Zubax Mitochondrik LV Datasheet

Zubax Robotics
Akadeemia rd. 21/1, Tallinn 12618, Estonia
info@zubax.com
Q&A: forum.zubax.com

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Overview

Mitochondrik LV an integrated module (functionally identical to an integrated circuit) that enables third-party hardware engineers to design sophisticated custom motor controllers using the cutting-edge motor control technology – **Télega**[1]. With Mitochondrik, a regular hardware engineer without prior experience with motor control applications can design a custom field-oriented control (also known as sine wave drive, or vector control) electronic speed controller (ESC) in a few days. Mitochondrik reduces the time to market and the required engineering expertise for vehicle designers while allowing them to keep manufacturing of key components in-house, thus maintaining a high level of vertical integration.

Features

- Built-in step-down DC-DC converter, MOSFET driver, and the MCU running the Télega motor control solution
- Compatible with any PMSM/BLDC motor
- 13 – 51 V input voltage range (4 – 12S $LiCoO_2$ battery).
- Sensorless control algorithm, providing low noise and up to 15% energy efficiency improvement
- Self-diagnostics and health status reporting
- Highly configurable. All parameters can be changed. The firmware can be upgraded by the user
- Uses highly reliable AEC-Q compatible components with an extended temperature range: -40°C to 105°C
- Enables designs with continuous power output up to 4 kW
- Allows for perfect motor responsiveness with minimum RPM undershoots or overshoot
- Good EMI immunity due to RF shielding on both sides of the PCB
- Embedded hardware and software protections
- Supports a rich set of communication interfaces:
  - Double redundant UAVCAN[2]
  - High-speed UART, for board-level communication
  - USB2.0 (driverless compatibility with GNU/Linux, MS Windows, macOS)
  - Standard RC PWM
- High-quality assurance:
  - Every manufactured unit undergoes a strict testing procedure The testing log for each produced unit is available to the user

Applications

- High-quality propeller drive controllers for unmanned aerial vehicles
- Fuel pumps for jet engines and gas turbines
- Electric drives for ground robots and small ground electric vehicles (E-bikes, scooters, etc.).
- Pump and propeller drives for unmanned electric watercrafts
- Control moment gyro drives for small satellites

[1] Refer to https://zubax.com/technologies/telega for more information
[2] Refer to https://uavcan.org/ for more information

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1 Overview

Mitochondrik LV is an integrated module for motor control. It incorporates all the necessary hardware needed to build an advanced motor controller for virtually any PMSM or BLDC motor. Mitochondrik is best suited for creating low and medium power electric drives with a power level of up to 7 kW. Mitochondrik runs Zubax Télega which is a state-of-the-art motor control technology. Zubax Télega employs new approaches to digital signal processing, which in combination with a proprietary field-oriented control (FOC) algorithm enable a significant improvement in energy efficiency, better dynamic characteristics and higher robustness compared to traditional PMSM/BLDC drives. Mitochondrik supports a wide variety of communication interfaces and auxiliary features that enable easy integration into the end application. This includes doubly redundant UAVCAN interface, USB, UART, and RC PWM input. Mitochondrik drastically reduces time to market by incorporating most of the complexity of motor controller development in one single package.

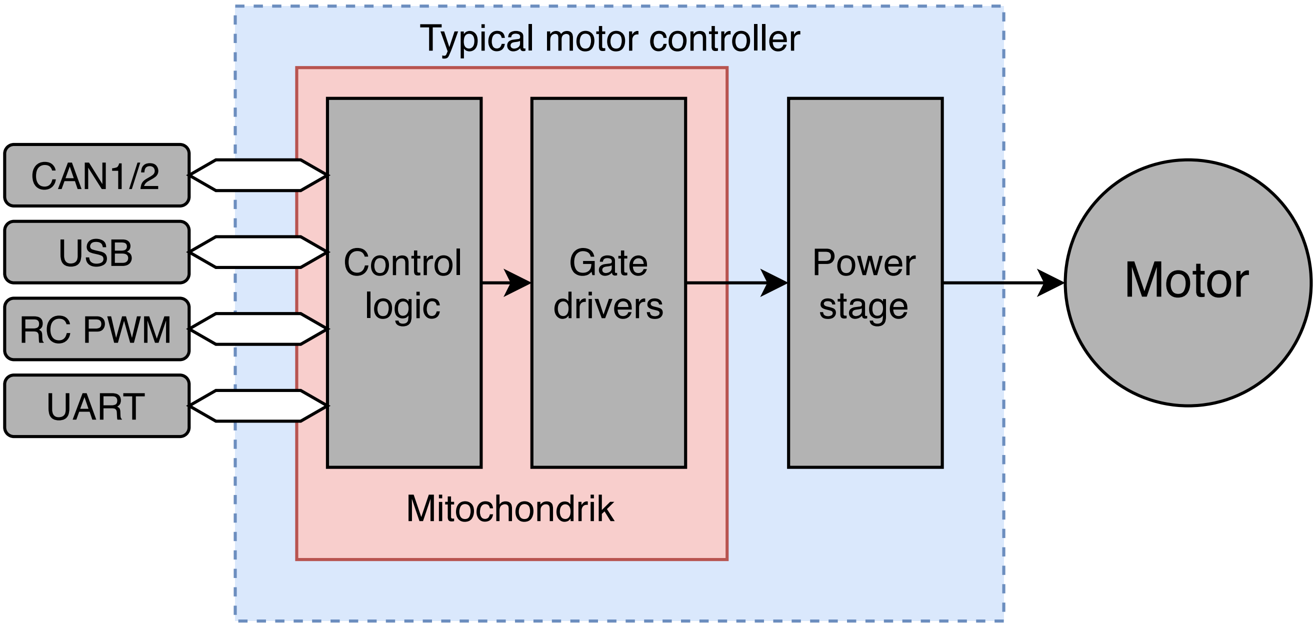


Figure 1.1: Block diagram of the typical Mitochondrik-based motor controller

2 Pin configuration and functions

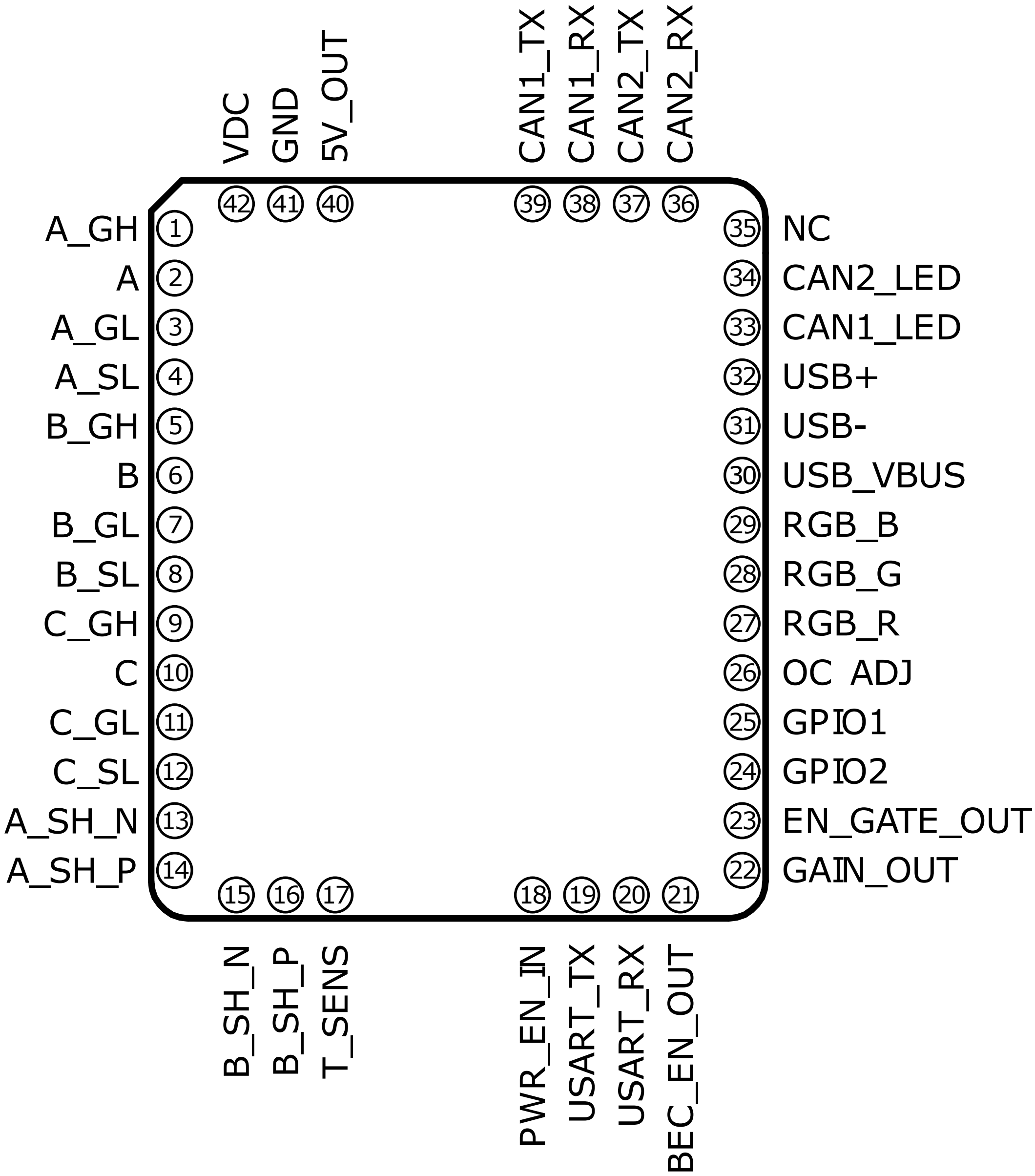


Figure 2.1: Mitochondrik pinout

The following table gives the pin configurations of the Mitochondrik. Some pins can serve multiple functions and may be software configured. Refer to Télega reference manual for more details.

Table 2.1: Pin functions

Pin	Pin name	Type[a]	Description
1	A_GH	O	Gate drive output for high-side MOSFET, half-bridge A.
2	A	I	Phase A high-side source sense input.
3	A_GL	O	Gate drive output for low-side MOSFET, half-bridge A.
4	A_SL	I	Phase A low-side source sense. Connect to the low-side power MOSFET source.
5	B_GH	O	Gate drive output for high-side MOSFET, half-bridge B.
6	B	I	Phase B high-side source sense input.
7	B_GL	O	Gate drive output for low-side MOSFET, half-bridge B.
8	B_SL	I	Phase B low-side source sense. Connect to the low-side power MOSFET source.
9	C_GH	O	Gate drive output for high-side MOSFET, half-bridge C.
10	C	I	Phase C high-side source sense input.
11	C_GL	O	Gate drive output for low-side MOSFET, half-bridge C.
12	C_SL	I	Phase C low-side source sense. Connect to the low-side power MOSFET source.
13	A_SH_N	I	Phase A shunt amplifier input. Connect to the low-side of the current shunt resistor.
14	A_SH_P	I	Phase A low-side source sense and shunt amplifier input. Connect to the low-side power MOSFET source and high-side of the current shunt resistor
15	B_SH_N	I	Phase B shunt amplifier input. Connect to the low-side of the current shunt resistor.
16	B_SH_P	I	Phase B low-side source sense and shunt amplifier input. Connect to the low-side power MOSFET source and high-side of the current shunt resistor
17	TEMP_SENSE	I	Temperature sensor input.
18	PWR_EN_IN	I	Power enable input.
19	UART_TX	O	UART transmit output.
20	UART_RX	I	UART receive input.
21	BEC_EN_OUT	O	Logic signal output to control external power source for UAVCAN interface.
22	GAIN_OUT	O	Logic output indicating instantaneous current amplifier gain level.
23	EN_GATE_OUT	O	Power stage enable output. May be used for an indication of the operational state of MOSFET driver.
24	GPIO2	I/O	General purpose IO 2.
25	GPIO1	I/O	General purpose IO 1 / RC PWM Input / thermistor input.
26	OC_adj	I	Overcurrent protection trip set pin. Connect a resistor from this pin to ground to set the trip point for the internal overcurrent protection circuitry.
27	RGB_R	O	RGB LED indication output. Red channel.
28	RGB_G	O	RGB LED indication output. Green channel.
29	RGB_B	O	RGB LED indication output. Blue channel.
30	USB_VBUS	I	USB Vbus input (5V).
31	USB -	I/O	USB data line D-.
32	USB +	I/O	USB data line D+.
33	CAN1_LED	O	UAVCAN1 interface activity indication LED output.
34	CAN2_LED	O	UAVCAN2 interface activity indication LED output.
35	NC	-	Should be left floating
36	CAN2_RX	I	UAVCAN2 interface receive data input. Connect to CAN transceiver RX pin.
37	CAN2_TX	O	UAVCAN2 interface transmit data output. Connect to CAN transceiver TX pin.
38	CAN1_RX	I	UAVCAN1 interface receive data input. Connect to CAN transceiver RX pin.
39	CAN1_TX	O	UAVCAN1 interface transmit data output. Connect to CAN transceiver TX pin.
40	5V_OUT	P	Onboard DC-DC converter power output. May be used to power external circuitry.
41	GND	P	Device power ground.
42	VDC	P	Device power supply.

[a]
- I - input pin
- O - output pin
- I/O - input/output pin
- P - power pin

3 Characteristics

3.1 Absolute maximum ratings

Stresses that exceed the limits specified in this section may cause permanent damage to the device. These are stress ratings, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended operating conditions 3.3. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

Table 3.1: Absolute maximum ratings

Symbol	Parameter	Min	Max	Unit
V_{inv}	Supply voltage	-0.3	56	V
T_{stor}	Storage temperature	-55	85	°C

3.2 Electrostatic discharge (ESD) ratings

Table 3.2: ESD ratings

Symbol	Parameter	Model	Value	Unit
V_{ESD}	Electrostatic discharge	Human-body model, per ANSI/ESDA/JEDEC JS-001	±1000	V
		Charged-device model, per JEDEC specification JESD22-C101	±500	V

3.3 Recommended operating conditions

Table 3.3: Recommended operating conditions

Symbol	Parameter	Note	Min	Max	Unit
V_{oper}	Supply voltage		8	51	V
T_{oper}	Operating temperature		-40	105	°C
ϕ_{oper}	Operating humidity	Condensation not permitted	0	100	%RH
h_{oper}	Operating altitude	Above mean sea level (MSL)		10	km

3.4 Power stage characteristics

Table 3.4: Power stage characteristics[a]

Symbol	Parameter	Min	Typ	Max	Unit
V_{GSh}	High-side MOSFET gate-source voltage during on-state	9	10.5	12	V
V_{GSl}	Low-side MOSFET gate-source voltage during on-state	9.5	11	12.5	V
F_{sw}	Transistor switching frequency	30		47	kHz
DT	Transistor dead time (configurable in the firmware)	100		1000	nsec
I_{source_max}	Peak source gate drive current			1.7	A
I_{sink_max}	Peak sink gate drive current			2.3	A
I_{drive_avg}	Average gate driving current		30		mA
V_{shunt}	Shunt resistor voltage range for linear current measurement	-0.3		0.3	V

[a] These parameters are required for the power stage board design.

3.5 Battery elimination circuit (BEC) characteristics

Table 3.5: BEC characteristics

Parameter	Value	Unit
Output voltage	4.9	V
Voltage tolerance	2	%
Maximum load current	500	mA
Voltage ripple	100	m$V_{\text{p-p}}$

3.6 General purpose digital I/O characteristics

Table 3.6: GPIO characteristics in output mode

Parameter	Min	Max	Unit
Output voltage High	2	3.3	V
Output voltage low	0	0.4	V
Max current		±20	mA

Table 3.7: GPIO characteristics in input mode

Parameter	Min	Max	Unit
Input low level voltage	-0.3	1.075	V
Input high level voltage	1.485		V
GPIO1 Maximum voltage		7	V
GPIO2 Maximum voltage		3.6	V

3.7 Communication interfaces

3.7.1 CAN bus

Table 3.8: Characteristics of CAN bus interfaces

Parameter	Min	Typ	Max	Unit
Bit rate	20		1000	Kbps
Low-level input voltage	-0.3	0	1.6	V
High-level input voltage	2.1	3.3	5.5	V
Low-level output voltage	0	0	0.5	V
High-level output voltage	2.8	3.3	3.4	V
Source current via data pins			8	mA

3.7.2 Serial interface characteristics

Table 3.9: Serial interface characteristics

Parameter	Min	Typ	Max	Unit
Low-level input voltage	-0.3	0	1.6	V
High-level input voltage	2.1	3.3	5.5	V
Low-level output voltage	0	0	0.5	V
High-level output voltage	2.8	3.3	3.4	V
Source current via data pins			8	mA

3.7.3 USB interface characteristics

Table 3.10: USB interface characteristics

Parameter	Min	Typ	Max	Unit
Low-level voltage	0	0	0.3	V
High-level voltage	2.8	3.3	3.6	V
Vbus voltage	2.8	3.3	5.5	V

3.7.4 RC PWM interface characteristics

Table 3.11: RC PWM input characteristics

Parameter	Min	Typ	Max	Unit
Input voltage	-0.3	5	7	V
PWM impulse capture resolution		1		usec
PWM impulse duration	0.001		60	msec
PWM signal period		20	60	msec
RC PWM pull down resistance	15	20	25	kΩ

3.8 Mechanical characteristics

The drawing 3.1 document the basic mechanical characteristics of Zubax Mitochondrik.

Table 3.12: Mechanical characteristics

Symbol	Parameter	Value	Unit	Note
m	Mass	7.8	g	PLS2 connectors not included

The Mitochondrik module can be mounted on a printed circuit board using plug-in connectors or soldered using pin connectors specified in section 6. The example of its land pattern on the carrier PCB is shown on the drawing 3.2.

3.9 Device identification

The hardware version number reported by Mitochondrik is (in the form major.minor): 1.6.

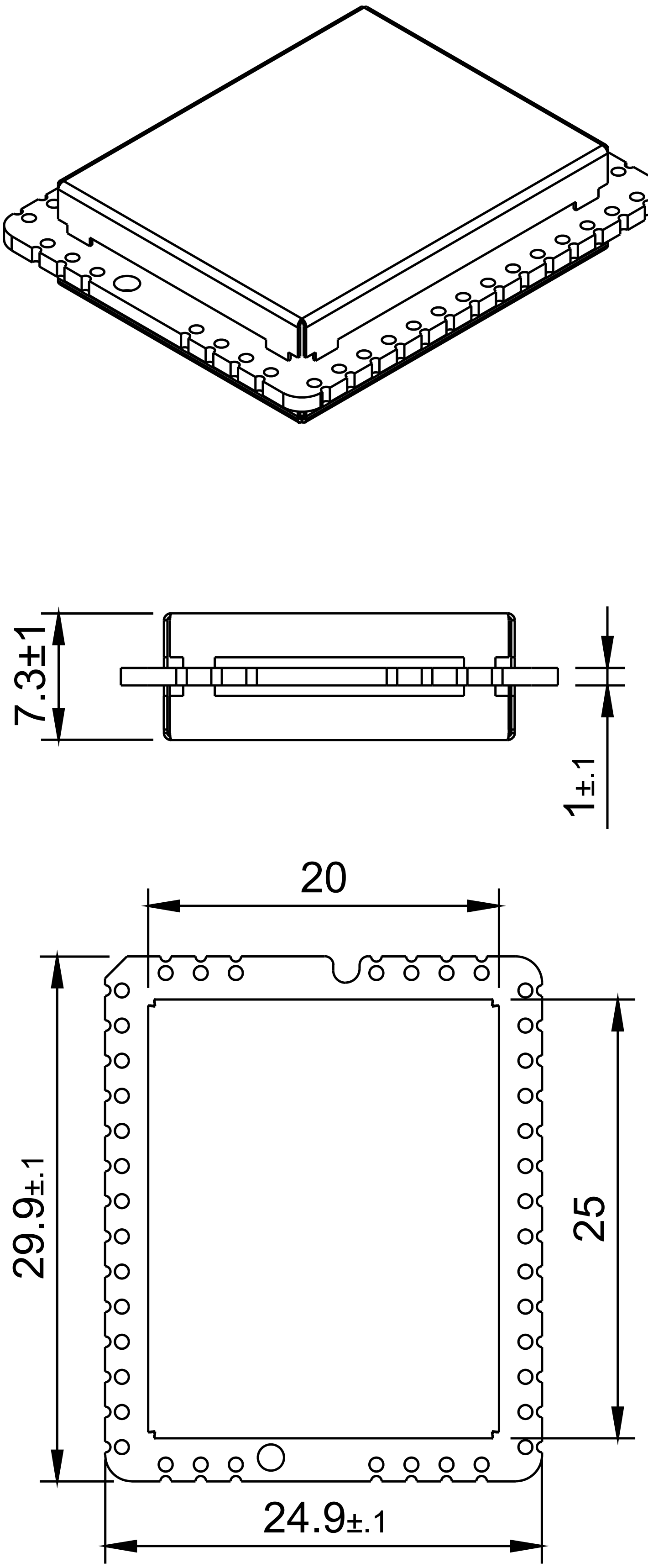


Figure 3.1: Mitochondrik package drawing
(all dimensions are in mm)

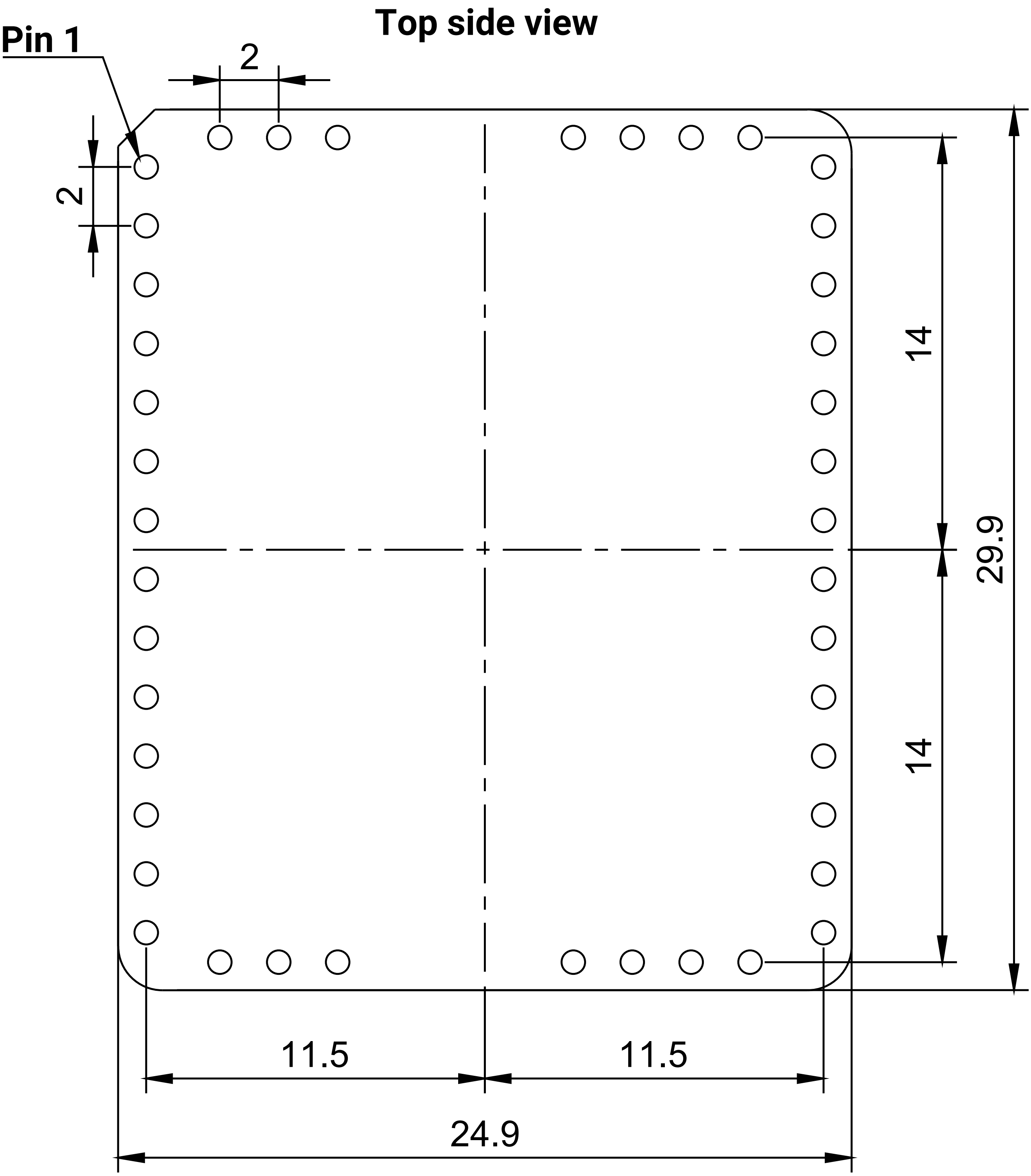


Figure 3.2: Mitochondrik recommended land pattern (all dimensions are in mm)

4 Detailed description

4.1 Typical application schematic

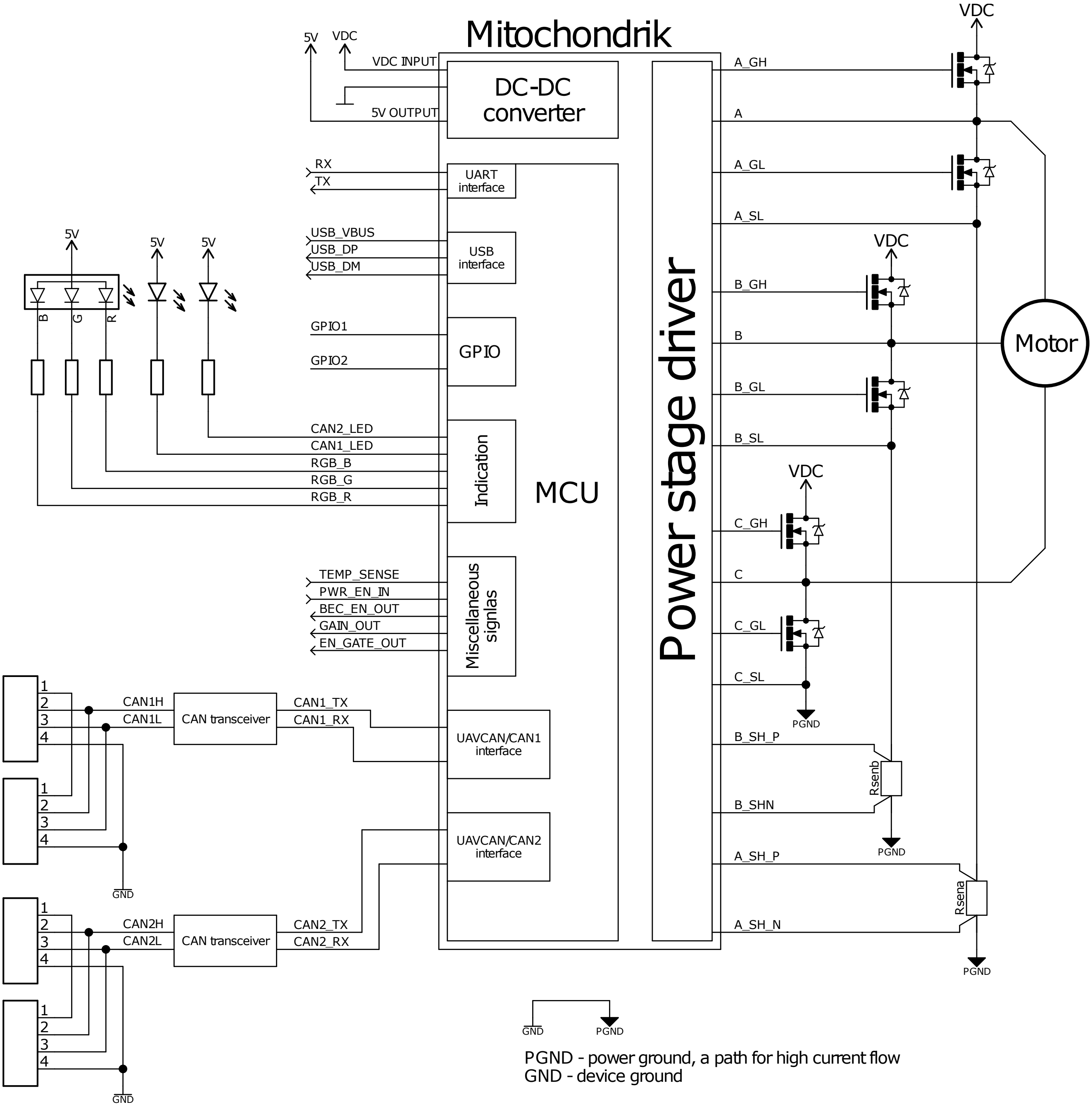


Figure 4.1: Mitochondrik typical application schematic

Mitochondrik fully replaces an electronic control scheme of the typical motor controller. It reduces external component count by integrating three half-bridge drivers, two current shunt amplifiers, and a switching buck converter. The only things that are to be designed to develop a complete motor controller are the power stage and some communication interfaces. The typical schematic of the complete controller based on the Mitochondrik is shown on the figure 4.1. The following sections explain the basic principles of operation and design of this scheme using this module.

4.2 Power stage

4.2.1 Three-phase gate driver

Mitochondrik includes three half-bridge transistor gate drivers, each capable of driving high-side and low-side N-channel power MOSFETs. They can drive up to 1.7 A source, 2.3 A sink peak currents with a 30 mA average output current. The high-side gate drive supply voltage is generated using a charge-pump architecture that provides the gate bias voltage not lower than 10.5 V across the full operating voltage range. The low-side gate drive supply voltage is generated using a linear regulator which provides 11 V on the x_GL outputs. The switching speed of the transistors can be regulated by means of gate resistors. The switching frequency and the dead time value can be adjusted in the range of 100 - 1000 ns in the firmware [3].

The design of MOSFET external gate circuits, including the selection of gate resistors, protective circuits and so on, are well covered in the literature. For example, for power stage design "MOSFET Gate Drive Circuit Application note" [4] from Toshiba can be used.

Care should be taken when routing the power stage signals. Even though the average drive current is not too large, gates are actually driven in a pulsed way and drive current can reach 2.3 A. Track width should be selected accordingly. The recommended value is 0.5 mm for 35 um copper width. Another thing to focus on is high-side drive voltage and phase voltage. These signals may be considered high-voltage. Phase voltage reaches system power voltage level and high-side drive voltage is even higher by about 12 V. So in case of using high voltage supply (more than 50 V) track clearance becomes important. In the case of common 2-4 layers FR4 PCBs with soldering mask minimum clearance for high voltage tracks for outer layers should be no less than 0.3 mm and for inner layer – 0.25 mm.

4.2.2 Phase currents measurement

Mitochondrik integrates two bidirectional current-shunt amplifiers for monitoring the current level through each of the external half-bridges using a low-side shunt resistor. Current shunt resistor value and power rating are determined by the target current range and operating temperature range. In order to utilize the maximum dynamic range of current measurement current shunt value should be selected using the following formula:

$$R = \frac{1.4}{10 \cdot I_{max}} \tag{4.1}$$

The minimum power rating of a current shunt is determined by the following formula:

$$P = I_{max}^2 \cdot R \tag{4.2}$$

Where I_{max} is the maximum measured current.

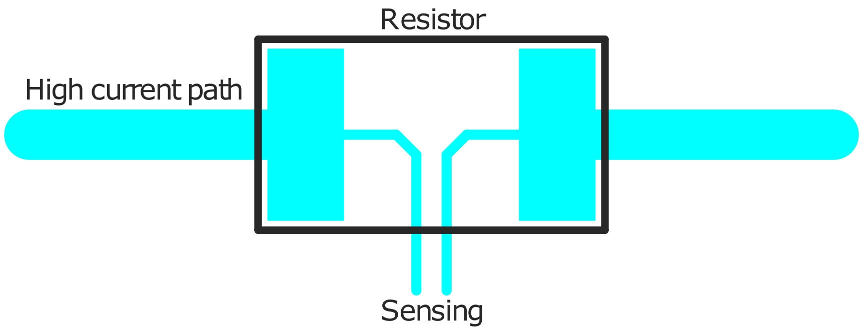


Figure 4.2: Current shunt signals recommended routing

The best practice for current shunt measurements is a four-terminal connection, also known as Kelvin sensing. This technique uses separate pairs of current-carrying and voltage-sensing electrodes to make more accurate measurements. In this case, the signal from the current shunt is inherently a differential signal and should be routed as a differential pair, as shown in the figure 4.2. The current shunt footprint can also affect

[3] Refer to Telega reference manual for more information.
[4] https://toshiba.semicon-storage.com/info/docget.jsp?did=59460

the measurement. To achieve better accuracy, which is crucial for the FOC algorithm, the special technique described in the application note[5] from Analog Devices may be used.

4.3 Fault protections

There are several protections embedded into Mitochondrik aimed at eliminating the possibility of major malfunctions that may lead to catastrophic consequences. All protections can be divided into latched and non-latched. When the latched protection is triggered, the firmware goes into a Fault state, and detailed error information is displayed both by means of a status indication[6] and through communication channels[7]. To release the latched protection, either a reboot or zero setpoint is required. Non-latched protections are triggered on the fly, without completely stopping the motor, which allows, for example, saving an aircraft during the flight.

Protections may be divided into software and hardware types by their origin. Software protections are implemented either in the firmware or the higher-level controller while hardware protections come from the power stage driver. The firmware provides the most critical software protections, for example:

- Protection against phase wire break that completely disables the power stage in case of such an event.
- Stall detection. Detects motor rotor stall and automatically restarts the motor as fast as possible.

Software protection against several less critical situations may be implemented in the host controller that manages the Mitochondrik-based device as Mitochondrik can constantly report the following vital data:

- Mitochondrik internal temperature.
- Power stage temperature.
- Motor windings temperature (requires the installation of the temperature sensor to the motor).
- DC bus voltage.
- DC bus current.

The full list of software protections and their detailed description fall outside of the scope of this document. Refer to the Télega reference manual for this information.

Mitochondrik has embedded latched hardware protections that prevent immediate failure of the power stage. When these protections are triggered Télega reports the Hardware fault error. Hardware protections are described in the table 4.1.

Table 4.1: Hardware faults protections

Protection	Description
Overcurrent	Protects the device from overcurrent event due to the motor winding short circuit or power stage malfunction. Described in detail in the section 4.3.1.
Current shoot-through	Prevents shoot-through current that may occur in case if the low-side transistor is turned on before the high-side transistor is completely turned off by automatically inserting the pause (dead time). The dead time can be increased in the firmware.
Undervoltage lockout (UVLO)	Disables the power stage drivers if the input voltage drops below the minimum value necessary for the gate drivers to work properly.
Overheat	Prevents fatal overheat of the power stage driver.
Gate driver fault	Disables all MOSFETs on the power stage if the voltage on the external MOSFET gate does not increase or decrease after a certain time. This fault may be encountered if the x_GH or x_GL pins are shorted to the PGND, x, or VDC_INPUT pins. A gate driver fault may be encountered if the gate resistor is too big that increases the transistor turn-on time too much.

4.3.1 Overcurrent protection

Overcurrent protection is implemented using a V_{DS} sensing circuit for each power MOSFET that is embedded into Mitochondrik. The sense circuit measures the voltage drop from the drain to the source of the external MOSFETs while the MOSFET is enabled. This voltage is compared to the hardware-programmed trip voltage to determine if an overcurrent event has occurred. The trip current can be set by connecting a resistor between OC_adj pin and ground using following equations:

[5] https://www.analog.com/media/en/analog-dialogue/volume-46/number-2/articles/optimize-high-current-sensing-accuracy.pdf
[6] Described in details in section 4.8.
[7] Refer to https://kb.zubax.com/display/MAINKB/Error+codes.

$$V_{DS(trip)} = \frac{R_{OC\_adj}}{R_{OC\_adj} + 1000} \times 3.3 \tag{4.3}$$

$$I_{trip} = \frac{V_{DS(trip)}}{R_{DS(on)}} \tag{4.4}$$

Where

R_{OC_adj} is the value of overcurrent protection setting resistor in Ohm.

$R_{DS(on)}$ is power MOSFET on state resistance in Ohm.

When the overcurrent event is detected Mitochondrik will start cycle-by-cycle current limiting to prevent permanent damage to the power stage. It must be specially noted that MOSFET transistor's $R_{DS(on)}$ is not constant and depends on the transistor's temperature, gate-source voltage, and current through the transistor. The most significant contribution to this comes from temperature change. This affects the protection trip current, reducing it considerably with temperature rise, which should be taken into account.

For example, BSC040N08NS5ATMA were used in the power stage design (2 transistors per half-bridge), its $R_{DS(on)}$ at 25°C is 4.3 mΩ and $1k\Omega$ resistor is used to set the overcurrent protection trip level. This gives $V_{DS(trip)}$:

$$V_{DS(trip)} = \frac{1000}{1000 + 10000} \times 3.3 = 0.3\ \text{V} \tag{4.5}$$

The protection will trip when the following condition is met:

$$I_{max} R_{dson} = V_{DS(trip)} \tag{4.6}$$

Using this equation I_{max} can be calculated:

$$I_{max} = \frac{0.3}{0.0043} = 69.7\ \text{A} \tag{4.7}$$

But if the transistor heats up during operation I_{max} can drastically decrease as its R_{dson} at 105°C is already close to 6 mΩ.

$$I_{max} = \frac{0.3}{0.006} = 50\ \text{A} \tag{4.8}$$

4.4 Integrated DC-DC converter

Mitochondrik features an integrated step-down DC-DC converter, that is used to power Mitochondrik itself directly from the battery voltage (or any other power source utilized by the motor) without the need for any external components. It may also be used to power some external electronics like LEDs, CAN transceivers, temperature sensors, etc.

One of the popular use cases of the DC-DC converter output is to provide power for the UAVCAN line. The firmware features control of this functionality with a dedicated pin named BEC_ENABLE_OUT. For example, this signal can control P-channel MOSFET that is connected in series between Mitochondrik 5V_OUT pin and UAVCAN power line. Attention should be paid to protect DC-DC output from possible short circuits. Although the converter itself has protection against short circuits and will not be damaged, the same buck converter is used to power Mitochondrik MCU and in case of a short circuit on 5 V line, it may reboot which may lead to critical failure. One of the most common types of short circuit protection is using fuses. It is worth noting that typical trip time of self-resetting fuse is in the order of hundreds of msec which is far beyond acceptable time limits. Efuse can serve as a good replacement for this purpose. A good example is TPD3S014DBVR from TI that not only serves as an Efuse but also limits the current and has embedded ideal diode into it. The typical battery elimination circuit (BEC) implementation is shown in the figure 4.3.

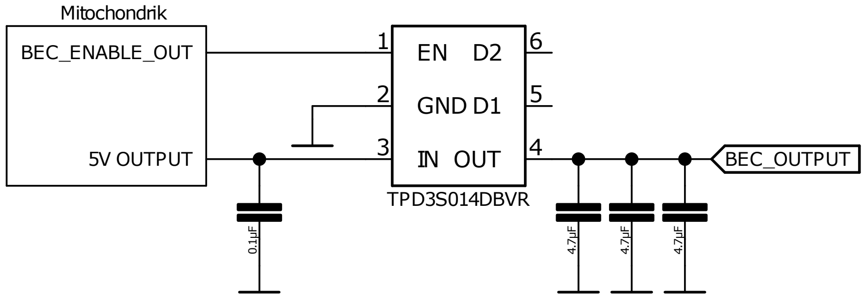


Figure 4.3: Typical battery elimination circuit (BEC) connection scheme

4.5 Electrostatic discharge (ESD) precautions

ESD represents a dire threat to modern electronics. Care should be taken to eliminate this threat when designing a product. A general rule may sound like this: if a signal leaves the PCB in the form of a connector or wire pad or any else it should be protected. A decent approach to deal with ESD is by using TVS diodes. TVS diodes should be placed close to the place where the signal leaves the board (usually connector) and should have a good low-impedance connection to the ground net for optimal performance.

Table 4.2: Recommended devices for Mitochondrik protection against ESD

Signal lines	Recommended device	Manufacturer
GPIO2 and 3.3 V lines	SMF3.3	Littelfuse
UART, GPIO1	SMF5.0A	Littelfuse
USB data and power lines	PRTR5V0U2X,215	Nexperia USA Inc.

4.6 General-purpose I/O lines

Mitochondrik has 2 general-purpose I/O digital lines. GPIO1 has two alternate functions, described in sections 4.7 and 4.9.4. In case GPIO lines are exposed outside of the ESC, some TVS protection is highly recommended, as shown in the figure 4.4.

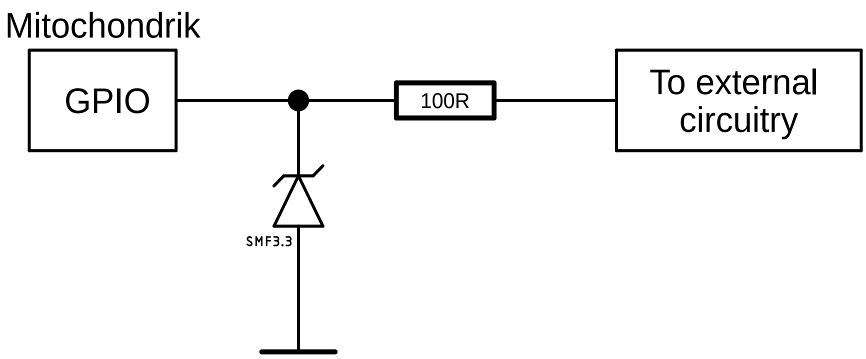


Figure 4.4: General purpose digital I/O lines implementation example

4.7 Motor temperature measurement

Mitochondrik module can measure the temperature of motor windings by means of PTC thermistor, connected between **GPIO1 pin** and system ground as shown in the figure 4.5. It supports the following thermistors: KTY84/130, KTY81/120, KTY83/120. No additional components are needed to connect the thermistor. The thermistor model is selected in the firmware.

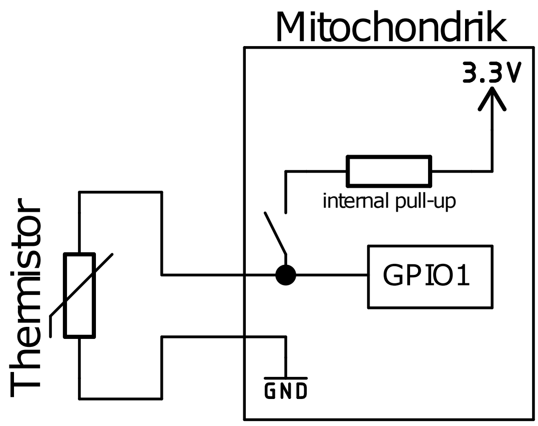


Figure 4.5: Thermistor connection

4.8 Indication

Mitochondrik has 5 lines dedicated to the indication of its internal state and activities. Most of them are supposed to drive LEDs connected to the pins directly with a current limiting resistor as shown in the figure 4.6. All indication pins type is open drain.

CAN1_LED and CAN2_LED lines indicate any activity on corresponding data lines. They blink once if at least one CAN frame was successfully transmitted or successfully received in the last 25 milliseconds on the respective CAN bus. They glow steadily when the intensity of CAN traffic is higher than 40 frames per second.

RGB_R, RGB_G, RBG_B lines are dedicated to status indication. It is recommended to connect a single RGB LED to these lines. It should be clearly visible from the outside of the ESC. The behavior of the RGB status LED is specified in the tables 4.3 and 4.4.

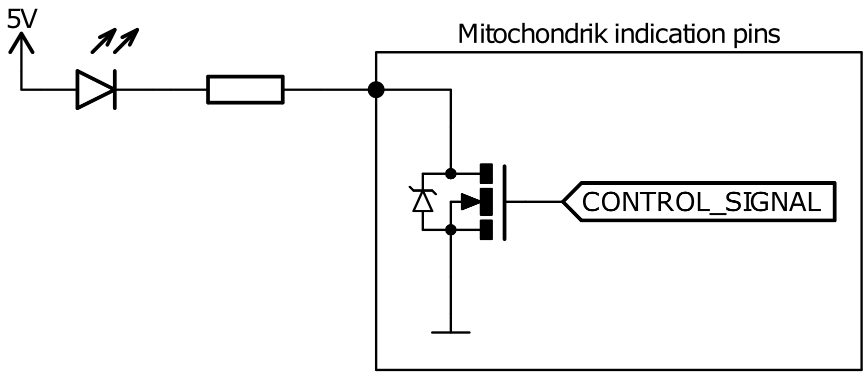
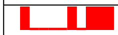


Figure 4.6: LED connection

Table 4.3: Status LED during boot

Color	Status	Description
Yellow	No application to boot	The firmware has not been flashed to the ESC or FLASH has been damaged.
Blue	Application upgrade is in progress	
Green	Boot canceled	The device firmware has not been properly signed.
Magenta	Ready to boot	Glows after the device power-up or restart event until the application starts.

Table 4.4: Status LED behavior

LED pattern (step 80 ms)	Status	Description
	Idle, ready to run	The ESC is ready and waiting for the setpoint.
	Idle, hardware fault	The power stage is not ready or current is tripped.
	Idle, hardware test fault	The motor is not connected or there is a short circuit on the output of the ESC.
	Idle, invalid motor parameters	Some motor parameters are not properly initialized or the motor identification hasn't been performed.

4.9 Communication interfaces

4.9.1 CAN bus

Mitochondrik is equipped with two CAN interfaces (CAN1, CAN2) that are meant to be used as a primary communication interface with the aid of UAVCAN protocol. It should be noted that only MAC level of CAN bus is embedded into Mitochondrik, appropriate CAN transceiver should be used. In general, the user is not limited to the CAN bus implementation but it is highly recommended to follow UAVCAN hardware design recommendations[8] for purposes of compatibility with existing UAVCAN devices.

CAN2 (the secondary CAN bus interface) can only be used in configurations with redundant CAN bus. If the bus is not redundant, only CAN1 (the primary CAN bus interface) can be used. If unused, pins should be left unconnected.

4.9.2 Serial communication interface

Mitochondrik is equipped with one serial communication interface (UART). It can be used to communicate with the device using proprietary binary serial protocol Popcop[9]. This interface does not require external components if the external logic is compatible with 3.3 V or 5 V. But due to low noise immunity of the UART interface it should mainly be considered as a configuration interface and should not be used for control purposes in high power applications. If the UART interface is exposed outside of the ESC, some TVS protection is highly recommended. Please refer to the application scheme 4.7. Serial port settings are specified in the table 4.5.

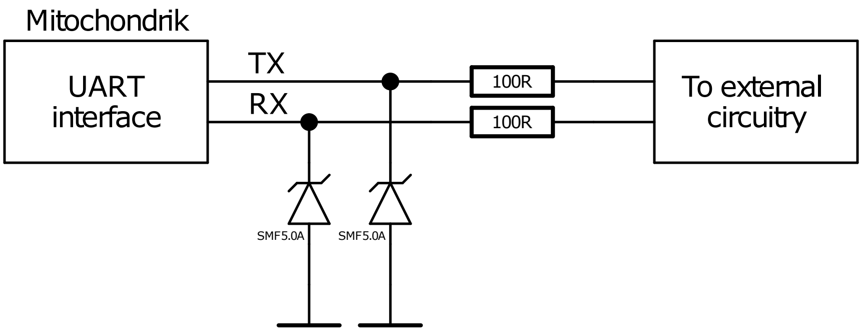


Figure 4.7: Serial interface implementation example

Table 4.5: Serial communication settings

Symbol	Parameter	Value	Unit
	Baud rate	115200	bps
	Data bits	8	
	Parity check	No	
	Stop bits	1	

4.9.3 USB interface

Mitochondrik has one USB interface and acts as a USB communications class device. Once connected to USB host it will enumerate as a serial port that can be used to communicate with the device using a proprietary

[8] Refer to https://uavcan.org/Specification/8._Hardware_design_recommendations/.
[9] Refer to https://github.com/Zubax/popcop.

binary serial protocol Popcop. It is well known that the USB interface may malfunction in a noisy environment of a power drive controller, hence it is recommended to use USB as a configuration interface. In case it is exposed outside of the ESC, some TVS protection is highly recommended. Please refer to the application scheme 4.8. It should be noted that values of series resistors on USB data lines should be kept low (<10 Ω) as any substantial resistance on these lines degrades signal integrity and leads to interface malfunction.

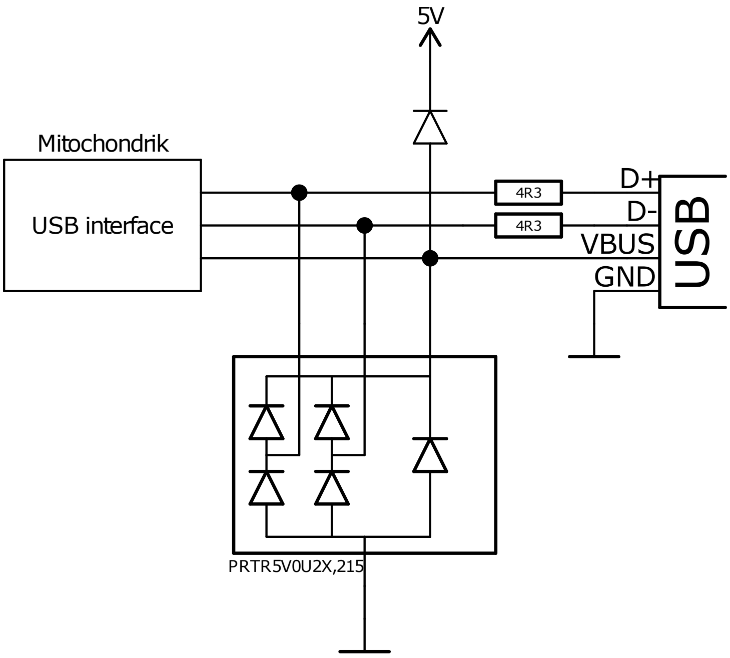


Figure 4.8: USB interface implementation example

4.9.4 RC PWM interface

Although RC PWM may be considered an outdated interface due to its analog nature that makes it both pretty slow and prone to errors caused by electromagnetic interference, it is still probably the most widespread ESC interface in the industry. It is possible to use it with Mitochondrik directly without the need for any type of interface converter. It should be connected to the **GPIO1 pin** of the Mitochondrik and then enabled and configured in the firmware. In case it is exposed outside of the ESC, some TVS protection is highly recommended, as shown in the figure 4.9.

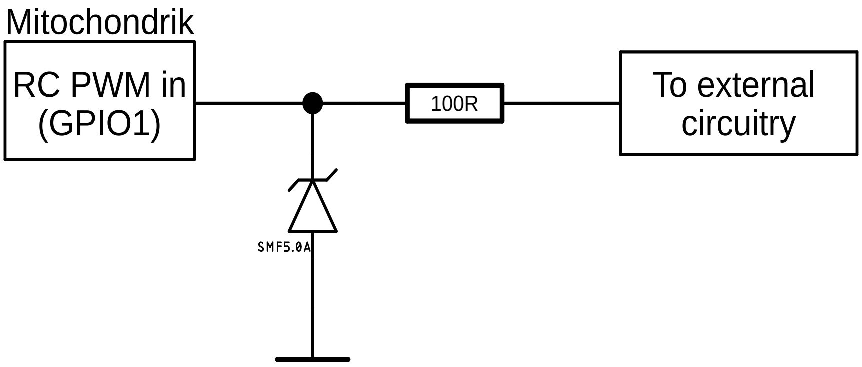


Figure 4.9: RC PWM input implementation example

4.10 Miscellaneous signals

4.10.1 Power stage temperature sensing

Mitochondrik constantly monitors the power stage temperature. For reading power stage temperature analog sensor connected to pin **TEMP_SENSE** is used. The sensor should be placed as close to power transistors as possible. Or at least it should be thermally coupled with transistors. To achieve the best performance MCP9700T-E/TT sensor is recommended. A typical application scheme is shown in the figure 4.10.

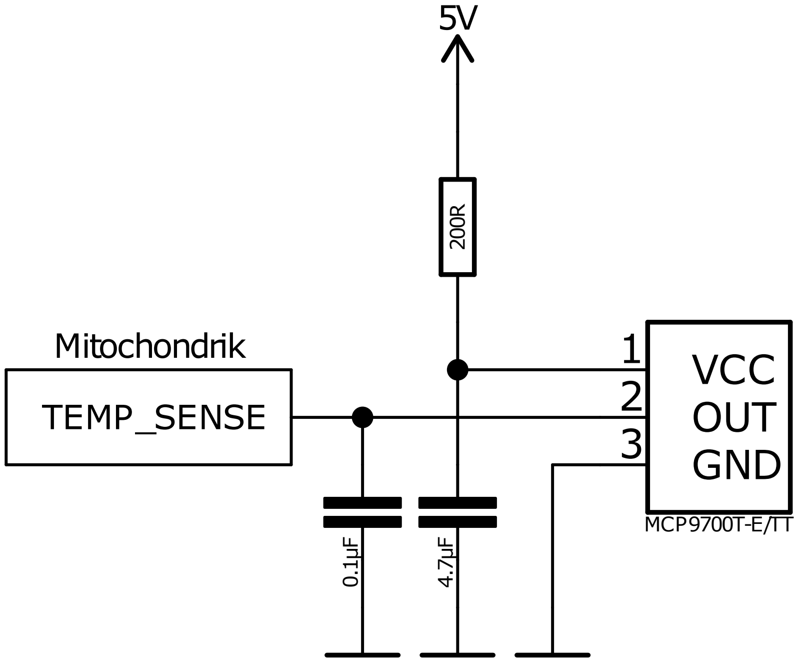


Figure 4.10: Recommended power stage temperature sensor scheme

4.10.2 Current amplifier gain setting output

This signal is available at pin GAIN_OUT. The main purpose of this pin is to indirectly report phase current magnitude as Mitochondrik has automatic current amplifier amplification factor control. This is the open-drain pin with internal weak pull-up to 3.3 V.

Table 4.6: GAIN_OUT pin logic state description

Logic state	Description
0	Current amplifier works in high gain mode, which means phase current is on the lower side
1	Current amplifier works in low gain mode, which means phase current is on the higher side

This pin should be mainly used for debugging and indication purposes. If unused, it can be left unconnected.

4.10.3 Low-power mode

Mitochondrik supports low-power mode, which can be used in applications where ESC complete shutdown is needed for power saving reasons. In this mode, the embedded DC-DC converter is disabled, all interfaces and gate drive circuits and therefore the inverter are turned off. This mode can be activated by pulling PWR_EN_IN pin down. In order to turn the Mitochondrik back on the PWR_EN_IN pin should be released. PWR_EN_IN should only be connected to open-drain type outputs, as shown in the figure 4.11. Max voltage on the PWR_EN_IN pin is 3 V. If not used, it can be left unconnected.

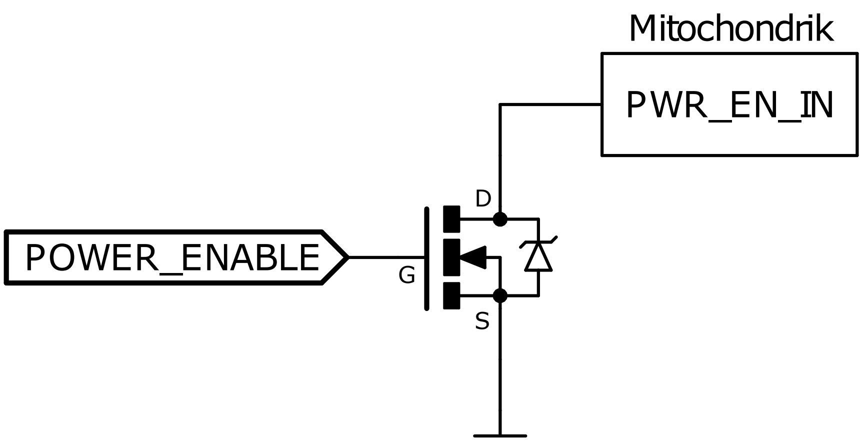


Figure 4.11: Power control implementation

4.10.4 Power stage activity status indication

This signal is available at pin EN_GATE_OUT. When this pin is logic low the MOSFET driver embedded into Mitochondrik goes to a low power sleep mode. This pin can be used to monitor periods of Mitochondrik motor operation activity. If unused, it can be left unconnected.

5 Quality assurance

Every manufactured Mitochondrik module undergoes an automated testing procedure that validates that the device is functioning as designed. The test log for every manufactured device is available on the web at `https://device.zubax.com/device_info`. This feature can be used to facilitate the traceability of purchased devices and provide additional safety assurances.

Every manufactured device has a strong digital signature stored in its non-volatile memory which proves the origins of the product and eliminates the risk of sourcing unlicensed or counterfeit hardware. This signature is referred to a Certificate of Authenticity (CoA). Look at Zubax Knowledge Base to learn more about the certificate of authenticity and how it can be used to trace the origins of your hardware.

6 Accessories

Accessories:

- 2mm pitch connectors.

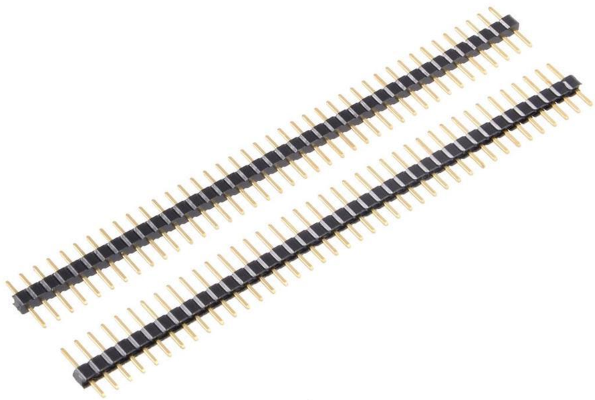


Figure 6.1: 2 mm pitch connectors

Please contact your supplier for ordering information.

7 Reference designs

To ease the process of development of new motor controllers using Mitochondrik, Zubax Robotics provides a set of open-source reference designs for different power levels. They are:

- Bloxa[10] – low power ultra-compact motor controller.
  - Continuous power output up to 200 W.
  - UAVCAN interface.
  - Compact design only slightly bigger than Mitochondrik itself.
- Sadulli[11] – an integrated drive for light drones (motor and controller are combined in one single package).
  - Continuous power output up to 500 W.
  - UAVCAN interface.
  - 4006 or 4014 type BLDC motor with up to 17-inch propeller.
  - Integrated motor temperature sensor.
- OpenMyxa[12] – medium power controller for the integrated drive.
  - Continuous power output up to 2.8 kW.
  - Doubly redundant UAVCAN interface.
  - USB interface.

[10] https://github.com/Zubax/Bloxa
[11] https://github.com/Zubax/Sadulli
[12] https://github.com/Zubax/OpenMyxa