

TTC 2700 Family

System Manual

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≡ 1 Introduction

1.1 General

This is the System Manual for the TTC 2700 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 2700 Family, which is part of the TTC 2000 Series, includes the following variants:

- TTC 2740 [16]
- TTC 2785 [18]

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 2700 Family. Please see your release package for additional user documentation, including:

- Software Manual [12]
- I/O Driver Manual for each variant:
 - TTC 2740 I/O Driver Manual [17]
 - TTC 2785 I/O Driver Manual [19]
- Mounting Requirements Document [8]
- Product Drawing [9]
- Quick Start Guide [10]
- Safety Manual [11]

1.3 Notation

In the context of this document, the terms *TTC 2700* and *TTC 2700 Family* refer to *all* of the products in the TTC 2700 Family.

NOTE

The information given in this System Manual is valid for *all* variants in the TTC 2700 Family, unless otherwise stated.

1.4 Support

The Release Note [14], [7] and [13] contains known issues.

Further information, including the latest software releases and most recent documents, can be found on the TTControl Service Area at <https://servicearea.ttcontrol.com/>.

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 2700 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 2700 Family. For variant-specific information, see section [2.2](#).

2.1.1 Communication interfaces

- 8x 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)
- 2x LIN Master
- Supported 8x SENT inputs with SPC¹ functionality

2.1.2 Safety features

- 3x Internal secondary shut-off paths for HS outputs
- I/O Diagnostic measures
- Watchdog
- Voltage monitor for internal supply rails

2.1.3 Additional features

- Real Time Clock (RTC)

2.1.4 Power supply

- Supply voltage: 8 to 32 V
- Separate supply pins for CPU subsystem and I/O subsystem
- Load dump protection
- 4x fixed sensor supplies with an output voltage of 5 V
 - SSUP_0
 - SSUP_1
 - SSUP_2
 - SSUP_3

¹. upcoming feature

2. PRODUCT OVERVIEW

- 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_4
- Each sensor supply can deliver up to 750 mA load current continuously
- All sensor supplies have identical hardware designs
- Sensor supply and battery monitoring

2.1.5 Wake-up sources

- 2x 100Base-T1
- 1x Real Time Clock (RTC)
- 1x CAN FD
- 1x Terminal 15
- 1x Wake-up pin

2.1.6 Physical specifications

- Dimensions: 317 x 220.5 x 41.2 mm
- Weight: 2.7 kg
- Operating ambient temperature: - 40 to + 85 °C
- Storage temperature: - 40 to + 85 °C
- Housing IP6k7- and IP6k9k-rated die-cast aluminum housing
- 4x 48 pin connector
- 1x 2-slot HSD connector
- Pressure equalization with water barrier
- Operating altitude 0 to 4000 m

Other device dimensions, including tolerances, weight and other physical specifications for the TTC 2700 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].

2.1.7 Inputs and outputs

- 132x I/Os: 70x out, 62x in, including:
 - 46x PWM HS with current measurement
 - 12x digital out LS with current measurement (variant dependent)
 - 8x SENT inputs with SPC ² functionality
- 3x status LEDs

All inputs and outputs of each TTC 2700 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 2700 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

2. upcoming feature

2. PRODUCT OVERVIEW

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.

2.1.8 Core

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

2.1.9 Software

- C-programming API
- PXROS RTOS with mixed-criticality support
- CODESYS 3.x ³
- 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 2700.

2.2 TTC 2700 Family variants

The following TTC 2700 Family variants are described in this System Manual:

- TTC 2740 [16]
- TTC 2785 [18]

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

3. upcoming feature

Feature		TTC 2740	TTC 2785
CPU	32-bit TC 399	Yes	Yes
	Int. FLASH	16 MB	16 MB
	Int. SRAM	6.47 MB	6.47 MB
	Int. FEE	1 MB	1 MB
Memory	Ext. Serial FLASH	32 MB	32 MB
	Ext. EEPROM		
	Ext. FRAM		8 kB
Interface	CAN FD	8	8
	CAN1 is ISOBUS compliant	Yes	Yes
	CAN termination	1	1
	100BASE-T1	2	0
	100BASE-TX	0	2
	LIN	2	2
Outputs	Digital high-side 4 A	12	12
	Digital low-side 4 A	12	0
	PWM high-side 4 A	40	40
	PWM high-side 8 A	6	6
	PWM low-side 4 A	0	12
	Status LED	3	3
Inputs	Analog IN 4-mode (V/I/R)	32	32
	Analog IN 2-mode(V)	14	14
	Timer IN/SENT	8	8
	Timer IN/CL	8	8
Power			
	Sensor supply fixed (5 V)	4	4
	Sensor supply variable (5 to 12.75 V)	1	1
	Sensor GND	8	8
	Terminal 15	1	1
	Wake-up	1	1

Table 1: TTC2700 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 specific user applications of the overall system that the TTC 2700 device is built into. Therefore, it needs to be ensured that these regulations and standards are fulfilled by the TTC 2700 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 damaged.
See [8] for further details.
- The label on the housing contains important information. The label must not be destroyed or made unreadable.
- The TTC 2700 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 2700 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

3. INSTRUCTIONS FOR SAFE OPERATION

- 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 ambient temperature of the device does not exceed the maximum allowed operating ambient 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 2700 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) [[15](#)] 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 2700 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 2700 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 2700 power stages.

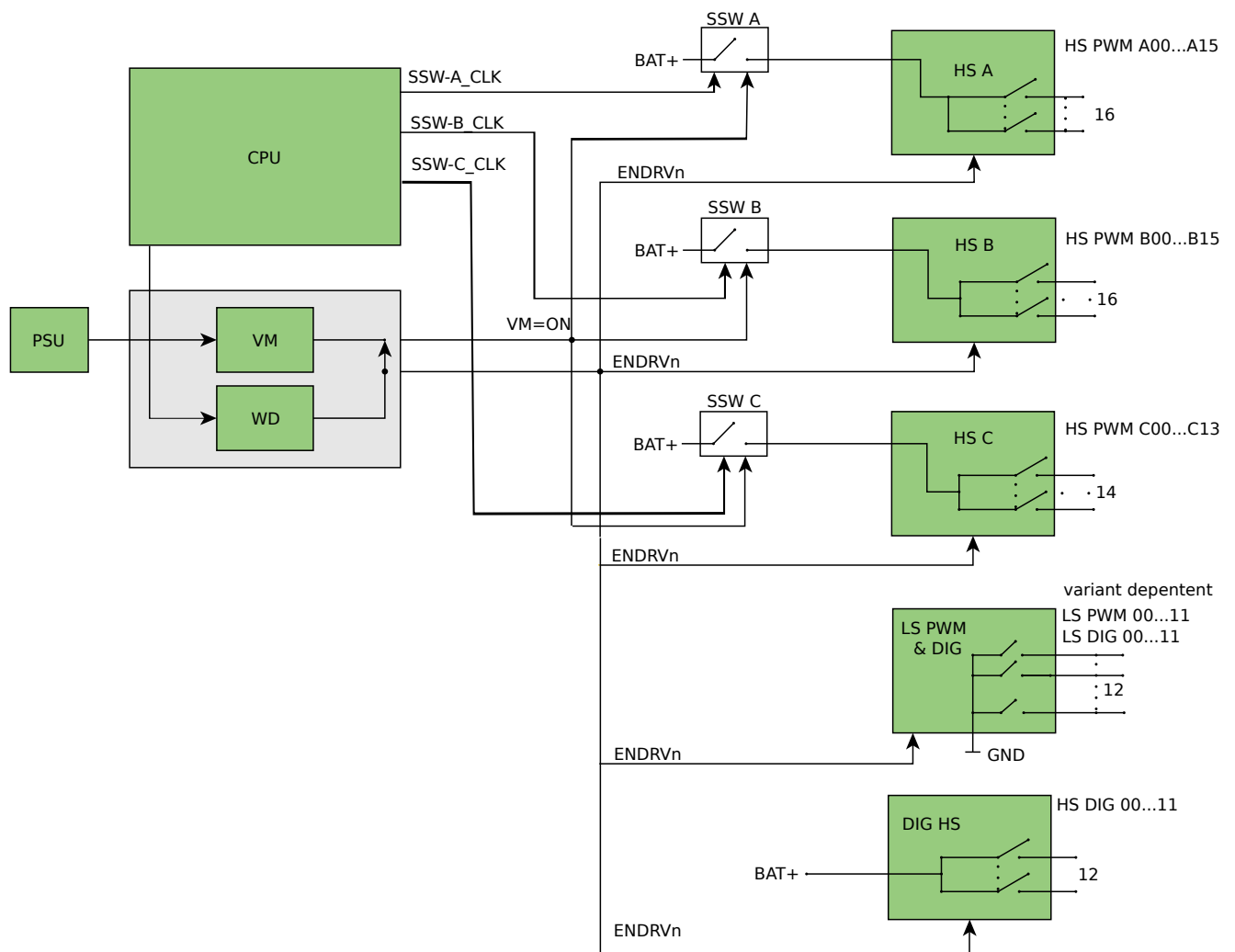


Figure 1: Safety concept

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

TC399		
Cache per CPU	Program	32 kB
	Data	16 kB
SRAM per CPU	PSPR	64 kB
	DSPR	240 kB (core 0/1) 96 kB (core 2-5)
	DLMU	64 kB
SRAM global	LMU	768 kB
	DAM	128 kB
EMEM	TCM & XCM	2+2 MB
Program Flash		PF0-PF4: 3 MB (each) PF5: 1 MB
	Total	16 MB
Data Flash	DF0	1 MB
	DF1	128 kB

Table 2: System CPU memory specifications

7. INTERNAL STRUCTURE

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
	buffer hit	3	6
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

¹PWS: Configured PFlash Wait States (Includes cycles for PFlash access cycles only). ECC correction latency is only incurred when the incoming data requires ECC correction.

²With pipelining

³DFlash runs on FSI clock. $f_{CPU} = 3 \cdot f_{FSI}$.

⁴DCWS: Configured DFlash Corrected Wait States (Includes cycles for DFlash access cycles and ECC correction latency).

⁵The 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 6 Core/TC 399

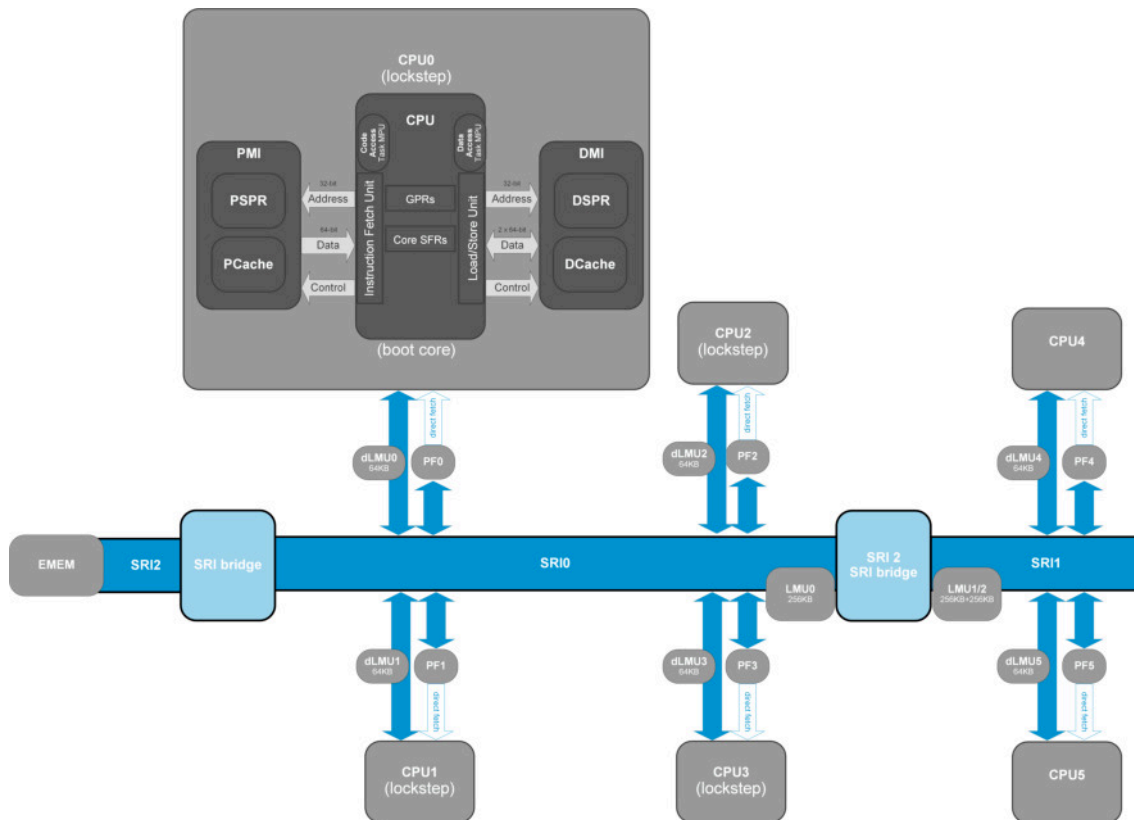


Figure 2: Detailed block diagram for 6 core (TC 399)

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 strategy allows a higher current consumption at lower board temperatures and brings the ECU to a safe state immediately while switching off loads if it detects that the board temperature is above the allowed maximum. See table 4 for board temperature limits that trigger 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 $T_{\text{ECU}}/T_{\text{ambient}}$ 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 board temperature	- 40	+ 125	°C
T	Temperature measurement range	- 50	+ 150	°C
$T_{\text{tol-m}}$	Temperature tolerance between - 5 °C and + 125 °C	-5	+ 5	K
$T_{\text{safe state}}$	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 3 shows the main and HSD connectors for the TTC 2700 device. The main connectors, A, B, C and D consist of 192 pins divided into 4x 48 pin connectors. The HSD connectors, E and F, are variant dependent (see section 2.2 for further details).

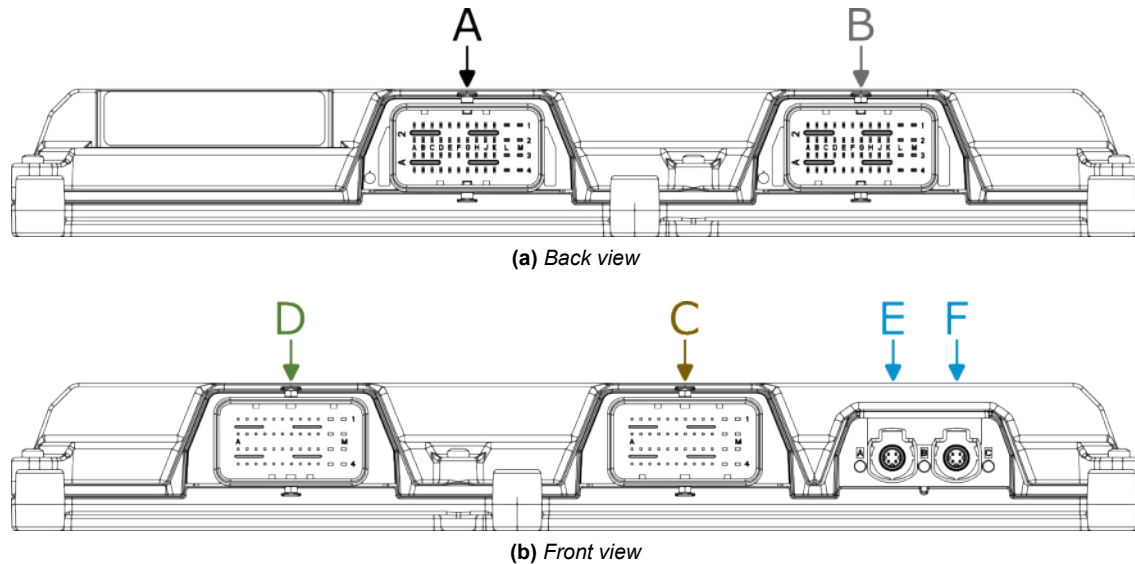


Figure 3: Connector view.

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:

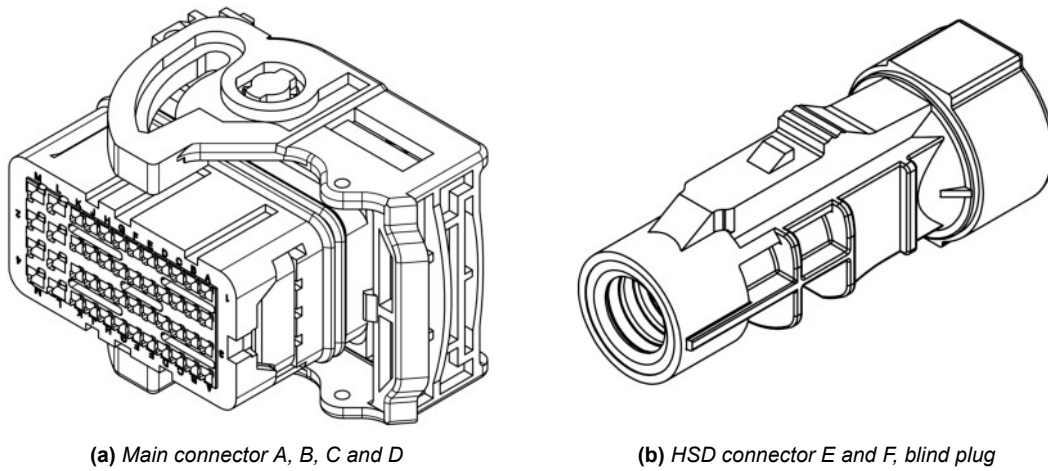
Connector	Description	Part no.	Supplier
A	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, black coding, mat sealed	64320-1311	Molex
A	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, right wire output, black coding, mat sealed	64320-3311	Molex
B	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, grey coding, mat sealed	64320-1318	Molex
B	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, right wire output, grey coding, mat sealed	64320-3318	Molex
C	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, brown coding, mat sealed	64320-1319	Molex
C	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, right wire output, brown coding, mat sealed	64320-3319	Molex

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D	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, green coding, mat sealed	64320-1315	Molex
D	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, right wire output, green coding, mat sealed	64320-3315	Molex
A, B, C, D	CMC wire cap for 48 circuits and 28 circuits, CMC receptacle, mat sealed	64320-1301	Molex
E, F	Waterproof housing, A coding ¹	D4K14A-1D5A5-A	Rosenberger

Table 5: Recommended plug housings for mating connectors

¹Part number for non-waterproof housing for HSD connector E and F: D4K10A-1D5A5-A



(a) Main connector A, B, C and D

(b) HSD connector E and F, blind plug

Figure 4: Plug housings**NOTE**

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

8.1.2 Crimping contacts

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

Connector	Description	Part no.	Supplier
A, B, C, D	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, C, D	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, C, D	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, C, D	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, B, C and D, used to plug unused terminals in the connector to ensure tightness.

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

Table 7: Recommended terminal cavities for mating connectors

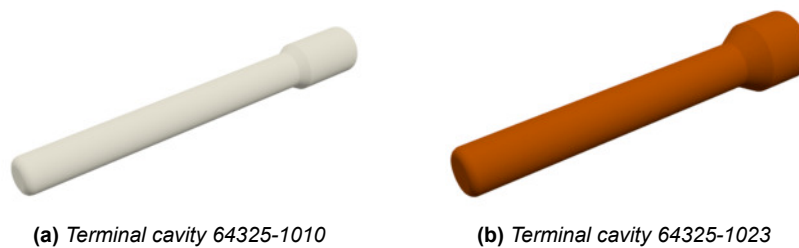


Figure 5: Terminal cavities

8.1.4 Blind plugs

TTControl recommends the following blind plug for the HSD connector:

Connector	Description	Part no.	Supplier
E, F	Blind plug	D4Z023-002Z	Rosenberger

Table 8: Recommended blind plug for the HSD connector

Figure 4b 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 the summary of test reports [15] for further information.

8.1.5 Tools

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

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

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A, B, C, D	I/O pin hand crimp tool wire size 0.35 mm ²	63811-9100	Molex
A, B, C, D	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

8.1.6 Cables

TTControl recommends the following cables for mating connectors:

Connector	Description	Function	Recommendation
A, B, C, D	2.0 mm ²	BAT+Power BAT+CPU BAT- HS OUT (8 A)	Automotive standard
A, B, C, D	Twisted stranded wire pair, FLRY 2x0.5 mm ²	CAN	Automotive standard
A, B, C, D	0.75 mm ²	all other functions	Automotive standard
E, F	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.

≡ 9 TTC 2700 Family pinning

The pins on the TTC 2700 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 sections 10 and 11.

A full overview of all 192 pins, including a complete group-by-group overview, can be found in the Software Manual [12]. Instructions on how to use the pins/pin groups is given in the variant-specific I/O Driver Manual [17, 19]. 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, AN4_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**

NOTE The notation of pin groups in this document will differ from the notation provided in the software manual. For example, connector A and pin J3 will be noted as "TT_PIN_AJ3" in the software manual.

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

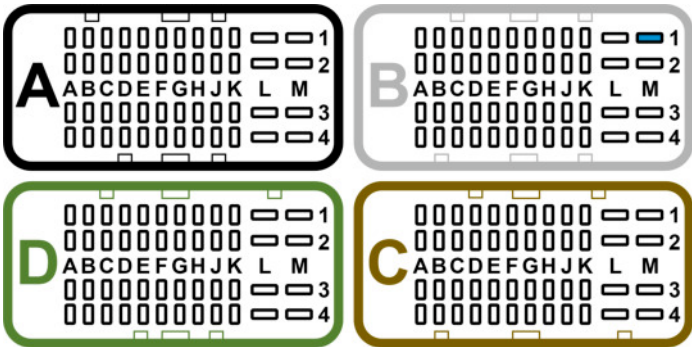


Figure 6: BAT+ CPU pinout

Connector	Pin	Pin name	Variant
B	M1	BAT+CPU	All

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

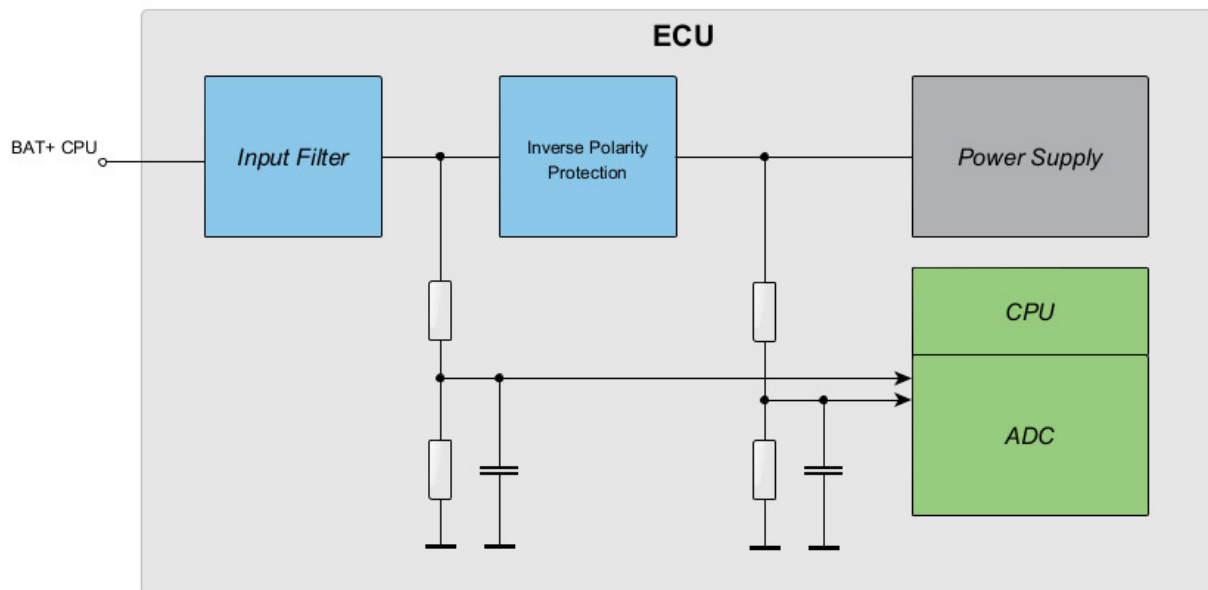


Figure 7: Supply pin for the internal ECU logic for BAT+ CPU

Maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{in-max}	Permanent non-destructive supply voltage ¹	-32	32	V
V_{in-lim}	Peak non-destructive supply clamping voltage < 1 ms ^{1 2}	-40	42	V
I_{in-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, $R_i = 2 \Omega$) ¹		350	ms
$I_{BAT+ max}$	Permanent input current ³		4.3	A

Table 12: BAT+ CPU maximum ratings

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

²1 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.

³External loading (e.g. SSUP) has to be considered to avoid overloading the internal circuitry.

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Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	470		μF
V_{BAT+}	Supply voltage for start up ¹	8	32	V
V_{BAT+}	Supply voltage for full operation ²	4.5	32	V
$I_{BAT+ \text{ idle}}$	Supply current at $V_{BAT+} = 8 \text{ V}$ ¹		210	mA
$I_{BAT+ \text{ idle}}$	Supply current at $V_{BAT+} = 12 \text{ V}$		140	mA
$I_{BAT+ \text{ idle}}$	Supply current at $V_{BAT+} = 24 \text{ V}$		80	mA
$I_{BAT+ \text{ STBY}}$	Standby supply current (Terminal 15 and wake up off) ³		100	μA
$I_{BAT+ \text{ STBY}}$	Standby supply current ³ (CAN Wake-up configured)		500	μA

Table 13: BAT+ CPU characteristics

¹8 V is the initial voltage for start-up at the beginning of the ECU operational cycle.

²See section 10.1.1.

³ $T_{ECU} = -40 \text{ to } +85 \text{ }^{\circ}C$

10.1.1 Low-voltage operation

The TTC 2700 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 3, *Starting profile values for systems with 12 V nominal voltage, U_N* , and Table 4, *Values for systems with 24 V nominal voltage, U_N*). The TTC 2700 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 "ISO 16750 functional status".

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

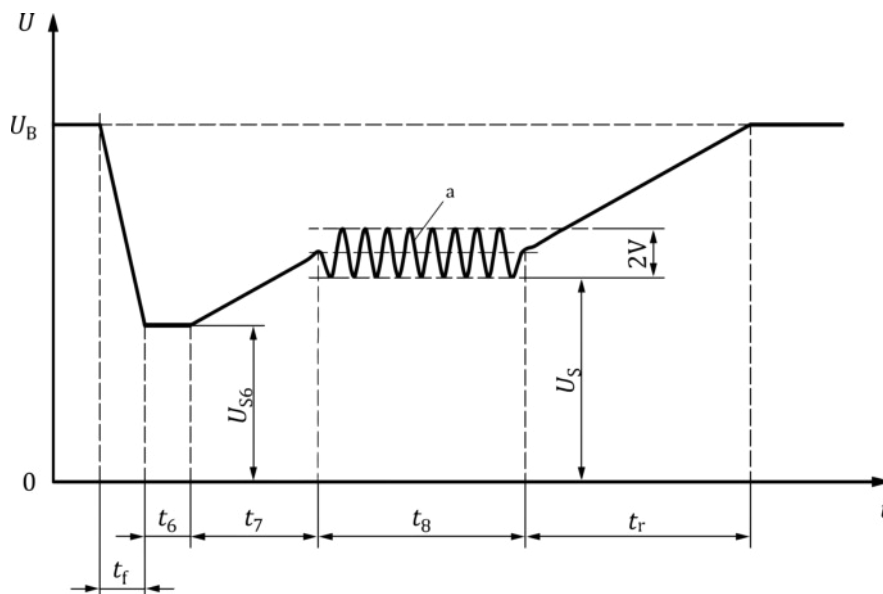


Figure 8: ISO 16750-2 – Starting profile

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 not in 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
T_{in}	First order low pass filter	1.5	2.5	ms
V_{nom}	Nominal battery supply range ¹	0	33	V
V_{tol-0}	Zero reading error ²	-67	67	mV
V_{tol-0}	Zero reading error	-80	80	mV
V_{tol-p}	Proportional error ²	-3	3	%
V_{tol-p}	Proportional error	-4	4	%
LSB	Nominal value of 1 LSB		13.4	mV

Table 16: BAT+ CPU voltage monitoring

¹The 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)

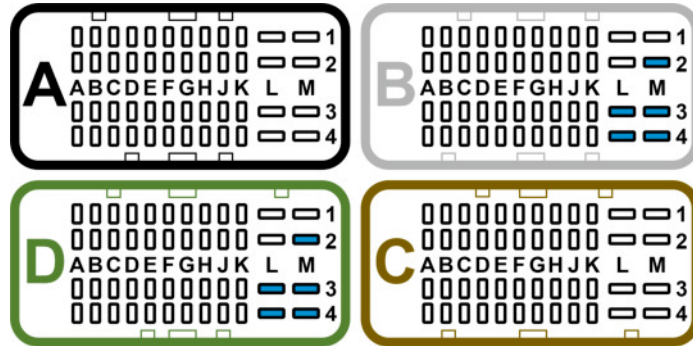


Figure 9: BAT+ Power pinout

Connector	Pin	Pin name	Variant
B	L4	BAT+ Power	All
B	L3	BAT+ Power	All
B	M4	BAT+ Power	All
B	M3	BAT+ Power	All
B	M2	BAT+ Power	All
D	L4	BAT+ Power	All
D	L3	BAT+ Power	All
D	M4	BAT+ Power	All
D	M3	BAT+ Power	All
D	M2	BAT+ Power	All

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

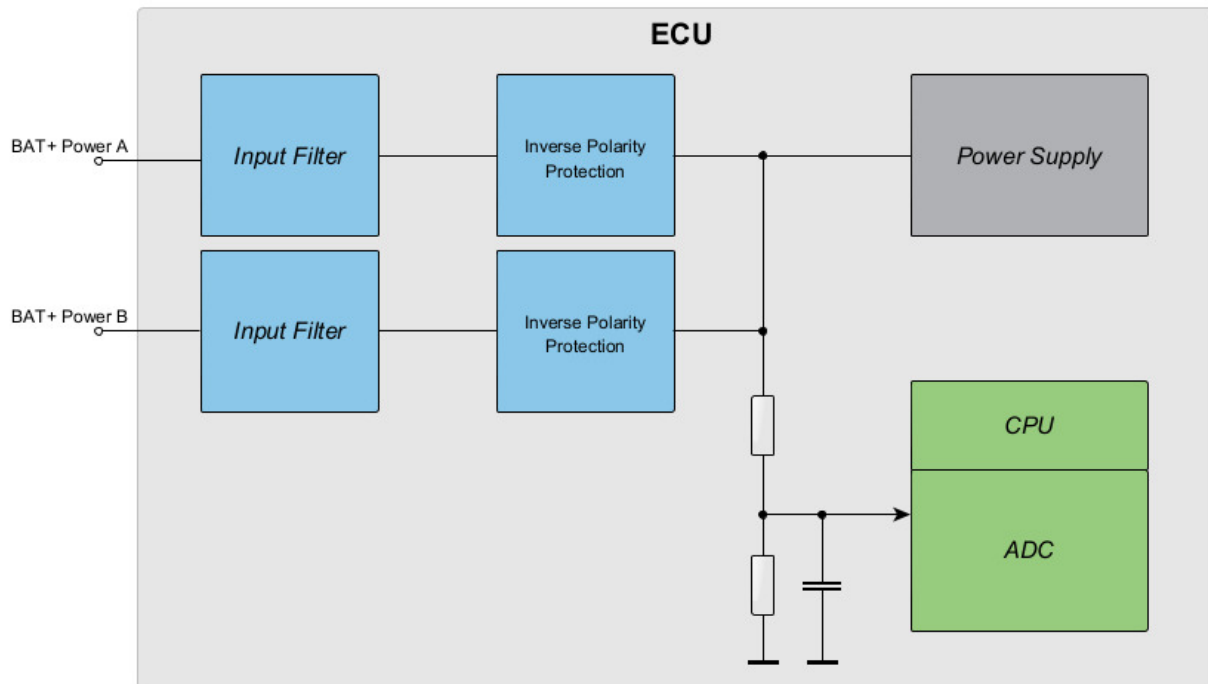


Figure 10: Supply pin for the internal ECU logic for BAT+ Power

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, $R_i = 2 \Omega$) ¹		350	ms
I_{in-max}	Permanent battery supply current (all pins in parallel with symmetrical wire connection) ³		80	A
I_{in-max}	Permanent battery supply current per pin ³		8	A
$I_{in-total}$	Total load current, 12 V and 24 V battery operation ⁴		TBD	A
$I_{in-total}$	Total load current, 12 V and 24 V battery operation ^{4 5}		80	A

Table 18: BAT+ Power maximum ratings

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

²1 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.

³This 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.

⁴Variant dependant

⁵ $T_{ECU} = -40$ to $+85$ °C

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	706	1058	μF
V_{BAT+}	Supply voltage for full operation	6	32	V

Table 19: BAT+ Power characteristics

10.3 Negative power supply (BAT-)

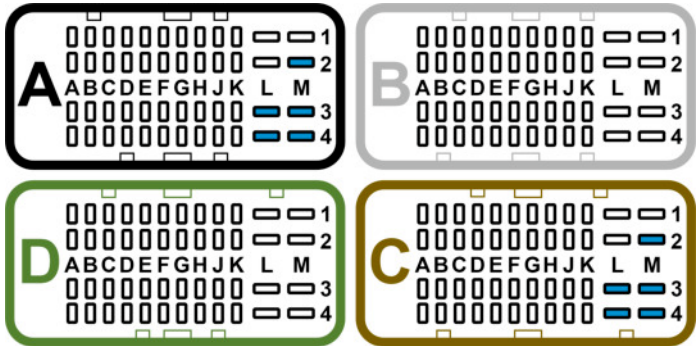


Figure 11: BAT- pinout

Connector	Pin	Pin name	Variant
A	L4	BAT-	All
A	L3	BAT-	All
A	M4	BAT-	All
A	M3	BAT-	All
A	M2	BAT-	All
C	L4	BAT-	All
C	L3	BAT-	All
C	M4	BAT-	All
C	M3	BAT-	All
C	M2	BAT-	All

Table 20: BAT- pin group

Functional description

Supply pins for negative power supply.

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

10. SUPPLY

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$I_{\text{out-max}}$	Permanent current per pin		8	A
$I_{\text{out-max}}$	Permanent current all pins		80	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 (see section 10.1)		3	A
$I_{BAT+ Power A}$	Fuse trip current ¹ (see section 10.2)		45	A
$I_{BAT+ Power B}$	Fuse trip current ¹ (see section 10.2)		45	A

Table 23: Recommended fuses for power supply path protection

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

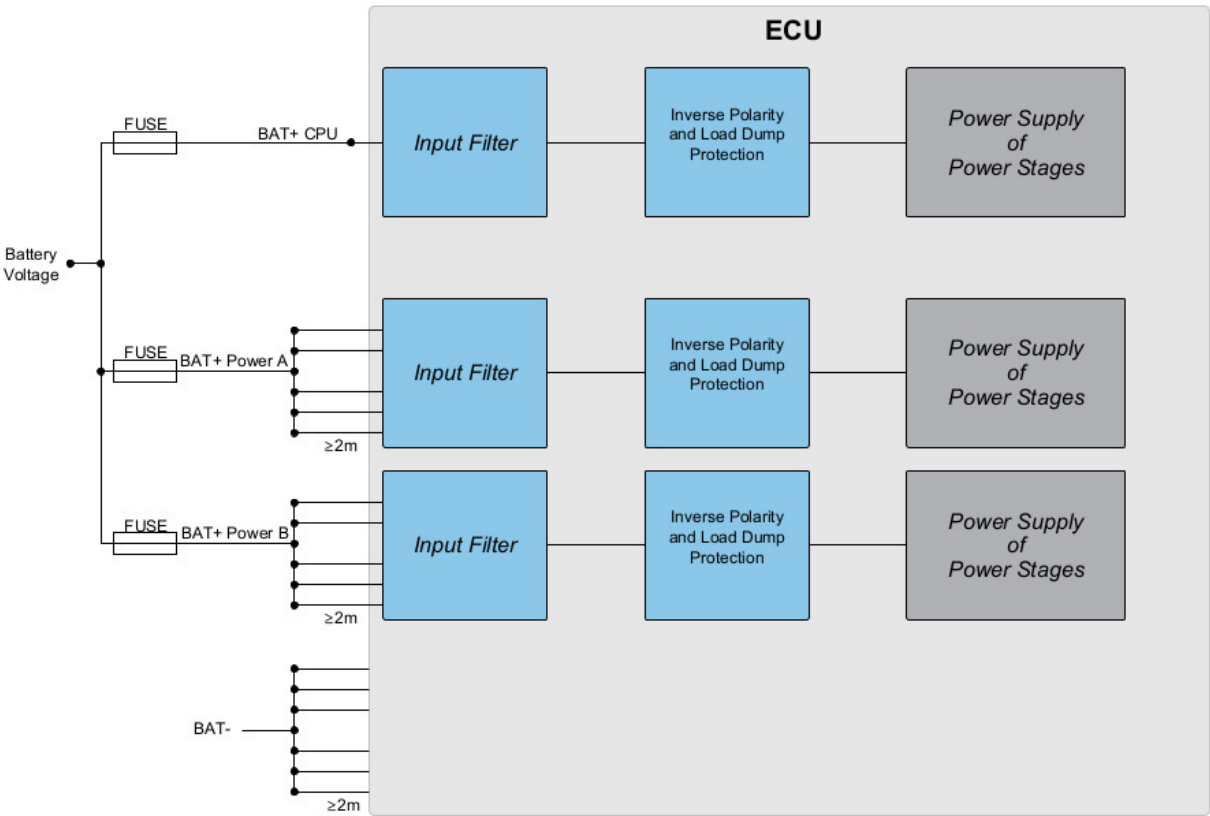


Figure 12: Battery supply – Fuse

NOTE

It is necessary to use wires with the same total cross-sectional area and length ($\geq 2\text{m}$) instead of one thick cable for load-carrying supply lines (BAT+ Power and BAT-). In this case, an even current distribution can be achieved, even with slightly different contact resistances. It is recommended to use all pins of BAT+ Power and BAT-.

≡ 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 board temperature range: -40 to +125 °C, unless stated otherwise.

NOTE

The notation of pin groups in this document will differ from the notation provided in the software manual. For example, connector A and pin J3 will be noted as "TT_PIN_AJ3" in the software manual.

11.1 Sensor GND

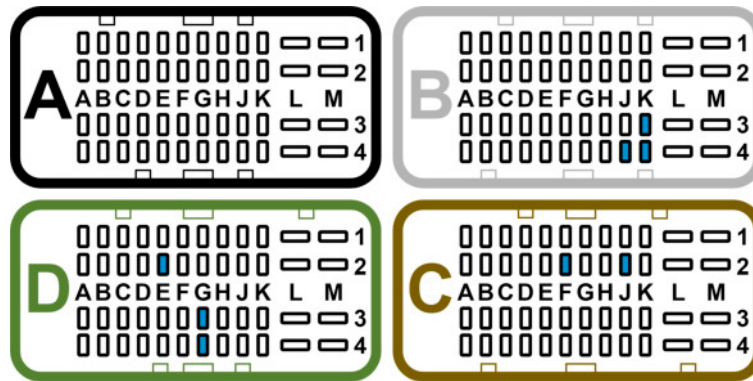


Figure 13: Sensor GND pinout

Connector	Pin	Pin name	Variant
D	F2	SNS_GND	All
D	J2	SNS_GND	All
B	J4	SNS_GND	All
C	E2	SNS_GND	All
B	K3	SNS_GND	All
B	K4	SNS_GND	All
C	G3	SNS_GND	All
C	G4	SNS_GND	All

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
$I_{out-max}$	Permanent current per pin ¹		1	A

Table 25: Sensor GND maximum ratings

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

11.2 Terminal 15

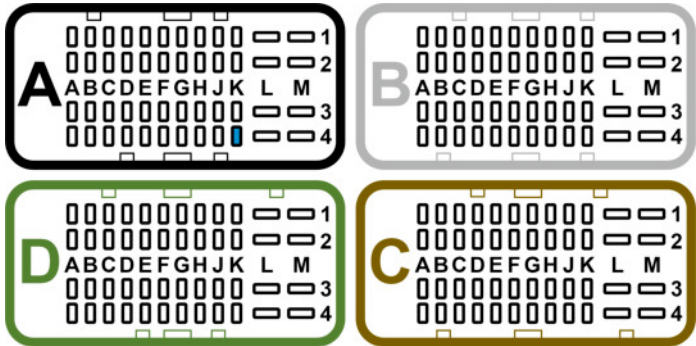


Figure 14: T15 pinout

Connector	Pin	Pin name	Variant
A	K4	T15	All

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 functionality⁴ (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

4. 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	k Ω
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		2.6	V
V_{ih}	Input voltage for high level ¹	5		V
τ_{in}	Input low pass filter	167.2	212.8	μ s

Table 28: T15 characteristics

¹ 8 V is the start up voltage at the beginning of the ECU operational cycle

11.3 Wake-up

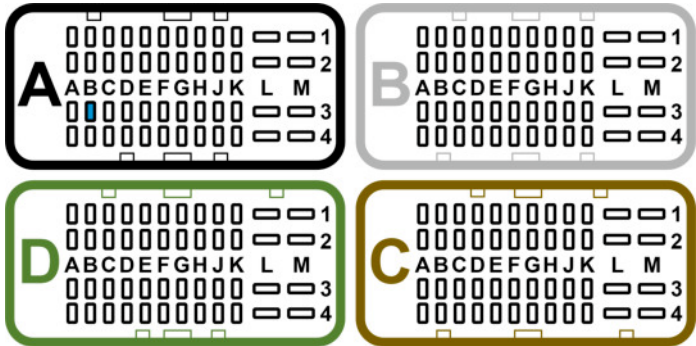


Figure 15: Wake-up pinout

Connector	Pin	Pin name	Variant
A	B3	WAKE_UP	All

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.

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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		2.4	V
V_{ih}	Input voltage for high level ¹	4.1		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 ECU operational cycle

² There is an additional 50 μs delay in the digital circuitry of Wake-up handling.

11.4 Sensor supply 5 V

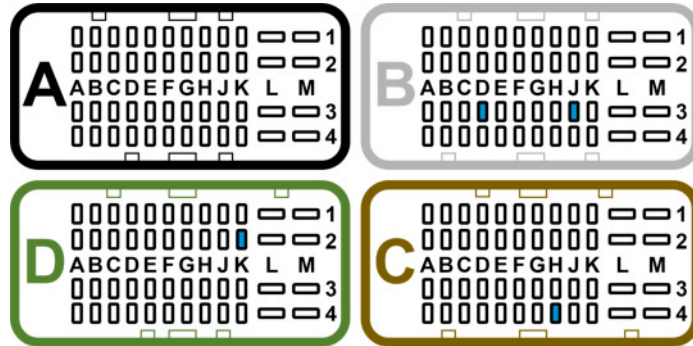


Figure 16: Sensor supply 5 V pinout

Connector	Pin	Pin name	Variant
B	D3	SSUP_00	All
B	J3	SSUP_01	All
C	H4	SSUP_02	All
D	K2	SSUP_03	All

Table 32: Sensor supply 5 V pin group

Supported functions

- SSP_5V (main)

Functional description

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

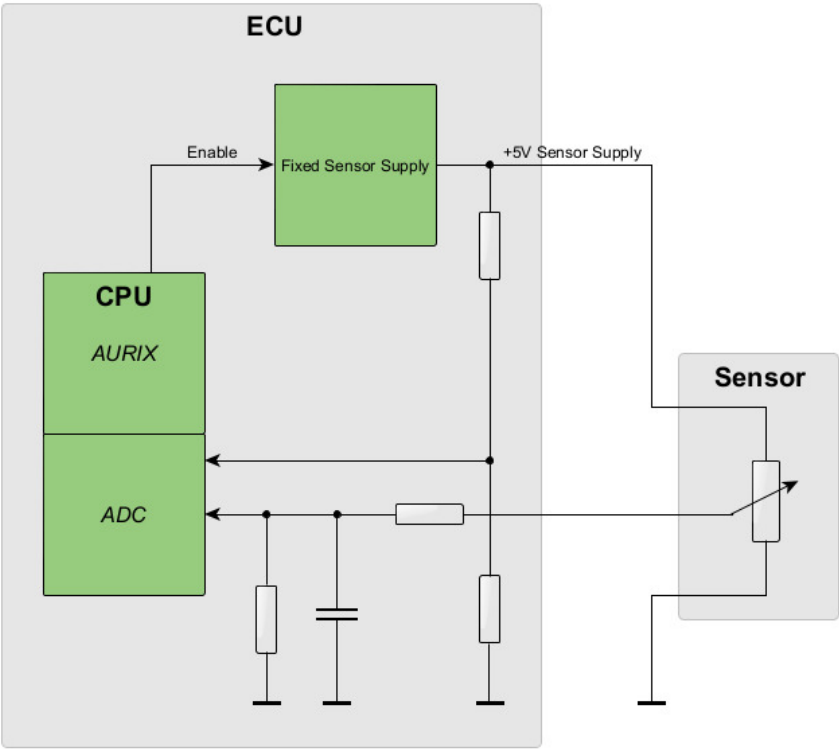


Figure 17: Sensor supply 5 V

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

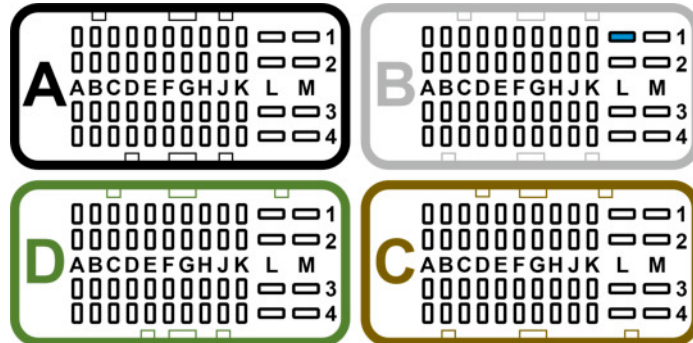


Figure 18: Sensor supply variable pinout

Connector	Pin	Pin name	Variant
B	L1	SSUP_04	All

Table 35: Sensor supply variable pin group

Supported functions

- SSP_VAR (main)

Functional description

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 11.12 for further information.

TTControl recommends using this pin with the maximum possible wire size (FLRY type), in order to reduce the 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	0	750	mA

Table 37: Sensor supply variable characteristics

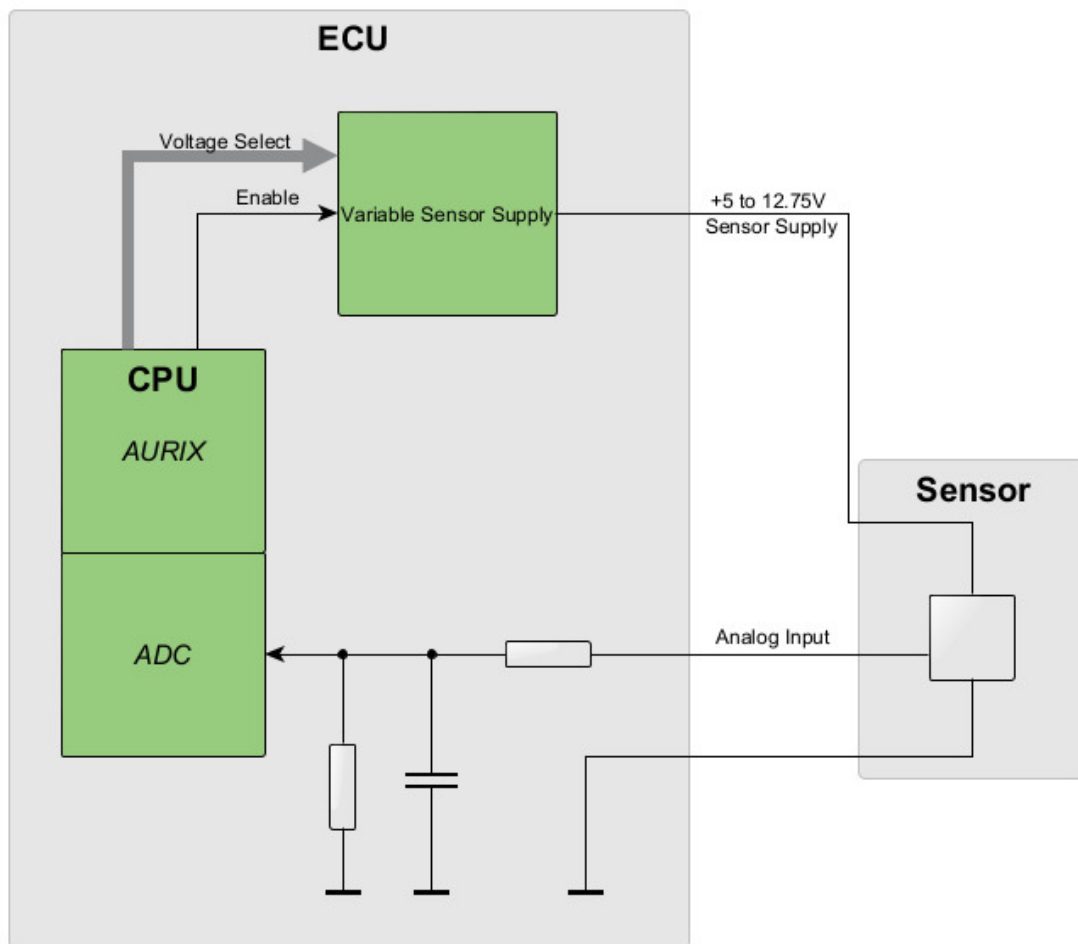


Figure 19: Sensor supply variable

11.6 Analog input 4-mode

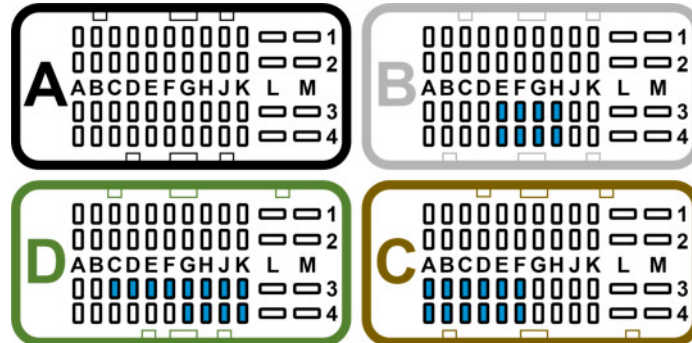


Figure 20: Analog input 4-mode pinout

Connector	Pin	Pin name	Variant
B	E4	AN4_IN_00 ²	All
B	E3	AN4_IN_01 ²	All
B	F4	AN4_IN_02 ¹	All
B	F3	AN4_IN_03 ¹	All
B	G4	AN4_IN_04 ²	All
B	G3	AN4_IN_05 ²	All
B	H4	AN4_IN_06 ¹	All
B	H3	AN4_IN_07 ¹	All
C	F3	AN4_IN_08 ²	All
C	F4	AN4_IN_09 ²	All
C	E4	AN4_IN_10 ¹	All
C	D4	AN4_IN_11 ¹	All
C	C4	AN4_IN_12 ²	All
C	E3	AN4_IN_13 ²	All
C	D3	AN4_IN_14 ¹	All
C	C3	AN4_IN_15 ¹	All
D	C3	AN4_IN_16 ²	All
D	D3	AN4_IN_17 ²	All
D	E3	AN4_IN_18 ¹	All
D	F3	AN4_IN_19 ¹	All
D	G3	AN4_IN_20 ²	All
D	H3	AN4_IN_21 ²	All
D	J3	AN4_IN_22 ¹	All
D	K3	AN4_IN_23 ¹	All

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D	G4	AN4_IN_24 ²	All
D	H4	AN4_IN_25 ²	All
D	J4	AN4_IN_26 ¹	All
D	K4	AN4_IN_27 ¹	All
C	A4	AN4_IN_28 ²	All
C	B4	AN4_IN_29 ²	All
C	A3	AN4_IN_30 ¹	All
C	B3	AN4_IN_31 ¹	All

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**)
 - ¹available for 16 out of 32 pins, see table 38
- ADC_RIN_100K_HP (**main**)
 - ²available for 16 out of 32 pins, see table 38
- DIN_5V

Functional description

Multipurpose analog inputs with 12-bit resolution.

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, allowing a 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

¹Due to thermal reasons only one of the 32 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.

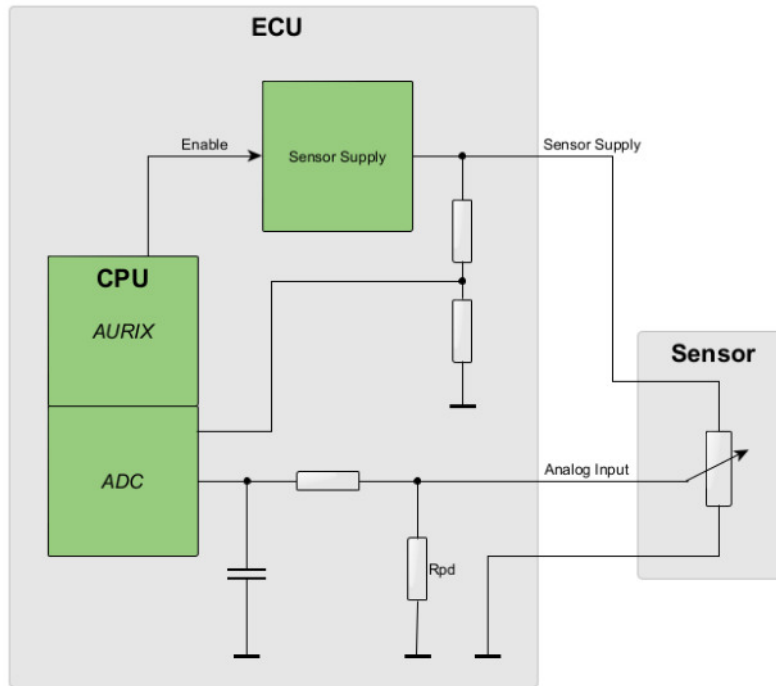


Figure 21: Analog voltage input (ratiometric)

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	k Ω
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}	-10	10	mV
V_{tol-0}	Zero reading error ^{3 4}	-15	15	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

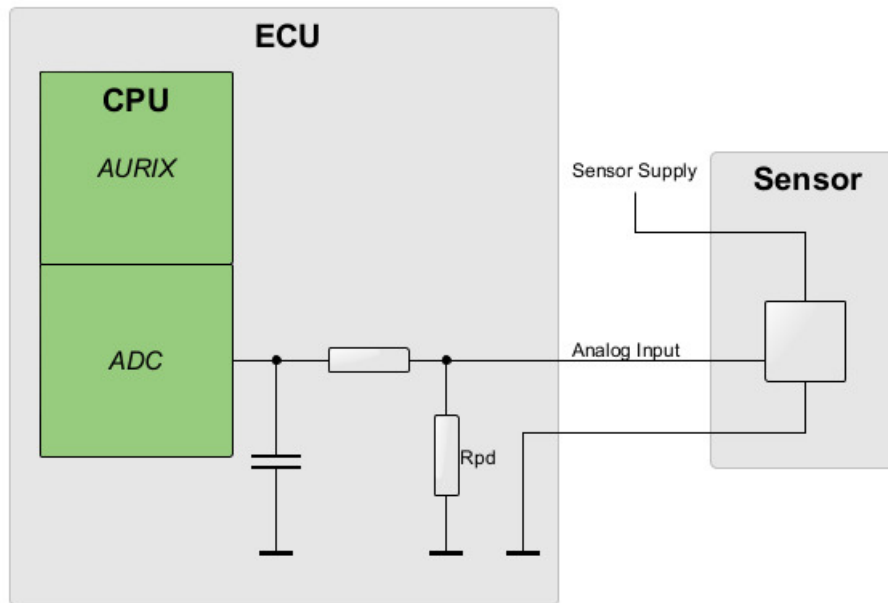
Table 40: 5 V Analog input (ratiometric) – characteristics

¹For full accuracy.

² $T_{ECU} = -40$ to $+85$ °C.

³This includes the conversion error of the TTC 2700 and the sensor supply error. The total measurement error is the sum of the error of TTC 2700 and the error of the ratiometric sensor (measurement tolerance).

⁴The total measurement error is the sum of zero reading error and the proportional error.


Figure 22: 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-0}	Zero reading error ^{2 3 4}	-10	10	mV
V_{tol-0}	Zero reading error ^{3 4}	-15	15	mV
V_{tol-p}	Proportional error ^{2 3 4}	-0.4	0.4	%
V_{tol-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

¹For full accuracy.

² $T_{ECU} = -40$ to $+85$ °C.

³This includes the conversion error of the TTC 2700 only. The total measurement error is the sum the error of TTC 2700 and the absolute sensor error (measurement tolerance plus tolerance of external sensor reference).

⁴The 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 BAT-, 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.

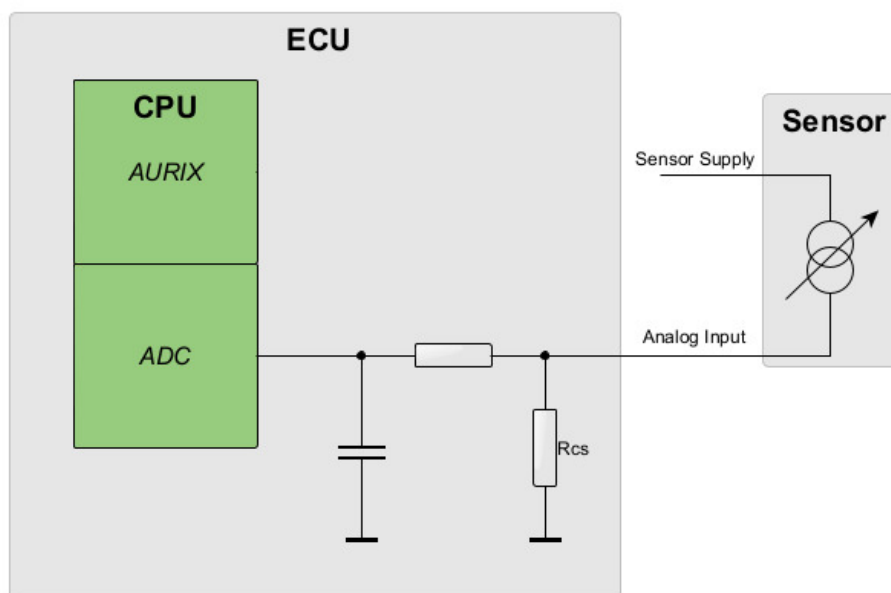


Figure 23: Analog current input

11. SPECIFICATION OF INPUTS AND OUTPUTS

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}	-85	85	μA
I_{tol-0}	Zero reading error ³	-135	135	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

¹This is the load resistor value for the current loop sensor.

² $T_{ECU} = -40$ to $+85$ °C

³The 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 k Ω resistance sensor measurement.

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

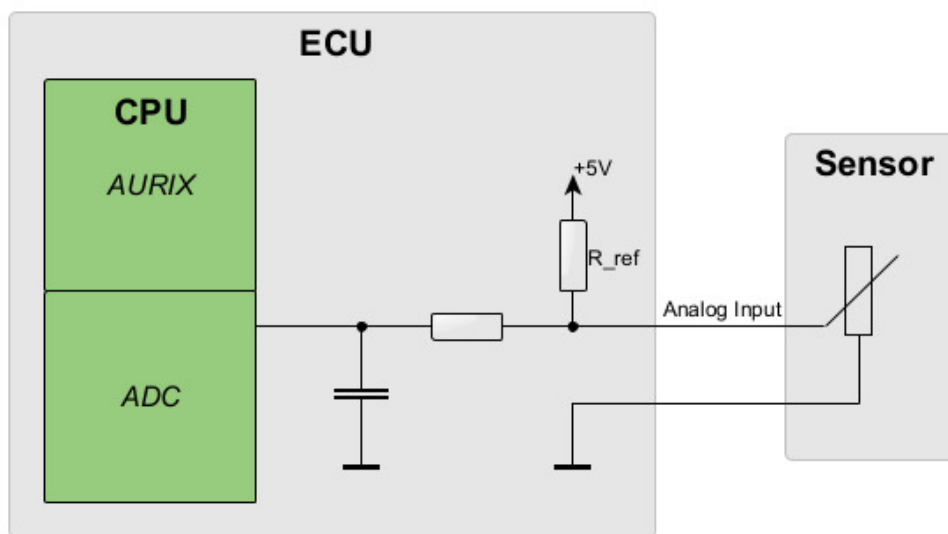
The actual resistor value of the sensor is computed from the measured input voltage together with the known reference resistor value. Be aware that this measurement setup has the highest accuracy and resolution if the sensors resistance is in the magnitude of the reference resistors value.

The resistance mode may also be used as digital input with switches connected to BAT-, see figure 26. 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 BAT-, 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
T_{in}	Input low pass filter	2.2	3.8	ms
R_{ext_range}	Resistance measurement range	0	100	k Ω

Table 43: Analog resistance input – characteristics

Figure 24: Analog resistance input

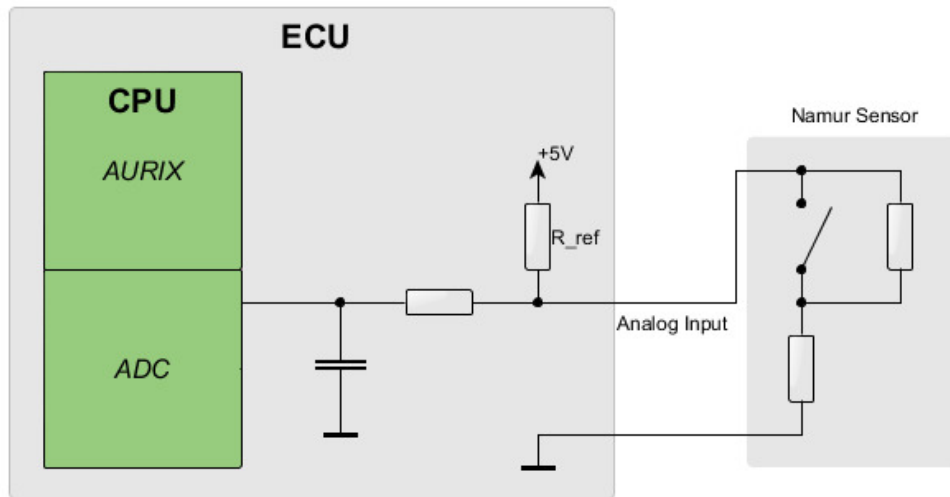


Figure 25: Namur type sensor (only for switches to BAT-)

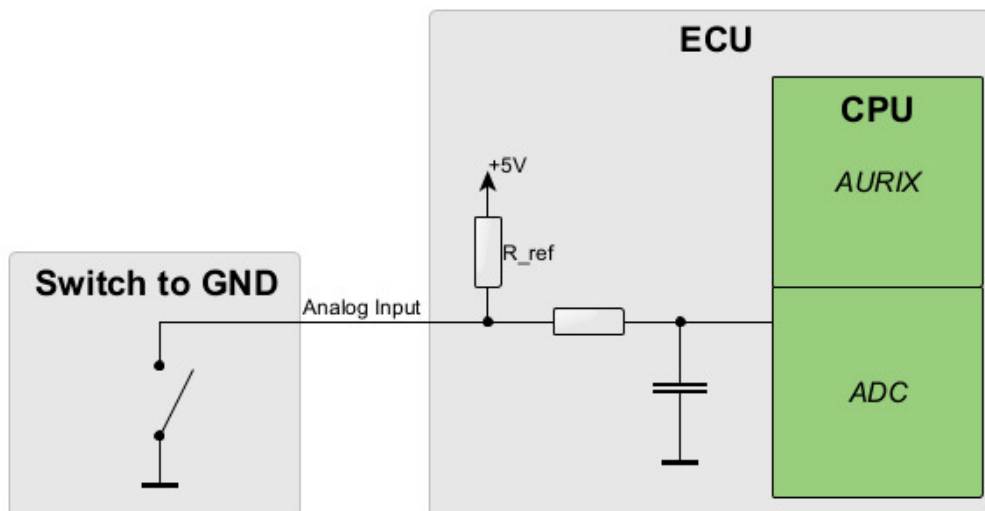


Figure 26: Switch input (only for switches to BAT-)

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 k Ω to 20 k Ω	-2	2	%
R_{tol-m}	Measurement tolerance for 50 k Ω	-3.5	3.5	%
R_{tol-m}	Measurement tolerance for 100 k Ω	-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 k Ω to 20 k Ω	-3	3	%
R_{tol-m}	Measurement tolerance for 50 k Ω	-5	5	%
R_{tol-m}	Measurement tolerance for 100 k Ω	-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 k Ω to 10 k Ω	-1	1	%
R_{tol-m}	Measurement tolerance for 20 k Ω	-1	1	%
R_{tol-m}	Measurement tolerance for 50 k Ω	-2	2	%
R_{tol-m}	Measurement tolerance for 100 k Ω	-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 k Ω to 10 k Ω	-1.5	1.5	%
R_{tol-m}	Measurement tolerance for 20 k Ω	-2.5	2.5	%
R_{tol-m}	Measurement tolerance for 50 k Ω	-4	4	%
R_{tol-m}	Measurement tolerance for 100 k Ω	-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	98	107	k 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

Table 48: 5 V digital input – characteristics

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

11.7 Analog input 2-mode

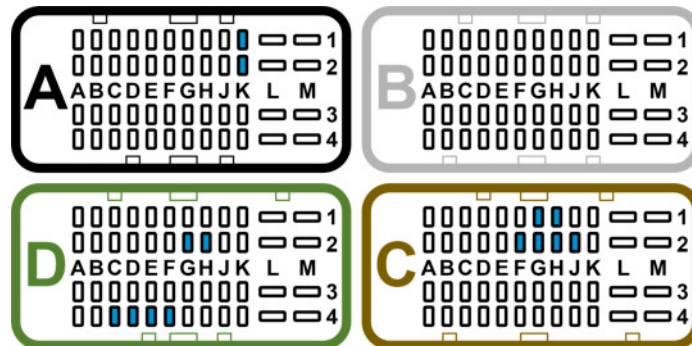


Figure 27: Analog input 2-mode pinout

Connector	Pin	Pin name	Variant
D	C4	AD2_IN_00	All
D	D4	AD2_IN_01	All
D	E4	AD2_IN_02	All
D	F4	AD2_IN_03	All
D	H2	AD2_IN_04	All
D	G2	AD2_IN_05	All
C	F2	AD2_IN_06	All
C	G2	AD2_IN_07	All
C	H2	AD2_IN_08	All
C	J2	AD2_IN_09	All
C	G1	AD2_IN_10	All
C	H1	AD2_IN_11	All
A	K1	AD2_IN_12	All
A	K2	AD2_IN_13	All

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

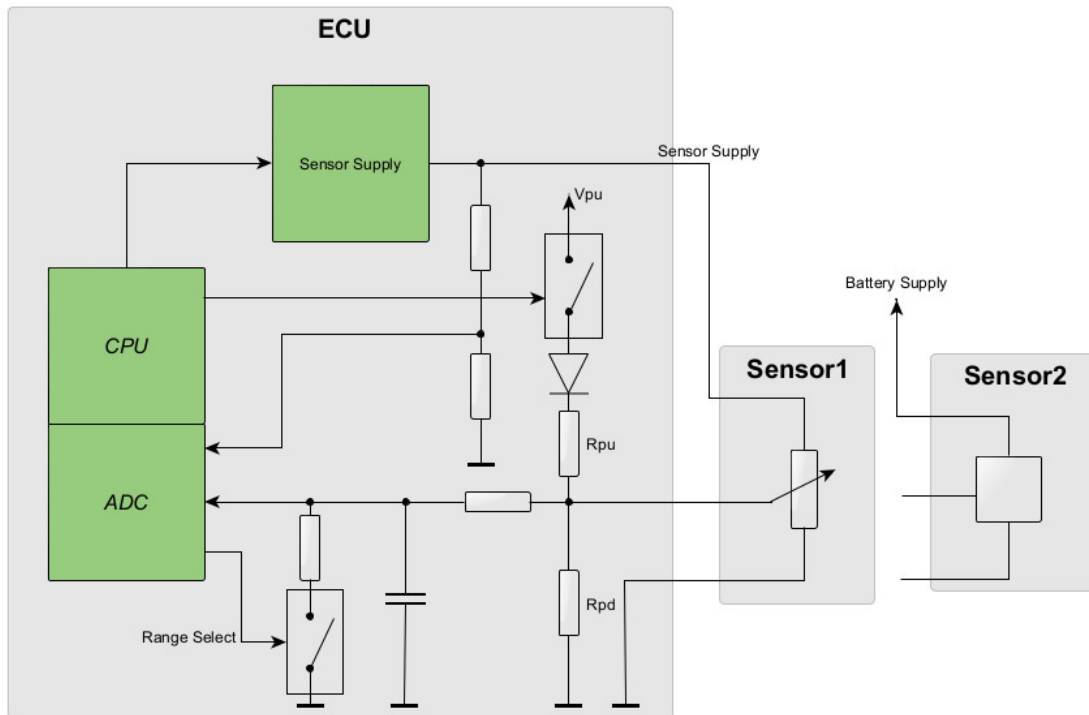


Figure 28: Analog voltage input (sensor 1 RAT_5V, sensor 2 ABS_5V or ABS_32V)

Functional description

Multipurpose analog inputs with 12-bit resolution.

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.

Maximum ratings

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

Table 50: Analog input 2-mode maximum ratings

¹ It is recommended to not connect a voltage supply higher than the configured amount (5 or 32 V).

11.7.1 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
R_{pd}	Pull-down resistor	196	214	k Ω
R_{pu}	Pull-up resistor	13.2	14.0	k Ω
τ_{in}	Input low pass filter	2.7	3.5	ms
	Resolution		12	bit
V_{tol-0}	Zero reading error ^{1 2}	-10	10	mV
V_{tol-0}	Zero reading error ²	-15	15	mV
V_{tol-p}	Proportional error ^{1 2}	-0.4	0.4	%
V_{tol-p}	Proportional error ²	-0.6	0.6	%
LSB	Nominal value of 1 LSB		1.22	mV
V_{in}	Input voltage measurement range	0	5	V

Table 51: Characteristics of Analog input 2-mode analog voltage input 5 V

¹ $T_{ECU} = -40$ to $+85$ °C

² The total measurement error is the sum of zero reading error and the proportional error.

11. SPECIFICATION OF INPUTS AND OUTPUTS

32 V mode:

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
R_{pd}	Pull-down resistor	196	214	k Ω
R_{pu}	Pull-up resistor	13.2	14.0	k Ω
τ_{in}	Input low pass filter	2.2	2.8	ms
	Resolution		12	bit
V_{tol-0}	Zero reading error ^{1 2}	-50	50	mV
V_{tol-0}	Zero reading error ²	-80	80	mV
V_{tol-p}	Proportional error ^{1 2}	-2	2	%
V_{tol-p}	Proportional error ²	-2.5	2.5	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range	0	32	V

Table 52: Characteristics of Analog input 2-mode analog voltage input 32 V

¹ $T_{ECU} = -40$ to $+85$ °C

² The total measurement error is the sum of zero reading error and the proportional error.

11.7.2 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
R_{pd}	Pull-down resistor	196	214	k Ω
R_{pu}	Pull-up resistor	13.2	14.0	k Ω
τ_{in}	Input low pass filter	2.2	3.5	ms
	Resolution		12	bit
V_{il}	Input voltage for low level ¹		<x>	V
V_{ih}	Input voltage for high level ¹	<x>		V
V_{pu}	Pull-up voltage (5 V mode)	4.4	4.7	V
V_{pu}	Pull-up voltage (32 V mode)	4.4	4.7	V

Table 53: Analog input 2-mode digital input

11. SPECIFICATION OF INPUTS AND OUTPUTS

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

11.8 Timer input/SENT

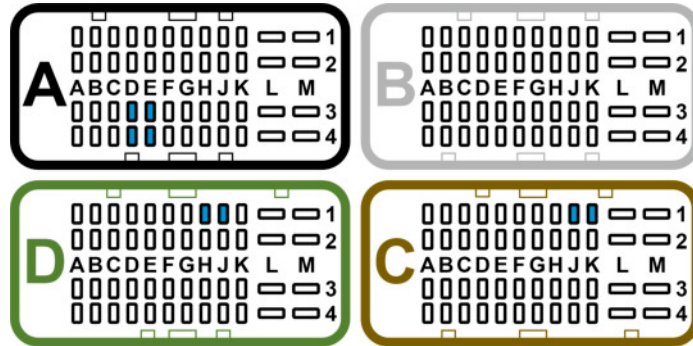


Figure 29: TIN/SENT pinout

Connector	Pin	Pin name	Variant
A	D4	Timer_SENT_00	All
A	D3	Timer_SENT_01	All
A	E4	Timer_SENT_02	All
A	E3	Timer_SENT_03	All
D	J1	Timer_SENT_04	All
D	H1	Timer_SENT_05	All
C	K1	Timer_SENT_06	All
C	J1	Timer_SENT_07	All

Table 54: 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

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

11. SPECIFICATION OF INPUTS AND OUTPUTS

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 SPC⁵ 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™.

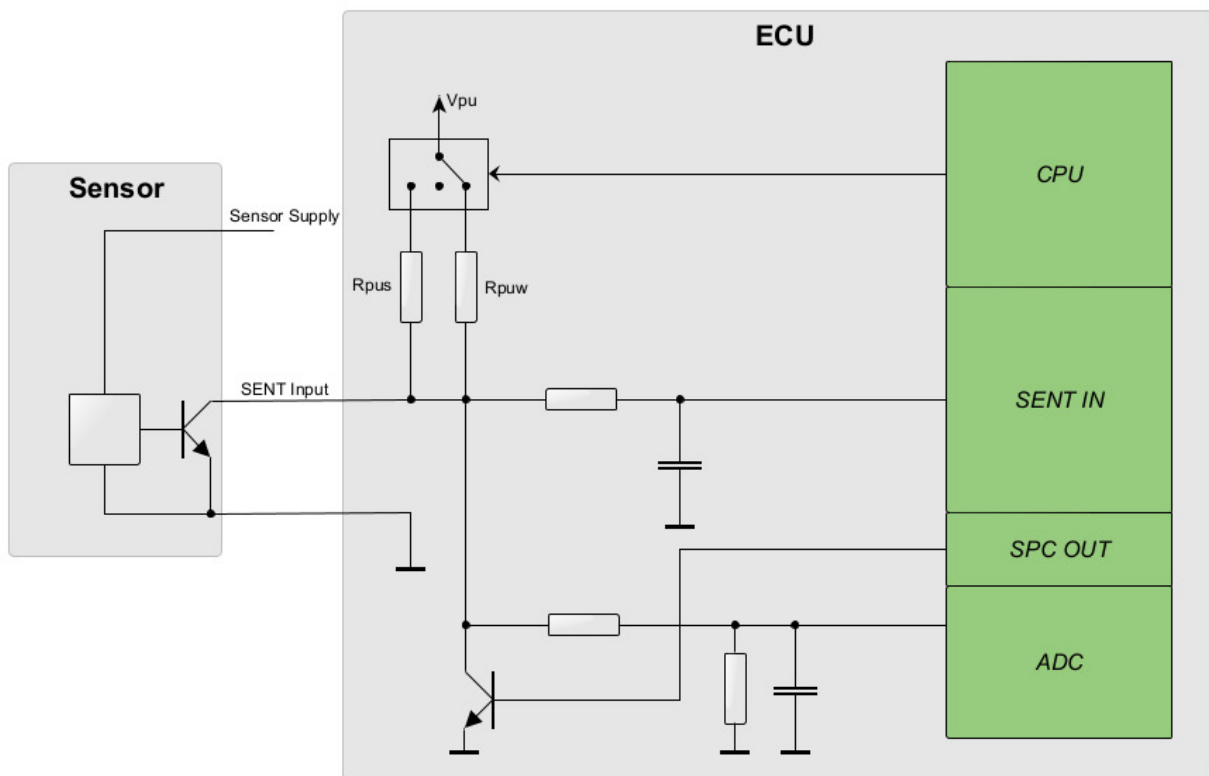


Figure 30: Digital input for frequency/timing measurement with NPN-type 2-pole sensor

5. Short PWM Code

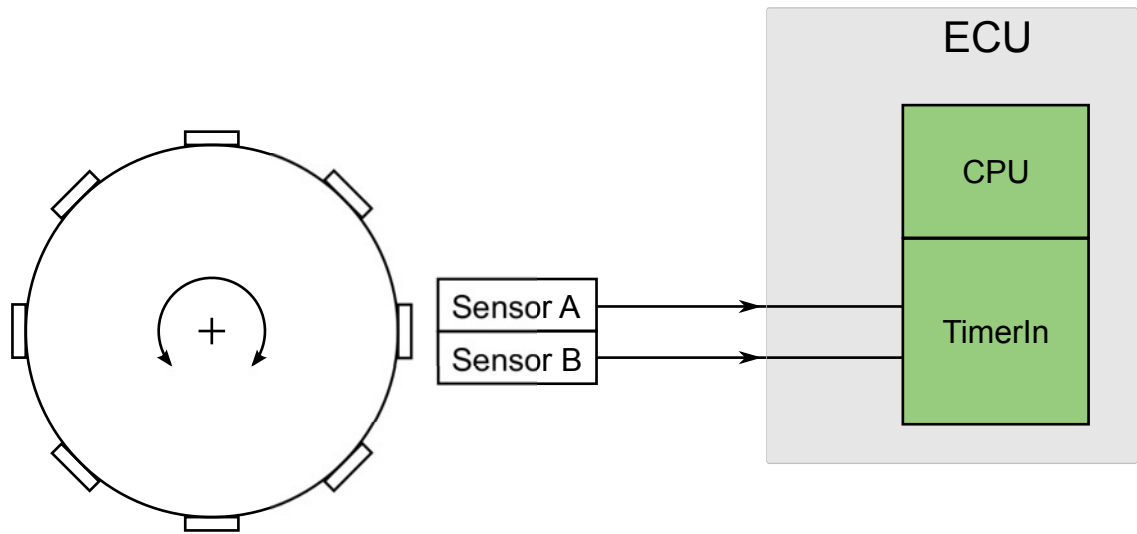


Figure 31: Digital input pair for encoder and direction

Maximum ratings

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

Table 55: TIN/SENT maximum ratings

Characteristics

Symbol	Parameter	Min	Max	Unit
R_{puw}	Weak pull-up resistor	12	12.4	k Ω
R_{pus}	Strong pull-up resistor	2.16	2.24	k Ω
V_{pu}	Pull-up voltage (open load) ¹	4.4	4.7	V
τ_{in}	Input low pass filter	1.9	2.1	μ s
f_{in}	input frequency range	0.1	20k	Hz
τ_{min}	Minimum on/off time to be measured	20		μ s
V_{il}	Input voltage for low level		2	V
V_{ih}	Input voltage for high level	3.2		V
t_{res}	Timer resolution	0.2	1	μ s

Table 56: TIN/SENT characteristics

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

11.8.1 Analog input



Selected via function ADC_VIN_32V.

Symbol	Parameter	Min	Max	Unit
	Resolution		12	bit
R_{puw}	Weak pull-up resistor	12	12.4	k Ω
R_{pus}	Strong pull-up resistor	2.16	2.24	k Ω
V_{pu}	Pull-up voltage (open load) ²	4.4	4.7	V
V_{in}	Input voltage range	0	32	V
τ_{in}	Input low pass filter (analog path)	4.3	5.7	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 57: *TIN/SENT analog 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.

11.8.2 Digital input



Selected via function DIN_32V.

Symbol	Parameter	Min	Max	Unit
R_{puw}	Weak pull-up resistor	12	12.4	k Ω
R_{pus}	Strong pull-up resistor	2.16	2.24	k Ω
V_{pu}	Pull-up voltage (open load) ¹	4.4	4.7	V
T_{in}	Input low pass filter	4.3	5.7	ms
V_{il}	Input voltage for low level ²		<x>	V
V_{ih}	Input voltage for high level ^{2 3}	<x>		V

Table 58: *TIN/SENT digital input*

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

² Values <x> are configured by the application software.

³ The input voltage may go up to 32 V, but must never exceed the battery supply voltage.

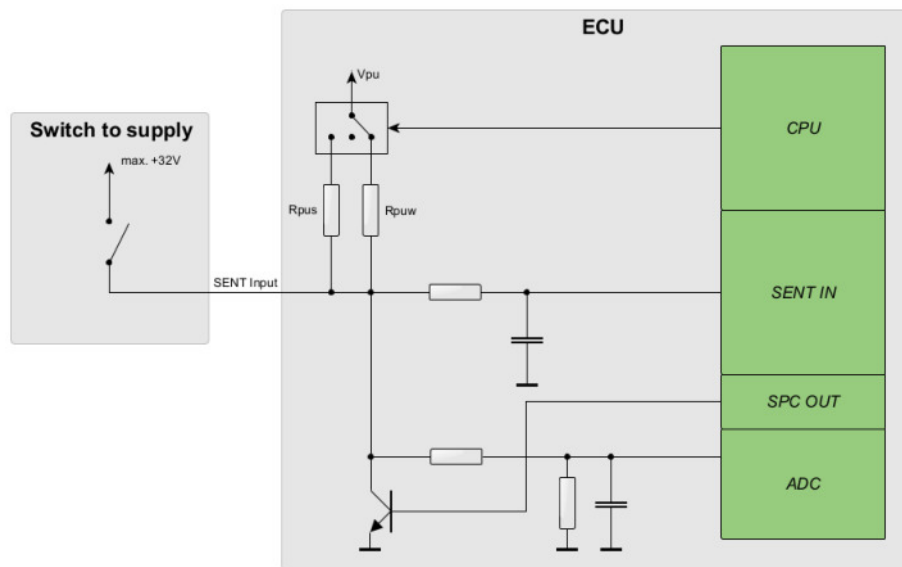


Figure 32: Digital input for switch connected to (battery) supply voltage

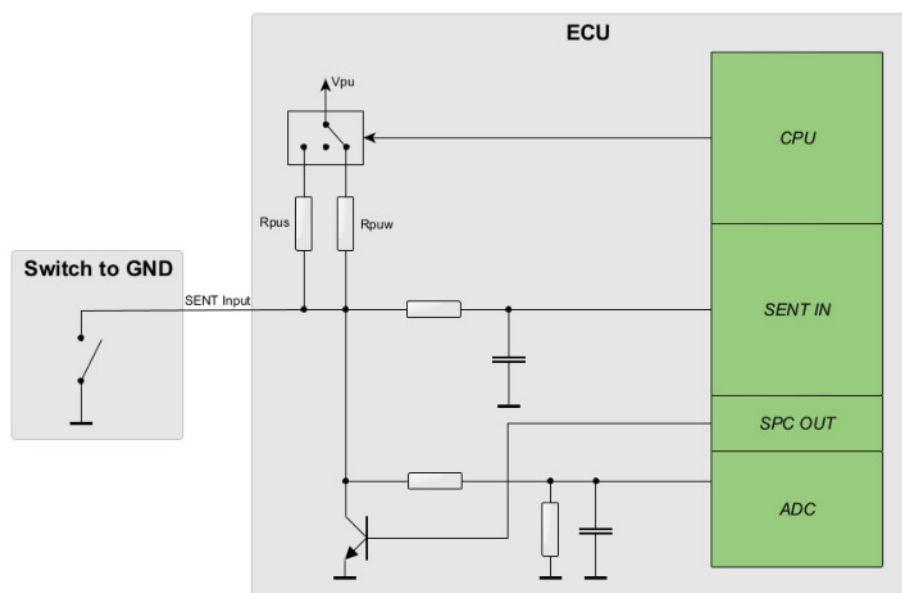


Figure 33: Digital input for switch connected to BAT-

11.9 Timer input/current loop

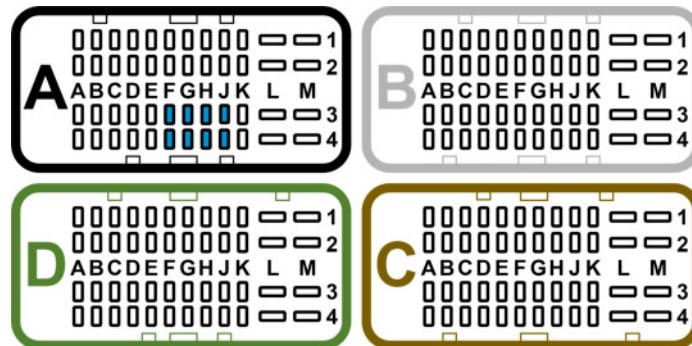


Figure 34: TIN/CL pinout

Connector	Pin	Pin name	Variant
A	F4	Timer_CL_00	All
A	F3	Timer_CL_01	All
A	G4	Timer_CL_02	All
A	G3	Timer_CL_03	All
A	H4	Timer_CL_04	All
A	H3	Timer_CL_05	All
A	J4	Timer_CL_06	All
A	J3	Timer_CL_07	All

Table 59: TIN/CL pin group

Supported functions

- TIN_PWD_CL (main)
- TIN_INC
- TIN_CNT
- ADC_VIN_32V
- ADC_CIN_CL_25mA
- DIN_32V

Functional description

Timer inputs can be used as digital (7/14 mA) current loop sensor inputs. See figure 35.

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:

11. SPECIFICATION OF INPUTS AND OUTPUTS

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 60: TIN/CL maximum ratings

Characteristics

Symbol	Parameter	Min	Max	Unit
R_{cs}	Current sense resistor ¹	89	98	Ω
τ_{in}	Input low pass filter	1.6	1.8	μs
f_{in}	Input frequency range	0.1	20k	Hz
t_{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
R_{pud}	Pull-up/pull-down resistor (voltage mode)	7.5	10	k Ω
V_{pu}	Pull-up voltage (open load) (voltage mode) ⁴	4.25	4.8	V
V_{in}	Input voltage range (voltage mode)	0	32	V
τ_{in}	Input low pass filter (voltage mode)	1.6	1.8	μs
V_{il}	Input voltage for low level (voltage mode)		2	V
V_{ih}	Input voltage for high level (voltage mode)	3		V

Table 61: TIN/CL characteristics

¹With software setting for digital (7/14 mA) current loop sensor inputs (ABS-type sensors).

²Fault detection window for defect digital (7/14 mA) current loop sensor inputs with too low current.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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.

⁴ This is the input voltage with pull-up setting, without the sensor connected.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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	k Ω
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)	4.3	5.7	ms
$V_{\text{tol-0}}$	Zero reading error ^{1 3}	-50	50	mV
$V_{\text{tol-0}}$	Zero reading error ³	-80	80	mV
$V_{\text{tol-p}}$	Proportional error ^{1 3}	-3	3	%
$V_{\text{tol-p}}$	Proportional error ³	-4	4	%
LSB	Nominal value of 1 LSB		8	mV

Table 62: TIN/CL – characteristics of analog voltage input

Characteristics of analog current input

Symbol	Parameter	Min	Max	Unit
R_{cs}	Current sense resistor	89	98	Ω
I_{in}	Input current range	0	25	mA
τ_{in}	Input low pass filter (analog path)	4.3	5.7	ms
$I_{\text{tol-0}}$	Zero reading error ^{1 3}	-85	85	μA
$I_{\text{tol-0}}$	Zero reading error ³	-135	135	μA
$I_{\text{tol-p}}$	Proportional error ^{1 3}	-2	2	%
$I_{\text{tol-p}}$	Proportional error ³	-2.5	2.5	%
LSB	Nominal value of 1 LSB		13.4	μA

Table 63: TIN/CL – characteristics of analog current input

¹ $T_{\text{ECU}} = -40$ 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.

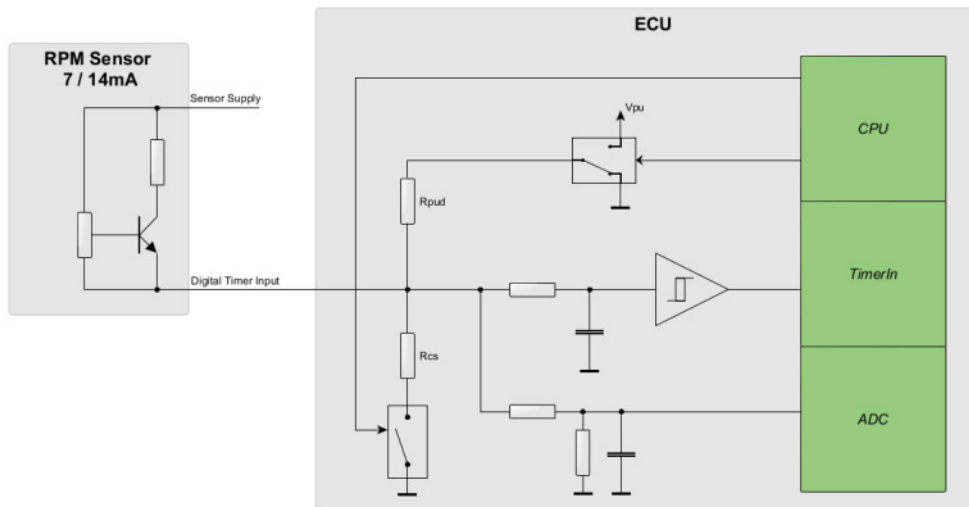


Figure 35: Digital input for frequency measurement with ABS-type 7/14 mA, 2 pole sensor

11.9.2 Digital input



Selected via function DIN_32V.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	15	25	nF
T_{in}	Input low pass filter	4.4	5.7	ms
R_{pu}	Pull-up resistor	4.6	4.8	k Ω
V_{pu}	Pull-up voltage	4.2	4.6	V
V_{il}	Input voltage for low level ¹		<x>	V
V_{ih}	Input voltage for high level ^{1 2}	<x>		V

Table 64: TIN/CL – 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 the battery supply voltage.

11.10 High-side PWM output

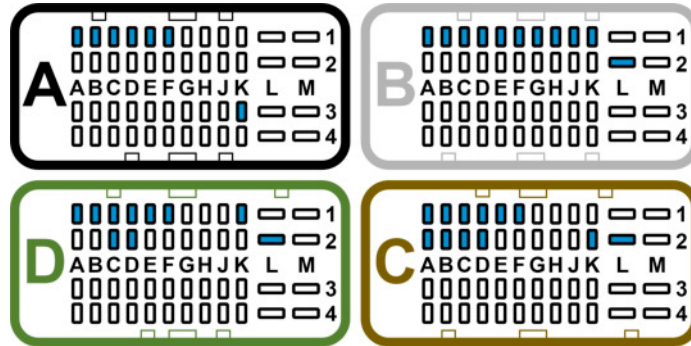


Figure 36: PWM HS 4A+CM+FM pinout

Connector	Pin	Pin name	Function	Ext./Second. Shut-off	Power stage
A	A1	HS_OUT_A02	PWM_HS_4A_FC	A	a
A	B1	HS_OUT_A03	PWM_HS_4A_FC	A	a
A	D1	HS_OUT_A04	PWM_HS_4A_FC	A	b
A	C1	HS_OUT_A05	PWM_HS_4A_FC	A	b
A	F1	HS_OUT_A06	PWM_HS_4A_FC	A	c
A	E1	HS_OUT_A07	PWM_HS_4A_FC	A	c
C	A1	HS_OUT_A08	PWM_HS_4A_FC	A	d
C	A2	HS_OUT_A09	PWM_HS_4A_FC	A	d
C	D1	HS_OUT_A10	PWM_HS_4A	A	e
C	C1	HS_OUT_A11	PWM_HS_4A	A	e
C	F1	HS_OUT_A12	PWM_HS_4A	A	f
C	E1	HS_OUT_A13	PWM_HS_4A	A	f
C	L2	HS_OUT_A14	PWM_HS_4A	A	g
C	K2	HS_OUT_A15	PWM_HS_4A	A	g
B	A1	HS_OUT_B02	PWM_HS_4A_FC	B	h
A	K3	HS_OUT_B03	PWM_HS_4A_FC	B	h
B	C1	HS_OUT_B04	PWM_HS_4A_FC	B	i
B	B1	HS_OUT_B05	PWM_HS_4A_FC	B	i
B	E1	HS_OUT_B06	PWM_HS_4A_FC	B	j
B	D1	HS_OUT_B07	PWM_HS_4A_FC	B	j
B	G1	HS_OUT_B08	PWM_HS_4A_FC	B	k
B	F1	HS_OUT_B09	PWM_HS_4A_FC	B	k
B	J1	HS_OUT_B10	PWM_HS_4A	B	l

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B	H1	HS_OUT_B11	PWM_HS_4A	B	l
B	L2	HS_OUT_B12	PWM_HS_4A	B	m
B	K1	HS_OUT_B13	PWM_HS_4A	B	m
D	D2	HS_OUT_B14	PWM_HS_4A	B	n
D	C2	HS_OUT_B15	PWM_HS_4A	B	n
C	B1	HS_OUT_C02	PWM_HS_4A	C	o
C	B2	HS_OUT_C03	PWM_HS_4A	C	o
C	D2	HS_OUT_C04	PWM_HS_4A	C	p
C	C2	HS_OUT_C05	PWM_HS_4A	C	p
D	B1	HS_OUT_C06	PWM_HS_4A	C	q
D	A1	HS_OUT_C07	PWM_HS_4A	C	q
D	D1	HS_OUT_C08	PWM_HS_4A	C	r
D	C1	HS_OUT_C09	PWM_HS_4A	C	r
D	F1	HS_OUT_C10	PWM_HS_4A	C	s
D	E1	HS_OUT_C11	PWM_HS_4A	C	s
D	L2	HS_OUT_C12	PWM_HS_4A	C	t
D	K1	HS_OUT_C13	PWM_HS_4A	C	t

Table 65: PWM HS 4A+CM+FM pin groups

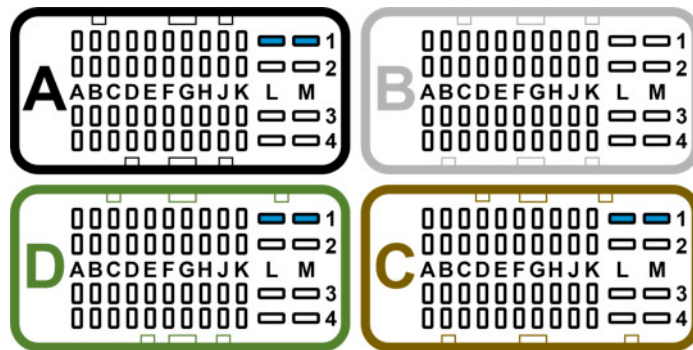


Figure 37: PWM HS 8A+CM+FM pinout

Connector	Pin	Pin name	Variant	Ext./Second. Shut-off	Power stage
A	L1	HS_OUT_A00	All	A	u
A	M1	HS_OUT_A01	All	A	u
D	L1	HS_OUT_B00	All	B	v
D	M1	HS_OUT_B01	All	B	v
C	L1	HS_OUT_C00	All	C	w
C	M1	HS_OUT_C01	All	C	w

Table 66: 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 65
 - available for 24 out of 40 pins, see table 65
- PWM_HS_4A_FC (main)
 - available for PWM HS 4A+CM+FM pin groups only, see table 65
 - available for 16 out of 40 pins, see table 65
- PWM_HS_8A (main)
 - available for PWM HS 8A+CM+FM pin group only, see table 66
- 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, the voltage monitor, or the main CPU can disable the output stage (off state). Furthermore, the application software could also trigger disabling the output stages.

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.

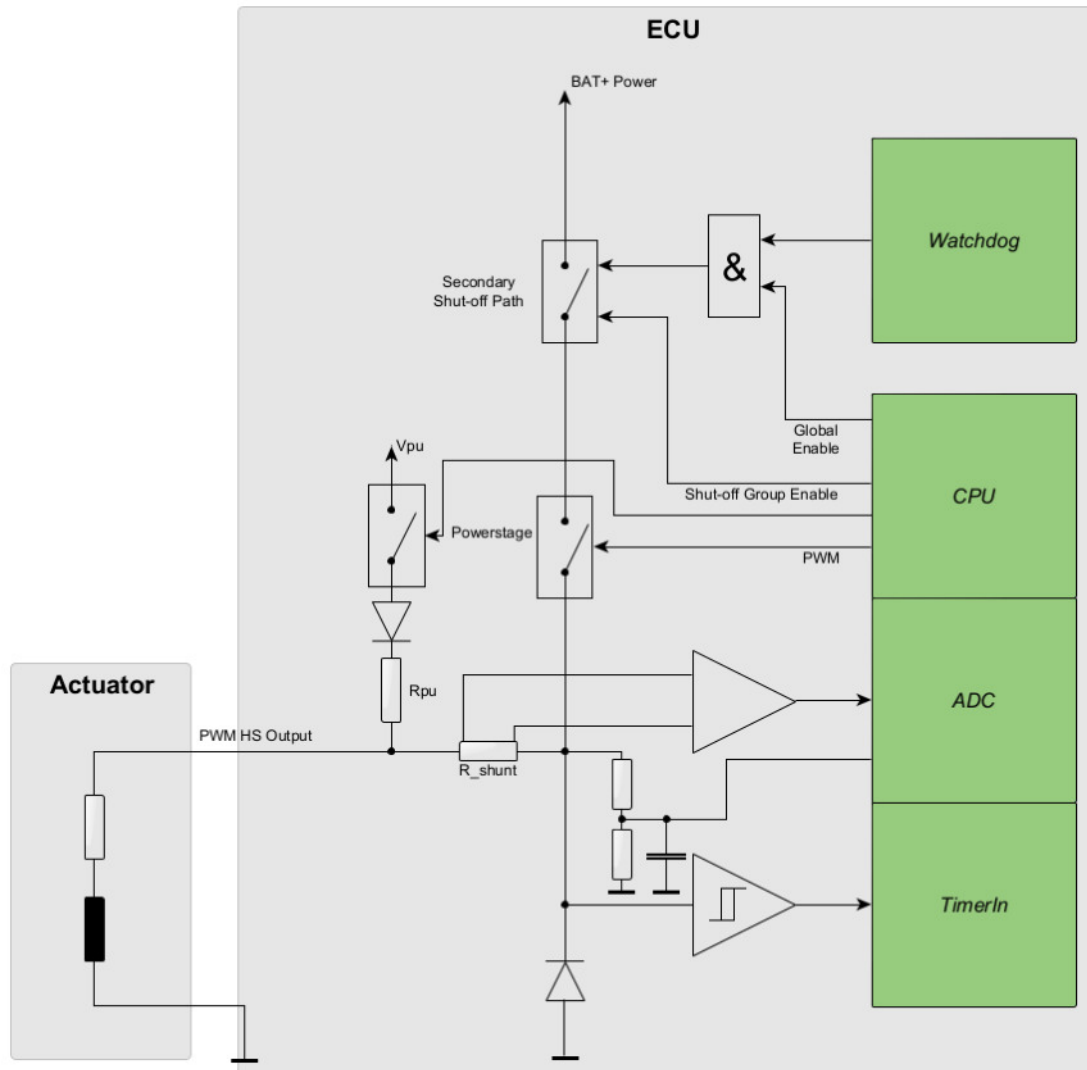


Figure 38: High-side output stage with PWM functionality

Mutually exclusive mode

The TTC 2700 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 below.

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 tables 68 and 69.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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. The double-channel pairs are next to each other in ascending order, starting from the first pin (even & odd), e.g., HS_OUT_A02 and HS_OUT_A03, HS_OUT_A04 and HS_OUT_A05, and so on, are pairs. See tables 65 and 66 (pin groups) 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 $3 \text{ A} \times 2 \times 0.85 = 5.1 \text{ A}$). 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.

Maximum ratings

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

Table 67: High-side PWM output maximum ratings

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

11.10.1 High-side PWM outputs 4 A/8 A

i Selected via functions PWM_HS_4A and PWM_HS_8A (see tables 65 and 66, 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	k Ω
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		μ s
$T_{min-off}$	Minimum off time ²	200		μ s
R_{on}	On-resistance		150	m Ω
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

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I_{peak}	Peak load current ⁵		6	A
$R_{\text{load_min}}$	Minimum coil resistance (12 V) ⁶	2		Ω
$R_{\text{load_min}}$	Minimum coil resistance (24 V) ⁶	4		Ω
$R_{\text{load_max}}$	Maximum load resistance ⁷		1	k Ω
$C_{\text{load_max}}$	Maximum load capacitance ⁸		200	μF
$I_{\text{tol-0}}$	Zero reading error ^{3 9 10}	-20	20	mA
$I_{\text{tol-0}}$	Zero reading error ^{9 10}	-30	30	mA
$I_{\text{tol-p}}$	Proportional error ^{3 10}	-2	2	%
$I_{\text{tol-p}}$	Proportional error ^{9 10}	-2.5	2.5	%
LSB	Nominal value of 1 LSB		2.5	mA
$f_{\text{g_LP}}$	Cut-off frequency of 2nd low pass filter ¹¹	60	86	Hz
$f_{\text{g_LP_LC}}$	Cut-off frequency of 2nd low pass filter ¹¹	240	360	Hz

Table 68: High-side PWM output 4 A – characteristics

¹ Not all values for PWM frequency are possible, refer to the I/O Driver Manuals [17, 19] for supported frequency values.

² When the output is configured as safety-critical (instead of zero).

³ $T_{\text{ECU}} = -40$ 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: $I_{\text{tol}} = \pm(I_{\text{tol-p}} \cdot I_{\text{load}} + I_{\text{tol-0}})$

¹¹ An active low pass filter (2nd 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.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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	k Ω
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		μ s
$T_{min-off}$	Minimum off time ²	200		μ s
R_{on}	On-resistance		75	m Ω
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 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	k Ω
I_{tol-0}	Zero reading error ^{3 8 9}	-20	20	mA
I_{tol-0}	Zero reading error ^{8 9}	-30	30	mA
I_{tol-p}	Proportional error ^{3 9}	-2	2	%
I_{tol-p}	Proportional error ^{8 9}	-2.5	2.5	%
LSB	Nominal value of 1 LSB		5	mA
f_{g_LP}	Cut-off frequency of 2nd low pass filter ¹⁰	60	86	Hz

Table 69: High-side PWM output 8 A – characteristics

¹Not all values for PWM frequency are possible, see section PWM - Pulse Width Modulation driver of the variant I/O Driver Manual [17, 19] for supported frequency values.

²When the output is configured as safety-critical (instead of zero).

³ $T_{ECU} = -40$ to $+85$ °C

⁴For 12 V systems

⁵For $t < 180$ ms

⁶Additionally to observing the maximum load current limit, there is also a minimum load resistance limit, depending on the battery supply voltage.

⁷Exceeding this value will trigger open load detection.

⁸The 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.

⁹The total error (I_{tol}) is the sum of proportional error and zero reading error: $I_{tol} = \pm(I_{tol-p} \cdot I_{load} + I_{tol-0})$

¹⁰An active low pass filter (2nd 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.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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 BAT-, 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 BAT-	Short to BAT+
$0\% < X < 100\%$	x	x	x	x

Table 70: PWM-operated high-side output

x = detected

– = not detected

- **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 BAT-. 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 BAT-, 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 BAT-	Short to BAT+
on	x	x	x	x
off	x	x	–	x

Table 71: Digitally operated high-side output

x = detected

– = not detected

11.10.2 Analog input



Selected via function ADC_VIN_32V.

Characteristics of analog input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	15	25	nF
τ_{in}	Input low pass filter	4.3	5.7	ms
R_{pu}	Pull-up resistor	4.6	4.8	k Ω
V_{pu}	Pull-up voltage	4.2	4.6	V
	Resolution		12	bit
V_{tol-0}	Zero reading error ^{1 2}	-50	50	mV
V_{tol-0}	Zero reading error ²	-80	80	mV
V_{tol-p}	Proportional error ^{1 2}	-3	3	%
V_{tol-p}	Proportional error ²	-4	4	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range ³	0	32	V

Table 72: High-side PWM output – characteristics of analog 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 The input voltage may go up to 32 V but must never exceed the battery supply voltage.

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 this alternative input function.

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	ms
R_{pu}	Pull-up resistor	4.6	4.8	k Ω
V_{pu}	Pull-up voltage	4.2	4.6	V
V_{il}	Input voltage for low level ¹		<x>	V
V_{ih}	Input voltage for high level ^{1 2}	<x>		V

Table 73: High-side PWM output – characteristics of digital input

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

²The input voltage may go up to 32 V, but must never exceed the battery supply voltage.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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 this alternative input function.

Characteristics of timer input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
T_{in}	Input low pass filter	2	2.4	μs
R_{pu}	Pull-up resistor	4.6	4.8	k Ω
V_{pu}	Pull-up voltage	4.2	4.6	V
f_{max_oc}	Maximum input frequency ¹		1.5	kHz
f_{max_pp}	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		2.5	V
V_{ih}	Input voltage for high level ⁴	3.75		V

Table 74: High-side PWM output – characteristics of timer input

¹With open collector sensor output

²With push-pull sensor output stage

³Due to the dynamic range of the timer, there is a minimum frequency when a timer overflow occurs. At lower frequencies, the status will remain as "measurement in progress". Signal timeouts as such have to be detected by the application software.

⁴The input voltage may go up to 32 V but must never exceed the battery supply voltage.

11.11 Low-side PWM output

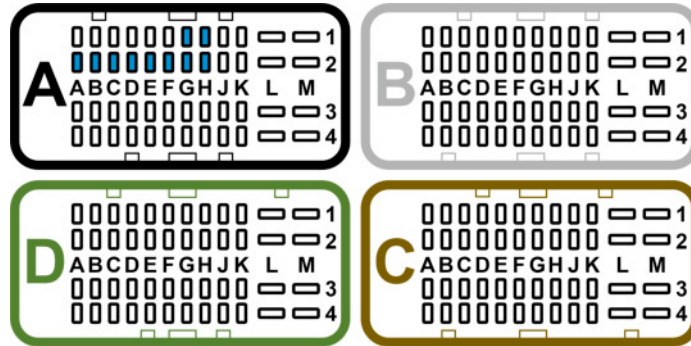


Figure 39: PWM LS 4A+CM pinout

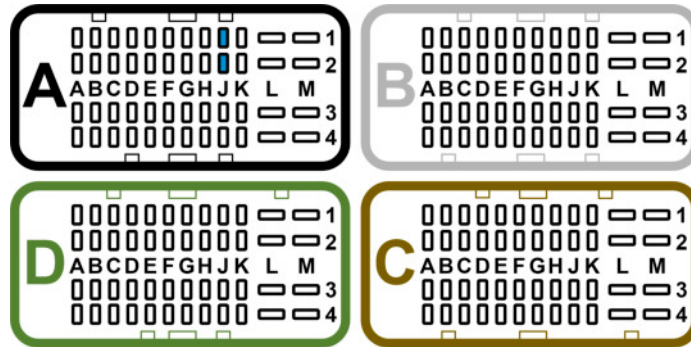


Figure 40: PWM LS 4A+CM+FM pinout

Connector	Pin	Pin name	Variant
A	B2	LS_00	TTC 2785
A	A2	LS_01	TTC 2785
A	C2	LS_02	TTC 2785
A	D2	LS_03	TTC 2785
A	E2	LS_04	TTC 2785
A	F2	LS_05	TTC 2785
A	G1	LS_06	TTC 2785
A	G2	LS_07	TTC 2785
A	H1	LS_08	TTC 2785
A	H2	LS_09	TTC 2785
A	J1	LS_10 ¹	TTC 2785
A	J2	LS_11 ¹	TTC 2785

Table 75: PWM LS 4A+CM and PWM LS 4A+CM+FM pin groups

11. SPECIFICATION OF INPUTS AND OUTPUTS

Supported functions

- PWM_LS_4A (main)
- ADC_RAT_5V
- ADC_VIN_5V
- ADC_VIN_32V
- DIN_5V
- DIN_32V
- TIN_PWD
 - ¹Available for 2 out of 12 pins, see table 75.
 - Not supported by software.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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 due to bad accuracy. 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.

Use case and functional behavior

The low-side outputs have several use-cases, including:

- Third level of safety switch-off
- High-frequency PWM for motor control (4 kHz)
- stand-alone PWM

 The current measurement of the low-side outputs can only measure the current in the conduction phase of the switch, not the current through the freewheeling diode. This is only applicable to stand-alone PWM.

As a safety switch, the low-side switch is permanently on, except if an error occurs. Therefore, the load current is completely measured, and no freewheeling phase exists. This measurement is primarily intended as a plausibility check to detect short to BAT- or short to BAT+ failures. The primary measurement and current control is done by the high-side current measurement.

For motor control, an H-bridge configuration is used, and the primary measurement and current control is also done by the high-side current measurement of the diagonally opposed high-side switch.

For stand-alone PWM, an estimation is required to determine the current through the freewheeling diode. The conservative estimation assumes Continuous Conduction Mode (CCM), where the inductance is considered large enough to prevent the current in the freewheeling phase from dropping to zero. The average current in the freewheeling phase is equal to the average current in the conduction phase. In that case, the measured current, averaged only over the conduction phase, is divided by the PWM duty cycle to estimate the load current. If the load has low inductance or is purely resistive, the current drops to zero in the non-conduction phases, and the true current is less than the indicated measured current. This is not suitable for accurate current control.

11. SPECIFICATION OF INPUTS AND OUTPUTS

Maximum ratings

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

Table 76: 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 (supported 5 V functions)	9.8	10.2	k Ω
V_{pu}	Pull-up voltage (supported 5 V functions)	4.9	5.1	V
R_{pu}	Pull-up resistor (supported 32 V functions)	6.1	6.34	k Ω
V_{pu}	Pull-up voltage (supported 32 V functions)	3	3.2	V
R_{on}	On-resistance		100	m Ω
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}	-3.5	3.5	%
I_{tol-p}	Proportional error ³	-4	4	%
f_{PWM}	PWM frequency ⁴	50	1k	Hz
f_{PWM}	short time PWM frequency ^{4 5}	50	4k	Hz

Table 77: 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 [17, 19] 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.

Characteristics of analog voltage input

5 V mode:

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
T_{in}	Input low pass filter	2.7	3.5	ms
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	k Ω
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
	Resolution		12	bit
V_{tol-0}	Zero reading error ^{1 2}	-10	10	mV
V_{tol-0}	Zero reading error ²	-15	15	mV
V_{tol-p}	Proportional error ^{1 2}	-0.4	0.4	%
V_{tol-p}	Proportional error ²	-0.6	0.6	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range	0	5	V

Table 78: Low-side PWM output – characteristics of analog voltage input – 5 V mode

¹ $T_{ECU} = -40$ to $+85$ °C

² The total measurement error is the sum of zero reading error and the proportional error.

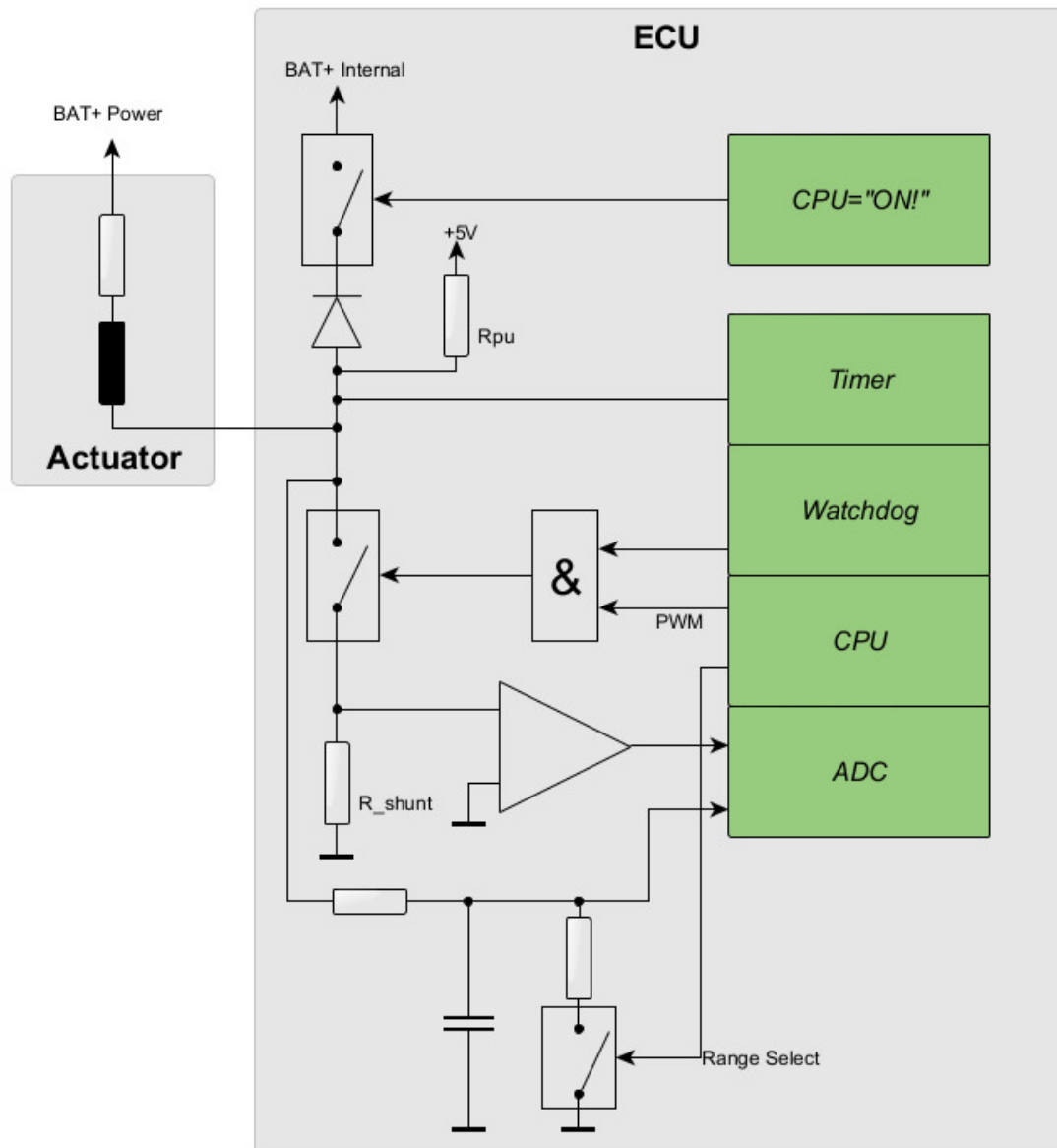


Figure 41: Low-side output stage with PWM functionality

11. SPECIFICATION OF INPUTS AND OUTPUTS

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	k Ω
V_{pu}	Pull-up voltage	3	3.2	V
	Resolution		12	bit
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}	-2	2	%
V_{tol-p}	Proportional error ³	-2.5	2.5	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range ²	0	32	V

Table 79: Low-side PWM output – 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 the battery supply voltage.

³ The total measurement error is the sum of zero reading error and the proportional error.

11.11.2 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	k Ω
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	k Ω
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
	Resolution		12	bit
V_{il}	Input voltage for low level ¹		<x>	V
V_{ih}	Input voltage for high level ¹	<x>		V

Table 80: Low-side PWM output – characteristics of digital input

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

11.11.3 Timer input



Selected via function TIN_PWD.

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 (5 V mode)	9.8	10.2	k Ω
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	k Ω
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
f_{max_oc}	Maximum input frequency ¹		1.5	kHz
f_{max_pp}	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		2.5	V
V_{ih}	Input voltage for high level ⁴	3.75		V

Table 81: Low-side PWM output – characteristics of timer input

¹With open collector sensor output

²With push-pull sensor output stage

³Due to the dynamic range of the timer, there is a minimum frequency when a timer overflow occurs. At lower frequencies, the status will remain as "measurement in progress". Signal timeouts as such have to be detected by the application software.

⁴The input voltage may go up to 32 V but must never exceed the battery supply voltage.

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

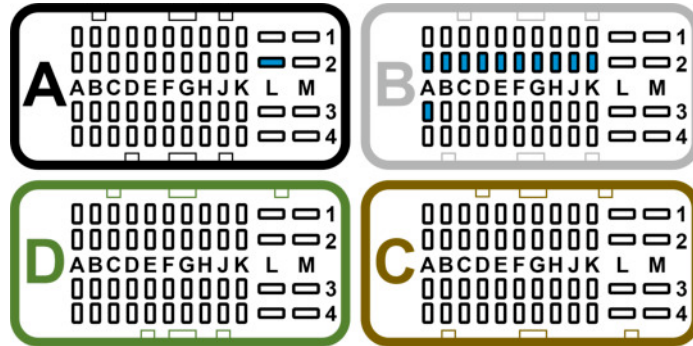


Figure 42: DOP HS 4A+CS/LPO pinout

Connector	Pin	Pin name	Variant	Power stage
B	B2	HS_OUT_00	All	x
B	A2	HS_OUT_01	All	x
B	D2	HS_OUT_02	All	y
B	C2	HS_OUT_03	All	y
B	F2	HS_OUT_04 ¹	All	z
B	E2	HS_OUT_05 ¹	All	z
B	H2	HS_OUT_06 ¹	All	aa
B	G2	HS_OUT_07 ¹	All	aa
B	K2	HS_OUT_08	All	ab
B	J2	HS_OUT_09	All	ab
B	A3	HS_OUT_10	All	ac
A	L2	HS_OUT_11	All	ac

Table 82: DOP HS 4A+CS/LPO pin group

Supported functions

- DOP_HS_4A (main)
- LPO_PVG
- LPO_VOUT_LP
- LPO_VOUT
 - ¹available for 4 out of 12 pins, see table 82
- LPO_ESO
- ADC_VIN_32V
- DIN_32V

11. SPECIFICATION OF INPUTS AND OUTPUTS

Functional description

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).

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), in order to reduce the 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_04 - HS_OUT_07) 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.

Mutually exclusive mode

The TTC 2700 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 below.

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. The double-channel pairs are next to each other in ascending order, starting from the first pin (even & odd), e.g., HS_OUT_00 and HS_OUT_01, HS_OUT_02 and HS_OUT_03, and so on, are pairs. See Table 82 (pin group) 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 $3 \text{ A} \times 2 \times 0.85 = 5.1 \text{ A}$). 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.

Maximum ratings

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

Table 83: DOP HS 4A+CS/LPO maximum ratings

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

11.12.1 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 11.12.2 for additional description, and figure 43 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 BAT-	Short to BAT+
on	x	–	x	–
off	x	x	–	x

Table 84: High-side digital PVG output – diagnostic functions

x = detected
– = 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	k Ω
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
R_{on}	On-resistance		150	m Ω
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}	-20	20	mA
I_{tol-0}	Zero reading error ³	-30	30	mA
I_{tol-p}	Proportional error ^{1 3}	-15	15	%
I_{tol-p}	Proportional error ³	-17	17	%

Table 85: 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.

11.12.2 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 2700 uses the BAT+ CPU pin as a reference voltage input. The principle schematic is shown in figure 43. The output is open loop controlled. The ADC input is for diagnostic purposes only and can be evaluated by the application software.

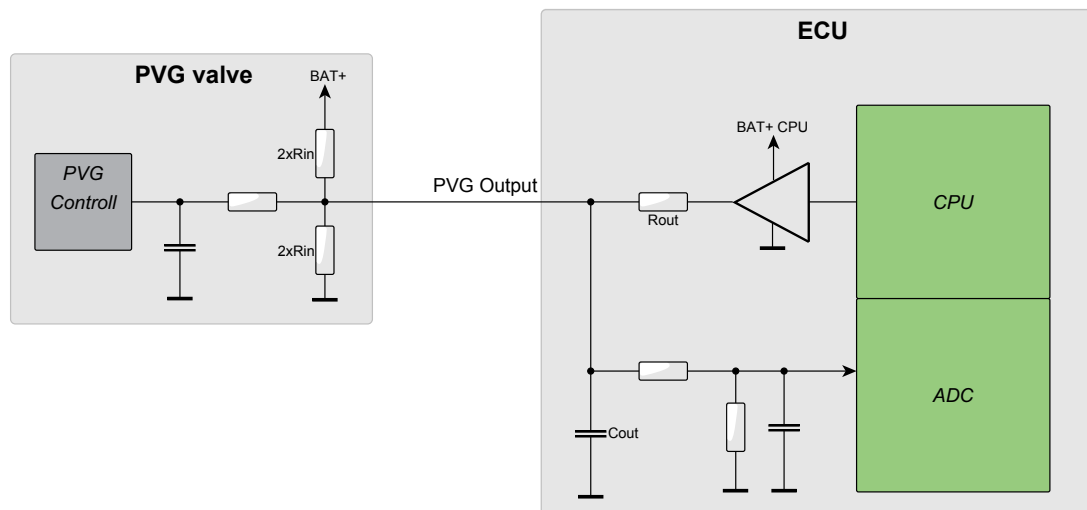


Figure 43: Output stage in PVG mode

11. SPECIFICATION OF INPUTS AND OUTPUTS

Characteristics of PVG

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin capacitance	430	530	nF
R_{out}	Output resistance	2.52	2.63	k Ω
V_{nom}	Nominal voltage range (BAT+ + 8 to 32 V nominal load resistance) ^{1 2}	$0.1 \cdot BAT+$	$0.9 \cdot BAT+$	V
V_{tol-0}	Zero reading error (BAT+ + 8 to 32 V nominal load resistance) ^{1 3 4}	-100	100	mV
V_{tol-p}	Proportional error (BAT+ + 8 to 32 V nominal load resistance) ^{1 3 4}	-2	2	%

Table 86: Characteristics of PVG

¹ $T_{ECU} = -40$ to $+85$ °C

² The standard PVG valves are controllable between 25 % and 75 % of 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.

⁴ The specified tolerances are only valid in the actual range of the PVG valves, which is 25% to 75% of BAT+. When it is 10% to 90% of BAT+, the tolerance can be twice as high.

11.12.3 V_{OUT} outputs



Selected via functions LPO_VOUT and LPO_VOUT_LP (see table 82 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.

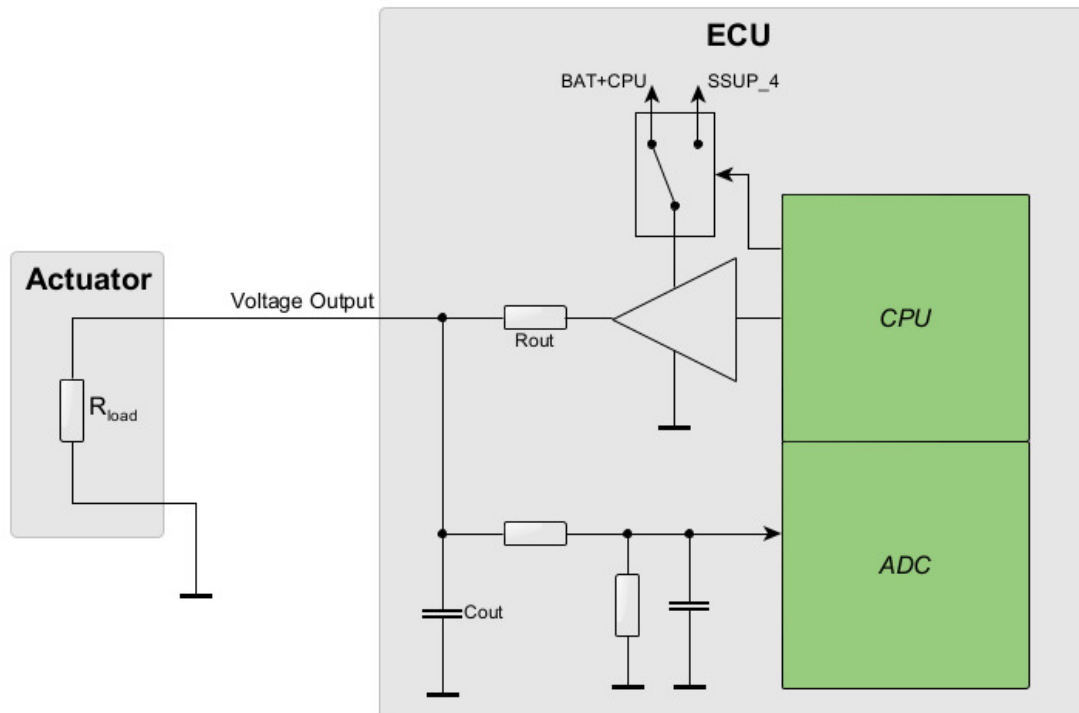


Figure 44: Output stage with standard and low-precision V_{OUT} function

NOTE

Figure 44 shows a switch between BAT+CPU (low-precision mode) and SSUP_4 (standard mode). For pins which support function LPO_VOUT, variable sensor supply can be used as 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	k Ω
R_{load}	Nominal load	10		k Ω
V_{nom}	Nominal voltage range (open load) (BAT+ = 8 to 32 V) ¹	0	$0.99 \cdot V_{SSUP_4}$	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 87: 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 (R_{OUT}) 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 $R_L = 10$ k Ω to BAT-, the open load voltage (V_{set}) must be set to 12.55 V ($V_{set} = V_{OUT} \frac{R_L + 2.55 \text{ k}}{R_L}$) 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_00 to HS_OUT_03 and HS_OUT_08 to HS_OUT_11 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 four pins can only be switched together.

If they are switched this way, higher voltages than SSUP4 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.

11.12.4 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 this alternative input function.

Characteristics of analog input

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

Table 88: High-side digital output – characteristics of analog 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 The input voltage may go up to 32 V, but must never exceed the battery supply voltage.

11.12.5 Digital input



Selected via function DIN_32V.

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

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	430	530	nF
T_{in}	Input low pass filter	9.5	12	ms
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	k Ω
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
	Resolution		12	bit
V_{il}	Input voltage for low level ¹		<x>	V
V_{ih}	Input voltage for high level ^{1 2}	<x>		V

Table 89: High-side digital output – characteristics of digital input

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

²The input voltage may go up to 32 V but must never exceed the battery supply voltage.

11.13 Low-side digital output

NOTE

TBD: Whole chapter - characteristics, figures and text - need to be UPDATED

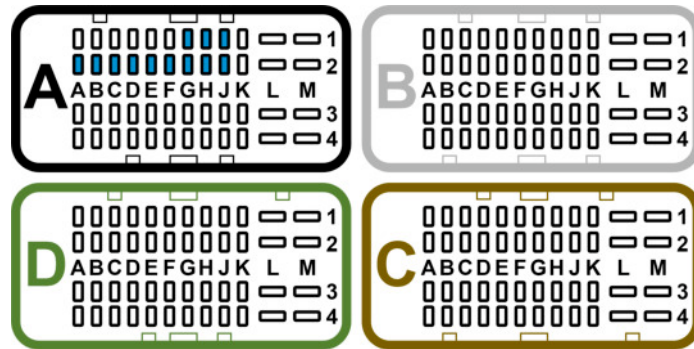


Figure 45: DOP LS 4A+CS pinout

Connector	Pin	Pin name	Variant
A	B2	LS_00	TTC 2740
A	A2	LS_01	TTC 2740
A	C2	LS_02	TTC 2740
A	D2	LS_03	TTC 2740
A	E2	LS_04	TTC 2740
A	F2	LS_05	TTC 2740
A	G1	LS_06	TTC 2740
A	G2	LS_07	TTC 2740
A	H2	LS_08	TTC 2740
A	H1	LS_09	TTC 2740
A	J2	LS_10	TTC 2740
A	J1	LS_11	TTC 2740

Table 90: DOP LS 4A+CS pin group

Supported functions

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

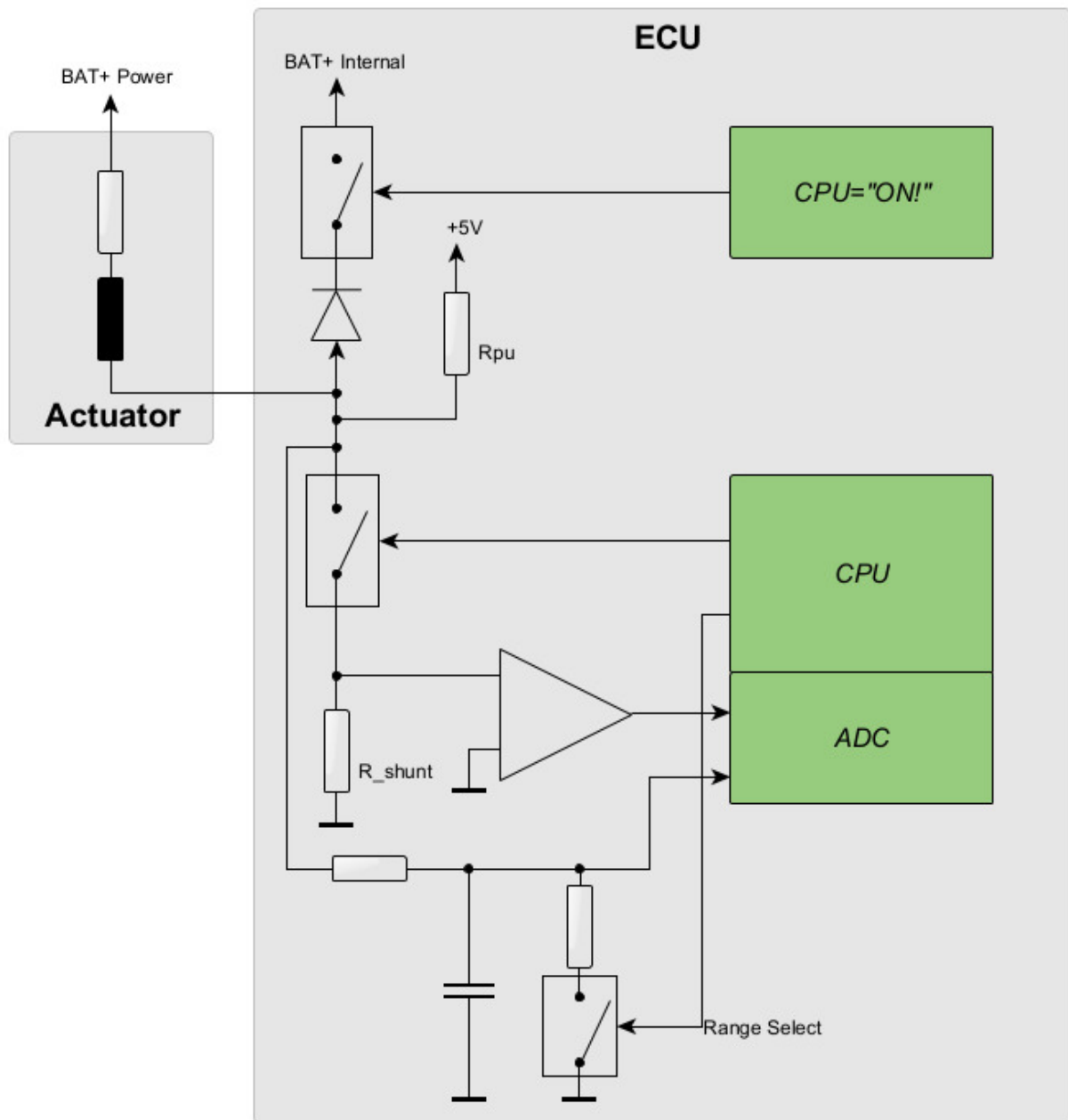


Figure 46: Low-side switch for resistive and inductive loads

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 due to bad accuracy. 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 $3 \text{ A} \times 2 \times 0.85 = 5.1 \text{ A}$). 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 BAT-	Short to BAT+
on	x	x	–	x
off	x	–	x	–

Table 91: Low-side digital output – diagnostic functions

x = detected

– = not detected

11. SPECIFICATION OF INPUTS AND OUTPUTS

Maximum ratings

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

Table 92: DOP LS 4A+CS 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)	9.2	9.6	k Ω
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	k Ω
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
R_{on}	On-resistance		5	m Ω
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}	-675	675	mA
I_{tol-0}	Zero reading error ³	-1120	1120	mA
I_{tol-p}	Proportional error ^{1 3}	-8	8	%
I_{tol-p}	Proportional error ³	-12	12	%

Table 93: DOP LS 4A+CS 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.

11.13.1 Analog inputs



Selected via functions 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
T_{in}	Input low pass filter	9.2	11.5	ms
R_{pu}	Pull-up resistor (5 V mode)	9.2	9.6	k Ω
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
	Resolution		12	bit
V_{tol-0}	Zero reading error ^{1 2}	-10	10	mV
V_{tol-0}	Zero reading error ²	-15	15	mV
V_{tol-p}	Proportional error ^{1 2}	-0.4	0.4	%
V_{tol-p}	Proportional error ²	-0.6	0.6	%
LSB	Nominal value of 1 LSB		1.2	mV
V_{in}	Input voltage measurement range	0	5	V

Table 94: Low-side digital output – characteristics of analog voltage input – 5 V mode

¹ $T_{ECU} = -40$ to $+85$ °C

² The total measurement error is the sum of zero reading error and the proportional error.

11. SPECIFICATION OF INPUTS AND OUTPUTS

32 V mode:

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
τ_{in}	Input low pass filter (32 V mode)	0.8	1	ms
R_{pu}	Pull-up resistor (32 V mode)	7.8	8.1	k Ω
V_{pu}	Pull-up voltage (32 V mode)	4.1	4.35	V
	Resolution		12	bit
V_{tol-0}	Zero reading error ^{1 3}	-80	80	mV
V_{tol-0}	Zero reading error ³	-135	135	mV
V_{tol-p}	Proportional error ^{1 3}	-2	2	%
V_{tol-p}	Proportional error ³	-2.5	2.5	%
LSB	Nominal value of 1 LSB		13.4	mV
V_{in}	Input voltage measurement range ²	0	32	V

Table 95: Low-side digital output – 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 the battery supply voltage.

³ The total measurement error is the sum of zero reading error and the proportional error.

11.13.2 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)	9.2	9.6	k Ω
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
R_{pu}	Pull-up resistor (32 V mode)	7.8	8.1	k Ω
V_{pu}	Pull-up voltage (32 V mode)	4.1	4.35	V
	Resolution		12	bit
V_{il}	Input voltage for low level ¹		<x>	V
V_{ih}	Input voltage for high level ¹	<x>		V

Table 96: Low-side digital output – characteristics of digital input

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

11.14 LIN

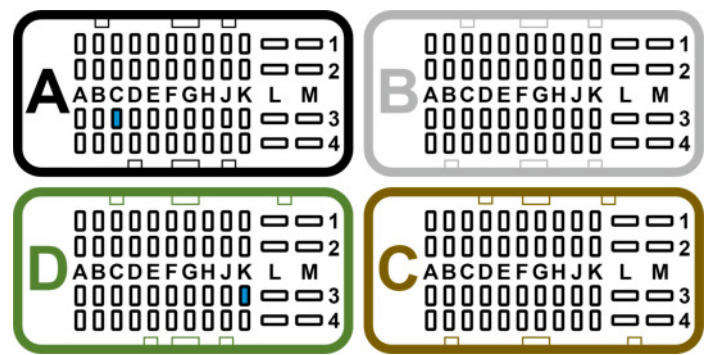


Figure 47: LIN pinout

Connector	Pin	Pin name	Variant
A	C3	LIN_00	All
C	K3	LIN_01	All

Table 97: 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.

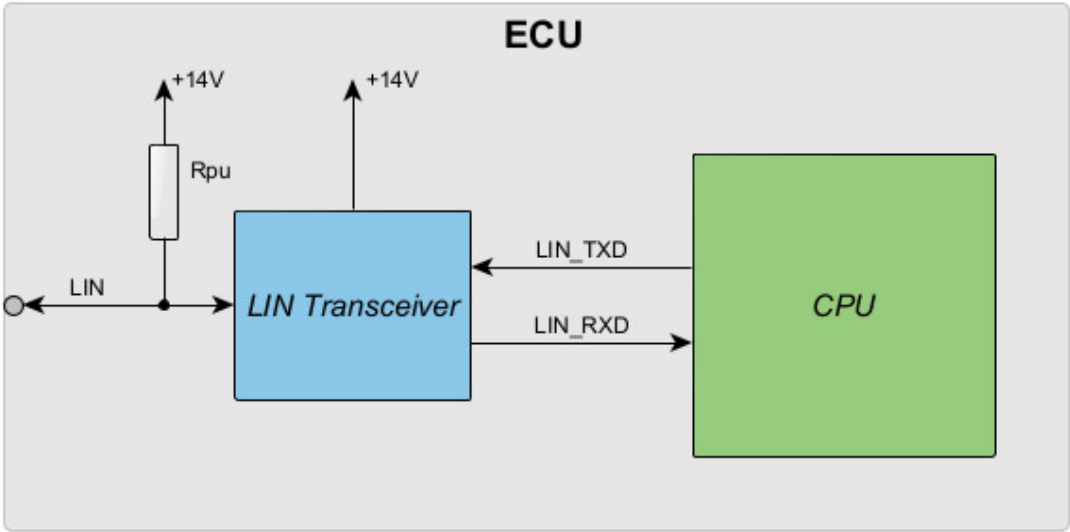


Figure 48: LIN interface

Maximum ratings

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

Table 98: 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 99: LIN characteristics

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

11.15 CAN FD

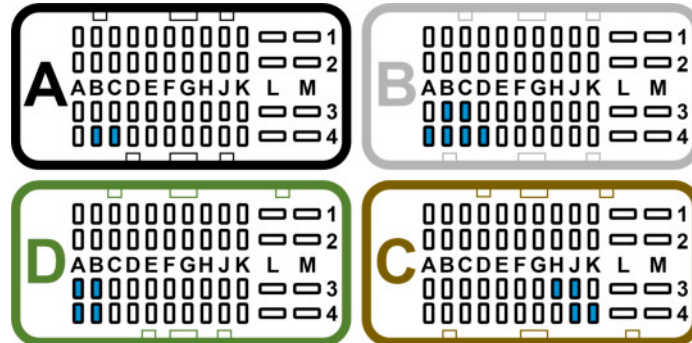


Figure 49: CAN FD pinout

Connector	Pin	Pin name	Variant
B	B4	CAN_00_L	All
B	A4	CAN_00_H	All
B	C3	CAN_01_L ¹	All
B	B3	CAN_01_H ¹	All
A	C4	CAN_02_L ²	All
A	B4	CAN_02_H ²	All
B	D4	CAN_03_L	All
B	C4	CAN_03_H	All
C	J3	CAN_04_L	All
C	H3	CAN_04_H	All
C	K4	CAN_05_L	All
C	J4	CAN_05_H	All
D	B3	CAN_06_L	All
D	A3	CAN_06_H	All
D	B4	CAN_07_L	All
D	A4	CAN_07_H	All

Table 100: CAN FD pin group

Supported functions

- CAN (main)
- CAN_ISO
 - ¹Available for interface 1 only
- CAN_WAKE

11. SPECIFICATION OF INPUTS AND OUTPUTS

- ²Available 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 50 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 (R_{diff}) is given in table 102.

ISOBUS CAN1

Due to the requirements of the ISOBUS standard [6], CAN FD has a lower EMC protection than other CAN interfaces. In CAN1 the high impedance RF termination is removed. 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 50 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 101: CAN FD maximum ratings

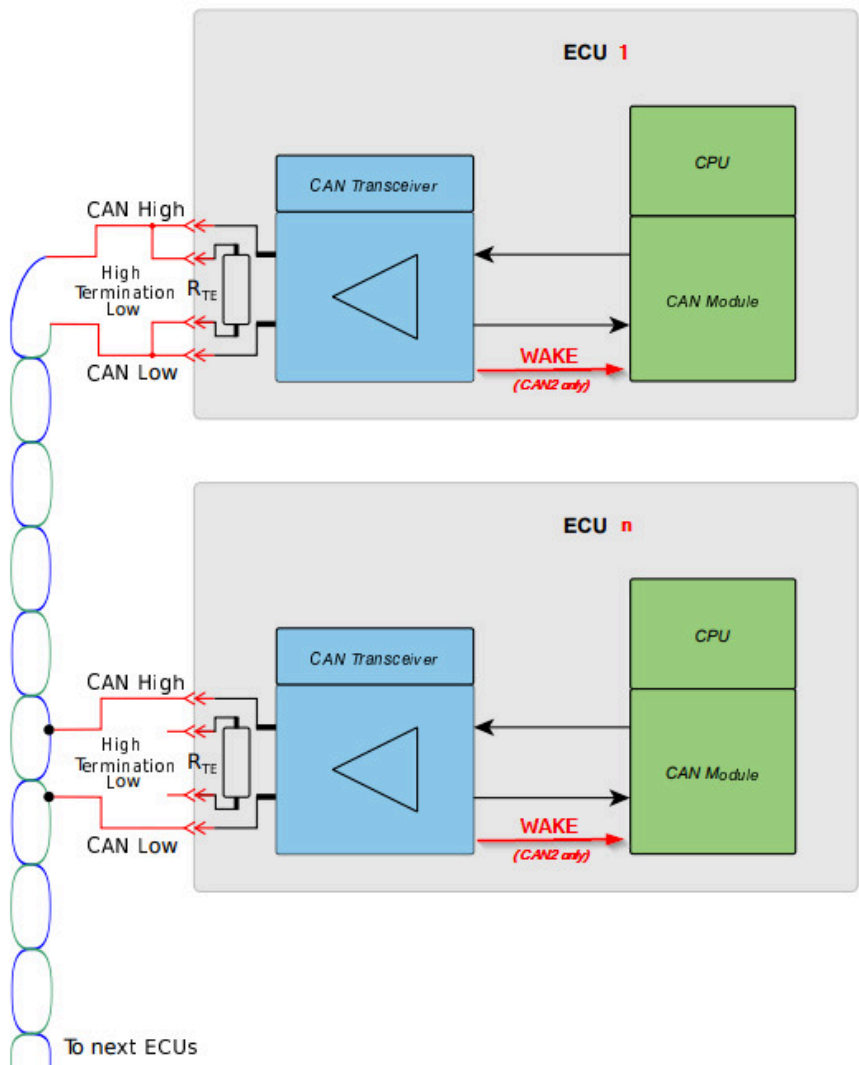


Figure 50: CAN FD block schematic

11. SPECIFICATION OF INPUTS AND OUTPUTS

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin output capacitance		100	pF
V_{in-CMM}	Input common mode range ¹	-12	12	V
V_{in-dif}	Differential input threshold voltage ($V_{CAN_H} - V_{CAN_L}$)	0.5	0.9	V
$V_{out-dif}$	Differential output voltage dominant ($V_{CAN_H} - V_{CAN_L}$)	1.5	3	V
$V_{out-dif}$	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	k Ω
R_{diff}	Differential internal resistance	3.7	3.9	k Ω

Table 102: CAN FD characteristics

¹Due 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.

²Pay 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.

³For typical network sizes and topologies (networks with stub wires) and more than two nodes, the practical limit is 500 kbit/s.

⁴Any value that conforms to CAN protocol standard definition is valid.

⁵ISOBUS CAN variant.

11.16 CAN termination

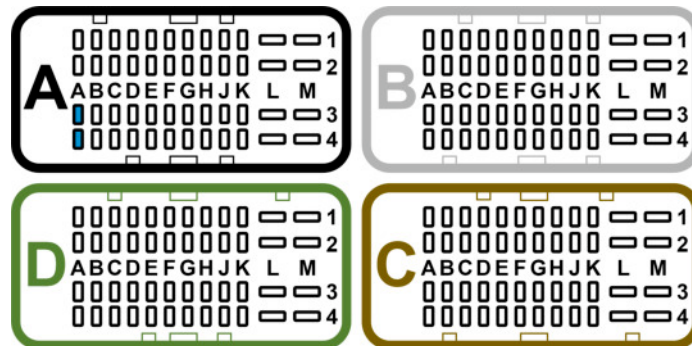


Figure 51: CAN termination pinout

Connector	Pin	Pin name	Variant
A	A4	CAN_TERM_H	All
A	A3	CAN_TERM_L	All

Table 103: CAN termination pin group

Supported functions

- CAN_TER (main)

Functional description

For easy termination of the CAN bus, there is one built-in 120 Ω termination resistor consisting of two 60 Ω resistors (split termination) on the TTC 2700 which are accessible via two separate connector pins. They can be used for any CAN port.

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

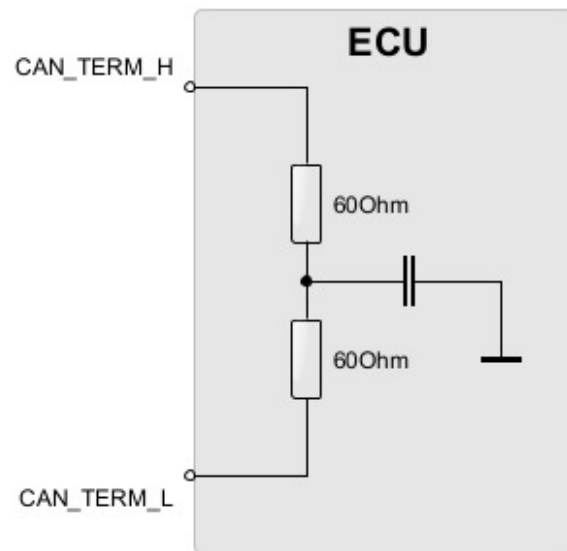


Figure 52: CAN termination block schematic

11.17 100BASE-T1

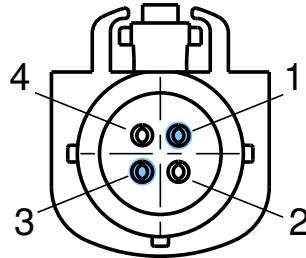


Figure 53: HSD connector pinout

Connector	Pin name	Pin number	Variant
E	BRR_00_TRX_P	1	TTC 2740
E	(Not connected)	2	TTC 2740
E	BRR_00_TRX_N	3	TTC 2740
E	(Not connected)	4	TTC 2740
F	BRR_01_TRX_P	1	TTC 2740
F	(Not connected)	2	TTC 2740
F	BRR_01_TRX_N	3	TTC 2740
F	(Not connected)	4	TTC 2740

Table 104: 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 E and F in variant TTC 2740.

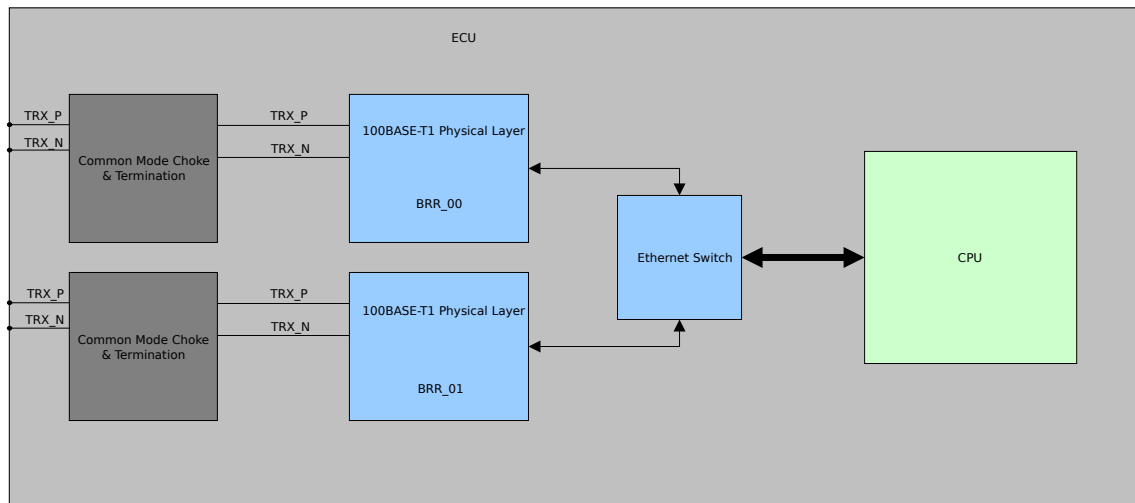
11. SPECIFICATION OF INPUTS AND OUTPUTS

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 105: 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.


Figure 54: Ethernet interface - 100BASE-T1

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 106: 100BASE-T1 maximum ratings

Characteristics

Symbol	Parameter	Min	Max	Unit
V_{in-CMM}	Input common mode range	- 32	32	V
$V_{out-dif}$	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	k Ω

Table 107: 100BASE-T1 characteristics

11.18 100BASE-TX

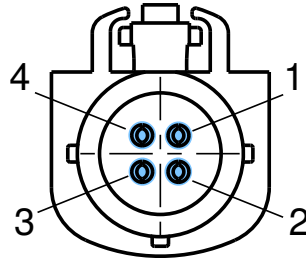


Figure 55: HSD connector pinout

Connector	Pin name	Pin number	Variant
E	ETHERNET_00_TX+	1	TTC 2785
E	ETHERNET_00_RX-	2	TTC 2785
E	ETHERNET_00_TX-	3	TTC 2785
E	ETHERNET_00_RX+	4	TTC 2785
F	ETHERNET_01_TX+	1	TTC 2785
F	ETHERNET_01_RX-	2	TTC 2785
F	ETHERNET_01_TX-	3	TTC 2785
F	ETHERNET_01_RX+	4	TTC 2785

Table 108: 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 E and F in variant TTC 2785.

Make sure to use appropriate cabling according to the Ethernet standard. TTCControl 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.

11. SPECIFICATION OF INPUTS AND OUTPUTS

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 $\pm$ 15 Ω
AU	e.g., G&G X9207	100 Ω

Table 109: 100BASE-T1 recommended cables

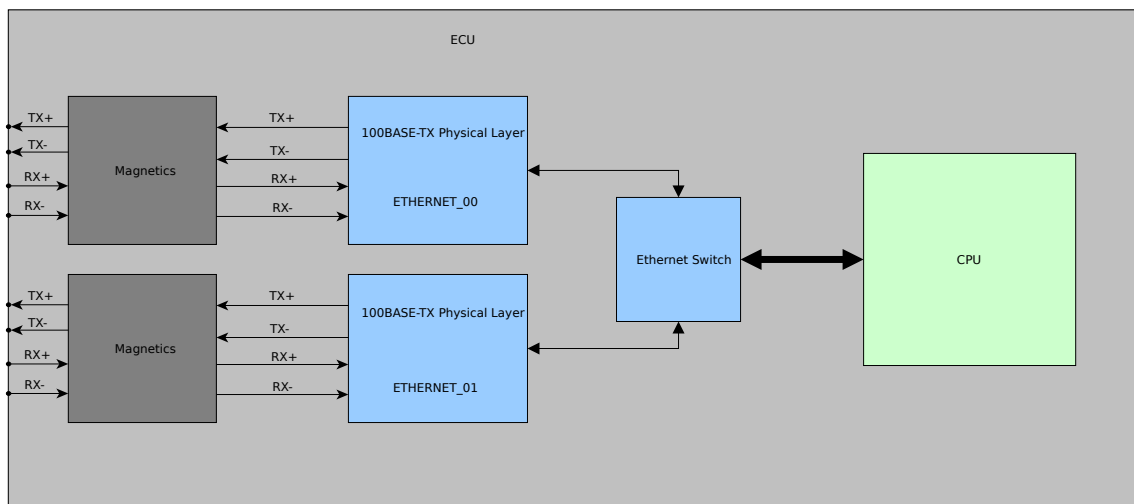


Figure 56: Ethernet interface - 100BASE-TX

Maximum ratings

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

Table 110: 100BASE-TX maximum ratings

11.19 Real-Time Clock (RTC)

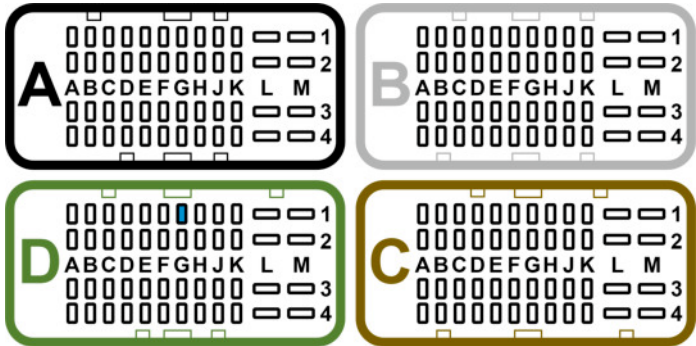


Figure 57: RTC pinout

Connector	Pin	Pin name	Variant
D	G1	RTC_BACKUP_BAT	All

Table 111: RTC pin group

Supported functions

- RTC_BACKUP_BAT (main)

Functional description

The TTC 2700 includes a real-time clock with a backup power system for exact system time- and date-keeping after every power cycle.

The real-time clock module is either supplied by the internal 5 V supply, vehicle battery, or by the external RTC battery pin.

When TTC 2700 is connected to the vehicle battery via the BAT+ CPU pin, the RTC is supplied by the vehicle battery independent of whether the device is operational or in power-off mode. When both the RTC backup battery and BAT+ CPU are disconnected, the real-time clock is supplied by an internal capacitor. The capacitor provides approximately 7 minutes of backup time when fully charged. Charging an empty capacitor takes at least 5 minutes.

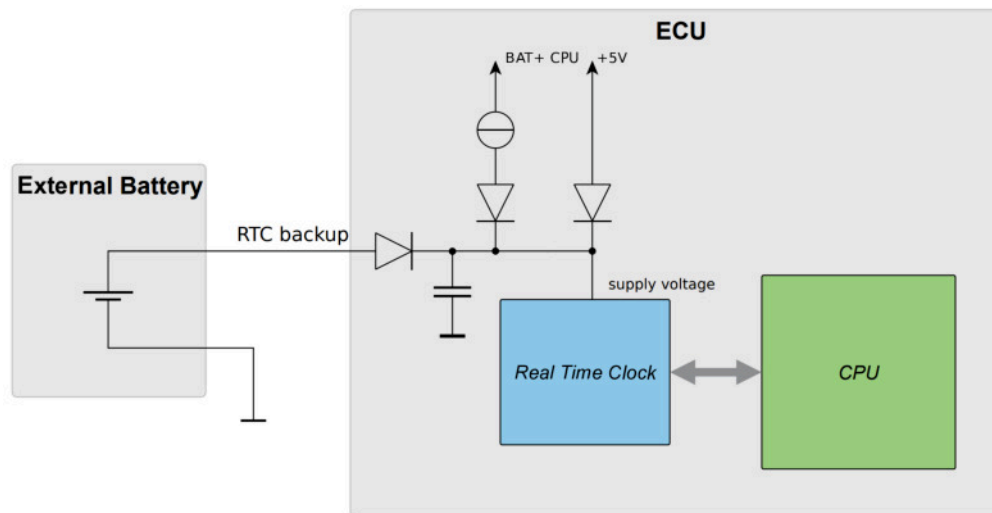


Figure 58: Voltage supply of real-time clock

Maximum ratings

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

Table 112: Real-time clock maximum ratings

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
I_{in}	Steady state input current (after 1 min, 3.6 V)		10	μA
I_{in}	Steady state input current for high voltage operation (after 1 min, 16 V)		260	μA
I_{in}	Steady state input current for high voltage operation (after 1 min, 32 V)		600	μA
V_{in}	Input voltage	2.5	32	V
V_{in}	Input voltage ¹	1.8	32	V
$\delta t/day$	Time variation per day at +25 °C		+/- 1.5	s/day
RTC_{res}	Real-time clock resolution	1		s

Table 113: Real-time clock – characteristics

¹ $T_{ECU} = -40$ to $+85$ °C.

12 Application notes

12.1 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 R_{line} , and can therefore be compensated.

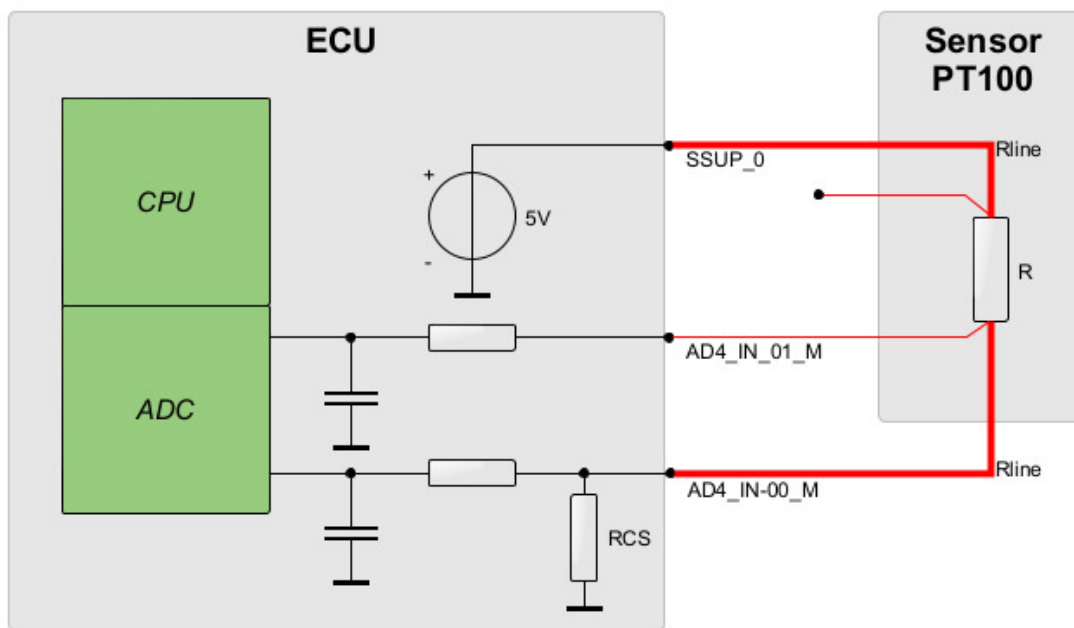


Figure 59: PT100

Calculation

$$U_{PT100} = U_{SSUP} - AN4_IN_01_M - (AN4_IN_01_M - AN4_IN_00_M)$$

$$U_{PT100} = U_{SSUP} - 2 * AN4_IN_01_M + AN4_IN_00_M$$

$$I_{PT100} = AN4_IN_00_M + AN4_IN_00_R$$

$$R_{PT100} = U_{PT100} / I_{PT100}$$

12.2 Power stage alternative functions

This application note describes the DOs and DON'Ts when using the alternative functions of the TTC 2700 high- and low-side power stages.

12.2.1 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 alternative input functions, 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.

12.2.2 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 function of the ECU. Switches which are directly switching to battery voltage must not be used with this alternative input function.

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

Workarounds for safety critical applications:

- Usage of external switches connected to BAT-.

Short circuits to battery supply need to be excluded in the system architecture.

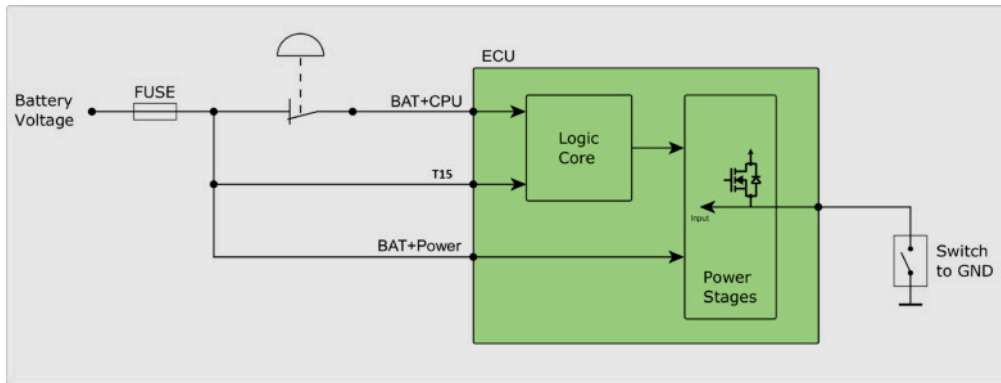
- Battery supplied switches and sensors need to be supplied via a digital output of the TTC 2700.

12.2.2.1 Valid Wiring Examples

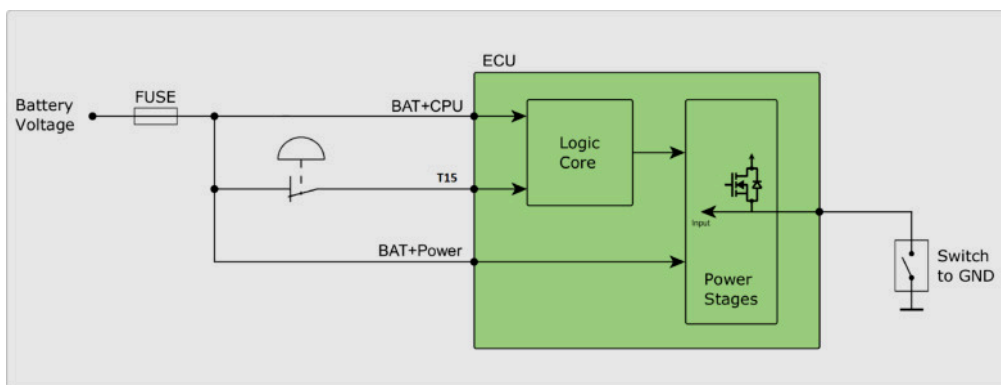
The following wiring examples for external switches and analog sensors connected to battery supply (PWM/digital high-side output) and to GND are allowed and can help avoiding system fault scenarios:

Switch connected to GND:

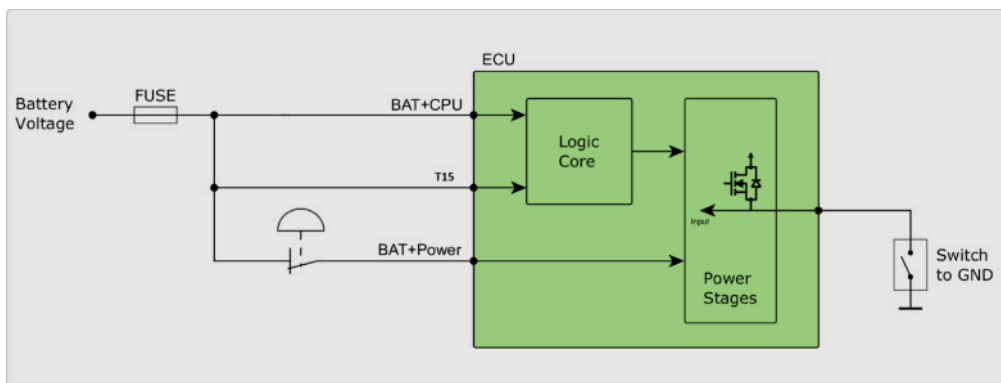
Usage of external switches connected to GND. Short circuits to battery supply needs to be excluded in the system architecture.



(a) BAT+CPU



(b) T15



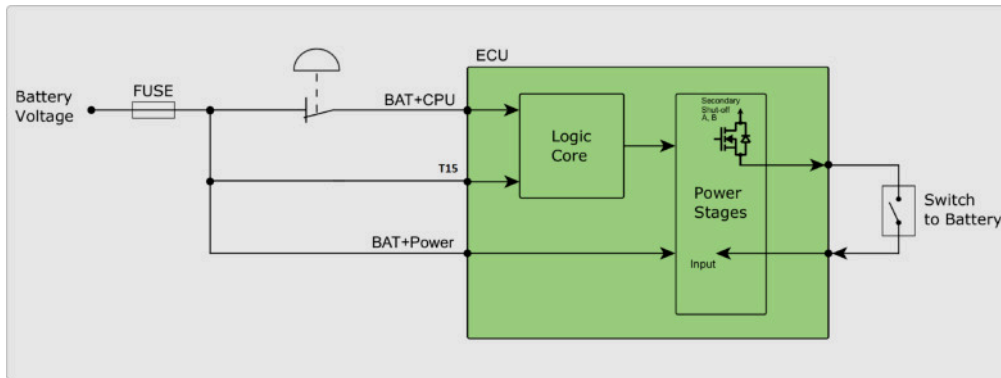
(c) BAT+Power

Figure 60: Switches connected to GND

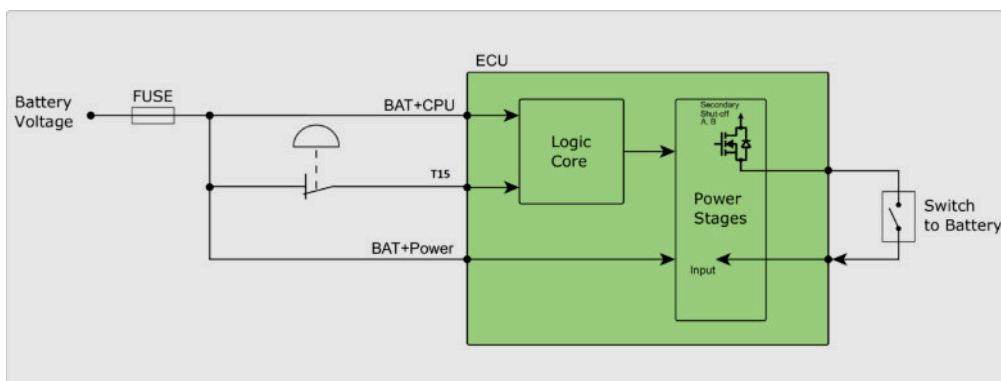
Switches connected to high-side PWM output stage:

Digital switches and analog sensors are supplied via an TTC 2700 high-side PWM output pin, the switch/sensor output is monitored by an alternative (high-side PWM) input.

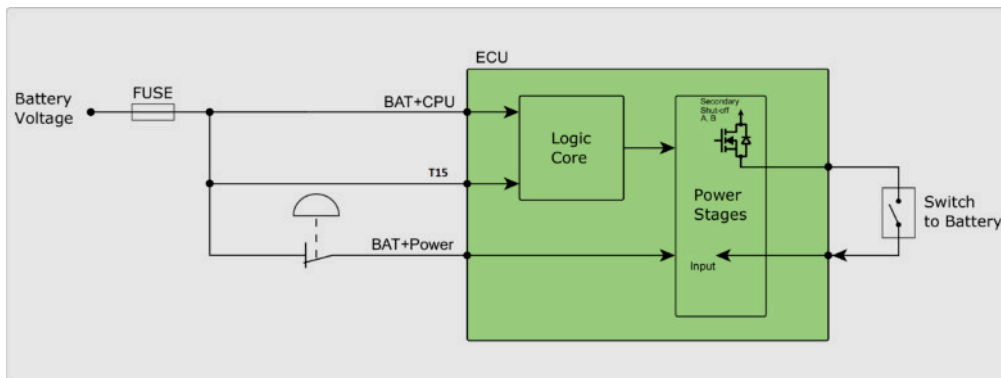
 The sourcing high-side PWM output stage (Must be out of the same secondary shut-off path (A, B or C) as the alternative input pin. For example HS_PWM_A02 (output/source) supplies a digital sensor and its sensor output is monitored by HS_PWM_A07 (input), both IOs are out of secondary shut-off path A. See figure 1 for secondary shut-off paths and their relation to the alternative inputs.



(a) BAT+CPU



(b) T15



(c) BAT+Power

Figure 61: Switches connected to high-side PWM output stage

Switches connected to digital high-side output stage:

Digital switches and analog sensors are supplied via an TTC 2700 digital high-side output pin, the switch/sensor output is monitored by an alternative (digital high-side) input.

HS_OUT_00 - HS_OUT_11 are not equipped with secondary shut-off paths. These high-side output stages can not be used by themselves for safety critical applications. If the alternative input function of HS_OUT_00 - HS_OUT_11 is used, the connected sensor must be supplied by a digital output stage from these outputs.

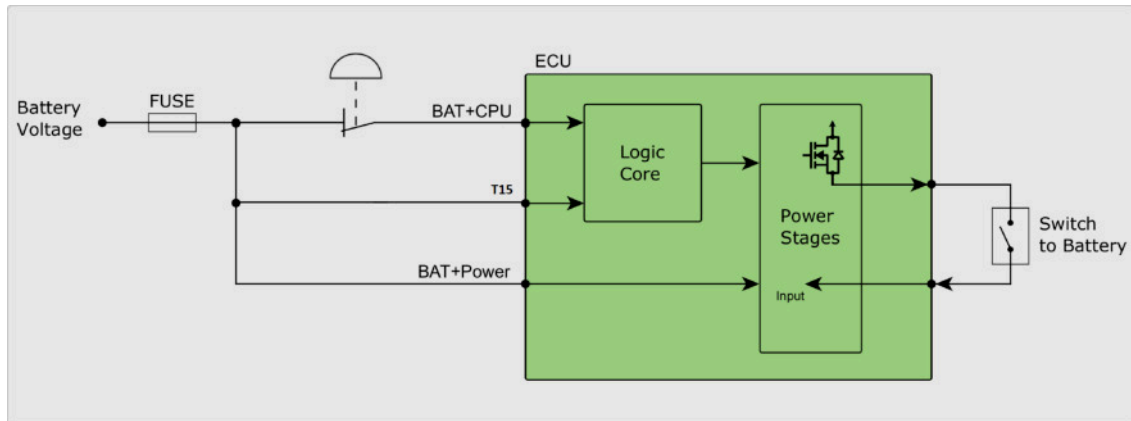


Figure 62: Switch connected to digital high-side output stage

12.2.2.2 Invalid Wiring Examples

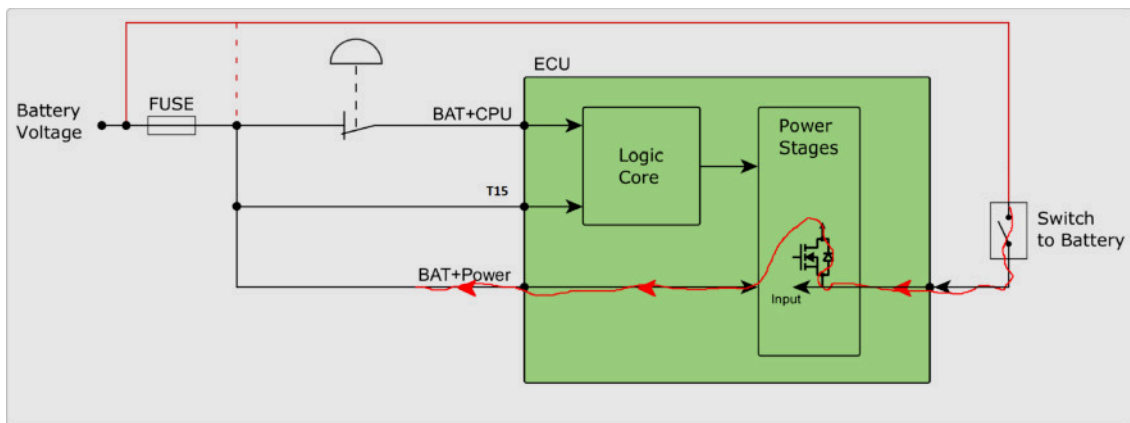
The following wiring examples of external switches or analog sensors connected to battery supply are not allowed and must be avoided for safety critical systems.

Nonconforming wiring can lead to the destruction of the TTC 2700.

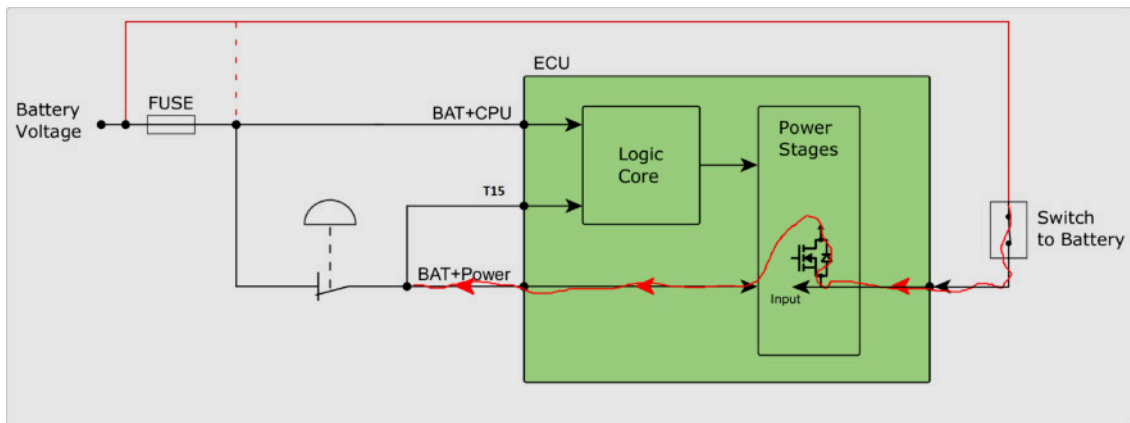
Stop switch / blown fuse / T15 wiring

Digital switches and analog sensors are supplied directly from the battery.

If for example the fuse is blown, BAT+ Power is disconnected (loose connection) or the stop switch is pressed, digital switches or analog sensors are still supplied. The current flows over the closed switch and the parasitic body diode of the output stage is used as an input. All the load current of all other outputs now flows via the body diode of this single output stage. This may overload and even destroy this output stage.



(a) BAT+CPU



(b) BAT+Power

Figure 63: Switches connected to battery supply

12.3 GND connection of housing

The TTC 2700 housing is not directly connected to BAT-. In the case of chassis mounting, this prevents GND 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.

12.4 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.

12.5 Inductive loads at low-side switches

When load inductivities are above 100 mH, either the current has to be lowered or an external freewheeling diode or clamping device parallel to the coil has to be used. The clamping device has to clamp below 50 V.

Examples for clamping devices are:

- Varistor
- Bidirectional Transzorb® diode
- Zener diode with antiseri-diode or a suitably sized resistor ¹

¹ The required resistor can be found by dividing 50 V/(maximum possible coil current). This can be a cost-effective solution, but it increases the steady power dissipation, which makes it unsuitable for some cases.

12.6 Handling of high-load current

Load distribution

The permanent input current of the TTC 2700 I_{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 2700 in its operating ambient temperature range (-40 °C to +85 °C) the total current $I_{in-total}$ 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. The two outputs of a double-channel high-side power stage follow this naming convention: HS_OUT_even, HS_OUT_even+1 (e.g. HS_OUT_10, HS_OUT_11).

Total load current

Operating all high-side power stages ON (100% DC operation) with maximum rated current (4 A) that would result in a load current $I_{in-total}$ in excess of 208 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 $I_{in-total}$. This value can only be applied if an equal load distribution over different power stages is ensured - which implicit a different $I_{in-total}$ limit set by the different number of power stages in each TTC 2700 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 10 pins can be (and are recommended to be) used in parallel to increase the overall current capability.

For the maximum battery supply current of 80 A, all 10 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:

$$I_{BAT} = I_{power-stage} \quad (1)$$

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:

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

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 2700.

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 GND, 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. The cable length between BAT+ Power A and BAT+ Power B wires should be about the same in order to avoid an unbalanced current flow between the two wires, connector pins and inputs, see figure 12.

NOTE

It is necessary to use wires with the same total cross sectional area and length ($\geq 2\text{m}$) instead of one thick cable for load-carrying supply lines (BAT+ Power and BAT-). In this case, an even current distribution can be achieved, even with slightly different contact resistances. It is recommended to use all pins of BAT+ Power and BAT-.

13 Debugging

The TTC 2700 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 2700 device, you will need the components shown in the tables below. Items shown in table 114 are provided in the TTC 2700 device Starter Kits. Items shown in table 115 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 114: Debugging components (TTControl GmbH)

Component	Description	Order code	Supplier
PowerDebug E40	Lauterbach base station	LA-3503	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 115: Debugging components (other)

¹former order code

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

NOTE

Items in table 115 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 64 for further details.
16-pin OCDS	Alternative to 16-pin JTAG. See figure 65 for further details.
6-pin FTDI	USB-TTL-232R connector (5 V) for the UART connection. See figure 66 for further details.
10-pin JTAG/DAP/UART	Connection to the ECU. See figure 67 for further details.

Table 116: JTAG debug adapter connectors

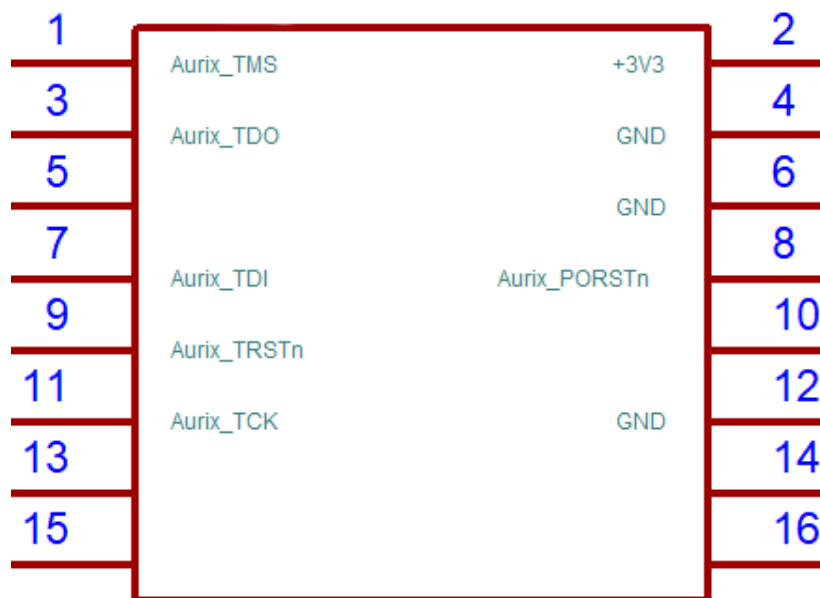


Figure 64: Pinning schematic for the JTAG connector

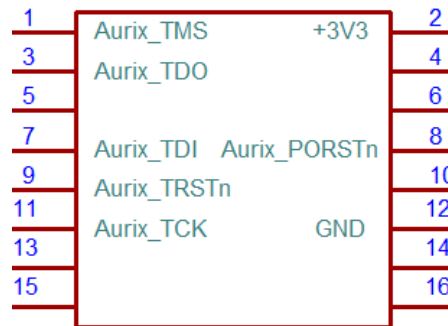


Figure 65: Pinning schematic for the OCDS connector (JTAG alternative)

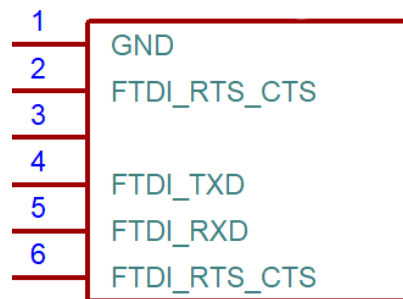


Figure 66: Pinning schematic for the USB-FDTI connector

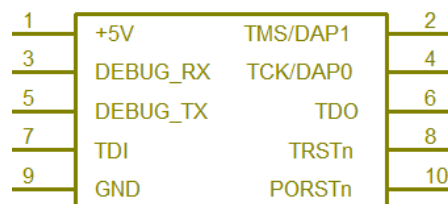


Figure 67: Pinning schematic for the ECU interface

13.3 TRACE32

Instructions for connecting your components and setting up TRACE32 can be found in the Release Notes [14], [7] and [13], 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

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

References

- [1] IEC. IEC 61131-3:2013, *Programming languages (3rd ed.)*. International Standard, International Electrotechnical Commission (IEC), 2013.
- [2] IEEE. IEEE 802.3™-2008 – *Standard for Ethernet*. International Standard, Institute of Electrical and Electronics Engineers, 2008.
- [3] ISO. ISO 16750-1:2006, *Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 1: General (2nd ed.)*. International Standard, International Organization for Standardization (ISO), 2006.
- [4] ISO. ISO 16750-2:2012, *Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 2: Electrical loads (4th ed.)*. International Standard, International Organization for Standardization (ISO), 2012.
- [5] ISO. ISO 11898:2015, *Road vehicles – Controller area network (CAN) –Part 1 Data link layer and physical signalling*. International Standard, International Organization for Standardization (ISO), 2015.
- [6] ISO. ISO 11783-1:2017, *Tractors and machinery for agriculture and forestry — Serial control and communications data network*. International Standard, International Organization for Standardization (ISO), 2017.
- [7] TTControl GmbH. TTC 2700 Hardware Release Note. D-TTC2700-DN-20-002, TTTech, BU Off-Highway, Product Development.
- [8] TTControl GmbH. TTC 2700 Mounting Requirements Document. D-TTC2700-M-02-001, TTTech, BU Off-Highway, Product Development.
- [9] TTControl GmbH. TTC 2700 Product Drawing. D-TTC2700-C-02-001, TTTech, BU Off-Highway, Product Development.
- [10] TTControl GmbH. TTC 2700 Quick Start Guide. D-TTC2700-G-20-004, TTTech, BU Off-Highway, Product Development.
- [11] TTControl GmbH. TTC 2700 Safety Manual. D-TTC2700-M-20-002, TTTech, BU Off-Highway, Product Development.
- [12] TTControl GmbH. TTC 2700 Software Manual. D-TTC2700-M-20-003, TTTech, BU Off-Highway, Product Development.
- [13] TTControl GmbH. TTC 2700 Software Release Note Bootloader. D-TTC2700-DN-20-003, TTTech, BU Off-Highway, Product Development.
- [14] TTControl GmbH. TTC 2700 Software Release Note I/O Driver. D-TTC2700-DN-20-001, TTTech, BU Off-Highway, Product Development.
- [15] TTControl GmbH. TTC 2700 Summary of Test Reports. D-TTC2700-RP-20-002, TTTech, BU Off-Highway, Product Development.
- [16] TTControl GmbH. TTC 2740 ECU Datasheet. D-TTC2700-S-20-005, TTTech, BU Off-Highway, Product Development.
- [17] TTControl GmbH. TTC 2740 I/O Driver Manual. D-TTC2700-G-20-002, TTTech, BU Off-Highway, Product Development.
- [18] TTControl GmbH. TTC 2785 ECU Datasheet. D-TTC2700-S-20-002, TTTech, BU Off-Highway, Product Development.
- [19] TTControl GmbH. TTC 2785 I/O Driver Manual. D-TTC2700-G-20-003, TTTech, BU Off-Highway, Product Development.

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

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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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