BLACK SHIELD V2.X FOR OPENSCAN COMMUNITY

SHORT DESCRIPTION

The Black Shield is a Printed Circuit Board (PCB) for OpenScan devices. It provides convenience by simplifying the electronics part of the project. The shield unifies all electronics. It comes with power management for Raspberry Pi, driver slots, LEDs, and terminals for endstops.

REQUIREMENTS AND GETTING STARTED

For a full OpenScan device, the following additional components are needed:

- RPi 3B+ or more powerful (Pi Zero not sufficient/recommended)
- RPi-compatible camera
- USB-C PD charger 24W+ with **12V and 2A+** rating
- Nema17 motors of your choice
- For best compatibility, an RPi 4 with 4GB and IMX519, as well as a powerful, 65W single USB-C PD charger is recommended.

The whole shield comes in one piece with multiple sections connected via "mouse bites", which are break-away elements. *Carefully bend the board close to the mouse bites* without pressing on components of the board. The mouse bites should break with minimal effort. A flat plier or edge of a table helps in localizing the bend!

PRE-FLIGHT CHECK – WITHOUT RPI

Unfortunately, shipping companies are sometimes not careful with handling things, so the Black Shield comes with status LEDs, guiding users through a checklist to test for functionality. Please follow the pre-flight checklist for your Black Shield and PSU before fully assembling everything. **Without** installing the RPi, motor drivers and motors, connect the Black Shield to a PSU and switch it on:

1. Testing your USB-C PD PSU for 12V:
   a. *Ideal scenario*: you see **four bright green** LEDs. The Black Shield is powered with the correct **12V**. Continue with Pre-Flight Instructions.
   b. Four *dim* green LEDs. Your PSU delivers less than 12V, probably 9V. Probable cause is your USB-C PD PSU does not support 12V and uses 9V instead.
   c. Four LEDs are off, but a single Blue LED is on, then your USB-C charger is not using PD and only provides the standard 5V any USB port delivers.
2. Testing the DCDC functionality: The **single blue** LED is lighting up. The DCDC converter is working and running and is delivering **5V** to the RPi gpio header.

Input: 100-240V~50/60Hz 1.5A Max
Output:
USB-C1/C2: 5V⎓3A,9V⎓3A,12V⎓3A,15V⎓3A,20V⎓5A (100W Max) *port C1 and C2 are OK*
USB-C3: 5V⎓3A,9V⎓2.22A,12V⎓1.67A,15V⎓1.33A,20V⎓1A (20W Max)
USB-A: 4.5V⎓5A,5V⎓3A,9V⎓2A,12V⎓1.67A,20V⎓1A (22.5W Max)
Total Output: 120W Max *C3 probably not OK*

Compatibility of USB-C PD charger is, unfortunately, an issue with "unorthodox" chargers. Fortunately, USB-C chargers come with functionality and voltages printed on them for all ports. Search for **12V** and the current rating behind to find the right port.

PRE-FLIGHT CHECK – WITH RPI

When your Black Shield passes the previous test, then it is ready to be installed onto the RPi. When switching on the Black Shield with RPi (SD card and motor drivers for initial test not needed), *a **single orange*** LED at the other end of the GPIO pin socket should light up, indicating that **3.3V** is delivered by the RPi to the Black Shield. Your Black Shield now has all voltage levels working – **12V**, **5V** and **3.3V** – and is ready to be used for your OpenScan Device.

MOTOR DRIVER INSTALLATION AND CONFIGURATION
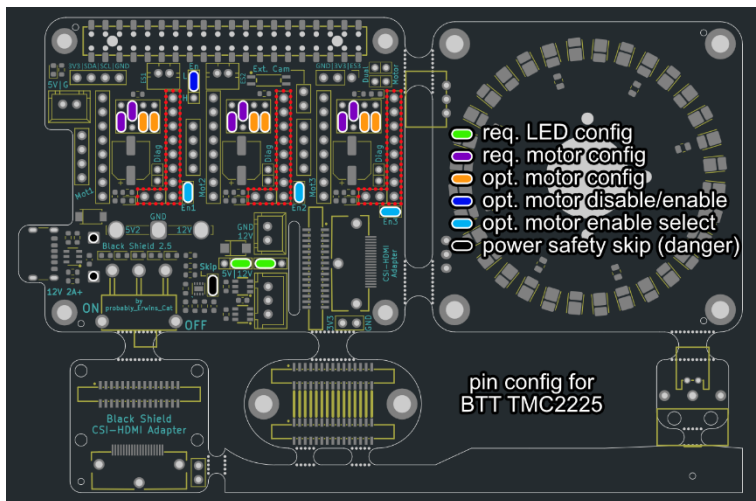
The motor drivers usually have color coded pin header, black and red for the TMC2225. They must be inserted with the correct orientation, see image above, red dashed line. The drivers also come with a tiny pinout, indicating the orientation.

The board needs minimal pre-flight setup. Motor drivers require configuration of "microsteps", purple-marked jumper positions. Current OpenScan software is

assuming **16** microsteps in standard configuration. **The user must install jumpers for MS1 and MS2.** For TMC2225, you can follow the provided configuration, as seen in the image: [**Low**, **High**, Low, Low] from left to right. This configures [**MS1**, **MS2**, MS3/UART, UART/SLP]. When using other drivers, please refer to their manual for microstepping. Some jumpers are optional and depend on the drivers used, i.e. *Enable* functionality and UART communication channel. I recommend installing also the optional drivers, because some firmwares/configurations require them (and also to not lose the left-over jumpers!).

LEDs also need a pre-flight setup for selecting the Voltage and functionality. The light provided needs 12V power line. The Black Shield also supports *NeoPixel* with 5V, however, not implemented in current firmwares.

The V_{ref} is set to a reasonably low value per default, 0.8V, as most OpenScan devices only require low torque for moving rotors and turntables. Large custom OpenScan designs might require higher torques. If you experience skipping in your motors, you can carefully adjust the V_{ref} and thereby the motor current and torque. Higher currents might require a stronger PSU.

<div style="background:#4a9fd4;color:white;text-align:center;">PHYSICAL ENDSTOP CONFIGURATION</div>

The Black Shield supports endstops. The rotor benefits from absolute coordinates the rotor endstop provides. For endstops (ES), there is a **recommended** way for configuration that the Black Shield follows:

- Endstop: wires attached to **COM/Base** and **NC** (normally closed) terminal
- RPI/circuit: Wires attached to GND and free GPIO pin (ES pin)
- ES pin configured as (internal) pull-up

This implementation triggers the endstop routine when *anything* breaks the circuit going from ES pin to GND or when something is wrongly configured/defect. This is a safety measure. *Normally*, the circuit is only broken when the microswitch is pressed, which triggers the endstop routine correctly.

The software is agnostic where the endstop is located and which the rotor moves first. In the software, the user can set the minimum and maximum angle for rotor movement, defining the coordinate system *after* the endstop routine is triggered. Further the motor movement direction can be set. The user must try out whether the maximum or minimum angle is the assumed position of the endstop and in which direction the rotor is moving. *Unfortunately, this step involves trial and error depending on the firmware/software you are using.*

## MOTOR DRIVER CONFIGURATION – UART (FUTURE SOFTWARE ONLY)

RPi can alternatively communicate via UART with drivers for configuration. At the current state, only a development branch of Composer can use UART. However, future firmware, OpenScan3, will include modularized software and UART support. The Black Shield already includes all hardware requirements for UART.

Under UART, MS1 and MS2 will not configure microsteps, but the UART address, i.e. two drivers *must not* have the same address. Remove the optional jumper from position 3 and 4 to enable UART communication. Use jumpers on positions 1 and 2 to give each driver a unique address, e.g. [L,L], [L,H], [H,L] and [H,H].

If the user uses virtual endstops, i.e. sensorless homing, then the physical endstops *must be unplugged* from the Black Shield, since the *physical* and *virtual* endstop share the same GPIO and would interfere with each other! Add a jumper to the DIAG header. The RPi can now read out the driver, needed for sensorless homing. A small red LED will indicate when the sensorless homing routine is triggered.

GPIO CONFIGURATION

Community-driven Firmware *Meanwhile* or *Composer* are recommended for the Black Shield, as there are already pre-built configurations provided. Future software "OpenScan3" will follow. In those firmwares, you must go to *Settings* and select the shield version you have, i.e. *Black Shield*. All settings will automatically be applied. After rebooting, most devices will work without further interventions. Note, the software assumes you are using motor slot "Mot1" for the rotor, and "Mot2" for the turntable.
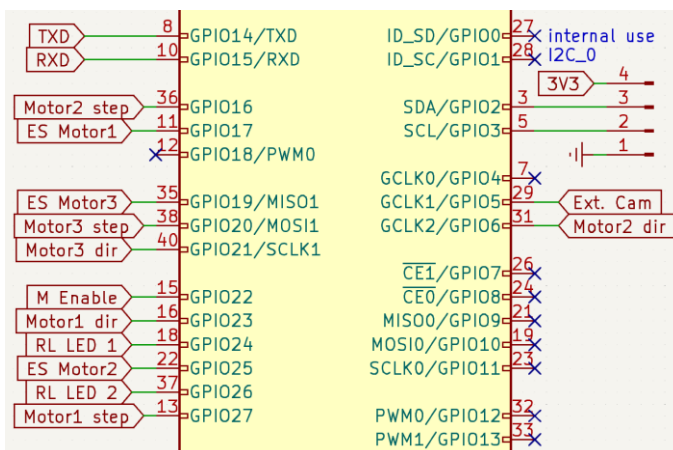
When using other firmware, the GPIO must be manually configured. You must enter the GPIO of the official Black Shield schematics into the (advanced) settings of the firmware of the corresponding functions, e.g. rotor direction, rotor step, LED On/Off, and so on. Please see the pinout of the schematics or documentation.

GEAR CONFIGURATION, STEPS PER FULL REVOLUTION

Every OpenScan device uses a stepper motor to rotate a shaft/gear that rotates a turntable or rotor. *The software is agnostic about the de sign details of the Scanner at first*, so the user must manually configure parameters like gear ratio and steps per full rotation, so that commands like "move rotor by +15°" is translated properly into the correct number of microsteps "move gear by 1707 steps".

This configuration is already included in *Meanwhile* and *Composer* and is automatically updated when selecting the Black Shield in the configuration. In the case of updates of the CAD design or software, those parameters can vary slightly, so it is always a good idea to double check the pre-configured values with the recommended.

For custom scanners: To calculate the number of microsteps per full rotation, the user must know the number of gear teeth of the two meshing gears, resulting in the gear_ratio of (large:small gear). The microsteps per full rotation can then be calculated [e.g. for Mini]:

$$\text{steps\_per\_rotation} = 200 \cdot \text{microstepping}[16] \cdot \text{gear\_ratio}[128/10]$$

MOTOR PINOUT – AABB, ABAB, ABBA

Stepper motors come with 4 (rarely with 6) pins split up in 2 pins per coil. Unfortunately, the nomenclature of those pins, their coloring and pairing is not really standardized. A messed-up pin order is not the end of the world but will prevent your motors from working properly. Your motor, when connected to the shield, will most likely work out-of-the box but not guaranteed. If you are unlucky, the motor will make a buzzing sound due to wrong pinout. In case, follow this re-pinning guide:

- The shield expects a pairing of AABB for the coils A and B.
- Switch the pins **2** and **4** while the device is off. Either you transformed A**B**B**A** to A**A**B**B** (yay), or A**B**A**B** to A**B**A**B** (nothing changed)**.** Test again.
- If still buzzing, switch now pin 2 and 3. You transformed A**B**A**B** to A**A**B**B**.

PRINTING THE PARTS AND ASSEMBLY

If this is your first device, just print the most recent version of V2 and skip this section. *Some parts come with integrated support structures that must be removed*.

While most parts are compatible between all versions of V2.X, some parts have small changes that partially interrupt inter-version compatibility. When you plan on upgrading, please check beforehand which parts must be reprinted. All printable files of all versions will stay available in the design GitHub of OpenScan.

You will find minimalistic assembly instructions in the GitHub repo. Due to incremental design changes, the provided images might not always correspond to your V2.X model but may be taken from a previous version 2.Y. Don't worry, the parts will look very similar, and every part has a *leading number in the file name, corresponding to the assembly step*.

Note, the Black Shield comes with **height adjustable GPIO header**! By carefully pushing and wiggling, you can slowly move the header up or down in the socket. Make sure the header sits properly on your Raspberry Pi before fully assembling the electronics compartment.
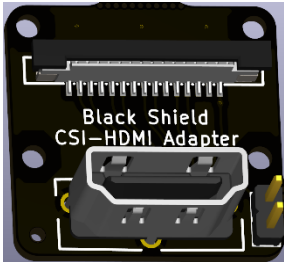
CSI CABLE EXTENSION

Whenever you are building a larger scanner, you will find typical CSI cables too short, e.g. the golden camera cables stop at 500mm length. This is sufficient for the Mini V2.X but the Midi needs approx. 650mm length for full range of the rotor. The Black Shields comes with dedicated CSI cable extension that screws to the base. This also makes routing the long flat cables slightly easier. Use the rounded head screws and nylon lock nuts.
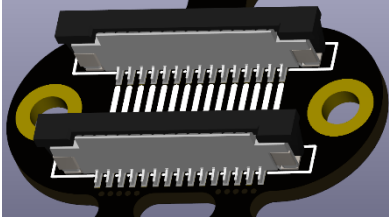
CSI-HDMI ADAPTER
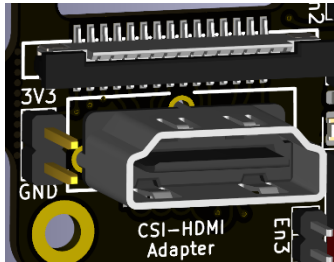
The Black Shield comes with an optional CSI-HDMI adapter. Your standard Mini or Midi does not need this adapter, but perhaps tinkerers will enjoy it. Very long flat flexible cables of the camera have poor signal integrity that might be needed in custom OpenScan devices of large size. HDMI cables have superior signal integrity. Thus, when transporting camera data a long way, you want to send it via HDMI cables instead of flat flexible cables. The CSI-HDMI adapter is pairing the data lines of the camera into the differential pairs of HDMI cables. Tests confirmed that you can transport camera

signals easily through 5-meter HDMI cables with IMX519. However, due to the plethora of camera models and signal pinouts, I cannot guarantee that the adapter will work for all camera models and could only test and confirm functionality with the usually used cameras.
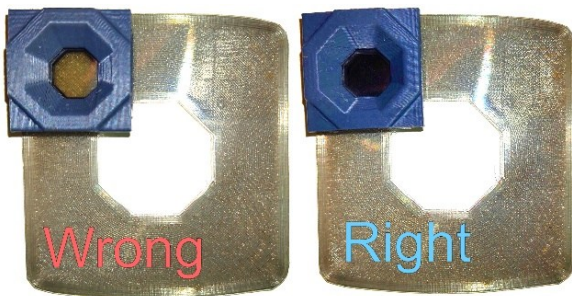
For the best image quality for photogrammetry, you want to suppress as many bright reflections as possible. This is done by illuminating *linearly* polarized light onto objects and only capture 90°-rotated light, e.g. *vertically* and *horizontally* polarized light. The light that can pass two polarizers depends on the angle between the polarization axes. An angle of 90° results in virtually no light passing, see right image. Look through **both** polarizers and check that no light passes. If so, then this relative orientation of both polarizers is the 90° polarization configuration.

Use the optional printable cutting guide and a sharp blade.

Polarizer for Camera: One small sheet must be inserted to the tiny slit of the camera eye piece, blueish piece above. *Non-adhesive* should be used here. You can use the cutting guide to cut out the rectangular center piece of sheet of polarizer foil. Afterward, cut out the hexagonal center piece for the next step.

Polarizer for Light: If you are using *non-adhesive* foil (contained in the kit), you must sandwich the foil between the assembled imaging unit and the polarizer hood. Alternatively, use a droplet of CA glue and glue it on the polarizer. If you are using *adhesive* foil, you can trim the foil to the size of the diffusor, and glue it on, see image above. The cutting guide comes with both outlines.

Don't forget to remove the protective films and prevent fingerprints! Both can influence the polarization and reduce image quality significantly!

WARRANTY CLAIMS AND SUPPORT

Please be aware this is a DIY project, and I cannot take responsibility for damaged devices when not handling carefully. Currently, less than 3% of users reported (partially user-caused) damage and most of them were minor issues, like one of the many LEDs of the ring light being dead. I try to help with replacing parts as conveniently as possible (even in user-caused damage) if necessary. While the Black Shield is simple enough constructed that I have all the tools, can repair damages, and replacing components, this does not mean that every user has and can (or want). Thus, I offer a limited replacement service, where the user sends back a damaged shield, and I send back a new shield. Up to now, I could repair all (user-caused) damage. To keep e-waste to a minimum, repaired shields are then sold at a discount for tinkerers.

AVAILABILITY OF SCHEMATICS

The schematics for all versions of the Black Shield are always available on discord as PDF for future references. The schematics will also be added to the updated official OpenScan documentation. For educational purposes and support for tinkerers, I added many comments of essential and optional parts. With that, anyone with basic knowledge in KiCAD or similar can develop and improve on my design. However, I reserve the right to *not* share the Gerber files *publicly* with any anonymous person to protect the project and community from copycats, i.e. aliexpress...

KO-FI SUPPORT

The Black Shield is currently only produced in small quantities. To provide the Black Shield to more users and continue the support and integration of more features, financial support would be greatly appreciated. If you consider yourself a frequent user of photogrammetry, I would appreciate one-time or monthly donations under:

https://ko-fi.com/probably_erwins_cat

This helps separating the production and sale cost of the Black Shield from the prototyping, development and inventory costs in the future as much as possible, so future Black Shields and accessories can be developed independent of sales price and potentially can be provided less expensive in the future. For questions and support, you can write to me on various platforms, GitHub, Discord and Ko-Fi:

probably_erwins_cat