KREPE Flight Computer Hardware Manual

Matt Ruffner

February 12, 2021

Contents

List of Figures

List of Tables

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 a metal shell known as KREM that acts as a Faraday cage, inhibiting any inadvertent RF radiation from the capsule. 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, 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).
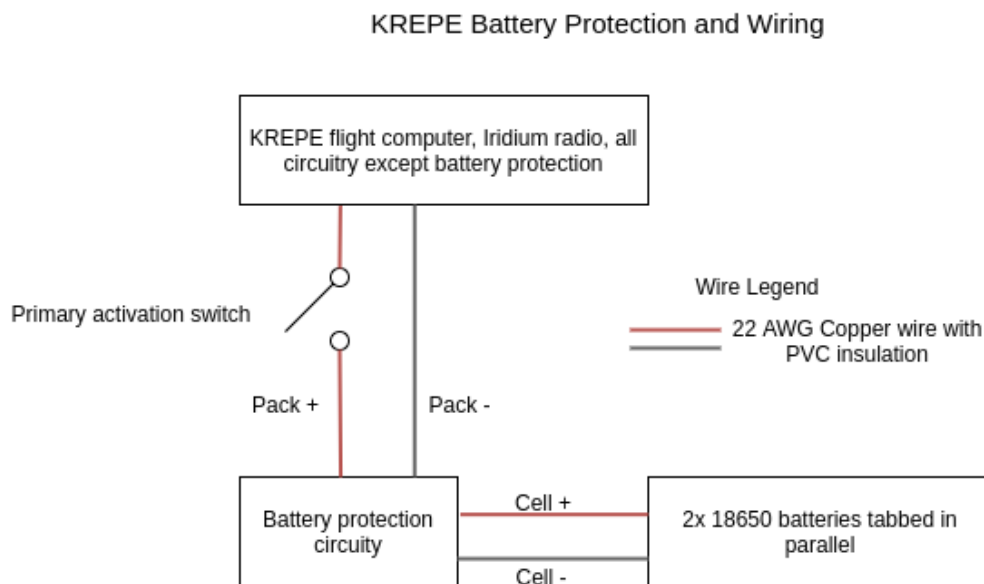
KREPE Battery Protection and Wiring

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 and the register a temperature that is sufficient to have melted the polycarbonate bolts that hold the KREM together, secondary activation occurs. If the temperature is not sufficient, the flight computer re-enters dormant mode. 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
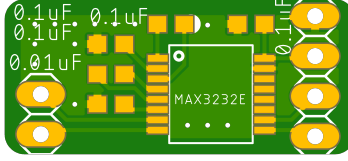[3]https://www.ti.com/product/MAX3232E

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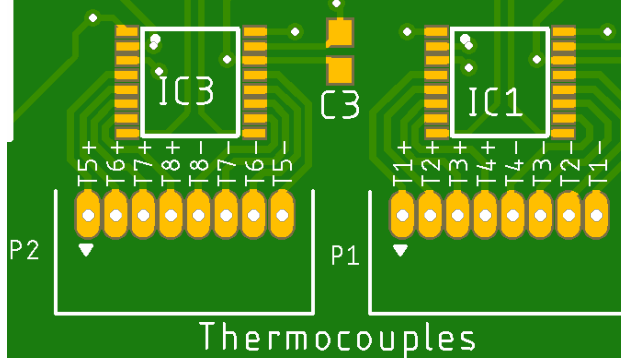
Figure 4: Thermocouple connection wiring with resepect to the analog mux chips IC3 (MUX2) and IC1 (MUX1).

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 DW01-P 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
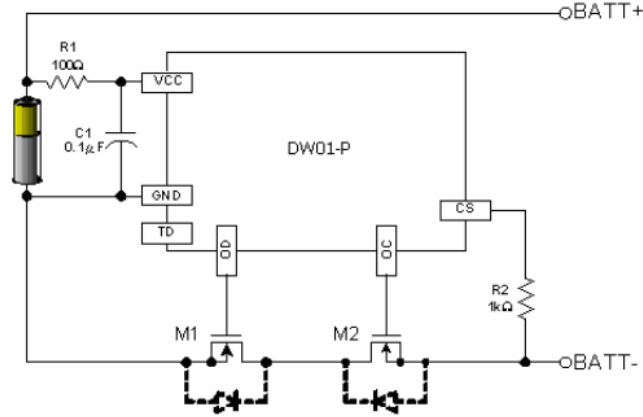
Figure 6: Battery protection circuitry.

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.
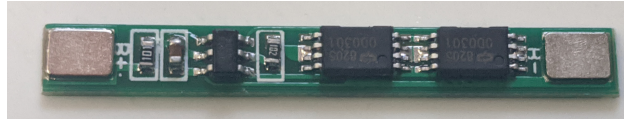
Figure 7: Battery protection PCB.

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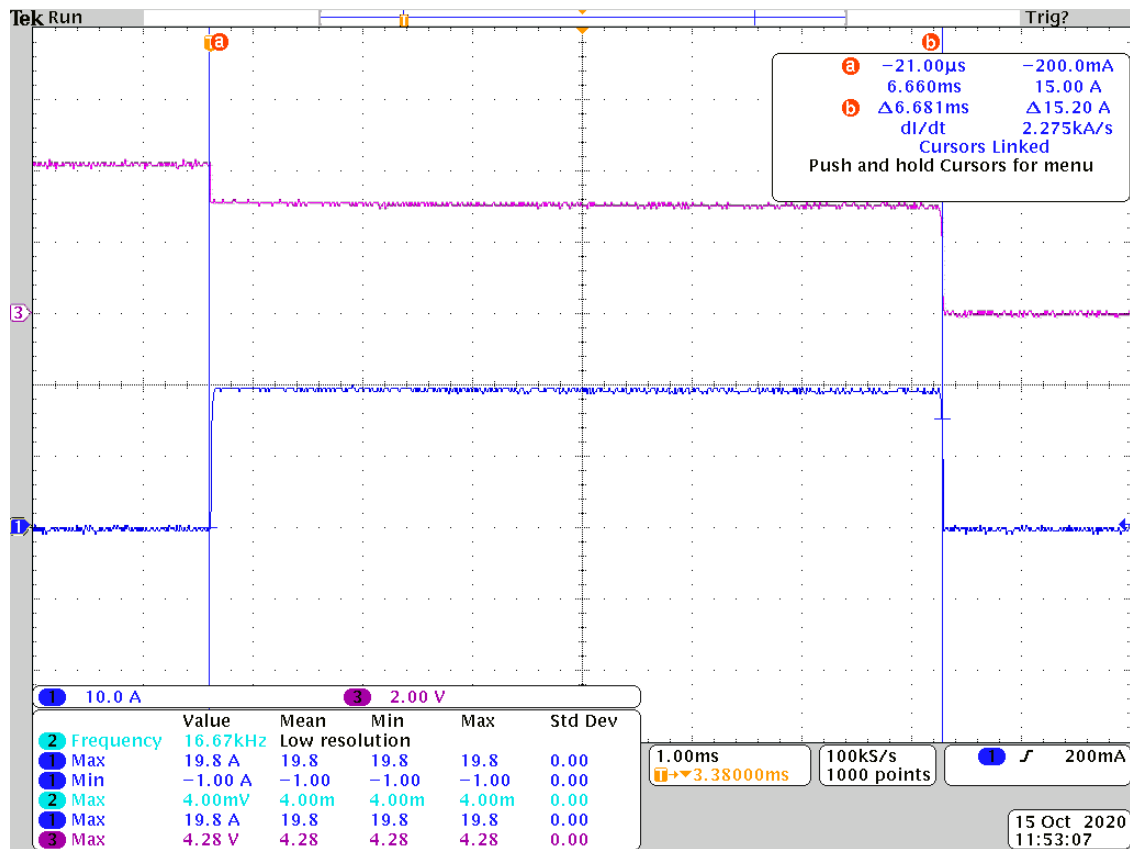
Figure 8: The battery protection circuity disconnecting the cells after 6ms of over current condition. Blue: current. Purple: pack voltage.

A   Schematics
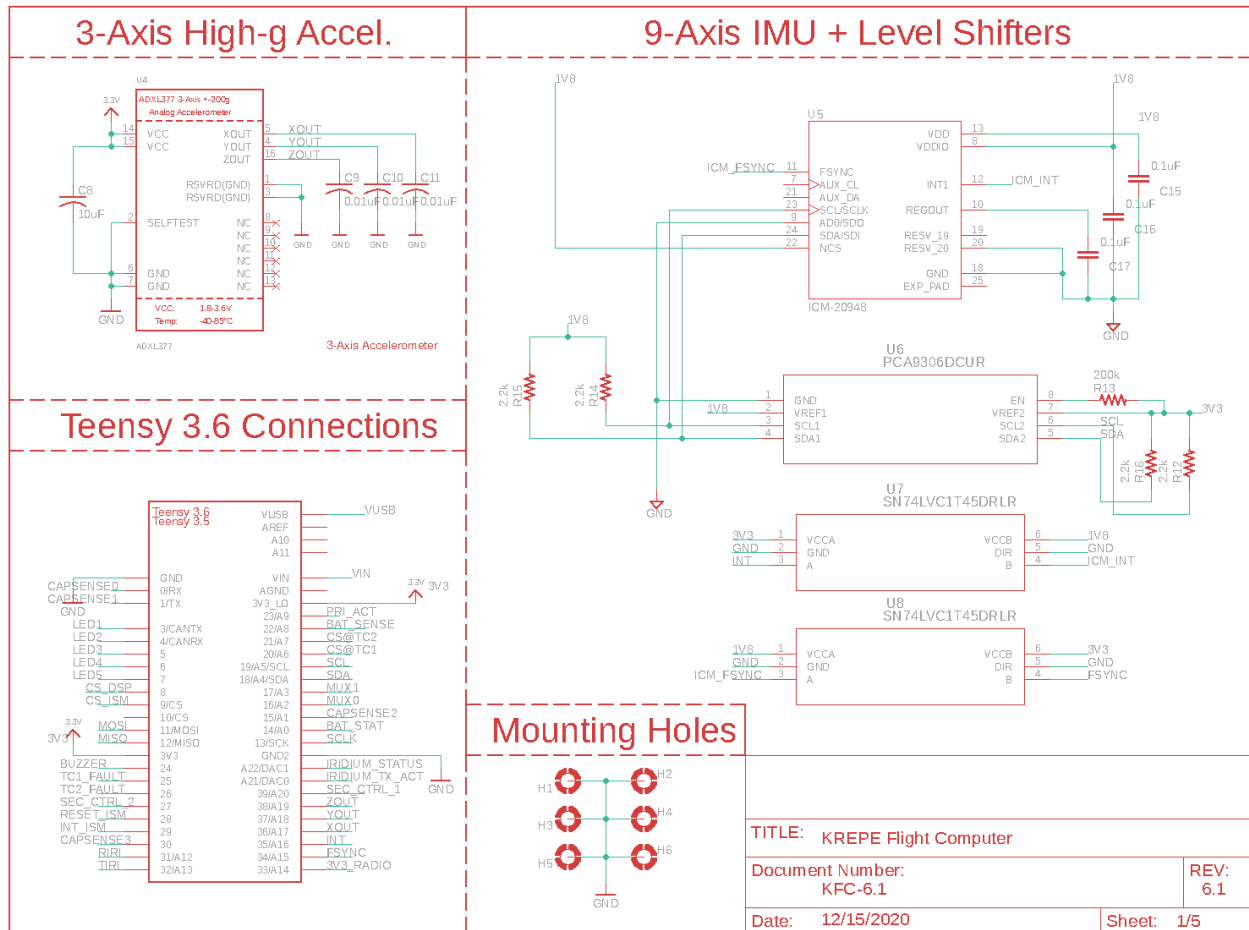
Figure 9: Page one of schematics.
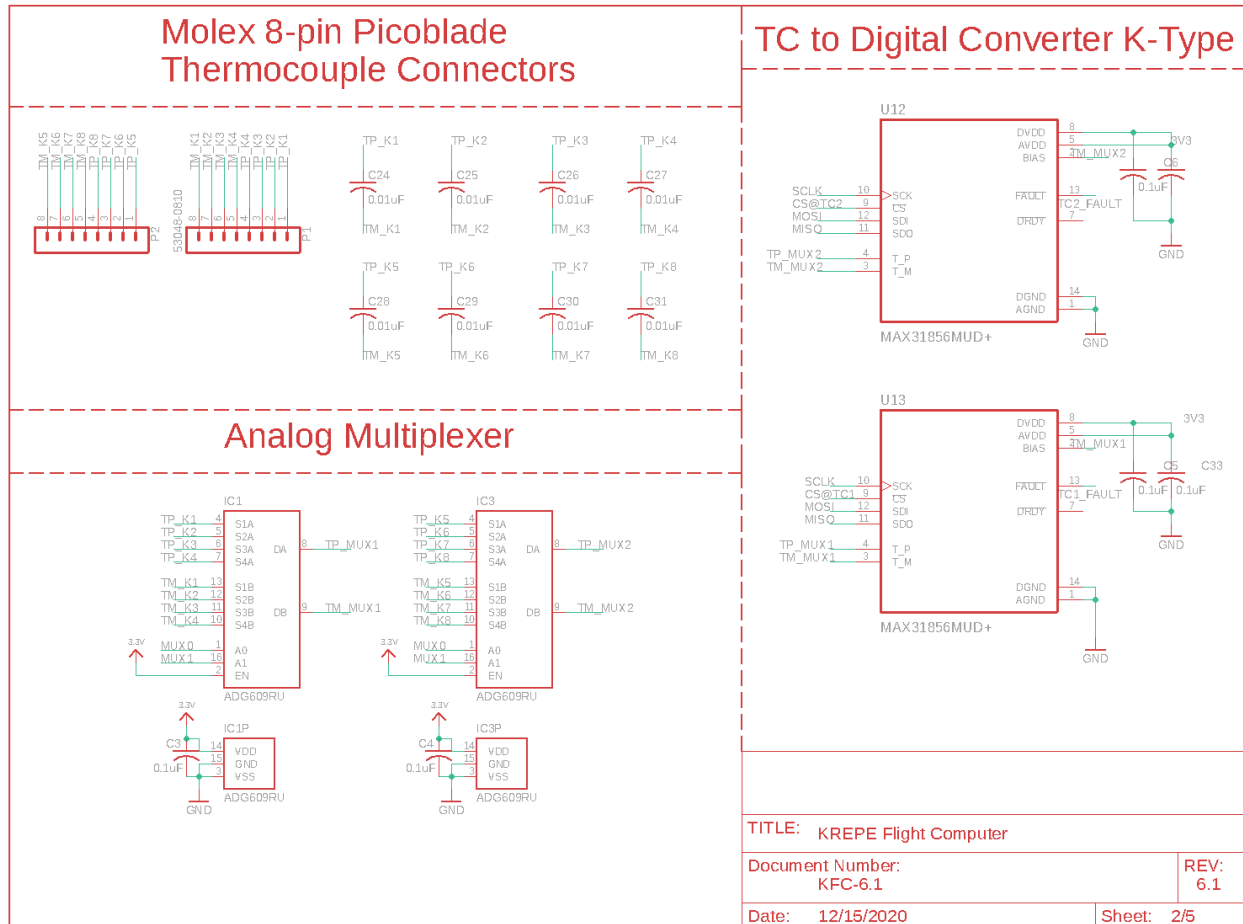
Figure 10: Page two of schematics.
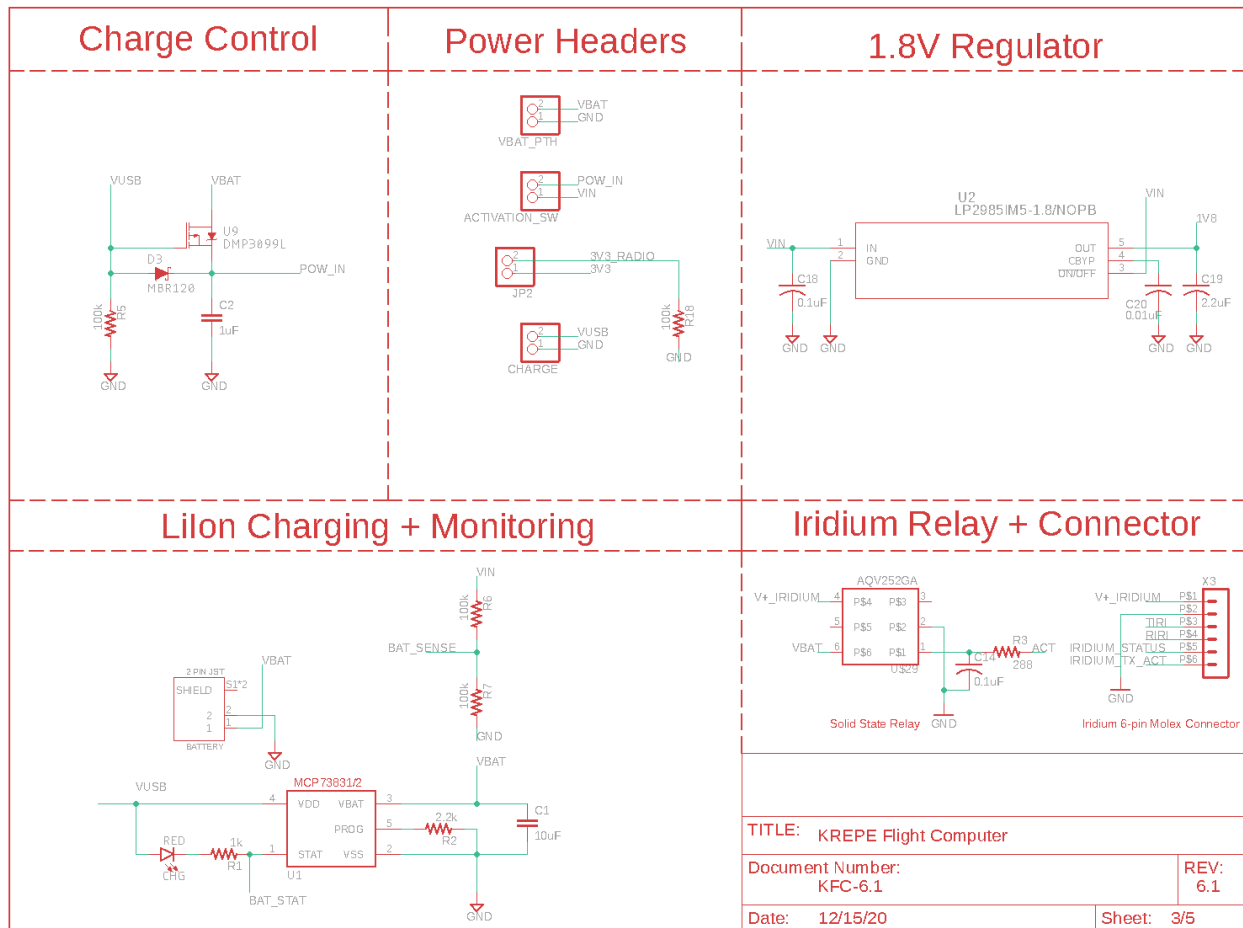
Figure 11: Page three of schematics.
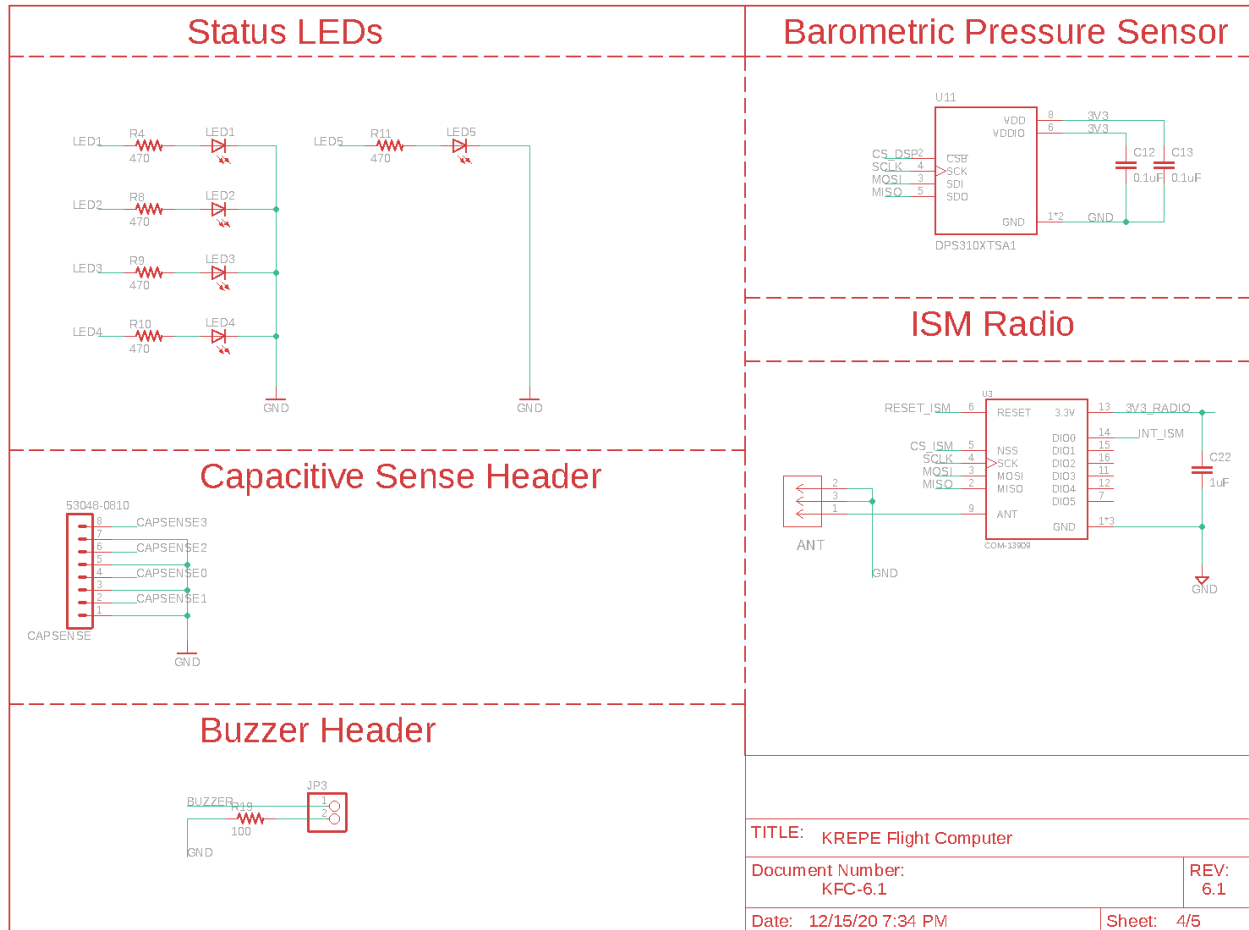
Figure 12: Page four of schematics.

B   Board Renderings
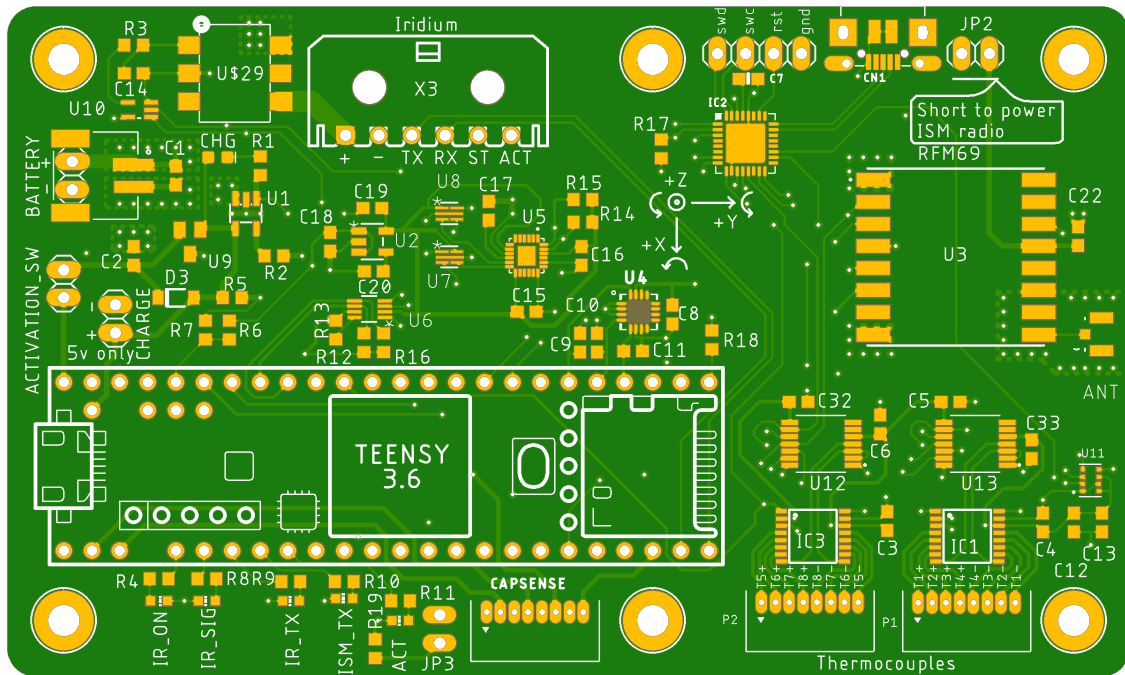
Figure 13: Rendering of the top of the KREPE control board, V1.1.
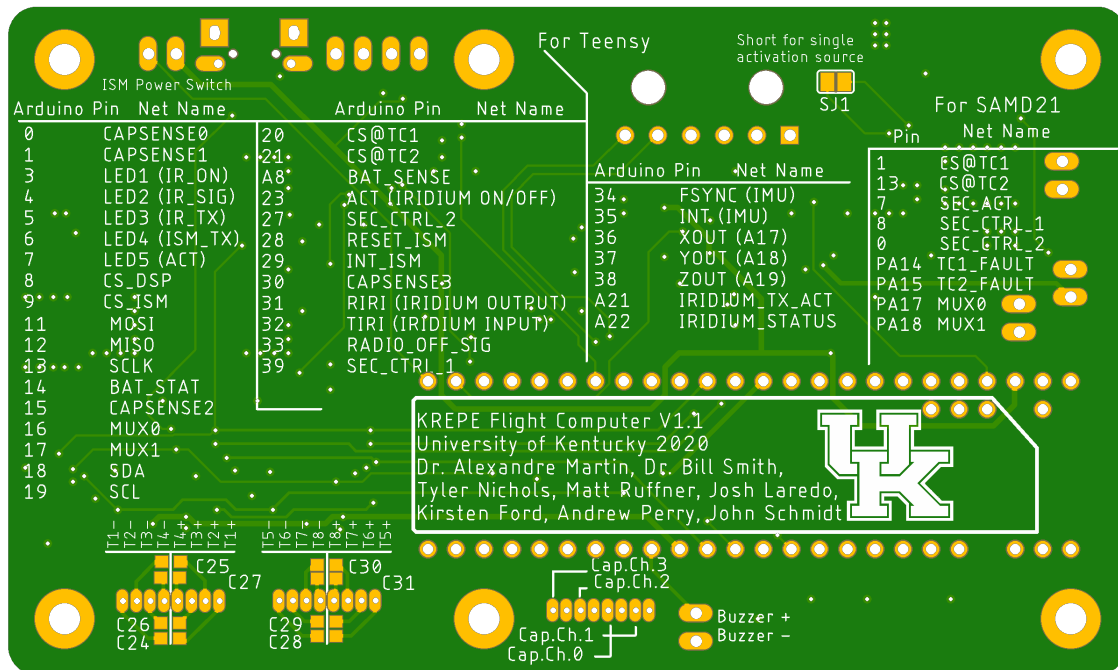
Figure 14: Rendering of the bottom of the KREPE control board, V1.1.

C   Teensy 3.5 Reference

Welcome to Teensy® 3.5
32 Bit Arduino-Compatible Microcontroller
To begin using Teensy, please visit the website & click Getting Started.
www.pjrc.com/teensy

All digital pins have
Interrupt capability.
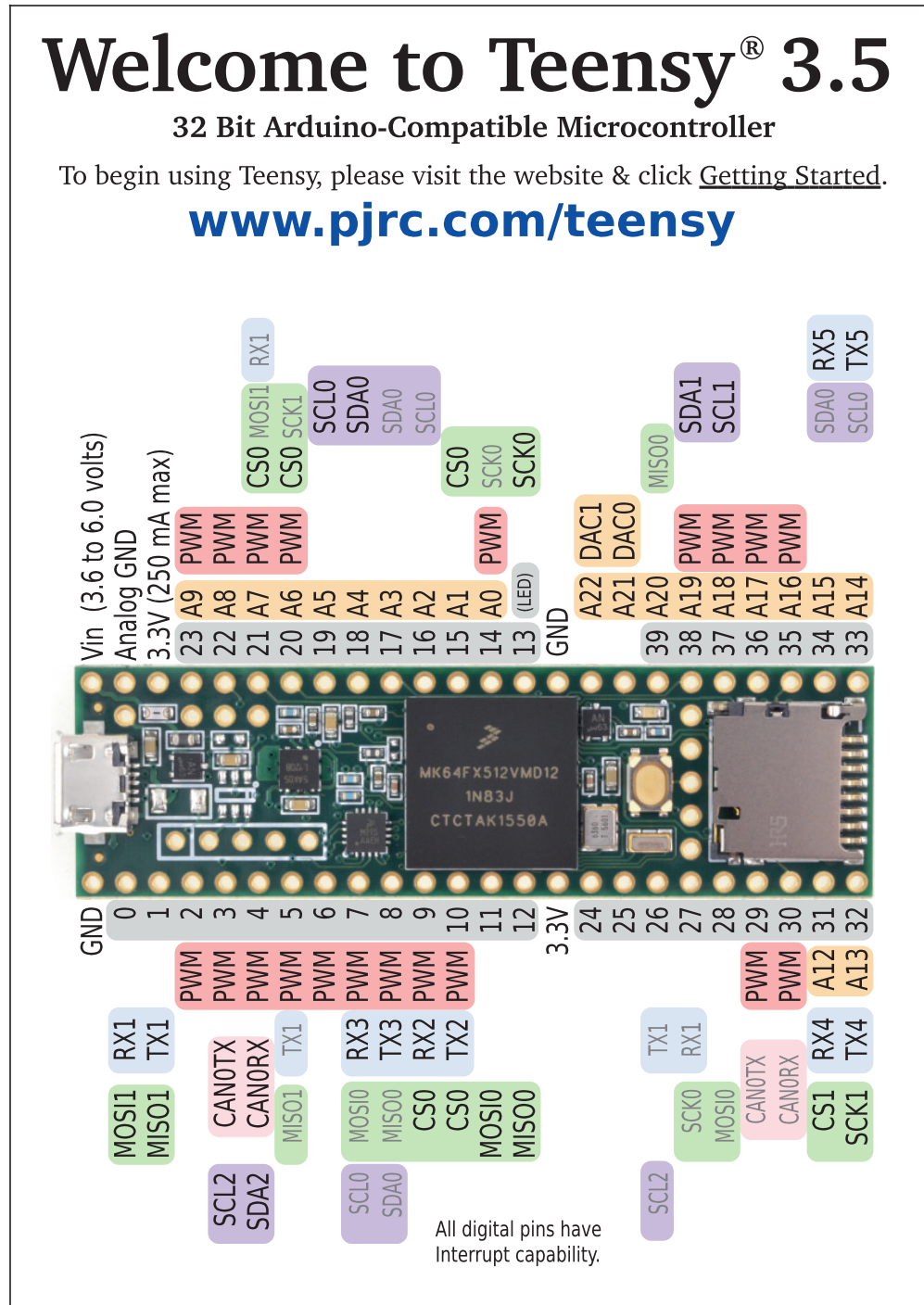
Figure 15: Teensy 3.5 Front

Teensy® 3.5 Back Side

Additional pins and features available on the back side

Cut to separate VIN from VUSB, if using a battery charger or external power.
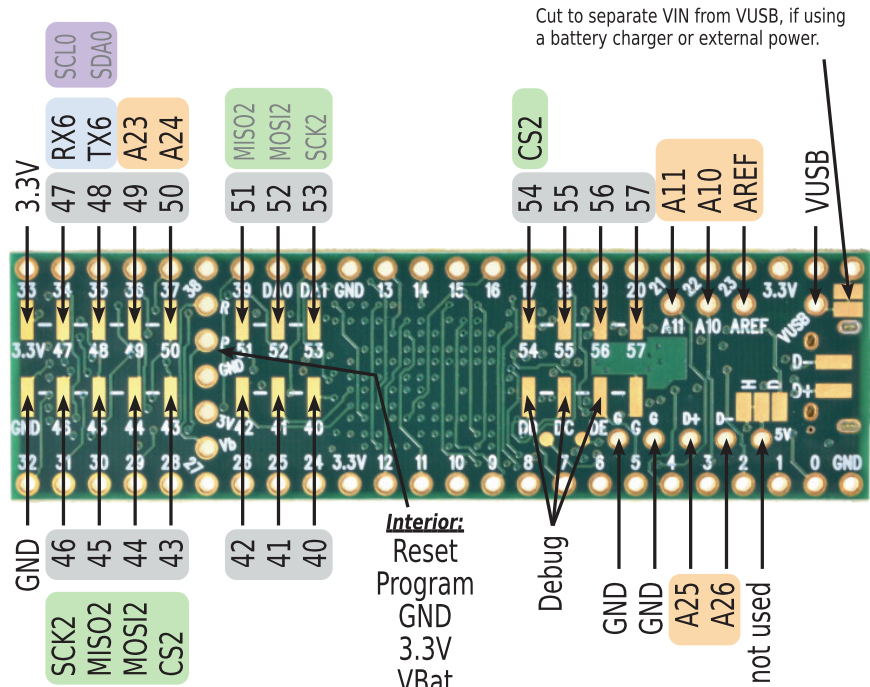
Teensy 3.5 pins with digital I/O are 5 volt tolerant. Other pins are **not** 5V tolerant. Do not apply more than 3.3V to A10, A11, A21, A22, A25, A26, AREF, Program or Reset.

Interior:
Reset
Program
GND
3.3V
VBat
3V coin cell for RTC

For solutions to the most common issues
and technical support, please visit:

www.pjrc.com/help

Teensy 3.5 System Requirements:
  PC computer with Windows 7, 8, 10 or later
    or Ubuntu Linux 12.04 or later
    or Macintosh OS-X 10.7 or later
  USB Micro-B Cable

7 14833 87942 8

Figure 16: Teensy 3.5 Back
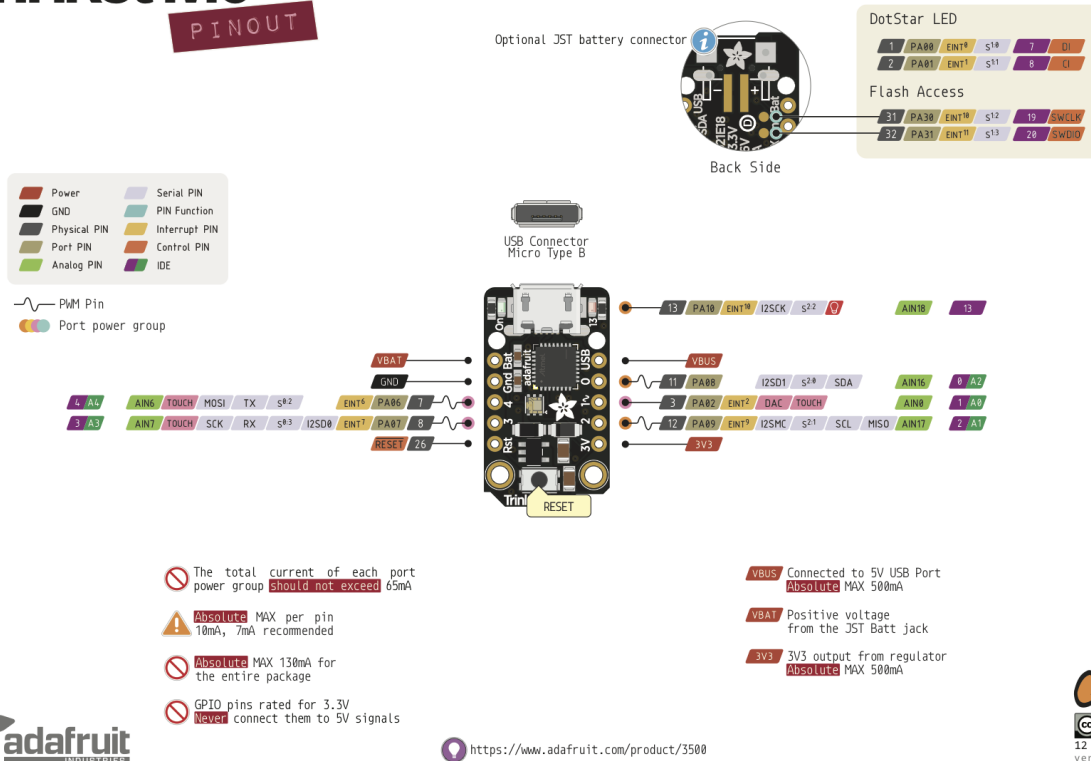
Figure 17: Trinket-M0 Arduino Reference (for ARP chip).

D Partslist

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