Orbitool SO3 v1.4

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Should a tool-board magic smoke come out because of user error? Why?

Should a tool-board be destroyed by a fault in your 3D printer? Why?

My answer is NO! And this is what this tool-board is all about!

We are hobbits, professionals and let's face it, we do mistakes, and when the magic smoke shows up everybody is disappointed, even if we know it's a user fault. In this board, I promise you the *magic smoke* is kept inside extremely tight!

Smokeless Features

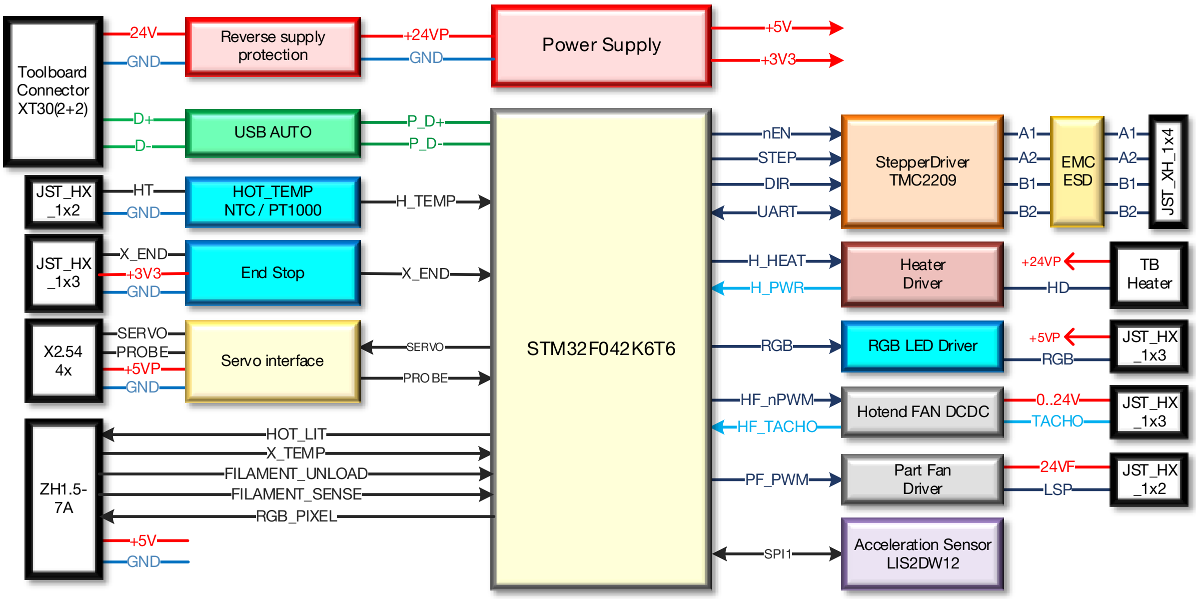
- Optimized for Smart Orbiter v3 shape and features
- STM32F042 microcontroller running on 48MHz
- Automotive USB communication with Raspberry PI
- Onboard LIS2DW12 accelerometer
- TMC2209 extruder stepper driver
- Direct connection to SO3 integrated board
- 1x PWM controlled part fan outputs
- DC-DC converter based Hot-end fan driver, compatible with 12/24V fan types with RPM speed input signal
- Hot-end temperature sensor input compatible with standard NTC or PT1000 temperature sensor types
- I/O for bed level sensor
- X-Stop sensor input
- Onboard temperature sensor
- Advanced thermal management

Protection Features

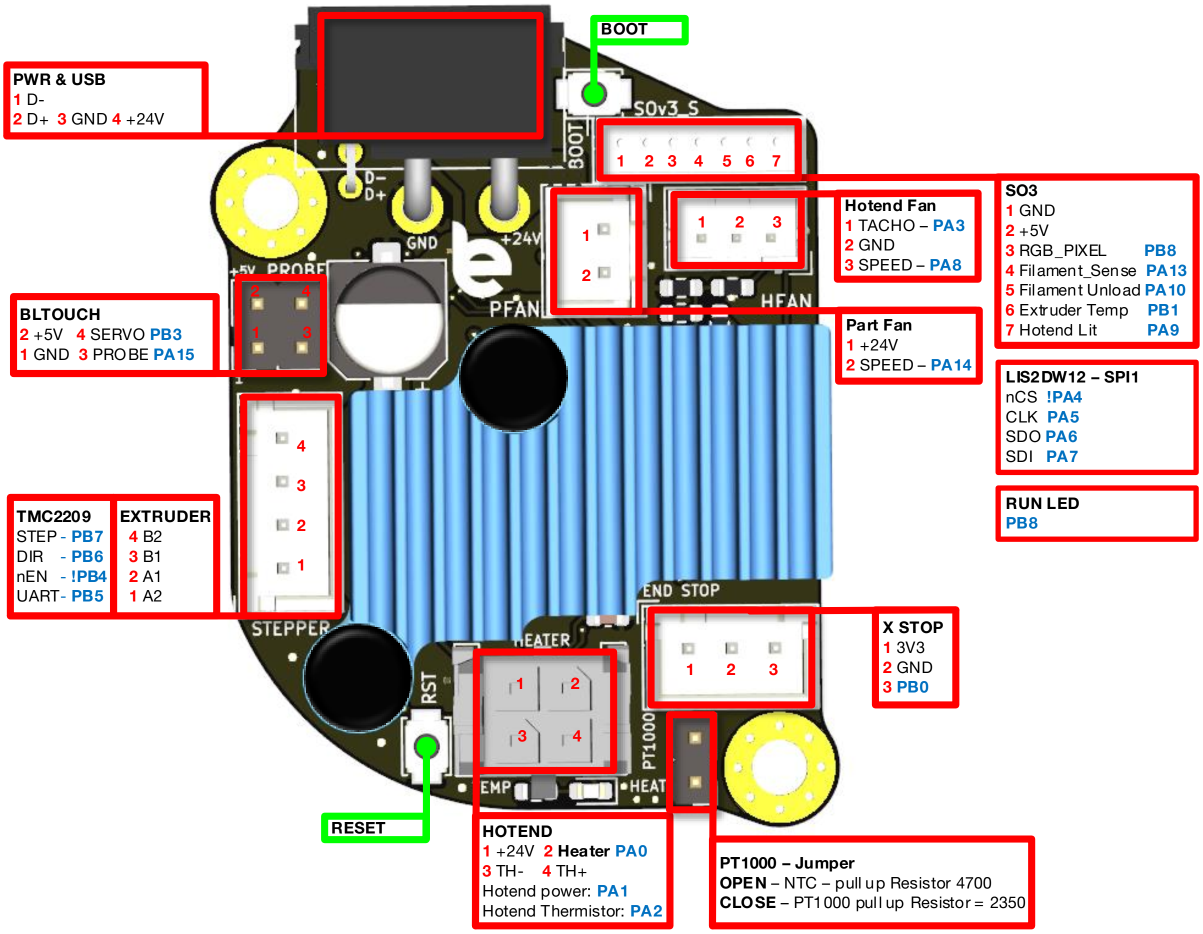
- Active short circuit protected Hot-end output
- Active short circuit protected fan driver outputs
- Active Protection circuit against reverse power supply connection
- Protection against loss of GND supply
- Analog and digital inputs protected against short to +24V supply voltage
- USB data lines protected against short circuits to GND and +24V
- EMI interference and ESD protection an all inputs and outputs
- Heater thermal runaway protection in case of short between heater and sense thermistor wires

1 Block Diagram

Block diagram for Orbitool SO3 v1.4.



2 Pinout definition



3 Features description

3.1 Introduction

For me electrical robustness of a design is part of the requirements. One of my main design goals was to integrate protection against common user errors and 3D printer defects.

In the end nothing is more frustrating than powering up your new board and let the *magic smoke* out. Even if is due to user fault the disappointment is still there.

This design is based on automotive technology where protection to all kind of hazards is state of the art long time ago.

This document describes the main specific features of the tool-board.

3.2 Power supply concept

The board is supplied via XT30(2+2) connector which includes the +24V, GND, USB_DATA+ and USB_DATA- signals.

From the connector the board is supplied via a protection circuit against reverse power supply connection. In case by any user error the board supply voltage lines are reversed this event will not cause any damage to the Orbitool SO3 board.

In case of reversed supply voltage, the board will simply not start up it will behave like it’s not powered.

The microcontroller is supplied from a 3.3V LDO supplied from the onboard 5V DC-DC buck converter for the highest power supply efficiency and lowest possible power consumption.

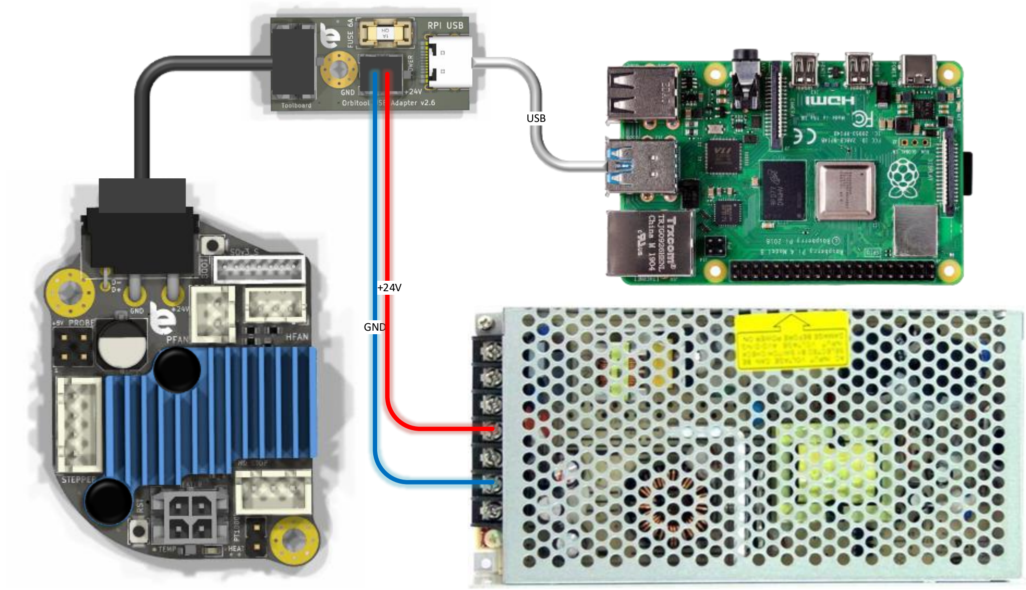
3.3 USB communication interface

The tool-board is equipped with automotive grade USB interface. The main difference being the higher electrical robustness of the automotive USB, while keeping high communication speed possible. Therefore, in case of short to GND or up to +28V of the USB data lines the tool-board will not be damaged and will work properly after the short circuit is removed.

Protection against loss of GND avoid tool-board and RPI USB port damage in case of GND connection loss. GND connection loss leads to USB data lines to be biased to the 24V power supply range and without protection circuit the USB port will be damaged.

The USB interface of the Raspberry PI is not robust against these electrical hazards which may occur in a 3D printer. Therefore, the tool-board shall be supplied and connected to the Raspberry Pi using the supplied USB adapter board, which has the onboard protection circuits to protect the Raspberry PI USB port.

SO3 tool-board wiring diagram.



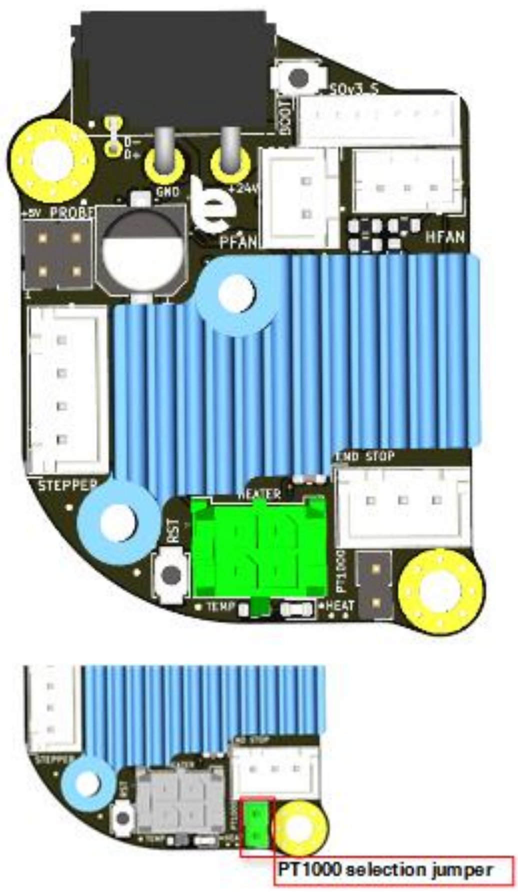
3.4 Hot-end & temperature sensor

The hot-end temperature input circuit accepts two type of thermal sensor elements,

- **100k NTC** - ATC Semitec 104GT-2, included in the SO# hotend – Pull up resistor value 4700
- **PT1000** selectable via closing Jumper PT1000 – Pull up resistor value 2350 for connecting custom hot ends to the SO3

The senor input is protected against short circuit to supply voltage of 24V.

The SO3 tool-board has protection circuit against dangerous thermal runaway due short circuit between hotend GND and thermistor GND connection. Without this protection the hotend heater would turn ON with 100% power and go into dangerous thermal runaway which of course represent fire hazard condition, and Klipper can do nothing against it. Probability of this failure of course is small but considering the severity of the outcome this board is the first to implement a protection against this event.



Hotend heater driver circuit

The hot-end heater driver circuit has an active short circuit protection.

The circuit measures the heater current and in case the current rises over a predefined threshold i_{OC_HOT} it switches OFF the heater MOSFET until the next PWM cycle to prevent tool-board damage.

To avoid that the heater driver is stuck accidentally due to a fake error detection, the max PWM duty cycle shall be limited to 99.5% meaning *max_power: 0.995*.

The heater power will not be affected and will allow the heater driver to automatically recover from an unlikely event of fake error detection.

The Heater current is feedback to Klipper which can calculate the actual power consumption of the heater element. This can be used to detect failures in the heater element like short circuit or loss of heating power.

You may say yes, other boards have also protection with onboard fuses. Well, that is simply not enough to protect MOSFETs from being damaged because fuses have long reaction time, about 1-2s range. Their mission is to protect the circuit from catching fire in case of a defect but it cannot protect the heater driver MOSFET from getting destroyed. This active protection reacts within 10ms ensuring the driver stage is switched off before its damaged due to a short circuit or overload event.

To display the actual power of the heater you will need to include the following section:

```
[adc_temperature HOT_P]
temperature1:119 # value in Watts
voltage1:1.91
temperature2:239 # value in Watts
voltage2:3.82

[temperature_sensor Hotend_power]
sensor_pin: SO3:PA2
sensor_type: HOT_P
min_temp = -10
max_temp = 100
```

The hot-end power or current can be displayed based on preference. The power is calculated considering 24V power supply.

To improve the heater power calculation the heater PWM is forced to 100Hz (instead of the 10Hz default of Klipper).

```
max_power: 0.995 # limit heater power to 99.5% to enable autorecovery from short detection
pwm_cycle_time: 0.01
```

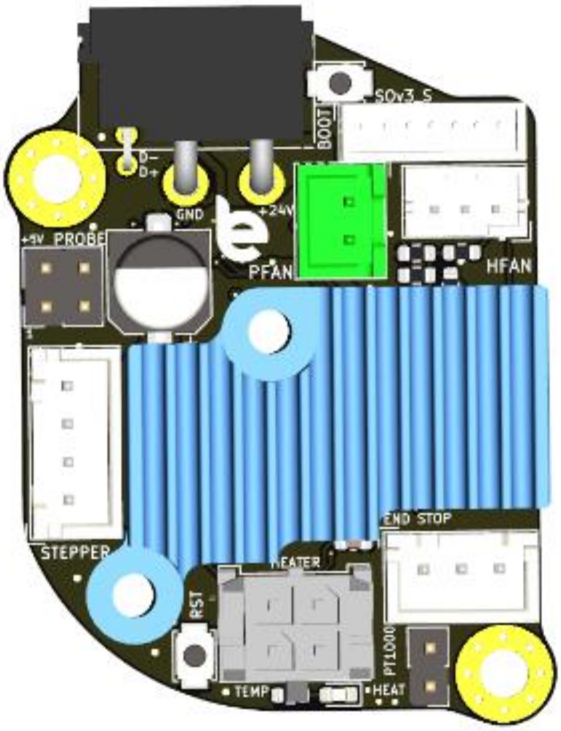
3.5 Fan driver outputs

The part-fan driver has similar protection circuit like the hot-end driver, in case of overcurrent the fan driver is switched OFF until the next PWM cycle.

The PWM duty cycle of the fan driver shall be limited to 99.5% meaning *max_power: 0.995* to avoid fan driver stuck OFF due to an unlikely event a fake error detection.

Configuration of the part-fan driver:

```
[fan_generic part_fan]
pin: SO3:PA14
max_power: 0.995
shutdown_speed: 0.0
cycle_time: 0.01
kick_start_time: 0.2
hardware_pwm: False
```

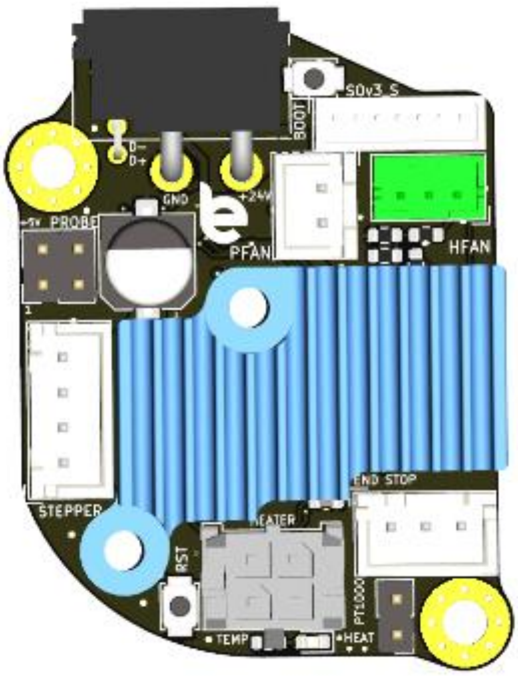


3.6 Hot-end fan output

The hot-end fan circuit is implemented using a microcontroller-controlled DC-DC converter.

It is implemented in this way because PWM control of three wire fans with speed signal will affect the speed signal.

PWM (Pulse Width Modulation) control means switching ON and OFF the fan power supply fast, like one hundreds of times every second. This means there are moments when the fan is actually not supplied with power. In those moments also the speed sensing electronics is not supplied therefore it cannot provide a reliable signal. As result the Speed signal is scrambled with the PWM control and the speed measurement is completely invalid.



One advantage of this control circuit beside the reliable speed signal is the possibility to limit the max voltage according to the fan type the user have.

This output supports 12V or 24V fan types.

The fan voltage is defined by defining the max power value as follows in the fan configuration section:

- **12V** fan – max_power: 0.5
- **24V** fan – max_power: 1.0

The Smart orbiter is equipped with 24V fan type so default should be *max_power :1.0*.

To reduce hotend fan noise its power can be reduced down to 60%. In case of clogs while printing very slow the power needs to be increased.

Configuration of the Hotend fan driver:

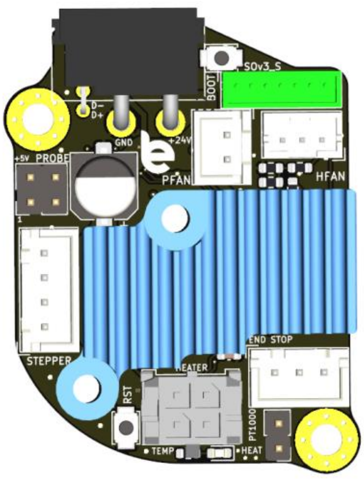
```
[heater_fan hotend_Fan]
pin: !SO3:PA8
tachometer_pin: SO3:PA3
heater: extruder
cycle_time: 0.0001 #10KHz PWM frecvency
heater_temp: 75
fan_speed: 1.0
hardware_pwm: false
shutdown_speed: 0.0
max_power: 1.0
tachometer_ppr: 2
tachometer_poll_interval: 0.001
```

* Note the PWM control frequency of the circuit must be set to 10KHz, *cycle time: 0.0001*

3.7 SO3 Extruder smart features connector

SO3 tool-board features a connection to the Smart Orbiter v3 internal electronics, fully supporting its features:

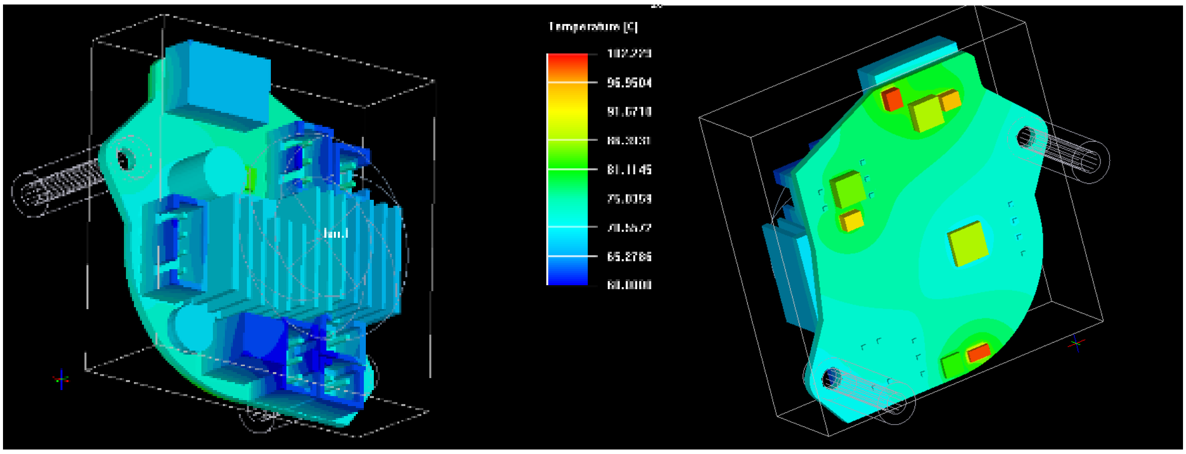
- Filament sensing and auto load
- Filament auto unload
- RGB LED lit filament input
- White LED hotend lit
- Extruder temperature sensor



3.8 Thermal considerations

Closed printer chamber requires tool-board operation in high ambient temperature condition. In addition, this tool-board is mounted on the backside of the stepper motor which transfers a considerable amount of heat. Therefore, the circuits of this tool-board are designed to have low temperature drift and efficient thermal management to make sure none of the components heats over their maximum allowed operation temperature.

I really done lots of thermal simulations using finite elements simulations and real-life measurements using Flir thermal camera (simulation results from Orbiter 2 SO2 tool-board but the basic design is the same with the SO3).



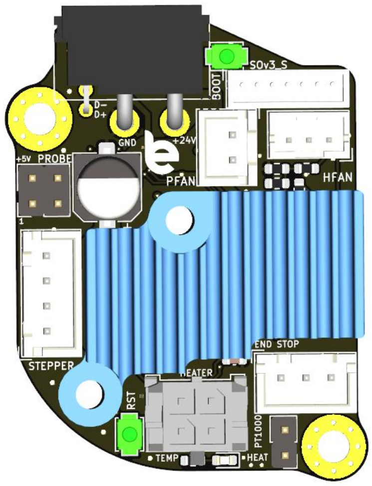
The SO3 tool-board is safe to operate in maximum **60°C** ambient (printer chamber) conditions.

However, it is possible to use the SO3 tool-board in closed chamber temperatures over **60°C** up to **80°C** with additional measures:

- Reduce stepper current from 0.85A to 0.5÷0.6A
- Use active cooling by adding a small 20x20mm or 25x25mm fan to the back of the tool-board which blows a small amount of air toward the SO3 tool-board heatsink. The power supply lines of the fan can be connected in parallel with the hotend fan.

4 Microcontroller programming

1. Connect the board to the host Raspberry Pi via USB adapter cable.
2. Follow the following steps to enter the microcontroller into DFU mode:
   - press the BOOT and RESET switch,
   - release the RESET while keeping the BOOT button pressed,
   - release BOOT switch button after 3 seconds.
   - The buttons might be a little tricky to access. Hint, use some ceramic screwdriver or simple toothpicks to push the buttons and avoid creating any short over the board with metal tools



3. Connect to your host raspberry pi via SSH
4. Run lsusb from the command prompt
   - Make sure you see an STM32 in DFU mode listed
5. Run dfu-util --list from the command prompt
   - note the text inside the [xxxx:yyyy] (default is -> 0483:df11)
6. Run cd ~/klipper from the command line to enter the Klipper directory
7. Run make menuconfig settings should be:
   - Cristal oscillator – 8Mhz

```
(Top)
                         Klipper Firmware Configuration
[*] Enable extra low-level configuration options
    Micro-controller Architecture (STMicroelectronics STM32)  --->
    Processor model (STM32F042)  --->
    Bootloader offset (No bootloader)  --->
    Clock Reference (8 MHz crystal)  --->
    Communication interface (USB (on PA11/PA12))  --->
    USB ids  --->
    Optional features (to reduce code size)  --->
()  GPIO pins to set at micro-controller startup
```

   - Set custom USB ID to *SO3Tool*

```
(Top) → USB ids
                         Klipper Firmware Configuration
(0x1d50) USB vendor ID
(0x614e) USB device ID
[ ] USB serial number from CHIPID
(SO3Tool) USB serial number
```

- Optional features (to reduce code size):

```
(Top) → Optional features (to reduce code size)
                    Klipper Firmware Configuration
[*] Support GPIO "bit-banging" devices
[ ] Support LCD devices
[*] Support external sensor devices
[*] Support lis2dw 3-axis accelerometer
[ ] Support software based I2C "bit-banging"
[ ] Support software based SPI "bit-banging"
```

- Hit Q to Exit and Save

8. Run make clean to clean up the make environment

9. Run make flash FLASH_DEVICE=0483:df11

10. In case you encounter some errors but still having the message of File downloaded successfully than you are good to proceed to the next step.

```
DFU mode device DFU version 011a
Device returned transfer size 2048
DfuSe interface name: "Internal Flash  "
Downloading to address = 0x08000000, size = 23004
Download        [=========================] 100%        23004 bytes
Download done.
File downloaded successfully
Transitioning to dfuMANIFEST state
dfu-util: can't detach
Resetting USB to switch back to runtime mode
roby@Machcube:~/klipper $
```

11. Press the RESET button to restart the MCU and enter normal operating mode

12. Run ls /dev/serial/by-id/* should return a device beginning with:

/dev/serial/by-id/usb-Klipper_stm32f042x6_SO3Tool-if00

13. Copy this virtual serial port name to the SO3.cfg config file MCU section

```
[mcu SO3]
serial: /dev/serial/by-id/usb-Klipper_stm32f042x6_SO3Tool-if00
restart_method: command
```

Manual definition of USB ID, flashing the MCU with Klipper will always result in the same serial ID.

Your tool-board should now be usable with Klipper. Use the example config file to get started. Best option is to copy the config file into the same directory as printer.cfg.
Add [include SO3.cfg] to the beginning of your printer.cfg to include the file.
Comment out the unused sections I/O features of the SO3 config.

5 Electrical characteristics

5.1 Absolute maximum ratings

Important Note: The Orbitool SO3 board can withstand these limits without electrical damage, however long-term exposition to these limits is not recommended. Device absolute maximum rating is not the same with functional range.

The maximum ratings may not be exceeded under any circumstances!

Table 1 Orbitool SO3 absolute maximum ratings

Nr.	Parameter	Min	Max	Unit
A1	Temperature range	-20	85	°C
A2	Supply voltage	-30	30	V
A3	Extruder stepper current		1	A
A4	Hot-end heater current		6.8	A
A5	Part fan output current		1	A
A6	Hot-end Fan		0.5	A
A7	USB Data lines	-1	28*	V
A8	Hot-end temperature sensor input	-1	28*	V
A9	End stop input	-1	28*	V
A10	Z sensor I/O interface	-1	+15	V
A11	ESD-Protection level for handling (Human Body Model, HMB)	-8	8	kV

*Should not exceed the power supply voltage

5.2 Full Operational limits

Table 2 Orbitool SO3 electrical characteristics

Nr.	Parameter	Symbol	Min	Typ	Max	Unit
	General					
P1	Operating temperature range	t_o	-20		60	°C
P2	Max ambient temperature with active cooling	t_{o_cooled}			80	°C
P3	Power supply voltage	v_{PWR}	20		28	V
P4	Power supply voltage measurement accuracy	a_{PWR}	-3		3	%
	Extruder stepper					
P5	Extruder stepper current (max 60°C chamber temp)	i_{MOT_60}			0.85*	A
P6	Extruder stepper current (max 80°C chamber temp)	i_{MOT_80}	0.5		0.6	A
	Hot-end heater					
P7	Hot-end heater nominal current	i_{HEATER}			5	A
P8	Hot-end heater overcurrent switch OFF threshold	i_{OV_HOT}	5.9	6.8	7.2	A
P9	Hot-end overcurrent detection time	t_{OV_HOT}			10	ms
P10	Hot-end power measurement accuracy	a_{P_HOT}	-6		6	%
	Part Fan					
P11	Part fan output nominal current	i_{PART_FAN}			1	A
P12	Part fan overcurrent switch OFF threshold	i_{OC_PART}	1.2	2	2.5	A
P13	Part fan overcurrent detection time	t_{OC_PART}			5	ms
P15	Part fan PWM frequency	f_{PART_FAN}		100		Hz
	Hot-end Cooling fan					
P16	Hot-end fan output nominal current	i_{HOT_FAN}			0.4	A
P17	Hot-end fan current limitation	$i_{CL\_HOT\_FAN}$	2	3	3.9	A
P18	Hot-end fan PWM frequency	f_{HOT_FAN}	9	10	20	Khz
	Internal supplies					
P19	Internal 5V supply protection current limitation	i_{SC_5V}	2	3	3.9	A
P20	Internal 3.3V supply protection current limitation	i_{SC_3V3}	220	350	550	mA

*Parameter derating with ambient temperature