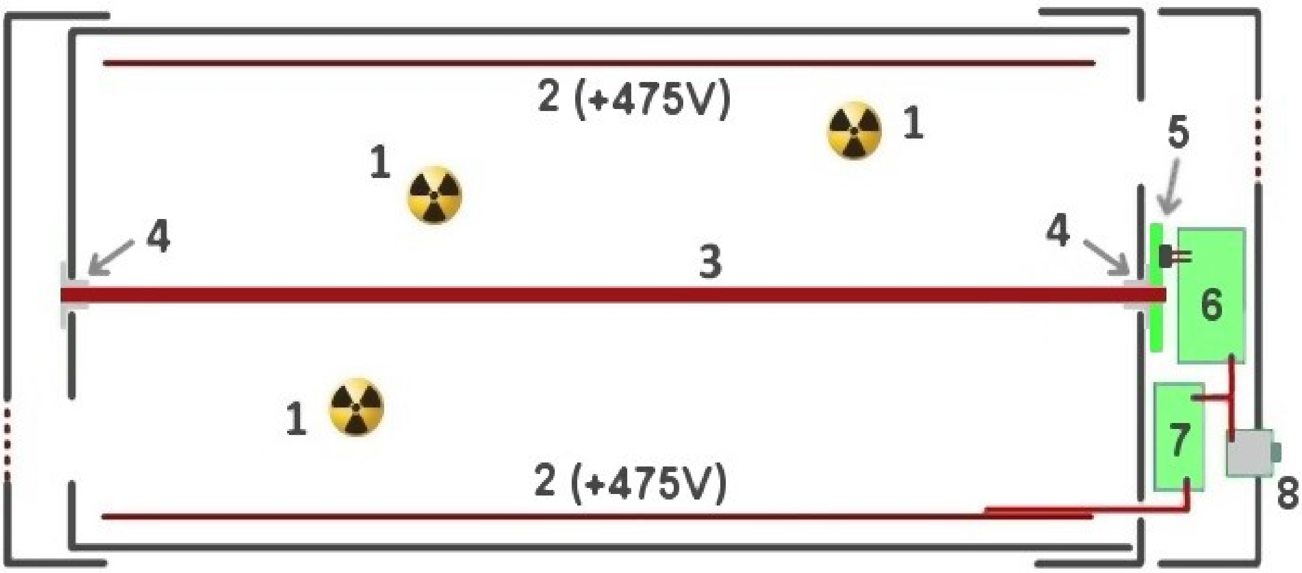
Theremino System

Ion chamber Electronics

Version 7

Functional wiring diagram

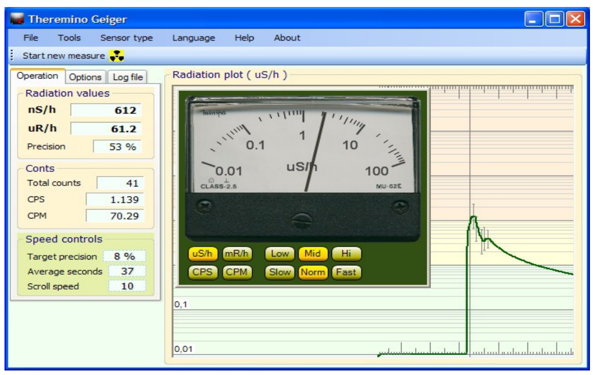


Each disintegration of Radon **(1)** ionizes the air and produces thousands of electron-ion pairs. The strong electric field in the chamber quickly attracts the ions toward the center electrode **(3)**, insulated with plastic grommets **(4)** and electrically connected to the FET**(5)**.

The electrons are attracted the coating **(2)**. In a few milliseconds all the electrons produced by the disintegration of the single crossing the high voltage generator **(7)**, the amplifier **(6)** and the FET **(5)** and recombine with the positive ions.

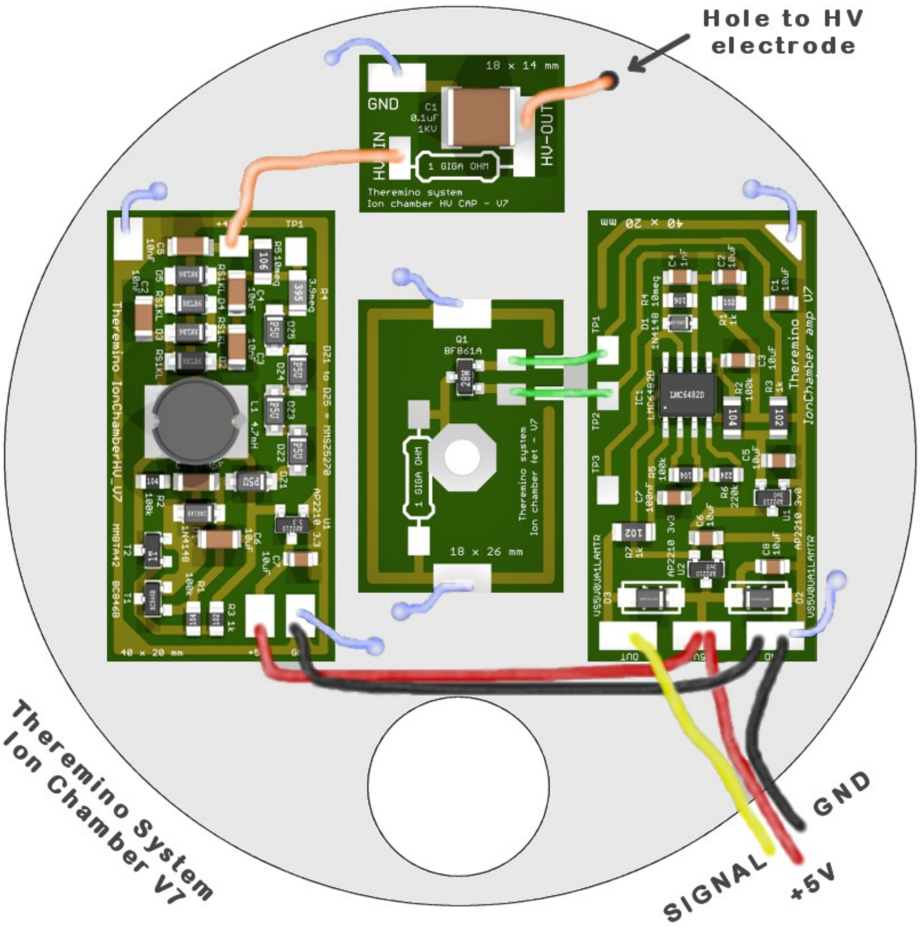
The weak current of electrons is first amplified by the FET. Then the amplifier and discriminator pulse width **(6)**, discard pulses of low energy and the island sun alpha disintegrations produced by radon and its descendants.

The output connector **(8)** can be connected directly to a Standard PIN configured as a simple "Counter" (Not "FastCounter" that would be wasted for a few pulses per second of Radon).



Normally you use a Theremino_Master module, that provides the power for the ion chamber and sends counts to Theremino_Geiger software, via USB. A single Master can power up to twelve ion chambers, with links to hundreds of meters long and collect all of the data. Some of these could be replaced with Geiger sensors for Alpha, Beta and Gamma rays or with environmental sensors, to measure, for example, the mm of rainfall, temperature and humidity.

View all links

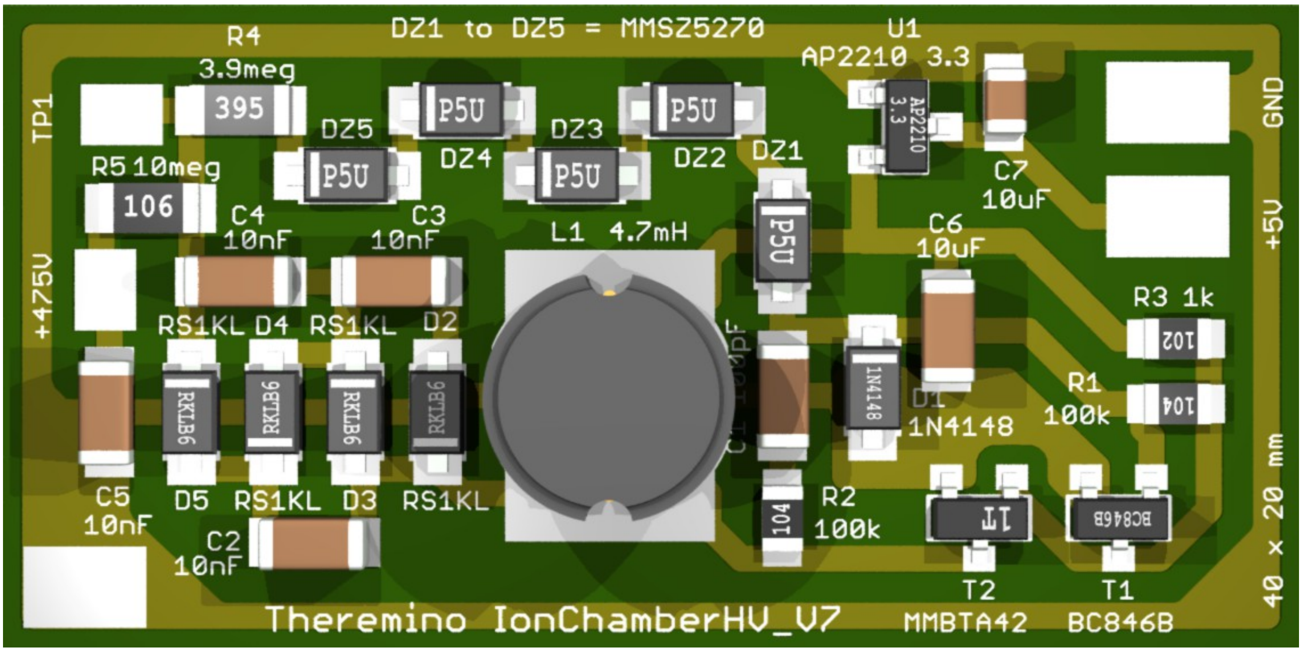


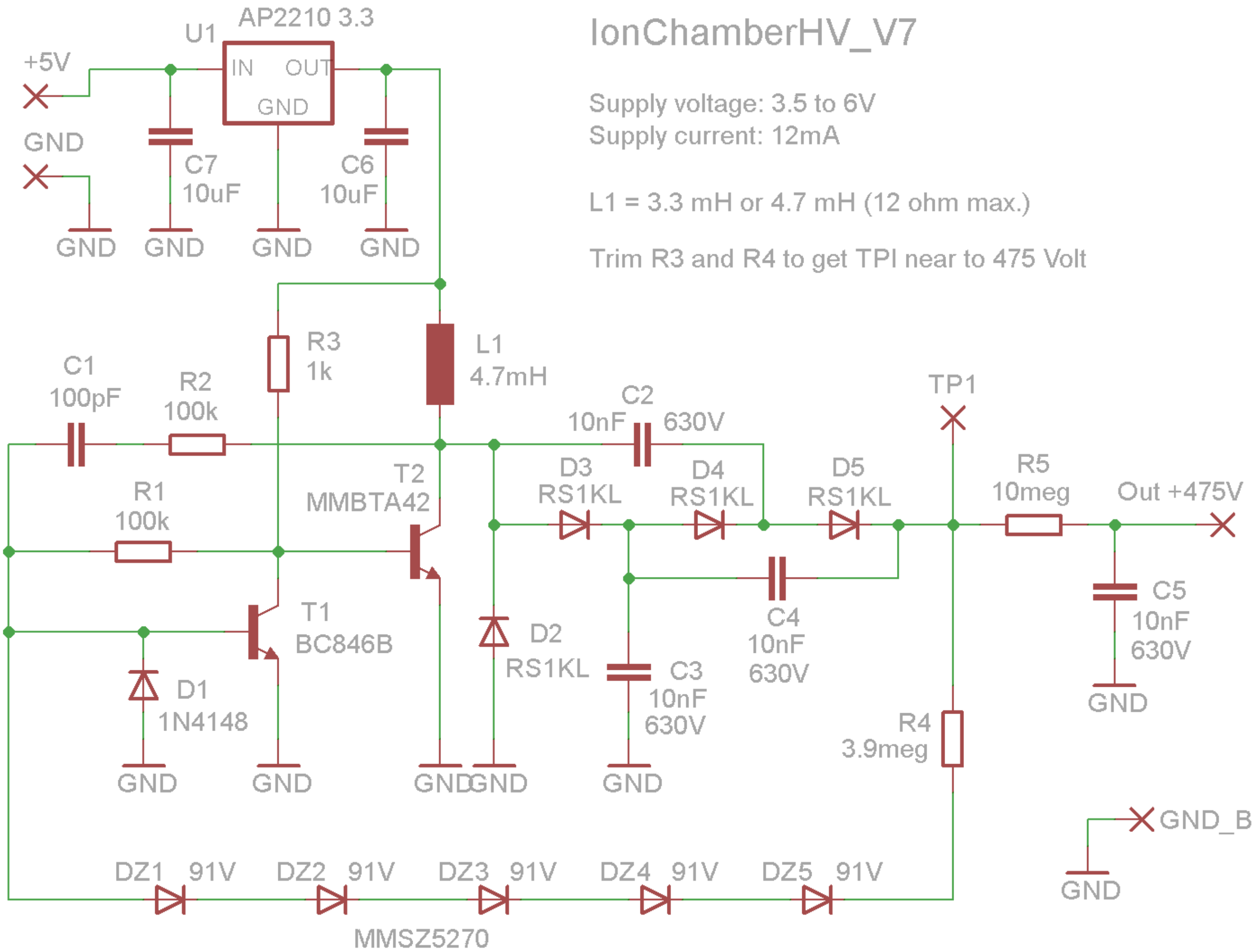
The PCB modules have become so small and light that you can secure them with rigid tinned copper wires (blue in this image).

The anchor wires are welded to the surface of tinplate (or to the surface coated with copper tape in the professional versions of the chamber).

Furthermore (but we will see it better later), by covering the FET with a rectangular screen and the hole with a fine brass mesh, it is possible to make the open chamber work, with the electronics completely accessible, as seen in this image. And this is a great convenience when measuring components before closing the chamber.

High Voltage Generator – Version 7





High voltage generator - Notes

This new version "IonChamberHV_V7" is considerably more stable than the previous ones, the voltage produced varies by only one or two volts, with temperature variations of +/- 30 degrees centigrade. Instead the previous versions in the same conditions also varied by 50 volts and more.

In addition, the accuracy of the voltage has also increased and it can be expected that, in the absence of defects or errors, all specimens will give a voltage of 475 +/-2 volts, without the need for calibration.

It is probably not necessary but later on this page we explain how to check the voltage and how to check that the stabilizer has a good voltage reserve.

Check the voltage

The output voltage of about 475 Volts is not critical, the number of counts changes little with voltages from 450 to 500 Volts, but you can control it if you want. To measure the produced voltage it is not possible to use a normal tester, so you have to use the probe of this page:
http://www.theremino.com/blog/gamma-spectrometry/hardware-tests#hv

Modify the voltage

The nominal voltage is 475 Volts. A voltage lower than 470 or higher than 480 volts could be caused by zener or other components faulty.

If the voltage is not right first of all you should look for the faulty component, however if necessary you can change the voltage by acting on R3 and R4.

- By raising the value of R3 the voltage decreases (but it is better not to vary R3 by much)
- By raising the value of R4 the voltage increases (it is better to act on R4 than on R3, but also in this case it is not good to vary it much)

Check that the voltage can rise to 600 Volts and beyond

This control ensures that the stabilization continues to function, even with low power supply voltage and extreme ambient temperatures (however, avoid letting the chamber work outdoors for long periods as it suffers from humidity).

To do this check the voltage meter is kept connected and the diode D1 is shorted, by doing this the voltage should rise a lot.

Normally the voltage will rise to approximately 600 - 700 Volts. If the voltage exceeds 600 Volts you can rest assured that the stabilization works with a lot of margin, if it does not exceed them this could be due to a too low L1 (less than 3 mH) or to other components a little out of characteristics.

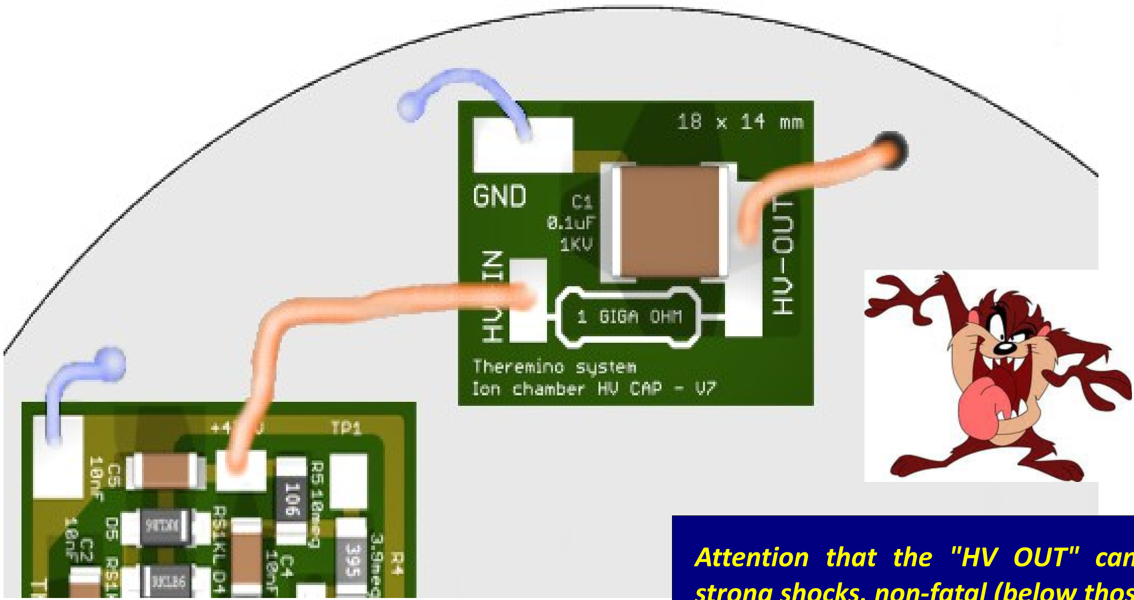
To increase this voltage reduce R3 to 820 ohm (if even with 820 ohms the 600 volts are not reached then there must be an error or a faulty component). Changing R3 also changes the working voltage, you will have to check it again and probably you will have to retouch R4.

High Voltage Generator - Links

The output of the high voltage generator module is connected to the "HV CAP V7" module with an insulated wire (orange in this picture).

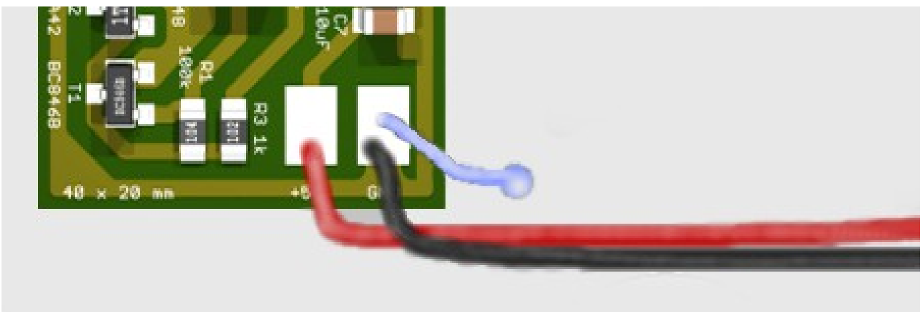
The HV CAP module eliminates any residual noise from generator switching by means of a 1 giga ohm resistor and a 0.1 uF 1000 V capacitor.

A second insulated wire carries the filtered voltage to feed the outer circular electrode of the chamber, passing through a hole. Those who want to build with maximum reliability could also add a tube of insulating sheath at the passage point, to increase the insulation and to prevent the walls of the hole from affecting the insulating coating of the wire.



Attention that the "HV OUT" can give strong shocks, non-fatal (below those of a "Taser"), but very unpleasant.

The generator module (like all the other modules) is fixed by means of two bare wires, blue in this image, welded to the base in tinplate or covered with adhesive copper tape.

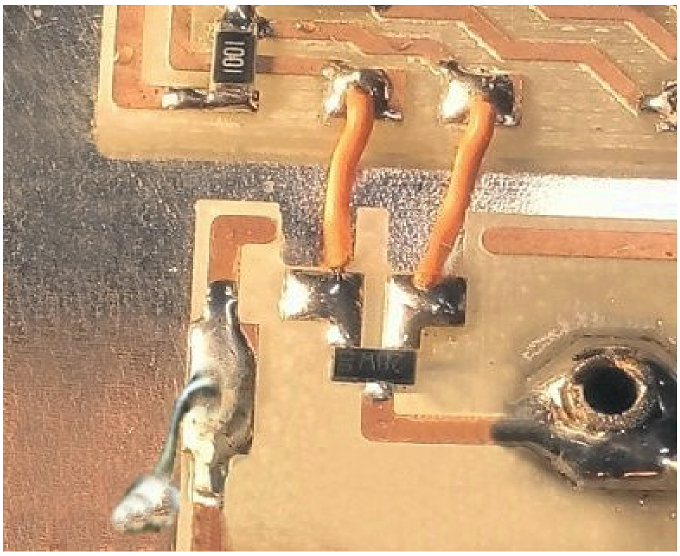


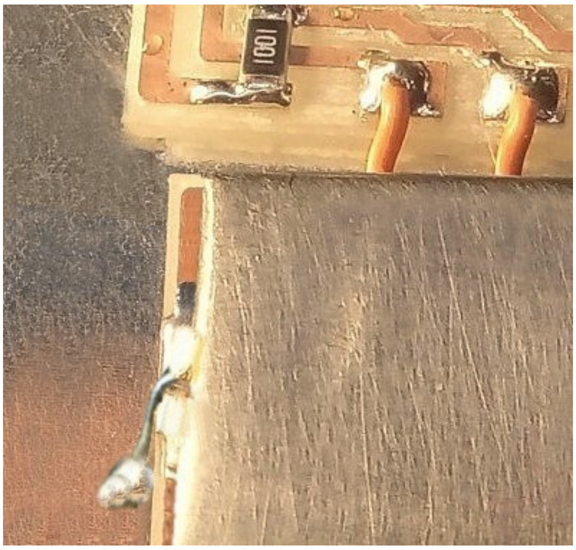
The power supply voltage of the generator module comes from the 5 volts supplied by the USB, by means of the two isolated red and black wires.

The FET and the central electrode

The GATE of the FET and the central electrode are the most sensitive parts of the whole chamber. They must therefore be prepared, welded and shielded with care.

The FET module (like all other modules) is fixed by means of two bare wires welded to the base in tinplate or covered with adhesive copper tape. This module is then covered with a tin shield (tinned iron sheet) and the lid is welded on both sides.





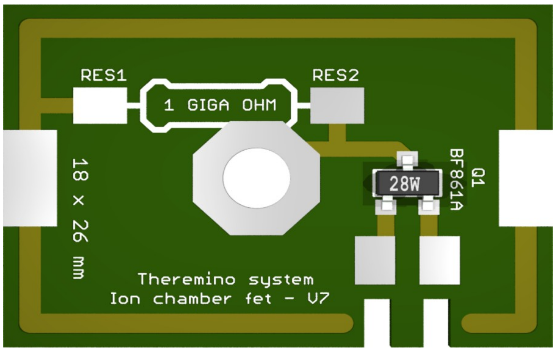
In the left image you can see the FET without shield, with the two wires that carry the signal to the amplifier.

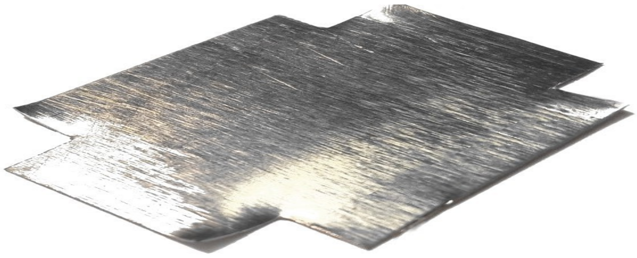
In the right image you can see that the screen has been applied. Here you can see only the welding on the left but for strength the screen must be welded to both pads.

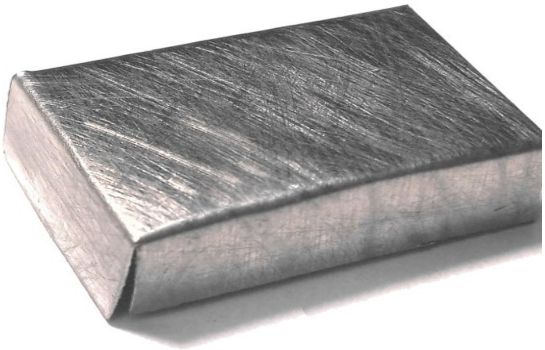
Shields

The shield to be applied on the FET must be 17 x 22 mm.

It is prepared by cutting the tin plate with scissors and then folding it with pliers.



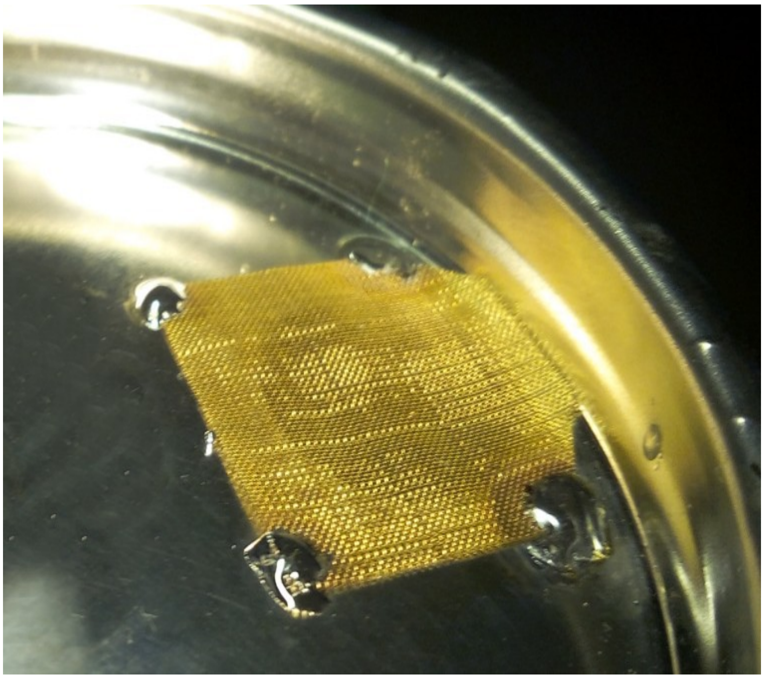




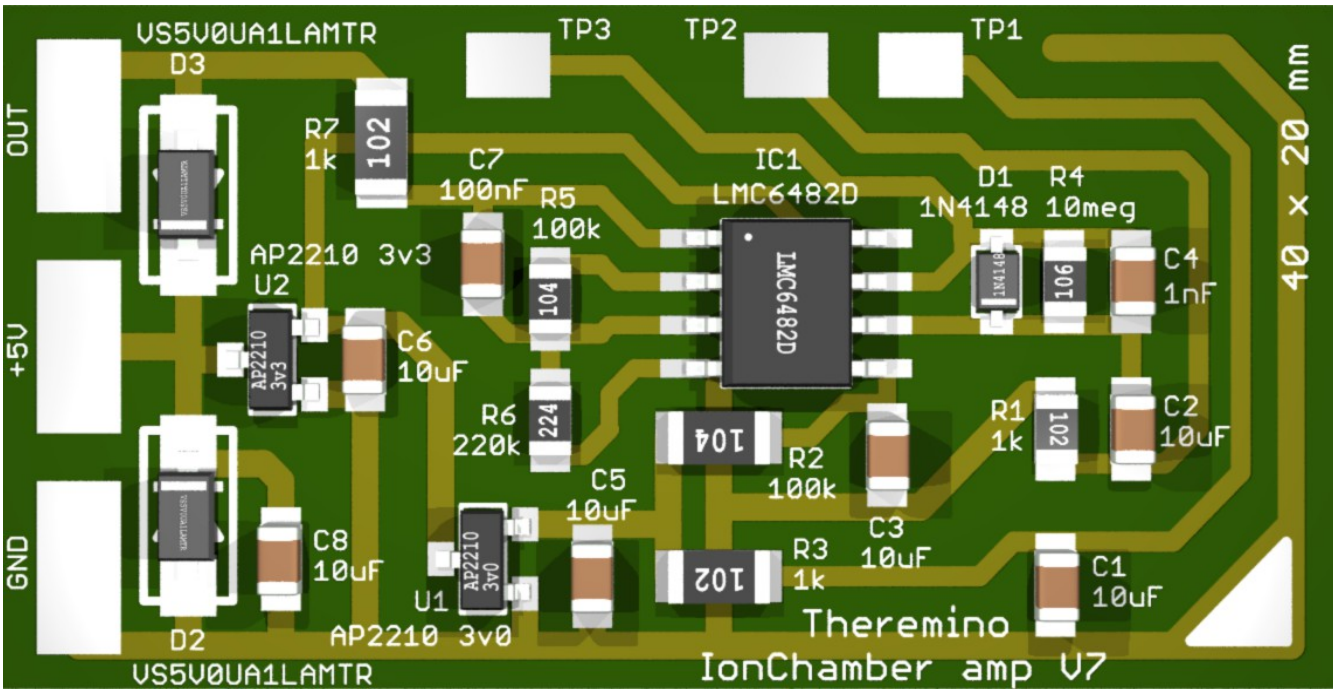
In addition to the FET circuit, the internal electrode is also very sensitive to noises arriving from the electrical system.

Therefore, if you do not shield the holes, just bring your hands together and it will cause strong disturbances. It would therefore become impossible to carry out tests and measurements with the chamber open.

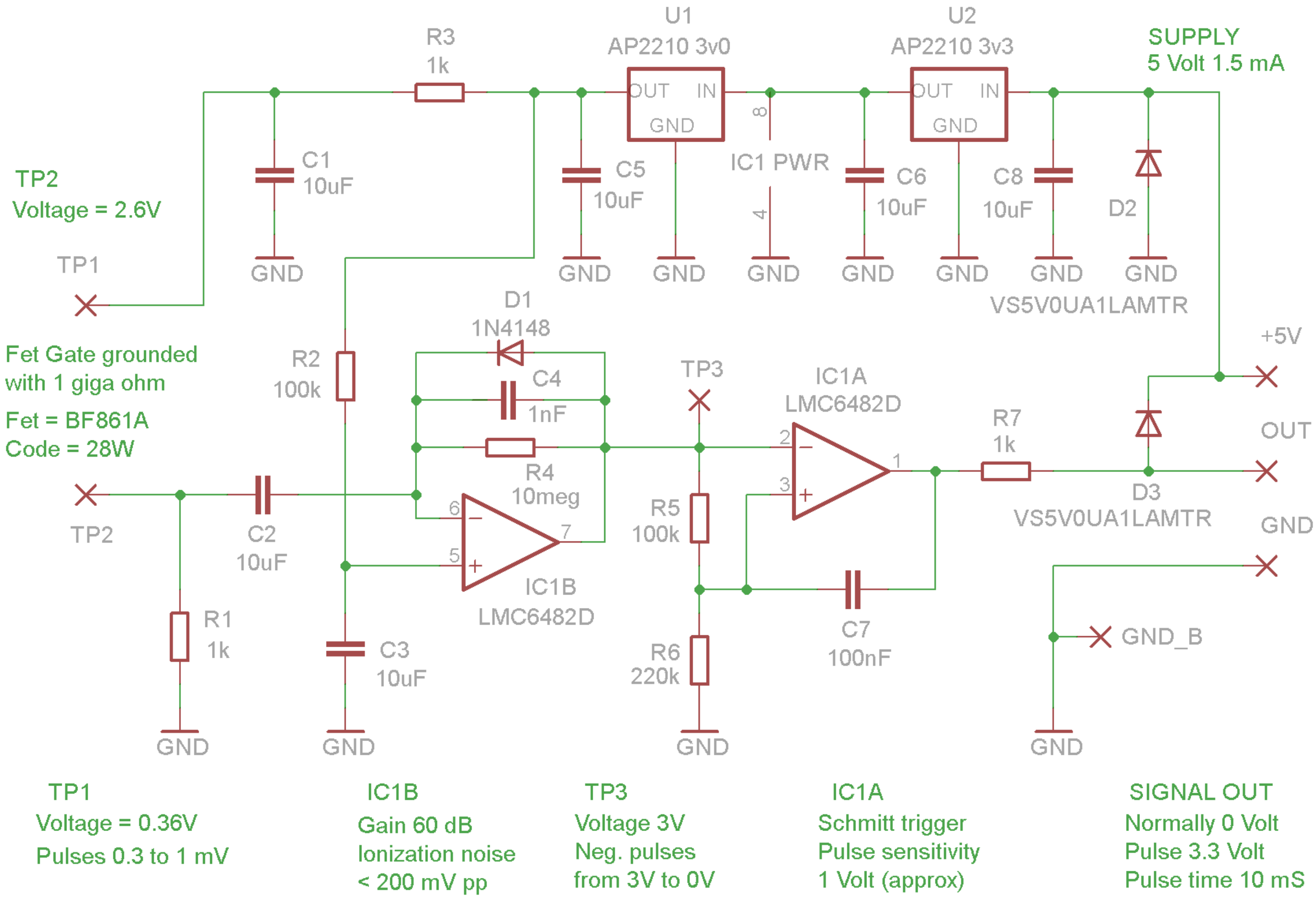
To shield the internal electrode, a square of fine brass mesh is welded onto the holes, as seen in the image on the right..



Signal amplifier - Version 7



Theremino - Ion chamber amp - V7



Signal Amplifier - Operation

The **U2** regulator transforms the 5 Volt of the USB, which is very noisy (even 100 mV of noise), into a very stable 3.3 Volt with noise around 500 uV. The **U1** regulator produces a further stabilized 3 volts. **R3** and **C1** filter out the noise and feed the FET with an almost noise-free 2.6 Volt voltage (only a few microvolts).

The **FET** amplifies about 5000 times the very weak current pulses (about 1 pA), produced by the ionizations and produces high pulses about 5 uA. These pulses pass through **C2** which eliminates the DC component and lets only the variations pass. The current pulses are then amplified by **IC1B** and transformed into negative voltage pulses of a few Volts amplitude.

R2 and **C3** filter the 3 Volt voltage from residual noise. The 3 volt voltage on pin 5 sets an accurate reference for **IC1A**, which then stabilizes with an output voltage of 3 volts.

C4 limits the bandwidth and increases the signal-to-noise ratio. **R4** limits the gain and **D1** limits the overshoot of the pulses as they return to the baseline.

At the output of **IC1B** on point **TP3** there are the pulses produced by the disintegrations but they are not all of the same amplitude. The weakest drop from the basic 3 Volts down to 2.5 Volts, the strongest drop down to zero. This happens because some disintegrations take place near the outer wall or in the terminal areas of the cylinder, where the electric field is weakest.

R5, **R6**, **C7** and **IC1A** act as a “schmitt trigger” which lets only the pulses that exceed a certain voltage pass through. The limit voltage is given by the value of **R6**.

With **R6** = 100k, only the pulses that drop by at least one and a half Volt are counted.
With **R6** = 220k, only the pulses that drop by at least 1 Volt are counted.
With **R6** = 330k, only the pulses that drop by at least 0.7 Volt are counted.
With **R6** = 470k, only the pulses that drop by at least half a Volt are counted.

Increasing the value of **R6** also increases the sensitivity of the chamber because the events that occur in the terminal areas of the cylinder where the electric field is weakest are also collected. But increasing the sensitivity also makes the camera more sensitive to mechanical disturbances. Better not to exceed 220k, otherwise the camera would become too sensitive to external noise and vibrations.

In the latest ion chambers we have adopted a standard value of **220k** for **R6**.

At the output of **IC1A** the pulses are positive and all the same both in height and in width (3.3 Volt and about 5 mS).

Resistor **R7** carries the signal to the output wire and isolates **IC1B** from the capacitance of the wire. In this way there are no auto-oscillations and overshoots even with very long cables. Cables up to lengths of many hundreds of meters can therefore be used.

Diodes **D2** and **D3** are special components that protect the electronics during thunderstorms, blocking any extra-voltages coming from the connection cable. In the past some chambers, which had very long cables, collected enough magnetic energy from lightning to burn out. With these diodes it will never happen again.

Signal amplifier - Connecting Cables

If the wire that goes to the Theremino Master PIN is short you can use the normal male female extension cables unshielded. It can also connect several extensions in series to increase the length.

If the cable is longer than a few meters it is good that it is shielded (a standard microphone cable with the cord strain relief and the two wires red and black is fine).

For safety reasons and according to the law, the cable, even if shielded, should not go in the ducts or pipes in the electrical system.

Important: If the cable is longer than a few meters, you must stop the signal wire and connect it through a 100k resistor, placed within a few centimeters from the Master PIN. This prevents noise from the cable may exceed the tolerable voltage input from Pin (3.3 volt maximum). If it exceeds 3.6 volts, with current greater than 100 uA, the micro-controller interrupts the communication with the USB. If communication is lost then you must manually restore the HAL application, press the button "Recognize"

Signal amplifier - Checking the voltages

To ensure that the chamber works well, just mount it carefully and test it with Theremino Geiger. But, having a meter, it would not hurt to also give a controlled voltages.

Turn on, wait thirty seconds, and then check with a multimeter the voltage between GND and points TP1, TP2 and TP3.

During this check, since you are taking the top cover open, you must try not to disturb the FET. Do not put your hand in the hole, remove any energy-saving lamps. Avoid shaking the chamber and maybe connect the tester with wires and wait 30 seconds, without moving anything, that tensions stabilize.

Also seek to shield the upper part, partially closing the lid. All lids and jar must be earthed. Those with their lower and upper anchors welded wire with a provisional, so that you can open and close during the tests.

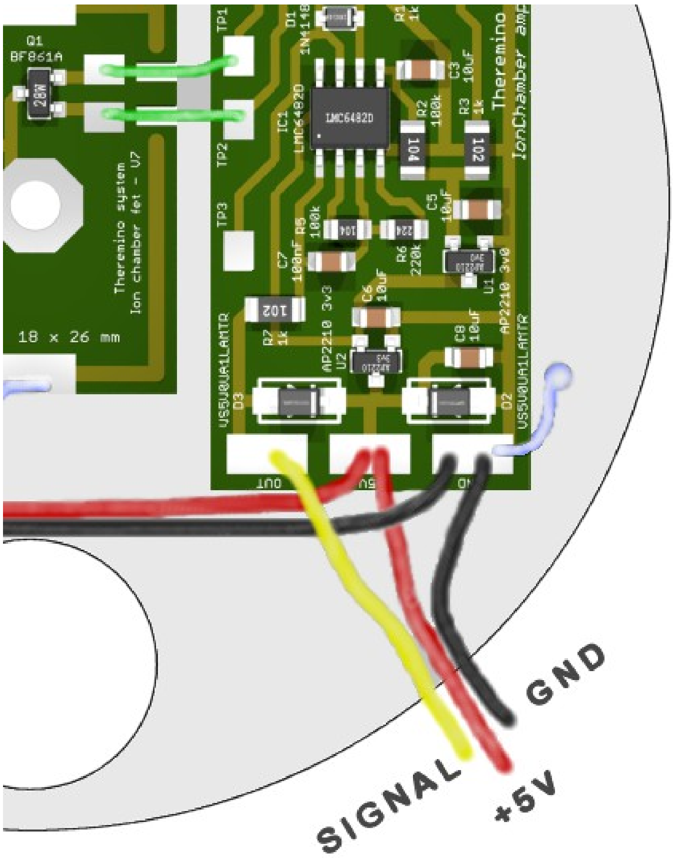
- On TP1 there must be about 2.6 volts
- On TP2 there should be about 0.36 volts
- On TP3 there should be about 3 volts

By placing an oscilloscope you can either measure the noise at TP3 show that the pulses, as explained in the last pages of this document.

Signal amplifier - Connections

The amplifier module receives the signal from the FET by means of two small insulated wires (green in this image).

Note that these wires pass through two slots cut into the FET PCB. The two slots will then be covered by the shielding plate.



The amplifier module (like all the other modules) is fixed by means of two bare wires, blue in this image, welded to the base in tinplate or covered with adhesive copper tape.

The three wires at the bottom (yellow, red and black) go to the output connector and from there they will continue with a shielded cable up to the pins of a Theremino Master module.

To make the wiring, small insulated wires with an external diameter of about 1.2 - 1.5 mm are used.

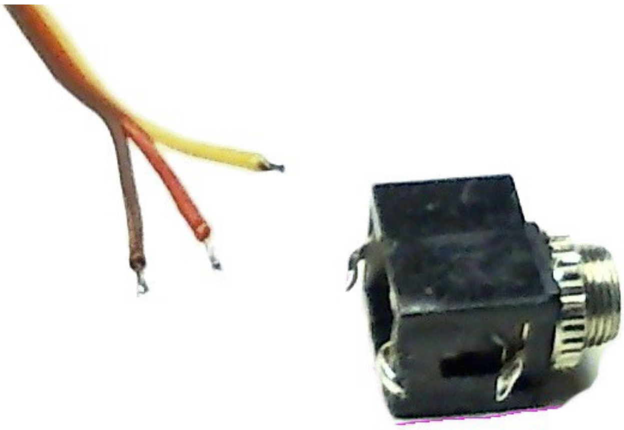
On eBay you can find excellent colored threads covered in silicone.

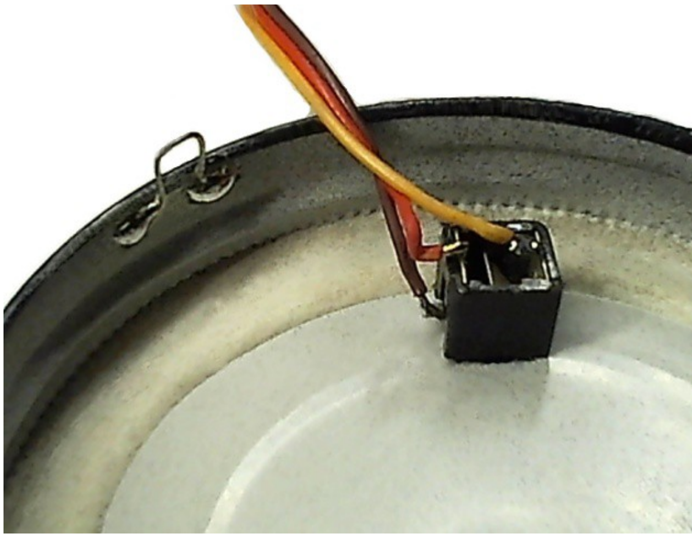
The advantage of these wires is that they are soft and with a large number of copper wires inside.
In addition, the insulating coating is easy to peel and does not melt during welding.
If you get used to using them you won't be able to do without them anymore.

Prepare the jack

The threads of good quality are obtained by extension male-female, we must get used to sacrifice. From a single extension yields a female with 15 cm cable and a length of 15 cm cable (the male is usually not needed and it is thrown away). Sacrificing the extension costs less than buying separate cables and connectors.

First of all, strip, and tin arricciolare well the three wires.





Shorten the terminals of female jack with the clippers, stagnarli well and finally solder the three wires to the socket. Check that the brown wire is connected to the base, the red wire to the central and the yellow wire to the tip of the jack. If necessary, insert a jack and check with the tester.

Place a piece of heat-shrinkable sheath, heat it with the lighter or even better with a hot air gun or with a modified dryer (with an outlet pipe metal to reduce the size of the flow of outgoing air).

The connector should be well insulated and the cable must exit the base. Cut the top of the sheath, heat and crush again. Minimize the size of the connector. If it is too large it becomes difficult to close the cover.

Connect to ground covers

The treble hooks that connect with the jar lids have not only a mechanical function, but also serve to connect them electrically grounded.

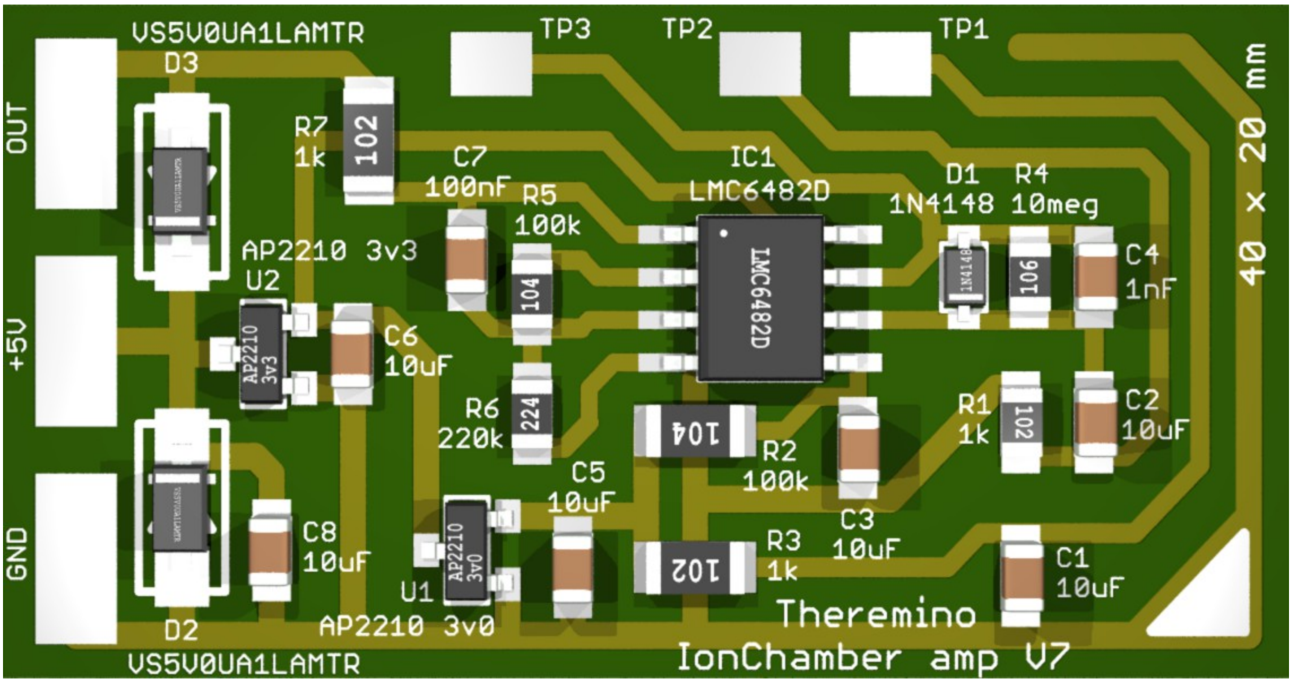
Before doing the electrical tests, you must connect bottom cover. We recommend that you solder all of the first top cover and solder at least one for each of the other two.

The ion chamber is terribly sensitive to electric fields. If you miss part of the shield does not work, Or generates additional pulses, which do not come from Radon but from the surrounding environment.

If you miss part of the shield also tests on noise TP3 with the oscilloscope will not be significant and you will see a strong ripple at mains frequency (20 msec cycle equal to 50Hz).

Test the chamber with the oscilloscope

To ensure that the chamber functions well enough to mount it carefully and test it with TheremínoGeiger but who possessed an oscilloscope could also do some additional tests.



With the version 7 it is possible to make measurements even with the chamber open, provided that the holes towards the internal chamber are well covered with a fine brass mesh and that the central circuit of the FET is covered with the earthed metal shield.

Furthermore, to minimize the disturbances coming from the electrical system, it would be good to work on a large metal surface connected to ground with a wire. You can use a sheet of aluminum or iron, or a large sheet of copper-plated vetronite.

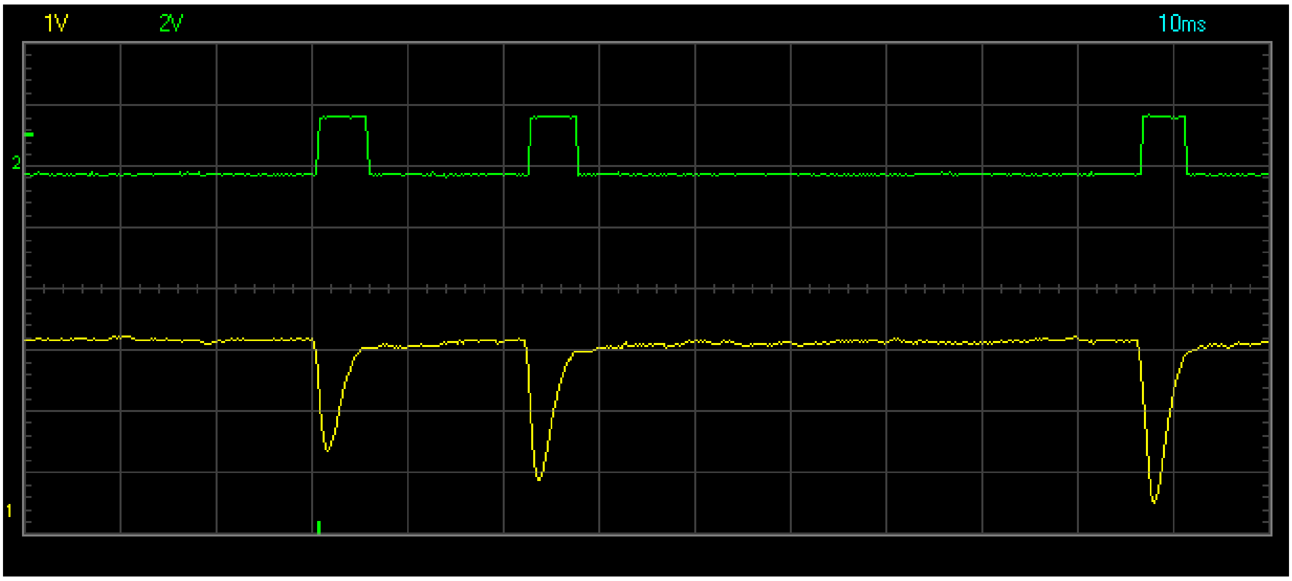
Normally you use a oscilloscope or sometimes a tester to measure voltages.

The main points where to make the measurements are:

- **GND** which is used as a zero voltage reference.
- **TP3** where there is the signal produced by radon before being squared.
- **OUTPUT** which is the squared output signal.
- **TP1** and **TP2** to measure the voltages on the FET (about 2.6V and about 0.36V)
- Top side of **C6** to control the 3.3 volts produced by the U2 regulator.
- Top side of **C5** to control the 3 volts produced by the U1 regulator.

Test the chamber with the oscilloscope - 2

In the test with the oscilloscope should especially check that the signal is noise-free signal that is that the parties are flat with no pulse. If the chamber is well-built noise should be less than 100mV (less than a tenth of a yellow square on the graph, which is set to 1 volt per panel).



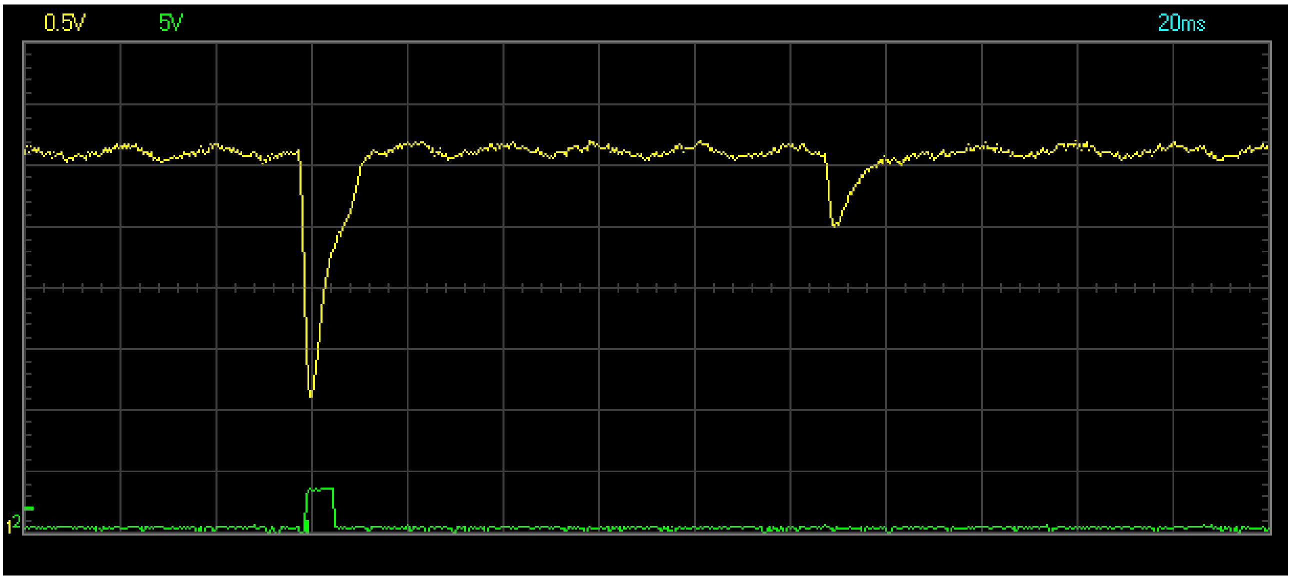
The yellow trace is the signal on TP3. In this point the pulses produced by the Radon are wide few milliseconds and fall of some volts, compared to the normal voltage that is approximately 3 Volts.

Some impulses down only half a volt, others may be much stronger and drop to zero volts but most of the pulses is expected to fall to a volt or two.

The pulses of amplitude greater than about 1 volt, produce a positive pulse output off about 5 or 10 mS (green trace). To see also the output pulse must be connected one of the oscilloscope probes to the output signal, called "OUT" in the wiring diagram.

Test the chamber with the oscilloscope - 3

The graph below shows an ion chamber with the top cover slightly raised specifically to increase the noise. The yellow trace (which corresponds to TP3) has been set to a half volts per square so as to highlight the undulations.



In this image, the noise coming from the electrical obvious cause high waves about 150 mV and with a period of 20 ms (50 Hz electricity network). The track will also see small steps very thick, produced by switching power supply.

The maximum tolerable noise are approximately 500 mV peak-to-peak, besides you can check false counts produced by the noise and the loss of several pulses of Radon.

If the noise exceeds 200 mV (in practice when they begin to become apparent to the oscilloscope) you should try to figure out where to come and find ways to eliminate them.

Very noised track

It can happen that the track is noisy, with random noise, also very large. The track swings in an uncontrolled way and, in some moments causes bursts of counts. The bursts of pulses are easily recognizable by ear. Their appearance in the graph of Theremino Geiger is shown on the following pages (Appendix 3).

The reasons that cause these noises may be many:

- Central electrode not securely attached that moves into the terminal hole.
- Sparkles caused by moisture or sections of coating is not electrically connected.
- Adjustments of mechanics.
- Dust or other small particles (midges), which are then attracted to and repelled by the high voltage. (the particles are charged and discharged repeatedly like these: ***Video1*** – ***Video2*** - ***Video3***)

A chamber newly built or mistreated is noisier. After a certain time the high voltage paste all the particles to the walls and mechanical stabilizes. If it does not, thoroughly clean the inside with compressed air and check the mechanics, the weldings and the internal conductive coating.

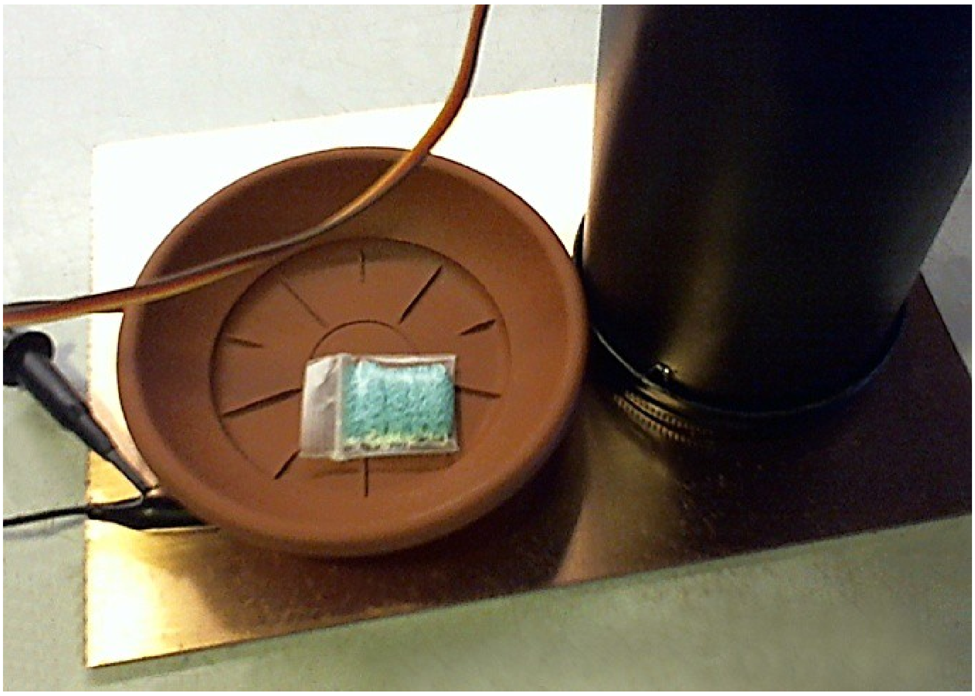
Test the chamber with thorium - 1

Normally the chamber generates approximately one pulse every two minutes, then test and see signals with an oscilloscope is pretty boring. Fortunately, in addition to Radon (Rn222) there is also the isotope Thoron (Rn220) that seems made to test the ion chambers. The Thoron behaves like the Radon but you can create and remove quickly. The Thoron decade also much faster than the Radon (about 1 minute instead of 4 days).

Radon comes down from the Radio and uranium (relatively abundant in the natural environment) and Thoron descends from Torio, who was also present in nature and readily available with good concentration in the gas mantles for camping lamps.

The nets can be bought on eBay for a few dollars, look for words such as: "Thorium", "Mantle", "Geiger counter test source", "Thorium", "Mantle camp." There are also meshes that do not contain Thorium then make sure you buy the right ones. If in doubt, write to the seller, to confirm explicitly that the mesh is slightly radioactive.

The nets are not dangerous if you avoid spread around their fragments, of respirarli or eating them. The nets can lose fragments and dust of thorium, then immediately seal them in plastic bags thick and not ever open them. When I'm not in a plastic bag, you have to handle them with care. If you want to split them into several samples gear well. Use a mask to avoid breathing the fragments, cover the table with a sheet of paper. Do not blow or breathe loudly while you work. At the end of the sheet of paper, folded carefully, it will contain dust and microscopic fragments that are harmless when diluted in water or in the ground (it is from them that come).



To fill the chamber ion Thoron you have to act a bit 'weird. The Thoron (and Radon) are highly volatile and need very little gas to disperse in the air. Therefore you must keep the mesh in a closed area without drafts. The ideal is that it fits on a saucer jar of the chamber, you lay the mesh in the saucer and then pose the chamber above. In this way the Thorium is located in a chamber almost sealed and slowly fills Thoron.

Test the chamber with thorium - 2

The Thoron is heavier than air, so it fills up before the saucer and then begins to fill the jar from the bottom. Within a few minutes the pulses generated from the chamber and greatly increase the frequency of a few tens of minutes after the chamber is completely full of Thoron.

In this graph we see that the area to the left, without net, the pulses are from one minute to one every several minutes. After positioning the mesh pulses thicken almost immediately. But the climb is very slow because the integration time is set to 1800 seconds to 30 minutes. Wanting a quicker response, you should press "New Measure", immediately after placing the rack.

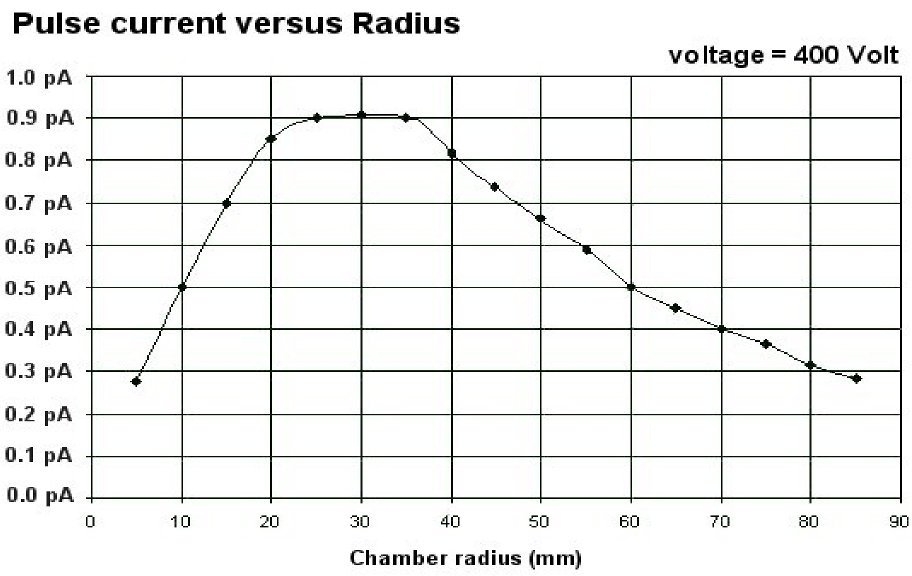
If the saucer close properly and there are no strong air currents, the number of counts can increase to more than 300 Bq/m3 (more than 10 pCi/l). Sometime you should hear even more ticks per second.

To make the rebuttal takes off the saucer and is passed clean air in the chamber, holds it up and waving a piece of cardboard. Better not blow into the chamber because the wind could dampen it.

By doing these tests it turns out that it takes some time to clean the chamber. Probably the Thoron paste electrostatic effect on the walls and the chamber remains "dirty" long. This same effect occurs if you make measurements in locals little radioactive, after measuring a local very radioactive. Radon has a much slower decay of Thoron so the chamber can remain contaminated for weeks. We therefore recommend that, before every important measure, to position the camera outdoors or in a very airy and check that the number of pulses per minute is low. Wait until the pulses fall, or clean the chamber with plenty of air. Better to use a dryer with cold air and compressed air that would be too violent.

Appendix 1 - Dimensions and electric field

The literature indicates that the ion chambers for maximum electrical signal beam ion chamber should be comparable to, or greater than, the average path of the alpha rays in the air (about 4 cm), In addition, the electric field must be sufficient to deliver fast electrons and ions, before they recombine.



According to this graph, we need at least 110 volts per centimeter and the chamber must have a minimum radius of 25 mm.

We have verified this information with our one liter chamber with 40 mm radius:

Chamber voltage (1)	Volt/cm	Pulse voltage (2)	Pulse rise time
20 Volt	5	0.6 Volt	15.0 mS
40 Volt	10	1.0 Volt	9.0 ms
100 Volt	25	1.2 Volt	4.0 mS
150 Volt	38	1.5 Volt	3.0 mS
200 Volt	50	1.5 Volt	2.5 mS
300 Volt	75	1.6 Volt	2.0 mS
400 Volt	100	1.7 Volt	1.5 mS
500 Volt	125	1.8 Volt	1.1 mS
800 Volt	200	1.9 Volt	1.0 mS

(1) *chamber radius = 40 mm*

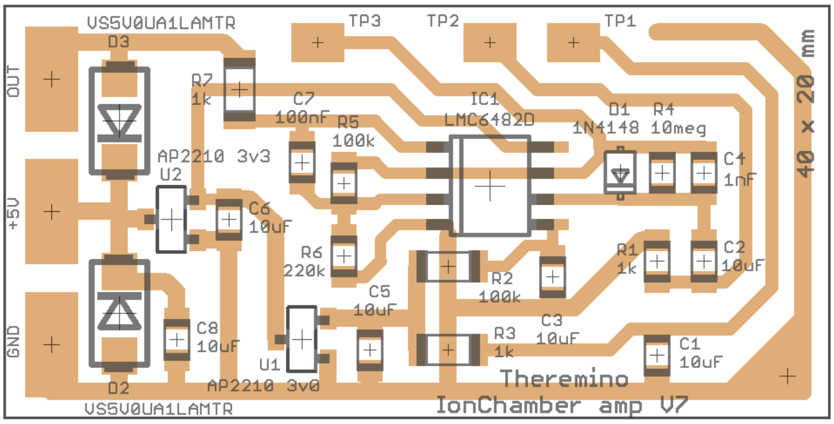
(2) *voltage amplified by 1000*

Therefore we decided to use an electric field of about 110 - 120 volts per centimeter, as the radius of our chamber is 4 cm, the voltage should be about 440 - 480 volts.

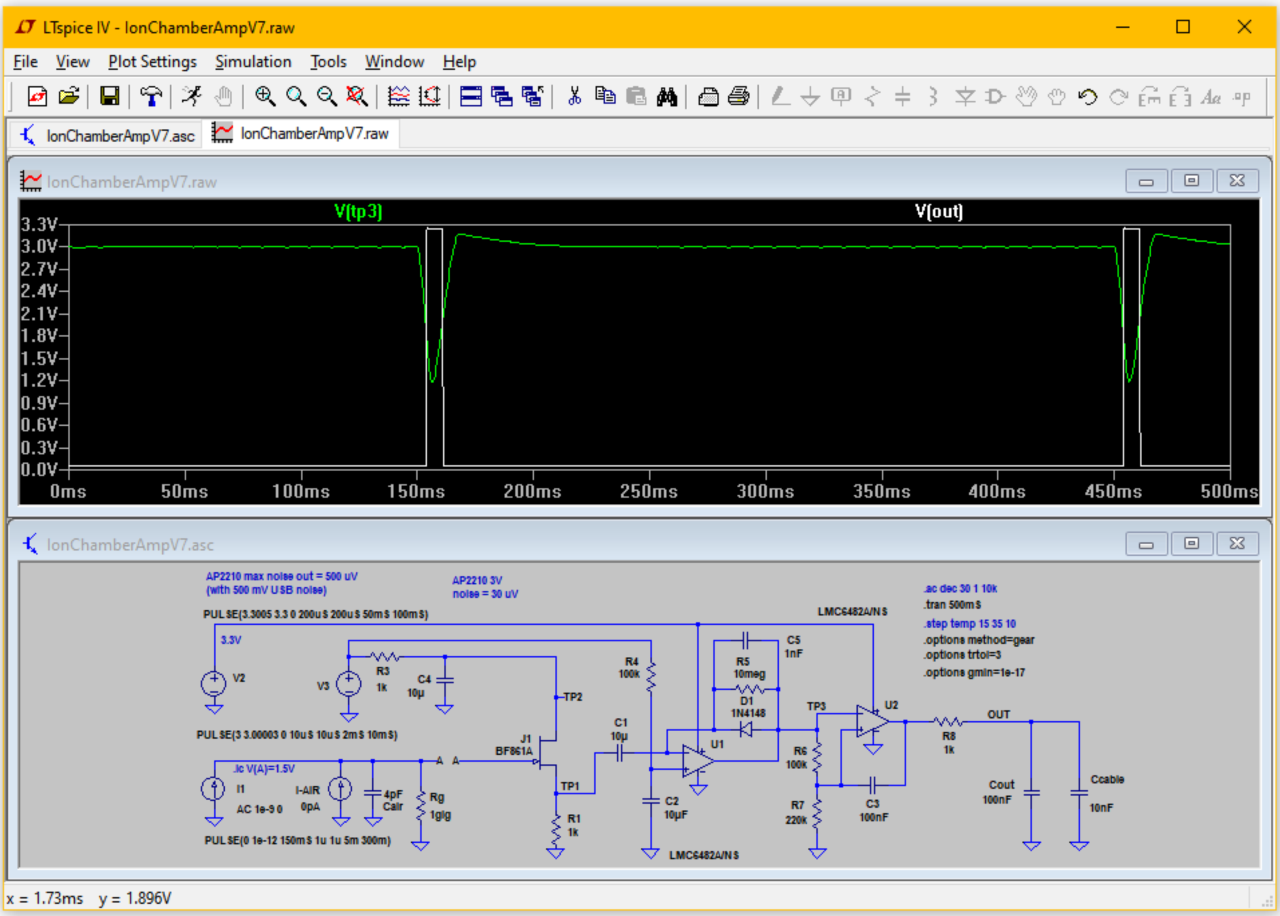
Finally, the standardized voltage we decided to use is 475 +/- 5 volt.

Appendix 2 - Simulations and printed circuits

In the file ***IonChamberV7.zip*** are available wiring diagrams and PCB in Eagle format, the rendering of Eagle3D and electrical simulations in LTSpice format.



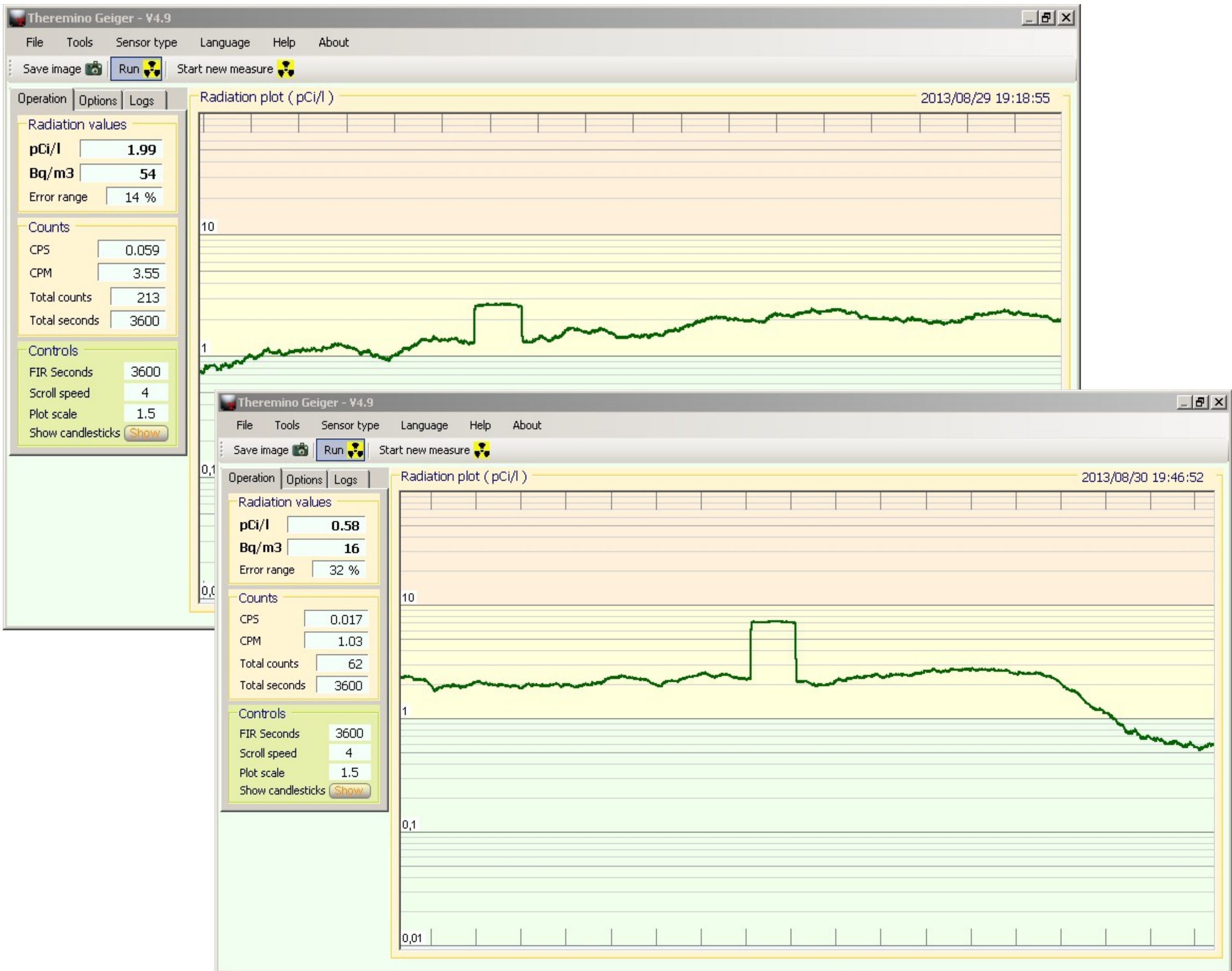
The latest version of all the files can be downloaded from here:
www.theremino.com/en/blog/geigers-and-ionchambers/ionchamber-improvements#version7



Appendix 3 - Pulses not caused by Radon

Various mechanisms may produce spurious pulses, not caused by radon. For example the humidity that makes the air conductive. Or a dust particle can enter (dust jumps between the two electrodes and creates many problems). Or a heavy vehicle passing could produce strong vibrations. Or strong electrical noises like storm lightnings.

In all these cases are produced bursts of many pulses concentrated in a short time. These events are easily distinguishable because they cause a step in the graphs of duration equal to the set filter. In the next image the filter was 3600 seconds (one hour) and you see that when the time of the filter curve returns to its normal level.



To avoid these problems, use dust filters on the two external covers, insert an isolation for vibration, with soft foam and place the camera on the floor near a wall or in a sheltered corner. In difficult cases, you may think to prepare a plan isolated with a large heavy tile, granite or marble, suspended on a layer of foam.

Avoid that the environment in the extent to produce loud noises, animals or children can move the camera and avoid too violently to open the windows and doors slamming.

Appendix 4 – Dust filters

The dust filters are two, on the outside covers holes. Here is a simple and effective way to secure them. A second square of brass mesh is welded on one corner. On the opposite corner is welded a metal plate or a piece of stiff wire. In this way, the filter can be taken on and off easily. Place the filter being careful to cover well the hole and fold the plate to secure it.

The filter can be open cell foam (try to blow the air to see if it goes well). Or it could be filter paper for vacuum cleaners or even a piece of thin cloth.

The presence of a second brass mesh, greatly increases the shielding for the electromagnetic fields. With double mesh, also approaching a hand to the hole, the noise at mains frequency (measured with the oscilloscope on TP3) do not increase appreciably.