]	0	<x>	V
V_{ih}	Input voltage for high level [3] [4]	<x>	32	V
V_{in}	Input voltage range [4]	-0.5	BAT+ Power +0.5	V

Table 76: *High-side digital output – characteristics of digital input*

[1] T_{ECU} = -40 to +85 °C
[2] The total measurement error is the sum of zero reading error and the proportional error.
[3] Values <x> are configured by the application software.
[4] The input voltage may go up to 32 V, but must never exceed battery supply voltage.

11.12.3 Timer input

Selected via function TIN_PWD.

11.13 High-side digital/PVG/V_{OUT} output

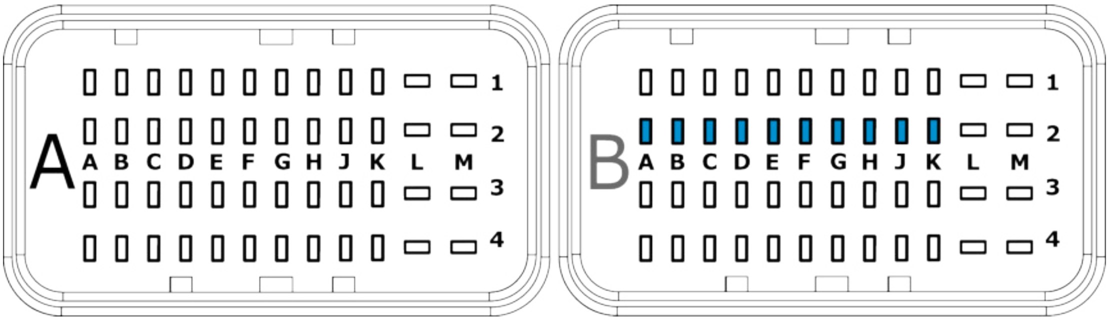

Figure 46: *DOP HS 4A+CS/LPO pinout*

Connector	Pin	Pin name	Function
B	A2	HS_OUT_18	LPO_VOUT_LP
B	B2	HS_OUT_19	LPO_VOUT_LP
B	C2	HS_OUT_20	LPO_VOUT_LP
B	D2	HS_OUT_21	LPO_VOUT_LP
B	E2	HS_OUT_22	LPO_VOUT_LP
B	F2	HS_OUT_23	LPO_VOUT_LP
B	G2	HS_OUT_24	LPO_VOUT, LPO_VOUT_LP
B	H2	HS_OUT_25	LPO_VOUT, LPO_VOUT_LP
B	J2	HS_OUT_26	LPO_VOUT, LPO_VOUT_LP
B	K2	HS_OUT_27	LPO_VOUT, LPO_VOUT_LP

Table 77: *DOP HS 4A+CS/LPO pin group*

Supported functions

- DOP_HS_4A **(main)**
- LPO_PVG
- LPO_VOUT_LP
  - available for all pins, see table 77
- LPO_VOUT
  - available for 4 out of 10 pins, see table 77
- ADC_VIN_32V
- DIN_32V

Functional description

10x output stages for interfacing to PVG type hydraulic valve groups (PVG mode), for low power analog voltage loads (V_{OUT} mode) or for high power inductive/resistive loads (high-side digital mode).

All ten outputs can be configured independently of each other.

If an error is detected in a safety-critical resource, the watchdog or the main CPU will disable the output stage (off state).
For diagnostic reasons, the output signal is looped back to the CPU, and the value measured is compared with the value set. When the output is not used, the loop-back signal can be used as an analog input or as a digital input.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

NOTE Pins with LPO_VOUT available to them (HS_OUT_24 - HS_OUT_27) can only switch between low-precision and standard as a group and not individually. When using one of these pins as a high-side output or as a PVG output, all must be switched to low-precision.

Power stage pairing

If outputs are used in parallel, always combine two channels from the same double-channel power stage and use the digital output mode. See section 46 for using the right power stage outputs in parallel.

Due to thermal limits, the resulting total load current of this output pair has to be de-rated by a factor of 0.85 (e.g., combining two 3 A outputs would result in a total load current of 3 A x 2 x 0.85 = 5.1 A). The application software must ensure that both outputs are switched on at the same point in time, otherwise the over-current protection may trip.

For balanced current distribution through each of the pin pairs, the cable routing must be symmetrical if pin-pairs or multiple pins are wired in parallel to support higher load currents.

Mutually exclusive mode

The TTC 2300 uses double-channel high-side power stages. For load levelling, it is recommended that loads which are switched on mutually exclusive (which means either load A, or load B is on, but not A and B at the same time), are connected to the same double-channel power stage. This reduces the thermal stress of the components. The power stage pairing is given in section 46.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input/output voltage under overload conditions	-0.5	$V_{BAT+power}$ +0.5	V

Table 78: *DOP HS 4A+CS/LPO maximum ratings*

11.13.1 High-side digital outputs

Selected via function DOP_HS_4A.

For diagnostic reasons, the output signal is looped back to the CPU, and the value measured is compared with the value set. When the output is not used, the loop-back signal can be used as an analog input or as a digital input.

See section 11.12 for additional description, and figure 45 for the relevant circuit diagram.

Diagnostic functions

Load monitoring is the detection of overloads, external short circuits of the load output to positive or negative supply (BAT+/BAT-), or any other power output and detection of load loss.

Output signal	Status signal			
	Normal	Open load	Short to GND	Short to U_{BAT}
on	◯	x	◯	x
off	◯	◯	x	◯

◯ = detected
x = not detected

Characteristics of high-side digital output

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	430	530	nF
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	kΩ
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
R_{on}	On-resistance		150	mΩ
I_{load}	Nominal load current		3	A
I_{max}	Maximum load current [1]		4	A
I_{peak}	Peak load current [2]		30	A
$I_{tol\text{-}0}$	Zero reading error [1] [3]	-20	20	mA
$I_{tol\text{-}0}$	Zero reading error [3]	-30	30	mA
$I_{tol\text{-}p}$	Proportional error [1] [3]	-15	15	%
$I_{tol\text{-}p}$	Proportional error [3]	-17	17	%

Table 80: *Characteristics of high-side digital output*

[1] T_{ECU} = -40 to +85 °C
[2] Peak current for maximal 100 ms. Exceeding this value will trigger overload protection and switch off the power stage. Steady state operation goes only up to 3 A/4 A depending on temperature.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.13.2 PVG outputs

Selected via function LPO_PVG.

Proportional Valve Groups (PVG) are a group of hydraulic load-sensing valves with integrated electronics allowing advanced flow controllability, e.g., for load-independent flow control.

For diagnostic reasons in output mode, the output signal is looped back to the CPU, and the measured value is compared to the set value. If the difference between these two values is above a fixed limit, an overload is detected, and the output is disabled. The protection mechanism tries re-enabling the output 10 times per operational cycle.

NOTE Do not use two outputs in parallel to increase driving strength, as this may impair the protection function of the LPO stage.

The PVG output can be used to control PVG valves of the types PVEA, PVEH and PVES. These types of valves apply a low pass filter to the input signal and use the resulting DC voltage in relation to the valves supply voltage (BAT+) as a parameter for flow control.

The TTC 2300 uses the BAT+ CPU pin as a reference voltage input. The principle schematic is shown in figure 47. The output is open loop controlled. The ADC input is for diagnostic purposes only and can be evaluated by the application software.

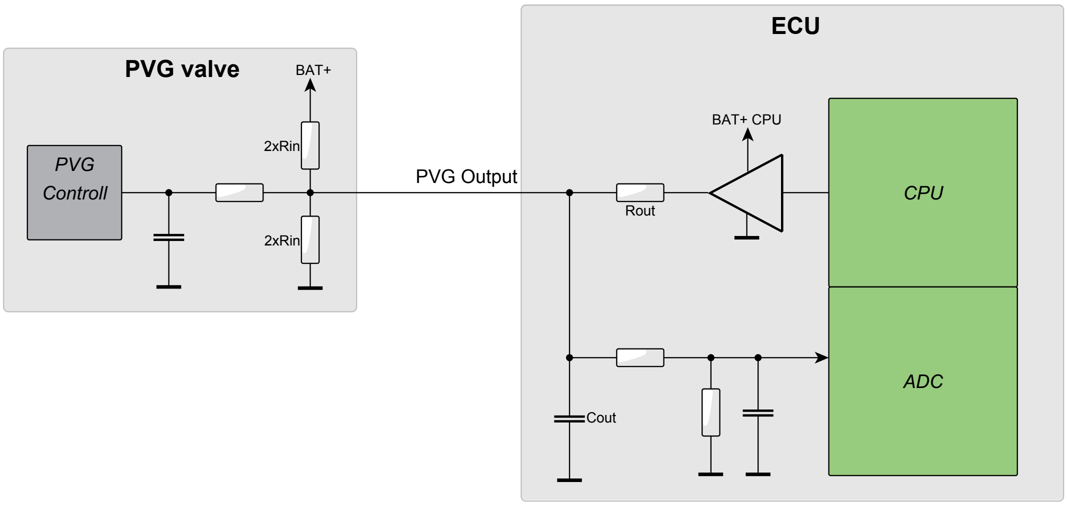

Figure 47: *Output stage in PVG mode*

Characteristics of PVG

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin capacitance	430	530	nF
R_{out}	Output resistance	2.52	2.63	kΩ
V_{nom}	Nominal voltage range (BAT+ + 8 to 32 V nominal load resistance) [1] [2]	0.1 · BAT	0.9 · BAT+	V
$V_{tol\text{-}0}$	Zero reading error (BAT+ + 8 to 32 V nominal load resistance) [1] [3]	-100	100	mV
$V_{tol\text{-}p}$	Proportional error (BAT+ + 8 to 32 V nominal load resistance) [1] [3]	-2	2	%

Table 81: *Characteristics of PVG*

[1] T_{ECU} = -40 to +85 °C
[2] The standard PVG valves are controllable between 25 % and 75 % of the BAT+. This specification parameter shows the hardware-related control limits.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.13.3 V_{OUT} outputs

Selected via functions LPO_VOUT and LPO_VOUT_LP (see table 77 for applicable pins).

In V_{OUT} mode, the outputs generate a DC voltage that can be used to connect to any high-impedance analog input. The load resistance of the receiving device defines the maximum possible output voltage.

In PVG mode, PVG valves have a well-defined input resistance, and the output signal settings can be calculated in advance by considering the characteristics of the output stage. In voltage mode, however, a PID controller must be applied to generate the desired output voltage. This results in a certain settling time, which depends on the parameter set of the PID controllers.

The V_{OUT} mode output can be used to control PVG valves of the type PVEU or other generic resistive loads.

For diagnostic reasons, the output signal is looped back to the CPU in output mode, and the measured value is compared to the set value. If the difference between these two values is above a fixed limit, an overload is detected and the output is disabled. The protection mechanism tries to re-enable the output 10 times per operational cycle.

NOTE Do not use two outputs in parallel to increase driving strength, as this may impair the protection function of the LPO stage.

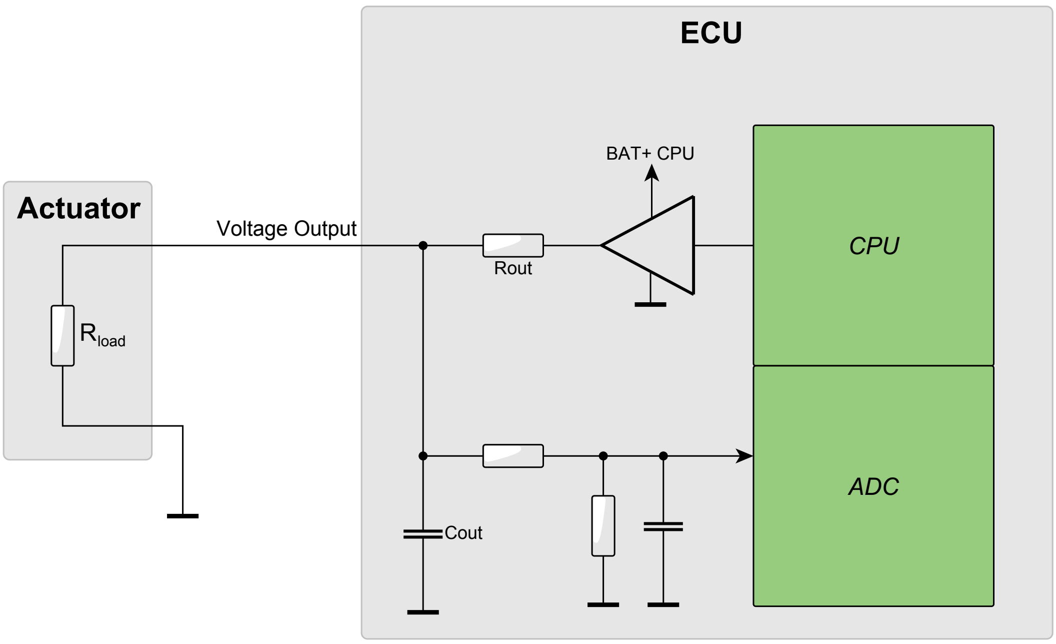

Figure 48: *Output stage in V_{OUT} mode*

NOTE Figure 48 shows BAT+CPU supply. For pins which support function LPO_VOUT, variable sensor supply can be used instead for a stable voltage that is independant of the battery.

Characteristics of V_{OUT}

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin capacitance	430	530	nF
R_{out}	Output resistance	2.52	2.63	kΩ
R_{load}	Nominal load	10		kΩ
V_{nom}	Nominal voltage range (open load) (BAT+ = 8 to 32 V) [1]	0	$0.99 \cdot V_{SSUP\_2}$	V
V_{nom_lp}	Nominal voltage range (open load) (BAT+ = 8 to 32 V) [1]	0	$0.99 \cdot V_{BAT}$	V
V_{tol-0}	Zero error (BAT+ = 8 to 32 V nominal load resistance) [2] [3]	-65	65	mV
V_{tol-0}	Zero error (BAT+ = 8 to 32 V nominal load resistance) [3]	-95	95	mV
V_{tol-p}	Proportional error (BAT+ = 8 to 32 V nominal load resistance) [2] [3]	-3	3	%
V_{tol-p}	Proportional error (BAT+ = 8 to 32 V nominal load resistance) [3]	-4	4	%

Table 82: *Characteristics of V_{OUT}*

[1] In the V_{OUT} setting, the open load voltage is only open loop controlled. The load creates a voltage divider with the well-defined output resistance (Rout) of the V_{OUT} stage. This effect must be considered in the application software. To get a desired (loaded) output voltage, the proper open load voltage must be calculated and set to a (higher) open load voltage level. For example, with a load RL = 10 kΩ to ground, the open load voltage (Vset) must be set to 12.55 V ($Vset = V_{OUT} \frac{RL+2.55\ k}{RL}$) to get an output voltage of 10 V.
[2] T_{ECU} = -40 to +85 °C
[3] The total measurement error is the sum of zero reading error and the proportional error.

Standard mode LP_V_{OUT}

The supply of the pins HS_OUT_24 - HS_OUT_27 can be switched to the variable sensor supply as a stable voltage source, which is independent of the battery. This allows to improve precision and avoid variations of the output voltage due to load dependent and other fluctuations of the battery voltage. These for pins can only be switched together.

If they are switched this way, higher voltages than SSUP2 at the pins must be avoided. This includes the use of the DOP_HS_4A function on all affected pins, otherwise a reverse connection of the internal circuitry can distribute such voltage to all affected pins.

11.13.4 Analog input

Selected via function ADC_VIN_32V.

For standard analog sensors, please use Analog 4-mode 11.6 and Analog 2-mode 11.7.

External switches which are directly switching to battery voltage must not be used with alternative inputs.

Characteristics of analog input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	430	530	nF
τ_{in}	Input low pass filter	9.5	12	ms
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	kΩ
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
	Resolution		12	bit
$V_{tol\text{-}0}$	Zero reading error [1] [3]	-65	65	mV
$V_{tol\text{-}0}$	Zero reading error [3]	-95	95	mV
$V_{tol\text{-}p}$	Proportional error [1] [3]	-3	3	%
$V_{tol\text{-}p}$	Proportional error [3]	-4	4	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range [2]	0	32	V
V_{in}	Input voltage range [2]	-0.5	$V_{BAT+power}$ +0.5	V

Table 83: *Characteristics of analog input*

[1] T_{ECU} = -40 to +85 °C
[2] The input voltage may go up to 32 V, but must never exceed battery supply voltage.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.13.5 Digital input

Selected via function DIN_32V.

External switches which are directly switching to battery voltage must not be used with alternative inputs.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	430	530	nF
τ_{in}	Input low pass filter	9.5	12	ms
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	kΩ
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
	Resolution		12	bit
V_{il}	Input voltage for low level [1]	0	<x>	V
V_{ih}	Input voltage for high level [1] [2]	<x>	32	V
V_{in}	Input voltage range [2]	-0.5	$V_{BAT+power}$ +0.5	V

Table 84: *Characteristics of digital input*

[1]Values <x> are configured by the application software.
[2]The input voltage may go up to 32 V but must never exceed battery supply voltage.

11.14 Low-side digital output

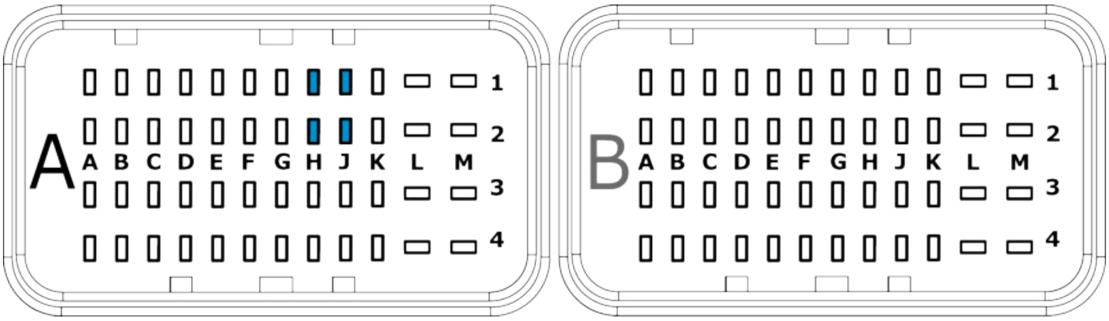

Figure 49: *DOP LS 4A+CM pinout*

Connector	Pin	Pin name	Variant
A	H1	LS_08	TTC 2380, TTC 2385, TTC 2390
A	H2	LS_09	TTC 2380, TTC 2385, TTC 2390
A	J1	LS_10	TTC 2380, TTC 2385, TTC 2390
A	J2	LS_11	TTC 2380, TTC 2385, TTC 2390

Table 85: *DOP LS 4A+CM pin group*

Supported functions

- DOP_LS_4A **(main)**
- ADC_RAT_5V
- ADC_VIN_5V
- ADC_VIN_32V
- DIN_5V
- DIN_32V

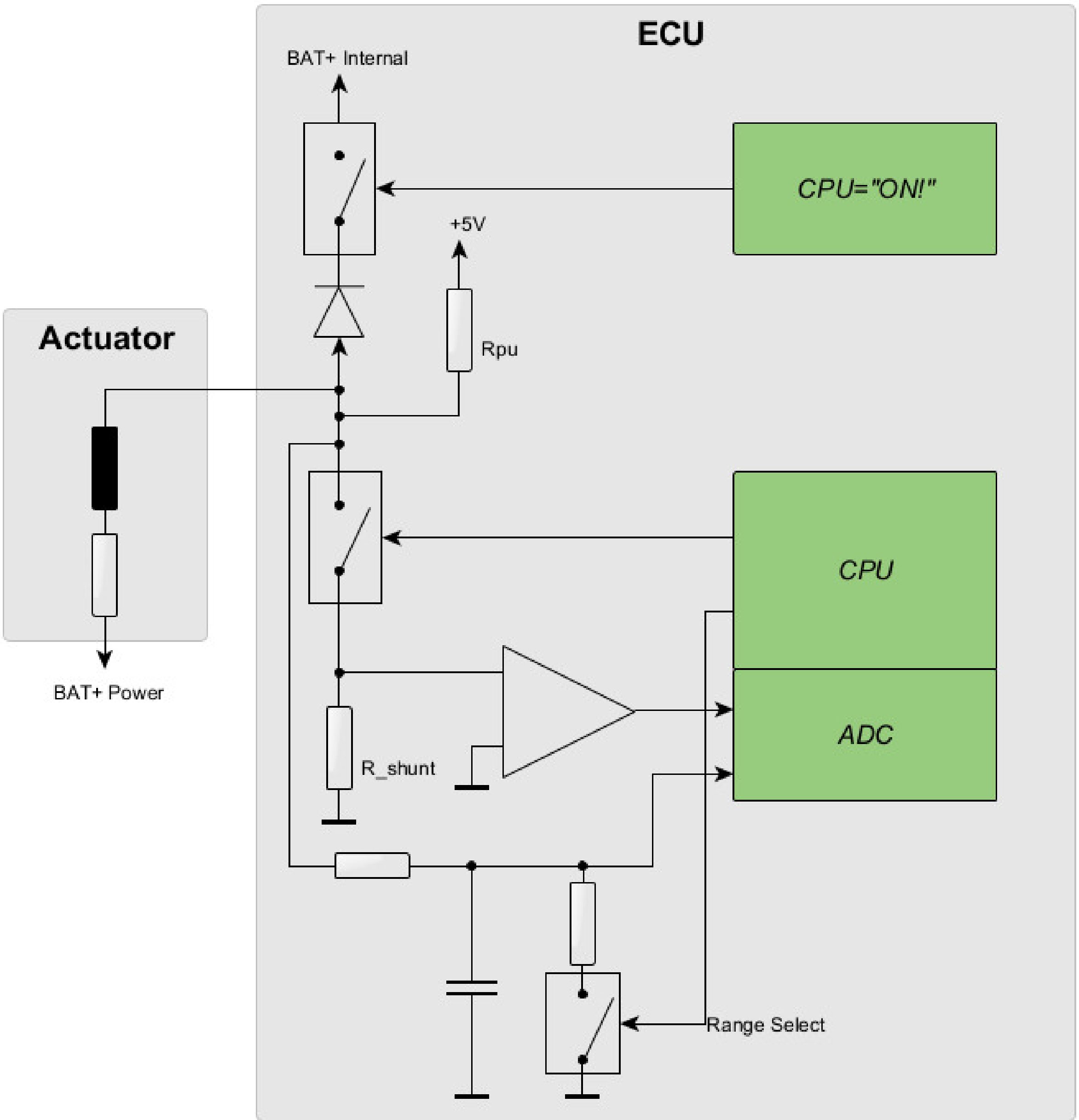

Figure 50: *Low-side switch for resistive and inductive loads*

Functional description

Low-side power output stages with reverse polarity protected freewheeling diodes to BAT+ for inductive and resistive loads with a high-side connection. The freewheeling diodes are switched off if the CPU is off to prevent a BAT+ phantom supply.

A current measurement loop is provided but cannot be used for current control application. The intended use is a plausibility check of the High-side PWM current measurement when it is combined with the Low-side PWM in digital output mode to be able to shut off in case of a short circuit of the load to the battery.

TTControl recommends using these pins with the maximum possible wire size (FLRY type), to reduce voltage drop and prevent the crimp contact from overheating in case of maximum load current.

Power stage pairing

If higher load current is needed, the output stages can be used in parallel.

Due to thermal limits, the resulting total load current of this output pair has to be de-rated by a factor of 0.85 (e.g., combining two 3 A outputs would result in a total load current of 3 A x 2 x 0.85 = 5.1 A). The application software has to make sure that both outputs are switched on at the same point in time, otherwise the over-current protection may trip.

For balanced current distribution through each of the pin pairs, the cable routing must be symmetrical if pin-pairs or multiple pins are wired in parallel to support higher load currents.

Diagnostic functions

Load monitoring is the detection of overloads, external short circuits of the load output to positive or negative supply (BAT+/BAT-) or any other power output and detection of load loss.

In this output stage, the load diagnostic functions are based on current and voltage measurements. In case of an excessive overload or a short circuit to BAT+, the output will turn off to protect the output stage.

Output signal	Status signal			
	Normal	Open load	Short to GND	Short to U_{BAT}
on	◯	◯	x	◯
off	◯	x	◯	x

◯ = detected
x = not detected

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input/output voltage under overload conditions	-0.5	$V_{BAT+power}$ +0.5	V
V_{OUT}	Output voltage under overload conditions [1]		33	V

Table 87: *DOP LS 4A+CM maximum ratings*

[1] Inductive load transients will be clamped internally to BAT+ via free wheeling diode.

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	kΩ
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
R_{pu}	Pull-up resistor (32 V mode)	6.1	6.34	kΩ
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
R_{on}	On-resistance		50	mΩ
I_{load}	Nominal load current		3	A
I_{max}	Maximum load current [1]		4	A
I_{peak}	Peak load current [2]		6	A
I_{tol-0}	Zero reading error [1] [3]	-95	95	mA
I_{tol-0}	Zero reading error [3]	-125	125	mA
I_{tol-p}	Proportional error [1] [3]	-3.4	3.4	%
I_{tol-p}	Proportional error [3]	-4.3	4.3	%

Table 88: *DOP LS 4A+CM characteristics*

[1] T_{ECU} = -40 to +85 °C
[2] Peak current for maximal 100 ms. Exceeding this value will trigger overload protection and switch off the power stage. Steady state operation goes only up to 3 A/4 A depending on temperature.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.14.1 Analog inputs

Selected via functions ADC_RAT_5V, ADC_VIN_5V and ADC_VIN_32V.

Characteristics of analog voltage input

5 V mode:

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
τ_{in}	Input low pass filter	2.7	3.5	ms
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	kΩ
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
	Resolution		12	bit
$V_{tol\text{-}0}$	Zero reading error [1] [3]	-7	7	mV
$V_{tol\text{-}0}$	Zero reading error[3]	-12	12	mV
$V_{tol\text{-}p}$	Proportional error [1] [3]	-0.4	0.4	%
$V_{tol\text{-}p}$	Proportional error[3]	-0.6	0.6	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range[2]	0	32	V
V_{in}	Input voltage range[2]	-0.5	$V_{BAT+power}$ +0.5	V

Table 89: *Characteristics of analog voltage input – 5 V mode*

32 V mode:

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
τ_{in}	Input low pass filter	2.2	2.8	ms
R_{pu}	Pull-up resistor	6.1	6.34	kΩ
V_{pu}	Pull-up voltage	3	3.2	V
	Resolution		12	bit
$V_{tol\text{-}0}$	Zero reading error [1 3]	-48	48	mV
$V_{tol\text{-}0}$	Zero reading error[3]	-64	64	mV
$V_{tol\text{-}p}$	Proportional error [1 3]	-2.1	2.1	%
$V_{tol\text{-}p}$	Proportional error[3]	-2.3	2.3	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage meaurement range[2]	0	32	V
V_{in}	Input voltage range[2]	-0.5	$V_{BAT+power}$ +0.5	V

Table 90: *Characteristics of analog voltage input – 32 V mode*

[1] T_{ECU} = -40 to +85 °C
[2] The input voltage may go up to 32 V but must never exceed battery supply voltage.
[3] The total measurement error is the sum of zero reading error and the proportional error.

11.14.2 Digital inputs

Selected via functions DIN_5V and DIN_32V.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
τ_{in}	Input low pass filter	2.2	3.5	ms
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	kΩ
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
R_{pu}	Pull-up resistor (32 V mode)	6.1	6.34	kΩ
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
	Resolution		12	bit
V_{il}	Input voltage for low level [1]	0	<x>	V
V_{ih}	Input voltage for high level [1]	<x>	32	V

Table 91: *Characteristics of digital input*

[1] Values <x> are configured by the application software.

11.15 LIN

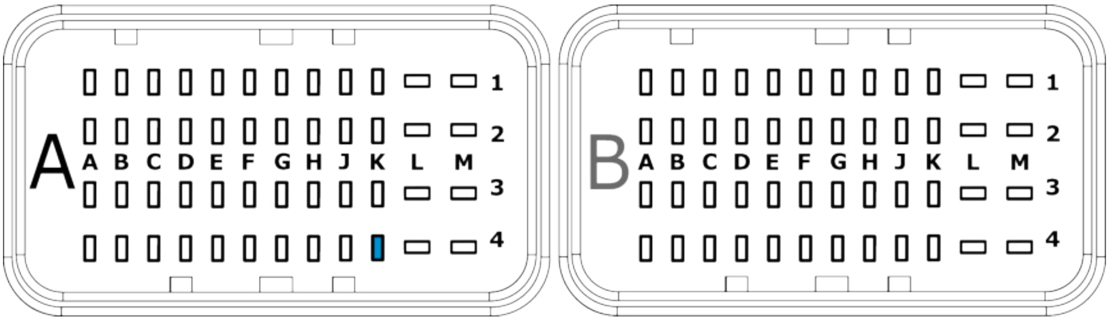

Figure 51: *LIN pinout*

Connector	Pin	Pin name
A	K4	LIN

Table 92: *LIN pin group*

Supported functions

- LIN **(main)**

Functional description

LIN is configured in master mode.

LIN is a bidirectional half duplex serial bus for up to 10 nodes.

NOTE A common ground (chassis) or a proper ground connection is necessary for LIN operation. If you connect to an external device (e.g., to a PC with a LIN interface), make sure not to violate the maximum voltage ratings when connecting to the LIN connection.

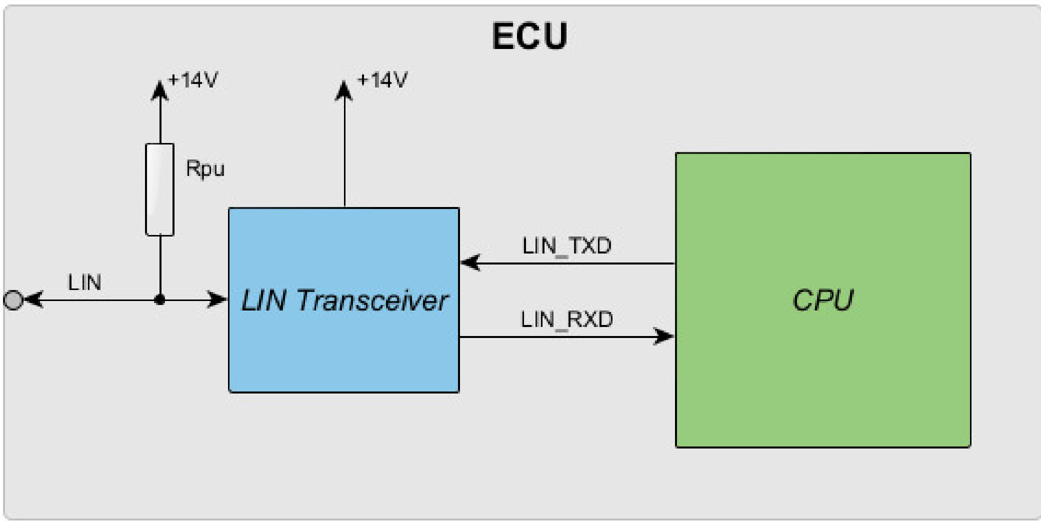

Figure 52: *LIN interface*

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{LIN}	Bus voltage under overload conditions	-1	33	V

Table 93: *LIN maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin output capacitance	200	400	pF
V_{BUSdom}	Receiver dominant state		$0.4 \cdot V_{Bat\_LIN}$	V
V_{BUSrec}	Receiver recessive state	$0.6 \cdot V_{Bat\_LIN}$	-	V
V_{OL}	Output low voltage		2	V
V_{Bat_LIN}	LIN supply voltage [1]	13	15	V
R_{pu}	Pull-up resistor	0.95	1.05	kΩ
S_{Tr}	Baud rate		20	kBd

Table 94: *LIN characteristics*

[1] For battery voltages higher than V_{Bat_LIN} +0.5 V.

11.16 CAN FD

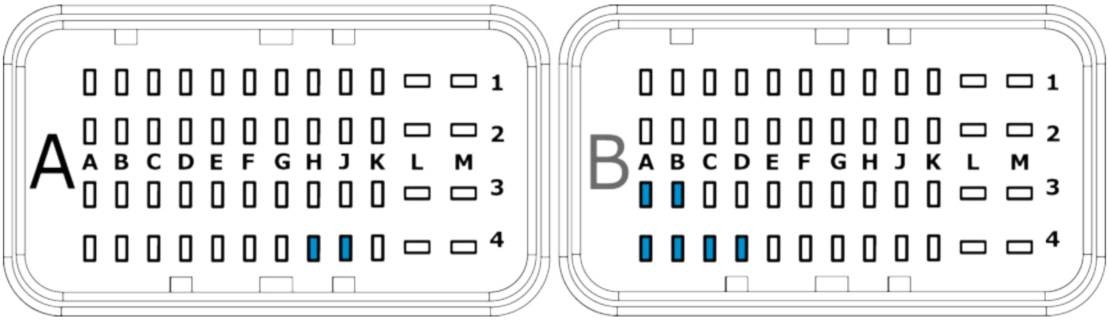

Figure 53: *CAN FD pinout*

Connector	Pin	Pin name
B	A4	CAN0_H
B	B4	CAN0_L
B	A3	CAN1_H
B	B3	CAN1_L
A	H4	CAN2_H
A	J4	CAN2_L
B	C4	CAN3_H
B	D4	CAN3_L

Table 95: *CAN FD pin group*

Supported functions

- CAN (**main**)
- CAN_ISO
  - available for interface 1 only
- CAN_WAKE
  - available for interface 2 only

Functional description

NOTE A common ground (chassis) or a proper ground connection is necessary for CAN operation.

The CAN interface supports Flexible Data (FD) rate frame format (see [5]) with bit rates from 1 Mbit/s up to 2 Mbit/s.

CAN is a bidirectional, twisted pair bus. It requires termination with 120 Ω in 2-control units, whereas the others remain unterminated.

Termination must be fit at the ends of the bus line to prevent wave reflection. Termination is necessary to enter into recessive state. See figure 54 for details.

In case of connecting with an external device (e.g., PC with CAN-interface for downloading software) please make sure that the maximum voltage ratings are not violated when connecting to or disconnecting from the CAN bus.

The CAN interface is ISO 11898-2/-5 compliant, except for the input resistance. This input resistance is lower due to an RF termination, which drastically improves EMC immunity and is used, required and proven for its performance in the automotive industry for many years. The differential internal resistance is given in table 96.

ISOBUS CAN1

Due to the requirements of the ISOBUS standard [6], CAN FD has a lower EMC protection than other CAN interfaces. The high impedance RF termination is removed. To achieve equivalent RF immunity, TTControl recommends using CAN FD with a termination. That is, CAN FD must be connected at the terminated end of the CAN bus line. TTControl recommends using either an internal CAN termination or an equivalent circuit. See figure 54 for details.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{CAN_H}, V_{CAN_L}	Bus voltage under overload conditions (e.g., short circuit to supply voltages)	-58	58	V

Table 96: *CAN FD maximum ratings*

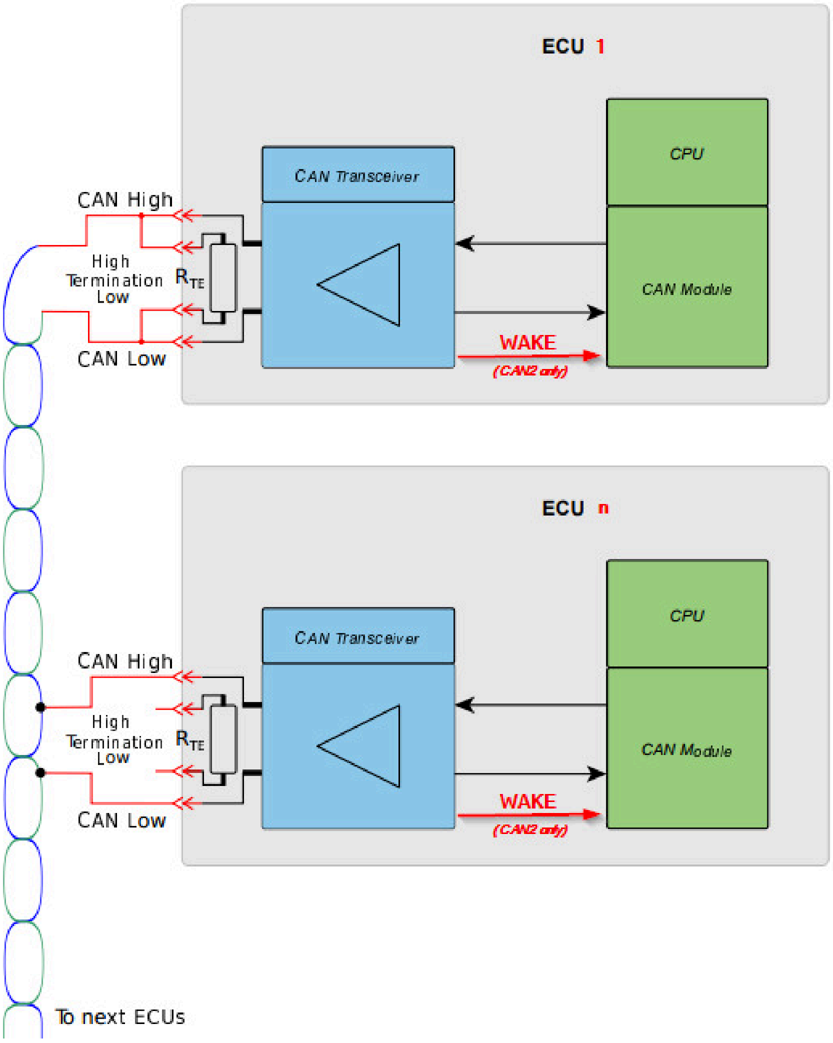

Figure 54: *CAN FD block schematic*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin output capacitance		100	pF
$V_{in\text{-}CMM}$	Input common mode range [1]	-12	12	V
$V_{in\text{-}dif}$	Differential input threshold voltage (V_{CAN_H} - V_{CAN_L})	0.5	0.9	V
$V_{out\text{-}dif}$	Differential output voltage dominant (V_{CAN_H} - V_{CAN_L})	1.5	3	V
$V_{out\text{-}dif}$	Differential output voltage recessive state (V_{CAN_H} - V_{CAN_L})	-0.1	0.1	V
V_{CAN_L}, V_{CAN_H}	Common mode idle voltage (recessive state)	2	3	V
I_{CAN_CNL}	Output current limit	-40	-200	mA
I_{CAN_CNH}	Output current limit	40	200	mA
S_{Tr}	Bit rate [2] [3] [4]	50	2000	kbit/s
R_{diff}	Differential internal resistance [5]	27	29	kΩ
R_{diff}	Differential internal resistance	3.7	3.9	kΩ

Table 97: *CAN FD characteristics*

[1] Due to high current in the cable harness, the individual ground potential of the control units can differ up to several V. This difference will also appear as common mode voltage between a transmitting and a receiving control unit, and will not influence the differential bus signal, as long as it is within the common mode limits.
[2] Pay attention to the limitations of CAN. The arbitration process allows 1 Mbit/s operation only in small networks and reduced wire length. For example, a so-called ”private CAN”, which is a short point-to-point connection (less than 10 m) between two nodes only, can be operated at 1 Mbit/s.
[3] For typical network sizes and topologies (networks with stub wires) and more than two nodes, the practical limit is 500 kbit/s.
[4] Any value that conforms to CAN protocol standard definition is valid.
[5] ISOBUS CAN variant.

11.17 CAN termination

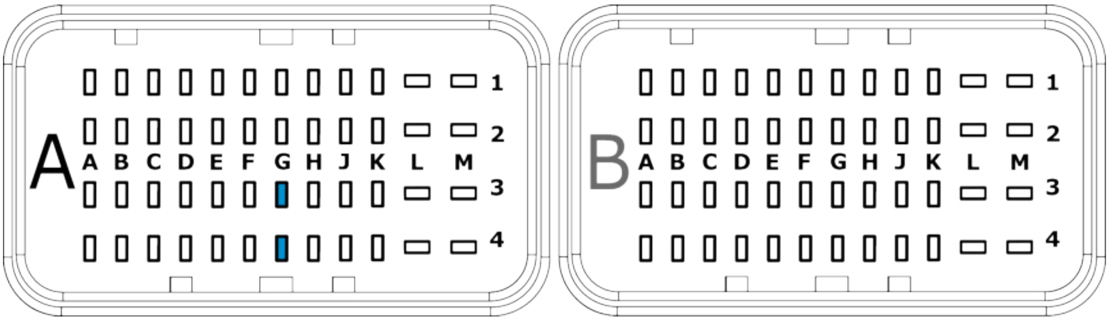

Figure 55: *CAN termination pinout*

Connector	Pin	Pin name
A	G3	CAN_TERM-
A	G4	CAN_TERM+

Table 98: *CAN termination pin group*

Supported functions

- CAN_TER **(main)**

Functional description

For easy termination of the CAN bus, there are four built in 120 Ω termination resistors on the TTC 2300 which are accessible via 2 connector pins each. They can be used for any CAN port.

The 120 Ω termination of a control unit is realized with two serial 60 Ω resistors (split termination).

To get an impedance of 60 on the whole bus, a termination resistor of 120 Ω is required in two control units.

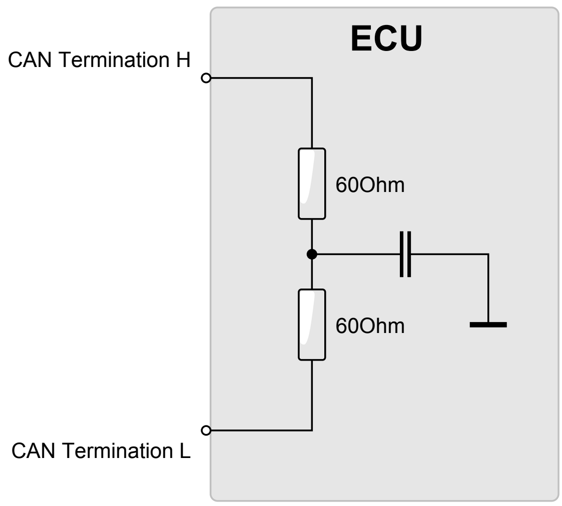

Figure 56: *CAN termination*

11.18 100BASE-T1

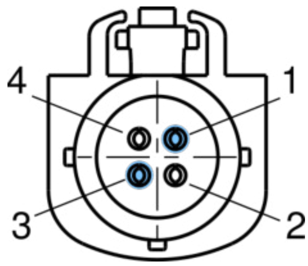

Figure 57: *HSD connector pinout*

Connector	Pin	Pin name	Variant
C, D	1: BRR_00_TRX_P	100BASE-T1	TTC 2380
C, D	2: (Not connected)	100BASE-T1	TTC 2380
C, D	3: BRR_00_TRX_N	100BASE-T1	TTC 2380
C, D	4: (Not connected)	100BASE-T1	TTC 2380

Table 99: *100BASE-T1 pin group*

Supported functions

- 100BASE-T1 **(main)**

Functional description

The standardized 100BASE-T1 Ethernet (also known as BroadR-Reach) link is an advancement of the IEEE 802.3 100BASE-TX Fast Ethernet standard and was standardized by OPEN ALLIANCE. It uses a single unshielded twisted pair cable (UTP) and is therefore low in costs. The 100BASE-T1 Ethernet link is capable of 100 Mbit/s full-duplex transmission rate.

The 100BASE-T1 interface supports Ethernet-based communication with other ECUs, and fast application download with the UDP communication protocol.

The 100BASE-T1 signals are located in HSD connectors C and D in variant TTC 2380.

Make sure to use appropriate cabling according to the 100BASE-T1 standard. The recommended cables are:

Cable group	Cable name	Impedance
D9	e.g., LEONI Dacar 686-3	100 Ω
AQ	e.g., G&G 2Speed 132, LEONI Dacar 676	100 Ω

Table 100: *100BASE-T1 recommended cables*

TTControl recommends a Rosenberger HSD Cable Assembly or an equal with HSD connector housing code A to achieve the highest possible performance.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{T1}	Bus voltage under overload conditions (i.e., short circuit to supply voltages)	- 32	32	V

Table 101: *100BASE-T1 maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
$V_{in\text{-}CMM}$	Input common mode range	- 32	32	V
$V_{out\text{-}dif}$	Differential output voltage	-1	1	V
V_{T1_P}, V_{T1_M}	Common mode idle voltage	-0.1	0.1	V
S_{Tr}	Bit rate		100	Mbit/s
$R_{in\_AC\_dif}$	Input resistance AC	90	110	Ω
$R_{in\_DC\_dif}$	Input resistance DC	1.8	2.2	kΩ

Table 102: *100BASE-T1 characteristics*

11.19 100BASE-TX

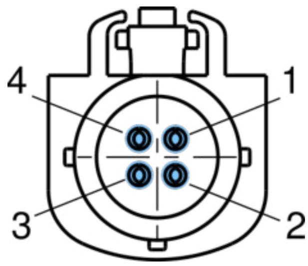

Figure 58: *HSD connector pinout*

Connector	Pin name	Pin number	Variant
C	1: ETHERNET_00_TX+	1	TTC 2385, TTC 2390
C	2: ETHERNET_00_RX-	2	TTC 2385, TTC 2390
C	3: ETHERNET_00_TX-	3	TTC 2385, TTC 2390
C	4: ETHERNET_00_RX+	4	TTC 2385, TTC 2390
D	1: ETHERNET_01_TX+	1	TTC 2385, TTC 2390
D	2: ETHERNET_01_RX-	2	TTC 2385, TTC 2390
D	3: ETHERNET_01_TX-	3	TTC 2385, TTC 2390
D	4: ETHERNET_01_RX+	4	TTC 2385, TTC 2390

Table 103: *100BASE-TX pin group*

Supported functions

- 100BASE-TX **(main)**

Functional description

The 10 to 100 Mbit/s full duplex Ethernet port is designed for IEEE 802.3 compliance [2]. The 100BASE-TX interface supports Ethernet-based communication with other ECUs, and fast application download with the UDP communication protocol.

The 100BASE-TX signals are located in HSD connectors C and D in variant TTC 2385 and TTC 2390.

Make sure to use appropriate cabling according to the Ethernet standard. TTControl recommends a Rosenberger HSD Cable Assembly from type LD5-101-XXXX-Y-Y or an equal with HSD connector housing code A to achieve the highest possible performance.

Cable group	Cable name	Impedance
D5	e.g., G&G K6750, X6656, LEONI Dacar 535, 535-2, 636, 636-2	100 Ω
AF	e.g., G&G X6238, LEONI Dacar 566	90 ±15 Ω
AU	e.g., G&G X9207	100 Ω

Table 104: *100BASE-T1 recommended cables*

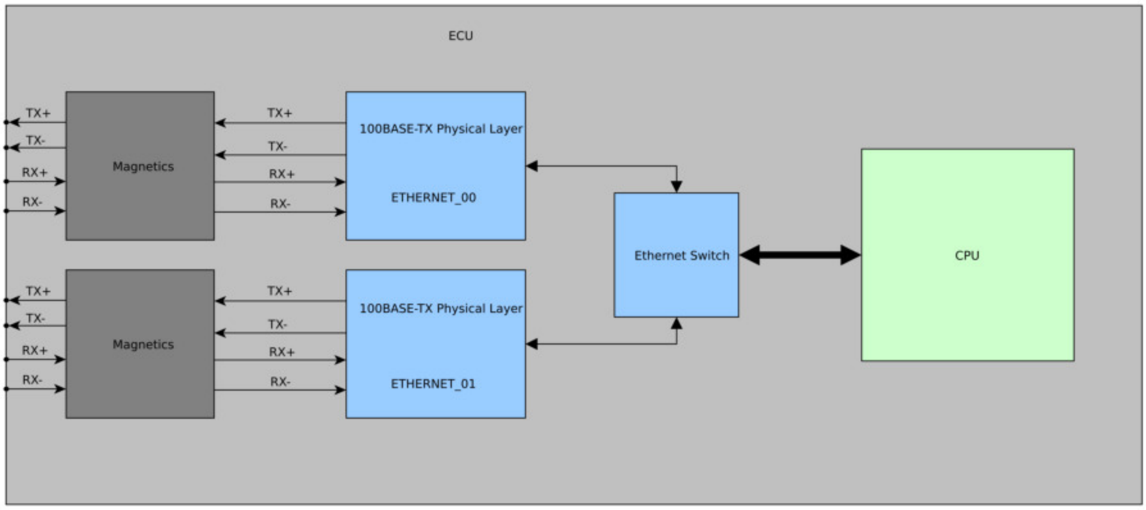

Figure 59: *Ethernet interface*

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$V_{in\text{-}CMM}$	Input common mode voltage range 50/60 Hz AC, 60 s test duration		1000	V_{RMS}

Table 105: *100BASE-TX maximum ratings*

11.20 Emergency shut-off

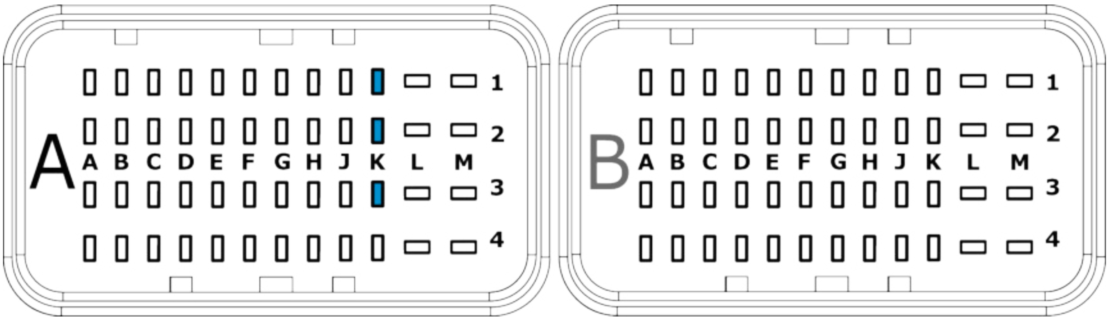

Figure 60: *Emergency shut-off pinout*

Connector	Pin	Pin name
A	K1	EMS_IN_A
A	K2	EMS_IN_B
A	K3	EMS_OUT

Table 106: *Emergency shut-off pin group*

Supported functions

- EMS_IN **(main)**
  - available for pins EMS_IN_A and EMS_IN_B only
- LPO_ESO **(main)**
  - available for pin EMS_OUT only
- LPO_PVG
  - available for pin EMS_OUT only
- LPO_VOUT_LP
  - available for pin EMS_OUT only
- ADC_VIN_32V
- DIN_32V

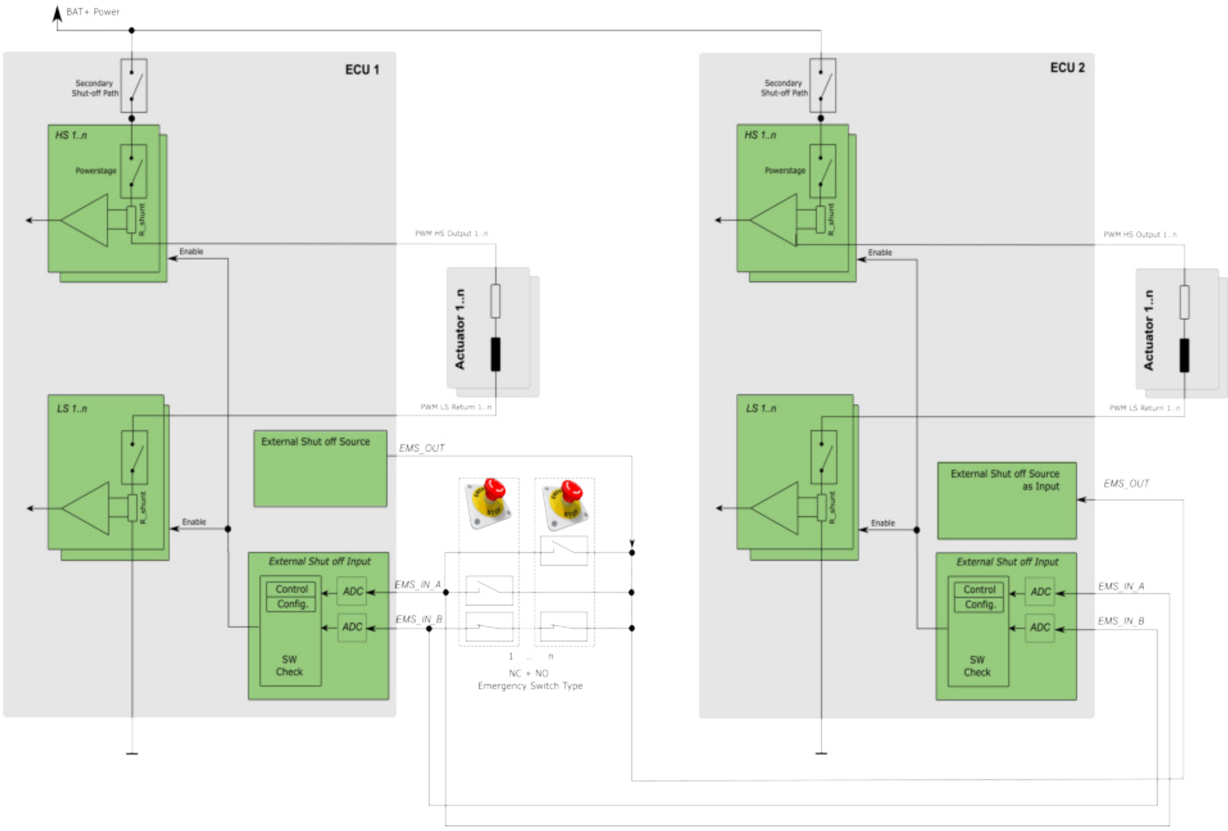

Figure 61: *Emergency shut-off block schematic*

Functional description

The emergency shut-off switch can use dual redundant channels, e.g., one NO and one NC contact can be used.

It is also possible to cascade two ECUs of the TTC 2300 family to the same set of emergency shut off switches by tying their corresponding EMS signals together.

The EMS_OUT delivers a dynamic (AC) output signal which allows detection of short circuits and interruptions. This signal can be detected phase synchronously on the EMS_IN_A/B inputs with some tolerance range to indicate closed EMS switch, its absence indicates an open switch.

To cascade two devices, all three signals EMS_OUT, EMS_IN_A and EMS_IN_B must be connected to their counterparts. Only the EMS master ECU generates an EMS_OUT signal. In the context of EMS signals, the slave ECU must measure the EMS_OUT signals periodically, but it does not generate a signal by itself. Its EMS_OUT port is only used as input.

Both ECUs must do a range check on the signal to detect short to GND or BAT error conditions.

The combined impedance of all connected inputs and the internal EMS_OUT readback in a configuration of two ECUs is 3.7 kΩ . Together with an external leakage impedance of up to 50 kΩ, it would be reduced to 3.46 kΩ load resistance for the output stage. In this case, the output voltage of EMS_OUT is reduced to 58 % of BAT.

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in}	Input voltage under overload conditions	- 1	33	V

Table 107: *Emergency shut-off maximum ratings*

EMS_OUT Characteristics

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin capacitance	430	530	nF
R_{out}	Output resistance	2.44	2.54	kΩ
R_{in}	Pull-down resistance	75.5	78.5	kΩ
R_{load}	Nominal load	3.5		kΩ

Table 108: *EMS_OUT characteristics*

EMS_IN Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
τ_{in}	Input low pass filter	2.2	2.8	ms
R_{pd}	Pull-down resistor	16.1	16.8	kΩ
$V_{tol\text{-}0}$	Zero reading error [1] [3]	-48	48	mV
$V_{tol\text{-}0}$	Zero reading error[3]	-64	64	mV
$V_{tol\text{-}p}$	Proportional error [1] [3]	-2.1	2.1	%
$V_{tol\text{-}p}$	Proportional error[3]	-2.3	2.3	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage meaurement range[2]	0	32	V
V_{in}	Input voltage range[2]	-0.5	$V_{BAT+power}$ +0.5	V

Table 109: *EMS_IN characteristics*

12 Application notes

12.1 Ground loss detection (BAT-)

Under certain circumstances, a loss of the negative battery supply may lead to an unwanted fault current through the valves or other loads connected to the high-side outputs.

Conditions for an unwanted fault current:

- Interruption of the BAT- connection
  - the BAT- connection cabling is interrupted
  - connector B (which carries all BAT- connections) disconnects, while connector A remains properly connected
- Loads connected directly to BAT- externally (this can be avoided by connecting the ground return path to a low-side output of the ECU).

NOTE Any current on the sensor GND connection (see section 11.1) will add to the possible fault current.

Consequently, the internal supply current of the ECU and the load power connected to the sensor supplies will find their way to the connected external loads. The current flows via the freewheeling diodes (essential for PWM operation) must be connected to the output. In this case, the voltage on the BAT- pins and the internal ground of the ECU will increase by several volts. This results in a significantly smaller ECU supply voltage, though it is sufficient to run the internal supplies, including the CPU. Hence, even with ground voltage offset, networks like CAN can keep running without any issues.

The supply current (up to 300 mA) flow is distributed over the connected loads, and depending on the different load resistances and PWM operation points, each load will take a different share of the supply current. This current is visible in the current measurement result of each power stage. Even if an overcurrent is detected and the power stage is fully switched off as a consequence, the current will continue to flow through the freewheeling diodes.

Preventative action

To prevent this type of failure:

- use all four parallel GND pins, see section 11.1 for relevant pins
- do not connect the BAT- supply over a single thick cable with only one connection point
- ensure that the connector cable has adequate strain relief.

If none of these measures are applicable or sufficient, then:

- Connect the housing of the TTC 2300 to GND by mounting it directly to the chassis, or by using a crimp (see section 8.1.2) with a cable connected to BAT- redundantly to the mounting base.

NOTE The TTC 2300 housing is not connected to BAT- internally. However, there is a circuit monitoring the housing voltage relatively to BAT- supply. Both of these voltages are equal when the ECU is functioning as expected.

- Enable the safety-related software for this function.

NOTE In case of loss of the BAT- connection, the ECU will stop, and the ECU power supply will be switched off immediately. The remaining current distributed over the loads is less than 1 mA in total. Please be aware that a loss of contact to the housing will immediately stop the operation of the ECU if the safety-related software function is enabled.

12.2 PT100 sensors

The following describes the three-wire measurement of a PT100 temperature sensor with enhanced precision.

A compensation of the line resistances of a sensor, that is connected via three or four wires, is possible when using two measurement inputs. One input is set to voltage mode, while the other is set to current mode. Its current sensing resistor is then used for a ratiometric measurement of the sensor resistance. The voltages measured at the two inputs represent the voltage drop at the line resistance Rline, and can therefore be compensated.

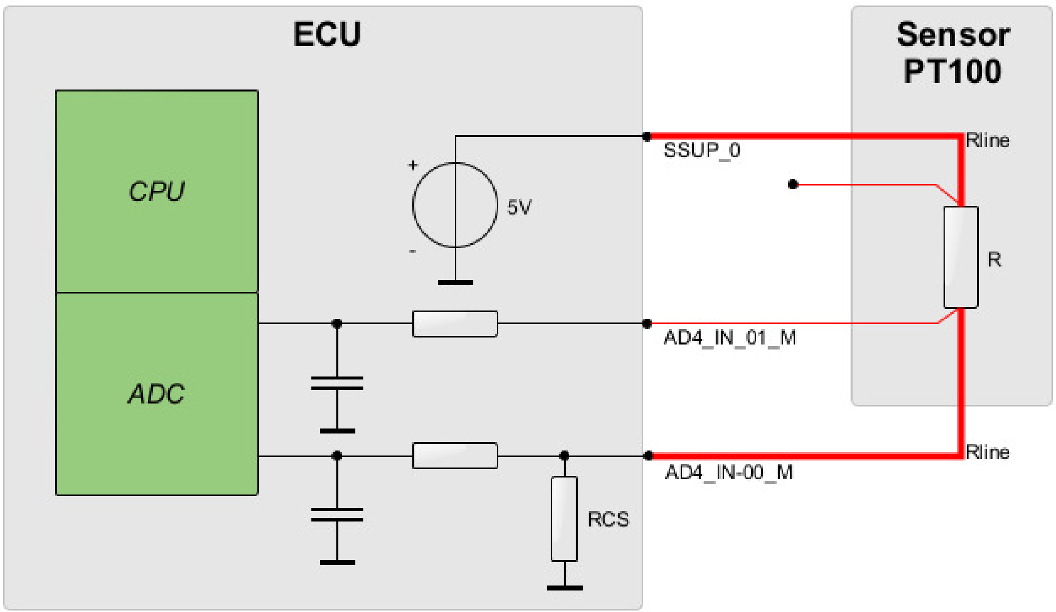

Figure 62: *PT100*

Calculation

U_PT100 = U_SSUP - AD4_IN_01_M - (AD4_IN_01_M - AD4_IN_00_M)

*U_PT100 = U_SSUP - 2 * AD4_IN_01_M + AD4_IN_00_M*

I_PT100 = AD4_IN_00_M + AD4_IN_00_R

R_PT100 = U_PT100 / I_PT100

12.3 Power stage alternative functions

This application note describes the DOs and DON'Ts when using the alternative functions of the TTC 2300 high- and low-side power stages.

12.3.1 High-side output stages

High-side power stages can alternatively be used as analog, digital or frequency inputs.

BAT+ Power +0.5 V

In all high-side power stages there is a parasitic diode that conducts if the output voltage or, in case of altenrative input function, the input voltage is externally driven higher than the voltage on the BAT+ Power supply pins. The input voltage on all high-side stages, including the alternative input functions, must never exceed the power stage supply BAT+ Power +0.5 V. This application requirement is valid in active, stand-by and power-off state of the ECU.

To counteract such fault scenarios, maximum ratings and specified wiring examples must be followed and are essential for safe operation.

12.3.2 Wiring examples

Attention!

In many applications, external switches (open collector, open drain (NPN) or a push-pull type), push-buttons or analog sensors have to be monitored by an alternative input of the ECU. Switches which are directly switching to battery voltage must not be used with alternative inputs.

For safety critical applications, however, additional restrictions apply. See the following sections.

Workarounds for safety critical applications:

- Usage of external switches connected to GND.

  Short circuits to battery supply need to be excluded in the system architecture.
- Battery supplied switches and sensors need to be supplied via a digital output of the TTC 2300.

12.4 Ground connection of housing

The TTC 2300 housing is not directly connected to ground. In the case of chassis mounting, this prevents ground loops or excessive current flow through the Negative Power Supply (BAT-) pins, and cables in case of partly power connection loss in the negative supply rail of the vehicle. Instead of a direct connection, the housing is capacitively connected to BAT-. In order to discharge static electricity, a 1 MΩ resistor is equipped between the housing and BAT-.

NOTE It is possible to mount the housing without any additional isolation directly to the vehicle chassis.

12.5 Inductive loads at PWM outputs

Inductive loads in PWM operation generate current through the freewheeling diodes, but these diodes have, at the same current, a power dissipation that is several times greater than the high-side switches themselves. Therefore, the duty cycle has a great influence on the power dissipation of the output devices. The duty cycle results from the relationship between coil resistance and supply voltage. A low resistance at a high supply voltage is the worst combination, because it results in a low duty cycle, and therefore in a long conduction time of the diodes.

12.6 Handling of high-load current

Load distribution

The permanent input current of the TTC 2300 $I_{\text{in-max}}$ is limited due to thermal limits and contact current limits. As the power stages do not have negligible power dissipation, each load current leads to a rise in temperature within the device. To ensure proper operation of the TTC 2300 in its temperature range (-40 °C to +85 °C) the total current $I_{\text{in-total}}$ driven by the power stages must be limited and the load must be evenly distributed. If two output stages are operated in mutually exclusive states (e.g., output channel 00 is only activated in state 1 and output channel 01 is only activated in state 2; never activated at the same time), then, as a rule of thumb, these outputs should be driven by a double-channel high-side power stage due to only one active channel at a time.

Total load current

Operating all high-side power stages ON with maximum rated current (4 A) that would result in a load current $I_{\text{in-total}}$ in excess of 120 A, which is far beyond any allowed limit to ensure no violation of the allowed contact current limit as well as overall thermal limits. Therefore, the maximum allowed load current, which can be controlled simultaneously with different power stages, is separately given as the maximum total load current $I_{\text{in-total}}$. This value can only be applied if an equal load distribution over different power stages is ensured - which implicit a different $I_{\text{in-total}}$ limit set by the different number of power stages in each TTC 2300 variant, e.g., the same current distributed over 40 output stages cannot be driven with 20 output stages due to the square rise of the power dissipation of the output stages and the respective thermal limit.

Calculation of the battery supply current

For the PWM- and digital output stage supply pins BAT+ Power, up to 6 pins can be used in parallel to increase the overall current capability.

For the maximum battery supply current of 45 A, all 6 pins must be used in parallel with the maximum possible wire size (FLRY type) to reduce voltage drop and prevent overheating of the crimp contact. To define a proper cabling, it is important to calculate the maximum average battery supply current first.

For a single digital output power stage it is simply calculated as:

$$I_{BAT} = I_{power-stage} \tag{1}$$

If, for example, one power stage is loaded with 2 A, it will also load the battery supply with 2 A. For PWM output stages with inductive load it is calculated as:

$$I_{BAT} = I_{power-stage} * (\text{duty cycle}/100) \tag{2}$$

Example:

A load current of 2 A with a duty cycle of 25 % results in an average battery current of 0.5 A. More precisely explained: a single power stage with 100 Hz PWM frequency will draw 2.5 ms in duration 2 A out of the battery followed by 7.5 ms with 0 A. The average current is 0.5 A, the RMS current is higher.

However, with a couple of used PWM power stages, there is no significant difference between average and RMS current, due to different phase operation of the individual power stages.

Once the maximum battery supply current for the individual application is calculated, the required minimum number of battery supply wires and/or cabling diameter can be defined.

12.7 Cable harness

The following general layout rules for the cable harness must be obeyed to enable safe operation of the TTC 2300.

The ECU is limited to a total load current for the power stages connected to the BAT+ power pins. When all loads are tied toward ground, the load current will be carried by these supply pins as well. As each contact pin is thermally limited to 12 A, multiple supply pins work in parallel for the power stages supply. Consequently, the system designer must be careful with the cable harness design to ensure an even supply current distribution on all pins.

Example

Do not use a cable with a length of two meters and a large diameter for a connection between a fuse box and the ECU, and do not crimp it to some piggy tails with a small diameter in the connector area. Small differences between the contact pressure can lead to a big imbalance. In the worst case, one contact carries most of the current load and is overloaded at maximum current.

It is necessary to use six wires with the same total cross-sectional area as one thick cable. All wires must have the same length (≥2m) and diameter. In this case, an even current distribution can be achieved, even with slightly different contact resistances.

13 Debugging

The TTC 2300 debug interface, available for development-only devices, is supported by the Lauterbach TRACE32 tools for the Infineon TriCore microcontrollers.

13.1 Components

To debug your TTC 2300 device, you will need the components shown in the tables below. Items shown in table 110 are provided in the TTC 2300 device Starter Kits. Items shown in table 111 must be purchased separately.

Component	Description	Supplier
Debug adapter board	interface between ECU and debugger	TTControl
Debug cable	to connect the ECU to the debug adapter	TTControl

Table 110: *Debugging components (TTControl GmbH)*

Component	Description	Order code	Supplier
Power Debug Interface USB 3	Lauterbach base station	LA-3500	Lauterbach
Debugger for TriCore Automotive PRO	ribbon cable, to connect debug adapter to base station	LA-3203 LA-2707[1]	Lauterbach
License for Multicore Debugging	required for multicore debugging	LA-7960X	Lauterbach
Conv. AUTO26 to JTAG16-TriCore	converter for Debugger to JTAG/DAP	LA-3849	Lauterbach
FTDI cable	to connect debug adapter for UART	TTL-232R-5V	FTDI
AC/DC power supply adapter	adapter for base station supply		
USB connector	to connect base station and PC		

Table 111: *Debugging components (other)*

[1] former order code

For detailed specifications, please contact the supplier or refer to the supplier's website.

NOTE Items in table 111 listed with two order codes refer to the current and former order codes. Please contact the supplier for further clarification, if needed.

13.2 Connectors

There are 4 connector types on the TTC debug adapter board:

Connector	Description
16-pin JTAG	Connection to the Lauterbach debugger (either directly for older models, or via the Lauterbach adapter). See figure 63 for further details.
16-pin OCDS	Alternative to 16-pin JTAG. See figure 64 for further details.
6-pin FTDI	USB-TTL-232R connector (5 V) for the UART connection. See figure 65 for further details.
10-pin JTAG/DAP/UART	Connection to the ECU. See figure 66 for further details.

Table 112: *JTAG debug adapter connectors*

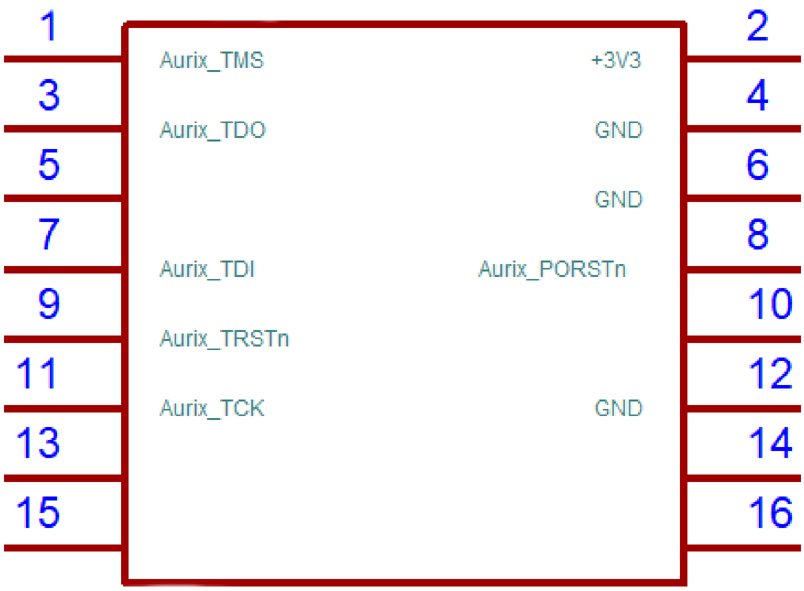

Figure 63: *Pinning schematic for the JTAG connector*

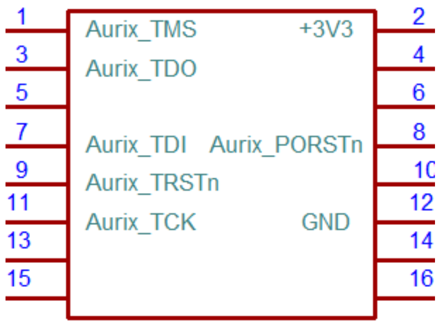

Figure 64: *Pinning schematic for the OCDS connector (JTAG alternative)*

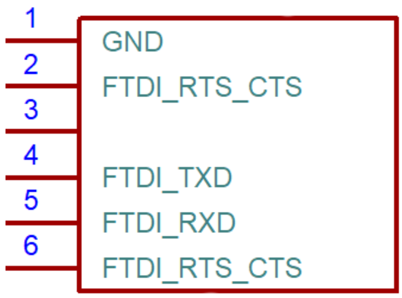

Figure 65: *Pinning schematic for the USB-FDTI connector*

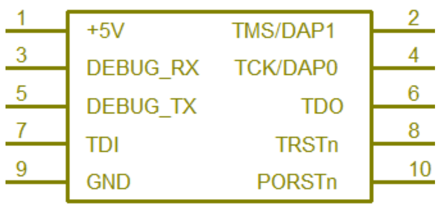

Figure 66: *Pinning schematic for the ECU interface*

13.3 TRACE32

Instructions for connecting your components and setting up TRACE32 can be found in the Release Notes [10], in section *3.3 Trace32*.

Glossary

Entry	Description
ADC	Analog-to-Digital Converter
CAN	Controller Area Network
CAN FD	Controller Area Network Flexible Data-Rate
CL	Current Loop
CM	Current Measurement
CPU	Central Processing Unit
CS	Current Sense
Core SFR	Core Special Function Register (also given as CFSR)
DAM	Default Application Memory
DAP	Debug Access Port
DCWS	DFlash Corrected Wait State
DFLASH (DF)	Data Flash Memory
DLMU	Direct-connected Local Memory Unit
DMI	Data Memory Interface
DSPR	Data Scratchpad RAM
ECU	Electronic Control Unit
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMEM	Extension Memory
FEE	Flash Emulated EEPROM
FM	Frequency Measurement
FPU	Floating-Point Unit
FSI	Flash Standard Interface
FTDI	Future Technology Devices International Limited
GND	Ground
GPR	General Purpose Register
HP	High Precision
HSD	High Speed Data
HSM	Hardware Security Module

Entry	Description
HS	High-side
I/O	Input/Output
JTAG	Joint Test Action Group
KB	2^{10} bytes
LMU	Local Bus Memory Unit
LPO	Low Power
LP	Low Precision
LSB	Least Significant Bit
LS	Low-side
MB	2^{20} bytes
MPU	Memory Protection Unit
MRD	Mounting Requirements Document
OCDS	On-Chip Debug System
PD	Product Drawing
PFLASH (PF)	Program Flash Memory
PID	Proportional Integral Derivative
PMI	Program Memory Interface
PSPR	Program Scratchpad RAM
PSW	Program Status Word
PVEU	Proportional Valve Electrical actuator
PVG	Proportional Valve Group
PWM	Pulse Width Modulation
PWS	PFlash Wait States
RAM	Random Access Memory
RTC	Real Time Clock
SENT	Single Edge Nibble Transmission
SPC	Short PWM Code
SRAM	Static Random Access Memory
SRI	Shared Resource Interconnect
SSW_A	Safety Switch A

Entry	Description
SSW_B	Safety Switch B
SSW	Safety Switch
STR	Summary of Test Reports
TBD	To Be Defined
TCM	Trace or Common Memory
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
UTP	Untwisted Pair
XCM	eXtended Common Memory
XTM	eXtra Trace Memory

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Referenced norms and standards

Document no.	Rev.	Document title
ISO 16750-1	2006	Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 1: General
ISO 16750-2	2012	Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 2: Electrical loads
ISO 16750-3	2012	Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 3: Mechanical loads
ISO 16750-4	2010	Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 4: Climatic loads
ISO 16750-5	2010	Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 5: Chemical loads
ISO 13849	2015	Road vehicles – Safety of machinery - Safety-related parts of control systems – Part 1: General principles for design (ISO 13849-1:2015); German version EN ISO 13849-1:2015
IEC 61508	2010-04	Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements
ISO 25119	2010-06	Tractors and machinery for agriculture and forestry – safety-related parts of control systems – Part 1: General principles for design and development
EN 16590	2014-02	Tractors and machinery for agriculture and forestry – safety-related parts of control systems – Part 1: General principles for design and development
ISO 26262	2018	Road vehicles – functional safety
ISO 19014	2018	Earth-moving machinery – Functional safety
ISO 11783	2015-03	Tractors and machinery for agriculture and forestry – serial control and communications data network
EN 13309	2010-10	Construction machinery – Electromagnetic compatibility of machines with internal power supply
ISO 13766	2018-04	Earth-moving and building construction machinery – Electromagnetic compatibility (EMC) of machines with internal electrical power supply
UNECE Regulation 10.5	2017-02	Regulation No 10 of the Economic Commission for Europe of the United Nations (UNECE) – Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility [2017/260]
IEC 61000-6-2	2005-01	Electromagnetic Compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments
IEC 61000-6-4	2006-07	Electromagnetic Compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments
IEC 61000-4-2	2001-04	Electromagnetic Compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test

IEC 61000-4-3	2006-02	Electromagnetic Compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radiofrequency, electromagnetic field immunity test
IEC 61000-4-4	2004-07	Electromagnetic Compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test
IEC 61000-4-5	2005-11	Electromagnetic Compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test
IEC 61000-4-6	2013-10	Electromagnetic Compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields
ISO 11542-2		Plastics – Ultra-high-molecular-weight polyethylene (PE-UHMW) molding and extrusion materials – Part 2: Preparation of test specimens and determination of properties
ISO 11452-4	2011	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Harness excitation methods
ISO 7637-2	2011	Road vehicles – Electrical disturbances from conduction and coupling – Part 2: Electrical transient conduction along supply lines only
ISO 7637-3	2016	Road vehicles – Electrical disturbances from conduction and coupling – Part 3: Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines
ISO 11898-1	2015	Road vehicles – Controller area network (CAN) – Part 1: Data link layer and physical signalling
ISO 13850	2016	Safety of machinery – Emergency stop function – Principles for design
SAE J2716		SENT (Single Edge Nibble Transmission)
SAE J2602		LIN Network for Vehicle Applications
IEC 60204-1	2016	Safety of machinery – Electrical equipment of machines
ISO 14982	2009	Agricultural and forestry machines – electromagnetic compatibility

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