Muon Telescope

Sawaiz Syed

May 4, 2017

Contents

Abstract

The assembly, software, and operation of a three paddle plastic scintillator detector.

Chapter 1

Components

1.1 Scintillator Panel

Large scintillator panel with embedded fibre loop to channel light to attached photosensor. The tile has a loop pattern with a single fibre to attempt to gather light from as much of the effective area of scintillator and minimize losses from tight curves and open fibre ends. The fibre groove follows along the top surface and comes out perpendicular to end face. A rendering of a assembled panel is shown in Figure 1.1.

Figure 1.1: Fully assembled Scintillator panel.

1.1.1 Theory

The scintillator panel is a doped plastic (available from many suppliers Eljen being the one used in our assemblies) that emits light in response to being struck by an electron, alpha particle, ion, or high energy photon. The light emitted (blue in our case) is then expected to hit the embedded fibre that can absorb that light, and retransmit at the lower green frequency based on the characteristics of the fibre. This green light is captured and guided by the fibre to the end of finger where it can be read out. Each event is expected to produce about 30 photons, with a lower number reaching the sensor placed on the fibre side. The outer surface has coatings applied to shield from external light and attempt to maximise efficiency by reflecting internal light. A exploded view of all the components is shown in Figure 1.2.

1.1.2 Assembly

Currently the parts must be hand assembled although further production may yield an injection moulding scheme. The following lists the procedure to construct a single plate.

Milling

The fingers are cut from 10mm thick scintillator and are 145 mm x 145 mm. The groove is cut with a ball mill under water flow to prevent deformation of the plastic due to heat. The milled sides are then polished (Novus plastic polish works well) and then are washed with alcohol.

Gluing

The optical fibres are cut to length (score and breaking) and the end is polished. It is placed into the groove with a two-part optical cement. This binds the fibre to the milled plastic providing an optical bond. Forcing the fibre to match the contour milled.

Covering

The fingers are then covered with either degreased aluminium foil and electrical tape or a coating of reflective spray followed by a dip inside rubberized coating (successful tests have been done with Spaz Stix Ultimate Mirror Chrome and Plasti Dip) providing a more even surface finish and reduced labour. This covering shields external light, and provides higher efficiency by capturing stray photons by reflecting them back towards the fibre optic.

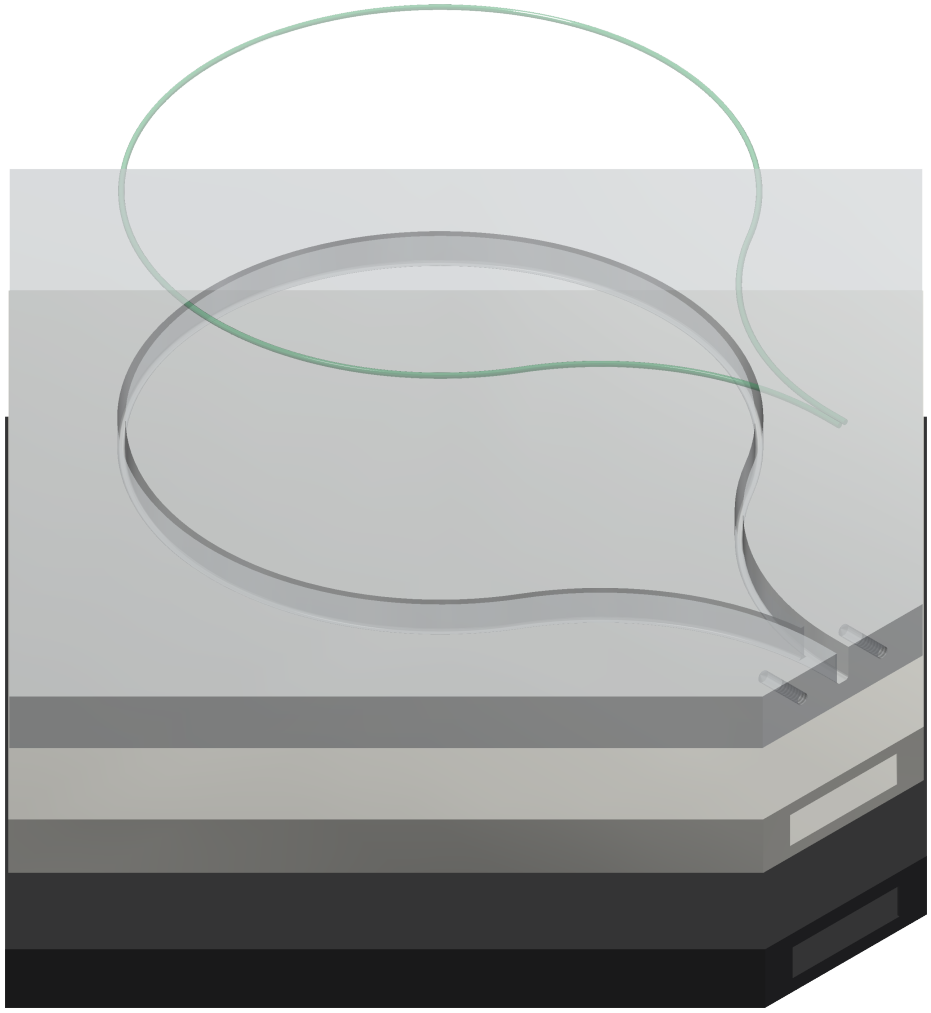


Figure 1.2: Exploded view showing coatings and fibre.

1.2 MPPC Sensor

The board stack has a MPPC, preamp, temperature sensor, and LED. Having the preamp on board, just millimetres from the sensor allows excellent signal integrity, even in high noise environments. Also, having the temperature sensor on the sensor, allows for fine adjustment due to local temperature fluctuations, as the gain is dependent on temperature and bias voltage, a constant gain can be maintained by changing the bias in response to temperature.

1.2.1 Hardware

This board houses a surface mount 2.0 mm MPPC by Hamamatsu. Specifically, `S13360-20**VE` series. The signal is amplified with a TI OPA846 op-amp. There is a LED as well as a 100K NTC thermistor. The boards are all 7 mm tall, 25 mm

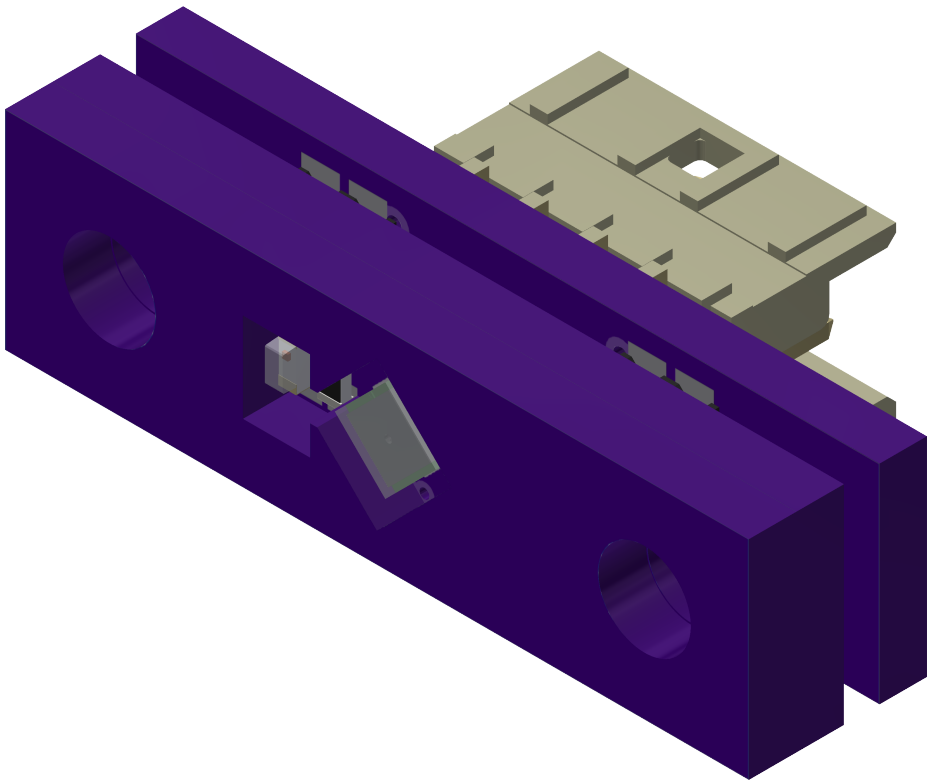


Figure 1.3: Assembled MPPC sensor board stack.

wide and approximately 6.4 mm in depth without the pins. The spacer board blocks out excess light from reaching the MPPC, and provides isolation from the LED forcing it to go through the scintillator. It is attached with two 4-40 screws that can go directly into scintillator or a mounting block.

1.2.2 Cable

There are eight pins attached to back of the final board. Those pins break out all signals needed. There is a corner mark on the PCB that lies in the top left corner. On single ended signals, *Sig-* is connected to *GND*.

The cable used is a 28AWG CAT6 cable, Monoprice's Slimrun line is an option. This provides 8 conductors that are twisted pairs, along with an 8P8C connector. Wiring standard used is the following positions.

MPPC High Voltage BOM

Ref-Des	Function	Description	P/N	Digikey P/N	QTY	Unit Price	Ext Price
C9, C10	Op-amp Power Filter	CAP CER 1UF 25V X5R 0402	GRM155R61E105MA12D	490-10018-1-ND	1	0.03250	0.03
C11	HV Filter	CAP CER 0.047UF 50V X7R 0402	GRM155R71H473KE14D	490-10702-1-ND	1	0.01320	0.01
C7	Decoupling	CAP CER 1UF 10V X5R 0603	CL10A105KP8NNNC	1276-1182-1-ND	1	0.01400	0.01
C8	Decoupling	CAP CER 10UF 10V X5R 0603	GRM188R61A106ME69D	490-10475-1-ND	1	0.06560	0.07
D1	MPPC	2.0mmx2.0mm MPPC	S13360-2050VE	S13360-2050VE	1	22.00000	22.00
D2	Led	LED GREEN CLEAR 0603 R/A SMD	LTST-S270GKT	160-1475-1-ND	1	0.11220	0.11
J1,J2	Spring Connector	BATTERY CONN 1.2H 1.6MM DR 4CKT	788640001	WM11203CT-ND	2	0.25470	0.51
R9, R10	Op-amp Power Filter	RES SMD 10 OHM 5% 1/16W 0402	RC0402JR-0710RL	311-10JRCT-ND	2	0.00470	0.01
R2	NTC Therm	THERMISTOR NTC 100KOHM 0.5% 0603	NCP18WF104D03RB	490-11811-1-ND	1	0.31270	0.31
R11, R12, R14	51 ohm Term	RES SMD 51 OHM 5% 1/16W 0402	RC0402JR-0751RL	311-51JRCT-ND	3	0.00470	0.01
R13, R15	Op-amp Gain/ HV Filter	RES SMD 1K OHM 0.1% 1/16W 0402	RT0402BRD071KL	YAG1386CT-ND	2	0.12760	0.26
U1	Op-Amp	IC OPAMP VFB 1.75GHZ SOT23-5	OPA846IDBVT	296-14776-1-ND	1	3.74460	3.74
J3	Output Header	MINITEK	98424-F52-08ALF	609-5175-1-ND	1	1.04000	1.04
				PCB Manufacture	3	1.35000	4.05
				Assembly	1	5.38000	5.38
				Testing (Labour)	0.05	30.00000	1.50
						Subtotal	39.05

Table 1.1: Bill of Materials, all prices in USD.

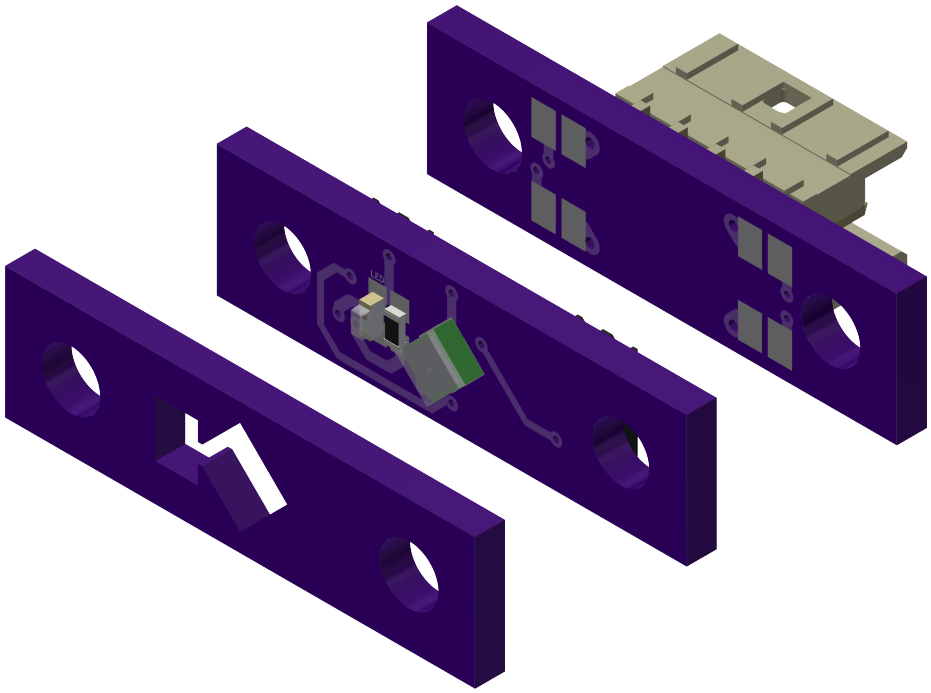


Figure 1.4: Exploded view of MPPC sensor side.

1.3 MPPC High Voltage Supply

Surface mount module that provides 52.5 V to 57.5 V in 20 mV increments. Also contains a 2 input 24bit ADC to allow for closed loop control of the voltage, and read in a thermistor mounted near the sensor. Rendering of a fully assembled module shown in Figure 1.9.

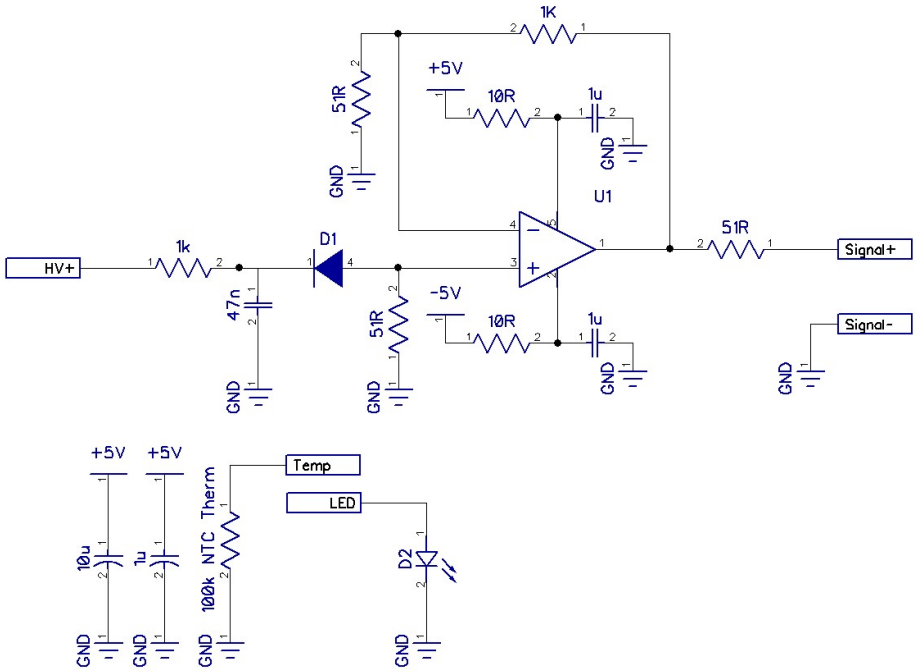


Figure 1.5: Schematic of the preamp, D1 is the MPPC.

Sensor Interface Cable BOM

Ref-Des	Function	Description	P/N	Supplier P/N	QTY	Unit Price	Ext Price
J3-F	Output Header Jack	CONN IDC SOCKET 8POS 2MM GOLD	89361-708LF	609-3140-ND	1	1.08800	1.09
W1	3 foot Ethernet Cable	Cat6 28AWG UTP Ethernet Network Cable	14812	14808	0.5	2.29000	1.16
				Assembly (Labour)	0.1	30.00000	3.00
				Testing (Labour)	0.05	30.00000	1.50
						Subtotal	6.05

Table 1.2: Bill of Materials, all prices in USD.

1.3.1 Hardware

The module uses a MAX1932 APD bias voltage boost converter and NAU7802SGI 24bit Analog to Digital converter (ADC) for reading temperature and output voltage. The complete bill of materials including assembly and testing is detailed in Table 1.5.

High Voltage

The module uses a MAX1932 APD bias voltage boost converter to create and maintain the output voltage. The voltage range, and step size is dictated with setting `R2`, `R3`, and `R4`. The minimum and maximum voltage set using the equations for on page 7 of the datasheet, and there are 8 bits (256) intermediate values that are possible the corresponding schematic is show in in Figure 1.11. The high switching portion was designed with general SMPS design requirements (short high current loops, separated ground planes, EMI shielding) providing a low ripple output ($< 5\,\mathrm{mV}_{pp}$ ripple) and no significant back EMF.

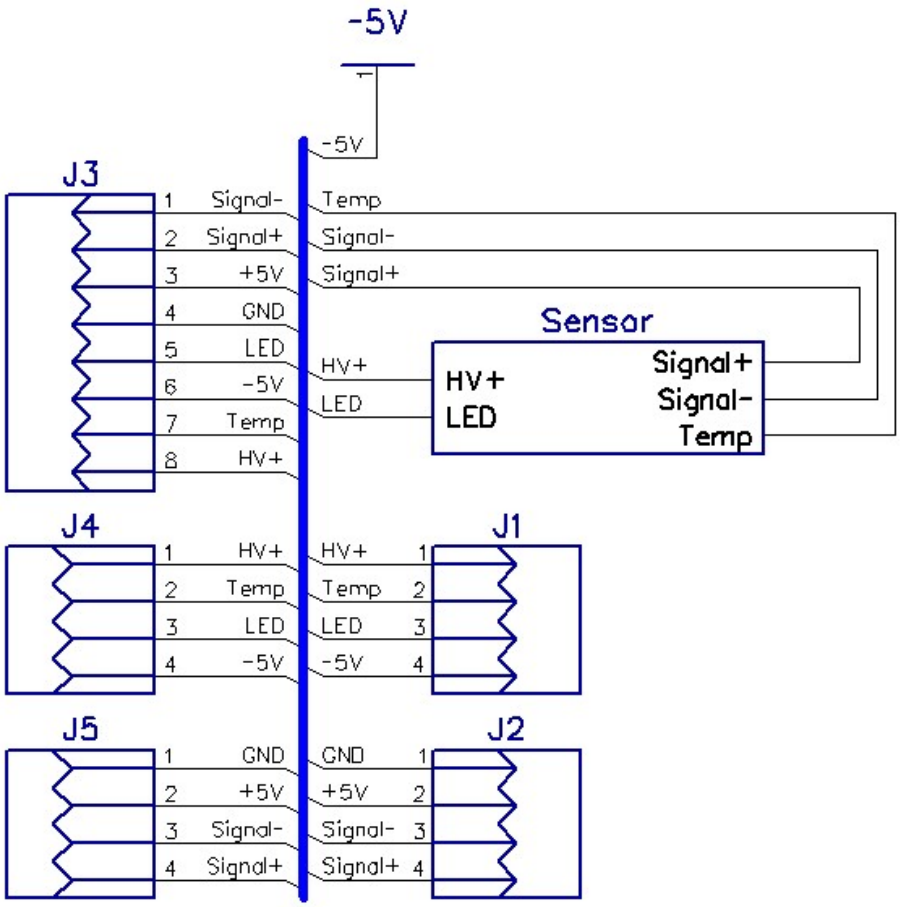


Figure 1.6: The interconnects between the boards as well as the header in the back.

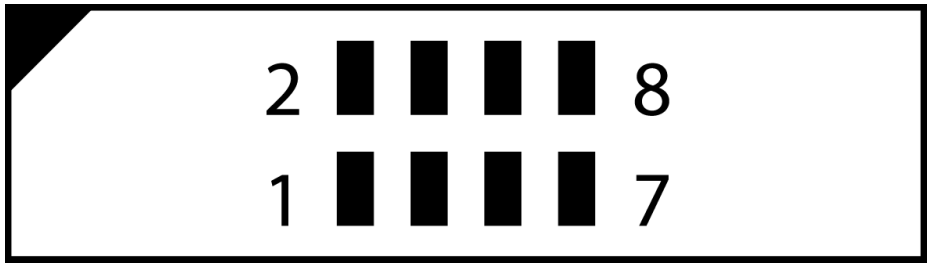


Figure 1.7: Pin numbering for Table 1.6.

ADC

The analogue to digital converter is a one designed for high precision and low sampling rate. The NAU7802SGI is marketed at the load sensing market, but the high precision and low sampling rate lends itself well to the closed loop control and monitoring application. The high voltage is divided by 50 and the thermistor is put across a equivalent 100K static resistor to go along with the 100K NTC found on the MPPC

Sensor Interface Cable Connections

Pin	Function	Type
1	Signal -	Output
2	Signal +	Output
3	$+V_S$	Power
4	Ground	Power
5	LED	Input
6	$-V_S$	Power
7	High Voltage	Power
8	Thermistor	Output

Table 1.3: Pinout on the back side with pins facing you and the cut corner on top left.

RJ-45 Pin	Cable Colour	Signal	Abv
MD0+	White Orange	High Voltage	HV+
MD0-	Orange	Ground	GND
MD1+	White Green	Test	LED
MD1-	Blue	Thermistor	TEMP
MD2+	White Blue	+Voltage	+Vcc
MD2-	Green	-Voltage	-Vcc
MD3+	White Brown	Signal+	Sig+
MD3-	Brown	Signal-	Sig-

Table 1.4: Pinout on the back side with pins facing you and the cut corner on top left.

sensor module to act as a voltage divider, see Figure 1.12 for details.

1.3.2 Software

Each module has two buses that run to it, I^2C (pronounced I-two-C) and SPI. SPI requires data, clock, and a chip-select meaning each device on the bus will need an independent chip select. I^2C devices have a fixed address therefore it is not possible to have multiple devices on the same bus. This can be remedied by placing multiple devices in front of a I^2C multiplexer. Table 1.6 lists their functions.

High Voltage

The SPI bus is connected directly to the MAX1932. Chip select is active low and data is sent MSB (most significant bit first). Sending bytes to it sets the voltage. Setting them to `0x00` turns off the DC-DC converter portion. As values increase to `0xFF (127)`, the output voltage falls, linearly. Example code for Arduino that cycles through all possible values is shown in Listing 1.1.

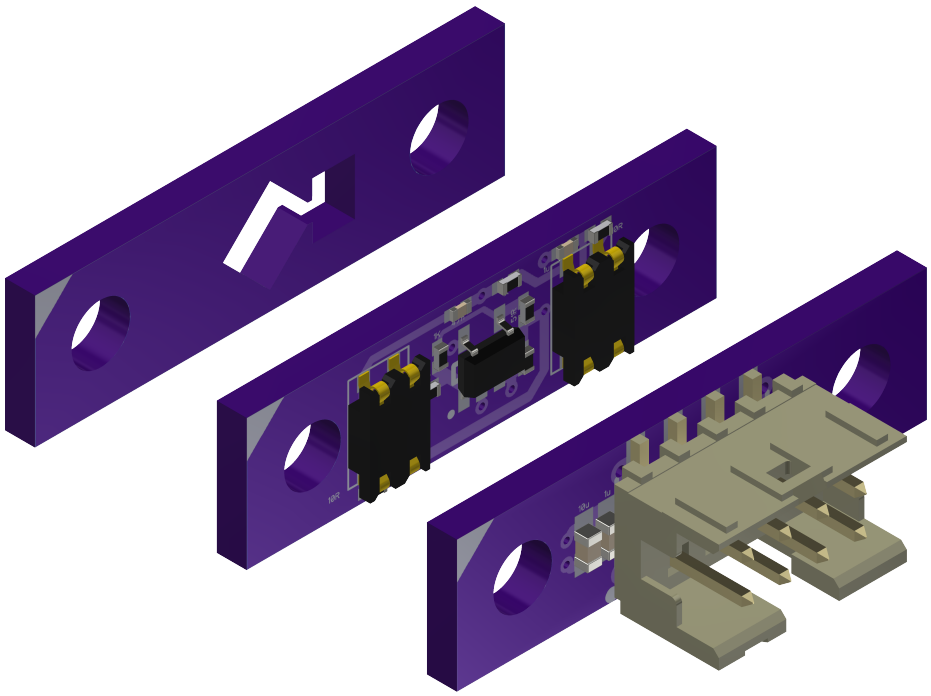


Figure 1.8: Exploded view of connector side.

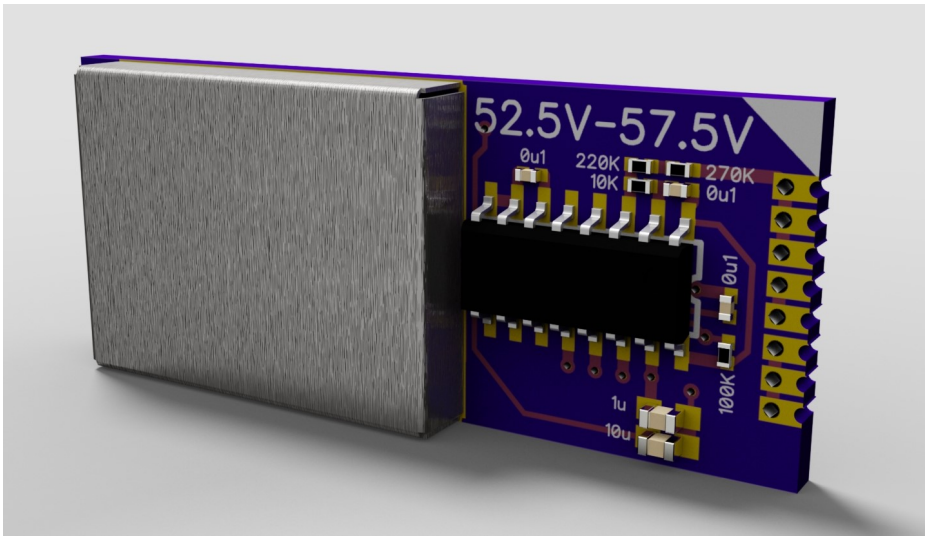


Figure 1.9: Board rendering with EMI shield.

```
//Example Arduino code that loops through all voltages.
//SCLK --> Pin 13 for Uno or Duemilanove
//DIN ---> Pin 11 for Uno or Duemilanove

#include <SPI.h>
#define CS 2 //Any pin
```

MPPC High Voltage BOM

Ref-Des	Function	Description	P/N	Digikey P/N	QTY	Unit Price	Ext Price
C1	Input Decoupling	1F 16V Ceramic Capacitor X7R 1206	160R18W105KV4E	709-1068-1-ND	1	0.0890	0.09
C2	Boost Capacitor	0.047F 500V Ceramic Capacitor X7R 1206	C1206C473KCRACTU	399-6743-1-ND	1	0.1300	0.13
C3	Pre Filter Capacitor	0.10F 250V Ceramic Capacitor X7R 1206	C1206C104KARACTU	399-4674-1-ND	1	0.1485	0.15
C4	Post Filter Capacitor	CAP CER 1UF 100V X7R 1206	12061C105KAT2A	478-6226-1-ND	1	0.1570	0.16
C5	Compensation Capacitor	CAP CER 0.22UF 16V Y5V 0402	CL05F224ZO5NNNC	1276-1060-1-ND	1	0.0112	0.01
D1	Boost Diode	DIODE GEN PURP 100V 200MA SOD80	LL4148	LL4148FSCT-ND	1	0.0420	0.04
L1	Boost Inductor	FIXED IND 150UH 320MA 2.4 OHM	SRN4018-151M	SRN4018-151MCT-ND	1	0.2400	0.24
L2	Smoothing Inductor	FIXED IND 330UH 90MA 15.99 OHM	CBC2518T331K	587-3059-1-ND	1	0.1400	0.14
Q1	Boost Switch	MOSFET N-CH 100V 0.17A SOT-23	BSS123L	BSS123LCT-ND	1	0.1032	0.10
R1	Current Sens Resistor	RES SMD 806 OHM 0.1% 1/16W 0402	RT0402BRD07806RL	YAG1481CT-ND	1	0.1276	0.13
R2, R6	Adjustment Span/Temp	RES SMD 100K OHM 0.1% 1/16W 0402	RT0402BRD07100KL	YAG1343CT-ND	2	0.1276	0.26
R3	Minimum Voltage Res	RES SMD 2.37KOHM 0.1% 1/16W 0402	CPF0402B2K37E1	A102770CT-ND	1	0.2082	0.21
R4	DAC Resistor	RES SMD 24.9KOHM 0.1% 1/16W 0402	RT0402BRD0724K9L	YAG1393CT-ND	1	0.1276	0.13
R5	Compensation Res	RES SMD 20 OHM 0.1% 1/16W 0402	CPF0402B20RE1	A102706CT-ND	1	0.1973	0.20
U1	Boost Controller	IC SUPPLY BIAS APD 12-TQFN	MAX1932ETC+T	MAX1932ETC+TCT-ND	1	7.2828	7.28
U2	ADC	IC ADC 24BIT I2C/SRL 16-SOP	NAU7802SGI	NAU7802SGI-ND	1	1.3442	1.34
C6	0.1uF	0.10F 10V Ceramic Capacitor X5R 0402	CL05A104KP5NNNC	1276-1022-1-ND	2	0.0048	0.01
C7	1uF	1F 6.3V Ceramic Capacitor X6S 0402	GRM155C80J105KE15D	490-6281-1-ND	1	0.0055	0.01
C8	10uF	10F 6.3V Ceramic Capacitor X5R 0603	GRM155R60G106ME44D	490-10693-1-ND	1	0.0380	0.04
S1	RF Shield	RFI SHIELD CAN 20X15X3MM	SO2-20150300	952-2632-ND	1	3.5300	3.53
R7	220k 1%	RES SMD 220K OHM 1% 1/16W 0402	RC0402FR-07220KL	311-220KLRCT-ND	1	0.0054	0.01
R9	270k 1%	RES SMD 270K OHM 1% 1/16W 0402	RC0402FR-07270KL	311-270KLRCT-ND	1	0.0054	0.01
R8	10k 0.1%	RES SMD 10K OHM 1% 1/16W 0402	RC0402FR-0710KL	311-10.0KLRCT-ND	1	0.0054	0.01
				PCB Manufacture	1	1.5333	1.53
				Assembly	1	9.3000	9.30
				Testing (Labour)	0.05	30.0000	1.50
				Calibration (Labour)	0.05	30.0000	1.50
						Subtotal	28.03

Table 1.5: Bill of materials All prices in USD.

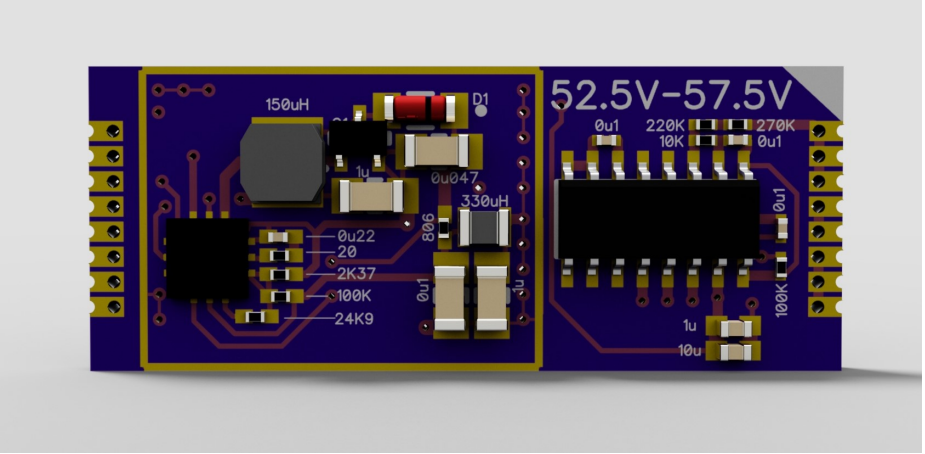


Figure 1.10: EMI shield removed showing switching region.

```
7
void setup(){
9     Serial.begin(9600);
      pinMode(CS, OUTPUT);
11    digitalWrite(CS, HIGH);
      SPI.begin();
13    SPI.setBitOrder(MSBFIRST);
}
15
void loop(){
17    for(int i = 0 ; i < 256 ; i++){
          digitalWrite(CS, LOW);
19        SPI.transfer(i);
```

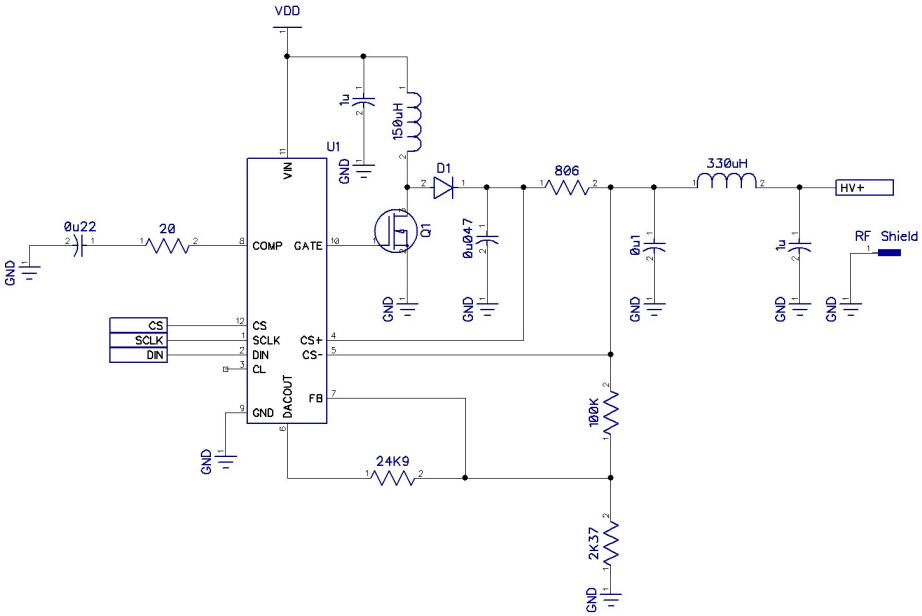


Figure 1.11: Schematic for high voltage boost converter.

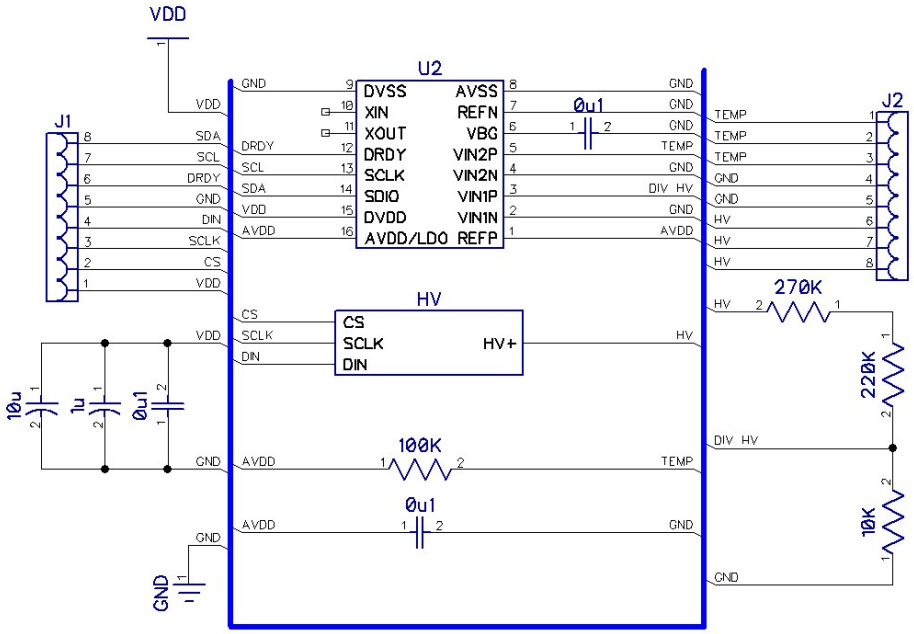


Figure 1.12: Schematic showing contacts, adc, and high voltage hierarchy block.

```
            digitalWrite(CS, HIGH);
21          Serial.println(i);
        }
23  }
```

MPPC High Voltage Pinout

Pin	Label	Description
1	`3V3`	Regulated 3.3 V in
2	`CS`	*SPI* bus Chip Select
3	`SCLK`	*SPI* bus clock
4	`DIN`	*SPI* bus data in
5	`GND`	Common Ground
6	`DRDY`	ADC conversion done
7	`SCL`	I^2C bus clock
8	`SDA`	I^2C bus data

Table 1.6: Pins and thier fuctions.

Listing 1.1: "max1932.ino"

ADC

The ADC communicates through the I^{2}C bus, the device address is permanently programmed to `0101010 (0x2A)`. It is fully compliant with the I^{2}C protocol and the datasheet has the register map (page 28) and protocol description (page 14).

```
#include "nau7802/NAU7802.h"
#include "nau7802/NAU7802.cpp"
#include <Wire.h>

// Create the NAU7802 ADC object
NAU7802 adc = NAU7802();

void setup(void) {
    Serial.begin(9600);
    Wire.begin();        // Join i2c bus
    adc.begin();         // Initalize ADC
    adc.avcc2V4();       // Set voltage range to 0-2.4V
}

void loop(void) {
    // Read Channel 1
    adc.selectCh1();  // Channel 1 has 50x Divided High voltage
    Serial.print("Chanel 1: ");
    Serial.println(adc.readmV());

    // Read Channel 2
    adc.selectCh2();  // Channel 2 has thermistor
    Serial.print("Chanel 2: ");
    Serial.println(adc.readmV());
}
```

Listing 1.2: "nau7802.ino"

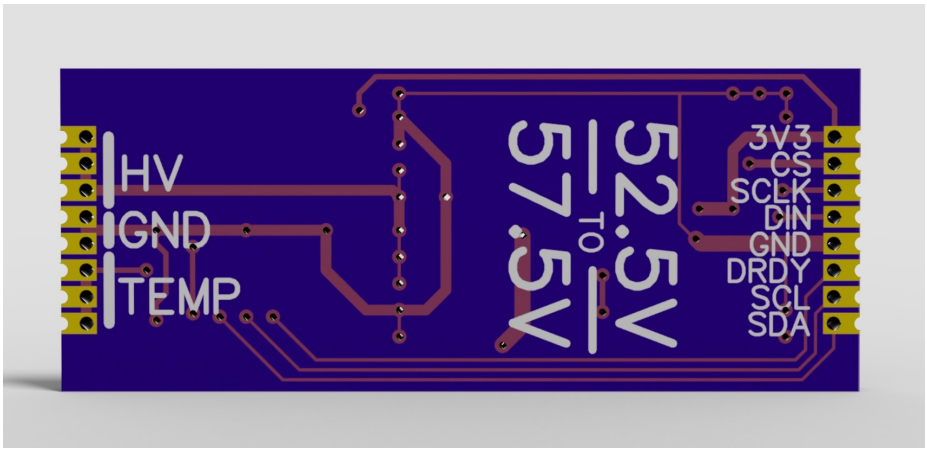


Figure 1.13: Back is flat to allow flush mounting to mother-board.

```
//Arduino library for interfacing with the nau7802 24bit ADC
#ifndef __NAU7802_H__
#define __NAU7802_H__

//Uncomment one of the following based on needs.
#define NAU7802_DEFAULT_WIRE
// #define NAU7802_SOFTWARE_WIRE
// #define NAU7802_ESP8266_WIRE

#include <Arduino.h>
#include <Wire.h>

#ifdef NAU7802_SOFTWARE_WIRE
#include <SoftwareWire.h>
#endif //NAU7802_SOFTWARE_WIRE

#define NAU7802_I2CADDR    0x2A         //Static Adress

#define NAU7802_PU_CTRL    0x00         //REG0x00:PU_CTRL      Powerup Control
#define NAU7802_CTRL1      0x01         //REG0x01:CTRL1        Control 1
#define NAU7802_CTRL2      0x02         //REG0x02:CTRL2        Control 2

#define NAU7802_OCAL1_B2   0x03         //REG0x03:OCAL1_B2     CH1 OFFSET Calibration[23:16]
#define NAU7802_OCAL1_B1   0x04         //REG0x04:OCAL1_B1     CH1 OFFSET Calibration[15:08]
#define NAU7802_OCAL1_B0   0x05         //REG0x05:OCAL1_B0     CH1 OFFSET Calibration[07:00]
#define NAU7802_GCAL1_B3   0x06         //REG0x06:GCAL1_B9     CH1 GAIN   Calibration[31:24]
#define NAU7802_GCAL1_B2   0x07         //REG0x07:GCAL1_B2     CH1 GAIN   Calibration[23:16]
#define NAU7802_GCAL1_B1   0x08         //REG0x08:GCAL1_B1     CH1 GAIN   Calibration[15:08]
#define NAU7802_GCAL1_B0   0x09         //REG0x09:GCAL1_B0     CH1 GAIN   Calibration[07:00]

#define NAU7802_OCAL2_B2   0x0A         //REG0x0A:OCAL2_B2     CH2 OFFSET Calibration[23:16]
#define NAU7802_OCAL2_B1   0x0B         //REG0x0B:OCAL2_B1     CH2 OFFSET Calibration[15:08]
#define NAU7802_OCAL2_B0   0x0C         //REG0x0C:OCAL2_B0     CH2 OFFSET Calibration[07:00]
#define NAU7802_GCAL2_B3   0x0D         //REG0x0D:GCAL2_B3     CH2 GAIN   Calibration[31:24]
#define NAU7802_GCAL2_B2   0x0E         //REG0x0E:GCAL2_B2     CH2 GAIN   Calibration[23:16]
#define NAU7802_GCAL2_B0   0x0F         //REG0x0F:GCAL2_B0     CH2 GAIN   Calibration[15:08]
#define NAU7802_GCAL2_B1   0x10         //REG0x10:GCAL2_B1     CH2 GAIN   Calibration[07:00]

#define NAU7802_I2C_CTRL   0x11         //REG0x11:I2C_CTRL     I2C Control

#define NAU7802_ADC_B2     0x12         //REG0x12:ADC_OUT_B2   ADC Conversion Result [23:16]
#define NAU7802_ADC_B1     0x13         //REG0x13:ADC_OUT_B1   ADC Conversion Result [15:08]
#define NAU7802_ADC_B0     0x14         //REG0x14:ADC_OUT_B0   ADC Conversion Result [07:00]

#define NAU7802_ADC_REG    0x15         //REG0x15:ADC_REG      ADC Registers

#define NAU7802_OTP_B1     0x16         //REG0x16:OTP_B1       OTP[15:08]
#define NAU7802_OTP_B0     0x17         //REG0x17:OTP_B0       OTP[07:00]

#define NAU7802_RES_00     0x18         //REG0x18:RES_00       RESERVED
#define NAU7802_RES_01     0x19         //REG0x19:RES_01       RESERVED
#define NAU7802_RES_02     0x1A         //REG0x1A:RES_02       RESERVED

#define NAU7802_PGA_REG    0x1B         //REG0x1B:PGA_REG      Pre-Gain Amplifier
#define NAU7802_POW_CTRL   0x1C         //REG0x1C:POW_CTRL     Power Control

#define NAU7802_RES_03     0x1D         //REG0x16:RES_03      RESERVED
#define NAU7802_RES_04     0x1E         //REG0x1E:RES_04      RESERVED

#define NAU7802_REV_ID     0x1F         //REG0x1F:READ_ONLY  MFG test and RevisionID
```

```
//REG0x00:PU_CTRL     Powerup Control
#define NAU7802_AVDDS     7  //AVDD source select          1:Internal LDO        0:AVDD Pin Input              (0-Default)
#define NAU7802_OSCS      6  //System clock source select  1:External Crystal    0:Internal RC OScillator      (0-Default)
#define NAU7802_CR        5  //Cycle ready (Read Only)     1:ADC Data Ready      0:No ADC Data                 (0-Default)
#define NAU7802_CS        4  //Cycle start ADC             1:Start ADC           0:Stop ADC                    (0-Default)
#define NAU7802_PUR       3  //Power up ready (Read Only)  1:Power up, Ready     0:Power down, not ready       (0-Default)
#define NAU7802_PUA       2  //Power up analog circuit     1:Power up anlaog     0:Power down analog           (0-Default)
#define NAU7802_PUD       1  //Power up digital circuit    1:Power up digital    0:Power down digital          (0-Default)
#define NAU7802_RR        0  //Register Reset              1:Reset all save RR   0:Normal Operation            (0-Default)

//REG0x01:CTRL1       Control 1
#define NAU7802_CRP       7  //Conversion Ready Polarity   1:Active Low          0:Active high                 (0-Default)
#define NAU7802_DRDY_SEL  6  //DRDY pin fuction            1:Output clock        0:Output conv ready           (0-Default)

#define NAU7802_VLDO2     5  //Select LDO Voltage          1      1      1      1     0     0     0     0      (0-Default)
#define NAU7802_VLDO1     4  //Select LDO Voltage          1 2V4  1 2V7  0 3V0  0 3V3 1 3V6 1 3V9 0 4V2 0 4V5  (0-Default)
#define NAU7802_VLDO0     3  //Select LDO Voltage          1      0      1      0     1     0     1     0      (0-Default)

#define NAU7802_GAINS2    2  //Select gain                 1      1      1      1     0     0     0     0      (0-Default)
#define NAU7802_GAINS1    1  //Select gain                 1 128  1 x64  0 x32  0 x16 1 x8  1 x4  0 x2  0 x1   (0-Default)
#define NAU7802_GAINS0    0  //Select gain                 1      0      1      0     1     0     1     0      (0-Default)

//REG0x02:CTRL2       Control 2
#define NAU7802_CHS       7  //Analog input channel        1:Channel 2                0:Channel 1              (0-Default)

#define NAU7802_CRS2      6  //Converstion Rate samp/sec   1      1      1      1     0     0     0     0      (0-Default)
#define NAU7802_CRS1      5  //Converstion Rate samp/sec   1 320  1 N/A  0 N/A  0 N/A 1 80  1 40  0 20  0 10   (0-Default)
#define NAU7802_CRS0      4  //Converstion Rate samp/sec   1      0      1      0     1     0     1     0      (0-Default)

#define NAU7802_CAL_ERR   3  //Calibration Error           1:Calibration failed       0:No                     (0-Default)
#define NAU7802_CALS      2  //Start Calibration           1:Start calibration        0:Calibration finished   (0-Default)

#define NAU7802_CALMOD1   1  //Calibration Selection       1:Gain Cal  1:Offset Cal   0:RESERVED  0: Offset Cal (0-Default)
#define NAU7802_CALMOD0   0  //Calibration Selection       1:System    0:System       1:RESERVED  0: Internal   (0-Default)

//REG0x11:I2C_CTRL    I2C Control
#define NAU7802_CRSD      7  //Pull SDA low on conversion  1:Enalbe                   0:Diable                 (0-Default)
#define NAU7802_FRD       6  //Fast ADC DATA               1:Enalbe REQ REG0x15[7]:1  0:Disable                (0-Default)
#define NAU7802_SPE       5  //Enable strong pullup        1:Enalbe 1K6 pullup        0:Disable 1K6 pullup     (0-Default)
#define NAU7802_WPD       4  //Disable weak pullup         1:Disable 50K pullpup      0:Enable 50K pullup      (0-Default)
#define NAU7802_SI        3  //Short Inputs                1:Short Inputs             0:Inputs floating        (0-Default)
#define NAU7802_BOPGA     2  //PGA bunout current source   1:2.5uA Current to PGA+    0:Current disabled       (0-Default)
#define NAU7802_TS        1  //Temprature Sensor Select    1:Temprature to PGA        0:Temp disabled          (0-Default)
#define NAU7802_BGPCP     0  //Bandgap chopper             1:Disable                  0:Enable                 (0-Default)

class NAU7802 {
 public:
  NAU7802();

  #ifdef NAU7802_DEFAULT_WIRE
  boolean begin(uint8_t addr = NAU7802_I2CADDR);
  #endif //NAU7802_DEFAULT_WIRE

  #ifdef NAU7802_SOFTWARE_WIRE
  boolean begin(uint8_t sda, uint8_t scl, uint8_t addr = NAU7802_I2CADDR);
  #endif //NAU7802_SOFTWARE_WIRE

  #ifdef NAU7802_ESP8266_WIRE
  boolean begin(uint8_t sda, uint8_t scl, uint8_t addr = NAU7802_I2CADDR);
  #endif //NAU7802_ESP8266_WIRE
```

```
  long readADC();
  float readmV();

  void selectCh1();
  void selectCh2();
  void selectTemp();

  void rate010sps();
  void rate020sps();
  void rate040sps();
  void rate080sps();
  void rate320sps();

  void pga128x();
  void pga64x();
  void pga32x();
  void pga16x();
  void pga8x();
  void pga4x();
  void pga2x();
  void pga1x();
  void pgaDisable();

  void extAvcc(float extAvcc);
  void avcc2V4();
  void avcc2V7();
  void avcc3V0();
  void avcc3V3();
  void avcc3V6();
  void avcc3V9();
  void avcc4V2();
  void avcc4V5();

private:
 #ifdef NAU7802_DEFAULT_WIRE
 TwoWire wire = TwoWire();
 #endif //NAU7802_DEFAULT_WIRE

 #ifdef NAU7802_SOFTWARE_WIRE
 SoftwareWire wire = SoftwareWire(2,3);
 #endif //NAU7802_SOFTWARE_WIRE

 #ifdef NAU7802_ESP8266_WIRE
 TwoWire wire = TwoWire();
 #endif //NAU7802_ESP8266_WIRE

 uint8_t _i2caddr;
 float _avcc = 3.3;

 void resetSettings();

 void write(uint8_t reg, uint8_t val);
 void writeBit(uint8_t reg, uint8_t bit);
 void clearBit(uint8_t reg, uint8_t bit);


 uint8_t  read(uint8_t reg);
 uint32_t read24(uint8_t reg);
 uint32_t read32(uint8_t reg);
 boolean  readBit(uint8_t reg, uint8_t bit);
```

```
183
    void  readUntilTrue(uint8_t reg, uint8_t bit);
185   void  readUntilFalse(uint8_t reg, uint8_t bit);
};
187
#endif //__NAU7802_H__
```

Listing 1.3: "NAU7802.h"

```
//Readout for nau7802
2 #include "NAU7802.h"

4 //Instantiates a new NAU7802 class
//====================================
6 NAU7802::NAU7802() {
}
8
// Setups the HW
10 //====================
#ifdef NAU7802_DEFAULT_WIRE
12 boolean NAU7802::begin(uint8_t addr) {
    _i2caddr = addr;
14  wire = TwoWire();
    wire.begin();
16  resetSettings();
    return true;
18 }
#endif //NAU7802_DEFAULT_WIRE
20
#ifdef NAU7802_SOFTWARE_WIRE
22 boolean NAU7802::begin(uint8_t sda, uint8_t scl, uint8_t addr) {
    _i2caddr = addr;
24  wire = SoftwareWire(sda,scl);
    wire.begin();
26  resetSettings();
    return true;
28 }
#endif //NAU7802_SOFTWARE_WIRE
30
#ifdef NAU7802_ESP8266_WIRE
32 boolean NAU7802::begin(uint8_t sda, uint8_t scl, uint8_t addr) {
    _i2caddr = addr;
34  wire = TwoWire();
    wire.begin(sda,scl);
36  resetSettings();
    return true;
38 }
#endif //NAU7802_ESP8266_WIRE
40
void NAU7802::resetSettings(){
42  writeBit(NAU7802_PU_CTRL, NAU7802_RR);          //Reset Registers
    clearBit(NAU7802_PU_CTRL, NAU7802_RR);          //Clear Reset Registers
44  writeBit(NAU7802_PU_CTRL, NAU7802_PUD);         //Power up digital
    readUntilTrue(NAU7802_PU_CTRL, NAU7802_PUR);    //Wait until power up
46  writeBit(NAU7802_PU_CTRL, NAU7802_PUA);         //Power up analog

48  writeBit(NAU7802_ADC_REG, 4);                   //Diasble chopper funcition
    writeBit(NAU7802_ADC_REG, 5);                   //Diasble chopper funcition
50
```

```
  writeBit(NAU7802_PGA_REG, 0);                   //Diasble chopper funcition
  writeBit(NAU7802_PGA_REG, 4);                   //Bypass PGA

  writeBit(NAU7802_CTRL2, NAU7802_CALS);          //Begin calibration
  readUntilFalse(NAU7802_CTRL2, NAU7802_CALS);    //Wait for calibration to finish

  writeBit(NAU7802_I2C_CTRL, NAU7802_SPE);        //Enable Strong Pullup

  writeBit(NAU7802_PU_CTRL,   NAU7802_CS);        //Start Conversion
}

//Reads set channel
//=========================
long NAU7802::readADC(){
  readUntilTrue(NAU7802_PU_CTRL,NAU7802_CR);
  uint32_t adcVal = read24(NAU7802_ADC_B2);
  writeBit(NAU7802_PU_CTRL, NAU7802_CS);
  if(adcVal & 0x00800000){
    adcVal = ~adcVal+1;
    adcVal = -1*(adcVal & 0x00FFFFFF);
  }
  return adcVal;
}

float NAU7802::readmV(){
  return (_avcc/(float)16777216)*(float)readADC();
}

//Select channel
//=============
void NAU7802::selectCh1(){
  clearBit(NAU7802_CTRL2, 7);
}
void NAU7802::selectCh2(){
  writeBit(NAU7802_CTRL2, 7);
}
void NAU7802::selectTemp(){
}

//Set Sampling rate
//=================
void NAU7802::rate010sps(){
  clearBit(NAU7802_CTRL2, 4);
  clearBit(NAU7802_CTRL2, 5);
  clearBit(NAU7802_CTRL2, 6);
}
void NAU7802::rate020sps(){
  clearBit(NAU7802_CTRL2, 4);
  clearBit(NAU7802_CTRL2, 5);
  writeBit(NAU7802_CTRL2, 6);
}
void NAU7802::rate040sps(){
  clearBit(NAU7802_CTRL2, 4);
  writeBit(NAU7802_CTRL2, 5);
  clearBit(NAU7802_CTRL2, 6);
}
void NAU7802::rate080sps(){
  clearBit(NAU7802_CTRL2, 4);
  writeBit(NAU7802_CTRL2, 5);
  writeBit(NAU7802_CTRL2, 6);
}
```

```
112 void NAU7802::rate320sps(){
      writeBit(NAU7802_CTRL2, 4);
114   writeBit(NAU7802_CTRL2, 5);
      writeBit(NAU7802_CTRL2, 6);
116 }

118 //Set Pre-Gain Amplifier
    //======================
120 void NAU7802::pga128x(){
    }
122 void NAU7802::pga64x(){
    }
124 void NAU7802::pga32x(){
    }
126 void NAU7802::pga16x(){
    }
128 void NAU7802::pga8x(){
    }
130 void NAU7802::pga4x(){
    }
132 void NAU7802::pga2x(){
    }
134 void NAU7802::pga1x(){
    }
136 void NAU7802::pgaDisable(){
    }
138
    //Set AVCC, Internal LDO
140 //======================
    void NAU7802::extAvcc(float extAvcc){
142   clearBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Disable LDO
      _avcc=extAvcc;
144 }
    void NAU7802::avcc2V4(){
146   writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
      writeBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 2.4V
148   writeBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 2.4V
      writeBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 2.4V
150   _avcc=2.4;                                   //Local AVCC variable
    }
152 void NAU7802::avcc2V7(){
      writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
154   writeBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 2.7V
      writeBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 2.7V
156   clearBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 2.7V
      _avcc=2.7;                                   //Local AVCC variable
158 }
    void NAU7802::avcc3V0(){
160   writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
      writeBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 3.0V
162   clearBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 3.0V
      writeBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 3.0V
164   _avcc=3.0;                                   //Local AVCC variable
    }
166 void NAU7802::avcc3V3(){
      writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
168   writeBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 3.3V
      clearBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 3.3V
170   clearBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 3.3V
      _avcc=3.3;                                   //Local AVCC variable
172 }
```

```
void NAU7802::avcc3V6(){
  writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
  clearBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 3.6V
  writeBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 3.6V
  writeBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 3.6V
  _avcc=3.6;                                   //Local AVCC variable
}
void NAU7802::avcc3V9(){
  writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
  clearBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 3.9V
  writeBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 3.9V
  clearBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 3.9V
  _avcc=3.9;                                   //Local AVCC variable
}
void NAU7802::avcc4V2(){
  writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
  clearBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 4.2V
  clearBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 4.2V
  writeBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 4.2V
  _avcc=4.2;                                   //Local AVCC variable
}
void NAU7802::avcc4V5(){
  writeBit(NAU7802_PU_CTRL, NAU7802_AVDDS);    //Enable LDO
  clearBit(NAU7802_CTRL1, NAU7802_VLDO2);      //Set AVCC to 4.5V
  clearBit(NAU7802_CTRL1, NAU7802_VLDO1);      //Set AVCC to 4.5V
  clearBit(NAU7802_CTRL1, NAU7802_VLDO0);      //Set AVCC to 4.5V
  _avcc=4.5;                                   //Local AVCC variable
}

//Low level read and write procedures
//==================================

void NAU7802::write(uint8_t reg, uint8_t val) {
  wire.beginTransmission(_i2caddr);
  wire.write((uint8_t)reg);
  wire.write(val);
  wire.endTransmission();
}

void NAU7802::writeBit(uint8_t reg, uint8_t bit) {
  uint8_t val = read(reg) | (1<<bit);
  write(reg, val);
}

void NAU7802::clearBit(uint8_t reg, uint8_t bit) {
  uint8_t val = read(reg) & ~(1<<bit);
  write(reg, val);
}

uint8_t NAU7802::read(uint8_t reg) {
  wire.beginTransmission(_i2caddr);
  wire.write((uint8_t)reg);
  wire.endTransmission();

  wire.requestFrom((uint8_t)_i2caddr, (uint8_t)1);
  return wire.read();
}

boolean NAU7802::readBit(uint8_t reg, uint8_t bit){
  //create bitmask
  uint8_t bitmask = 1<<bit;
```

```
234   if(read(reg) & bitmask){
        return true;
236   }
      return false;
238 }

240 uint32_t NAU7802::read24(uint8_t reg) {
      uint32_t val;
242
      wire.beginTransmission(_i2caddr);
244   wire.write((uint8_t)reg);
      wire.endTransmission();
246
      wire.requestFrom((uint8_t)_i2caddr, (uint8_t)3);
248   val = wire.read();     // receive high byte
      val <<= 8;             // shift byte to make room for new byte
250   val |= wire.read();    // receive mid byte
      val <<= 8;             // shift both bytes
252   val |= wire.read();    // receive low byte
      return val;
254 }

256 uint32_t NAU7802::read32(uint8_t reg) {
      uint32_t val;
258
      wire.beginTransmission(_i2caddr);
260   wire.write((uint8_t)reg);
      wire.endTransmission();
262
      wire.requestFrom((uint8_t)_i2caddr, (uint8_t)4);
264   val = wire.read();     // receive [31:24] byte
      val <<= 8;             // shift byte
266   val = wire.read();     // receive [23:16] byte
      val <<= 8;             // shift bytes
268   val |= wire.read();    // receive [15:08] byte
      val <<= 8;             // shift bytes
270   val |= wire.read();    // receive [07:00] byte
      return val;
272 }

274 void NAU7802::readUntilTrue(uint8_t reg, uint8_t bit) {
      //create bitmask
276   uint8_t bitmask = 1<<bit;
      bool readUntil = false;
278   //Just keep reading until bit requested is true
      while(readUntil == false){
280     if(read(reg) & bitmask){
          readUntil=true;
282     }
      }
284 }

286 void NAU7802::readUntilFalse(uint8_t reg, uint8_t bit) {
      //create bitmask
288   uint8_t bitmask = 1<<bit;
      bool readUntil = false;
290   //Just keep reading until bit requested is false
      while(readUntil == false){
292     if(~read(reg) & bitmask){
          readUntil=true;
294     }
```

```
296     }
}
```

Listing 1.4: "Nau7802.cpp"

1.4 MPPC Interface

A single assembled board breaks out singals and provides all the interfaces that 4 MPPC Sesnor boards need. The power to each module is supplied via the MPPC high voltage modules attached board. It is able to be run independently for testing and debugging, or on a backplane with many others for more channels.

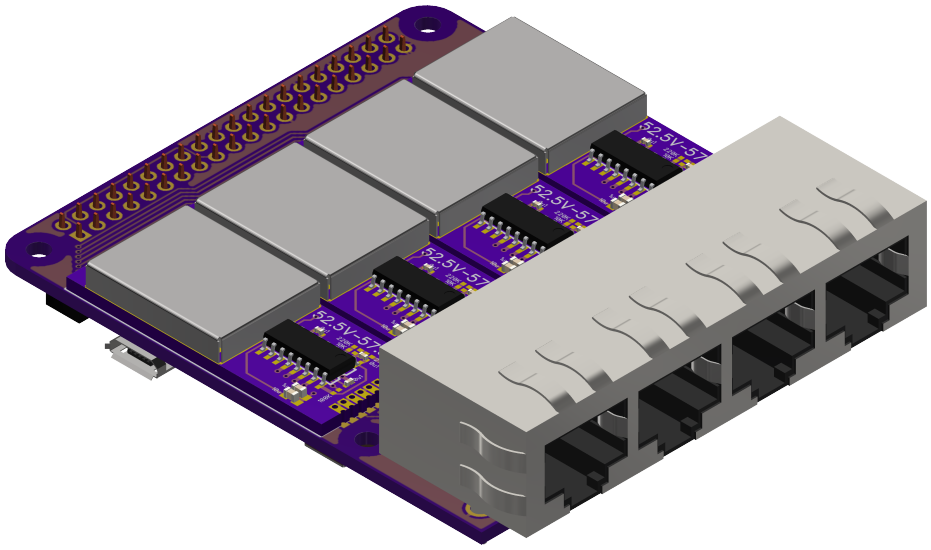


Figure 1.14: Top view of assembled MPPC interface board.

1.4.1 Hardware

The board attaches directly to a Raspberry Pi using the centered GPIO headers. The Raspberry Pi is mounted to the board via four standoffs. It is a stand alone board requiring no backplane. This board can be mounted via the M5 screw holes around the edge.

Power

Power is supplied through two pins on the edge connector, or via the micro USB port on board. There is a 600mA buck regulator that provides power when the USB port is used. The board should be powered by 3.3V and a negative power supply module with convert it to -3.3V for the biasing for the op-amps.

High Voltage

High voltage is supplied through a daughter board. Each channel has a independent voltage source that can be temperature modulated and monitored via the on board ADC. Further information about the modules can be found in Section.

Microcontroller

The side of the board has a Arduino compatible (ATmega328) microcontroller, along with a USB part, USB to UART converter and other supporting circuitry. The button is connected to the reset pin. The programing port on board is a Tag-Connect 6 pin, and is only used for programing the Arduino bootloader.

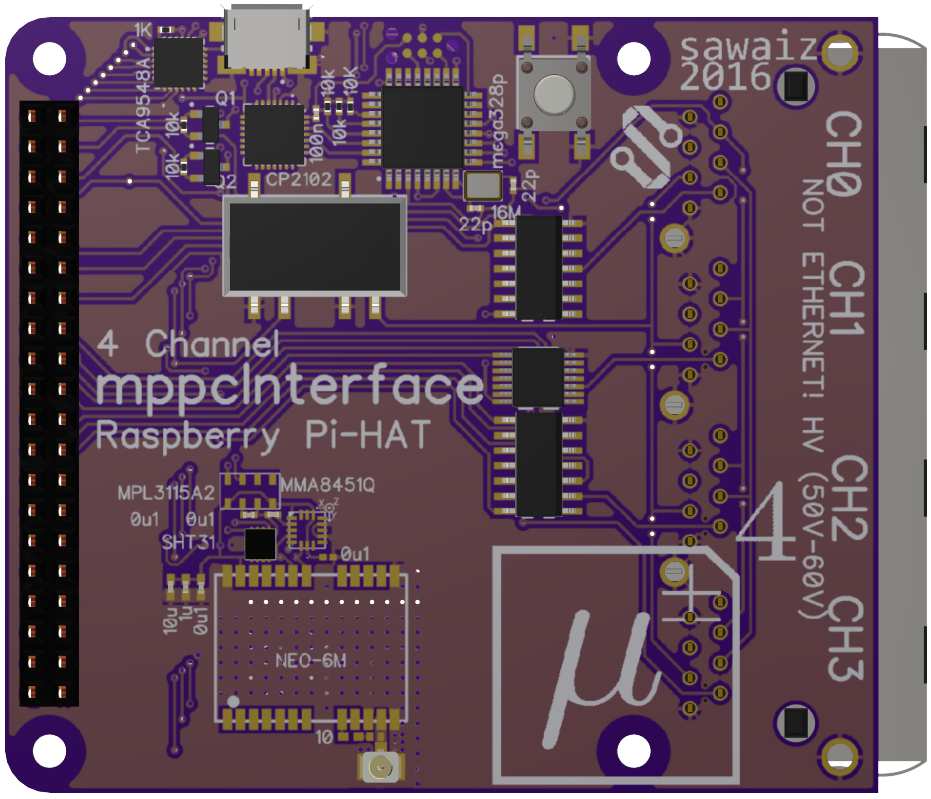


Figure 1.15: Bottom of populated board showing sensors and AVR.

I2C Switch

As all the ADC modules on the daughter boards have the same address, a 8 channel I2C switch ([TCA9548A](http://www.ti.com/lit/ds/symlink/tca9548a.pdf)) is used to communicate to them independently. The pins attached to it are referenced as master, as the microcontroller is acting as the master controlling it.

Pinout

There are eight RJ-45 jacks on the edge of the board, each jack has the following pinout. The signal lines are kept on a single twisted pair so if a differential signal is used, higher signal integrity is maintained. The pinout matches that of the MPPC sensor board.

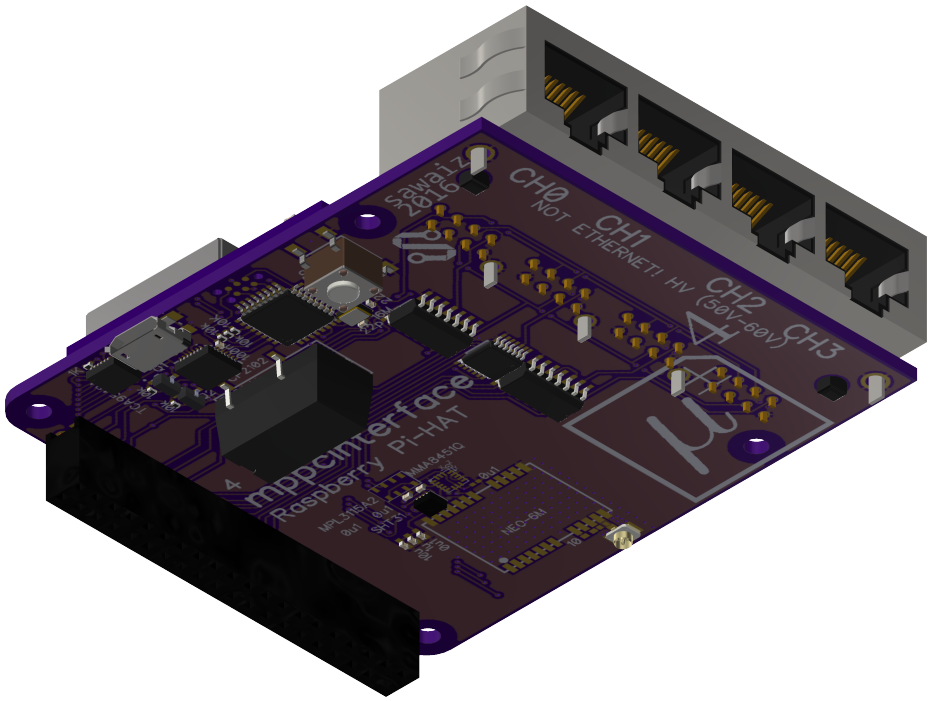


Figure 1.16: Isometric view of bottom.

1.4.2 Software

The device acts as both a master and slave device. It takes instructions from an external I2C bus, and executes them on the AVR microcontroller to set voltages, provide telemetry, and preform closed loop control.

AVR Firmware

The microcontroller on board takes commands sent to the whole module, and forwards them to each daughterboard. It primary control loop involves reading the temperature, finding the associated required bias voltage based on the temperature and setting the voltage on the high voltage supply, then checking if the output voltage is within specification of the required output, and fixing it if not. This loops for all eight channels. Otherwise there is an instruction queue of commands that come into the module.

Module

The master can communicate to up to 128 slave devices the address is set within software. The master can request the temperature, or current voltage of any of the eight channels on board, select between different voltage to temperature curves, and set the bias voltage, or pulse the LED on the modules.

1.5 Frame

The frame is constructed out of 4 m of Misumi 2020 aluminium extrution, cast angle brackets, t-nuts, M5 screws, and rubber feet. The assembly process requires only a 4 mm hex key.

1.5.1 Construction

The frame is designed to be easy to assembly, take apart, and modify for diffrent experiments and highly rugged. It is constructed out of metric aluminium extrution and cast aluminium angle brackets, with rubber feet at the bottom. A full bill of materials is shown in Table 1.7. The panels it is meant to hold fit within the 20 mm extrution hegight, and the remining area is filled ithe a soft tubing spring. The panels are supourted on both sides by $^{3}/_{32}$ inch acrylic sheet and a addtion panel provides a mounting location for the electronics. The assembly process requires only a 4 mm hex key, and can be made vibration resistant through the application of threadlocker (blue color code).

Bill of Materials

Description	**Item**	**Supplier**	**QTY**	**Unit**	**Ext**
Aluminium Extrustion	`KHFS5-2020-1000`	Misumi	4	6.41	25.64
Angle Brackets	`HBLFSNF5`	Misumi	64	0.63	40.32
M5 T-Nuts	`HNKK5-5`	Misumi	$^{156}/_{100}$	15.26	23.81
M5x6	`91292a189`	McMaster-Carr	$^{28}/_{50}$	4.63	2.59
M5x10	`91292A124`	McMaster-Carr	$^{128}/_{100}$	8.15	11.20
M5x25	`91292a129`	McMaster-Carr	$^{4}/_{25}$	6.85	1.10
Acrylic Sheet	`8560k182`	McMaster-Carr	$^{7}/_{6}$	8.96	10.45
Rubber Feet	`9540K717`	McMaster-Carr	$^{4}/_{25}$	7.42	1.19
Labor			2	30.00	60.00
				Subtotal	XXX.XX
				Tax	%8.000
				Transport	%XX.XX
				Total (USD)	189.24

Table 1.7: Materials required for one frame.

Aluminum Extrustion Cut List

Description	**QTY**	**Length (mm)**	**Note**
Vertical Beam	4	396	M5 thread tapped one end 20 mm deep
Horizontal Beam	16	150	

Table 1.8: One vertical and four horizontal to be cut from each 1 m section. 1 mm kerf.

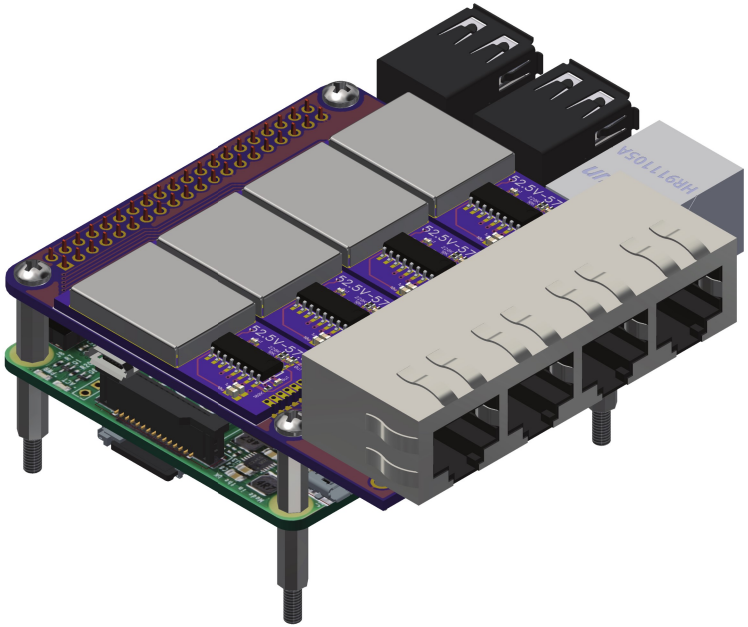
Assembly

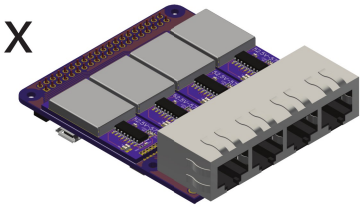
Insert assembly PDF output form Illistrator

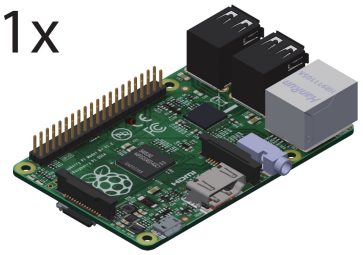
Chapter 2

Assembly

Four Channel MPPC Interface



1x 

1x 

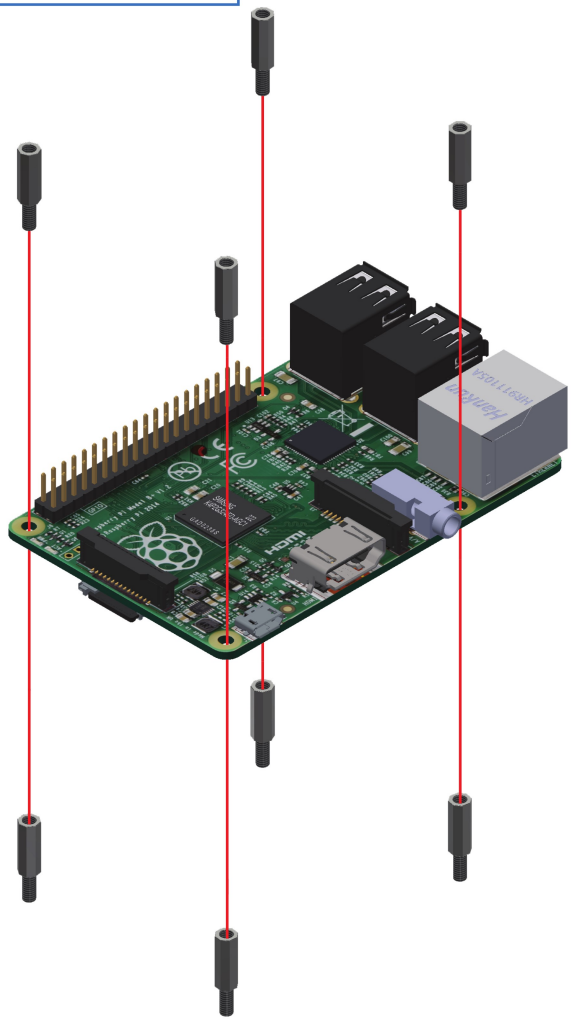
8x M2.5x11mm Standoff 

4x M2.5x6mm Pan Screw 

1x Raspberry Pi Model B+ 

8x M2.5x11mm Standoff 

1



Flash OS on SD card

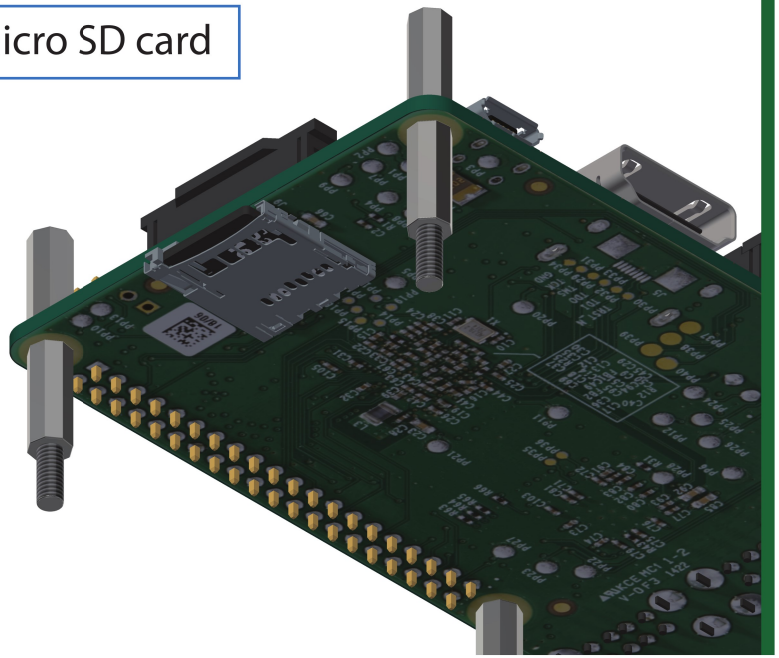
2

https://downloads.raspberrypi.org/raspbian_lite_latest

```
> df -h
Filesystem      Size  Used Avail Use% Mounted on
/dev/sda1       112G  107G  4.5G  97% /
/dev/sdb1       120G  2.4G  118G   2% /dev/sdx1
> sudo umount /dev/sdx
> sudo dd bs=4M if=<imagePath.img> of=</dev/sdx>
```

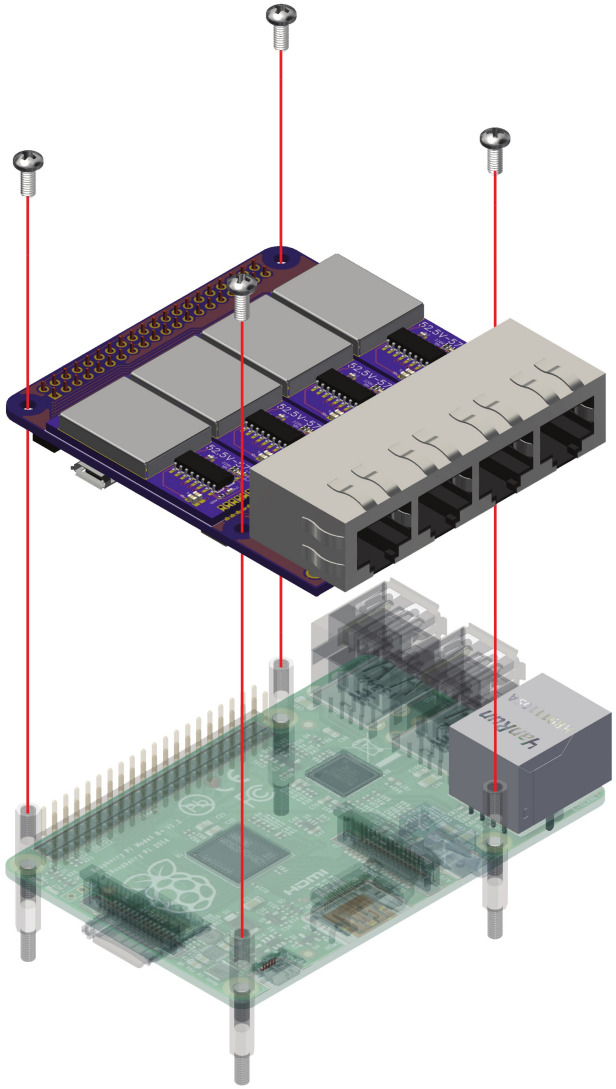
Insert micro SD card

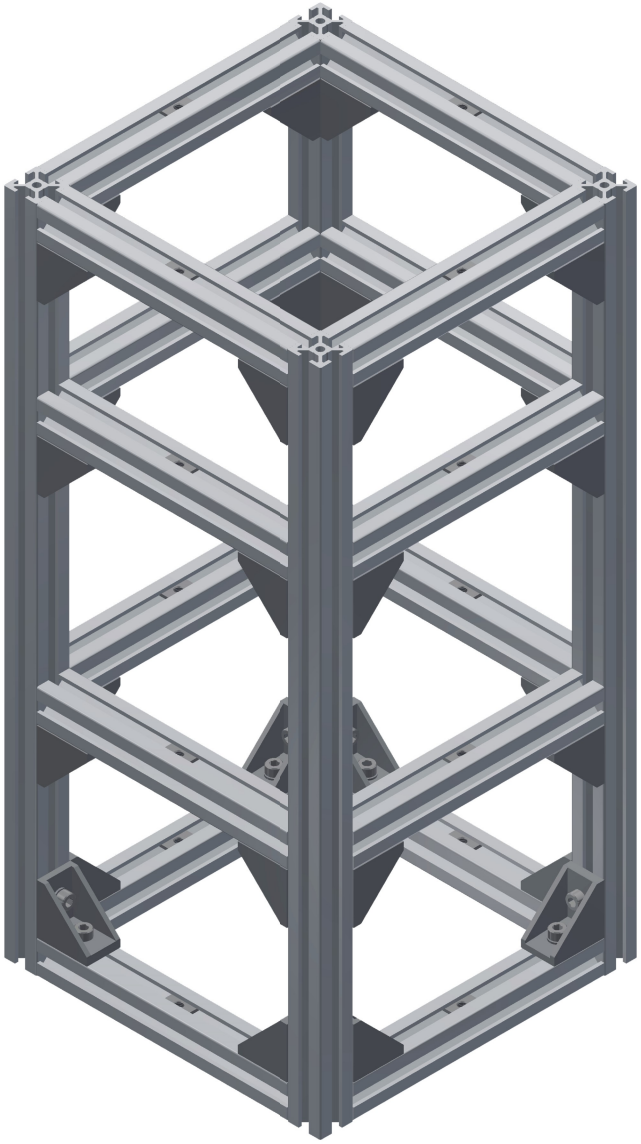
3



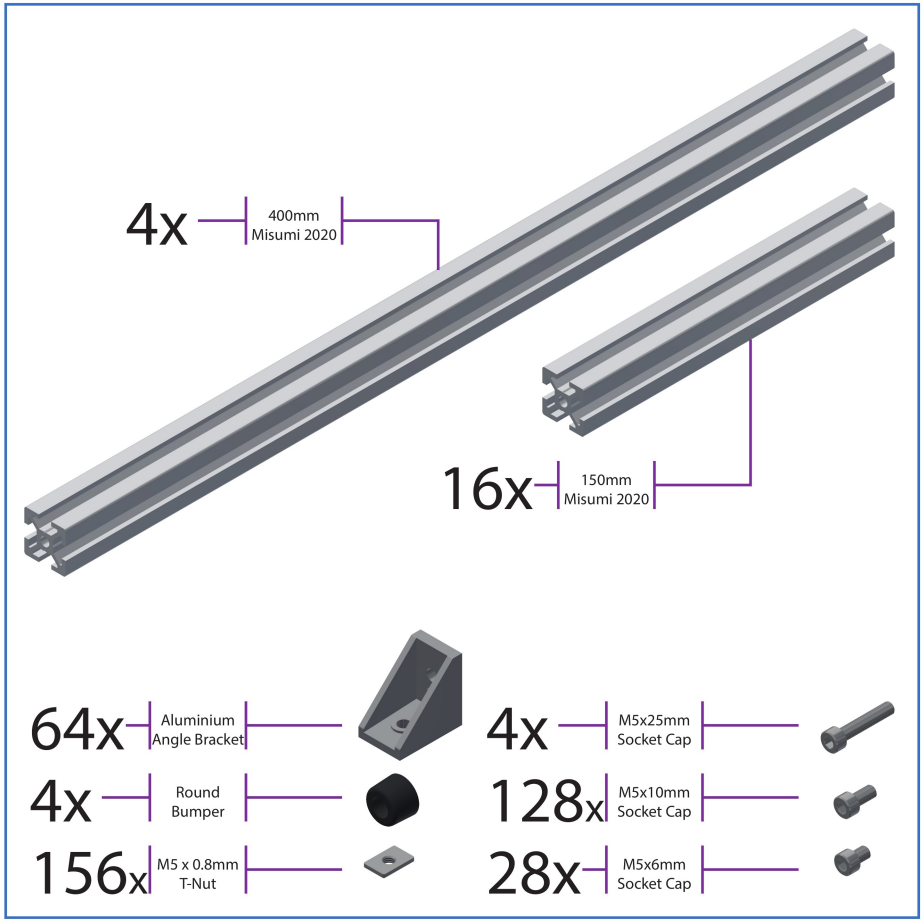
4x M2.5x6mm Pan Screw

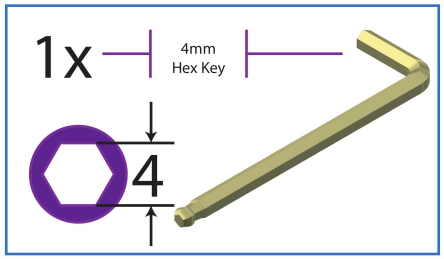
4





Muon Telescope Frame



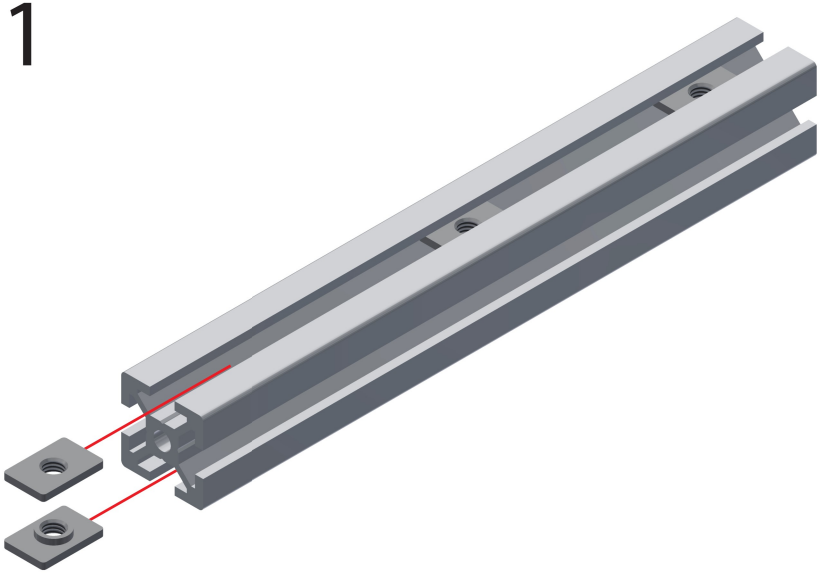


16x

1x 150mm Misumi 2020

4x M5 x 0.8mm T-Nut

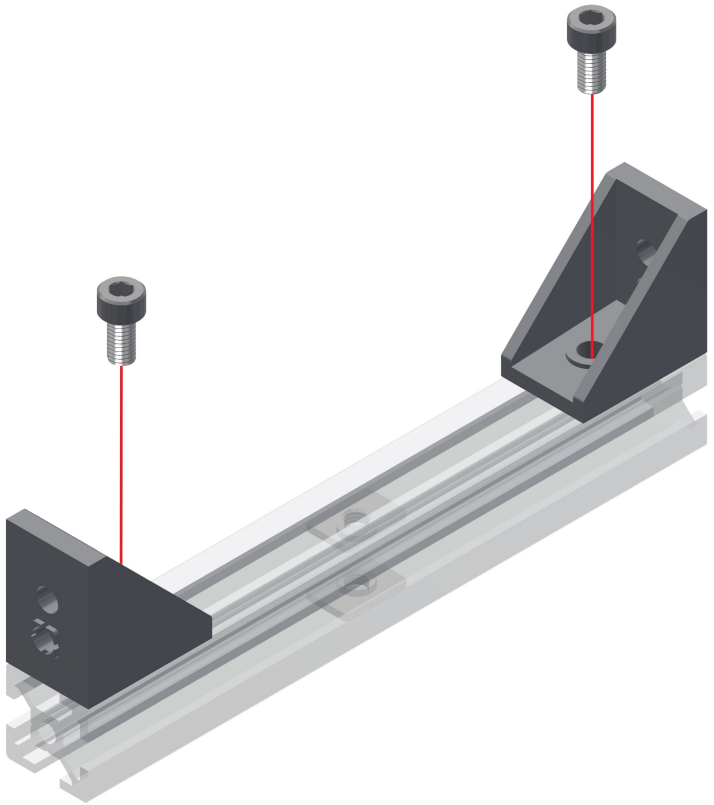
1



2x Aluminium Angle Bracket

2x M5x10mm Socket Cap

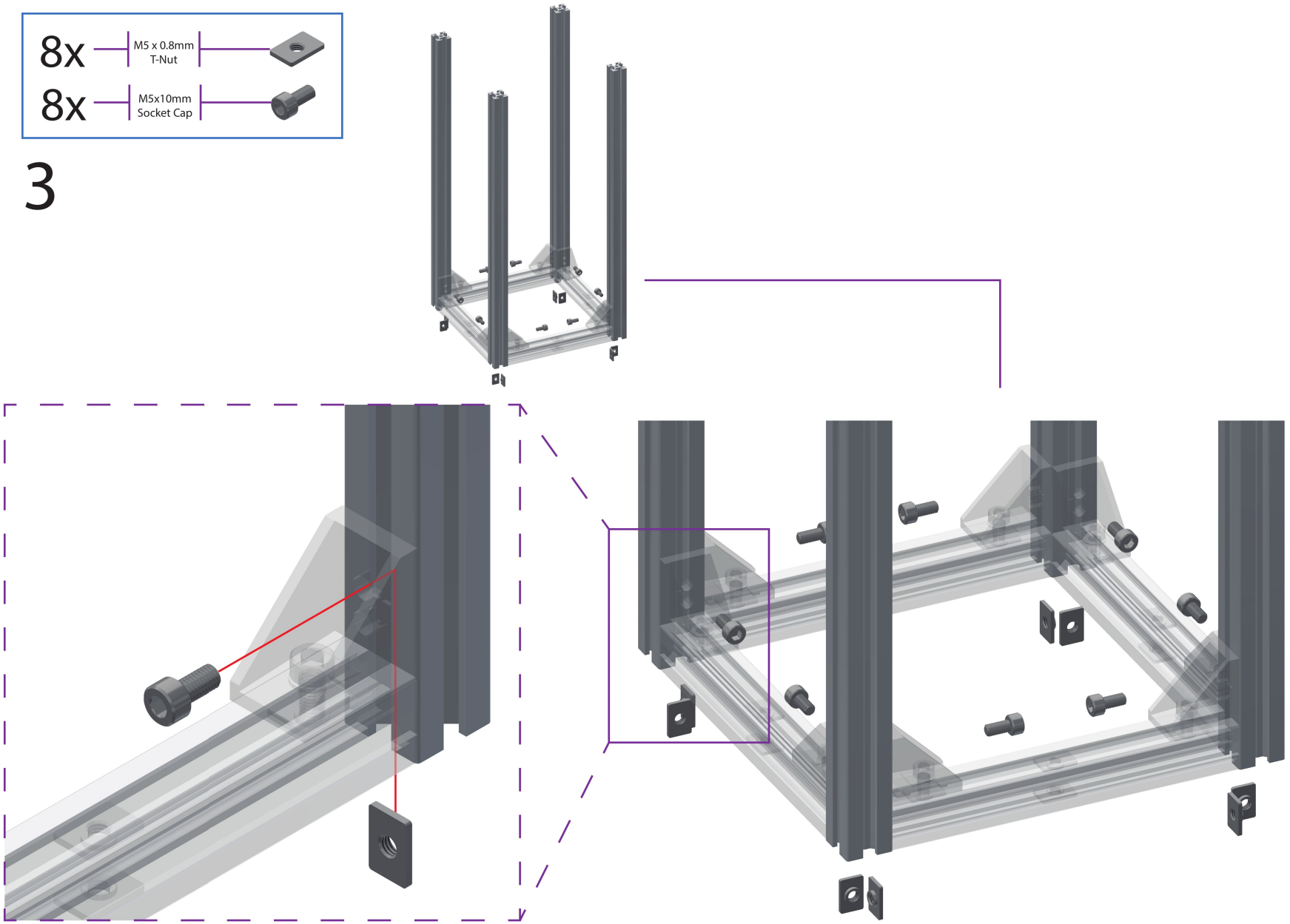
2



8x M5 x 0.8mm T-Nut

8x M5x10mm Socket Cap

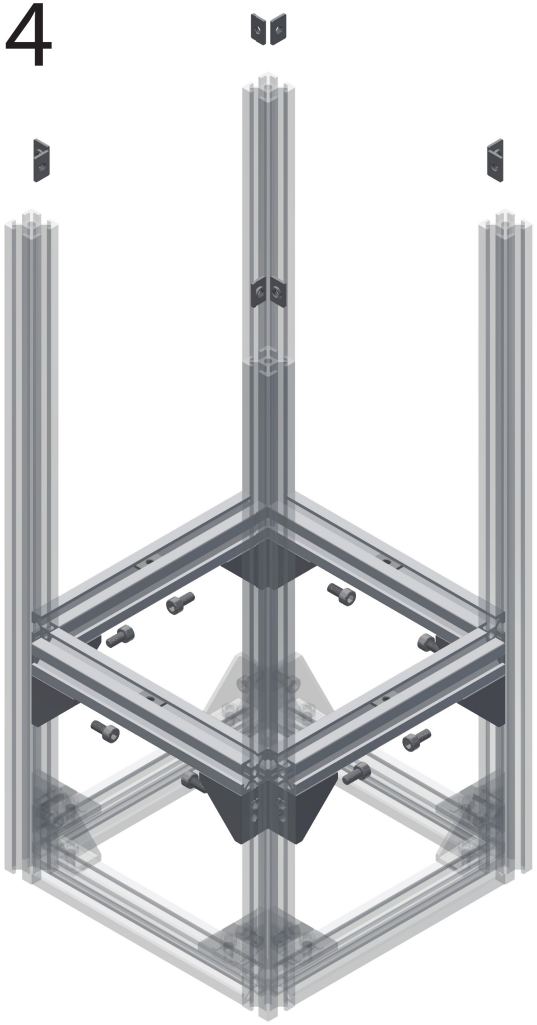
3



8x M5 x 0.8mm T-Nut

8x M5x10mm Socket Cap

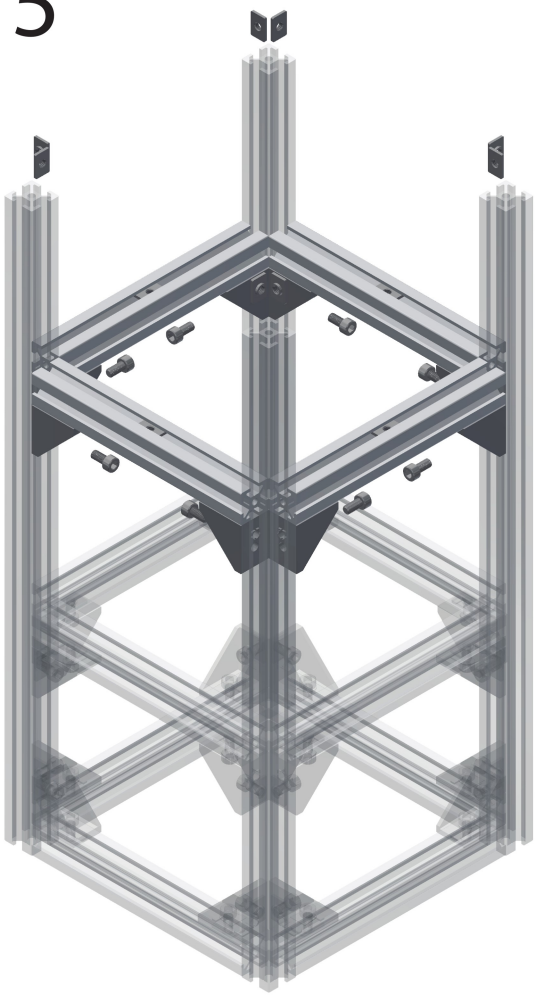
4



8x M5 x 0.8mm T-Nut

8x M5x10mm Socket Cap

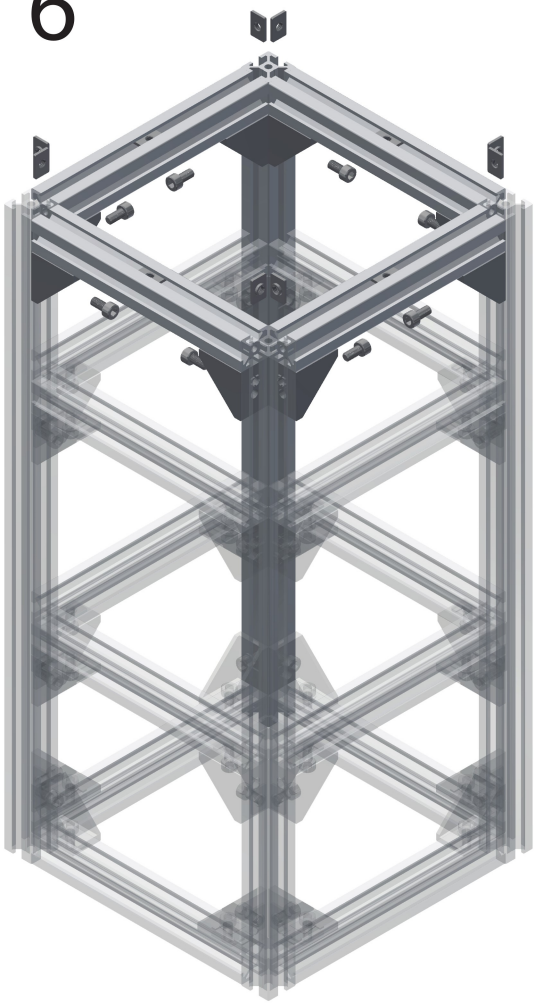
5



8x M5 x 0.8mm T-Nut

8x M5x10mm Socket Cap

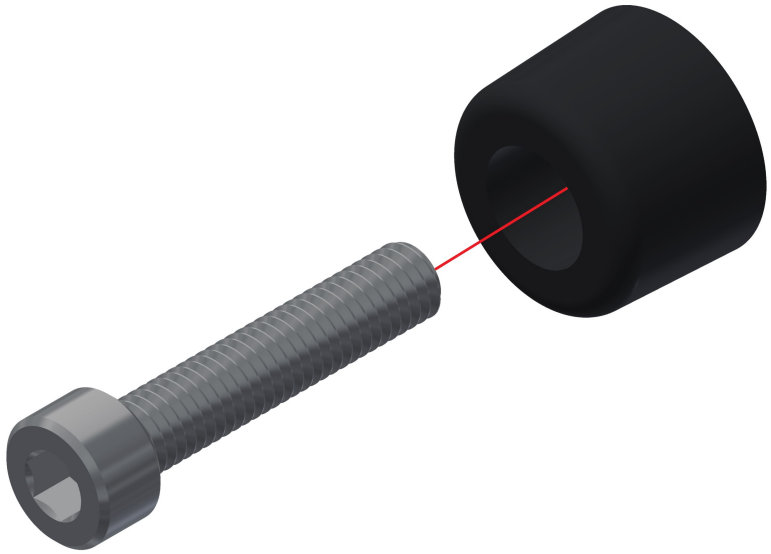
6

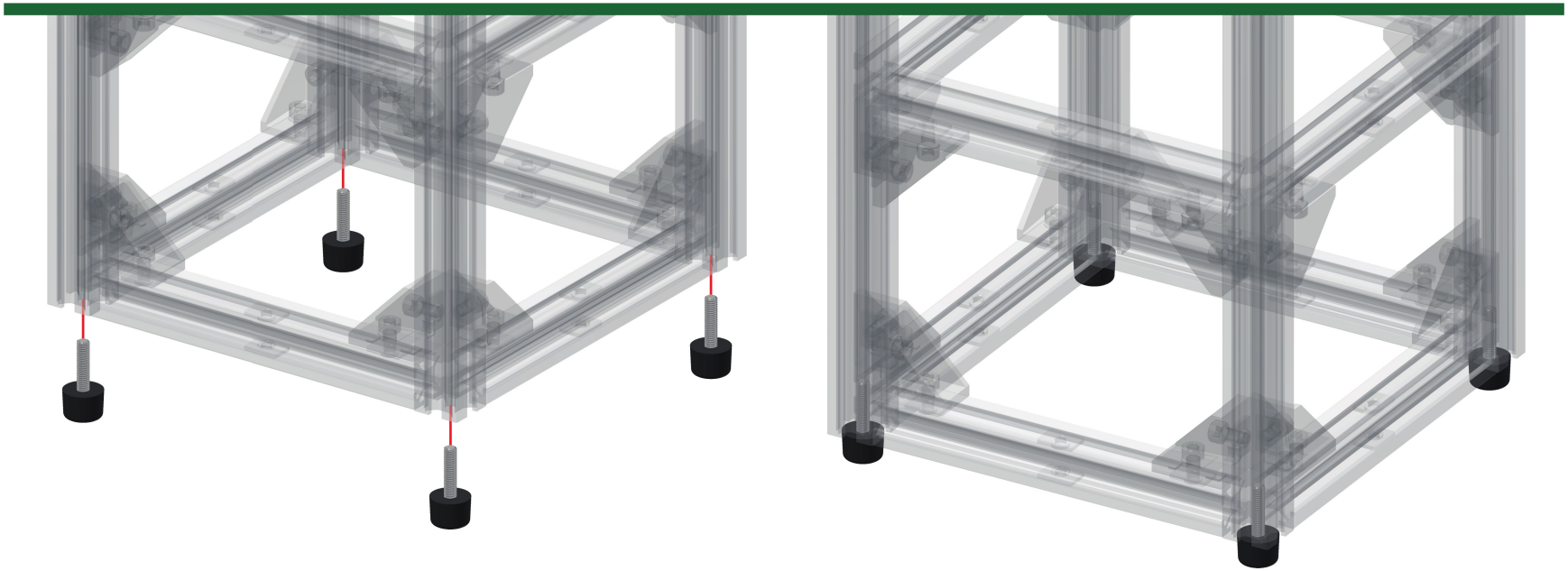


4x Round Bumper

4x M5x25mm Socket Cap

7





Chapter 3

Software

3.1 Structure

3.1.1 Technologies

The application is built on many modren web technologies. This allows the applicaiton to be easily scaleable, modular, and deplyable. The following sections list the technologies and how they are used.

Docker

Docker is a linux containerization platform. By created virtual containers that share the same underlying kernel, docker is able to provide an internal routing network as well as seperation and modularity of modules designed. Docker is also being used for deployment, instead of requiring the user to install multiple packages and configure them, or doing so though a makefile designed for the distro installation, we are able to target just the processor arcetecture, meaning installing docker on either a ARM or x86 processor is the only requirement. The containers are configured to install debian and then only the software required for the execution of that module, this allows debugging and testing of single modules, and removal of modules not needed for an application.

Node.js

Node.js is a Javascript runtime built on Chrome's V8 engine. It us used for back-end processing and is the server-side languge we use. Its event driven asyncronous model allows serving multiple requests without blocking. It is also highly extensible via NPM (Node Package Manager) which provides many modules to speed up workflow. Some of the modules we use as well as thier funcitons are shown below.

- *Express* - Web server for hosting dynamic content. Backbone of our REST API.

- *Sequelize* - MySql interface that allows direct queries.
- *RaspIO* - Input-output capabilities for the Raspberry Pi.

We also have many custom built modules such as those for communicating with the GPS module and other hardware that is specific to our design.

MySQL

MySQL is a open source relational database that is used to store and acsess data produced by the detectors. MySQL provides a convient command line interface and allows database replicaiton for .The database scheema an structure is described in its own section.

Polymer

Polymer is a library designed to make using web-components introducted and accepted in the latest web standards easy to use and implement. Web componets allow html imports allowing web front-ends to be built modularly. It also includes a library of web componets that follow Google's material design guidleines preseinting a consistant style. With HTML imports, the HTML of the page is able to only fetch what it needs, and speeds up page loading. It also allows easy reuse of sections designed. Polymer also includes a data-binding system allowing communication between providied and custom built modules.

NGINX

NGINX is a high preformance low recource web server. It is being used to not only serve the static content, but also to proxy-pass the requests for dynamic content and load balalcne them between the intacnes running in other containers.

Firebase

Firebase provides a full backend server management interface as well as hosting, database, and other tools. We wil be primarily using it for its user authentication. It intergrates easily into polymer, and can provide security tokens to users.

Slack

Slack is a business focused highly intergrateable instant messaging platform designed to replace fragmented email communication. We will be using it for sending the state of the machine and getting its ip address, location and other onformation on boot.

3.1.2 Architecture

The architecture is designed in a manner to maximise the utility of all the modules and compnents created. Becasue of this the archetecture varies depending on if it is a server, a client, or takes both roles.

3.1.3 Operation

Building and running the system is fairly simple and requires a single command to bring all the docker containers up.

```
cd cosmicNetwork
sudo docker-compose up --file arm.dockercompose.yml --build
```

3.2 Custom Packages

Several custom node.js packages need to be created to interface with the hardware. These are kept seperately and added via npm dependencies. They are written in javascript and designed to work with the raspberry pi.

- *Coincidence* - Counts number of interupts per given time period. This is used to read both the single channel and coincidence counts.
- *NXP MPL3115A2* - Pressure and temprature sensor.
- *Sensirion SHT3x* - Temprature and humididty sensor.
- *MPPC Interface* - Sends and recives voltage, temprature, target voltage and test led data.
- *uBLOX NEO6M* - GPS module with dead reckoning.

3.3 Development Tools

The minimalist software pacakage possible are commands that can print out raw data to the terminal. The dev-tools codebase does just that. The readme for that coves how to use it.