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HYDAC INTERNATIONAL

Volution family

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Revision History

Date	Author	Version	Comment
2023-04-26	TTC	1.0.0	• Initial draft version
2024-06-12	TTC	1.1.0	• Added list of figures, list of tables, revision History • Fixed figure 6 • Removed HS OUT • Added characteristics for PVG and V_{out} outputs • Corrected CAN-related text • Remove mentions of ADC_RIN_100K_HP • Added H-bridge outputs to variants table • Fixed typos and formatting

1 Introduction

1.1 General

This is the System Manual for the Volution 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 Volution family, which is part of the Volution Series, includes the following variants:

- Volution 144 [6]

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 Volution family. Please see your release package for additional user documentation, including:

- Software Manual [12] (not released yet)
- I/O Driver Manual for each variant:
  - Volution 144 I/O Driver Manual [7]
- Mounting Requirements Document [8]
- Product Drawing [9]
- Safety Manual [11] (not released yet)
- Release Notes [10]
- ECU Datasheet [6]

1.3 Notation

In the context of this document, the terms Volution and *Volution family* refer to the *all* products in the Volution family.

NOTE

> The information given in this System Manual is valid for *all* variants in the Volution family, unless otherwise stated.

1.4 Support

The Release Note [10] contains known issues.

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

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

2 Product overview

The Volution Series is a series of robust and powerful ECUs which are designed to control brushed dc motors. The interaction with other ECUs in the overall system is achieved via communication interfaces such as CAN.

The Volution family has been designed for sensor/actuator management for both safety and non-safety applications.

2.1 Features

2.1.1 Communication interfaces

- 2x CAN FD
  - 1x Wake-up capable
  - 1x CAN ISOBUS compliant

2.1.2 Safety features

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

2.1.3 Power supply

- Supply voltage: 8 to 32 V
- Supply pins for CPU subsystem and I/O subsystem. BAT+Power is able to supply BAT+CPU with power, but not vice versa
- Load dump protection
- 1x fixed sensor supplies with an output voltage of 5 V
  - SSUP_0
- The sensor supply can deliver up to 150 mA load current continuously
- Each sensor supply has a capacitive load of up to 100 µF
- Sensor supply and battery monitoring

2.1.4 Physical specifications

- Dimensions: See[9]
- Weight: See[9]
- Operating temperature (ambient): - 40 to + 85 °C
- Mounting interface temperature (conduction cooling interface): - 40 to + 85 °C
- Storage temperature: - 40 to + 85 °C
- Housing IP6K7- and IP6K9-rated: See [8]
- 2x 28 pin connector

- Pressure equalization membrane
- Operating altitude 0 to 4000 m

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

2.1.5 Inputs and outputs

- 18x I/Os: 10x out, 8x in, including:
  - 4x PWM HS with current measurement
  - 2x H-Bridge output 8A
  - 2x H-Bridge output 16A
  - 4x Analog input 4-mode
  - 2x Analog input 2-mode
  - 4x Timer input
- Option to use H-Bridges of the same current capabilities in parallel

All inputs and outputs of each Volution 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_HS_outputs. DC motors can be connected and controlled in 4-quadrant operation by the Volutions powerful H-Bridge outputs.

The Volution family is designed to support a variety of analog and digital sensor types. Many software-configurable input options can be selected to adapt to different sensor types. A group of individually configurable analog inputs with a precision voltage range from 0 to 5 V. Those analog inputs can be set to different voltage ranges by software in order to achieve the best analog accuracy and resolution. The analog inputs can also be configured as a current input or for resistive measurements.

2.1.6 Core

- Infineon Aurix 32-bit super-scalar TriCore CPU
- Internal EEPROM emulation

2.1.7 Software

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

Programming options

The unit may be programmed in C.

2.2 Volution family variants

The following Volution family variants are described in this System Manual:

- Volution 144 [6]

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

Feature	Volution 144
CPU	
32-bit TC 377	Yes
Int. FLASH	16 MB
Int. SRAM	6.59 MB
Int. EEPROM emulation	1 MB
External memory	
Serial FLASH/RAM/EEPROM/FRAM	0 / 0 / 0 / 0
Interface	
CAN FD	2
CAN0 is ISOBUS compliant	Yes
CAN termination	2
100BASE-T1	0
100BASE-TX	0
LIN	0
Outputs	
H-Bridge 8 A	2
H-Bridge 16 A	2
Digital high-side 4 A	0
Digital low-side 4 A	0
PWM high-side 4 A	4
PWM high-side 8 A	0
PWM low-side 4 A	0
Inputs	
Analog IN 4-mode (V/I/R/LED)	4
Analog IN 2-mode(V)	2
Timer IN/SENT	0
Timer IN/CL	4
Power	
Sensor supply fixed (5 V)	1
Sensor supply variable (5 to 12.5 V)	0
Sensor GND	1
Terminal 15	1
Wake-up	0
Emergency shut-off path	
External shut-off interfaces	3

Table 1: *Volution family variants*

3 Instructions for safe operation

3.1 General

- Carefully read, understand, and follow the instructions and specifications listed in this document before operating the device.
  Failure to comply with these instructions or operation of the device outside the intended field of operation may result in serious damage to machinery and may seriously affect the safety of users. TTControl cannot be held liable for any personal injury or property damage resulting from improper installation or use of the device, non-compliance with the instructions in this document, or non-compliance with the intended field of operation. Non- compliance will result in the exclusion of any liability and warranty.
- The regulations and standards which apply are highly dependent on the specfic user applications of the overall system that the Volution device is built into. Therefore, it needs to be ensured that these regulations and standards are fulfilled by the Volution by comparing Declaration of Conformity, ECE regulation certificate and Summary of Test Reports (see 4 and 5 for further details).
- Always operate the product within the electrical and environmental specifications and follow the mounting instructions provided by TTControl. Usage of the product outside the specifications may be hazardous to persons or property.
- Only skilled and trained personnel are allowed to operate this device.
- The device must be stored, handled and installed carefully while being mounted and operated using the types of connectors specified in this document.
  Particular care must be taken to ensure that the pressure equalization membrane is not damanged. See [8] for further details.
- The label on the housing contains important information. The label must not be destroyed or made unreadable.
- The Volution 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 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 opening 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 Volution family products are programmable electronic control units for sensor/actuator management and designed for use in safety-related applications.

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

- construction
- snow groomers
- fire engines

- agricultural
- municipal sectors
- automotive

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

3.3 Improper use

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

3.4 Checks to be done before commissioning the device

- Check the supply voltage before connecting the device.
- Check that the device connector and the cable harness are free of defects.
- Check the correct dimensioning of the wires in the cable harness.
- Always disconnect the power supply before conducting any maintenance or repair work to the machine where the device is mounted (for example, welding or maintenance of the battery system).
- Choose a mounting location for the device so that the operating temperature of the device does not exceed the maximum allowed operating temperature.
- Choose a mounting location for the device which prevents any ergonomic hazard to the user/operator.
- A protective fuse must be installed between the vehicle's battery and the power supply input (BAT+) of the device.
- The device is water-resistant according to IP67 and IP6K9K. Ingress protection is given only when all connectors are plugged in, or the device has blind plugs installed.
- 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 Volution 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) [5] 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:

- EN ISO 13849:2015, PL d

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

5 Compliance

The Volution family conforms to the following directives and regulations:

- Machinery Directive 2006/42/EG
- 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 mounting or thermal requirements 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

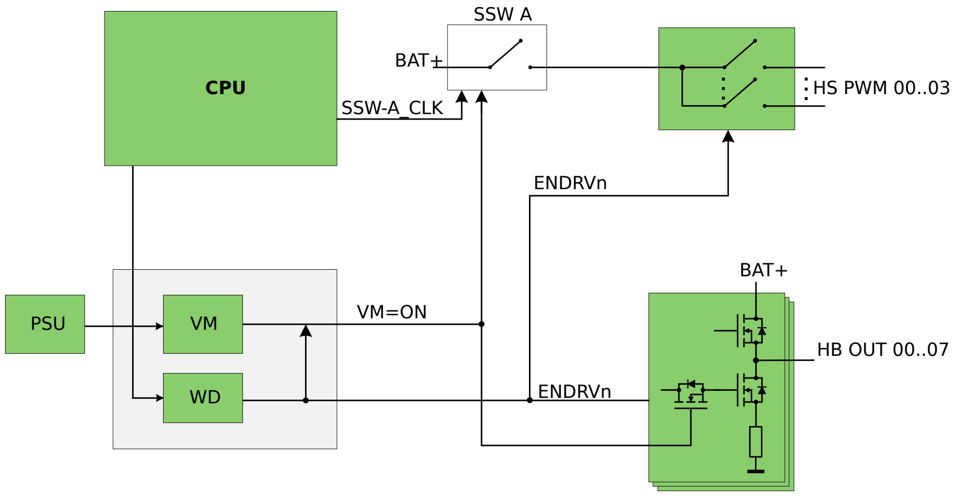


Figure 1: *Safety concept*

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

Design goal

Fail-silent ECU for safety-related application (up to ISO 13849:2015, PL d).
The following features are implemented for the ISO 13849:2015, PL d domain:

- Voltage monitoring via dedicated safety mechanism
- Power supply sequencing via dedicated safety circuits
- Window watchdog for monitoring of CPU execution
- Safety switch and reset path (Aurix CPU, and CAN transceivers)
- Aurix safety CPU host has capability for HW disabling of CAN1 with CAN_WAKE function only

7.2 System CPU

CPU MPU

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

Bus MPU

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

7.2.1 Memory

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

Table 2: *System CPU memory specifications*

7.2.2 CPU access – stall cycles

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

Table 3: *System CPU access – stall cycles*

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

7.2.3 3 Core/TC 377

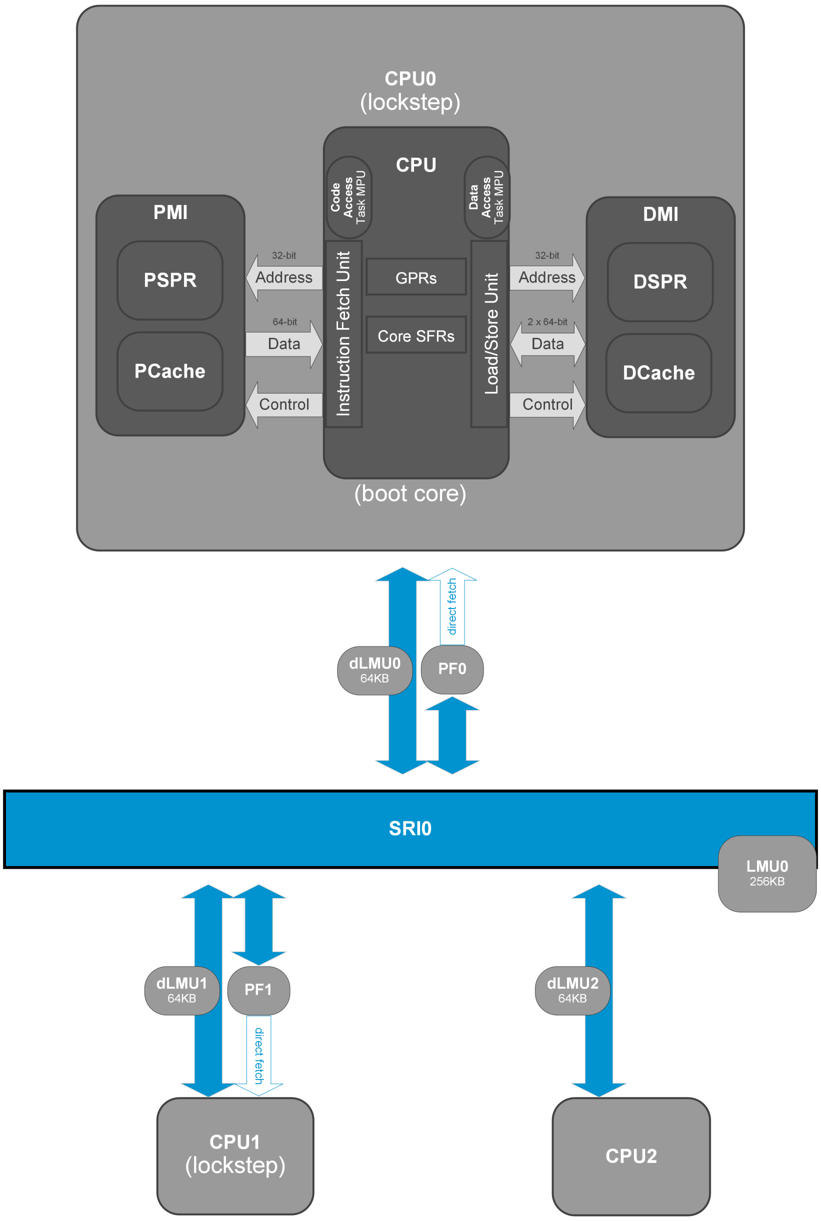


Figure 2: *Detailed block diagram for 3 core (TC 377)*

7.3 Thermal Management

7.3.1 Board Temperature Sensor

Functional description

To measure the temperature T_{ECU} within the housing, 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.

Dependent on the T_{ECU} board temperature, the maximum current limit for high-side output stages is adjusted, see e.g.11.7.2. This is a strategy to allow higher current consumption at lower temperatures and to bring the ECU immediately to a safe state and switch off loads if over temperature is detected. See 7.3.1 for temperature limits triggering the safe state.

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

The (internal) ECU temperature T_{ECU} is close to ambient temperature, when there is no load driven by the power stages at all. The ECU temperature may rise by 40 K above ambient temperature, when there is significant output load (many outputs activated with high load current at the same time). 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 more information please contact TTControl.

Characteristics

Symbol	Parameter	Min	Max	Unit
	Operating temperature (ambient)	- 40	+ 85	°C
	Mounting interface temperature (conduction cooling interface)	- 40	+ 85	°C
	Storage temperature	- 40	+ 85	°C
T_{ECU1}	ECU operating temperature (full load)	- 40	+ 85	°C
T_{ECU2}	ECU operating temperature (reduced load)	+ 85	+ 120	°C
T	Temperature measurement range	- 50	+ 150	°C
$T_{tol\text{-}m}$	Temperature tolerance of the sensor between - 5 °C and + 125 °C	-5	+ 5	K
$T_{safe\ state}$	Temperature [1] (The T_{ECU} has been taken into account.)	- 40	+ 125	°C

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

NOTE The ECU still operates above 85 °C. The output current is derated linearly with the temperature above 85 °C.

8 Connector

Figure 4 shows the main and HSD connectors for the Volution 144 device. The main connectors, A and B, consist of 56 pins divided into 2x 28 pin connectors.

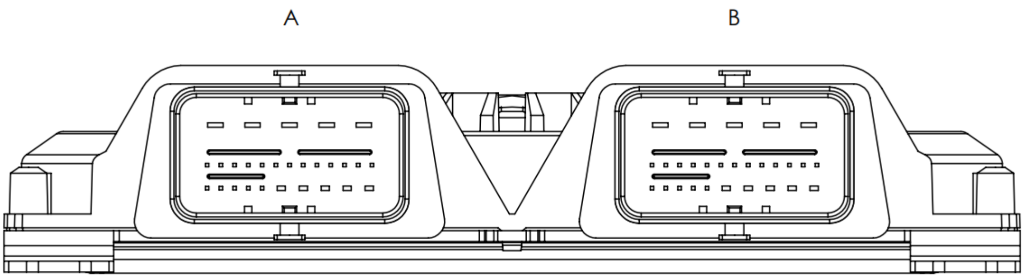


Figure 3: *Connector view (prototype)*

8.1 Mating connector and crimp contacts

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

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

NOTE The Volution 144 has a maximum of 20 mating cycles.

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, 2.80 mm, CMC receptacle, 28 circuits, left wire output, black coding, mat sealed	64318-1011	Molex
A	0.635 mm, 1.50 mm, 2.80 mm, CMC receptacle, 28 circuits, right wire output, black coding, mat sealed	64318-3011	Molex
B	0.635 mm, 1.50 mm, 2.80 mm, CMC receptacle, 28 circuits, left wire output, gray coding, mat sealed	64318-1018	Molex
B	0.635 mm, 1.50 mm, 2.80 mm, CMC receptacle, 28 circuits, right wire output, gray coding, mat sealed	64318-3018	Molex
A, B	CMC wire cap for 28 circuits, CMC receptacle, mat sealed	64320-1301	Molex

Table 5: *Recommended plug housings for mating connectors*

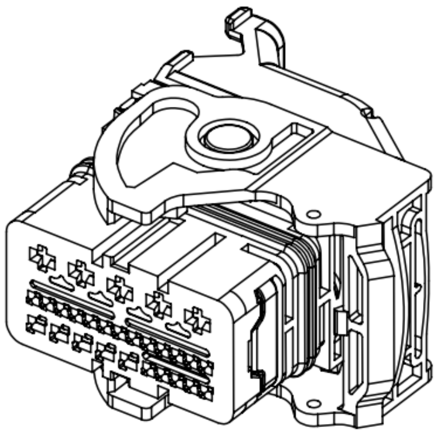


Figure 4: *Main connector A and B*

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

8.1.2 Crimping contacts

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

Connector	Description	Part no.	Supplier
A, B	2.80 mm CMC CP female terminal, tin plated, for tab dimensions 2.8 mm x 0.8 mm, wire size 3.0 mm^2 - 5.0 mm^2	64324-1019	Molex
A, B	1.50 mm CMC CP female terminal, tin plated, for tab dimensions 1.5 mm x 0.8 mm, wire size 0.5 mm^2 - 1.0 mm^2	64323-1029	Molex
A, B	1.50 mm CMC CP female terminal, tin plated, for tab dimensions 1.5 mm x 0.8 mm, wire size > 1.0 mm^2 - 2.0 mm^2	64323-1039	Molex
A, B	0.635 mm CMC CP female terminal, tin plated, for square 0.635 mm x 0.635 mm, wire size 0.5 mm^2	64322-1039	Molex
A, B	0.635 mm CMC CP female terminal, tin plated, for square 0.635 mm x 0.635 mm, wire size 0.75 mm^2	64322-1029	Molex

Table 6: *Recommended crimping contacts for mating connectors*

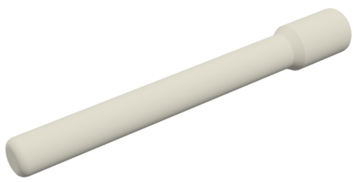
NOTE The table above provides a reduced selection of crimping contacts that can be used with your device. Please contact your supplier for further options.

8.1.3 Blind plug terminal cavity

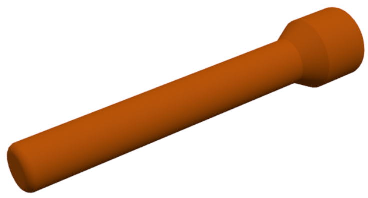
TTControl recommends the following terminal cavity for mating connectors A and B, used to plug unused terminals in the connector to ensure tightness.

Connector	Description	Part no.	Supplier
A, B	0.60 mm terminal cavity (White)	064325-1010	Molex
A, B	1.50 mm terminal cavity (Orange)	064325-1023	Molex
A, B	2.80 mm terminal cavity (Blue)	064325-1091	Molex

Table 7: *Recommended terminal cavities for mating connectors*



(a) *Terminal cavity 64325-1010*



(b) *Terminal cavity 64325-1023*

(c) *Terminal cavity 64325-1091*

Figure 5: *Terminal cavities*

8.1.4 Tools

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

Connector	Description	Part no.	Supplier
A, B	Power pin extraction tool	63813-2300	Molex
A, B	Power pin hand crimp tool wire size 0.5 mm^2 - 1.0 mm^2	63811-8900	Molex
A, B	Power pin hand crimp tool wire size 1.0 mm^2 - 2.0 mm^2	63811-9000	Molex
A, B	I/O pin extraction tool	63811-2400	Molex
A, B	I/O pin hand crimp tool wire size 0.35 mm^2	63811-9100	Molex
A, B	I/O pin hand crimp tool wire size 0.5 mm^2 - 0.75 mm^2	63811-9200	Molex

Table 8: *Recommended tools for mating connectors A and B*

8.1.5 Cables

TTControl recommends the following cables for mating connectors:

Connector	Description	Function	Recommendation
A, B	Between 3.0 mm^2 and 5.0 mm^2 [1]	BAT+Power BAT+CPU GND H-Bridge 16 A	Automotive standard
A, B	Twisted stranded wire pair, FLRY 2x0.5 mm^2	CAN	Automotive standard
A, B	2.0 mm^2	H-Bridge 8 A HS PWM 4A+CM+FM	Automotive standard
A, B	0.75 mm^2	all other functions	Automotive standard

Table 9: *Recommended cables for mating connectors*

[1] The cable diameter selection for the maximum voltage drop of +/-1 V at a maximum application current on the BAT+POWER and the T31/GND.

9 Volution family pinning

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

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

A full overview of all 96 pins, including a complete group-by-group overview, can be found in the Software Manual [11]. Instructions on how to use the pins/pin groups is given in the variant-specific I/O Driver Manual [7]. For pin groups that are categorised as *safety-critical*, see the Safety Manual [11] for further details.

NOTE

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

10 Supply

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 power stages (BAT+ power)

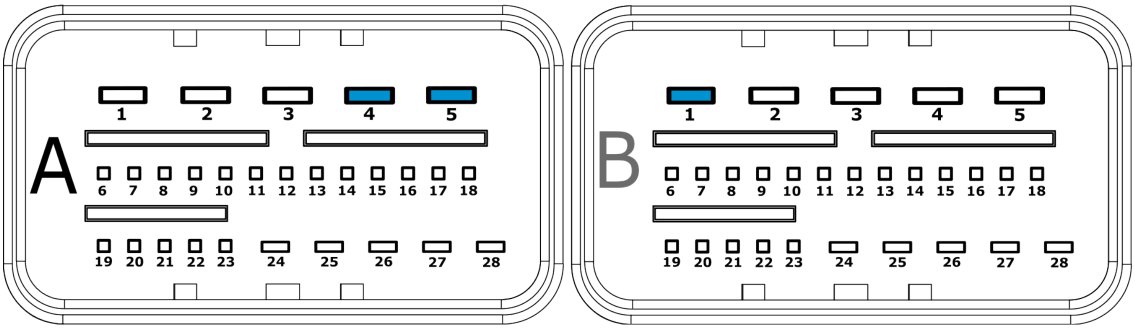


Figure 6: *BAT+ POWER pinout*

Connector	Pin	Pin name
A	4	BAT+ Power
A	5	BAT+ Power
B	1	BAT+ Power

Table 10: *BAT+ POWER pin group*

Functional description

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

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

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

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$V_{BAT+\ max}$	Permanent non-destructive supply voltage [1]	-32	32	V
$V_{BAT+\ lim}$	Peak non-destructive supply clamping voltage < 1 ms [1] [2]	-45	42	V
$I_{BAT+\ lim}$	Peak non-destructive supply clamping current < 1 ms [1] [2]	-10	100	A
T_d	Load dump protection according to ISO 7637-2, Pulse 5, Level IV (superimposed 174 V, R_i >= 2 Ω) [1]		350	ms
I_{in-max}	Permanent battery supply current (all 3 pins in parallel with symmetrical wire connection) [3]		48	A
I_{in-max}	Permanent battery supply current per pin [3]		16	A
$I_{in-total}$	Total load current, 12 V and 24 V battery operation [4]		48	A
$I_{in-stby}$	At 28 V and +85 °C		<1	mA

Table 11: *BAT+ power maximum ratings*

[1] The control unit is protected by a transient suppressor, specified by clamp voltage, current and duration of voltage transient.
[2] 1 ms pulse width, non-repetitive. The pulse width is defined as the point at which the peak current decreases to 50 % of the maximum value.
[3] This battery supply current is related to the total load current of all high-side and H-Bridge power-stages. At worst, all outputs are in non-PWM mode or with maximum duty cycle operated, the battery current equals the total load current. With typical PWM-operation the battery supply current is significant lower than the total load current.
[4] T_{ECU} = -40 to +85 °C

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	1584	2376	µF
V_{BAT+}	Supply voltage for full operation	6	32	V

Table 12: *BAT+ power characteristics*

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

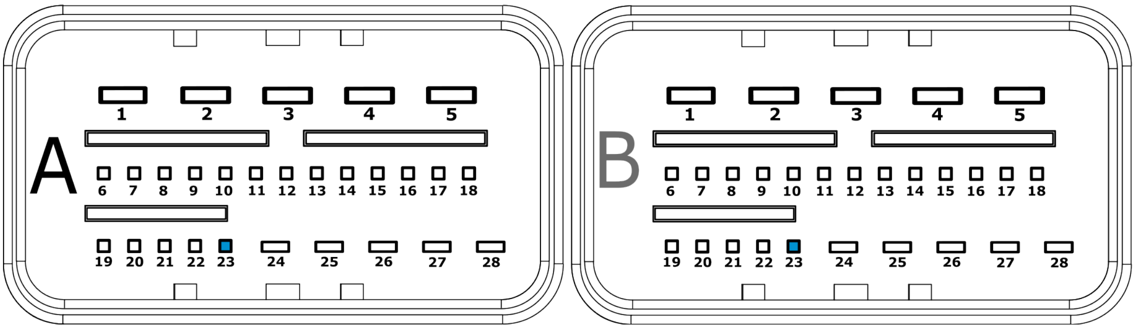


Figure 7: *BAT+ CPU pinout*

Connector	Pin	Pin name
A	23	BAT+CPU
B	23	BAT+CPU

Table 13: *BAT+ CPU pin group*

Functional description

Supply pin for positive power supply of internal electronics and sensor supply output stages.

BAT+ CPU pin is equipped with inverse polarity protection.

When BAT+ CPU is removed due to any circumstances, the ECU will still stay on as it will be provided with power through BAT+ Power for troubleshooting and safety purposes.

BAT+ Power can also provide BAT+ CPU with power, but not vice versa.

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

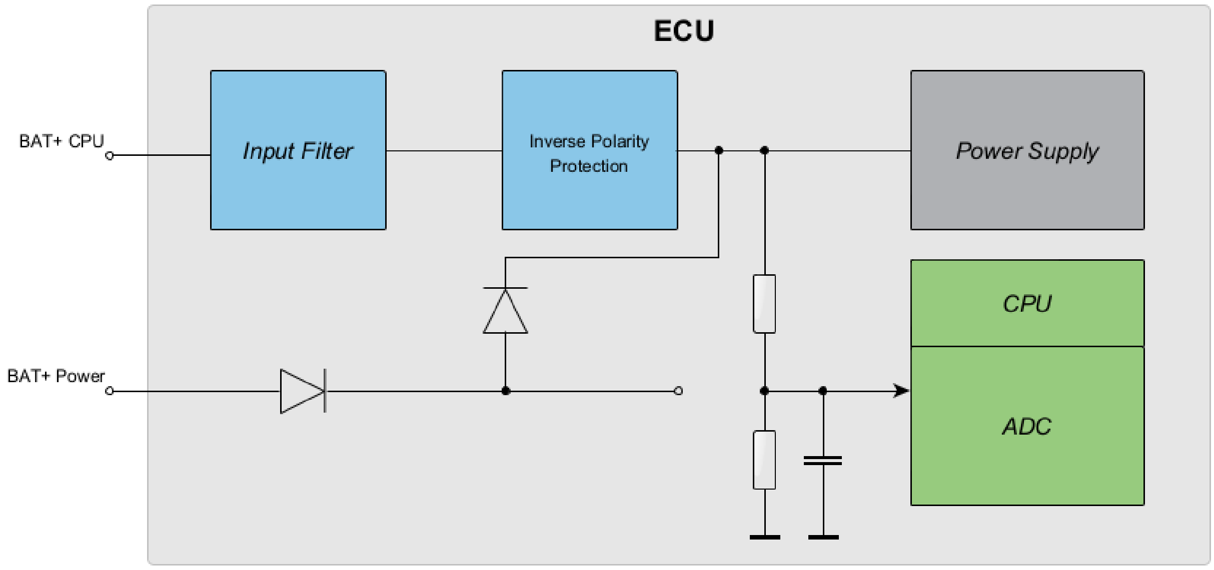


Figure 8: *Supply pin for the internal ECU logic*

Maximum ratings

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

Table 14: *BAT+ CPU maximum ratings*

[1]The control unit is protected by a transient suppressor, specified by clamp voltage, current and duration of voltage transient.
[2]1 ms pulse width, non-repetitive. The pulse width is defined as the point at which the peak current decreases to 50 % of the maximum value.

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	189.8	280.9	µF
V_{BAT+}	Supply voltage for start up [1]	8	32	V
V_{BAT+}	Supply voltage for full operation [2]	4.5	32	V
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 8 V [1]		210	mA
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 12 V		140	mA
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 24 V		80	mA
$I_{BAT+\ STBY}$	Standby supply current (Terminal 15 and wake up off)			µA
$I_{BAT+\ STBY}$	Standby supply current (Terminal 15 and wake up off) [3]		100	µA
$I_{BAT+\ STBY}$	Standby supply current [3] (CAN partial network enable) [4]		500	µA

Table 15: *BAT+ CPU characteristics*

[1]8 V is the initial voltage for start-up at the beginning of the drive cycle.
[2]See section 10.2.1.
[3]T_{ECU} = -40 to +85 °C
[4]Sensor supply is always lower than BAT+ CPU

10.2.1 Low-voltage operation

The Volution 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 [2]. The initial minimum supply voltage at the beginning of the drive cycle is 8 V. After start-up, the CPU will remain operational down to 4.5 V, e.g., during cold-start cranking. The H-Bridge driver turns off at voltages below <4,5 V on its VM pin. If 4,5 V is present on the wire harness it will go into UVLO and rise an error flag to the MCU.

The minimum supply voltage during cold-start cranking is defined by ISO 16750-2:2012 [2] (see Table 16, and Table 17). The Volution core system complies with ISO 16750-2:2012, level I, II (functional status C), III and IV for 12-V systems and level I, II (functional status A) and III (functional status B) for 24-V systems, see "SO 16750 functional status".

Restrictions during cold-start cranking also apply to sensor supplies. For further information, see sections 11.3.

For Volution ISO 16750 code specification, see section 4.

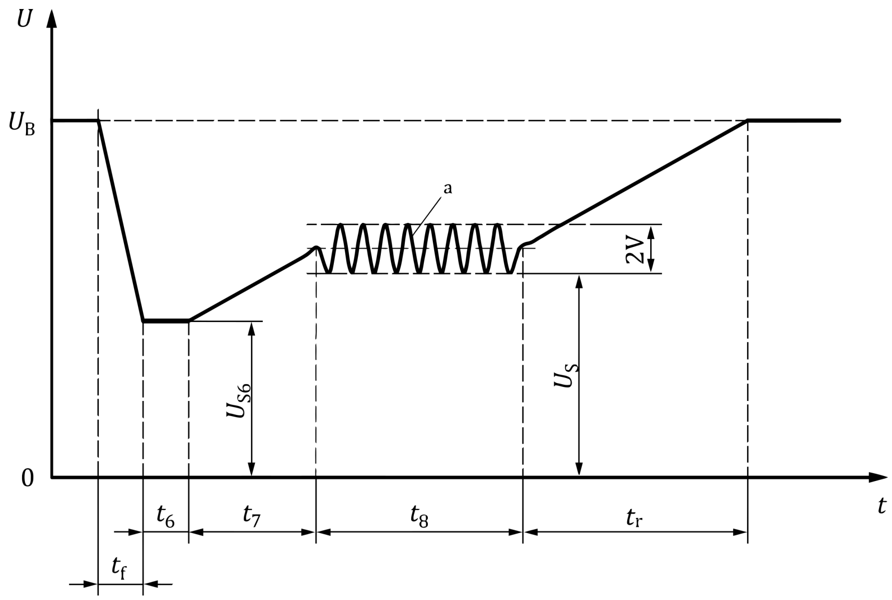


Figure 9: *ISO 16750-2 – Starting profile*

Key t: time
U: test voltage
t_f: falling slope
t_r: rising slope
t_6, t_7, t_8: duration parameters(in accordance with Table 3 and Table 4 of ISO 16750-2)
U_B: supply voltage for generator notin operation (see ISO 16750-1 [1])
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 16: *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 17: *ISO 16750 functional status (24 V)*

Voltage monitoring

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

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

Table 18: *BAT+ CPU voltage monitoring*

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

10.3 Negative power supply (BAT-)

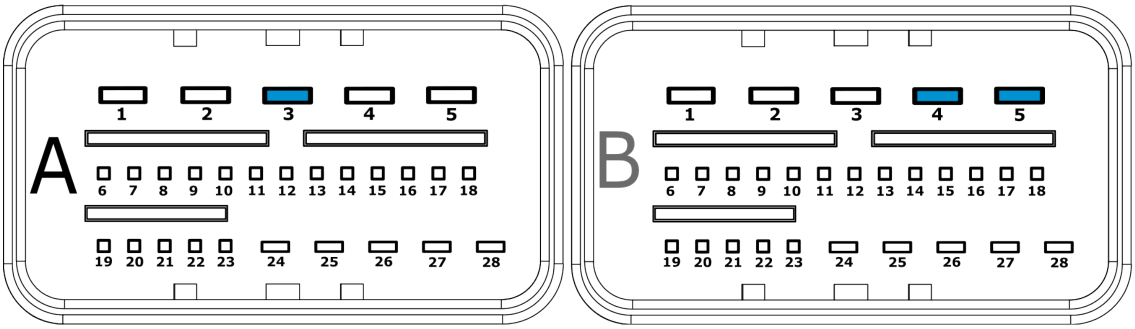


Figure 10: *BAT- pinout*

Connector	Pin	Pin name
A	3	GND
B	4	GND
B	5	GND

Table 19: *BAT- pin group*

Functional description

Supply pins for negative power supply.

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

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$I_{out\text{-}max}$	Permanent current per pin		16	A
$I_{out\text{-}max}$	Permanent current all pins		48	A

Table 20: *BAT- maximum ratings*

10.4 Fuse

WARNING

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

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

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

Table 22: *Recommended fuses for power supply path protection*

[1] The used fuse trip current is dependent on the application. The maximum current load must be considered, see section 10.1

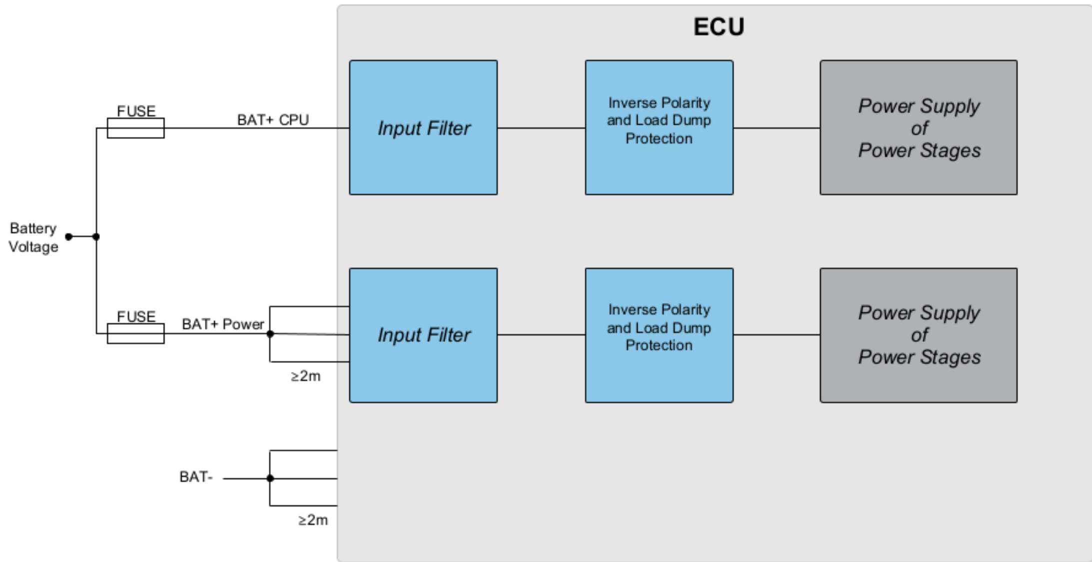


Figure 11: *Battery supply – Fuse*

NOTE

It is necessary to use wires with the same total cross-sectional area and length (≥2m) 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

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.

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 and a short name. In some cases, the generic long name is given to a section describing multiple pin groups, in which each individual pin group is given by its short name. Acronyms can be found in the glossary 1.

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

11.1 Sensor GND

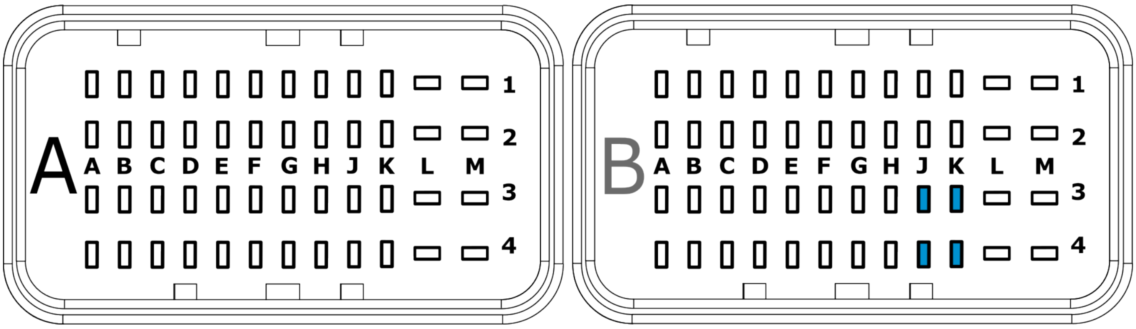


Figure 12: *Sensor GND pinout*

Connector	Pin	Pin name
A	15	SNS_GND
B	9	SNS_GND

Table 23: *Sensor GND pin group*

Functional description

Supply pins for analog sensor GND connection.

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

Maximum ratings

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

Table 24: *Sensor GND maximum ratings*

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

11.2 Terminal 15

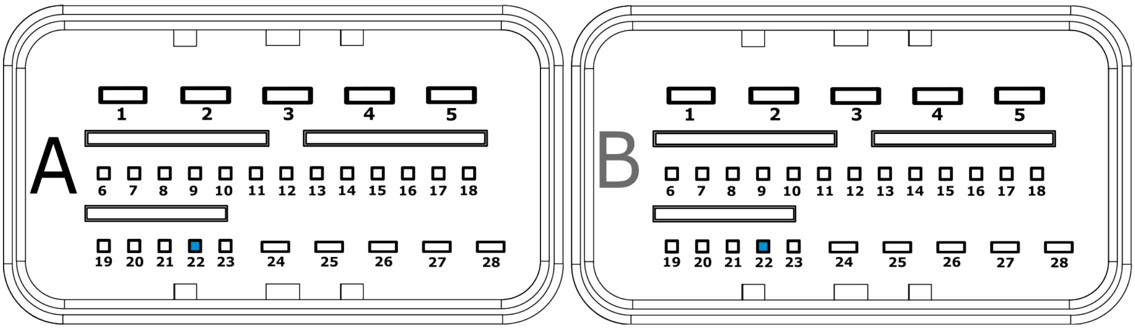


Figure 13: *T15 pinout*

Connector	Pin	Pin name
A	22	T15
B	22	T15

Table 25: *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 can activate its keep-alive functionality[1] (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 26: *T15 maximum ratings*

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF

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

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

Table 27: *T15 characteristics*

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

11.3 Sensor supply 5 V

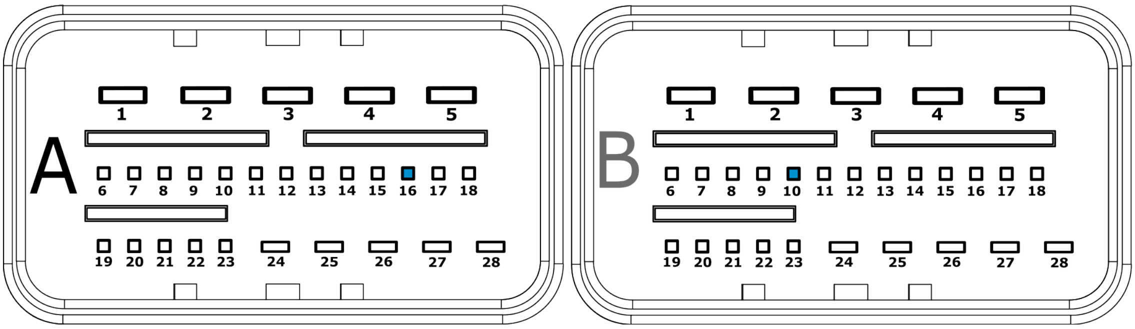


Figure 14: *Sensor supply 5 V pinout*

Connector	Pin	Pin name
A	16	SSUP_0
B	10	SSUP_0

Table 28: *Sensor supply 5 V pin group*

Supported functions

- SSP_5V **(main)**

Functional description

One independent 5 V sensor supply 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.

Safety critical considerations

The fixed 5 V sensor supply can be used to energize external sensors with a defined and steady output voltage.

If at least one safety-critical analog input is assigned to a sensor supply, the analog voltage feedback signal is used for diagnostic purposes implemented in the I/O Driver with a DC claim of 99 %.

Alternatively if no analog input is assigned to a specific sensor supply output, the application software can still read and evaluate the measured voltage level.

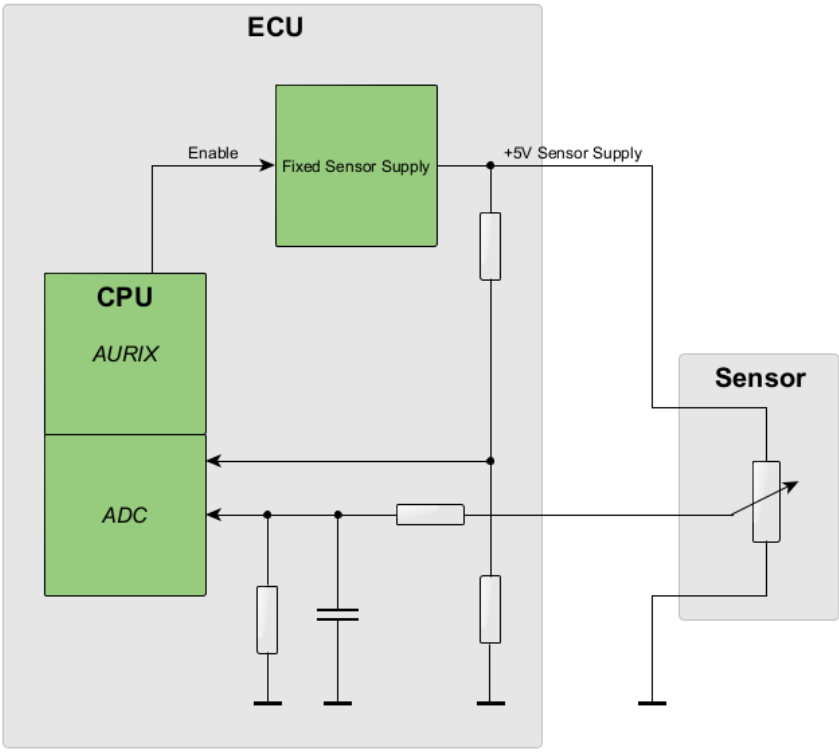


Figure 15: *Sensor supply 5 V*

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 29: *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	150	mA

Table 30: *Sensor supply 5 V characteristics*

11.4 Analog input 4-mode

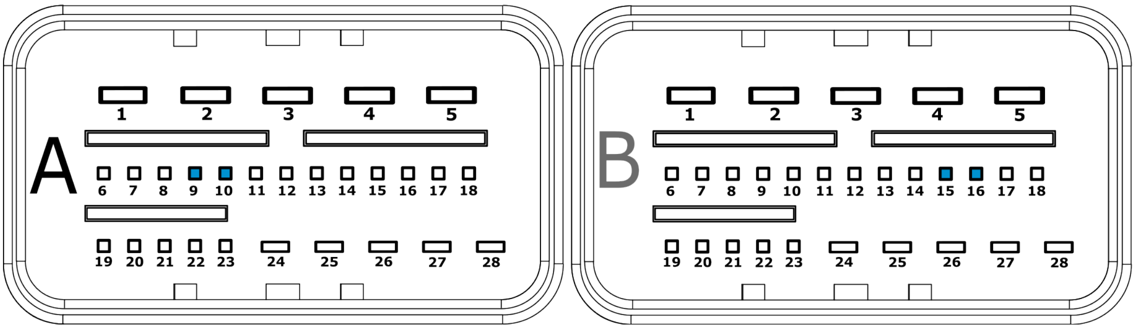


Figure 16: *Analog input 4-mode pinout*

Connector	Pin	Pin name	Function
A	9	AD3_IN_00	ADC_RIN_100K
A	10	AD3_IN_01	ADC_RIN_100K
B	15	AD3_IN_02	ADC_RIN_100K
B	16	AD3_IN_03	ADC_RIN_100K

Table 31: *Analog input 4-mode pin group*

Supported functions

- ADC_RAT_5V **(main)**
- ADC_VIN_5V **(main)**
- ADC_CIN_25mA **(main)**
- ADC_RIN_100K **(main)**
- LED
- DIN_5V

Functional description

4x multipurpose analog inputs with 12-bit resolution.

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

Safety critical considerations

Analog inputs can be used as single input or redundant paths to directly measure the signals of simple binary switches up to current sensing elements, ratiometric output voltages, or resistive sensor types. It can also be used as LED driver in combination with a Sensor Supply output.

For diagnostic purposes, in functional mode voltage/current input, the I/O Driver will provide a 'Signal Range Check' and/or 'Internal comparison' of redundant measurement paths configurable via an API function with a DC claim of 60 % and 99 %.

It is the responsibility of the system integrator to provide diagnostic measures in functional mode resistive and digital input.

Independently of the functional mode, the inputs can be used redundantly claiming a DC of 90-99 % [2].

Maximum ratings

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

Table 32: *Analog input 4-mode maximum ratings*

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

11.4.1 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.

2. range given as concrete DC depends on characteristic (failure modes) of input elements (e.g., sensors)

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.

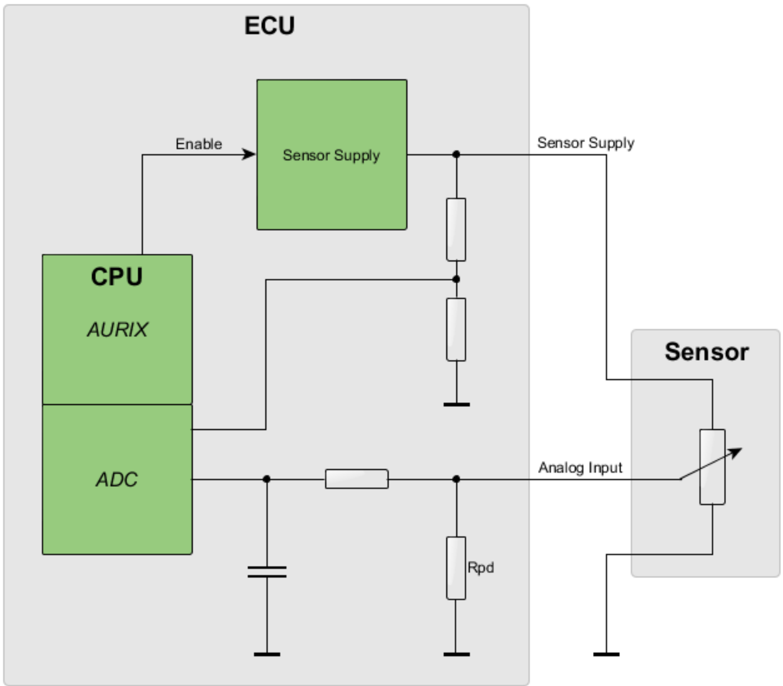


Figure 17: *Analog voltage input (ratiometric)*

Characteristics of 5 V analog input (ratiometric)

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

Table 33: *5 V Analog input (ratiometric) – characteristics*

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

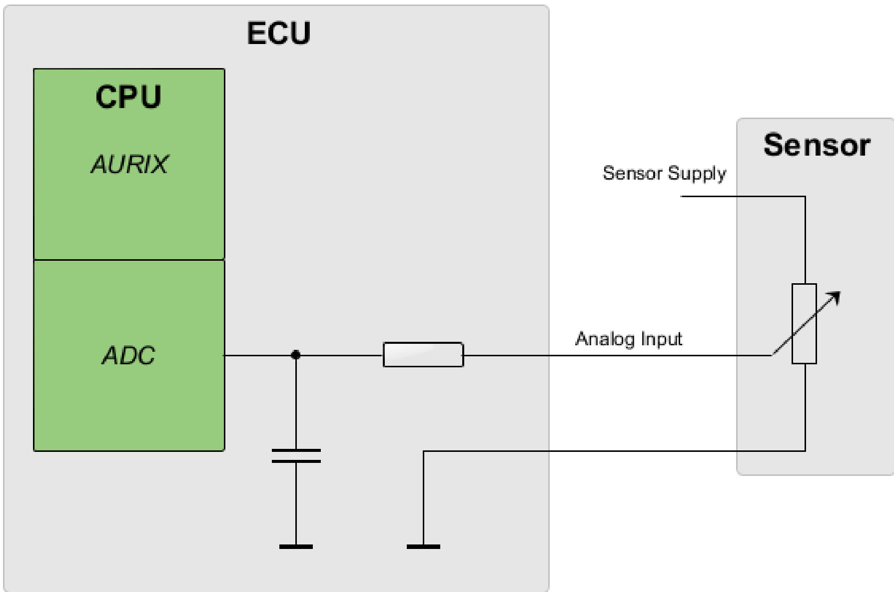


Figure 18: *Analog voltage input (absolute)*

Characteristics of 5 V analog input (absolute)

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

Table 34: *5 V Analog input (absolute) – characteristics*

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

11.4.2 Analog current input

Selected via function ADC_CIN_25mA.

Analog input for 0 to 25 mA sensor measurement.

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

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

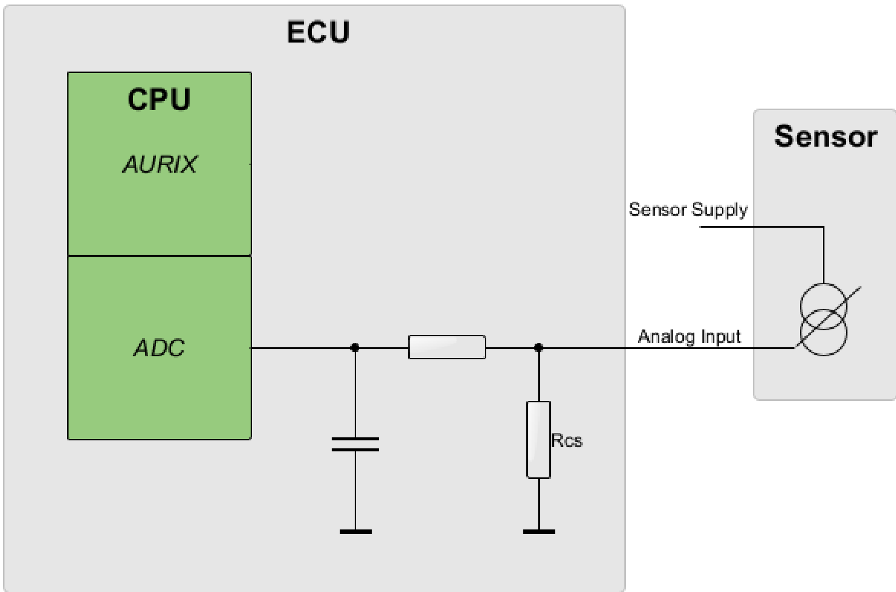


Figure 19: *Analog current input*

Characteristics of analog current input

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

Table 35: *Analog current input – characteristics*

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

11.4.3 Analog resistance input

Selected via function ADC_RIN_100K (see table 31 for applicable pins).

Input for 0 to 100 kΩ resistance sensor measurement.

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

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

The resistance mode may also be used as digital input with switches connected to ground, see figure 22. The use of switches to BAT+ is not allowed.

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

Characteristics of analog resistance input

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

Table 36: *Analog resistance input – characteristics*

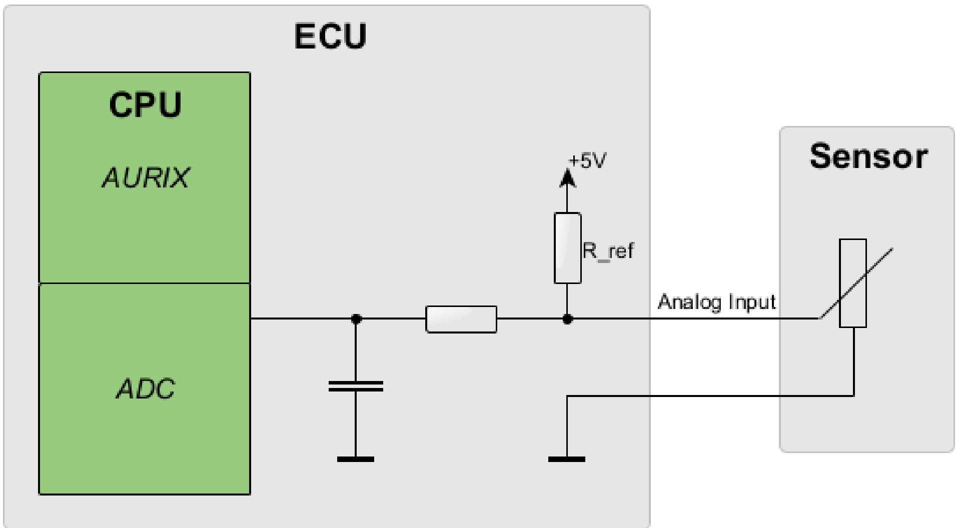


Figure 20: *Analog resistance input*

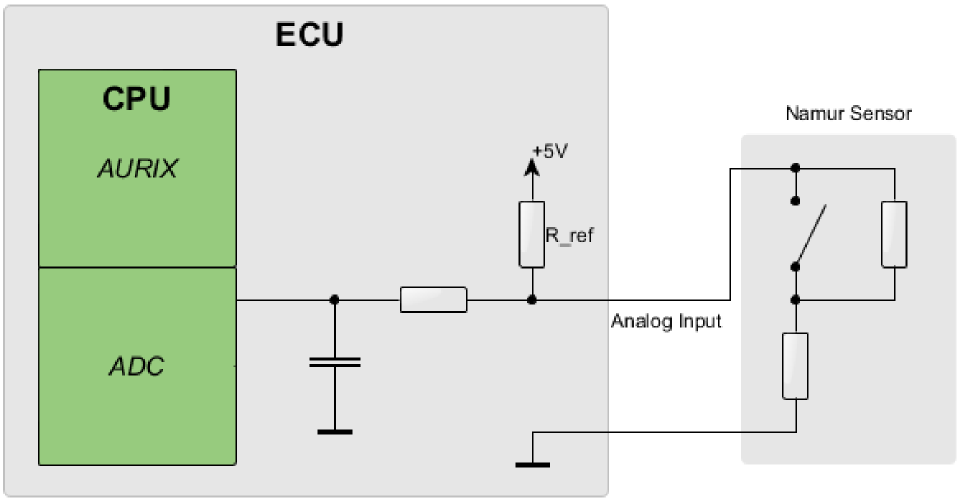


Figure 21: *Namur type sensor (only for switches to ground)*

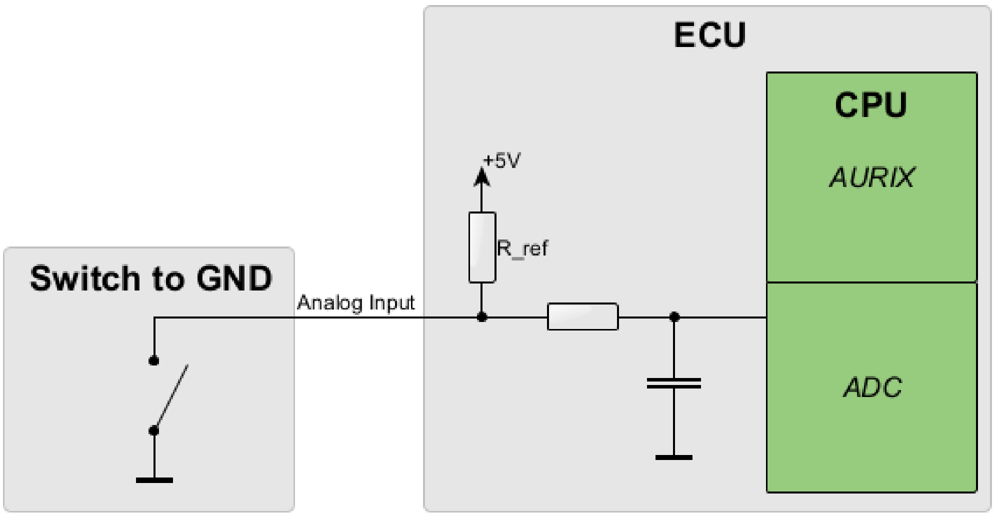


Figure 22: *Switch input (only for switches to ground)*

Tolerance of analog resistance input measurements

Tolerance at T_{ECU} = -40 to +85 °C:

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

Table 37: *Tolerance at T_{ECU} = -40 to +85 °C*

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

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

Table 38: *Tolerance at T_{ECU} = -40 to +125 °C*

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

11.4.4 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	Ω
τ_{in}	Input low pass filter	2.2	3.8	ms
V_{il}	Input voltage for low level [1]		<x>	V
V_{ih}	Input voltage for high level [1]	<x>		V
LSB	Nominal value of 1 LSB		1.22	mV

Table 39: *5 V digital input – characteristics*

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

11.5 Analog input 2-mode

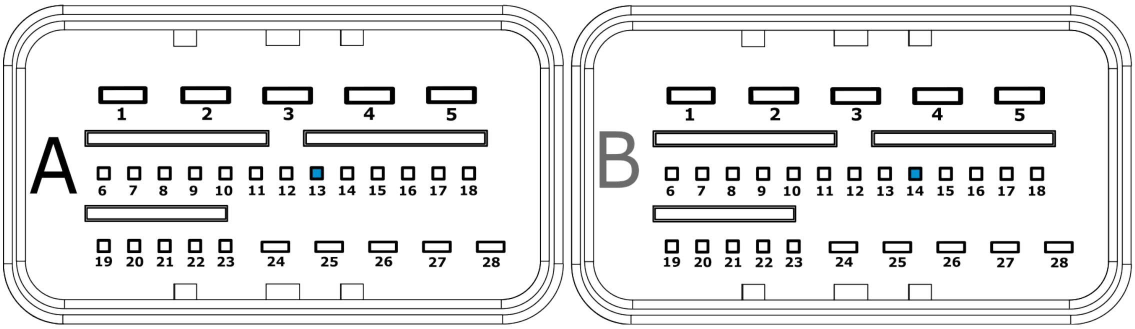


Figure 23: *Analog input 2-mode pinout*

Connector	Pin	Pin name	Function
B	14	LS_08	NODE_ID_00
A	13	LS_09	NODE_ID_01

Table 40: *Analog input 2-mode pin group*

Supported functions

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

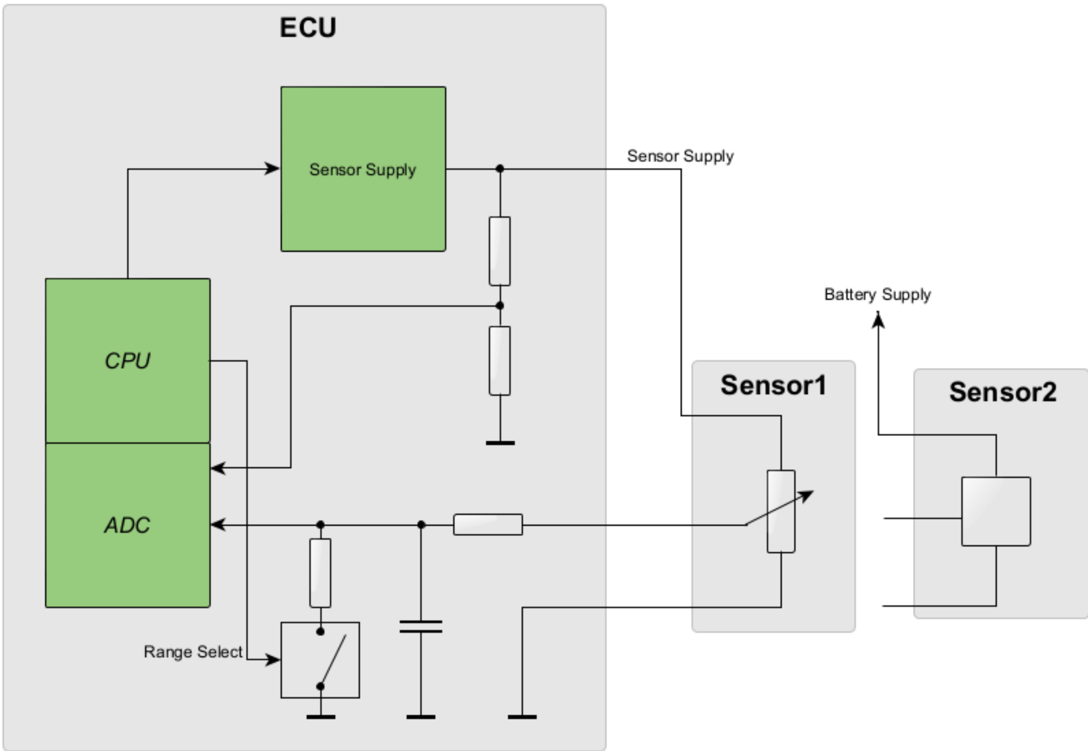


Figure 24: *Analog voltage input (sensor 1 RAT_5V, sensor 2 ABS_5V or ABS_32V)*

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 41: *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).

11.5.1 Analog inputs

Selected via functions ADC_RAT_5V, ADC_VIN_5V and ADC_VIN_32V.

Characteristics of analog voltage input

5 V mode:

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

Table 42: *Characteristics of Analog input 2-mode analog voltage input 5 V*

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

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 (5 V mode)	6.1	6.34	kΩ
V_{pu}	Pull-up voltage (5 V mode)	3	3.2	V
	Resolution		12	bit
$V_{tol\text{-}0}$	Zero reading error [1] [3]	-48	48	mV
$V_{tol\text{-}0}$	Zero reading error [3]	-64	64	mV
$V_{tol\text{-}p}$	Proportional error [1] [3]	-2.1	2.1	%
$V_{tol\text{-}p}$	Proportional error [3]	-2.3	2.3	%
LSB	Nominal value of 1 LSB		8	mV
V_{in}	Input voltage measurement range [2]	0	32	V
V_{in}	Input voltage range [2]	-0.5	$V_{BAT+power}$ +0.5	V

Table 43: *Characteristics of Analog input 2-mode analog voltage input 32 V*

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

11.5.2 Digital inputs

Selected via functions DIN_5V and DIN_32V.

Characteristics of digital input

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	7.5	12	nF
τ_{in}	Input low pass filter	2.2	3.5	ms
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	kΩ
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
R_{pu}	Pull-up resistor (32 V mode)	6.1	6.34	kΩ
V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
	Resolution		12	bit
V_{il}	Input voltage for low level [1] [2]	0	<x>	V
V_{ih}	Input voltage for high level [1] [2]	<x>	32	V

Table 44: *Analog input 2-mode digital input*

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

11.6 Timer input/current loop

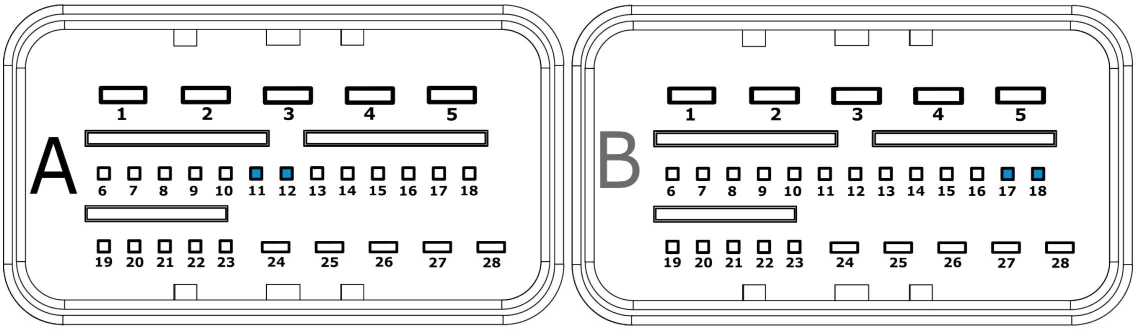


Figure 25: *TIN/CL pinout*

Connector	Pin	Pin name
A	11	Timer_CL_00
A	12	Timer_CL_01
B	17	Timer_CL_02
B	18	Timer_CL_03

Table 45: *TIN/CL pin group*

Supported functions

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

Functional description

4x timer inputs can be used as digital (7/14 mA) current loop sensor inputs. See figure 26.

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

TTControl recommends one of the following 2 options:

1. Use a digital output for supplying the sensor. When the device is switched off, the ECU can perform an application-controlled shutdown, e. g., in order to operate a cooling fan to cool down an engine until the temperature is low enough or to store data in the non-volatile memory of the ECU. If the application controlled shut-down is finished, the ECU switches off and consumes less than 1 mA of battery current (including sensors).
2. `Terminal 15` is used to supply the current loop sensor directly.
   Note that `Terminal 15` is often used to switch relays or other inductive loads directly. This may cause transients in excess of ±50 V, for which the sensor must be specified.

Maximum ratings

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

Table 46: *TIN/CL maximum ratings*

Characteristics

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

Table 47: *TIN/CL characteristics*

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

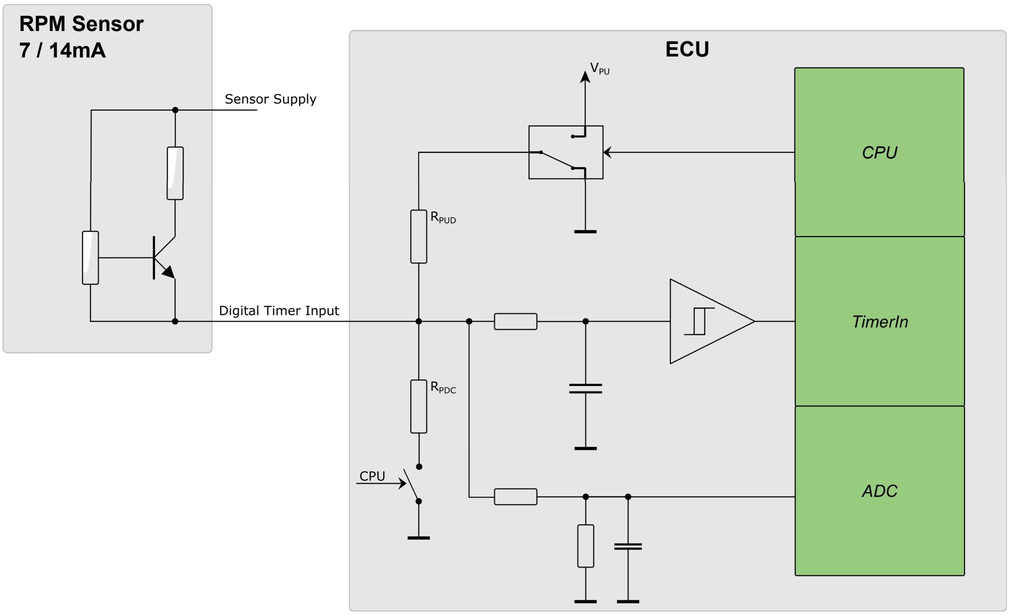


Figure 26: *Digital input for frequency measurement with ABS-type 7/14 mA, 2 pole sensor*

11.6.1 Analog inputs

Selected via functions ADC_VIN_32V, or ADC_CIN_CL_25mA for current mode.

Characteristics of analog voltage input

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

Table 48: *TIN/CL – characteristics of analog voltage input*

Characteristics of analog current input

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

Table 49: *TIN/CL – characteristics of analog current input*

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

11.6.2 Digital input

Selected via function DIN_32V.

Characteristics of digital input

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

Table 50: *TIN/CL – characteristics of 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 my go up to 32 V, but must never exceed the battery supply voltage.

11.7 High-side PWM output

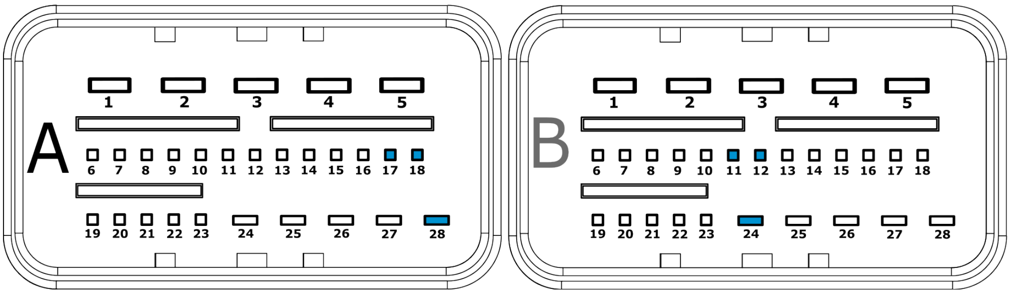


Figure 27: *PWM HS 4A+CM+FM pinout*

Connector	Pin	Pin name
B	11, 12	HS_OUT_00
B	24	HS_OUT_01
A	28	HS_OUT_02
A	17, 18	HS_OUT_03

Table 51: *PWM HS 4A+CM+FM pin groups*

Supported functions

- PWM_HS_4A **(main)**
  - available for PWM HS 4A+CM+FM pin groups only, see table 51
- ADC_VIN_32V
- LED
  - available for PWM HS 4A+CM+FM pin groups only, see table 51
- DIN_32V
- TIN_PWD

Functional description

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

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

For diagnostic and safety reasons, the actual PWM output signal is looped back to a timer input 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.

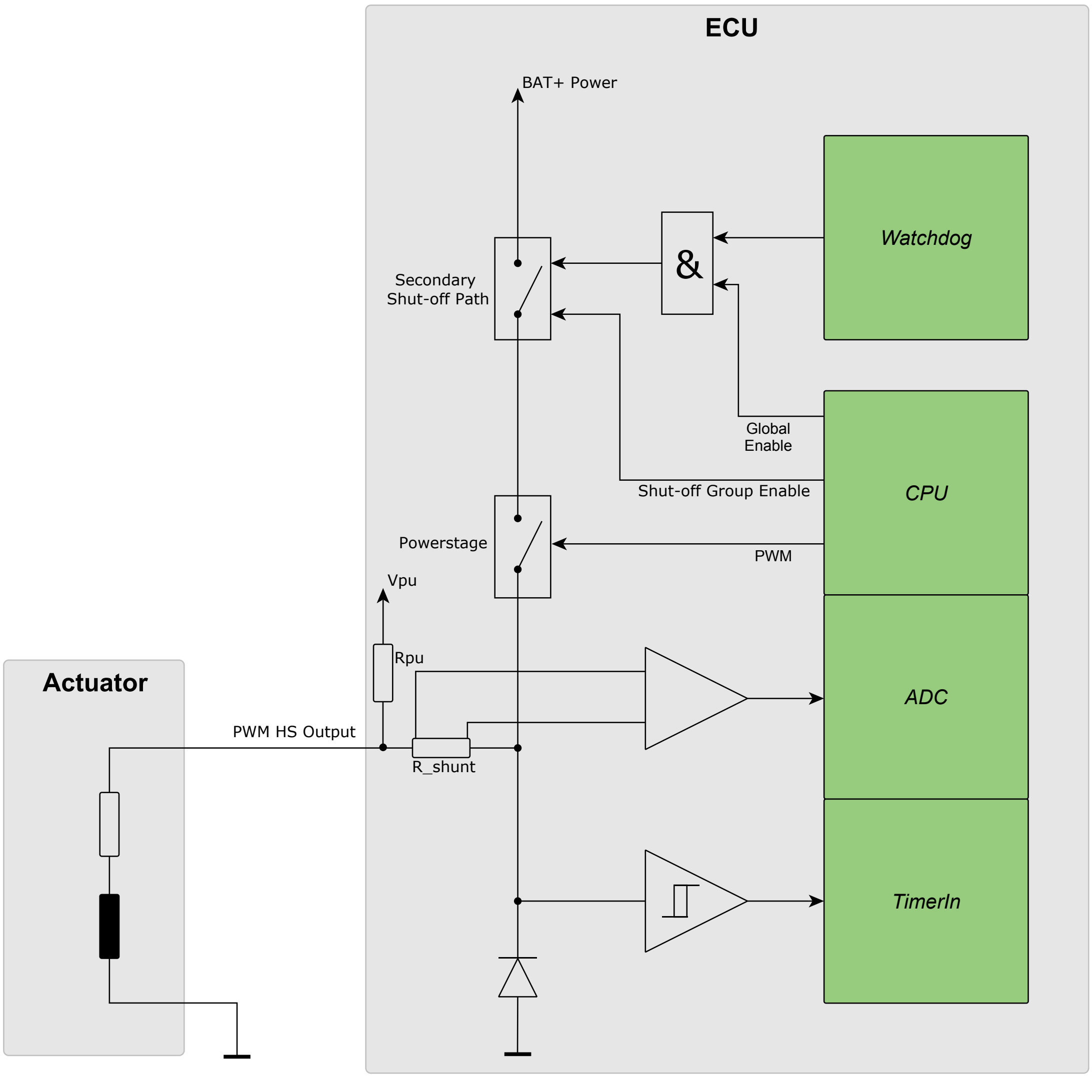


Figure 28: *High-side output stage with PWM functionality*

Power stage pairing

If outputs are used in parallel, always combine two channels from the same double-channel power stage and use the digital output mode. See pinouts 27 to use the right power stage outputs in parallel.

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

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

Mutually exclusive mode

The Volution uses double-channel high-side power stages. For load levelling, it is recommended that loads which are switched on mutually exclusive (which means either load A, or load B is on, but not A and B at the same time), are connected to the same double-channel power stage. This reduces the thermal stress of the components. The power stage pairing is given in section 11.7.

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 section 11.7.2.

Maximum ratings

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

Table 52: *High-side PWM output maximum ratings*

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

11.7.1 Safety critical considerations – high-side PWM output

High-side PWM outputs operating resistive, inductive and capacitive loads feature redundant shut-off paths.

Shut-off paths:

- CPU and Watchdog by disabling PWM high side stages
- CPU and Voltage Monitor by disabling safety switches (overrides a faulty high-side PWM output)

For diagnostic purposes, in functional mode high-side PWM output, the I/O Driver provides a continuous monitoring (PWM feedback) mechanism (plausibility check, detection of open load and short circuit, etc.). In functional mode, high-side PWM Current Measurement provides a signal range check.

It is the responsibility of the system integrator to provide diagnostic measures in functional mode high-side digital output and digital input.

In addition to the online monitoring mechanisms, the shut-off paths are tested at the beginning of each driving cycle.

To provide limp-home functionality (limited operation), two safety switches are available, each featuring a subset of available outputs.

11.7.2 High-side PWM outputs 4 A

Selected via function PWM_HS_4A (see table 51 for applicable pins).

Characteristics of high-side PWM output 4 A

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

Table 53: *High-side PWM output 4 A – characteristics*

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

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 the detection of load loss.

The diagnostic functions are different between PWM and digital operation:

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

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

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

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

◯ = detected
x = not detected

11.7.3 Analog input

Selected via function ADC_VIN_32V.

11.7.4 LED

Selected via function LED.

11.7.5 Digital input

Selected via function DIN_32V.

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

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

Characteristics of digital input

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

Table 56: *High-side PWM output – characteristics of digital input*

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

11.7.6 Timer input

Selected via function TIN_PWD.

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

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

Characteristics of timer input

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

Table 57: *High-side PWM output – characteristics of timer input*

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

11.8 CAN FD

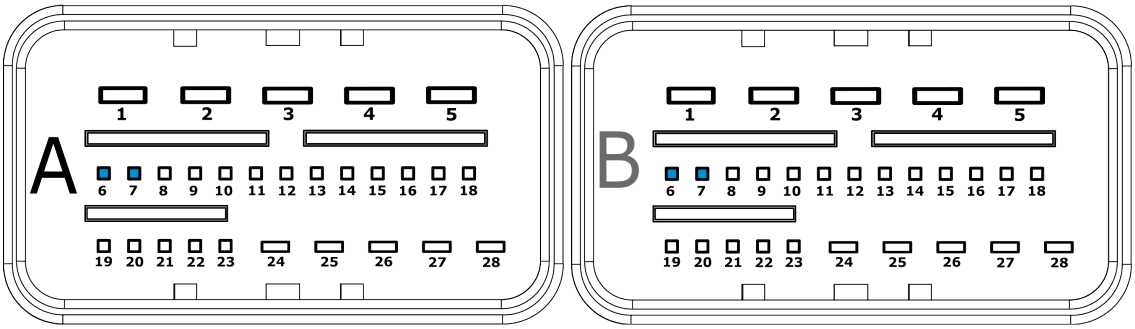


Figure 29: *CAN FD pinout*

Connector	Pin	Pin name
A	7	CAN0_H
A	6	CAN0_L
B	7	CAN1_H
B	6	CAN1_L

Table 58: *CAN FD pin group*

Supported functions

- CAN (**main**)
- CAN_ISO
  - available for interface 0 only
- CAN_WAKE
  - available for interface 1 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 [3]) with bit rates from 1 Mbit/s up to 2 Mbit/s.
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 30 for details.

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

The CAN interface is ISO 11898-2/-5 compliant, except for the input resistance. This input resistance is lower due to an RF termination, which drastically improves EMC immunity and is used, required and proven for its performance in the automotive industry for many years. The differential internal resistance is given in table 60.

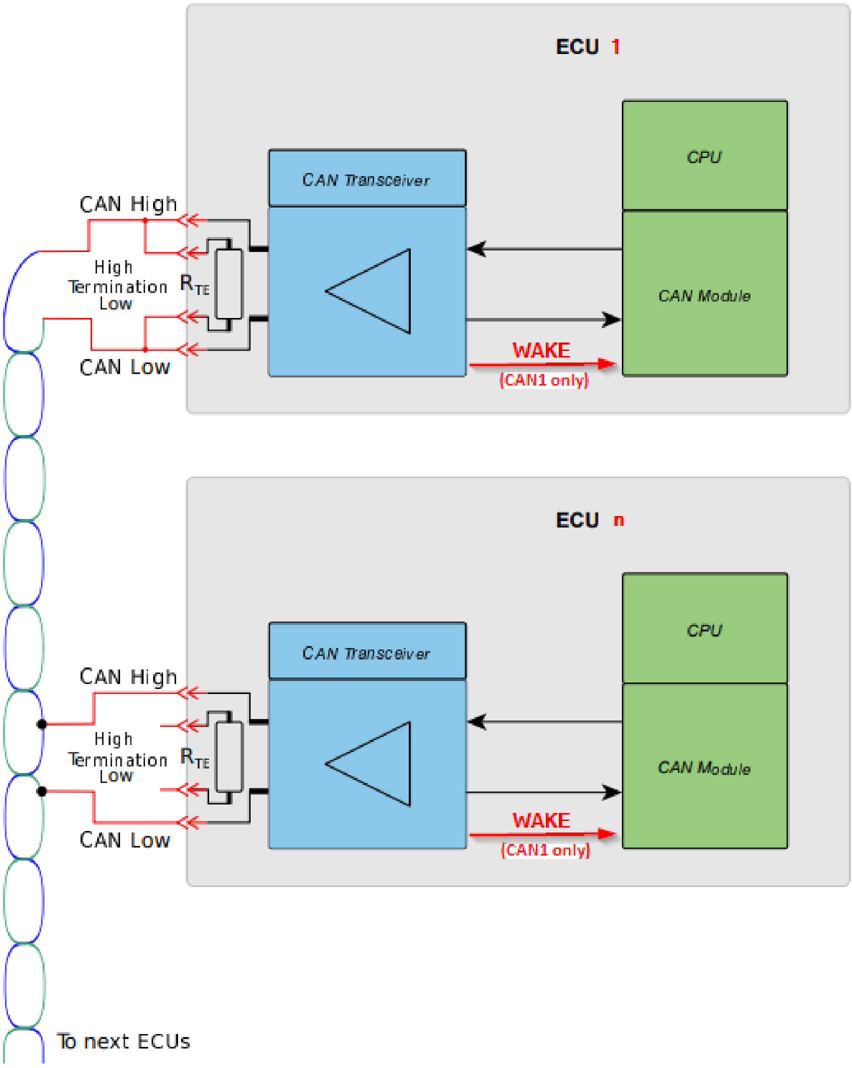


Figure 30: *CAN FD block schematic*

ISOBUS CAN0

Due to the requirements of the ISOBUS standard [4], CAN0 has a lower EMC protection than other CAN interfaces. The high impedance RF termination is removed. To achieve equivalent RF immunity, TTControl recommends using CAN0 with a termination. That is, CAN0 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 32 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 59: *CAN FD maximum ratings*

Characteristics

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

Table 60: *CAN FD characteristics*

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

11.9 CAN termination

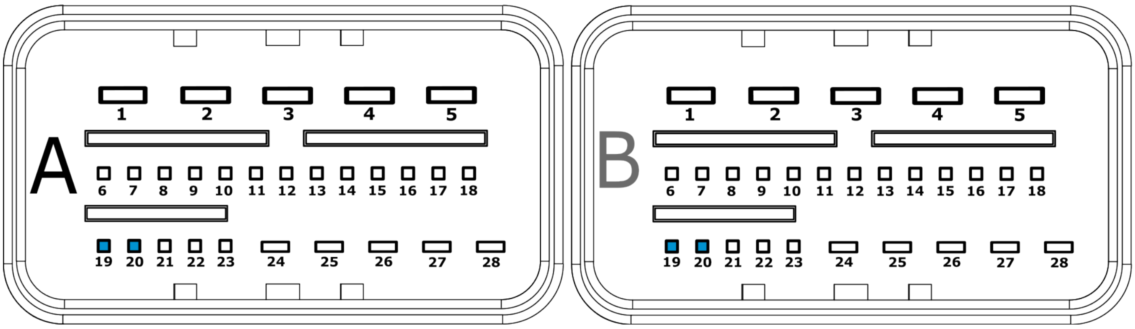


Figure 31: *CAN termination pinout*

Connector	Pin	Pin name
A	20	CAN0_TERM_H
A	19	CAN0_TERM_L
B	20	CAN1_TERM_H
B	19	CAN1_TERM_L

Table 61: *CAN termination pin group*

Supported functions

- CAN_TER **(main)**

Functional description

For easy termination of the CAN bus, there are four built in 120 Ω termination resistors on the Volution which are accessible via 2 connector pins each. They can be used for any CAN port. The 120 Ω termination of a control unit is realized with two serial 60 Ω resistors (split termination). To get an impedance of 60 on the whole bus, a termination resistor of 120 Ω is required in two control units.

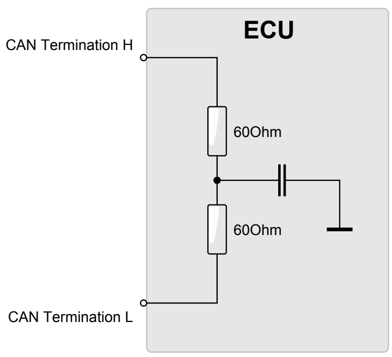


Figure 32: *CAN termination*

11.10 H-Bridge output 8 A

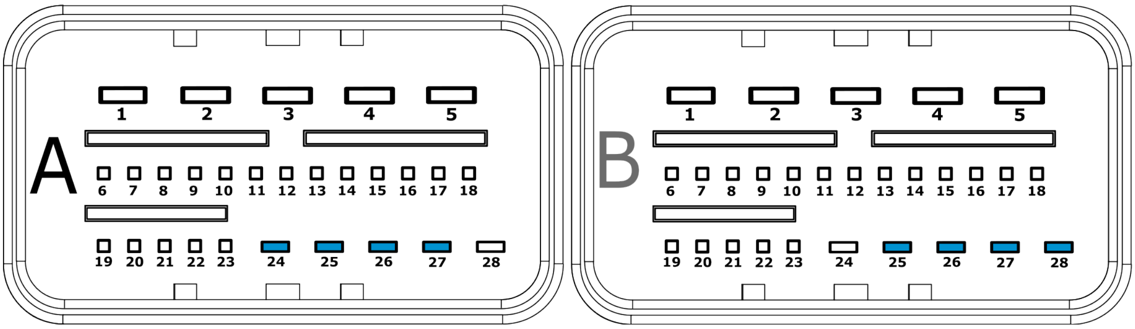


Figure 33: *H-Bridge 8 A pinout*

Connector	Pin	Pin name	H-Bridge output
A	24, 25	HB_OUT_02	H-Bridge 8 A output - 1
A	26, 27	HB_OUT_03	H-Bridge 8 A output - 1
B	25, 26	HB_OUT_06	H-Bridge 8 A output - 2
B	27, 28	HB_OUT_07	H-Bridge 8 A output - 2

Table 62: *H-Bridge 8 A pin groups*

Supported functions

- H-Bridge 8 A

Functional description

Load impedance for proper operation of 8 A output:

- Minimum inductance Value (for brushed DC-motor operation): 700 µH (12/24 V-BN), 450 µH (12 V-BN only)
- Minimum resistance Value (for brushed DC-motor operation): 0.4 Ω (12/24V-BN), 0.2 Ω (12 V-BN only)
- Maximum common-mode capacitive interconnection of up to 1000 pF per H-Bridge output load to vehicle's/chassis' ground-level based on loads winding physics

NOTE However there will be a kind of short-protection with shut-off also of course, i.e. necessary in case of a motor's winding or cable harness fault.

It is able to provide a higher output current to the maximum of 25 A for a limited time of 50 ms, then a linear ramp down to 8 A occurs within in the next 50 ms. This can be used as a startup current.

The Volution 144 has an output frequency of 10 kHz.

The Volution 144 detects and shuts of at short to ground, open load, short to VBAT.

Due to use of a special PWM technique that is aligned in the center and a synchronized phase shifting between all H-Bridge outputs, the acting output PWM frequency on the motor is 20kHz. This results in a smaller input current ripple of the ECU and smaller output ripple current, caused by the motors behaviour, due to the faster switching frequency.

From motor current control perspective, all operating modes (e.g. forward drive, reverse drive and breaking), are encoded in one PWM, resulting in a unipolar 4 quadrant motor controller.

The Volution 144 measures the low-side current every cycle and provides a mean current over 2 periods. Other currents are able to be calculated off the basis of this measurement.

The Volution 144 has a built-in current control, which is based off a PID regulator, that needs to be parametrized by the I/O driver. The application can set, dependent on the motor system, proportional, integral and differential values for the controller that is being worked with.

It is built with the following current limitations:

- A software pd controlled current limiter with a maximum current of 25 A.
- The hardware limitations for short to ground and short to battery are 61 A at 25 °C and 36 A at 110 °C.
- Time dependent (ramp down after 50 ms to nominal value).
- Temperature dependent:
  - Above 93 °C: No increased startup current possible. The maximum is the nominal limit
  - At 120 °C: Lowest value depending on controller configuration (~0 A)
  - In between linear interpolation

NOTE Parallel operation of the H-Bridge outputs to the same dedicated load is permitted. Cable wire-diameter nominal values shall be equal. This applies especially for outputs that are to be connected via multiple connector pins. The difference in cable wire-length shall be less than 10%

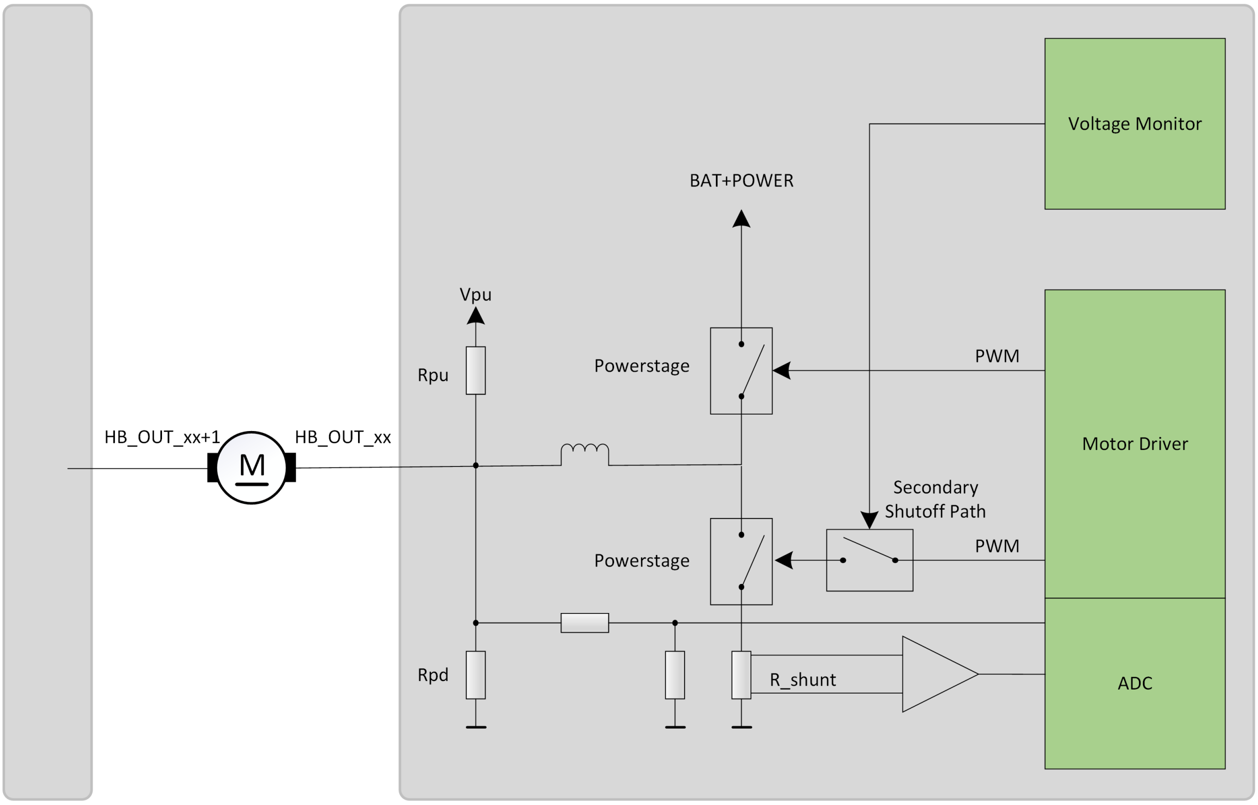


Figure 34: *Half-Bridge part of the H-Bridge output stage*

11.11 H-Bridge output 16 A

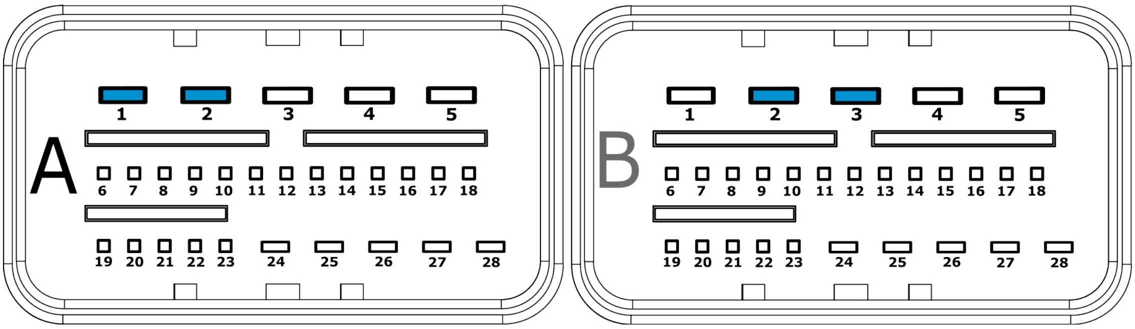


Figure 35: *H-Bridge 16 A pinout*

Connector	Pin	Pin name	H-Bridge output
A	1	HB_OUT_00	H-Bridge 16 A output - 1
A	2	HB_OUT_01	H-Bridge 16 A output - 1
B	2	HB_OUT_04	H-Bridge 16 A output - 2
B	3	HB_OUT_05	H-Bridge 16 A output - 2

Table 63: *H-Bridge 16 A pin groups*

Supported functions

- H-Bridge 16A

Functional description

Load impedance for proper operation of 16 A output:

- Minimum inductance Value (for brushed DC-motor operation): 500 µH (12/24 V-BN), 350 µH (12 V-BN only)
- Minimum resistance Value (for brushed DC-motor operation): 0.2 Ω (12/24 V-BN), 0.1 Ω (12 V-BN only)
- Maximum common-mode capacitive interconnection of up to 1000 pF per H-Bridge output load to vehicle's/chassis' ground-level based on loads winding physics

NOTE However there will be a kind of short-protection with shut-off also of course, i.e. necessary in case of a motor's winding or cable harness fault.

It is able to provide a higher output current to the maximum of 50 A for a limited time of 50 ms, then a linear ramp down to 16 A occurs within in the next 50 ms. This can be used as a startup current.

The Volution 144 has an output frequency of 10 kHz.

The Volution 144 detects and shuts of at short to ground, open load, short to VBAT.

Due to use of a special PWM technique that is aligned in the center and a synchronized phase shifting between all H-Bridge outputs, the acting output PWM frequency on the motor is 20kHz. This results in a smaller input current ripple of the ECU and smaller output ripple current, caused by the motors behaviour, due to the faster switching frequency.

From motor current control perspective, all operating modes (e.g. forward drive, reverse drive and breaking), are encoded in one PWM, resulting in a unipolar 4 quadrant motor controller.

The Volution 144 measures the low-side current every cycle and provides a mean current over 2 periods. Other currents are able to be calculated off the basis of this measurement.

The Volution 144 has a built-in current control, which is based off a PID regulator, that needs to be parametrized by the I/O driver. The application can set, dependent on the motor system, proportional, integral and differential values for the controller that is being worked with.

It is built with the following current limitations:

- A software pd controlled current limiter with a maximum current of 48 A.
- The hardware limitations for short to ground and short to battery are 112 A at 25 °C and 67 A at 110 °C.
- Time dependent (ramp down after 50 ms to nominal value).
- Temperature dependent:
  - Above 93 °C: No increased startup current possible. The maximum is the nominal limit
  - At 120 °C: Lowest value depending on controller configuration (~0 A)
  - In between: Linear interpolation

NOTE Parallel operation of the H-Bridge outputs to the same dedicated load is permitted. Cable wire-diameter nominal values shall be equal. This applies especially for outputs that are to be connected via multiple connector pins. The difference in cable wire-length shall be less than 10%

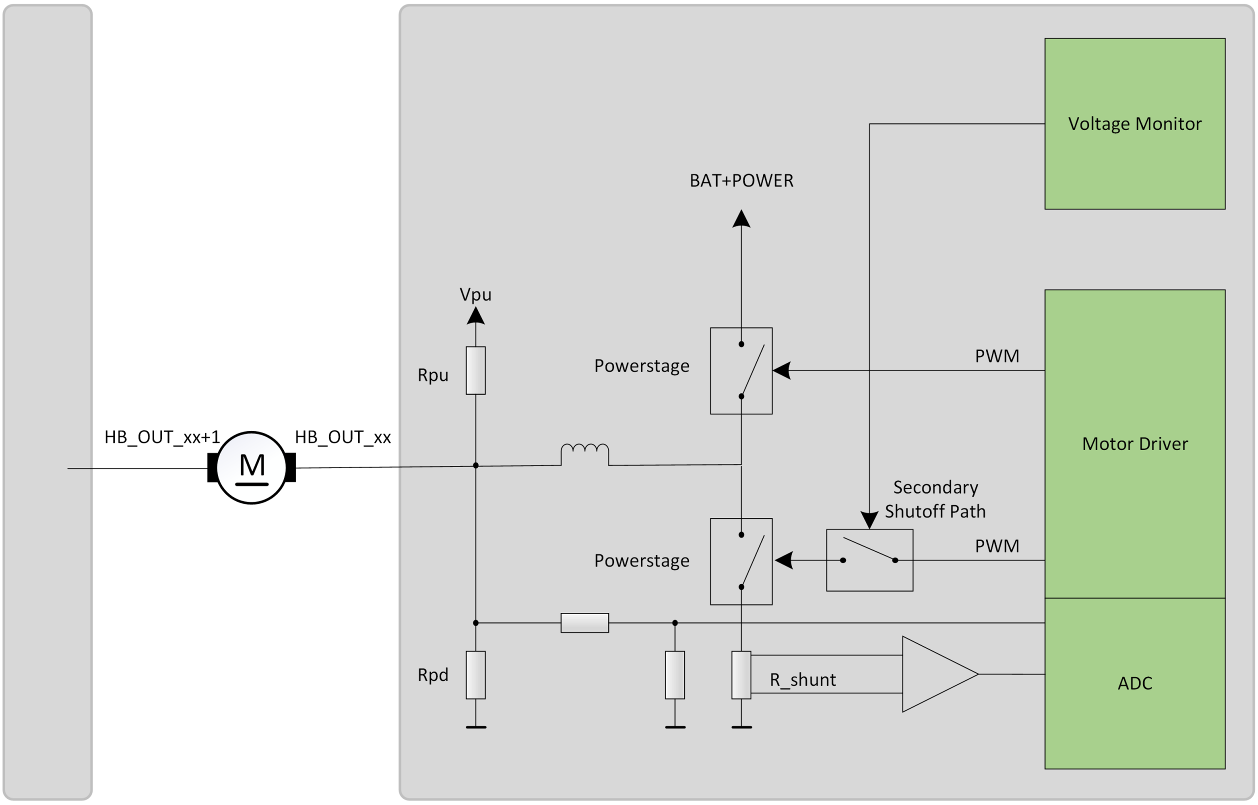


Figure 36: *Half-Bridge part of the H-Bridge output stage*

11.12 Emergency shut-off

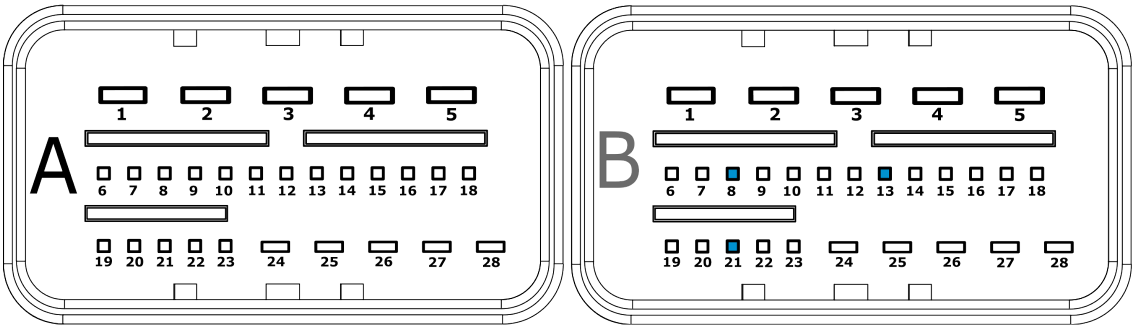


Figure 37: *Emergency shut-off pinout*

Connector	Pin	Pin name
B	8	EMS_IN_A
B	21	EMS_IN_B
B	13	EMS_OUT

Table 64: *Emergency shut-off pin group*

Supported functions

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

Functional description

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

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

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

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

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

Safety critical considerations

Two dedicated input pins in combination with a dedicated voltage output (alternating signal) are provided to directly connect up to three emergency stop buttons (only featuring one source signal). The reaction in case of activating the emergency stop button can be configured by the system integrator/customer via the APDB header, and allows switching off one of the two shut-off groups, or both simultaneously.

The type of emergency stop button (normal-open, normal-closed or mixed) can also be configured in the APDB.

The emergency shut-off functionality is executed independently of the application software.

For diagnostic purposes, the I/O Driver provides a continuous monitor mechanism to detect open load (e.g., broken wires) or short circuits (e.g., input wires or button internally).

Maximum ratings

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

Table 65: *Emergency shut-off maximum ratings*

EMS_OUT Characteristics

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

Table 66: *EMS_OUT characteristics*

EMS_IN Characteristics

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

Table 67: *EMS_IN characteristics*

11.12.1 PVG output

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 drive cycle.

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 Volution uses the BAT+ CPU pin as a reference voltage input. The principle schematic is shown in figure 38. The output is open loop controlled. The ADC input is for diagnostic purposes only and can be evaluated by the application software.

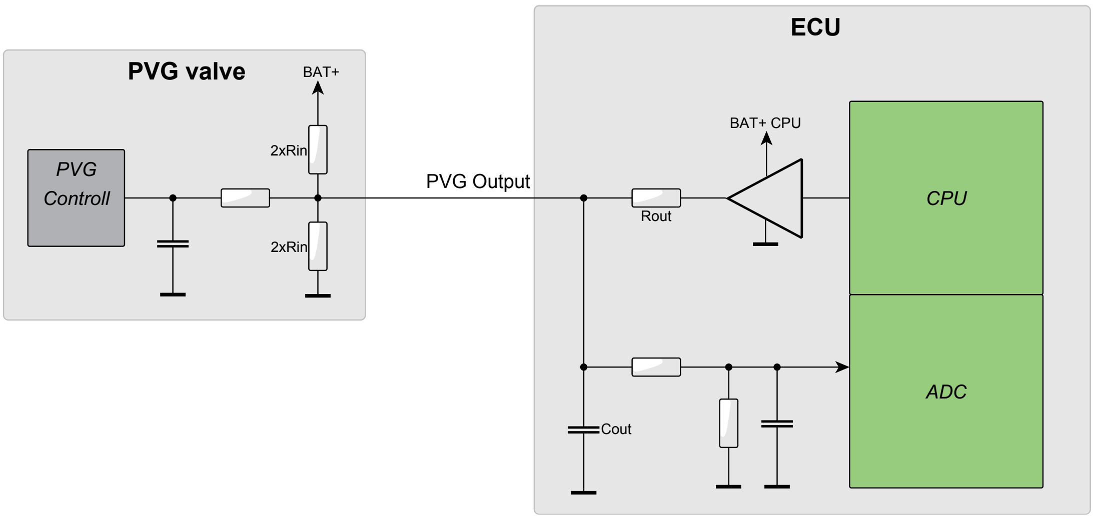


Figure 38: *Output stage in PVG mode*

Characteristics of PVG

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

Table 68: *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.

11.12.2 V_{OUT} output

Selected via functions LPO_VOUT_LP.

In V_{OUT} mode, the output 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 drive cycle.

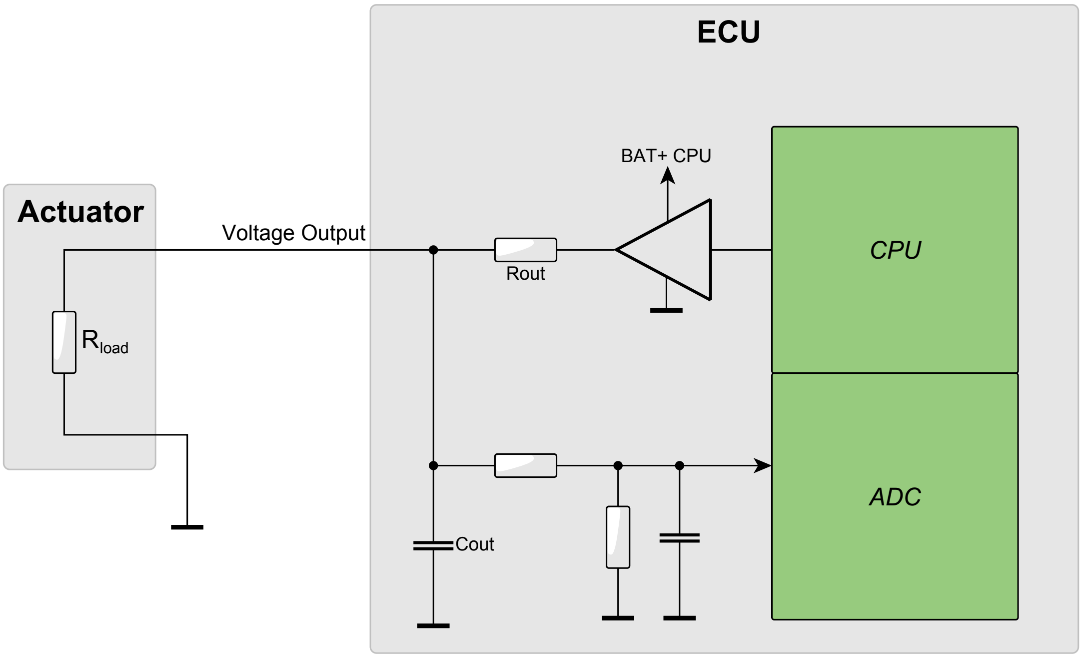


Figure 39: *Output stage in V_{OUT} mode*

Characteristics of V_{OUT}

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

Table 69: *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 RL = 10 kΩ to BAT-, the open load voltage (Vset) must be set to 12.55 V (Vset $= V_{OUT} \frac{RL+2.55\ k}{RL}$) to get an output voltage of 10 V.
[2] T_{ECU} = -40 to +85 °C
[3] The total measurement error is the sum of zero reading error and the proportional error.

12 Application notes

12.1 Ground loss detection (BAT-)

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

Conditions for an unwanted fault current:

- Interruption of the BAT- connection
  - the BAT- connection cabling is interrupted
  - connector B (which carries all BAT- connections) disconnects, while connector A remains properly connected

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

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

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

Preventative action

To prevent this type of failure:

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

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

- Connect the housing of the Volution 144 to GND by mounting it directly to the chassis, or by using a crimp (see section 8.1.2) with a cable connected to BAT- redundantly to the mounting base.

NOTE The Volution 144 housing is not connected to BAT- internally. However, there is a circuit monitoring the housing voltage relatively to BAT- supply. Both of these voltages are equal when the ECU is functioning as expected.

- Enable the safety-related software for this function.

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

12.2 PT100 sensors

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

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

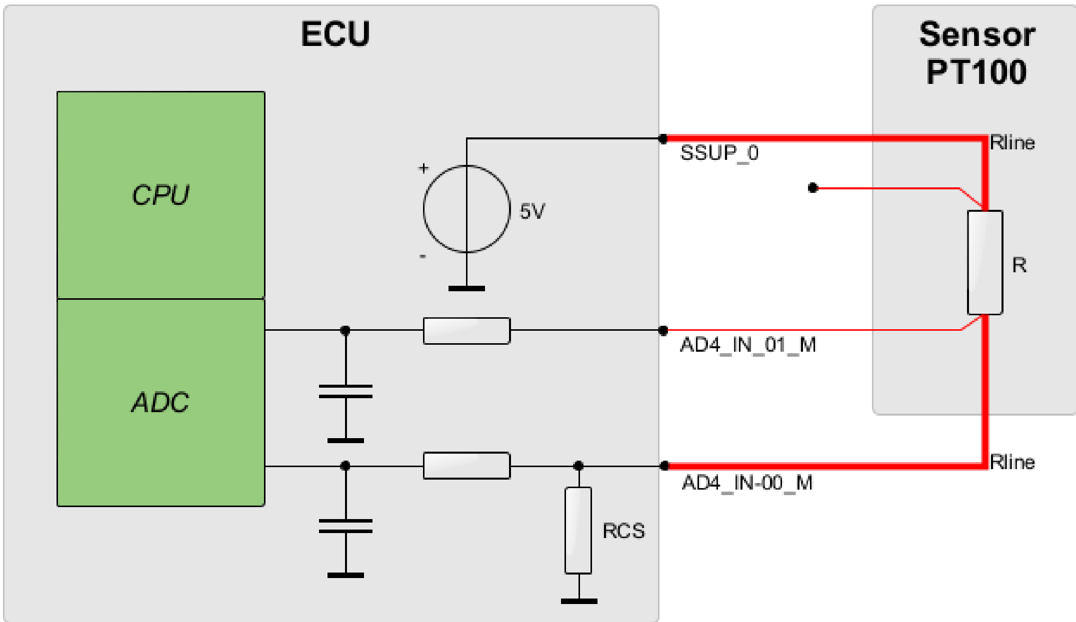


Figure 40: *PT100*

Calculation

U_PT100 = U_SSUP - AD4_IN_01_M - (AD4_IN_01_M - AD4_IN_00_M)

*U_PT100 = U_SSUP - 2 * AD4_IN_01_M + AD4_IN_00_M*

I_PT100 = AD4_IN_00_M + AD4_IN_00_R

R_PT100 = U_PT100 / I_PT100

12.3 Power stage alternative functions

This application note describes the DOs and DON'Ts when using the alternative functions of the Volution 144 high-side power stages.

12.3.1 High-side output stages

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

BAT+ Power +0.5 V

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

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

12.3.2 Wiring examples

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-.

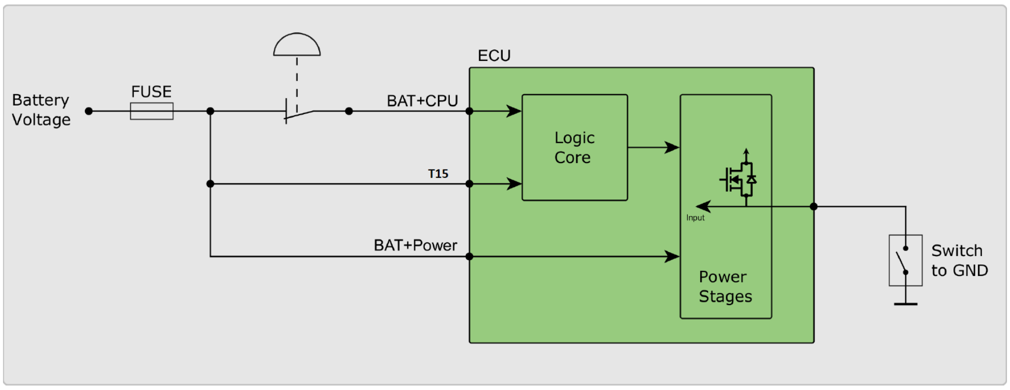
  Short circuits to battery supply need to be excluded in the system architecture.
- Battery supplied switches and sensors need to be supplied via a digital output of the Volution.

12.3.2.1 Valid Wiring Examples

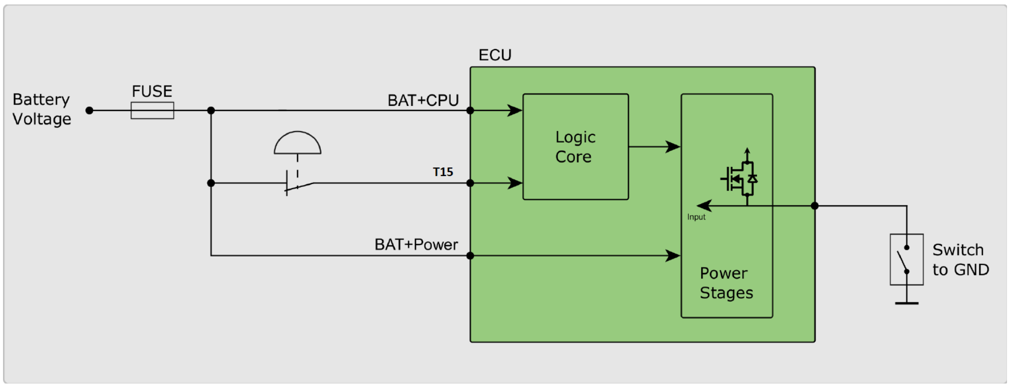
The following wiring examples for external switches and analog sensors connected to battery supply (PWM/digital high-side output) and to GND are allowed and can help avoiding system fault scenarios:

Switch connected to GND:

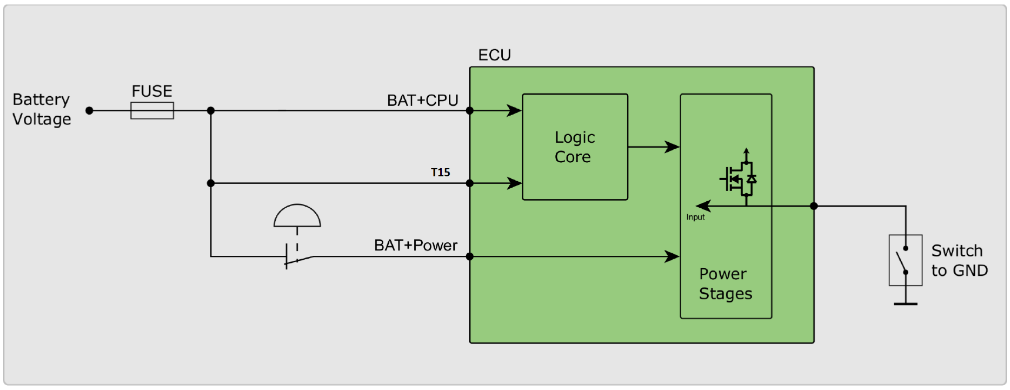
Usage of external switches connected to GND. Short circuits to battery supply needs to be excluded in the system architecture.



(a) *BAT+CPU*



(b) *T15*



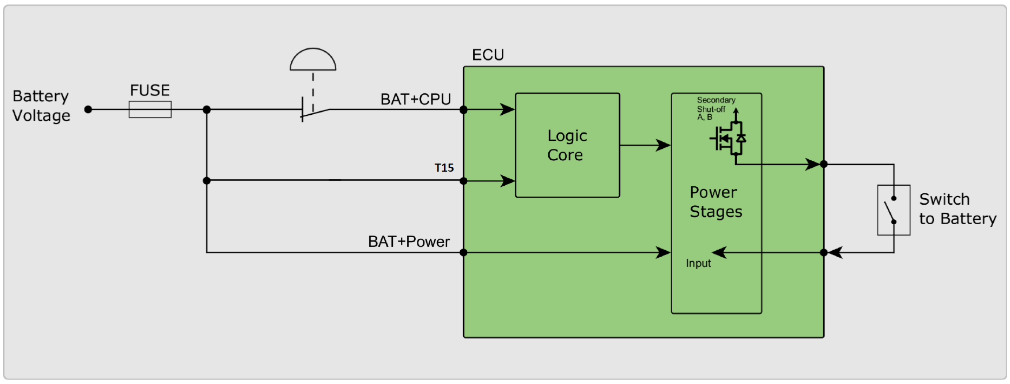
(c) *BAT+Power*

Figure 41: *Switches connected to GND*

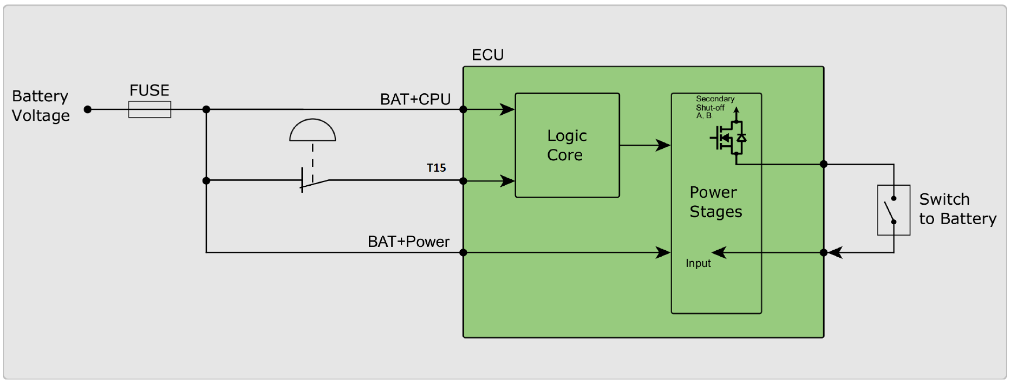
Switches connected to high-side PWM output stage:

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

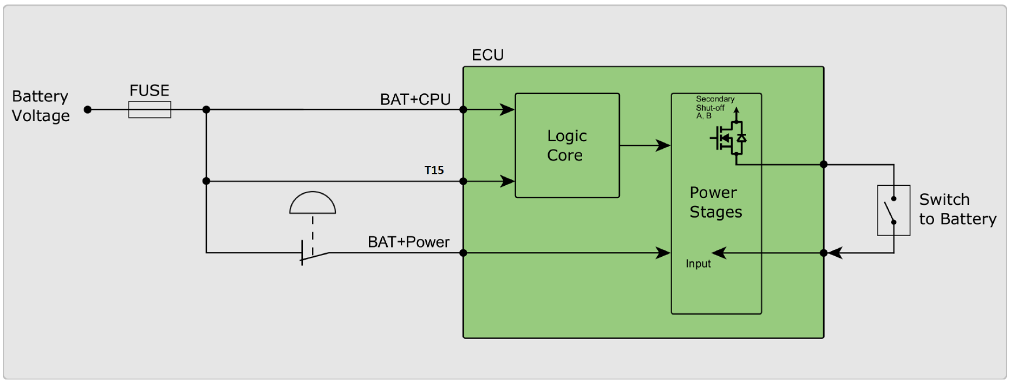
The sourcing high-side PWM output stage (HS_PWM_00 - HS_PWM_17) must be out of the same secondary shut-off path (A or B) as the alternative input pin. For example HS_PWM_00 (output/source) supplies a digital sensor and its sensor output is monitored by HS_PWM_07 (input), both IOs are out of secondary 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 42: *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 Volution digital high-side output pin, the switch/sensor output is monitored by an alternative (digital high-side) input.

HS_OUT_18 - HS_OUT_27 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_18 - HS_OUT_27 is used, the connected sensor must be supplied by a digital output stage from these outputs.

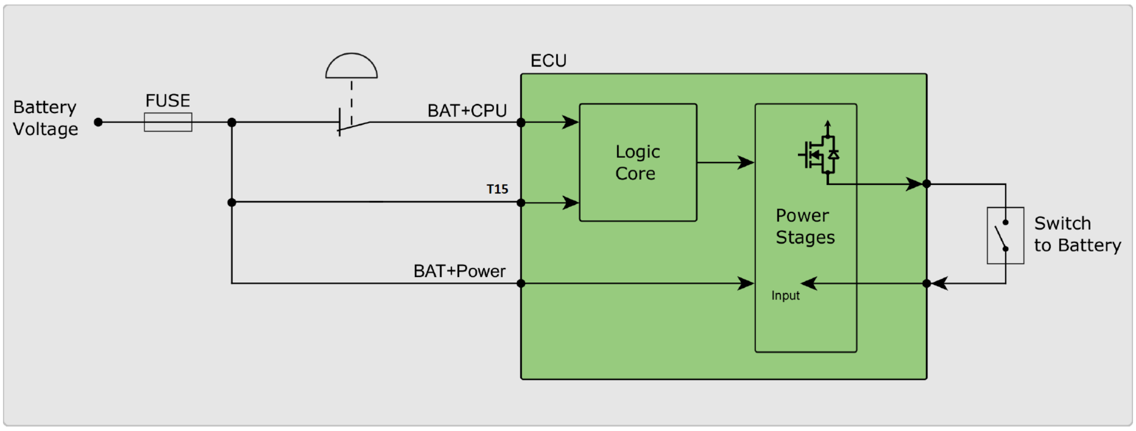


Figure 43: *Switch connected to digital high-side output stage*

12.3.2.2 Invalid Wiring Examples

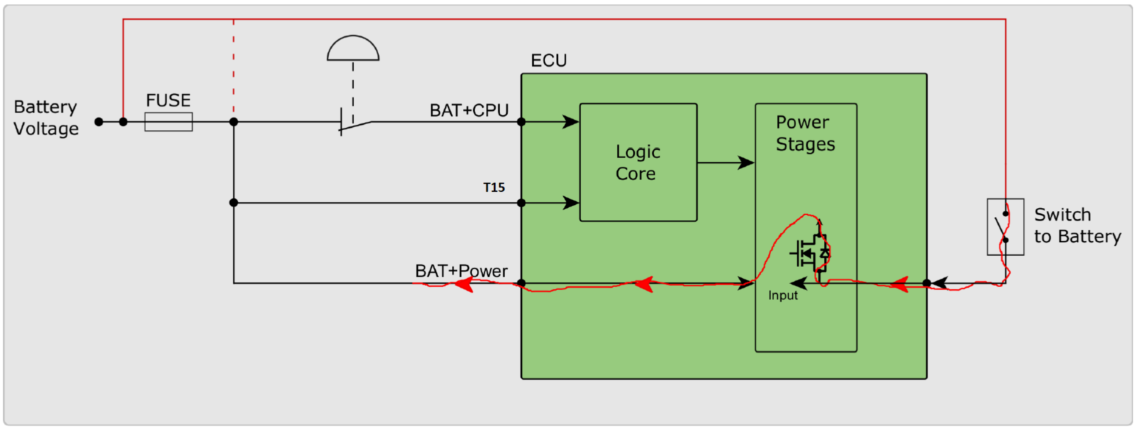
The following wiring examples of external switches or analog sensors connected to battery supply are not allowed and must be avoided for safety critical systems.

Nonconforming wiring can lead to the destruction of the Volution.

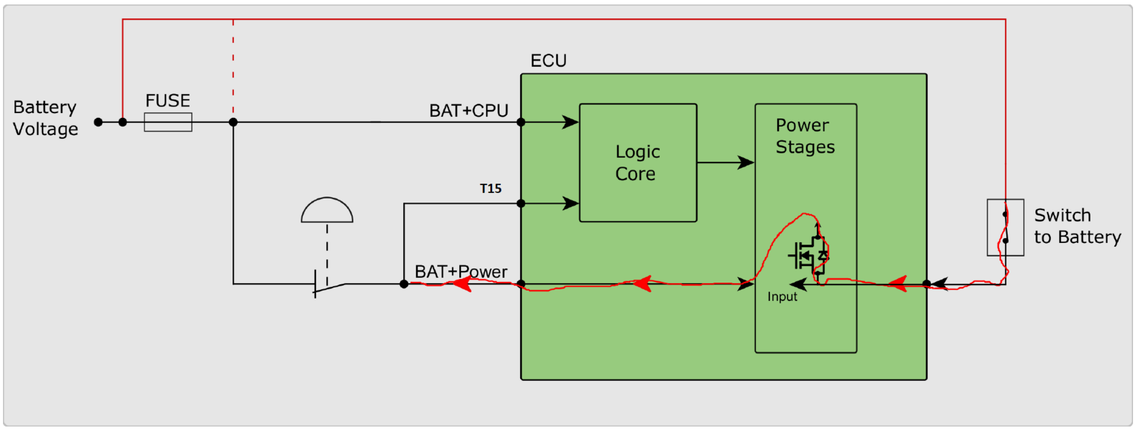
Stop switch / blown fuse / T15 wiring

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 44: *Switches connected to battery supply*

12.4 Cable harness

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

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.

NOTE It is necessary to use wires with the same total cross sectional area and length (≥2m) 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-.

12.5 Ground connection of housing

The Volution 144 housing is not directly connected to ground. In the case of chassis mounting, this prevents ground loops or excessive current flow through the Negative Power Supply (BAT-) pins, and cables in case of partly power connection loss in the negative supply rail of the vehicle. Instead of a direct connection, the housing is capacitively connected to BAT-. In order to discharge static electricity, a 1 MΩ resistor is equipped between the housing and BAT-.

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

12.6 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.

12.7 Handling of high-load current

Load distribution

The permanent input current of the Volution 144 $I_{in\text{-}max}$ 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 Volution 144 in its temperature range (-40 °C to +85 °C) the total current $I_{in\text{-}total}$ 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 00 and output channel 01 is only activated in state 2; never activated at the same time), then, as a rule of thumb, these outputs should be driven by a double-channel high-side power stage due to only one active channel at a time.

Total load current

Operating all high-side and H-Bridge power stages ON with maximum rated current (4, 8 and 16 A) that would result in a load current $I_{in\text{-}total}$ in excess of 64 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 $I_{in\text{-}total}$. This value can only be applied if an equal load distribution over different power stages is ensured - which implicit a different $I_{in\text{-}total}$ limit set by the different number of power stages in each Volution 144 variant, e.g., the same current distributed over 8 output stages cannot be driven with 4 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 H-Bridge output stage supply pins BAT- Power, up to 3 pins can be used in parallel to increase the overall current capability.

For the maximum battery supply current of 48 A, all 3 pins must be used in parallel with the maximum possible wire size (FLRY type) to reduce voltage drop and prevent overheating of the crimp contact. To define a proper cabling, it is important to calculate the maximum average battery supply current first.

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

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

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

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

Example:

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

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

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

13 Debugging

The Volution 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 Volution device, you will need the components as shown in tables below. Items shown in table 70 are provided in the Volution device Starter Kits. Items shown in table 71 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 70: *Debugging components (TTControl GmbH)*

Component	Description	Order code	Supplier
Power Debug Interface USB 3	Lauterbach base station	LA-3500	Lauterbach
Debugger for TriCore Automotive PRO	ribbon cable, to connect debug adapter to base station	LA-3203 LA-2707[3]	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 71: *Debugging components (other)*

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

Items in table 71 listed with two order codes refer to the current and former order codes. Please contact the supplier for further clarification, if needed.

3. former order code

Document Number:
D-TTC-H-BRIDGE-G-20-001

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 45 for further details.
16-pin OCDS	Alternative to 16-pin JTAG. See figure 46 for further details.
6-pin FTDI	USB-TTL-232R connector (5 V) for the UART connection. See figure 47 for further details.
10-pin JTAG/DAP/UART	Connection to the ECU. See figure 48 for further details.

Table 72: *JTAG debug adapter connectors*

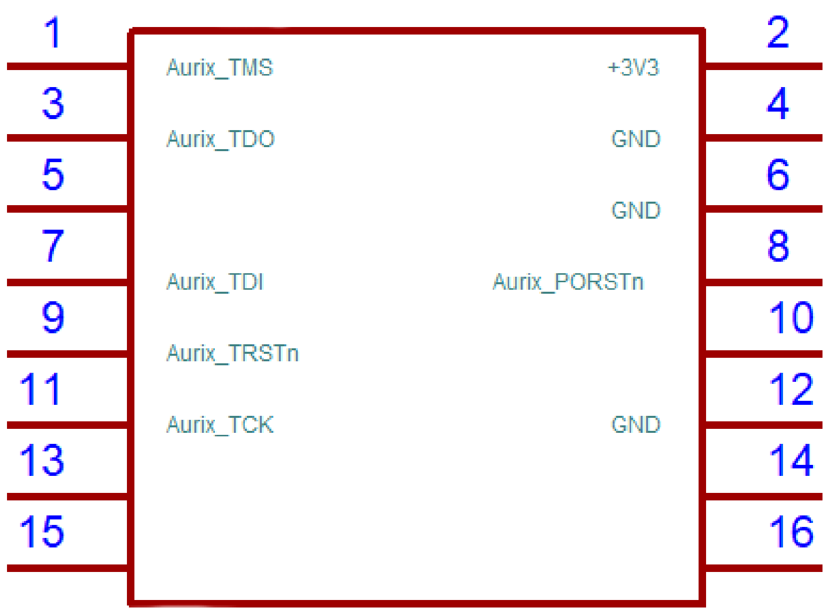


Figure 45: *Pinning schematic for the JTAG connector*

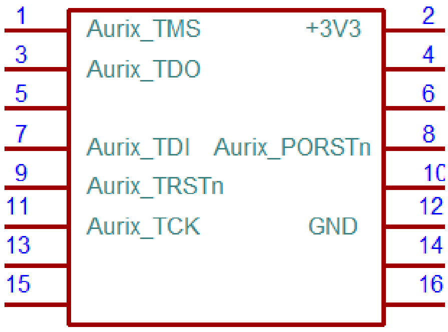


Figure 46: *Pinning schematic for the OCDS connector (JTAG alternative)*

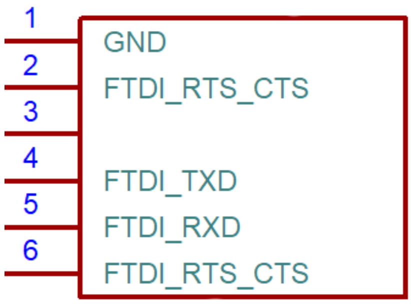


Figure 47: *Pinning schematic for the USB-FDTI connector*

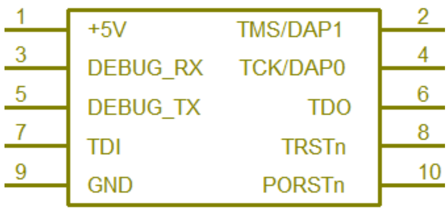


Figure 48: *Pinning schematic for the ECU interface*

13.3 TRACE32

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

Glossary

Entry	Description
ADC	Analog-to-Digital Converter
CAN	Controller Area Network
CAN FD	Controller Area Network Flexible Data-Rate
CL	Current Loop
CM	Current Measurement
CPU	Central Processing Unit
CS	Current Sense
Core SFR	Core Special Function Register (also given as CFSR)
DAM	Default Application Memory
DAP	Debug Access Port
DCWS	DFlash Corrected Wait State
DFLASH (DF)	Data Flash Memory
DLMU	Direct-connected Local Memory Unit
DMI	Data Memory Interface
DSPR	Data Scratchpad RAM
ECU	Electronic Control Unit
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMEM	Extension Memory
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
HS	High-side

Entry	Description
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 Measurement
PWS	PFlash Wait States
RAM	Random Access Memory
SRAM	Static Random Access Memory
SRI	Shared Resource Interconnect
SSA	Safety Switch A
SSB	Safety Switch B
STR	Summary of Test Reports
TBD	To Be Defined

Entry	Description
TCM	Trace or Common Memory
TTC	TTControl
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
UTP	Untwisted Pair
XCM	eXtended Common Memory
XTM	eXtra Trace Memory

References

[1] 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.

[2] 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.

[3] 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.

[4] 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.

[5] TTControl GmbH. TTC H-Bridge Summary of Test Reports. D-TTC-H-BRIDGE-AC-02-001, TTTech, BU Off-Highway, Product Development.

[6] TTControl GmbH. Volution 144 ECU Datasheet. D-TTC-H-BRIDGE-E-20-001, TTTech, BU Off-Highway, Product Development.

[7] TTControl GmbH. Volution 144 I/O Driver Manual. D-TTC-H-BRIDGE-G-20-004, TTTech, BU Off-Highway, Product Development.

[8] TTControl GmbH. Volution 144 Mounting Requirements Document. D-TTC-H-BRIDGE-M-02-001, TTTech, BU Off-Highway, Product Development.

[9] TTControl GmbH. Volution 144 Product Drawing. D-TTC-H-BRIDGE-C-02-004, TTTech, BU Off-Highway, Product Development.

[10] TTControl GmbH. Volution 144 Release Notes. D-TTC-H-BRIDGE-DN-20-001, TTTech, BU Off-Highway, Product Development.

[11] TTControl GmbH. Volution 144 Safety Manual. D-TTC-H-BRIDGE-M-20-001, TTTech, BU Off-Highway, Product Development.

[12] TTControl GmbH. Volution 144 Software Manual. D-TTC-H-BRIDGE-G-20-005, TTTech, BU Off-Highway, Product Development.

TTControl
HYDAC INTERNATIONAL

Referenced norms and standards

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

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

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