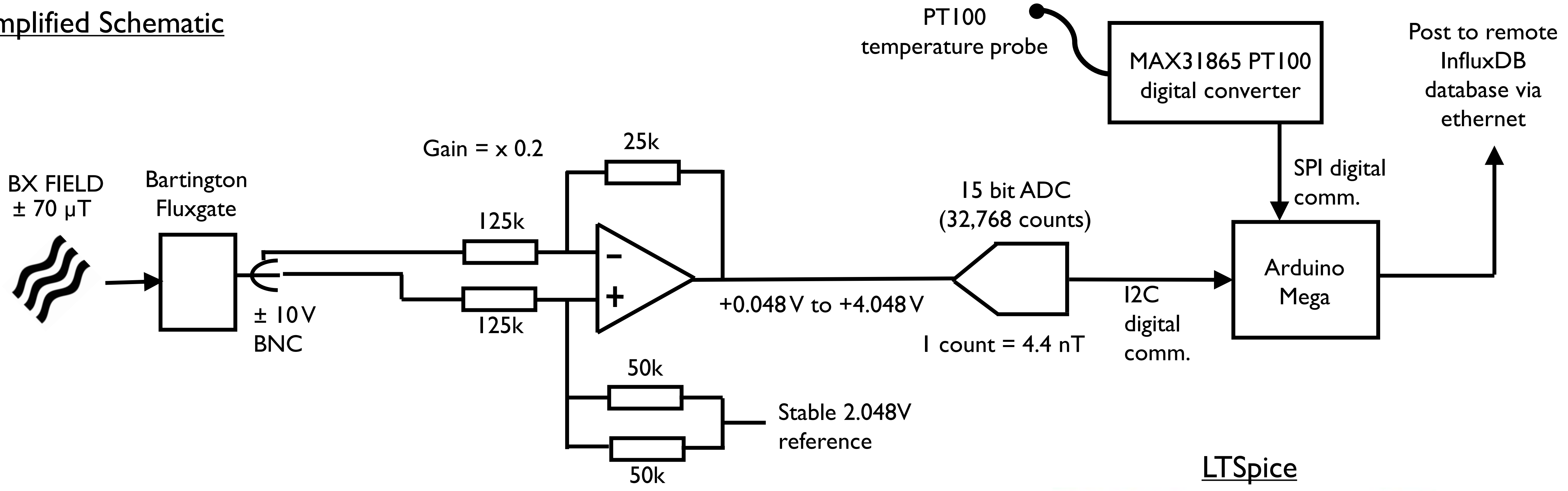
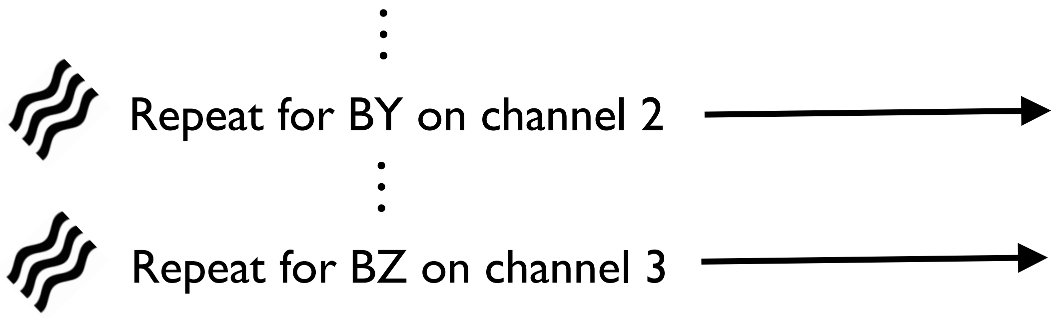
Environment Logger Summary, Tests, and Calibration

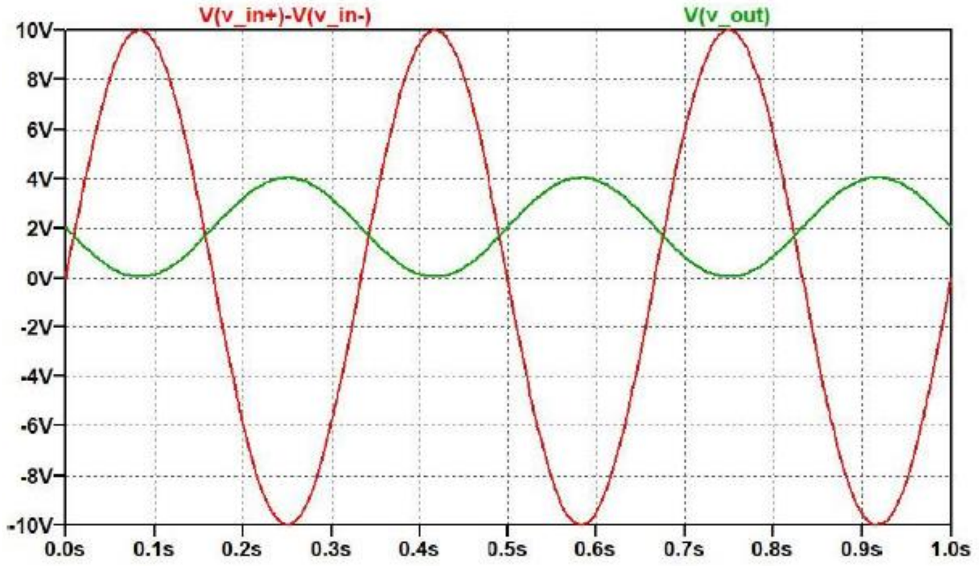
T. Barrett

Simplified Schematic





LTSpice

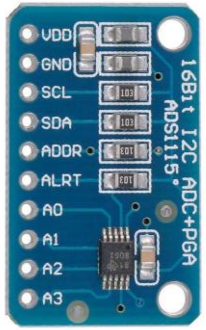


Microcontroller Pins Required

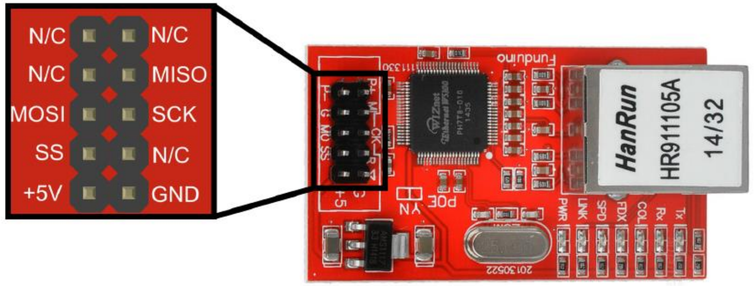
ADS1115 (4 channel ADC)

2-wire I2C

- SCL (serial clock)
- SDA (serial data)
- VDD (+5V)
- GND



Mini W5100 (LAN chip)



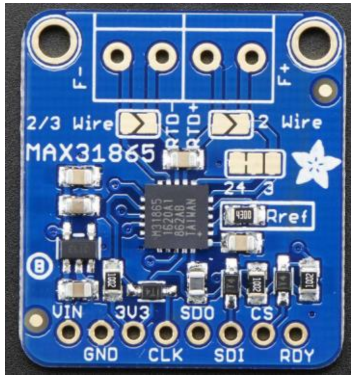
SPI

- CLK
- MISO
- MOSI
- CS (use pin 10, because it's defined in Arduino library)
- VDD (+5V)
- GND

MAX31865 (PT100 amplifier)

SPI

- CLK
- MISO
- MOSI
- CS
- VDD (+5V)
- GND



- Can use hardware SPI or software SPI. Hardware SPI is faster, because there is an internal peripheral device designed to shift the bits out and generate the signals.

- Arduino Mega hardware SPI pins:

CLK	52
MISO	50
MOSI	51

- Arduino Mega I2C pins:

SCL	D21
SDA	D20

Microcontroller Memory Required

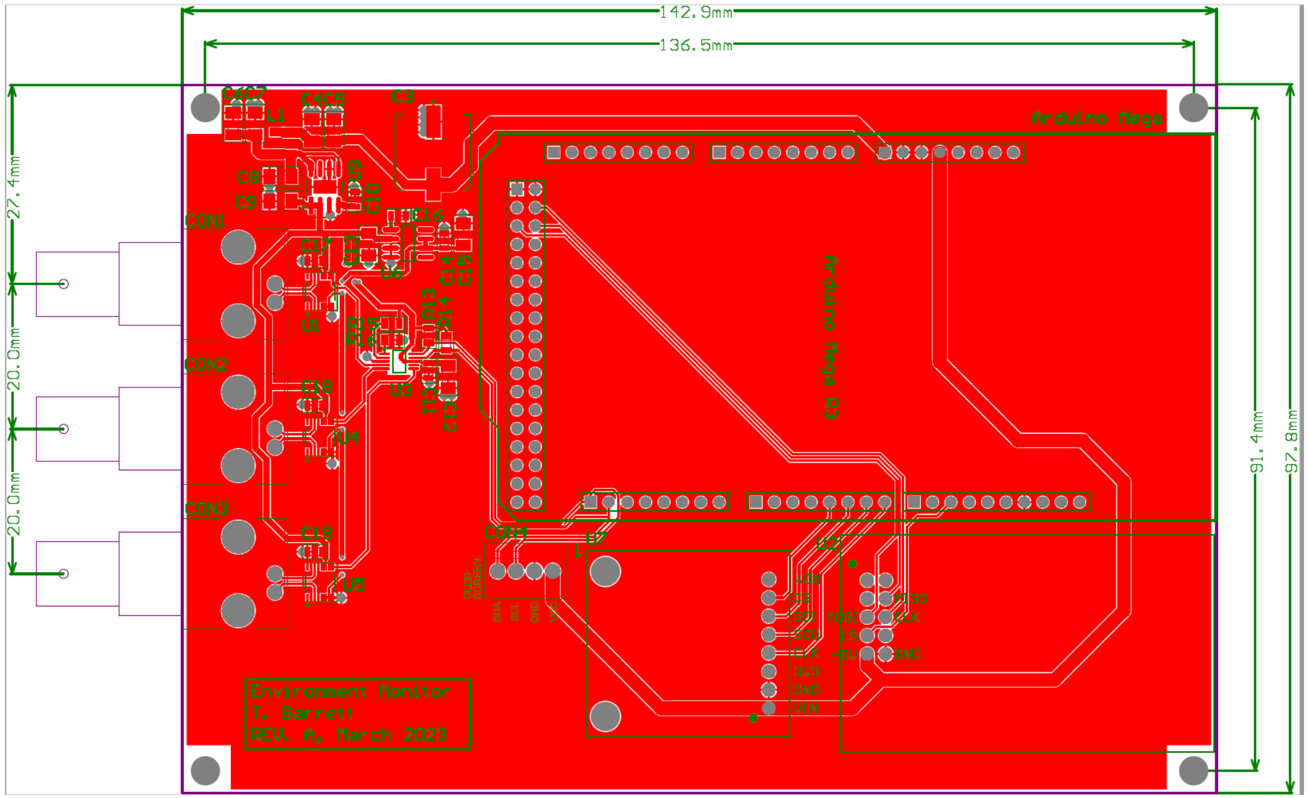
- Ethernet sketch requires 18,294 bytes
- Temperature sketch requires 4,004 bytes
- ADC sketch requires 3,236 bytes
- Basic OLED sketch requires 7,016 bytes

← Total is **32,550 bytes**…
(more than available on Nano… need to use Arduino Mega)

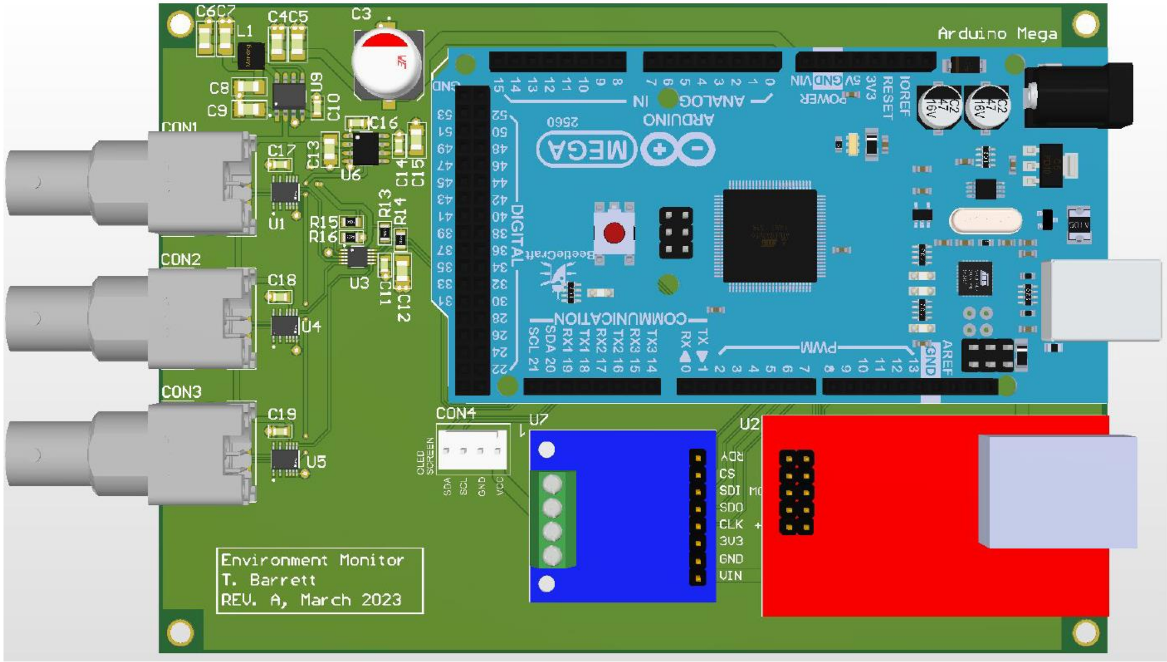
- Arduino Nano has 32 KB flash memory (2 KB used by bootloader). So, **30,720 bytes** available for program. This is equivalent to 30.72 kilobytes, or 30 kibibytes.

- Arduino Mega has 256 KB memory (8 KB used by bootloader). So should be 248 kibibytes available to use. Which is 248 x 1024 = **253,952 bytes**.

PCB Design

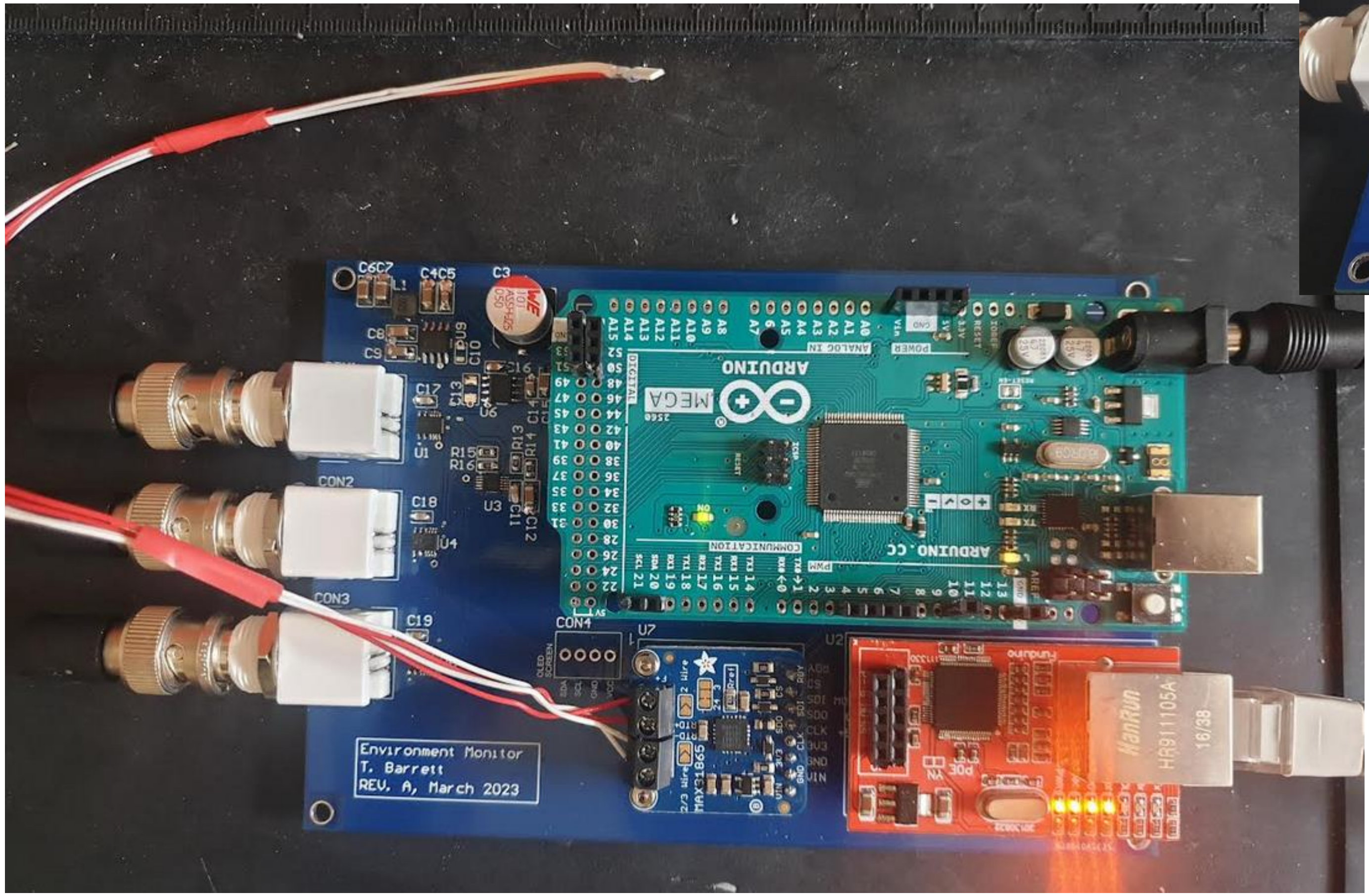


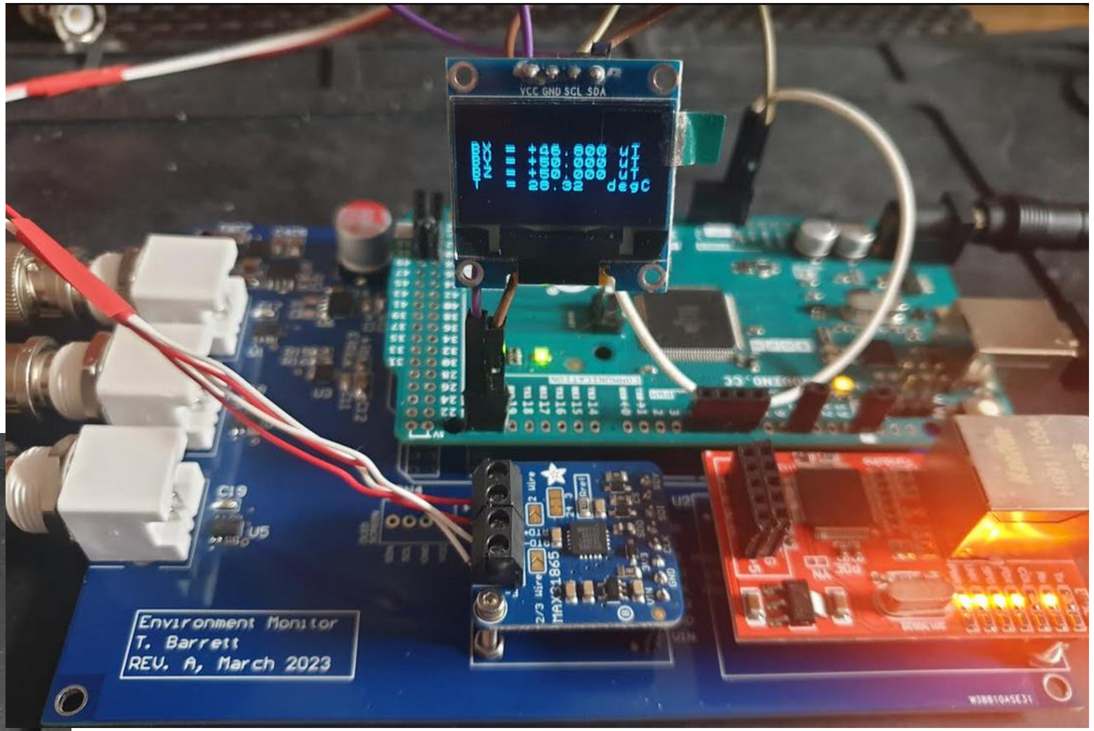
142.9mm
136.5mm
27.4mm
20.0mm
20.0mm
91.4mm
97.8mm
Arduino Mega
CON1
CON2
CON3
Environment Monitor
T. Barrett
REV. A, March 2023

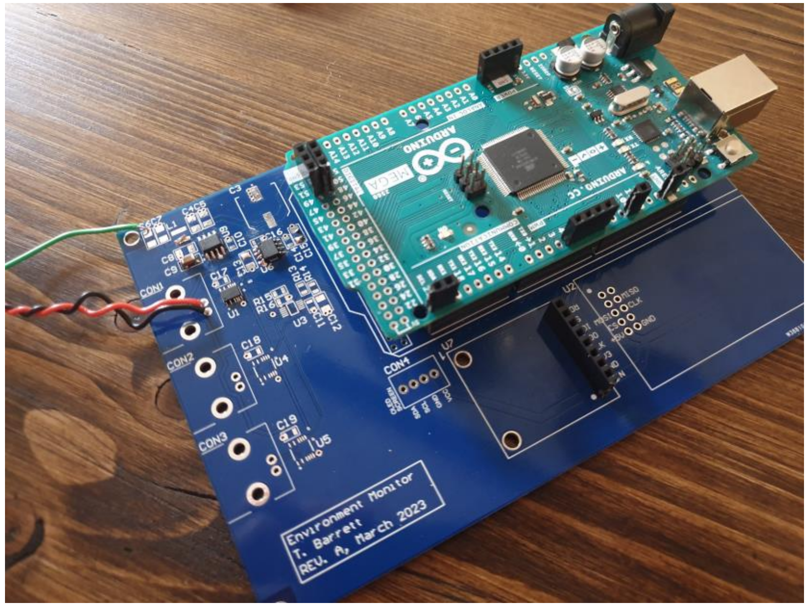


Arduino Mega
CON1
CON2
CON3
CON4
U7
U2
Environment Monitor
T. Barrett
REV. A, March 2023

Assembled Board







Structure of Firmware

Power On

- → Startup functions → Initialise ethernet chip, ADC, and PT100 converter
- → MAIN LOOP (every X seconds, e.g. every 20 sec)
  - → Collect N readings from ADC **channel 1** and take average (takes 1.73 ms per reading, e.g. **173ms** for 100 readings)
  - → Collect N readings from ADC **channel 2** and take average (takes 1.73 ms per reading, e.g. **173ms** for 100 readings)
  - → Collect N readings from ADC **channel 3** and take average (takes 1.73 ms per reading, e.g. **173ms** for 100 readings)
  - → Obtain PT100 reading (takes **77 ms**)
  - → Connect to remote InfluxDB server, post data, read response, disconnect from server (takes **25 ms**)
  - → Update OLED display screen

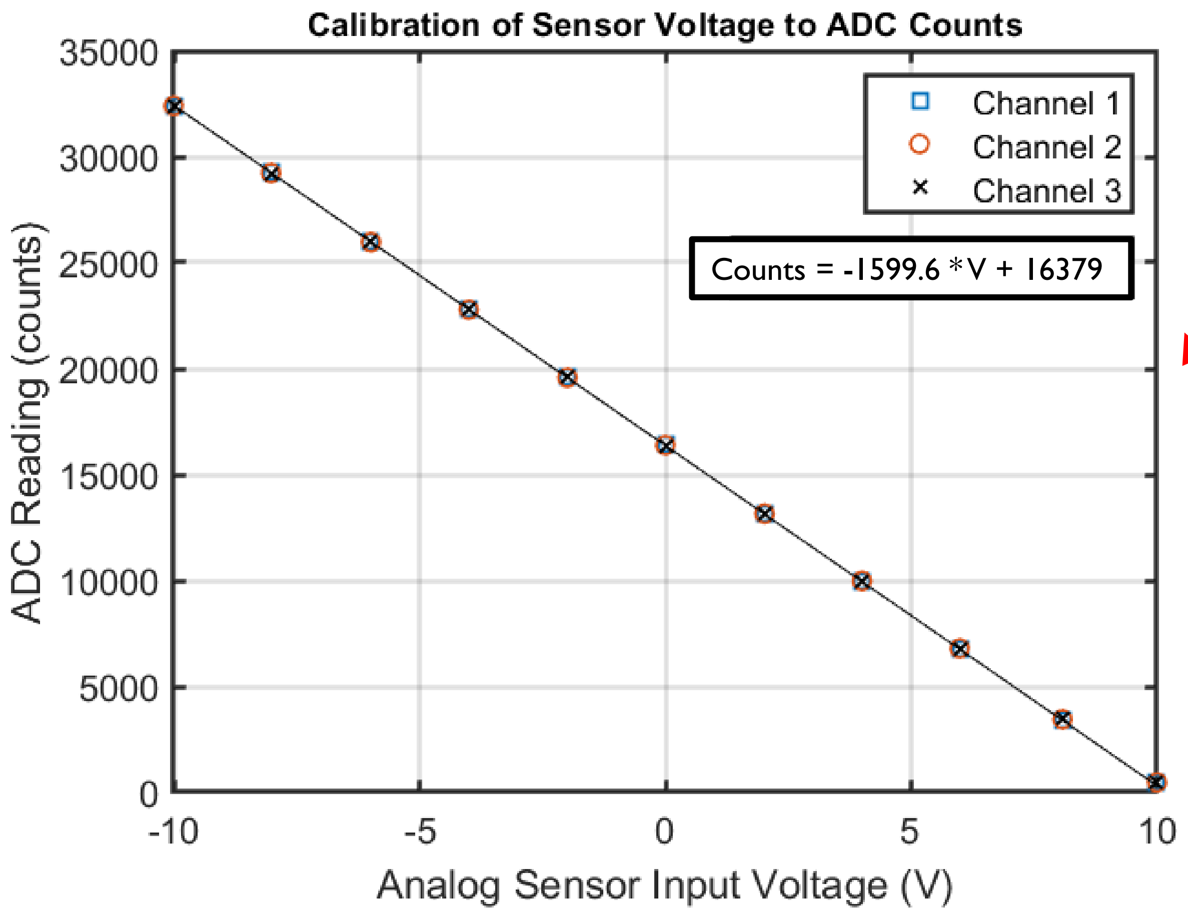
~620 ms

Data format in InfluxDB
(each datapoint is a field, with no tags).

All fields share a common time-stamp (may be useful later if wanting to do correlation, etc)

```
> select * from environment
name: environment
time                BfieldX  BfieldY  BfieldZ  Temperature
----                -------  -------  -------  -----------
1679480819612869393 -0.05019 -0.05134 -0.05259 15.6
1679480820260547315 -0.04975 -0.05164 -0.05233 15.6
1679480824909216380 -0.05006 -0.05138 -0.05268 15.6
1679480829906937124 -0.05019 -0.05173 -0.05224 15.63
1679480834902413949 -0.05023 -0.05186 -0.05263 15.63
1679480839899016220 -0.05072 -0.05138 -0.05294 15.67
```

ADC Calibration of all channels



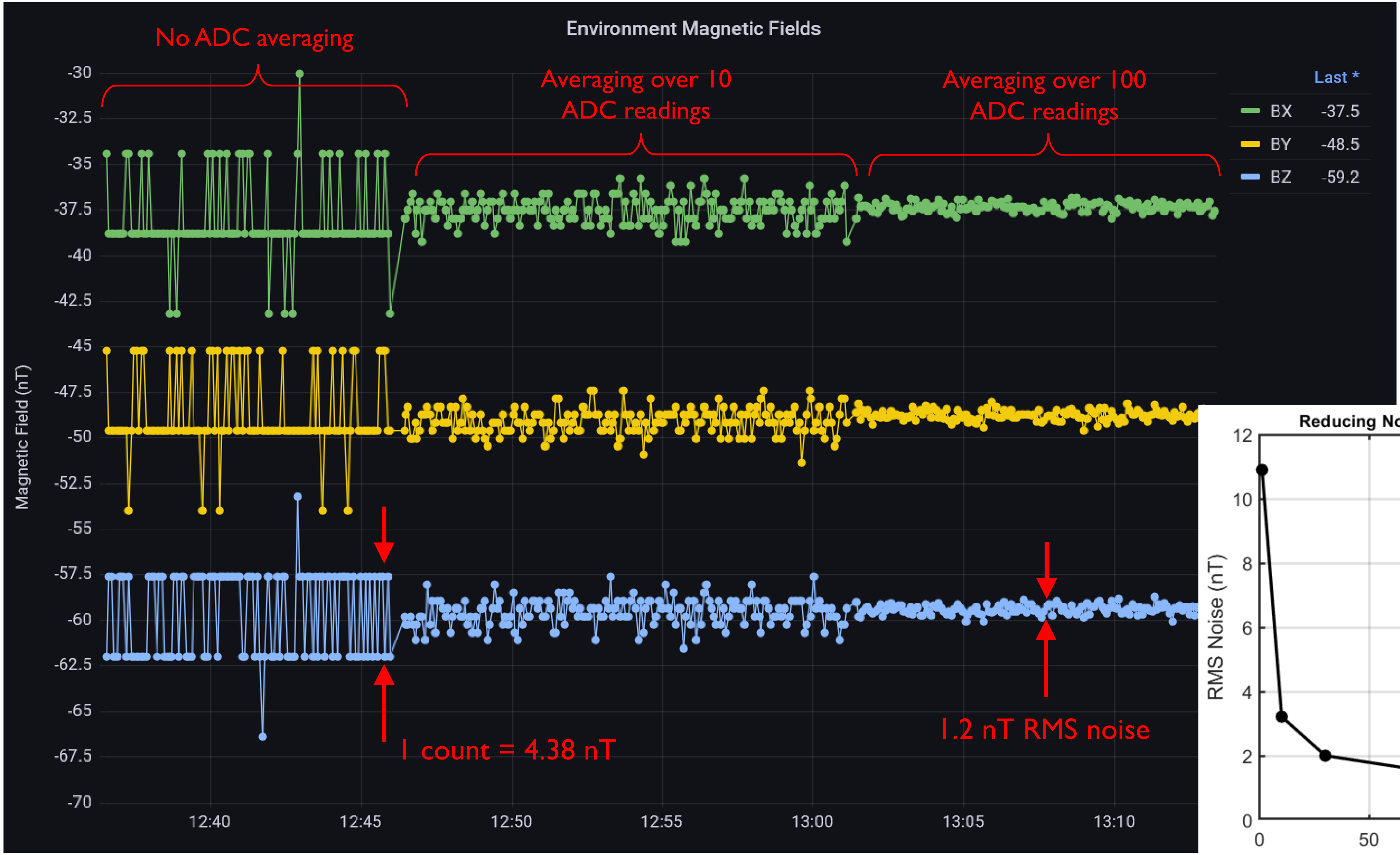
Note:

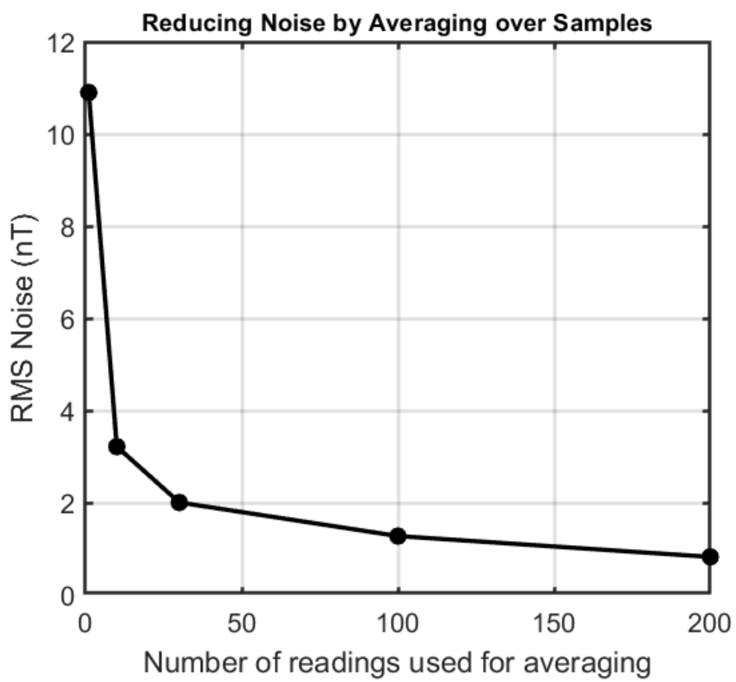
Although the ADS1115 ADC is technically a 16 bit ADC (and should therefore go up to 65,536 counts), this is only true when working in differential mode. In that case, one of the 16 bits is the sign bit, and the other 15 bits are for data. However, differential mode requires dedicating x2 of the ADC inputs, and I would need to have then 6 channels available for all 3 magnetic field directions. The ADC only has 4 channels though, so to avoid needing a second ADC, I am running each channel in single-ended mode. This means you can never get negative values, and so effectively sacrifice the sign bit, leaving an effective 15 bit resolution (32,768 values).

Expected 0.000125 volts per bit from ADC setting gain=1
This is 8000 counts per volt.
Expected additional gain of 0.2 from LT1997-2 funnel amplifier

So **expect**: 8000 x 0.2 = **1600 counts / volt**
This is close to the **measured** value of **1599.6 counts / volt**

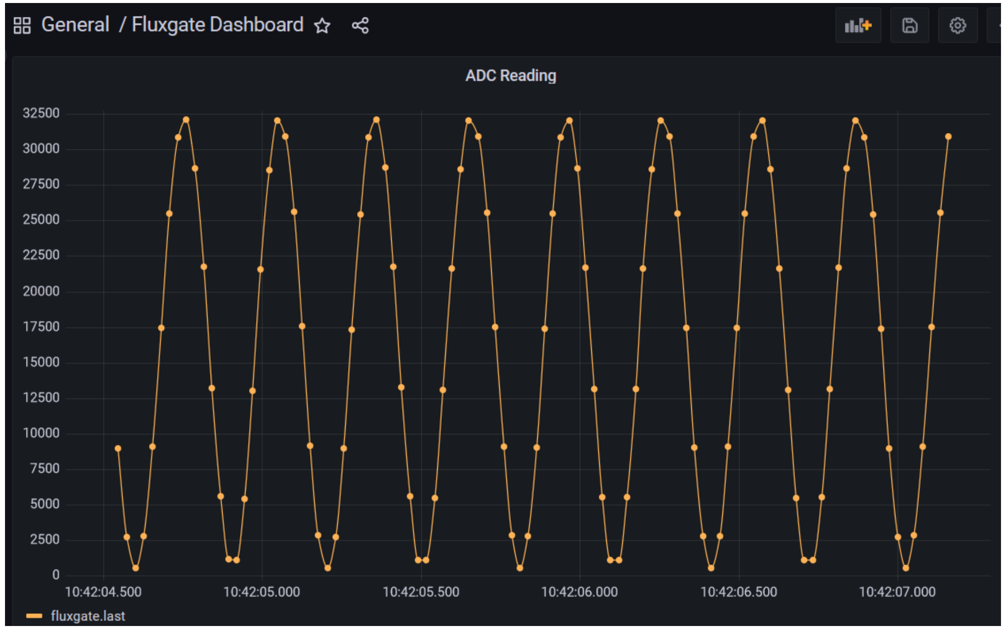
Effect of averaging the ADC Counts before posting to InfluxDB



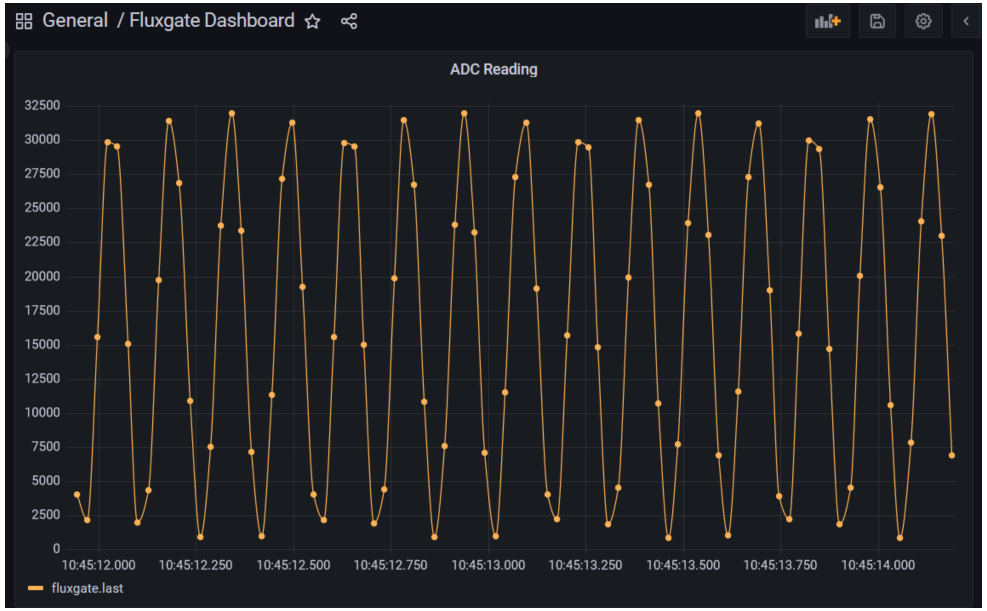


Measuring a 20 Hz sine wave

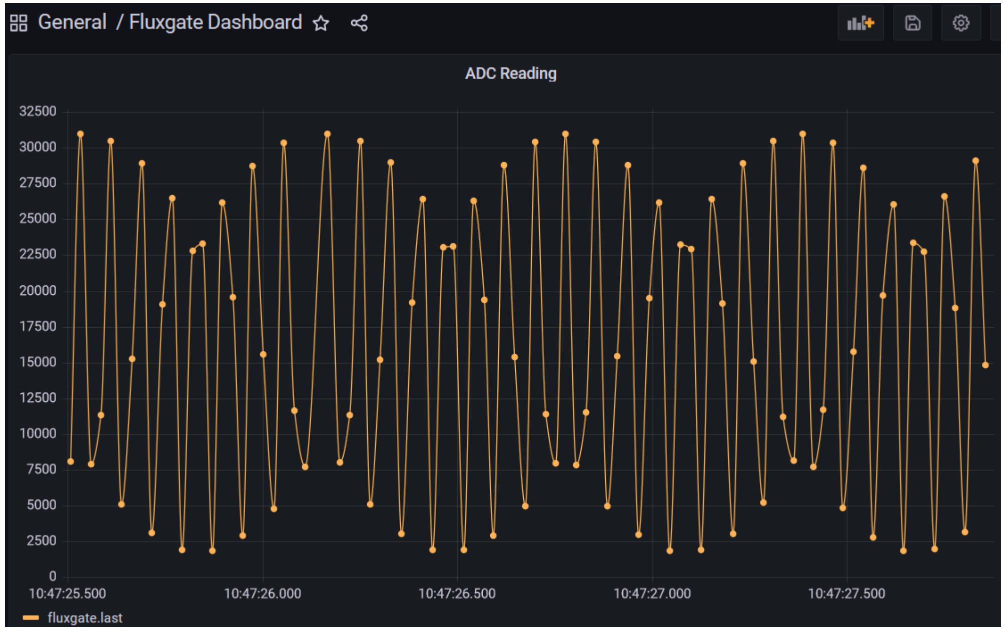
Measuring a 50 Hz sine wave



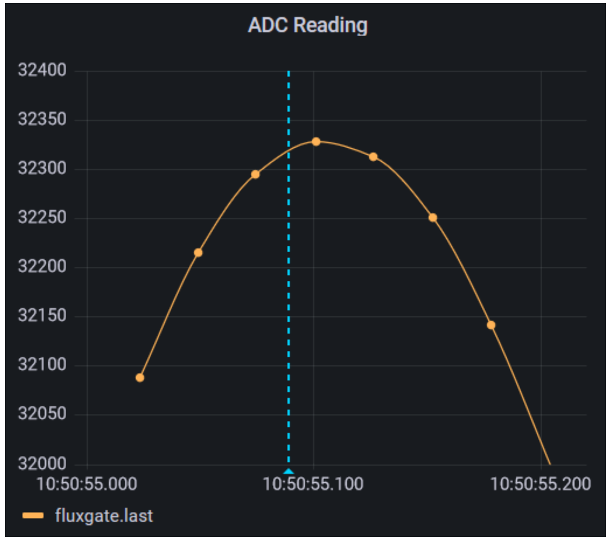
Measuring a 100 Hz sine wave



Measuring a 200 Hz sine wave (some aliasing)



- 5 Hz sine wave, 20 V p-p (+-10V)



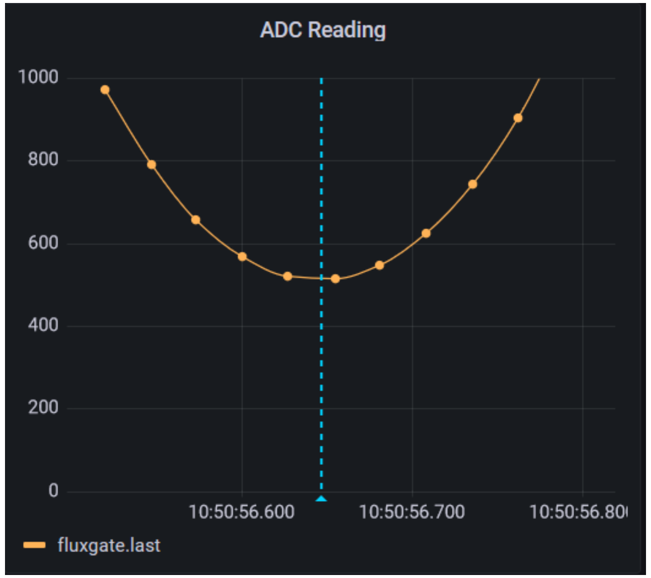
- Measuring the time to collect 10 values from ADC:

```
Total time for burst: 17336 us
Time per conversion: 1.734 ms
```

- Corresponds to 577 samples / second (should be able to measure up to 288 Hz signals without aliasing)

- Max and min counts seems to be around 32330 and 520 counts

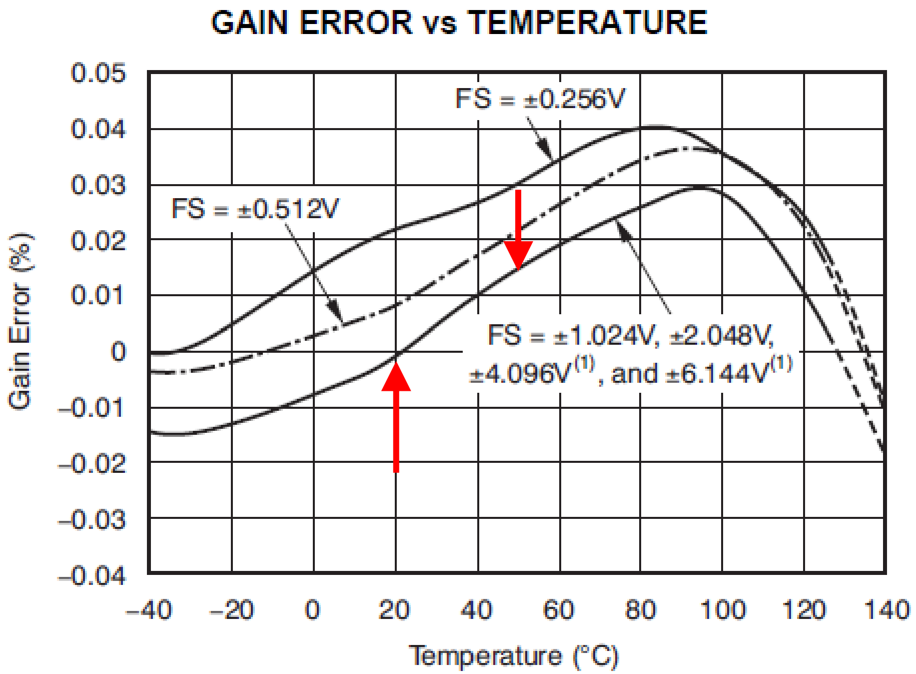
→ means I am able to capture the full +-10V range successfully.

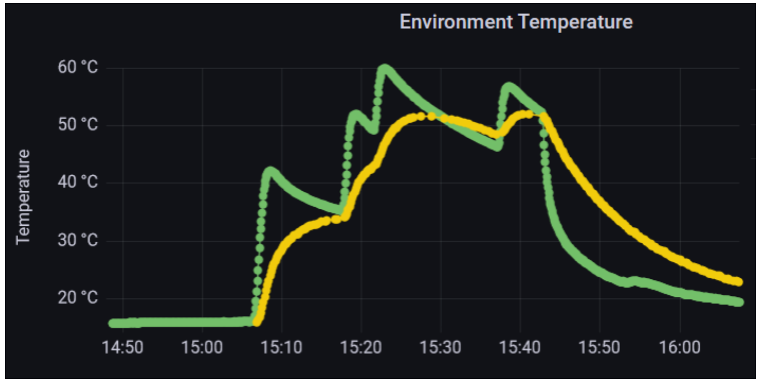


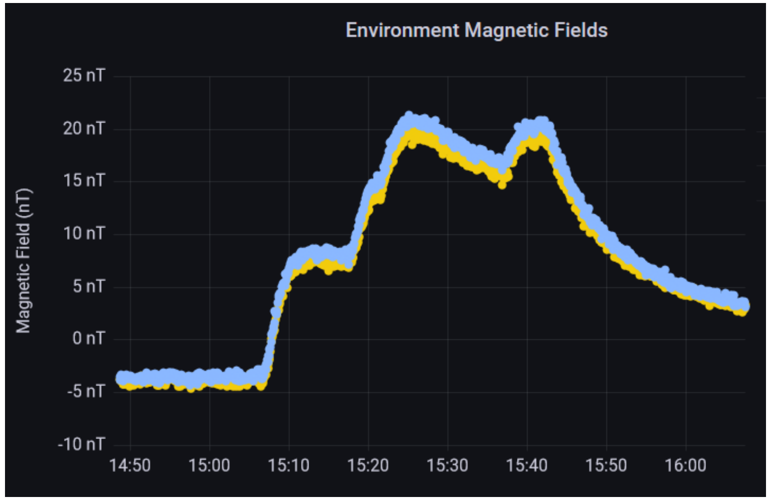
Checking Behaviour of System when Heated to 50°C

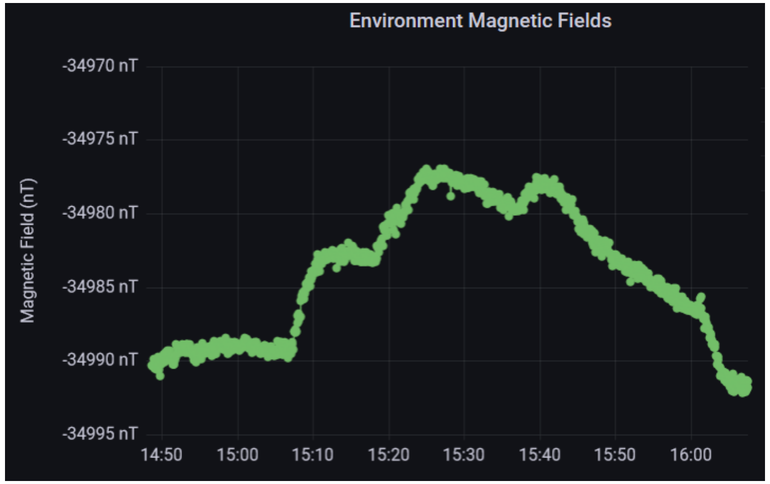
- Applied a BX field of -34990 nT (5V) , and a BZ field of 0 nT.
- BZ changed by 12 nT when Temperature went from 16 to 35 °C
- BX changed by 6 nT when Temperature went from 16 to 35 °C
- BZ changed by 12 nT when Temperature went from 35 to 52 °C
- BX changed by 5 nT when Temperature went from 35 to 52 °C
- BZ changes by 12 nT in 18°C, or 0.67 nT / °C
- BX changes by 6 nT in 18°C, or 0.33 nT / °C
- At 50°C, we can expect a change of ~12-24 nT from room temperature. This corresponds to 2.5 – 5.5 ADC counts.
- LT1997-2 has a gain error of 1 ppm/°C (0.2 ppm/°C typical).

ADS1115 datasheet says we can expect 0.015% change in gain when increasing from room temperature up to 50°C

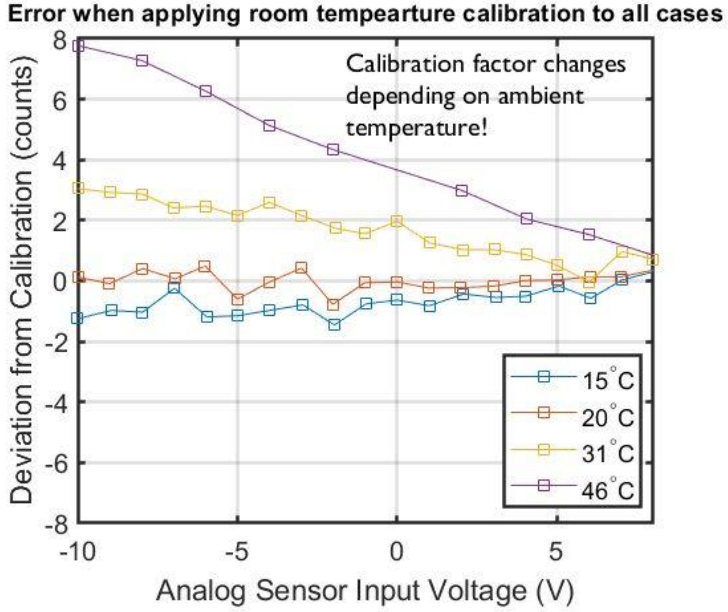


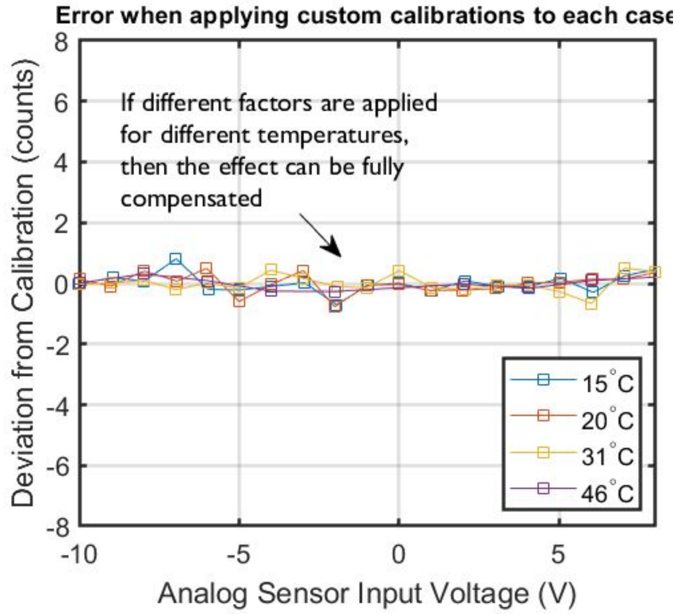




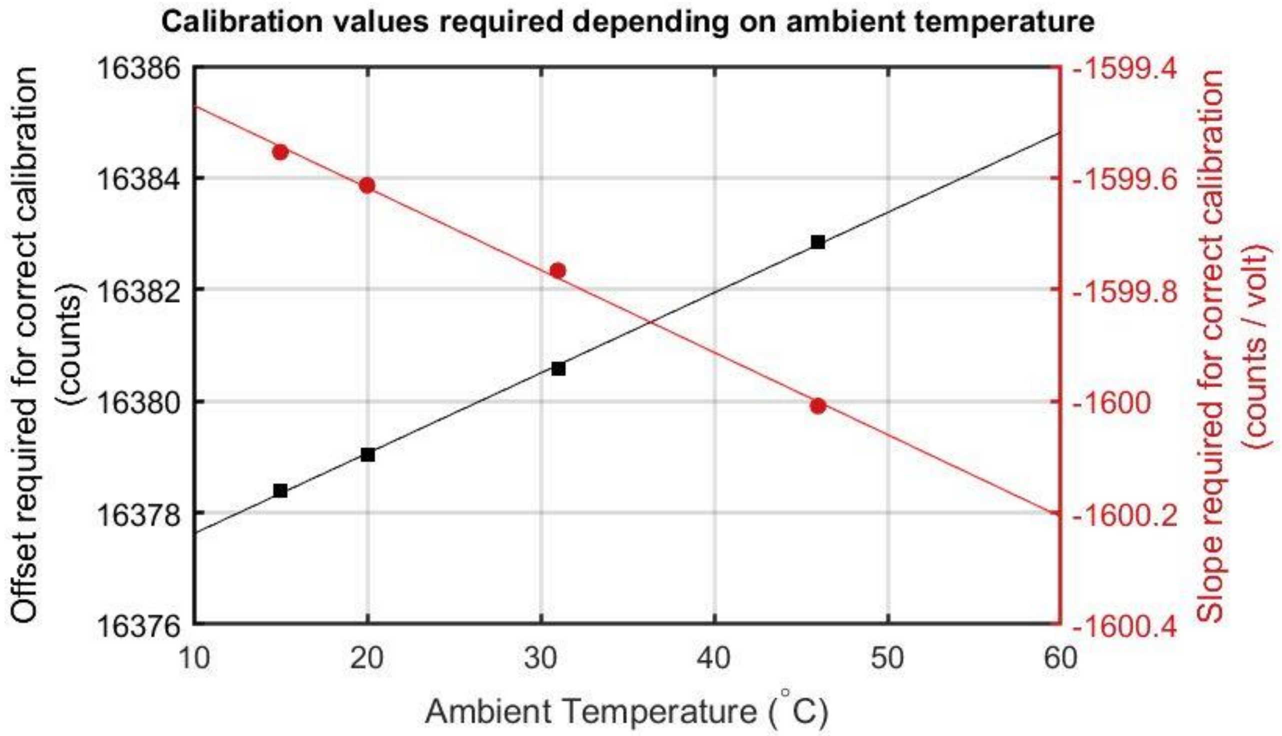


Temperature Dependence of Calibration Factors





- A temperature-dependent calibration factor was therefore included in the firmware. (i.e. first we measure the temperature, and then calculate the most appropriate calibration factors – offset and slope - to use)



Behaviour of system when heated to 50°C *after* adding temperature-dependent calibration

Since the system is heated up fast (in an oven), the PT100 probe heats up faster than the analog circuitry on the PCB, and so there is a delay of around 5 minutes before the calibration becomes accurate.

In the real system, when dealing with slow changes to the room temperature, this will not be present.

The error in the magnetic field reading is now less than 1nT at 50 °C.

This is a big improvement on the error of 24nT before, when the temperature –dependent calibration was not used.