Using a LED as a single photon detector

We came across a very interesting article here that we thought warranted further investigation. A fuller explanation of the semiconductor physics behind this experiment where the LED is operating in 'Geiger-mode', just beyond its breakdown voltage, is given in the article.

The up-front caveat is that this experiment only works with certain LEDs. From a small drawer of about twenty red LEDs we found one that worked.

The circuit is very easy to set up consisting of a single reverse biased LED in series with two resistors. You will also need a CRO and a 0-25V, continuously variable, smooth DC power supply.

The circuit is shown in Figure 1.

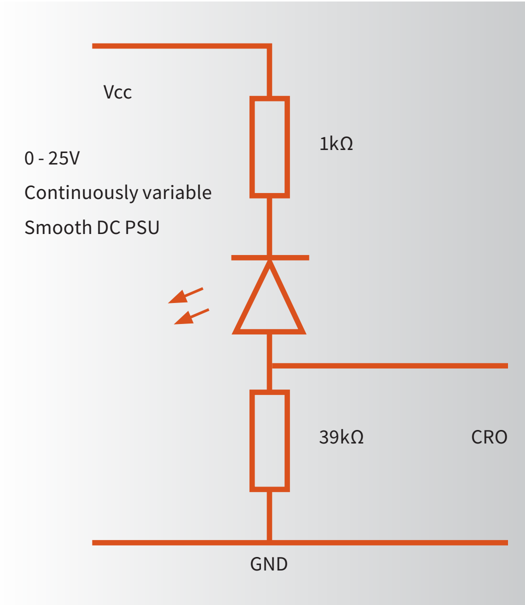

Figure 1 - Circuit diagram.

Set up the circuit as shown then slowly increase the supply voltage. If you have a suitable LED at some point you will see a trace with 'spikes' as shown in Figure 2.

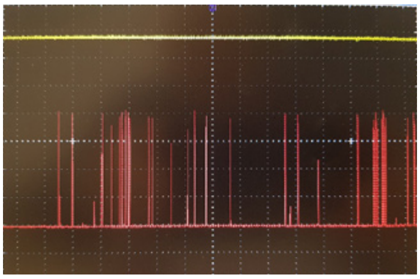

Figure 2 - Initial trace.

At this point it is worth confirming that there are more 'spikes' when it is brighter and fewer when it is darker. Using the CRO we can get a more detailed look at these 'spikes'. Adjusting the timebase we get an image as shown in Figure 3.

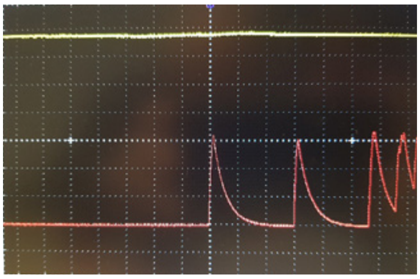

Figure 3 - A more detailed look at the 'spikes'.

In this image we can see the exponential decay nature on the falling edge of the pulse and 'after-pulsing' (where a charge produced during an avalanche is 'delayed' and later triggers a second avalanche) at the right of the image.

An even closer look at the pulse is shown in Figure 4. Here we can also see an initial rounding as the leading edge approaches its maximum value.

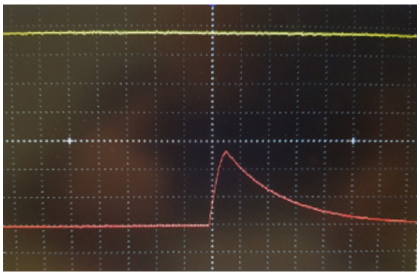

Figure 4 - Rounding of the rising edge.

In Figure 5 we can see that it takes approximately six divisions, each division being 2 µs, for the trailing edge to decay from max to near zero.

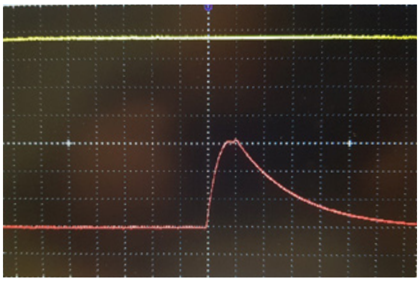

Figure 5 - The decay time.

A bit of a simplification, but we can consider the circuit to be that of a capacitor, the capacitance of the LED pn junction, and a series resistor (40 kΩ). Assuming that it takes 5 CR seconds to decay from max to near zero then 5CR = 12 µs. CR = 12/ 5 µs = 2.4 µs. Taking R as 40 kΩ (1 kΩ + 39 kΩ) gives us an estimated value of 60 pF for the capacitance of the LED pn junction.

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Developing this idea further.

Another excellent article on using LEDs as a single photon detector can be found here.

In this article a simple discriminator circuit is added to produce square pulses which are then counted by a microcontroller. Two programs for a Teensy 3.2 microcontroller are provided in the article, one acts as a simple counter (with programmable gate time) and the other records the time interval between successive pulses. Datasets are written to the serial monitor of a computer. Statistical analysis is described for both datasets the latter being analogous to the work done by Rutherford, Geiger and Marsden. <<

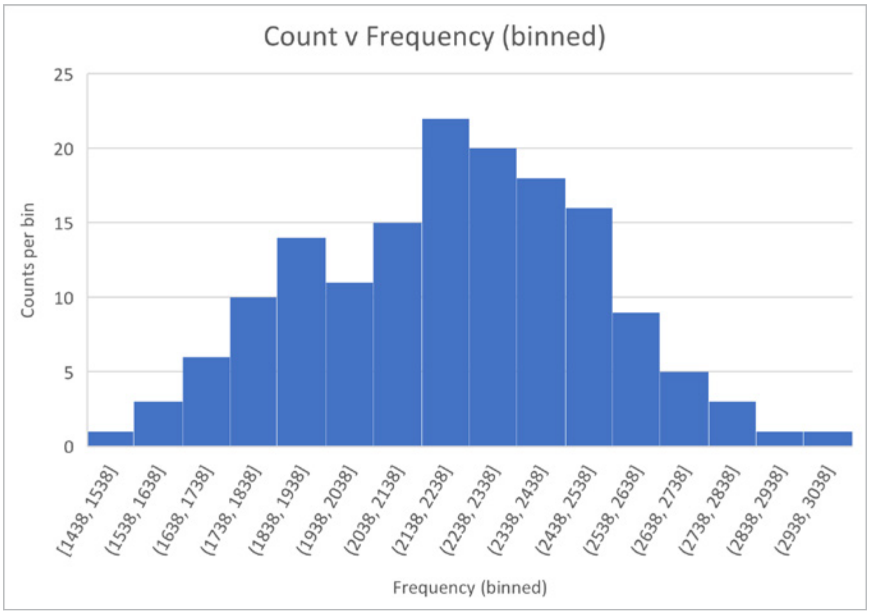

Figure 7 - Histogram showing 155 data values, mean = 2199.4 (experiment 4 in link above)

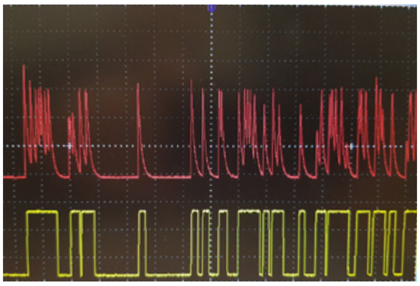
Figure 6 - Yellow trace shows discriminator output (experiment 3 in link above).

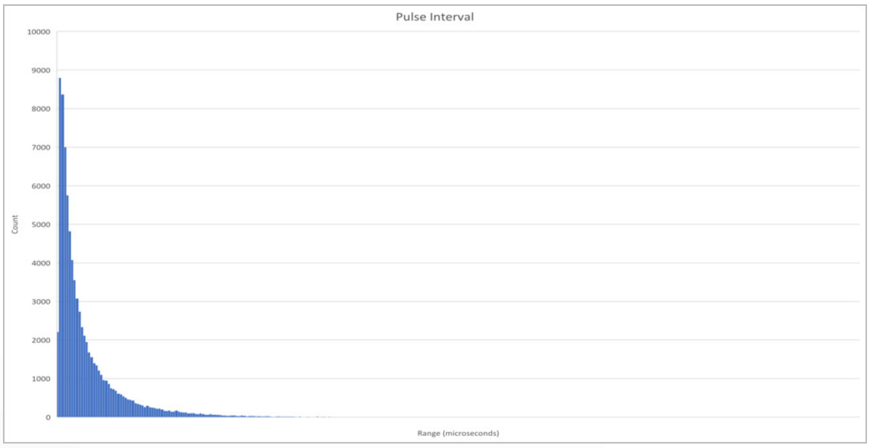

Figure 8 - Histogram of pulse interval data collected over 10 s (> 80 000 values, experiment 5 in link above).

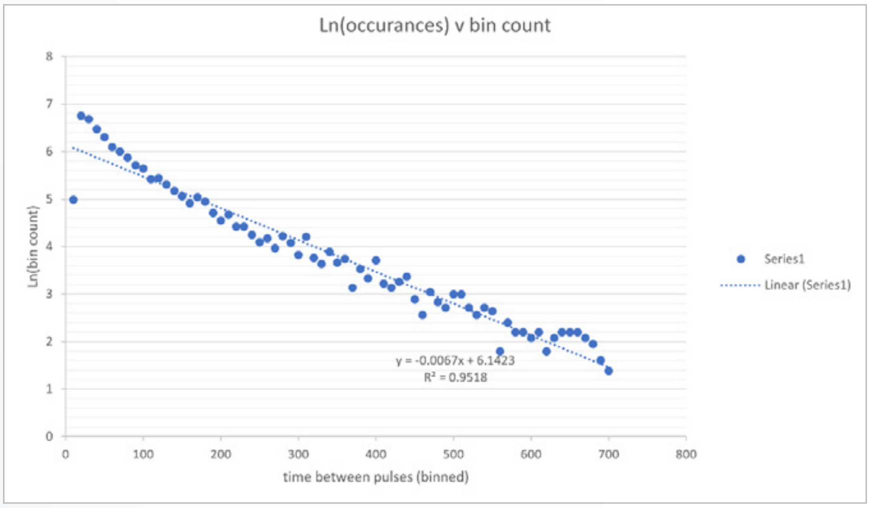

Figure 9 - Graph of Ln(occurrences) v binned inter pulse time.