



silixcon

ESC3-SC controller series

Full datasheet

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Chapter 1: Introduction

The SC is a ESC3 family controller with excellent performance-to-weight ratio. It can be used in wide range of applications, especially in industry and automotive. Using most modern technologies it achieves extreme dynamics and maximum efficiency, it implements smooth start or regenerative braking, all this with minimum dimensions. The SC controller is capable of driving all common types of electric motors.

Applications

- Automotive or industrial motor control
- Electric hand tools and equipment
- Hi-end sport motorbikes, e-bikes, surf boards
- Combustion engine starter-generators
- Military inertial stabilization
- Professional drones, RC models
- Research & development
- Servo drive

Chapter 2: Safety and warnings

2.1 Product purpose

All ESC3 controllers are designated for 3-phase PMSM and induction motor control. Any other use of product or its parts without siliXcon written permission is prohibited. Software tools supplied with the ESC3 controllers are designed exclusively for siliXcon's products. Their other uses are not allowed.

2.2 Warnings

Read carefully all instructions and and make sure you understand them *before* you start using the ESC3 controller. Pay special attention for instructions and warnings in this chapter.

2.2.1 Safety

- ESC3 controller is electronic device and should be installed or replaced by trained personell only. Incompetent manipulation could lead to electrical shock, burns or property damage.
- Wear safety glasses and use properly insulated tools to prevent short-circuits
- Use the ESC3 controller only in proper enviroment. Check the temperature, water resistance and dust resistance (described in chapters 5 and 7 of this document).
- ESC3 controller can be used in vehicles. Secure the vehicle against uncontrolled operation (lift it of the ground, block wheels ...) before you start any work on the vehicle. There is always small chance, that motor can run out of control and cause injury.
- ESC3 controllers are usually powered from battery. Battery is able to supply very high currents and create electric arcs when short-circuited. Always disconnect the battery and use insulated tools to prevent short-circuiting the battery. Do not wear metal jewelry and do not use metal items that can accidentally short-circuit the battery.
- Read carefully the manual for used battery and battery charger. Many safety issues are related to battery and proper charger.
- ESC3 controllers are not designed to be used in life-critical applications.
- ESC3 controllers are capable of regenerative braking. This feature is not considered to be safety brake and can be used only on vehicle with independent mechanical brake.

2.2.2 Electrical risks

- Power stage of ESC3 controller contains high quality capacitors that could remain charged long after battery is disconnected. To avoid electric shock, always check voltage between BATT+ and BATT– terminals of the ESC3 controller. When needed, capacitors could be discharged by shorting BATT+ and BATT– via resistor.
- Always disconnect battery (or other power supply) and discharge power stage capacitors before handling ESC3 controller (replacing controller, connecting or disconnecting cables ...)
- Do not disconnect battery when motor is controlled. Overvoltage and damage of controller could occur. If a mechanical switch or contactor is used between battery and controller, bypass it always by proper diode in reverse direction.

- Sparking could occur when connecting controller to the battery. Do not use the controller in explosive environment. Use precharge feature with contactor control or anti-spark connectors to minimize this problem.
- ESC3 controllers has functions, that protects connected battery. This is only additional feature and can not be used instead of proper battery fuse and proper BMS. Using battery without fuse or BMS could lead to battery damage, explosion or fire.

2.2.3 Thermal issues

- ESC3 controller and power wires could became hot during operation. Check their temperature before handling.
- Use power wires with sufficient crosssection. Using too small wire crosssection leads to generation excessive amount of heat. This could result in faster insulation degeneration, shortcuts or even fire.
- Provide sufficient cooling for the ESC3 controller. This usually requires tightening the controller to heatsinking. Secure the screws and bolts against vibrations by glue or spring lock washer.

2.2.4 Communication and control issues

- Turn off ESC3 controller and disconnect it from power supply before you upgrade firmware or change settings via USB.
- Using USB for run-time settings and debugging is not advised. If you decide to do it, it is on your own risk. It is recommended to use galvanically isolated communication (CAN Bus or isolated UART) for run-time settings and debugging.
- Never connect USB to controller during battery charging. This could provide path for short-circuit current. Do not do it especially when the host PC and charger are connected to the wall plug.
- Do not change internal software parameters when motor is controlled. This could lead to unexpected and potentially dangerous states. Always stop the motor before you change settings. Change of settings could cause motor to spin-up. Secure the vehicle (lift it of the ground) before you start setting parameters.

2.2.5 Device's lifespan

- Device's operation at (or near to) limit values (voltage, current or temperature) reduces its lifespan.
- Exposing device to repetitive short-cuts on its protected outputs reduces its lifespan and increases risk of malfunction.

2.3 EMC

ESC3 controller creates electromagnetic interference, that could influence other electronic devices. Character and amount of the interference is dependent on various factors (such as voltage level, maximum currents, wiring topology, wiring geometrical properities ...). EMC should be tested carefully with each new end-product and with any change in existing end-product.

2.4 Warranty

ESC3 controller contain no serviceable parts. Its disassemble leads to immediate void of warranty. Controller firmware and supplied software tools are considered to be a part of the ESC3 controller. Any unauthorized changes in the software or firmware leads to immediate void of warranty.

ESC3 controller and supplied software contain system of user accounts and passwords with different access rights. Any attempt (successful or not) for unauthorized access leads to immediate void of warranty.



Chapter 3: Ordering codes

3.1 Product identification – *MPN* and *s/n*

Each product is identified by two identification numbers. First number is *MPN* (manufacturer part number) and second number is *s/n* (serial number). First number fully defines type and variant of the product and is not unique – two products with same number can (and will) exist. Second number is *s/n*, and is unique for each product. Two products with same *s/n* can not exist. Both numbers are printed on product's tag, as shown in the figure 3.1.

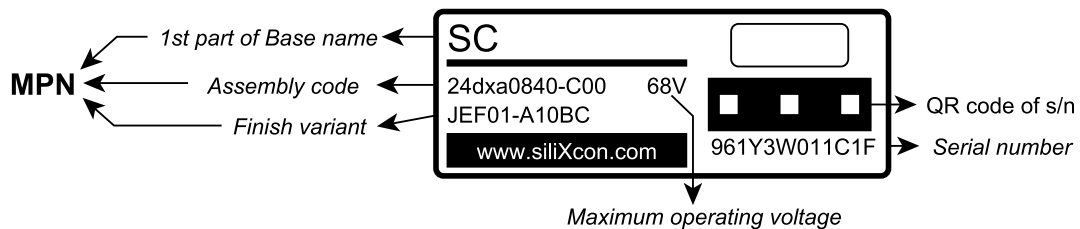


Figure 3.1: SC controller product tag

MPN consists of several parts, as shown in the figure 3.2. First part of the *MPN* is so called *Base name*. This name denotes firmwares that could be loaded into the product. For each *Base name* could be available one or more firmwares. Examples of *Base names* and compatible firmwares:

- *SC-felix* – firmwares for ground vehicles (bikes, motorcycles, scooters, cars ...)
 - LYNX – firmware for e-bikes
- *SC-raptor* – firmwares for RC models (cars, planes, boats, drones ...)
 - FALCON – firmware for drones and planes
- *SC-serpent* – firmwares for electric drives in industry
 - OPHION – firmware for industrial applications
- Custom firmware – siliXcon can develop custom firmware to meet customer requirements

Second part of the *MPN* is so called *Assembly code*. It defines size of the controller, its voltage and current rating, present communication interfaces, compatible motor sensors and power features of the controller. Exact meaning and available variants are listed in following sections of this datasheet.

Third part of the *MPN* is so called *Finish variant*. It defines some additional HW configuration, used signal and power wiring, heatsing and enclosure. Exact meaning and available variants are listed in following sections of this datasheet.

3.2 Product variants

The SC controller is very versatile product. To match all specific requirements, multiple properites can be adjusted, so many variants exists. Different variants are denoted by different *MPN*. Each field in the *MPN* stands for one thing, that can be configured. *MPN* consists of many fields (as shown in the figure 3.2) and each field can be configured almost independently. This gives very large amount of available configurations. The most common combinations are referred as *standard variants*, *default variants* and also as controller *models*.

- Standard configuration – the most usual configurations of controller. Samples are available in this configuration only. This configuration has usually shortest delivery time. In following description is this configuration denoted by gray background of the text. MPN (manufacturer part numbers) are assigned to individual controller models as follows:
 - **SC-felix model 1** – SC-felix_24dxa0840-C00.JEF01-A10BC
 - **SC-felix model 2** – SC-felix_24dxa1040-C00.JEF01-A10BC
 - **SC-raptor model 1** – SC-raptor_24dxa0840-C00.JEF01-A10BC
 - **SC-raptor model 2** – SC-raptor_24dxa1040-C00.JEF01-A10BC
 - **SC-serpent model 1** – SC-serpent_24dxa0840-C00.JEF01-A10BC
 - **SC-serpent model 2** – SC-serpent_24dxa1040-C00.JEF01-A10BC
- Other configuration – any non-standard configuration of the controller described in this datasheet.
- OEM solution – controller could be customized even deeper, than described in this datasheet. Contact siliXcon for more information.

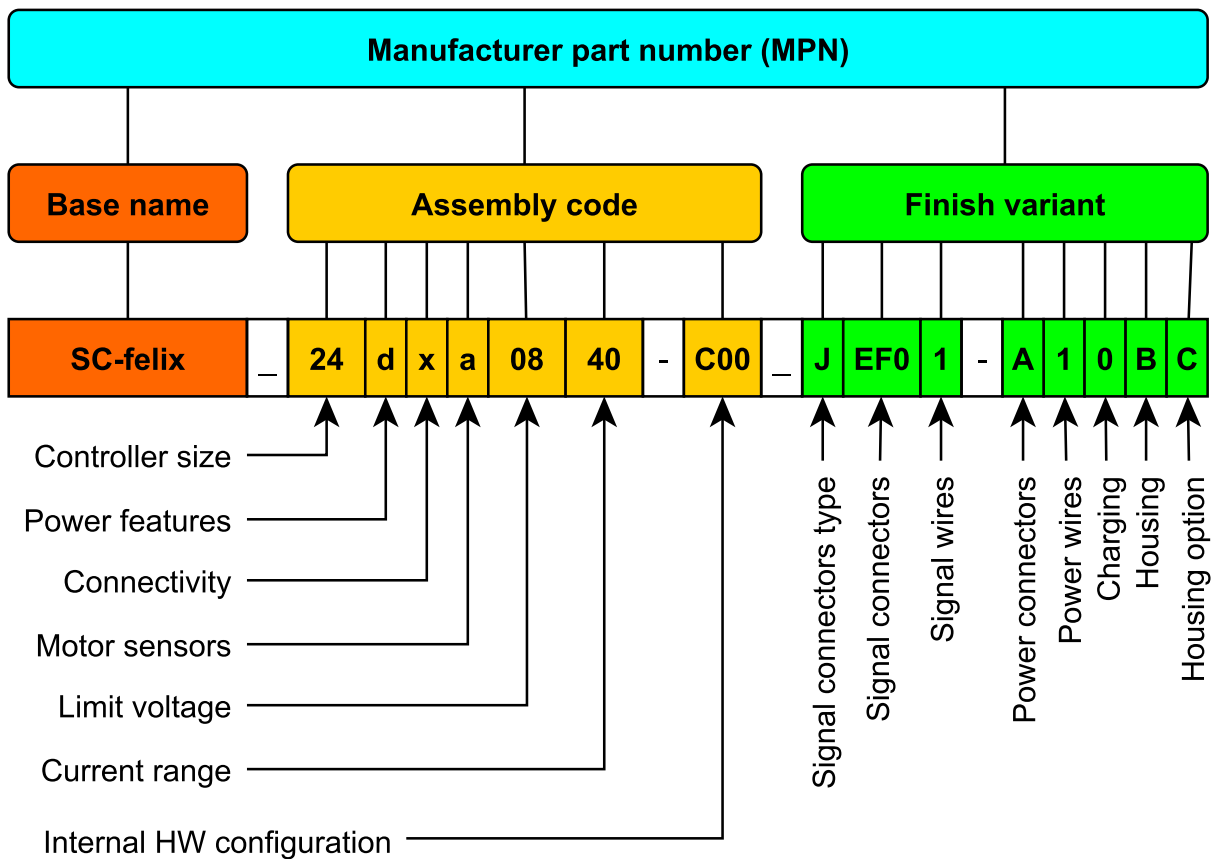


Figure 3.2: Example of MPN

3.2.1 Assembly code

Assembly code refer to modification in assembly of PCB. Behavior of these modifications is described in following parts of this datasheet:

- *Power features* – refer to sections 8.4, 8.5 and 8.6.
- *Connectivity* – refer to section 9.4.
- *Motor sensors* – refer to chapter 10.
- *Limit voltage* – refer to section 4.1.
- *Current range* – refer to section 4.4.
- *Internal HW configuration* – refer to chapter 8 and sections 9.4 and 9.5.

Table 3.1: Assembly code of the SC controller

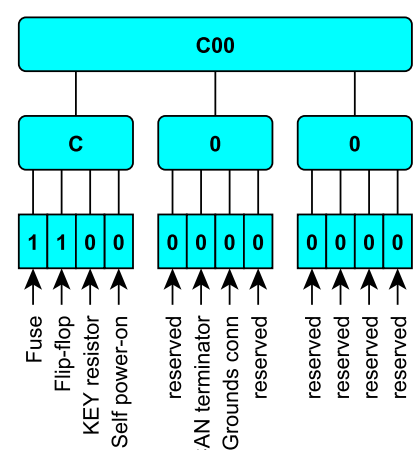
Letter	Variant	Description
Controller size		Size of the controller – number of transistors in the power stage
	24	24 transistors
Power features		Additional features for powering the controller
	d	No additional features
	e	Capacitors precharge
	f	Capacitors precharge + power switch without current sense
	g	Capacitors precharge + power switch with current sense
	h	Power switch without current sense
	j	Power switch with current sense
Connectivity		Present communication interfaces
	x	USB, isolated CAN Bus, isolated 5 V UART, GPIO
Motor sensors		Compatible motor sensors
	a	Analog sensor input (Sin-Cos), Hall sensors compatible, single-ended digital sensor compatible (SSI)
	r	Resolver input (Sin-Cos, resolver), digital sensors compatible (SSI, BiSS, Incremental sensor)
Limit voltage		Absolute maximum voltage (see chapter 4)
	06	60 V
	08	80 V
	10	100 V
Current range		Measuring current range
	40	400 A (amplitude)
Internal HW configuration		Solder jumpers, fuses, CAN terminator ...
	C00	Internal fuse connected, Flip-flop circuit, IOGND and GND isolated, no CAN terminator
	???	Refer to subsection 3.2.1

Internal HW configuration

Internal HW configuration describes all small modifications in hardware, such as solder jumpers, connection of CAN terminator or presence of fuse between BATT+ and KEY pins. Each item can be present (marked with 1) or not present (marked with 0). 12 bits are used for description and they form 12 bit binary number. This number is converted to the hexadecimal form. Meaning of bits and examples are listed in following table 3.2.

Table 3.2: Internal HW configuration encoding

Variant	Fuse	Flip-flop	KEY resistor	Self power-on	reserved	CAN terminator	Grounds conn (Note 1)	reserved	reserved	reserved	reserved	reserved
C00	x	x										
820	x						x					
C20	x	x					x					



Note 1: When selected, IOGND and GND connected together – galvanic isolation is not present

3.2.2 Finish variants

Finish variants describes different modifications of signal wiring, power wiring and housing. These modifications are described in following parts of this datasheet:

- *Signal connectors type, Present signal connectors, Signal wires* – refer to chapter 11.
- *Power connectors, Power wires* – refer to chapter 11.
- *Housing, Housing option* – refer to chapter 5.

Table 3.3: Finish variants of the SC controller

Letter	Variant	Description
Signal connectors type		Used type of the signal connectors
	J	JST JWPF (refer to table 3.4)
	W	No connectors, wires only (refer to table 3.4)
	Z	Custom combination
Present signal connectors		Which signal connectors are present
	EF0	Connectors: USB, CAN, 5V UART, Powering, Control I/O 1, Control I/O 2, Motor sensors
	???	Refer to subsection 3.2.2 according previous letter.
Signal wires		Crossection, insulation and length of signal wires
	1	10 cm, AWG 24, PVC insulation
Power connectors		Present power connectors
	A	Amass AS 150 for battery, Amass XT150 for motor
	B	Amass AS 150 for battery, M6 cable lugs for motor
	6	M6 cable lugs
Power wires		Crossection, insulation and length of power wires
	1	10 cm, 10 mm ² (AWG7), SIFF insulation
	other	other length, crossection and insulation on request
Charging		Type of charging, if present
	0	No charging
	N	Normal charging
	S	Step-up charging
Housing		Style of heatsing and enclosure
	E	Assembled, non-waterproof
	B	Assembled and sealed enclosure, waterproof
	Z	Custom housing, contact siliXcon for more information
Housing option		Color of heatsink, color and technology of the plastic cover
	C	Black elox heatsink (rev_3)
	other	Other options on request, contact siliXcon for more information

Note 1: No warranty, only limited product testing.

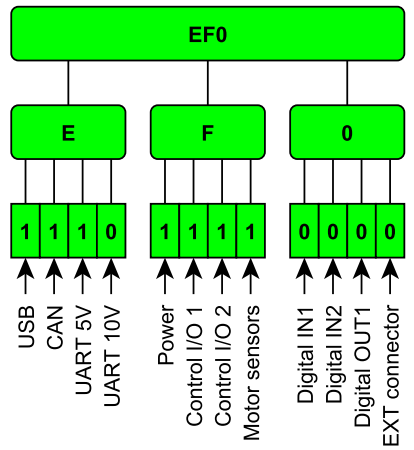
Present signal connectors

Three characters marked as *Present signal connectors* in figure 3.2 are encoded differently for each previous character. Basically, 12 connectors could be present on SC controller. If connector is present, on corresponding position is 1, if connector is not present, on corresponding position is 0. It forms 12 digit binary number. This binary number is converted to hexadecimal number which has exactly three characters. These characters are part of the *MPN* on this position – *Present signal connectors*.

Letter J and W – JST JWPF connectors and bare wires If the letter on position *Signal connectors type* is J (JST JWPF connectors are used) or W (only signal wires without connectors are soldered to the PCB), following table are used for creating *MPN*. Encoding mechanism is as it was described before – 12 connectors are represented by 12 ones or zeroes, result number is then converted to hexadecimal.

Table 3.4: Present signal connectors for **W** (wires only) and **J** (JST JWPF)

Variant	USB	CAN Bus	UART 5 V	UART 10 V	Power	Control I/O 1 (analog)	Control I/O 2	Motor sensors	Digital IN1	Digital IN2	Digital OUT1	EXT connector
000												
CD2	x	x			x	x		x				x
CD0	x	x			x	x		x				
CF8	x	x			x	x	x	x	x			
CF0	x	x			x	x	x	x				
EF0	x	x	x		x	x	x	x				
ED0	x	x	x		x	x		x				



3.3 Connectors ordering codes

If ordering custom combination of connectors, complementary connectors or spare connectors, please refer to the table below. Second column is code of connector which goes from the controller, third column is code of complementary connector to it, this connector goes from battery, motor, display etc...

Table 3.5: JST JWPF connectors order codes

Connector name	Connector ordering code	Complementary connector ordering code
USB	JM4_USB/11	C-JF4_USB/11
Power	JF3_PWR/11	C-JM3_PWR/11
Digital out 1	JF2_DO1/11	C-JM2_DO1/11
UART COM +5V	JF4_UARTCOM5/11	C-JM4_UARTCOM5/11
UART COM +10V	JF4_UARTCOM10/11	C-JM4_UARTCOM10/11
EXT connector	JF4_UARTEXT10/11	C-JM4_UARTEXT10/11
Control I/O 1 (Analog in)	JF4_CNTRL1/11	C-JM4_CNTRL1/11
Control I/O 2	JF8_CNTRL2/11	C-JM8_CNTRL2 /11
CAN	JM3_CAN/11	C-JF3_CAN/11
PAS	JM3_PAS/11	C-JF3_PAS/11
Digital in 1	JM2_DI1/11	C-JF2_DI1/11
Digital in 2	JM2_DI2/11	C-JF2_DI2/11
Motor sensors	JM8_MSENS/11	C-JF8_MSENS/11

Note: All listed connectors are with wires, length 11 cm, AWG24, PVC insulation.

Table 3.6: Power connectors order codes

Connector name	Connector ordering code	Complementary connector ordering code
Set of battery connectors AS150 (Note 2)	AS150-SET	—
Motor connector XT150 (female)	XT150-F	C-XT150-M
Charger connector XT60 (female)	C-XT60-F	XT60-M

Note 1: All listed connectors are without wires – connectors only.

Note 2: Set consists of one pair of black connectors and one pair of red connectors. Red male connector is the antispark one.

Table 3.7: JST JWPF connectors housings and crimps

Connector	Male order code	Female order code
2 pin	JM2	JF2
3 pin	JM3	JF3
4 pin	JM4	JF4
8 pin	JM8	JF8
crimps	CONTACT_SWPT-001T-P0.25-M	CONTACT_SWPR-001T-P0.25-F



Chapter 4: Electrical specifications

4.1 Input voltage

Table 4.1: Voltage rating

Parameter	Assembly code			
	0440	0640	0840	1040
Non-operational overvoltage limits	16 – 40 V DC	16 – 60 V DC	16 – 80 V DC	16 – 100 V DC
Safe voltage range	18 – 36 V DC	18 – 55 V DC	18 – 74 V DC	18 – 92 V DC
Operating voltage range	18 – 34 V DC	18 – 51 V DC	18 – 68 V DC	18 – 84 V DC
Battery configuration	8 S	12 S	16 S	20 S
Battery nominal voltage	28.8 V DC	43.2 V DC	57.6 V DC	72 V DC

Note: specifications are valid only in motor mode with field weakening turned off. Contact siliXcon for more information when using motor in generator mode and/or when using field weakening.

Non-operational overvoltage limits: outside given range is controller in critical error and power stage is completely turned off, hardware damage is possible. When overvoltage conditions pass over, controller remains shut down and has to be disconnected from battery manually. After reconnecting it to battery again, controller may work, but its reliability could be lower due to partial damage of FETs caused by overvoltage. If controller is shut down by undervoltage, no risk of hardware damage is taking place, but still it has to be disconnected from battery and then connected to battery with sufficient voltage.

Safe voltage range: outside given range controller power stage is shut down, there is no risk of damage until voltage reaches non-operational overvoltage limits. Limiter is cycle-by-cycle type, crossing safe voltage range results in power limiting or power stage shutdown to prevent further damage. When voltage gets back to limits, power stage is re-enabled again automatically. When using regen braking, controller could limit braking power to prevent battery reaching *Safe voltage range limit*.

Operating voltage range: inside given range controller is active and output power is not limited.

Battery configuration: number of cells in series for Li-ion or Li-Po battery pack.

Battery nominal voltage: nominal voltage of Li-ion or Li-Po battery pack.

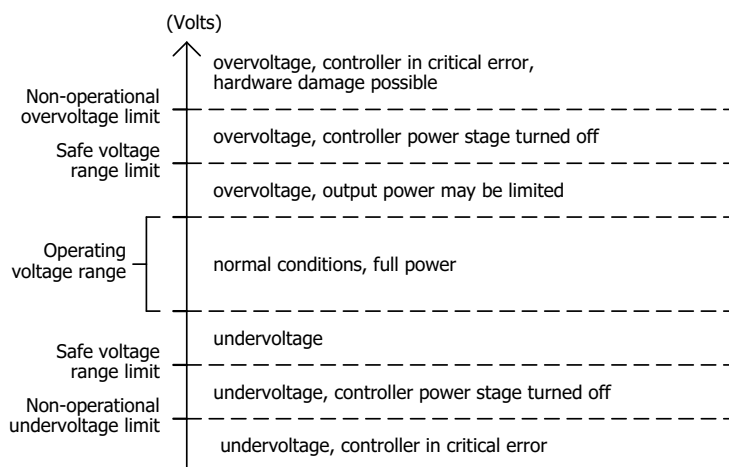


Figure 4.1: Controller voltage limits

4.2 Back-EMF of the permanent magnet motors

Motor with permanent magnets induce voltage (back-EMF) when spinning. This voltage is proportional to motor's rpm. When operating the motor over its nominal rpm, the amplitude of the back-EMF should never exceed *Non-operational overvoltage limit*. This could be achieved by proper settings of flux-weakening (refer to *Driver manual*). In addition, battery can not be disconnected from controller during such operation (not by manual switch nor by safety feature of possibly integrated BMS). Impedance of the used battery has to be comparable to impedance of the motor.

4.3 Motor nominal voltage

The SC controller is basically DC to AC converter and it can drive many types of electric motors. Considering nominal voltage, electric motors can be divided to the two main groups – DC motors and AC motors. Nominal voltage of these two groups of motors are defined in a different way, so the relationship between nominal voltage of motor and nominal voltage of battery is different. These voltages should match in the following way:

For DC motors – brushed DC motor and brushless DC motor (called also BLDC or trapezoidal motor) – nominal voltage of the motor should be equal to nominal voltage of battery pack, because nominal voltage of the motor is defined as *DC voltage*.

For AC motors – induction motor and brushless AC motor (called also BLAC or sinusoidal motor) – nominal voltage of the motor should be 1.414 times lower than battery nominal voltage, because nominal voltage of the motor is defined as *link voltage* (RMS value of sinusoidal voltage between two phases).

4.4 Output power and current

Similar to nominal voltage, nominal current is defined in different way for *AC motors* and for *DC motors*. Also motor power is calculated in different way. For each group of motors there is one table with current and power output rating.

Table 4.2: Power and current rating of the SC controller with BLDC motor connected

Parameter	Assembly code			
	0440	0640	0840	1040
Maximal power dissipation	120 W (2)			
Nominal power (60 min)	6900 W	9500 W	10900 W	12600 W
Nominal current (60 min)	240 A	220 A	190 A	175 A
Battery current	240 A	220 A	190 A	175 A
Peak power (10 sec)	11500 W	15100 W	17300 W	18000 W
Peak current (10 sec)	400 A	350 A	300 A	250 A

Note 1: listed power (peak and nominal) is output power from the controller (input power to the motor). Output power from the motor (mechanical power) is dependent on the efficiency of the motor and controller setting.

Note 2: Controller bottom pad thermally connected to infinite heatsink which does not exceed 60°C

Table 4.3: Power and current rating of the SC controller with BLAC or induction motor connected

Parameter	Assembly code			
	0440	0640	0840	1040
Maximal power dissipation	120 W (2)			
Nominal power (60 min)	6700 W	9000 W	10600 W	11500 W
Nominal current (60 min)	190 A	170 A	150 A	130 A
Battery current	235 A	210 A	185 A	160 A
Peak power (10 sec)	9900 W	14800 W	17000 W	17600 W
Peak current (10 sec)	280 A	280 A	240 A	200 A

Note 1: listed power (peak and nominal) is output power from the controller (input power to the motor). Output power from the motor (mechanical power) is dependent on the efficiency of the motor and controller setting.

Note 2: Controller bottom pad thermally connected to infinite heatsink which does not exceed 60°C

4.5 Additional electrical parameters

Table 4.4: Additional electrical parameters

Parameter	Value	Notes
PWM frequency	20 kHz	
Minimum pulse width	1 μ s	
Maximum electrical revolutions	100 000 el. RPM	
Minimum motor inductance	15 μ H	phase to phase
Battery / power supply impedance	—	comparable or less than motor impedance (Note)

Note: The higher the battery impedance is, the higher are voltage spikes caused by flowing current. If the voltage spikes are higher than Non-operational overvoltage limit, damage of the controller could occur.

4.6 Output protection and current limiting

Inputs and outputs of the controller are protected against shorting it to each other in following manner:

- Each phase is protected against shorting it to another phase
- Phase A and C are protected against shorting it to BATT+ and BATT–
- Signal pins with voltage lower than 5 V are protected against shorting them to each other.

Advanced protections such as maximal power protection, undervoltage, overvoltage, thermal protection or cycle-by-cycle current limiting are also implemented in the SC controller. These advanced protections are described in detail in the *Driver manual*.

4.7 EMC specifications and guidelines

Controller performs very rapid switching of high currents. This is a key principle of its operation and it can generate electromagnetic interference. The EMC performance is always matter of the whole product, not only of the controller itself.

RC network is connected between power stage of the controller and aluminium heatsinking to improve the EMC performance. Schematic of this network is shown in the figure 4.2.

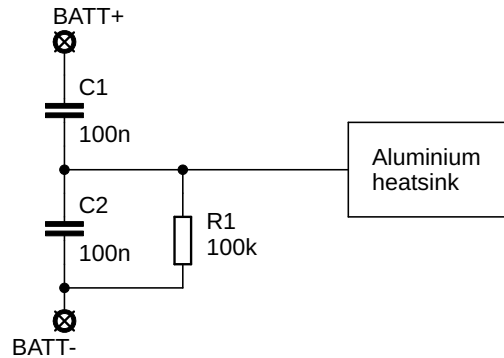


Figure 4.2: RC network between power stage and heatsink

To improve EMC performance, following guidelines should be kept in mind:

- Use power wires with appropriate cross-section. Higher cross-section means lower resistance, lower voltage drops and lower thermal losses.
- If possible, use short wires. Similarly to the previous point, shorter wires have lower resistance.
- Use shielded cables. Shielding should be connected to appropriate ground. Shielding should be connected only on one side of the cable to prevent ground loops.
- Use twisted pairs. Wires with differential signals (such as CAN Low and CAN High) should be twisted together. Wires with non-differential signals should be twisted together with appropriate ground.
- Twist power wires. To improve EMC performance, twist BATT+ with BATT- and twist together phases A, B and C.
- Place signal wires separately from power wires. When crossing power wires with signal wires, power wires should be perpendicular to signal wires.
- If possible, connect motor chassis to BATT- close to the controller. If the motor chassis can not be connected to BATT- directly, connect safety capacitor (Y capacitor) between them.
- To prevent ground loops, use galvanic isolation.
- Use signals with appropriate grounds. Do not mix signal grounds and power grounds. Even if the power ground and signal grounds are galvanically connected inside of the controller, they can not be mixed up outside of the controller.

Chapter 5: Mechanical specifications

5.1 Basic information

Table 5.1: Basic mechanical parameters of the SC controller

Parameter	Bare board	Sealed enclosure
Width	114 mm	131 mm
Height	29 mm	35 mm
Depth	50 mm	66 mm
Weight	55 g	570 g

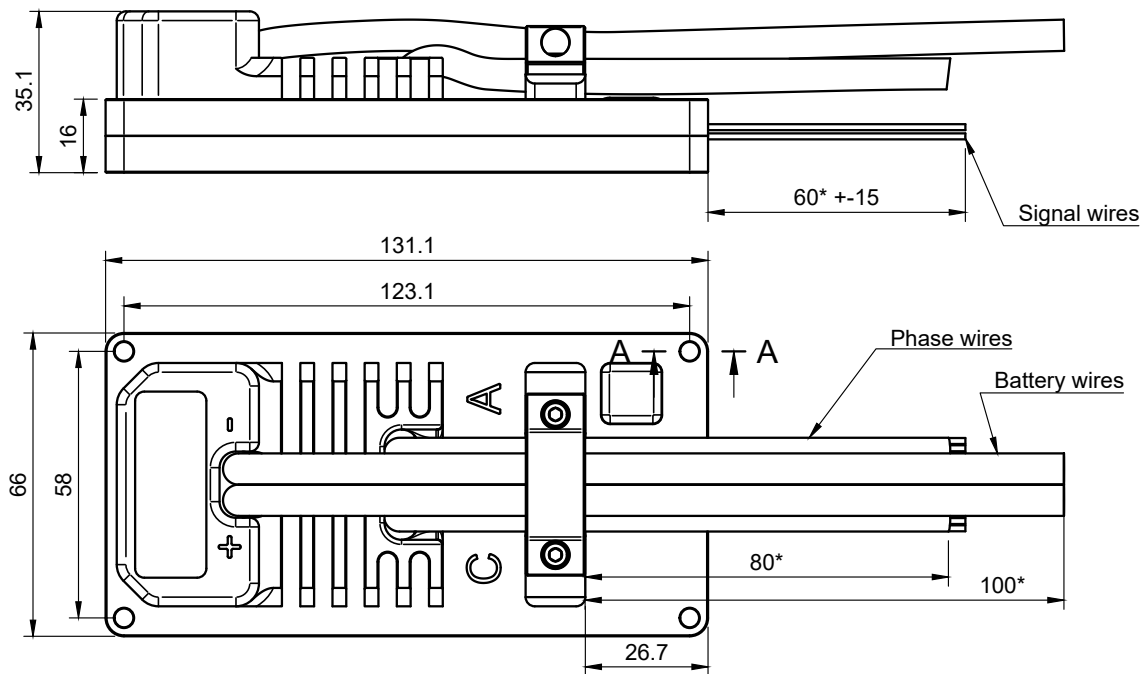


Figure 5.1: Dimensions of the SC controller

Mounting torque Recommended mounting torque for M4 screws is $T_{M4} = 3\text{Nm}$ and for M5 screws is $T_{M5} = 6\text{Nm}$.

Chapter 6: Enviromental specifications

Table 6.1: Storage and operation conditions of the SC controller

Parameter	Value			
	min.	typ.	max.	units
Temperature				
Operation (no power limitation)	-20		60	°C
Operation (limited power) (1)	-20		80	°C
Humidity				
Operation	5		85	%
Ingress of dust and water				
Internal electronics – sealed (2)		IP65		
Internal electronics – non-sealed (3)		IP40		
Connectors – JST JWPF (4)		IPX7		
Connectors – Amass AS150 and XT150		—		
Other connectors	according manufacturer specification			

Note 1: Long device operation at high temperatures reduces device's life

Note 2: Sealed enclosure and cables secured against any movement

Note 3: Non-sealed enclosure or cables not secured against movement

Note 4: All connectors has to be properly mated

Chapter 7: Thermal specifications

Table 7.1: SC controller thermal specification

Parameter	Value	Conditions
Maximal power dissipation	120 W	controller thermally connected to infinite heatsink which does not exceed 60°C
	15 W	controller in aluminium housing, in still air of temperature 25°C
Thermal resistance	0.25 K/W	to the bottom pad of aluminium housing
Limiting temperature	90°C	Temperature is measured inside the controller, near transistors, above this temperature is output power limited to prevent controller overheat.

7.1 Power dissipation calculation

During controller operation heat is generated inside the controller. Two major mechanisms are taking place: conductance losses and switching losses. First mechanism is in low-voltage high-current (such as SC controllers) application dominant, the second one is rather marginal. Conductance losses are proportional to resistance and square of current, switching losses are proportional to frequency, battery voltage, motor current and switching time of transistors.

You should also consider the type of driven motor, because their nominal values has different meaning.

For **AC motors** (BLAC, Induction) the nominal values are RMS value of *link* voltage and RMS value of *phase* current.

For **DC motors** (BLDC, brushed motor) the nominal values are DC value of voltage and DC value of current.

With respect to the facts listed above, the calculation of power losses is different for DC motors and for AC motors. In addition, the losses are affected by assembly variant of controller. Power dissipation is calculated from this formula:

$$P_{TOT} = 1 + k_c \cdot I_N^2 + k_s \cdot V_{BATT} \cdot I_N \quad [W] = [A]; [V]; [A]$$

V_{BATT} is battery voltage in volts, I_N is nominal current of motor in Amps (DC value for DC motors and RMS value for AC motors). Units of result P_{TOT} are Watts. Coefficient k_c describes conductance losses and coefficient k_s describes switching losses. Both coefficients are dependent on assembly variant and on type of motor. All of them are listed in table 7.2.

Table 7.2: Power losses coefficients for SC controllers

Assembly code	DC motor		AC motor	
	k_c	k_s	k_c	k_s
0440	0.0019	0.00084	0.0028	0.0023
0640	0.0021	0.00087	0.0032	0.0024
0840	0.0029	0.00095	0.0043	0.0026
1040	0.0034	0.00097	0.0051	0.0026

7.2 Mounting notes

To achieve maximal performance and reliability of controller you should provide sufficient cooling for it. Below are listed several tips, which could help to achieve this:

- Place controller in well ventilated area. Rather use sealed, waterproof housing and put it out of the vehicle than putting it inside. Contact with moving air improves cooling.

- If possible, fasten the controller to large metal parts, such as frame. It works as heatsink and help to conduct heat away.
- If using external heatsink or fastening controller to metal parts, make sure that both surfaces are flat, clean and fit to each other. After that, apply suitable amount of thermal grease to both surfaces.
- When applying thermal grease, use rather little of it than too much.
- If thermal grease is not available, you could use normal grease instead.



Chapter 8: Powering interface

This chapter deals with controller powering – its activating and deactivating and problematics connected with it. Summary powering scheme is shown in the figure 8.1.

The SC controller has several advanced features that allow to control its power state. Flip-flop circuit allows controller to be powered up and down by two pushbuttons and it also enable the auto power-off feature. Capacitors precharge with contactor control allows to connect controller to battery without sparking. Presence of *power switch* enables controller to use battery charging (either normal or step-up charging) or control power for vehicle power grid.

8.1 Control electronics powering, flip-flop circuit

Control electronics is powered from pin 1 KEY. This allows to start control electronics before battery is connected to the power stage. Control electronics and power stage are not galvanically isolated, so the same battery has to be used for powering control electronics and power stage. Pin 1 KEY has to be connected to battery positive pole via fuse. Optionally, KEY switch can be also used. Internal fuse can be used, if the split power of the power stage and control part of the controller is not required (see figure 8.1).

Pin 2 POWER is used for managing controller power state. Input of the flip-flop circuit is connected to this pin. Flip-flop circuit allows to control power state by pulses. Positive pulse sets the flip-flop and power on the controller, negative pulse resets the flip-flop and power off the controller. Presence of the flip-flop circuit is not mandatory and can be configured by changing *finish variant* (see section 3.2.2). Presence of the flip-flop circuit also enables the auto power-off feature of the controller – controller can power itself down automatically, by software.

When the flip-flop circuit is disabled, power state of the controller is not driven by positive and negative pulses, it is controlled by voltage level. Logic HIGH (voltage higher than 5 V) on the pin 2 POWER activates the controller. Controller remains powered on as long as the voltage is higher than 5 V.

8.2 KEY resistor

Pin 2 POWER can be connected internally to pin 1 KEY. Controller is then powered on automatically each time, when power is connected to pin 1 KEY. In this configuration is auto power off capability still working, controller can power itself down. If done so, power from the pin 1 KEY has to be re-connected to power on the controller again. KEY resistor is placed during manufacturing of the controller, its presence is reflected to MPN of the controller in part *Internal HW configuration* (refer to section 3.2.1).

8.3 Internal fuse

Control electronics is powered from pin 1 KEY. This pin could be connected internally to BATT+ terminal by **internal fuse**. Fuse's presence is indicated in MPN, in part *Internal HW configuration*; refer to section 3.2.1 and table 3.2. If internal fuse is not present (or is blown), connect pin 1 KEY with BATT+ via external, non-reversible, fuse. KEY switch could be also connected in series with external fuse. For correct function of battery voltage measurement, pins 1 KEY and BATT+ has to be connected by low impedance (either internal or external fuse).

8.4 Automated capacitors precharge and discharge

Power stage of the controller employs a capacitor bank with high capacity high-quality and low-ESR electrolytic capacitors. These capacitors are required for proper function of the controller. When connecting controller to the battery, sparking could occur because of high inrush current. This high inrush current is caused by charging



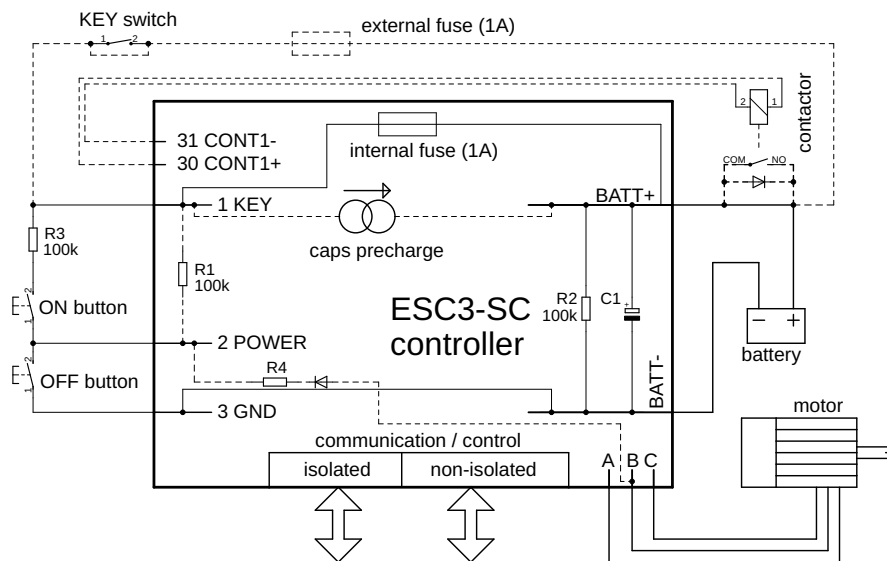


Figure 8.1: SC controller powering scheme

the discharged capacitors. Capacitors could stay charged for a long time after battery is disconnected (even several hours). This could lead to electric shock and injury even if controller is completely disconnected.

To avoid this inrush current, sparking and persistent charge hold, controller is equipped with automated capacitors precharge/discharge feature. This option is enabled when capacitors precharge *power feature* is present (letters **e**, **f** and **g**). It is highly recommended to use this option in all applications, where the controller is not connected to battery permanently.

As first step, only negative pole of the battery is connected to the controller. Then, positive pole of the battery is connected to control electronics – pin 1 KEY. Control electronics powers up, perform self-tests and then use internal current source to precharge power stage capacitors to a predefined voltage level. After that, battery positive pole could be connected to the power stage of the controller. This is done automatically by battery (line) contactor. When using capacitors precharge feature, internal fuse cannot be present and is removed during controller assembly. As shown in the figure 8.2, external fuse has to be used when powering control electronics. KEY switch is also typically used. When this switch is closed, control electronics is activated, capacitors are precharged and then the battery contactor is closed to connect battery to power stage of the controller. After this, controller is ready for operation.

After the control stage of the controller is left unpowered, the capacitors are discharged using an internal resistor (R2 in the figure 8.1). Usage of this option is not recommended in applications, where controller is connected to battery permanently because this resistor increase self-discharge of the battery.

Either self-discharge resistor is present or not, always check the voltage between terminals BATT+ and BATT- before handling the controller.

8.5 Contactor control

SC controller is equipped with one output for contactor control. It is typically used to control battery contactor during controller power-on process. This contactor is closed after capacitors are precharged.

Contactor output is open drain type – CONT1+ is connected to the KEY pin permanently and CONT1- is connected to ground by the MOS-FET. CONT1- and CONT1+ pins are capable of switching induction load, recirculation diode is built into the controller. Connection of contactor output is shown in the figure 8.2.

Contactor output is capable of PWM switching, current measurement and control. This can emulate lower voltage for the contactor. For example, 12 V line contactor can be safely used even if battery has 48 V. *Attack & hold* feature is also enabled by using PWM. To close the contactor is typically need nominal voltage of the contactor. Once is the contactor is closed, lower voltage (than nominal) is enough to keep the contactor closed. Period of closing the contactor is called *attack*, period of keeping contactor closed is called *hold*. Using *attack & hold* feature helps to reduce power consumption and stress, but has to be configured properly. Otherwise, contactor contacts can be damaged due to insufficient contact force.

Always bypass battery (line) contactor with proper diode in reverse direction to protect the controller from overvoltage possibly caused by PMSM motor over its nominal speed.

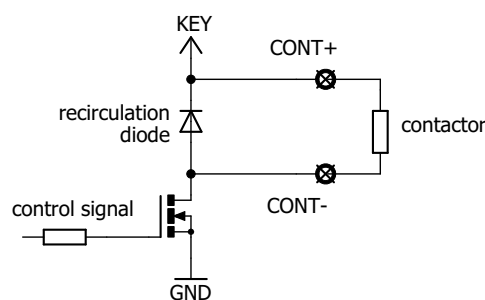


Figure 8.2: Connection of contactor output

8.6 Power switch and charging

SC controller could be equipped with *power switch*. This is bi-directional MOS-FET switch connected between BATT+ and pin SW+. This switch is capable of driving high current loads (such as power grid of the vehicle, lights ...) or connect charger to the battery. Current capability of the *power switch* is 15 A and could be also equipped with current measurement.

Presence of the *power switch* and current measurement is denoted in MPN by letter *power features*. Variants **d**, **e** stands for no *power switch*, variant **f** and **h** means *power switch* without current measurement, variant **g** and **j** is for *power switch* with current measurement. Refer to section 3.2 and 3.2.1. If the variant without current measurement is used, overcurrent protection has to be guaranteed externally, for example by using proper fuse. Variant with current measurement does not need any overcurrent protection, in case of overcurrent is the switch disconnected automatically.

8.6.1 Normal charging

Power switch could be used to connect charger to battery during charging. Normal charging means that appropriate charger is used. Voltage and current rating of the charger and battery must match. SC controller acts as additional safety feature because it monitors battery current and voltage and can disconnect the charger if the values are out of limits. Positive pole of the charger is connected to the *power switch*, negative pole of the charger is connected to the negative terminal of the battery. Connection is shown in the figure 8.3. Normal charging is more effective than step-up charging, but proper charger has to be used.

8.6.2 Step-up charging

SC controller also supports step-up charging. In this case controller acts as step-up (boost) converter, using connected motor inductance to boost charger voltage to battery voltage. Positive pole of the charger is connected to the *power switch*, negative pole of the charger is connected to the phase B of the controller. In this mode is

charging voltage and current driven by the SC controller, any power source could be used as charger. Used source has to have **sufficient current capacity** and its **voltage has to be lower than voltage of discharged battery**. Connection of step-up charging is shown in the figure 8.3. Step-up charging is not as effective as normal charging, certain amount of heat is generated in controller itself and in motor winding. Advantage is, that almost any power supply can be used for charging, the only two requirements are voltage lower than voltage of discharged battery and sufficient current capability.

Warning: When charger is connected to the SC controller, negative terminal of the charger must not be connected to the negative terminal of the battery. Otherwise, short-circuit could take place. Do not connect any other equipment (such as laptop via USB) to the SC controller during charge. This could provide current path for the short circuit !!!

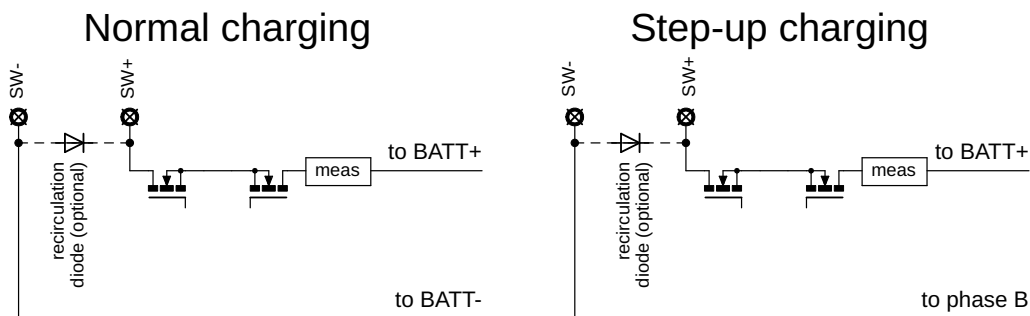


Figure 8.3: Normal and step-up charging connection

8.6.3 Switching loads

Power switch can be also used for switching loads with high current requirements such as vehicle lights or vehicle power grid. Load is then connected between BATT– and output of the *power switch*. When switching high current inductive loads, recirculation diode has to be added externally. If no external recirculation diode is added, only 1 A induction load can be switched by *power switch*.

8.7 Self power-on

The SC controller could be powered on from off-state, when motor starts to spin. Motor with permanent magnets has to be used. When enabled, resistor R4 with diode between phase B and POWER input is added (see picture 8.1). When motor starts to spin, it induces voltage and this voltage activates the controller. Refer to section 3.2.1), to part *Internal HW configuration* when choosing proper *MPN* of the product. When using self power-on ability, flip-flop circuit has to be present.

This ability could be used as anti-theft system for vehicle. When motor starts to spin without proper activation, controller powers up, lock the motor and also could start alarm or perform other required action. Another usage of the self power-on ability is for wind turbines. When turbine starts to spin, controller is powered on automatically.

8.8 Power pins specifications

Table 8.1: Power control pins

Pin	Name	Description	Direction	Parameters, max. range
1	KEY	Power input for internal electronics, capacitors precharge and contactors, can be connected to BATT+ via internal fuse	Power I/O	$0-V_{NOM}$, max. 1 A
2	POWER	Controller ON/OFF input, active high	Input	$0-V_{NOM}$, max. 10 mA
3	GND	Ground, internally connected to BATT-	Power I/O	0 V, max.1 A

Note 1: All pins are related to the pin 3 GND.

Note 2: V_{NOM} is upper limit of *Operating voltage range*, refer to section 4.1.

Table 8.2: Contactor and charger pins

Pin	Name	Description	Direction	Parameters, max. range
8	SW-	<i>Power switch</i> negative terminal, internally connected to BATT-	Power I/O	0 V, max. 15 A
		Step-up charging negative terminal, internally connected to phase B		
9	SW+	<i>Power switch</i> positive terminal, PWM, voltage and current measurement	Power I/O	$0-V_{NOM}$, max. 15 A
30	CONT+	Contacto positive output, internally connected to KEY	Power output	$0-V_{NOM}$, max. 1 A
31	CONT-	Contacto negative output, open drain type	Power output	$0-V_{NOM}$, max. 1 A

Note 1: All pins are related to the pin 3 GND.

Note 2: V_{NOM} is upper limit of *Operating voltage range*, refer to section 4.1.

8.9 Controller powering methods

Constant ON

Easiest and most straightforward method. Controller is powered on, when battery is connected to the power terminals BATT+ and BATT- and it remains powered on as long as the battery is connected. Sparking will occur when connecting battery to controller. After some time this can lead to damage of contacts. If using this method, controller has to have internal fuse connected and KEY resistor (R1) has to be present. Pin 2 POWER has no function in this powering method. Schematics of the connection is shown in the figure 8.4. First character of *Internal HW configuration* will be **A** (part of *MPN*. Refer to section 3.2.1).

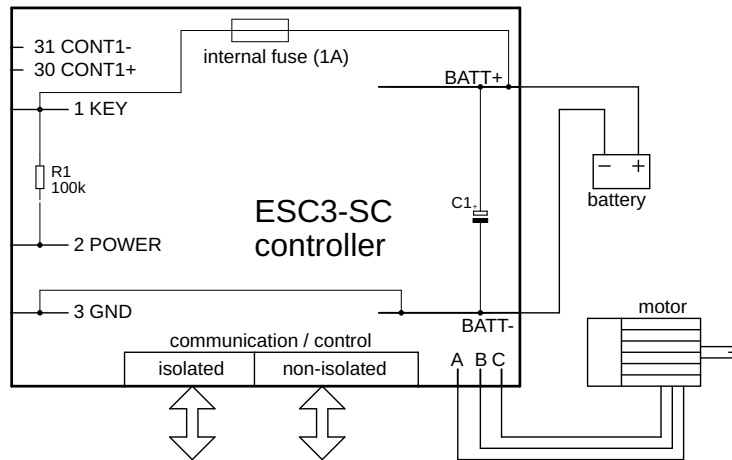


Figure 8.4: Constant on powering scheme

8.9.1 ON/OFF switch with external fuse

Another possibility is to use ON/OFF switch to control power state of the controller. This switch is connected between battery and pin 1 KEY. External fuse has to be connected in series, internal fuse can not be used. Resistor R1 is connected and flip-flop circuit is disabled. First character of *Internal HW configuration* will be **2** (part of *MPN*. Refer to section 3.2.1). Pin 2 POWER is not used. Battery is connected directly to the controller without line contactor. Schematics of the connection is shown in the figure 8.5.

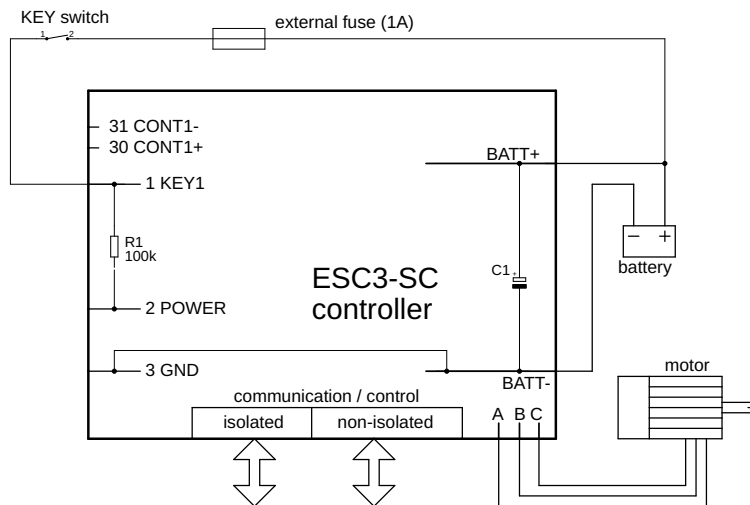


Figure 8.5: ON/OFF switch powering scheme

8.9.2 ON/OFF switch with capacitors precharge and contactor

Connection is same as in paragraph before (ON/OFF switch), with only one difference. Battery is not connected directly to the controller, line contactor in series is used. When the KEY switch is closed, control electronics is powered up, it runs the self-tests and then current source is used to precharge the power stage capacitors. Once the capacitors are charged, battery contactor is closed and battery is then connected to the power stage. Controller is now ready for operation. Schematics of the connection is shown in the figure 8.6.

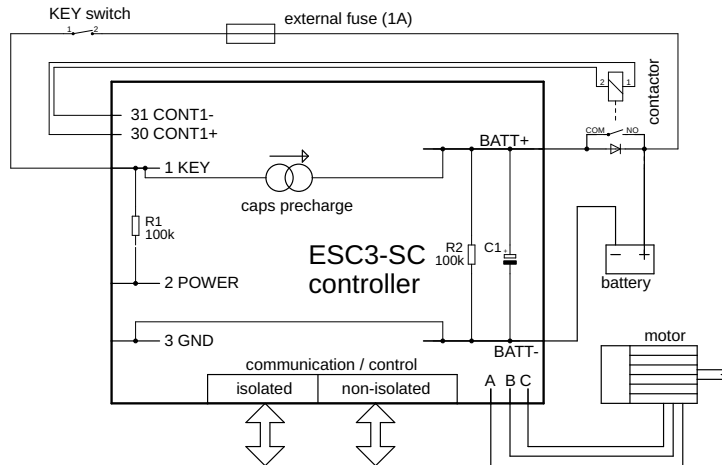


Figure 8.6: ON/OFF switch with contactor powering scheme

8.9.3 Two buttons control (recommended)

SC controller power state can be controlled by two pushbuttons. Flip-flop circuit and internal fuse are used. First character of *Internal HW configuration* will be **C** (part of *MPN*. Refer to section 3.2.1).

Battery is connected directly to the power terminals of the controller. Controller is powered on by pressing the ON button and powered off by pressing OFF button. KEY switch, external fuse and battery contactor are not used in this case. Using OFF button is not mandatory, controller can be turned off by software. Schematics of the connection is shown in the figure 8.7.

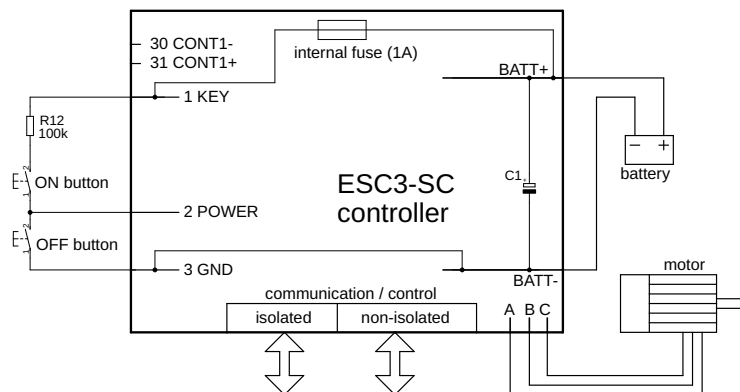


Figure 8.7: Two buttons powering scheme

8.9.4 Two buttons control with capacitors precharge and contactor (recommended)

This powering method is very similar to the previous one. Internal fuse has to be removed and battery is connected to the pin 1 KEY via external fuse instead. Optionally, KEY switch can be used in addition. First

character of *Internal HW configuration* will be 4 (part of *MPN*. Refer to section 3.2.1).

Battery is not connected to positive power terminal directly, it is used battery contactor. To power on the controller, KEY switch has to be closed first (if present). Then, ON button should be pushed to power on control electronics. Electronics runs the self-tests, use current source to precharge the capacitors and then it closes the battery contactor. After that, controller is ready for operation. Controller is powered off by pressing the OFF button or automatically by software. Schematics of the connection is shown in the figure 8.8.

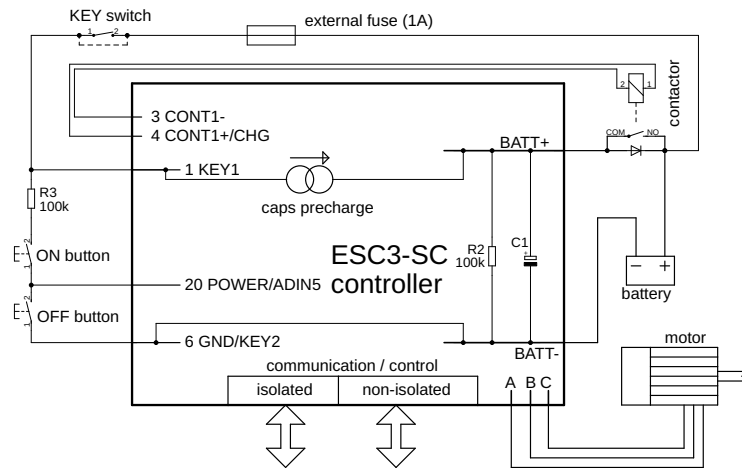


Figure 8.8: Two buttons with contactor powering scheme

8.9.5 Two buttons with auto power-off and self power-on

This powering method is very similar to the 'Two buttons control' described in section 8.9.3. SC controller could be powered on and off by two pushbuttons. Controller is also capable of turning itself off by software. In addition, controller could be powered on automatically, when motor starts to spin. Motor with permanent magnets has to be used. Schematics of the connection is shown in the figure 8.9.

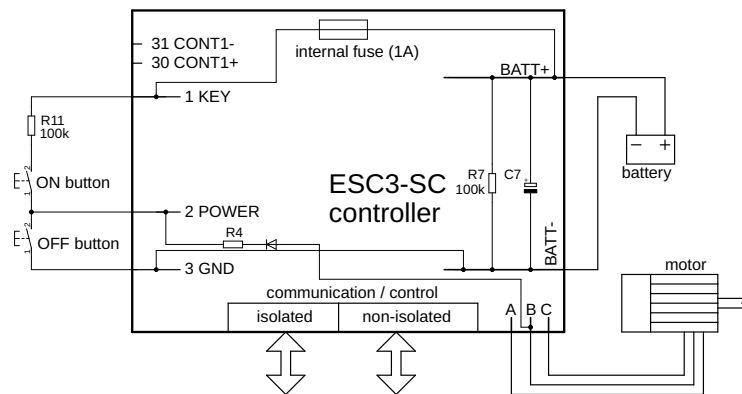


Figure 8.9: Two buttons powering scheme

Chapter 9: Control interface

9.1 Power supplies in the controller

The SC controller has several power supplies, and power pins, each of them is intended for specific use. Block schematic is shown in the figure 9.1. These supplies are:

- Battery power supply – pins 01 KEY and 03 GND. Battery is connected to these pins via fuse (internal or external, internal is 1 A non-reversible fuse). Voltage is present even if the controller is powered off. Voltage is equal to V_{BATT} , maximum current consumption is 1 A.
- Contactor control – pins 30 CONT+ and 31 CONT-. Pin 30 CONT+ is connected to the pin 01 KEY internally. Pin 31 CONT- is open-drain type and in on-state is connected to the GND/BATT-. Refer to the section 8.5 for detail information.
- Motor sensors power supply – pins 29 HALL+5V and 24 HALLGND. Power supply for powering motor sensors. Voltage is 5 V, maximum current consumption is 50 mA. This power supply is galvanically connected with battery.
- Isolated power supply – power supply for GPIOs. IO+3V, IO+5V, IO+10V and IOGND. This power supply is galvanically isolated from battery, but is **not** isolated from CAN power supply and UART power supply. These communication power supplies are derived from the *isolated power supply*.
- *Power switch* – pins 8 SW- and 9 SW+. Switched power output with current capability of 15 A. Pin 9 SW+ is connected to BATT+ via bi-directional MOS-FET switch. Pin 8 SW- is connected either to BATT- or phase B, depending on configuration of *Power switch*. Refer to section 8.6 for detail information.
- Extension power supply – pins 45 EXTGND and 42 EXT+10V. Power supply for powering extensions / add-ons (external charger switch, external RGB LED ...). Voltage is 10 V, maximum current consumption is 100 mA. This power supply is galvanically connected with battery.

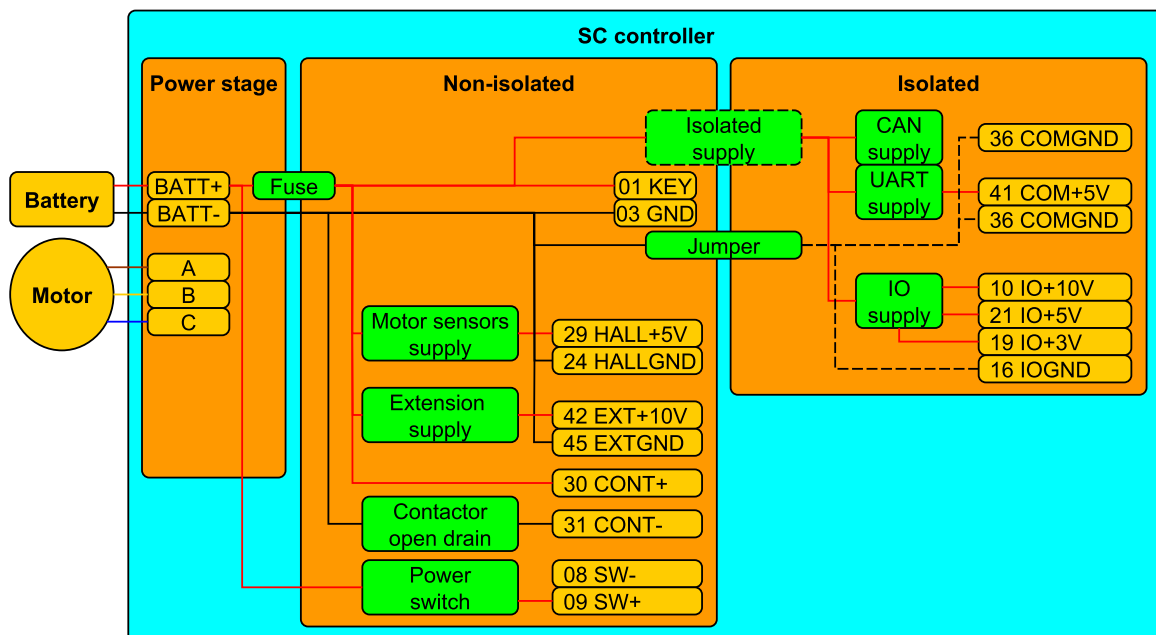


Figure 9.1: Block schematic of controller power supplies

9.2 Galvanic isolation

Some interfaces of the SC controller are galvanically isolated from rest of the controller. This feature enables easy and safe cooperation between controller and other systems. If connected correctly, galvanic isolation helps to reduce electrical interference and give more options to connect system grounds and power supplies properly.

The SC controller is equipped with one galvanically isolated part. To this part belongs CAN Bus, UART and GPIOs. These three interfaces are galvanically isolated from rest of the controller (power stage, battery, USB, digital inputs ...) but they are **not** isolated from each other – CAN Bus, UART and GPIOs use the same ground, which is accessible on pin IOGND (pins 16, 18, 20 and 22). When galvanic isolation is not needed, IOGND can be connected with BATT– controller manufacturing. This is reflected do the controller's *MPN*, in part *Internal HW configuration* is changed bit *grounds conn* from 0 to 1. Block schematic is shown in the figure 9.2. Grounds are isolated by default.

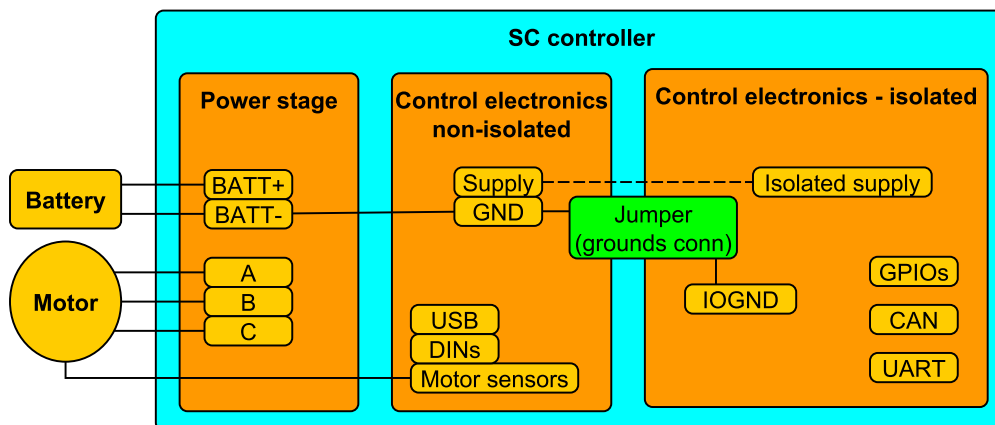


Figure 9.2: SC block schematics – galvanic isolation

9.3 Built-in LED

The SC controller has built-in LED which indicates propagation of the control program in microprocessor. When controller is powered on, following steps take place:

1. Bootloader – check some very basic information as firmware version and checksums. If ok, it passes control to the main program. During this stage is built-in LED not driven and it lights very briefly. If controller remains in this state for longer than few seconds, there is some problem with firmware. Try to update the firmware.
2. Main program – lits the built-in LED and starts initialization of the *Driver*. When initialized (successfully or not), main program passes control of the built-in LED to the *Driver*.
3. Driver – the part of the firmware, that deals with motor control. It also controls the built-in LED to indicate its own state:
 - LED is turned off – *Driver* was successfully initialized and motor could be driven or is driven already.
 - LED lights solidly – *Driver* status word is different than 0. Some *High priority limiter* could took place. If condition for LED light passed away, built-in LED is turned off after 2 seconds timeout. Refer to the *Driver manual* for more information about *High priority limiters* and *Driver* status word.

- LED is blinking – some error occurred during *Driver* initialization or during runtime. LED blinks for 16 times, then waits for longer time and repeat sequence again. Each blink has meaning of one bit from controller error word. Long blink is for logic 1, short blink is for logic 0. Blinks go from LSB to MSB. Refer to the *Driver* manual for more information about controller error word.

9.4 Communication

9.4.1 USB

The SC controller is equipped with native USB communication. USB pins are **not** galvanically isolated from power stage of the controller (it is recommended to use USB isolator). USB is intended for system maintenance like firmware update or off-line settings and is not intended for run-time settings and debugging. The best practice is to power off the controller, disconnect it from power source/battery and after that connect controller via USB to computer. USB provides enough power for microprocessor but left the power stage unpowered.

Run-time control, diagnostics and debugging via USB is possible but not recommended. If not connected properly, ground loops could take place and increase electrical interference. This can result in unreliable or not working USB connection or even hardware damage to controller or connected computer. Better way, how to do run-time diagnostics and debugging is to use UART or CAN communication which are both galvanically isolated. If using run-time USB connection, you have to connect controller *first* to battery (or another power source) and *after* that connect USB. Connecting USB first leads to powering microprocessor from USB and leaving the power stage unpowered, even if battery is connected additionally.

USB driver installation, communication between controller and computer and firmware updates are described in *OS Manual*.

Table 9.1: USB pins

Pin	Name	Description	Direction	Parameters, max. range
4	USB+5V	USB 5V	Power input	5 V max. 300 mA
5	USBGND	USB ground, internally connected to BATT–		0 V
6	USBDM	USB data –	Input/output	0–3.3 V, 5 V tolerant, max. 10 mA
7	USBDP	USB data +		

Note: All pins are related to the pin 5 USBGND.

9.4.2 CAN Bus

CAN Bus is modern type of communication bus, widely used in industry and automotive. The SC controller is equipped with one, galvanically isolated, CAN Bus interface which is excellent for fast and real-time communication with speed up to 1 Mbps. Typical example of CAN Bus usage are electrical vehicles. Each wheel has its own motor and controller, controllers communicate with superior system and with each other via CAN Bus.

When connecting multiple devices via CAN Bus, their CAN high and CAN low pins are connected to the bus. CAN ground has to be connected with appropriate grounds of the other devices on the bus. Usually, ground is used as shielding. Both ends of the CAN Bus line should be terminated by 120 Ω resistor. This resistor is present in the SC controller and could be connected during controller manufacturing. Its connection is reflected in the *MPN*, in part *Internal HW configuration* (refer to section 3.2.1). Example of CAN Bus connection is shown in the figure 9.3.

Communication with computer via CAN Bus, required hardware and driver installation is described in detail in *OS Manual*.

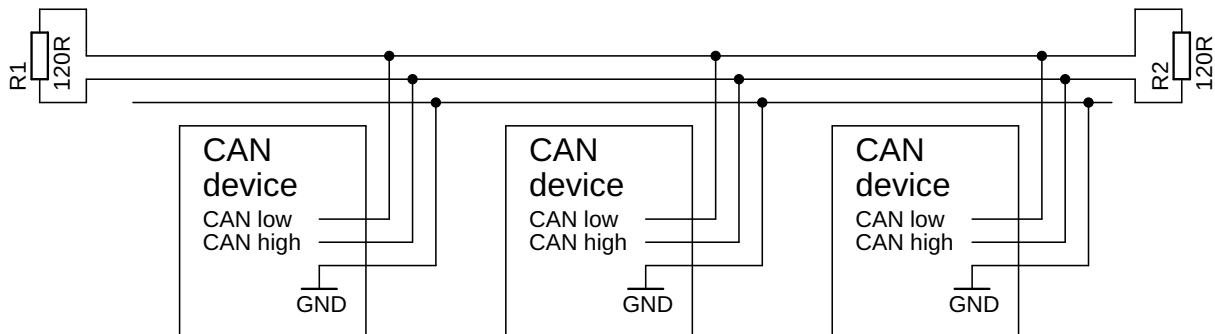


Figure 9.3: Connection of CAN Bus

Table 9.2: CAN Bus pins

Pin	Name	Description	Direction	Parameters, max. range
38	CANL	Galvanically isolated CAN LOW	Input/output	0–5 V, max. 10 mA
37	CANH	Galvanically isolated CAN HIGH		
36	COMGND	Galvanically isolated CAN ground Power output	0 V, max. 100 mA	

Note: All pins are related to the pin 36 COMGND.

9.4.3 Serial communication (UART)

The SC controller is equipped with one, galvanically isolated, UART by default. Logical levels are 0 V and 5 V. When UART is combined with UART-to-USB adapter, it can be used for controller run-time settings, diagnostics and debugging. USB-to-UART driver installation and communication between computer and controller is described in *OS Manual*.

On request, UART COM can be replaced with I²C bus. Pins COMRXD and COMTXD then work as SCL and SDA signals.

Table 9.3: UART COM pins

Pin	Name	Description	Direction	Parameters, max. range
39	COMRXD	Galvanically isolated UART COM RX	Input	0–5 V, max. 20 mA
		Non-isolated UART COM RX	Input	0–3.3 V, 5 V tollerant max. 20 mA
		I ² C SCL	Output	
40	COMTXD	Galvanically isolated UART COM TX	Output	0–5 V, max. 20 mA
		Non-isolated UART COM TX	Output	0–3.3 V, 5 V tollerant max. 20 mA
		I ² C SDA	I/O	
36	COMGND	Galvanically isolated UART COM ground	Power output	0 V, max. 100 mA
41	COM+5V	Galvanically isolated supply		5 V, max. 100 mA
10	IO+10V	GPIO 10 V power supply		10 V, max. 50 mA

Note: All pins are related to the pin 36 COMGND.

9.4.4 Extension port

Extension port is communication interface for extension modules, such as extension LED, external battery switch for charging and other accessory for ESC3 controllers. When using Wifi or Bluetooth, extension port is internally connected to the module and can not be used by external accessory.

Table 9.4: UART EXT pins

Pin	Name	Description	Direction	Parameters, max. range
43	EXTRXD	UART EXT RX	Input	0–3.3 V, 5 V tollerant, max. 20 mA
44	EXTTXD	UART EXT TX	Output	
45	EXTGND	UART ground	Power output	0 V, max. 100 mA
42	EXT+10V	Power supply		10 V, max. 100 mA

Note: All pins are related to the pin 45 EXTGND.

9.5 Digital inputs

If necessary, SC controller could be equipped with three separate digital inputs. These pins are not galvanically isolated and are derived from section of motor sensors pins. It means that not all combinations of digital input pins and motor sensors can exists. If pins ENCB/DATA, ENCA/CLK or pin ENCC/OUT are occupied by certain type of motor sensor, it can not work as digital input pin. On request it is possible to create custom combination of motor sensor and digital input to meet specific requirement. For digital input pins specifications refer to the table 10.1.

9.6 General purpose inputs/outputs

The SC controller has five general input/output¹ pins, which are all galvanically isolated. In a input mode, these pins can either work as digital or analog input pins. Analog inputs has 16 bit resulation and sampling frequency about 1 kHz. They are also equipped with internal pull-up and pull-down resistors, which can be connected by software. This allows to change measurement range if needed. In addition, pull-up resistor enables to use potentiometer and pushbutton simultaneously on one GPIO pin. If used as digital inputs, pins can be configured as counters or timers, they could serve for reading PWM and PPM signals.

Combination of IO+10V, IO+5V, IO+3V, IOGND and GPIOs can create multiplexer for pushbuttonsn, up to four pushbuttons can be connected to one GPIO pin. Schematic is shown in the figure 9.4.

These pins are powered from galvanically isolated power supply, which is common for GPIO pins, UART and CAN Bus. Supply voltages IO+3V, IO+5V and IO+10V are all derived from this power supply. If SC controller is used in e-bike or similar vehicle, pin 14 GPIO1 is typically used for regen/brake and pin 15 GPIO0 is used for accelerator.

¹GPIOs has impedance about 47 kΩ by default, this can be changed on request – to work as low-impedance outputs

Table 9.5: GPIO pins

Pin	Name	Description	Direction	Parameters, max. range
11	GPIO4	Isolated general purpose analog/digital I/O	Input/output	47 kΩ impedance (2) max. 10 mA 0–8.5 V (3) –3.5–7.5 V (4) 0–12 V (5)
12	GPIO3			
13	GPIO2			
14	GPIO1	Isolated general purpose analog/digital I/O, typically brake		
15	GPIO0	Isolated general purpose analog/digital I/O, typically accelerator		
10	IO+10V	GPIO 10 V power supply	Power output	10 V, max. 50 mA
17	IO+3V	GPIO 3 V power supply		3 V, max. 50 mA
19				
21	IO+5V	GPIO 3 V power supply		5 V, max. 50 mA
23				
16	IOGND	GPIO ground		5 V, max. 250 mA
18				
20				
22				

Note 1: All pins are related to the pin 16 IOGND.

Note 2: Input / output impedance is 47 kΩ by default, can be changed on request

Note 3: Internal resistor disconnected, parameter /common/ioconf set to 0 (refer to chapter 12.5.1).

Note 4: Internal resistor connected as pull-up, parameter /common/ioconf set to 1 (refer to chapter 12.5.1).

Note 5: Internal resistor connected as pull-down, parameter /common/ioconf set to 2 (refer to chapter 12.5.1).

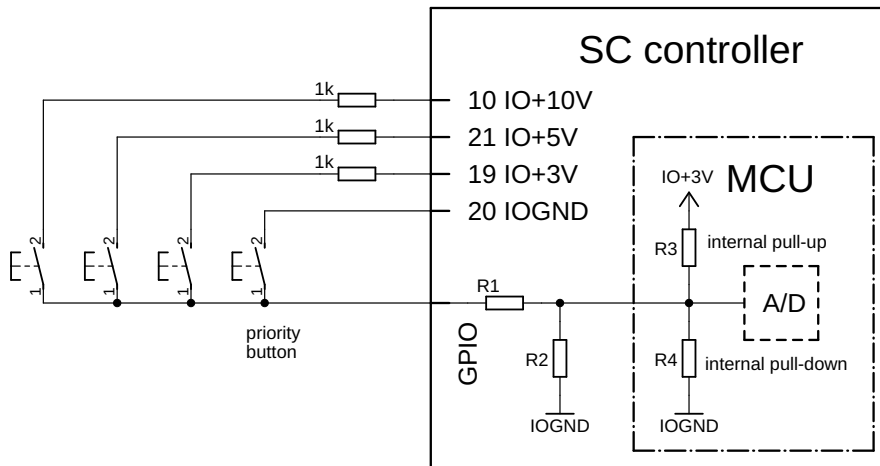


Figure 9.4: Four buttons multiplex schematic

Chapter 10: Motor sensors interface

Motor sensors interface of the SC controller is discussed in detail in this chapter. Physical principles and general advantages / disadvantages of the sensors are also briefly described in this chapter (more detail information can be found in the *Driver manual*).

10.1 Rotor position

Rotor position (rotor angle) is the first variable to be sensed. This parameter is required by the motor driver algorithm. Especially when driving a PMSM motor, rotor position is updated periodically, as well as other measurements (motor currents and voltages). Based on these measurements and on demanded motor control mode, the driver algorithm switches the transistors in power stage of the controller.

In certain situations, the rotor position can be estimated from measurements of voltage and current. In this case rotor position sensor is not needed and motor is driven in *sensorless* mode. Situations, where rotor position sensor is present and working, are called *sensored* mode.

10.1.1 Sensored control

Advantages	Disadvantages
<ul style="list-style-type: none"> • Stable operation at zero-RPM • Do not depend on motor parameters • Sensor can be used for other purposes than motor control (trip counter, servo positioning ...) 	<ul style="list-style-type: none"> • Additional hardware needed (sensor, wires...) • Certain probability of hardware issues (sensor mounting position tolerance, vibrations ...) • Possible problems with sensor interference

10.1.2 Sensorless control

Advantages	Disadvantages
<ul style="list-style-type: none"> • No additional hardware needed (cheaper and more robust solution) • No positioning errors and smooth operation at higher speeds 	<ul style="list-style-type: none"> • Motor parameters needed (could vary with temperature) • Sometimes do not work properly at zero-RPM

10.2 Motor temperature

Another parameter to be sensed is the temperature of motor. The temperature is sensed in order to protect insulation of the motor winding against thermal degradation. Temperature sensing in permanent magnet motor is also important to protect permanent magnets against demagnetization by temperature.

Motor temperature can be sensed by temperature sensor integrated in motor winding. Another possibility is to estimate motor temperature from resistance of motor winding.

10.2.1 Temperature sensor

Advantages	Disadvantages
<ul style="list-style-type: none"> • Better accuracy • Works even when motor is not driven • Sensing can be done in particular spots, where the risk of overheat is the highest 	<ul style="list-style-type: none"> • Additional hardware needed (sensor, wires...) • Possible problems with sensor interference

10.2.2 Sensorless temperature estimation

Advantages	Disadvantages
<ul style="list-style-type: none"> • No additional hardware needed • Can be turned on for each motor • Average winding temperature is obtained 	<ul style="list-style-type: none"> • Worse accuracy • Motor has to be driven (current needs to flow) • Motor parameters are needed • Can not be used in certain situation (field weakening, non-linear conditions, magnetic saturation ...) • Can not be used when BLDC driver algorithm is used

10.3 Electrical interface

This section describes the electrical interface of the SC controller which is used to obtain measurements from motor sensors (rotor position sensor and possibly also temperature sensor). Aim of this section is not to describe sensor physical principles. For more information regarding the sensor categories, principles, advantages / disadvantages and a selection guide, please refer to the *Driver manual*.

Motor control interface pins of the SC controller are listed in table 10.1. This interface has separated power supply with outputs on pins 35 HALL+5V and 24 HALLGND. Current capability of this power supply is 50 mA. This supply is not galvanically isolated from the battery. Using motor sensors' ground (pin 24 HALLGND) helps to connect all grounds properly without ground loops. Shielding of motor sensors' cable should be also connected to this pin.

Some pins from the motor sensors interface have some additional function. This function can be used only if the pin is not needed for the chosen motor interface. For example pin 34 ENCB/DATA has ability to measure time events – it can be used for PWM / PPM signal decoding.

Table 10.1: Motor sensors pins

Pin	Name	Description	Variant	Direction	Parameters
24	HALLGND	Hall sensors supply ground, internally connected to BATT-	h, a, r, d	Power output	0 V, max. 50 mA
29	HALL+5V	Hall sensors supply voltage	h, a, r, d	Power output	5 V, max. 50 mA
35					
25	HALLW/COM	Hall sensor W	h, a	Input	0–3.3 V 5 V tollerant max. 10 mA
		Raw analog resolver common input	r	Input	
		Analog Sin-Cos SIN-, COS-	a	Input	
		Incremental encoder reference input	a	Input	
		BiSS MA- (clock)	r, d	Output	
26	HALLV/SIN	Hall sensor V	h, a	Input	
		Raw analog resolver SIN	r	Input	
		Analog Sin-Cos SIN+	a	Input	
		BiSS SLO- (data)	r, d	Input	
27	HALLU/COS	Hall sensor U	h, a	Input	
		Raw analog resolver COS	r	Input	
		Analog Sin-Cos COS+	a	Input	
28	TEMP	Motor temperature sensor in	h, a, r, d	Input	
		General purpose analog input	h, a, r, d	Input	
33	CLK	SSI/SPI clock (CLK)	r, d	Output	
		Raw analog resolver excitation	r	Output	
		BiSS MA+ (clock)	r, d	Output	
34	ENCB/DATA	SSI/SPI data (MISO)	r, d	Input	
		Raw analog resolver excitation	r	Output	
		BiSS SLO+ (data)	r, d	Input	
		Incremental encoder B	r, d	Input	
		Digital input 1 (DIN1) (Servo PWM / PPM channel 1 input)	h, a, r, d	Input	
32	ENCA	SPI data (MOSI)		Output	
		Incremental encoder A	a	Input	
		Digital input 2 (DIN2) (Servo PWM / PPM capable)	h, a, r, d	Input	

Note 1: All pins are related to the pin 24 HALLGND.

Note 2: Column *Variant* determines function of the pin. Corresponding letter can be found in section 3.2.1 marked as *Motor sensors*.

10.4 Rotor angle sensors interface types

Several interfaces of rotor angle sensors exist. Usually, rotor angle sensor has one interface as output of the rotor position. Sensors with multiple interfaces also exist. In such case, user can choose which interface will be used. For example RLS AM4096 chip supports output of UVW commutation signal, Sin-Cos signal, incremental encoder signal and digital SSI interface.

10.4.1 UVW commutation signal

This signal is usually produced by three Hall sensors placed inside the motor in 120° (rarely by 60°) span along one electrical revolution. It can be also emulated by some advanced sensors, such as RLS AM4096. UVW commutation signal is composed of three digital signals. Each signal has two switchpoints per electrical revolution (first switchpoint is from log. HIGH to log. LOW, second is from log. LOW to log. HIGH). Signals are shifted by 120° from each other (variants with signals shifted by 60° also exist). Example of the signals are shown in the picture 10.1. Example of connection is shown in the figure 10.2.

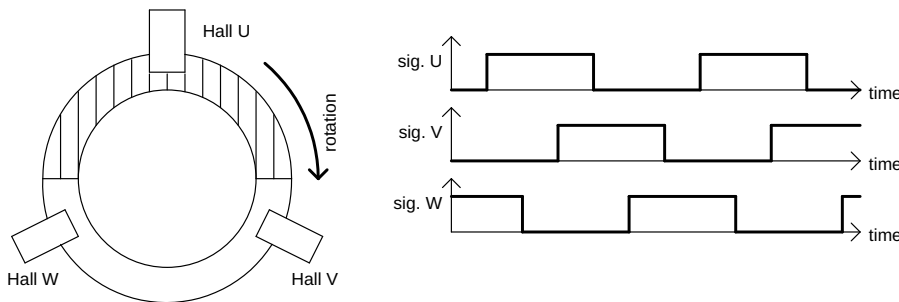


Figure 10.1: Example of UVW commutation signals

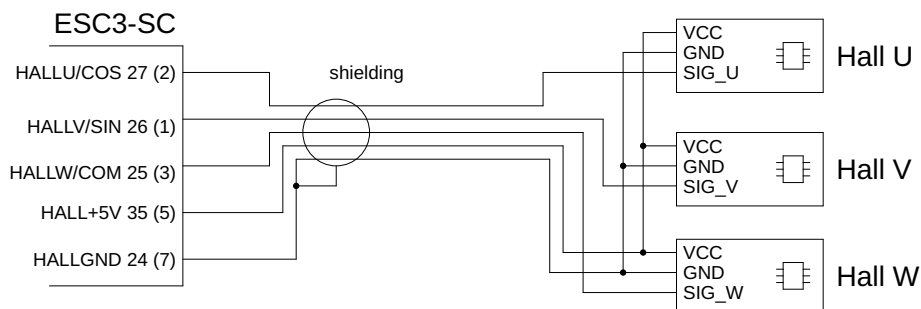


Figure 10.2: Connection of UVW commutation signal to the controller

When the UVW commutation signal is processed, it gives six discrete levels of rotor position for one electrical revolution. In the six switchpoints between the levels, the motor position is known with the least ambiguity. This information is enough when BLDC motor driver algorithm is used. If the VECTOR control algorithm is used, these six switchpoints is not enough and positions between them has to be extrapolated. UVW commutation signal may not be the ideal choice (especially in applications where a high precision / motion control is required at low RPM) for VECTOR driver algorithm since the position estimation is needed. Rotor position measurement using the UVW commutation signal is shown in the figure 10.3.

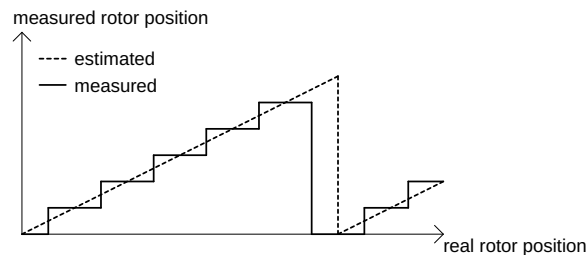


Figure 10.3: Rotor position estimation from UVW commutation signal

Advantages

- Sense electrical (not mechanical) revolutions. No angle multiplication error occurs – it is suitable for motors with many polepairs.
- Low frequency digital signal – good immunity against electrical interference.
- Perfect solution for BLDC motors
- Cheap

Disadvantages

- Interpolation needed when used in VECTOR control algorithm
 - 13% ripple of generated torque during steady operation
 - About 13% to 50% torque ripple during stall or very low speed operation
-

Electrical interface parameters

- Sensor supply: 5 V, 50 mA
- Input type: with pull-up resistor (compatible with open-collector and with push-pull sensor output)
- Input impedance: 1 k Ω

Recommended types of Hall switches

- Infineon TLE4946-L2
- similar Hall switches types with *bipolar* sensing principle

10.4.2 Resolver interface

Resolver is motor angle sensor with one excitation winding and two sense (sine and cosine) windings, electrically perpendicular to each other. Resolver is fed by AC voltage of known amplitude and frequency to the excitation winding. Voltage is measured on both sense windings (sine and cosine winding). Voltage across these sense windings has the same waveform as the voltage across the excitation winding. Amplitude of the sensed voltages is modulated by rotor position, as shown in the figure 10.4. Electrical connection of resolver to SC controller is shown in the figure 10.5.

Resolver is common rotor angle sensor in industry, it is used in high-end drives and servos. Resolvers are usually constructed to sense mechanical revolutions (one period of the modulated sine or cosine voltage corresponds to one mechanical turn). There are also resolvers that has many polepairs and can sense electrical revolution.

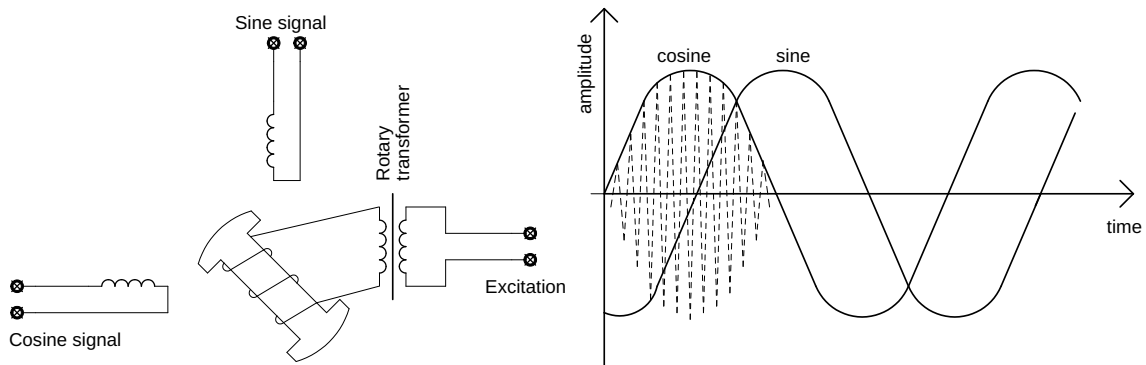


Figure 10.4: Resolver working principle

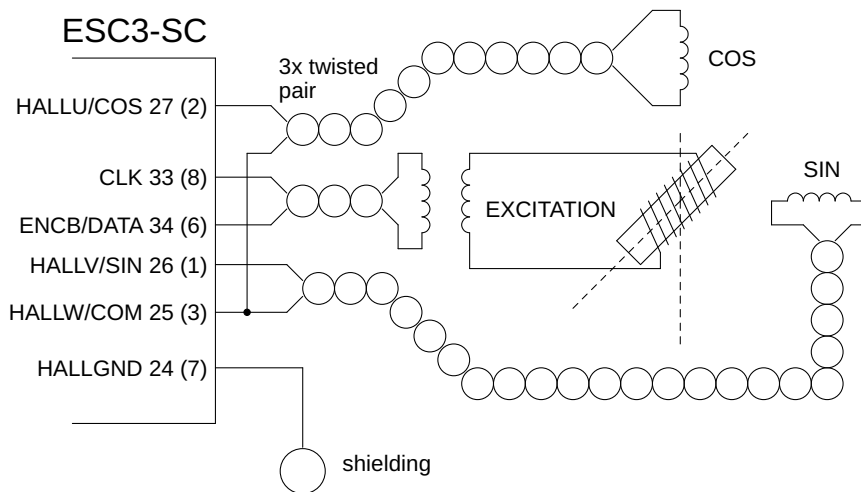


Figure 10.5: Resolver connection to the SC controller

Advantages

- Absolute and continuous position sensing
- Suitable for VECTOR driver algorithm
- Suitable for position servo drives
- No offset in sense winding voltage – easy to setup the drive.
- Robust solution with no semiconductors or active electronics

Disadvantages

- Sense usually mechanical revolutions. Angle multiplication error could occur when using motor with many polepairs and number of resolver’s polepairs does not match to number of polepairs of motor.
- Analog interface – could be sensitive to electrical interference.
- Higher weight, larger dimensions
- Higher price

Electrical interface parameters:

- Excitation voltage (amplitude): 3.3 V
- Excitation frequency: 10 kHz
- Sense input measurement range: ± 3.3 V (DC offset is not acceptable)
- Maximum resolver transformation ratio: 1
- Input impedance: 4.7 k Ω

Recommended types of resolvers:

- Tamagawa Seiki TS2610N171E64
- Tamagawa Seiki TS2640N321E64

10.4.3 Sin-Cos signal

Sin-Cos signal is composed of two analog signals of sinusoidal shape. Signals are phase-shifted by quarter of period and one period of sine (or cosine) signal corresponds to one mechanical turn of the motor (see figure 10.6 for illustration). This type of signal is usually produced by sensor consisting of cylindrical permanent magnet glued to rotor and sensor chip located on the stator in defined distance from the cylindrical magnet. Connection of sensor with Sin-Cos interface to the SC controller is shown in the figure 10.7.

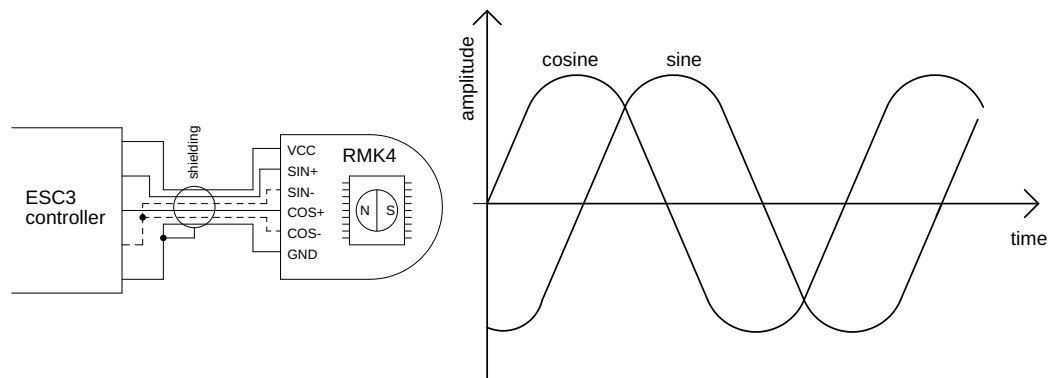


Figure 10.6: Sin-Cos sensor working principle

Advantages

- Absolute and continuous position sensing
- Suitable for VECTOR driver algorithm
- Suitable for position servo drives
- Usually very small dimensions

Disadvantages

- Typically sense mechanical revolutions. Angle multiplication error could occur when using motor with many polepairs.
- Analog interface – could be sensitive to electrical interference.
- Need output offset calibration (can be done automatically by the controller)
- Complicated semiconductor device prone to high temperatures, EMI ...

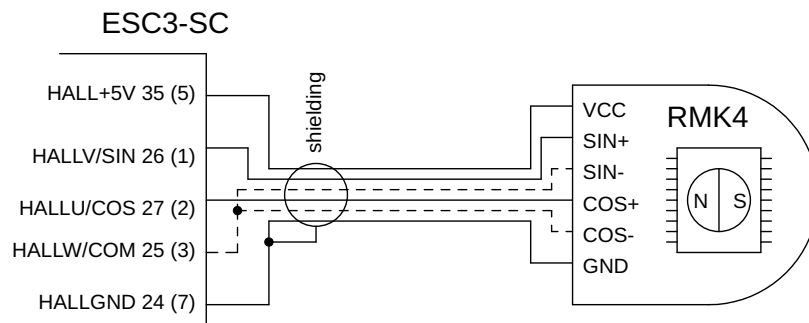


Figure 10.7: Connection of sensor with Sin-Cos interface

Electrical interface parameters:

- Sensor supply: 5 V, 50 mA
- Analog inputs type: single-ended or differential
- Input impedance: 1 k Ω

Recommended types of sensors with Sin-Cos output:

- RLS AM512B (evaluation board RMK1B)
- RLS AM256 (evaluation board RMK2)
- RLS AM8192B (evaluation board RMK3B)
- RLS AM4096 (evaluation board RMK4)
- Infineon TLE 5012

10.4.4 Digital interface (SSI / SPI / BiSS)

Advanced rotor position sensors are able to convert rotor position into the form of binary number. This number is then periodically sent to the SC controller to update the measured rotor position. Multiple hardware layers and multiple protocols for the communication exists.

The SC controller implements serial data interface for the needs of digital communication with rotor angle sensor. This interface consists of one clock line (from the controller to the sensor) and one data line (from the sensor to the controller). Second data line (from the controller to the sensor) could be also present (when using SPI interface). Data and clock line could be operated either in single-ended or differential mode. Communication protocol can be also selected (or custom protocol can be implemented – contact siliXcon for more information).

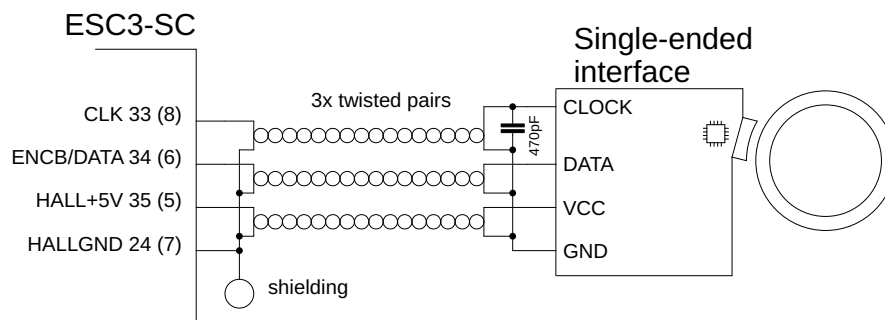


Figure 10.8: Connection of single-ended serial interface

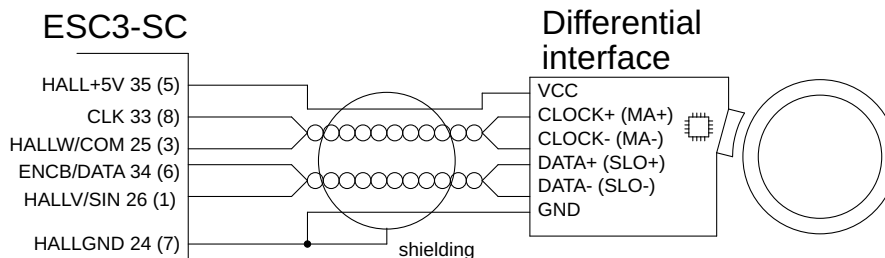


Figure 10.9: Connection of differential serial interface

Advantages

- Absolute and continuous position sensing
- Suitable for VECTOR driver algorithm
- Suitable for position servo drives
- Usually very small dimensions
- Possibility to check sensor connection and valid data (BiSS protocol)

Disadvantages

- Sense mechanical revolutions. Angle multiplication error could occur when using motor with many polepairs.
- Line impedance match needed for high communication rates
- Complicated semiconductor device prone to high temperatures, EMI ...
- High communication speed is required (20 kHz update rate), which leads to clock speed of units of MHz
- Possible latency problems at high speeds (due to on-board sensor data processing)

Electrical interface parameters:

- Sensor supply: 5 V, 50 mA
- Digital I/O type: single-ended or differential
- Digital I/O levels: 0 V / 3.3 V (5 V tollerant)
- Clock frequency: up to 10 MHz
- Input impedance: 4.7 k Ω

- Supported protocols: SSI, BiSS, SPI

Examples of rotor angle sensors with digital output:

- Zettlex InCoder series
- Renishaw RESOLUTE series
- RLS AM8192B (evaluation board RMK3B)
- RLS AM4096 (evaluation board RMK4) ¹
- Infineon TLE 5012
- Allegro A133x

10.4.5 Incremental encoder interface

Incremental sensor interface consists of, at least, two digital inputs (Enc A and Enc B). Sensor produces pulses on these two inputs. Each pulse means increment (or decrement) of current position by certain value. Since the pulses are phase-shifted by quarter of period, direction of rotation can be determined from the phase shift.

When the absolute position (not only relative – the increments) is required, third input (Enc REF) is needed. This input provides short pulse once per turn of the sensor. This pulse marks the zero position of the sensor. Motor has to do one full mechanical turn to provide reference pulse and find the zero position (this procedure is called 'homing'). Then, the absolute position can be counted. Working principle of the incremental sensor is shown in the figure 10.10. Connection of the sensor to the SC controller is shown in the figure 10.11.

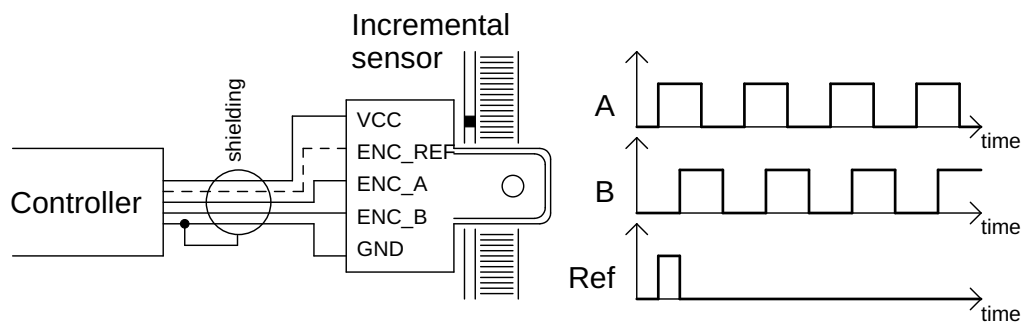


Figure 10.10: Incremental sensor working principle

Advantages

- Continuous position sensing
- Sufficient precision
- Suitable for driving induction machines

Disadvantages

- Sense mechanical revolutions. Angle multiplication error could occur when using motor with many polepairs
- Reference input and 'homing' procedure needed if the absolute position is required
- Not suitable for permanent magnet motors

¹When using AM4096 in SSI mode, parameter SSIfg of the sensor has to be set to 0. RMK4 evaluation board has this parameter set correctly from manufacturer. When buying bare AM4096 chip, this parameter has to be set additionally using the chip's TWI interface. Refer to manufacturer documentation for more information.

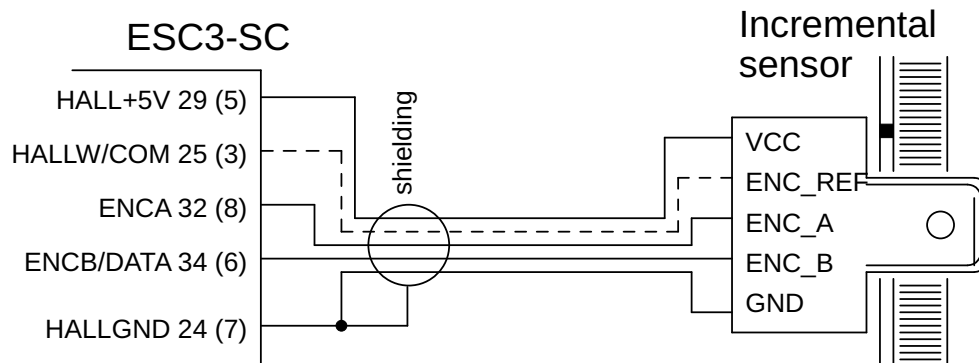


Figure 10.11: Connection of incremental sensor to the SC controller

Electrical interface parameters:

- Sensor supply: 5 V, 50 mA
- Input type: with pull-up resistor (compatible with open-collector and with push-pull sensor output)
- Input impedance: 1 k Ω

10.5 Winding temperature measurement

The SC controller has ability to measure temperature of motor winding using temperature sensor. Temperature sensor is connected between pin 28 TEMP and pin 24 HALLGND. Internal connection of the TEMP pin in the controller is shown in the figure 10.12. Various types of the sensors are supported, they has to meet following criteria:

- Measured temperature change results in change of resistance (thermocouples are not supported)
- Resistance of the sensor has to be within specified range (see specifications below)

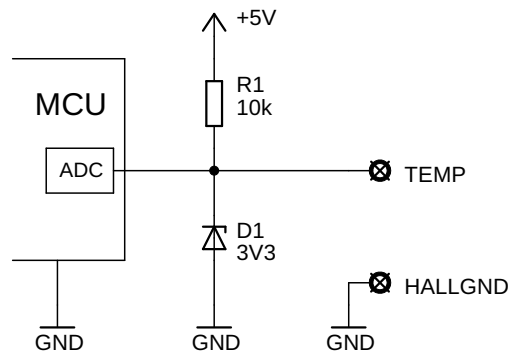


Figure 10.12: Internal connection of the TEMP pin

Electrical specifications

- Maximum voltage: 3.3 V
- Short-cut output current: 0.5 mA
- Resistance measure range: 15 Ω – 10 k Ω

Recommended temperature sensors

- **KTY81**
- any NTC with suitable resistance value
- any PTC with suitable resistance value

Chapter 11: Pinouts

11.1 Board pinout

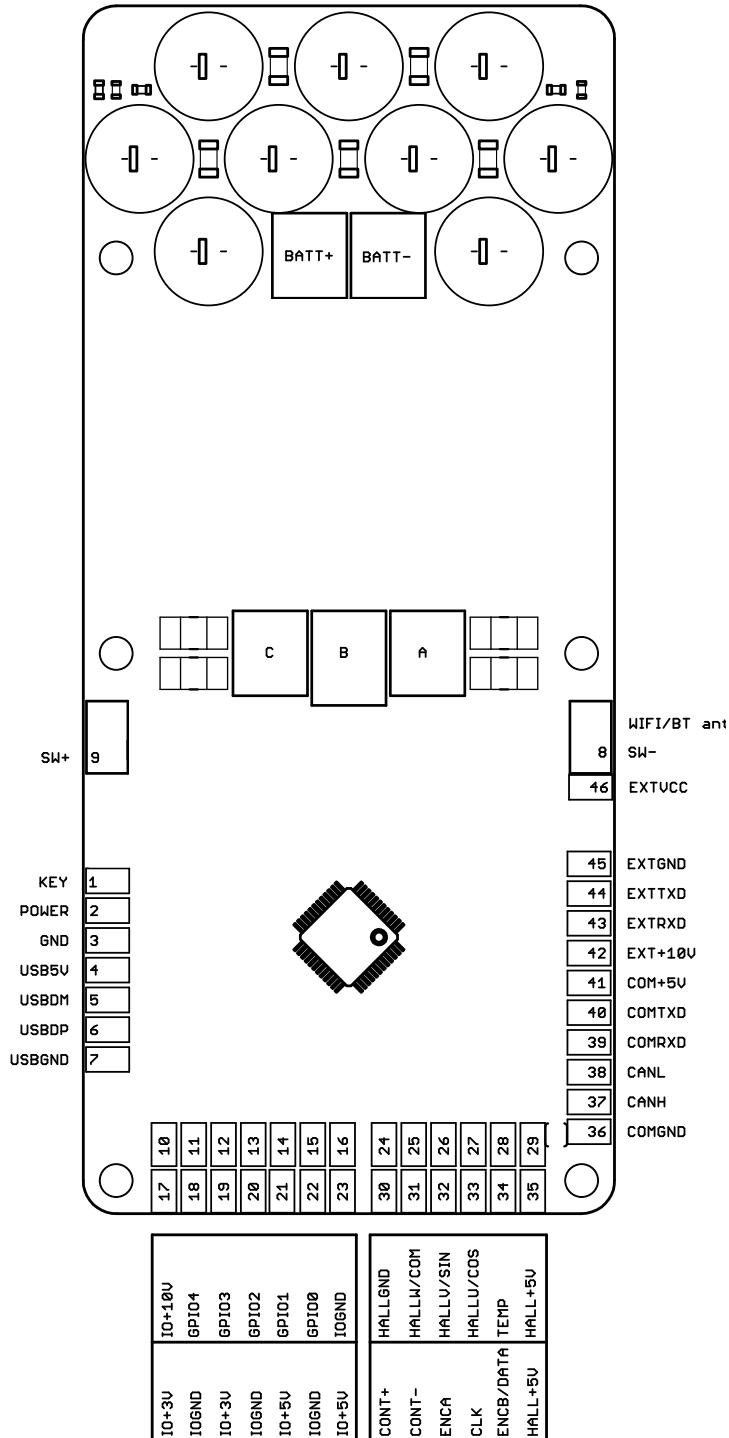


Figure 11.1: SC controller board pinout

11.2 Pin list & overview

Table 11.1: SC controller pin list

Pin	Name	Description	Direction
1	KEY	Control power supply	Power output
2	POWER	Controller ON/OFF input, active high	Input
3	GND	Ground, internally connected to B–	Power output
4	USB+5V	USB 5V	Power input
5	USBGND	USB ground, internally connected to B–	Power input
6	USBDM	USB data –	I/O
7	USBDP	USB data +	I/O
8	SW–	<i>Power switch</i> positive terminal	Power I/O
9	SW+	<i>Power switch</i> negative terminal	Power I/O
10	IO+10V	I/O 10 V power	Power output
11	GPIO4	General purpose I/O	I/O
12	GPIO3		
13	GPIO2		
14	GPIO1		
15	GPIO0		
16	IOGND	I/O ground, internally connected to B–	Power output
17	IO+3V	I/O 3 V power	
18	IOGND	I/O ground, internally connected to B–	
19	IO+3V	I/O 3 V power	
20	IOGND	I/O ground, internally connected to B–	
21	IO+5V	I/O 5 V power	
22	IOGND	I/O ground, internally connected to B–	
23	IO+5V	I/O 5 V power	Power output
24	HALLGND	Motor sensors supply ground, internally connected to B–	
25	HALLW/COM	Hall sensor W / common input / MA–	I/O
26	HALLV/SIN	Hall sensor V / SIN+ / SLO–	
27	HALLU/COS	Hall sensor U / COS+	
28	TEMP	Temperature sensor in / GPIO	Power output
29	HALL+5V	Motor sensors 5 V supply	
30	CONT+	Contactactor output +	Power output
31	CONT –	Contactactor output -	
32	ENCA	Encoder A	I/O
33	CLK	Clock / MA+ / Excitation	
34	ENCB/DATA	Encoder B / Data / SLO+ /DI1 / Excitation	
35	HALL+5V	Motor sensors 5 V supply	Power output



Table 11.2: SC controller pin list

Pin	Name	Description	Direction
36	COMGND	Communication ground (CAN and USART)	Power output
37	CANH	CAN High	I/O
38	CANL	CAN LOW	I/O
39	COMRXD	Communication UART RX / I ² C SCL	Input
40	COMTXD	Communication UART TX / I ² C SDA	Output
41	COM+5V	Communication 5 V supply	Power output
42	EXT+10V	Extension 10 V supply	Power output
43	EXTRXD	Extension RXD	Input
44	EXTTXD	Extension TXD	Output
45	EXTGND	Extension ground, internally connected to B-	Power output
	BATT+	Battery/power source input +	Power input
	BATT-	Battery/power source input -	Power input
	A	Motor phase A	Power output
	B	Motor phase B	Power output
	C	Motor phase C	Power output

11.3 Signal connectors pinout

11.3.1 JST JWPF connectors (variant J)

Table 11.3: USB connector


JST JWPF 4-pin male JM4_USB	Connector pin	Wire color	SC pin	Function
 4 3 2 1	1	● white	06 USBDP	USB data+
	2	● green	05 USBDM	USB data-
	3	● black	07 USBGND	USB ground
	4	● red	04 USB+5V	USB 5 V supply

Table 11.4: Power connector

JST JWPF 3-pin female JF3_PWR	Connector pin	Wire color	SC pin	Function
 1 2 3	1	● brown	01 KEY	Supply in/out
	2	● yellow	02 POWER	Power control input
	3	● black	03 GND	Ground

Table 11.5: Digital OUT1 connector


JST JWPF 2-pin female JF2.DO1	Connector pin	Wire color	SC pin	Function
	1	● brown	30 CONT+	Contact+ output
	2	● green	31 CONT-	Contact- output

Table 11.6: UART COM connector (5 V variant)



JST JWPF 4-pin female JF4.UARTCOM5	Connector pin	Wire color	SC pin	Function
	1	● black	36 COMGND	Communication GND
	2	● white	40 COMTXD	UART TX
	3	● blue	27 COMRXD	UART RX
	4	● red	41 COM+5V	+5 V output

Table 11.7: UART COM connector (10 V variant)

JST JWPF 4-pin female JF4.UARTCOM10	Connector pin	Wire color	SC pin	Function
	1	● black	36 COMGND	Communication GND
	2	● white	40 COMTXD	UART TX
	3	● blue	39 COMRXD	UART RX
	4	● orange	42 EXT+10V	+10 V output

Note: This connector marked with red shrinking tube is used for EXT connector – connector for accessory

Table 11.8: CAN connector

JST JWPF 3-pin male JM3.CAN	Connector pin	Wire color	SC pin	Function
	1	● black	36 COMGND	Communication GND
	2	● yellow	37 CANH	CAN high
	3	● green	38 CANL	CAN low

Table 11.9: Control I/O 1 (analog) connector

JST JWPF 4-pin female JF4_CNTRL1	Connector pin	Wire color	SC pin	Function
	1	● black	16 IOGND	Isolated ground
	2	● blue	14 GPIO1	Analog input (brake)
	3	● green	15 GPIO0	Analog input (throttle)
	4	● red	23 IO+5V	Isolated +5 V supply

Table 11.10: Control I/O 2 connector


JST JWPF 8-pin female JF8_CNTRL2	Connector pin	Wire color	SC pin	Function
 <p>1 2 3 4 5 6 7 8</p>	1	● orange	10 IO+10V	Isolated +10 V supply
	2	● yellow	11 GPIO4	Isolated analog input
	3	● blue	12 GPIO3	Isolated analog input
	4	● green	13 GPIO2	Isolated analog input
	5	● white	17 IO+3V	Isolated +3.3 V supply
	6	● black	18 IOGND	Isolated ground
	7	● black	20 IOGND	Isolated ground
	8	● red	21 IO+5V	Isolated +5 V supply

Table 11.11: Motor sensors connector – *Motor sensors variant h, a*¹



JST JWPF 8-pin male JM8_MSENS_G	Connector pin	Wire color	SC pin	Function
 <p>4 3 2 1 8 7 6 5</p>	1	● green	26 HALLV/SIN	Hall V, Sin+ signal
	2	● blue	27 HALLU/COS	Hall U, Cos+ signal
	3	● yellow	25 HALLW/COM	Hall W, Sin-, Cos-
	4	● white	28 TEMP	Temperature sensor
	5	● red	35 HALL+5V	Sensor supply
	6	● brown	34 ENCB/DATA	Encoder B input
	7	● black	24 HALLGND	Sensor ground
	8	● violet	32 ENCA	Encoder A input

Table 11.12: Motor sensors connector – *Motor sensors variant r, d*¹

JST JWPF 8-pin male JM8_MSENS	Connector pin	Wire color	SC pin	Function
 <p>4 3 2 1 8 7 6 5</p>	1	● green	26 HALLV/SIN	Sin+, Data-
	2	● blue	27 HALLU/COS	Cos+,
	3	● yellow	25 HALLW/COM	Sin-, Cos-, Clock-
	4	● white	28 TEMP	Temperature sensor
	5	● red	35 HALL+5V	Sensor supply
	6	● brown	34 ENCB/DATA	Excitation-, Data+
	7	● black	24 HALLGND	Sensor ground
	8	● orange	33 CLK	Excitation+, Clock+

¹This pinout is valid for board revisions **h** and newer. For older revisions is used connector JM8_MSENS in all variants.

Table 11.13: Digital IN1 connector


JST JWPF 2-pin male JM2_DI1	Connector pin	Wire color	SC pin	Function
	1	● green	24 HALLGND	Ground
	2	● orange	34 ENCB/DATA	Digital signal 1

Table 11.14: Digital IN2 connector



JST JWPF 2-pin male JM2_DI2	Connector pin	Wire color	SC pin	Function
	1	● blue	24 HALLGND	Ground
	2	● orange	32 ENCA	Digital signal 2

Table 11.15: EXT connector (10 V variant)

JST JWPF 4-pin female JF4_UARTEXT10	Connector pin	Wire color	SC pin	Function
	1	● black	45 EXTGND	Ground
	2	● white	44 EXTTXD	Extension TX
	3	● green	43 EXTRXD	Extension RX
	4	● orange	42 EXT+10V	Extension +10 V

11.4 Power connectors pinout

11.4.1 Amass AS150, XT150 (variant A)



Figure 11.2: Battery connector pinout – Amass AS150 (controller side)

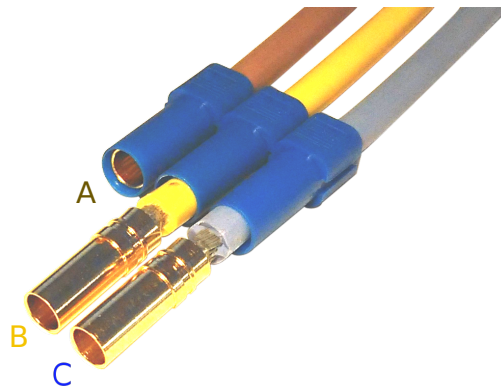


Figure 11.3: Motor connector pinout – Amass XT150 female (controller side)



Figure 11.4: Charger input pinout – Amass XT60 female (controller side)

11.4.2 Wires and cable lugs connectors (variants A, W, 5, and 6)

Connection of power wire is determined by its color. It applies for assembly variants with bare wires, cable lugs and Amass XT150, where the color is the only possible mean, how to determine connection of wire. Colors of wires are assigned as follows:

- black – battery +
- red – battery –
- / ● green or brown – motor phase A
- yellow – motor phase B
- blue – motor phase C

Chapter 12: yOS interface

All ESC3 controllers runs yOS – proprietary real-time operating system. This operating system is similar to Linux; items (directories and files) are organized in tree-like structure. States of hardware inputs are represented as values of variables in directory. Similarly, states of hardware outputs can be represented as values of variables in filesystem.

Variables representing state of hardware inputs are called *state variables*. These variables can not be modified by user or OS itself, because they only reflects what is happening in the input of the controller. State variables are time-dependent and their values are refresed automatically. For work with *state variables* is used command **stat**.

Another type of variables in yOS is *parameter*. This variable is not dependent on state of hardware input and can be modified by user or yOS. Parameters are used for configuration of hardware inputs. Setting parameter to certain value affects behavior of hardware inputs. For work with *parameters* is used command **param**.

Everything about filesystem, variable types and working with them is described in detail in *OS manual*.

12.1 Firmware structure and versions

Whole controller firmware (called release) is divided into few functional blocks, as shown in the figure 12.1. Some blocks are common for all ESC3 product, some of them differs from type to type and each block has its own version. Following part of this datasheet describes **COMMON I/O** block of firmware with version 1.0.

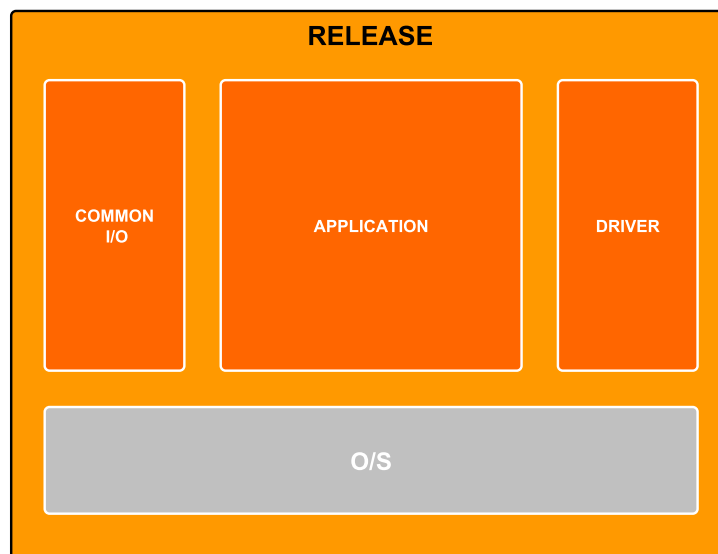


Figure 12.1: Block structure of release

12.2 Product signature

Each product has ability to identify itself during communication. This is done by *device signature*, which is number dedicated to certain type of the product. *Device signature* for the SC controller is number **11**.

12.3 Hardware inputs

State variables, representing hardware inputs, are located in directory `/common` in the root directory of the filesystem.

12.3.1 `Vthermistor`

`Vthermistor` (float) [V]

Thermistor voltage in volts. Thermistor is connected to pins 24 HALLGND and 28 TEMP. Thermistor has 10 k Ω pull-up resistor. Connection is shown in the figure 12.2.

12.3.2 `Rthermistor`

`Rthermistor` (float) [Ω]

Thermistor resistance in ohms. Thermistor is connected to pins 24 HALLGND and 28 TEMP. Thermistor has 10 k Ω pull-up resistor. Connection is shown in the figure 12.2.

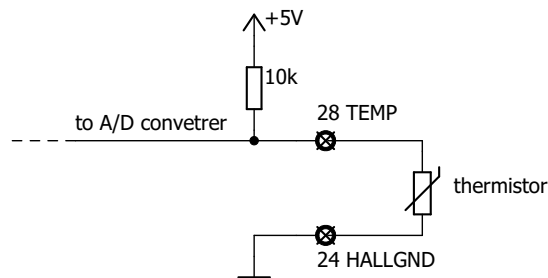


Figure 12.2: Thermistor connection

12.3.3 `gpio0`, `gpio1` ... `gpio4`

`gpio0` (int16) [mV]

`gpio1` (int16) [mV]

...

`gpio4` (int16) [mV]

Value on pin 15 GPIO0 (or other GPIOs) in real units, depending on application it can be milivolts, milliseconds or microseconds. When measuring voltage, effect of internal pull-up and pull-down resistor is counted, real voltage on pin of controller is displayed.

12.3.4 `gdin0`, `gdin1` ... `gdin4`

`gdin0` (int8)

`gdin1` (int8)

...

`gdin4` (int8)

Representation of digital state of pin 15 GPIO0 (or other GPIOs). Valid values of `gdin` and corresponding voltage levels are listed in table 12.1.

Table 12.1: g_{din} voltage threshold values

g _{din} value	pin voltage		
	ioconf = 0 (pin floating)	ioconf = 1 (pull-up)	ioconf = 2 (pull-down)
3	> 7.8 V	> 6.8 V	> 10.8 V
2	4.2 V < V _{g_{din}} < 7.8 V	4.2 V < V _{g_{din}} < 6.8 V	4.2 V < V _{g_{din}} < 10.8 V
1	2.6 V < V _{g_{din}} < 4.2 V	2.6 V < V _{g_{din}} < 4.2 V	2.6 V < V _{g_{din}} < 4.2 V
0	< 2.6 V	0.6 V < V _{g_{din}} < 2.6 V	< 2.6 V
-1	not defined	< 0.6 V	not defined

12.3.5 dout1

dout1 (int8)

CONT– pin output state representation. Digital outputs are open-drain type, when output is in ON-state, it is connected to the ground of the controller and value of the `dout1` state is 1. When pin is in OFF-state, it is disconnected (floating) and value of the `dout1` state is 0.

12.3.6 ch1, ch2

ch1 (uint16) [us]

ch2 (uint16) [us]

Raw servo pwm pulse length in microseconds. Pin 32 ENCB/DATA could be mapped to channel 1 and pin 34 ENCC/OUT could be mapped to channel 2.

12.3.7 ichg

ichg (int16) [10 mA]

Charger current in 10 mA (if value of `ichg` is 100, charger current is 1000 mA). During normal charging is this current equal to battery current. During step-up charging is this current always higher than battery current.

12.3.8 uchg

din1 (int16) [10 mV]

Charger voltage in 10 mV (if value of `uchg` is 1200, charger voltage is 12 V). During normal charging is the voltage almost equal to battery voltage. During step-up charging is charger voltage always lower than battery voltage.

12.3.9 gndio

gndio (int16) [10 mV]

Voltage between ground of the controller and galvanically isolated ground. Voltage is in 10 mV (if value of `gndio` is 100, voltage between grounds is 1 V). Reference is ground of the controller, so if the potential of isolated ground is higher than potential of controller ground, measured value is positive. This state is used for internal debug purposes only. Precision of the measurement is 1 V.

12.4 Input and output ID

Each state representing input or output pin has its own unique ID. This ID is used for mapping pins into application – rewriting IDs easily remap used pin. States and their IDs are listed in table 12.2.

Table 12.2: Input and output states and their IDs

ID (dec)	ID (hex)	State	Pin	Pin name
1	0x01	– error –		– error –
8	0x08	gpio0	15	GPIO0
9	0x09	gpio1	14	GPIO1
10	0x0A	gpio2	13	GPIO2
11	0x0B	gpio3	12	GPIO3
12	0x0C	gpio4	11	GPIO4
16	0x10	gdin0	15	GPIO0
17	0x11	gdin1	14	GPIO1
18	0x12	gdin2	13	GPIO2
19	0x13	gdin3	12	GPIO3
20	0x14	gdin4	11	GPIO4
32	0x20	din1	32	ENCA/CLK
33	0x21	din2	34	ENCB/DATA
34	0x22	din3	33	ENCC/OUT
48	0x30	ch1	32	ENCA/CLK
49	0x31	ch2	34	ENCB/DATA
64	0x40	ichg		
65	0x41	uchg		
66	0x42	gndio		
72	0x48	Vthermistor	28	TEMP
73	0x49	Rthermistor	28	TEMP
128	0x80	dout1	31	CONT–

12.5 Configuration of hardware inputs and outputs

12.5.1 ioconf0, ioconf1 ... ioconf4

ioconf0 (int16)

ioconf1 (int16)

...

ioconf4 (int16)

Internal pull-up and pull-down resistors can be configured by setting this parameter or pin functionality could be completely changed:

- 0 – no pull-up, nor pull-down
- 1 – internal pull-up connected
- 2 – internal pull-down connected
- 32 – pulse length measure, value of `gpio` is length of pulse in microseconds
- 64 – pulse length measure, value of `gpio` is length of pulse in milliseconds

12.5.2 contactor

contactor1 (directory)

Configuration of contactor is present in this directory. Following parameters configure contactor:

- **attack** (uint8) [%] / [V] – duty of PWM when contactor is switching from opened to closed state. To make contactor move requires more current than holding it closed so this PWM duty is higher than hold PWM duty. Duty can be set in range 0% – 100%). Voltage on contactor is then dependent on battery voltage. When set value is negative, it is not duty but average voltage in volts, voltage on contactor is then not dependent on battery voltage.
- **attacktime** (uint16) [ms] – time of contactor attack in milliseconds. It is the time, when PWM duty is higher to make contactor close. After the contactor is closed, PWM duty is lowered.
- **hold** (uint8) [%] / [V] – duty of PWM when contactor is closed and it only holds its position. To hold contactor closed is required less current, so the PWM duty can be lowered. Duty can be set in range 0% – 100%). Voltage on contactor is then dependent on battery voltage. When set value is negative, it is not duty but average voltage in volts, voltage on contactor is then not dependent on battery voltage.

12.6 Other configuration parameters

In directory /common are also located some other parameters that are associated with the *Common I/O* block of firmware. They are described in this section.

12.6.1 mtempssel

mtempssel (uint8)

This parameter configures, which pin will be used as input for motor temperature sensor.

- 0 – motor temperature sensor is not used
- other value – *Input ID* of the pin, where is motor temperature sensor connected. Refer to table 12.2.

12.6.2 beep_vol

beep_vol (uint16)

Controller can beep using connected motor's winding. This parameter sets volume of the beeping. Valid values are in range 0 – 1000.

12.6.3 appsel

appsel (uint8)

This parameter selects, which application will be loaded when controller starts. 0 is the default value and other values should not be used, since they can cause unpredictable behaviour of the controller.

12.6.4 ppmconf

ppmconf (uint16)

Configuration of PPM input. Value 0 is for normal PPM configuration, value 255 is for inverse PPM signal. Other values are not acceptable and can result in unexpected behaviour.

12.7 Commands

Some commands are associated with *Common I/O* block of firmware. They are described in this section.

12.7.1 shutdown

shutdown

Power off the controller. Works only if the flip-flop circuit is used. Refer to chapter ??, especially to section ?? for more information about flip-flop circuit and controller powering. Note: this command switches on DOUT2 pin as side effect.

12.7.2 cont

cont [contactor number] [on/off]

This command switches on or off contactor with [contactor number]. If the value of parameter

- 0 – *Power switch*
- 1 – Contactor 1
- 2 – Contactor 2
- 3 – Contactor 3

12.7.3 beep

beep [tone] [length] [modulation]

Play tone [tone] with length [length] and with modulation [modulation].

12.7.4 play


play [tones]

Play sequence of tones [tones].

Related documents

- ESC3-AM controller series datasheet
- ESC3-SL controller series datasheet
- yOS v2.0 & SWtools reference manual
- Driver v1.0 reference manual
- Application interface reference manual

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