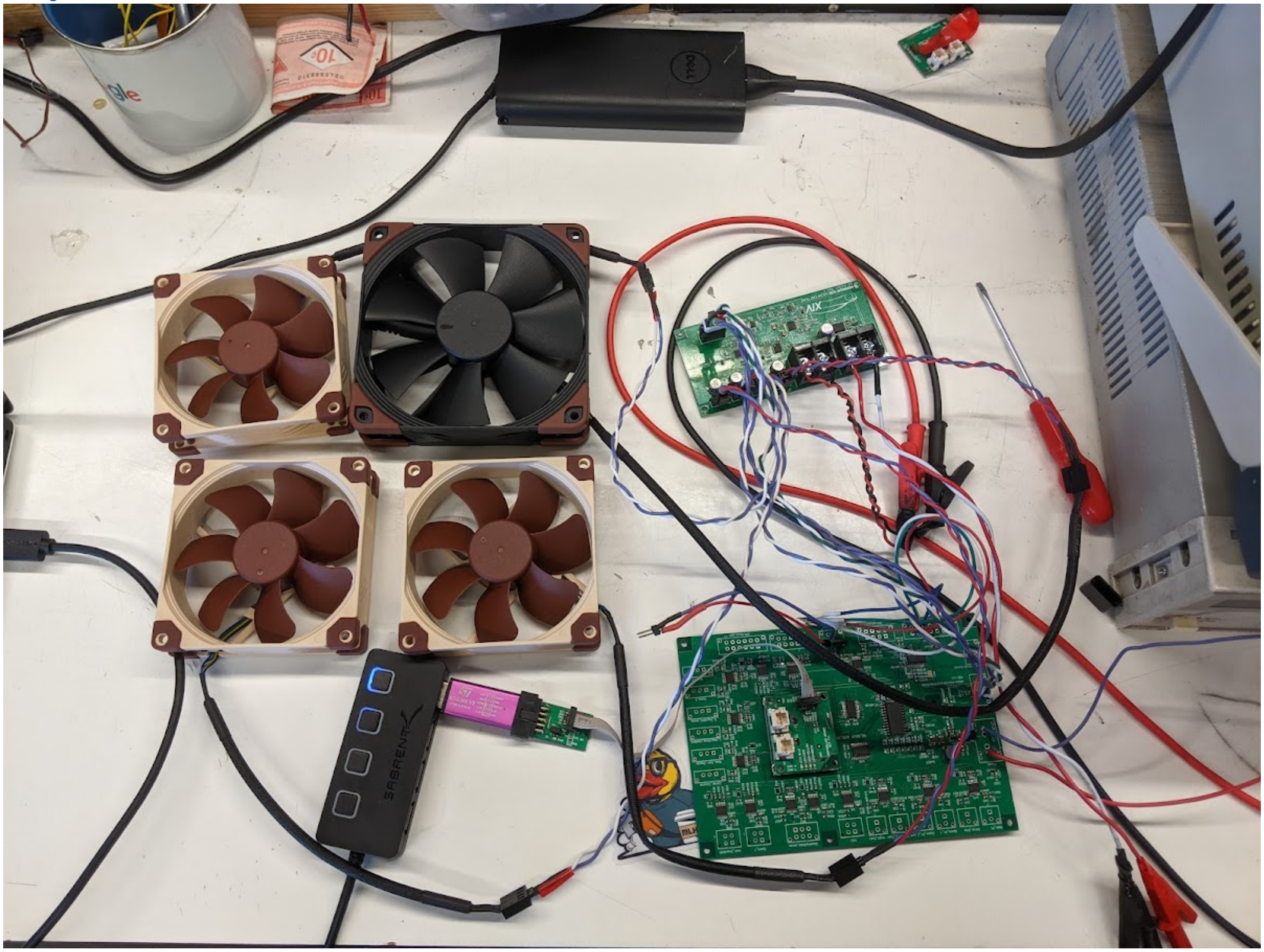
UV Cutoff rev 1 validation

https://university-of-waterloo-solar-car-team.365.altium.com/designs/4CDFD99A-AAE8-4765-A5CD-FDD08CF73953?variant=[No Variations]#design



General notes:

- used a Rev 3.0 PD assembled as rear
- 12V nocuta fans
  - one NF-F12
  - three NF-A9's
- used an electronic load as a substitute for horn (set to 3 ohms)
- anytime I refer to power_distribution firmware, it is under the pd_smoketest branch
- two separate power supplies, one for PD and one for UV cutoff, both supplied with 13.5V (unless I have specified something else)

U2 IS NOT POPULATED FROM HERE ON OUT

Testing Fan and Horn

First I tested the horn with a power supply; I simply soldered two wires to both terminals (I'm pretty sure the horn is not polarized) and I set a power supply for 12V with a 5.0A limit.

Once I powered on the power supply, the horn didn't make any noise. So I turned of the supply and incremented the current limit by 1A. I repeated this process until I got to 9A which was when the horn started blasting very loudly (be prepared to turn it off). I then turned on the supply again and waited for about 3 seconds to see the current draw of the horn, which was about 4.7A the horn has an inrush of 9A and then it will draw 4.7A.

I tried taping the opening of the horn to reduce the sound, but it was still very loud and it even vibrated.

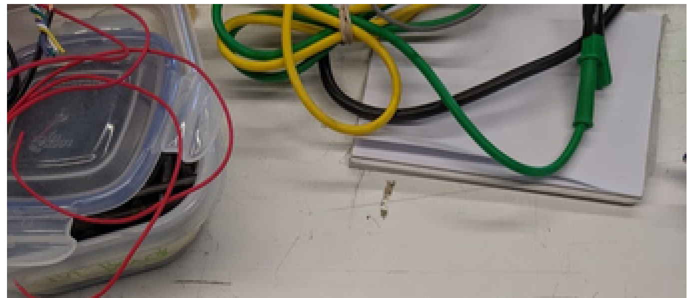
So instead of continuing to use the horn to test UV cutoff, I used an electronic load set to 3 ohms

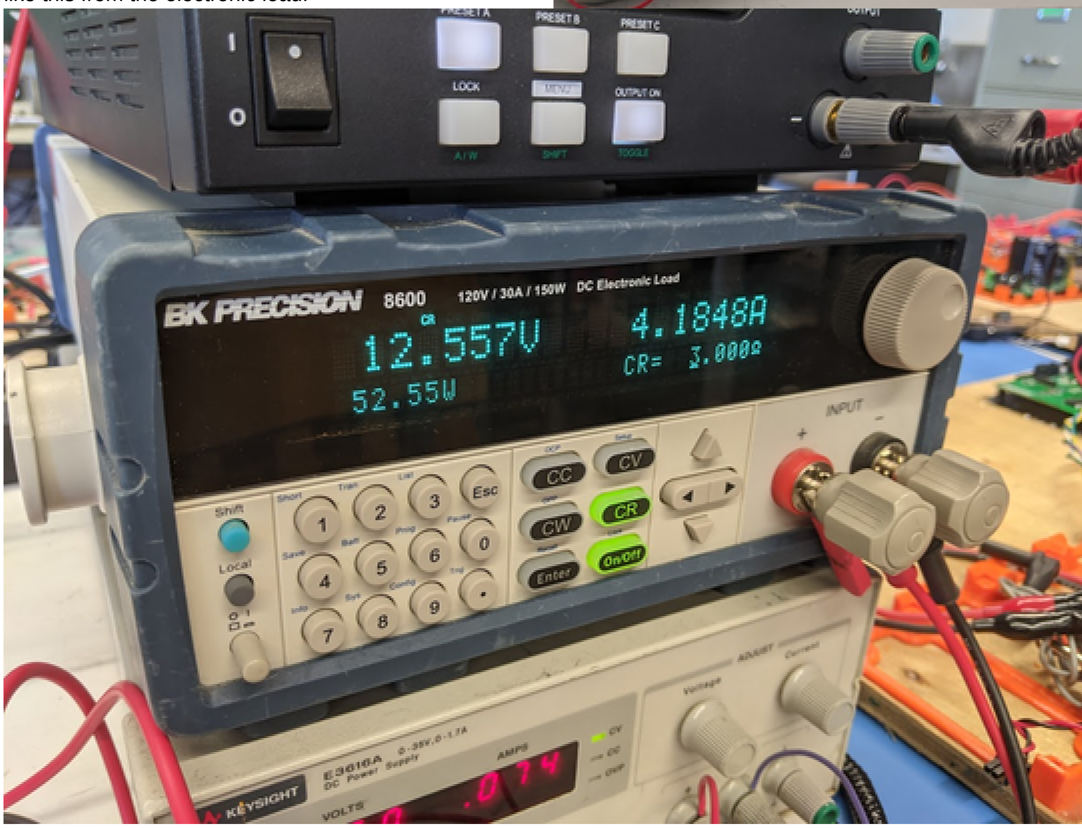
(13.5V / 4.7A 3 ohms).

After connecting the electronic load to the horn terminal block, I connected the fan to one of the fan connectors.

I flashed a controller board with power_distribution from the pd_smoketest branch and placed in onto a rear, Rev 3.0 PD (firmware accounts for rear and front). I connected the board together through the 6 interfacing wires (see P6 on UV cutoff, and see UV Cutoff Interface on PD).

I first powered on PD (with 13.5V), and then UV cutoff (with 13.5V) using separate power supplies. The fan should spin and you should see something like this from the electronic load:





I then powered off UV cutoff and plugged in the fan into a different plug; I did this until I confirmed that all fan connectors work.

<u>Testing fan enable and horn enable</u>

This section is for making sure that I didn’t mess up the 6-pin harness that connects both UV cutoff and PD together.

In the smoke_test.h file under /powerdistribution/inc/, I first commented out FRONT_OUTPUT_FAN.

```c
// These will be turned on when front PD is detected.
const Output g_turn_on_front[] = {
  FRONT_OUTPUT_CENTRE_CONSOLE,
  FRONT_OUTPUT_PEDAL,
  FRONT_OUTPUT_STEERING,
  FRONT_OUTPUT_DRIVER_DISPLAY,
  FRONT_OUTPUT_INFOTAINMENT_DISPLAY,  // aka main display
  FRONT_OUTPUT_LEFT_DISPLAY,
  FRONT_OUTPUT_RIGHT_DISPLAY,
  FRONT_OUTPUT_REAR_DISPLAY,
  FRONT_OUTPUT_LEFT_CAMERA,
  FRONT_OUTPUT_RIGHT_CAMERA,
  FRONT_OUTPUT_MAIN_PI,  // driver display + telemetry pi
  FRONT_OUTPUT_SPEAKER,
//  FRONT_OUTPUT_FAN,  // on UV cutoff via gpio pin (not on load switch)
  FRONT_OUTPUT_LEFT_FRONT_TURN_LIGHT,
  FRONT_OUTPUT_RIGHT_FRONT_TURN_LIGHT,
  FRONT_OUTPUT_DAYTIME_RUNNING_LIGHTS,
  FRONT_OUTPUT_HORN,  // on UV cutoff via gpio pin (not on load switch)
  FRONT_OUTPUT_5V_SPARE_1,
  FRONT_OUTPUT_5V_SPARE_2,
  FRONT_OUTPUT_SPARE_1,
  FRONT_OUTPUT_SPARE_2,
  FRONT_OUTPUT_SPARE_3,
  FRONT_OUTPUT_SPARE_4,  // on MCI's BTS7040
  FRONT_OUTPUT_SPARE_5,  // on rear fan 1's BTS7200 channel
  FRONT_OUTPUT_SPARE_6,  // on rear fan 2's BTS7200 channel
};
```

Then when I powered on both UV cutoff and PD, I checked to make sure that neither one of the four fan connectors would spin a fan. I was able to see that the electronic load was drawing about 4.1802A and the voltage for each fan connector was around 0.0004V (very close to zero).

Test point readings:

Test point	Reading (volts)
FAN_I_SENSE	0.0033
HORN_I_SENSE	0.2569

Then I commented out FRONT_OUT_HORN (and uncommented FRONT_OUTPUT_FAN). Then when I powered both boards, I checked to make sure that zero current/no current was being drawn by the electronic load, which happened (the terminals of the horn was also 0V). Also each fan connector was around 13.488V.

Test point	Reading (volts)
FAN_I_SENSE	0.1486
HORN_I_SENSE	0.0002

<u>Testing UV lockout/cutoff function</u>

I first powered PD with 13.5V, and then I powered UV cutoff (connected with a fan and an electronic load set to 3 ohms) with 13.5V using separate power supplies.

I first decremented the voltage for UV cutoff by 1V. I found out that the board "locks out/cuts off" at 8.5V (the fan stopped spinning and the voltage of the electronic load dropped to zero). When I decremented the voltage at 7.5V, I got a message through minicom that said "UV lockout was triggered".

```
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4009 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4009 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4009 mA
[1] projects/power_distribution/src/front_uv_detector.c:12: UV lockout was triggered
```

I then incremented (by 1V) and the fan started spinning once the voltage reached 10.5V (and the voltage of the electronic load went up to ~10.476V).

Now I decided to decrement the voltage for UV cutoff by 0.1V (starting at 13.5V). I found out that the board “locks out/cuts off” at 8.7V (the fan stopped spinning and the voltage of the electronic load dropped to zero). When I decremented the voltage to 7.8V, that’s when I got the “UV lockout was triggered” message.

I then incremented (by 0.1V) and the fan started spinning once the voltage reached 10.2V (and the voltage of the electronic load went up to ~10.176V).

These specific values aren’t really important since U2 was not populated during this testing.

Validating UV_VBAT_I_SENSE

While UV cutoff was connected to PD, I decided to measure the test points:

UV cutoff powered on:

Test point	Reading (volts)
FAN_I_SENSE	0.1678
HORN_I_SENSE	0.2575
C13 (VBAT_I_SENSE)	3.2725

UV cutoff powered off:

Test point	Reading (volts)
FAN_I_SENSE	0.0004
HORN_I_SENSE	0.0002
C13 (VBAT_I_SENSE)	3.2840

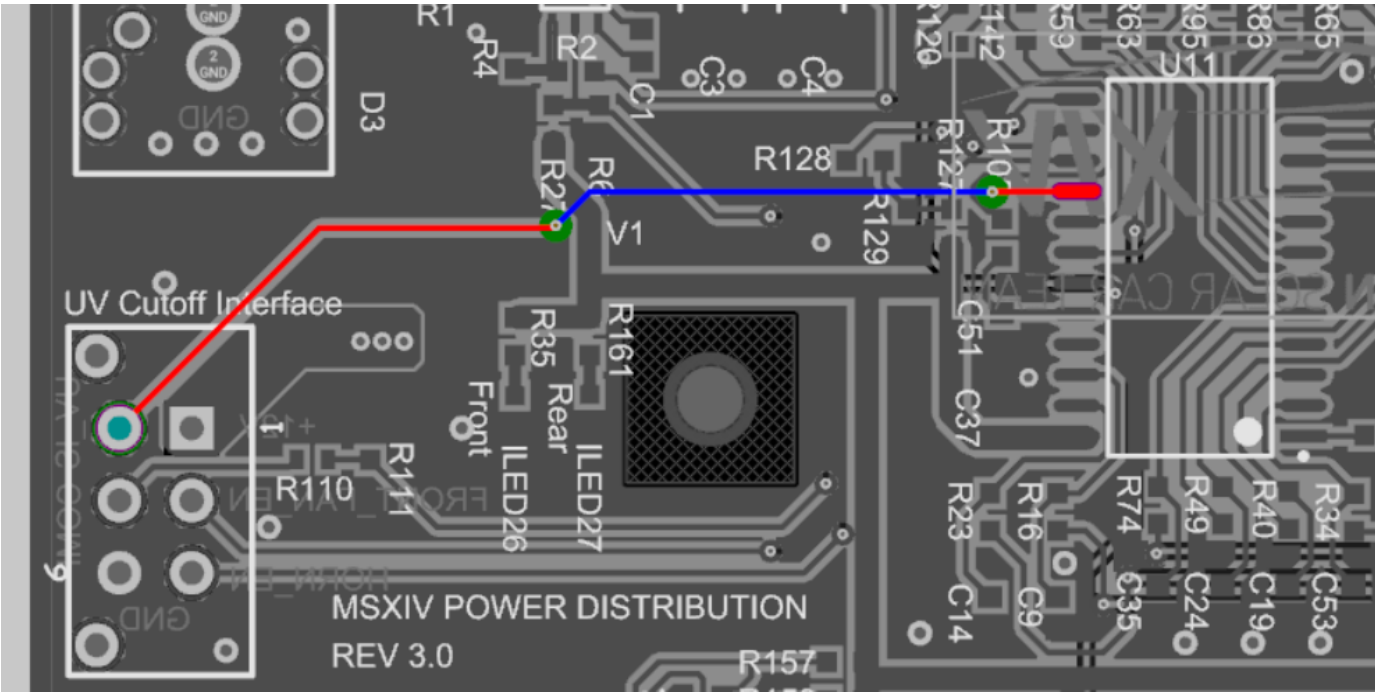
In both situations, it doesn’t make sense that VBAT_I_SENSE is about 3.27V.

Another problem I have noticed while running the power_distribution firmware is that the current displayed in minicom was around 4000mA for these situations where:

- UV cutoff was powered on and connected to PD
- UV cutoff was powered off and connected to PD
- UV cutoff was powered off and disconnected from PD

```
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4009 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4010 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4009 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4009 mA
[1] projects/power_distribution/src/front_uv_detector.c:12: UV lockout was triggered
```

This gave me reason to believe that the issue wasn’t from UV cutoff but from PD instead. With UV cutoff disconnected, I powered on PD and measured its UV_VBAT_IS pad/pin/trace, which was about 3.276V. This voltage matched the VBAT_I_SENSE pad/pin/trace on UV cutoff when UV cutoff was connected to PD, even when UV cutoff was powered off or powered on. Because the UV_VBAT_IS trace on PD only connected to U11, I then decided to measure the voltage at each pin.



U11 of PD (while UV cutoff is disconnected):

Pin	Reading (volts)
1: OUT(put)	2.7819
2: SPARE 2 3 IS	0.0002
3: STR_PDL_IS	0.0003
4: SPEAKER/SOLAR_SENS_IS	0.0015
5: L R DVR DISP IS	0.0032
6: MCI_IS	0.0005
7: 5V SPARE IS	0.0004
8: MAIN_REAR_PI_IS	0.0014
9: DVR_REAR_DISP	0.0029
10: PA6 MUX SEL1	3.3041
11: PA5 MUX SEL2	3.3039
12: GND	0.0003
13: PA3_MUX_SEL4	3.3039
14: PA4 MUX SEL3	3.3039
15:	0.0009
16: UV_VBAT_IS	3.2776
17: FAN IS	0.0031
18: MAIN_DISP/BMS_IS	0.0013
19: LEFT/REAR_RIGHT_CAM_IS	0.0015
20: SPARE 1 IS	0.0011
21: (closed)	0.0004
22: FRONT/REAR_TURN_LIGHT_IS	0.0004
23: DAYTIME/REAR_BRK_IS	0.0003
24: 3V3	3.3041

As shown in the above table, every current sense pin is very close to zero, where as pin 16 (UV_VBAT_IS) is almost 3.3V. I decided to check for a short (using a DMM) at this point but I didn't hear an audible "beep" - I should've been looking at the resistance on the screen of the DMM because it would have saved me time from doing this next section of modifying code.

The original PD code was configured such that every 0.5s (maybe 1.5s), U11 will be quickly flip through all the mux selections (which are the current sense pins). That is the output of U11 (pin 1) should have the same reference voltage as the selected/muxed pin.

So now I wanted to try muxing a pin other than pin 16; I did this by modifying current_measurement_config.c file located here: firmware_xiv/projects/power_distribution/src/

Since minicom automatically detects the PD as a front variant, I decided to comment out all of the rear_current_measurements.

So I decided to test FRONT_OUTPUT_SPEAKER with UV_VBAT_IS. First I muxed FRONT_OUTPUT_SPEAKER:

```
const CurrentMeasurementConfig g_rear_current_measurement_config = {
  .outputs_to_read =
      (Output[]){
//          REAR_OUTPUT_BMS,
//          REAR_OUTPUT_MCI,
//          REAR_OUTPUT_CHARGER,
//          REAR_OUTPUT_SOLAR_SENSE,
//          REAR_OUTPUT_REAR_CAMERA,
//          REAR_OUTPUT_FAN_1,
//          REAR_OUTPUT_FAN_2,
//          REAR_OUTPUT_LEFT_REAR_TURN_LIGHT,
```

```
const CurrentMeasurementConfig g_front_current_measurement_config = {
  .outputs_to_read =
      (Output[]){
          //          FRONT_OUTPUT_CENTRE_CONSOLE,
          //          FRONT_OUTPUT_PEDAL,
          //          FRONT_OUTPUT_STEERING,
          //          FRONT_OUTPUT_DRIVER_DISPLAY,
          //          FRONT_OUTPUT_INFOTAINMENT_DISPLAY,
          //          FRONT_OUTPUT_REAR_DISPLAY,
          //          FRONT_OUTPUT_LEFT_DISPLAY,
          //          FRONT_OUTPUT_RIGHT_DISPLAY,
          //          FRONT_OUTPUT_LEFT_CAMERA,
          //          FRONT_OUTPUT_RIGHT_CAMERA,
          //          FRONT_OUTPUT_MAIN_PI,
                    FRONT_OUTPUT_SPEAKER,
          //          FRONT_OUTPUT_LEFT_FRONT_TURN_LIGHT,
          //          FRONT_OUTPUT_RIGHT_FRONT_TURN_LIGHT,
          //          FRONT_OUTPUT_DAYTIME_RUNNING_LIGHTS,
//                    FRONT_OUTPUT_UV_VBAT,
      },
  .num_outputs_to_read = 1,
};
```

FRONT_OUTPUT_SPEAKER left uncommented:

Pin	Reading (volts)
1: OUT(put)	0.0268
4: SPEAKER/SOLAR_SENS_IS	0.0268
16: UV_VBAT_IS	3.2937

As you can see from the table, pin 1 matches pin 4, by my even if pin 4 is being muxed, it is nowhere near 3.3V. Also pin 16 is around 3.3V.

Then I tested all pins off:

```
const CurrentMeasurementConfig g_front_current_measurement_config = {
  .outputs_to_read =
      (Output[]){
          //          FRONT_OUTPUT_CENTRE_CONSOLE,
          //          FRONT_OUTPUT_PEDAL,
          //          FRONT_OUTPUT_STEERING,
          //          FRONT_OUTPUT_DRIVER_DISPLAY,
          //          FRONT_OUTPUT_INFOTAINMENT_DISPLAY,
          //          FRONT_OUTPUT_REAR_DISPLAY,
          //          FRONT_OUTPUT_LEFT_DISPLAY,
          //          FRONT_OUTPUT_RIGHT_DISPLAY,
          //          FRONT_OUTPUT_LEFT_CAMERA,
          //          FRONT_OUTPUT_RIGHT_CAMERA,
          //          FRONT_OUTPUT_MAIN_PI,
//                    FRONT_OUTPUT_SPEAKER,
          //          FRONT_OUTPUT_LEFT_FRONT_TURN_LIGHT,
          //          FRONT_OUTPUT_RIGHT_FRONT_TURN_LIGHT,
          //          FRONT_OUTPUT_DAYTIME_RUNNING_LIGHTS,
//                    FRONT_OUTPUT_UV_VBAT,
      },
  .num_outputs_to_read = 0,
};
```

All outputs commented:

Pin	Reading (volts)
1: OUT(put)	0.0300
4: SPEAKER/SOLAR_SENS_IS	0.0012
16: UV_VBAT_IS	3.2930

You can see that pin 1 drops closer to zero, but pin 16 is still near 3.3V.

Then I muxed FRONT_OUTPUT_UV_VBAT:

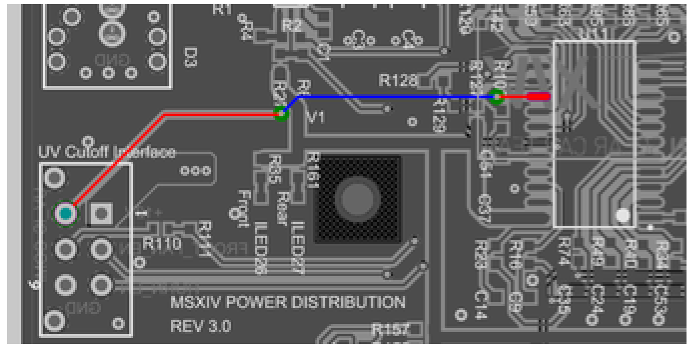
```
const CurrentMeasurementConfig g_front_current_measurement_config = {
  .outputs_to_read =
      (Output[]){
          //          FRONT_OUTPUT_CENTRE_CONSOLE,
          //          FRONT_OUTPUT_PEDAL,
          //          FRONT_OUTPUT_STEERING,
          //          FRONT_OUTPUT_DRIVER_DISPLAY,
          //          FRONT_OUTPUT_INFOTAINMENT_DISPLAY,
          //          FRONT_OUTPUT_REAR_DISPLAY,
          //          FRONT_OUTPUT_LEFT_DISPLAY,
          //          FRONT_OUTPUT_RIGHT_DISPLAY,
          //          FRONT_OUTPUT_LEFT_CAMERA,
          //          FRONT_OUTPUT_RIGHT_CAMERA,
          //          FRONT_OUTPUT_MAIN_PI,
//                    FRONT_OUTPUT_SPEAKER,
          //          FRONT_OUTPUT_LEFT_FRONT_TURN_LIGHT,
          //          FRONT_OUTPUT_RIGHT_FRONT_TURN_LIGHT,
          //          FRONT_OUTPUT_DAYTIME_RUNNING_LIGHTS,
                     FRONT_OUTPUT_UV_VBAT,
      },
  .num_outputs_to_read = 1,
};
```

FRONT_OUTPUT_UV_VBAT left uncommented:

Pin	Reading (volts)

1: OUT(put)	2.7769
4: SPEAKER/SOLAR_SENS_IS	0.0013
16: UV_VBAT_IS	3.2776

Even though pin 1 is about 0.5V less than pin 16, I still assumed that pin 16 was being muxed - which doesn't change the fact that pin 16 is still near 3.3V.



At this point I decided to check PD again for shorts between 3V3 and pin 16, but there weren't any definite locations since the UV_VBAT_IS trace directly connects to pin 16 of U11 (i.e. there are no other components in between).

So using the DMM again, I probed a resistance roughly 25 ohms between pin 16 and 3V3. I also tried measuring other current sense pins with 3V3, and their resistances were in the Megaohms - this meant that there was an issue with the soldering of U11, the board itself, or U11 itself. There were no visual bridges between the pins of U11 and the likelihood of the board being the issue itself is very unlikely, so I decided to take U11 off with a heat gun. I then probed the resistance between pin 16 and pin 24 (the 3V3 pin of U11) and I measured the same resistance of 25 ohms. I also probed the resistance between pad 16 and 3V3 on PD just to make sure it wasn't the board's fault (I got a zero load). This confirmed that there was an issue with U11 all long.

I replaced U11 with the same component from an old rev PD and to double check that there aren't issues with this newly replaced U11, the voltages of the pins are as follows (resetting the power_distribution code to its original state):

(UV cutoff disconnected):

Pin	Reading (volts)
1: OUT(put)	0.0558
2: SPARE 2 3 IS	0.0001
3: STR_PDL_IS	0.0032
4: SPEAKER/SOLAR_SENS_IS	0.0014
5: L R DVR DISP IS	0.0031
6: MCI_IS	0.0023
7: 5V SPARE IS	0.0005
8: MAIN_REAR_PI_IS	0.0015
9: DVR_REAR_DISP	0.0032
10: PA6 MUX SEL1	3.3055 (periodically changes)
11: PA5 MUX SEL2	3.3057 (periodically changes)
12: GND	0.0002
13: PA3_MUX_SEL4	3.3052 (periodically changes)
14: PA4 MUX SEL3	3.3054 (periodically changes)
15:	0.0014
16: UV_VBAT_IS	0.0129
17: FAN IS	0.0031
18: MAIN_DISP/BMS_IS	0.0013
19: LEFT/REAR_RIGHT_CAM_IS	0.0014
20: SPARE 1 IS	0.0012
21: (closed)	0.0028
22: FRONT/REAR_TURN_LIGHT_IS	0.0021
23: DAYTIME/REAR_BRK_IS	0.0003
24: 3V3	3.3055

Now you can see that the voltage at pin 16 is something much more reasonable now that I have replaced U11. However, there is still an issue where the current readings in minicom as shown here:

```
[0] projects/power_distribution/src/main.c:121: Initializing power distribution...
[0] projects/power_distribution/src/main.c:134: Detected front power distribution board...[0] libraries/ms-common/src/stm32f0xx/i2c.c:86: Timeout: 2 waiting for 0 to change
[0] libraries/ms-common/src/stm32f0xx/i2c.c:86: Timeout: 2 waiting for 0 to change
[0] libraries/ms-common/src/stm32f0xx/i2c.c:86: Timeout: 2 waiting for 0 to change
[0] libraries/ms-common/src/stm32f0xx/i2c.c:86: Timeout: 2 waiting for 0 to change
[0] libraries/ms-common/src/stm32f0xx/i2c.c:86: Timeout: 2 waiting for 0 to change
[1] projects/power_distribution/src/main.c:199: Failed to initialize fan control! Status=5
[0] projects/power_distribution/src/main.c:213: Power distribution successfully initialized as front.
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 0
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 1
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 2
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 3
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 4
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 5
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 6
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 7
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 8
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 9
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 10
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 11
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 12
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 13
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 14
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 15
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 16
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 17
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 18
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 19
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 20
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 21
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 22
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 23
[0] projects/power_distribution/src/main.c:115: Smoke test: turning on output 24
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 10 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 33 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 32 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 32 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 33 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 39 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 36 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 35 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 38 mA
[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 39 mA
```

When I have one fan and the horn connected to UV cutoff, the current draw is ranges from 32 - 39mA which doesn't make sense because the power supply connected to UV cutoff displays a current of about 4.29A. I decided to check the voltage of the IS pins (pin 4) of the following load switches:

Component	Reading (volts)
U4	0.0033
U5	0.2501
U1	0.1498

As you can see from the table, 0.0033V is quite a bit lower than 0.1498V and 0.2501V. Referring back to the datasheet of U4:

9 Diagnosis

For diagnosis purpose, the BTS7004-1EPP provides a sense current signal (I_{IS}) at pin IS. In case of disabled diagnostic (DEN pin set to "low"), IS pin becomes high impedance.

This basically means that if the DEN pin is low (low voltage), then IS becomes high impedance (which explains the low voltage 0.0033V).

So then I decided to check the voltage of the DEN pins (pin 3) of the load switches:

Component	Reading (volts)
U4	0.0404
U5	2.7325
U1	2.7244

As you can see from the table, 0.0404V is significantly lower than 2.7V so I knew that the DEN pin of U4 was set to low, but it needs to be set to high so that the IS pin does **not** become a high impedance.

Through inspection, I found that R24 and R22 weren't soldered properly.

- R24 connects to the IS pin (after resoldering it closes the connection between the IS pin and R25 [to 6-pin PD connector])
- R22 connects to the DEN pin (after resoldering it closes the connection between the DEN pin and FUSED_VBAT+)

After resoldering both resistors, the voltages for the IS and DEN pins of U4 are:

Pin	Reading (volts)
IS	0.2621
DEN	2.6721

So now the voltages are more in line with the other load switches.

<u>Current Readings in minicom</u>

This section contains screenshots of the UV VBAT current readings in minicom for different scenarios. In the publish_data.c file located in /firmware_xiv/projects/power_distribition/src/, I've commented out this line here so I could focus on current readings:

```
if (!status_ok(tx_code)) {
//      LOG_WARN("Failed to TX output %d: status code %d\n", current_id, tx_code);
}
```

As of July 26, 2021, the current is scaled for a BTS7040 rather than a BTS7004 which is the MPN of U4. The current readings are off (minicom doesn't match what the power supply draws). I will try to update this once there's an update for the pd_smoketest branch.

Test case	Power supply current draw (amps)	minicom current readings
4 fans running + horn	4.81	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 476 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 391 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 397 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 388 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 393 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 482 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 403 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 385 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 385 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 400 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 413 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 419 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 422 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 426 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 416 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 432 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 429 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 425 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 423 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 425 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 429 mA
3 fans running + horn (three NF-A9's)	4.45	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 406 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 399 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 393 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 391 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 385 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 391 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 393 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 396 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 397 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 391 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 393 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 391 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 394 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 384 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 399 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 384 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 387 mA
2 fans running + horn (two NF-A9's),	4.36	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 379 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 385 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 387 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 387 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 387 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 388 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 388 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 384 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 382 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 379 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 381 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 384 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 390 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 379 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 385 mA

1 fan running + horn (one NF-A9)	4.29	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 379 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 382 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 374 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 379 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 372 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 382 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 377 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 377 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 384 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 381 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 374 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 379 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 377 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 375 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 378 mA
horn by itself	4.19	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 366 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 371 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 366 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 366 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 369 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 368 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 366 mA
4 fans running w/o horn	0.69	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 55 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 58 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 49 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 58 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 51 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 54 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 60 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 54 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 49 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 63 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 54 mA
3 fans running w/o horn (three NF-A9's)	0.28	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 23 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 30 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 26 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 23 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 17 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 23 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 22 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 17 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 11 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 16 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 22 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 20 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 23 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 44 mA

2 fans running w/o horn (two NF-A9's)	0.19	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 13 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 16 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 13 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 13 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 11 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 13 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 14 mA
1 fan running w/o horn (one NF-A9)	0.09	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 10 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 7 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 10 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 13 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 11 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 5 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 4 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA
0 fans and no horn	0.02	[0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA [0] projects/power_distribution/src/publish_data.c:52: UV VBAT CURRENT IS 0 mA

U2 IS NOW POPULATED FROM HERE ON OUT (July 27, 2021):

- I soldered on an alternative op amp: TLV2401QDBVRQ1 (made by Texas Instruments)
    - the op amp used in the schematic is a: OPA197 (also made by Texas Instruments)

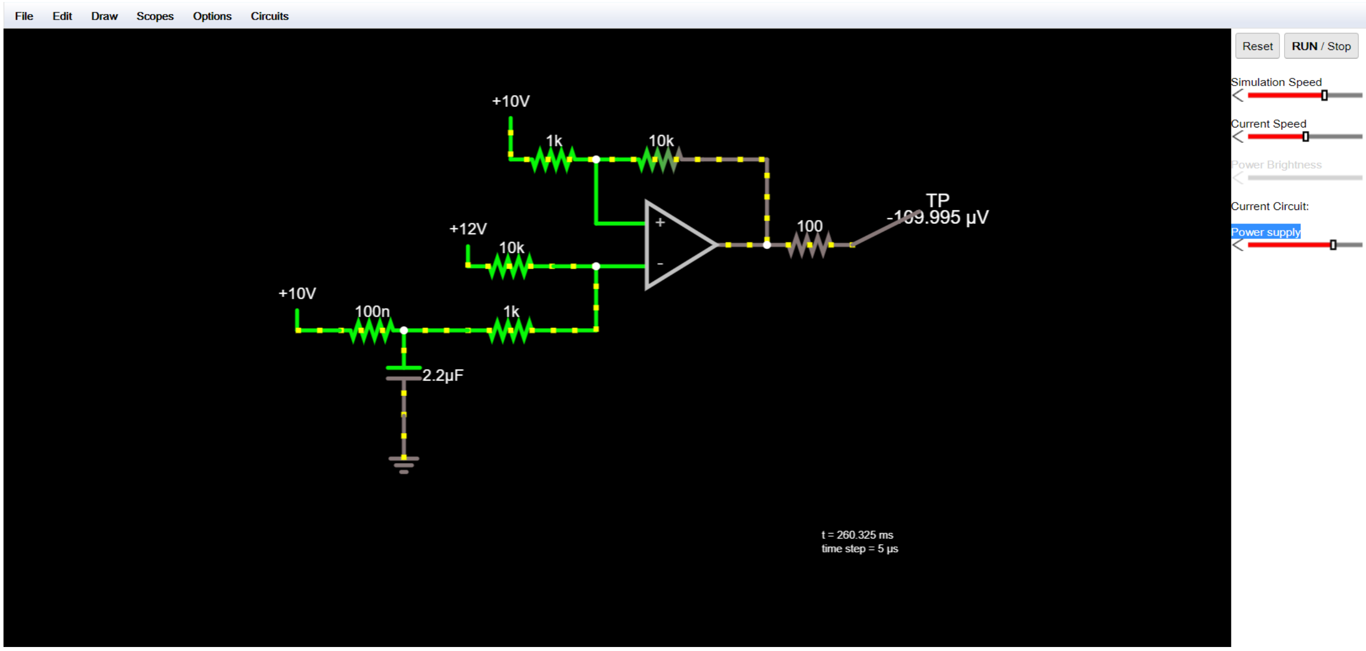
Now that I soldered on the alternative op amp, I decided to check the cutoff functionality of the board again (I specifically decided to look for when the current draw to UV cutoff dropped to 0.00A rather than looking for the lock out message in minicom).

So for the first time powering the board after soldering the new op amp, I found out that the cutoff voltage was at **11.80V**, which is not close to the ideal 10V. Using Falstad and LTspice, I decided to simulate a different cutoff voltage by changing the following resistors:

- R1
- R2
- R6
- R9

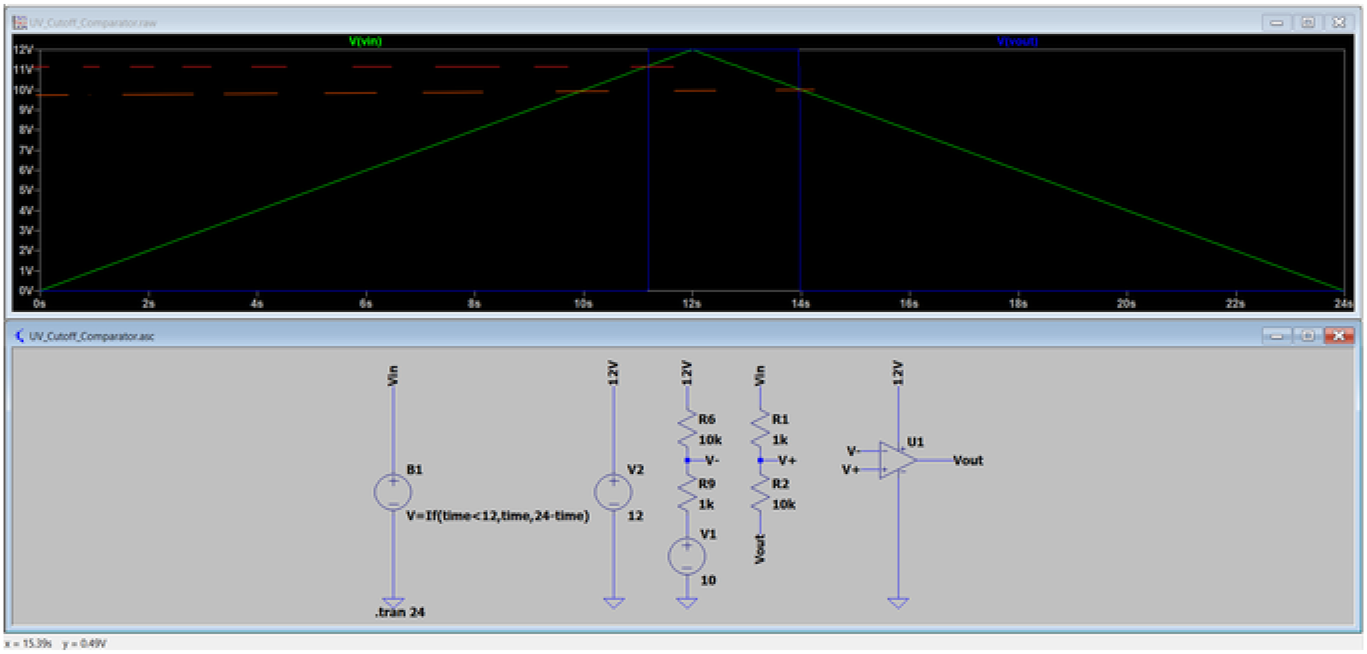
This Falstad simulation can be found here.

- you can adjust the "Power supply" voltage to simulate using a real power supply
    - I started at 13.5V, then decreased the voltage until the test point (connected to the 100 ohm resistor) turned gray, which kinda represents zero volts
- note that the 10V rail represents the LDO regulator and the 12V rail represents the connection from PD



The LTspice file made by @ Liam Hawkins can be found here:

- the file looks like this and when you run the simulation, you should be able to get something like this when you probe Vin and Vout (Vin represents would represent a power supply and Vout would simply be the test point [technically pin 1 of U2])
- notice that Vout turns “on” when Vin is about 11V (red dotted line) and
- notice that Vout turns “off” when Vin is about 10V



So for whatever reason, the original design configuration where:

- R1 = R9 = 1k
- R2 = R6 = 10k

was not providing the correct cutoff voltage (whether that would be because of impedance in the bay or the biasing of the amp, which is most likely the issue since we are using a different op amp).

Below is a table that shows different resistor combinations that I have tried:

PD supplied with 12V, using 4 fans and horn (default resistor values shown in purple):

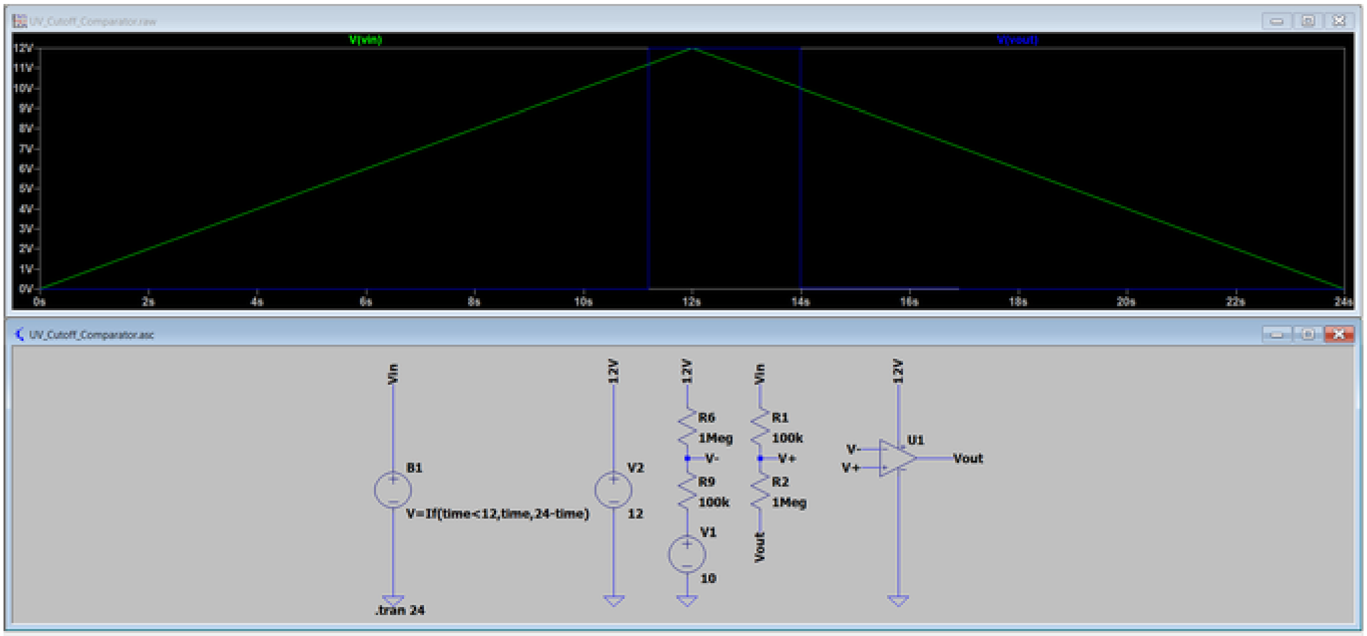
R1 (ohms)	R2 (ohms)	R6 (ohms)	R9 (ohms)	Cutoff voltage (volts)	Pin 4 reference (U2) at 13.5V (volts)	Falstad cutoff (volts)	Reference where board starts drawing current (volts)
1k	10k	10k	1k	11.80V	11.440V	10V	did not test
1k	10k	10k	100	11.80V	11.436V	9.7	did not test
100	10k	10k	1k	11.42V	11.441	10.3V	did not test
100	100	10k	1k	7.02V	11.441	8.5V	did not test
100	100	10k	100	7.06V	11.438	8V	did not test
1k	1k	3.3k	1k	8.14	11.878	8.9V	did not test
10k	1M	1M	10k	10.02	10.018	10V	10.14V
100k	1M	1M	100k	10.46V	10.110	10V	11.20V

(At the time of changing the resistors, I didn't screenshot all the simulations in LTspice)

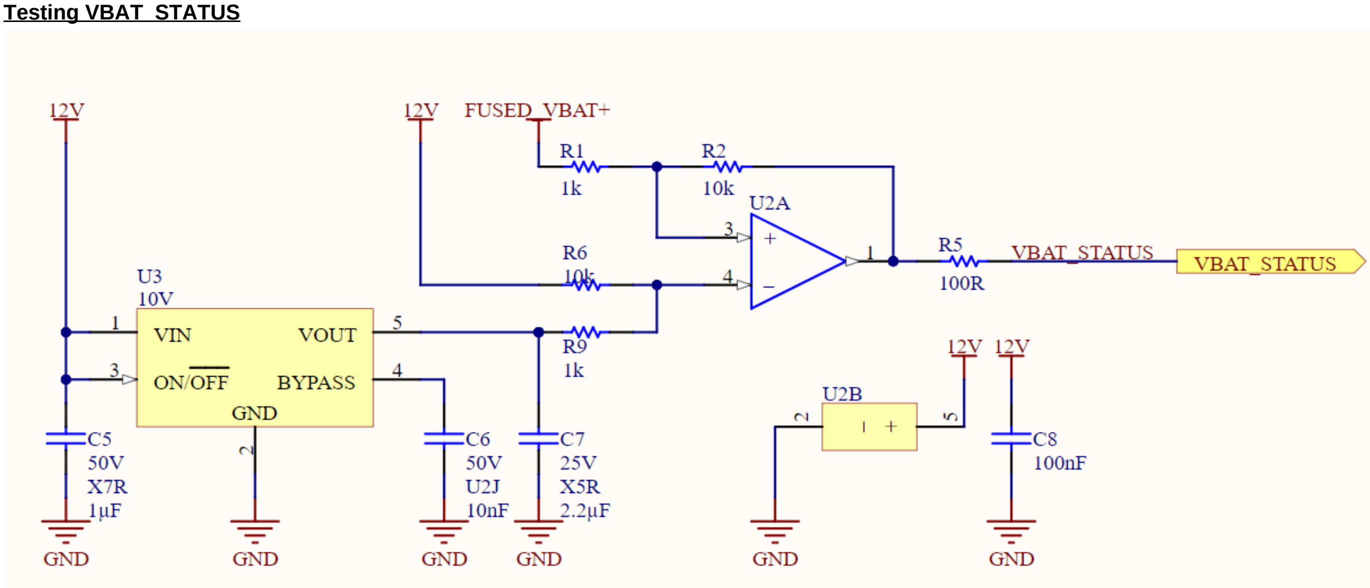
So as you can see in the table, the row with the blue values provide a pretty nice cutoff voltage. My thinking behind choosing those values was to kinda keep the same ratio between the resistors from the original design. Although the cutoff voltage is essentially at 10.00V, the voltage where the board turns back on is 10.14V (which isn't really an issue even though it isn't close to 11V).

I then tested using the row with the green values (multiply the purple values by 100) which shows that I got a cutoff voltage of 10.46V and the board turns back on at 11.20V. These values are close to the original LTspice sim and this test kinda also confirms that the biasing of the op amp was an issue in the purple row.

Simulating the green row in LTspice:



Testing VBAT_STATUS



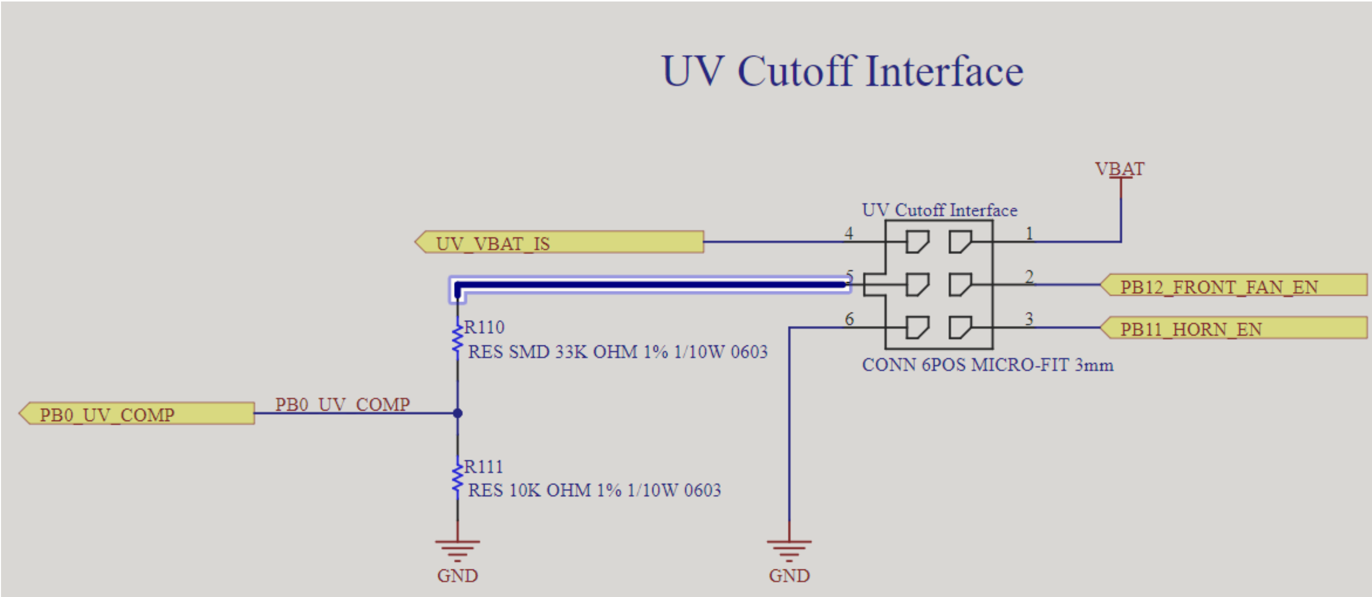
So using the configuration from the green row:

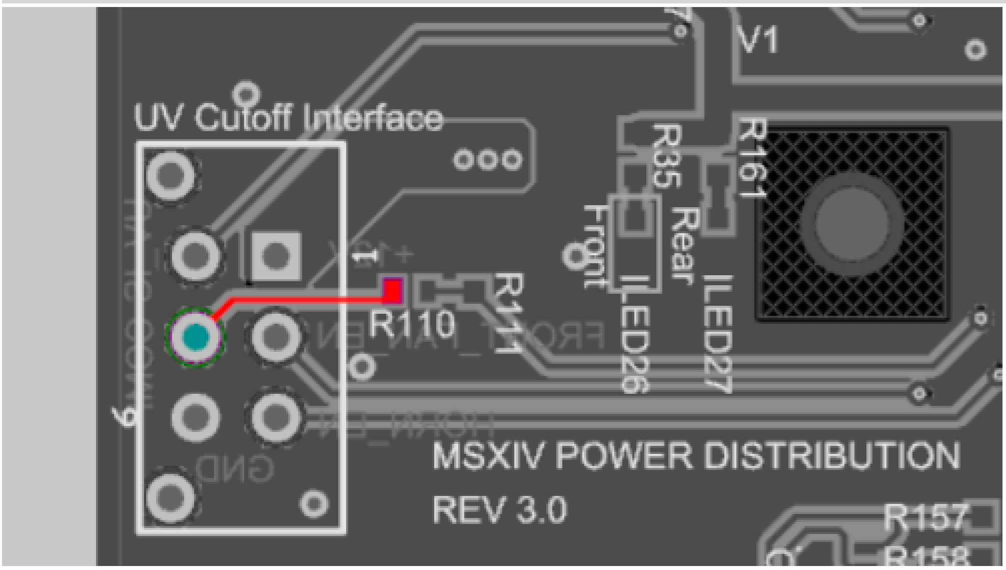
- R1 = R9 = 100k
- R2 = R6 = 1M

I measured the voltage of pin 1 while the board was on and when the board "locked out":

Test case	Reading (volts)
13.5V	9.505
10V (cutoff)	0.0894

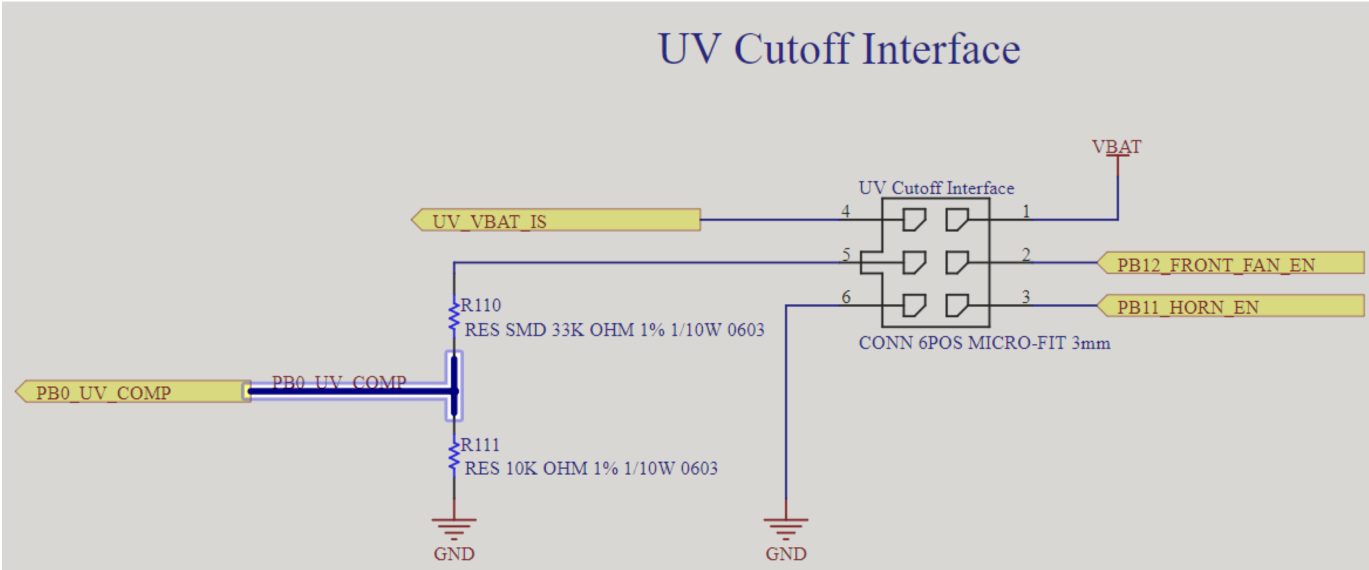
I also checked the voltage of this trace shown here (from PD):

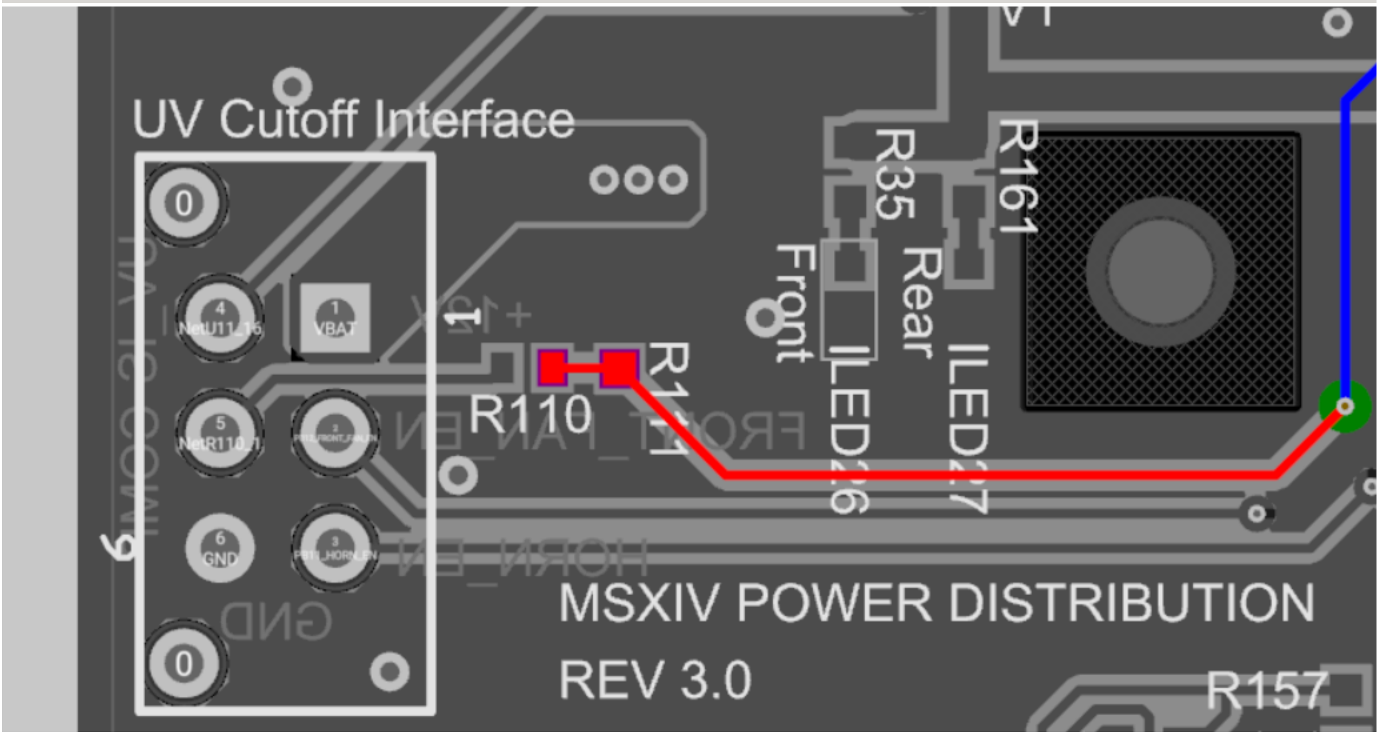




Test case	Reading (volts)
13.5V	9.424
10V (cutoff)	0.0891

I then checked the voltage of this trace shown here:





Test case	Reading (volts)
13.5V	2.2065
10V (cutoff)	0.0210

These values from these 3 tables make sense and it seems that VBAT_STATUS is working correctly.