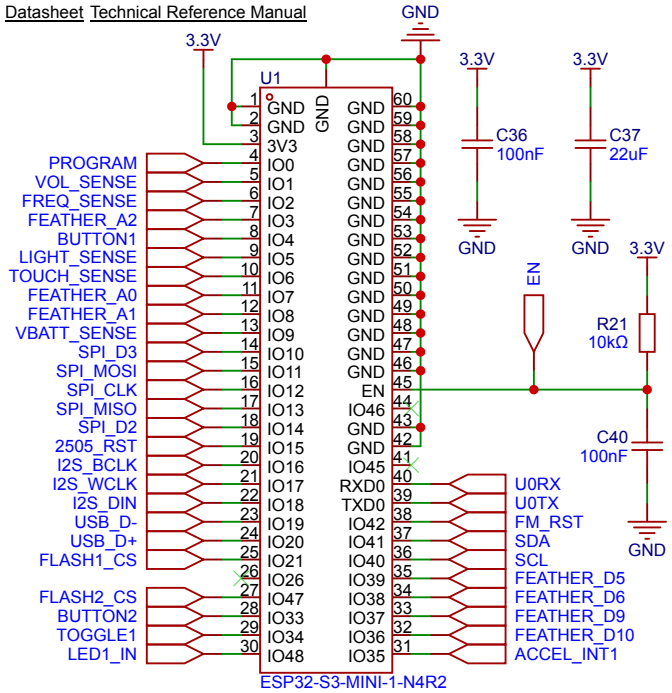
General notes: Decoupling capacitors are placed near the component they decouple, with notations if they are intended to decouple specific power supplies. Capacitors are ceramic unless otherwise notated and have voltage rating of minimum 2x expected voltage.

ESP32-S3-MINI-1-N4R2: Microcontroller

Datasheet Technical Reference Manual

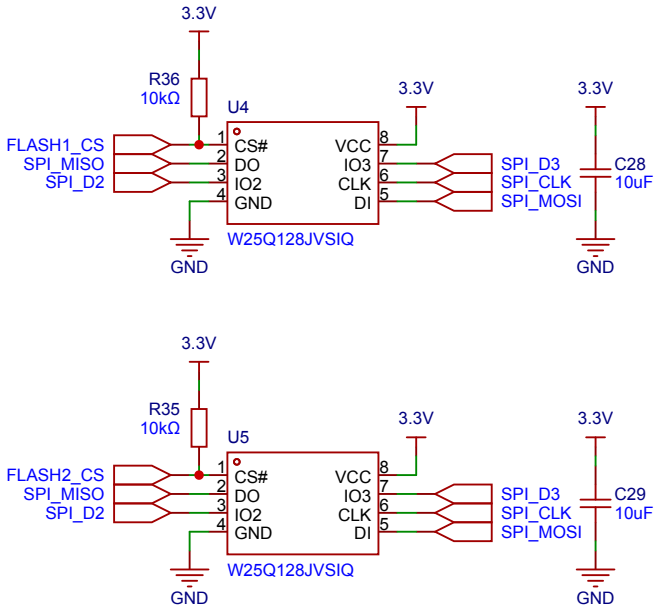


For ease of firmware development, pins were assigned for compatibility with previous board revisions, even when doing so resulted in suboptimal peripheral use (e.g. SPI_D3 should ideally be on IO9)

RC circuit on EN is recommended by datasheet to allow for power to stabilize.

W25Q128JV: Flash Storage

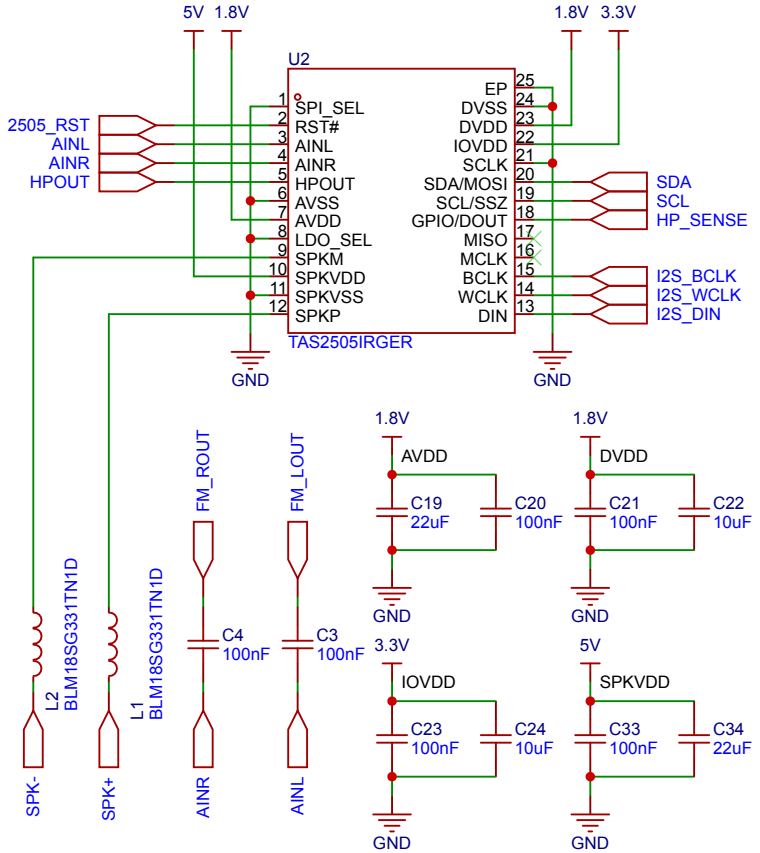
Datasheet



Each chip provides 16MB (128 Mbit) of storage. This specific storage IC was selected due to availability as a JLCPCB Basic Part.

TAS2505: DAC + Audio Amplifier

Datasheet Application Reference Guide



Both TAS2505 and SI4702 want AC-coupling capacitors on the FM output/analog input. Value is taken from TAS2505's datasheet.

HP_SENSE is connected to a GPIO here instead of the ESP32 to save a pin and to try and isolate the headphone analog domain somewhat.

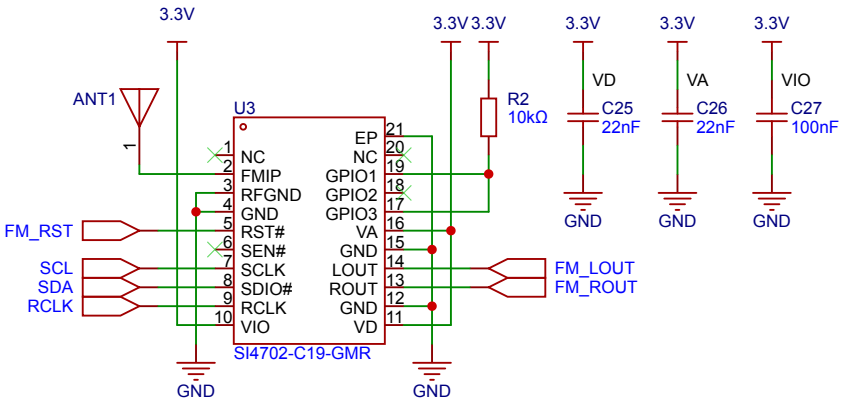
Ferrite beads L1 and L2 should be placed close to the TAS2505 to minimize RF emission from class D amplification.

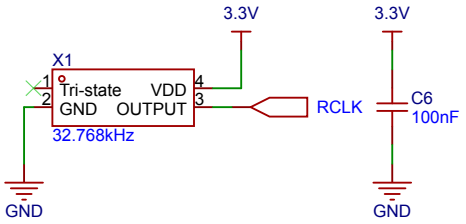
SI4702: FM tuner

Datasheet AN383 (Layout Guidelines)

Antenna design based on:
S. -m. Song, L. Jin, Y. Zheng and G. -q. Yang, "A miniaturized FM chip antennas for handset devices" doi: 10.1109/MMWCST.2012.6238213.

With testing we found the best performance in our specific environment with a 29mm-wide spiral (7mm wider than in the paper) on layers 1 & 4 with no matching network. Differing fabrication details - especially layer thickness and substrate material - may change these results.





Pulling GPIO1 and GPIO3 high triggers busmode selection method 2 and within that mode, 2-wire (or I2C) operation. This works because we're not using the built-in crystal oscillator and the GPIOs aren't that useful.

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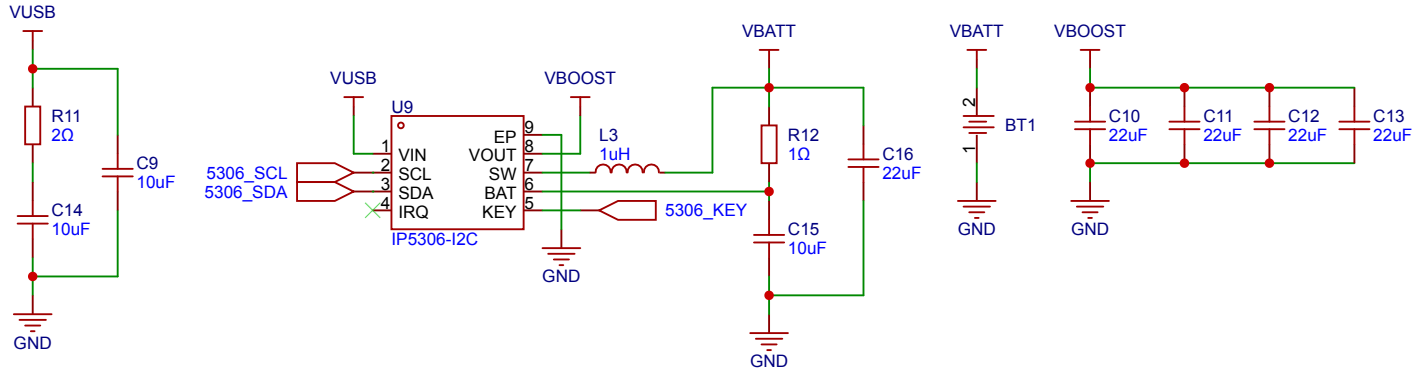
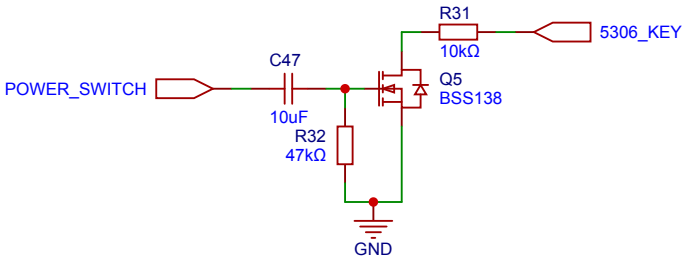
IP5306: Battery and Power Management

Datasheet



The I2C variant of the IP5306 utilizes pins 2-4 for I2C. These pins are normally LED1, LED2, and LED3 (used to indicate battery level). SCL and SDA work as expected; the datasheet labels pin 4 (LED3) as IRQ but is otherwise completely silent on its behavior.

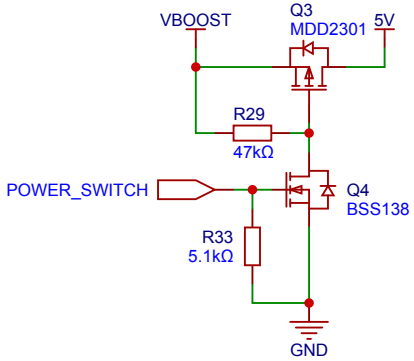
IP5306 Workarounds



(POWER_SWITCH is floating when off and connected to VBATT when on)

Normally the KEY pin is connected through a momentary switch to GND. When on battery power, a press of between 30ms and 2s turns on the boost converter. This simulates a pulse when POWER_SWITCH becomes high. Duration depends on exact V_th of Q5 and battery charge level but is 300-800ms.

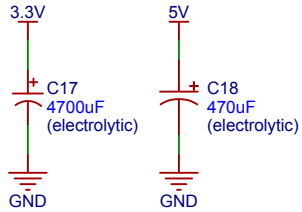
IP5306 automatically turns off power after 32s of low power draw



(POWER_SWITCH is floating when off and connected to VBATT when on)

When connected to USB power, the IP5306 always powers VBOOST. To allow turning off the radio even on USB power, this disconnects VBOOST from downstream 5V rail when POWER_SWITCH is floating.

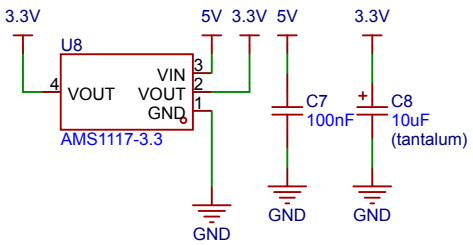
On battery power, this will also turn off the boost converter by removing power draw.

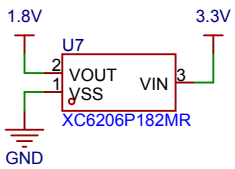


When USB power is disconnected, VBOOST is briefly unpowered while the IP5306 starts the boost converter. Without intervention this would result in browning out the ESP32-S3 and other ICs. To compensate, we add a significant amount of bulk capacitance on the 3.3V rail, and additional capacitance on the 5V rail to ensure the 5V rail doesn't sag under 3.3V.

Voltage Regulators

AMS1117 Datasheet XC6206 Datasheet





The AMS1117 regulator specifically requests a tantalum capacitor on its output for stabilization. Given that the 1.8V regulator was placed immediately next to the TAS2505's decoupling capacitors on both the 3.3V and 1.8V side, we concluded that additional capacitance wasn't necessary

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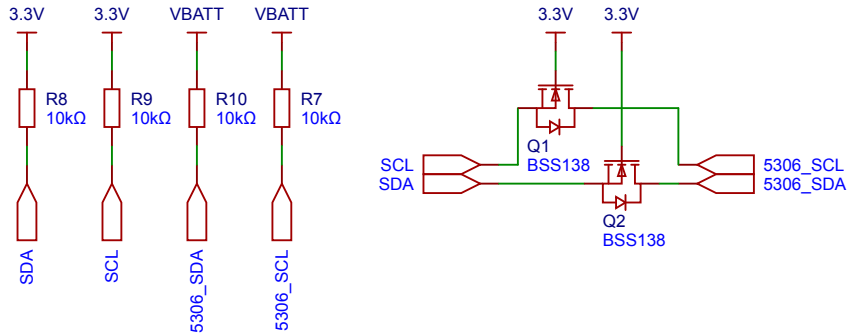
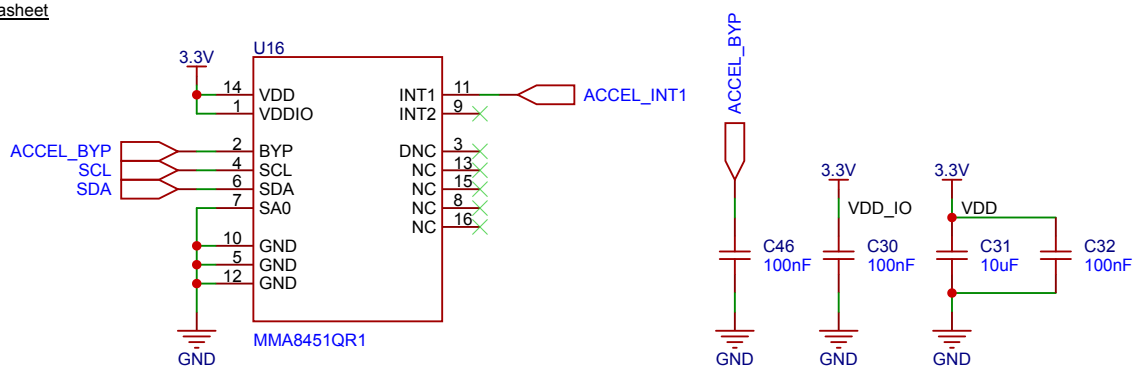
I2C Bus



The IP5306-I2C datasheet does not explicitly specify whether it is tolerant to 3.3V logic (which would be lower than VBATT in almost all cases). We added a level shifter for safety.

MMA8451Q: Accelerometer

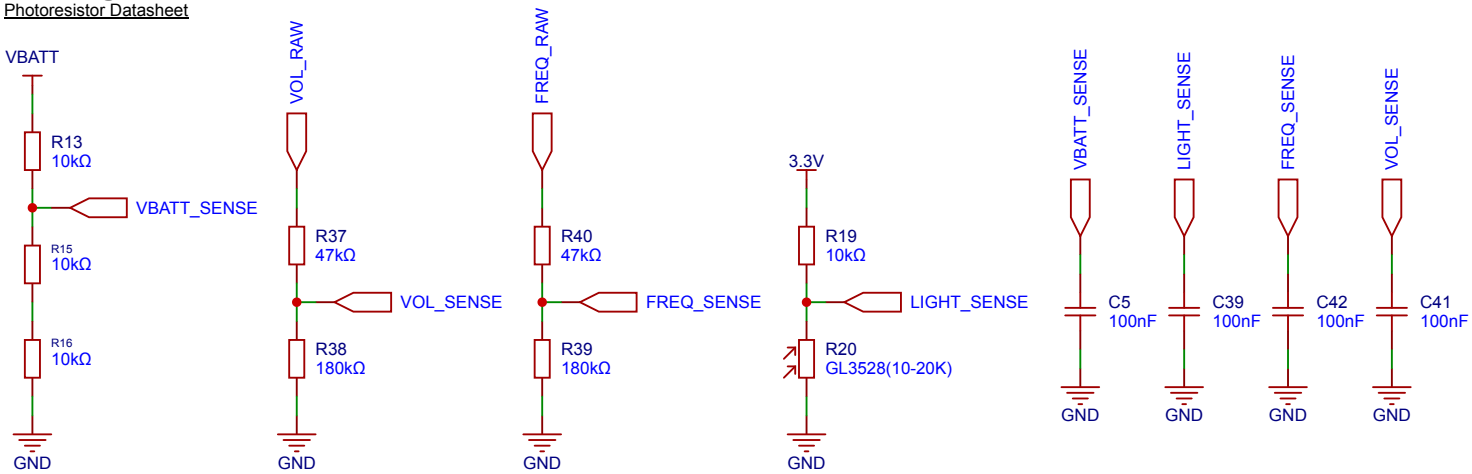
Datasheet



One specific note: we found that this accelerometer's reporting of polarity when detecting pulses was significantly more accurate when only measuring on a single axis, rather than multiple.

Analog Sensors

Photoresistor Datasheet



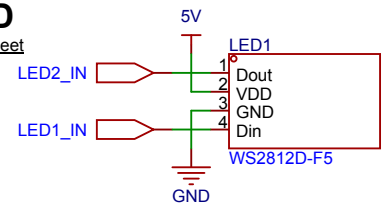
The front daughterboards regulate VOL_RAW and FREQ_RAW to between 0V and 3.1V, based on an old version of the ESP-IDF documentation. However, after producing those boards, we learned that variance in ADC reference voltage made this problematic. We added the resistor dividers on VOL_SENSE and FREQ_SENSE to ensure they would be within the ADC's measurable range.

The resistor divider for VBATT similarly ensures that battery voltage is within the ESP32-S3 ADC range (with full attenuation). R13 should be placed as close to the battery as possible to minimize voltage drop over the power traces.

The ESP-IDF documentation recommends 100nF bypass capacitors on ADC inputs to minimize noise.

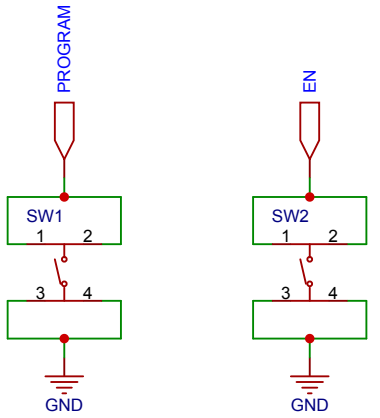
LED

Datasheet



This is a WS2812 (NeoPixel) LED in through-hole package to better simulate vintage technology.

Microswitches



SW1 is labeled as "PROG"; SW2 is labeled as "RST"

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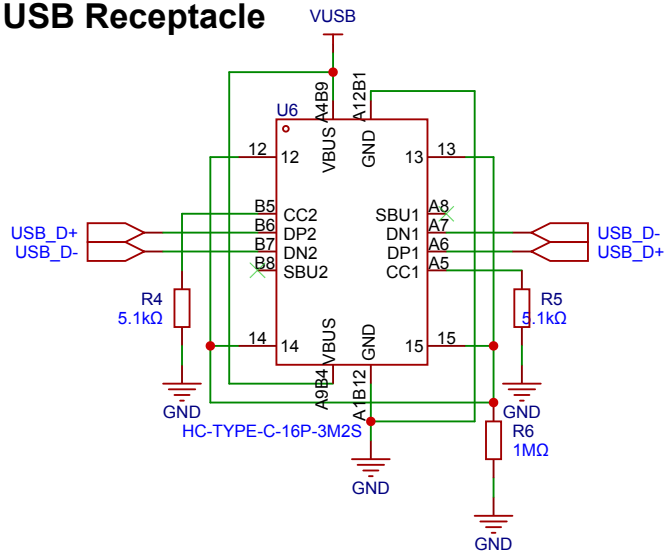
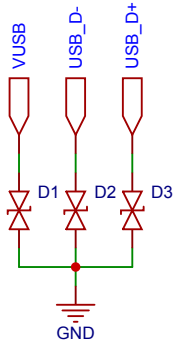
USB Receptacle



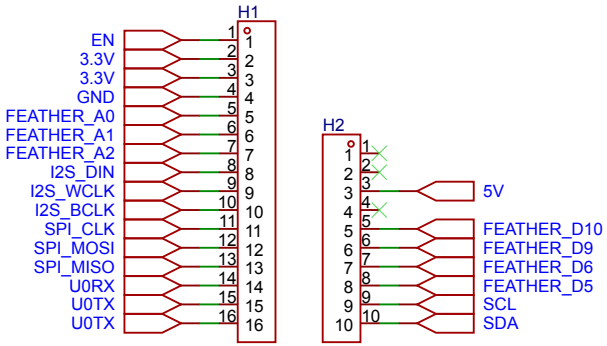


Connecting DP1/DP2 and DN1/DN2 allows the receptacle to work in both orientations, but the traces must be short. Sources are divided on whether the receptacle shield should be grounded, floating, or grounded through a resistor. We opted for the latter.

D1, D2, and D3 provide ESD protection.

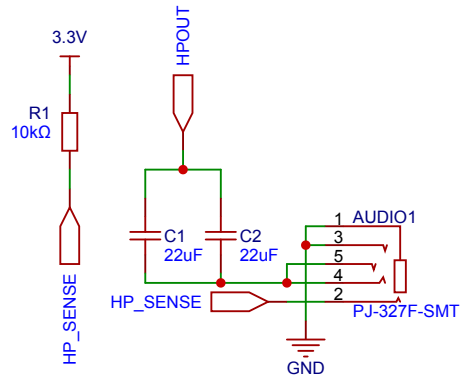
Adafruit Feather-compatible Headers

Specification



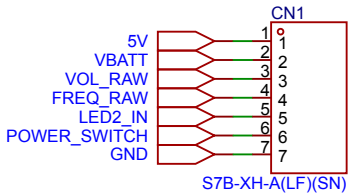
H1 and H2 are 2.54mm headers compatible with the Adafruit Feather specification, though are not exactly to spec. VBAT(T) is not exposed (and of course we lack the required JST 2-pin battery connector), and instead of VUSB we expose our 5V rail (which may be USB or boosted from battery). Our "EN" signal is connected to the Feather RST pin; we do not support the Feather EN pin (which is technically required by spec to depower the 3.3V supply to the FeatherWing)

Headphone Jack



This is a TRRS (4-conductor) 3.5mm jack. Pins 1 and 2 are normally disconnected, but connected together by the sleeve of an inserted plug allowing us to detect when a plug is inserted. Pin 5 connects to the tip (left audio channel) and pin 4 connects to the first ring (right audio channel). Depending on the headset, the sleeve or the second ring can be the microphone, but since we aren't using it, we short both to ground. Finally, the capacitors AC couple the audio signal.

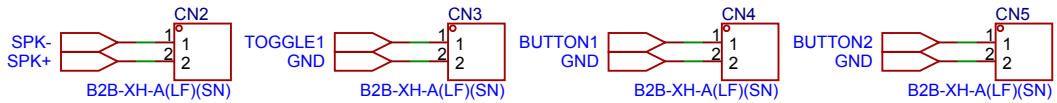
Front Daughterboard Connector



This is a JST XH (2.54mm) 7-pin connector that runs to the front daughterboard, which contains the volume and frequency switch/potentiometers + the status LED. As noted on the daughterboard schematic, the pinouts on each end of our 7-pin cables were reversed, i.e. pin 1 on one end connects to pin 7 on the other.

(This is in contrast to the I2C connectors below, where pin 1 on one end connects to pin 1 on the other)

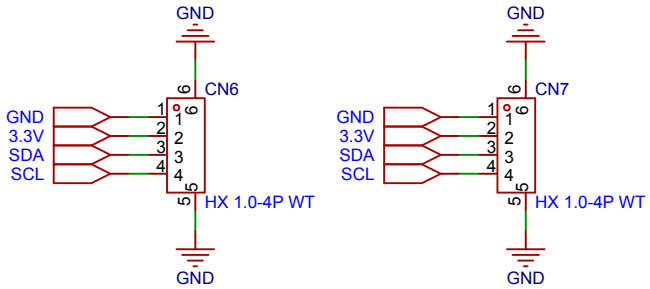
Other Connectors



These connectors are all JST XH (2.54mm) 2-pin connectors. The connectors are keyed for polarity, but none of these devices are polarized.

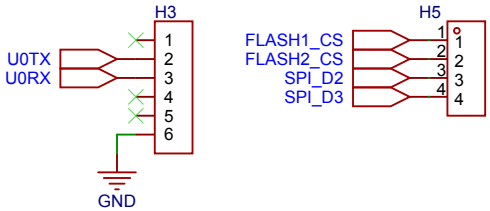
BUTTON1 refers to the triangle button; BUTTON2 is the circle button. TOGGLE1 is the FM/PM toggle switch on the rear.

I2C Connectors



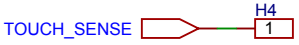
These connectors are JST SH (1.00mm) 4-pin connectors, compatible with both Adafruit Stemma QT and SparkFun QWIIC. One is used to connect the magnet daughterboard; the other is available for expansion.

Debug Headers



These 2.54mm headers are unpopulated but expose pins for debugging that are otherwise unexposed.

Capacitive Touch Sensing



The ESP32-S3 supports capacitive touch with no external components required, so this pad connects directly to the microcontroller. It is soldered to stranded wire which is in turn screwed to the carraige bolts in the radio's feet. There is an additional R1.25mm hole on the PCB intended for strain relief on that wire.

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