siliXcon

ESC3–SL controller series

Full datasheet

rev_C

28th November, 2018

Contents

List of Figures

List of Tables

Chapter 1: Introduction

The SL is automotive grade controller from ESC3 family, it can deliver maximum power whilst keeping weight as low as possible. It can be used in wide range of applications, especially in industrial and automotive. Using the most modern technologies it achieves extreme dynamics, maximum efficiency, sensorless control or regenerative braking, all kinds of protection or galvanic isolation, all this with minimum dimensions. The SL controller is capable of driving all common types of electric motors.

Applications

- Automotive or industrial motor control
- Hi-end sport motorbikes, e-bikes
- Combustion engine starter-generators
- Military inertial stabilization
- 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 jewelery 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 containts 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 enviroment. 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 crossection. Using too small wire crossection 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 heatsing. 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 properites ...). 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 viod 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 acces rigts. Any attempt (succesfull or not) for unautohorized 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.

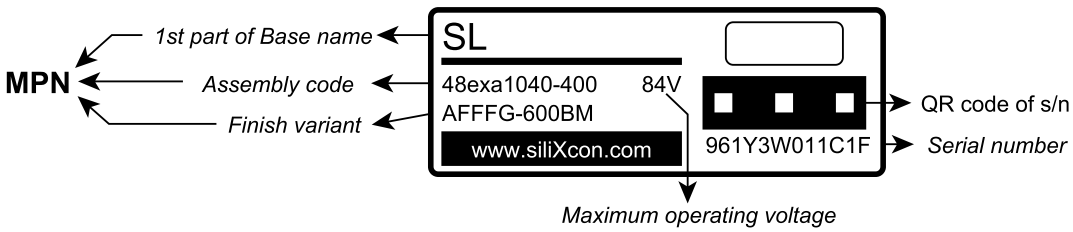


Figure 3.1: SL controller product tag

MPN constists 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:

- *SL-felix* – firmwares for ground vehicles (bikes, motocycles, scooters, cars ...)
  - LYNX – firmware for e-bikes
- *SL-raptor* – firmwares for RC models (cars, planes, boats, drones ...)
  - FALCON – firmware for drones and planes
- *SL-serpent* – firmwares for electric drives in indrustry
  - 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 used pinout of the signal connector, power terminals, heatsing and enclosure and some additional HW configuration. Exact meaning and available variants are listed in following sections of this datasheet.

3.2 Product variants

The SL 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 reffered as *standard variants*, *default variants* and also as controller *models*.

- Standard cofiguration – 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:
  - **SL-felix model 1** – SL-felix_48exa1060-400_AFFFG-600BM
  - **SL-raptor model 1** – SL-raptor_48exa1060-400_AFFFG-600BM
  - **SL-serpent model 1** – SL-serpent_48exa1060-400_AFFFG-600BM
- 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.

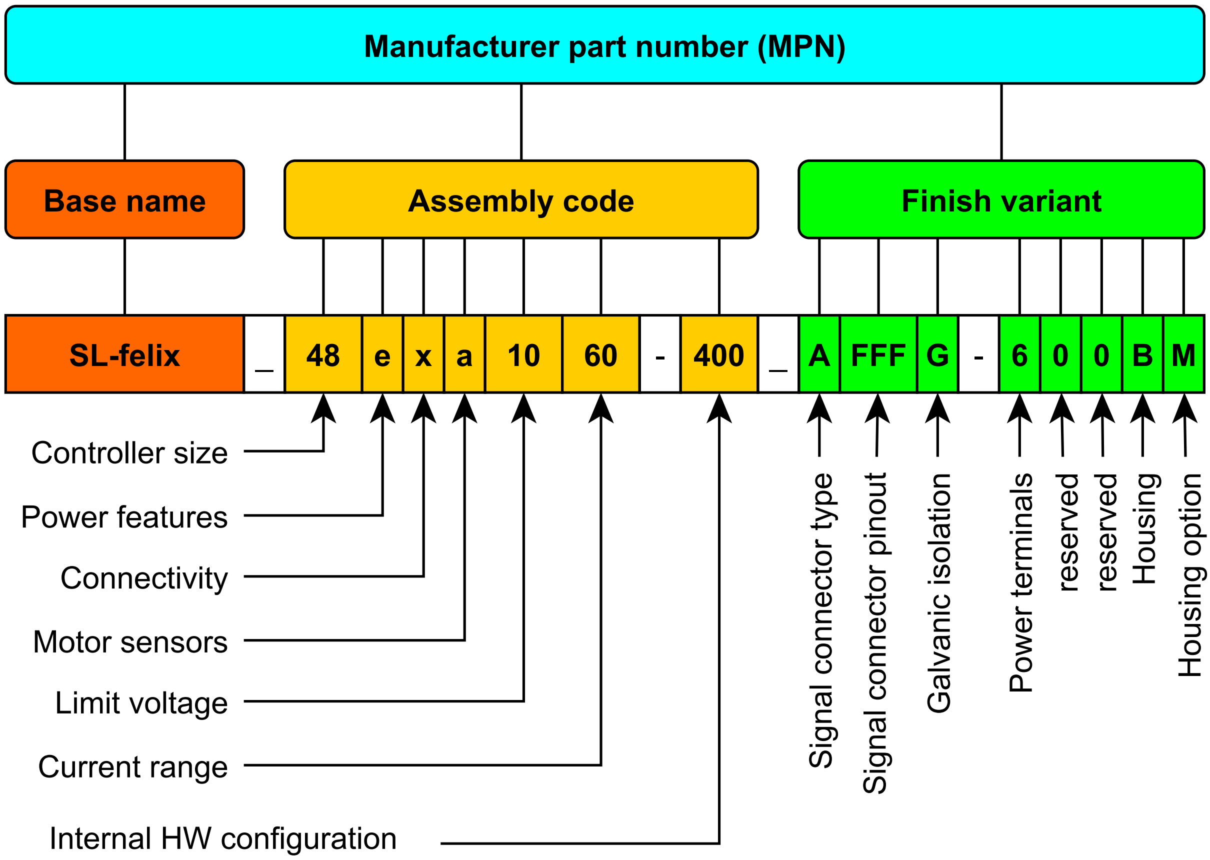


Figure 3.2: Example of *MPN*

3.2.1 Assembly code

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

- *Power features* – refer to sections 8.3, 8.4, and 8.5
- *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.

Table 3.1: Assembly code of the SL controller

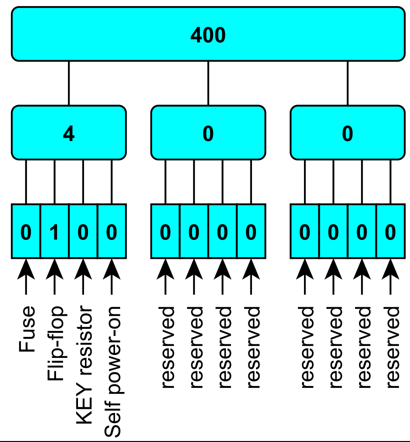
Letter	**Variant**	**Description**
Controller size		Size of the controller – number of transistors in the power stage
	48	48 transistors
Power features		Additional features for powering the controller
	e	Capacitors precharge
	f	Capacitors precharge + power switch without current sense
	g	Capacitors precharge + power switch with current sense
	h	Power switch without current sense
	j	Power switch with current sense
Connectivity		Present communication interfaces
	x	USB, D/A inputs, isolated CAN Bus, isolated GPIO, isolated 5 V UART
Motor sensors		Compatible motor sensors
	a	Analog sensor input (Sin-Cos), Hall sensors compatible, single-ended digital sensor compatible (SSI), sensorless control
	r	Resolver input (Sin-Cos, resolver),
		digital sensors compatible (SSI, BiSS, Incremental sensor)
Limit voltage		Absolute maximum voltage (see section 4.1)
	10	100 V
Current range		Measuring current range (see section 4.4)
	60	600 A (amplitude)
Internal HW configuration		Solder jumpers, fuses, capacitors discharge ...
	400	No internal fuse, flip-flop circuit, no KEY resistor
	C00	Internal fuse, flip-flop, no precharge, no KEY resistor (ready to low-power mode)
	???	Refer to subsection 3.2.1

Internal HW configuration

Internal HW configuration describes all small modifications in hardware, such as solder jumpers, presence of fuse between BATT+ and KEY pins or elecrolytic capacitors precharge/discharge. Each item can be connected / present (marked with 1) or disconnected (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. Functionality is described in chapter 8.

Table 3.2: Internal HW configuration encoding

Variant	Fuse	Flip-flop	KEY resistor	Self power-on	reserved	reserved	reserved	reserved	reserved	reserved	reserved	reserved
400		x										
C00	x	x										



3.2.2 Finish variants

Finish variants describes different modificaions in signal connector pinout and housing. These modifications are described in following parts of this datasheet:

- *Signal connectors type*, *Signal connector pinout*, – refer to chapter 11
- *Galvanic isolation* – refer to section 9.2
- *Power terminals* – used type of the power terminals
- *Housing*, *Housing option* – refer to chapter 5

Table 3.3: Finish variants of the SL controller

Letter	Variant	Description
Signal connector type		Used type of the signal connectors
	A	Ampseal 35 connector (refer to chapter 11)
Signal connector pinout		Used pinout variant of the connector
	FFF	4 D/A inputs, 5 GPIO, 3.3 V and 5 V supply, UART, POWER input (refer to table 3.4 and chapter 11)
	A41	5 D/A inputs 3 digital inputs, 2 GPIO, 2 x 5 V supply, pin 10 is VCC+5V (this variant is pin-compatible with Sevcon GEN4, refer to table 3.4 and chapter 11)
	???	Refer to subsection 3.2.2 according previous letter.
Galvanic isolation		Define if galvanic isolation is employed or not
	G	Galvanic isolation, GND and IOGND **not connected** together
	N	GND and IOGND **connected** together
Power terminals		Present power terminals
	6	M6 terminals
Reserved		Reserved for future use
	00	Reserved for future use
Housing		Style of heatsing and enclosure (refer to chapter 5)
	B	Sealed enclosure, waterproof (IP67)
	Z	Custom housing, contact siliXcon for more information
Housing option		Color of heatsink, color and technology of the plastic cover
	M	Black elox heatsink, gray injection molded cover
	other	Other options on request, contact siliXcon for more information

Signal connector pinout variants

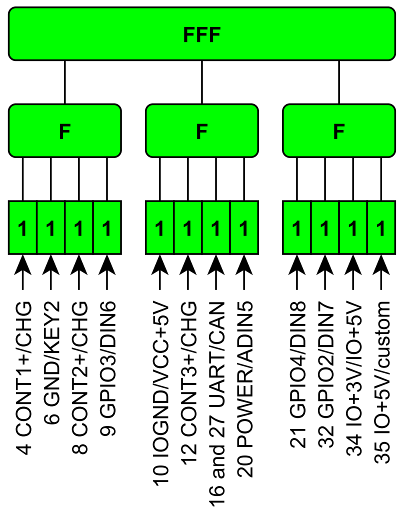
Three characters marked as *Signal connector pinout* in figure 3.2 are used to describe different pinout variants of the signal connector. Some pins (listed in table 3.4) has two possible functions. If the one function is configured, corresponding bit is 1, if the other function is configured, corresponding bit is 0. Together it created binary number of 12 digits. This binary number is converted to hexadecimal format. It gives the three characters of *Signal connector pinout*.

Table 3.4: Pins with multiple functions

Bit (0 = LSB)	Pin	Function if bit is 1	Function if bit is 0
11	4 CONT1+/CHG	**Contactor 1 +**	Charger (swich) input
10	6 GND/KEY2	**GND**	KEY2
9	8 CONT2+/CHG	**Contactor 2 +**	Charger (swich) input
8	9 GPIO3/DIN6	**GPIO3**	DIN6
7	10 IOGND/VCC+5V	**IOGND**	VCC+5V
6	12 CONT3+/CHG	**Contactor 3 +**	Charger (swich) input
5	16 and 27 UART/CAN	**UART (RXD/TXD)**	CAN (CANL/CANH)
4	20 POWER/ADIN5	**POWER**	ADIN5
3	21 GPIO4/DIN8	**GPIO4**	DIN8
2	32 GPIO2/DIN7	**GPIO2**	DIN7
1	34 IO+3V/IO+5V	**IO+3V**	IO+5V
0	35 IO+5V/custom	**IO+5V**	custom voltage

Table 3.5: Pinout variants ot the Ampseal 35 connector

Variant	4 **CONT1+**/CHG	6 **GND**/KEY2	8 **CONT2+**/CHG	9 **GPIO3**/DIN6	10 **IOGND**/VCC+5V	12 **CONT3+**/CHG	16 and 27 **UART**/CAN	20 **POWER**/ADIN5	21 **GPIO4**/DIN8	32 **GPIO2**/DIN7	34 **IO+3V**/IO+5V	35 **IO+5V**/custom
FFF	1	1	1	1	1	1	1	1	1	1	1	1
A41	1	0	1	0	0	1	0	0	0	0	0	1
FEF	1	1	1	1	1	1	1	1	1	1	1	1
AC1	1	0	1	0	1	1	0	0	0	0	0	1



3.3 SL accessories ordering codes

Table 3.6: SL accessories and order codes

Accessory	Description	Order code
Ampseal 35 housing	complementary connector for controller's Ampseal 35	AMP35-F
Ampseal crimp terminal	crimp terminals for complementary Ampseal	CONTACT_AMP-F

Chapter 4: Electrical specifications

4.1 Input voltage

Table 4.1: Voltage rating

Parameter	**Assembly code**		
	0660	**0860**	**1060**
Non–operational overvoltage limits	16 – 60 V DC	16 – 80 V DC	16 – 100 V DC
Safe voltage range	18 – 55 V DC	18 – 74 V DC	18 – 92 V DC
Operating voltage range	18 – 51 V DC	18 – 68 V DC	18 – 84 V DC
Battery configuration	12 S	16 S	20 S
Battery nominal voltage	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 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 get 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.

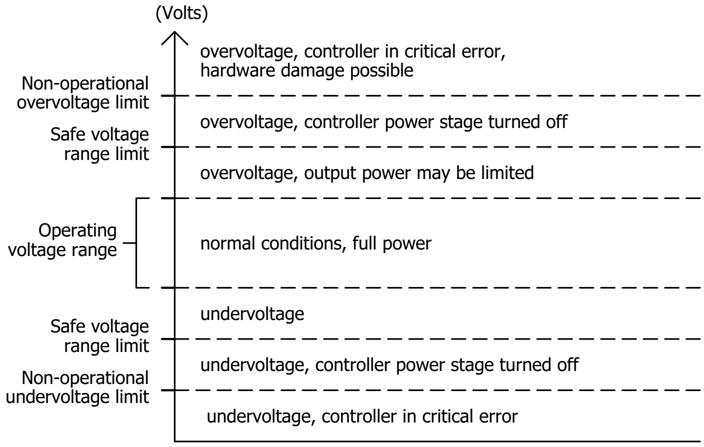


Figure 4.1: Controller voltage limits

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 achived 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 SL 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 SL controller with BLDC motor connected

Parameter	Assembly code		
	0660	**0860**	**1060**
Maximal power dissipation	300 W (2)		
Nominal power (60 min)	17700 W	21300 W	24500 W
Nominal current (60 min)	410 A	370 A	340 A
Battery current	410 A	370 A	340 A
Peak power (10 sec)	25900 W	28800 W	36000 W
Peak current (10 sec)	600 A	500 A	500 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 SL controller with BLAC or induction motor connected

Parameter	Assembly code		
	0660	**0860**	**1060**
Maximal power dissipation	300 W[1]		
Nominal power (60 min)	16900 W	20500 W	23800 W
Nominal current (60 min)	320 A	290 A	270 A
Battery current	395 A	355 A	330 A
Peak power (10 sec)	22200 W	28900 W	34400 W
Peak current (10 sec)	420 A	410 A	390 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 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 $BATT-$
- All pins of the Ampseal 35 connector are protected against shorting them to BATT+ and $BATT-$ (galvanic isolation has to be enabled). Pins 15 HALLGND anf 26 HALL+5V are protected only with non-reversible fuse.
- Pins of Ampseal 35 connector 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 SL controller. These advanced protections are described in detail in the *Driver manual*.

4.6 Additional electrical parameters

Table 4.4: Additional electrical parameters

Parameter	**Value**	**Notes**
PWM frequency	20 kHz	
Minimum pulse width	1 µs	
Maximum electrical revolutions	100 000 el. RPM	
Minimum motor inductance	15 µH	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.

rev_C
28/11/2018

4.7 EMC specifications and guidelines

Controller performs very rapid switching of high currents. This is a key principle of it's 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 batween power stage of the controller and aluminium heatsing to improve the EMC performance. Schematic of this network is shown in the figure 4.2.

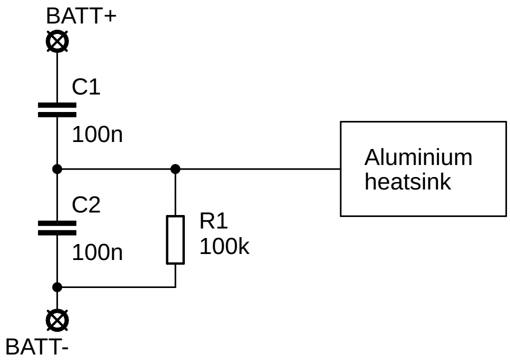


Figure 4.2: RC network between power stage and heatsink

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 BAT−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 SL controller

Parameter	Value
Width	148 mm
Height	64 mm
Depth	96 mm
Weight	1200 g
Ingress of dust and water	IP67

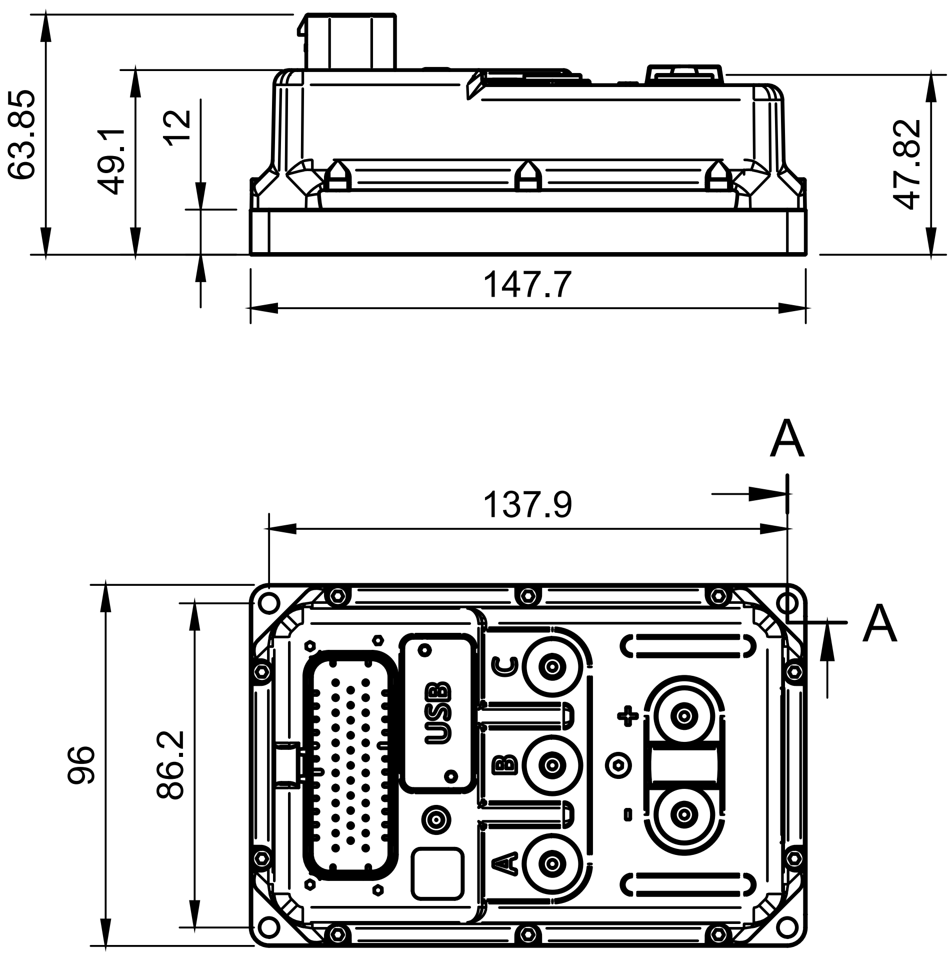


Figure 5.1: Dimensions of SL controller

Mounting torque Recommended mounting torque for M5 screws is $T_{M5} = 6\,\mathrm{Nm}$ and for M6 screws is $T_{M6} = 10\,\mathrm{Nm}$.

Chapter 6: Enviromental specifications

Table 6.1: Storage and operation conditions of the SL 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 – Ampseal 35 mated (2)		IP65		
Internal electronics – Ampseal 35 unmated		IP40		
Power terminals (3)		IP00		

Note 1: Long device operation at high temperatures reduces device's life
Note 2: Ampseal 35 connector has to be properly assembled and mated
Note 3: Power terminals are exposed. Ingress protection has to be added externally, if needed.

Chapter 7: Thermal specifications

Table 7.1: SL controller thermal specification

Parameter	Value	Conditions
Maximal power dissipation	300 W	controller thermally connected to infinite heatsink which does not exceed 60°C
	20 W	controller in aluminium housing, in still air of temperature 25°C
Thermal resistance	0.1 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 SL 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 vlaue 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 additon, the losses are affected by assembly variant of controller. Power dissipation is calculated from this formula:

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

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 coeficients for SL controllers

Assembly code	DC motor		AC motor	
	k_c	k_s	k_c	k_s
0660	0.0017	0.00087	0.0026	0.0024
0860	0.0021	0.00095	0.0031	0.0026
1060	0.0023	0.00097	0.0035	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 thremal grase, use rather little of it than too much.
- If thermal grase is not available, you could use normal grase 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 SL 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. Additional ON/OFF switch (working as tether safety switch / kill switch) could be also added. 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 (killswitch, tether safety 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 20 POWER/ADIN5 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. It can be configured by changing *finish variant* (see section 3.2.2). The flip-flop circuit also enables the auto power-off feature of the controller – controller can power itself down automatically, by software and OFF button is not needed.

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 20 POWER/ADIN5 activates the controller. Controller remains powered on as long as the voltage is higher than 5 V.

Pin 20 POWER/ADIN5 is configured as POWER by default. It means that it controlls power state of the controller, as was described before. This pin can be reconfigured to work as analog/digital input, by changing *finish variant* (see section 3.2.2). If the key resistor is disabled in *finish variant* (refer to the table 3.2), input of the flip-flop is connected to the pin 1 KEY by resistor R1 internally (see figure 8.1). 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.

8.2 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 fuse. KEY switch could be also connected in series with external fuse. Pin 1 KEY is used for battery voltage measurement. For correct function of battery voltage measurement, pins 1 KEY and BATT+ has to be connected by low impedance (either internal or external fuse).

8.3 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 charging discharged capacitors. Capacitors

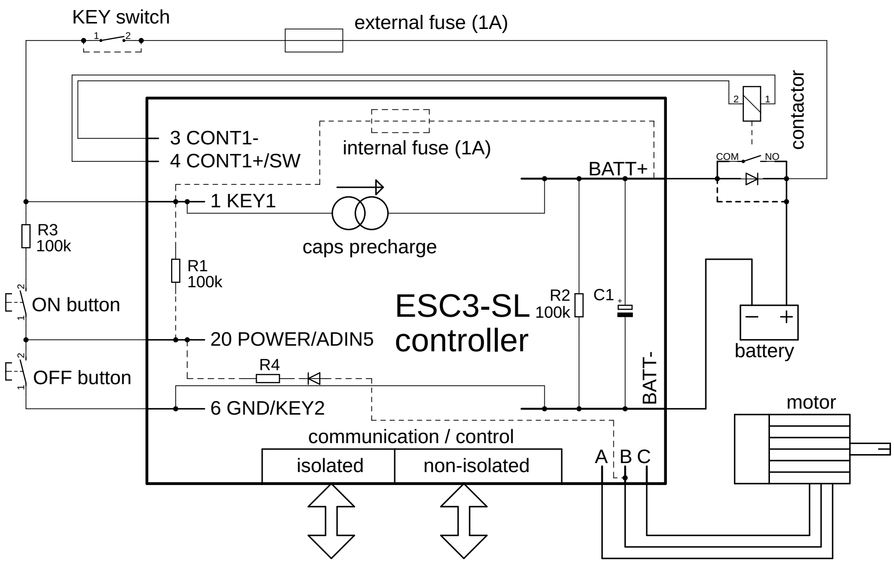


Figure 8.1: SL controller powering scheme

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 and sparking and persistent charge hold, controller is equipped with automated capacitors precharge/discharge feature. This option is enabled in variants with *power feature* varians **e**, **f** and **g**. It is highly recommended to use this option in all aplications, 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 8.1, 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). Resistor R2 increases self-discharge of a battery in applications, where controller is connected directly to the battery without contactor.

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

8.4 Contactor control

SL controller is equipped with three outputs for contactor control. First contactor output is typically used to control battery contactor during controller power-on process. This contactor is closed after capacitors are precharged. Second and third contactor could be used for control of auxiliary devices, such as fans.

Contactor output is open drain type – CONT1+/SW is connected to the KEY1 pin permanently and CONT1− is connected to ground by the MOS-FET. CONT1− and CONT1+/SW are capable of switching induction load, recirculation diode is built into the controller. Connection of contactor output is shown in the figure 8.2. CONT+/SW pins are shared between contactor control and *power switch* output (described in section 8.5). If one (or two or three) contactor is not needed, these pins could could be assigned to *power switch*. This *power switch* is required for battery charging through the controller. Usage of these shared pins is defined in *finish variant* in part *Signal connector pinout* (refer to the section 3.2.2 and table 3.4).

If any number of CONT+/SW pins are assigned to *power switch*, corresponding CONT− still works as open-drain power output and can switch loads, but recirculation diode is not present and has to be added externally when switching inductive loads[1].

Contactor outputs are 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.

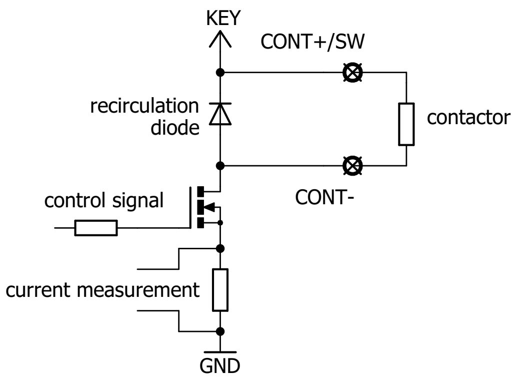


Figure 8.2: Connection of contactor output

8.5 *Power switch* and charging

SL controller could be equipped with *power switch*. This is bi-directional MOS-FET switch connected between BATT+ and pins 4 CONT1+/SW, 8 CONT2+/SW and 12 CONT3+/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 *power features* letter. Variant **d** and **e** stands for no *power switch*, variant **f**and **h** means *power switch* without current measurement and 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 guaranted externally, for example by using proper fuse. Variant with current measurement does nod need any overcurrent protection, in case of overcurrent is the switch disconnected automatically.

[1]Even non-inductive load connected with long wires is considered to be inductive load because wires has parasitic inductance, which can cause voltage spikes when recirculation diode is not present

If *power switch* is present, any number of CONT/SW pins can be assigned to the *power switch* instead of contactor function. This assignment is reflected in *finish variant* of the MPN, in part *Signal connector pinout* (refer to section 3.2.2). Current rating of one CONT/SW pin is 6 A maximum. *Power switch* current rating is then sum of rating of individual used pins, but only to the maximum of the 15 A, which is maximum for the *power switch* itself.

8.5.1 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. SL 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 it the figure 8.3. Normal charging is more effective than step-up charging, but proper charger has to be used.

8.5.2 Step-up charging

SL 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 SL 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 it 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 requiements are voltage lower than voltage of discharged battery and sufficient current capability.

Warning: When charger is connected to the SL 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 SL controller during charge. This could provide current path for the short circuit !!!

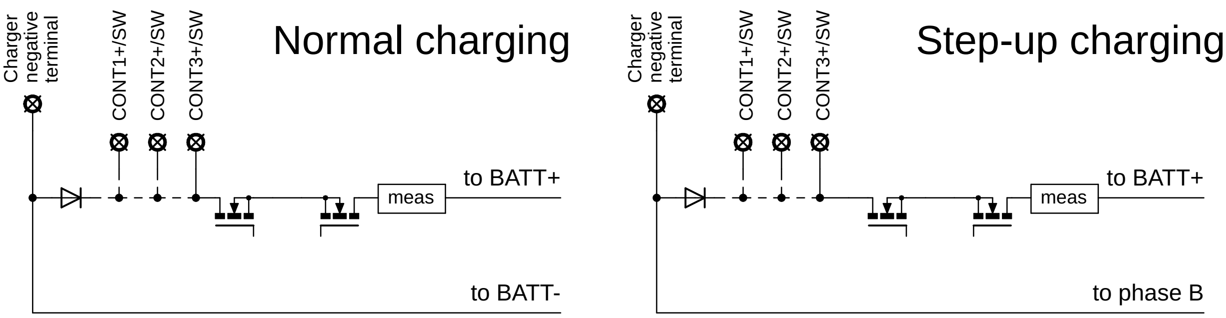


Figure 8.3: Normal and step-up charging connection

8.5.3 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*.

8.6 Self power-on

The SL 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 beween 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.

8.7 Power pins specifications

Table 8.1: Power control pins

Pin	**Name**	**Description**	**Direction**	**Parameters max. range**
1	KEY1	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
6	GND/KEY2	Ground, internally connected to BATT−	Power I/O	0 V, max. 3 A
		similar to KEY1	Power I/O	0–V_{NOM}, max. 1 A
20	POWER/ADIN5	Controller ON/OFF input, active high	Input	0–V_{NOM}, max. 10 mA
		Analog or digital input	Input	0–V_{NOM}, max. 10 mA
3	CONT1−	Contactor 1 negative output, open-drain type with current measurement	Power output	0–V_{NOM}, max.1 A
7	CONT2−	Contactor 2 negative output, open-drain type with current measurement	Power output	0–V_{NOM}, max.1 A
11	CONT3−	Contactor 3 negative output, open-drain type with current measurement	Power output	0–V_{NOM}, max.1 A
4	CONT1+/SW	Contactor 1 positive output, internally connected to KEY1	Power output	0–V_{NOM}, max.1 A
		Charging positive input with voltage and current measurement	Power input	0–V_{NOM}, max. 6 A
8	CONT2+/SW	Contactor 2 positive output, internally connected to KEY1	Power output	0–V_{NOM}, max.1 A
		Charging positive input with voltage and current measurement	Power input	0–V_{NOM}, max. 6 A
12	CONT3+/SW	Contactor 3 positive output, internally connected to KEY1	Power output	0–V_{NOM}, max.1 A
		Charging positive input with voltage and current measurement	Power input	0–V_{NOM}, max. 6 A

Note 1: All pins are related to the GND.
Note 2: V_{NOM} is upper limit of *Operating voltage range*, refer to section 4.1.

8.8 Controller powering methods

8.8.1 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, flip-flop circuit has to be disabled and resistor R1 is used. Pin 20 POWER/ADIN5 should be configured as ADIN5. First character of *Internal HW configuration* will be **2** (part of *MPN*. Refer to section 3.2.1). 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).

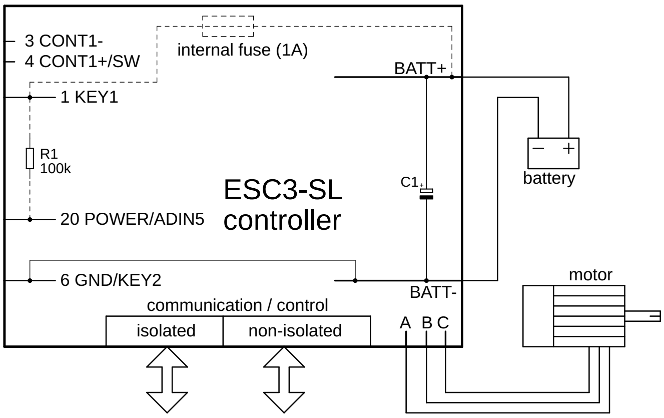


Figure 8.4: Constant on powering scheme

8.8.2 ON/OFF switch

Another possibility is to use ON/OFF switch to control power state of the controller. This switch is connected between battery and pin 1 KEY1. External fuse should be connected in series, internal fuse can not be used. Resistor R1 is used, flip-flop circuit has to be disabled. Pin 20 POWER/ADIN5 has to be configured as ADIN5. Battery is connected directly to the controller without line contactor. Schematics of the connection is shown in the figure 8.5.

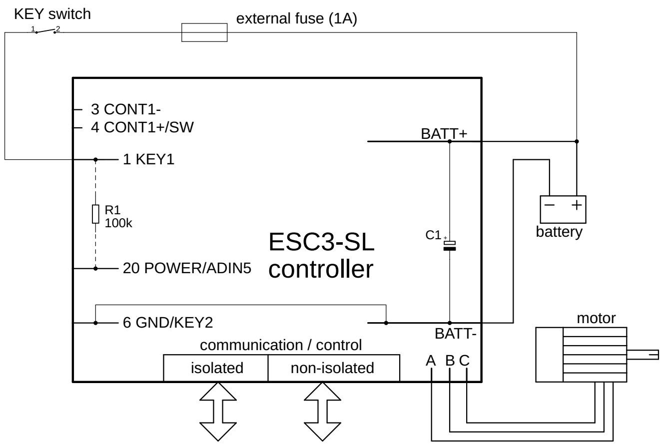


Figure 8.5: ON/OFF switch powering scheme

8.8.3 ON/OFF switch with capacitors precharge and contactor

Connection is same as in previous paragraph (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.

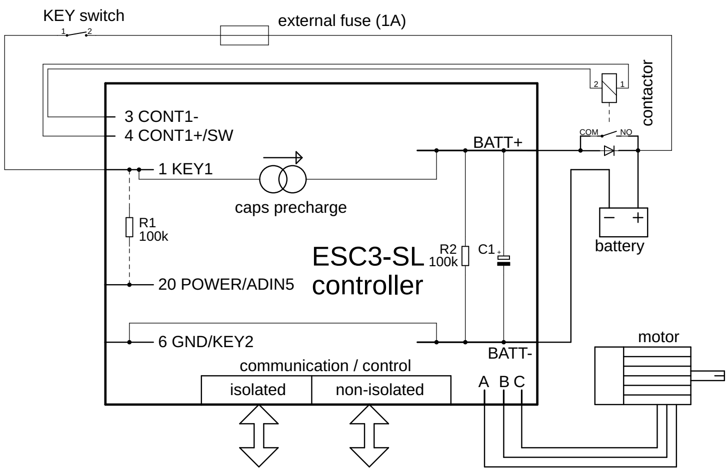


Figure 8.6: ON/OFF switch with contactor powering scheme

8.8.4 Two buttons control

SL controller power state can be also controlled by two pushbuttons. Pin 20 POWER/ADIN5 has to be configured as POWER and internal fuse is 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.

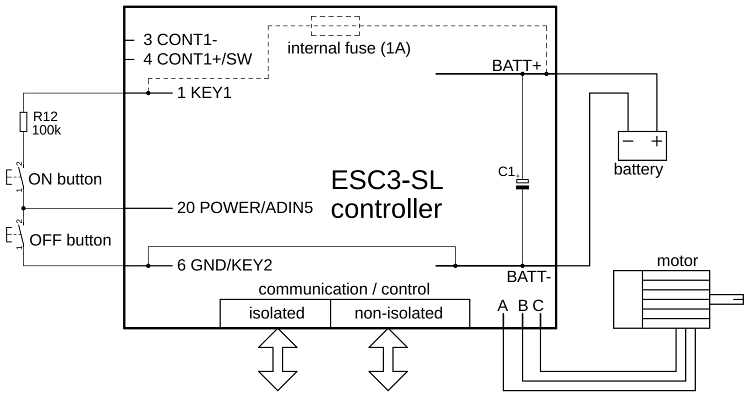


Figure 8.7: Two buttons powering scheme

8.8.5 Two buttons control with capacitors precharge and contactor

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.

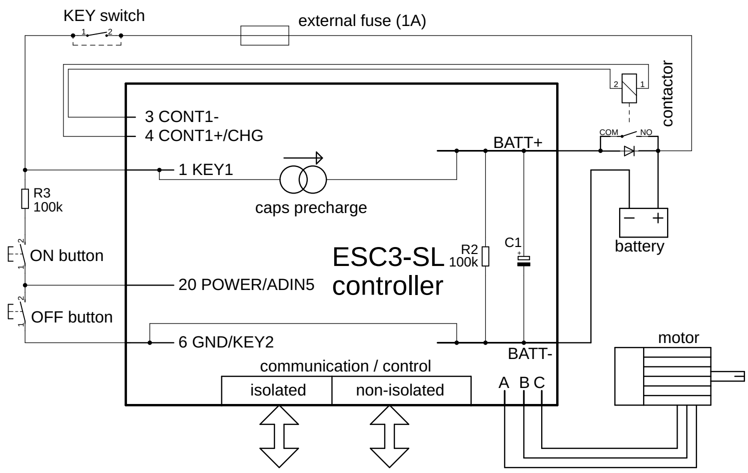


Figure 8.8: Two buttons with contactor powering scheme

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

This powering method is very similar to the 'Two buttons control' described in section 8.8.4. SL 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.

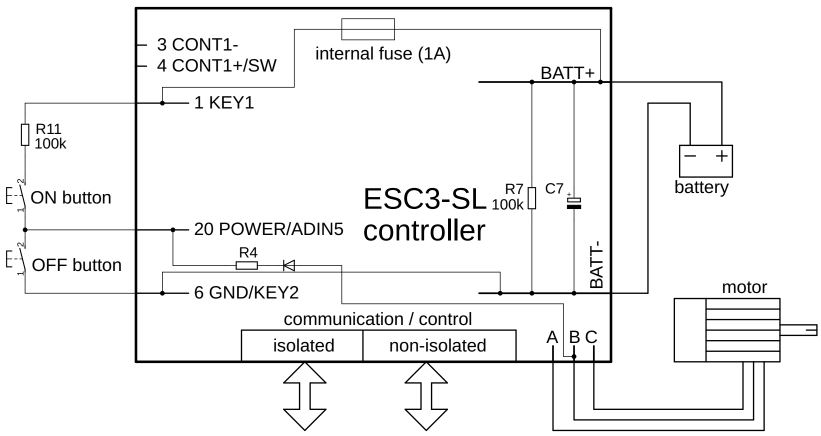


Figure 8.9: Two buttons powering scheme

Chapter 9: Control interface

9.1 Power supplies in the controller

The SL 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 – pin 01 KEY and 06 GND. Battery is connected to these pins via fuse. Voltage is present even if the controller is powered off. Voltage is equal to V_{BATT}, maximum current consupmtion is 1 A.
- Contactor control – pins CONT+ pins and CONT− pins. CONT+ pins are connected to the pin 01 KEY internally. CONT− pins are open-drain type and in on-state they are connected to the GND/BATT−. Refer to the section 8.4 for detail information.
- Motor sensors power supply – pins 26 HALL+5V and 15 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, pins 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 SW+. Switched power output with current capability up to 15 A (depending on number of assigned pins). SW+ pins are connected to BATT+ via bi-directional MOS-FET switch. Refer to section 8.5 for detail information.

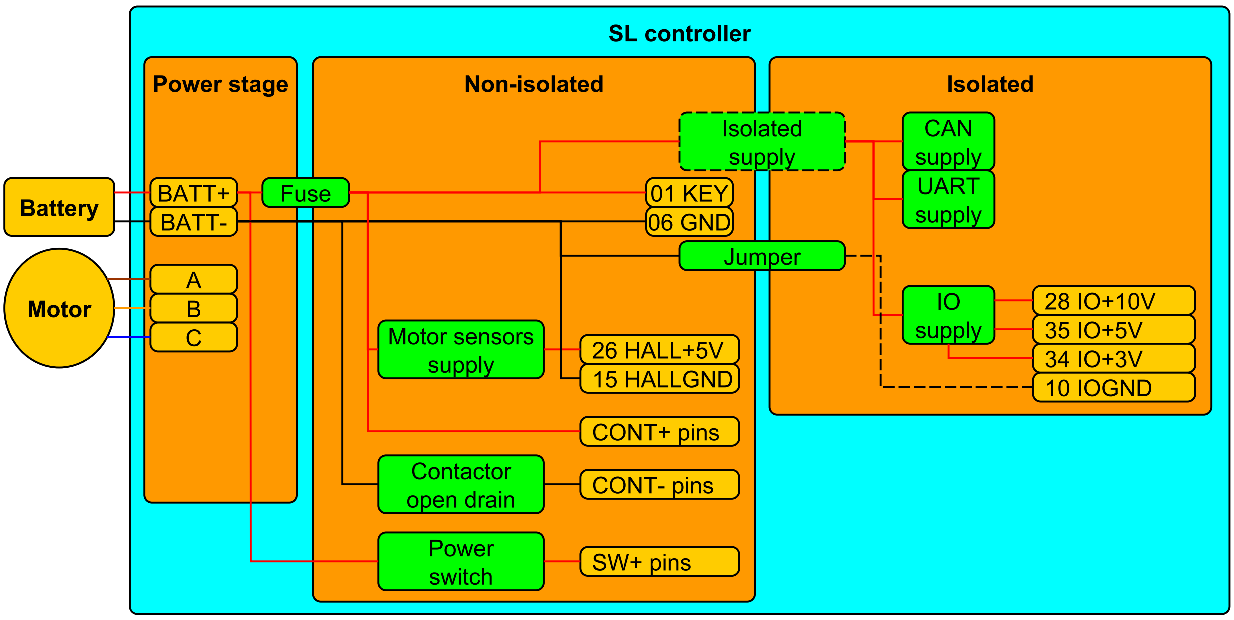


Figure 9.1: Block schematic of controller power supplies

9.2 Galvanic isolation

Some interfaces of the SL controller are galvanically isolated from rest of the controller. This feature enables easy and safe cooperatin 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 SL 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 10 IOGND/VCC+5V (if configured ad IOGND and not as VCC+5V). When galvanic isolation is not needed, IOGND can be connected with BATT− by jumper. Block schematic is shown in the figure 9.2.

Jumper is not connected by default and grounds are galvanically isolated(denoted by letter *galvanic isolation* in the MPN, described in section 3.2.2). Jumper, that connects isolated and non-isolated part is located next to the USB connector. From the two jumpers i is the one closer to the USB connector. To connect isolated ground to the BATT− move the jumper to the position closer to the phase terminals.

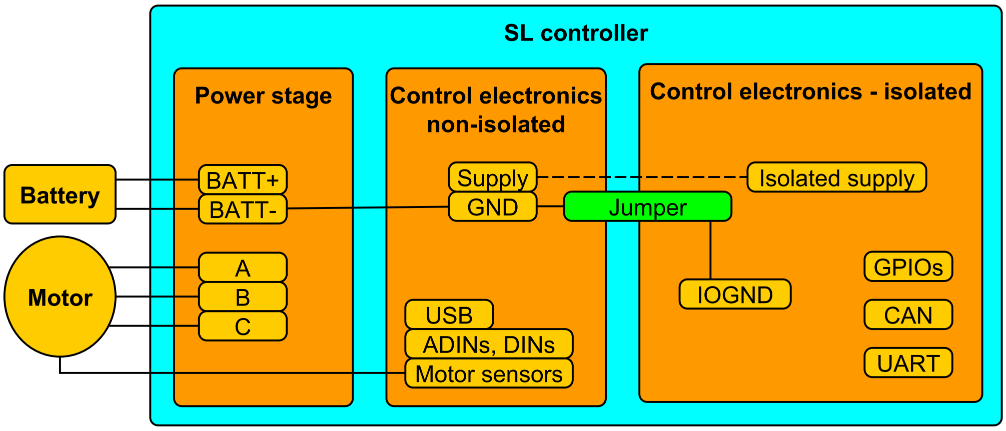


Figure 9.2: SL block schematics – galvanic isolation

9.3 Built-in RGB LED

The SL controller has bult-in RGB LED to indicate some basic facts during start-up and operation. Each color has it's meaning:

- **Red** – is controlled by *Driver* block of firmware and has the same meaning as built-in LED in other ESC3 controllers:
  - Turned off – *Driver* was successfully initialized and motor could be driven or is driven already.
  - 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 occured 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.
- **Green**
  - Lights solidly – transistors in power stage of the controller are not switching, power stage is deactivated but ready.
  - Blinks – error of *Control* block of the firmware.

- **Blue** – lights when *Driver* is activated and transistors in power stage of the controller are switchng.

Compounds of the RGB led are combined and could indicate combination of the events listed above:

- Solid purple – motor is driven (transistors are switching) and some limiter (such as overcurrent or overtemperature) was triggered.
- Solid yellow – motor is not driver (transistors are not switching) and some limiter (such as overcurrent or overtemperature) was triggered.

9.4 Communication

9.4.1 USB

The SL controllers are equipped with native USB communication. USB B-type connector is situated between Ampseal 35 connector and phase terminals, under small hood. 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 recommened. 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*.

9.4.2 CAN Bus

CAN Bus is modern type of communication bus, widely used in industry and automotive. The SL 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. No external resistor is needed, termination resistor is integrated in the SL controller. One of its end is connected to pin 13 CANH, the second end is connected to pin 2 CANTERM. When termination of CAN Bus is needed, connect pin 2 CANTERM to pin 24 CANL.

Pins 13 CANH and 24 CANL are always used for CAN Bus. Pins 16 RXD/CANH and 27 TXD/CANL could be used either for CAN Bus[1] or for Serial communication (UART), depending on selected *finish variant*, part *Internal HW configuration*; refer to section 3.2.2. Example of CAN Bus connection is shown in the figure 9.4.

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

[1]It is the same CAN Bus interface as on pins Pins 13 CANH and 24 CANL. Pin 13 CANH is connected to pin 16 RXD/CANH and pin 24 CANL is connected to pin 27 TXD/CANL

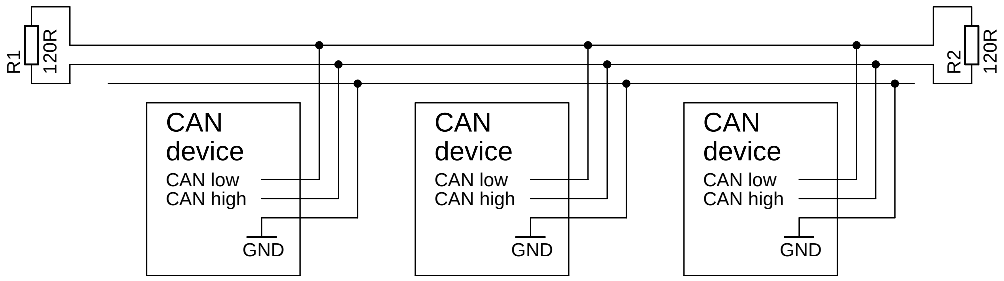


Figure 9.3: Connection of CAN Bus

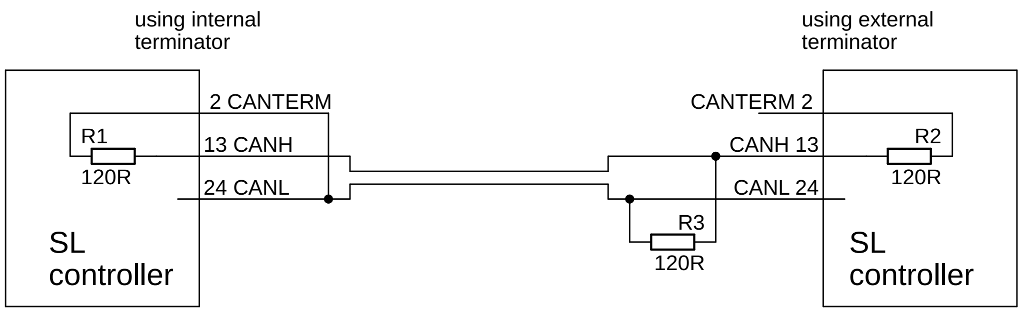


Figure 9.4: Usage of internal or external CAN termination resistor

Table 9.1: CAN Bus pins and UART pins

Pin	Name	Description	Direction	Parameters max. range
2	CANTERM	120 Ω CAN Bus terminator resistor	I/O	0–5 V, max. 10 mA
10	IOGND/VCC+5V	Isolated CAN Bus ground	Power output	0 V, max. 100 mA
		5 V power supply output (non-isolated)	Power output	5 V, max. 100 mA
13	CANH	Isolated CAN HIGH	I/O	0–5 V, max. 10 mA
16	RXD/CANH	Isolated UART RXD	Input	
		Isolated CAN HIGH	I/O	
24	CANL	Isolated CAN LOW	I/O	
27	TXD/CANL	Isolated UART TXD	Output	
		Isolated CAN LOW	I/O	

Note: All pins are related to the IOGND, which is connected to BATT− if galvanic isolation disabled by jumper.

9.4.3 Serial communication (UART)

The SL 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*.

9.5 General purpose inputs/outputs

Depending on chosen *Pinout version*, the SL controller could have up to five general input/output pins, which are galvanically isolated by default. In a input mode, these pins can either work as digital or analog input pins. Analog inputs has 16 bit resulotion 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.

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. When needed, these voltages could be changed to custom values. If SL controller is used in e-bike or similar vehicle, pin 23 GPIO1 is typically used for regen/brake and pin 22 GPIO0 is used for accelerator. Combination of IO+10V, IO+5V, IO+3V, IOGND and GPIOs can create multiplexer for pushbuttosn, up to four pushbuttons can be connected to one GPIO pin. Schematic is shown in the figure 9.5.

Table 9.2: Isolated GPIO pins

Pin	Name	Description	Direction	Parameters max. range
10	IOGND/VCC+5V	Isolated GPIO ground (7)	Power output	0 V max. 100 mA
		5 V power supply output (non-isolated)	Power output	5 V max. 100 mA
34	IO+3V/IO+5V	Isolated 3 V power supply output (7)	Power output	3 V max. 100 mA
		Isolated 5 V power supply output (7)	Power output	5 V max. 100 mA
		Isolated power supply of custom voltage (7)	Power output	max. 100 mA
35	IO+5V/custom	Isolated 5 V power supply output (7)	Power output	5 V max. 100 mA
		Isolated power supply of custom voltage (7)	Power output	max. 100 mA
28	IO+10V	Isolated 10 V power supply output (7)	Power output	10 V max. 100 mA
22	GPIO0	Isolated general purpose analog/digital I/O, typically accelerator	I/O	DINs: 0–V_{NOM} max. 10 mA GPIOs: 47 kΩ impedance (3) max. 10 mA 0–8.5 V (4) −3.5–7.5 V (5) 0–12 V (6)
23	GPIO1	Isolated general purpose analog/digital I/O, typically brake	I/O	
32	GPIO2/DIN7	Isolated general purpose analog/digital I/O	I/O	
		Non-isolated digital input	Input	
9	GPIO3/DIN6	Isolated general purpose analog/digital I/O	I/O	
		Non-isolated digital input	Input	
21	GPIO4/DIN8	Isolated general purpose analog/digital I/O	I/O	
		Non-isolated digital input	Input	

Note 1: All pins are related to the IOGND, which is connected to BATT− if galvanic isolation disabled by jumper.
Note 2: V_{NOM} is upper limit of *Operating voltage range*, refer to section 4.1.
Note 3: When GPIO pins are configured as GPIO (not as ADIN), input / output impedance is 47 kΩ by default. This can be changed on request – to work as low-impedance outputs
Note 4: Internal resistor disconnected, parameter `/common/ioconf` set to 0 (refer to chapter 12.5.1.
Note 5: Internal resistor connected as pull-up, parameter `/common/ioconf` set to 1 (refer to chapter 12.5.1.
Note 6: Internal resistor connected as pull-down, parameter `/common/ioconf` set to 2 (refer to chapter 12.5.1.
Note 7: When galvanic isolation is disabled, all GPIO pins (including IOGND, IO+3V and IO+5V) are **NOT** protected against shorting to BATT+, BATT− or any phase.

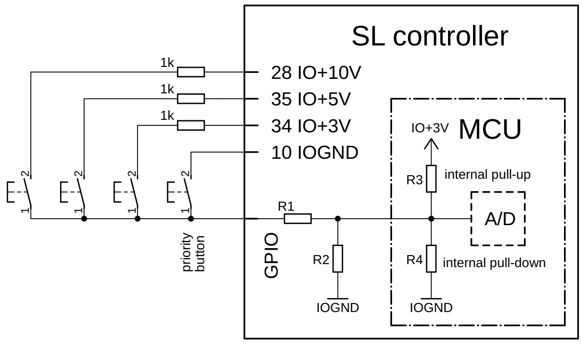


Figure 9.5: Four buttons multiplex schematic with GPIO pin

9.6 Analog/digital input pins

The SL controller is equipped with four analog or digital input pins by default. It could be equipped with another one analog or digital input pin and three digital input pins. All these pins are not galvanically isolated and they are related to BATT−. Pins are protected against shorting it to BATT−, BATT+ and any motor phase. Pins also have common pull-up/pull-down switch. It means that all pins can be connected via resistor either to BATT− or to BATT+ internally by software.

Table 9.3: Non-isolated ADIN pins

Pin	**Name**	**Description**	**Direction**	**Parameters max. range**
6	GND/KEY2	Ground, internally connected to BATT−	Power I/O	0–V_{NOM}, max. 1 A
		Power input for internal electronics, capacitors precharge and contactors		
10	IOGND/VCC+5V	Isolated GPIO ground	Power output	0 V, max. 100 mA
		5 V power supply output (non-isolated)	Power output	5 V, max. 100 mA
18	ADIN1	Analog or digital input	Input	0–V_{NOM} max. 10 mA
30	ADIN2			
19	ADIN3			
31	ADIN4			
20	POWER/ADIN5	Controller ON/OFF input, active high	Input	0–V_{NOM}, max. 10 mA
		Analog or digital input	Input	0–V_{NOM}, max. 10 mA
32	GPIO2/DIN7	Isolated general purpose analog/digital I/O	I/O	DINs: 0–V_{NOM} max. 10 mA GPIOs: refer to table 9.2
		Digital input	Input	
9	GPIO3/DIN6	Isolated general purpose analog/digital I/O	I/O	
		Digital input	Input	
21	GPIO4/DIN8	Isolated general purpose analog/digital I/O	I/O	
		Non-isolated digital input	Input	

Note 1: All digital input pins are related to the BATT−, galvanically isolated pins are related to IOGND.
Note 2: V_{NOM} is upper limit of *Operating voltage range*, refer to section 4.1.

Chapter 10: Motor sensors interface

Motor sensors interface of the SL 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 positon (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**
• 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 ...)	• Additional hardware needed (sensor, wires...) • Certain probabily of hardware issues (sensor mounting position tolerance, vibraions ...) • Possible problems with sensor interference

10.1.2 Sensorless control

Advantages	**Disadvantages**
• No additional hardware needed (cheaper and more robust solution) • No positioning errors and smooth operation at higher speeds	• 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
• Better accuracy • Works even when motor is not driven • Sensing can be done in particular spots, where the risk of overheat is the highest	• Additional hardware needed (sensor, wires...) • Possible problems with sensor interference

10.2.2 Sensorless temperature estimation

Advantages	Disadvantages
• No additional hardware needed • Can be turned on for each motor • Average winding temperature is obtained	• 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 algortihm is used

10.3 Electrical interface

This section describes the electrical interface of the SL 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 categhories, principles, advantages / disavantages and a selection guide, please refer to the *Driver manual*.

Motor control interface pins of the SL controller are listed in table 10.1. This interface has separated power supply with outputs on pins 26 HALL+5V and 15 HALLGND. Current capability of this power supply is 50 mA. This supply is not galvanically isolated from the battery. Using motor sensors' ground (pin 15 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 25 ENCB/DATA has ability to measure time events – it can be used for PWM / PPM signal decoding.

Table 10.1: Motor sensors pins

<table>
<tr><th>Pin</th><th>Name</th><th>Description</th><th>Variant</th><th>Direction</th><th>Parameters</th></tr>
<tr><td>15</td><td>HALLGND</td><td>Hall sensors supply ground, internally connected to BATT− (3)</td><td>h, a, r, d</td><td>Power output</td><td>0 V, max. 50 mA</td></tr>
<tr><td>26</td><td>HALL+5V</td><td>Hall sensors supply voltage (3)</td><td>h, a, r, d</td><td>Power output</td><td>5 V, max. 50 mA</td></tr>
<tr><td rowspan="5">29</td><td rowspan="5">HALLW/COM</td><td>Hall sensor W</td><td>h, a</td><td>Input</td><td rowspan="23">0–3.3 V
V_{NOM} tollerant
max. 10 mA</td></tr>
<tr><td>Raw analog resolver common input</td><td>r</td><td>Input</td></tr>
<tr><td>Analog Sin–Cos SIN−, COS−</td><td>a</td><td>Input</td></tr>
<tr><td>BiSS MA− (clock)</td><td>r, d</td><td>Output</td></tr>
<tr><td>Incremental encoder reference input</td><td>h, a</td><td>Input</td></tr>
<tr><td rowspan="4">17</td><td rowspan="4">HALLV/SIN</td><td>Hall sensor V</td><td>h, a</td><td>Input</td></tr>
<tr><td>Raw analog resolver SIN</td><td>r</td><td>Input</td></tr>
<tr><td>Analog Sin–Cos SIN+</td><td>a</td><td>Input</td></tr>
<tr><td>BiSS SLO- (data)</td><td>r, d</td><td>Input</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">HALLU/COS</td><td>Hall sensor U</td><td>h, a</td><td>Input</td></tr>
<tr><td>Raw analog resolver COS</td><td>r</td><td>Input</td></tr>
<tr><td>Analog Sin–Cos COS+</td><td>a</td><td>Input</td></tr>
<tr><td rowspan="2">33</td><td rowspan="2">TEMP</td><td>Motor temperature sensor in</td><td>h, a, r, d</td><td>Input</td></tr>
<tr><td>General purpose analog input</td><td>h, a, r, d</td><td>Input</td></tr>
<tr><td rowspan="5">14</td><td rowspan="5">ENCA/CLK</td><td>SSI/SPI clock (CLK)</td><td>r, d</td><td>Output</td></tr>
<tr><td>BiSS MA+ (clock)</td><td>r, d</td><td>Output</td></tr>
<tr><td>Raw analog resolver excitation</td><td>r</td><td>Output</td></tr>
<tr><td>Incremental encoder A</td><td>h, a</td><td>Input</td></tr>
<tr><td>Servo PPM / PWM channel 2 input</td><td>h, a</td><td>Input</td></tr>
<tr><td rowspan="5">25</td><td rowspan="5">ENCB/DATA</td><td>SSI/SPI data (MISO)</td><td>r, d</td><td>Input</td></tr>
<tr><td>Raw analog resolver excitation</td><td>r</td><td>Output</td></tr>
<tr><td>BiSS SLO+ (data)</td><td>r, d</td><td>Input</td></tr>
<tr><td>Incremental encoder B</td><td>h, a</td><td>Input</td></tr>
<tr><td>Servo PPM / PWM channel 1 input</td><td>h, a</td><td>Input</td></tr>
</table>

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 variant*.
Note 3: Protected by non-reversible fuse

10.4 Rotor angle sensors interface types

Several interfaces of rotor angle sensors exist. Usually, rotor angle sensor has one interface as output of he rotor position. Sensors with multiple interfaces also exists. 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 exists). Example of the signals are shown in the picture 10.1. Example of connection is shown in the figure 10.2.

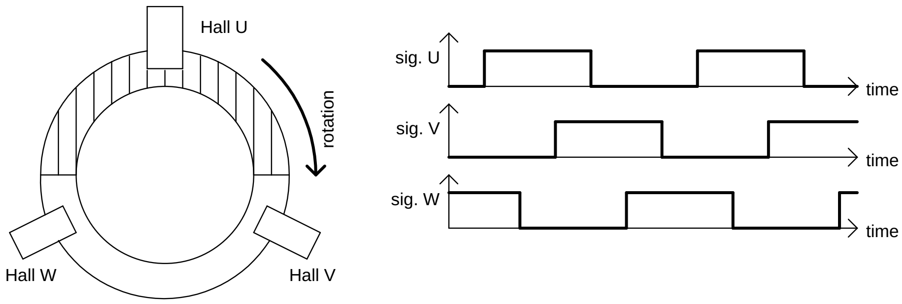


Figure 10.1: Example of UVW commutation signals

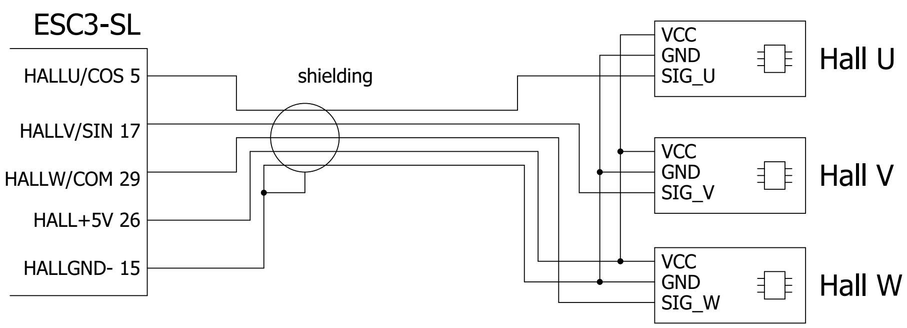


Figure 10.2: Connection of UVW commutation signal to the controller

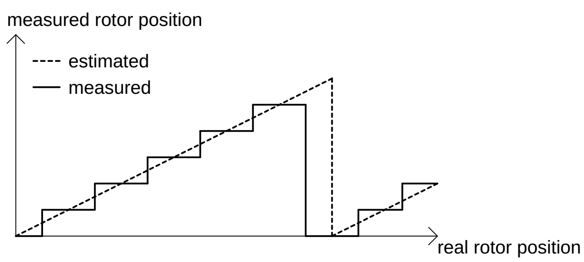


Figure 10.3: Rotor position estimation from UVW commuation signal

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 precission / motion control is required at low RPM) for VECTOR driver algorithm since the position estimation is needed. Rotor position measuremnt using the UVW commutation signal is shown in the figure 10.3.

Advantages	**Disadvantages**
• 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	• 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 kΩ

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 si fed by AC voltage of known amplitutde 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 SL 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.

Advantages	**Disadvantages**
• 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	• 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 dimenions • Higher price

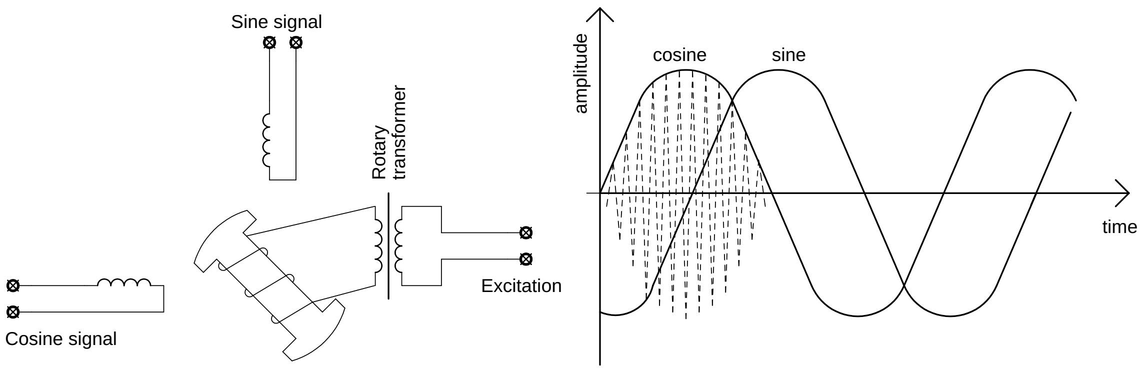


Figure 10.4: Resolver working principle

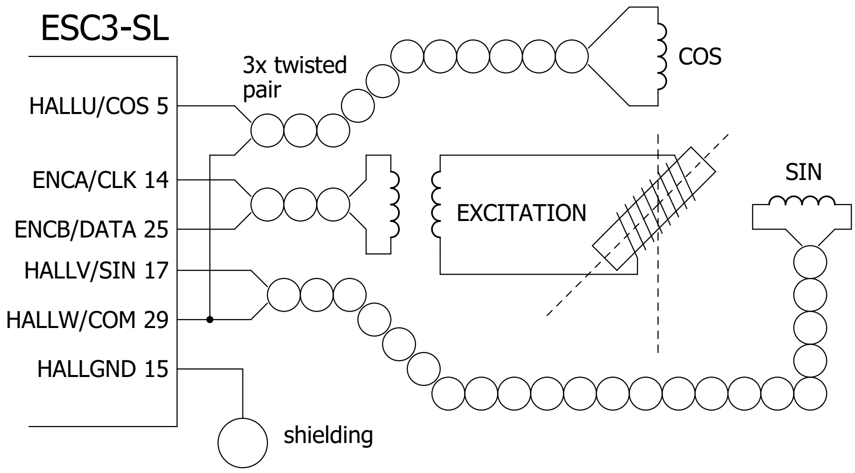


Figure 10.5: Resolver connection to the SL controller

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 kΩ

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 quater of period and one period of sine (or cosine) signal corresponds to one mechanical turn of the motor (see figure 10.6 for ilustration). 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 SL controller is shown in the figure 10.7.

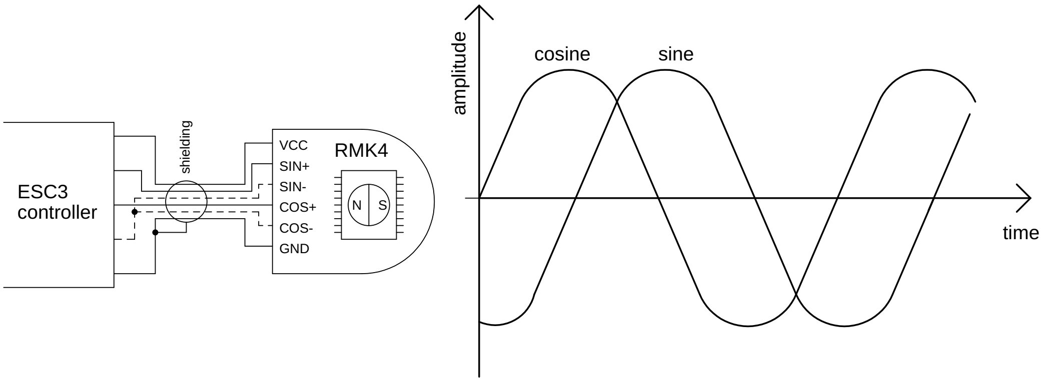


Figure 10.6: Sin-Cos sensor working principle

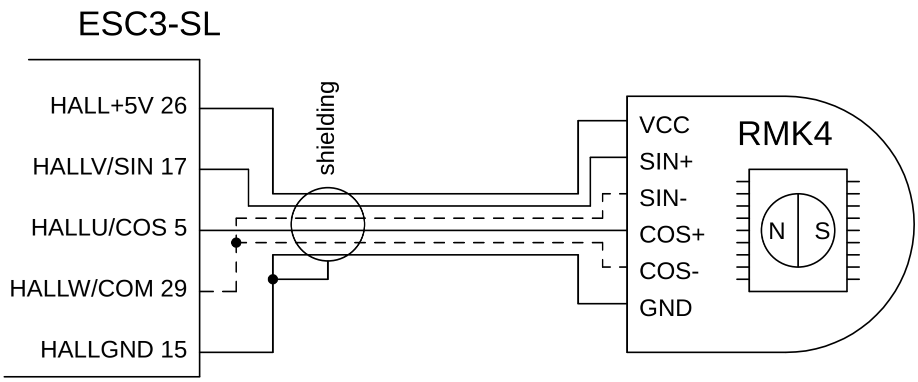


Figure 10.7: Connection of sensor with Sin-Cos interface

Advantages	Disadvantages
• Absolute and continuous position sensing • Suitable for VECTOR driver algorithm • Suitable for position servo drives • Usually very small dimensions	• 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 ...

Electrical interface parameters:

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

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 SL controller to update the measured rotor position. Multiple hardware layers and multiple protocols for the communication exists.

The SL 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).

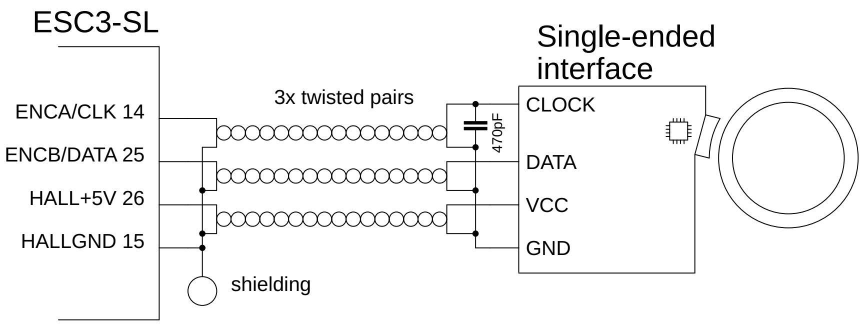


Figure 10.8: Connection of single-ended serial interface

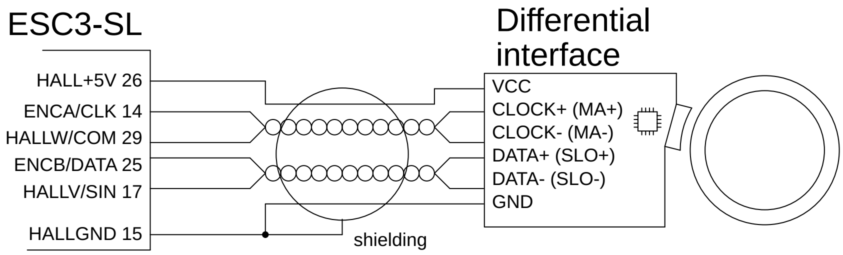


Figure 10.9: Connection of differential serial interface

Advantages	Disadvantages
• 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)	• 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 kΩ

- 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 inteface 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 quater 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 SL controller is shown in the figure 10.11.

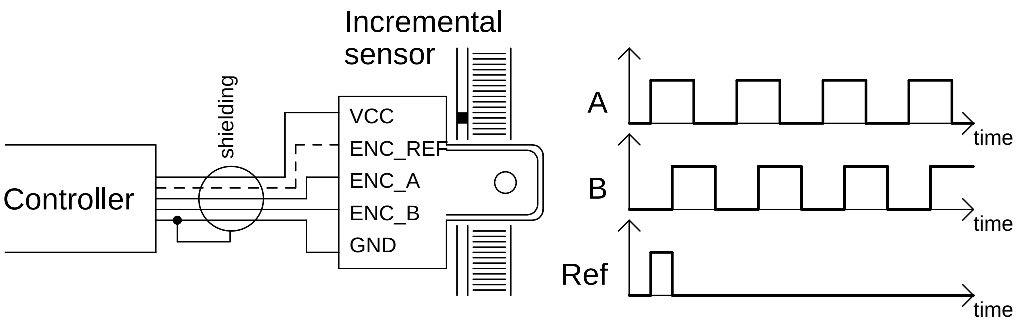


Figure 10.10: Incremental sensor working principle

Advantages	Disadvantages
• Continuous position sensing • Sufficient precision • Suitable for driving induction machines	• Sense mechanical revolutions. Angle multiplication error could occur when using motor with many polepairs • Reference input and 'homing' procedure needed if the absloute position is required • Not suitable for permanent magnet motors

[1] When using AM4096 in SSI mode, parameter SSIcfg 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.

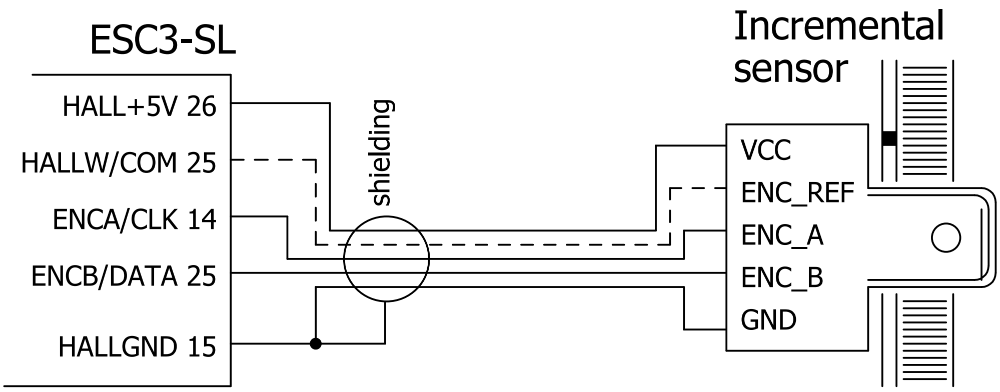


Figure 10.11: Connection of incremental sensor to the SL controller

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)

10.5 Winding temperature measurement

The SL controller has ability to measure temperature of motor winding using temperature sensor. Temperature sensor is connected between pin 33 TEMP and pin 15 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)

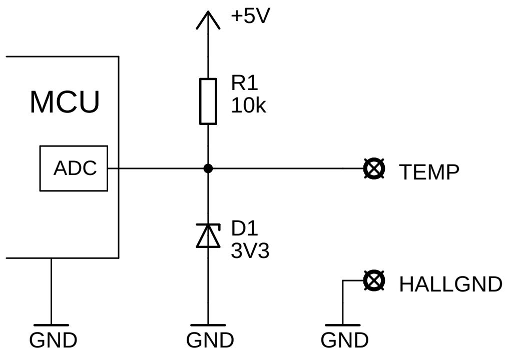


Figure 10.12: Internal connection of the TEMP pin

Electrical specifications

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

Recommended temperature sensors

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

Chapter 11: Pinouts

11.1 Ampseal 35 pinout

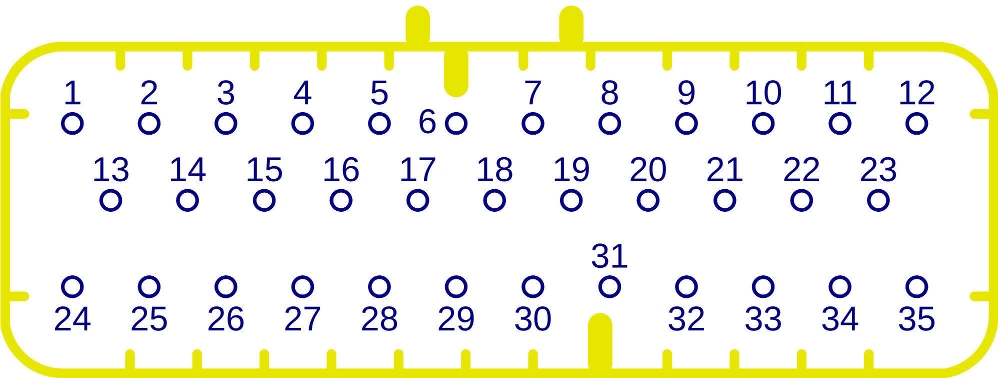


Figure 11.1: SL controller pinout – Ampseal 35

11.2 Pin list & overview

Table 11.1: SL controller pin list

<table>
<tr><th>Pin</th><th>Name</th><th>Description</th><th>Direction</th></tr>
<tr><td>1</td><td>KEY1</td><td>Control power supply</td><td>Power input</td></tr>
<tr><td>2</td><td>CANTERM</td><td>CAN Bus terminator 120 Ω</td><td>Input</td></tr>
<tr><td>3</td><td>CONT1−</td><td>Contactor 1 open drain output</td><td>Power output</td></tr>
<tr><td>4</td><td>CONT1+/SW</td><td>Contactor 1 supply output / charger input</td><td>Power I/O</td></tr>
<tr><td>5</td><td>HALLU/COS</td><td>Hall sensor U input</td><td>Input</td></tr>
<tr><td>6</td><td>GND/KEY2</td><td>Ground / Control power supply</td><td>Power I/O</td></tr>
<tr><td>7</td><td>CONT2−</td><td>Contactor 2 open drain output</td><td>Power output</td></tr>
<tr><td>8</td><td>CONT2+/SW</td><td>Contactor 2 supply output / charger input</td><td>Power I/O</td></tr>
<tr><td>9</td><td>GPIO3/DIN6</td><td>Isolated GPIO / Digital input</td><td>I/O</td></tr>
<tr><td>10</td><td>IOGND/VCC+5V</td><td>Isolated ground / 5 V supply</td><td>Power output</td></tr>
<tr><td>11</td><td>CONT3−</td><td>Contactor 3 open drain output</td><td>Power output</td></tr>
<tr><td>12</td><td>CONT3+/SW</td><td>Contactor 3 supply output / charger input</td><td>Power I/O</td></tr>
<tr><td>13</td><td>CANH</td><td>CAN Bus high</td><td>I/O</td></tr>
<tr><td>14</td><td>ENCA/CLK</td><td>Encoder A / Clock</td><td>I/O</td></tr>
<tr><td>15</td><td>HALLGND</td><td>Hall sensors ground</td><td>Power output</td></tr>
<tr><td>16</td><td>RXD/CANH</td><td>UART RX / CAN Bus high</td><td>I/O</td></tr>
<tr><td>17</td><td>HALLV/SIN</td><td>Hall sensor V input</td><td>I/O</td></tr>
<tr><td>18</td><td>ADIN1</td><td rowspan="2">Analog or digital input</td><td rowspan="3">Input</td></tr>
<tr><td>19</td><td>ADIN3</td></tr>
<tr><td>20</td><td>POWER/ADIN5</td><td>Activation input / Analog or digital input</td></tr>
</table>

Note: first function (before the slash) in pin name is the default one, second function (after the slash) is alternative function of the pin. These functions are not configurable by user.

Table 11.2: SL controller pin list

Pin	Name	Description	Direction
21	GPIO4/DIN8	Isolated GPIO / Digital input	I/O
22	GPIO0	Isolated input / output	I/O
23	GPIO1		
24	CANL	CAN Bus low	I/O
25	ENCB/DATA	Encoder B / Data	I/O
26	HALL+5V	Hall sensors 5 V power supply	Power output
27	TXD/CANL	UART TX / CAN Bus low	I/O
28	IO+10V	Isolated 10 V supply	Power output
29	HALLW/COM	Hall sensor W input	I/O
30	ADIN2	Analog or digital input	Input
31	ADIN4		
32	GPIO2/DIN7	Isolated GPIO / Digital input	I/O
33	TEMP	Motor temperature sensor	Input
34	IO+3V/IO+5V	Isolated 3 V supply	Power output
35	IO+5V/custom	Isolated 5 V supply	Power output

Note: first function (before the slash) in pin name is the default one, second function (after the slash) is alternative function of the pin. These functions are not configurable by user.

11.3 Ampseal 35 pinout variants

SL controllers can be deeply customized, several pins of Ampseal 35 connector there are more than one function available. Selected function is reflexted to the MPN, in part *Signal connector pinout*. Refer to section 3.2.2 and tables 3.4 and 3.5.

11.4 Ampseal 35 pinout with pin names

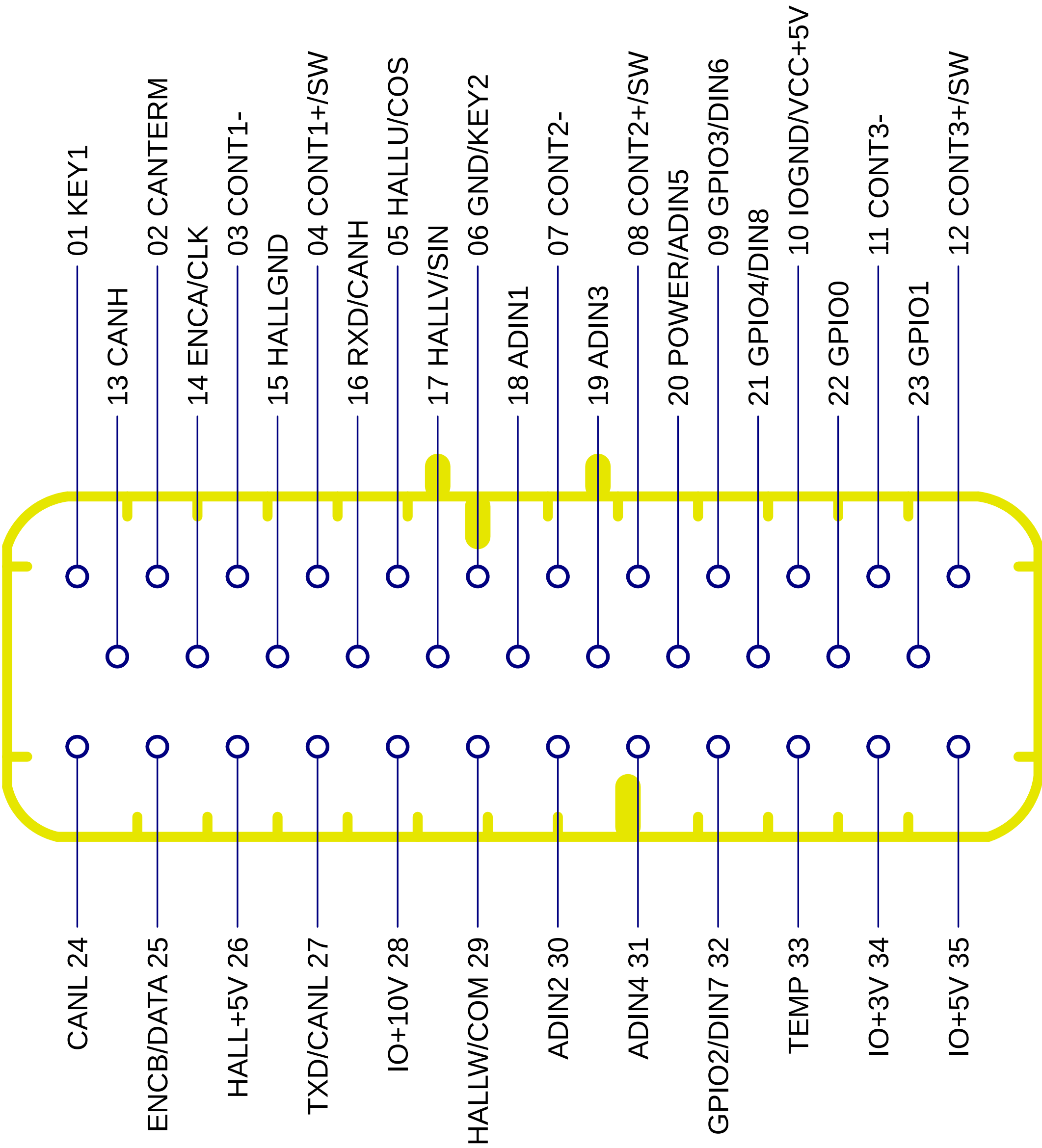


Figure 11.2: SL controller pinout – Ampseal 35 with pin names

Chapter 12: yOS interface

All ESC3 controllers runs yOS – propietary 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.

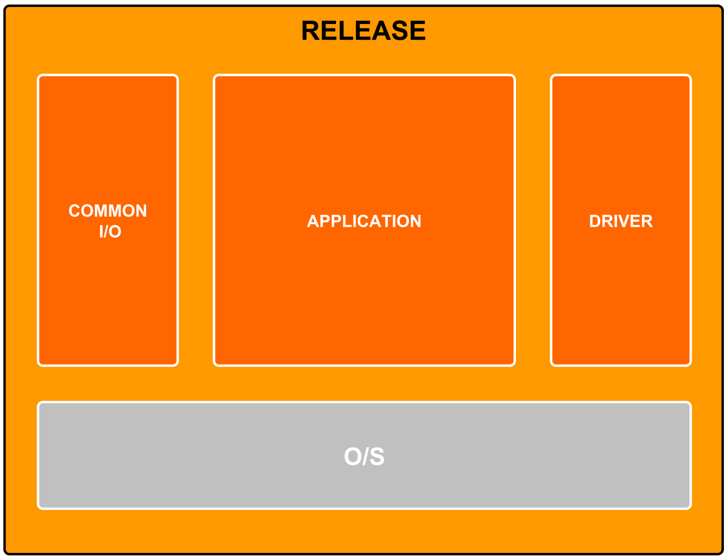


Figure 12.1: Block structure of release

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 SL controller is number **12**.

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 15 HALLGND and 33 TEMP. Thermistor has 10 kΩ 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 15 HALLGND and 33 TEMP. Thermistor has 10 kΩ pull-up resistor. Connection is shown in the figure 12.2.

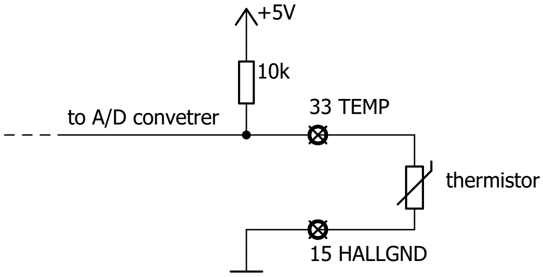


Figure 12.2: Thermistor connection

12.3.3 gpio0, gpio1 ... gpio4

```
gpio0 (int16) [mV]
gpio1 (int16) [mV]
...
gpio4 (int16) [mV]
```

Value on pin 22 GPIO0 (or other GPIOs) in real units, depending on application it can be milivolts, miliseconds 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 22 GPIO0 (or other GPIOs).Valid values of `gdin` and corresponding voltage levels are listed in table 12.1.

rev_C
28/11/2018

Table 12.1: `gdin` voltage treshold values

`gdin` value	pin voltage		
	`ioconf = 0` (pin floating)	`ioconf = 1` (pull-up)	`ioconf = 2` (pull-down)
3	$> 7.8\,\mathrm{V}$	$> 6.8\,\mathrm{V}$	$> 10.8\,\mathrm{V}$
2	$4.2\,\mathrm{V} < V_{gdin} < 7.8\,\mathrm{V}$	$4.2\,\mathrm{V} < V_{gdin} < 6.8\,\mathrm{V}$	$4.2\,\mathrm{V} < V_{gdin} < 10.8\,\mathrm{V}$
1	$2.6\,\mathrm{V} < V_{gdin} < 4.2\,\mathrm{V}$	$2.6\,\mathrm{V} < V_{gdin} < 4.2\,\mathrm{V}$	$2.6\,\mathrm{V} < V_{gdin} < 4.2\,\mathrm{V}$
0	$< 2.6\,\mathrm{V}$	$0.6\,\mathrm{V} < V_{gdin} < 2.6\,\mathrm{V}$	$< 2.6\,\mathrm{V}$
−1	not defined	$< 0.6\,\mathrm{V}$	not defined

12.3.5 ain1, ain2 ... ain5

```
ain1 (uint16) [10 mV]
ain2 (uint16) [mV]
...
ain5 (uint16) [mV]
```

Voltage on pin 18 ADIN1 (or other ADINs) in 10 mV (if value of `ain1` is 100, voltage on this pin is 1000 mV).

12.3.6 din1, din2 ... din8

```
din1 (uint8)
din2 (uint8)
...
din8 (uint8)
```

Digital state of pin 18 ADIN1 (or other ADINs). Logical states is dependent on configuration of pull-up / pull-down switch:

- no pull-up, nor pull-down: 0 when pin is disconnected (floating), 1 when pin is connected to positive voltage
- pull-up: 0 when pin is disconnected (floating) or connected to positive voltage, 1 when pin is connected to ground.
- pull-down: 0 when pin is disconnected (floating) or connected to ground, 1 when pin is connected to positive voltage.

Pull-up and pull-down resistors are configured by parameter `pupd` in directory `/control` (described below). Pins ADIN1 – ADIN5 are analog pins which can work as digital inputs. Treshold between logic 0 and logic 1 can be set by parameter `gpio_thr2` in directory `/control`. Logic on ADIN pins can be inverted by setting treshold to negative value.

12.3.7 dout1, dout2, dout3

```
dout1 (int8)
dout2 (int8)
dout3 (int8)
```

CONT1− (CONT2−, CONT3−) 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` (`dout2` or `dout3`) state is 1. When pin is in OFF-state, it is disconnected (floating) and value of the `dout1` (`dout2` or `dout3`) state is 0.

12.3.8 ccnt1, ccnt2, ccnt3

`ccnt1 (uint16) [mA]`
`ccnt2 (uint16) [mA]`
`ccnt3 (uint16) [mA]`
CONT− pins are equipped with current measurement. States `ccnt` are measured currents in miliamps.

12.3.9 ch1

`ch1 (uint16) [us]`
Raw servo pwm pulse length in microseconds. Pin 25 ENCB/DATA could be mapped to channel 1.

12.3.10 vspl

`vspl (uint16) [mV]`
Voltage of internal +10 V power supply in milivolts.

12.3.11 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.

12.3.12 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.

12.3.13 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 higer than potential of controller ground, measured value is positive.

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	22	GPIO0
9	0x09	gpio1	23	GPIO1
10	0x0A	gpio2	9	GPIO2/DIN6
11	0x0B	gpio3	32	GPIO3/DIN7
12	0x0C	gpio4	21	GPIO4/DIN8
16	0x10	gdin0	22	GPIO0
17	0x11	gdin1	23	GPIO1
18	0x12	gdin2	9	GPIO2/DIN6
19	0x13	gdin3	32	GPIO3/DIN7
20	0x14	gdin4	21	GPIO4/DIN8
24	0x18	ain1	18	ADIN1
25	0x19	ain2	30	ADIN2
26	0x1A	ain3	19	ADIN3
27	0x1B	ain4	31	ADIN4
28	0x1C	ain5	20	ADIN5/POWER
32	0x20	din1	18	ADIN1
33	0x21	din2	30	ADIN2
34	0x22	din3	19	ADIN3
35	0x23	din4	31	ADIN4
36	0x24	din5	20	ADIN5/POWER
37	0x25	din6	9	GPIO2/DIN6
38	0x26	din7	32	GPIO3/DIN7
39	0x27	din8	21	GPIO4/DIN8
48	0x30	ch1		
56	0x38	ccnt1	3	CONT1–
57	0x39	ccnt2	7	CONT2–
59	0x3A	ccnt3	12	CONT3–
64	0x40	ichg		
65	0x41	uchg		
66	0x42	gndio		
67	0x43	vspl		
72	0x48	Vthermistor	33	TEMP
73	0x49	Rthermistor	33	TEMP
128	0x80	dout1	12	CONT1–
129	0x81	dout2	12	CONT2–
130	0x82	dout3	12	CONT3–

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 miliseconds

12.5.2 gpio_thr2

`gpio_thr2 (int16) [mV]`
Treshold berween logical 0 and 1 for pins ADIN1 – ADIN5 in 10 mV (when number 100 is set, treshold is 1000 mV). When negative value is set, treshold is same as with positive value but logic of ADIN pins is inverted.

12.5.3 pupd

`gpio_thr (uint8)`
Pins ADIN1 – ADIN5 and DIN6 – DIN8 has common internal pull-up and pull-down switch. Switch is controlled by this parameter:

- 0 – no pull-up, nor pull-down
- 1 – pull-up resistors for all ADIN and DIN pins
- 2 – pull-down resistors for all ADIN and DIN pins

12.5.4 contactor1, contactor2, contactor3

`contactor1 (directory)`
`contactor2 (directory)`
`contactor3 (directory)`
Each present contactor has its own directory with settings. This folder contains following parameters:

- `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 higer 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 miliseconds. 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 mtempsel

`mtempsel (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 conected. Refer to table 12.2.

12.6.2 beep_vol

`beep_vol (uint16)`
Controler 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.

12.6.5 ledbright

`ledbright (uint8)`
Sets brightness of the RGB LED.

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 beep

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

12.7.3 play

`play [tones]`
Play sequence of tones `[tones]`.

Related documents

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

Legal notice