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 created in an electron gun. 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 photon would then go to power the experiment, while the lower-energy electron wouldn't have enough energy and would go to the electron dump and fall into a detector. Therefore for every photon that goes into the experiment, there is a resulting electron. Theoretical physicists use this information to calculate the energy of the photon that goes into the experiment. The electron that goes into the detector creates a single very high energy photon that goes through optical fibers to a scintilliser.

Current technology uses a device called the photomultiplier tube as a scintilliser, which still relies on vacuum technology. In a photomultiplier tube, a photon would hit a charged dynode plate, which would release a shower of electrons. These electrons would be bent by a magnet into another dynode plate which would produce a proportionally larger shower of electrons. By the end of a series of 10 – 12 dynodes, the energy of the photon is multiplied by 10^6 or about a million times. These tubes are very efficient in multiplying the energies of the photon through they are not very practical. They are very large, especially compared to the space which they are detecting in the detector. They also burn out quickly and take up a very large supply of electricity. They are also very sensitive to strong magnetic fields when they are used due the magnetic used to make each series of electrons hit each dynode so they need to be separated certain distance away from the where the detector actually exists. The very strong magnetic fields in the actual accelerator experiment as well as the tracking magnet keep it from working properly. Therefore scientists are trying to find a solution to this problem by using different ways to detect low intensity photons. An effective and inexpensive photo-diode would be very helpful to experimental particle physicists. They would be able to wire these photodiode 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 rooms 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 more convenient.

The solution we proposed is that instead of using a series of dynodes to multiply the energy of the photon hitting the detector, we would have it just hit a highly charged plate, creating just one very high energy electron, which could then be detected. This method is more efficient than the photomultiplier tube because the photodiode, as it is called, is much smaller in size than a photomultiplier tube. It also uses less electricity and is not sensitive to strong magnetic fields. It's also cheaper to implement than photomultiplier tubes. The only problem is that instead of multiplying the energy 10^6 times, they only multiply it 10^4 or about 10,000 times. Therefore, physicists aren't sure if they are capable of detecting single photons that are produced by the detector.

What we planned to do is to build a circuit that would make a LED make a very low intensity pulse of photons and a circuit that could interpret the information that came from the photodiode. By pulsing very low intensity photons into the photodiode, we were going to find out if the photodiode was capable of detecting single photons.

Problem and Hypothesis

Problem – A better photo-detector is needed in modern particle accelerator to make it more space and cost efficient

Hypothesis – The new photodiode is a sensitive enough photo-detector that is cost efficient as well as space efficient while having other advantages such as being unaffected by magnetic fields

Procedure

The first part of the experiment was to design two circuits that would serve their purposes. One is needed to power the LED that would supply the source of the light. It would have to turn a square wave that is produced by a generator into distinguishable signal ~~when it is detected~~. To have the LED produce the small amounts of photons with a measurable yield, ~~we would create a pulse.~~ This is done by using an operational amplifier with a negative feedback loop. A pulse would ~~normally~~ release a large amount of energy in a short amount of time. Therefore, the circuit also needs to be attenuated so that the LED would produce very low amounts of photons ~~when it is in action.~~ Then it would be possible to test the new photo-diode because it would supply ~~the experiment with~~ a controllable amount of low-intensity electrons. ~~The sensitivity of the photodiode can be tested~~ Another circuit would then need to be made to connect it to the oscilloscope, ~~where the signal that comes out of the photodiode would be in a form that could be analyzed.~~

A box also should be built to contain all the mechanisms that make up the system. It should be very tightly sealed so to minimize all other ambient light sources besides the light from the LED. This would keep all the other photons that come 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. Also, due to the nature of the experiment, a very small amount of ambient light could greatly skew the results. The photodiode would then 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 held spaces where the photodiode and the LED ~~would sit~~ so that when the box was closed, these two devices could still be operated.

An oscilloscope was used to analyze and display the data that came from the experiment. An oscilloscope is a device that measures the electrical potential of different circuits. 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. Therefore, the oscilloscope would be able to show how what kind of signal was put into the setup and also what signal came out of the device. It would show how the device changed the signal and also to see how far and how accurately the output could be distinguished from the input signal.

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

A signal was successfully transferred 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.

Conclusion