How to get stable I2C and CAN connection

In this guide, our team will provide universal methods for protecting data buses from interference and approaches for quickly assessing bus functionality.

We live in a world saturated with millions of various radio signal sources, both natural and artificial. Any radio signal, given favorable conditions, can induce an electric field in any conductor. It is important to note that any conductors capable of carrying electrical current can act as either receivers of interference or emitters of interference (if current is present in the conductor). Some interference is insignificant and does not affect device operation; for example, it may be below the data bus frequencies or significantly above them. However, when multiple devices are located nearby and their data bus frequencies coincide, they can negatively affect each other, leading to degraded performance or even complete failure.

A commonly used method for protecting digital signals from external interference or shielding signals from interference generated by others is shielding individual functional blocks on the printed circuit board, individual conductors in a cable, or the entire cable. Radio interference can disrupt the operation of digital circuits not only through digital channels but also by propagating through power lines.

In the case of shielding individual wires or the entire cable, it is crucial to properly connect the shielding braid; otherwise, the data transmission quality may be reduced. The braid density impacts performance, and in addition to shielding sleeves for covering cables, there are pre-assembled cables with specified braid density typically listed in the product specifications.

There are numerous methods available to protect the power lines of devices containing both digital and analog functional blocks. These methods include, for example, the use of separate power supplies, filter circuits and their assemblies, variations in the topology (design) of the printed circuit board, and the materials used for the printed circuit board that prevent interference from passing between blocks or from external sources.

In a typical mobile stabilization system, the primary power source is a rechargeable battery (RB) or the onboard power supply of the carrier. However, due to mismatched permissible voltage levels, additional DC-DC converters are required. It is essential to carefully select the DC-DC converter, choosing a switching frequency that does not fall within the frequency range used for the device's operation. Simple and inexpensive DC-DC converters can generate interference at various frequencies, "polluting" the overall power supply from the RB or the carrier's onboard network, emitting interference through individual components or stages, which can be critical in densely packed device layouts. Additionally, they may transmit interference received on the incoming/outgoing power cables through themselves or reflected interference from other devices.

The SimpleBGC32 stabilization system utilizes I2C and CAN buses for communication with external modules. During the design of the gimbal or in the testing phase, if data transmission issues arise, the controller may begin to count errors. With a low number of errors, the stabilization quality may decline, whereas a high number will cause the gimbal to stop functioning and report problems. The I2C error counter is always visible in the information field of the GUI under the WRITE button. The CAN and I2C counters can be viewed on the Debug tab → Request state.

Standard methods

Let’s take a closer look at popular methods for interference protection on various data cables. Currently, the market offers a wide range of components for cable devices that significantly enhance noise immunity without incurring substantial costs.

The appropriate method heavily depends on the frequency of the interference affecting operation. If it is not possible to determine the frequency, several methods should be tested.

Ferrite ring and bead

The most commonly used type of filtering device is the repeated threading of individual wires or the entire cable through a ferrite core. Fixing beads onto the finished cable using additional fasteners is also a suitable option.

The effectiveness of this method depends on:

– The selection of the material from which the filter is made; it is essential to carefully review the manufacturer's specifications;

– The density of the wire's layout against the surface of the ferrite core. Thick insulation or loose winding adversely affects the performance of the filtering device. After winding, it is necessary to secure the wire and the position of the core (as described below) using heat-shrink tubing, nylon ties, adhesive compounds, etc;

– The placement of the filtering device on the cable. It is essential to position the filtering device at one end of the cable, closer to the source of interference. In some cases, particularly with long cables, the use of two or more filtering devices on a single cable may be required. In cases of significant noise within the cable or in the environment through which the cable is routed, ferrite boxes, tubes, and other devices are also used;

– If the cable is custom-made for a project, it may be worth considering compact ferrite cores with multiple holes (e.g., Choke with Six-Hole Ferrite Core), through which individual wires or a group of wires can be threaded before terminating with connectors or contacts.

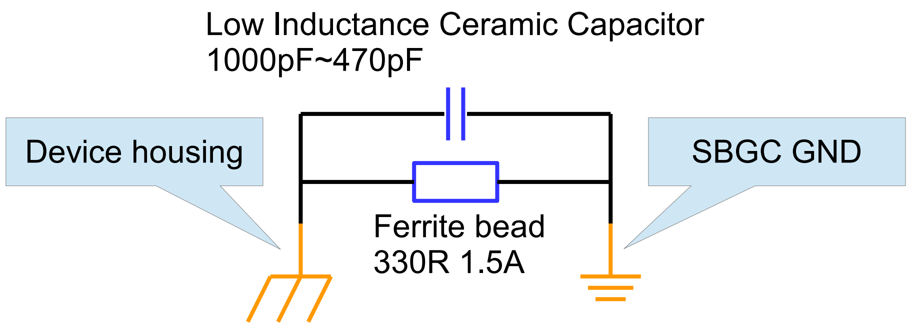
Shielding braid (sleeve) of the cable

Another commonly encountered type of cable protection from interference is the use of shielded cables with a shielding layer inside or a shielding sleeve made of conductive (high magnetic permeability) materials, such as copper, aluminum, etc.

The effectiveness of this method primarily depends on the connection point of the shielding braid to the device's chassis or a common wire. The number of connection points and the choice of where to connect the shielding braid are usually determined based on the installation conditions and the application of the device and its components. It is generally recommended to connect the shielding braid to the device's chassis or to a specially routed bus for this purpose. The connection must be of the highest quality and provide a reliable electrical contact.

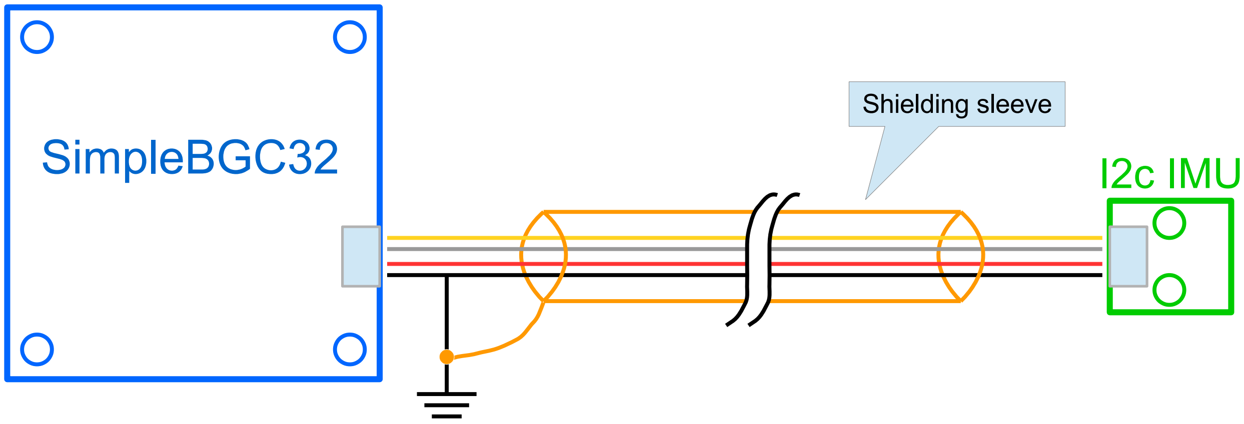
Standard controllers such as the SimpleBGC32, Pro controllers, and CAN MCU have metallization in the mounting holes of the printed circuit boards, but this metallization is not connected to the controller's circuits. Controllers may operate under various conditions, and the device chassis can be "polluted" by numerous interferences.

When it is necessary to connect the controller's common wire (GND) to the device's chassis, this should be done at a single point using a common solution:

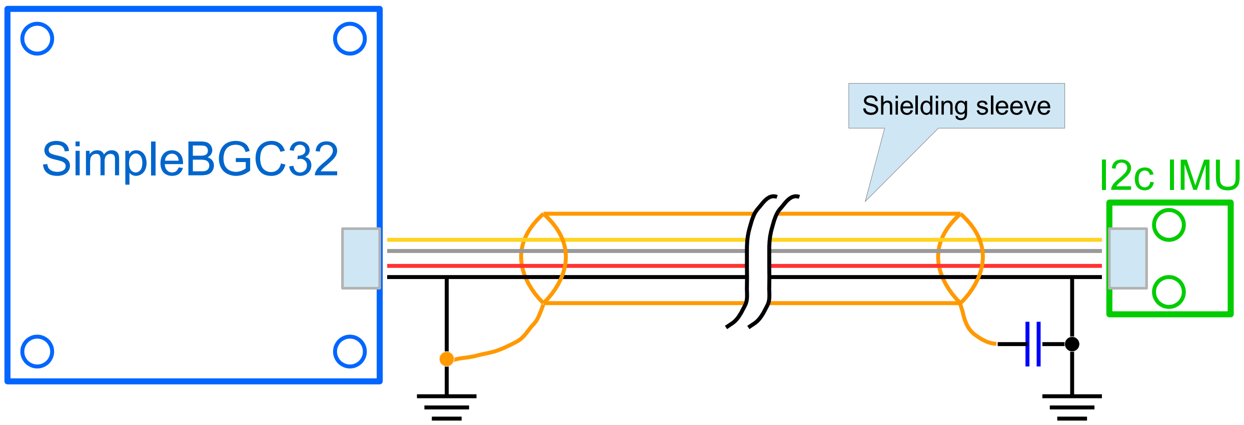


If the device's chassis is not made of conductive materials or if such requirements are not necessary, the shielding braid can be connected to the common wire (GND).

Typically, potential sources of interference are considered. If the interference frequency is below or approximately equal to 1 MHz (see the illustration below for an example of cable shielding for I2C IMU), the shielding braid should be connected to the common wire only on one side, at the signal source. Connecting the shielding braid at both ends creates a closed loop that acts as an antenna, and the current flowing through the braid will be a source of active interference. Additionally, if there is a significant distance between the connection points (usually when the cable ends are far apart), a potential difference may arise at the connection points due to stray currents (electric fields of natural and artificial origin), leading to interference in the conductors running inside the braid due to mutual induction. An explanatory illustration is provided below.



If the interference frequency exceeds 1 MHz (see Figure B), the inductive resistance of the shielding braid increases, and capacitive coupling currents create a significant voltage drop across it, which is transmitted to the conductors inside the cable through the capacitance between the braid and the conductors. Moreover, if the length of the cable is comparable to the wavelength, the antenna effect significantly increases the interference current on the braid. Therefore, in this case, the shielding braid should be connected to the common wire not only at both ends but also at regular intervals along the entire length of the cable. In finished devices, challenges may arise with multiple connection points; additionally, a return current may begin to flow through the braid, similar to an auxiliary common wire. Thus, it is recommended to use a ceramic capacitor of small value with low inductance for the second connection point, in the range of 100 nF to 1 nF. Many manufacturers of radio components offer special series of filtering capacitors.

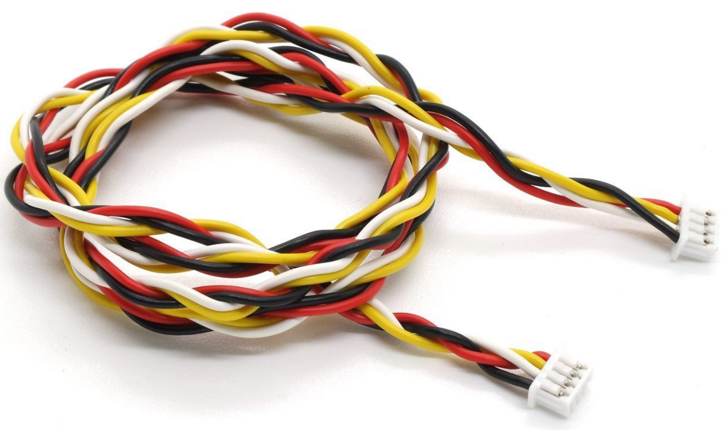


It is also important to consider the quality of the device's chassis or common wire and its immunity to interference from other devices. If several circuit boards (modules) are connected to the device's chassis or common wire, it may lead to the creation of a "dirty ground." The most preferred method is to connect multiple circuit boards to the common wire at a single point.

Additionally, the density characteristics of the shielding braid should be taken into account. If a separate shielding sleeve is used, it must be appropriately sized (according to the diameter of the cable inside); excessive stretching of the sleeve can create gaps in the braid and reduce its effectiveness. Cable manufacturers may use various types of shielding braids, which can have solid and non-solid structures, as well as different materials for the braid itself. Carefully review the specifications for the cable.

Separation or twisting of wire groups in the cable

Cables for high-speed data transmission often have twisted wire groups. This method is also suitable for our system, but it is necessary to study the cable's construction, pairing, and twisting density. An example of a cable with twisted conductors and twisted groups of conductors is shown below:



Use of signal level converters

Intermediate devices may be used to boost data signal levels between cables. Two or more such devices are required if multiple devices need to be connected. External power, compatible with the device, is necessary for proper operation.

Below, recommended methods will be listed for each type of connection.

The I2C connection

In our system, the I2C connection operates at a frequency of 400 kHz, and when the "I2C high speed" option is enabled, the frequency increases to 800 kHz.

General recommendations for routing the I2C bus in the stabilization system:

- Do not route near potential sources of interference: power cables, motor cables and high-speed communication lines of other devices (if the cable is unshielded);
- When routing lines through slip rings, check the resistance of the lines passing through the slip ring in both static and dynamic conditions before use;
- Close placement of lines in the slip ring may cause interference. Carefully examine the arrangement of lines in the slip ring before assembling the device, and alternate the lines accordingly, for example, separating signal lines with power wires from motor power lines. There is no exact working layout; it is best to select a compatible option for the specific device;
- Check the quality of the cable before routing, whether it is a pre-made cable or a self-assembled one. Measuring the electrical resistance from the connector pin to the terminal on the opposite side allows for a quick assessment of the contact quality between the wire strands and the metal contact;
- If I2C devices from third-party manufacturers, such as IMUs, magnetometers, etc., are used, it is important to ensure that the SDA and SCL lines are pulled up to +3.3 V like in our devices;

The most commonly used methods for reducing noise affecting the operation of the I2C bus or I2C cable include:

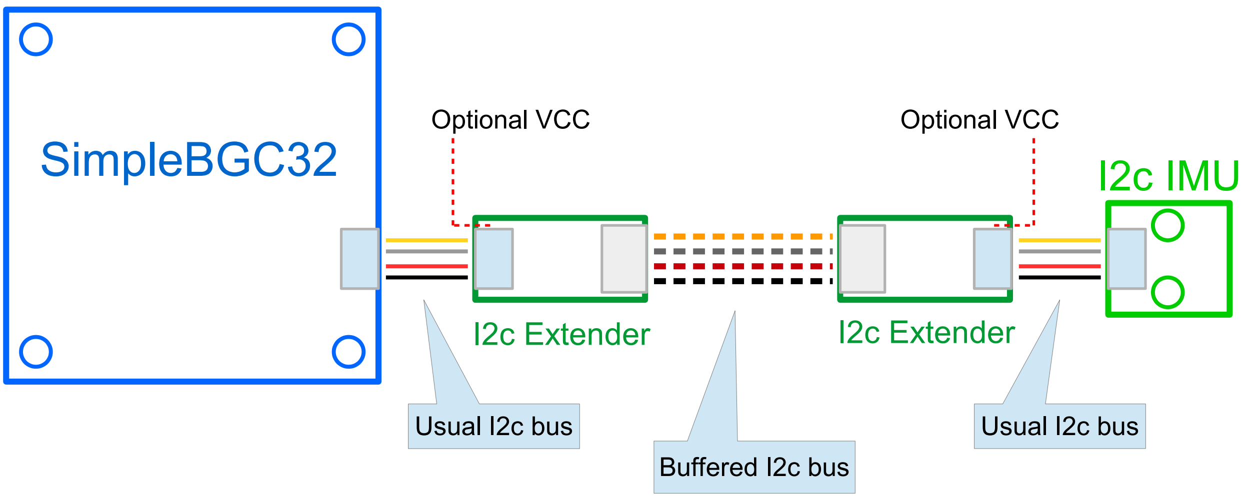
- Add ferrite rings to the motor cables, one for each three-phase cable. The cable should be threaded through the ring several times, and the ring should be positioned as close as possible to the connector on the controller board. Secure the position of the ring and the cable on it;

- For I2C lines, use a shielded cable (with an internal shielding layer) or a shielding sleeve (made from conductive materials such as copper, aluminum, etc.). The connection methods are described in the "Standard Methods" section;
- For the battery, use a shielded cable (with a shielding layer inside) or a shielding sleeve (made

from conductive materials, such as copper, aluminum, etc.). The same connection methods as those for signal cables are applicable;

- A ferrite ring can be placed on one or both sides of the I2C cable. It helps mitigate interference if the cable is of considerable length. Intermediate rings can also be used near the slip ring. This method works effectively in conjunction with other methods;
- Add some spacing between SCL and SDA by twisting SCL with the GND wire and SDA with the VCC wire. Two to three twists over 10 mm of wire is sufficient. This method also works when routing I2C lines through a slip ring and is suitable for routing lines alongside power lines;
- Replace the pull-up resistors on the side of the endpoint device, usually the I2C sensor. Factory-installed resistors are typically 3.3 kΩ; it is recommended to replace them with 2.4 kΩ or even 1.8 kΩ. It is essential to check the signal waveform with an oscilloscope. The signal edges and slopes on the oscilloscope should be sufficiently steep;
- Use our I2C Extender. The module enables stable communication via I2C between remote devices. Two devices create an interference-resistant I2C bus between them. Another device is required for connecting to this bus.

It is possible to use a pair of modules to optimize the operation of a device that is maximally distant from the controller board. The illustration below depicts the operational principle using the example of connecting an IMU sensor to the SimpleBGC32 controller with the help of a pair of I2C extenders.

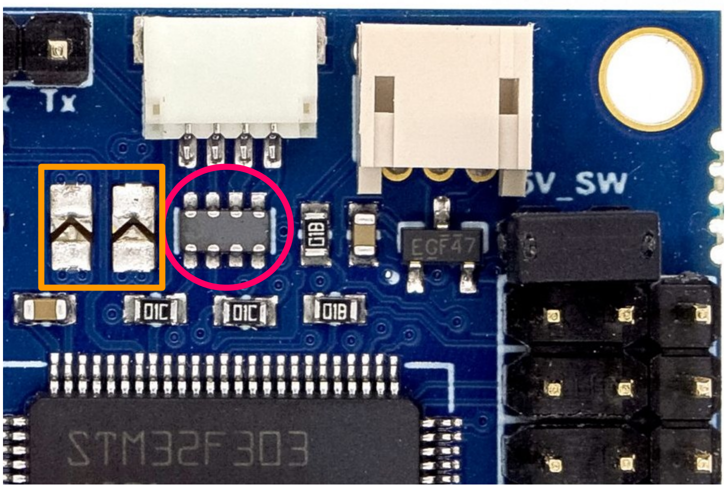


Checking the I2C connection

First of all, the I2C bus utilizes a parallel connection of devices, and device addresses prevent data streams from different devices from getting mixed up. Not all devices have manufacturer-defined addresses. It is essential to verify the correctness of the selected address for the connected device, especially for IMUs and encoders. After this verification, it is recommended to read and check the bus for functionality.

Methods suitable for quickly checking the I2C connection between devices:

- Visual inspection of the cable from connector to connector. It is necessary to check the integrity of the insulation and the conductive wires. If mechanical connections are made by twisting the conductive wires, they should be replaced with soldered connections. Insulate and protect the solder joint from bending, considering that after soldering, the conductive wires lose their flexibility, and the transition area from rigid to flexible can be easily damaged;
- Checking the quality of the connectors on the PCBs of the connected devices. The pins in the connectors should provide a good electrical contact, and the housing should be securely fixed;
- Checking the power lines: the VCC line should supply the voltage level that is as close as possible to the required specifications. In our system, +5 V is used to power the devices, with pull-up resistors connected to 3.3V for SDA and SCL. The GND line should have as low a resistance as possible;
- Checking the circuit from the processor to the connector, either visually or with simple tools. In our devices, the master device (stabilization controller) includes an inductive filter BLA31BD601SN4D between the microcontroller ports (as well as +5 V and GND) and the connector, indicated by a pink oval. The filter has a limit of 100 mA per channel and may fail if this limit is exceeded. For higher power consumers, use separate +5 V and GND pins on the controller or solder the contacts (orange rectangle) to bypass the filter, which may require external filtering;



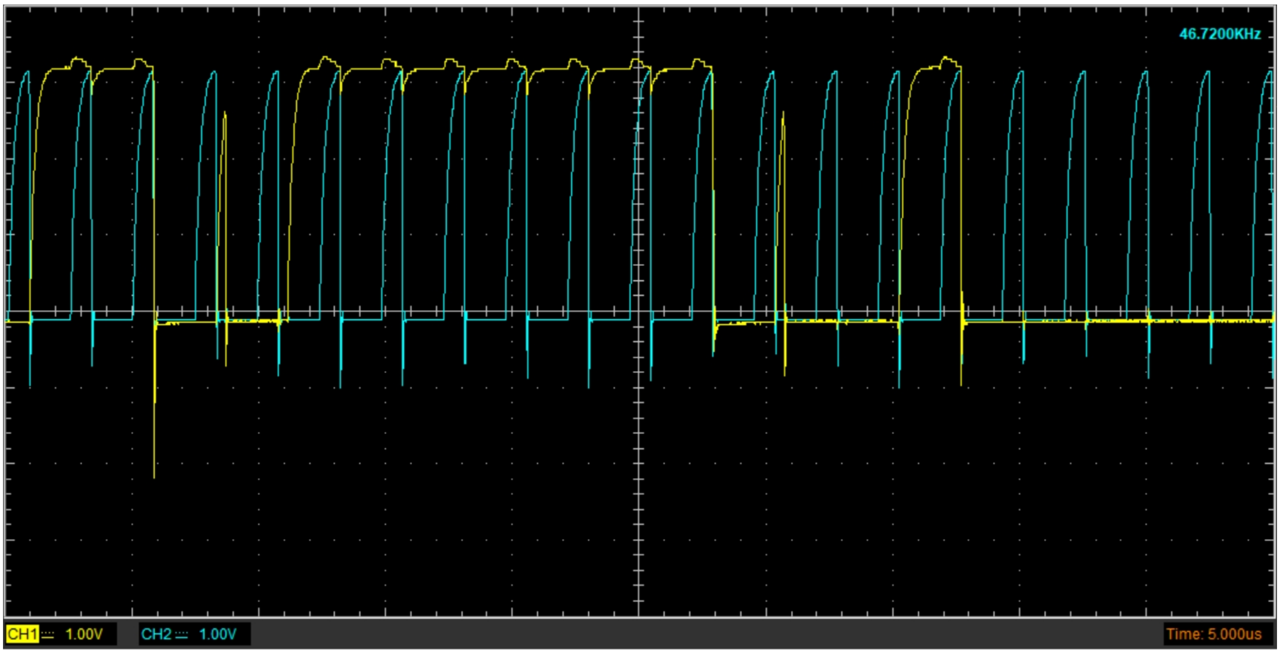
- Control of the signal shapes for SDA and SCL using an oscilloscope. This requires knowledge of how the I2C bus operates and experience in using the instrument;

– An example of the I2C signal waveform when connecting devices with a standard cable is shown below. The colors of the graphs correspond to: yellow for SDA and blue for SCL.

  The graphs show the ringing at the base of the pulses and the flatness of the rising edge - such factors affect the shape of the pulse, and an incorrect pulse shape can lead to data reading errors.

  In practice, it is difficult to achieve perfectly rectangular pulses in real working devices, and the shape inaccuracies are taken into account during the design of both the hardware and software environments.

  This method helps determine the completeness of the pulse; the pulses should be clearly defined and should have a consistent amplitude, approximately corresponding to 3.3V.



– Testing a device or group of devices on known functional equipment is the simplest and most obvious method when there are multiple identical devices available. This allows for different connection and grouping configurations to identify the faulty equipment. However, without reviewing the previous recommendations, connecting faulty equipment to functional devices may risk damaging the operational equipment as well.

The CAN connection

The SimpleBGC32 system utilizes a proprietary CAN protocol, with the CAN bus operating at a frequency of 2 Mbps.

General recommendations for routing the CAN bus in the stabilization system include next:

- The CAN bus is more resilient than I2C, however, it is still advised to avoid routing signal lines near heavily loaded power cables, motor power cables, and high-speed data transmission lines (especially if they lack protective shielding);
- The CAN bus in our devices operates through a CAN transceiver, which has a minimum power supply voltage threshold of 4.5 V. Therefore, when using a long cable, a non-original cable, or when the endpoint device is powered from a separate power source, ensure that the CAN transceiver receives a voltage of at least 4.7 V. During intensive data transmission, voltage levels near the threshold can also cause operational issues;
- Our original cable for CAN devices features twisted pairs of wires — VCC and GND, along with CAN H and L — twisted at a frequency of one twist per 10 mm. Both groups are twisted in opposite directions at a frequency of one twist per 15 mm. It is strongly recommended to use the original cables. If using a third-party cable, ensure that it has a similar wire twisting configuration;
- Before installation, verify the quality of the cable, whether it is pre-assembled or self-constructed. Measure the electrical resistance from the pin of one connector to the pin of the other connector. This will allow for a quick assessment of the contact quality between the wire conductors and the metal contacts;
- The H and L signal lines form a differential pair, and in some cases, to save on wiring or lines in a slip ring, it is sufficient to route only the CAN bus signal lines.

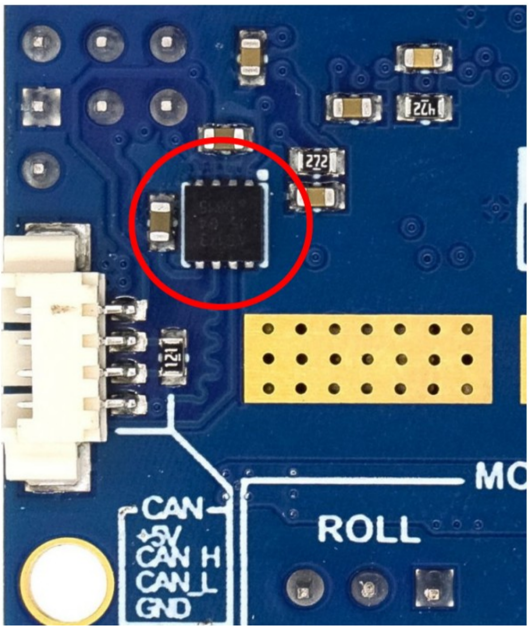
Methods to reduce noise levels affecting the operation of the CAN bus:

- The CAN bus is quite noise-resistant, but proper operation requires the use of twisted cables, such as the original CAN cable or a similar one from third-party manufacturers. Twisted cables are an effective method for combating interference from external sources;
- Cable shielding also enhances protection against high-energy induced interference, which twisting the cable conductors alone cannot mitigate;
- SimpleBGC32 controllers equipped with a CAN bus feature a split CAN terminator on their side, consisting of two 60 Ω resistors with a capacitor. This design helps prevent reflections and filter out noise. On the module side, such as with the CAN IMU, a standard 120 Ω terminator is used. If the device is a terminal device, it's essential to solder the terminator jumper to enable its functionality;
- Adding a common mode choke after the CAN transceiver and before the cable increases resistance to common-mode signals, which in a differential communication line are considered interference.

Checking the CAN connection

Devices on the CAN bus can be connected to the main controller in a daisy-chain, star, or mixed configuration. Like I2C bus devices, they also require assigned addresses, which can be set either mechanically (e.g., as with CAN DRV) or programmatically. Once the device address is selected, the devices begin operation. However, if errors occur, the following recommendations for testing the connection are provided:

- Some devices, such as the CAN IMU, have a terminator jumper that should only be soldered if the device is the last in the bus;
- Visual inspection of the cable from connector to connector is essential. The integrity of the insulation and conductive cores must be checked. If mechanical connections are made by twisting conductive wires, they should be replaced with soldered connections. It is important to insulate and protect the solder joint from bending, considering that after soldering, the conductive wires become inflexible, and the transition area from rigid to flexible can be easily damaged;
- Inspection of the quality of connectors on the boards of connected devices is necessary. The pins in the connectors must provide a reliable electrical contact, and the housing should be securely fastened;
- Testing on known working devices is crucial. If multiple identical and compatible devices are available and the previous steps did not accurately identify the fault, the equipment can be connected and grouped in various configurations to isolate the faulty unit. The device processors are connected to the CAN bus through CAN transceivers, which will mitigate unwanted effects from malfunctioning devices;



- On connected devices, if an oscilloscope is not available, the average voltage can be measured with a standard multimeter: approximately 2.7 V for CAN-High and around 2.2 V for CAN-Low. This method is suitable for quickly identifying faults in the bus;
- Check the power supply to the CAN transceiver (highlighted in red), which is typically located near the CAN connector and features a termination circuit composed of resistors and capacitors. The transceiver is powered by both +3.3 V and +5 V supply lines, and both voltage levels are crucial for proper operation. Voltage levels can be checked at any pins on the controller. If the +5 V supply drops below +4.5 V, the transceiver will stop functioning;

– Control the signal shapes of CAN High and Low using an oscilloscope. This requires knowledge of how the CAN bus operates and experience with the equipment. This method helps determine the shape and completeness of the pulses, which should be clearly defined. Using two channels of the oscilloscope allows for a quick assessment of the quality of the differential signal: both signals should mirror each other without offsets and incomplete amplitude. An example of the CAN signal waveform when connecting devices with a standard cable is shown below. The graph colors correspond as follows: CAN High is represented in yellow, and CAN Low is represented in blue.