# KREPE Flight Computer Hardware Manual

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# 1 Introduction

This document contains information about the flight computer for the KREPE mission as well as the safety precautions taken to ensure the flight hardware is not a danger to the ISS or its astronauts. In addition to electrical designs and schematics, this document contains pin names, links to datasheets, and implementation notes. The following sections outline the subsystems of the flight computer, pin names for software usage, and datasheets. Other details about the power subsystem including battery type and rating are also included.

The entire flight ready assembly is referred to as KREPE, which consists of a capsule containing the science (flight computer, batteries, etc.) and an metal shell known as KREM that acts as a Faraday cage inhibiting any inadvertent RF radiation from the probe. Both primary and secondary activation must occur for the capsule to become fully active and begin RF transmissions. To avoid accidental activation of hazardous subsystems, multiple secondary activation criteria must be met. Primary and secondary activation processes are discussed in sections 1.1,1.2, and 2.1.1.

The subsystems of the flight computer are outlined in Sec. 2. Pin definitions are listed with each hardware or sensor component along with any relevant information regarding safety or implementation. Electrical schematics, microcontroller reference cards, and a partslist are shown in Appendices A, E, and D, respectively.

## 1.1 Primary Activation

Primary activation is triggered by a pin pulled out of KREPE by astronauts. Once the pin is pulled, a mechanical switch[1] is closed and the flight computer boots to dormant mode where it consumes minimal power. The Iridium radio is not powered on in dormant mode. After pulling the pull tab, a piece of copper tape is put over the hole and primary activation is the complete. Copper tape ensures the KREM is completely sealed with regard to EMI.

A schematic showing battery protection and primary activation circuitry activation is shown in Fig. 1. Less than 5 inches of copper 20 AWG PVC insulated wire is used to connect the batteries to the first power function (battery protection circuitry).

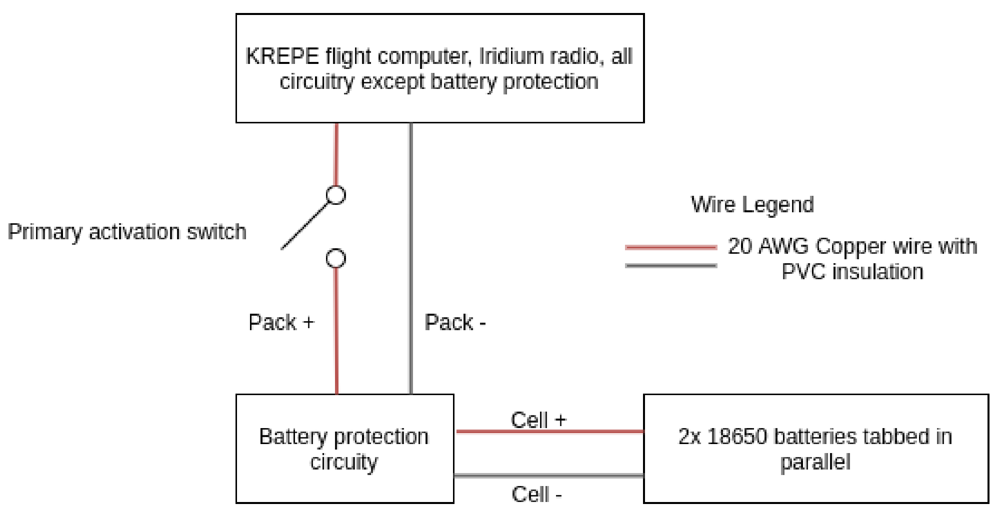


Figure 1: Activation and battery protection schematic overview.

[1] https://www.digikey.com/product-detail/en/omron-electronics-inc-emc-div/D2SW-3L1H/Z12268-ND/1811989

## 1.2 Secondary Activation

Once primary activation is complete and the flight computer is in dormant mode, a digital input to the flight computer is configured as an interrupt to sense when the KREM separates from around the capsule. When this interrupt is triggered, the flight computer checks the status of the thermocouples. If the thermocouples register a temperature that is sufficient to have melted the polycarbonate bolts that hold the KREM together, secondary activation occurs. No radio transmissions are attempted before secondary activation.

# 2 Subsystems

## 2.1 Radio Communications

KREPE has two radios, a debug radio used for ground work and an Iridium satellite modem used both on the ground and during the mission. The following subsections explain the conditions necessary for enabling the satellite modem during the mission and also restate that the debug radio is physically disabled prior to final integration and is never powered on or used during the actual mission.

### 2.1.1 Radio Power Control

There are two inhibits to powering on the iridium, as denoted in Table 1. The separation of the KREM must be detected and the temperature of the capsule must be determined to be above the activation threshold temperature, $T_a$.

Table 1: Inhibits to Ididium radio activation.

| Sensor | Monitored by | Description |
|---|---|---|
| Thermocouples | Teensy | Thermocouple temperature reported by Teensy |
| KREM Interrupt | Teensy | KREM presence detected by Teensy |

### 2.1.2 Iriduim Radio

We are using the A3LA-RS type modem seen on the NAL Research site [2]. The RF specifications, taken from the module's datasheet are shown in Fig. 3.

| | |
|---|---|
| Operating Frequency: | 1616 to 1626.5 MHz |
| Duplexing Method: | TDD |
| Multiplexing Method: | TDMA/FDMA |
| Link Margin: | 12 dB average |
| Average Power during a Transmit Slot (Max): | 7W |
| Average Power during a Frame (Typical): | 0.6W |
| Receiver Sensitivity at 50Ω (Typical): | –118 dBm |

Figure 2: RF specifications of the AL3A-RS Iridium modem.

**Iridium Serial Interface** A 3.3V TTL to RS232 adapter is needed to interface with the AL3A-RS. This small serial converter board is wired in between the flight computer and Iridium module. The serial converter uses a MAX3232E RS-232 line driver and receiver [3].

[2] http://www.nalresearch.com/IridiumHardware.html
[3] https://www.ti.com/product/MAX3232E

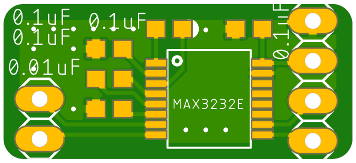


Figure 3: TTL to RS232 serial converted module.

### 2.1.3 Debug Radio

The KREPE flight computer features a secondary debug radio used for ground testing that is not enabled for the real mission. Maximum output power according to the radio datasheet [4] is 100mW.

Table 2: Radio module interface signals.

| Teensy Pin | Net Name | Description | Teensy Configuration |
|---|---|---|---|
| 28 | RESET_ISM | Pull low to enable RFM69 | `OUTPUT` |
| 29 | INT_ISM | GPIO0 interrupt from RFM69 | `INPUT` |
| 33 | RADIO_OFF_SIG | Pulled high when the RFM69 is disabled | `INPUT` |

The datasheet for this antenna can be found at https://cdn.taoglas.com/datasheets/FXP290.07.0100A.pdf.

## 2.2 Thermal Measurement

The thermal measurement subsystem is used to take readings from up to eight thermocouples (TCs) to characterize the temperature profile that is experienced by the probe upon re-entry. As KREPE heats during re-entry, this subsystem detect the increase in temperature and is also used as a secondary activation criteria. Table 3 shows the pins used to control the TC conversion chips and analog multiplexers making multi-TC readings possible.

Table 3: Analog mux selection and thermocouple fault status pins.

| Teensy Pin | Net Name | Description | Teensy Configuration |
|:---:|:---:|:---:|---:|
| 16 | MUX0 | MUX select pin 0 | `OUTPUT` |
| 17 | MUX1 | MUX select pin 1 | `OUTPUT` |
| 25 | TC1_FAULT | U13 fault (active low) | `INPUT` |
| 26 | TC2_FAULT | U12 fault (active low) | `INPUT` |

### 2.2.1 Thermocouple Connections

The 8 TC connections are done with 2 analog multiplexers IC1 and IC3 (MUX1 and MUX2). The MUX select pins go to both of these chips to select a certain channel. The table of MUX(0/1) select values versus two selected TCs are shown in Table 4.

[4] https://cdn.sparkfun.com/datasheets/Wireless/General/RFM69HCW-V1.1.pdf

Table 4: Truth table for multiplexer select pins and their relation to the pairs of TC that are selected.

| MUX0 | MUX1 | TC number |
|---|---|---|
| 0 | 0 | 1, 5 |
| 0 | 1 | 2, 6 |
| 1 | 0 | 3, 7 |
| 1 | 1 | 4, 8 |

Pin connections on headers P1 and P2 show the connections for TC 1-8 lead wire pairs. Figure 4 shows the pinout on the silkscreen.

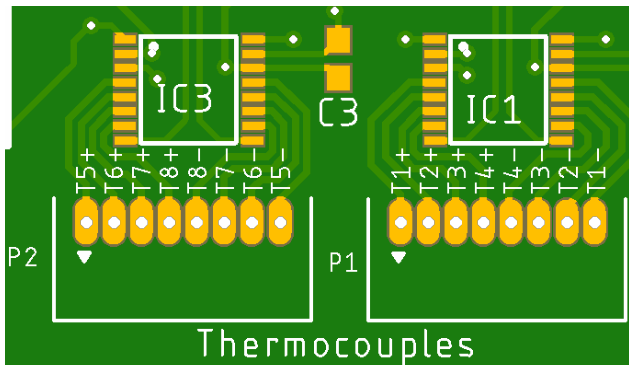


Figure 4: Thermocouple connection wiring with resepect to the analog mux chips IC3 (MUX2) and IC1 (MUX1).

## 2.3 Visual Status Indicators

The KREPE flight computer features several light emitting diodes (LEDs) to provide visual feedback during ground testing. Pin mappings and intended information denoted by each LED is shown in Table 5.

Table 5: Debug LED Connections.

| Teensy Pin | Net Name | Teensy Configuration |
|---|---|---|
| 3 | LED1 - IRIDIUM ON | `OUTPUT` |
| 4 | LED2 - IRIDIUM SIGNAL OK | `OUTPUT` |
| 5 | LED3 - IRIDIUM RADIO TRANSMITTING | `OUTPUT` |
| 6 | LED4 - ISM RADIO TRANSMITTING | `OUTPUT` |
| 7 | LED5 - GENERAL ACTIVITY | `OUTPUT` |

## 2.4 Auxillary Sensors

The KREPE flight computer features several auxillary sensors that will be used to better characterize reentry. Measurements from an ADXL377 3-axis ±200g accelerometer, ICM-20948 9-axis IMU, and DSP310 barometric pressure sensor are collected after secondary activation. Measurements from these auxiliary sensors are not used for activation.

Table 6: Pins connecting to the ADXL377 and ICM-20948.

| Teensy Pin | Net Name | Description | Teensy Configuration |
|---|---|---|---|
| 36 A17 | XOUT | Analog out from accel (x axis) | `INPUT` |
| 37 A18 | YOUT | Analog out from accel (y axis) | `INPUT` |
| 38 A19 | ZOUT | Analog out from accel (z axis) | `INPUT` |
| 35 | INT | Interrupt from ICM-20948 | `INPUT` |
| 34 | FSYNC | Synchronization signal to ICM-20948 | `OUTPUT` |

## 2.5 Power and Batteries

Batteries are provided by JSC and rated at 3200mAh. System power is provided by two of these cells tabbed in parallel (tabbing performed and documented by JSC). Battery classification, product, and model number can be seen in Fig. 2.5 (taken from battery specification sheet).

**Battery Classification and Product Code**

| | |
|---|---|
| 4.1 Battery Classification | Lithium Ion Battery |
| 4.2 Product Code | BJ-A300180AA |
| 4.3 Model Name | NCR18650B-H07XA |
| 4.4 Cell Type | NCR18650BL |

Figure 5: Sanyo battery specifications from the datasheet.

Charge current is limited to to 450 milliamps (mA), a charge rate of $C/12$ with the two (2) 3200 milliamp-hour (mAh) system Battery Charge power can be delivered via Teensy USB or the `CHARGE` header. Charging input voltage is expected to be 5 volts. Charge voltage to the batteries is regulated to 4.2 volts by the charge management IC, an MCP73831[5], with status connections to the Teensy as shown in Table 7.

charging when not installed vs charging when installed.

Charging is only performed on the ground and there is no provision for charging in flight. Schematics and electrical connections are shown in Fig. 11 in Appendix A.

### 2.5.1 Battery Status Interface

Table 7: Pins to monitor battery voltage and charging status.

| Teensy Pin | Net Name | Description | Teensy Configuration |
|---|---|---|---|
| 14 | BAT_STAT | LiPo charge state | `OUTPUT` |
| 22 A8 | BAT_SENSE | Halved battery voltage for monitoring | `INPUT` |

### 2.5.2 Battery Protection

Protection circuitry is implemented on the flight board to support 2P1S LiIon packs for system power. We are using a DW108 Voltage and Current Protection IC [6].

[5](https://www.microchip.com/wwwproducts/en/MCP73831)

[6]https://cdn.sparkfun.com/assets/learn_tutorials/2/5/1/DW01-P_DataSheet_V10.pdf

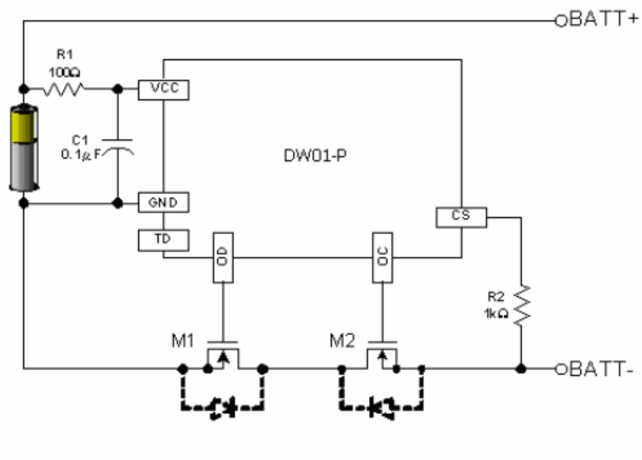


Figure 6: Battery protection circuitry.

Protection circuitry as implemented on the KREPE flight computer PCB is shown in Fig. 6. Our two batteries are in parallel where the battery image is shown in Fig. 6, and BATT+ and BATT- face system power i.e. to the flight computer. This protection circuitry is upstream of the primary activation switch. The battery protection PCB can be seen in Fig. 7.

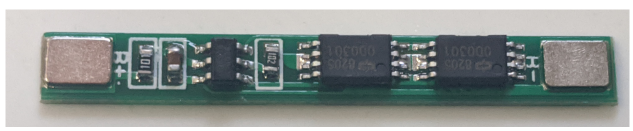

Figure 7: Battery protection PCB.

**Over-current protection** The battery protection PCB can be seen preventing over current draw in Fig. 8. After 6 milliseconds, the battery cells are disconnected from the output and current draw

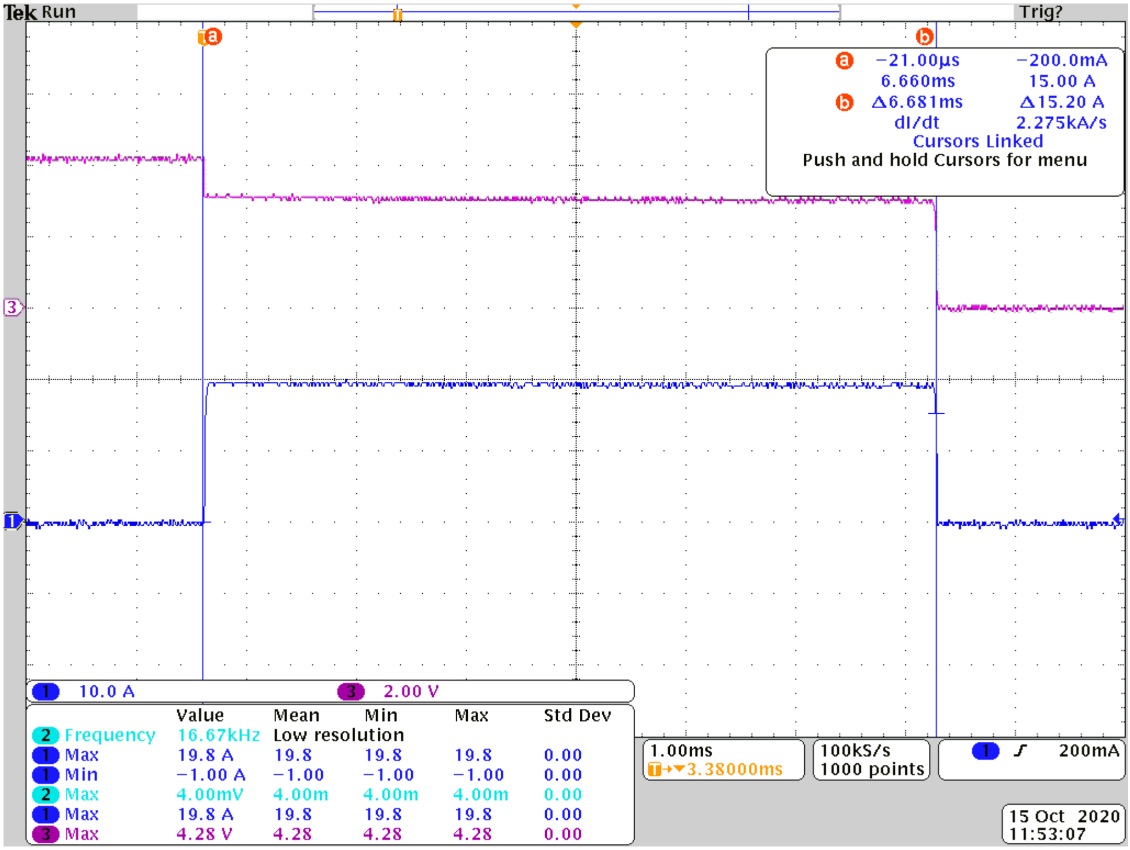


Figure 8: The battery protection circuity disconnecting the cells after 6ms of over current condition. Blue: current. Purple: pack voltage.

# A Schematics

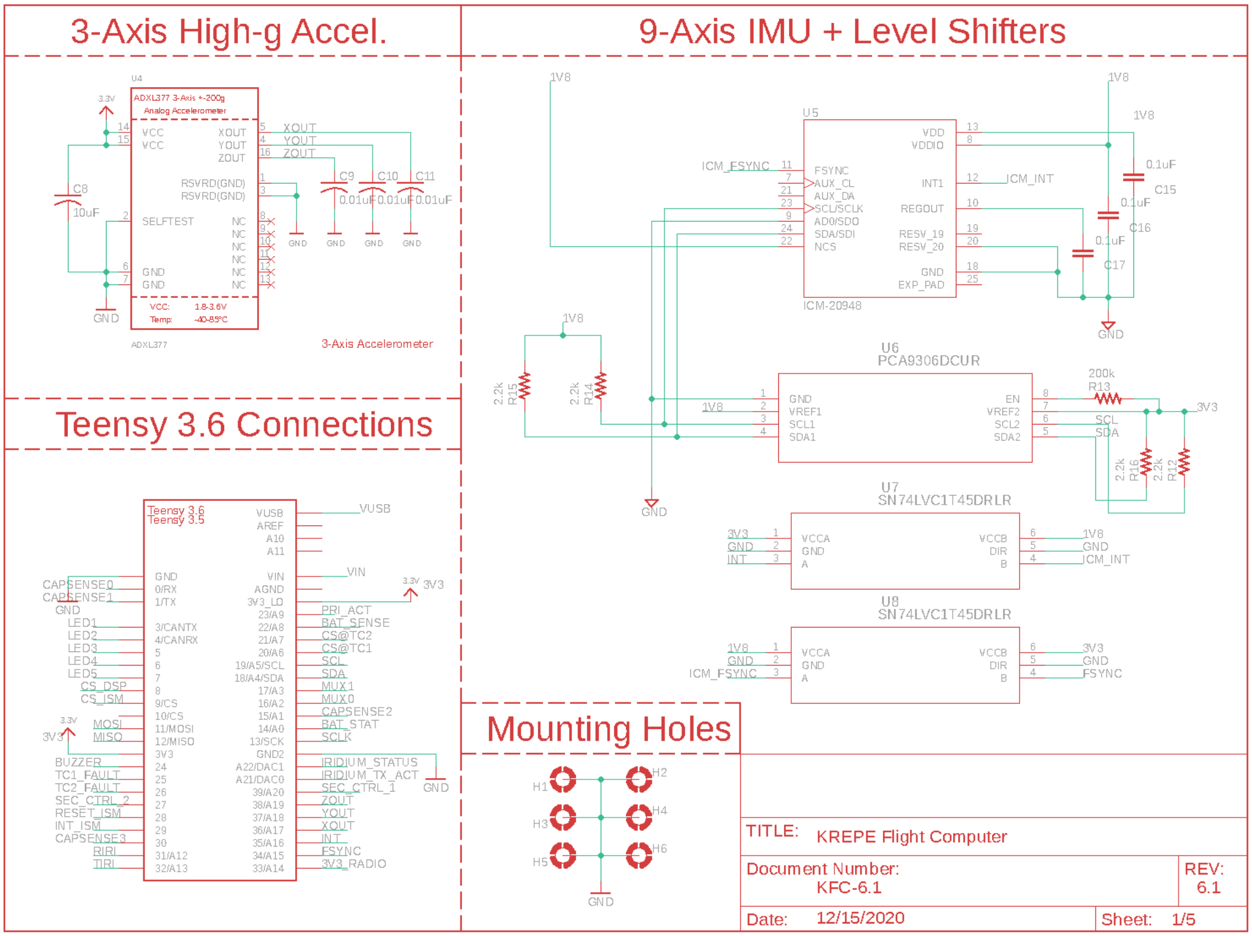


Figure 9: Page one of schematics.

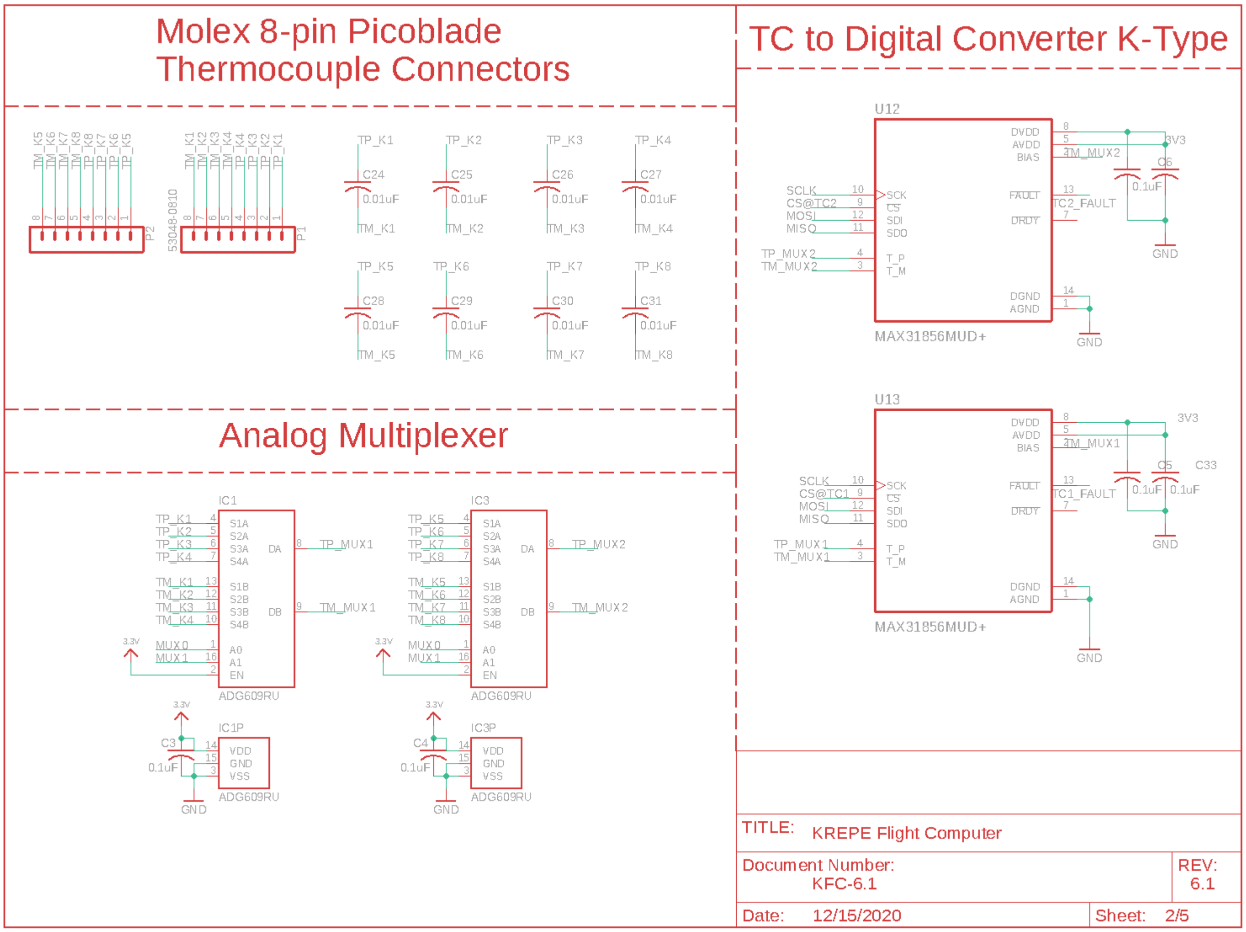


Figure 10: Page two of schematics.

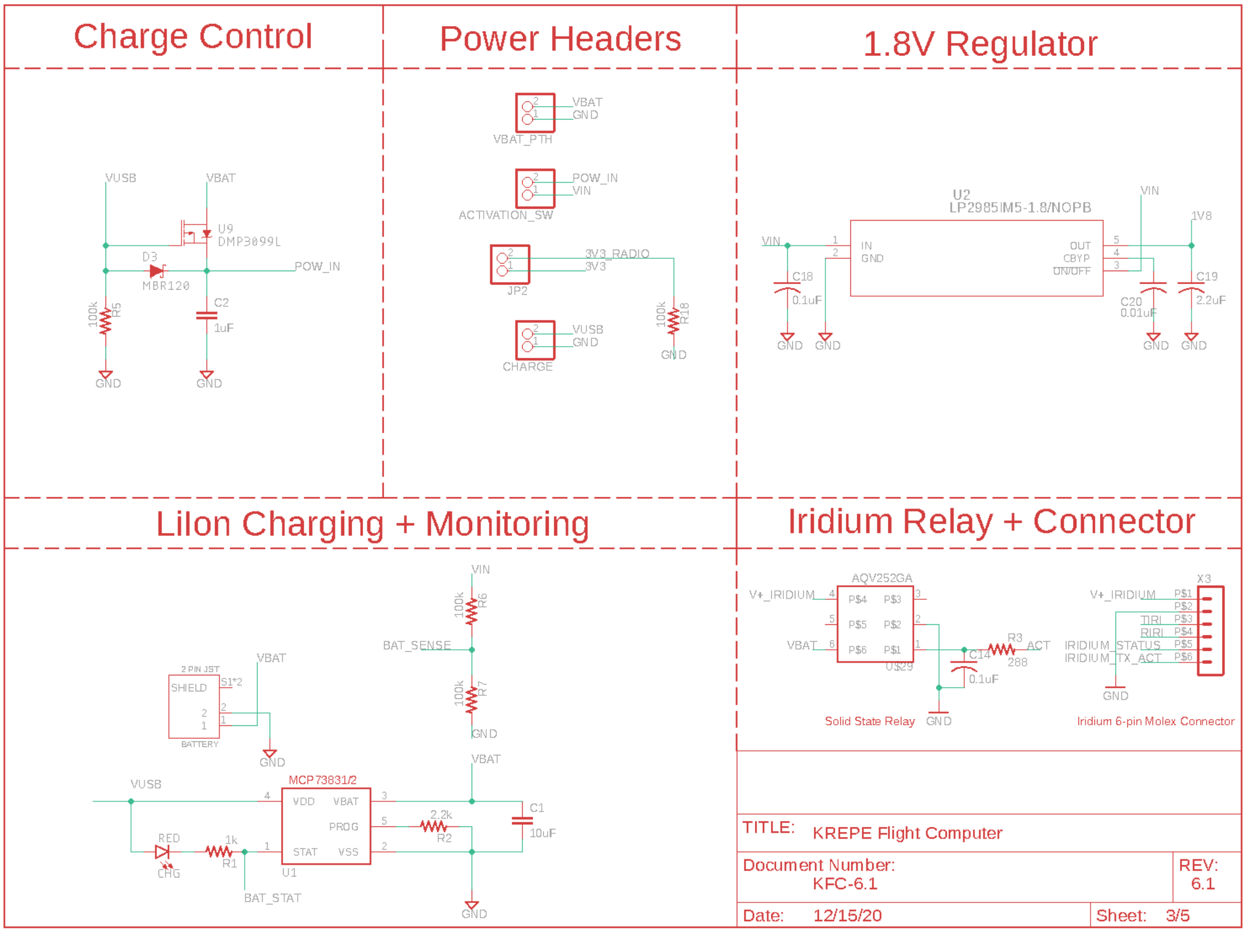


Figure 11: Page three of schematics.

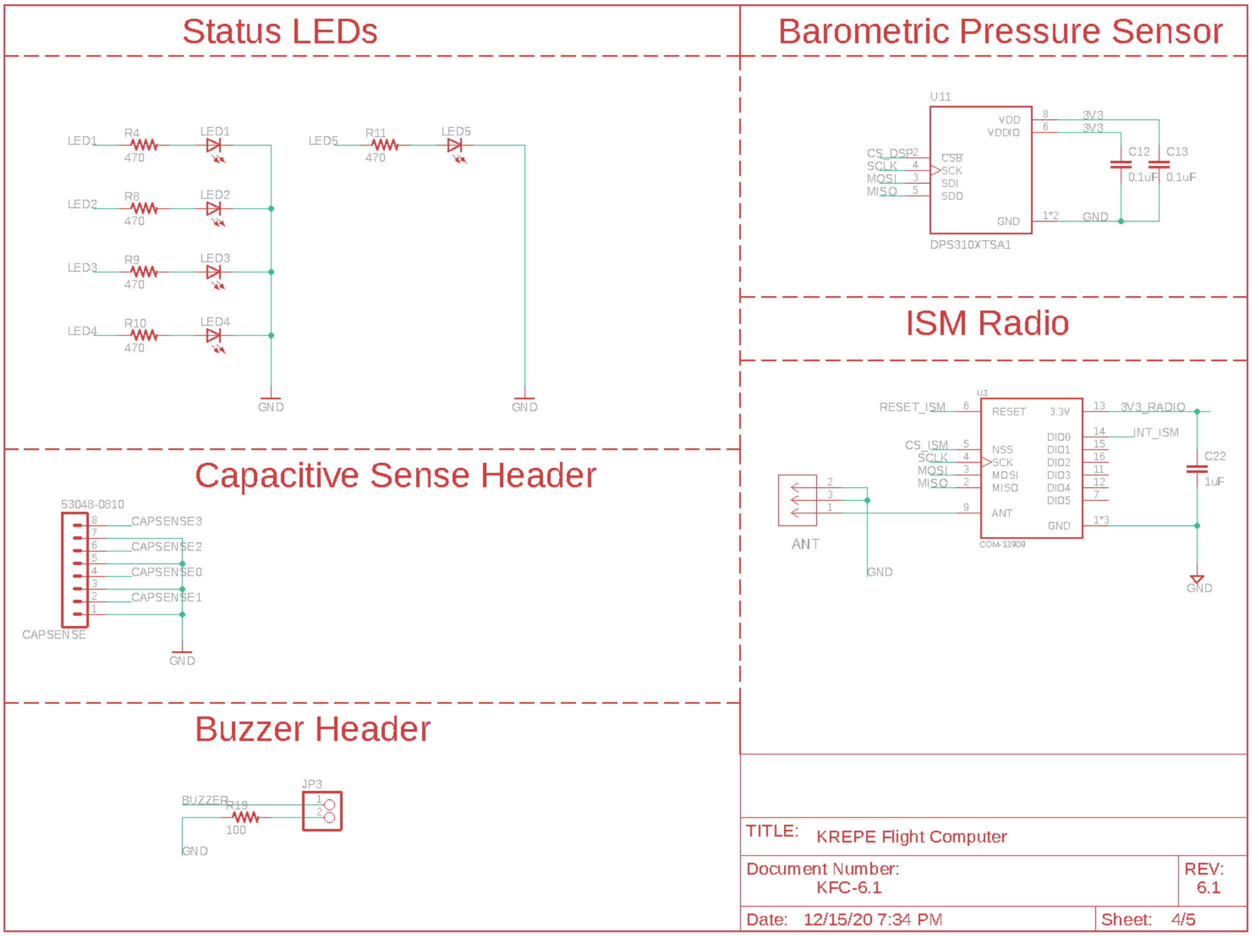


Figure 12: Page four of schematics.

## B Board Renderings

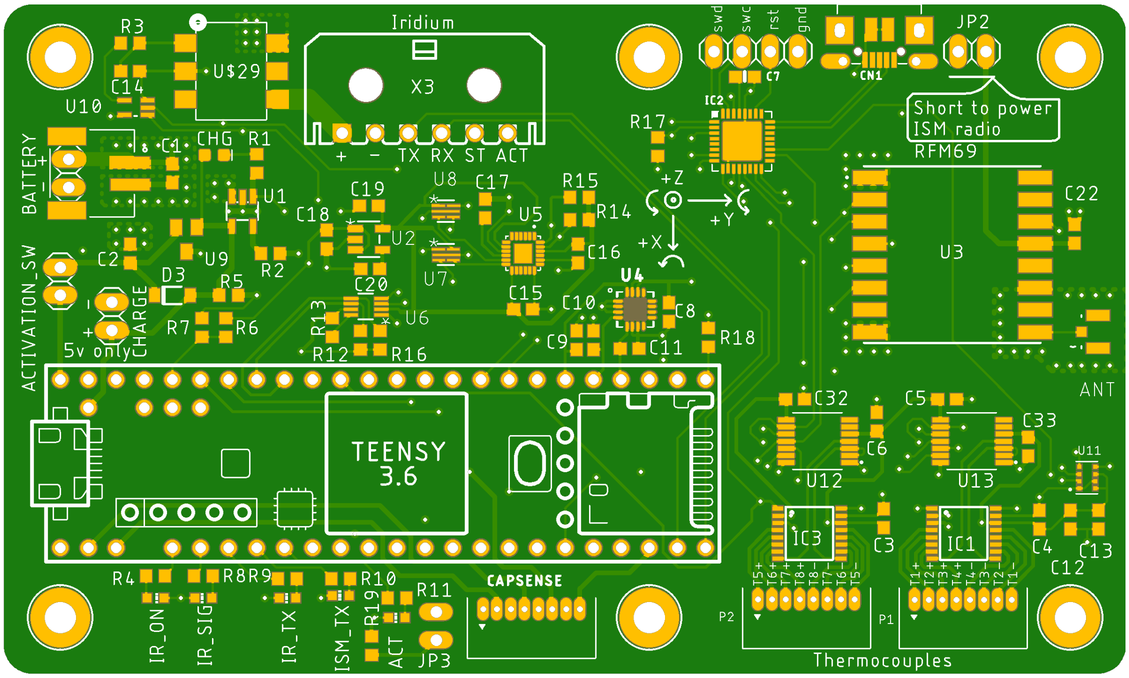

Figure 13: Rendering of the top of the KREPE control board, V1.1.

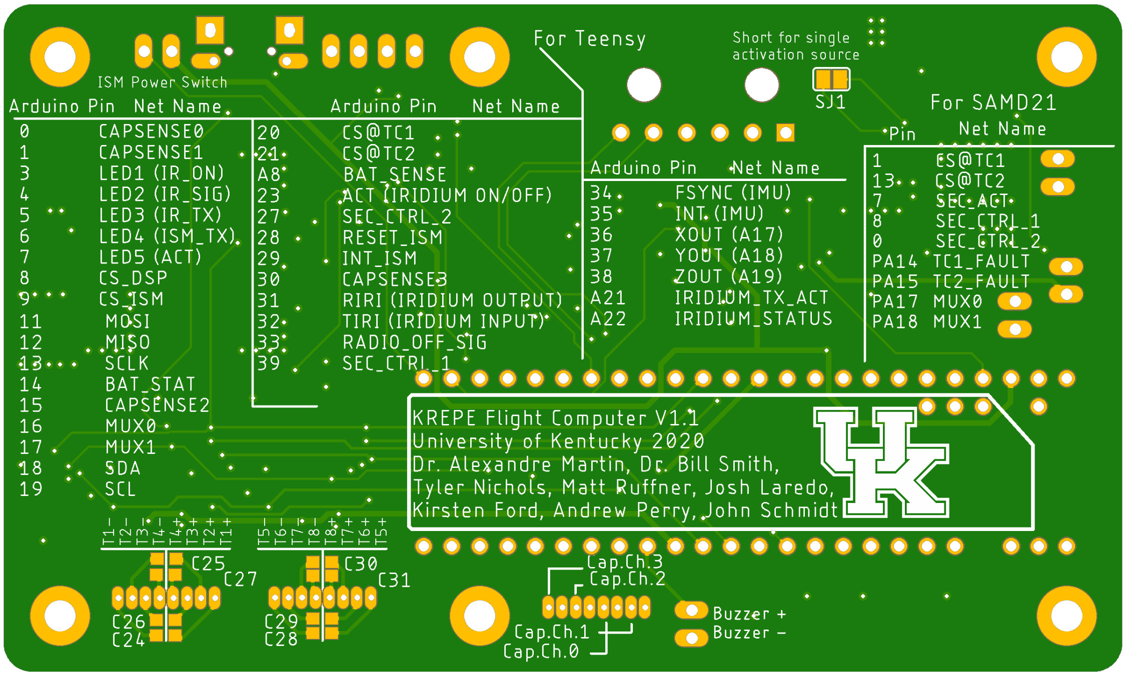

Figure 14: Rendering of the bottom of the KREPE control board, V1.1.

# C Teensy 3.5 Reference

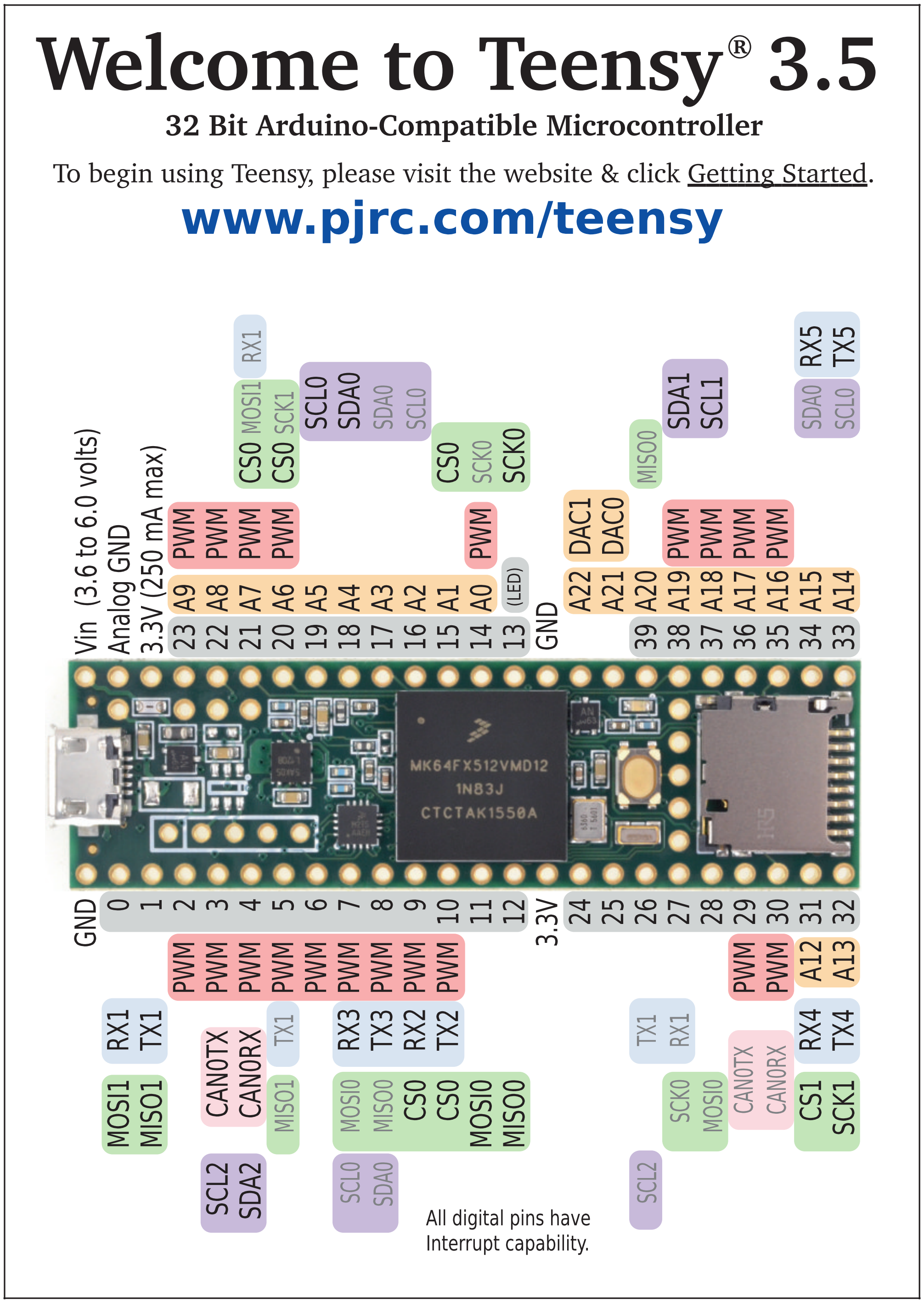


Figure 15: Teensy 3.5 Front

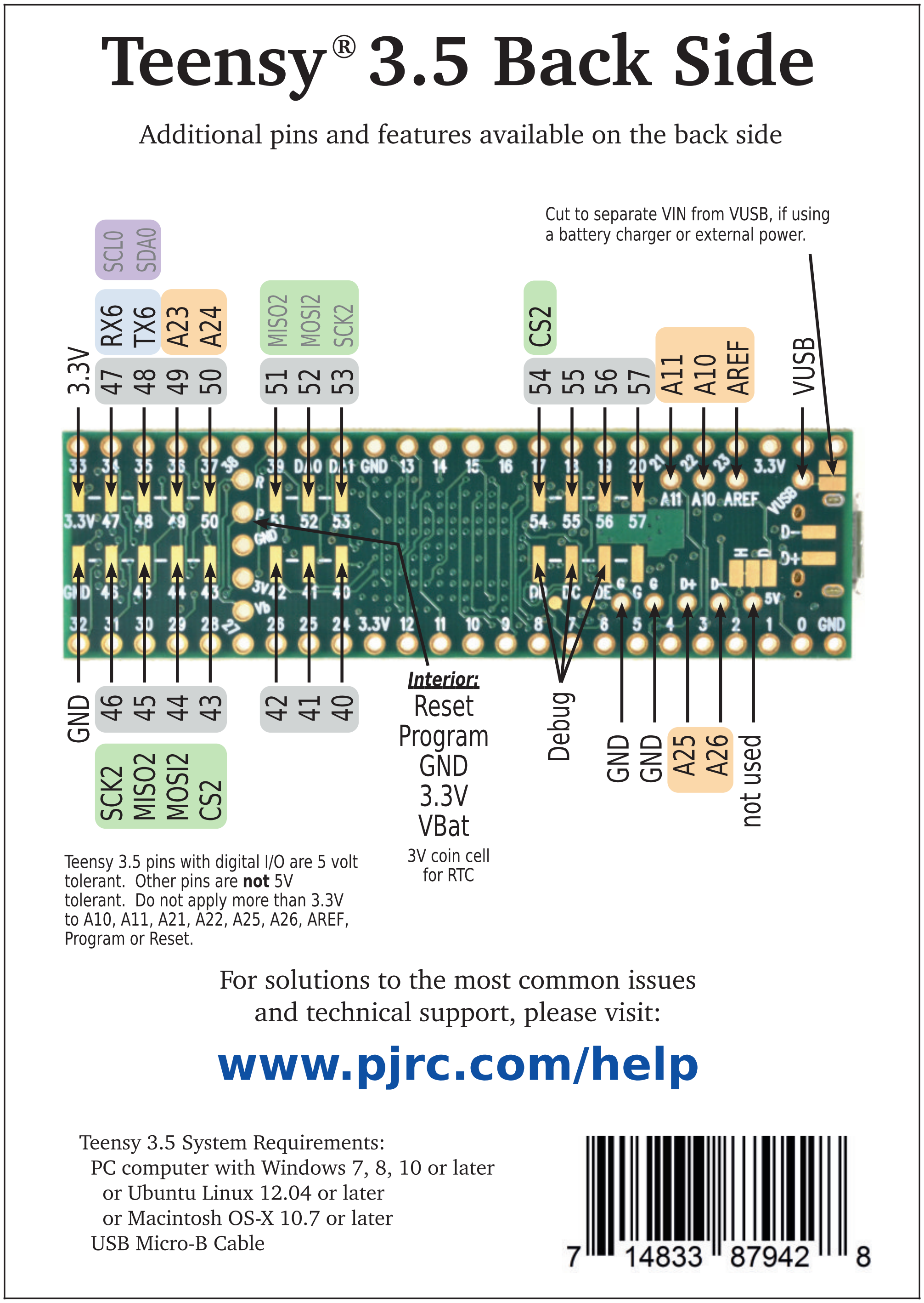


Figure 16: Teensy 3.5 Back

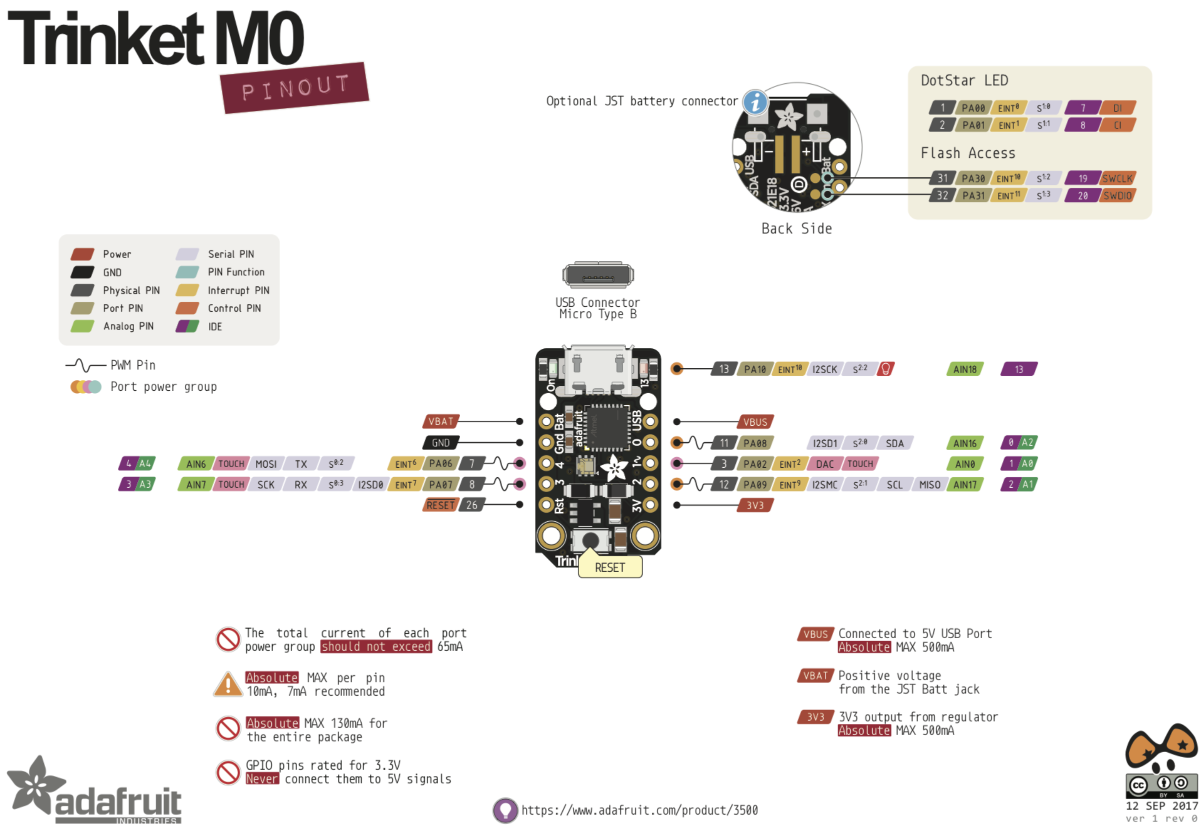


Figure 17: Trinket-M0 Arduino Reference (for ARP chip).

# D Partslist

Partlist

Exported from flight-computer.sch at 7/23/20 8:11 PM

EAGLE Version 9.6.2 Copyright (c) 1988-2020 Autodesk, Inc.

Assembly variant:

| Part | Value | Device | Package | Library | Sheet |
|---|---|---|---|---|---|
| ACTIVATION_SW | | PINHD-1X2 | 1X02 | pinhead | 3 |
| ANT | U.FL-R-SMT-1(10) | U.FL-R-SMT-1(10) | CONN_R-SMT-1(10) | ufl | 4 |
| BATTERY | 2 PIN JST | S2B-PH-SM4-TB(LF)(SN) | JST_S2B-PH-SM4-TB(LF)(SN) | S2B-PH-SM4-TB_LF__SN_ | 3 |
| C1 | 10uF | C-EUC0603 | C0603 | rcl | 3 |
| C2 | 1uF | C-EUC0603 | C0603 | rcl | 3 |
| C3 | 0.1uF | C-USC0603 | C0603 | adafruit | 2 |
| C4 | 0.1uF | C-USC0603 | C0603 | adafruit | 2 |
| C5 | 0.1uF | C-USC0603 | C0603 | adafruit | 2 |
| C6 | 0.1uF | C-USC0603 | C0603 | adafruit | 2 |
| C7 | 1uF | CAP_CERAMIC0603_NO | 0603-NO | microbuilder | 5 |
| C8 | 10uF | C-USC0603 | C0603 | adafruit | 1 |
| C9 | 0.01uF | C-USC0603 | C0603 | adafruit | 1 |
| C10 | 0.01uF | C-USC0603 | C0603 | adafruit | 1 |
| C11 | 0.01uF | C-USC0603 | C0603 | adafruit | 1 |
| C12 | 0.1uF | C-EUC0603 | C0603 | rcl | 4 |
| C13 | 0.1uF | C-EUC0603 | C0603 | rcl | 4 |
| C14 | 0.1uF | C-USC0603 | C0603 | adafruit | 3 |
| C15 | 0.1uF | C-EUC0603 | C0603 | rcl | 1 |
| C16 | 0.1uF | C-EUC0603 | C0603 | rcl | 1 |
| C17 | 0.1uF | C-EUC0603 | C0603 | rcl | 1 |
| C18 | 0.1uF | C-USC0603 | C0603 | rcl | 3 |
| C19 | 2.2uF | C-USC0603 | C0603 | rcl | 3 |
| C20 | 0.01uF | C-USC0603 | C0603 | rcl | 3 |
| C22 | 1uF | C-EUC0603 | C0603 | rcl | 4 |
| C24 | 0.01uF | C-USC0603 | C0603 | adafruit | 2 |
| C25 | 0.01uF | C-USC0603 | C0603 | adafruit | 2 |

| | | | | | |
|---|---|---|---|---|---|
| C26 | 0.01uF | C–USC0603 | C0603 | adafruit | 2 |
| C27 | 0.01uF | C–USC0603 | C0603 | adafruit | 2 |
| C28 | 0.01uF | C–USC0603 | C0603 | adafruit | 2 |
| C29 | 0.01uF | C–USC0603 | C0603 | adafruit | 2 |
| C30 | 0.01uF | C–USC0603 | C0603 | adafruit | 2 |
| C31 | 0.01uF | C–USC0603 | C0603 | adafruit | 2 |
| C32 | 0.1uF | C–USC0603 | C0603 | adafruit | 2 |
| C33 | 0.1uF | C–USC0603 | C0603 | adafruit | 2 |
| CAPSENSE | 53048−0810 | 53048−0810 | 53048−0810 | con−molex−picoblade | 4 |
| CHARGE | | PINHD−1X2 | 1X02 | pinhead | 3 |
| CHG | RED | LED−RED0603 | LED−0603 | SparkFun−LED | 3 |
| CN1 | 4U#20329 | USB_MICRO_20329_V2 | 4UCONN_20329_V2 | microbuilder | 5 |
| D3 | MBR120 | MBR120 | SOD123FL | gsynth | 3 |
| H1 | MOUNT–PAD–ROUND2.8 | MOUNT–PAD–ROUND2.8 | 2,8−PAD | holes | 1 |
| H2 | MOUNT–PAD–ROUND2.8 | MOUNT–PAD–ROUND2.8 | 2,8−PAD | holes | 1 |
| H3 | MOUNT–PAD–ROUND2.8 | MOUNT–PAD–ROUND2.8 | 2,8−PAD | holes | 1 |
| H4 | MOUNT–PAD–ROUND2.8 | MOUNT–PAD–ROUND2.8 | 2,8−PAD | holes | 1 |
| H5 | MOUNT–PAD–ROUND2.8 | MOUNT–PAD–ROUND2.8 | 2,8−PAD | holes | 1 |
| H6 | MOUNT–PAD–ROUND2.8 | MOUNT–PAD–ROUND2.8 | 2,8−PAD | holes | 1 |
| IC1 | ADG609RU | ADG609RU | TSSOP16 | analog−devices | 2 |
| IC2 | ATSAMD21E | ATSAMD21E | QFN32_5MM | microbuilder | 5 |
| IC3 | ADG609RU | ADG609RU | TSSOP16 | analog−devices | 2 |
| JP1 | | PINHD−1X4 | 1X04 | pinhead | 5 |
| JP2 | | PINHD−1X2 | 1X02 | pinhead | 3 |
| JP3 | | PINHD−1X2 | 1X02 | pinhead | 4 |
| LED1 | | LEDCHIP−LED0603 | CHIP−LED0603 | adafruit | 4 |
| LED2 | | LEDCHIP−LED0603 | CHIP−LED0603 | adafruit | 4 |
| LED3 | | LEDCHIP−LED0603 | CHIP−LED0603 | adafruit | 4 |
| LED4 | | LEDCHIP−LED0603 | CHIP−LED0603 | adafruit | 4 |
| LED5 | | LEDCHIP−LED0603 | CHIP−LED0603 | adafruit | 4 |
| P1 | 53048−0810 | 53048−0810 | 53048−0810 | con−molex−picoblade | 2 |
| P2 | 53048−0810 | 53048−0810 | 53048−0810 | con−molex−picoblade | 2 |
| R1 | 1k | R–US_R0603 | R0603 | rcl | 3 |
| R2 | 2.2k | R–US_R0603 | R0603 | rcl | 3 |
| R3 | 288 | R–US_R0603 | R0603 | adafruit | 3 |
| R4 | 470 | R–US_R0603 | R0603 | rcl | 4 |
| R5 | 100k | R–US_R0603 | R0603 | rcl | 3 |
| R6 | 100k | R–US_R0603 | R0603 | rcl | 3 |
| R7 | 100k | R–US_R0603 | R0603 | rcl | 3 |
| R8 | 470 | R–US_R0603 | R0603 | rcl | 4 |
| R9 | 470 | R–US_R0603 | R0603 | rcl | 4 |
| R10 | 470 | R–US_R0603 | R0603 | rcl | 4 |
| R11 | 470 | R–US_R0603 | R0603 | rcl | 4 |
| R12 | 2.2k | R–US_R0603 | R0603 | rcl | 1 |
| R13 | 200k | R–US_R0603 | R0603 | rcl | 1 |
| R14 | 2.2k | R–US_R0603 | R0603 | rcl | 1 |
| R15 | 2.2k | R–US_R0603 | R0603 | rcl | 1 |
| R16 | 2.2k | R–US_R0603 | R0603 | rcl | 1 |
| R17 | 10k | R–US_R0603 | R0603 | rcl | 5 |
| R18 | 100k | R–US_R0603 | R0603 | rcl | 3 |
| R19 | 100 | R–US_R0603 | R0603 | rcl | 4 |
| SJ1 | | SJ | SJ | jumper | 5 |
| U$1 | TEENSY_3.5/3.6_BASIC | TEENSY_3.5/3.6_BASIC | TEENSY_3.5/3.6_BASIC | Teensy356 | 1 |
| U$29 | AQV252GA | AQV252GA | DIP6 | TI_radio | 3 |
| U1 | MCP73831/OT | MCP73831/OT | SOT23−5L | adafruit | 3 |
| U2 | LP2985IM5−1.8/NOPB | LP2985IM5−1.8/NOPB | MF05A | gsynth | 3 |
| U3 | COM−13909 | COM−13909 | MOD_COM−13909 | COM−13909 | 4 |
| U4 | ADXL377 | ACCEL_ADXL377 | LFCSP16_LQ | microbuilder | 1 |
| U5 | ICM−20948 | ICM−20948 | QFN40P300X300X105−25N | ICM−20948 | 1 |
| U6 | PCA9306DCUR | PCA9306DCUR | DCU8 | gsynth | 1 |
| U7 | SN74LVC1T45DRLR | SN74LVC1T45DRLR | DRL6 | gsynth | 1 |
| U8 | SN74LVC1T45DRLR | SN74LVC1T45DRLR | DRL6 | gsynth | 1 |
| U9 | DMP3099L | DMP3099L | SOT23 | gsynth | 3 |
| U10 | SN74LVC1G08DCKR | SN74LVC1G08DCKR | SOT65P210X110−5N | SN74LVC1G08DCKR | 5 |
| U11 | DPS310XTSA1 | DPS310XTSA1 | XDCR_DPS310XTSA1 | DPS310XTSA1 | 4 |
| U12 | MAX31856MUD+ | MAX31856MUD+ | SOP65P640X110−14N | MAX31856 | 2 |
| U13 | MAX31856MUD+ | MAX31856MUD+ | SOP65P640X110−14N | MAX31856 | 2 |
| VBAT_PTH | | PINHD−1X2 | 1X02 | pinhead | 3 |
| X3 | | HEADER_POS6_43650−0600 | 43650−0600 | con−molex−micro−fit−3_0 | 3 |

# E Arduino Pin Mapping

| Arduino Pin | Net |
|---|---|
| Teensy 3.5 | |
| 0 | CAPSENSE0 |
| 1 | CAPSENSE1 |
| 3 | LED_IRIDIUM_ON |
| 4 | LED_IRIDIUM_SIGNAL_OK |
| 5 | LED_IRIDIUM_TRANSMITTING |
| 6 | LED_ISM_TRANSMITTING |
| 7 | LED_ACTIVITY |
| 8 | CS_DSP |
| 9 | CS_ISM |
| 11 | MOSI |
| 12 | MISO |
| 13 | SCLK |
| 14 | BAT_STAT |
| 15 | CAPSENSE2 |
| 16 | MUX0 |
| 17 | MUX1 |
| 18 | SDA |
| 19 | SCL |
| 20 | CS@TC1 |
| 21 | CS@TC2 |
| A8 | BAT_SENSE (A8) |
| 23 | PRI_ACT (IRIDIUM ON/OFF) |
| 24 | BUZZER |
| 25 | TC1_FAULT (ACTIVE LOW) |
| 26 | TC2_FAULT (ACTIVE LOW) |
| 27 | SEC_CTRL_2 |
| 28 | RESET_ISM |
| 28 | INT_ISM |
| 30 | CAPSENSE3 |
| 31 | RIRI (IRIDIUM OUTPUT) |
| 32 | TIRI (IRIDIUM INPUT) |
| 33 | RADIO_OFF_SIG |
| 34 | FSYNC (IMU) |
| 35 | INT (IMU) |
| 36 | XOUT (A17) |
| 37 | YOUT (A18) |
| 38 | ZOUT (A19) |
| 39 | SEC_CTRL_1 |
| A21 | IRIDIUM_TX_ACT |
| A22 | IRIDIUM_STATUS |
| | |
| Safety Processor (ATSAMD21E16B) | |
| 1 | CS@TC1 |
| 13 | CS@TC2 |
| 7 | SEC_ACT |
| 8 | SEC_CTRL_1 |

| | |
|---|---|
| 0 | SEC_CTRL_2 |
| PA14 | TC1_FAULT |
| PA15 | TC2_FAULT |
| PA17 | MUX0 |
| PA18 | MUX1 |