Low-Intensity Photon Detection (Work in Progress)

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(Date)

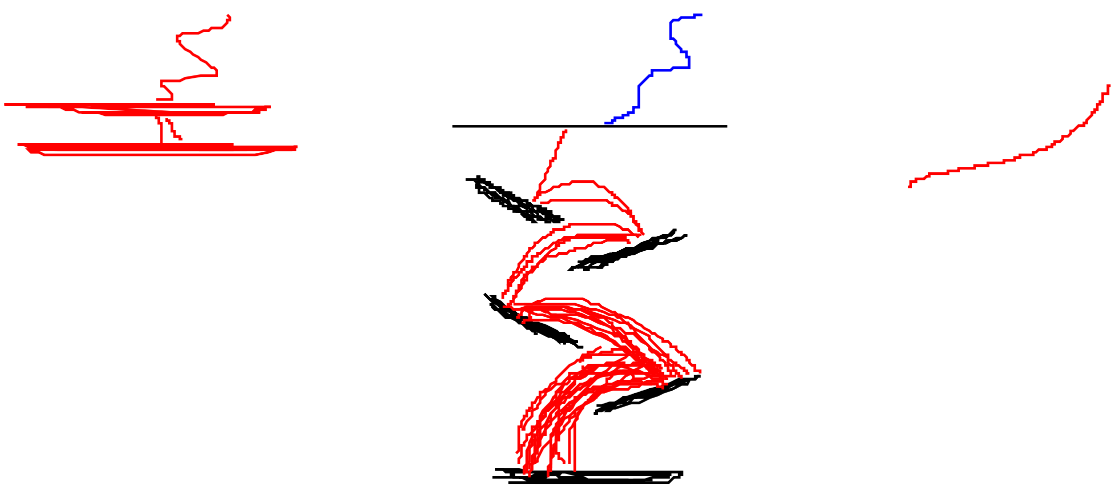
Introduction

This study of low-intensity photon detection was driven by the need for a small, inexpensive and efficient photo detector. These detectors, to be used by experimental ~~particle~~ physicists, would be used to determine how much energy went into an experiment in a particle accelerator. First, electrons are separated from their corresponding atoms in an electron gun, and then accelerated by an electric field. These electrons would then shoot through a thin piece of material, where if they hit a nucleus, the electron might lose some energy and produce a resulting photon. The photons that were created would then be used by colliding it with a experimental target. All the resulting electrons would then be bent away from the experiment by a strong electric field. The electrons that created photons by colliding with the nucleus of an atom would have lower energy that those which did not collide. They would be more bent than by the electrical field and fall into photon tagging detectors, while the rest of the electrons that did not produce a photon would fall into the electron dump. Therefore for every photon that goes into the experiment, there is a resulting electron that falls into the photon tagging detector. Experimental physicists use the energies of the electrons that fall into the photon tagging detector to calculate and “tag” the energy of each photon that goes into the experiment. The electron that goes into the photon tagging detector creates visible photons that go through optical fibers to a photon sensor.

Current ~~photo sensing~~ technology uses a device called the photomultiplier tube as the primary photo detector, which still relies on vacuum technology. In a photomultiplier tube, a photon would hit a charged cathode, which would release a shower of electrons. These electrons would be bent by an electric field into another dynode plate which would produce a proportionally larger shower of electrons. (if the entire process is done using electric fields, then why will strong magnetic fields ruin the performance of the photomultiplier tube?) At the end of a series of 10 – 12 dynodes, the energy of the initial photon is multiplied by 10^6 or about a million times. ~~(it seems that the energy being multiplied the important factor here. The number of particles moving is from one to a million, yet the energy of the initial photon is also being multiplied as well.)~~ These tubes are very efficient in multiplying the energy of the photon although they are not very practical. (how are they too small? And if they are, can't they be made larger?) They are very large, especially compared to the space which they are detecting in the detector. They also burn out quickly (if they don't "burn out" what do they do? And are they expensive to replace? I heard that they were high maintenance.) and take up a very large supply of electricity. (if they require high voltage, then to acquire it, you would need high amperage at regular voltage which is the same as large amounts of electricity.) They are also very sensitive to strong magnetic fields present near the experiments where they are ideally located. The very strong magnetic fields in the actual accelerator experiment as well as the tagging spectrometer keep it from working properly. Therefore scientists are trying to find a solution to this problem by using different ways to detect low-energy photons. An effective and inexpensive photo-diode would be very helpful to experimental particle physicists. They would be able to wire these photodiodes directly into the detector, which would make the entire system dramatically less complicated. There would be less fiber-optic cable running out of the detector and entire arrays full of photomultiplier tubes would be unneeded. Each photo-diode would also be much cheaper and easier to replace than a photo-multiplier tube. All in all, it would make experimental particle physics less complex as well as make it more cost effective.

The solution we studied is that instead of using a series of dynodes to amplify the signal of the photon hitting the detector, we would have it hit just one highly charged plate, creating pulse of electricity, which could then be detected. This method is more efficient than the photomultiplier tube because the hybrid-photodiode, as it is called, is much smaller in size than a photomultiplier tube. It also requires less voltage and is not sensitive to strong magnetic fields. The only problem is that instead of multiplying the energy 10^6 times, they only multiply it 10^4 or about 10,000 times. Currently, it is not clear whether if they are capable of detecting single photons that are produced by the detector.

The LED was made to emit a very low intensity pulse of photons and a circuit was built that could interpret the information that came from the photodiode. By pulsing very low-intensity photons pulses into the hybrid photodiode and looking at the results, the sensitivity of the photodiode can be determined. It would then be determined whether the photodiode was capable of detecting single photons.



Problem and Hypothesis

Problem – A better photo-detector is needed in modern physics experiments to make it more compact and less sensitive to magnetic fields.

Proposed solution – The new hybrid-photodiode is a photo-detector that is sensitive enough to detect very low intensity photon pulses, while being space efficient as well as being less sensitive magnetic fields

Procedure

The first part of the research project (not an experiment?) was to design two electronic circuits to test photo-detectors with a controlled source of low-intensity light pulses. One was needed to drive the LED that served as the source of the light. It turned a square wave that is produced by an electronic pulse generator into a narrow voltage spike. This very narrow voltage spike that is fed into the LED made it produce a flash of light that lasts for a very short time. The conversion from a square wave to a narrow spike was accomplished by using an operational amplifier with a negative feedback loop. A high-amplitude voltage spike releases a large number of photons in a short amount of time. Therefore, the circuit also needed to be attenuated so that the LED produced very small amounts of photons per pulse. This controlled low-intensity pulser was necessary for testing the hybrid photo-diode because it supplied the experiment with a controllable amount of low-intensity electrons. The second circuit amplifies the signals received from the hybrid-photodiode so that they can be displayed on an oscilloscope.

A box also was built to contain all the mechanisms that make up the system. It was very tightly sealed so to minimize all other ambient light sources besides the light from the LED. This kept all the other photons from various sources in the room from interfering with the experiment. Also, black drapes were placed over the box to further block the ambient light from penetrating into the experiment. These steps were taken to make the experiment as reliable as possible. Due to the nature of the experiment, a very small amount of ambient light could greatly skew the results. Else, the photodiode would not be able to differentiate between the random photon spikes that result from ambient light or the spikes that come photons released by the LED. The box also contained electrical feed-through connections to the photodiode and the LED so that they could still be operated when the box was entirely shut.

An oscilloscope was used to analyze and display the data that came from the experiment. An oscilloscope is a device that measures the difference in electrical potential of two points in a circuit. One of the circuits that the oscilloscope measured was connected to the input signal that was fed into the LED. Another was connected to the circuit that was coming out of the photo-detector. The oscilloscope then showed the comparison between the input and output signals with regard to time.

Review of Literature

- To be added to when resources are used
- ... figure it out later after I finished

Results

The experiment produced no answer to the problem posed in the introduction

(Shouldn't the circuit diagram be in the procedure?)

A signal was successfully transformed from a square wave to a pulse. This step is necessary so that a correct input can be put into the testing LED. With a pulse, the LED would constantly flash, demonstrating a recognizable and measurable signal that could be detected by the photo-diode. On the oscilloscope, the two colored lines that showed the electrical potential of the two circuits jumped in unison with each other and there was a clear correlation between the change of voltage in the square wave input and a corresponding spike in the pulse output.

The photo-detector was also successful in detecting low intensity photons to a limited degree. Input pulses into the LED produced corresponding output spikes from the photo-detector. This shows that the photo-detector can detect photons as a whole. It is the control we used for the experiment to see if the photo-detector as well as our circuit worked. Then the amperage of the signal that led into LED was greatly reduced. This would allow us to simulate the conditions in a particle accelerator. As the input amperage was turned down, he output spike became smaller and less designable, eventually dissolving into the static ambient light around it.

The experiment failed to provide any conclusive results that would determine whether the new photo-diode was suited for a photodiode because there was no way of knowing exactly how many photons were in the box or were produced by the LED. Therefore, there was no way of measuring how much photons it was actually detecting and how sensitive the photo-detector was. For the photodiode to be successfully used in a particle accelerator, it must be able to detect every photon that hits it. At this point in the experiment, there is no way tell exactly how sensitive the photodiode is due to the lack of a control on the electrons in the box. Also, it was not a very accurate test of the sensitivity of the photo-detector because enough ambient light got in to disrupt the experiment. As the amperage of the input signal was reduced, the output signal did not disappear and become undetectable, the signal generated by the random and static ambient light was so large that it masked the signal that was coming from the LED. It wasn’t that the photo-detector couldn’t pick up the signal from the LED, it was just the signal from the LED just became very diminished and indistinguishable from the random ambient light.

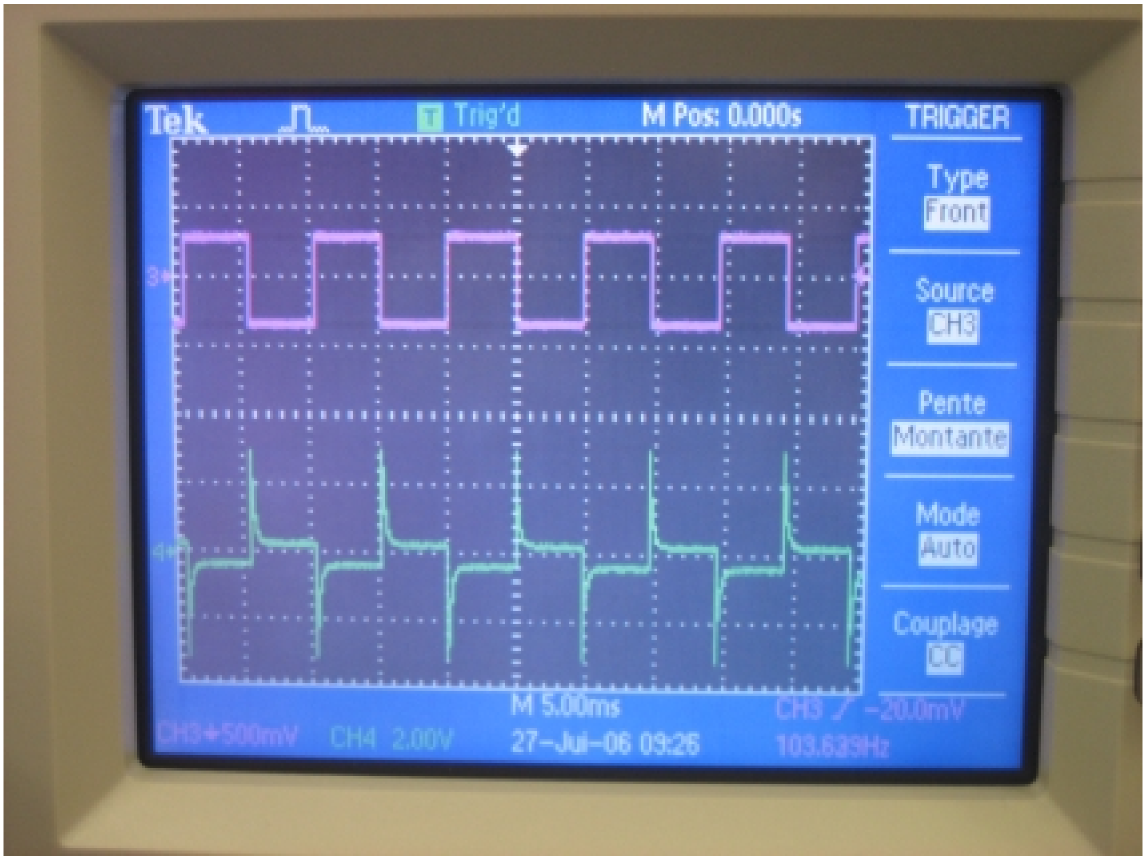
A more conclusive result could be achieved if there was a known photo-detector, such as a photomultiplier tube, to detect the amount of photons that were present in the container. This would provide a control necessary to determine the exact sensitivity of the photodiode. Also, a more accurate result could be achieved if the ambient light is further reduced from the container. If more measures are taken the result would be more accurate, due to the smaller degree of randomness that the ambient light provides.

Results

The research project determined the sensitivities of the Hybrid photodiode.

The operational amplifier works on a negative feedback loop. As the input increases, so does the output. Then, part of the output is then fed into the input, resulting in an even higher output. This positive feedback loop will continue until the input stops increasing. As soon as that happens, then the input and output would quickly equalize themselves and eventually, the output would have no voltage once again. In essence, it outputs the derivate of its input. The results of this transformation are shown on an oscilloscope.

The Oscilloscope is the main instrument used to measure the difference in voltages of two points in a circuit.



(Fig. 2. The display panel of the oscilloscope showing the electrical potential before and after the Operational Amplifier circuit)

The top line is the signal square wave that was fed into the Op. Amp circuit, while the bottom line is the output of the circuit. The two wires of the oscilloscope were connected to a specific testable point on the circuit as well as a ground. The oscilloscope compares the voltages of two different locations. The voltage of a circuit was compared with a definite constant, a ground. Therefore the voltage of the circuit at a certain point could be determined. The input and the output lines on the oscilloscope show a great correlation with each other. Each change of potential in the square wave circuit corresponds identically to a spike in the pulsing circuit. The voltages were set up so that a change of 500 mill volts on the square wave circuit would correspond to a spike of 3 volts.

Conclusion

The experiment did not come up with a conclusive result in the time allotted. Therefore, the data neither supported nor not supported the hypothesis. The theory has yet to be tested further. From the data that was gathered so far, the photodiode has shown success in detecting photons. A photodiode still could be considered a viable alternative to photomultiplier tubes, but more testing is required before this action could be considered a workable alternative.

Revisions – (to be removed upon completion)

Blue Text – Corrections based upon your suggestions

Highlighted – Questions

Dark Red Text – Added after deliberation to further clarify

Red Text – Points of discussions