

Photon-Counting Means Sensitivity

The two main types of detection used with photomultipliers are *photon-counting* and *analog*. This Application Brief will help you select the technique that is best for your data.

Photon-Counting Mode

When photons of light strike the cathode of a photomultiplier tube (PMT), they dislodge electrons. These electrons pass from the cathode into the dynode chain (a series of high-voltage steps), which amplifies and directs them, to the anode. Figure 1 shows the output of a typical PMT, at different light levels.

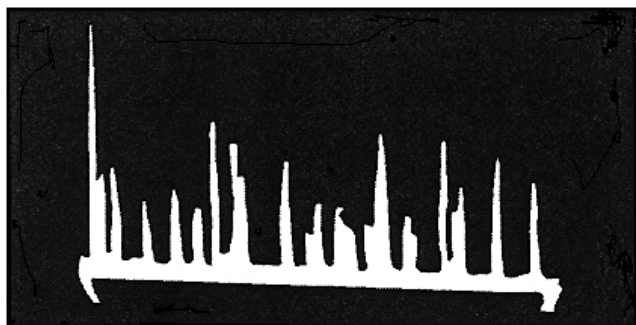


Figure 1. Amplified current spikes from photons striking the cathode of the PMT.

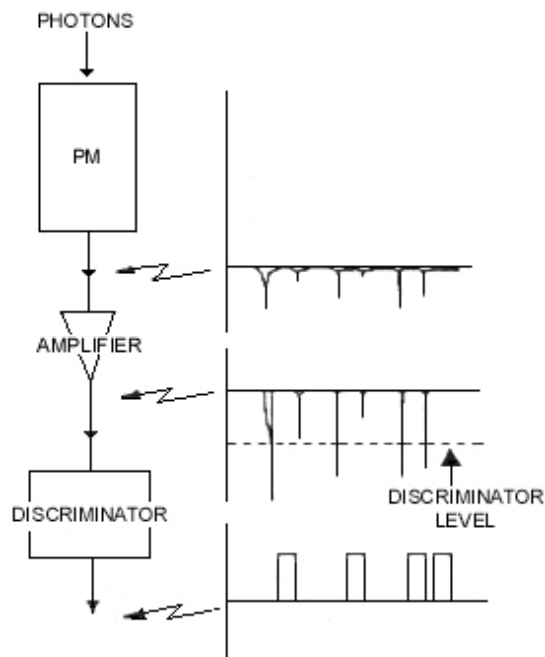


Figure 2. Block diagram of a photon counter.

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The pulses are then transmitted to an amplifier, then on to a discriminator, which filters out the lower-intensity noise pulses (Figure 2). A second amplifier (not shown in Figure 2) changes the voltage to a useable level.

The advantages of photon-counting are:

- The signal-to-noise ratio of the data is higher. Most noise is generated after the cathode, usually in the dynode chain. These noise pulses are lower intensity and are removed by the discriminator (Figure 2). In the analog system, noise gets added directly to the signal, and thus cannot be removed.
- The stability of a photon-counting system is better. All PMTs need a high-voltage supply. A small change in the voltage supplied will not affect the pulse count of a photon-counting system, but will affect the analog portion because of the integration of pulse height changes.
- Photon counting is unaffected by an RC time constant, which is an inherent part of analog systems' electronics. (The RC time-constant refers to an electronic circuit made of a resistor and capacitor.) Analog systems rely on RC time-constants to reduce noise, but thereby extract a price. One problem introduced by the RC time-constant is accuracy. An RC circuit discharges only 67% of its charge after one time constant has elapsed. For example, with a time constant of one second, 33% of the signal still is stored within the circuit, reducing the accuracy. Another problem is the speed of the electronics. At any signal level, RC circuits approach their final value exponentially; thus, the faster you scan, the more skewed your data look. This effect does not happen to digital signals, such as with photon counting.
- The precision, or practical range, of photon counting is greater than most analog systems. The range for photon counting is usually based on the PMT or the bandpass of the first amplifier, in the range of 3–4 million counts per second. Analog systems are usually based on the range of the analog-to-digital converter (ADC).

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The typical ADC has a 12-bit range, limiting your range to two to the twelfth power (2^{12} or 4096 different voltages). For photon-counting, on the other hand, the range is 0 to 3 million. This means that small changes and signals will be more clearly resolved via photon-counting, and won't be lost when a large signal encroaches.

Analog Mode

In analog mode, electrons also are generated by photons of light striking the cathode of a PMT. The resulting analog signal from the anode is the DC portion of the pulses. Bear in mind that this DC current is the sum of all pulses regardless of their source (cathode, dynode chain, leaky components, etc.). Therefore, the noise is more tightly bound to

the signal. There are, however, two advantages of analog over photon-counting:

- Analog is suited for higher-intensity signals such as absorption measurements. At this high signal level, the noise component is usually so small it can be neglected.
- Analog systems are usually cheaper to build. The components in photon-counting systems are either hand-picked, or have stricter tolerances, making them more expensive.

Photon-Counting vs. Analog

With strong light intensity, such as in absorption measurements, analog methods may be adequate. For low-light techniques, such as fluorescence or Raman spectroscopies, photon-counting enables you to extract the maximum information from your data.

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