TTControl
HYDAC INTERNATIONAL

TTC 2030 Family

TTC 2030 Family System Manual

Product version 01.00

Original instructions

Document type:	System Manual
Document number:	D-TTC2030-M-20-002
Document revision:	0.8.0
Document date:	2023-07-04
Classification:	Confidential
Status:	Draft Release

TTControl GmbH
Schoenbrunner Str. 7, A-1040 Vienna, Austria,Tel. +43 1 585 34 34 – 0, Fax +43 1 585 34 34 – 90, office@ttcontrol.com

Table of contents

1 Introduction

1.1 General

This is the System Manual for the TTC 2030 Family. This document provides detailed information about the products, including applicable safety standards and guidelines, instructions for safe operation, connectors and parts, the I/O features, and other hardware-related topics.

The TTC 2030 Family, which is part of the TTC 2000 Series, includes the following variants:

- TTC 2038 [11]
- TTC 2038XS [13]

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

1.2 Further documentation

This System Manual is one of many user documents for the TTC 2030 Family. Please see your release package for additional user documentation, including:

- Software Manual [9]
- I/O Driver Manual for each variant:
  - TTC 2038 I/O Driver Manual [12]
- Mounting Requirements Document [6]
- Product Drawing [7]
- Quick Start Guide [5]
- Safety Manual [8]

1.3 Notation

In the context of this document, the terms *TTC 2030* and *TTC 2030 Family* refer to the *all* products in the TTC 2030 Family.

NOTE The information given in this System Manual is valid for *all* variants in the TTC 2030 Family, unless otherwise stated.

1.4 Support

The Release Note [10] contains known issues.

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

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

2 Product overview

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

The compact TTC 2030 Family has been designed for sensor/actuator management for both safety and non-safety applications.

2.1 Features

Overview of features for variants in the TTC 2030 Family. For variant-specific information, see section 2.2.

2.1.1 Communication interfaces

- 2x CAN FD
  - 1x Wake-up capable
  - 1x CAN ISOBUS compliant
- 1x LIN
- Supported 4x SENT inputs with SPC [1] functionality

2.1.2 Safety features

- 2x Emergency-stop inputs (software configurable)
- 1x Internal secondary shut-off paths for HS outputs
- Watchdog
- Voltage monitor for internal supply rails

2.1.3 Power supply

- Supply voltage: 8 to 32 V
- Separate supply pins for CPU subsystem and I/O subsystem
- 1x 5 V/200 mA sensor supply
- Board temperature, sensor supply and battery monitoring

2.1.4 Physical specifications

- Dimensions: 147 x 92 x 38 mm
- Weight: 330 g
- Operating ambient temperature: - 40 to + 85 °C
- Storage temperature: - 40 to + 85 °C
- Housing IP6k7- and IP6k9k-rated die-cast aluminum housing
- 1x 48 pin connector
- Operating altitude 0 to 4000 m

1. upcoming feature

Other device dimensions, including tolerances, weight and other physical specifications for the TTC 2030 Family can be found in the Product Drawing (PD) [7]. Additional physical specifications, including thermal requirements, can be found in the Mounting Requirements Document (MRD) [6].

2.1.5 Inputs and outputs

- 32x I/Os: 16x out, 16x in, including:
  - 8x PWM HS with current measurement
  - 2x PWM LS with current measurement
  - 4x SENT inputs with SPC [1] functionality

All inputs and outputs of each TTC 2030 variants are protected against electrical surges and short circuits. In addition, internal safety measures allow the detection of open load, overload and short circuit conditions at the outputs. Proportional hydraulic components can be directly connected to the current-controlled PWM outputs. The TTC 2030 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
- CODESYS 3.x
- UDS Bootloader compatible
- CAN ISOBUS compliant

Programming options

The unit may be programmed in C or CODESYS 3.x. CODESYS is one of the most common IEC 61131-3 [1] programming systems running under Microsoft Windows. CODESYS supports several editors, including the Instruction List Editor, Sequential Function Chart Editor, and Function Block Diagram Editor. CODESYS produces native machine code for the main processor of the TTC 2030.

2.2 TTC 2030 Family variants

The following TTC 2030 Family variants are described in this System Manual:

- TTC 2038 [11]
- TTC 2038XS [13]

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

Feature	TTC 2038	TTC 2038XS
CPU		
32-bit TC 367	Yes	Yes
Int. FLASH	4 MB	4 MB
Int. SRAM	576 KB	576 KB
Int. EEPROM emulation	128 KB	128 KB
Interface		
CAN FD	4	4
CAN0 is ISOBUS compliant	Yes	Yes
LIN	1	1
Outputs		
Digital high-side 4 A	6	6
PWM high-side 4 A	8	8
PWM low-side 4 A	2	2
Inputs		
Analog IN 4 mode (V/I/R/LED)	8	8
Analog IN 2 mode(V)	2	2
Timer IN/SENT	4	4
Timer IN/CL	2	2
Power		
Sensor supply fixed (5 V)	1	1
Sensor GND	1	1
Terminal 15	1	1
Wake-up	1	1
Emergency shut-off path		
External shut-off interfaces	2	2

3 Instructions for safe operation

3.1 General

- Carefully read, understand, and follow the instructions and specifications listed in this document before operating the device.
  Failure to comply with these instructions or operation of the device outside the intended field of operation may result in serious damage to machinery and may seriously affect the safety of users. TTControl cannot be held liable for any personal injury or property damage resulting from improper installation or use of the device, non-compliance with the instructions in this document, or non-compliance with the intended field of operation. Non- compliance will result in the exclusion of any liability and warranty.
- The regulations and standards which apply are highly dependent on the specfic user applications of the overall system that the TTC 2030 device is built into. Therefore, it needs to be ensured that these regulations and standards are fulfilled by the TTC 2030 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 [6] for further details.
- The label on the housing contains important information. The label must not be destroyed or made unreadable.
- The TTC 2030 System Manual is written for a specific product version. Ensure that the *Product Version* on the title page of this document matches the version on the ECU label.
- All firmware, bootloaders, or runtime environments (e.g., CODESYS) used with the device must be authorized by TTControl. Any modifications made to the firmware, bootloader, or runtime environment must be authorized by TTControl.
- The device hardware does not require maintenance activities.
- Do not open and/or modify the device.
- Do not operate a prototype device outside laboratory conditions (e.g., in series products, ...).
- Check the TTControl Service Area regularly to see if updated versions of this document or additions to it are available.

3.2 Intended use

The TTC 2030 Family products are programmable electronic control units for sensor/actuator management and designed for use in safety-related applications.

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

- construction
- snow groomers
- fire engines

- agricultural
- municipal sectors
- automotive

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

3.3 Improper use

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

3.4 Checks to be done before commissioning the device

- Check the supply voltage before connecting the device.
- Check that the device connector and the cable harness are free of defects.
- Check the correct dimensioning of the wires in the cable harness.
- Always disconnect the power supply before conducting any maintenance or repair work to the machine where the device is mounted (for example, welding or maintenance of the battery system).
- Choose a mounting location for the device so that the operating temperature of the device does not exceed the maximum allowed operating temperature.
- Choose a mounting location for the device which prevents any ergonomic hazard to the user/operator.
- A protective fuse must be installed between the vehicle's battery and the power supply input (BAT+) of the device.
- The device is water-resistant according to IP67 and IP6K9K. Ingress protection is given only when all connectors are plugged in, or all unused pins are sealed.
- Refer to the MRD [6] for further guidelines and instructions.

3.5 Disposal

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

4 Standards and guidelines

The TTC 2030 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) [14] for details including information about ingress protection, and the electrical, mechanical and chemical capabilities of the devices.

4.1 Safety certification

Applicable functional safety standards:

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

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

TTControl
HYDAC INTERNATIONAL

5 Compliance

The TTC 2030 Family conforms to the following directives and regulations:

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

5.1 Regulatory information

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

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

NOTE

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

6 Mounting and Label

6.1 Mounting requirements

Any requirements for mounting, temperature and air flow conditions are defined in the Mounting Requirements Document (MRD) [6]. Furthermore, product dimensions and tolerances are defined in the Product Drawing [7].

6.2 Label information

Any information about the label and its content is defined in the Product Drawing [7].

7 Internal structure

7.1 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

7.1.1 Memory

Feature		TC367
Cache per CPU	Program	32 KB
	Data	16 KB
SRAM per CPU	PSPR	32 KB
	DSPR	192 KB
	DLMU	64 KB
SRAM global	LMU	n/a
	DAM	n/a
Program Flash	Size	4 MB
	Banks	PF0 = 3 MB, PF1 = 1 MB
Data Flash	DF0	128 KB
	DF1	128 KB

7.1.2 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 DAM		n/a	10	13
Data write access to DAM		n/a	7	7

[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).

7.2 Thermal Management

7.2.1 Board Temperature Sensor

Functional description

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

Depending on the T_{ECU} board temperature, the maximum current limit for high- and low-side output stages is adjusted, see e.g.10.12.1. This is a strategy to allow higher current consumption at lower temperatures and to bring the ECU immediately to a safe state and switch off loads if over temperature is detected. See 7.2.1 for temperature limits triggering the safe state.

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

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

For further information, please contact TTControl.

Characteristics

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

Table 4: *Board temperature sensor – characteristics*

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

8 Connector

8.1 Mating connector and crimp contacts

This section lists recommended plug housings for *mating* connectors, cables, crimping contacts, and blind plugs. For detailed specifications, please contact the supplier or refer to the supplier's website.

8.1.1 Mating Connector

TTControl recommends the following plug housings for mating connectors:

Connector	Description	Part no.	Supplier
main	0.635 mm, 1.50 mm, CMC receptacle, 48 circuits, left wire output, black coding, mat sealed	64320-1311	Molex

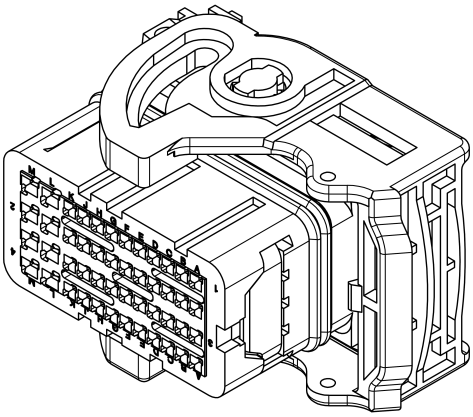

Figure 1: *Plug housing - Main connector*

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 the main connector:

Connector	Description	Part no.	Supplier
main	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
main	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
main	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
main	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

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 Tools

TTControl recommends the following tools for mating the main connector:

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

8.1.4 Cables

TTControl recommends the following cables for mating the main connector:

Connector	Description	Function	Recommendation
main	2.0 mm^2	BAT+Power BAT+CPU GND	Automotive standard
main	Twisted stranded wire pair, FLRY 2x0.5 mm^2	CAN	Automotive standard
main	0.75 mm^2	all other functions	Automotive standard

8.2 Fuse

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		30	A

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

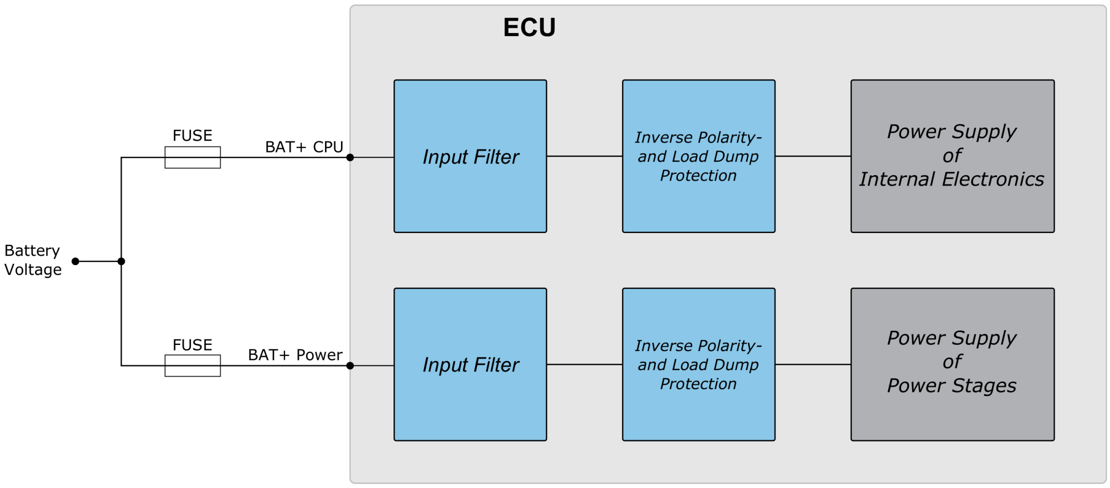

Figure 2: *Battery supply – Fuse*

9 TTC 2030 Family pinning

The pins on the TTC 2030 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 10.

A full overview of all 48 pins, including a complete group-by-group overview, can be found in the Software Manual [9]. Instructions on how to use the pins/pin groups is given in the variant-specific I/O Driver Manual [12]. For pin groups that are categorised as *safety-critical*, see the Safety Manual [8] for further details.

> Every pin can be identified by the pin number and pin name in this System Manual e.g. pin J4, AD4_IN _00. In the Software Manual, this pin is denoted by its software pin name e.g. TT_PIN_J4. Generally, the mapping is given as TT_PIN_<connector><pin#>.

10 Specification of inputs and outputs

The following section gives detailed information about the available pins groups, including which main and alternative functions are supported by each pin/pin group, which variants these functions are available for, the 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 generic long name (e.g. Timer IN/SENT) and a short name (e.g. TIN/SENT). In some cases the generic long name is given to a section describing multiple pin groups together (e.g PWM high-side outputs).

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

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

Pin	Pin name
L2	BAT+ Power
M1	BAT+ Power
M2	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 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.

Document Number:
D-TTC2030-M-20-002

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	Centralized load dump protection according to ISO 16750-2, Test B		350	ms
$I_{in\text{-}max}$	Permanent battery supply current (all 6 pins in parallel with symmetrical wire connection) [3]		24	A
$I_{in\text{-}max}$	Permanent battery supply current per pin [3]		8	A
$I_{in\text{-}total}$	Total load current, 12 V and 24 V battery operation [4] [5]		24	A

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

Characteristics

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

Document Number:
D-TTC2030-M-20-002

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

Pin	Pin name
L1	BAT+CPU

Table 13: *BAT+CPU pin group*

Functional description

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

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

BAT+ CPU pin is equipped with inverse polarity protection.

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

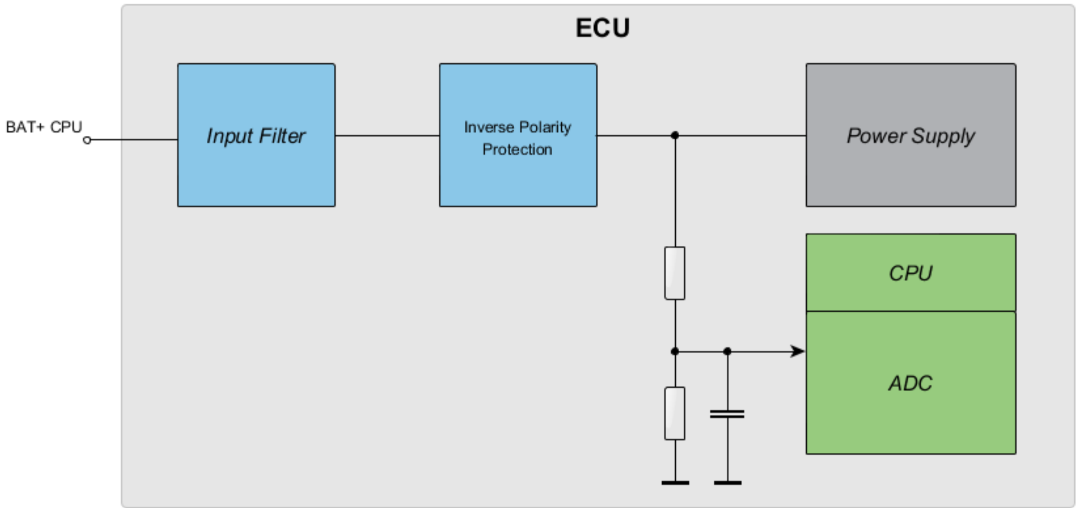

Figure 3: *Supply pin for the internal ECU logic*

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]	-40	42	V
$I_{in\text{-}lim}$	Peak non-destructive supply clamping current < 1 ms [1] [2]	-10	100	A
T_d	Centralized load dump protection according to ISO 16750-2, Test B		350	ms
$I_{BAT+\ max}$	Permanent input current at V_{BAT+} = 8 V, 25 °C		3	A

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

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Capacitance load at input	264		µF
V_{BAT+}	Supply voltage for start up [1]	8	32	V
V_{BAT+}	Supply voltage for full operation [2]	4.5	32	V
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 8 V [1]		210	mA
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 12 V		140	mA
$I_{BAT+\ idle}$	Supply current at V_{BAT+} = 24 V		80	mA
$I_{BAT+\ STBY}$	Standby supply current (Terminal 15 and wake up off) [3]		100	µA
$I_{BAT+\ STBY}$	Standby supply current [3] (CAN partial network enable) [4]		500	µA

[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 TTC 2030 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 [3]. 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 minimum supply voltage during cold-start cranking is defined by ISO 16750-2:2012 [3] (see Table 3, *Starting profile values for systems with 12 V nominal voltage, U_N*, and Table 4, *Values for systems with 24 V nominal voltage, U_N*). The TTC 2030 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 apply also for sensor supplies. For more information, see sections 10.7.

For TTC 2030 ISO 16750 code specification see section 4.

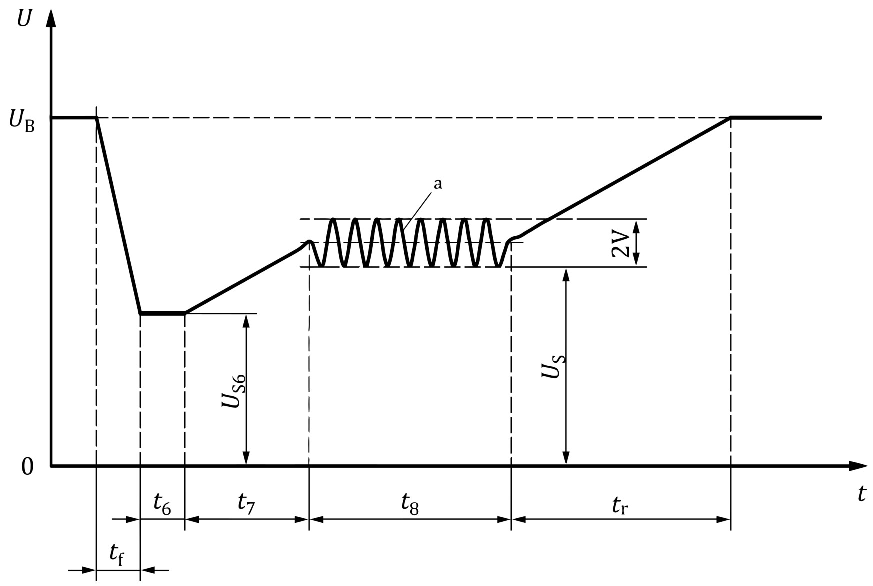

Figure 4: *ISO 16750-2, Figure 7 – Starting profile*

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 [2])
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

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

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

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	-80	80	mV
$V_{tol\text{-}0}$	Zero reading error [2]	-67	67	mV
$V_{tol\text{-}p}$	Proportional error	-4	4	%
$V_{tol\text{-}p}$	Proportional error [2]	-3	3	%
LSB	Nominal value of 1 LSB		13.4	mV

[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-)

Pin	Pin name
L3	GND
M3	GND
M4	GND

Table 19: *BAT- pin group*

Functional description

Supply pins for negative power supply.

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

Maximum ratings

Symbol	Parameter	Min	Max	Unit
$I_{out\text{-}max}$	Permanent current per pin		8	A
$I_{out\text{-}max}$	Permanent current all pins		24	A

10.4 Sensor GND

Pin	Pin name
G3	SNS_GND

Table 21: *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	A

10.5 Terminal 15

Pin	Pin name
K4	T15

Table 23: *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 (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

Characteristics

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

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

10.6 Wake-up

Pin	Pin name
A2	WAKE_UP

Table 26: *Wake-up pin group*

Functional description

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

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

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

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

Use case pre-boot sequence

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

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

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

Maximum ratings

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

Characteristics

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

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

10.7 Sensor supply 5 V

Pin	Pin name
H3	SSUP_0

Table 29: *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.).

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.

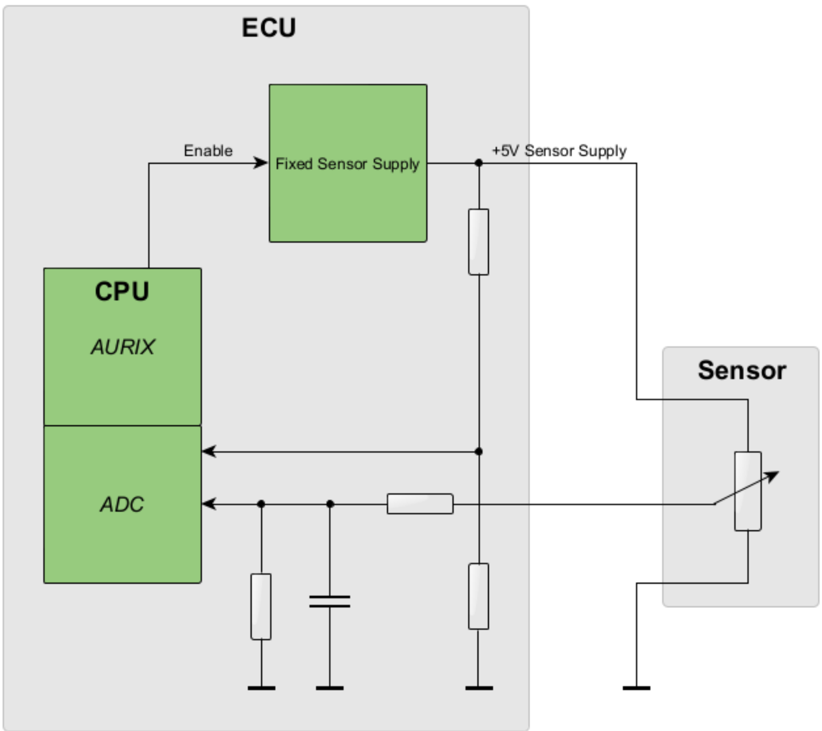

Figure 5: *Sensor supply 5 V*

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.

Maximum ratings

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

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin output capacitance	36.9	45.1	µF
V_{OUT}	Output voltage, at I_{load}	4.9	5.1	V
I_{load}	Load current	0	n/a	mA

10.8 Analog input 4-mode

Pin	Pin name	Function
J4	AD4_IN_00	ADC_RIN_100K_HP
H4	AD4_IN_01	ADC_RIN_100K_HP
E4	AD4_IN_02	ADC_RIN_100K
D4	AD4_IN_03	ADC_RIN_100K
C4	AD4_IN_04	ADC_RIN_100K_HP
B4	AD4_IN_05	ADC_RIN_100K_HP
A3	AD4_IN_06	ADC_RIN_100K
A4	AD4_IN_07	ADC_RIN_100K

Table 32: *Analog input 4-mode pin group*

Supported functions

- ADC_RAT_5V **(main)**
- ADC_VIN_5V **(main)**
- ADC_CIN_25mA **(main)**
- ADC_RIN_100K **(main)**
  - available for 4 out of 8 pins, see table 32
- ADC_RIN_100K_HP **(main)**
  - available for 4 out of 8 pins, see table 32
- LED
- DIN_5V

Functional description

8x multipurpose analog inputs with 12-bit resolution.

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

Safety critical considerations

Analog inputs can be used as single input paths or redundant to directly measure the signals of simple binary switches up to current sensing elements, ratiometric output voltages or resistive sensor types. In addition it can 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%.

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

Independent of the functional mode, the inputs can be used redundant 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

[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.

10.8.1 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:

- **Absolute** (ADC_VIN_5V) The sensor output voltage is a fixed value and directly corresponds to a physical value. For example, 2.5 V corresponds to 1 bar. Any tolerance in the reference voltage of the sensor and the ECU generates additional measurement inaccuracy.
- **Ratiometric** (ADC_RAT_5V) The sensor output voltage is a fixed percentage of the fixed sensor supply, the ratio corresponds to a physical value. For example, 50% corresponds to 1 bar (or 2.5 V if the sensor supply is exactly 5.00 V). Any tolerance in the reference voltage of the sensor and the ECU is completely compensated and will not generate additional measurement inaccuracy.

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

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

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

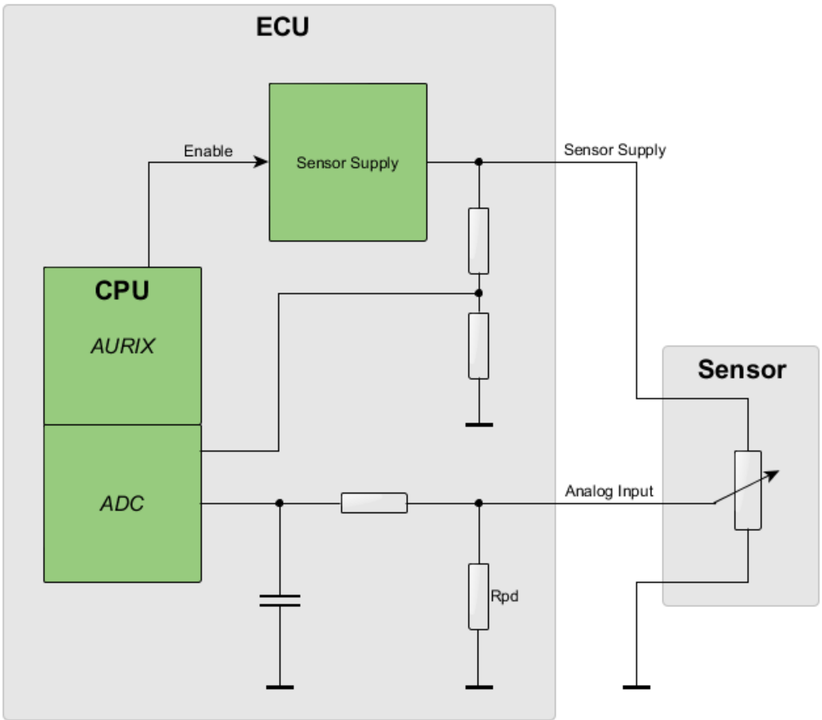

Figure 6: *Analog voltage input (ratiometric)*

Characteristics of 5 V analog input (Ratiometric)

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

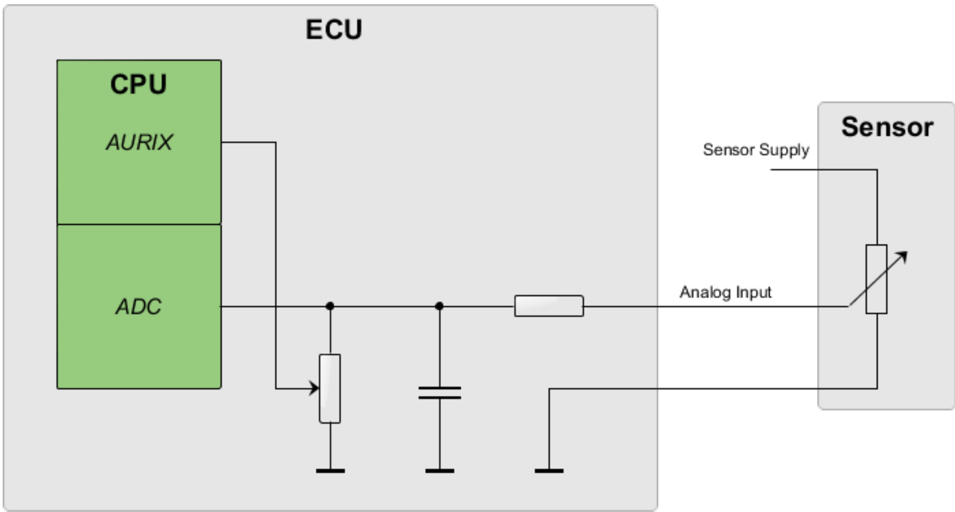

Figure 7: *Analog voltage input*

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 [3] [5]	-12	12	mV
$V_{tol\text{-}0}$	Zero reading error [2] [3] [5]	-7	7	mV
$V_{tol\text{-}p}$	Proportional error [3] [5]		0.4	%
$V_{tol\text{-}p}$	Proportional error [2] [3] [5]		0.6	%
LSB	Nominal value of 1 LSB		1.22	mV

[1] For full accuracy
[2] T_{ECU} = -40 to +85 °C
[3] Absolute measurement. This includes the conversion error of the TTC 2030 only. For the calculation of the total measurement error, it is necessary to sum the error of TTC 2030 and the absolute sensor error (measurement tolerance plus tolerance of external sensor reference).
[4] Ratiometric mode. This includes the conversion error of the TTC 2030 and the sensor supply error. For the calculation of the total measurement error, the error of TTC 2030 and the error of the ratiometric sensor (measurement tolerance) must be added.
[5] The total measurement error is the sum of zero reading error and the proportional error.

10.8.2 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 situation, 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. 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.

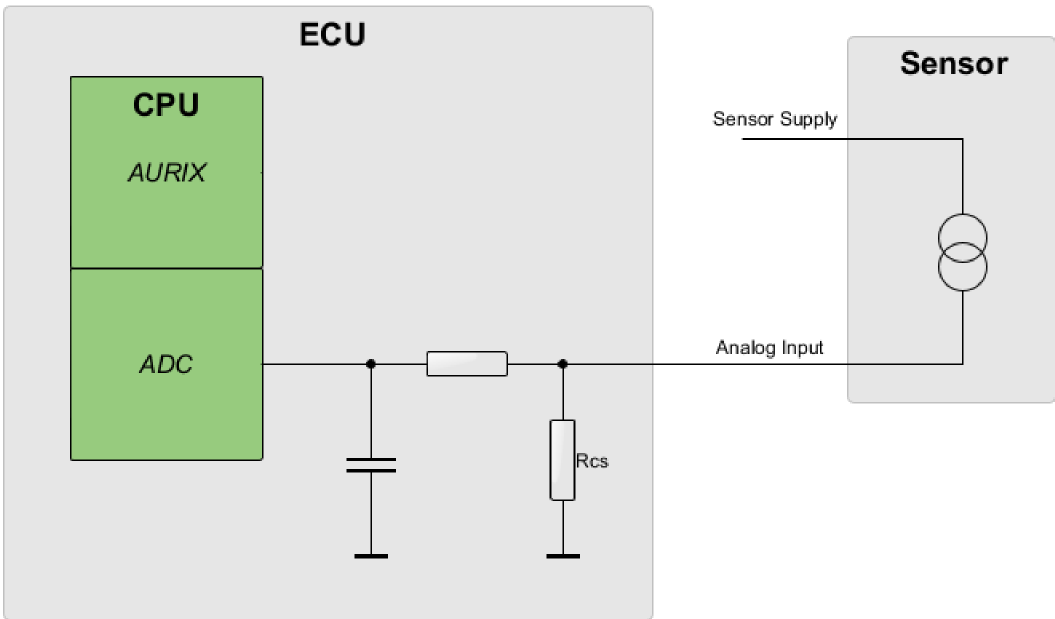

Figure 8: *Analog current input*

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 [3]	-150	150	μA
$I_{tol\text{-}0}$	Zero reading error [2] [3]	-100	100	μA
$I_{tol\text{-}p}$	Proportional error [3]	-1	1	%
$I_{tol\text{-}p}$	Proportional error [2] [3]		0.7	%
LSB	Nominal value of 1 LSB		12.21	μA

[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.

10.8.3 Analog resistance input

Selected via functions ADC_RIN_100K and ADC_RIN_100K_HP (see table 32 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 11. 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

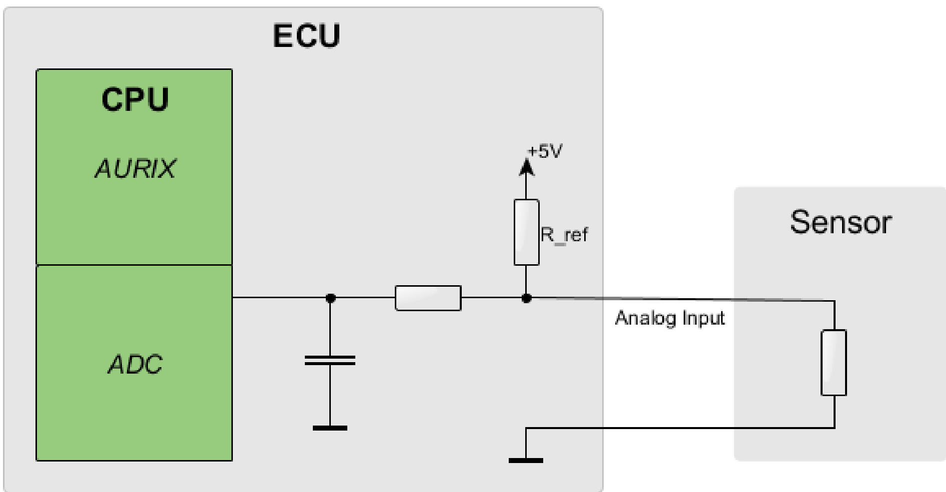

Figure 9: *Analog resistance input*

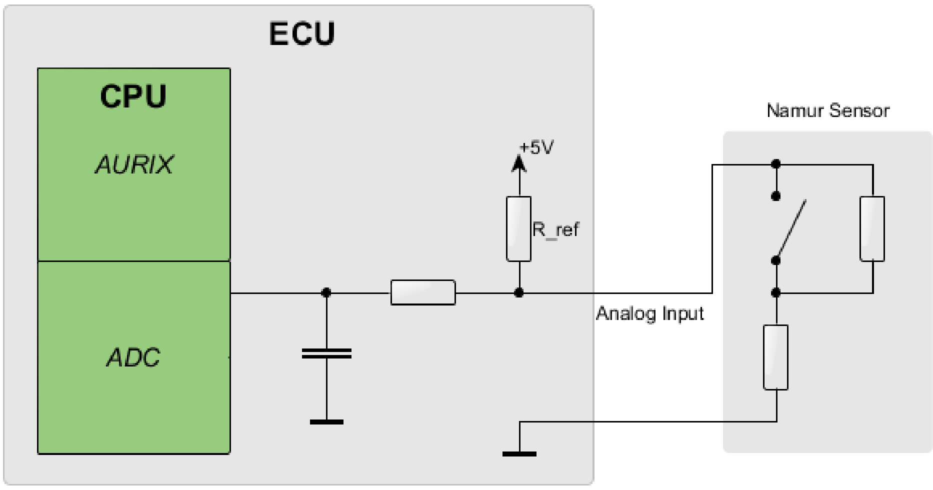

Figure 10: *Namur type sensor (only for switches to ground)*

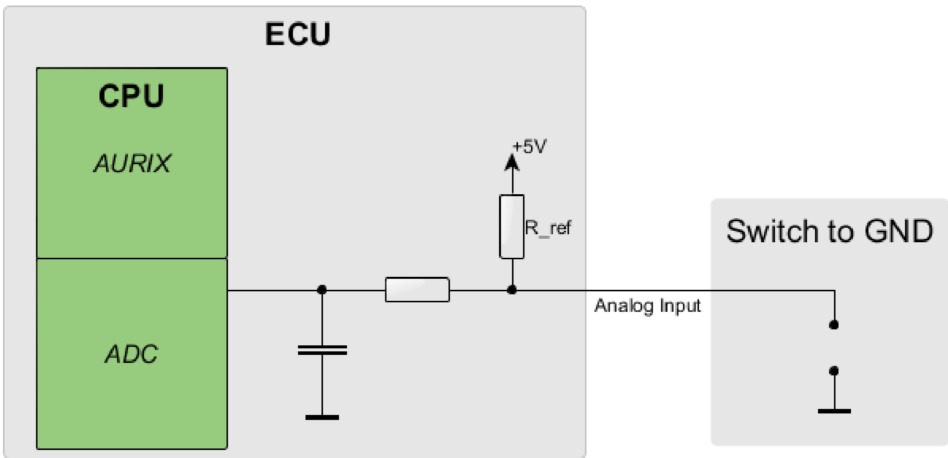

Figure 11: *Switch input (only for switches to ground)*

Tolerance of analog resistance input measurements (standard)

Tolerance at T_{ECU} = -40 to +85 °C:

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

Tolerance at T_{ECU} = -85 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 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	%

Tolerance of analog resistance input measurements (high precision)

Tolerance at T_{ECU} = -40 to +85 °C:

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

Tolerance at T_{ECU} = -85 to +125 °C:

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

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

10.8.4 LED

Selected via function LED.

10.8.5 Digital input 5 V

Selected via function DIN_5V.

Characteristics of 5 V digital input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	8	12	nF
R_{pd}	Pull-down resistor	107	112	Ω
τ_{in}	Input low pass filter			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

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

10.9 Analog input 2-mode

Pin	Pin name
L4	AD2_IN00
F3	AD2_IN01

Table 43: *Analog input 2-mode pin group*

Supported functions

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

Functional description

Characteristics

10.9.1 Analog inputs

Selected via functions ADC_RAT_5V, ADC_VIN_5V and ADC_VIN_32V.

10.9.2 Digital inputs

Selected via functions DIN_5V and DIN_32V.

10.10 Timer input/SENT

Pin	Pin name
E3	Timer_SENT_00
D3	Timer_SENT_01
C3	Timer_SENT_02
B3	Timer_SENT_03

Table 44: *TIN/SENT pin group*

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

Supported functions

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

Functional description

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

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

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

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

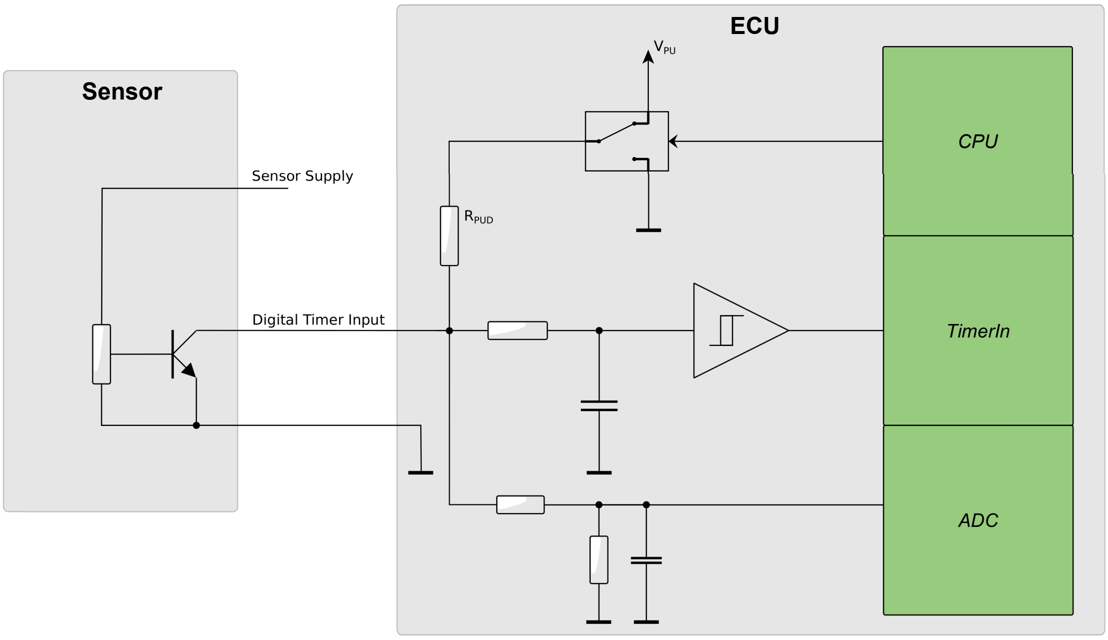

Figure 12: *Digital input for frequency/timing measurement with NPN-type 2-pole sensor*

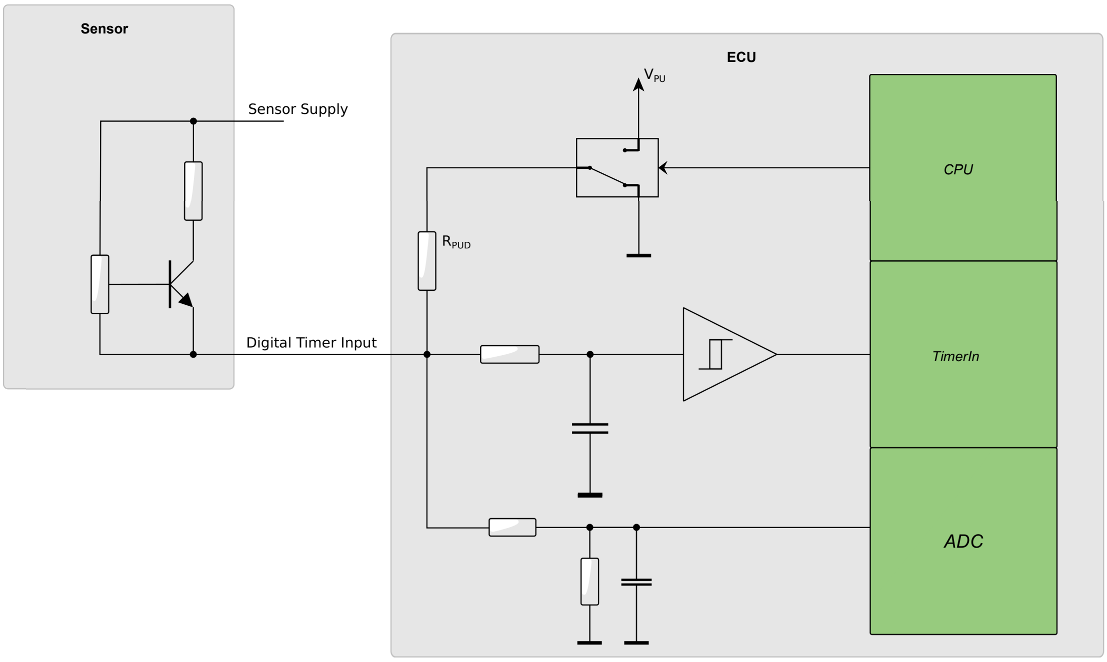

Figure 13: *Digital input for frequency/timing measurement with PNP-type 2-pole sensor*

Incremental encoder interfaces

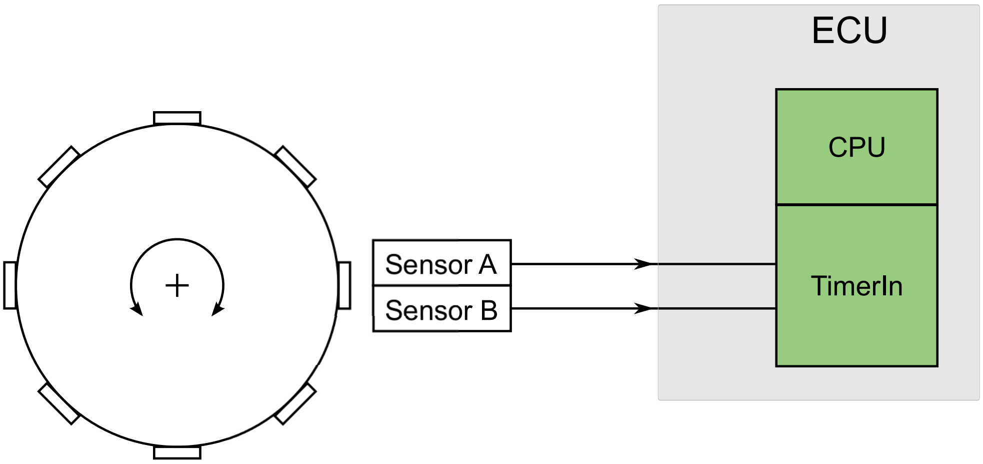

Figure 14: *Digital input pair for encoder and direction*

The combination of pins used to form an incremental encoder interface can't be chosen freely, i.e. is fixed in hardware. The following table outlines the possible encoder mappings for this variant:

Encoder Interface	Pin A	Pin B
Encoder 0	TT_PIN_G4	TT_PIN_F4
Encoder 1	TT_PIN_E3	TT_PIN_D3
Encoder 2	TT_PIN_C3	TT_PIN_B3

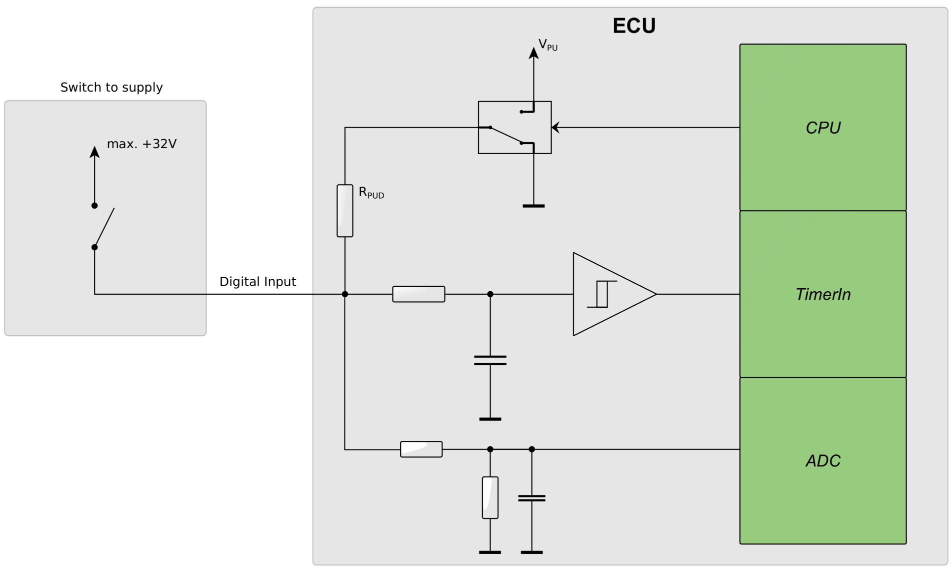

Figure 15: *Digital input for switch connected to (battery) supply voltage*

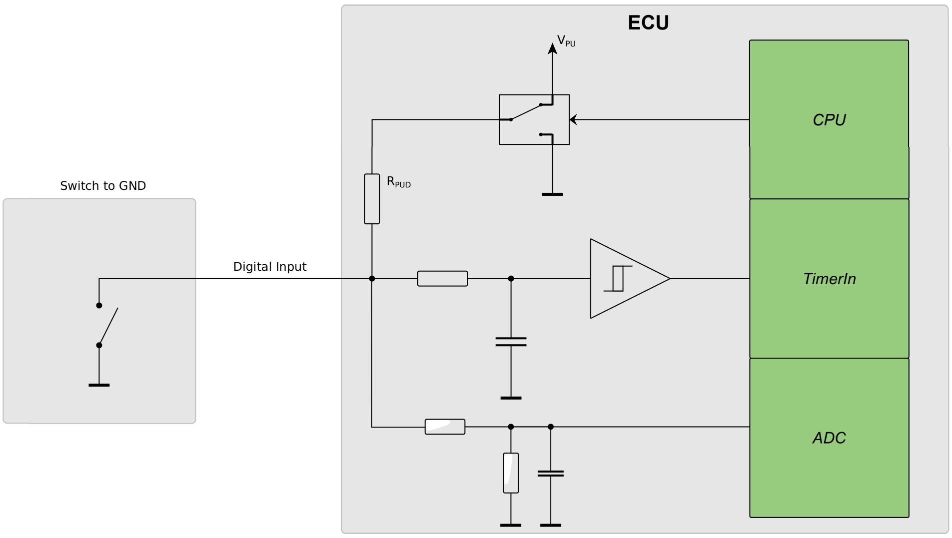

Figure 16: *Digital input for switch connected to ground*

Safety critical considerations

Timer inputs can be used as single input paths or redundantly to directly measure the signals of dedicated frequency sensors.

For diagnostic purposes, in functional mode timer and encoder input, the I/O Driver will provide a 'Frequency Range Check' configurable via an API function with a DC claim of 90-99%[3] .

Alternatively in functional mode analog, digital input and SENT interface it is in the responsibility of the system integrator to provide diagnostic measures.

Independent of the functional mode, the inputs can be used redundant claiming a DC of 90-99% [4] .

Maximum ratings

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

3. range given as concrete DC depends on strictness of the safety checks
4. range given as concrete DC depends on characteristic (failure modes) of input elements (e.g. sensors)

Characteristics

Symbol	Parameter	Min	Max	Unit
V_{in}	Input voltage under overload conditions	2.16	2.24	V
R_{pud}	Pull-up/pull-down resistor	12	12.4	kΩ
V_{pu}	Pull-up voltage (open load) [1]	4.4	4.7	V
τ_{in}	Input low pass filter	2.2	3.8	µs
F_{max}	Maximum input frequency range		20	kHz
F_{min}	Minimum input frequency	0.1		Hz
τ_{min}	Minimum on/off time to be measured	20		µs
V_{il}	Input voltage for low level	0	2.5	V
V_{ih}	Input voltage for high level	3.75	32	V
t_{res}	Timer resolution	0.2	1	µs

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

10.10.1 Analog input

Selected via function ADC_VIN_32V.

10.10.2 Digital input

Selected via function DIN_32V.

10.11 Timer input/current loop

Pin	Pin name
G4	Timer_CL_00
F4	Timer_CL_01

Table 48: *TIN/CL pin group*

Supported functions

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

Functional description

8x timer inputs can be used as digital (7/14 mA) current loop sensor inputs. See figure 17.

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

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

[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.

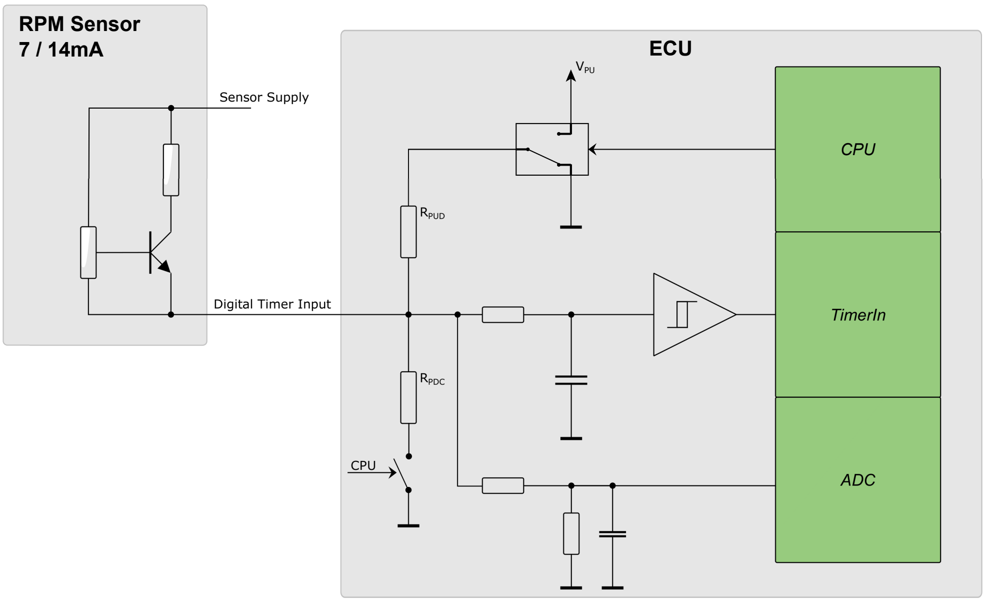

Figure 17: *Digital input for frequency measurement with ABS-type 7/14 mA, 2 pole sensor*

10.11.1 Analog inputs

Selected via functions ADC_VIN_32V, or ADC_CIN_CL_25mA for current mode.

Characteristics of analog volatge 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
$V_{tol\text{-}0}$	Zero reading error [3]	-80	80	V
$V_{tol\text{-}0}$	Zero reading error [1] [3]	-50	50	V
$V_{tol\text{-}p}$	Proportional error [3]	-4	4	%
$V_{tol\text{-}p}$	Proportional error [1] [3]	-3	3	%
LSB	Nominal value of 1 LSB		8	mV

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
$I_{tol\text{-}0}$	Zero reading error [3]	-150	150	µA
$I_{tol\text{-}0}$	Zero reading error [1] [3]	-100	100	µA
$I_{tol\text{-}p}$	Proportional error [3]	-2.6	2.6	%
$I_{tol\text{-}p}$	Proportional error [1] [3]	-2	2	%
LSB	Nominal value of 1 LSB		13.4	µA

[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.

10.11.2 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) [2]	4.25	4.8	V
V_{in}	Input voltage range	0	32	V
τ_{in}	Input low pass filter	1.6	1.8	µs
V_{il}	Input voltage for low level	0	2	V
V_{ih}	Input voltage for high level	3	32	V

[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.

10.12 High-side PWM output

Pin	Pin name	Function
K1	HS_OUT_00	PWM_HS_4A
J1	HS_OUT_01	PWM_HS_4A
H1	HS_OUT_02	PWM_HS_4A
G1	HS_OUT_03	PWM_HS_4A
F1	HS_OUT_04	PWM_HS_4A
E1	HS_OUT_05	PWM_HS_4A
D1	HS_OUT_06	PWM_HS_4A_FC
C1	HS_OUT_07	PWM_HS_4A_FC

Table 54: *PWM HS 4A+CM+FM pin groups*

Supported functions

- PWM_HS_4A **(main)**
  - available for 6 out of 8 pins, see table 54
- PWM_HS_4A_FC **(main)**
  - available for 2 out of 8 pins, see table 54
- ADC_VIN_32V
- LED
- 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. Some pins are designed for advanced control applications with a *Fast Current Measurement*.

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, 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 means, there is a reliable periodical state change of the output allowing permanent load monitoring that is independent of the operation point. So, even when the load is switched off, a short on the load can be detected.

TTControl recommends using these pins 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.

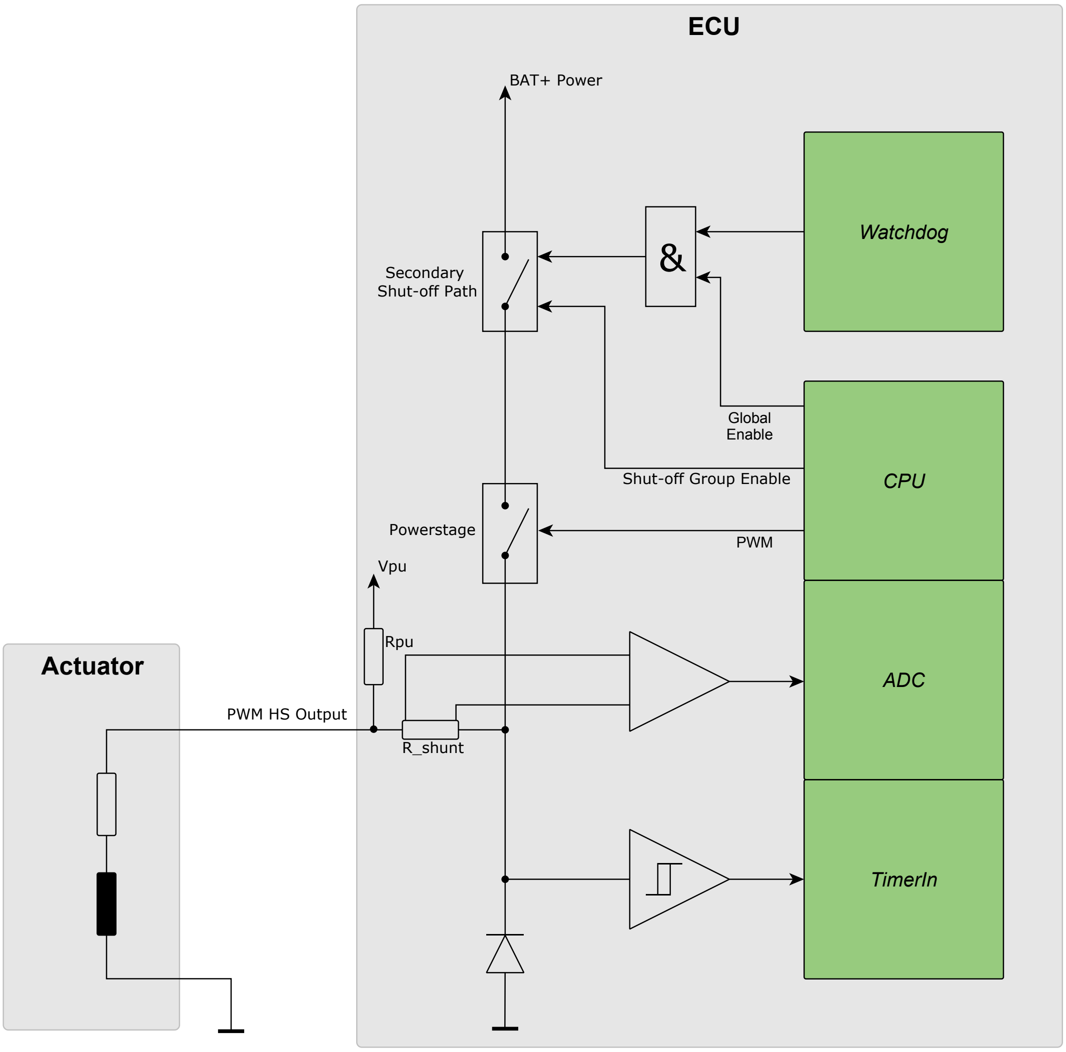

Figure 18: *High-side output stage with PWM functionality*

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:

- MCU and Watchdog by disabling PWM high side stages
- MCU 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, …). In functional mode high-side PWM Current Measurement it provides a signal range check.

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

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

Power stage pairing

If outputs shall be used in parallel, always combine two channels from the same double-channel power stage and use the digital output mode. The following channel combinations can be used to configure the right power stage outputs in parallel: J1/K1, H1/G1, F1/E1 and D1/C1.

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

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

Mutual exclusive mode

The TTC 2030 uses double-channel high-side power stages. For load levelling it is a benefit if 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 10.12.

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, see sections 10.12.1.

Maximum ratings

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

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

10.12.1 High-side PWM outputs 4 A

Selected via functions PWM_HS_4A (see tables 54, respectively, for applicable pins).

Characteristics of high-side PWM output 4 A

Symbol	Parameter	Min	Max	Unit
C_{out}	Pin input capacitance	15	25	nF
R_{pu}	Pull-up resistor	4.6	4.8	kΩ
V_{pu}	Pull-up voltage (open load)	4.2	4.6	V
f_{PWM}	PWM frequency [1]	50	1000	Hz
$T_{min\text{-}on}$	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

[1] Not all values for PWM frequency are possible, see the API documentation [12] for supported frequency values.
[2] When the output is configured as safety-critical (instead of zero).
[3] T_{ECU} = -40 to +85 °C
[4] For 12 V systems
[5] For t < 180 ms
[6] Additionally to observing the maximum load current limit, there is also a minimum load resistance limit, depending on the battery supply voltage.
[7] Exceeding this value will trigger open load detection.

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+ implicates 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 in order 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

Characteristics of current measurements

Symbol	Parameter	Min	Max	Unit
$I_{tol\text{-}0}$	Zero reading error [1] [2]	-30	30	mA
$I_{tol\text{-}0}$	Zero reading error [1] [2] [4]		20	mA
$I_{tol\text{-}p}$	Proportional error [1] [2]		2.6	%
$I_{tol\text{-}p}$	Proportional error [2] [4]		2	%
LSB	Nominal value of 1 LSB		2.5	mA
f_{g_LP}	Cut-off frequency of 2nd low pass filter [3]	60	86	Hz
$f_{g\_LP\_FC}$	Cut-off frequency of 2nd low pass filter [3]	240	360	Hz

[1] The measured value is clipped in software if below zero. So at some devices a small output current is necessary to get ADC-values greater than zero.
[2] The total error (I_{tol}) is the sum of proportional error and zero reading error:
$I_{tol} = \pm(I_{tol-p} \cdot I_{load} + I_{tol-0})$
[3] 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.
[4] T_{ECU} = -40 to +85 °C

10.12.2 Analog input

Selected via function ADC_VIN_32V.

10.12.3 LED

Selected via function LED.

10.12.4 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

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

TTControl
HYDAC INTERNATIONAL

10.12.5 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

[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.

10.13 Low-side PWM output

Pin	Pin name
A1	LS_00
B1	LS_01

Table 62: *PWM LS 4A+CM and PWM LS 4A+CM+FM pin groups*

Supported functions

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

Functional description

8x low-side switches with freewheeling diodes to BAT+ with separate reverse polarity protection, for inductive and resistive loads.

Maximum ratings

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

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

Characteristics

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	7.5	12	nF
R_{pu}	Pull-up resistor (5 V mode)	9.8	10.2	kΩ
V_{pu}	Pull-up voltage (5 V mode)	4.9	5.1	V
R_{pu}	Pull-up resistor (32 V mode)	6.1	6.34	kΩ

V_{pu}	Pull-up voltage (32 V mode)	3	3.2	V
R_{on}	On-resistance		50	mΩ
I_{load}	Nominal load current		3	A
I_{max}	Maximum load current [1]		4	A
I_{peak}	Peak load current [2]		6	A
$I_{tol\text{-}0}$	Zero reading error [3]	-125	125	mA
$I_{tol\text{-}0}$	Zero reading error [1] [3]	-95	95	mA
$I_{tol\text{-}p}$	Proportional error [3]	-4.3	4.3	%
$I_{tol\text{-}p}$	Proportional error [1] [3]	-3.4	3.4	%

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

10.13.1 Analog inputs

Selected via functions ADC_RAT_5V, ADC_VIN_5V and ADC_VIN_32V.

10.13.2 Digital inputs

Selected via functions DIN_5V and DIN_32V.

10.13.3 Timer input

Selected via function TIN_PWD.

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

Pin	Pin name	Function
K2	HS_OUT_08	LPO_VOUT_LP
J2	HS_OUT_09	LPO_VOUT_LP
H2	HS_OUT_10	LPO_VOUT_LP
G2	HS_OUT_11	LPO_VOUT_LP
F2	HS_OUT_12	LPO_VOUT_LP
E2	HS_OUT_13	LPO_VOUT_LP

Table 65: *DOP HS 4A+CS/LPO pin group*

Supported functions

- DOP_HS_4A **(main)**
- LPO_PVG
- LPO_VOUT_LP
- LPO_ESO
  - available for 2 out of 6 pins, see table 65
- ADC_VIN_32V
- LED
- DIN_32V

Functional description

6x output stages for interfacing to PVG type hydraulic valve groups (PVG mode), for low power analog voltage loads (V_{OUT} mode) or for high power inductive/resistive loads (high-side digital mode).

All six outputs can be configured independently of each other.

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

TTControl recommends using these pins 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.

Power stage pairing

If outputs are to be used in parallel, always combine two channels from the same double-channel power stage and use the digital output mode. The following channel combinations can be used to configure the right power stage outputs in parallel: K2/J2, H2/G2 and F2/E2.

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

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

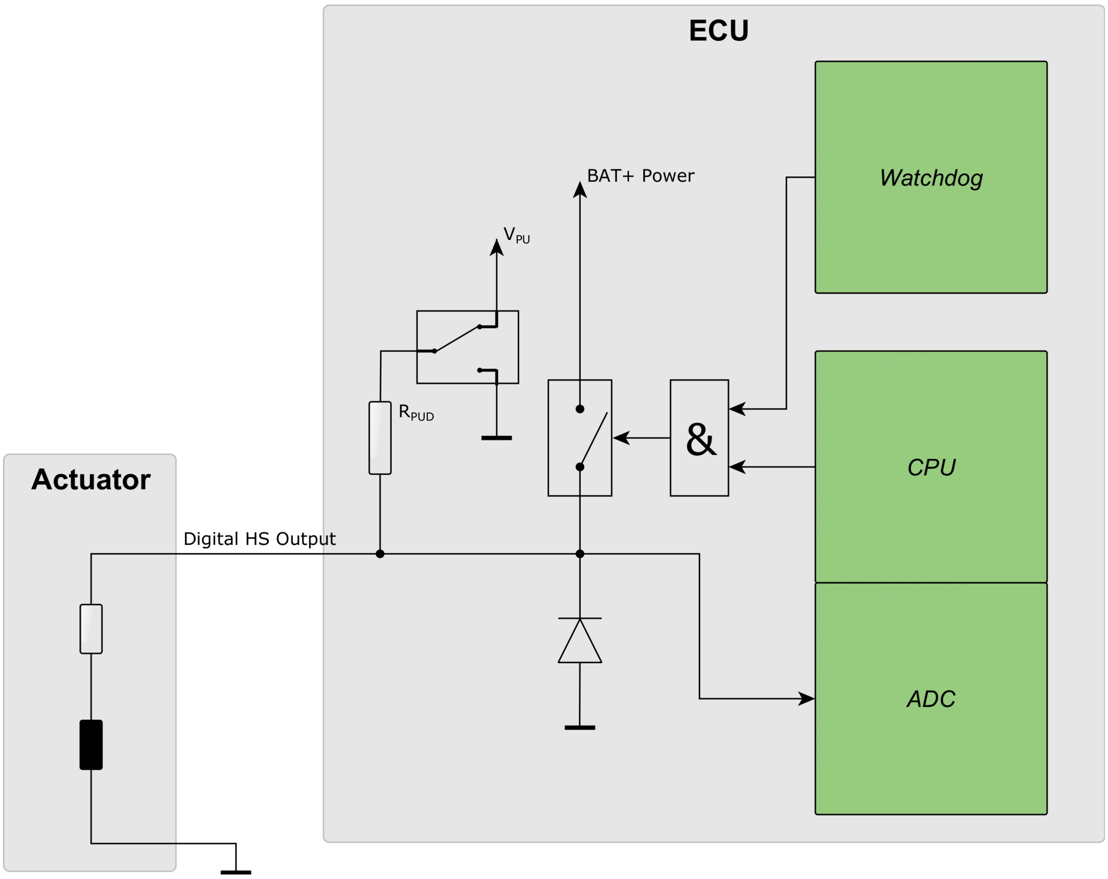

Figure 19: *Digital high-side power stage*

Mutual exclusive mode

The TTC 2030 uses double-channel high-side power stages. For load levelling it is a benefit if 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 10.14.

Maximum ratings

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

TTControl
HYDAC INTERNATIONAL

10.14.1 High-side digital outputs

Selected via function DOP_HS_4A.

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

See figure 19 for the relevant circuit diagram.

Diagnostic functions

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

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

◯ = detected
x = not detected

Characteristics of high-side digital output

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

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

TTControl
HYDAC INTERNATIONAL

10.14.2 PVG outputs

Selected via function LPO_PVG.

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

For diagnostic reasons in output mode, the output signal is looped back to the CPU, and the measured value is compared to the set value. If the difference between these two values is above a fixed limit, an overload is detected, and the output is disabled. The protection mechanism tries re-enabling the output 10 times per drive cycle. It is not allowed to use two outputs in parallel to increase driving strength.

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

The TTC 2030 uses the BAT+ CPU pin as a reference voltage input. The principle schematic is shown in figure 20. The output is open loop controlled. The ADC input is for diagnostic purposes only and can be evaluated by the application software.

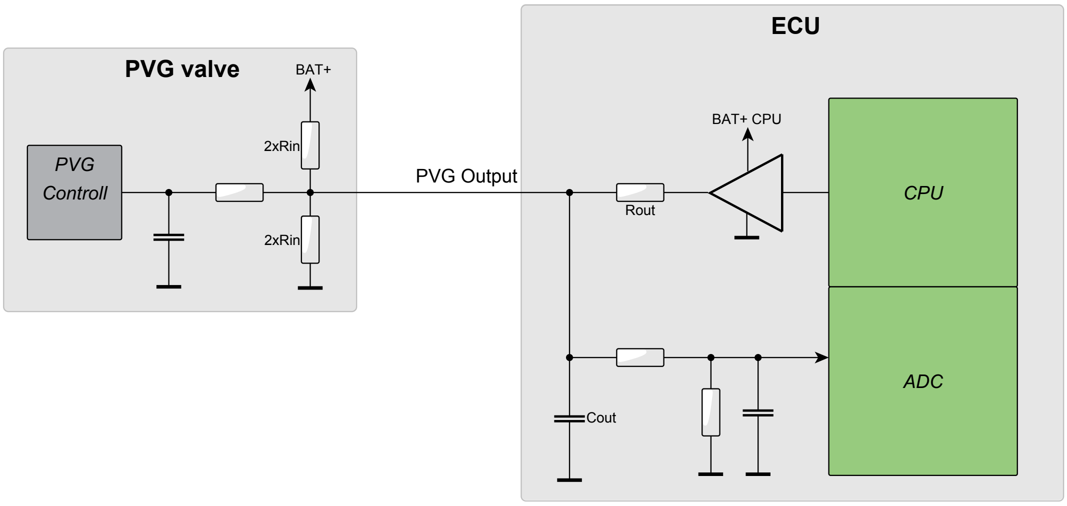

Figure 20: *Output stage in PVG mode*

Characteristics of PVG

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

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

10.14.3 V_{OUT} outputs

Selected via functions LPO_VOUT_LP (see table 65 for applicable pins).

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

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

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

For diagnostic reasons, the output signal is looped back to the CPU in output mode, and the measured value is compared to the set value. If the difference between these two values is above a fixed limit, an overload is detected and the output is disabled. The protection mechanism tries to re-enable the output 10 times per drive cycle. It is not allowed to use two outputs in parallel to increase driving strength.

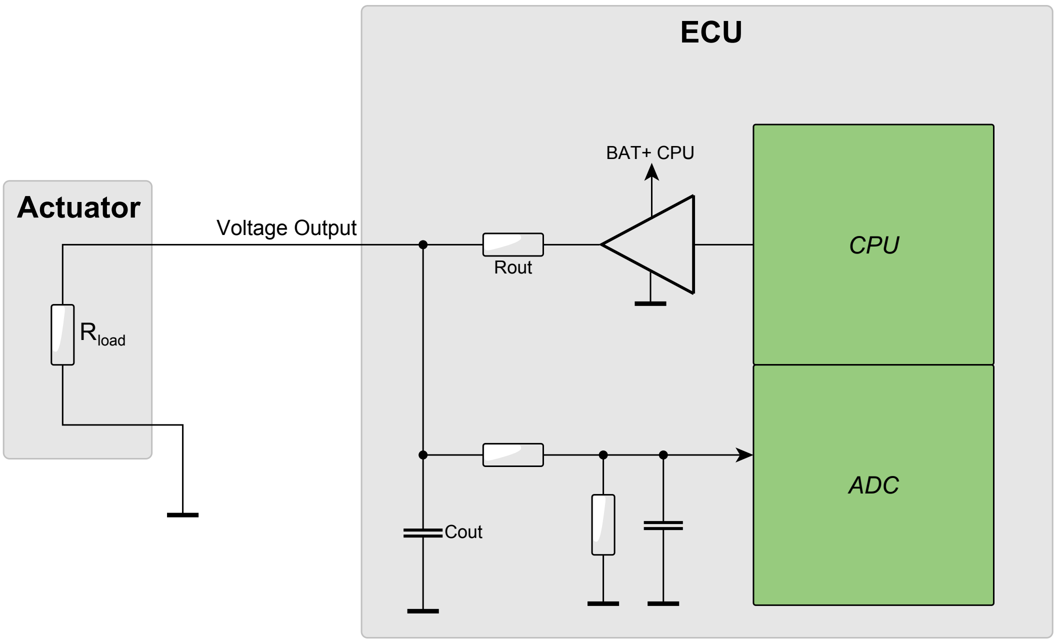

Figure 21: *Output stage in V_{OUT} mode*

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 nominal load resistance) [1]	$0.0 \cdot V_{BAT}$	$0.99 \cdot V_{BAT+CPU}$	V
$V_{tol\text{-}0}$	Zero error (BAT+ = 8 to 32 V nominal load resistance) [3]	-95	95	mV
$V_{tol\text{-}0}$	Zero error (BAT+ = 8 to 32 V nominal load resistance) [2] [3]	-65	65	mV
$V_{tol\text{-}p}$	Proportional error (BAT+ = 8 to 32 V nominal load resistance) [3]	4	4	%
$V_{tol\text{-}p}$	Proportional error (BAT+ = 8 to 32 V nominal load resistance) [2] [3]	3	3	%

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

10.14.4 Analog input

Selected via function ADC_VIN_32V.

This input type is suitable for low impedance switches and sensors only. For standard analog senors please use Analog 4-mode 10.8 and Analog 2-mode 10.9.

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

Characteristics of analog input

Symbol	Parameter	Min	Max	Unit
C_{in}	Pin input capacitance	430	530	nF
τ_{in}	Input low pass filter	9.5	12	ms
R_{pud}	Pull-up/pull-down resistor	2.52	2.63	kΩ
V_{pu}	Pull-up voltage (open load)	2.2	2.4	V
	Resolution		12	bit
V_{tol-0}	Zero reading error [3]	-95	95	mV
V_{tol-0}	Zero reading error [1] [3]	-65	65	mV
V_{tol-p}	Proportional error [3]	-4	4	%
V_{tol-p}	Proportional error [1] [3]	-3	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

[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.

10.14.5 LED

Selected via function LED.

TTControl
HYDAC INTERNATIONAL

10.14.6 Digital input

Selected via function DIN_32V.

This input type is suitable for low impedance switches and sensors only.

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

Characteristics of digital input

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

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

10.15 LIN

Pin	Pin name
D2	LIN

Table 73: *LIN pin group*

Supported functions

- LIN **(main)**

Functional description

LIN is configured in master mode.

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

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

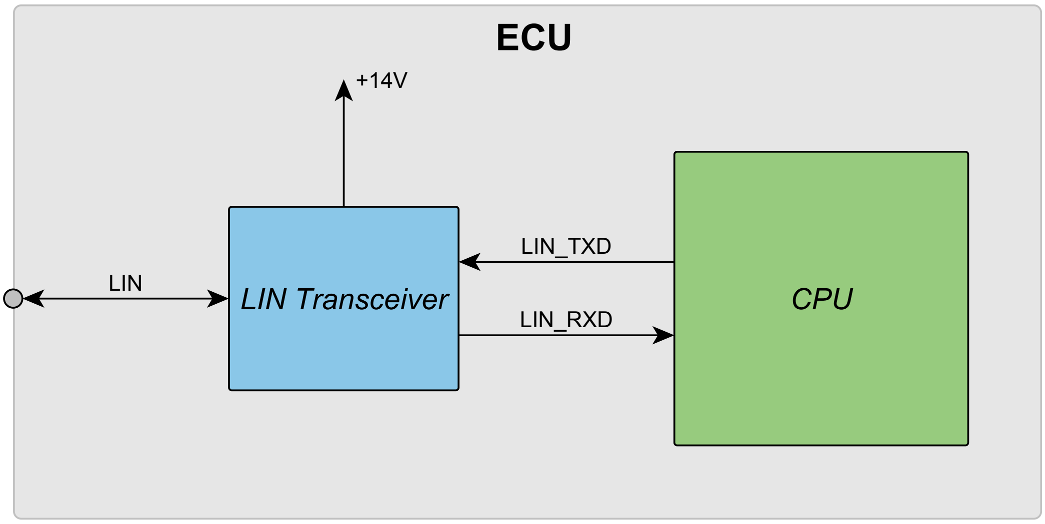

Figure 22: *LIN interface*

Maximum ratings

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

Characteristics

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

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

10.16 CAN FD

Pin	Pin name	Function
C2	CAN0_H	CAN_ISO
B2	CAN0_L	CAN_ISO
K3	CAN1_H	CAN_WAKE
J3	CAN1_L	CAN_WAKE

Table 76: *CAN FD pin group*

Supported functions

- CAN (**main**)
- CAN_ISO
  - available for interface 0 only
- CAN_WAKE
  - available for interface 1 only

Functional description

The CAN interface supports Flexible Data (FD) rate frame format (see [4]) with bit rates from 1 Mbit/s up to 2 Mbit/s.

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

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]	20	2000	kbit/s
R_{diff}	Differential internal resistance [5]	27	29	kΩ
R_{diff}	Differential internal resistance	3.7	3.9	kΩ

[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 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. By way of 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.

TTControl
HYDAC INTERNATIONAL

11 Application notes

11.1 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:

- The BAT- connection cabling is interrupted.
- Loads are connected directly to BAT- externally (this can be avoided by connecting the ground return path to a low-side output of the ECU).

NOTE Any current on the sensor GND connection (see section 10.4) will add to the possible fault current.

Consequently the internal supply current of the ECU, plus the load power connected to the sensor supplies, will find its way over the connected external loads. The current flows via the free wheeling diodes (essential for PWM operation) 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 CPU. Hence, even with ground voltage offset, networks like CAN can keep running without issue.

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 free wheeling diodes.

Preventative action

To prevent this type of failure:

- Use all three parallel GND pins, see section 10.4 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.

12 Debugging

The TTC 2030 debug interface, available for development-only devices, is supported by the Lauterbach TRACE32 tools for the Infineon TriCore microcontrollers.

12.1 Components

To debug your TTC 2030 device, you will need the components shown in the tables below. Items shown in table 79 are provided in the TTC 2030 device Starter Kits. Items shown in table 80 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 79: *Debugging components (TTControl GmbH)*

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

Table 80: *Debugging components (other)*

[1] former order code

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

NOTE Items in table 80 listed with two order codes refer to the current and former order codes. Please contact the supplier for further clarification, if needed.

12.2 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 23 for further details.
16-pin OCDS	Alternative to 16-pin JTAG. See figure 24 for further details.
6-pin FTDI	USB-TTL-232R connector (5 V) for the UART connection. See figure 25 for further details.
10-pin JTAG/DAP/UART	Connection to the ECU. See figure 26 for further details.

Table 81: *JTAG debug adapter connectors*

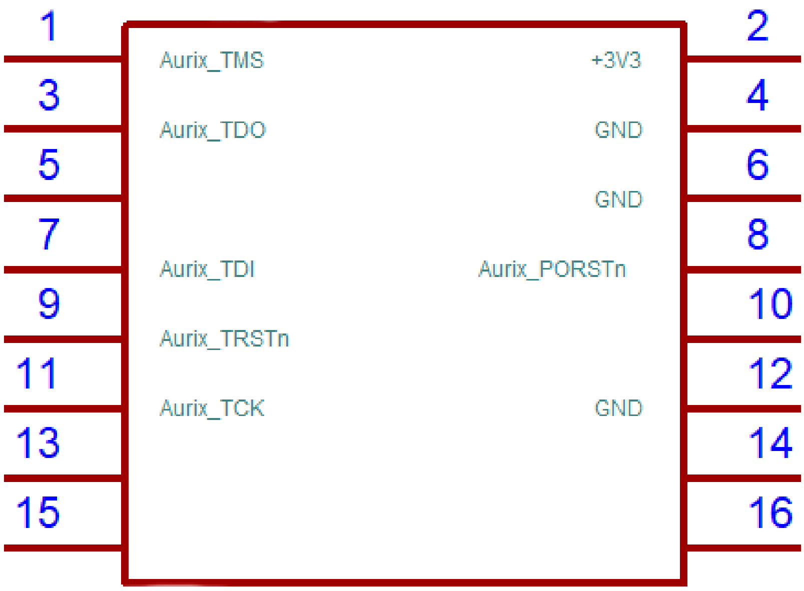

Figure 23: *Pinning schematic for the JTAG connector*

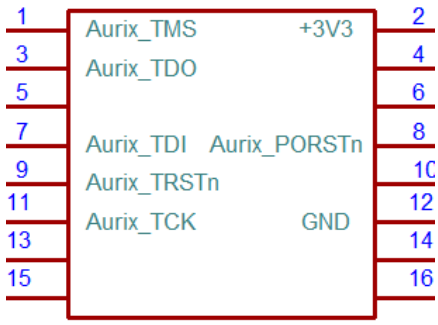

Figure 24: *Pinning schematic for the OCDS connector (JTAG alternative)*

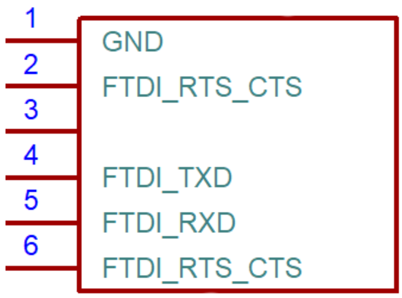

Figure 25: *Pinning schematic for the USB-FDTI connector*

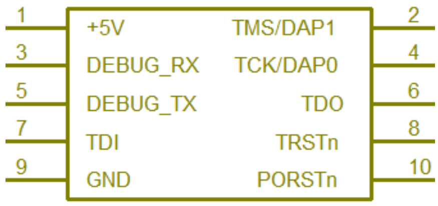

Figure 26: *Pinning schematic for the ECU interface*

12.3 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
RTC	Real Time Clock
SENT	Single Edge Nibble Transmission
SPC	Short PWM Code
SRAM	Static Random Access Memory
SRI	Shared Resource Interconnect
SSA	Safety Switch A
SSB	Safety Switch B

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

References

[1] IEC. IEC 61131-3:2013, *Programming languages (3rd ed.)*. International Standard, International Electrotechnical Commission (IEC), 2013.

[2] 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.

[3] 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.

[4] 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.

[5] TTControl GmbH. TTC 2030 Interface Board Quick Start Guide. D-TTC2030-G-20-004, TTTech, BU Off-Highway, Product Development.

[6] TTControl GmbH. TTC 2030 Mounting Requirements Document. D-TTC2030-M-02-003, TTTech, BU Off-Highway, Product Development.

[7] TTControl GmbH. TTC 2030 Product Drawing. D-TTC2030-C-20-001, TTTech, BU Off-Highway, Product Development.

[8] TTControl GmbH. TTC 2030 Safety Manual. D-TTC2030-M-20-001, TTTech, BU Off-Highway, Product Development.

[9] TTControl GmbH. TTC 2030 Software Manual. D-TTC2030-M-20-003, TTTech, BU Off-Highway, Product Development.

[10] TTControl GmbH. TTC 2030 Software Release Note. D-TTC2030-DN-20-001, TTTech, BU Off-Highway, Product Development.

[11] TTControl GmbH. TTC 2038 ECU Datasheet. D-TTC2030-E-20-002, TTTech, BU Off-Highway, Product Development.

[12] TTControl GmbH. TTC 2038 I/O Driver Manual. D-TTC2030-G-20-002, TTTech, BU Off-Highway, Product Development.

[13] TTControl GmbH. TTC 2038XS ECU Datasheet. D-TTC2038X-G-20-002, TTTech, BU Off-Highway, Product Development.

[14] TTControl GmbH. TTC 2300 Summary of Test Reports. , TTTech, BU Off-Highway, Product Development.

Referenced norms and standards

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

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

Legal disclaimer

THE INFORMATION GIVEN IN THIS DOCUMENT IS GIVEN AS A SUPPORT FOR THE USAGE OF THE PRODUCT AND SHALL NOT BE REGARDED AS ANY DESCRIPTION OR WARRANTY OF A CERTAIN FUNCTIONALITY, CONDITION OR QUALITY OF THE PRODUCT. THE RECIPIENT OF THIS DOCUMENT MUST VERIFY ANY FUNCTION DESCRIBED HEREIN IN THE REAL APPLICATION. THIS DOCUMENT WAS MADE TO THE BEST OF KNOWLEDGE OF TTCONTROL GMBH. NEVERTHELESS AND DESPITE GREATEST CARE, IT CANNOT BE EXCLUDED THAT MISTAKES COULD HAVE CREPT IN. TTCONTROL GMBH PROVIDES THE DOCUMENT FOR THE PRODUCT "AS IS" AND WITH ALL FAULTS AND HEREBY DISCLAIMS ALL WARRANTIES OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OR COMPLETENESS, OR OF RESULTS TO THE EXTENT PERMITTED BY APPLICABLE LAW. THE ENTIRE RISK, AS TO THE QUALITY, USE OR PERFORMANCE OF THE DOCUMENT, REMAINS WITH THE RECIPIENT. TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW TTCONTROL GMBH SHALL IN NO EVENT BE LIABLE FOR ANY SPECIAL, INCIDENTAL, INDIRECT OR CONSEQUENTIAL DAMAGES WHATSOEVER (INCLUDING BUT NOT LIMITED TO LOSS OF DATA, DATA BEING RENDERED INACCURATE, BUSINESS INTERRUPTION OR ANY OTHER PECUNIARY OR OTHER LOSS WHATSOEVER) ARISING OUT OF THE USE OR INABILITY TO USE THE DOCUMENT EVEN IF TTCONTROL GMBH HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

IF THE PRODUCT IS MARKED AS "PROTOTYPE", THE DELIVERED PRODUCT IS A DEVELOPMENT SAMPLE ("SAMPLE"). THE RECIPIENT ACKNOWLEDGES THAT THEY ARE ALLOWED TO USE THE SAMPLE ONLY IN A LABORATORY FOR THE PURPOSE OF DEVELOPMENT. IN NO EVENT IS THE RECIPIENT ALLOWED TO USE THE SAMPLE FOR THE PURPOSE OF SERIES MANUFACTURING.

TTCONTROL GMBH PROVIDES NO WARRANTY FOR ITS PRODUCTS OR ITS SAMPLES, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE AND TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW DISCLAIMS ALL LIABILITIES FOR DAMAGES RESULTING FROM OR ARISING OUT OF THE APPLICATION OR USE OF THESE PRODUCTS OR SAMPLES. THE EXCLUSION OF LIABILITY DOES NOT APPLY IN CASES OF INTENT AND GROSS NEGLIGENCE. MOREOVER, IT DOES NOT APPLY TO DEFECTS WHICH HAVE BEEN DECEITFULLY CONCEALED OR WHOSE ABSENCE HAS BEEN GUARANTEED, NOR IN CASES OF CULPABLE HARM TO LIFE, PHYSICAL INJURY AND DAMAGE TO HEALTH. CLAIMS DUE TO STATUTORY PROVISIONS OF PRODUCT LIABILITY SHALL REMAIN UNAFFECTED.

ANY DISPUTES ARISING OUT OF OR IN CONNECTION WITH THIS DOCUMENT SHALL BE GOVERNED SOLELY BY AUSTRIAN LAW, EXCLUDING ITS CONFLICT OF LAW RULES AND THE UNITED NATIONS CONVENTION ON CONTRACTS FOR THE INTERNATIONAL SALE OF GOODS. SUCH DISPUTES SHALL BE DECIDED EXCLUSIVELY BY THE COURTS OF VIENNA, AUSTRIA.

ALL PRODUCT NAMES AND TRADEMARKS MENTIONED IN THIS SYSTEM MANUAL ARE THE PROPERTY OF THEIR RESPECTIVE OWNERS, WHICH ARE IN NO WAY ASSOCIATED OR AFFILIATED WITH TTCONTROL GMBH.

TTC 2030 Family System Manual

Document version **0.8.0** of 2023-07-04

Document number: **D-TTC2030-M-20-002**