Photon Counting Detector Interface - PV16 Typical Questions.

The Constant Pulse Amplifier (CPVA) produces single (bipolar) logic pulses for each photon from a detector. It was designed for both Hybrid photomultipliers (PMT) and standard electron amplifier PMTs. It allows counting photons to one Gigahertz instead of just 10 Megahertz.

1. Why is this device needed? Single photon pulses are analog pulses not compatible with standard TTL or other logic families. The pulses from standard PMTs vary in height according to a Poisson distribution - which means that each photon output is of different amplitude. The CPVA puts out standard logic (two polarities) for each photon.

2. What is the advantage of photon counting? Photon counting is digital, so one can add repetitive signals for virtually unlimited dynamic range whereas analog signals are limited by amplifiers and Analog to Digital Converters. An analogy is the CD compared to a vinyl record. Photon counting is much less noisy, especially at high frequencies.

3. How is photon detection normally done? A discriminator or threshold sensing comparator is often used to produce a logic output from the detector. Since the pulses from the detector range from microvolts to volts, setting the discrimination level for photons without capturing noise is complicated. Often performance is compromised by changing the PMT voltage to reduce noise and by the limited dynamic range of the comparator.

4. How fast can one count photons? Photon counting up to several Gigahertz may be accomplished. Most photon counters limit themselves to about 10 Megahertz.

5. Why the limits to count rate? There are many reasons, but they may be summarized by Cost, Difficulty, and detector limits. . Also see #7
   a. Avalanche Photo Diodes have to be ‘quenched’ after a photon count, that is, the carriers have to be removed. This results in long dead times and after-pulsing. APD manufacturers brag about having only one false pulse for every 20 real photons. Single APD PMTs cannot count GHz rates because the recovery time is in the tens of nanoseconds
   b. Electron PMT devices have typical 10 microampere maximum current limits, so counting at GHz rates even for brief times will burn out the tube.
   c. Impedance mismatch between the PMT and the amplifier/discriminator leads to ringing, and a common cheap and simple way around this is to discriminate on the first pulse and use a one-shot (monostable multivibrator) to produce a standard 10 nanosecond output pulse. Thus, the ringing is buried in the width of the one-shot.
      i. What is wrong with this? Any additional photon signals occurring in the 10 nanosecond time interval are lost. Additionally, the maxumum count rate is limited.
      ii. What is an impedance mismatch? If a standard 50 ohm cable feeds into an impedance higher than 50 ohms, a reflected signal of the same polarity is generated. If the impedance is less than 50 ohms, a reflected inverted

pulse is generated. Since an electron multiplier is a wire hanging in space, it does not have a 50 ohm impedance, and matching into a coaxial cable is not easy.

d. Why Cost? Typical amplifiers and discriminators that work at 10 Megahertz are very cheap whereas multiple Gigahertz amplifiers and discriminator are much more expensive and difficult to design.

6. What is the fastest high speed photon counting PMT? The Hamamatsu Hybrid PMT can easily count photons in excess of 1 Gigahertz since the single photon output has a width of 600 picoseconds. This assumes high average count rates rather than counting just two closely spaced photons.

7. Can ordinary PMTs with 0.6 nanosecond rise time count near 1 GHz? Only for short times. The metal can Hamamatsu PMTs have fast rise and fall times, but the maximum output current is limited so that only occasionally can one count at high rates. They cannot count at sustained high rates or they will burn up. Older tubes that had only a few dynodes were able to count at 500 MHz because the lower gain produced acceptable output currents. But the signals were so small that an amplifier was required and these tubes are no longer made.

    a. Could one tie dynodes together to get lower gain and count faster? Yes. The impedance matching is very difficult and very high gain, high bandwidth amplifiers are needed.

8. What about Solid State PMTs? SS PMTs are essentially avalanche diodes operated in the Geiger mode - total breakdown - for single photon counting. They are often erroneously chosen for a small improvement in quantum detection efficiency over electron PMTs at a severe count rate loss. In other words, they have a very long dead time after counting a photon, and are prone to after-pulses that are not real. SS PMTs are inherently limited to very low light levels and lower count rates than electron PMTs. Extensive after-pulse corrections are usually needed by software.

    a. But APDs are advertised with bandwidths in the GHz range? These detectors are not single photon devices and are operating below the total breakdown voltage of the Geiger mode. They also have an extremely small detection area. They are not capable of detecting low levels of light anywhere close to single photons.

9. What are some of the advantages of the CPVA system?

    a. First, the gain is adjustable, so one can match the detector output to the best time response and nose level of the detector without regard to the following system.
    b. Second, the GHz bandwidth allows resolution and counting of photon pulses separated by less than one nanosecond which keeps rather than discards data.
    c. Third, the very wide dynamic range, low noise input produces no false photon pulses in the amplifier at any gain. There is no threshold to adjust.
    d. Fourth, the complementary 50 ohm outputs mean that one can send the signal matched and ring free through long coaxial cables and count and adjust the system at the same time.

10. Why should the CPVA be used with slower detectors? Even if the PMT puts out a 2

nanosecond wide pulse and is current limited, the ability to resolve closely spaced photons is greatly improved.

11. Why not just purchase a standard high frequency amplifier? Many RF amplifiers are not pulse stable and introduce ringing. Amplifiers provide a *linear* output either inverted or not inverted, depending on the amplifier, which is just adding noise and gain to the signal. If the gain is not adjustable, a compromise in the detector performance may be necessary. Even so, the output of the linear amplifiers is not constant with input, and the noise of the amplifier adds to that of the detector. This is not the case with the CPVA.

12. Why use the CPVA with the Hybrid Tube. The CPVA has a maximum gain of 65db which takes the sensitivity to the level required for the Hybrid tube. It was designed specifically for the Hamamatsu Hybrid PMT.

13. Why is the output of the CPVA not also constant pulse width? By allowing the output to follow the input pulse width, additional processing for overlapping pulses is possible. For example, a 2ns pulse might be one photon whereas a 4ns might be processed as two photons that overlap.
    a. An additional separate constant pulse width output interface is available with 600ps to 20 nanosecond output pulse width. Also, a TTL interface output is available up to 700 MHz. Yes, that IS 700 Megahertz TTL output.

14. Is there a difference between a 1ns single photon output and a 10ns single pulse out? Yes. Assuming the gain is the same in the two tubes, the pulse height of the 1ns output would be 10X as large. Narrower is always better. One can count faster, have lower gain which is always better, and the narrower pulse is less susceptible to external noise.

15. Micro-channel Plate (MCP) PMTs seem faster. Why not use these to count at high rates? This is not possible. MCP tubes have a permitted average current 1000x lower than ordinary PMTs which are quite low. Attempting to count at 100 MHz with a MCP for even a second will BURN OUT the tube and raise the noise level. MCP tubes are designed for timing and very very low light levels.

16. One company is selling a hybrid tube, but it is not a photon counting tube. What is it? Some companies add a built-in solid state amplifier to an APD or to a PIN diode and call this a Hybrid tube. These do not count photons and indeed it is not possible to do so this way. Some even say that ***any*** device that measures light is a photon counter, but that is a gross misuse of the term. There are new devices based on other principles such as superconducting devices that may count photons, but many are not readily available or affordable at this time.

17. What is a Hybrid Tube? A Digicon tube based on a combination of a photocathode and Avalanche Photodiode was developed for the Space Telescope. These followed the idea of intensifier tubes that have a photocathode in proximity to a fluorescent screen with a few thousand volts between them. The energy given to each photo-cathode electron by

the high voltage produces more photons at the fluorescent screen

a. In the Hybrid tube, the electron hits a semiconductor producing many electron-hole pairs which are then amplified even more in a non-geiger or non-breakdown mode. The total combined gain is just enough to see a single photon. Since the gain is only about 150,000 times, there is no heating or overload of the system even for high count rates. Additionally, the APD has a matched 50 ohm SMA connector output leading to very low ringing.
b. The best feature is that the peak output of the Hybrid tube is constant within 10% rather than the variable Poisson distribution. This greatly reduces noise and the setting of a detection level.

18. Why do you reference your competitors? We are price and performance competitive and don't make everything.

19. Why don't other companies publish their prices. Probably they don't want to be sued for causing heart failure.

Troubleshooting the PV16

1. If the output of the CPVA appears to be oscillating, remove the input. If the oscillation stops, then the source is causing the oscillation for one of several reasons:
    a. The input is picking up Cell phone radio at about 860 MHz typically even if the cable is shielded
    b. The input is grossly mismatched causing ringing
    c. The outputs of the CPVA are not BOTH terminated into 50 ohms
    d. The inputs and/or outputs of the CPVA are NOT TIGHT; Finger tight is enough If wiggling the cable creates output, it is mot likely not tight.
    e. The input or output SMA cable/s have the center pin pushed into the cable so that there is not good contact
    f. The PMT power supply has RF on the output which is feeding into the PMT
2. The output appears to ring
    a. Check to make sure the output is terminated into 50 ohms, AC or DC. Termination into 1 Megohm with a coaxial cable will cause ringing.
    b. One of the outputs is not terminated.
    c. An SMA cable is loose or the center pin is pushed in not connecting the output.
    d. The SMA cable is a cheap RG-174
    e. The SMA cable is an expensive RG-174
    f. USE RG58 for better results
3. No output is seen.
    a. There is no input.
    b. The gain is set to CCW maximum. Turn up the gain to maximum (CW) 15 turns for maximum gain.
    c. Check to see if the inverted or non-inverted output is triggering. The CPVA has both inverting and non-inverting output, so the Electron PMT will put out negative going pulses on the non-inverted output. So setting the trigger positive on the non-inverting output or negative on the inverting output in this case will likely not produce an output.
    d. Power plug is not completely pushed in. The power plug will have only 1/4" metal showing.