

A  
BACHELOR'S DEGREE IN TELECOMMUNICATION ENGINEERING

Bachelor's Thesis

ACADEMIC COURSE 2021/2022

# *Tree Inspection Kit*

## *handheld device*

AUTHOR:

Juan Del Pino Mena

SUPERVISED BY:

Sr. Andrés Roldán Aranda

DEPARTMENT:

Electronics and Computer Technology



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DE GRANADA



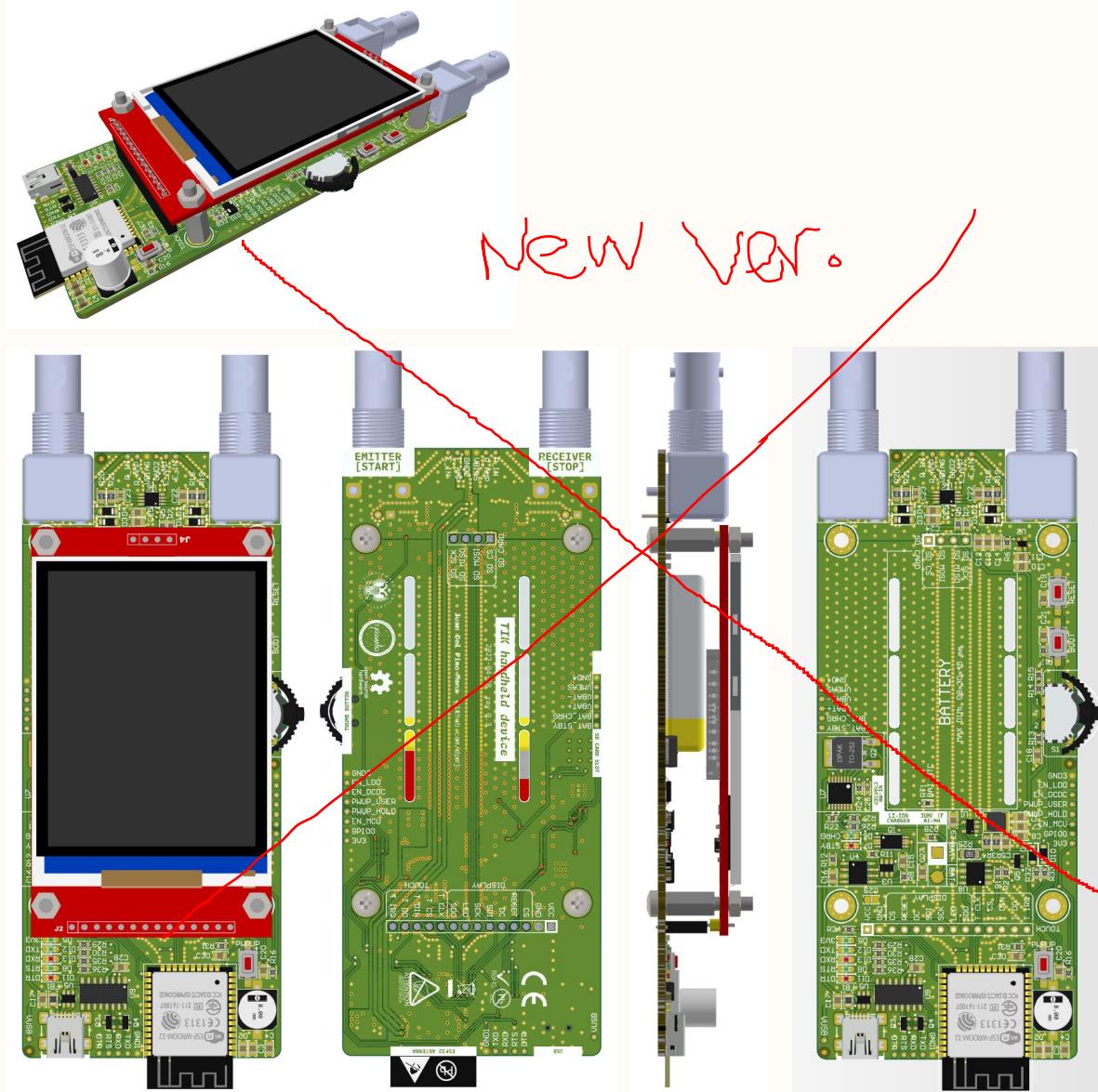
Project title: TIK\_HandheldDevice.PrjPcb

Date: 2022-05-29 Revision: 0.5

Sheet 1 of 20

*TO-DO  
INTRO*

*New ver.*



## *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.PjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-05-29** Revision: **0.5**

Sheet 2 of 20

Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología  
de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



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## Changelog

### # Revision 0.3 | 2022-04-28 [MANUFACTURED]

#### NEW                  FIXED

- Added multilayer connector to the battery
- Added a power budget & battery selection
- Adjusted the charging current resistor value of the TP4056 to match the battery capacity
- Added a expansion port and load cell connectors footprints. (4-pole jacks).
- Corrected LEDs' series resistors values
- Relocated the battery to below the PCB. This wastes space and makes the product wider, but solves a lot of space constraints between the LCD and the PCB.
- Removed VBIAS plane to avoid splitting planes for EMI considerations

### # Revision 0.3 | 2022-04-28

#### NEW                  FIXED

- Changed rotary encoder vertical for horizontal, side-placed, SMD type multipurpose 'thumb button'.
- Added a explanation of PCB trace widths.
- Adopted JLCPBCB 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.
- Changed numerical test point designators to net/rail names, to be quickly identified.
- Changed LEDs footprints from 0603 to 0805
- Corrected a faulty connection on the DW01A Lithium battery protection IC.
- The MCU has no longer the possibility of cutting battery charge. This is because ENABLE signals worked on 5V logic level and could cause damage to the ESP32.

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

#### NEW                  FIXED

- New schematic hierarchy and system's block diagram.
- Initial PCB layout
- Added a rotary encoder (vertical). Library contains a 90-degree rotary encoder alternative.
- Added a new alternative Ni-MH charger circuit.
- Added footprints for all necessary 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
- 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 0.4 | 2022-05-22 [PCB INCOMPLETE]

#### NEW                  FIXED

- 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 on every PDF exported sheet.
- Given more information about the ESP32 pin behaviour.
- Added a precise block diagram.
- Added support for an extension port.
- Added a HX711-based load cell adquisition system.
- Corrected I2C pins on the ESP32.
- Removed "same length" directive on UART and I2C nets.
- Improved routing.
- Removed I2C traces' via shielding.
- Solved all DRC warnings and errors.
- The ESP32's strapping pins default configuration is respected: modified pull-up/down resistors when needed to be according to the default boot setting.
- Corrected a pin assignment error between the schematic symbol and the footprint of the MDJ210 PNP BJT transistor.
- Removed PCB cutouts and thumb button side protuberance.

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

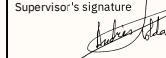
#### NEW                  FIXED

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

## Revision history and document index

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.PxjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-05-29** Revision: **0.5** Sheet 3 of 20

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Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



### SPI traces (@ 80 MHz, digital)

Er Effective  
Conductor Width (W)  
**0,254 mm**  
Conductor Height (H)  
**1,50 mm**  
Frequency (MHz)  
**80**

10-mil "default" trace width

Note:  
This calculator uses a complex formula presented by E. Hammarstad and O. Jensen, not the simplified formula presented by the IEC-2141A.

Wavelength Calculator  
Input Method  
 Frequency  
Frequency  
**80 MHz**  
Er Eff  
**2,8905**

Wavelength Information  
Period  
Speed of Light

CrossTalk Calculator  
Signal Rise Time  
**5 ns**  
Signal Voltage  
**3,3 V**  
Coupled Length  
**80 mm**  
Conductor Spacing (S)  
**0,254 mm**  
Conductor Height (H)  
**1,5 mm**

5 ns as a possible rise time of the SPI signal

$\lambda = \frac{C}{f * \sqrt{(ErEff)}}$

Wavelength Divide  
1/20 Wave Length  
**11.02083 cm**

Er Effective Information

Er Eff Calculator

Wavelength Divide

CrossTalk Coefficient  
**0,24555 dB**  
Coupled Voltage  
**3,20801 Volts**

Send to Wavelength Calculator

△ 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.

Wavelength Calculator  
Input Method  
 Frequency  
Frequency  
**80 MHz**  
Units  
 MHz  
Er Eff  
**2,8905**

Wavelength Information  
Period  
Speed of Light

CrossTalk Calculator  
Signal Rise Time  
**5 ns**  
Signal Voltage  
**3,3 V**  
Coupled Length  
**80 mm**  
Conductor Spacing (S)  
**0,254 mm**  
Conductor Height (H)  
**1,5 mm**

5 ns as a possible rise time of the SPI signal

$\lambda = \frac{C}{f * \sqrt{(ErEff)}}$

Wavelength Divide  
1/20 Wave Length  
**11.02083 cm**

Er Effective Information

Er Eff Calculator

Wavelength Divide

CrossTalk Coefficient  
**0,24555 dB**  
Coupled Voltage  
**3,20801 Volts**

△ 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)

Wavelength Calculator  
Input Method  
 Frequency  
Frequency  
**1 MHz**  
Er Eff  
**3,0260**

Wavelength Information  
Period  
Speed of Light

Conductor Impedance  
Conductor Width (W)  
**0,8 mm**  
Conductor Height (H)  
**1,5 mm**  
Conductor Gap (G)  
**0,254 mm**  
W/H = **0,533**

Formula Restrictions:  
0.1 < W/H < 2.0  
T = 13um  
? Help

$\lambda = \frac{C}{f * \sqrt{(ErEff)}}$

Wavelength Divide  
1/20 Wave Length  
**861.70030 cm**

Z<sub>0</sub>  
**60.6257 Ohms**

△ Er\_Eff calculated with a 0.8 mm wide trace. Trace length will not be a problem.

CrossTalk Calculator  
Signal Rise Time  
**2000 ns**  
Signal Voltage  
**3,3 V**  
Coupled Length  
**150 mm**  
Conductor Spacing (S)  
**0,254 mm**  
Conductor Height (H)  
**1,5 mm**

Estimated signal rise time. See simulations

$\lambda = \frac{C}{f * \sqrt{(ErEff)}}$

Wavelength Divide  
1/20 Wave Length  
**861.70030 cm**

CrossTalk Coefficient  
**-0,19079 dB**  
Coupled Voltage  
**0,03228 Volts**

△ 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

Via Characteristics  
Via Hole Diameter  
**0,3 mm**  
Internal Pad Diameter  
**0,6 mm**  
Ref Plane Opening Diam  
**1,016 mm**  
Via Height  
**1,6 mm**  
Via Plating Thickness  
**0,035 mm**

Ref Plane Opening  
Via Pad  
Via Plating  
Ref Plane

IPC-2152 with modifiers mode

Via Capacitance  
**0,5893 pF**  
Via DC Resistance  
**0,00086 Ohms**  
Power Dissipation  
**0,00326 Watts**

Via Inductance  
**1,2993 nH**  
Resonant Frequency  
**5751.849 MHz**  
Conductor Cross Section  
**0,0368 Sq.mm**

Via Impedance  
**46.956 Ohms**  
Step Response  
**30.4373 ps**  
Via Current  
**1.9514 Amps**

△ We are using only 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

Conductor Characteristics  
Solve For  
 Amperage  
 Conductor Width  
Parallel Conductors?  
 Yes  
Conductor Width  
**0,254 mm**  
Conductor Length  
**10 mm**  
PCB Thickness  
**1,6 mm**  
Frequency  
 DC  
**80 MHz**  
Distance to Plane  
**1,5 mm**

Options  
Solve For  
 Power Copper Weight  
 Plane Present?  
 Yes  
Units  
 Imperial  
 Metric  
Substrate Options  
Material Selection  
**FR-4 STD**  
Parallel Conductors?  
 No  
 Yes

IPC-2152 with modifiers mode  
Etch Factor: 1:1  
Skin Depth  
**7.37972 um**  
Power Dissipation  
**0,03469 Watts**  
Conductor DC Resistance  
**0,01529 Ohms**

Skin Depth Percentage  
**21.08 %**  
Power Dissipation in dBm  
**7.15023 dBm**  
Conductor Cross Section  
**0,0129 Sq.mm**

Voltage Drop  
**0,0230 Volts**  
Conductor Current  
**1.5064 Amps**

Print  
Solve!

△ Trace AC/DC characteristics in one centimetre of trace for a given frequency/DC and for a trace temperature increase of 10 °C over a standard ambient temperature of 25°C 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 the SPI bus. The skin depth is not optimal but this will depend on frequency and again, AC current is not a critical aspect here. It's a "good enough" approach.

### 0.35 mm traces

Conductor Characteristics  
Solve For  
 Amperage  
 Conductor Width  
Parallel Conductors?  
 Yes  
Conductor Width  
**0,35 mm**  
Conductor Length  
**10 mm**  
PCB Thickness  
**1,6 mm**  
Frequency  
 DC  
**1 MHz**  
Distance to Plane  
**1,5 mm**

Options  
Solve For  
 Power Copper Weight  
 Plane Present?  
 Yes  
Units  
 Imperial  
 Metric  
Substrate Options  
Material Selection  
**FR-4 STD**  
Parallel Conductors?  
 No  
 Yes

IPC-2152 with modifiers mode  
Etch Factor: 1:1  
Skin Depth  
**66.00620 um**  
Power Dissipation  
**0,03710 Watts**  
Conductor DC Resistance  
**0,01005 Ohms**

Skin Depth Percentage  
**100 %**  
Power Dissipation in dBm  
**15.6940 dBm**  
Conductor Cross Section  
**0,0196 Sq.mm**

Voltage Drop  
**0,0193 Volts**  
Conductor Current  
**1.9218 Amps**

Print  
Solve!

△ 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

Conductor Characteristics  
Solve For  
 Amperage  
 Conductor Width  
Parallel Conductors?  
 Yes  
Conductor Width  
**0,5 mm**  
Conductor Length  
**10 mm**  
PCB Thickness  
**1,6 mm**  
Frequency  
 DC  
**1 MHz**  
Distance to Plane  
**1,5 mm**

Options  
Solve For  
 Power Copper Weight  
 Plane Present?  
 Yes  
Units  
 Imperial  
 Metric  
Substrate Options  
Material Selection  
**FR-4 STD**  
Parallel Conductors?  
 No  
 Yes

IPC-2152 with modifiers mode  
Etch Factor: 1:1  
Skin Depth  
**66.00620 um**  
Power Dissipation  
**0,03974 Watts**  
Conductor DC Resistance  
**0,00654 Ohms**

Skin Depth Percentage  
**100 %**  
Power Dissipation in dBm  
**15.9921 dBm**  
Conductor Cross Section  
**0,0301 Sq.mm**

Voltage Drop  
**0,0161 Volts**  
Conductor Current  
**2.4647 Amps**

Print  
Solve!

△ 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 continuously need) with low losses.

### 0.8 mm traces

Conductor Characteristics  
Solve For  
 Amperage  
 Conductor Width  
Parallel Conductors?  
 Yes  
Conductor Width  
**0,8 mm**  
Conductor Length  
**10 mm**  
PCB Thickness  
**1,6 mm**  
Frequency  
 DC  
**1 MHz**  
Distance to Plane  
**1,5 mm**

Options  
Solve For  
 Power Copper Weight  
 Plane Present?  
 Yes  
Units  
 Imperial  
 Metric  
Substrate Options  
Material Selection  
**FR-4 STD**  
Parallel Conductors?  
 No  
 Yes

IPC-2152 with modifiers mode  
Etch Factor: 1:1  
Skin Depth  
**66.00620 um**  
Power Dissipation  
**0,04325 Watts**  
Conductor DC Resistance  
**0,00385 Ohms**

Skin Depth Percentage  
**100 %**  
Power Dissipation in dBm  
**16.3599 dBm**  
Conductor Cross Section  
**0,0511 Sq.mm**

Voltage Drop  
**0,0129 Volts**  
Conductor Current  
**3.3503 Amps**

Print  
Solve!

△ 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, aggressive 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 JLPCB 2-layer, FR-4, 1.6 mm height, 35 um conductor height (1 oz/ft<sup>2</sup>) board characteristics as reference.

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Supervisor's signature

Sheet title: **Trace width design**

Project title: **TIK\_HandheldDevice.PjtPcb**

Designer: **Juan Del Pino Mena**

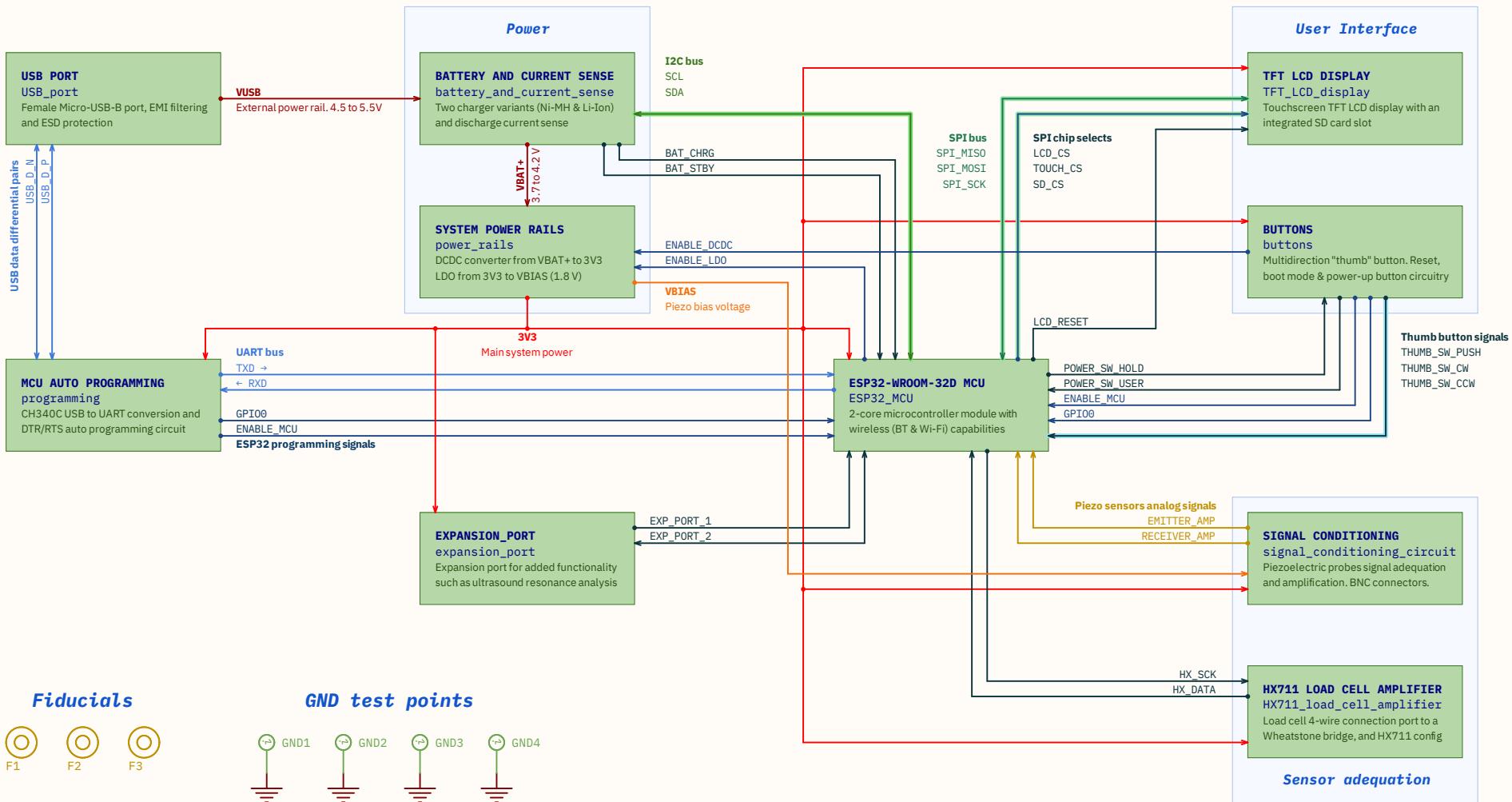
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Revision: **0.5**

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Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain

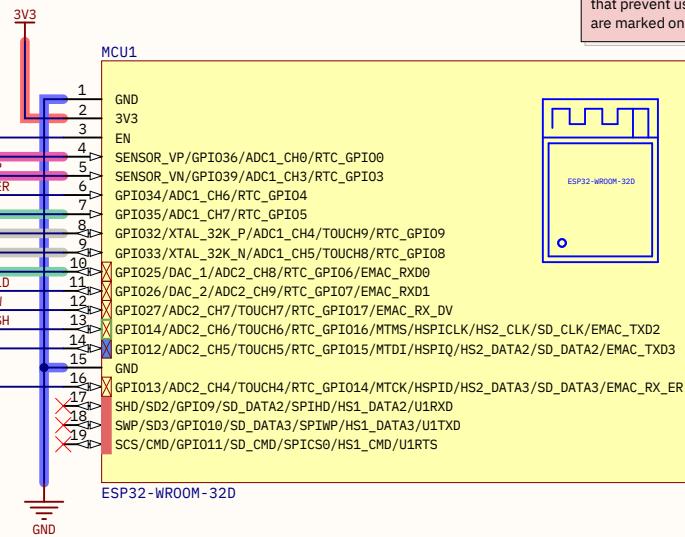




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Sheet title: **System blocks organization and connections**  
Project title: **TIK\_HandheldDevice.PjPcb**  
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Supervisor:  
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Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
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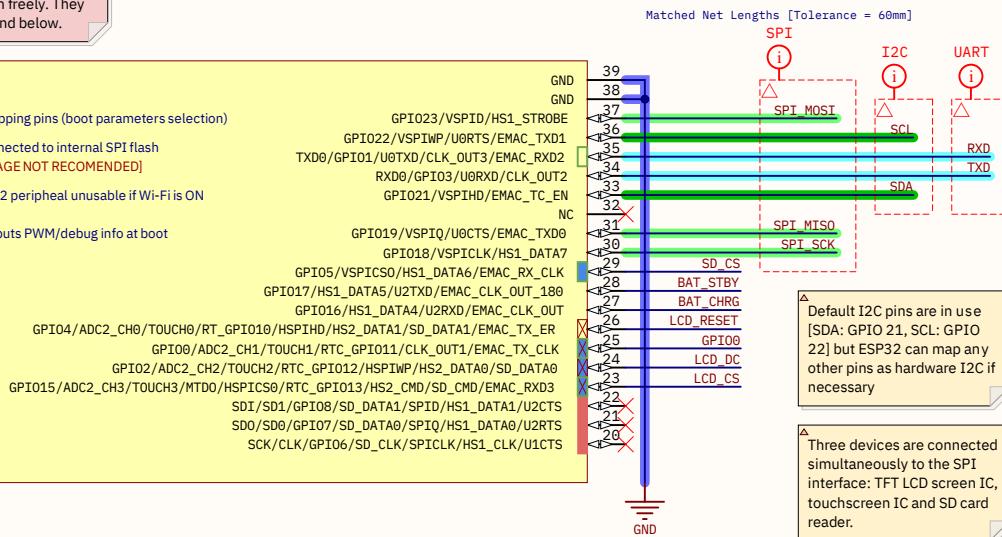
Sheet title: **System blocks organization and connections**  
Project title: **TIK\_HandheldDevice.PjPcb**  
Designer: **Juan Del Pino Mena**  
Date: **2022-05-29** Revision: **0.5** Sheet 5 of 20





Some ESP32's pins behave in a way that prevent using them freely. They are marked on the legend below.

- Strapping pins (boot parameters selection)
- Connected to internal SPI flash [USAGE NOT RECOMENDED]
- ADC2 periphel unusable if Wi-Fi is ON
- Outputs PWM/debug info at boot



Default I2C pins are in use [SDA: GPIO 21, SCL: GPIO 22] but ESP32 can map any other pins as hardware I2C if necessary

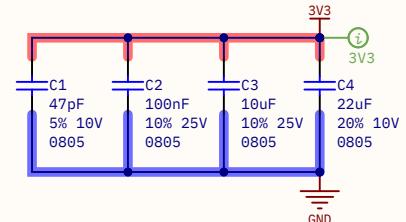
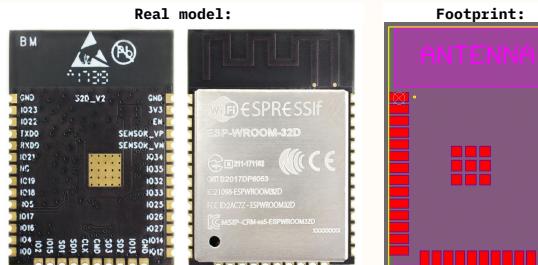
Three devices are connected simultaneously to the SPI interface: TFT LCD screen IC, touchscreen IC and SD card reader.

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.

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.

Voltage of Internal LDO (VDD_SDIO)			
Pin	Default	3.3 V	1.8 V
MTDI	Pull-down	0	1
Booting Mode			
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	RE Sampling FE Output
MTDO	Pull-up	0 0	1 1
GPIO5	Pull-up	0 1	0 1

Also, the ADC2 periphel 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.



Recommended bucket/bypass capacitors are 0.1  $\mu$ F and 10  $\mu$ F, 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  $\mu$ F 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.PjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-05-29** Revision: **0.5** Sheet 6 of 20

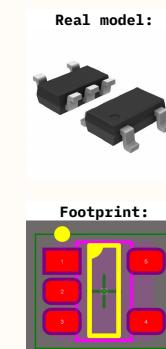
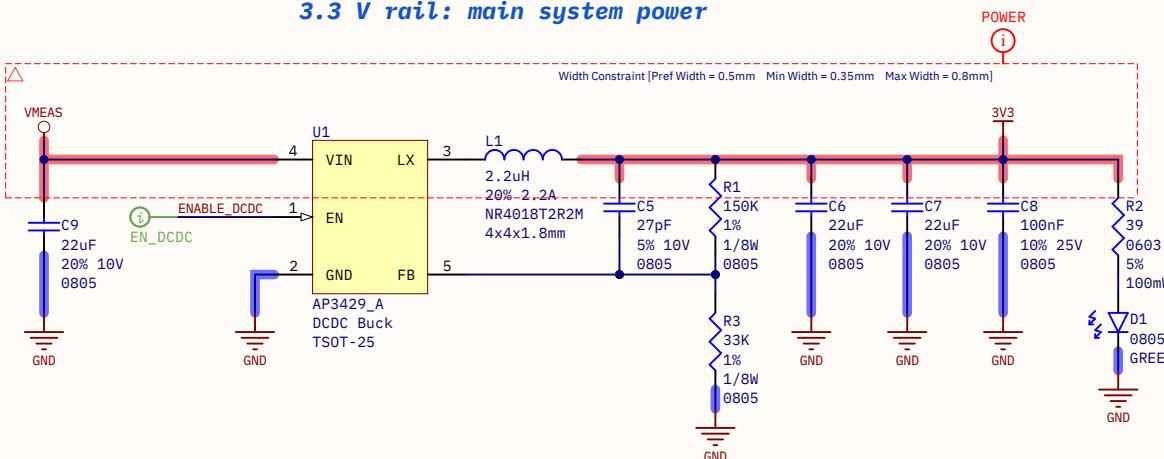
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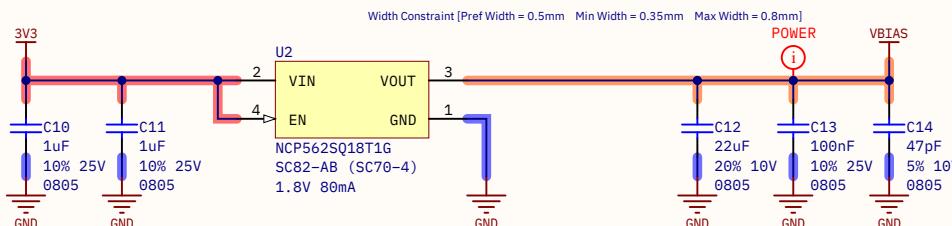
### 3.3 V rail: main system power

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 0.6 V const.

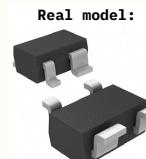
Resistors are adjusted as a voltage divider. So, if 3.3V are needed at the converter output:  $V_{FB} = 0.6V = V_{out} \cdot (R2)/(R1+R2) \rightarrow R2 = 2/9 \cdot R1$ . Resistor values must be high (kOhms) in order to maintain a low power consumption on the feedback circuit.



### 1.8 V rail: Vbias for signal conditioning circuit

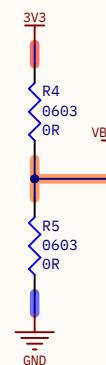


Recommended  $C_{in}$  is 1 uF, low ESR. Usage of multiple input capacitors to reduce ESR and ESL. There are no recommended values for  $C_{out}$  but these caps should probe more than enough to have low ESR and reduce ripple at a wide frequency range. Datasheet specifies a typical 100 uVRms noise on  $V_{out}$ , somewhat high.



### 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 acquisition circuit.  
Do NOT connect both OR 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  $V_{CC}/2$  you only have to add two  $\geq 10\text{ K}\Omega$  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 up to 2 amps. VBIAS is only for polarization of the probes and won't draw much current.

Designer's signature  
Supervisor's signature

Sheet title: Power rails  
Project title: TIK\_HandheldDevice.PjPcb

Designer: Juan Del Pino Mena

Date: 2022-05-29 Revision: 0.5 Sheet 7 of 20

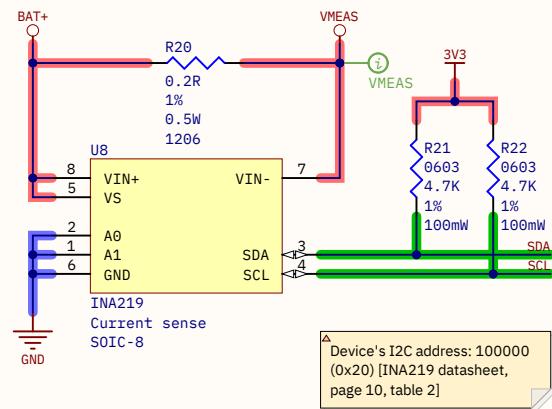
Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
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Granada, Granada, Spain



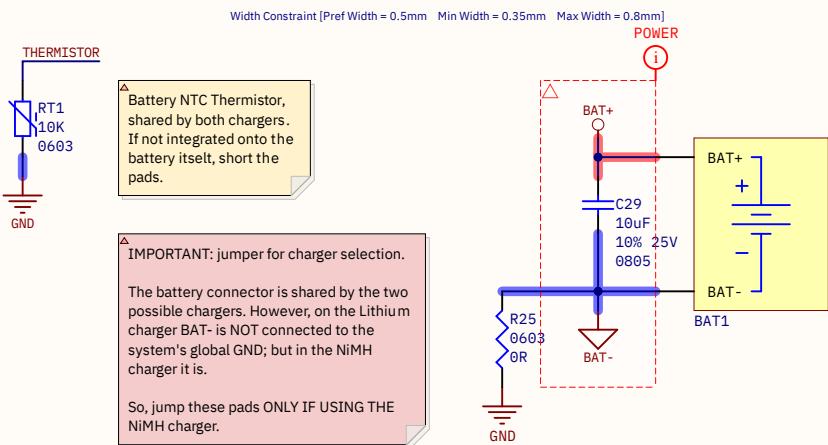
## Battery charging circuit variants



## Battery output current sense and voltage monitor

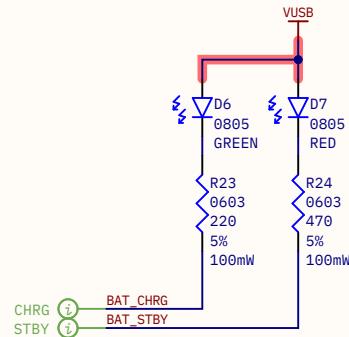


## Battery connector. Charger selection jumper. Battery thermistor



## 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.



## 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.PjPcb**

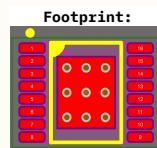
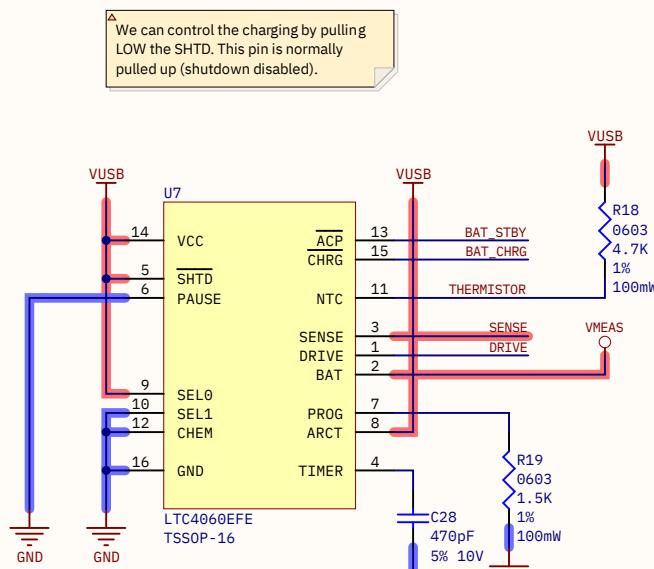
Designer: **Juan Del Pino Mena**

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Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
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C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



## NiMH/NiCd battery charger IC



Annotations for the real model and footprint:

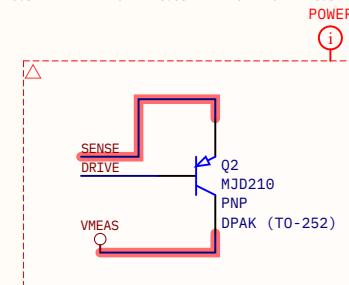
- TIMER capacitor and PROG resistor program the charge T<sub>max</sub> (maximum charging time, a security measure). [LTC4060 datasheet, page 13]. These values should complete a full charge in at most 1 h 6'.
- PROG resistor programs the maximum current that the battery will receive while charging. For 1.5 kΩ this is 0.93 A.
- 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.

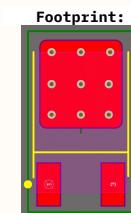
## External PNP BJT current driver

Width Constraint [Pref Width = 0.5mm Min Width = 0.35mm Max Width = 0.8mm]



Annotation for the current driver circuit:

- 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.



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Sheet title: **Battery charger**  
Project title: **TIK\_HandheldDevice.PjPcb**

Designer: **Juan Del Pino Mena**

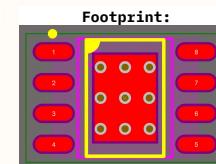
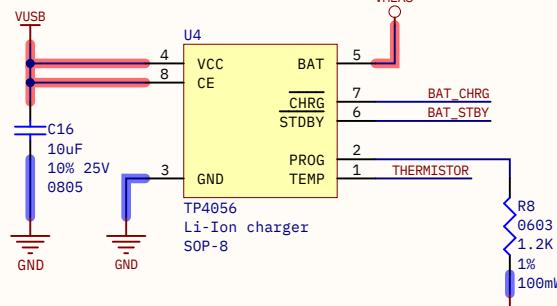
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Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología  
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C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



## Lithium battery charger IC

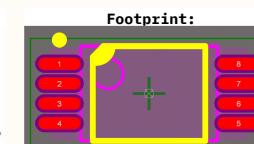
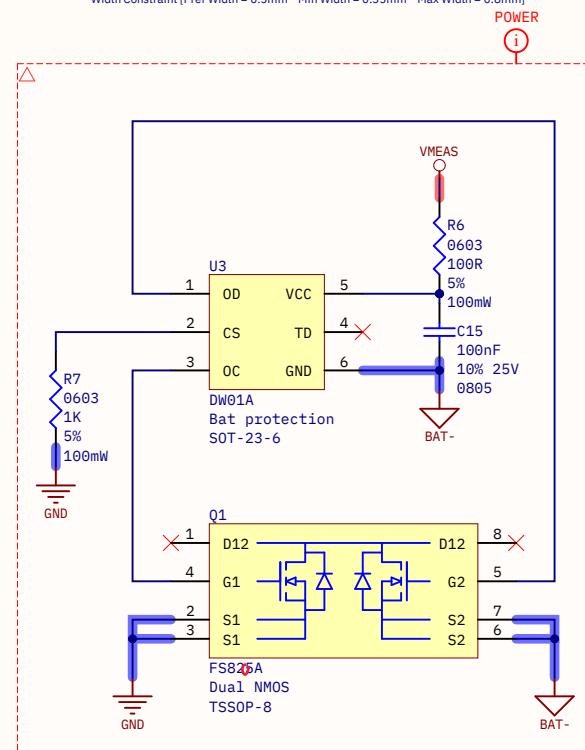
- △ The TP4056 datasheet recommends to connect a resistor of 0.2 to 0.5 Ohm between VUSB and its VCC pin. It does not explain why, but probably for chip temperature concerns.
- △ However, it is omitted as we don't have any resistor of these values available. As a note: not a single commercial TP4056 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 similarity. 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.



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

## Lithium battery protection

Width Constraint [Pref Width = 0.5mm Min Width = 0.35mm Max Width = 0.8mm]



## Battery charging circuitry for Li-Ion

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

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Sheet title: **Battery charger**

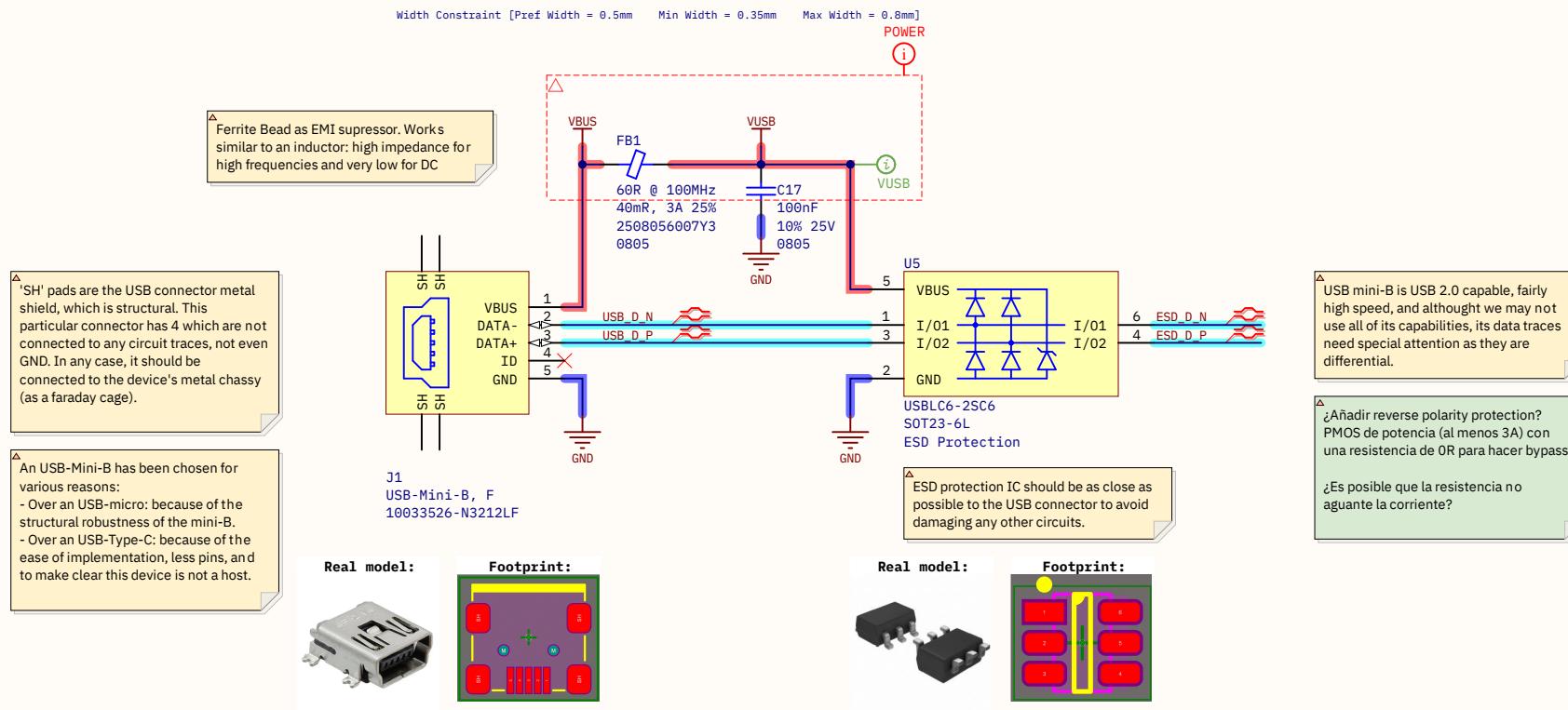
Project title: **TIK\_HandheldDevice.PjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-05-29** Revision: **0.5** Sheet 10 of 20

Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain





## 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

Supervisor's signature

Sheet title: **USB connector and ESD protection circuit**

Project title: **TIK\_HandheldDevice.PxjPcb**

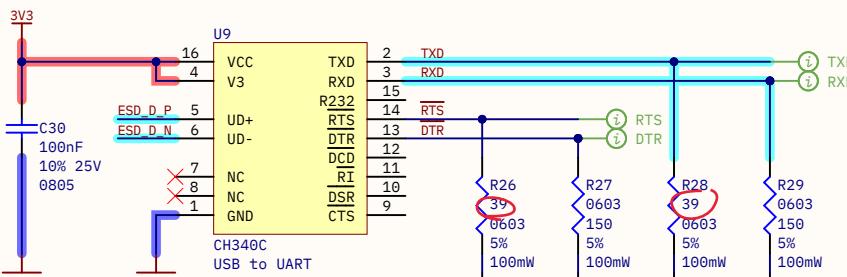
Designer: **Juan Del Pino Mena**

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Supervisor:  
 Sr. Andrés Roldán Aranda  
 Dpto. Electrónica y Tecnología  
 de Computadores  
 University of Granada  
 C/Fuente Nueva, s/n. 18001  
 Granada, Granada, Spain



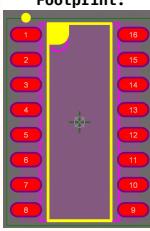
## USB to UART conversion



Real model:



Footprint:

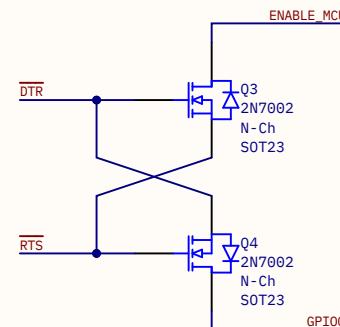


These LEDs serve as a visual testimony of UART communication and help during debugging.

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.

## 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)

## USB to UART and MCU programming

This circuit allows a computer to reprogram 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

Sheet title: **USB to UART and MCU programming**

Project title: **TIK\_HandheldDevice.PxjPcb**

Supervisor's signature

Desinger: **Juan Del Pino Mena**

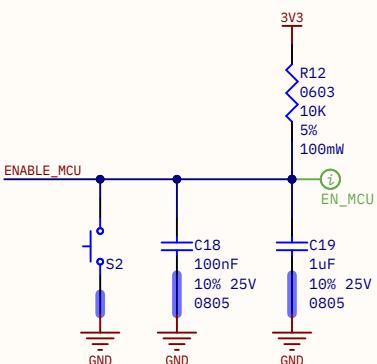
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Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología  
de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



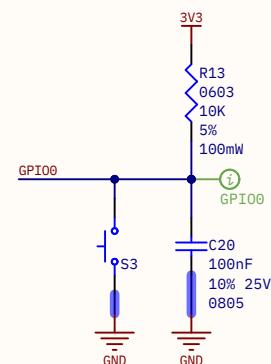
## Reset

To ensure power stability to the microcontroller during powerup, this RC filter introduces a delay on the ENABLE pin. Usual values are  $10\text{ k}\Omega$ ,  $1\text{ }\mu\text{F}$  ( $\tau = 10\text{ ms}$ ,  $t_{\{10-90\}} = 22\text{ ms}$ ). [ESP32-WROOM-32D datasheet, page 22]



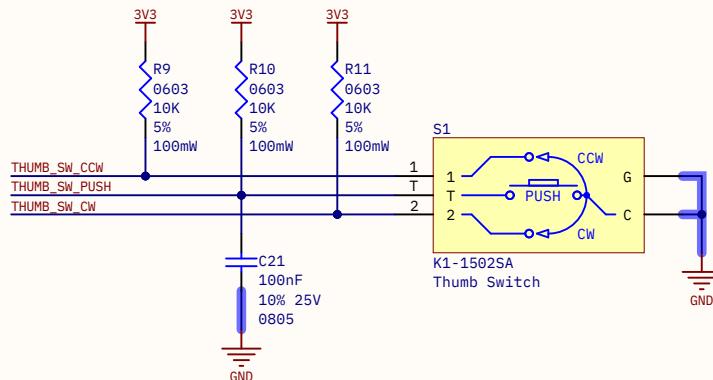
## Boot mode selection (debug)

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)

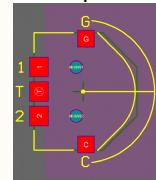
Horizontal SMD device, multi-directional / muti-function rotary slider button. Accessed from the right side.



Real model:



Footprint:



## Buttons

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

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Sheet title: **Buttons**  
Project title: **TIK\_HandheldDevice.PjPcb**

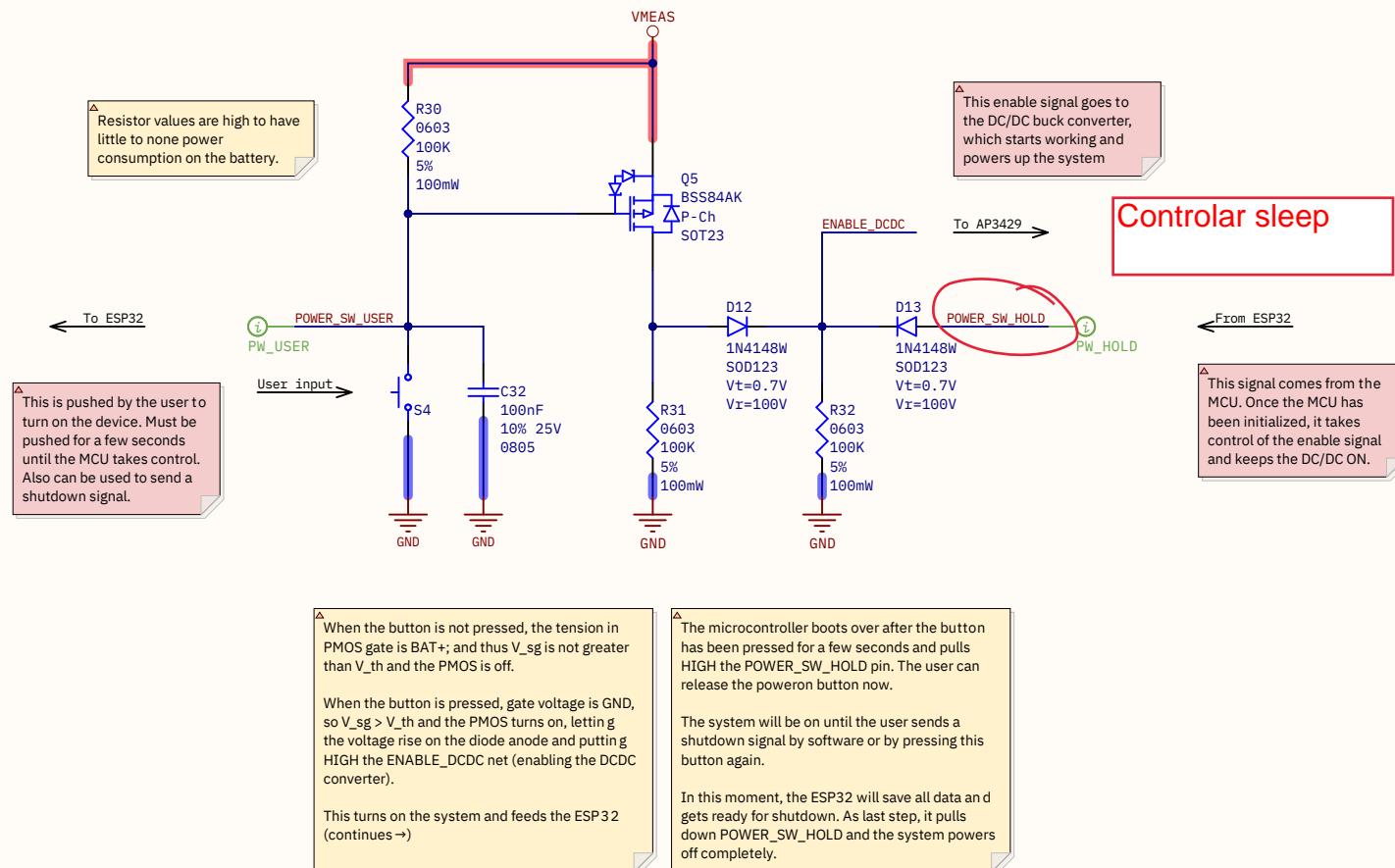
Designer: **Juan Del Pino Mena**

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Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología  
de Computadores  
University of Granada  
C/Fuente Nueva, s/n. 18001  
Granada, Granada, Spain



A



B

C

D

## 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.

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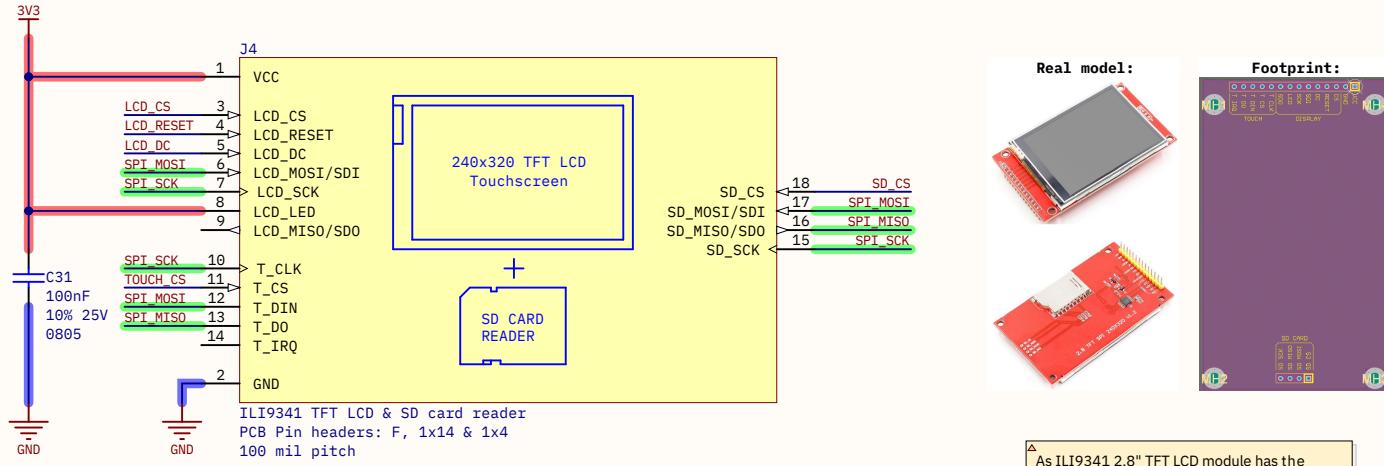
Sheet title: **Powerup button**  
Project title: **TIK\_HandheldDevice.PjPcb**

Desinger: **Juan Del Pino Mena**

Date: **2022-05-29** Revision: **0.5** Sheet 14 of 20

Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain





## 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.

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Supervisor's signature

Sheet title: LCD TFT touchscreen & SD card reader

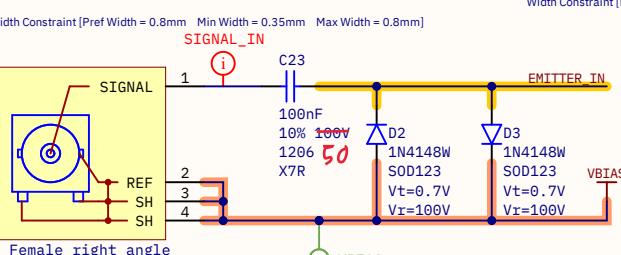
Project title: TIK\_HandheldDevice.PjPcb

Designer: Juan Del Pino Mena

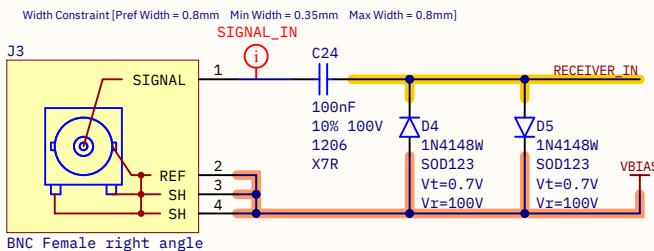
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Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain

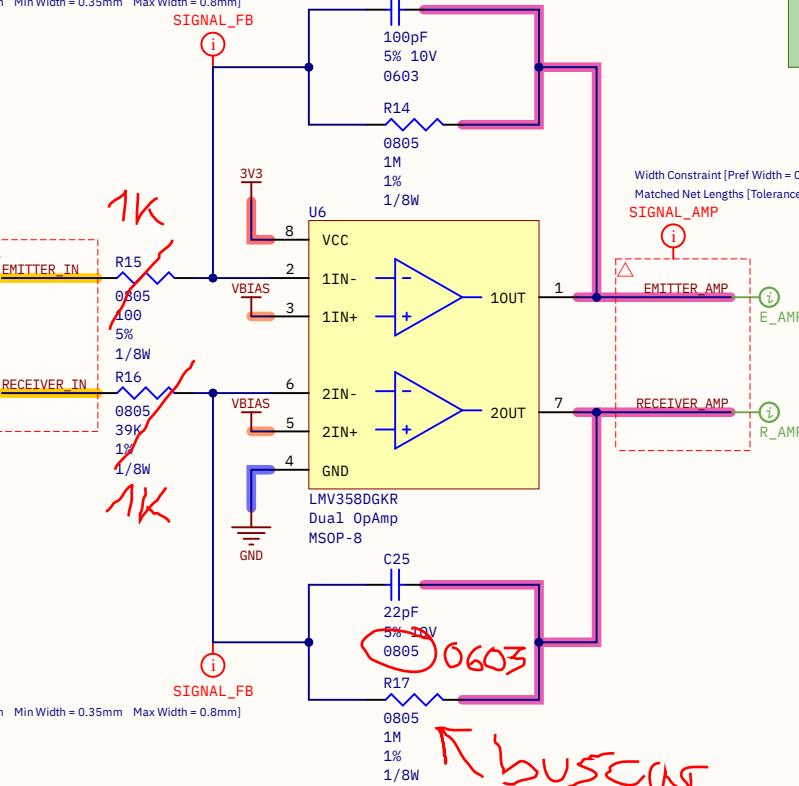




Width Constraint [Pref Width = 0.8mm Min Width = 0.35mm Max Width = 0.8mm]  
Matched Net Lengths [Tolerance = 10mm]



Width Constraint [Pref Width = 0.8mm Min Width = 0.35mm Max Width = 0.8mm]

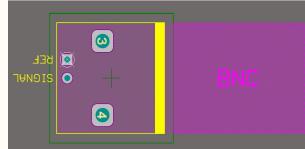


**SIGNAL\_CONDITIONING\_SIMULATIONS**  
**signal\_conditioning\_simulations**  
Results of simulating the adequation circuit with SPICE and realistic input waveforms

Real model:



Footprint:

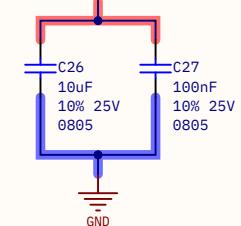
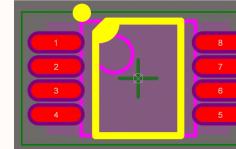


Emitter signal will be in the range of 15 V to 100 V and need to be clipped by the diodes. Then, the OpAmp will amplify to saturation so the emitter can be perceived by the instrument as a flank; whereas the receiver signal will most likely be amplified without any clipping.

Real model:



Footprint:



These are two charge mode amplifiers. This circuit is meant for sensors which are physically far from the acquisition system. It mitigates the effect of cables' capacitance.  
[James Karki (Texas Instruments)  
"Signal Conditioning Piezoelectric Sensors". Application Report  
SLOA033A. September 2000]

This OpAmp is meant for low voltages, low power, single-supply and it has its own ESD protection.

Bypass caps for the OpAmp, should be physically close to its power pins.

## 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 up to -100 V peak, so it needs clipping

Designer's signature  
Supervisor's signature

Sheet title: **Piezoelectric sensors conditioning circuit**

Project title: **TIK\_HandheldDevice.PjPcb**

Designer: **Juan Del Pino Mena**

Date: **2022-05-29**

Revision: **0.5**

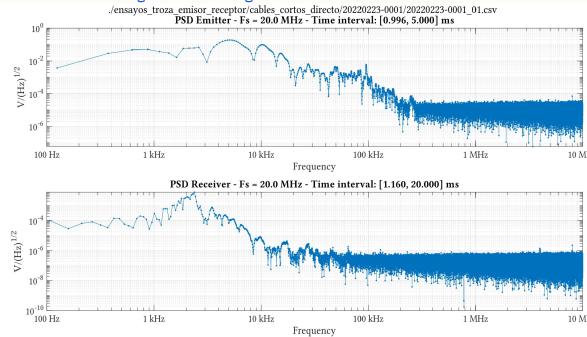
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Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



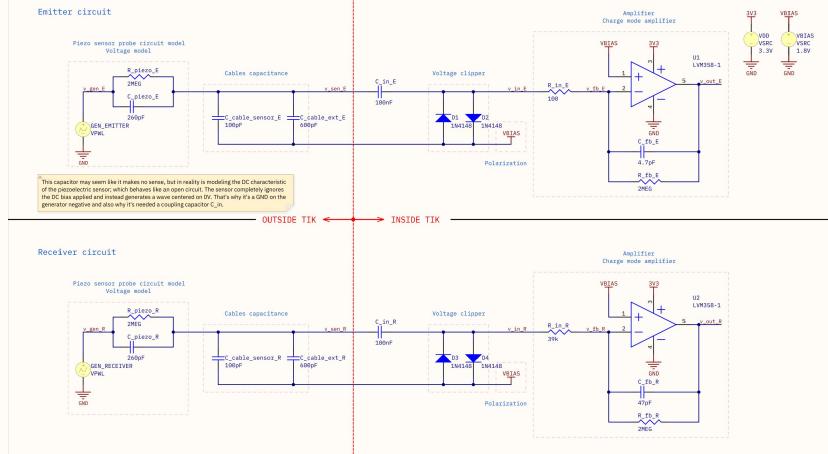
## Trunk signal's expected Voltage Spectral Density

Example VSD of a single trunk signal



## Simulated circuit

Circuit from a subproject inside ./SIMULATIONS



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 don't adjust to this model, behaving like an open circuit for DC and ignoring the VBIAS.

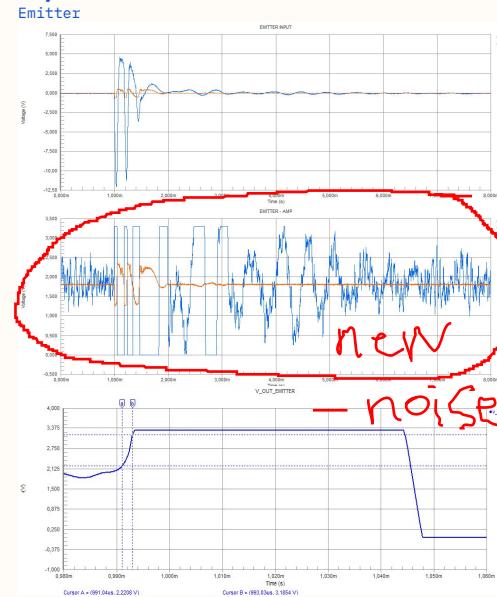
This is the reason behind the 100nF bypass capacitor. It allows us to center the input signals in the VBIAS DC voltage for our single-supply system.

These caps are rated for 100V as will have to stand a big voltage peak on their extremes.

## Spected frequency response



## Expected transient behavior



The emitter input signal can be of 10 to 20 V if the piezoelectric probe is hit very 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 adequation circuit for the emitter has more gain than 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.

Zoom over the first pulse. The expected rise time will be around 2 us, so the delay is of 1 sample ( $F_s = 500$  kHz)

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.



The adequation circuit for the emitter has more gain than it needs, so the output is saturated. This gives us a very step flank where the signal clearly begins and it's very easy to identify.

## 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  
Supervisor's signature

Sheet title: **Signal Conditioning Theoreticals**  
Project title: **TIK\_HandheldDevice.PjPcb**

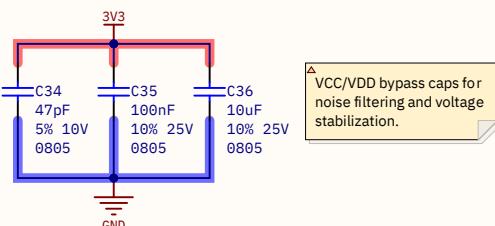
Designer: **Juan Del Pino Mena**

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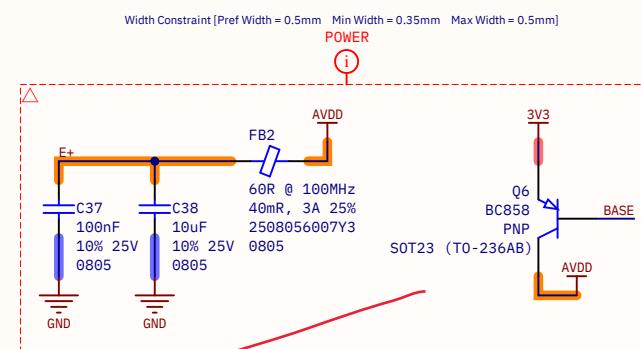
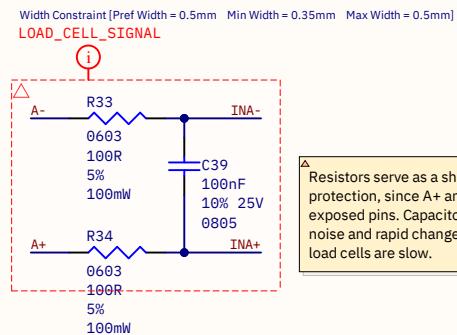
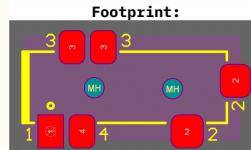
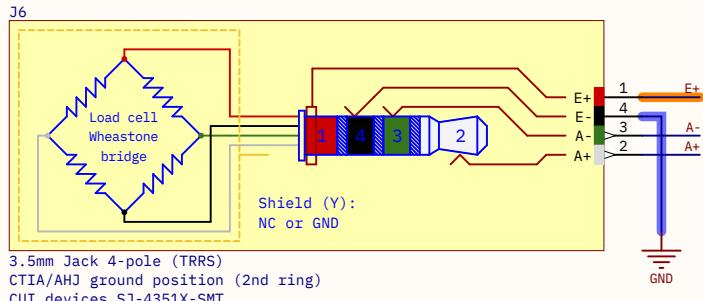
Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



A



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. Note that the shield is unconnected. A more appropriate alternative could be a RJ-11 6-pin connector, but was discarded because of the plug size.



BJT acts as a controllable current supply for the HX711's internal regulator.

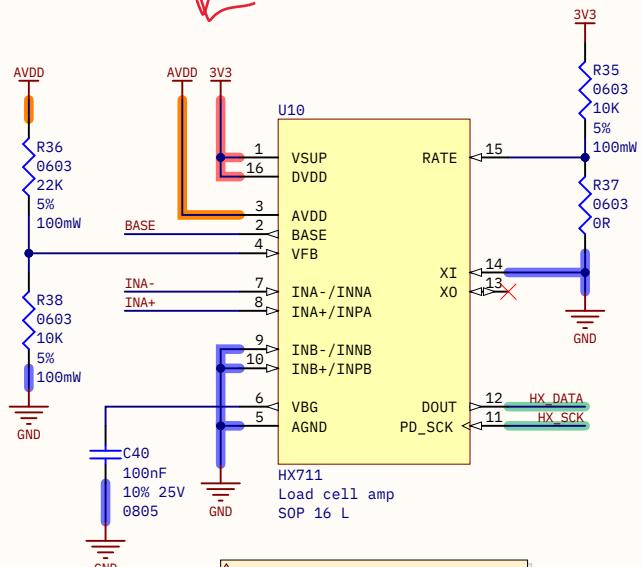
$\triangle$  VBG = VFB is a reference bypass output. It stays fixed at 1.25 V.

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

$\triangle$   $AVDD = VBG \cdot (R1 + R2) / R1$   
It should always be less than (VSUP - 100 mV)  
[HX711 datasheet, page 4]

$\triangle$  In this design:  
 $AVDD = 1.25 V \cdot (22 k\Omega + 10 k\Omega) / 20 k\Omega = 1.82 V$

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.



## 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.PjPcb**

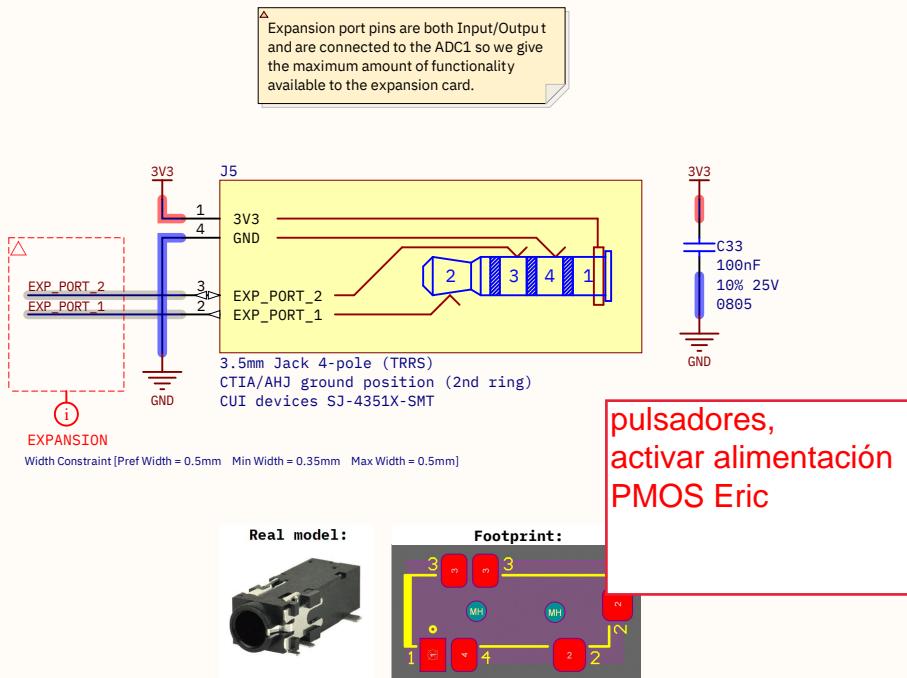
Designer: **Juan Del Pino Mena**

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Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
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## Expansion port connector



## Expansion port & jack connector

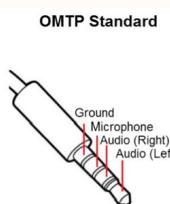
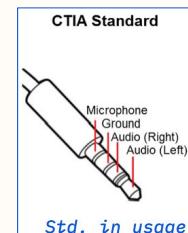
Expansion port for added functionality, such as an ultrasound resonance analysis for wood boards.  
Also, this sheet includes a description of the jack connector properties.

## 3.5mm jack connector considerations

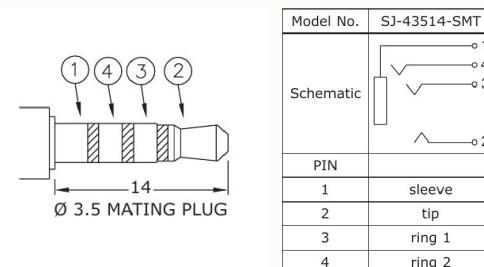
For both the load cell connector and the expansion port

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 modern, spread CTIA for the GND pin position (ring 2). The other possible option would be the OMTP standard (GND in sleeve).



The mating socket and plug are connected as follows. In this connector series there is the possibility of up to 6 pads, but all of them are connected to some of the 4 contacts of the plug and they only offer more mechanical integrity. [CUI Devices SJ-4351X-SMT Datasheet, page 2]



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Sheet title: Expansion port  
Project title: TIK\_HandheldDevice.PjPcb

Designer: Juan Del Pino Mena

Date: 2022-05-29 Revision: 0.5 Sheet 19 of 20

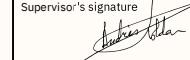
Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



A	Block	Component	Description/Conditions	Units	Supply voltage (V)	Current consumption per unit ( $\mu$ A)		Total dissipated power ( $\mu$ W)		Notes
						Typical	Maximum	Typical	Maximum	
	MCU	ESP32-WROOM-32D	MCU + wireless comm. Module	1	3.3	500 mA		1.7 W		Current spikes during wireless TX
Power rails		AP3429	DC/DC Buck converter IC	1	4.2	90 $\mu$ A		378 $\mu$ W		
		NCP562SQ18T1G	Low-Dropout regulator IC	1	3.3	3 $\mu$ A		9.9 $\mu$ W		
		150 k $\Omega$ + 33 k $\Omega$ voltage divider	FB pin feedback. Fixed consumption	1	3.3	18 $\mu$ A		59.4 $\mu$ W		
		[Optional] bypass voltage divider	Assuming 3V3/2 with 10 k $\Omega$ resistors	1	3.3	165 $\mu$ A		544.5 $\mu$ W		Consider only if populated
		Generic 0805 green LED	Assuming Vf = 3V & 39 $\Omega$ series resistor	1	3.3	7.7 mA		25.4 mW		Consider only if populated
Battery & current sense		INA219	Voltage & current sense IC	1	4.2	0.7 mA	1 mA	3 mW	4.2 mW	
		Generic 0805 green LED	Assuming Vf = 3V & 220 $\Omega$ series resistor	1	5.5	11.4 mA		62.5 mW		Consider only if populated
		Generic 0805 red LED	Assuming Vf = 2V & 470 $\Omega$ series resistor	1	5.5	7.5 mA		41 mW		Consider only if populated
		I2C pull-up resistor	Assuming line level is LOW, with 4.7k $\Omega$ resistors	2	3.3	0.7 mA		4.6 mW		
B		LTC4060EFE	NiMH/NiCd charger IC	1	5.5	2.9 mA	4.3 mA	16 mW	23.7 mW	
	[Optional] NiMH charger	MDJ201	Power PNP BJT. Ice=0.95 A, Ibe=120mA, Vce=1.8V, Vbe=0.7 V	1	--	--		1.71 W + 84 mW $\approx$ 1.8 W		Consider only if populated. 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.
		4.42 k $\Omega$ + NTC voltage divider	NTC pin. Assuming NTC at 50°C (3.54 k $\Omega$ )	1	5.5	691 $\mu$ A		3.8 mW		
[Optional] Li-Ion/Li-Po charger		TP4056	Li-Ion/LiPo charger IC, Vbus-Vbat=1.8 V, Ibat=1 A	1	5.5	150 $\mu$ A	500 $\mu$ A	1.8 W + 2.8 mW $\approx$ 1.8 W		
		DW01A	Battery protection IC	1	4.2	3 $\mu$ A	6 $\mu$ A	12.6 $\mu$ W	25.6 $\mu$ W	
		FS825A	Dual power NMOS, Rds(on)=25 m $\Omega$ , Ibat=1 A	1	--	--		50 mW (both NMOS)		
USB connector		USBLC6-2SC6	USB ESD protection IC	1	5.5	10 nA	150 nA	55 nW	825 nW	Consider only when USB is plugged
		CH340C	USB to UART converter IC	1	3.3	12 mA	30 mA	39.6 mW	99 mW	Worst case when programming
		2N7002	G.P. NMOS. Ib=0 A, Vds=3.3 V, Ids=330 $\mu$ A (during conmutation)	2	--	--		1 mW		Consider only when programming
Programming		Generic 0805 green LED	Assuming Vf = 3V & 39 $\Omega$ series resistor	2	3.3	7.7 mA		50.8 mW		Consider when programming, using UART and if populated.
		Generic 0805 red LED	Assuming Vf = 2V & 150 $\Omega$ series resistor	2	3.3	8.7 mA		57.4 mW		
		Buttons	Pull-up resistors	5	3.3	0 (not pushed)	330 $\mu$ A	0 (not pushed)	5.4 mW	Worst case: all pressed at once
C		BSS84AK	G.P. PMOS. Rsd(on) = 7.5 $\Omega$ , Ib=0, Isd = 77 $\mu$ A	1	--	--		45 nW		
	Power-up button	1N4148W	Small signal diode. Vf=0.7 V, If=26 $\mu$ A	2	--	--		36.4 $\mu$ W		Worst case: both ON
		100 k $\Omega$ pull-up resistor	100 k $\Omega$ pull-up resistor	1	4.2	42 $\mu$ A		176.4 $\mu$ W		
TFT LCD display		LCD TFT ILI9341 module	320x240p LCD (Measured)	1	3.3					Worst case: all pixels white, 60 FPS
	Signal conditioning	LMV358DGKR	General purpose dual OpAmp, with no load	1	3.3	140 $\mu$ A	340 $\mu$ A	462 $\mu$ W	1.1 mW	Both OpAmps, high Z load
		1N4148W	Small signal diode. Vf=0.7 V, If= $\mu$ A (Measured)	4	--					Consider only when measuring
Load cell amplifier		HX711	Load cell amplifier & ADC IC	1	3.3	1.4 mA		4.6 mW		Enters sleep if the data clock stops
		BC858	General purpose PNP BJT. Vce=1.8V, Ice=? $\mu$ A (Measured)	1	--					Consider only when HX711 is awake
		22 k $\Omega$ + 10 k $\Omega$ voltage divider	VFB pin feedback for AVDD=1.82 V regulation.	1	1.82	57 $\mu$ A		103.7 $\mu$ W		Consider only when HX711 is awake

## Power budget

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

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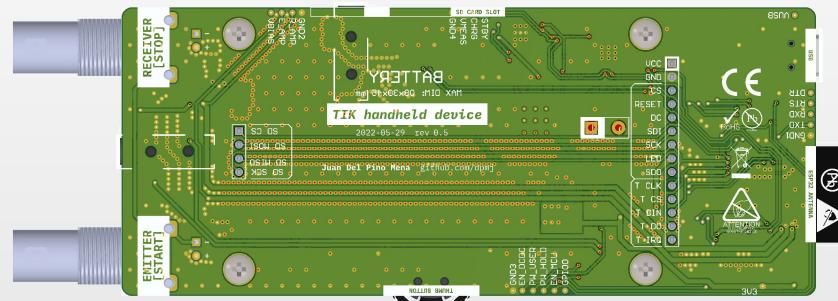
Sheet title: **Power budget**  
Project title: **TIK\_HandheldDevice.PjPcb**  
Desinger: **Juan Del Pino Mena**  
Date: **2022-05-29** Revision: **0.5** Sheet 20 of 20

Supervisor:  
Sr. Andrés Roldán Aranda  
Dpto. Electrónica y Tecnología de Computadores  
University of Granada  
C/Fuente Nueva, s/n, 18001  
Granada, Granada, Spain



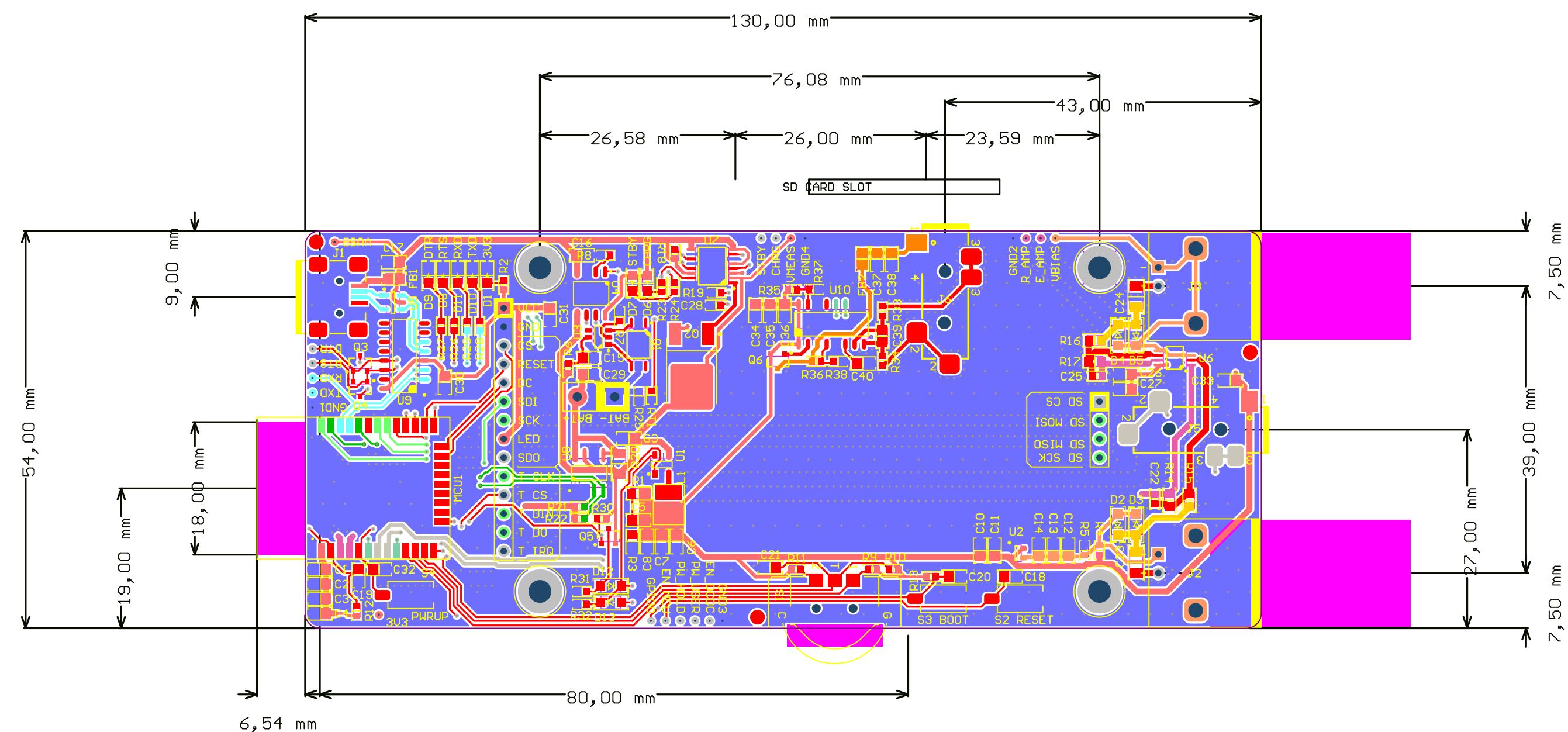
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**VISIBLE LAYERS:**

Board outline + Multilayer + Top overlay + Top layer + Keep-out + dimensions

**TRACKS & POLYGONS COLOR LEGEND:**

EMITTER/RECEIVER ANALOG SIGNALS	POWER REFERENCE GND/BAT-	SPI
GENERIC NET ON TOP LAYER	POWER RAIL 3V3/BAT+/VUSB/VMEAS/VSENSE	I2C
GENERIC NET ON BOTTOM LAYER	POWER RAIL VBIAS	SERIAL UART/USB

**TIK handheld device PCB**

PCB orientation: vertical. Screen facing front, BNCs on top, USB at the bottom, SD Card reader at the left, powerup button at the bottom front right, and multipurpose button on the right side.

Designer's signature:

Sheet title: TIK Handheld Device PCB

Dpto. Electronica y Tecnologia  
de Computadores  
University of Granada  
C/ Fuente Nueva, s/n, 18001  
Granada, Granada, Spain  
Sr. Andres Roldan Aranda

Supervisor's signature:

Project title: TIK\_HandheldDevice

Supervisor's signature:

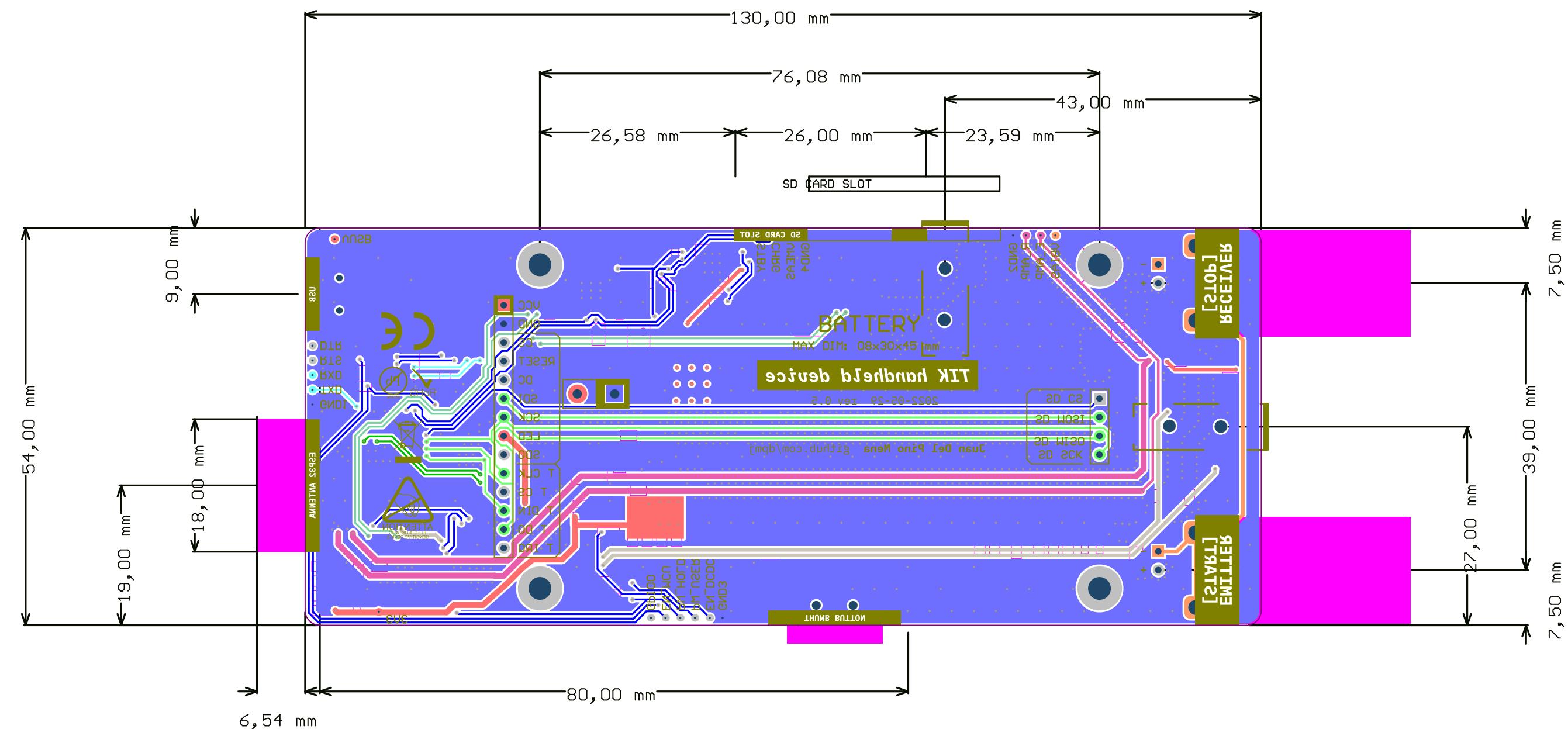
Designer: Juan Del Pino Mena

Supervisor: Andres Roldan Aranda



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## **VISIBLE LAYERS**

Board outline + Multilayer + Bottom  
overlay + Bottom layer + Keep-out  
dimensions

**TRACKS & POLYGONS COLOR LEGEND:**

 Emitter/Receiver Analog Signals	 Power Reference GND/BAT-	 SPI
Generic Net on Top Layer	 Power Rail 3V3/BAT+/VUSB/ VMEAS/VSENSE	 I2C
 Generic Net on Bottom Layer	 Power Rail VBIAS	 SERIAL UART/USB

# ***TIK handheld device PCE***

PCB orientation: vertical. Screen facing front, BNCs on top, USB at the bottom, SD Card reader at the left, powerup button at the bottom front right, and multipurpose button on the right side.

Designer's signature

Sheet title: TIK Handheld Device PCB

Dpto. Electronica y Tecnologia  
de Computadores  
University of Granada  
C/ Fuente Nueva, s/n, 18001  
Granada, Granada, Spain  
Sr. Andres Roldan Aranda

Supervisor's signature

Diseño: Juan Bel Rincón Mena

*Andrésolda*

Supervisor: Andres Roldan Aranda

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Date: 2022-05-29  
Revision: 0.5 Sheet 1 of 1





