Notes about Sparkfun Geiger Counter

This report is some observations and notes that I made during a test of Sparkfun Geiger Counter. The item was purchased in July 2011. The item has the SKU number SEN-09848 at Sparkfun web site. The report covers the HV supply, the mechanical assembly of the GM tube and the circuit solution to pick out the pulses when detecting radiation. The basic reason I did a closer look at the circuit was the fact that the device had trouble with higher counting rates. Looking at the produced pulses from the GM tube they seemed peculiar and I wanted to figure out why.

High Voltage Supply (HVS)

The schematic for the HVS can be seen in figure 1. This is a copy of the official version found on Sparkfun web site.

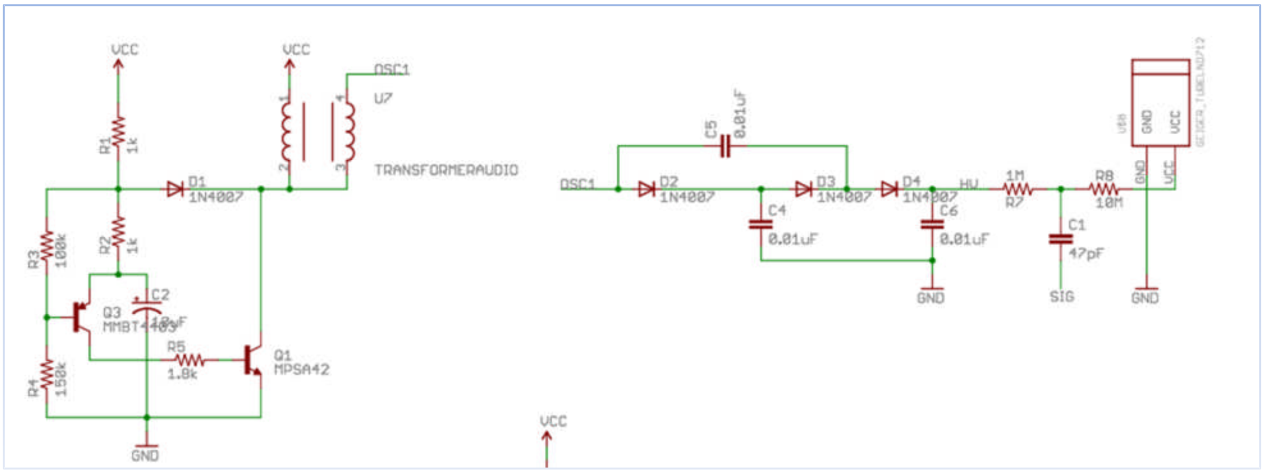

Figure 1

An oscillator consisting of Q1 and Q3 makes a square wave that is feeded to a step up transformer. The output from the transformer is rectified and multiplied and filtered. The output from the HV circuit is feed to the GM tube via R7 and R8. A measurement point is marked HV on the schematic in figure 2 above. We use this point as a measurement point in the following discussion.

On the web site you can also found the specification and data sheet for the GM tube. The GM tube has a recommended operating point of 500 volts and the operating range is specified to in the interval 450 – 650 volts.

An operating voltage below the recommended value will not harm the GM tube. However values considerable higher can surely harm the GN tube.

As can be seen from figure 2 a GM tube has five general working regions. Normally a Geiger Muller tube will work in region iV. In this region the GM tube cannot distinguish between different

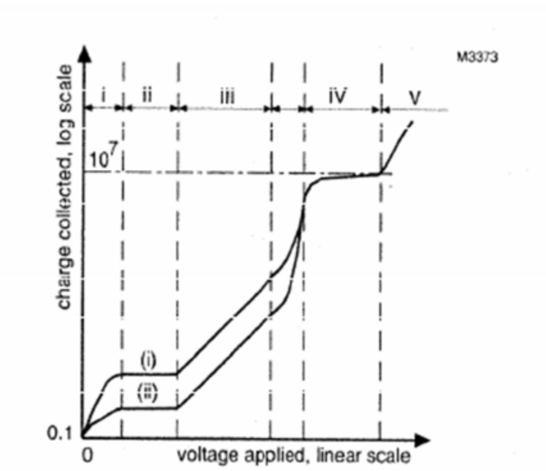

Figure 2

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types of radiation but on the other hand the sensitivity is excellent due to the avalanche effect. Going up to region V further increases the avalanche effect and produces a total ionization of the gas between the electrodes. You can even reach a self-sustaining discharge that will continue as long as the voltage is applied by a single detection event. This region shall be avoided due to that operation here can/will degrade the tube in a longer perspective. Also, the pulse will not be as clean and nice as in region iV due to secondary avalanche ionizations effects.

When reading the “tutorial” about the device I noted that the designer used a DVM (supposed to have an internal resistance of 10 MΩ) in series with a 10 MΩ resistor to measure the high voltage value. The measurement situation can be visualized as in figure 3.

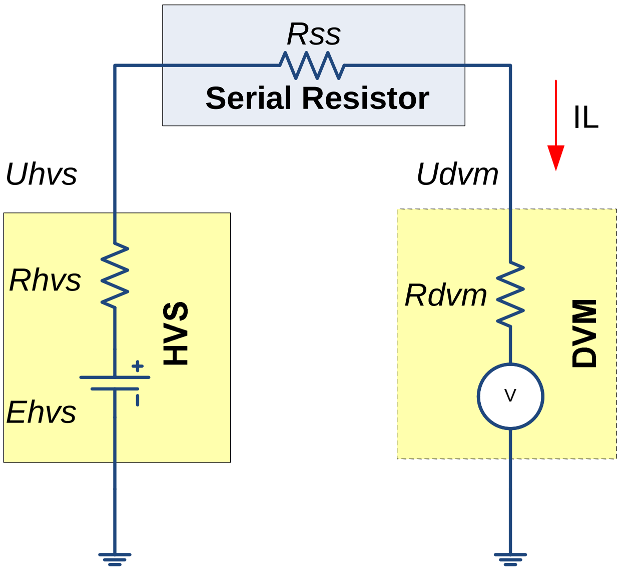

Figure 3

Here we have the following:

HVS = High Voltage Supply
DVM = Digital Voltmeter
Rss = Serial Resistor connected in series with DVM
Rhvs = Internal resistance of HVS
Ehvs = True voltage of the HVS
Uhvs = Measured voltage of the HVS at its terminal
Udvm = Measured voltage of DVM
Rdvm = Internal resistance of DVM
IL = Current through DVM

Applying Ohms law we will get the following:

$$iL = \frac{Ehvs}{Rhvs+Rss+Rdvm} \qquad (1)$$

Now according to the designer he/she did a measurement of the HVS voltage by using a 10 MΩ resistor (*Rss*) in series with the DVM. The DVM is assumed to have an internal resistance (*Rdvm*) of 10 MΩ. The measured value he/she did get according to the photo on the tutorial was 246 volts. The conclusion was made that the HVS voltage was the double value of this due to the voltage divider of *Rdvm* and *Rss.* It was assumed that Rhvs (internal resistance of the HVS) was zero. See equation 2 and 3.

$$Ehvs = \frac{Rhvs+Rss+Rdvm}{Rdvm} * Udvm \qquad (2)$$

$$Ehvs = \frac{0+10+10}{10} * 246 \approx 500 \qquad (3)$$

Therefore the conclusion was that the HVS voltage was about 500 volts. That value is also in accordance with the specifications for the GM tube.

I did exactly the same measurement on my own device and got 241 Volts.

But is this the correct value of the HVS voltage? Let's assume that *Rhvs* is rather high like 25 MΩ. Going back to figure 3 we would have the following:

$$IL = \frac{Udvm}{Rdvm} \rightarrow \frac{246}{10} = 24.6\ \mu A \qquad (4)$$

The voltage drop due to the internal resistance of the HVS would be:

$$Ehvs - Uhvs = IL * Rhvs \rightarrow 24.6 * 25 = 615\ Volts \qquad (5)$$

The true value of the voltage of the HVS, *Ehvs* would then be:

$$Ehvs = 615 + 246 + 246 = 1107\ Volts \qquad (6)$$

Of course will the voltage that you measure dependent on the internal resistance *Rdvm* and the serial resistor *Rss* you use. So what is the true value of the HVS voltage? Using a 1 Giga Ohms probe I measured a voltage of 1509 volts. I did a series of measurements with different resistors (load), se table1.

Rl	Up[V]
10	346
20	480
30	573
34,7	608
39,4	639
44,1	670
48,8	699
53,5	723
58,2	747
62,9	771
67,6	791
72,3	811
82,3	852
100	910
139,4	1015
182,3	1100
1000	1509

Table 1

From this data we get a graph as in figure 4.

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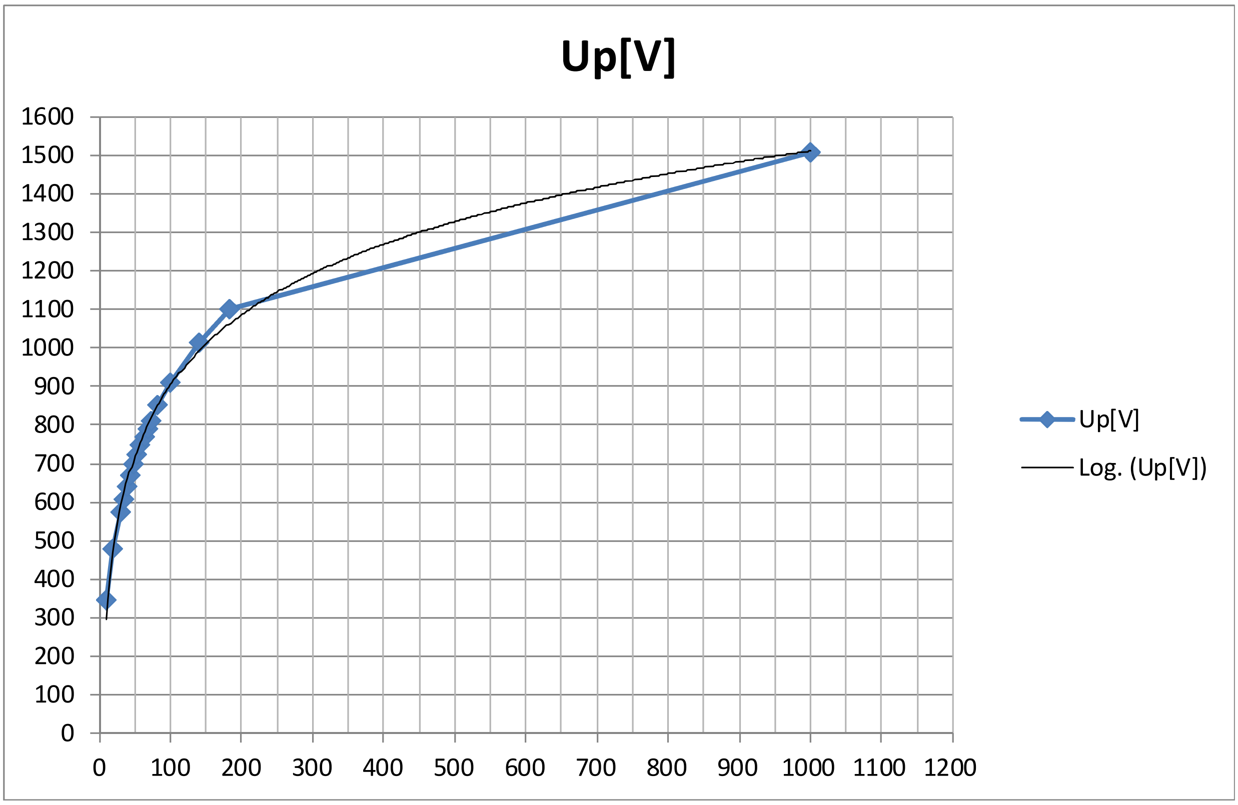

Figure 4

The blue line is a plot of the data points. The X axel is the resistive load in MΩ, the Y axel is the voltage in volts. The black line is a logarithmic curve with best fit to data points. As a note even 1 Giga Ohms seems to be loading the circuit too heavily due to the source internal resistance. However we are in much better position to draw conclusion of the real value of the HVS voltage.

The equation for the logarithmic curve is:

$$Up = 264.03422 * \ln(Rl) - 313.41478 \qquad (7)$$

Here Up is the voltage of the HVS, Rl is the used load.

The R2 fit of the curve is 0.99406 and that is a rather good fit.

Now according to Thévenin's theorem we can calculate the internal resistance by measuring the open circuit voltage (no load) and then making a load that will give half the voltage of the open circuit voltage. By extrapolating the logarithmic curve in figure 4 we could make an assumption that the open circuit voltage of the HVS is about 1550 volts. Half of this value is 775 volts. Solving Rl for 775 volts from equation 7 gives an Rl of about 61 Mega Ohms.

Now, the internal resistance of the HVS is not a linear curve of the load, the internal resistance is influenced by nonlinear elements like the diodes, the transformer etc. in circuit seen in figure 1. However it's is a good indication of the magnitude of the HVS internal resistance. And you can do the conclusion that the HVS voltage supplied to the GM tube is way above the specifications for the GM tube. This in turn will in a longer perspective degrade (damage) the GM tube.

Going back to the designers notes you can conclude that the dynamic (load dependent) internal resistance was in the order of 41 Mega Ohms during the measurement. It fits pretty well with the curve in figure 4.

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At the Sparkfun website you can find a comment about the HVS from member 115862. He measured the HVS to be 900 volts. He used a Fluke meter (with probably rather high input resistance ≈ 100 Mega Ohms). Also he has a fix to lower the voltage. He changed the value of C2, see figure 1, from 10 µF to 1 µF. After that he got a reading of 430 volts from the HVS. He probably still has an overvoltage of about 740 volts but doesn't realize it. But he was definitively on the right track.

GM Tube assembly

The next issue that is with the device is the mounting of the GM tube. The GM tube has a Mica window in front. The mica window is very thin and fragile. You have to have a Mica window on your of you GM tube if you want to detect alpha radiation. The alpha particles consist of two protons and two neutrons bound together into a particle identical to a helium nucleus. Generally alpha particles have a low penetration depth. It will only reach a few centimeters in air and will be stopped by an ordinary paper. The walls of the GM tube are made of some metal; the alpha particles will not penetrate through them. Therefore the use of a very thin Mica window in the front of the detector.

To protect the Mica window on the detector a red plastic cap has been placed at the end of the tube. You have to remove this if you want to detect alpha particles from for example an AM241 source. However the mounting of the GM tube is made in a way that it is difficult to remove the cap and almost impossible to put it back again. This is a design flaw. The main problem is the zip-tie. The zip-tie is pulled very hard and that in turn make a mechanical pressure on the protection cap. Se figure 5. I have to order two new GM tubes to do a replacement.

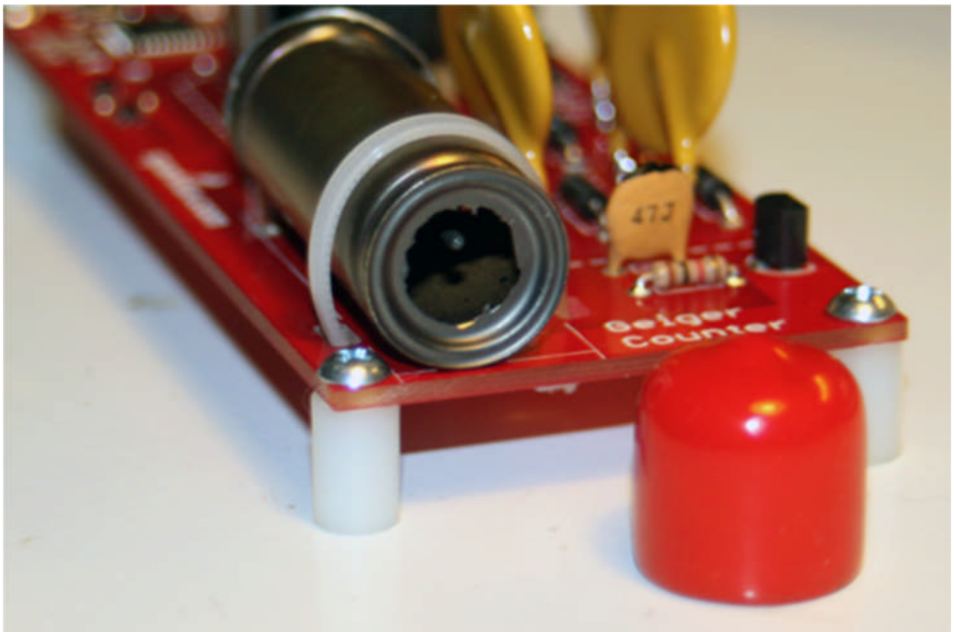

Figure 5

A solution would be to remove the zip-tie and make some distance under the GM tube by adding a rectangle bit of Teflon etc. However this would mean that you have to remove the anode (center) connection of the tube and that in turn will give some mechanical stress to the tube. By experience I know that this could easily give small cracks in the isolation sealing of the anode.

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So after doing some test with the mica window removed I tried to put on the cap again, and Zap, I didn’t barely touch the mica window in my attempts to put the cap back again but the mica window imploded and the GM tube was destroyed.

It is interesting to note that in the earlier incarnations of the device the GM tube was mounted in a way so that the end of the tube was over the edge of the circuit board. Unfortunately Sparkfun did a change of this when redesigning the PCB. You can see this more convenient design on some pictures on the tutorial on Sparkfun web site. The best solution would be to have some sort of distance under the tube so you easily could remove and install the protection cap.

GM Tube detector Circuit

The device detector circuit is very rudimentary. It does it suffer from the overvoltage feed which lead to long dead and recovery time for the tube (discussed in the section above). The long dead and recovery time means that it takes a long time before the tube has recovered from an ionization event and is prepared to register a new event. This in turn leads to that the device is only capable to very low count rates, not in accordance with the specifications from the manufacturer.

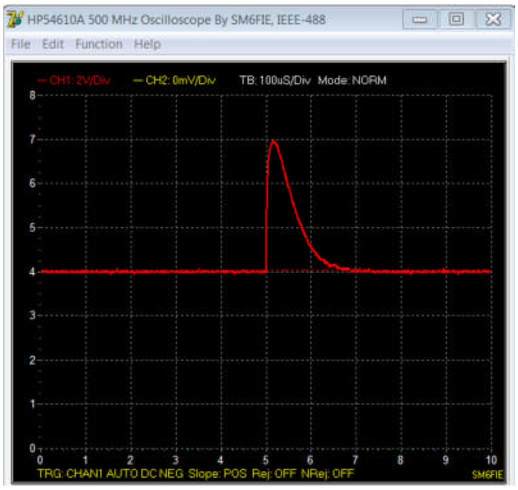

Figure 6

With a correct High Voltage you will get a pulse similar to that in figure 1 above. On the other hand if you supply a voltage far above the recommended operating voltage you will get a “pulse” similar to the one illustrated in figure 2 below.

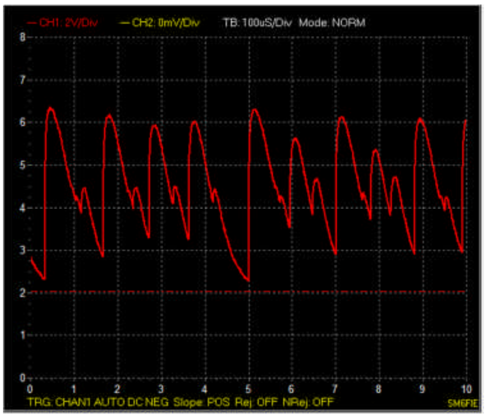

Figure 7

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Another issue is that the circuit solution is not the best on several other aspects.

1. The anode resistor shall be placed as close to the anode as possible thus reducing the capacitance added to the anode. Just 20 mm of anode lead can double the effect of dead time for the tube. It also important for maintaining the plateau length, minimize discharge currents and maximize the tube life. This consideration has not been taken into account on the current design.
2. The RC (R10/C9) network used in the detector circuit is far too big. It gives a time constant of about 8 mille seconds. In practice perhaps even the double value of this. This in turn limits the maximum count frequency to about 60 pulses per seconds. The actual GM tube can perform much better than that. I suspect that this is a design compensation due to the problem with the HVS described above. You cure the problem by the symptom rather than go to the root cause.
3. Best practice is to take out the counting signal from the cathode. Taken the signal from the anode will feed the power supply noise (switch noise) into the measurement circuit. At device switch on there will be a sharp transient pulse feed into the measurement circuit. Using a cathode circuit also eliminates the use of a high voltage blocking capacitor. Any extra capacitance added to the cathode has considerable lower effect compared to adding it to the anode side of the tube.
4. Last, but this is perhaps to demand too much. By adding a few components it will be possible to get a much higher counting rate. The trick is to use a discriminator and a differentiator circuit. By doing that and gating the two signals together even closely spaced pulses (common at high CPS) will be correctly counted.

Notes added 2011-08-25

I did replace GM LND712 tube with a 6107/BS212 GM tube. The specifications for 6107/BS212 GM tube have a recommended operating voltage of 620-720 volts. At zero count rate the current consumption will be zero µA and at very high count rate about 7-8 µA.

At zero count rate I measured the HV supply of Sparkfun Geiger Meter to be about 1500 volts. At very high count rate (the 6107/BS212 GM tube is very sensitive to Alfa radiation) the high voltage did drop to about 1000 volts. Going back to table 1 we get the closest figure to 1000 volts to be 1015 volts. This is for a load of 139.4 MΩ. The current is therefore about 1015/139.4 ≈7.3 µA. A good fit with the specifications for the GM tube. Looking at the output pulse at high count rates I also noted that they were distorted. The conclusion is that this is due to overvoltage of the tube. Overvoltage gives avalanche effects and produces partial total ionization of the tube (and will in a longer perspective degrade the tube).

I finally constructed my own stabilized HV power supply. I wanted to eliminate the big changes in voltage between a low count rate and a high count rates (see above). The change in voltage is about nine volts from zero count rates to full count rate.

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References:

www.spectron.us/SM6FIE/Electronics/HvProbe/High_Voltage_Probe.pdf