EMF 2022 Geiger Counter – Assembly Instructions

v2.1 – 2022

yannick.verbelen@inventati.org

The Geiger counter is designed with only through hole components that are easy to solder at any level of soldering experience. The text overlay on the circuit board is self-sufficient at guiding the assembly process, indicating which components go where. If you have already soldered circuits together, then you won't need a guide! But if you do need some help, here are step-by-step instructions to get you going.

0. Tools

To assemble the circuit board, you'll need the following tools:

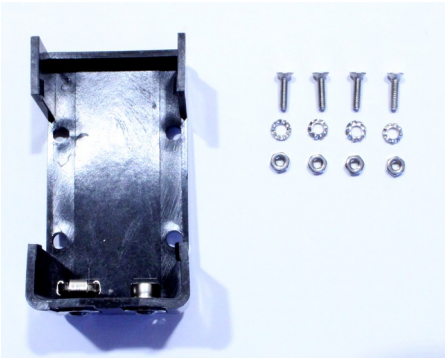
- A solder station or solder iron set to 350°C
- A moist sponge to clean the solder iron tip
- Solder wire, preferably a lead-tin alloy
- A screw driver with flat and Philips head
- A wire cutter
- Some acetone and a brush to wash flux residues off after soldering

And of course, you'll need a blank circuit board!

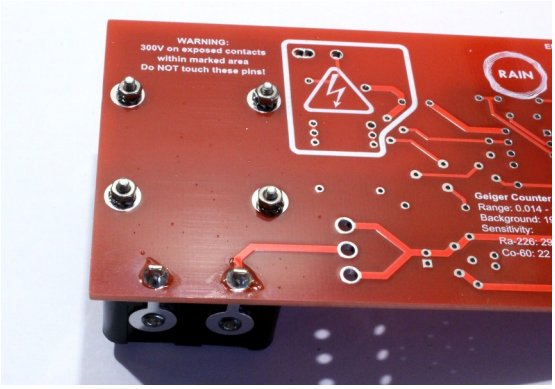
Place the Printed Circuit Board (PCB) on the table in front of you. It has 2 sides: the side with component values and outlines printed on it is the top side, this is the side you'll be pushing components through. The other side has calibration values printed on it and is the bottom side. This is the side components are actually soldered.

1. Battery

Components: Battery holder, 4 x screw, 4 x washer, 4 x nut



Plug the battery holder (position BT1) into the PCB such that the 4 mounting holes in the holder line up with corresponding holes in the PCB. Push one of the countersunk screws through the holder, with the head of the screw on the battery holder side. Drop a star washer over the protruding screw end on the bottom side of the PCB and loosely fix it in place with a nut. Repeat for the other 3 screws. Use a small Philips screwdriver to tighten each of the 4 screws until the countersunk heads are flush with the battery holder. Solder the 2 electrical contacts of the battery holder and trim the leads. Do not solder the nuts!

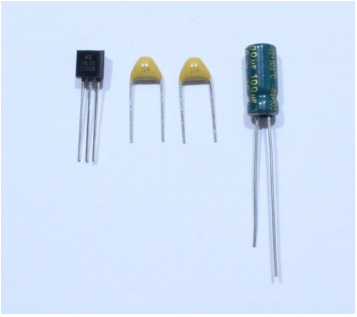


2. Switch
Components: Switch

Open the bag containing the switch and discard washers and nuts – these won't be needed. Push the switch in position next to the battery holder. It can be installed in either direction so don't worry about polarity. Solder the 2 electrical contacts of the switch, making sure the switch is flush with the PCB. Ask someone else to hold the switch in place if necessary.

3. Voltage regulator
Components: 78L05, 2 x 100nF capacitor, 100µF 16V capacitor

Beware: the 78L05 is a black component with 3 pins, but there are other parts on the board with an identical package!! Check the inscription on the package to verify you have the correct one, the text should be "WS 78L05" followed by smaller numbers.



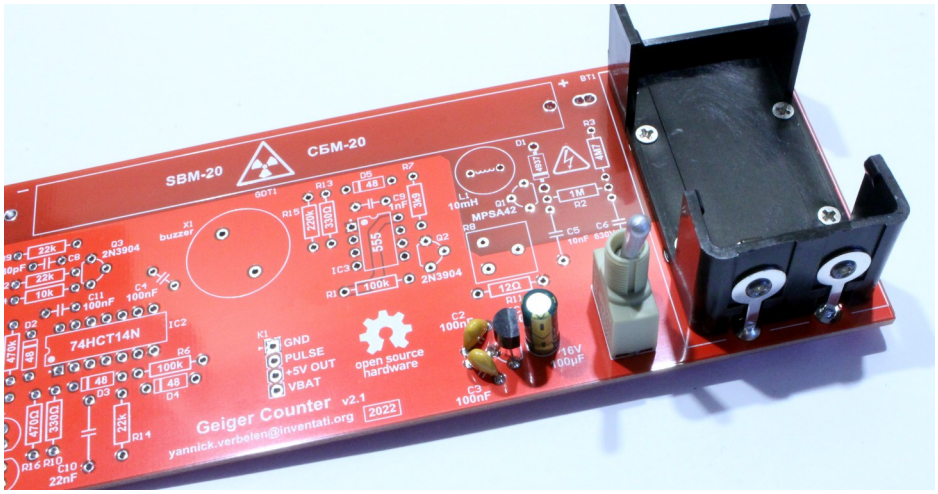
Push the voltage regulator in the IC1 position, right next to the switch. Bend the leads to fit it into the holes. Look at the white contour printed on the PCB for polarity; the chamfered side of the voltage regulator should line up with the line on the board, and the rounded side with the half circle. Push it far enough to have an equal length of leads on either side of the board, i.e. push it in

halfway. This is one of the few components in the circuit that doesn't have to be flush with the PCB. Friction will hold it in position. Next, install the 100µF electrolytic capacitor. It is easily recognisable as a green cylinder with gold coloured text printed on it.

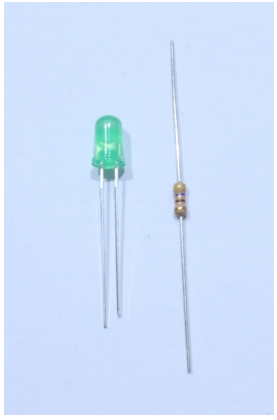
Beware: electrolytic capacitors are polarised, the longest of the leads is the positive side and the shortest of the leads the negative side. Search the position for C1 next to voltage regulator, and orient the capacitor such that the longest of the leads is towards the "+" symbol on the PCB.

Finally, look for 2 tiny yellow 100nF capacitors. They have the text "104" printed on them. Unlike electrolytic capacitors, these tiny ones don't have a polarity so they can be installed either way. Their positions are C2 and C3.

Solder all 4 components in place. The voltage regulator, like all semiconductor components, is quite sensitive to heat so try not to make it too hot while soldering: heating the leads for a few seconds should suffice.

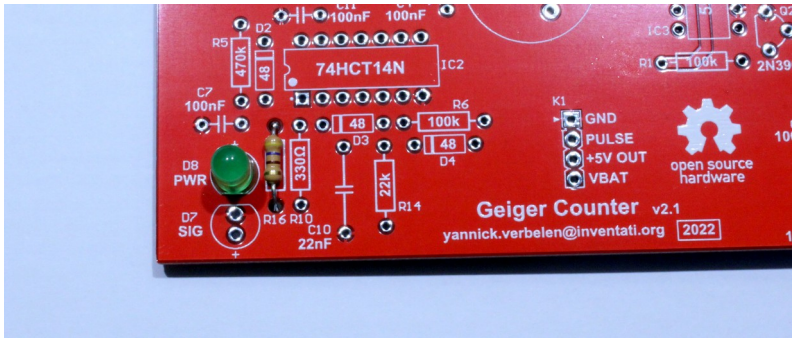


4. Power LED
Components: 470Ω resistor, green LED



Every circuit needs a green LED to indicate whether it's turned on or off. This LED has a spot in the bottom left corner of the board, at position D8. It's marked as "PWR". LEDs are polarised components, so they have to be installed in the correct orientation. One of the edges is chamfered, which corresponds with a straight line on the PCB. Just like capacitors, they also have one lead that is longer than the other, which indicates the "positive" side which is called the anode. Make sure the longest of the leads lines up with the "+" sign on the PCB.

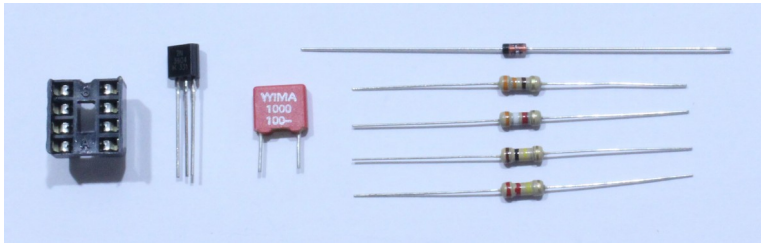
Right next to the LED is a spot for its series resistor, with a value of 470Ω, in position R16. Bend the leads slightly if necessary to prevent LED or resistor from falling out when flipping the board over, and solder both components in place.



POWER SUPPLY TEST
With the power supply components installed, it's time for a quick test. Insert a 9V battery in the holder, and flip the switch. If everything is soldered correctly so far, and the polarity of the voltage regulator and LED is correct, then the green LED should light up when the switch is flipped!

Remove the battery again after testing.

5. Oscillator
Components: 8-pin DIP socket, 2N3904 transistor, 1N4148 diode, 1nF capacitor, resistors of 330Ω, 3k9, 100k, and 220k.

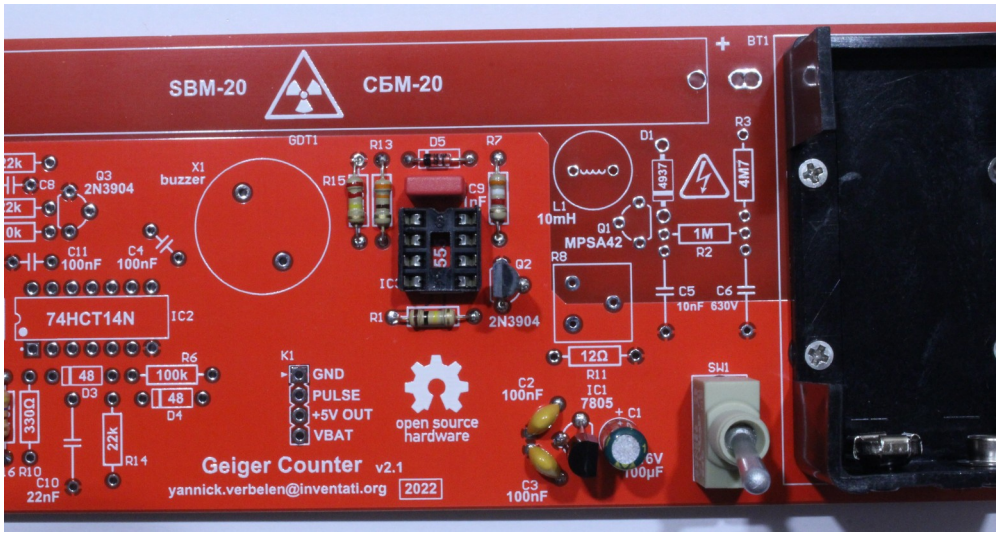


The oscillator circuit is built around a classic 555 timer IC, one of the oldest integrated circuits ever designed but still used today. The IC itself is rather fragile, so it's mounted in a socket instead of soldered directly to the PCB to save it from the solder iron's heat. Start with the socket, which must be mounted with the correct orientation. The orientation marker is a notch on one side, which matches a notch printed on the PCB. The notch should be pointing upward. Proceed with soldering the socket. This can be done easiest by holding the socket in place with one hand, and then applying a little bit of solder on the solder iron tip to immobilise the socket temporarily. Do this with 2 pins on either side, for example pins 1 and 5, or 4 and 8. Once it's stuck, solder the remaining pins and finish by resoldering the temporary pins properly. Don't install the IC yet, that's left for later!

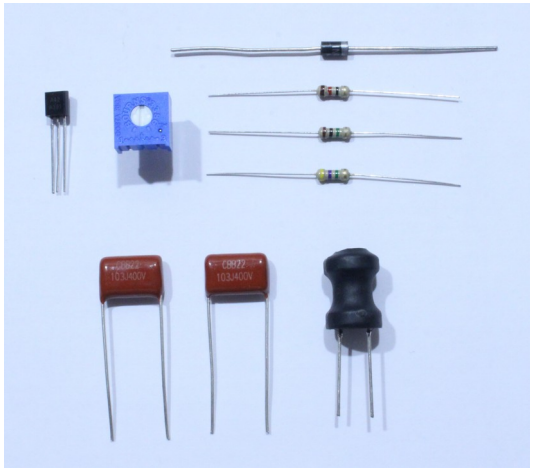
Next up are the discrete semiconductors: the 1N4148 diode and the 2N3904 transistor. The diode is a tiny orange glass cylinder with numbers "41" and "48" printed on it. Like a LED, diodes have an anode ("positive" side) and cathode ("negative" side), but for diodes, both leads have the same length. Instead, a black line one the glass body indicates the cathode, which corresponds to a line on the PCB at position D5. Next, install the 2N3904 transistor. It has a package that's identical to the voltage regulator, so make sure to check the text printed on the component: it should be labelled as "2N3904". The contour printed on the PCB indicates its orientation at position Q2. Solder both components and clip the leads short.

Next up is the 1nF capacitor, easily recognisable by its rectangular shape and red colour. Installed at position C9, it doesn't have a polarity so can be oriented either way.

Finally, install the 4 resistors. Look at the colour coding on each resistor to verify the values match with the positions R1 (100k), R7 (3k9), R13 (330Ω), and R15 (220k). Solder capacitor and resistors in place, and clip the leads short.



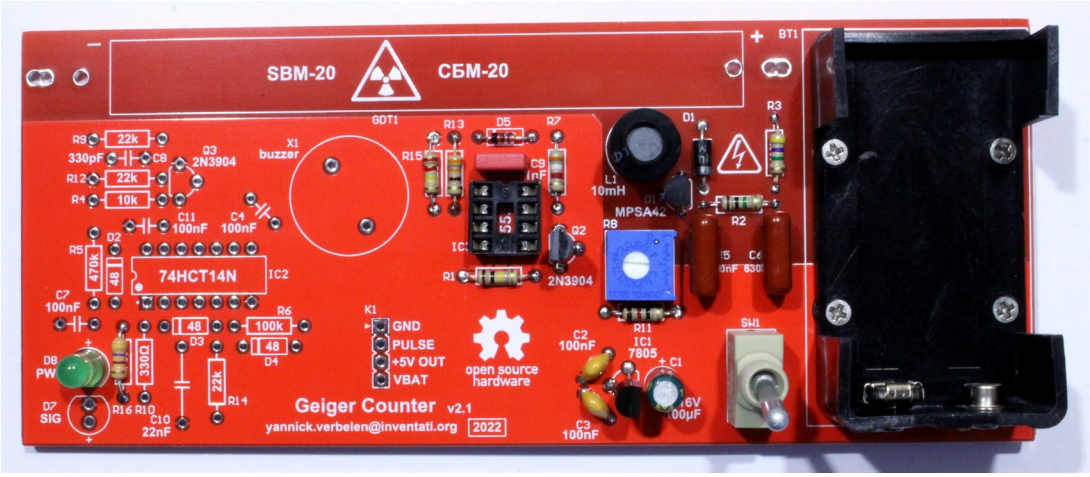
6. Boost stage
Components: MPSA42 transistor, 10 mH inductor, 10R trimmer, 1N4937 high voltage diode, resistors of 12Ω, 1M, and 4M7, 2 x 10 nF capacitor.



Switching current through an inductor will cause the voltage to spike, and that effect is used here to generate a high bias voltage for the SBM-20 Geiger tube.
As before, start with the semiconductor components. Look carefully for the high voltage transistor of type MPSA42, which has an identical package as the low voltage transistor from the previous step. Check the text printed on the package to verify it reads "A42". Its position is Q1. As with all diodes, the polarity of the 1N4937 is marked with a ring, which lines up with the marking at position D1. Solder Q1 and D1 in place.

Up next is the trimmer, a square blue component with with dial in the centre. Its pins have a triangular layout, and it only fits one way on the PCB footprint. As with the socket in the previous step, solder it in place by tinning one of the leads while holding down the component with the other hand. After soldering the remaining pins, trim all leads.

Next, install and solder the inductor at position L1, and the 2 high voltage capacitors at positions C5 and C6. None of these components has a polarity, so they can installed in either orientation.
Finally, solder the resistors of 12Ω, 12M, and 4M7 in positions R11, R2, and R3 respectively. Clip all the leads short.



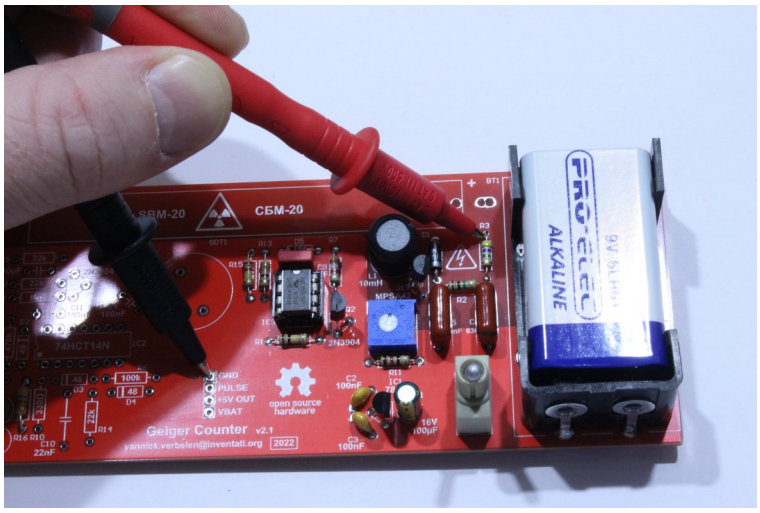
BOOST STAGE TEST
Install the NE555 in its socket, paying attention to its orientation. This IC has 8 pins and a notch, so make sure the notch on the package lines up with the notches on the socket and the PCB. The boost stage is now armed!

Pop the battery back into its holder, then grab a multimeter and turn it into DC voltage mode.

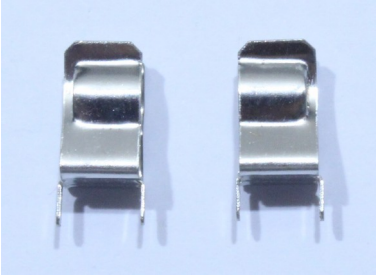
Flip the switch on the PCB, the green LED should light up and you may hear a faint high-pitched buzzing sound. Using the multimeter, measure the voltage between ground (a contact for ground can be found at K1) and the top end of resistor R3. The multimeter should show a voltage in excess of 150V. If the voltage is lower than 150V, stop here and check the circuit.

Using a small screwdriver, turn the dial of trimmer R8 very gently to increase the voltage, and watch the multimeter. Trim the output voltage of the boost stage to be around **300V** DC.

CAUTION: Although the charge stored in the capacitors C5 and C6 is quite small, touching any of the high voltage contacts while the capacitors are charged will result in an electric shock!
As long as the circuit is turned on, stay clear of any exposed metal within the area marked with a white contour line!



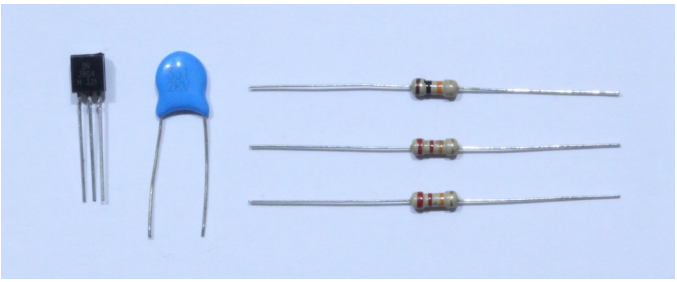
7. Geiger tube sockets
Components: 2 x GM tube socket.



At either end of the GM tube place holder at the top of the board, install a tube socket. Each socket has a “notch” that stops tubes from falling out sideways, so make sure to orient the sockets such that these notches are oriented outward.

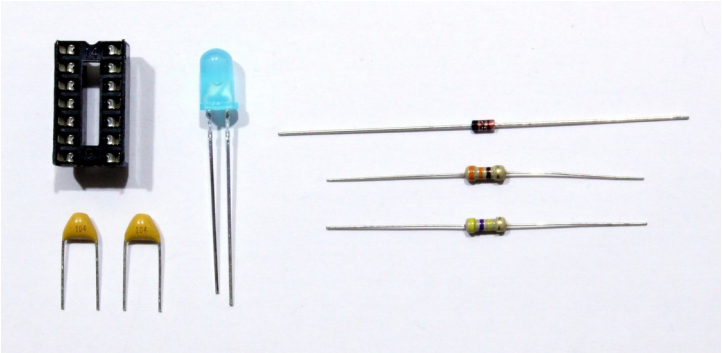
Don’t install the Geiger tube yet.

8. Pulse detector
Components: 2N3904 transistor, 2 x 22k resistor, 10 k resistor, 330 pF capacitor.



Solder a second 2N3904 transistor in position Q3, as with Q2 before. Proceed with the 330 pF capacitor, easily recognisable by its bright blue package. This capacitor doesn’t have a polarity and can be installed in either orientation in position C8. Finish up wih the resistors in positions R9, R12, and R4, and trim leads.

9. Pulse shaper
Components: DIP 14 socket, 1N4148 diode, blue LED, 2 x 100 nF capacitor, 330Ω and 470k resistor.

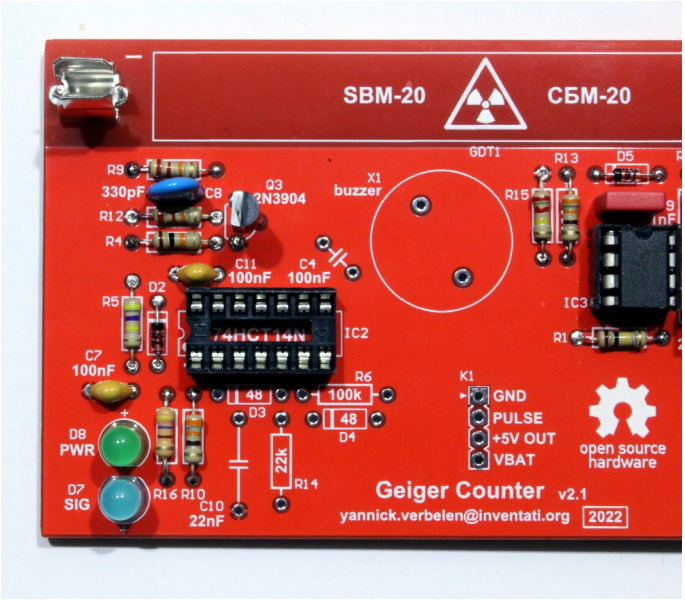


Pulses produced by a Geiger counter tube are very short, so they need to be stretched out to use them. The pulse shaper is an active circuit that changes the shape of the signal with a simple RC filter.

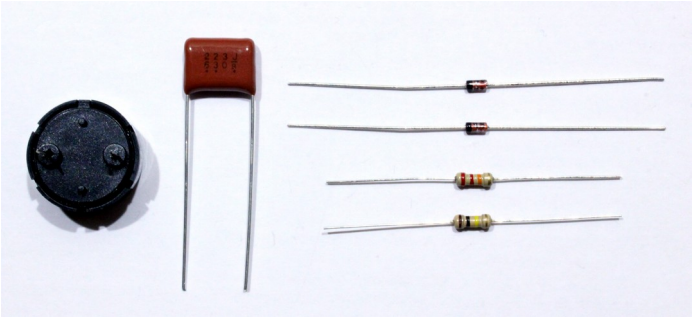
Start with the DIP 14 socket, and solder it in place using the same strategy as the DIP 8 socket before: hold it with one hand, then apply a little bit of solder to the tip of the solder iron an temporarily fix the corner pins in place. Once it's immobilised, do the other pins and finish up by resoldering the corner pins "properly".

Continue with the remaining components: solder the blue LED at position D7 taking care of its orientation (remember: long lead towards "+" on the PCB), and install the 1N4148 diode at position D2. Clip the leads.

Next, solder the 2 100 nF capacitors, one at position C7 and the other at position C11. Finish with the resistors: 330Ω at position R10, and 470k at position R5.



10. Buzzer
Components: 2 x 1N4148 diode, 22k resistor, 100k resistor, 22 nF capacitor, buzzer.



Almost there! Install the buzzer at position X1 and solder it in place. It doesn't have a polarity, so can be oriented either way. Continue with the 22 nF capacitor, a large brown capacitor that fits in position C10. Check its value, it should have the text "223" printed on it. Solder it in place as well. Like the buzzer, it doesn't have a polarity. Finish with the diodes in positions D3 and D4, and the resistors of 100k and 22k in positions R6 and R14 respectively. Clip the leads short.

11. Expansion port (optional)
Components: 100 nF capacitor, 4 way pin header

Do you intend to read pulses with an Arduino or other microcontroller, or use the Geiger Counter in a larger design? Then solder a 4 way header at position K1, which exposes the 9V battery voltage, the 5V supply voltage, ground, and a pulse out signal. VBAT can be used in either direction: it can be used to power an Arduino board for example, or it can be used to run the Geiger counter from an external supply if no 9V battery is installed.

The output is capacitively coupled with a 100 nF capacitor, installed at position C4.
If you don't intend to use the Geiger Counter with external boards, then skip this step and leave K1 and C4 unpopulated.

THE BEEP TEST
Install the SN74HC14N IC in its socket, paying attention to the polarity as indicated by the notch on the IC package and its socket.
Carefully install the SBM-20 Geiger tube in its socket. The polarity is marked on the tube with a "+" sign, and should be oriented towards the battery side.

Beware: the Geiger tube is an authentic Soviet era tube made in the 1970s and **very fragile**. Do not push down on the tube in the center, but only push on the brown bakelite rings.

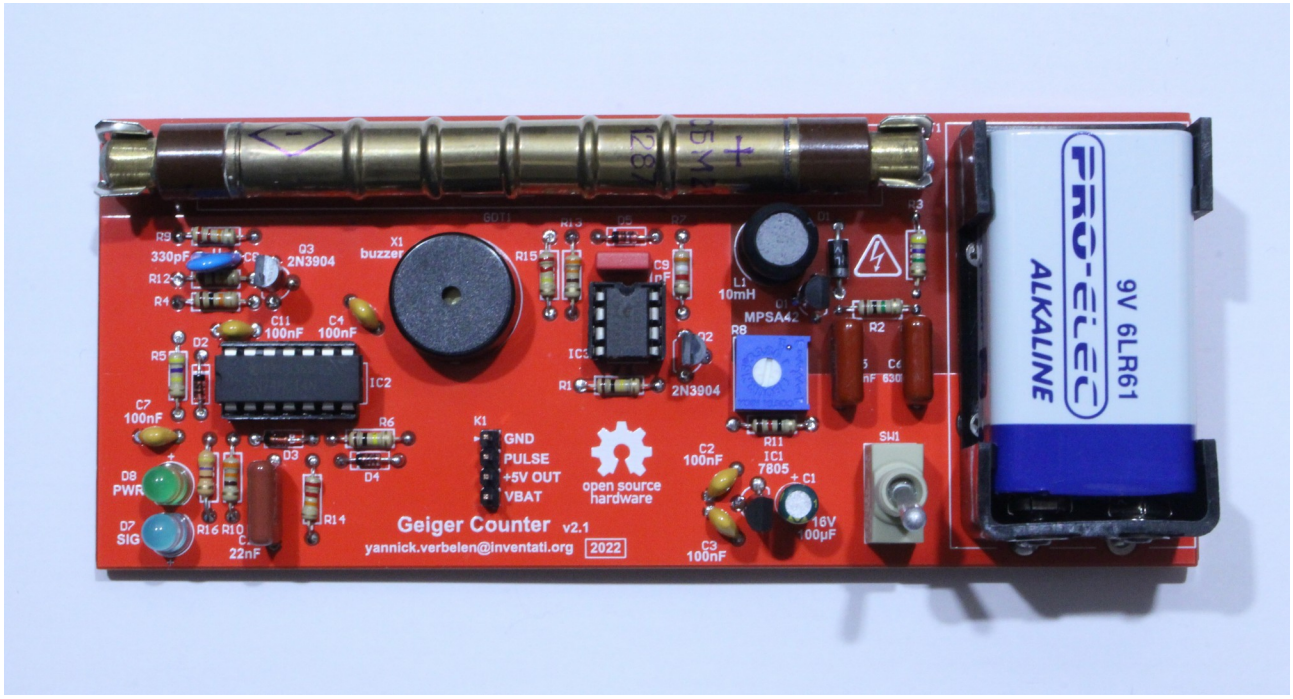
Re-insert the battery in its holder. The Geiger Counter is now ready for testing!

Flip the switch to turn it on. If everything is assembled as intended, the green LED should light up and you hear a short beep. The blue LED will also flash briefly.

If the green LED doesn't light up, check the battery and the position of the switch. Measure the resistance between the +5V OUT in and GND, if it's very low (under 100 ohms) you may have a short circuit on the solder side of the PCB.
If you don't hear a short beep when turning on, check the buzzer and polarity of the SN74HC14N in its socket.

If the blue LED doesn’t flash when turning on, check the LED polarity.

Due to the presence of natural radioactivity, the Geiger Counter will occasionally register a pulse. On average, the natural background radiation in Bristol is 19 beeps per minute.



12. Finishing touches
Components: 4 x silicone feet

Because the solder contains flux to facilitate the soldering process, some flux residues will remain on the PCB after assembly. These sticky residues are insoluble in water, but very easy to remove with apolar solvents such as acetone and a small brush.

Careful: acetone can also dissolve (some) plastics such as ABS, so keep it away from laptops! It is also easily flammable, so keep it away from hot solder iron tips.

Once cleaned, stick 3 or 4 of the self-adhesive silicone feet to the bottom of the PCB to lift it off the table, and preventing contact of the high voltage solder joints with conductive surfaces. Distribute the feet as far away from each other as possible for maximum stability, but don’t stick them on top of solder joints.

QUALITY CONTROL
Finally, get your Geiger Counter tested with a radioactive check source. Ask Yannick to test your Counter. If it passes the test, you'll get a Quality Control sticker for your counter, and you can take it home with you!

AND FINALLY…
The Geiger counter kit you've just assembled has a **commercial value of about $100**. Fortunately, thanks to our sponsors, the experience could be offered to you at EMF 2022 **free of charge**!

If you have enjoyed the workshop, please consider **making a voluntary donation**. Donations enable us to run this workshop at schools, and offer young people of disadvantaged backgrounds the opportunity to learn about particle physics with hands-on experiments.
BTC: 1LJQPXQPFZYVaPmcKmNKf28GJ1mrgf4MP1
Paypal: yannick.verbelen@gmail.com

Also consider **emailing our sponsors a picture of your geiger counter** and a few words of appreciation. In addition to sponsoring the electronic components, **Ingeniunda** is offering **free professional electronic engineering consultancy advice** to kick start your own project, or help commercialise existing ideas.

RAIN
ROBOTICS AND AI IN NUCLEAR
info@rainhub.org.uk

INGENIUNDA
info@ingeniunda.com

University of BRISTOL
physics-news@bristol.ac.uk