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A B C D

BACHELOR'S DEGREE IN TELECOMMUNICATION ENGINEERING

ACADEMIC COURSE 2021/2022

Tree Inspection Kit handheld device

Part of the Bachelor's Thesis:

"Development of an acoustic measurement system of the Modulus of Elasticity in trees, logs and boards"

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SUPERVISED BY:

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DEPARTMENT:

Electronics and Computer Technology

UNIVERSIDAD DE GRANADA

GRANASAT

IDIE Investigación y Desarrollo en INGENIERÍA DE EDIFICACIÓN Universidad de Granada

ADIME Acústica y Diagnóstico de Materiales y Estructuras

Life

LIFE WOOD FOR FUTURE

Project title:	TIK_HandheldDevice.PrjPcb		
Date: 2022-07-29	Revision: 0.6	Sheet 1 of 21	

Introduction

Objective

The present project has the goal of developing a handheld electronic device capable of measuring the MOE (Modulus Of Elasticity) of standing trees and logs from silviculture, so their wood can be classified for structural purpose.

The MOE (Modulus Of Elasticity) is the resistance of an object or substance to being elastically deformed when a stress is applied to it.

The device is equipped with the electronics needed to measure the delay between two signals which come from two piezoelectric sensors nailed into a piece of wood. It can be a standing tree, a tree trunk or a wooden board. The transit time of a wave travelling through the longitudinal axis of the wood is inversely related to the MOE and thus to the material rigidity. This device can also weight trunks to estimate its density by using a load cell.

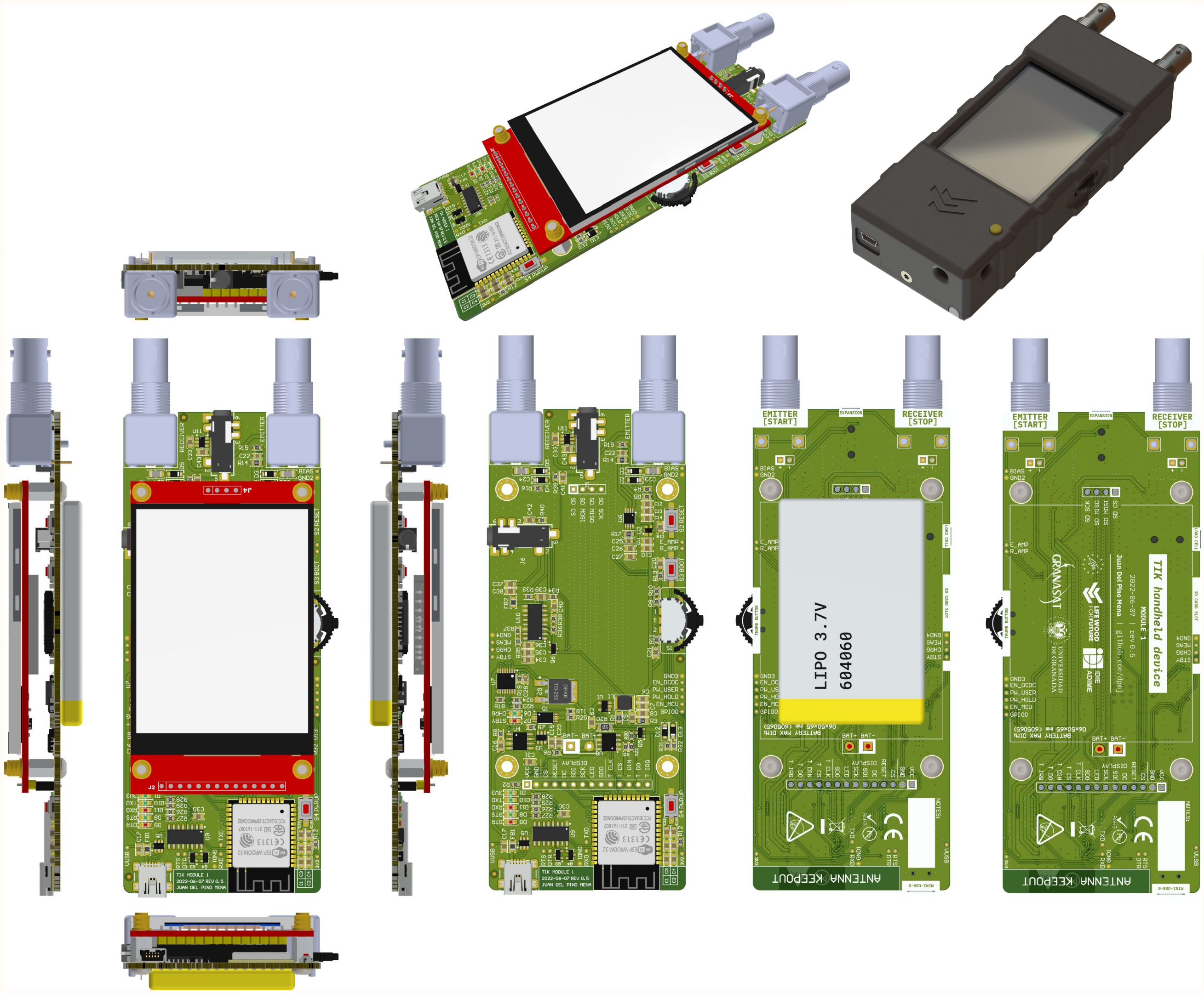
At the right side you can see some renders of the PCB (version 0.5) which has been manufactured.

Motivation

The poplar silviculture has many environmental advantages such as high carbon sequestration, they conserve the quality of the soil and act as water cycle regulators.
For a sustainable explotation, it is necessary that the wood is of quality. One of the figures on which wood is selected is stiffness, specially for structural applications. The MOE and stiffness are direclty related. The development of a measuring instrument for the MOE is of interest to know the wood properties as soon as possible.

Collaborators

This work has been possible thanks to the GranaSat electronics team. Huge thanks to all the IDIE-ADIME research team and to the LIFE Wood For Future programme for offering and financing the project.



Tree Inspection Kit handheld device

A device capable of determining the microsecond delay between 2 signals coming from piezoelectric probes nailed into a tree, trunk or wood board. This allows the indirect calculus of the Modulus of Elasticity in a non-destructive way.

Designer's signature

Supervisor's signature

Sheet title: **Introduction and PCB renders**

Project title: **TIK_HandheldDevice.PrjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-07-29** Revision: **0.6** Sheet 2 of 21

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SECTION	SHEET

Changelog

Revision 0.6 | 2022-07-29

NEW

- Completed documentation (final version)
- Added a DCDC converter substitute IC.
- Updated block diagram.

FIXED

- Changed 3D models to fit the real board.
- Added circuits' correction notes for future development.

Revision 0.5 | 2022-06-07 [MANUFACTURED VER.]

NEW

- Added multilayer connector to the battery
- Added a power budget & battery selection
- Adjusted the charging current resistor value of the TP4056.
- Added a expansion port and load cell connectors footprints. (4-pole jacks).
- Added support for jack plug switches.
- Applied JLCPCB design rules via .rul file.
- All vias are tented to avoid corrosion.
- Added detailed explanation of trace design with Saturn PCB toolkit.
- Applied a nice format to the BOM.
- Added an introduction, updated renders.
- Added mechanical drawings with 3D isometric views, part drawing views, measurements, layer stackup, drills, etc.
- Added Gerber and NC Drills fabrication jobs for ordering PCB and its stencil.

FIXED

- Corrected LEDs' series resistors values
- Relocated the battery below the PCB. This makes the product wider, but solves a lot of space constraints.
- Removed VBIAS plane to avoid splitting planes, for EMI considerations.
- A lot of cosmetic improvements and corrections on PCB top & bottom overlays.
- Replaced logos and added new ones.
- Improved routing.
- A few cosmetic changes on the schematic sheets and cover.
- Removed rooms.
- NTC connector changed, now it's meant for soldering the NTC cable from a battery.

Revision 0.4 | 2022-05-22

NEW

- Added parameters for fabrication groups and fabrication order
- Added a Bill of Materials. The one in this document is simple. Refer to the manually configured BOM of this project.
- Added a PCB track legend and description for visible layers.
- Given more info about ESP32 pins.
- Added a precise block diagram.
- Added support for an extension port.
- Added a HX711-based load cell adquisition system.

FIXED

- Corrected I2C pins on the ESP32.
- Removed "same length" directive on UART and I2C nets.
- Improved routing.
- Removed via shielding on I2C traces.
- Solved all DRC warnings and errors.
- Avoided disrupting the ESP32's strapping pins default configuration during boot.
- Corrected a pin assignment error between the schematic symbol and the footprint of the MDJ210 PNP BJT transistor.
- Removed PCB cutouts.

Revision 0.3 | 2022-04-28

NEW

- Changed rotary encoder vertical for horizontal, side-placed, SMD type multipurpuse 'thumb button'.
- Added a explanation of PCB trace widths.
- Adopted JLCPCB design rules.
- Full PCB component placement and routing, with no important DRC messages.
- Added silkscreen logos to the back of the PCB, as well as port markings, information and regulatory graphics: CE, WEEE, ESD sensitive warning and RoHS.

FIXED

- Changed numerical test point designators to net/rail names, to be quickly identified.
- Changed LEDs footprints.
- Corrected a faulty connection on the DW01A Lithium battery protection IC.
- The MCU has no longer the possibility to stop battery charging. This is because the ENABLE signals required by the chargers work on 5V and this could cause damage to the ESP32.

Revision 0.2 | 2022-04-23 [FIRST PCB]

NEW

- Schematic hierarchy and block diagram.
- Initial PCB layout
- Added a vertical rotary encoder. PCBLib contains a 90-degree alternative.
- Added an alternative Ni-MH charger.
- Added footprints for all neccessary components to the PCB Library.
- Added explanatory footprints and photos to schematic ICs.
- Added board mounting holes (making use of the TFT LCD module mounting hole positions)
- Added test points
- Added fiducials
- Added a power-up button
- Added net classes and parameter sets to most important nets: power, digital communications, analog signals, etc.

FIXED

- Removed errors in the lithium charger
- Removed errors in the adequation circuit
- Changed ESD USB Protection IC.
- Changed some adequation circuit values and made topology more clear.
- Revised all passive components values and sizes to match existing component disponibility.
- Corrected various pin definitions from the ESP32-WROOM-32D symbol

REVISION 0.1 | 2022-04-01 [FIRST VERSION]

NEW

- TFT LCD / SD card connections.
- First adequation circuit iteration
- LiPo battery charger with TP4056
- Auto programming circuit.

FIXED

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Document index and revision history

Detailed changelog and complete document sheets index.

All along the schematic pages, a sheet title and description will be written on this corner.

Designer's signature

Supervisor's signature

Sheet title:	Changelog and document index
Project title:	TIK_HandheldDevice.PrjPcb
Desginer:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6

Supervisor:
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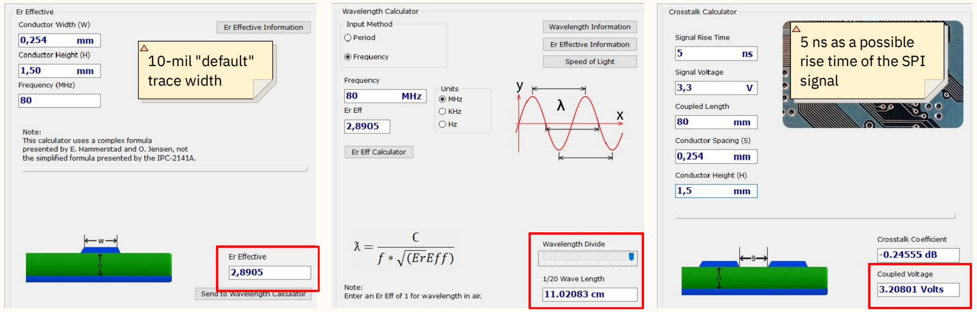
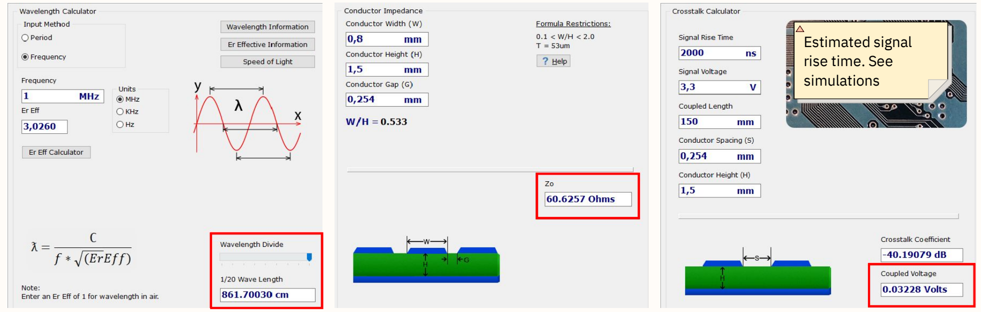
SPI traces (@ 80 MHz, digital)



SPI traces should not be longer than this result to avoid a transmission line. Note that this is rather a pessimistic value, as we are dividing the real wavelength by 20. Er Eff has been estimated with the expected fabrication characteristics.

As you can clearly see, a 2-layer, 1-6 mm height PCB is not great for signal integrity. We have great crosstalk between SPI lines. A common solution is to include GND copper between SPI lines with good connection to ground. This can be achieved by using via shielding.

Sensor analog signals (1 MHz max BW)

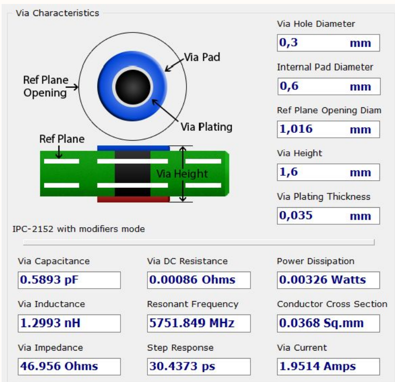


Er_Eff calculated with a 0.8 mm wide trace. Trace lenght will not be a problem.

We cannot totally match the 50-Ohm impedance of the cable but are fairly close. Besides, this is not by any means crytical in a low-speed design such as these, and there's no impedance control on the end of the lines

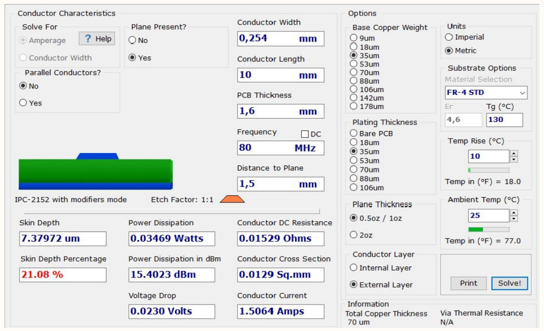
Crosstalk and EMI can be a problem given the needed precision. Place these far from high-speed, with via shielding, as well as a good GND/power planes below.

Via characteristics



We are using only use one type of via. We are far from the resonant frequency and the step response is very fast. Parasites are very low. In DC it can stand the required amount of current. Nevertheless, it should be always used various in parallel to ensure a low resistance path for power and returning currents.

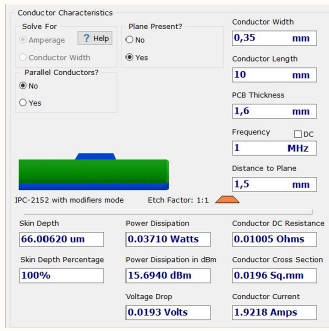
0.254 mm (10 mil) traces



Trace AC/DC characteristics in one centimetre of trace for a given frequency/DC and for a trace temperature increase of 10 ºC over a standard ambient temperature of 25ºC in a FR-4 dielectric.

0.254 mm (10 mil) is the default trace width. It's thin so we can save space, but has the worst DC characteristics and should not be used for power. These are the kind of traces used by by the SPI bus. The skin depth is not optimal but this will depend on frequency and again, AC current is not a crytical aspect here. It's a "good enough" approach.

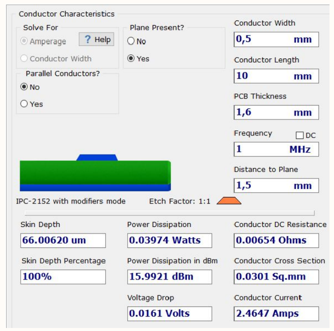
0.35 mm traces



0.35 mm traces are used by connecting power pins to the power net in low-power components whose pins are very close together and cannot fit a trace of more width without breaking design rules.

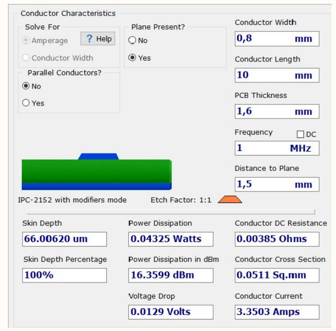
This trace width has good properties and can be used even for low-speed analog signals if needed.

0.5 mm traces



This is an optimal width in terms of area/specs for power delivery as it can withstand a lot of current (more than the system will continuosly need) with low losses.

0.8 mm traces



This trace width is employed by the analog signals to maintain good signal integrity at low line impedance.
It can also be used as a power main bus for ensuring low power losses across a distance and for devices with a pulsed, agressive power consumption such as the ESP32 and the LCD.

Trace & via characteristics

Trace width based on results from PCB Toolkit by Saturn PCB Design INC.
Used JLCPCB 2-layer, FR-4, 1.6 mm height, 35 um conductor height (1 oz/ft^2) board characteristics as reference.

Designer's signature	
Supervisor's signature	
Sheet title:	Trace width design
Project title:	TIK_HandheldDevice.PrjPcb
Desginer:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6
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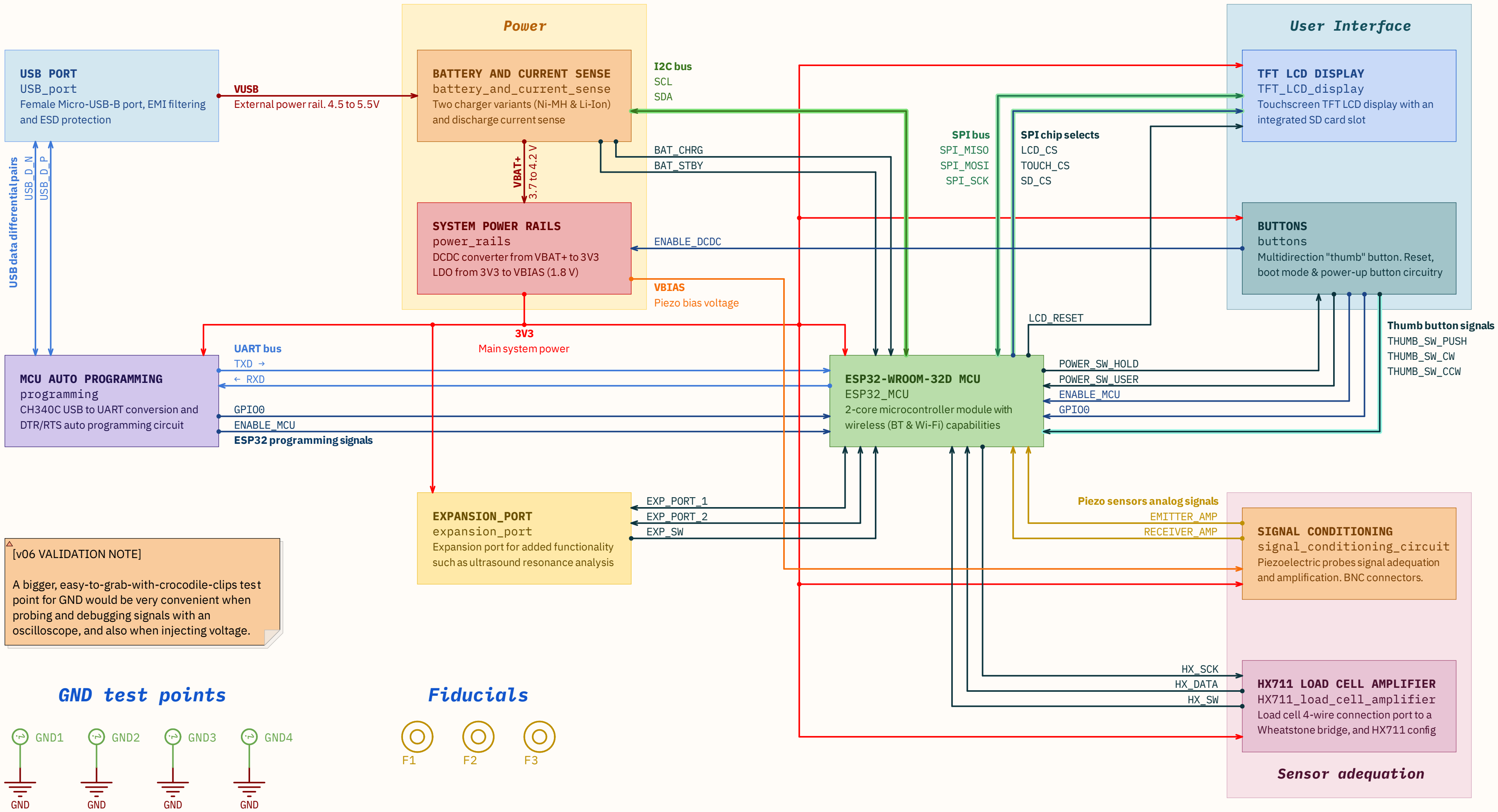

System blocks organization and connections

The project's global block diagram. Arrows show how modules are interconnected and include net names.
PCB includes 3 fiducials for fabrication purposes. GND test points are distributed along the PCB for easy access.

Designer's signature

Supervisor's signature

Sheet title:	System blocks organization and connections
Project title:	TIK_HandheldDevice.PrjPcb
Desginer:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6
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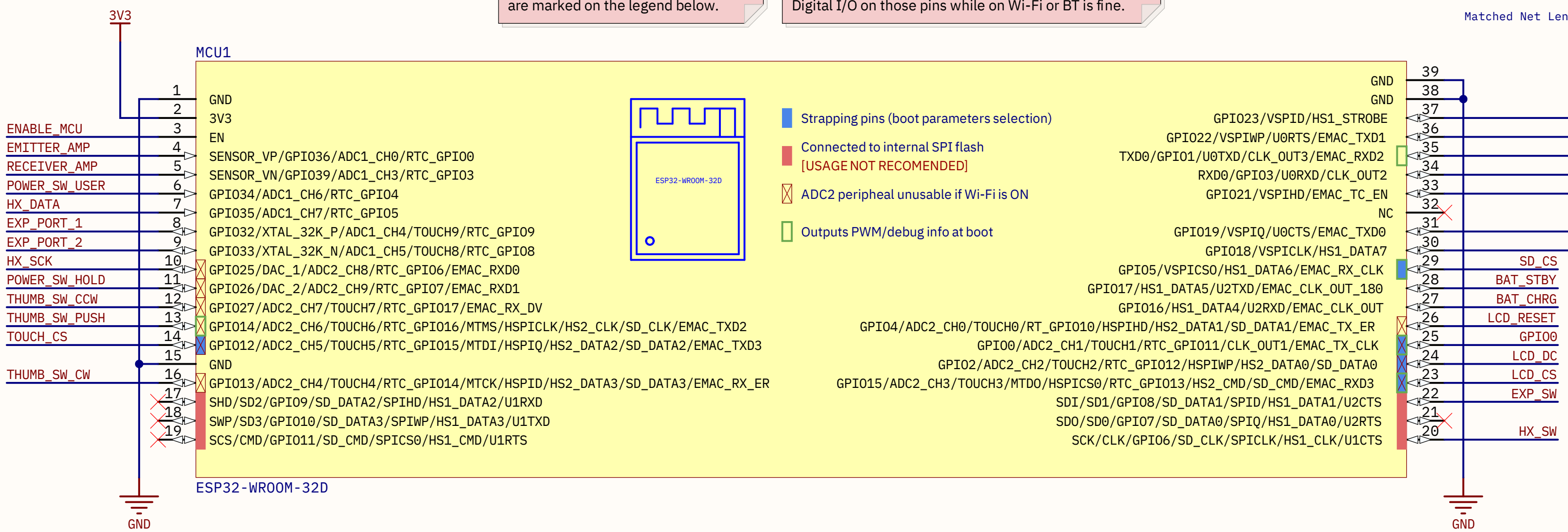
Some ESP32's pins behave in a way that prevent using them freely. They are marked on the legend below.

The ADC2 peripheal is not usable while using Wi-Fi or Bluetooth and should be left unused if not necessary. Digital I/O on those pins while on Wi-Fi or BT is fine.



Default I2C pins are in use [SDA: GPIO 21, SCL: GPIO 22] but we can map any other pins as hardware I2C.

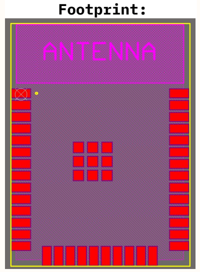
Three devices are connected simultaneously to the SPI interface: TFT LCD screen IC, touchscreen IC and SD card reader.

Strapping pins digital state are registered during reset and modify the boot sequence parameters according to the [ESP32 datasheet, table 5, page 21].
We must make sure that if pull-up/down resistors are connected to these pins (i.e for buttons) they do not alter the default configuration unintentionally.

Voltage of Internal LDO (VDD_SDIO)					
Pin	Default	3.3 V		1.8 V	
MTDI	Pull-down	0		1	
Booting Mode					
Pin	Default	SPI Boot		Download Boot	
GPIO0	Pull-up	1		0	
GPIO2	Pull-down	Don't-care		0	
Enabling/Disabling Debugging Log Print over U0TXD During Booting					
Pin	Default	U0TXD Active		U0TXD Silent	
MTDO	Pull-up	1		0	
Timing of SDIO Slave					
Pin	Default	FE Sampling FE Output	FE Sampling RE Output	RE Sampling FE Output	RE Sampling RE Output
MTDO	Pull-up	0	0	1	1
GPIO5	Pull-up	0	1	0	1

Real model:

Footprint:



[v06 VALIDATION NOTE]

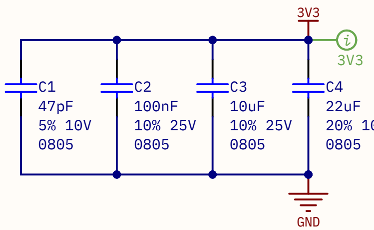
Footprint is adequate, no soldering errors found. SPI, I2C, UART and USB-to-serial work as expected. Programming circuit works and we can upload programs after cutting some tracks (see validation note on the right). Buttons are read correctly. ADC1 can register analog signals correctly.

Following the [ESP32-WROOM-32D datasheet, page 9] GPIO6 to GPIO11 (pins 17 to 22) will remain floating as they are connected to the integrated SPI flash memory and its usage is not recommended for other uses.

Although not recommended, GPIO6 and GPIO8 are used for a very basic task: reading plug switches.

[v06 VALIDATION NOTE]

The jack connector switches interfere with the SPI flash during programming resulting in a programming error. A different circuit (which doesn't pull up these pins) would be needed. As a temporary solution, both EXP_SW and HX_SW tracks were cut in the PCB.



Recommended bucket/bypass capacitors are 0.1 µF and 10 µF, ceramic, low ESR. Should be placed close to the chip and with short return paths. [ESP32-WROOM-32D datasheet, page 21]

Added one extra MLC 22 µF electrolytic cap to filter current spikes during ESP32 RF usage and a small 47pF capacitor to be more effective filtering high frequencies

ESP32-WROOM-32D MCU, Wi-Fi + Bluetooth module

This module integrates an ESP32-D0WD chip, a 240 MHz, dual-core processor with Wi-Fi and Bluetooth capabilities. This sheet describes its hardware configuration and I/O pins

Designer's signature

Supervisor's signature

Sheet title:	ESP32-WROOM-32D MCU
Project title:	TIK_HandheldDevice.PrjPcb
Desginer:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6

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3.3 V rail: main system power

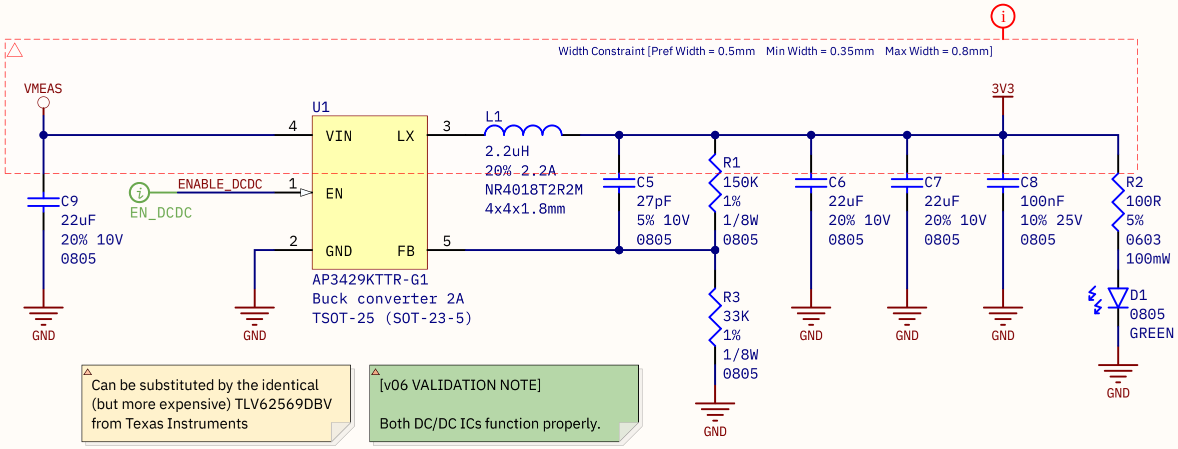
Typical Application Circuit. [AP3429/A datasheet, page 2]
with some values modified as needed and/or part availability.
Capacitors should be placed close to the chip and circuit should be traced in short loops.

Feedback voltage V_FB is regulated at 0.6 V.

Resistors are adjusted as a voltage divider. So, if 3.3V are needed at the converter output:

V_FB = 0.6V = V_out · (R2)/(R1+R2)
Thus, R2 = 2/9·R1

Resistor values must be high (kOhms) in order to maintain a low power consumption on the feedback circuit.

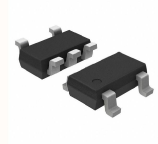


Can be substituted by the identical (but more expensive) TLV62569DBV from Texas Instruments

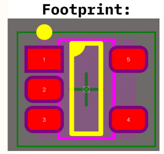
[v06 VALIDATION NOTE]

Both DC/DC ICs function properly.

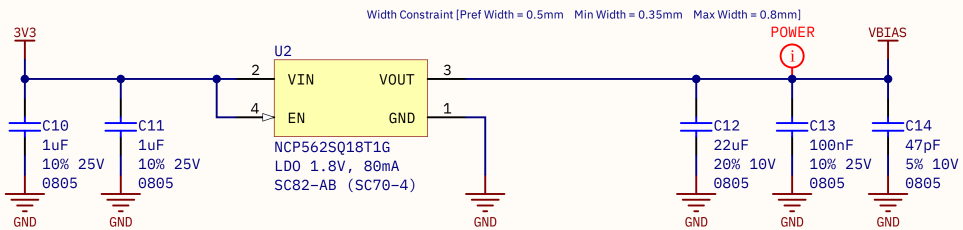
Real model:



Footprint:

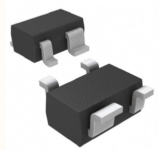


1.8 V rail: Vbias for signal conditioning circuit

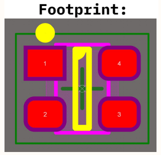


Usage of multiple input capacitors to reduce ESR and ESL. Recommended Cin is 1 uF. There are no recommended values for Cout but these 3 caps should probe more than enough for low ESR and ripple reduction at a wide frequency range.
Datasheet specifies a typical 100 uVrms noise on Vout, somewhat high.

Real model:



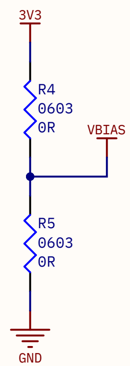
Footprint:



[v06 VALIDATION NOTE]

The LDO works as expected.

Optional 1V8 rail bypass jumpers



IMPORTANT:
1V8 rail is bypassable by soldering these optional 0-OHM resistors. This is for experimenting with different voltages and if it affects the overall performance of the adquisition circuit.

Do NOT connect both 0R resistors at the same time or it will jump VCC and GND. And keep the LDO disabled at all times.

This can also be used to insert a voltage divider. i.e.: if you want to reduce the rail voltage to VCC/2 you only have to add two >= 10 KOhm 0603 resistors. Just keep in mind that voltage won't be as stable as in a LDO as it will be greatly dependent on the load impedance.

If you do this, populate the LDO's output caps, so VBIAS it behaves as a small-signal GND.

Power rails

Battery DC/DC step-down converter and Vbias for signal conditioning circuit. 3V3 is the main system power and can deliver upto 2 amps. VBIAS is only for polarization of the probes and won't drag much current.

Designer's signature	
Supervisor's signature	
Sheet title:	Power rails
Project title:	TIK_HandheldDevice.PrjPcb
Desgniner:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6
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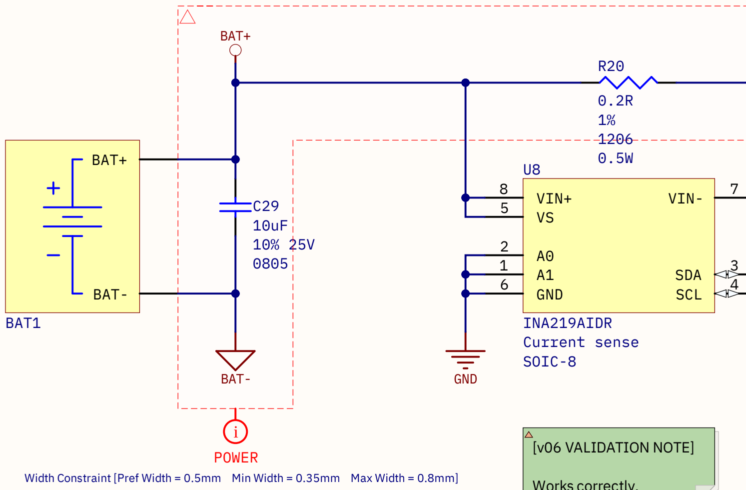
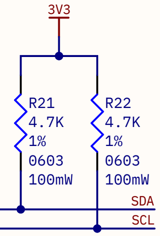
Battery output current sense and voltage monitor. Charger selection jumper. Battery thermistor

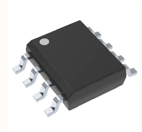




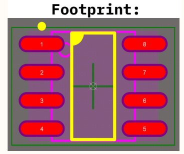
[v06 VALIDATION NOTE]

Works correctly.

Real model:



Footprint:

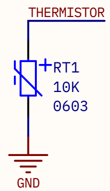


I2C bus termination resistors

Device's I2C address: 100000 (0x20) [INA219 datasheet, page 10, table 2]

All the current that passes by the battery also goes through the current sense resistor. When it's positive means that the battery is discharging and when it's negative means that it's charging. INA219 also reports the battery voltage.

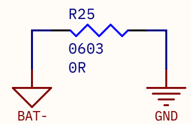
This way we can monitor via software the energy the battery receives and supplies, building a BMS (Battery Monitoring System)



Battery NTC Thermistor, shared by both chargers. If not integrated onto the battery itselt (third cable), short the pads.

[v06 VALIDATION NOTE]

Unverified as our battery does not has an NTC.



IMPORTANT: jumper for charger selection.

The battery connector is shared by the two possible chargers. However, on the Lithium charger BAT- is NOT connected to the system's global GND; but in the NiMH charger it is.

So, jump these pads ONLY IF USING THE NiMH charger.

Battery charging circuit variants

Two circuit variants are implemented BUT NOT USED SIMULTENEOSLY. Only one must be populated at a time.

The usage of one over the other will come by component disponibility.

[v06 VALIDATION NOTE]

The Lithium charger works fine for Li-Po batteries. Sometimes the protection circuit trips when using an external power supply. A workaround is lowering the voltage below 3 V and raising it again slowly until it powers on again. The Ni-MH charger remains untested.

CHARGER VARIANT #1: NiMH
battery_charger_Ni_MH
Charger to populate if battery chemistry is Nickel-Metal Hydride

CHARGER VARIANT #2: Li-Ion
battery_charger_Li-Ion
Charger to populate if battery chemistry is Lithium-Ion or Lithium-Polymer

Charging status indicator

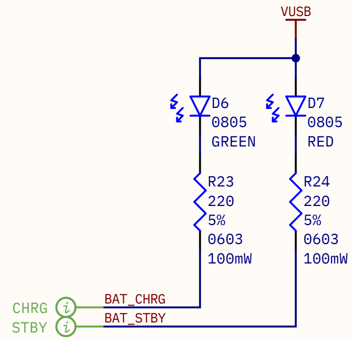
These signals come from both charging IC's.

They are status outputs that are normally on high impedance and they are pulled LOW when activated.

We can use these pins to turn on some LEDs and to notify the microcontroller of the charging status.

[v06 VALIDATION NOTE]

They do not light properly, probably due to a soldering problem. Revision pending.



Battery and current sense

Two circuit variants that will be implemented but not used simultaneously. The usage of one over the other will come by component disponibility. INA219 current sensor is independent and common for both systems.

Designer's signature

Supervisor's signature

Sheet title:	Battery and current sense
Project title:	TIK_HandheldDevice.PrjPcb
Designer:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6

Supervisor:
Sr. Andrés Roldán Aranda
Dpto. Electrónica y Tecnología de Computadores
University of Granada
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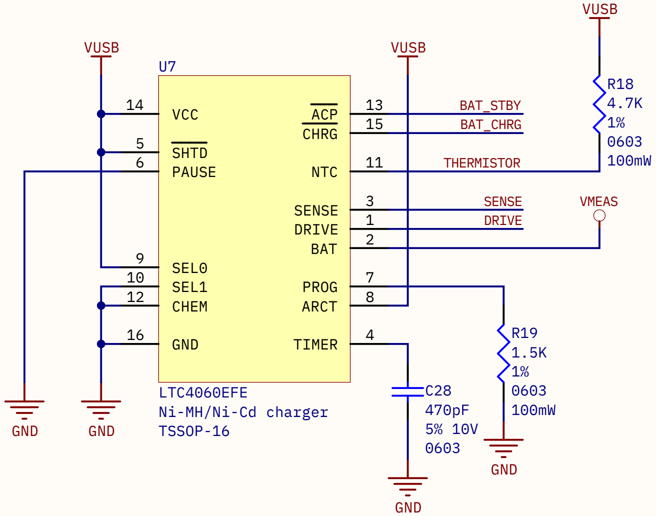
NiMH/NiCd battery charger IC

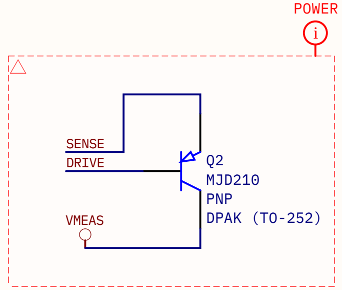
External PNP BJT current driver

[v06 VALIDATION NOTE]

NOT POPULATED AND UNTESTED.

We can control the charging by pulling LOW the SHTD. This pin is normally pulled up (shutdown disabled).





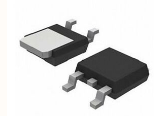
Following the [LTC4060 datasheet, page 13], if using a 10 K NTC thermistor, Its RHOT should be 4.42 kOhm, 1% to trigger the temperature warning at 45 ºC.
However, this value being too much specific is problematic.

This can be disabled by connecting a 0-ohm resistor in place of the thermistor.

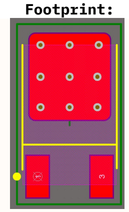
[CURRENTLY NOT IMPLEMENTED] This IC can do power path control. This is, to power the load from external source while charging the battery.

DRIVE pin on the LTC4060 provides a controlled sink current that drives the PNP base.
So, it's not necessary to have a base resistor.

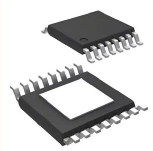
Real model:



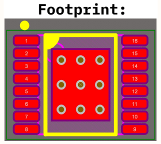
Footprint:



Real model:



Footprint:



TIMER capacitor and PROG resistor program the charge Tmax (maximum charging time, a security measure). [LTC4060 datasheet, page 13]. These values should complete a full charge in at most 1 h 6'

PROG resistor programs the maximum current that the battery will receive while charging. For 1.5 kOhm this is 0.93 A.

These parameters are heavity dependant of battery capacity. A larger battery cell package should receive more time / current.

i.e.: a 1000 mAh battery will charge at approx 1C with this configuration, but can be insufficient time for a 3000 mAh one.

Battery charging circuitry for Ni-MH

Battery charger circuit variant #1. By default the device uses a Nickel-metal hydride battery which are chemically and thermally more stable (and safer) than Lithium-based ones; at the cost of a lower charge/volume ratio.

Designer's signature	
Supervisor's signature	

Sheet title:	Battery charger		
Project title:	TIK_HandheldDevice.PrjPcb		
Designer:	Juan Del Pino Mena		
Date: 2022-07-29	Revision: 0.6	Sheet 9	of 21

Supervisor:
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Lithium battery charger IC

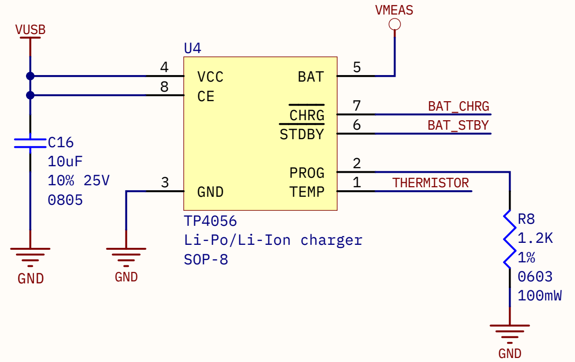
The TP4056 datasheet recommends to connect a resistor of 0.2 to 0.5 Ohm between VUSB and its VCC pin. It does not explain why, but probably for chip temperature concerns.

However, it is omitted as we don't have any resistor of these values available. As a note: not a single commercial TP4056 charger module uses any resistor at all (and they work fine at higher charge rates).

The TP4056 is only specified for charging single-cell Li-Ion batteries on its datasheet. However, many sites, forums and online stores list TP4056-based modules as compatible with both Li-Ion and Li-Po given the chemistry similatiry. Take this with caution.

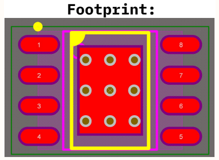
Resistor in PROG regulates the maximum battery charging current. At 2 kOhm, this is 580 mA. At 1 kOhm, it is > 1 A. Change according to battery capacity. [TP4056 english datasheet, page 3]

TEMP expects a NTC thermistor (of unspecified value). On some Lithium-Ion batteries this NTC can be integrated on the package.



Real model:

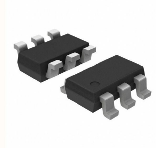
Footprint:



This device will get hot, and has a thermal pad to dissipate to PCB GND plane

Lithium battery protection

Real model:



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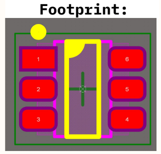
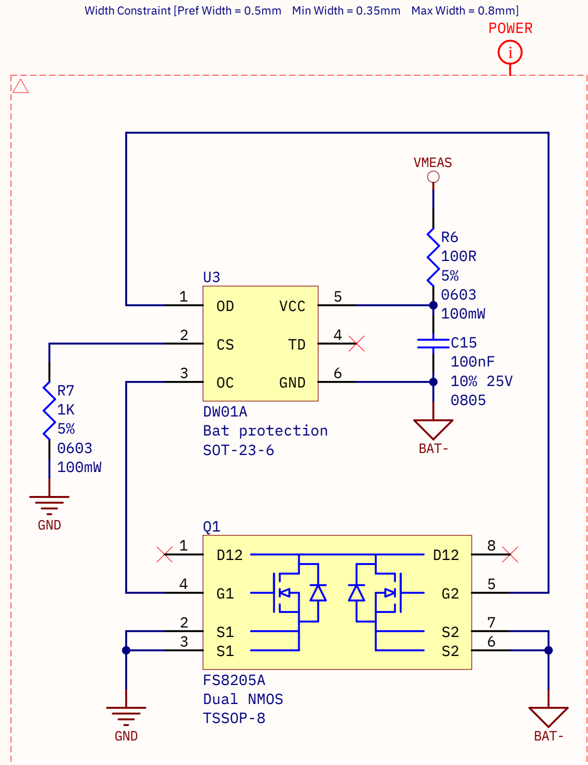


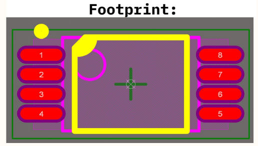


[v06 VALIDATION NOTE]

This charger works correctly and protection circuit trips under 2.8-3 V. Tested using a single-cell lithium-polymer battery.

Real model:

Footprint:



Battery charging circuitry for Li-Po & Li-Ion

Battery charger circuit variant #2. Li-Ion and Li-Po batteries offer much more power density at the cost of inestability. This circuit must NOT be placed if the Ni-MH charger is present on the board (and vice-versa).

Designer's signature

Supervisor's signature

Sheet title:	Battery charger
Project title:	TIK_HandheldDevice.PrjPcb
Designer:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6

Supervisor:
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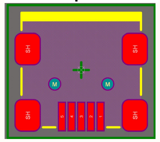
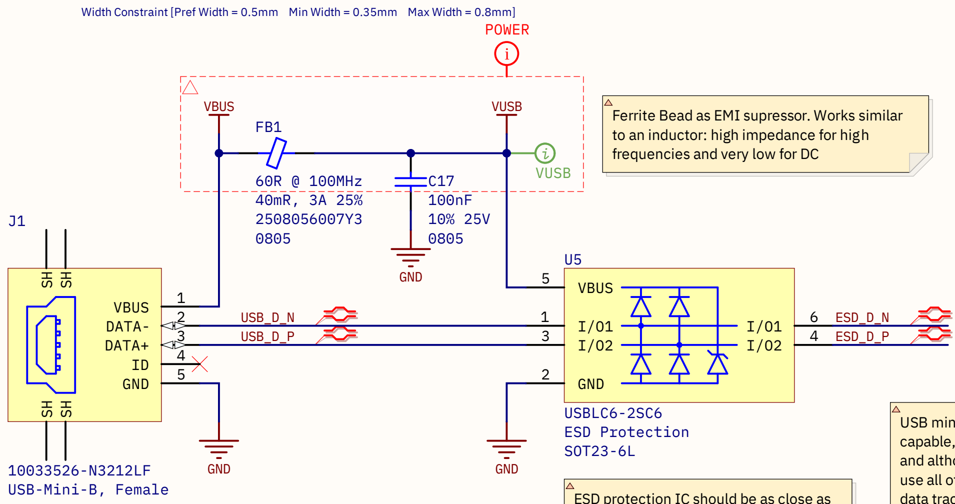
'SH' pads are the USB connector metal shield, which is structural. This particular connector has 4 which are not connected to any circuit traces, not even GND. In any case, it should be connected to the device's metal chassy (as a faraday cage).

An USB-Mini-B has been chosen for various reasons:
- Over an USB-micro: because of the structural robustness of the mini-B.
- Over an USB-Type-C: because of the ease of implementation, less pins, and to make clear this device is not a host.

Real model:

Footprint:





Ferrite Bead as EMI supressor. Works similar to an inductor: high impedance for high frequencies and very low for DC

USB mini-B is USB 2.0 capable, fairly high speed, and althought we may not use all of its capabilities, its data traces need special attention as they are differential.

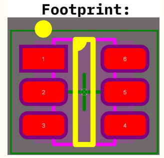
ESD protection IC should be as close as possible to the USB connector to avoid damaging any other circuits.

[v06 VALIDATION NOTE]

The selected USB-mimi-B port is very stiff and has a good quality of construction, however one must be cautious while soldering as its plastic can melt resulting in an unusable connector.

Real model:

Footprint:



USB connector and ESD protection circuit

USB is used as a programming interface, as well as a power source for the charging circuit. Since it's an external connector, it needs to have a protection circuit against electro-static discharge (ESD) and noise.

Designer's signature	Sheet title: **USB connector and ESD protection circuit**
	Project title: **TIK_HandheldDevice.PrjPcb**
Supervisor's signature	Designer: **Juan Del Pino Mena**
	Date: **2022-07-29** Revision: **0.6** Sheet 11 of 21

Supervisor:
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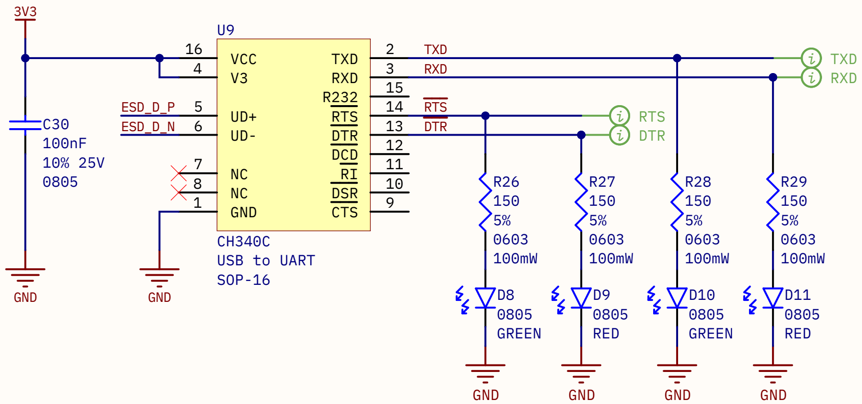
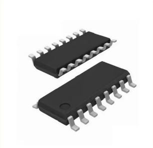
USB to UART conversion



Real model:



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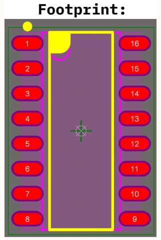


These LEDs serve as a visual testimonie of UART communication and help during debugging.

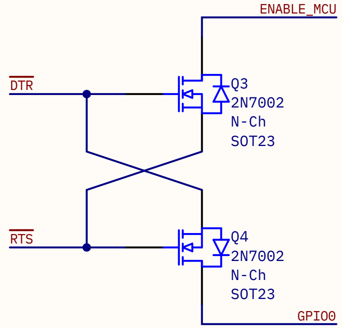
If they drag too much current they can be used with 1 kΩ resistors or be completely disconnected.

Should not be present on a commercial product.

[v06 VALIDATION NOTE]

This IC works correctly. However, debug LEDs are both not very visible (they blink fast for short times) and not very useful (sometimes redundant), so they can be removed.

Auto programming circuit



ESP32 GPIO0 is a Strapping pin. Strapping pins modify the device's boot mode during chip reset. GPIO0 is pulled up during reset by default. ENABLE_MCU is pulled up by an external pullup resistor

When GPIO0 is HIGH, it boots from internal SPI memory, but when it's LOW the boot sequence changes to 'Download' and we can upload a program to the MCU.

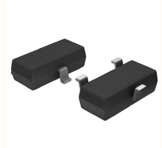
[ESP32 Datasheet, section 2.4, pages 19-20]

Circuit truth table

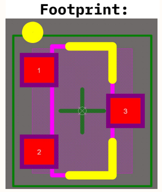
DTR	RTS	ENABLE_MCU	GPIO0
0	0	1	1
0	1	1	0
1	0	0	1
1	1	1	1

*(DTR, RTS active low)

Real model:



Footprint:



[v06 VALIDATION NOTE]

This circuit works correcly, the programming signaling sequence (RESET to Low, then GPIO0 to low) is correct and we can program the MCU.

USB to UART and MCU programming

This circuit allows a computer to the ESP32 via USB so it can be reprogrammed. This is possible by sending RTS and DTR signals with a determined timing so the device enters an alternative boot mode.

Designer's signature	
Supervisor's signature	
Sheet title:	USB to UART and MCU programming
Project title:	TIK_HandheldDevice.PrjPcb
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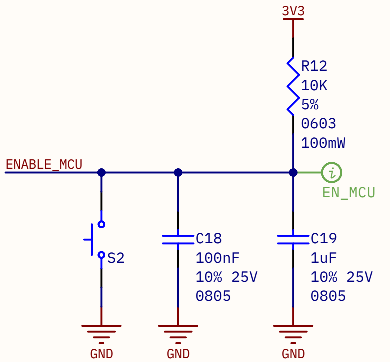
Reset

To ensure power stability to the microcontroller during powerup, this RC filter introduces a delay on the ENABLE pin. Usual values are 10 kΩ, 1 µF (τ = 10 ms, t_{10-90} = 22 ms).
[ESP32-WROOM-32D datasheet, page 22]



[V06 VALIDATION NOTE]

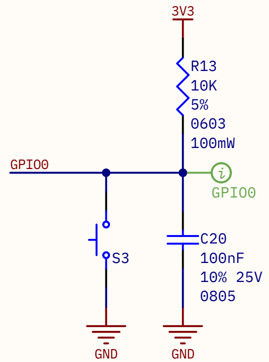
These buttons function properly.

POWERUP BUTTON
powerup_button
Power-up button circuitry for enabling the DCDC buck converter

Boot mode selection (debug)

Allows to force 'Download' boot sequence

Same design as in ESP32 DevKit boards.
100 nF cap are for debouncing and should be placed close to the buttons

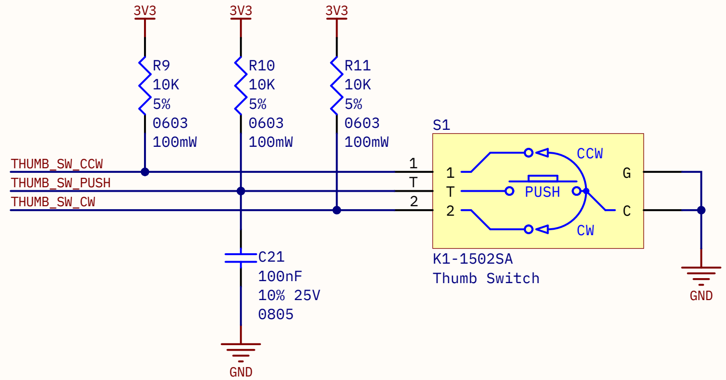


Multidirection 'thumb' button (UI navigation)

Horizontal SMD device, multi-directional / muti-function rotary slider button. Accessed from the right side.

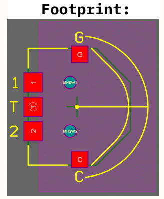
[V06 VALIDATION NOTE]

The 'thumb' button functions properly.



Real model:

Footprint:



Buttons

TIK buttons. Some of them are meant for debugging like boot mode selection and reset, and will not be accesible to the end user. The power-up button and the "thumb" button are meant to be part of the UI.

Designer's signature	
Supervisor's signature	
Sheet title:	Buttons
Project title:	TIK_HandheldDevice.PrjPcb
Desginer:	Juan Del Pino Mena
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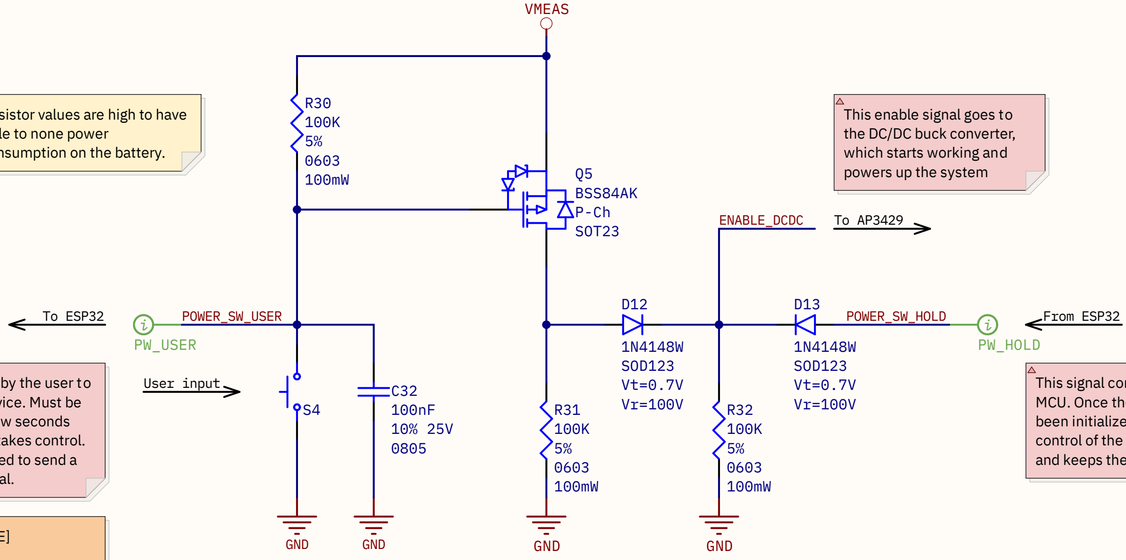
Resistor values are high to have little to none power consumption on the battery.

This enable signal goes to the DC/DC buck converter, which starts working and powers up the system



This is pushed by the user to turn on the device. Must be pushed for a few seconds until the MCU takes control. Also can be used to send a shutdown signal.

This signal comes from the MCU. Once the MCU has been initialized, it takes control of the enable signal and keeps the DC/DC ON.

[V06 VALIDATION NOTE]

In our tests, the node which this switch connects to exhibits a strong pull-down behaviour, son the PMOS is always active and so it prevents the system from turning off.

The most likely cause seems to be the microcontroller, which either pin has a non-high-impedance during startup that pulls-down the node; or it forces a certain voltage to its output.

In a later design, it should be tested on another pin.

When the button is not pressed, the tension in PMOS gate is BAT+; and thus V_sg is not greater than V_th and the PMOS is off.

When the button is pressed, gate voltage is GND, so V_sg > V_th and the PMOS turns on, letting the voltage rise on the diode anode and putting HIGH the ENABLE_DCDC net (enabling the DCDC converter).

This turns on the system and feeds the ESP32 (continues →)

The microcontroller boots over after the button has been pressed for a few seconds and pulls HIGH the POWER_SW_HOLD pin. The user can release the poweron button now.

The system will be on until the user sends a shutdown signal by software or by pressing this button again.

In this moment, the ESP32 will save all data and gets ready for shutdown. As last step, it pulls down POWER_SW_HOLD and the system powers off completely.

Powerup button

This circuit avoids using a power-up switch, which can shutdown the device without prior warning. The user pushes a button during a couple of seconds, in which the ESP32 will boot and keep the system on until a shutdown signal is sent.

Designer's signature

Supervisor's signature

Sheet title: **Powerup button**	
Project title: **TIK_HandheldDevice.PrjPcb**	
Desginer: **Juan Del Pino Mena**	
Date: **2022-07-29** Revision: **0.6**	Sheet 14 of 21

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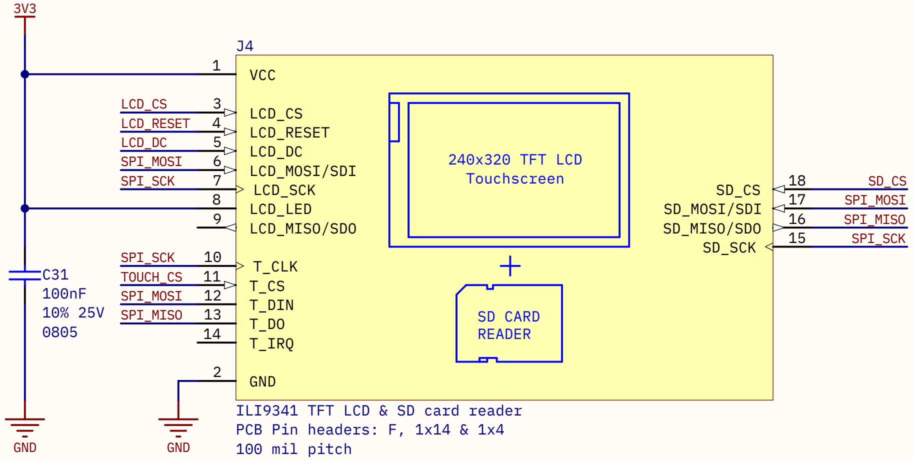
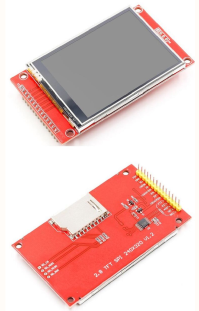
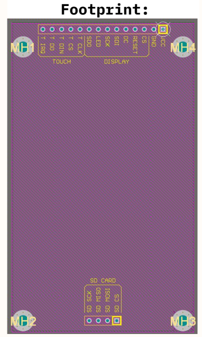


ILI9341 TFT LCD & SD card reader
PCB Pin headers: F, 1x14 & 1x4
100 mil pitch

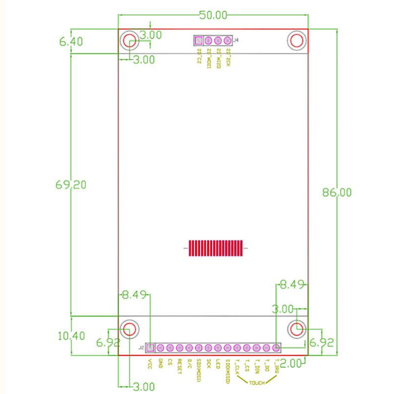
Real model:



Footprint:



As ILI9341 2.8" TFT LCD module has the bigger footprint and needs mechanincal support. Our PCB inherits its mounting holes position.



(Measures in mm)

[v06 VALIDATION NOTE]

Screen and touch works with no problems.

LCD TFT touchscreen & SD card reader

TIK uses an ILI9341 2.8" TFT LCD display module as a graphic user interface. This module has touchscreen capabilities and also integrates a SD card reader on one of its sides. All three elements are managed via SPI.

Designer's signature

Supervisor's signature

Sheet title:	LCD TFT touchscreen & SD card reader
Project title:	TIK_HandheldDevice.PrjPcb
Desginer:	Juan Del Pino Mena
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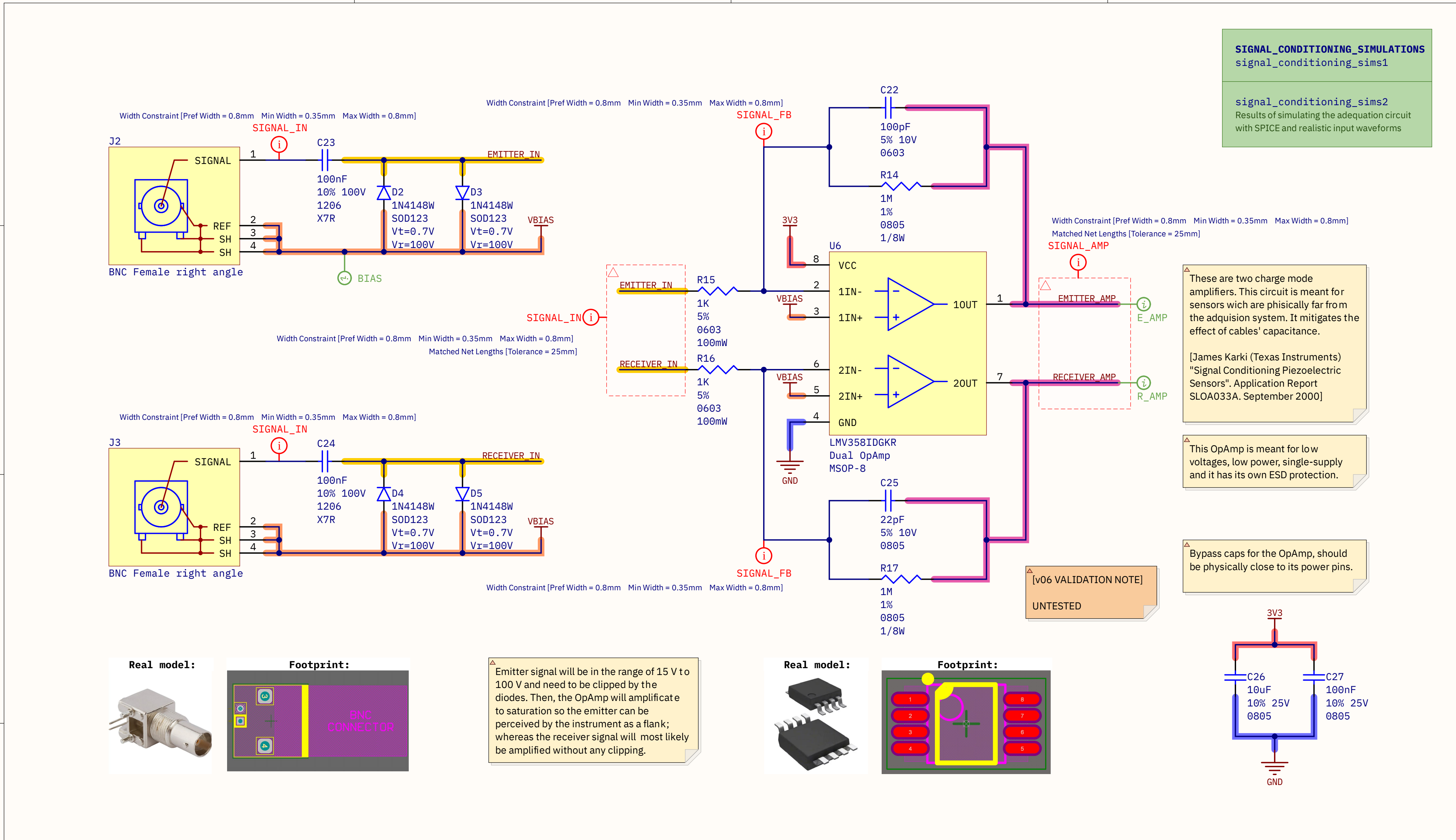

Piezoelectric sensors conditioning circuit

Two analog signals come from two piezoelectric sensors nailed into a tree or trunk. The way piezos work force us to use this circuit to convert charge into voltage. The piezo sensors used generated upto -100 V peak, so it needs clipping

Designer's signature

Supervisor's signature

Sheet title:	**Piezoelectric sensors conditioning circuit**
Project title:	**TIK_HandheldDevice.PrjPcb**
Designer:	**Juan Del Pino Mena**
Date: **2022-07-29**	Revision: **0.6**

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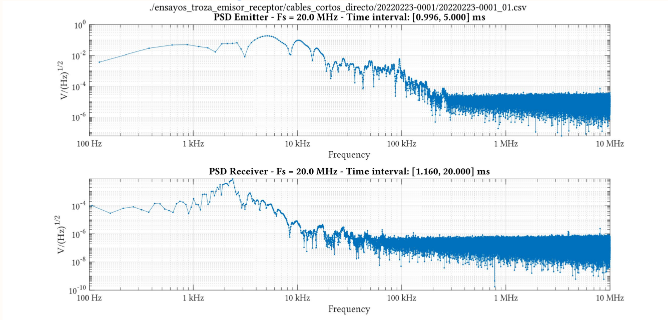
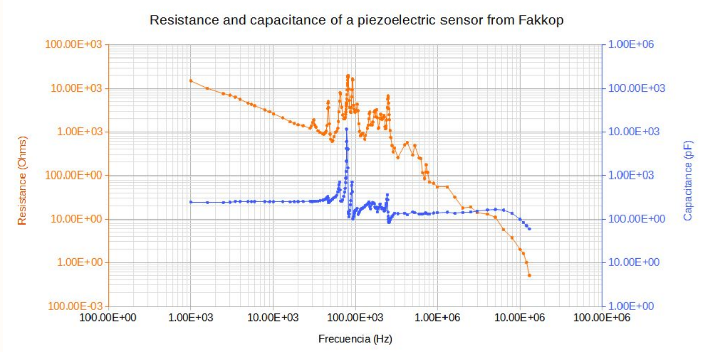
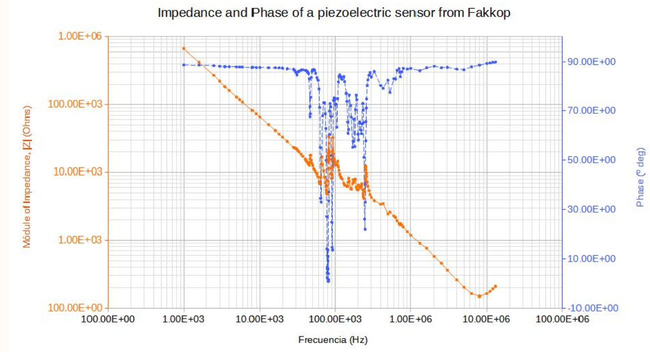
Trunk signal's Voltage Spectral Density

Example VSD of a generic trunk signal captured by the Piezoelectric sensors using an oscilloscope



Analyzed frequecy characteristic of Fakkop's piezoelectric sensors



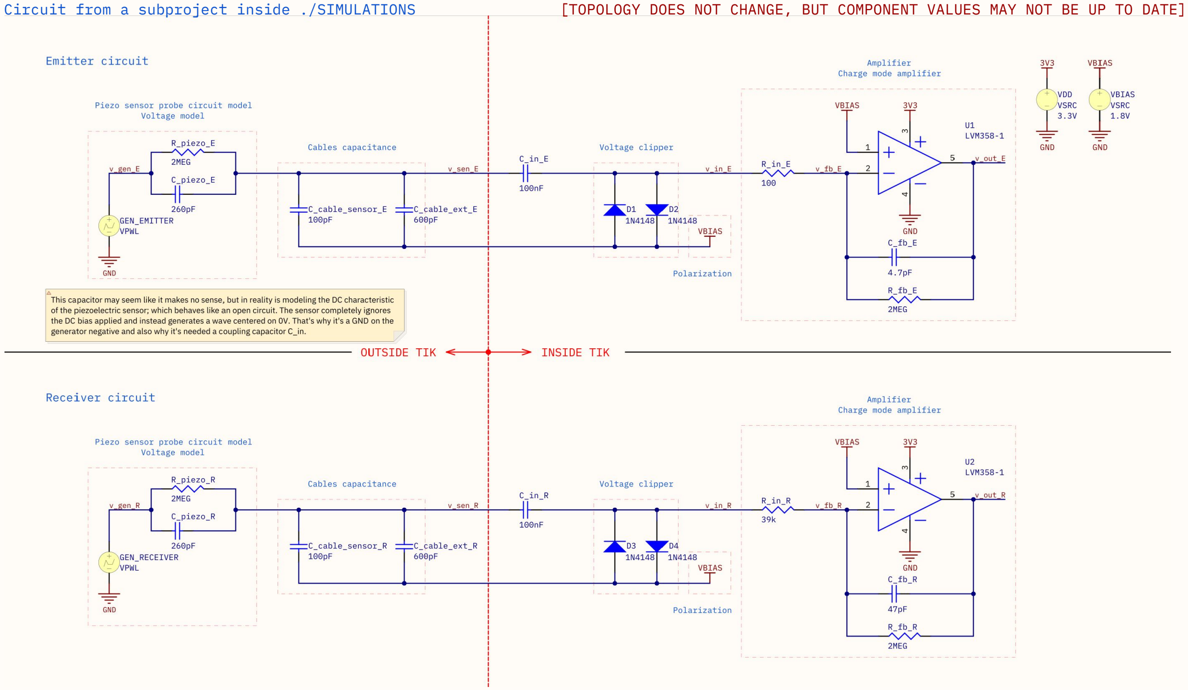


Circuit to simulate

Circuit from a subproject inside ./SIMULATIONS

[TOPOLOGY DOES NOT CHANGE, BUT COMPONENT VALUES MAY NOT BE UP TO DATE]

A piezoelectric is commonly modeled as a charge source in parallel with a resistor and a capacitor (charge model). This, however, is not practical for simulated analysis. Instead, we resorted to the voltage model, which is a voltage source in series with a resistor and a capacitor in parallel.



Nevertheless, in empirical analysis we found that our probes are far more complex than this simple model: They behave like an open circuit for DC (thus ignoring VBIAS). They have a great resistance and capacitance dependency on frequency, and a resonance around 100 kHz.

This is the reason behind the 100nF bypass capacitor. It allows us to center the input signals in the VBIAS DC voltage for our single-supply system. These caps should be rated for at least 50 V, as will have to stand a big voltage peak on their extremes.

Signal conditioning circuit simulations

SPICE simulations of the adequation circuit. These are only the results. You can find the simulation circuit and models on the ./SIMULATIONS/ folder inside this project.

Designer's signature	Sheet title: **Signal conditioning simulations. 1 of 2**
	Project title: **TIK_HandheldDevice.PrjPcb**
Supervisor's signature	Desginer: **Juan Del Pino Mena**
	Date: **2022-07-29** Revision: **0.6** Sheet 17 of 21

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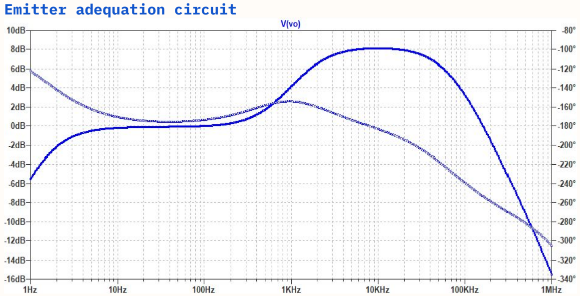
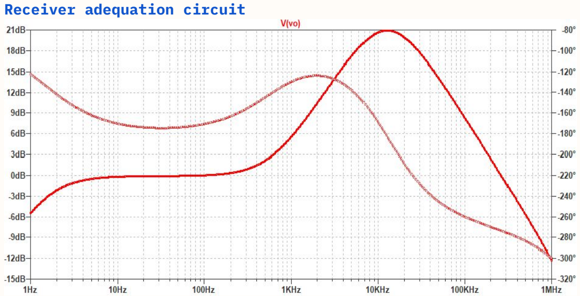
Expected frequency response

Emitter adequation circuit



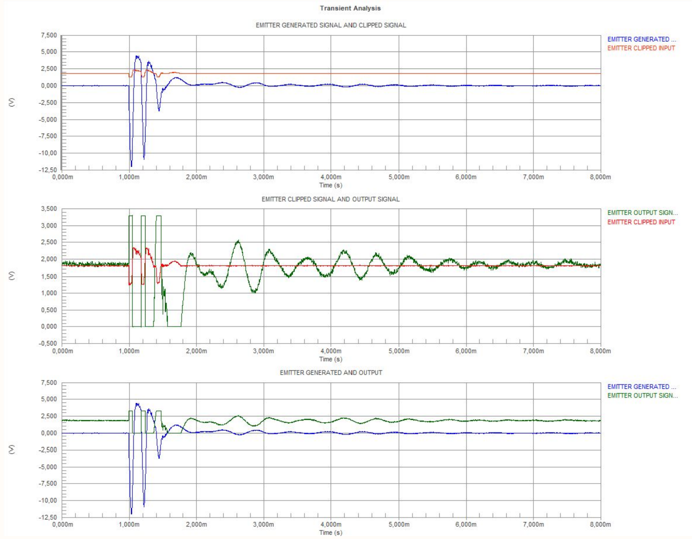
Receiver adequation circuit

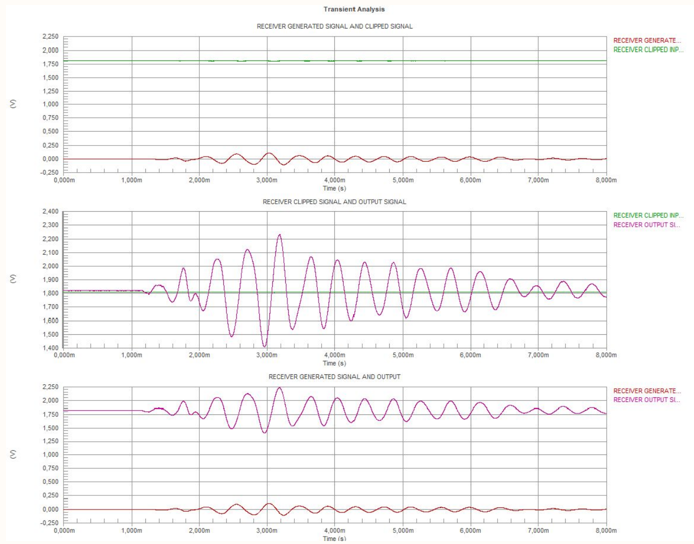


The adequation circuit for the emitter has more gain that it needs, so the output of the OpAmp is saturated.
This gives us a very step flank where the signal clearly begins and it's very easy to identify.
In this simulation it's clear that maybe it's not needed so much gain as the output is very noisy and could be easily false-triggered.

Expected transient behavior

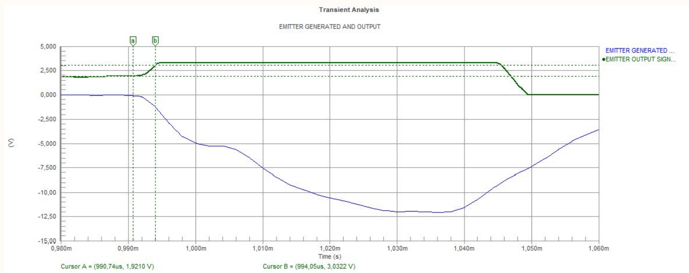
Emitter





The emitter input signal can be of 10 to 20 V if the piezoelectric probe is hitted softly and over 100 V if hammered hard. This voltage can damage electronics. As a countermeasure we use two 4148 diodes on the input that clip the signal to ±0.7 volts around VBIAS, allowing us to manipulate it without risk.

The receiver on the other hand has a very weak signal that needs to be amplified and centered over 1.8V.
We have to be more cautious in this case so we don't distort it as we have to sample and process it with precision.



Zoom over the first pulse. The expected rise time will be around 3 us, so the delay is of 1 TO 2 samples (Fs = 500 kHz)

Signal conditioning circuit simulations

SPICE simulations of the adequation circuit. These are only the results. You can find the simulation circuit and models on the ./SIMULATIONS/ folder inside this project.

Designer's signature	Sheet title: **Signal conditioning simulations. 2 of 2**
	Project title: **TIK_HandheldDevice.PrjPcb**
Supervisor's signature	Desgner: **Juan Del Pino Mena**
	Date: **2022-07-29** Revision: **0.6** Sheet 18 of 21

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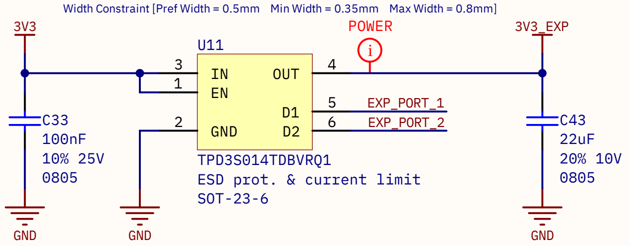
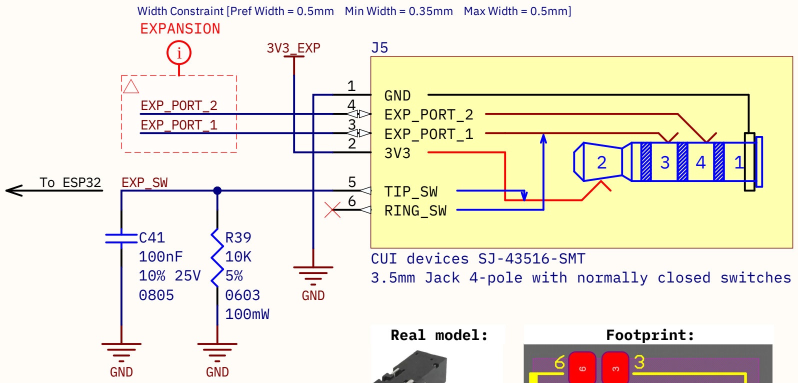
Current limiter and ESD protection



Since this is an external connector directly connected to the 3V3 rail, this will have a current limit switch and ESD protection IC to avoid damaging the device.

Expansion port connector

Expansion port pins are both Input/Output and are connected to the ADC1 so we give the maximum amount of functionality available to the expansion module.



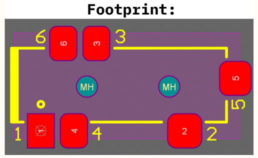
Plug detection switch circuitry operation: The switch is normally closed. So, normally EXP_SW is HIGH. When plugged in, the switch opens and EXP_SW will be LOW

[v06 VALIDATION NOTE]

UNTESTED

Real model:

Footprint:

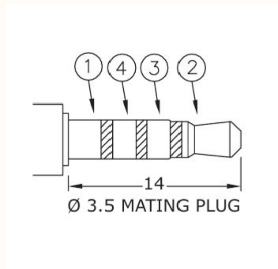


3.5mm jack connector considerations

We are using the 3.5mm jack connector in a non-standard application, as we are not transferring audio but power and/or analog and digital signals of different nature.

Nevertheless, we have adjusted the connector to somewhat fit the OMPT convention (GND in sleeve, signals in rings).

The mating socket and plug are connected as follows. In this connector series there is the possibility of upto 6 pads, the additional 2 pads being connected to switches for detecting the plug insertion. We only use the tip switch (pin 5) to allow using both the SJ-43516 as well as the SJ-43515 models. We prefer the 6-pad version as it offers more mechanical integrity. [CUI Devices SJ-4351X-SMT Datasheet, page 2]



Model No.	SJ-43516-SMT
Schematic	
PIN	
1	sleeve
2	tip
3	ring 1
4	ring 2
5	tip switch
6	ring switch

To avoid shorting GND and VCC, the 3V3 rail is located at the tip, so it will make contact the last. This also allows us to easily add the tip switch circuitry.

Expansion port & jack connector

Expansion port for added functionality, such as an ultrasould resonance analysis for wood boards.
Also, this sheet includes a description of the jack connector properties.

Designer's signature

Supervisor's signature

Sheet title: **Expansion port**

Project title: **TIK_HandheldDevice.PrjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-07-29** Revision: **0.6** Sheet 19 of 21

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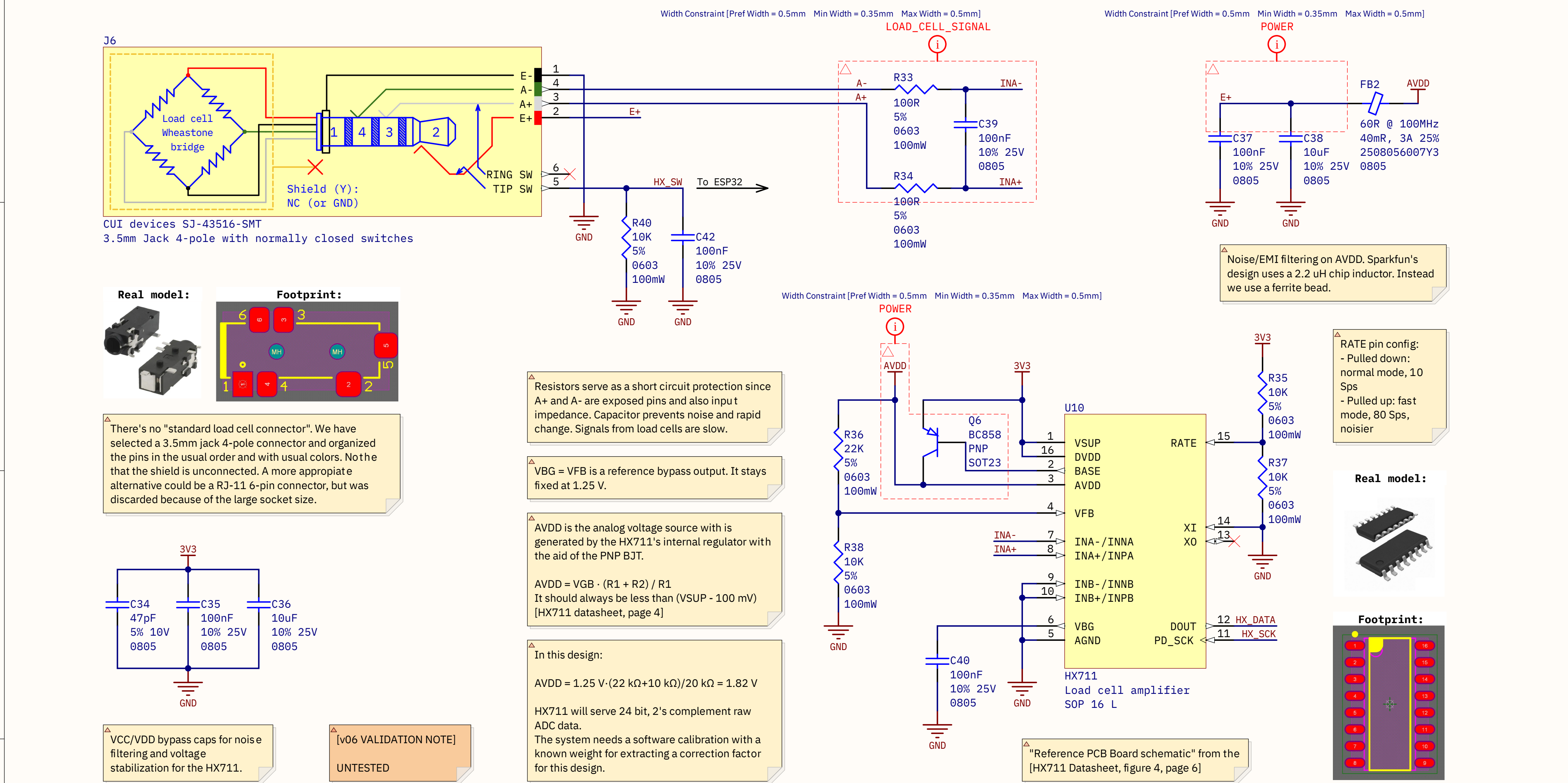

There's no "standard load cell connector". We have selected a 3.5mm jack 4-pole connector and organized the pins in the usual order and with usual colors. Nothe that the shield is unconnected. A more appropiate alternative could be a RJ-11 6-pin connector, but was discarded because of the large socket size.

Resistors serve as a short circuit protection since A+ and A- are exposed pins and also input impedance. Capacitor prevents noise and rapid change. Signals from load cells are slow.

VBG = VFB is a reference bypass output. It stays fixed at 1.25 V.

AVDD is the analog voltage source with is generated by the HX711's internal regulator with the aid of the PNP BJT.

AVDD = VGB · (R1 + R2) / R1
It should always be less than (VSUP - 100 mV)
[HX711 datasheet, page 4]

In this design:

AVDD = 1.25 V·(22 kΩ+10 kΩ)/20 kΩ = 1.82 V

HX711 will serve 24 bit, 2's complement raw ADC data.
The system needs a software calibration with a known weight for extracting a correction factor for this design.

Noise/EMI filtering on AVDD. Sparkfun's design uses a 2.2 uH chip inductor. Instead we use a ferrite bead.

RATE pin config:
- Pulled down: normal mode, 10 Sps
- Pulled up: fast mode, 80 Sps, noisier

VCC/VDD bypass caps for noise filtering and voltage stabilization for the HX711.

[v06 VALIDATION NOTE]

UNTESTED

"Reference PCB Board schematic" from the [HX711 Datasheet, figure 4, page 6]

HX711 load cell amplifier

This circuit is used to get weight measurements out from load cells in order to estimate the density of a trunk or board.
This design is based on the Sparkfun HX711 module by N. Seidle and A. Wende.

Designer's signature

Supervisor's signature

Sheet title:	HX711 load cell amplifier
Project title:	TIK_HandheldDevice.PrjPcb
Desgner:	Juan Del Pino Mena
Date: 2022-07-29	Revision: 0.6
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Block	Component	Description/Conditions	Supply voltage (V)	Current consumption per unit (µA)		Units	Total dissipated power (µW)		Notes
				Typical	Maximum		Typical	Maximum	
MCU	ESP32-WROOM-32D	MCU + wireless comm. Module	3.3	70 mA *	500 mA **	1	231 mW	1.7 W	* Average, measured, running demo ** Current spikes during wireless TX
Power rails	AP3429	DC/DC Buck converter IC	4.2	90 µA		1	378 µW		
	NCP562SQ18T1G	Low-Dropout regulator IC	3.3	3 µA		1	9.9 µW		
	150 kΩ + 33 kΩ voltage divider	FB pin feedback. Fixed consumption	3.3	18 µA		1	59.4 µW		
	[Optional] bypass voltage divider	Assuming 3V3/2 with 10 kΩ resistors	3.3	165 µA		1	544.5 µW		Consider only if populated
	Generic 0805 LED	Assuming Vf = 2V & 1 kΩ series resistor	3.3	1.3 mA		1	4.3 mW		Consider only if populated
Battery & current sense	INA219	Voltage & current sense IC	4.2	0.7 mA	1 mA	1	3 mW	4.2 mW	
	Generic 0805 LED	Assuming Vf = 2V & 1 kΩ series resistor	5.5	1.3 mA		2	8.6 mW		Consider only if populated
	I2C pull-up resistor	Assuming line level is LOW, with 4.7kΩ resistors	3.3	0.7 mA		2	4.6 mW		
[Optional] NiMH charger	LTC4060EFE	NiMH/NiCd charger IC	5.5	2.9 mA	4.3 mA	1	16 mW	23.7 mW	Consider only the populated charger variant. For charging ICs and BJT: consider only when charging the battery (else they are off). **In this case, power consumption comes from external supply not from the internal battery.**
	MDJ201	Power PNP BJT. Ice=0.95 A, Ibe=120mA, Vce=1.8V, Vbe=0.7 V	--	--		1	1.71 W + 84 mW ≈ 1.8 W		
	4.42 kΩ + NTC voltage divider	NTC pin. Assuming NTC at 50ºC (3.54 kΩ)	5.5	691 µA		1	3.8 mW		
[Optional] Li-Ion/Li-Po charger	TP4056	Li-Ion/LiPo charger IC, Vbus-Vbat=1.8 V, Ibat=1 A	5.5	150 µA	500 µA	1	1.8W + 2.8 mW ≈ 1.8 W		
	DW01A	Battery protection IC	4.2	3 µA	6 µA	1	12.6 µW	25.6 µW	
	FS825A	Dual power NMOS, Rds(on)=25 mΩ, Ibat=1 A	--	--		1	50 mW (both NMOS)		
USB connector	USBLC6-2SC6	USB ESD protection IC	5.5	10 nA	150 nA	1	55 nW	825 nW	**Consider only when USB is plugged**
Programming	CH340C	USB to UART converter IC	3.3	12 mA	30 mA	1	39.6 mW	99 mW	Worst case when programming
	2N7002	G.P. NMOS. Ib=0 A, Vds=3.3 V, Ids=330 µA (during conmutation)	--	--		2	1 mW		Consider only when programming
	Generic 0805 LED	Assuming Vf = 2V & 1 kΩ series resistor	3.3	1.3 mA		4	17.2 mW		Consider only if populated
Buttons	Pull-up resistors	Assuming line level is LOW, 10kΩ resistors	3.3	330 µA		5	5.4 mW		Worst case: all pressed at once
Power-up button	BSS84AK	G.P. PMOS. Rsd(on) = 7.5 Ω, Ib=0, Isd = 77 µA	--	--		1	45 nW		
	1N4148W	Small signal diode. Vf=0.7 V, If=26 µA	--	--		2	36.4 µW		Worst case: both ON
	100 kΩ pull-up resistor	100 kΩ pull-up resistor	4.2	42 µA		1	176.4 µW		
TFT LCD display	LCD TFT ILI9341 module	320x240p LCD (Measured)	3.3	45 mA *	120 mA **	1	148.5 mW	396 mW	* Average, **maximum spike measured, running demo program
Signal conditioning	LMV358DGKR	General purpose dual OpAmp, with no load	3.3	140 µA	340 µA	1	462 µW	1.1 mW	Both OpAmps, high Z load
	1N4148W	Small signal diode. Vf=0.7 V, If= ? A	--	--		4	--		Unknown
Load cell amplifier	HX711	Load cell amplif er & ADC IC	3.3	1.4 mA		1	4.6 mW		Enters sleep if the data clock stops
	BC858	General purpose PNP BJT. Vce=1.8V, Ice=? A	--	--		1	--		Unknown
	22 kΩ + 10 kΩ voltage divider	VFB pin feedback for AVDD=1.82 V regulation.	1.82	57 µA		1	103.7 µW		Consider only when HX711 is awake

There is not a tangible difference in the charger efficiency. However, we finally decide to implement the Lithium charger for its convenience, flat Li-Po batteries, IC stock availability and overall lower price.

NiMH charger worst-case efficiency		
Power in	Dissipated power	Efficiency
5.225 W	1.822 W	65.10%
Lithium charger worst-case efficiency		
Power in	Dissipated power	Efficiency
5.5 W	1.878 W	65.85%

Sum of total current consumption (battery only, not charging)	
Typical	Maximum
134.5 mA	**658.7 mA**

Li-Po batteries come in various formats. We have chosen a flat Li-Po, which is low profile (6x40x60mm) and has 1500 mAh (approx 5.5 Wh) of energy.

Sum of total dissipated power (battery power only, not charging)	
Typical	Maximum
469.6 mW	**2.25 W**

The estimated battery discharge time is around 11 hours typical, and 2 in the absolutely worst case scenario.

Power budget and battery selection

Detailed estimation of typical and worst-case power consumption per component in order to define battery requirements. Choosing an adequate battery.

Designer's signature

Supervisor's signature

Sheet title: **Power budget and battery selection**

Project title: **TIK_HandheldDevice.PrjPcb**

Desginer: **Juan Del Pino Mena**

Date: **2022-07-29** Revision: **0.6** Sheet 21 of 21

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