Revision 2 8/12/2018

Making a Dust Sensor using an Ionisation Chamber

Changes

1. Added signal smoothing information
2. Added charts showing that the response is inversely proportional to particle size but proportional to particle numbers.

Intro

This was a project to satisfy a curiosity of mine: “Could a household smoke alarm sensor be used to monitor air quality?”

Ionisation chambers draw very little current and can run on a 9v battery for tens of years. How often do you change your smoke alarm battery?

Makers around the world are looking into using dust sensors like the Sharp gp2y1010, DSM501, ZPH01 and SDS011 for environmental monitoring. The problem is, they all draw currents from 20mA to 100mA and so are not suited to long term battery operation. They also cost between 5GBP and 20+GBP, depending where you buy them.

Please bear in mind that this project outcome is not the finished sensor. That needs more work but it may encourage you to investigate and also to refine the circuit/calibrate the response.

Principle of Operation

A voltage applied to the terminals of an ionisation chamber give rise to a small current due to the ions (alpha particles) thrown out by a tiny piece of Americium radioactive material.

If smoke or dust enters the chamber they are attracted to the ions, become heavier therefore slower and the current flow is reduced.

A very high impedance amplifier is needed to detect this voltage change.

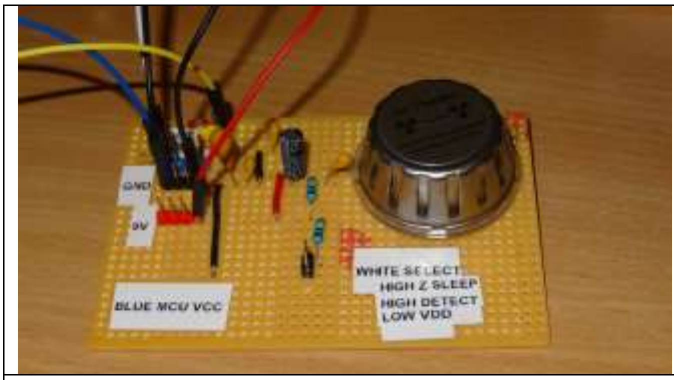
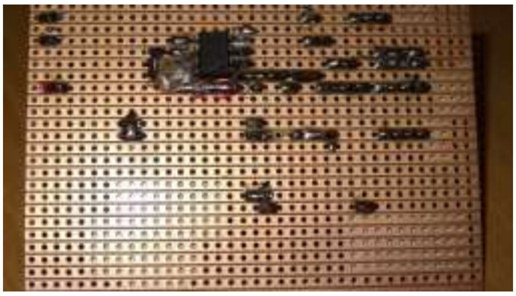
Humidity will also affect the current flow, but, due to its conductive nature tends to make the current flow increase. Since smoke detectors are looking for a drop in current this doesn’t matter for the home smoke alarms but it will matter for air quality monitoring.

Some home smoke sensors also include a sealed ionisation chamber to help cancel out the effects of temperature and humidity.

The development PCB

As you can see I used strip board to cobble this together. I figured the parallel tracks would enable me to provide a guard rail around the ionisation chamber output pin.

Top side of PCB		Track Side of PCB

		
The topside of the PCB has a couple of resistors to feed the ionisation chamber and test point plus a handful of capacitors to help reduce signal noise pick up. This is a development rig to investigate fitness for purpose and a properly designed PCB is really needed to help reduce signal noise.		The RE46C112 detector chip is soldered on the PCB tracks to minimise distance between the sense pin from the ionisation chamber and the detect input of the chip. Two tracks provide a guard rail for the output signal and the tracks are covered in wax to reduce moisture effects

Bill of Materials

Item	
NAP-07/HIS-07 ionisation chamber	Can be bought off Ebay for about £1.20 but come from China. On Aliexpress I found them for sale for £1.05. So, if you are going to wait anyway buy them from Aliexpress.
RE46C112 Smoke detector amp	Not available on Aliexpress. Price varies on Ebay – some advertise £1.11 but add £1.40 postage. Some advertise for £2.77 free postage. Bulk purchase from a chip supplier should see this come down to less than
2x 100uF Capacitors	Used for decoupling the supply voltages – low noise devices would be best.
2x0.1uf Capacitors	Used for decoupling the supply voltages – low noise devices would be best.
2x1m Ohm resistors	Some circuit diagrams use other values
Stripboard PCB	I used one 65mmx95mm. Price came in around £2. A dedicated PCB could be manufactured for a lot less.
header pins	I like my coloured header pins. I tend to use coloured pins to readily identify ground, supply and signals.

In all I made this for about £5 but I suspect it can be brought down to around £2 with a bespoke PCB and bulk purchasing of the RE46C112 chips.

Circuit Diagram

The RE46C112 datasheet is kind enough to provide a circuit diagram as below:-

Typical Application

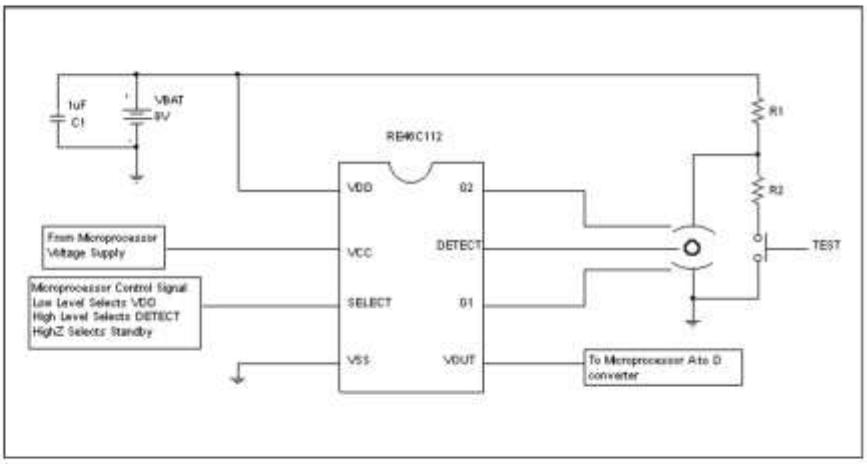


Figure 2

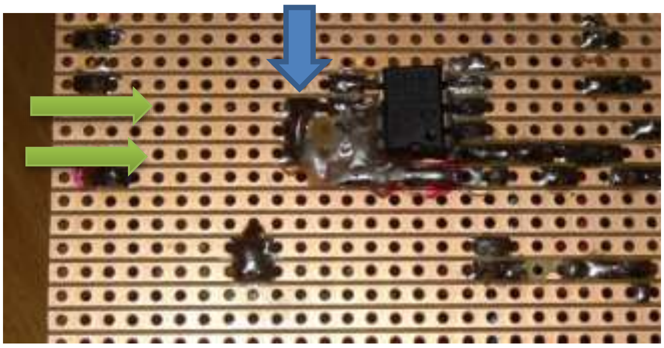
Most of this is self-explanatory. G1 and G2 are the guard amplifier output and guaranteed to be within 50mV of the DETECT signal and are used to shield the DETECT pin to reduce leakage.

R1 and R2 are not mentioned in the datasheet but other circuit diagrams use 1m Ohm and, sometimes, zero Ohm. I chose to use 1m Ohm because it means the normal current flow is limited to a maximum of 9uA. when using a 9v supply. Remember that dust/smoke causes the current to fall. The resistor used does affect the 'resting' voltage output from the amplifier chip. I did try 10K Ohm for a while (A load resistor of 10k was mentioned in the data sheet). The resting voltage was higher and I think the responsiveness to dust was greater – that's another thing to investigate but I really want R1 to be in the megohm region to limit current drain on the 9V battery.

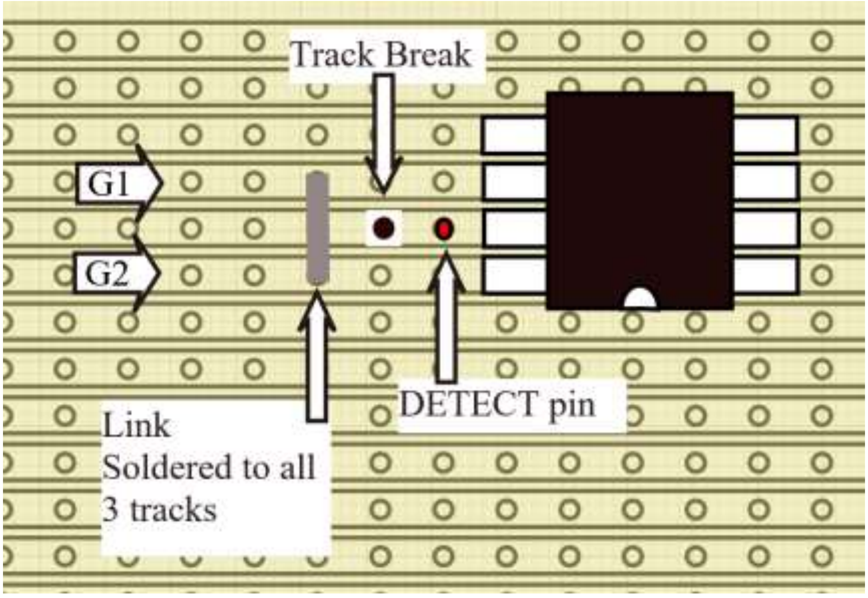
Guard Rail

Hard to see as I've covered the area with paraffin (candle) wax which is an insulator and keeps moisture away from the DETECT pin.

In this picture the two guard rails are highlighted (Green arrows). They are linked (Blue arrow) to form a complete guard. The DETECT input track is cut just before the link so that it is isolated.



Hopefully, this diagram clarifies the section under the wax.



After doing that cover the region with paraffin wax.

Arduino Sketch

To capture the sensor output as a real-time graph I used the Arduino-Plotter library https://github.com/devinaconley/arduino-plotter.

You can download the code from the above BUT when I manually installed it as a library it didn't work so I resorted to using the Arduino library manager – just search for Plotter. That worked except it didn't install the Listener code for the Serial Plotter in the Tools menu.

Having manually added that a window appears but I didn't get a chart so I used the Windows 64-bit listener outside the Arduino IDE.

If you go to the home page of the wiki you will find links to Listeners. These appear to be pre-set to use 115200 baud so don't mess with that setting in the plotter library.

Start your sketch then launch Listener.exe

Here's my sketch. The Plotter code runs very quickly and there's some noise on my signal so I resorted to averaging a number of readings and

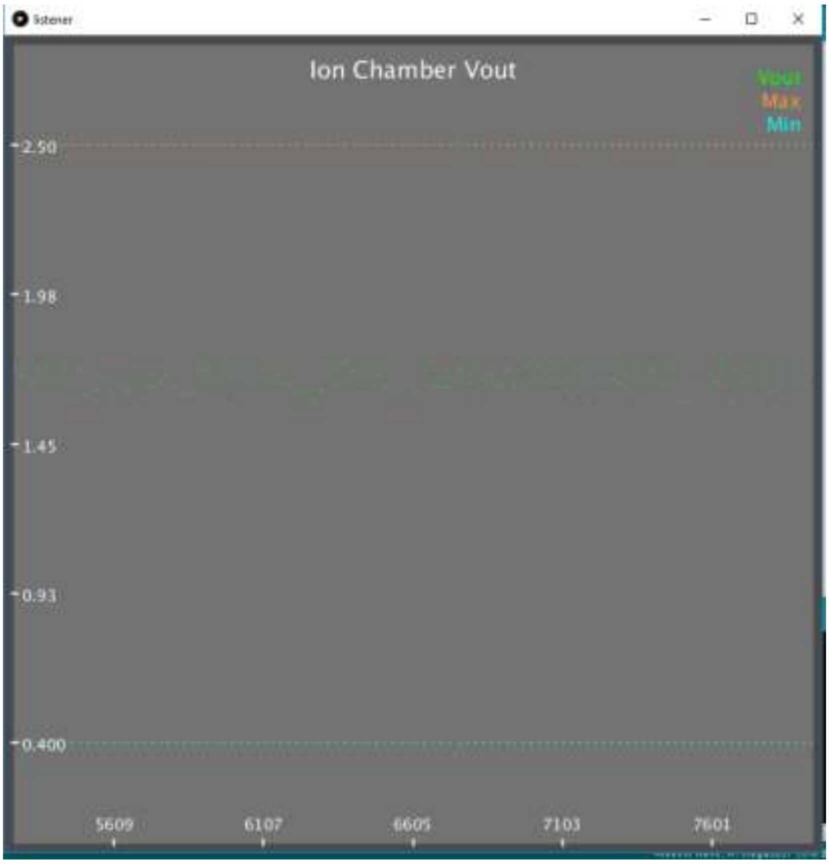
```
#include <Plotter.h>
#define GAIN    4.0         // multiply ADC voltage (Amplify signal)
#define NUM_AVG 20          // number of ADC readings to average
#define SIG A4              // analog input pin
#define CONTROL 10          // digital control pin
#define ADC_MAX_VOLT  5.0   // Depends on Arduino
#define ADC_MAX_REG 1024.0  // 10 bits on most


float Vout;     // Analogue voltage
float Max=2.50; // graph vertical range controllers
float Min=0.4;  // doing this stops plotter from adjusting vert axes
```

```
Plotter p;


void setup() {

  pinMode(CONTROL,OUTPUT);
  digitalWrite(CONTROL,HIGH);

  // now start the plotter

  p.Begin();

  p.AddTimeGraph( "Ion Chamber Vout", 100, "Vout",
Vout,"Max",Max,"Min",Min);

  Vout=ADC_MAX_VOLT*analogRead(SIG)/ADC_MAX_REG;
}

void loop()
{
  float avg=ADC_MAX_VOLT*analogRead(SIG)/ADC_MAX_REG;

  for (uint8_t c=0;c<NUM_AVG;c++)
    {
      avg=avg+ADC_MAX_VOLT*analogRead(SIG)/ADC_MAX_REG;
      delay(1);
    }

  Vout=GAIN*avg/NUM_AVG;

  p.Plot();
}
```

That's all there is to the initial code.

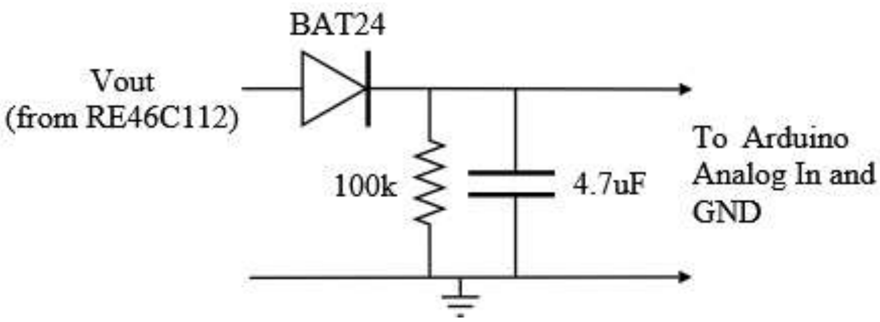
The output is shown next.

The green line is the amplified (x4) averaged signal. The noise is present on the +ve connector of the ionisation chamber **but not on the 9v supply** hence I conclude that what we are seeing is the random nature of radiation and it's hard to smooth out other than by averaging.



Smoothing the signal

After much investigation it was determined that the signal coming from the ionisation chamber was the source of the noise so I added a charge pump with a 0.5 second C-R time. This was done experimentally. Lower values didn't sufficiently iron out the randomness which I presumed was due to the random nature of atomic decay in the Americium used in smoke detectors. The circuit used was this :-



A BAT24 diode was chosen for its low forward voltage drop (~0.2v) since the voltages coming from the RE46C112 amplifier were under 1 volt.

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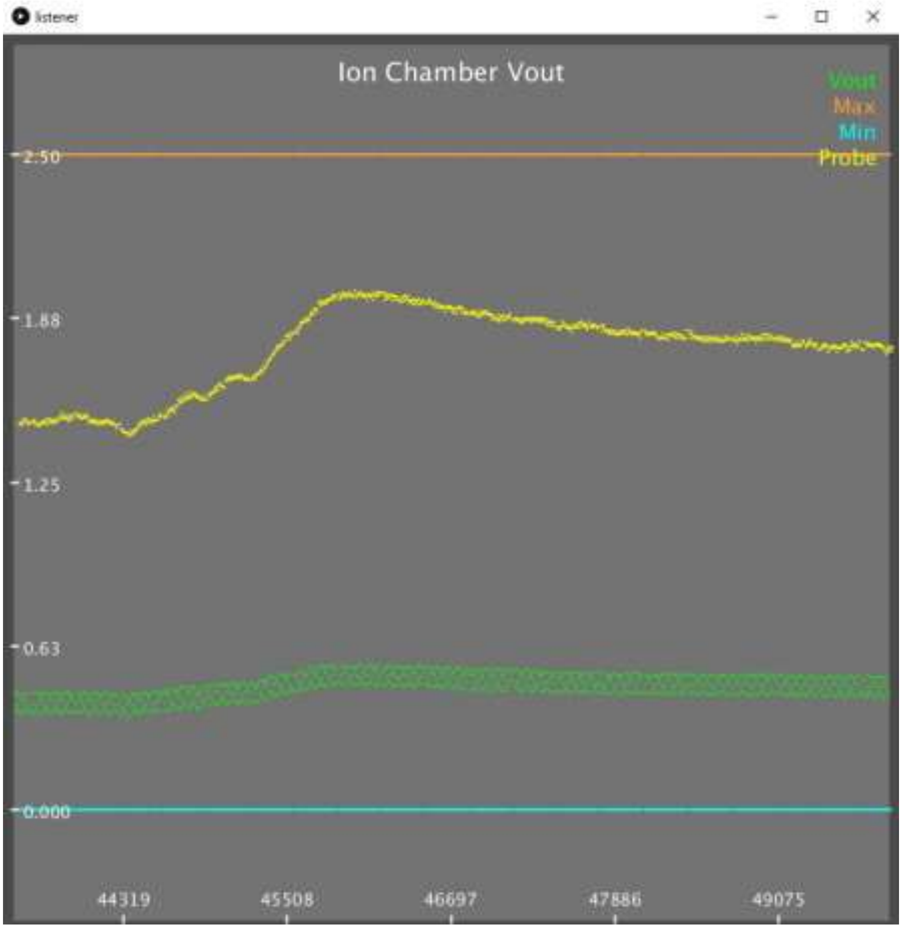
There was still some noise in the output but by applying a sliding average the end result was this:-



The green trace shows the unsmoothed signal response to a squirt of shoe deodoriser whilst the yellow trace shows the signal after electronic smoothing, averaging and amplification.

The response was quick – a matter of seconds.

Further software improvements could be to subtract the resting value from the signal then apply more amplification (gain).

The Arduino loop code was changed to this:-

```
#include <Plotter.h>

#define GAIN    5.0           // multiply ADC voltage (Amplify signal)
#define MAX_VERT  2.5
#define MIN_VERT  0.0

#define SIG A4              // ionisation chamber amp output
#define PROBE A0            // probe

#define CONTROL 10          // sets amp mode
#define ADC_MAX_VOLT  5.0   // Depends on Arduino
#define ADC_MAX_REG 1024.0  // 10 bits on most 12 bits (4096.0) on STM32
```

```
float Vout;     // Analogue voltage
float Probe;
float Max=MAX_VERT;  // graph range controllers
float Min=MIN_VERT;

Plotter p;

float avgProbe;   // used for averaging

void setup() {

  pinMode(CONTROL,OUTPUT);
  digitalWrite(CONTROL,HIGH);

  // now start the plotter

  p.Begin();

  p.AddTimeGraph( "Ion Chamber Vout", 1000, "Vout",
Vout,"Max",Max,"Min",Min,"Probe",Probe);

  Vout=ADC_MAX_VOLT*analogRead(SIG)/ADC_MAX_REG; // no gain - don't want
clutter on graph
  avgProbe=GAIN*ADC_MAX_VOLT*analogRead(PROBE)/ADC_MAX_REG;
}



void loop()
{
  avgProbe=Probe+GAIN*ADC_MAX_VOLT*analogRead(PROBE)/ADC_MAX_REG;
  avgProbe=avgProbe/2;

  // this is the raw Vout trace
  Vout=ADC_MAX_VOLT*analogRead(SIG)/ADC_MAX_REG;

  // used to display the averaged signal
  Probe=avgProbe;

  p.Plot();

}
```

Response Curve

The current flowing through the ionisation chamber is proportional to the velocity of the particles passing through it. When a dust particle attaches to an ion it slows the ion down hence reduces the current flowing.

The force pushing the particle, from +ve plate to –ve plate in the ion chamber, is constant because the voltage on the plates is constant and the particle’s charge is constant. So Newton’s law tells us that the energy given to the ion is:-

$E=Fi*Di$ where Fi is the force on the ion and Di is the distance travelled by the ion.

The ion's final kinetic energy is related to its velocity and is given by the equation:-

(1) $E=Mi*Vi^2/2$ where Mi is the mass of the ion and Vi is the terminal velocity of the ion

When a dust particle attaches itself to an ion the mass has increased but the energy remains the same because the force and distance have not changed hence

(2) $E=Mip*Vip^2/2$ where Mip is the mass of ion+particle and Vip the velocity

Combining (1) and (2)

$$Mip*Vip^2/2=Mi*Vi^2/2$$

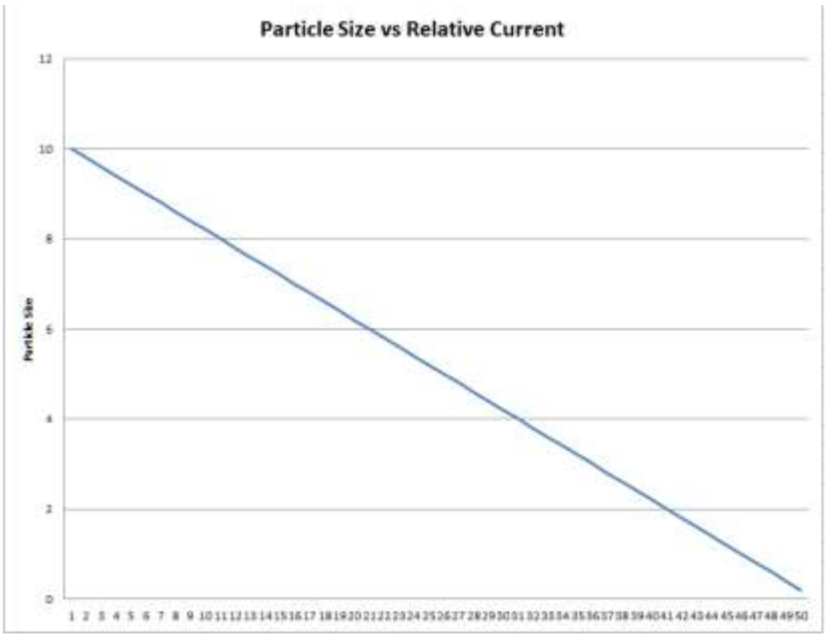
$$Mip/Mi=Vi^2/Vip^2$$

so:-

$$Vip=sqrt(Mi^2/Mip^2)/Vi$$

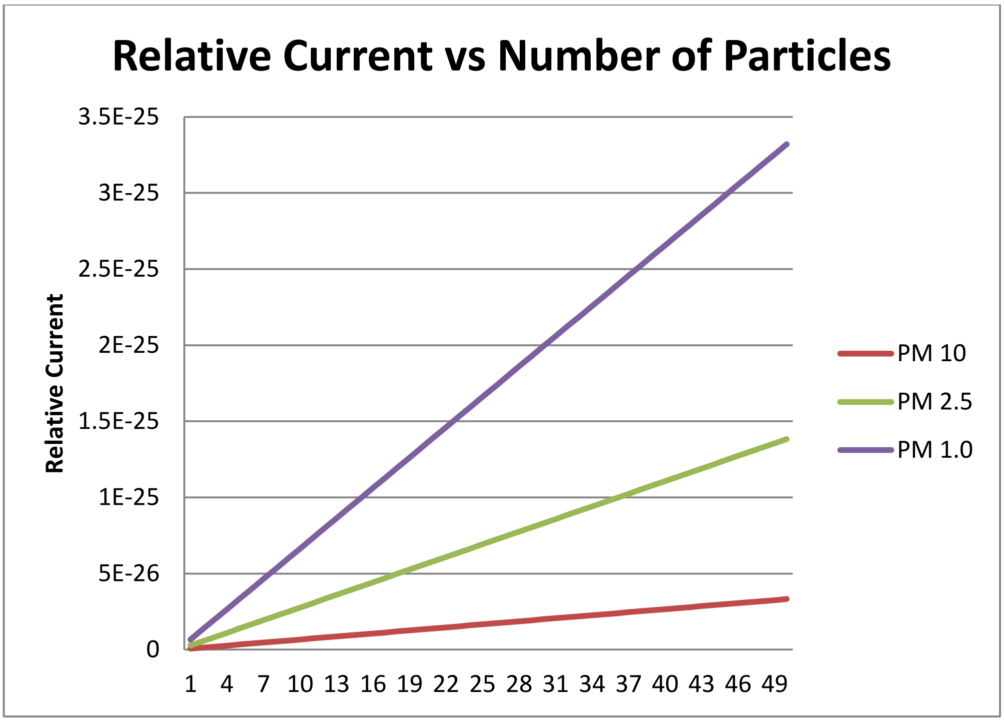
The mass of an alpha particle is 6.64*E-27 Kg whilst a 10uM smoke particle is around 6.18^E-13. The

This shows that the current flow, which proportional to velocity of the ions, is inversely proportional to the square root of the ratio of the masses. Using the velocity of an ion on its own, for comparison, this gave me the following chart:-



Note: Excel had trouble plotting very small numbers hence the horizontal axis. Never-the-less, it would appear that there is a linear correlation.

And when we compare relative current to the number of particles of the main sizes of interest (PM10,PM2.5 and PM1.0) we get the following :-



Whilst it is nice to have a linear relationship this cannot differentiate between particle sizes.

Where Next?

calibration

To make this useful for Air Quality measurements it needs to be located with a known, calibrated, dust (PM) sensor to see if the AQI can be calculated from the output readings. It certainly responds quickly to being squirted with an aerosol.

Fortunately, the response to dust is linear so we need two points of known density or known particle size to produce an equation which relates the sensor output to dust particle density.

proper pcb

I need to get some kicad whizkid to design a proper pcb even though I believe I tracked the noisy signal to the ion flow through the chamber.