Muon Hunter kit notes for CERN HST 2016
Summary of workings

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These notes were written to summarize the workings of the different modules and draw attention to a few parts of the circuit that could provide teaching opportunities when covering electrical circuits. Doing so would provide a chance to introduce a particle physics context when teaching a classical topic.

1 Safety warnings

Do not touch the high voltage components on the bottom board when operating the circuit.

Do not use the kit without the GM tubes connected.

Disconnect the micro USB connector when switching off the circuit.

The circuit is safe to touch after at least one minute after switch off.

Do not use the kit in a humid or wet environment.

Make sure the kit is kept dust free.

The high voltage capacitors have two $2.4M\Omega$ resistors in series to limit the current of the discharge. Not using the correct value of for these resistors will make the kit dangerous to use. It can deliver a severe electric shock in this case. It will damage the Geiger-Müller tubes at the same time, too.

2 High voltage supply

2.1 Principle of operation

The high voltage generated in this kit is based on Faraday's law of electromagnetic induction. By switching the L_1 inductor rapidly we can achieve a high voltage on the terminal of the inductor. This is then accumulated on the high voltage capacitors C_2 and C_3 in the circuit. See figure 2. The high voltage diodes are there to prevent the discharge of the capacitor backwards.

The high voltage generated depends on the switching frequency from the 555 circuit and the current going through the inductor each time. The current and the frequency can be changed by adjusting the RV_1 potentiometer.

The high voltage supply is not regulated: the highest voltage it can produce is about $700V$.

2.2 Exercises

Use figure 1 to work out the answers.

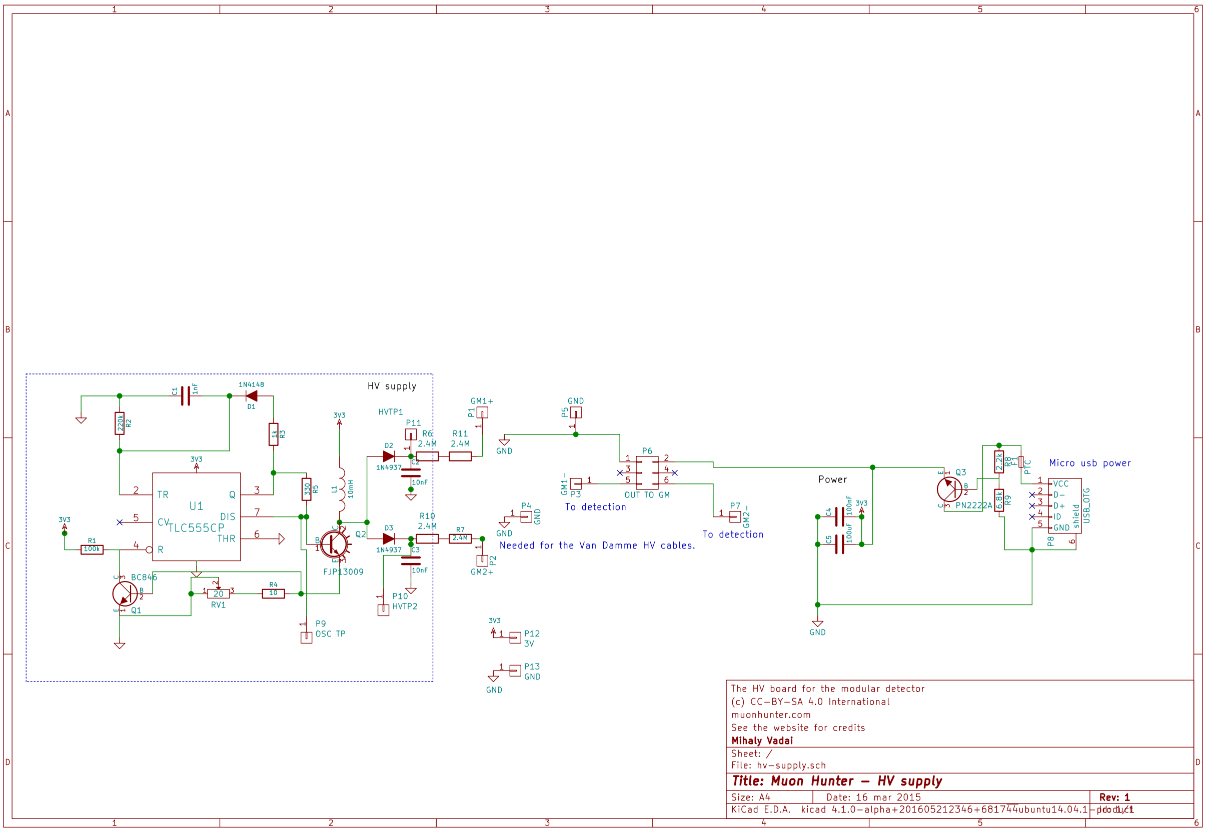

Figure 1: High voltage supply schematic

2.2.1

Determine the maximum current through the GM tube when the capacitors are charged to $700V$.

2.2.2

A typical discharge is $180\mu s$ long. What is the theoretical maximum count rate per second the kit can produce?

2.2.3

Calculate the approximate supply voltage at the emitter of Q_3 when $V_{cc} = 5.0V$. You can ignore the voltage drop on F_1.

3 Geiger detection circuit

3.1 Principle of operation

The anode of the tube is charged positively the cathode sits at ground. The particle detected ionizes the surface of the Geiger-Müller tube[1]. A charge leaving the steel inside the tube creates an electrostatic discharge in the low pressure gas inside the tube. The cathode of the Geiger-Müller tube swings positive as a result of the discharge.

This positive pulse is detected by the transistors Q_1 and Q_2. The transistors form an inverter, so the result of the discharge at the collector of Q_1 and Q_2 is a low pulse.

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[1] The material is steel in the STS-5 and SBM-20 tubes.

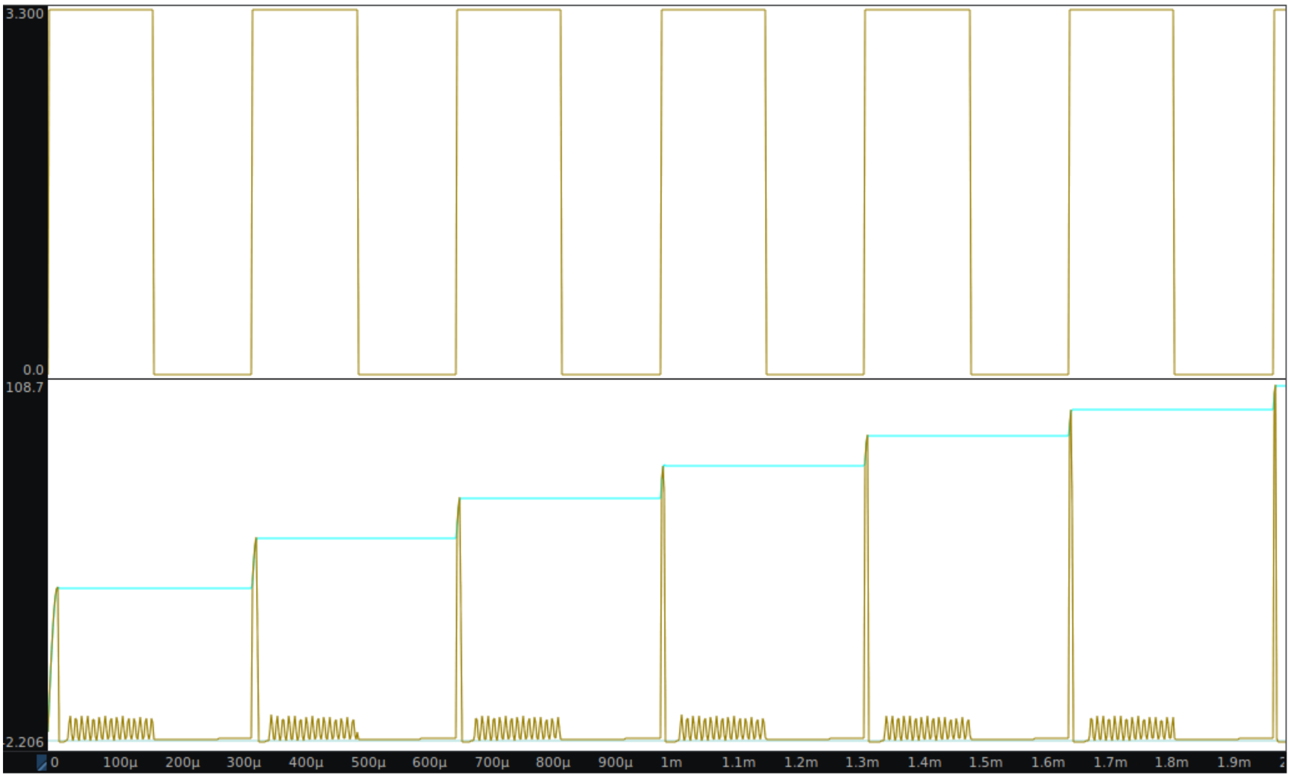

Figure 2: The principle of high voltage generation on C_2 and C_3. The top graph shows the oscillator; this can be measured on R_5 or the OSC test point on the kit. The bottom spikes can be measured on the anode of D_1. The cyan line represents the accumulated voltage on C_2. X axis is time in μs and ms, Y is voltage in V. Note: the actual measured values will be somewhat different in the kit, this is the output of a SPICE simulation at $3kHz$, 50% duty cycle.

3.2 Exercise

Use figure 3 to work out the answers.

3.2.1

Calculate the peak voltage at the base of the transistor Q_1 when the GM tube produces a $25V$ positive pulse.

4 Coincidence circuit

4.1 Principle of operation

Both coincidence signals are fed into the output enable line driver that is configured to shorten the pulse and serve as an AND gate. The RC circuit between the two gates does the pulse shortening. The low pulse arrives from U_{1B} and forces the capacitors terminal connected to the gate low. Then this decreases the voltage on the other terminal of the capacitor, too. The resistor R_2 then tries to keep this other terminal of the capacitor high causing a delay in the pulse propagation. This is when the pulse gets shorter. This shortened pulse then arrives by the next gate U_{1C}.

The pressure sensor communicates with the Raspberry Pi through the I2C interface and the pressure reading can be read from python.

4.2 Exercises

Use figure 4 to work out the answers.

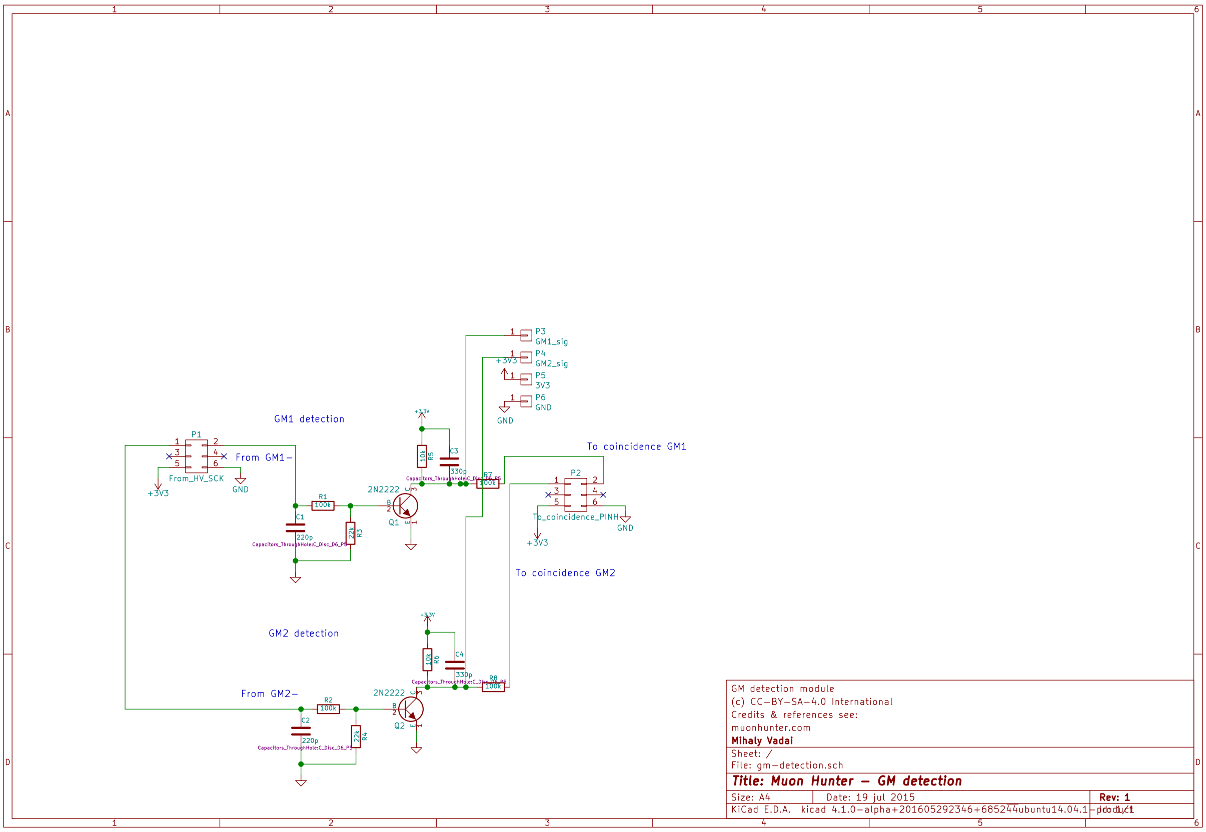

Figure 3: GM detection circuit schematic

4.2.1

The pulse is shortened to $10\mu s$ from $180\mu s$. How does this affect the theoretical maximum count rate of the detector?

4.2.2

At a normal $30cpm$ background for how long do we have to wait for a hit being an accidental coincidence at **a,** $10\mu s$ and at **b,** $180\mu s$ coincidence time window?

4.2.3

How long does it take for the C_1 capacitor charge through R_1 to the about 63% of V_{cc}?

5 User interface

5.1 Principle of operation

The AVR microcontroller detects the low pulses from the coincidence circuit as an interrupt. The muon interrupt takes priority over the individual GM interrupts. The coincidence detection comes from hardware and the AVR only registers the hits. It communicates through the I2C interface with the Raspberry Pi.

5.2 Exercises

Use figure 5 to work out the answers.

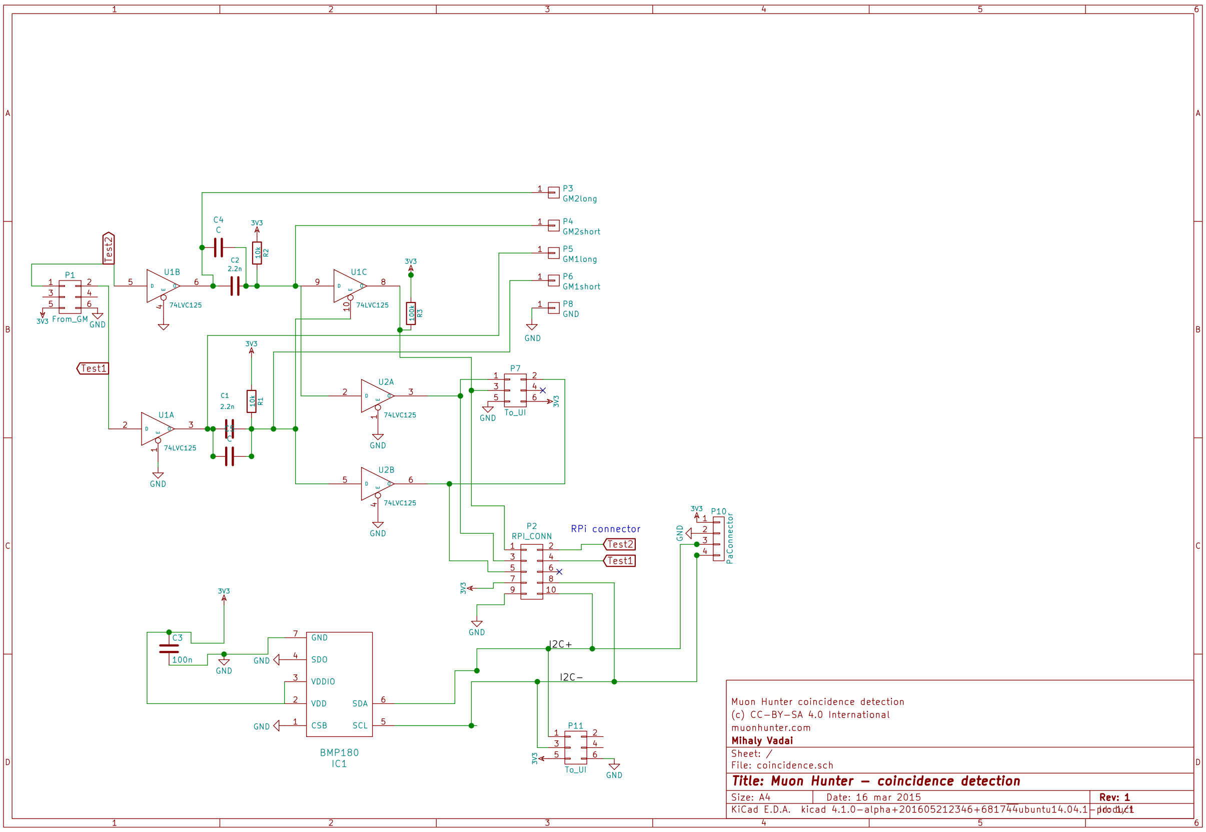

Figure 4: Coincidence circuit schematic

5.2.1

The main crystal has a frequency of 8.192 MHz at 20 ppm precision. Every tick of the timer happens at every $256 \cdot 256$ cycles. How many ticks are 1s? What is the uncertainty on the time measurement?

5.2.2

Assume the main frequency was 8.000 MHz at 20 ppm precision. What would be the uncertainty on 1s time interval in this case provided a tick is $256 \cdot 256$ cycles again?

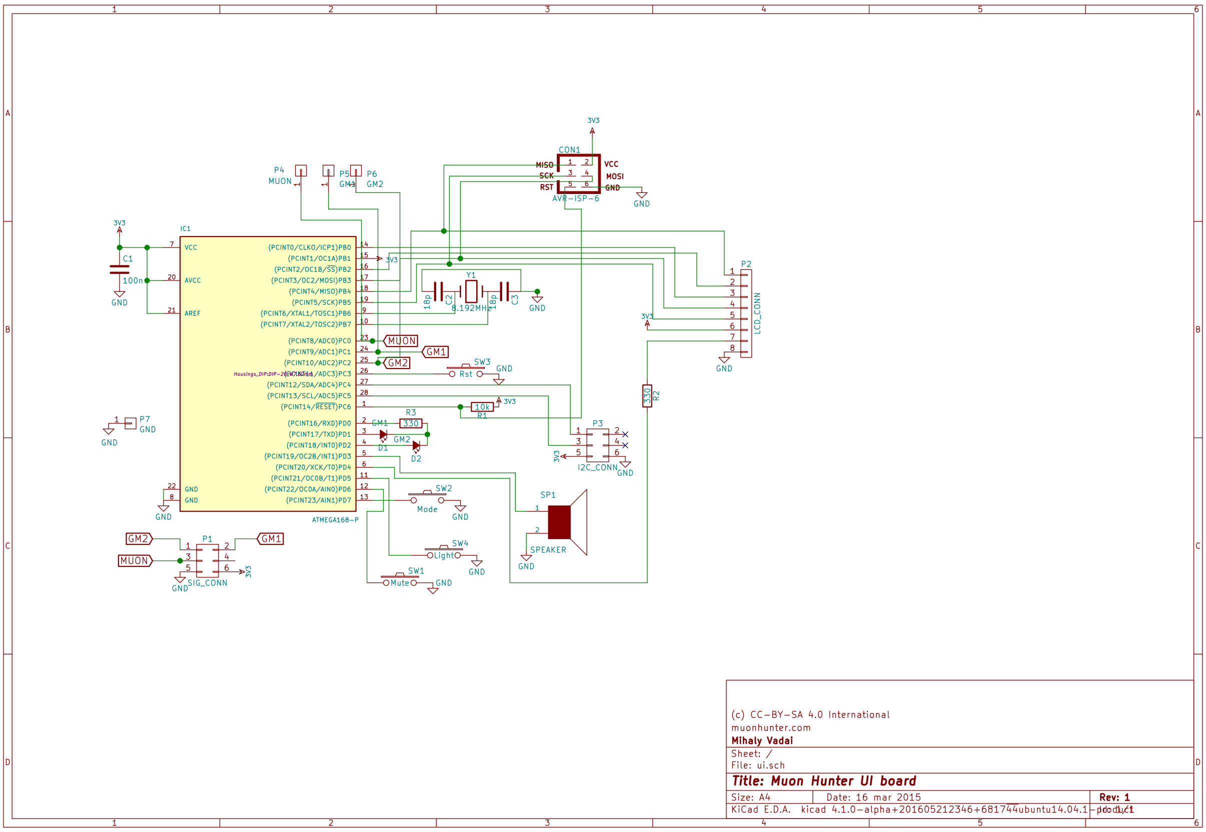

Figure 5: User interface schematic

6 Solutions

2.2.1 $I = \frac{V}{R} = \frac{700V}{4.8 \cdot 10^6 \Omega} = 0.15$ mA.

2.2.2 $f = \frac{1}{180 \cdot 10^{-6} s} = 5560 \frac{1}{s}$

2.2.3 R_8 and R_9 forms a potential divider. Therefore the voltage at the base is

$$V_{base} = V_{in} \frac{R_9}{R_9 + R_8} = 3.8V$$

The voltage drop on the base emitter junction is typically assumed to be $0.6V$, therefore $V_{emitter} = 3.2V$.

3.2.1 R_1 and R_3 forms a potential divider. Therefore the voltage at the base is

$$V_{base} = V_{in} \frac{R_3}{R_1 + R_3} = 4.5V$$

4.2.1 It doesn't, since the dead time of the tube itself is still $180\mu s$.

4.2.2 a, If GM_1 produces a $t = 10\mu s$ pulse and GM_2 a $10\mu s$ pulse and the rate is $f_1 = 30cpm = 0.5\frac{1}{s}$ then the time available for GM_2 to produce an accidental coincidence is $2tf_1$. If GM_2's count rate is $f_2 = 30cpm$, too, then the number of accidental coincidences per second is: $f_{ac} = 2f_1f_2t = 5 \cdot 10^{-6}\frac{1}{s}$. We'd have to wait $\frac{1}{f_{ac}} = 2 \cdot 10^5 s \approx 56h$ for one accidental coincidence.

b, Following the logic above the number of accidental coincidences at the same rate with $t = 180\mu s$: $f_{ac} = 2f_1f_2t = 9 \cdot 10^{-5}\frac{1}{s}$, so we'd have to wait $1/f_{ac} = 1.1 \cdot 10^4 s \approx 3h$ for one accidental coincidence.

Further reading on this topic can be found in a previous HST article, too, by Peter Dunne here: `http://teachers.web.cern.ch/teachers/archiv/hst2000/teaching/expt/muons/cascades.htm`.

4.2.3 $\tau = R_1C_1 = 10k\Omega \cdot 2.2nF = 22\mu s$

5.2.1 $\frac{8.192 \cdot 10^6}{65536} = 125.0000 \pm 0.0025$ ticks.

5.2.2 $\frac{8.000 \cdot 10^6}{65536} = 122.0700 \pm 0.0025$ ticks. Since the microcontoller works with a whole number of ticks, the 0.07 tick will be ignored each second, therefore this would introduce a systematic error of $1s$ every $14s$.

7 Further information

The main source of information about the kit including credits and licences is the web site: `http://www.muonhunter.com` and the blog on the same web site.

The source code for the AVR MCU and the Raspberry Pi scripts can be found here: `https://github.com/mvadai/muonhunter`

CERN HST 2015 experiments with the kit can be found here - look for work group 1: `http://indico.cern.ch/event/355973/other-view?view=standard` a summary is also on my blog: `http://www.muonhunter.com/blog/prototype-detector-cern`

This document can be downloaded from the CERN HST 2016 site: `https://indico.cern.ch/event/507180/`