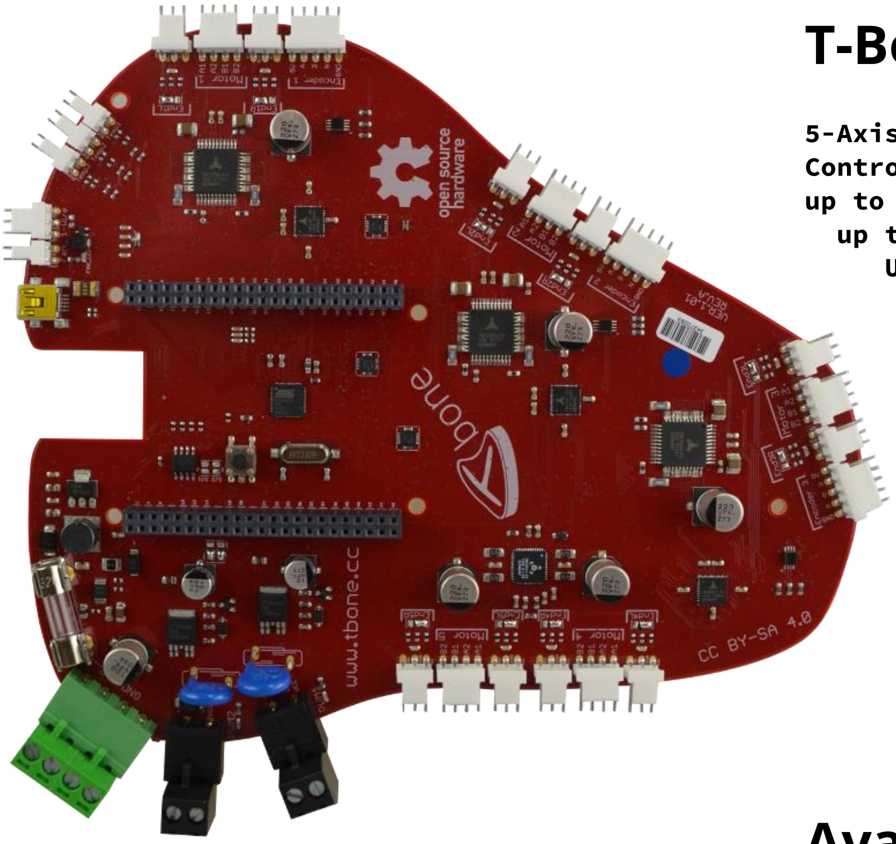
V 0.2

HARDWARE MANUAL



T-Bone

5-Axis Stepper Controller / Driver
up to 2.8A RMS (3x) / 24V
up to 1.1A RMS (2x) / 24V
USB interface

Avaible versions

T-Bone Rare
T-Bone Medium
T-Bone Well-Done
T-Bone Deluxe

T-Bone BBQ (breakout board)

coolStep™

stallGuard2™

All used electronic components are available on:

Digi-Key CORPORATION

T-Bone Team
Hamburg, Germany

www.tbone.cc

Table of contents

1 License

The T-Bone uses an Arduino Leonardo as a microprocessor. This is a derivate and is not connected to the Arduino Company. Any technical support needs to be provided directly to the T-Bone Team.

2 Features

The T-Bone offers several features which are described in this section. The motors refer to a 3D-Printer hardware setup. So the notations may differ from the hardware labels since the T-Bone Hardware is useable for a wide range of desktop manufacturing platforms.

Stepper Drivers

The drivers for X, Y, and Extruder (Motor 1 – 3) are supporting a maximum motor current of 4A peak (2.8 RMS), 9…30V, and 1/256 microstep resolution. The drivers are connected with a bidirectional Serial Peripheral Interface (SPI). Therefore it is possible to control maximum motor current, step resolutions, and other features remotely.
The Z-axis (Motor 4 and 5) of the T-Bone are in fact two axis. They can be used to drive two motors for the Z-axis simultaneously or separate for e.g. an additional extruder. The maximum current is 1.5A peak (1.1A RMS), 1/256 microsteps, up to 24V.

Stepper Controller

Motor 1 - 3 are connected with dedicated motion controller chips. They are responsible for all real-time related activities, like calculation of the motor acceleration, maximum speed, and step count to target a certain position. They can operate with linear or s-shaped acceleration profiles (what's the difference? You know it if you ever found your coffee-to-go on your shirt after the metro fitfully started to move.). S-Ramps reduce the jerk and make the movement smoother while accelerate and allow higher acceleration and thus faster movements. The Z-axes are using an integrated driver/controller chip doing the same job (beside the s-shaped ramp). All controllers are using the same clock rate, given by the Arduino™. The maximum step rate (microsteps per second) are depending on the clock rate and can be several MHz.

Arduino™-based Real-Time Controller

The stepper controllers are connected to an Atmel™ microcontroller, also with bidirectional SPI. Its main job is to send and receive data from the controllers and the BeagleBone™. Commands are buffered to decouple real-time operations of the T-Bone from the asynchronous UART interface to the BeagleBone™. Optionally the Atmel™ can also control the power switches for the extruder, heat bed, and fan. Also the thermistors are connected to both sides. (In case of controlling a 3D-Printer)
The Atmel microcontroller is running with the Arduino™ firmware. Therefore it's easy to modify the communication protocol for improvement or special requirements.

Comparison to other solutions

Most other solutions are using stepper drivers with unidirectional step/direction interface. These are two wires controlling the step rate of the motor and the rotation direction. Microstep resolution and maximum motor current are mostly fixed. Some solutions offer the possibility to set the current by an analog input pin.
The generation of the step rate, acceleration, maximum speed and positioning are usually done by the same Arduino™ which is also responsible for host communication, G-Code interpretation, and path planning. Therefore the maximum step rate and complexity of ramp generation is quite limited. Most solutions offer step rates of 10 – 20 kHz and are restricted to linear acceleration ramps.

	T-Bone		Others
	X, Y, Ext.	Z	All
Max Current	4A	1.5A	2A
RMS Current	2.8A	1.1A	1.4A
Microstepping	1/256	1/256	1/16
Step Rate	16 MHz	16 MHz	10 – 20 kHz
Set Step Resolution	Digital	Digital	fixed
Set Current	digital	Digital	fixed/analog
Acceleration	linear, s-shaped	Linear	Linear

Table 2.1 - Comparision with other products

Special features of the driver

The stepper driver chips of the T-Bone have some unique features. The most notable is the stallGuard2™ function. By measuring the electronic impulses coming back from the motor, the driver can "see" the current mechanical load of the axis. If the motor is blocked by a mechanical end stop, this is recognized and can be feeded back to the control electronics. It is also possible to adjust the motor current to the load level to increase the energy efficiency. This technology is calles coolStep™.
To enable stallGuard2™ the control software has to be slightly modified. The user also needs to set some additional parameters to adjust the sensing electronics to the particular characteristics of the used motor.

Applications examples for the T-Bone electronic

- 3D-Printers
- Milling machines
- Laser cutters
- Many many more

Electrical data

- Supply voltage: +12V … +24V DC nominal
- Motor current: 4A (2.8A RMS) X-, Y- , Extruder-Axis, 1.5A (1.1A RMS) Z-Axis

Integrated motion controller

- Motion profile calculation in real-time (TMC4361 and TMC5041 motion controller)
- On the fly alteration of motor parameters (e.g. position, velocity, acceleration)

Integrated bipolar stepper motor driver

- Up to 256 microsteps per full step
- High-efficient operation, low power dissipation (MOSFETs with low $R_{DS(ON)}$)
- Dynamic current control
- Integrated protection
- stallGuard2™ feature for stall detection
- Automatic load dependent motor current adaptation for reduced power consumption and heat dissipation (coolStep™)

Interfaces

- USB full speed (12Mbit/s) device interface to communicate with the ATmega32u4 ("Arduino Leonardo")

Software

- Arduino firmware for 3D-Printer support
- Beagle Bone python scripts for easily setting up the hardware and communicate with the ATmega32u4 over serial communication (UART0 & UART2)
- Beagle Bone web interface to control 3D-Printer via web interface and get live status

3 Order codes

The T-Bone is available in different versions. In the following table the versions are described and the related order codes are listed.

Version	Description
T-Bone Rare	Bare T-Bone board without components
T-Bone Medium	T-Bone board with SMD parts assembled. THT parts enclosed but unassembled
T-Bone Well-Done	Fully assembled T-Bone cape, ready to run. (Beagle Bone Black not included)
T-Bone Deluxe	Fully assembled T-Bone with preconfigured Beagle Bone Black Rev. C
BBQ Board	Breakout board for TRINAMIC ICs with several footprints

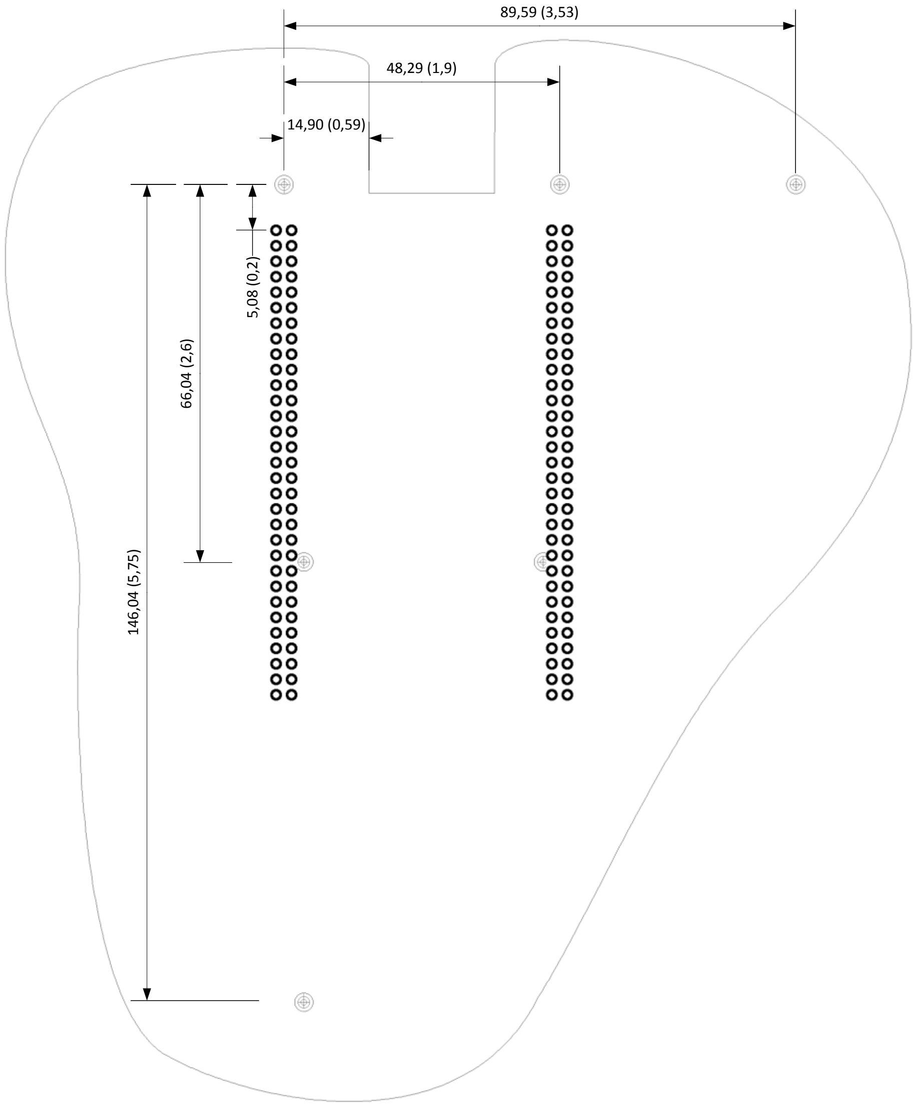
Table 3.1 : Available products

4 Mechanical and electrical interfacing

The T-Bone consists of a board which is designed to fit on top of the Beagle Bone Black single board computer.

4.1 Size of electronics

The T-Bone board with the controller / driver electronics has an overall size of 158.5mm x 185.8mm and four mounting holes in order to fit on the top of the Beagle Bone Black. The mounting holes have been designed for M3 screws (size of mounting holes: 3.2mm diameter each). There are two additional mounting holes to be able to screw the board on any surface.



Picture 4.1 - Board dimensions and position of mounting holes

4.2 Connectors

The T-Bone offers four connectors, a 6pin power and communication connector, an 8pin multi-purpose I/O connector, a 4pin motor connector and a mini-USB connector.

Overview of connector and mating connector types:

Label	Connector type
Power supply connector	Phoenix-Contact TERM BLOCK HDR 4POS R/A 5.08MM
High power outputs	Molex TERM BLOCK HDR 2POS R/A 5.08MM
Motor Connector	TE-Connectivity CONN HEADER RTANG 4POS .100 TIN
Endstops	TE-Connectivity CONN HEADER RTANG 3POS .100 TIN
Encoders	TE-Connectivity CONN HEADER RTANG 5POS .100 TIN
Temperature Inputs	TE-Connectivity CONN HEADER RTANG 2POS .100 TIN
Fan Output	TE-Connectivity CONN HEADER RTANG 2POS .100 TIN
1-Wire	TE-Connectivity CONN HEADER RTANG 2POS .100 TIN
USB connector	CONN USB MINI B

Table 4.2: Connectors and mating connectors, contacts and applicable wire

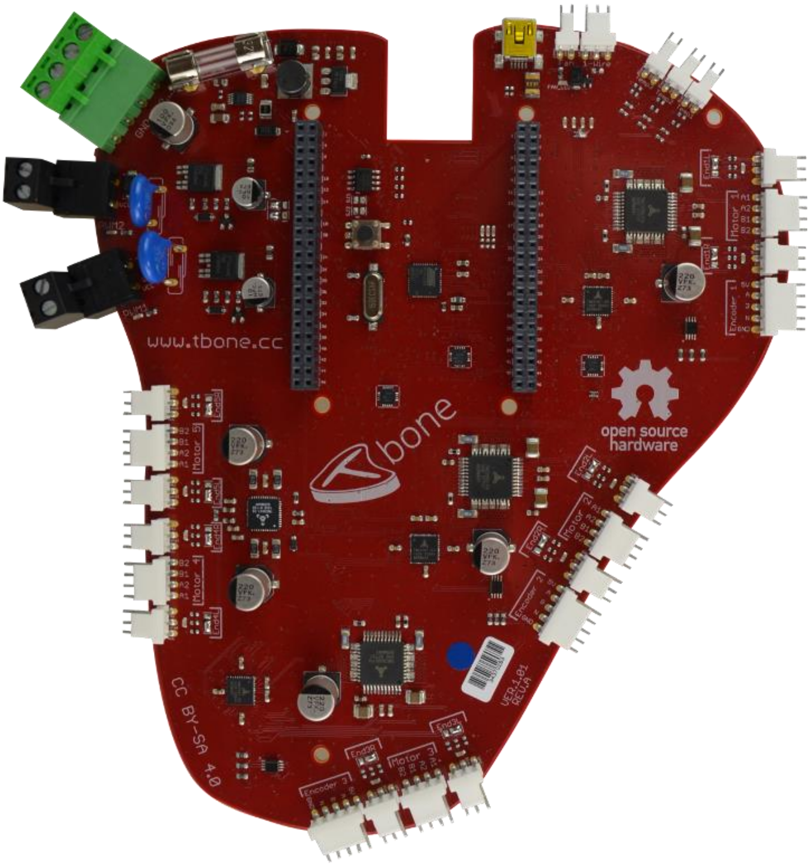


Figure 4.3: T-Bone connectors

4.2.1 Power Connector

A 4 pin with fuse between input and 24V VDD supply rail.

Pin	Label	Direction	Description
1	VDD	Power (Supply)	VDD (+12V...+24V)
2	VDD	Power (Supply)	VDD (+12V...+24V)
3	GND	Power (GND)	GND
4	GND	Power (GND)	GND

Table 4.3: Power connector

There is <u>no reverse polarity protection</u>!

4.2.2 High power output connectors

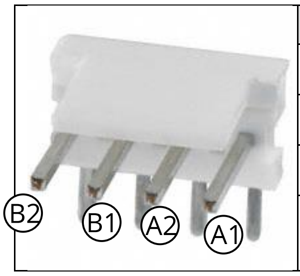
A 2 pin connector is available to connect high power devices such as heating cartridges or heating for 3D-Printing devices.

Pin	Label	Direction	Description
1	VDD	Power (Heater)	Connected to VDD
2	GND	Power (GND)	Connected to GND

Table 4.4: High power output connectors

4.2.3 Motor connector

As motor connector a 4pin MOLEX 2,54mm pitch single row connector is available. The motor connector is used for connecting the four motor wires of the two motor coils of the bipolar stepper motor to the electronics.

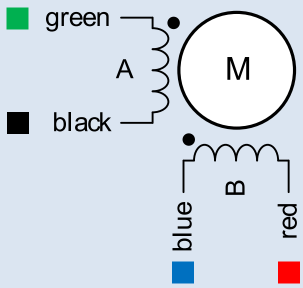


Pin	Label	Direction	Description
1	B2	Output	Pin 2 of motor coil B
2	B1	Output	Pin 1 of motor coil B
3	A2	Output	Pin 2 of motor coil A
4	A1	Output	Pin 1 of motor coil A

Table 4.5: Motor connector

Example for connecting a TRINAMIC QS4218 stepper motor:

T-Bone	QS4218 motor		
Motor connector pin	**Cable colour**	**Coil**	**Description**
1	Black	A	Motor coil A pin 1
2	Green	A-	Motor coil A pin 2
3	Blue	B-	Motor coil B pin 2
4	Red	B	Motor coil B pin 1



4.3 Mini-USB connector

A 5pin mini-USB connector is available on-board for serial communication with the derivated Arduino Leonardo (ATmega 32u4)

Pin	Label	Direction	Description
1	VBUS	Power	+5V supply from host
2	D-	Bidirectional	USB Data –
3	D+	Bidirectional	USB Data +
4	ID	Power (GND)	Connected to signal and system ground
5	GND	Power (GND)	Connected to signal and system ground

Table 4.6: Connector for USB

4.4 Power supply

For proper operation care has to be taken in regard to power supply concept and design.

There is no reverse polarity protection!

4.5 Communication

4.5.1 USB

For remote control and communication with a host system the T-Bone provides a USB 2.0 full-speed (12Mbit/s) interface (mini-USB connector). As soon as a USB-Host is connected the T-Bone is available as a common Arduino Leonardo in the Arduino IDE software.

The T-Bone supports USB self powered operation (when an external power is supplied via the power supply connector) and USB bus powered operation, also (no external power supply via power supply connector). During USB bus powered operation, only the communication to the Arduino Leonardo is available. Motor movements will not be possible. This mode has been implemented in order to enable configuration / parameter setting / read-out, firmware updates etc. by just connecting a USB cable between the T-Bone and a host PC. No additional cabling / external devices as e.g. power supply etc. are required in that case.

4.6 Inputs and outputs

4.6.1 High power outputs (2x – PWM controller)

The two pin connector of the T-Bone controls the heating bed and the hot end in the application of a 3D-Printer. The

Figure 4.7: The two high power outputs

4.6.2 Motor connectors (5x)

The four pin connectors of the T-Bone are used to connect bipolar stepper motors.

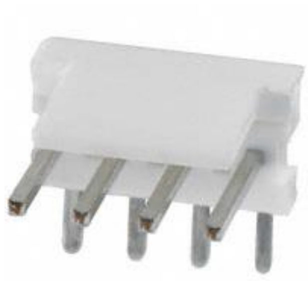


Figure 4.8: The five motor connectors

4.6.3 Endstop connectors

The ten endstop connectors of the T-Bone offer the possibility to limit the maximum travel range of the separate axis. For a 3D-Printer for example, there are two inputs for limiting switches for each axis. It is possible to connect all kind of end stop types since there is a +3V3 voltage, a GND and a signal conection.

Figure 4.9: Endstop connectors for the motion controller

4.6.4 Low power Output (PWM controlled)

The T-Bone provides one output for low currencies. In case of a 3D-Printer this output would be used to connect a fan. This offers the possibility to regulate the temperature in combination with the high power outputs with a PID-controller algorithm.

4.2 - Low power connector

4.6.5 One-Wire bus connector

To connect a One-Wire device, this connector is reserved. This could be a temperature sensor for example.

4.3 - One-Wire connector

4.6.6 Encoder inputs

Since the used motion controllers on this board provide the possibility to use a close-loop operation mode, there are 3 inputs for encoders. These

Figure 4.9: Encoder connectors

5 Functional description

The T-Bone is using a smart and proven concept for improvement and simplification at the same time: division of work. Dedicated motion control units are executing low-level, but time-critical functions. The BeagleBone can concentrate on complex tasks and user interfacing. Both parts are connected by an Arduino-compatible microcontroller, decoupling high-level and real-time programming.

The connection between the two boards is realized by a asynchronous UART interface. It's easy accessible in software, offers high data rates, and decouples the task-driven BeagleBone and the real-time operation of the T-bone.

The T-Bone contains the following main components:

- ATmega™ 32u4 microcontroller programmed as Arduino Leonardo running with 16MHz
- 256Kbytes EEPROM for storing configuration parameters for the Beagle Bone Black via the I²C bus [BBB_SRM]
- TMC4361 [TMC4361] motion controller
- TMC2660 [TMC2660] advanced stepper motor driver IC with stallGuard2™ and coolStep™
- TMC5041 [TMC5041] stepper controller-driver IC

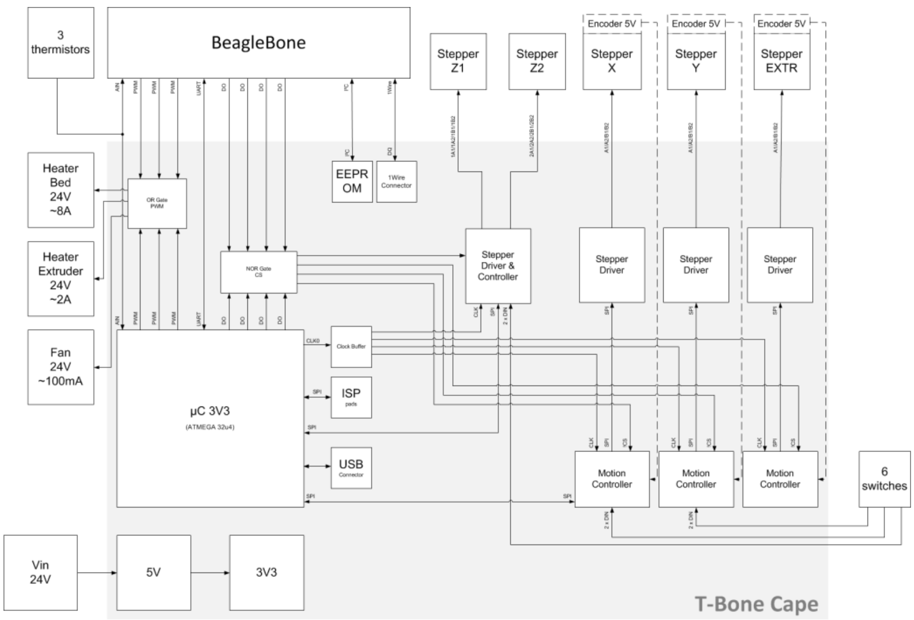


Figure 5.1: T-Bone block diagram

6 Startup operation instructions

This section will explain the steps to start up the T-Bone. In general it is possible to control the T-Bone with all devices which can establish a communication via UART e.g. Computer with respective interface, a Beagle Bone, a Raspberry Pi, an Arduino, etc.

There are many ways to use the T-Bone board. First it is described how the T-Bone is set into operation with a PC and a USB TTL Serial Cable. (Part Number: TTL-232-R-3V3)

First of all connect the motors you want to drive with the T-Bone. Afterwards connect a power supply in a range of 12V to 24V. Where the power supply voltage is connected to PIN 1 and 2 and GND is connected to PIN 3 and 4 (*Subchapter* ***4.2.1***). In this case an old Hewlett Packard Power supply is used. It provides a voltage of 18V.

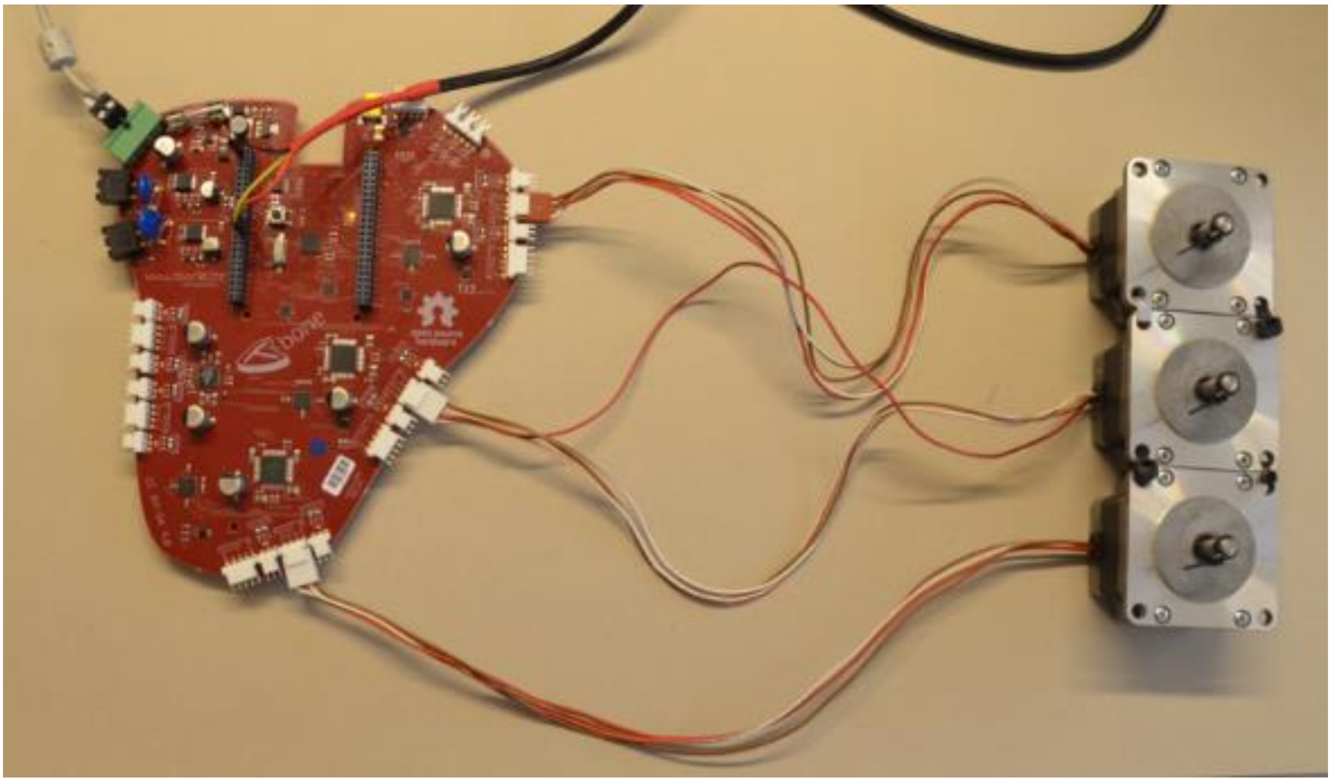


Figure 2 - T-Bone connected with motors, power supply and TTL-232R-3V3

As on ***Figure 5.1*** seen a TTL-232R-3V3 FTDI to Serial converter is connected. With this device you are able to send and receive commands. Just connect the GND pin of the converter with the pin 1, 2, 43, 44, 45 or 46 of P9. P9 is on the left of the T-Bone with the orientation seen on ***Figure 5.1***. Connect the TXD cable of the converter with P9 pin 24 and the RXD cable with P9 pin 26.

Now you are good to send the first instruction via a terminal program like HTerm. In this case the version 0.8.1beta was used. On the ***Figure 3*** below you can see the program set up, to communicate with the T-Bone. The received command `-128,0,40;` is send every second by the Arduino Leonardo and represents a heartbeat.

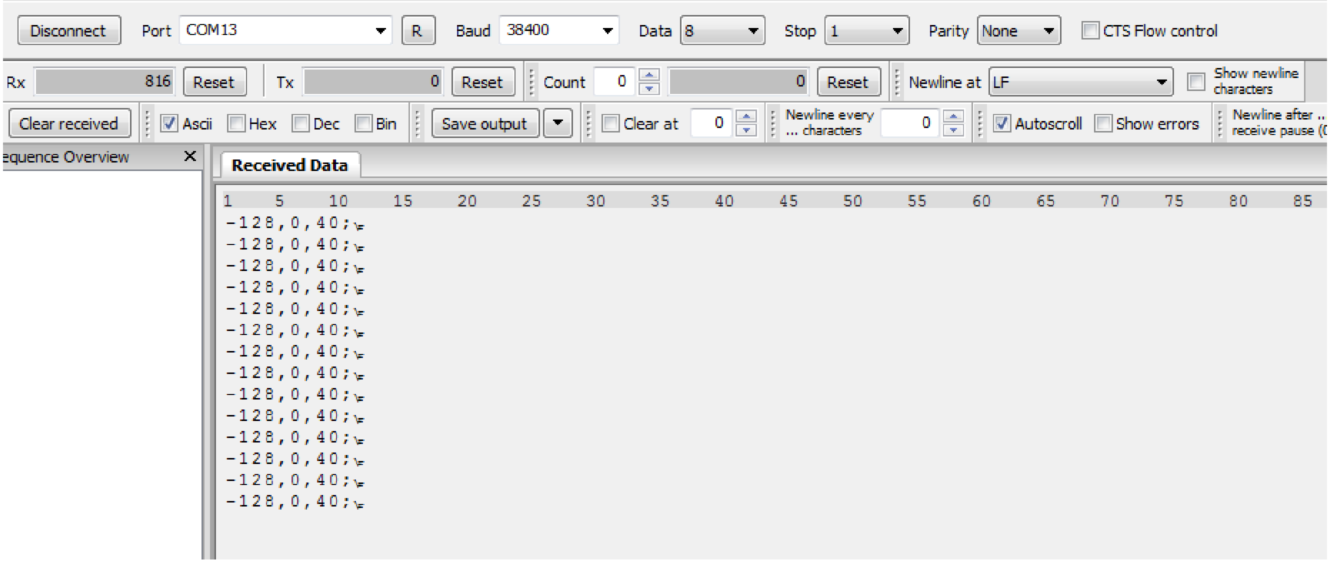


Figure 3 - HTerm set up receiving the heartbed of the T-Bone

6.1 Command set

Set Motor Current
1,<motor 1..5>,<current [mA]>;

Configure Encoder
2,<motor 1..3>,<enable=1/disable=-1>,<fs/rev motor>,<ustepping>,<increments encoder>,<1=differential/-1=single ended>,<inverted>;

Configure Endstops
Virtual Endstop: 3,<motor 1..5>,<1=right/-1=left>,0,<virtual endstop position>;
Real Endstop: 3,<motor 1..5>,<1=right/-1=left>,1,<-1=active low/1=active high>;

Invert Motor
4,<motor 1..5>,<1=non inverted/-1=inverted>

Initialize Motion
9;

Add Move
10,<motor 1..5>,<target position>,<115=stop at target/119=continue motion>,<Vmax>,<Amax>,0;
^^
Can be repeated, e.g.:
10,1,1000,115,100000,500000,0,2,2000,115,200000,1000000,0,3,1500,115,150000,750000,0;

Movement information
11,0;

Finish Movement
run from queue: 11,1;
empty queue: 11,-1;

Home axis
12,<motor 1..5>,<timeout>,<fast speed>,<slow speed>,<retract>,<aMax>...

Set Position
13,<motor 1..5>,<new position>;

Read Position
30,<motor 1..5>;

Queue status readout
31;

Read motor status
32,<motor 1..5>;
Returns: 32,<status register>,<Xactual>,<left endstop: 1=active/-1=inactive>,<right endstop: 1=active/-1=inactive>,<encoder position>;

6.2 Example command instruction set

Run motor 3 with 750mA (RMS):

Position	Velocity	Acceleration
102400	204800	819200
0	204800	819200
102400	204800	819200
0	204800	819200

Table 2 - Target parameters for example instruction set

```
9;
//Initialization

1,3,750;
//Set motor current to 750mA of motor axis 3

10,3,102400,115,204800,819200,0;
//Add first movement into motion queue (row 1 of table 3)

10,3,0,115,204800,819200,0;
//Add second movement into motion queue (row 2 of table 3)

10,3,102400,115,204800,819200,0;
//Add third movement into motion queue (row 3 of table 3)

10,3,0,115,204800,819200,0;
//Add fourth movement into motion queue (row 4 of table 3)

11,1;
//Run

11,-1;
//Empty queue
```

7 Operational ratings

The operational ratings show the intended or the characteristic ranges and should be used as design values.

In no case shall the maximum values be exceeded!

Symbol	Parameter	Min	Typ	Max	Unit
VDD	Power supply voltage for operation	12	24	24	V
TMC2660					
I_{COIL_peak}	Motor coil current for sine wave **peak** (chopper regulated, adjustable via software)	0		2.8	A
I_{COIL_RMS}	Continuous motor current (**RMS**)	0		2.0	A
TMC5041					
I_{COIL_peak}	Motor coil current for sine wave **peak** (chopper regulated, adjustable via software)	0		2.8	A
I_{COIL_RMS}	Continuous motor current (**RMS**)	0		2.0	A

Table 7.1: General operational ratings of module

8 Revision history

8.1 Document revision

Version	Date	Author	Description
0.1	2014-JUN	LJ	Initial version
0.2	2015-FEB	LJ	

Figure 8.1: Document revision

8.2 Hardware revision

Version	Date	Description
T-Bone_V09	2014-FEB	Prototype
T-Bone_V100	2014-MAR	
T-Bone_V101	2014-JUN	

Figure 8.2: Hardware revision

9 References

[TBONE]	T-Bone Team homepage Support system can be found on http://www.tbone.cc/
[TMC4361]	TMC4361 datasheet Additional information can be found on http://www.trinamic.com
[TMC2660]	TMC2660 datasheet Additional information can be found on http://www.trinamic.com
[TMC5041]	TMC5041 datasheet Additional information can be found on http://www.trinamic.com
[BBB_SRM]	Beagle Bone Black system reference manual Additional information can be found on http://www.beagleboard.com/
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