PMT Signal Amplification in Particle Detectors

Abstract

Photomultiplier tubes, devices that can detect relatively miniscule concentrations of photons and output a signal corresponding to the intensity of the photon concentration, can be used to detect Cherenkov radiation in particle detectors. However, the signal from these photomultiplier tubes can be easily drowned out by electrical noise. To counter this, amplifiers can be used to increase the signal to a readable level. To this end we are considering two different amplifiers, the cheap 741C and the more specialized 595-THS3202D. After some research, we found the 741C to be useless for the needs of the project and switched our focus on testing the capabilities of the 595. After building the amplifier into a small plastic container, we hooked it up to an experimental PMT setup and compared the output signal between the base PMT output and the amplified PMT output. We found that the 595 amplifier provides the required performance for use in the particle detector, being able to amplify the signal up to ten times greater than the original. Compared to the alternatives of an unamplified signal and the outclassed 741C amplifier, it is clear that the 595 is worth the price for it's ability to accurately amplify the high-frequency signals typical of the experimental setup it will be used in.

Introduction

As our knowledge of the physical world increases, modern physicists find themselves studying smaller and smaller particles in their attempts to find the most fundamental particles that all matter is composed of. In their pursuit, the physical phenomenon of Cherenkov radiation is exploited to help differentiate between different particles based on their mass. Cherenkov radiation is electromagnetic radiation that occurs when a charged particle moves faster than the speed of light through the same medium, causing the molecules in the medium to polarize and return to ground state rapidly, emitting electromagnetic radiation, most notably as a light blue glow. Using this concept, we can determine whether or not a particle is above a certain velocity threshold based on whether or not it emits Cherenkov radiation. Knowing the momentum of the particles, we can thus separate them based on mass.

In order to detect the radiation within the chamber of the experiment, we use a device called a photomultiplier tube, henceforth abbreviated as a PMT. A PMT is a cylindrical tube of varying width with a number of angled diode plates between a photocathode and anode plate inside of it. The operation of the device is reliant upon the photoelectric effect, which states that electrons are emitted from a substance when struck by photons. When photons from a light source enter the lens of the PMT, they strike the photocathode, emitting electrons which then move down to the first diode in the series. The electrons strike the diode, releasing an exponential torrent of electrons toward the next diode. The PMT is supplied with a high voltage, usually between 750 and 1500 volts, to produce even higher gain in between each diode. The process repeats itself until the electrons reach the anode and become an electrical signal many times greater than the initial photon input. Due to this cascading effect, if too many photons hit the photocathode, the resulting voltage at the anode can be great enough to destroy the device. In order to prevent this, high-voltage is only to be applied when used in experiments and only when there is a low amount of light.

Using this device, we can get a signal from only a single photon, much too small to be seen with the human eye. However, when measuring only a few photons, the signal is still relatively weak and can easily be lost in the noise. In order to get around this problem, an amplifier usually has to be used in order to increase the voltage of the signal to the point where it can easily be measured. An electrical amplifier works by drawing voltage from a separate power source and using it to increase the voltage between the input and output leads. Due to the nature of these physics experiments, the PMT amplifier must work quick enough that it is able to process the signal in the nanosecond range in which it occurs. To that end we were given two different amplifiers to use in our experiments to find which provided the best fit for use in a PMT to be used in a particle detector; the 741C op-amp, and the 595-THS3202D fast op-amp. The 741C is a very common amplifier, used in many modern day circuits, and is very cheap at roughly $0.50 a unit. The main issue we have with the 741C is it's unimpressive slew rate and low gain bandwidth. At 0.5 V/μs and 1MHz, respectively, we feel considerable doubt that this amplifier will be able to perform well enough to be used in the detector and have thus opted not to use it in out experiments. The 595-THS3202D, on the other hand, boasts a slew rate of 5100 V/μs and a gain bandwidth of 2000 MHz. However, this amplifier is also much more expensive than the 741C, costing as much as $7.90 per unit. In our experiments, we will determine whether the 741C is able to amplify the signal acceptably, or if we need to use the more expensive 595.

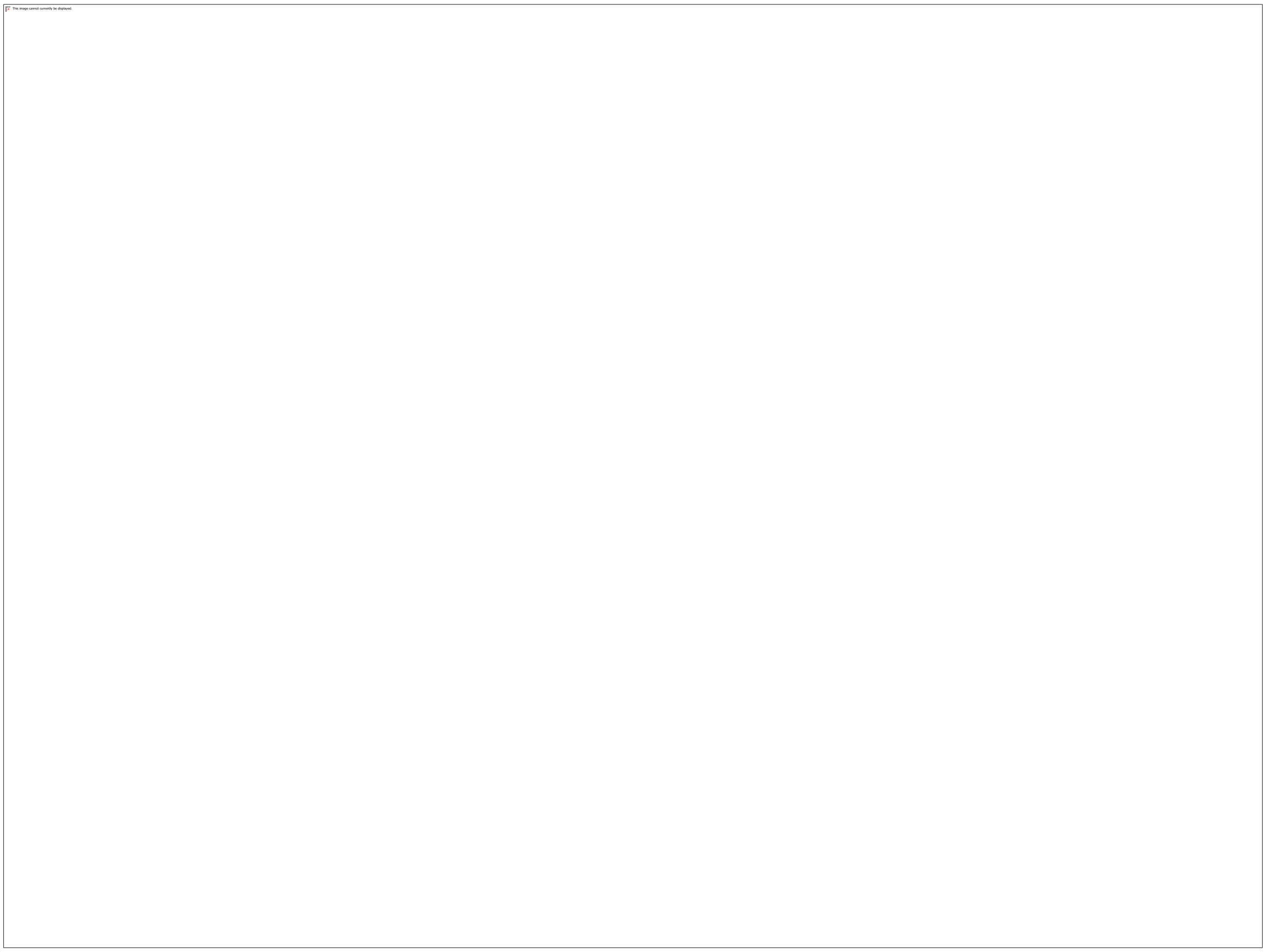
Methods

In order to test the amplifier's effect with a PMT, we first need a PMT and an experimental setup. We used a wooden box with a black interior that we placed the PMT in. A series of input and output leads were built into the side of the box so that we could connect the PMT without having to keep the box open. On the other side, cut a small hole and placed an LED in it, sealing it off with generous application of black electrical tape. The PMT was then hooked up to the interior-side leads and the box closed and locked, with a black cloth draped over it to further keep any outside light sources away. The exterior-side leads were then connected to the high-voltage unit and the oscilloscope we used to measure the amplifier. Using this setup, we were able to register a signal of around 25 mV with a 5 V LED. Once the PMT was set up, we moved on to preparing the amplifier. Our approach was to build the circuit and contain it in a small plastic box for ease of use. We first dismounted the amplifier from the chip it came on and attached it to a small circuit board. We then connected the amplifier to a switching power supply that we could connect to an AC wall output. We also added two sets of input and output terminals with a resistance of 47 ohms in an attempt to counter the reflected signals we encountered in earlier setups. While our initial plan was to use the oscilloscope to measure and compare the respective voltages of the amplified and unamplified PMT signal, we encountered some last-minute technical issues and have instead opted to merely test the base amplification factor and bandwidth gain of the setup. We accomplished this by switching out the PMT for a function generator and measuring the output.

Results

We were able to use the oscilloscope to graph the output of the amplified function generator and found that we accomplished an amplification factor ranging from 8 to 10 times greater than the original. We ran into the issue of recurring pulses, as can be seen in the graphs. We are certain that matching the impedance will get rid of these pulses, but have run out of time and have opted to present what we have.

1 microsecond pulse. Due to the scaling of the signal, the two outputs look almost the same. The oscilloscope shows that the blue (amplified) output is coming up at 2.0V a square, whereas the yellow (unamplified) output is only 500 mV, showing an amplification factor here of around 6.



15 nanosecond pulse. Again, the scale is similar to the first graph. Here the reflected pulses are more easily seen. These can be corrected by using cables with matching impedance.

Conclusion

In conclusion, we found that the 595 op-amp to be a perfectly viable, if a bit expensive, solution for PMT signal amplification within a testing environment. While our data is not as concise as we'd like it to be due to the numerous software and hardware hurdles we faced, we express reasonable confidence that it points to an optimized and efficient solution to the challenge of amplifying photomultiplier tubes.