SHORT CUT TO OPERATION

While you will want to study the information contained in this manual carefully to be sure that you get the most out of this detector, you may want to turn on the detector right away. The materials supplied in this kit should allow you to do so. But first, please review the set-up instructions below and the precautions for use on the following page to avoid any chance for errors. Also, be sure to make a backup copy of the diskette that is appropriate for your computer.

1) You will need an IBM PC or compatible computer and a +5 volt power supply. Turn them both off before proceeding.
2) Connect the RS-232 cable from the detector into the computer's serial pott Note which port is being used.
3) Connect the detector to the +5 volt power supply. Be sure to connect the YELLOW lead to the positive potential and the BLACK lead to the negative potential Insulate and store the striped leads.
4) With the power still turned off, remove the black, protective cap from the input window of the detector. Race the detector so that light from your experiment falls on the input window. Then, exclude all other light with covers, baffles, etc. Room lights may have to be dimmed or turned off.
5) Turn on the computer and +5 volt supply.

IMPORTANT!!! Now that the +5 volt supply is on, be sure that the input window remains protected from room light If the protective cover needs to be removed, shut off the +5 volts first

6) After the computer has booted up, insert the backup copy of the evaluation program into the disk drive. Change to that drive and type:
"EVAL40" followed by "enter" (do not type the quotes)

7) The "EVAL40" evaluation program should be running. It will ask for which serial port you have connected the detector to. Answer, and then press "enter"
8) A menu will appear, Turn on the high voltage power supply in the module to the proper set point by typing "7" or "D" followed by "enter".
9) Select keyboard control by pressing "1" and then type enter. A mode selection menu will appear,
10) Select continuous reading mode by pressing "2" or "C". Then, type "enter". You will be asked if you want to save the upcoming data to a file. Skip this by typing "N" followed by "enter". (Otherwise, type "Y" and follow the instructions.)
11) The computer display will now show the photon count value for 1 second reading rate. Press the F1 key to return to the mode selection menu.

IMPORTANT!! If the computer shows "OVERFLOW!!!", either the signal is too strong or there is too much background light hitting the detector window. Quickly switch off the +5. Rectify the problem and re-start the test

(Note: If the "OVERFLOW" continues for more than 5 seconds, the high voltage will be set to zero, the computer will beep and an error message will be displayed.)

PRECAUTIONS FOR USE

SUPPLY VOLTAGE

Do not exceed the maximum supply voltage of +6.0 volts. Do not reverse the supply potentials. Be sure that the +5 is connected to the Yellow lead, and the supply ground is connected to the Black lead, A mistake will blow an Internal protective fuse and require tine return of the detector for repair.

OVER EXPOSURE

This light detector is very sensitive and can be damaged by exposure to even subdued light Whenever the +5 power is on, the light to the detector must be under control!

DIS-ASSEMBLY

There are no user-serviceable components inside. The photomultiplier tube cannot be changed by the user. Due to the danger from the internal high voltage power supply, the user should not attempt dis-assembly of the detector assembly.

ENVIRONMENT

This detector assembly cannot be stored or operated above 50 ^{o}C because of potential damage to the photomultiplier tube. The assembly should not be stored below -20 ^{o}C or used below 5 ^{o}C. Do not use in a damp environment - do not let moisture collect on the unit When used below room temperature, particular care must be used to keep the detector dry. Do not allow the detector to be in an atmosphere rich in Helium gas - it penetrates the glass walls of the tube. Do not operate the detector in a vacuum.

CLEANING

For the window, use lens tissue moistened with alcohol and lightly rub clean and dry. For the housing, use a cloth or paper towel dampened with water and mild soap. Then wipe dry. Never get the detector wet If liquid is spilled and enters the housing at either end, do not use. Return the detector for service.

BACKGROUND INFORMATION

Although the detector modules described in this manual are very simple to use, they are based on tie most sensitive light measurement method available. They measure the light level by counting photons, one by one. For those interested In the technology or those attempting to optimize their application, some background is provided on the photon counting method and typical results. Additionally, the module circuitry and operation is described as well as the influence of the environment on the detector's accuracy and stability.

Photon Counting Basics

The photomultiplier tube is the heart of this detector assembly. It detects the incident light by photoemission. That means that the light photons are absorbed in a thin, semiconducting layer, called the photocathode. Absorption of the photon is accompanied by the raising of an electron from the valence band into the conduction band. In addition, the free electron is transported to the vacuum interface between the solid (thephotocathode) and the vacuum inside the tube. It is then ejected into the vacuum, becoming a photo-electron. Not all light photons will be absorbed and cause the release of an electron into the vacuum, instead, the probability of detection and electron escape (known as the quantum efficiency) varies with the wavelength of the light and the materials used to make the semiconducting layer. The H9319 Series is offered with two basic types of photocathode; the"bi-alkali" has good quantum efficiency over the range from 300 nm to 650 nm. The "multi-alkali" extends the range out to 850 nm but has higher background noise (see page 9). The quantum efficiency for these two photocathodes are shown in Figure 1, where the data should be understood as the ratio of the number of detected photo-electrons to the number of incoming photons in percent. Good performance in the detection of the photon is basic to low noise performance in photon counting.

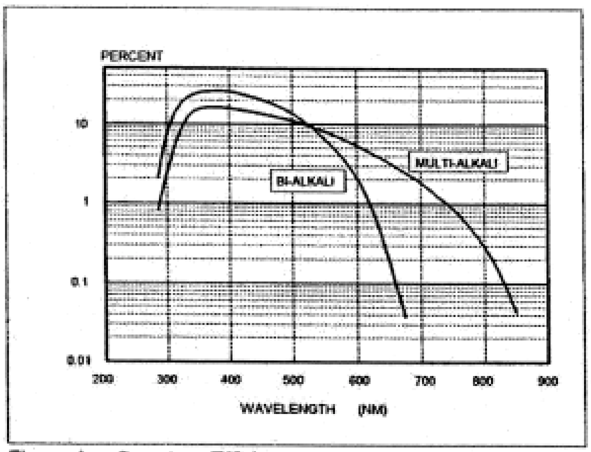


Figure 1. Quantum Efficiency

The photomultiplier tube amplifies each resulting photo-electron by utilizing secondary emission. Since the detected electron exists in a vacuum, it can be given energy by accelerating it in an electric field. If the accelerated electron is directed to strike a surface capable of secondary emission, a large number of electrons is released from the surface. The ratio in typical tubes is 5 to 7 released per incoming electron. In a photomultiplier tube, this multiplication is repeated many times by using 9 to 11 separate surfaces or dynodes. The end result is a charge pulse of 1 to 10 million electrons released from the tube to an external circuit all within the space of a few nanoseconds.

In the case of analog signal processing, the external circuit could be a resistor with some capacitance across it to integrate these charge pulses into an average voltage signal. A measurement of the voltage would

Indicate the strength of the Sight signal reaching the input window. But, in photon counting, the light signal is treated as discrete pulses to be amplified separately, and then detected or discriminated separately, This concept is commonly referred to as "single photon counting". If the pulses are totaled over a specific time interval, the count rate is then taken as an accurate measure of the intensity of the light source.

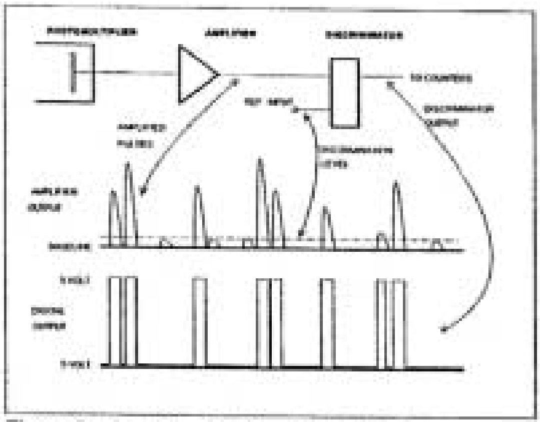


Figure 2. Amplification/Discrimination Process

In Figure 2, the wave form of the charge pulses is represented. It is assumed that the charge pulse has been converted into a high-speed voltage pulse and amplified. The figure illustrates that the pulses have both a random arrival as well as significant variation in amplitude from pulse to pulse. The variation in pulse height is caused by the quantized nature of the secondary emission of the dynodes. White the average gain of a dynode may be seven, the actual number of secondaries for each event may be eight, or six. Or even one or none. The first dynode is most important in setting the degree of uniformity of the charge pulses although the following dynodes play some role as well.

Assuming a fixed gain for the photomultiplier tube and amplifier circuit, we can see that the level marked "discrimination level in Figure 2 determines whether a current pulse from the tube will be detected and counted. Those pulses below the discrimination level are ignored. Some of those pulses might be due to the light signal. But, most likely, the majority are due to noise pulses from thermionic emission from the dynodes. It is important to realize that some thermionic pulses can originate from the photocathode. These pulses cannot be discriminated against as in the case of dynode pulses because their pulse height distribution overlaps the signal. These pulses can be observed by blocking all light from the photomultiplier and counting. The resulting count is referred to as the dark count.

It is common to study the degree of pulse height uniformity and the relative pulse height of the dark counts by measuring the "pulse height distribution" of the photomultiplier tube. This data is obtained by applying light to the tube and then measuring the number of charge pulses of a given amplitude over the whole range of possible poise amplitudes. A typical test result is shown in Figure 3.

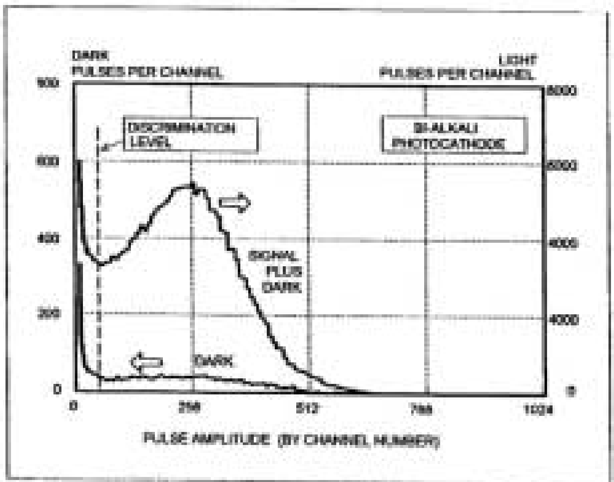


Figure 3. Pulse Height Distribution

Considering the curve of signal plus dark count, the wide range of amplitudes is evident. There is a tendency for the pulses to clump together causing a peak in the data. The meaning is simply that the multiplier gain was fairly constant for the photo-electrons that passed through the tube. The largest number of photo-electrons had a gain equivalent to channel 256. Also, note a drop in counts for lower pulse heights around channel 100, and that a "valley" is formed in the data. The valley aids in distinguishing the noise counts of the thermionic emission of the dynodes from the signal counts coming from the photocathode.

The dashed fine marked "discrimination level" has the same meaning as in Figure 2, Counts to the left of the dashed line are mostly due to dynode noise. These pulses will not be counted. Counts to the light of the dashed fine are presumed to be from the photocathode, and caused by the light signal. The second curve, marked "dark", Is taken with all light blocked front the photomultiplier tube. It can be seen that some of the counts overlap the same amplitude range as the light signal. As mentioned previously, these dark counts, originating from the cathode, cannot be eliminated by the discriminator.

In practice, the pulse height distribution is useful for deciding the qualify of a particular tube design, but is rather cumbersome to utilize when trying to decide the discriminator level in a production environment A method giving equivalent results is based on the "plateau curve" and is the method used In setting up the H9319 Series. First, the amplifier gain and discriminator level are set based on the certainly of good DC stability against temperature drift and good AC stability against the chance of oscillation. Then, a weak light is admitted to the input window with the high voltage set very low (about 600 volts). The photon count is taken and recorded along side the high voltage setting. The sequence is repeated as the high voltage is raised in 25 volt steps, A typical result is presented in Figure 4. Note that, after a certain point, further increases in the high voltage do not provide much change in the count rate. The region of the curve where the count rate is not sensitive to the high voltage is called the plateau, if the measured count rate is insensitive to high voltage changes, then the count rate must also be insensitive to gain changes due to ambient temperature changes or due to aging over the life of the tube. Both effects are detrimental in the analog mode. For the H9319 Series, the high voltage operating point is selected on the plateau where the slope of the curve is less than 10 percent change of the count rate per 100 volts. This selection of the operating point allows a substantial improvement in the overall stability of light measurement with photomultiplier tubes

Figure 4 also shows the count rate for the same range of voltages with the light extinguished. Note that the behavior differs significantly from the light curve. The difference is due to the range of relative pulse heights as reflected in the pulse height distributions shown in Figure 3. For the highest voltages, at approximately 1100 volts, Hie count rate inflects up. This m caused when the gain Is high enough to allow the dynode noise to overcome the discriminator.

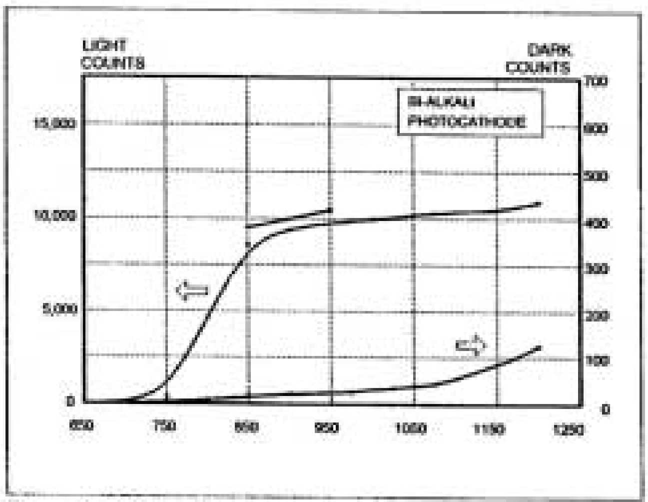


Figure 4. Plateau Curve

The above discussion shows clear advantages for the photon counting method in terms of permitting a differentiation between the signal and some sources of noise and reducing the effects of gain drift of the photomultiplier tube, in addition, It allows a simple way to measure what would normally be an extremely small signal current by just counting pulses. But, a penalty comes about when the light signal becomes strong. In the analog mode, strong light can be dealt with by reducing the size of the load resistors or, for even stronger light, simply by reducing the high voltage, thereby lowering the tube gain. No such method is practical in photon counting because,as soon as the voltage is towered, the plateau effect is lost and the pulse amplitude becomes too small to activate the discriminator.

In using the photon counting method, the biggest impediment to measuring brighter light signals is the speed limitations of the amplifiers, discriminators and counting circuits. As a single photon is detected, a pulse is produced having a width of 5 to 10 nanoseconds. While the circuitry is responding to any given photon, it cannot detect a new photon and produce a separate pulse, distinct from the first pulse. The circuitry Is "dead" for new pulses while it is processing the first pulse. Since the occurance of the photon is random in time, the pulse overlap Is a statistical problem. Intuitively, we expect that, as the light level increases, the chance for overlap will increase and the failure to produce separate pulses for every photon entering the detector will become a bigger problem. That failure Is reflected in a loss of linear response between the input light signal and the corresponding count rate. The design and application of faster circuitry to photon counting has proven very useful in extending the range of photon counting detectors.

A theory has been developed which allows the prediction of the degree of error to be expected. A good discussion is given by Knoll in Radiation Detection and Measurement From Knoll's explanation, if a counting detector is used with a "dead time" of DT and a measurement, M, is made; then the actual rate, N, is;

$$N = \frac{M}{1 - M\,DT}$$

Thus, if a count rate is taken to find the light level, one need only adjust the measured rate by application of the above formula. In practice, this approach has limited value in linearizing the detector's response to light. Some important limitations are;

1.) The value for the dead time, DT, is either not known accurately or varies from unit to unit.
2.) The AC coupling of the circuits commonly used to permit positive high voltage adds an unknown error to the measurement when the duty cycle becomes more than a few percent, (The baseline shifts as the pulse is presented to the discriminator.)
3.) The resistive divider may add a non-linear error (it usually causes a positive error) that is not related to the formula.
4.) The counting circuits designed by the user may limit the maximum counting speed below the speed of the tube/amplifier combination in an unknown manner.

The H9319 Series, as will be shown In detail later, improves on existing technology by:

1) High speed tubes and components are specified to reduce as much as possible the probability for pulse overlap.
2.) All components that can affect the dead time of the counter are in the same package and can be accurately measured and controlled.
3.) The dead time value to be used in the correction formula is not measured by loosely related effects: neither the amplifier bandwidth nor pulse pair resolution are used. Instead, the dead time is measured by working backwards. Linear steps of light are applied to the detector assembly and the corresponding count is taken. Then, the dead time value which closely solves the theoretical formula is determined. This value can then be applied with confidence to all other readings. The error will be no more than the error of the calibration source.

By including all of the components into a single detector assembly, complete control of the detector assembly is obtained. In this way the accuracy and linear range of the detector can be significantly enhanced.

Signal-to-Noise

Since the arrivial of a photon into a detector from most light sources is random, the signal-to-noise analysis must use a statistical approach. Photon counting is found to be similar to radioactive decay experiments in nuclear physics, where the number of possible events is very large, but the probability of any single event is very small.

In this case, the Poisson Distribution (a variation of the more general Binomial Distribution) is applicable.

If a total of N readings of a light source were taken with each individual reading denoted as n(, the average, nis:

$$\bar{n} = \frac{1}{N} \sum_{i=0}^{N} n_i$$

By the Poisson Distribution, the standard deviation (root mean square or r.m.s.) is simply:

$$\sigma = \sqrt{\bar{n}} \quad \text{r.m.s.}$$

And the signal-to-noise ratio is:

$$S / N = \frac{\bar{n}}{\sqrt{\bar{n}}} = \sqrt{\bar{n}}$$

Note that the signal-to-noise ratio depends only on the size of the average count A low count rate, measured over a longer time, will Improve the signal-to-noise ratio.

EXAMPLE: Figure 5 is a graph of 100 readings of a weak light source adjusted to give an average of 1000 counts per second. The data was taken with an H9319 set to one second integration time. By the definition above, the standard deviation should be the square root of 1000, or 31.6, To check the theory, the basic definition of r.m.s, noise was used. The average is:

$$\bar{n} = \frac{1}{100} (n_1 + n_2 + \ldots)$$
$$= \frac{1}{100} \; 100000 = 1000$$

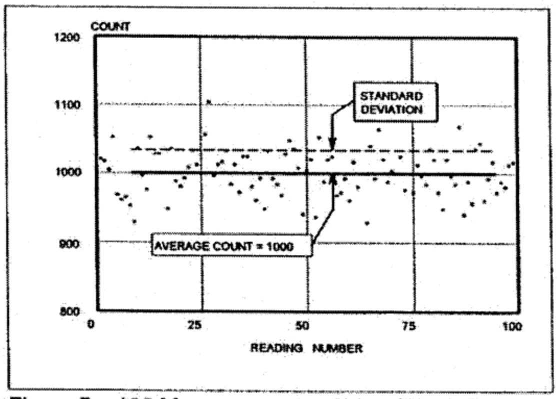


Figure 5. 100 Measurements of Very Weak Source

Yes, it worked out exactly! Next, differentials were calculated and squared, as for the usual, root mean square calculation.

$$\sum (\bar{n} - n_i)^2 = 109056$$

The standard deviation is:

$$\sigma = \sqrt{\frac{1}{100} \sum (\bar{n} - n_i)^2} = \sqrt{\frac{109056}{100}} = 33.02$$

The agreement with the theory is fairly good. Note also that the peak-to-peak deviation is much ferger than the r.m.s, value. A factor of 6 to 7 times the r.m.s. is usually used to estimate the peak-to-peak variation. In an application, if a single reading is to be taken, it can be 3 to 3.5 times the r.m.s, value away from the average.

With this simple result from the Poisson Distribution, we can develop a more detailed relationship between the available light Signal , the characteristics of the detector and the signal-to-noise ratio. First, it is important to determine how many photons are contained in a given light signal and then how effective the photomultiplier is in using them.

If we have a light flux of P( )power in watts at wavelength then the number of photons per second is:

$$\text{photons / sec} = \frac{P(\lambda)}{\text{energy of 1 photon}} = \frac{P(\lambda)}{h\ c\ /\ \lambda} = \frac{P(\lambda)\ \lambda}{h\ c}$$

$$c = 3.00 \times 10^{8}$$

$$h = 6.62 \times 10^{-34}$$

EXAMPLE: the number of photons of 500 nm wavelength in a light flux of 1 picowatt is:

$$\frac{1 \times 10^{-12} \qquad 500 \times 10^{-9}}{6.62 \times 10^{-34} \qquad 3.00 \times 10^{8}} = 2.52 \text{ million photons per second}$$

Ideally, the photomultiplier tube should convert all of the available photons to signal counts to get the best signal-to-noise ratio. But, in practical tubes, there are several significant limits to this goal. The most important limitation is the quantum efficiency of the photocathode as discussed previously (see page 3 and Figure 1), High quality,bi-alkali photocathodes can achieve 30 percent quantum efficiency at their peak response in the blue wavelength region, Multi-alkali photocathodes, while nearly as high in the blue, fall to 2 to 5 percent at the end of the visible Spectrum, out at700 nm. Once the photon is detected and a corresponding photo-electron exists, there is some chance that the photo-electron may deviate from the normal trajectory and miss the first dynode. The chance for this loss is greater for light striking -tie peripheral areas of the photocathode. Losses range from 5 to 50 percent.

For the- photo-electrons trial arrive at the first dynode, it is essential that the current gain be large and uniform. Otherwise, there will be more scatter In the pulse height distribution causing more charge pulses to fail to trip the discriminator. Typical losses in the discrimination process are 5 to 10 percent. Stretching the voltage applied to the first dynode (see page 15) is effective improving the first dynode gain and reducing the signal losses.

The combined loss due to all of these factors is called the counting efficiency (CE), It is the ratio of the counts coming from the discriminator output to the number of photons in the incoming light flux. Figure 6 shows the typical performance for the bi-alkali and

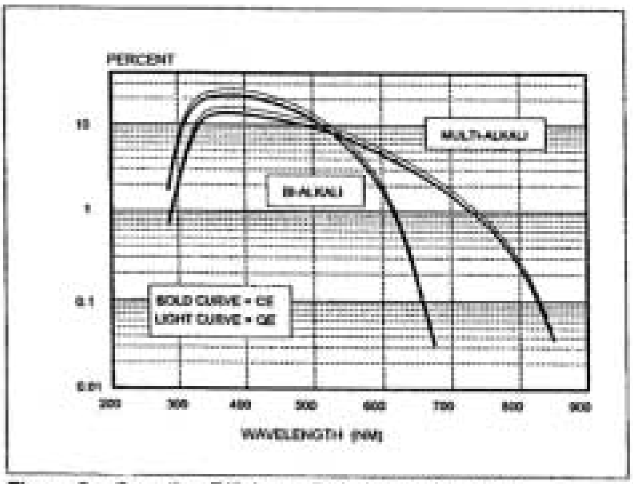


Figure 6. Counting Efficiency Relative to Quantum Efficiency for Bi-alkali and Multi-alkali Tubes

multi-alkali photomultiplier tubes. Their overall character is similar to the quantum efficiency curves.

With the knowledge of the counting efficiency, we can develop a relation between the signal count rate and the power of the light signal:

$$\text{signal count rate} = CE \; \frac{P(\lambda)\,\lambda}{h\;c} \; \text{cps}$$

EXAMPLE: Suppose 1 picowatt of light at 700 nm is available from an experimental set-up. What is the signal count rate resulting from the two types of photocathodes - bl-alkali and multi-alkali?

Bi-alkali:

$$\text{signal count rate} = \frac{0.01 \quad 1 \times 10^{-12} \quad 700 \times 10^{-9}}{100 \quad 6.62 \times 10^{-34} \quad 3.00 \times 10^{8}} = 352 \quad s^{-1}$$

Multi-alkali:

$$\text{signal count rate} = \frac{1.3 \quad 1 \times 10^{-12} \quad 700 \times 10^{-9}}{100 \quad 6.62 \times 10^{-34} \quad 3.00 \times 10^{8}} = 45800 \quad s^{-1}$$

As mentioned above, a photomultiplier tube outputs counts even though the tube is placed in complete darkness. Those counts that come from the thermionic emission of the dynodes can, for the most part, be eliminated through the discrimination process. But the thermionic emission from the photocathode cannot be eliminated because of overlap of the pulse height distributions. For the bi-alkali photomultiplier tubes, the dark count is typically 100 to 200 counts per second For the multi-alkali photomultiplier tubes, a lower bandgap of the semiconductor layer is used to obtain a longer wavelength cutoff and the dark count is much higher. Typical values are 10,000 counts per second. It is the fluctuation of the dark count that obscures the signal at the lowest light levels and defines the lowest light level that can be detected.

If we consider the steps in making a measurement of a weak light signal, we do not measure the signal directly, but measure the signal plus dark counts. Then to reduce the error of the average dark count, we should block the signal from the detector and measure the dark count alone. Subtraction yields the value of the signal. The noise of this measurement is composed of two separate readings, which should be added together vectorially.

$$\text{noise total} = \sqrt{\text{noise (signal + dark)} + \text{noise (dark)}}$$
$$= \sqrt{\text{noise (signal)} + 2\ \text{noise (dark)}}$$

If n and d are the signal and dark count respectively, then the signaMo-noise ratio is:

$$S / N = \frac{n}{\sqrt{n + 2d}} = \sqrt{\frac{n^2}{n + 2d}}$$

For the case where the signal is large compared to twice the dark count, the signal-to-noise reduces to the previous result on page 7; S/ N n. An increase to the signal-to-noise ratio can be made by increasing n, the total signal count .This is accomplished by getting more light signal using a photomultiplier with higher counting efficiency or extending the time over which the signal count rate is measured. Doubling any of these parameters will increase the signal-to-noise by 1.41.

For the case where 2d (twice the dark count) is large compared to the signal, then halving the dark count will give a 1.41 improvement to the signal-to-noise ratio. And doubting the measuring lime can be shown to improve the signal-to-noise by the same amount. However, improvements to either the light signal level or the counting efficiency are more effective - a doubling of either will nearly double the signal-to-noise ratio.

EXAMPLE: To illustrate the second case, consider a light signal at 700 nm containing 50,000 photons. What is the signal-to-noise ratio for a multi-alkali photomultiplier having 10,000 dark counts and a counting efficiency of 1.3 percent?

$$S / N = \sqrt{\frac{(0.013 \quad 50000)^2}{0.013 \quad 50000 + 2 \quad 10000}} = \sqrt{\frac{422500}{20650}} = 4.52$$

Now, suppose an improved or selected photomultiplier having twice the CE were available:

$$S / N = \sqrt{\frac{(0.026 \quad 50000)^2}{0.026 \quad 50000 + 2 \quad 10000}} = \sqrt{\frac{1690000}{21300}} = 8.91$$

If the equation for signal-to-noise ratio were set equal to one, we could solve for the light level needed to bring the signal just equal to the r.m.s, noise. This light level is known as the Noise Equivalent Power (or N.E.P.).

$$S / N = \sqrt{\frac{n^2}{n + 2d}} = 1$$

For dark counts more than a few counts per second, the value of n at the N.E.P. is be approximated as:

$$n = \sqrt{2d} \quad \text{at N.E.P.}$$

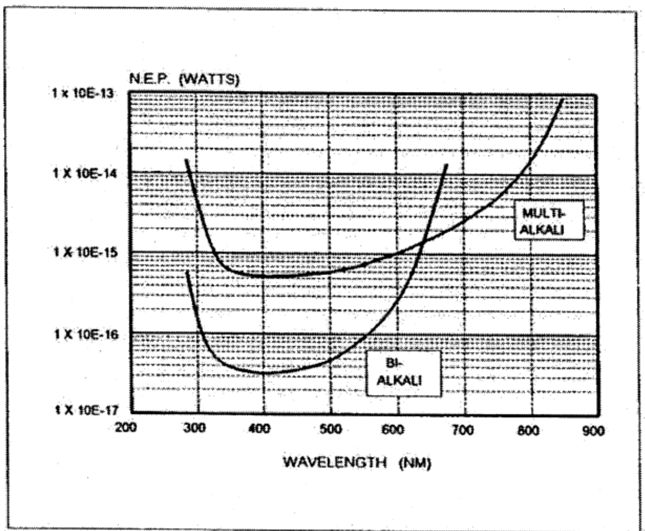


Figure 7. Noise Equivalent Power for Bi-alkali and Multi-alkali Photomultiplier Tubes

With the value of n known, we can use the graph of the counting efficiency from the data sheet to find the cor-responding light power. This has been done for typical bi-alkali and multi-alkali photomultiplier tubes and is shown in Figure 7. It is assumed that the measuring period is one second.

Accuracy and Stability

We know from the previous discussion that photomultiplier tubes are capable of quite high signal-to-noise ratios when given enough light For a count rate of 10 million, the r.m.s, noise is approximately ,03 percent of the average signal level. But to use this low noise result effectively, the stability and accuracy of the measurement has to be comparably high. Unfortunately, the photomultiplier tube has a number of properties that cause variation in the gain of the tube. To achieve accuracy on par with the noise performance, users normally have to resort to double beam techniques where tie photomultiplier tube measures relative light levels - the signal against a reference. The causes of the gain instability are:

Voltage Hysteresis: temporary instability of the gain due to charging of the dynode support structure by changes in the applied high voltage. Effects range from a few percent to as high as 30 percent.

Light Hysteresis: gain loss during the application of strong light A slow recovery to the initial gain occurs during weak or no light input Errors of a few percent are common and can be reduced by limiting the anode current to a few microamperes.

Ambient Temperature: The secondary emission ratio has a small temperature coefficient. But when ten dynodes are used together, the cumulative effect can be significant. Typical drift is 0.4 percent per degree C.

Aging: Over the long term, drift of the gain of the tube occurs due to physical and chemical changes to the tube. The effect depends on the overall anode current as well. Ten to 20 percent change over several years is common.

All of these effects occur due to changes in the gain of the photomultiplier tube. But, if photon counting is used for detecting fee signal out of the tube, the plateau effect reduces significantly the variation in signal output due to gain changes. For photomultipliers having typical peak to valley ratios of 2:1, an improvement of 4 or 5 in stability can be obtained as compared to the typical results from analog measurements. Some of the tests that reflect this advantage are the temperature drift of the responsivity and the stability at turn-on.

Another important comparison can be made between the analog and photon counting methods regarding baseline stability. In the analog approach, the anode must be referred to ground so as to direct-couple the amplifier circuits and other read-out electronics. When this is done, the photocathode must be connected to negative high voltage for proper tube bias. The high voltage applied to the photocathode, which is deposited on the glass bulb, causes glass scintillations and leakage current that give rise to higher dark noise. This noise often

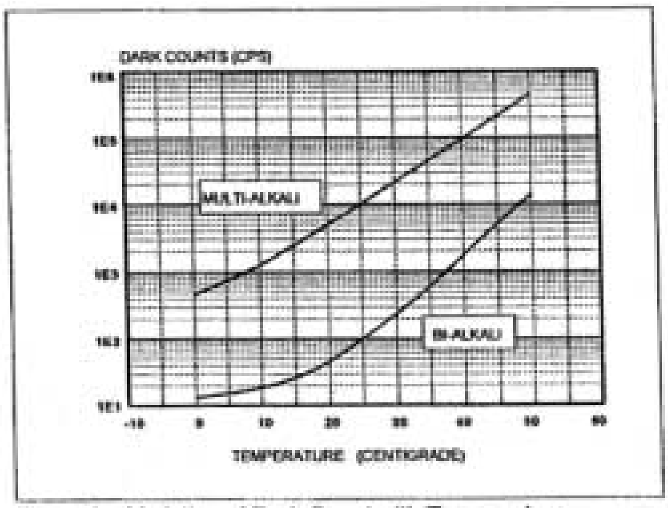


Figure 8. Variation of Dark Count with Temperature

fluctuates randomly and obscures weak signals. The effects become more pronounced for nearby ground planes and for moist or dirty insulators in contact with the glass bulb.

In photon counting, this difficulty can be completely eliminated. Because the signal from the anode is a pulse of current, the anode can be AC coupled to the amplifier circuits. Consequently, the photoeathode can be connected to ground with positive high voltage used to properly bias the anode With the photocathode at ground, the noise and instability due to the effects of moisture, contamination and nearby grounds are gone.

Temperature changes of the photomultiplier tube affect both the accuracy of the reading as well as the minimum detectable signal. Because the photocathode is a semiconductor, the thermionic emission is strongly dependent on the temperature - the emission or dark count rate doubles with every 4 to 6 degrees centigrade.Figure 8 shows the typical variation of the dark count with temperature. To counter the changing baseline, one must plan for frequent checks of the dark count in the absence of the signal and subtract off the dark count. It should also be understood that the increasing temperature will increase the noise and lower the sensitivity of the detector. It is best to take great care to reduce as much as possible the temperature that the photomultfplier is subjected to by limiting power consumption and keeping a distance from hot devices.

Another cause of high dark noise is exposure to bright light - especially sunlight, UV light, or fluorescent lighting even though the high voltage may be turned off. If exposure is allowed, then the dark count will be well above the level of dark count that is measured after storing in darkness for several hours. The cause is partly due to phosphorescence of the glass as well as to the filling of traps in the semiconductive layer (photocathode). Dark count levels can reach several hundred thousand counts per second immediately after exposure and take hours to get down to the specified level and overnight to reach the ultimate in best sensitivity. A typical result is shown in Figure 9. It is best to design the system operation to keep the input window of the photomultiplier in darkness whenever sample changes or system adjustments are to be made. For example, a shutter in front of the input window could be closed whenever there was a possibility of strong light xposure. Complete darkness is not needed. It is enough to keep the light down to the maximum range of the counter; i.e. about 100 picowatts.

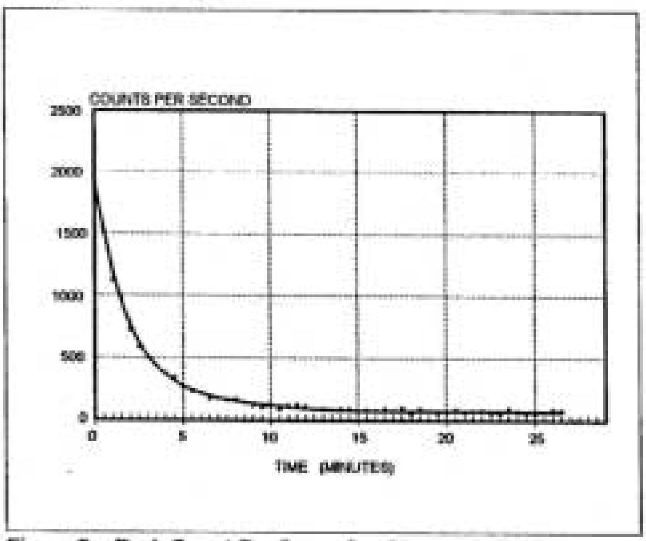


Figure 9. Dark Count Declines after Storage in Darkness

MODULE DESIGN AND OPERATION

The central goal for the design of the H9319 was to develop a photon counter with extended dynamic range. While designing the wideband amplifier circuits, it became obvious that most potential users would have difficulty in providing the follow-on counting circuits that would have sufficient speed, in fact, most available counters are slow enough to degrade the speeds that are achievable in the photomultiplier tube and amplifiers. Additionally, the counters would be likely to cause an unpredictable departure from linear response that the user may have trouble to characterize. The obvious solution was to integrate the counters in the same package and find a way to send out the accumulated count to the user. The inclusion of an 8 bit microcontroller with a serial, RS-232-C interface easily solved that problem. These concerns lead to a design in which the following major components are included;

Selected photomultiplier tube
High voltage power supply
High speed amplifier
Pulse discriminator
Pre-scaler
Counting circuits
Microcontroller
Housing with shielding

To ease the use of the detector assembly and to insure best performance, Hamamatsu tests and sets up the high voltage operating point, the discrimination level, and measures the dead time of the entire assembly. The dead time and high voltage are then programmed into the permanent memory of each unit. The microcontroller can then set the module to the proper high voltage and correct the data for pulse overlap without intervention by the user.

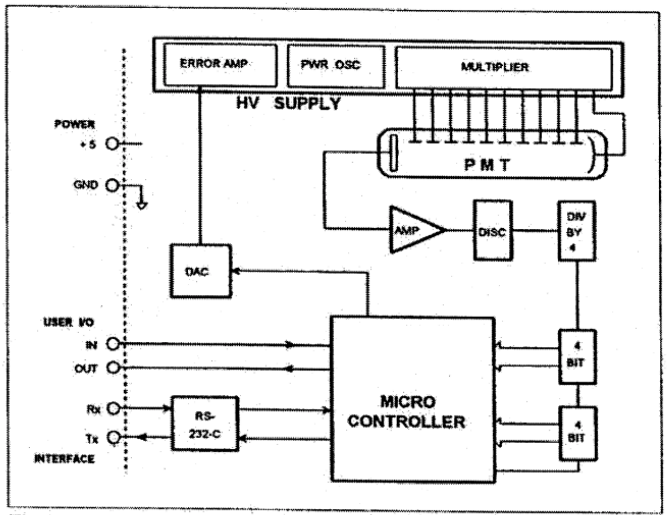


Figure 10. Block Diagram

It should be mentioned that, with a large number of circuits in the same package, it is possible to get too much heat build-up. The heat will raise the dark count and reduce the low-end sensitivity of the detector. To counter this potential problem, the Cockcroft-Walton high voltage supply was used to power the photomultiplier tube. Additionally, low power circuitry was selected for amplifiers, discriminator and counter circuits. And by reducing the bias for all circuits to +5 volt operation, the power consumption is held to under 250 milliwatts. (Note that the divider circuit alone for the traditional bias supply requires 330 milliwatts!)

The following material will discuss in more detail the circuits and components introduced here. The block diagram of Figure 10 should be used as a reference.

Basic Operation

When 5 volts is applied to the module, the microcontroller starts from reset and performs a short initialization of ifs onboard circuits. For example, the serial communication port (RS-232-C) and the precision timer, that sets the integration time, are set up at this time. Also, the digital to analog converter is set to zero to keep the high voltage power supply off. The microcontroller then enters the command processor, which is a program loop that simply waits for a command from the host computer. When a command is received, it is interpreted and executed.

To begin reading the light level, the host must first turn on the high voltage to the photomultiplier tube. This is done by sending the command "0" plus a carriage return, "Cr". Other programmable settings can also be sent at tills time to configure how long the light signal will be integrated, how many readings should occur in a sequence, and whether external triggering of the readings is desired. Once the configuration is programmed by the host either a command from Vie host or an external trigger will start the data-taking process.

With the reading process underway, the microcontroller clears the counters to zero and then gates the counters on to enable them to start counting. Since the high voltage to the photomultiplier is already on, the tube is sending a current pulse into the amplifier and discriminator circuitry for each detected photon entering the input window. The gate remains open to these current pulses and the counting continues until the precision timer in the microcontroller reaches 10 milliseconds. At this time the gate is closed to new counts, the value of the counters is read and saved in a temporary memory, and the counters are then cleared to zero. Finally the process is re-started as before with more signal counts being registered.

While the counting process is going ahead, the collected data is tested to be sure it has not exceeded the maximum allowed count. If not, it is then corrected for pulse overlap and then added to any previous reading. This process continues until the number of 10 millisecond readings equals the programmed integration period. If the end of the integration time has been reached, the microcontroller sends out the total of ail individual readings as a four byte, binary result on the serial interface to the host if a reading sequence has been programmed, the four bytes will be sent after the first 10 millisecond interval of the following reading has been started. Note that no time is lost for integration of the light signal due to communications with the host computer.

Following the completion of the measurement, the microcontroller returns to the command processor. The sequence can be re-started when needed or modification of the configuration can be made. At the end of each 10 millisecond interval, the microcontroller checks the serial port to see if a stop command (Cr) has been sent by the host. If the host needs to stop the reading process and re-gain control of the module, it can do so in this manner.

Photomultiplier Tube

The H9319 Series utilizes the 1 inch, low-profile series of photomultiplier tubes. This series was selected because of their high speed capability, small physical size and good selection of photocathode types. The H9319-01 uses a selected R1924A bi-alkali tube; the H9319-02 uses a selected R1925A multi-alkali tube. The quantum efficiency for both tubes is shown in Figure 1. Other tubes are available on special order such as the R3550A with a low noise, bi-alkali photocathode.

The low-profile tubes achieve high speed by using circular-cage multiplier design. Inherent pulse rise time is less than 2 nanoseconds. The input window has a piano-concave structure which helps maintain pulse response speed and improves the collection efficiency for electrons leaving the photocathode. Performance of the tube is also enhanced by stretching the voltage between the cathode and first dynode. To stretch the voltage, the normal divider ratio of 1:1:1: ....:1 is modified to 2:1:1:... or 3:1:1:.... In this case 3 to 1 is used as shown in Figure 11, The greater field strength in this section of the tube allows better control of the electron trajectory and better collection efficiency. An added benefit is improved first dynode gain due to the higher energy imparted to the electron and a consequent increase in secondary emission. Higher gain of the first dynode gives better peak-to-valley ratio, flatter plateaus and better operational stability (see page 5).

To guard against instability of the baseline, positive high voltage is used. The photocathode can then be referenced to ground with the anode biased to positive high voltage and AC-coupIed to the amplifier circuits. With the photocathode at ground potential, the detector module is less sensitive to the effects of moisture and contamination.

High Voltage Power Supply

The photomultiplier tubes used in the H9319 Series require bias voltages in the range of +1000 volts. Some adjustment of the voltage Is needed to set the operating point to the plateau as described on page 5. And since heat build-up causes a dramatic rise in the background noise of the tube, the H9319 Series uses the Cockcroft-Walton type of high voltage supply because of it's low power consumption. The schematic diagram for this supply is shown in Figure 11.

The basic idea of the Cockcroft-Waiton supply is the use of a network or ladder of diodes and capacitors to repetitively clamp and then rectify an AC power input. The H9319 power input is a 55 to 95 volt sine wave of 185 kHz. This voltage is generated by a re-designed, transistor oscillator and step-up transformer that permits operation with less than +5 volts of input power. Integer multiples of the peak-to-peak voltage are then available as DC voltages to bias the photomultiplier properly. The high frequency allows the use of small size components white maintaining low ripple interference. Since there are no resistors used to set the voltages as are normally used with resistive "divider" circuits, the power dissipation and consequent heat rise are greatly reduced.

The power supply must also give stability against changes in the load current, the +5 volt input power or the ambient temperature. And the design must allow for adjustment to the desired operating voltage. A feedback servo control circuit is used to do this. The voltage at the last multiplier section is reduced by a 1000 to 1 divider and connected to the input of an operational amplfier. This value is then compared with a reference voltage connected to the other input. Any difference between the reference voltage and divided-down, high voltage will result in a large change in the output of the operational amplifier. By connecting the output to the power oscillator, the feedback loop is closed. Any difference seen at the amplifier input will result in a correction going in the opposite direction so as to hold the high voltage constant. The components used in the circuit enable the drift of the supply to be held to within 50 parts per million per degree C. Any adjustment of the reference voltage will change the setting of the high voltage.

From the block diagram, one can see that the reference mentioned here is really a digital-to-analog converter. In this way, the user can control the high voltage applied to the tube very easily through the microcontroller by using the host computer.

Because of the low output resistance of the Cockcroft-Walton design, a rather large current can be supplied to the tube under high illumination. Since this high current flow in the tube can be damaging to both the power supply as well as the photomultiplier tube, a circuit (not shown in the block diagram) has been included to detect severe loading and reduce the voltage supplied to the power oscillator. The high voltage drops, preventing high anode current.

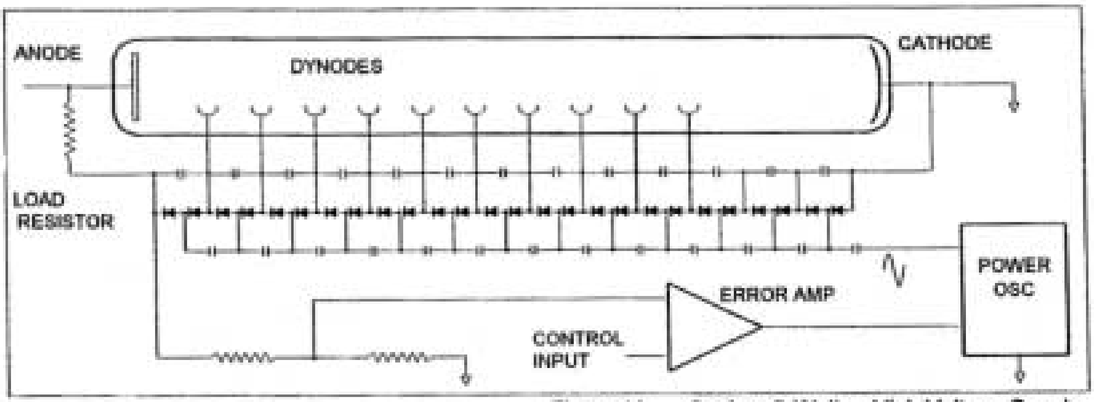


Figure 11. Cockcroft-Walton High Voltage Supply

Typically, the maximum anode current is reduced to several hundred microamperes at most and the primary input current to the high voltage circuit is limited to a safe level of 20 milliamperes. Of course, these levels cannot be tolerated by the tube for more than 10 seconds without risking damage to the tube.

Amplifier/Discriminator/Counter

With the bias voltages applied to the tube as mentioned, the typical output from the anode lead is about 2 million electrons for each photo-electron. Although this seems tike a lot of signal, the voltage pulse produced across a 50 ohm load is only 5 to 10 millivolts. Before the pulse can be accurately discriminated, it must be amplified by 20 to 30 times. This amplification must be done without reducing the speed of the pulse significantly or pulse overlap wilt severely limit the dynamic range of the assembly. For the H9319 Series, the gain is about 30 times with a bandwidth of 100 MHz. Figure 12 shows the actual photon pulse shape at the output of the amplifier.

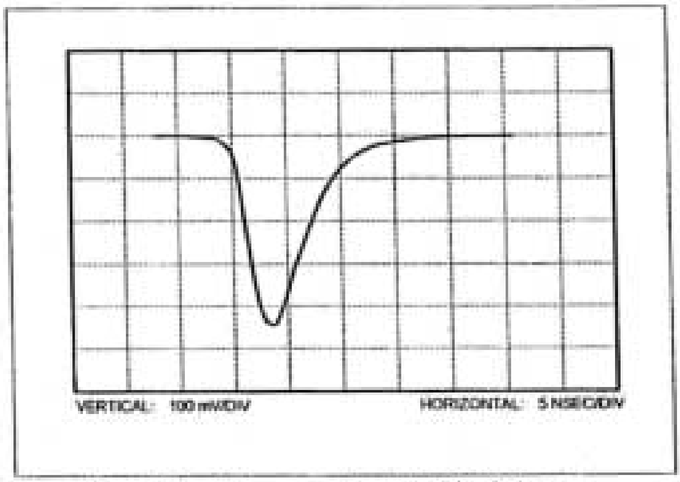


Figure 12. Pulse Response at Input to Discriminator

With this gain and bandwidth, the photon pulses are large enough that the discriminator can be set to 50 to 100 millivolts. With settings this high, typical high speed discriminators can operate with little risk of feedback oscillation or drift of their discrimination level.

Once the photon pulse is discriminated, it is in a digital format and can be processed by digital circuits. Before sending the pulses to the counters, they are first pre-scaled by a factor of four. Only the counted down output is available. If the pre-scaler received 1000 pulses (1000 photo-electrons were detected), then the output after preheating would be 250 pulses. This circuit is used because a gain in counting speed can be made without using power-hungry, high speed circuitry. To limit confusion, the count is restored to the original rate by multiplying by four in the microcontroller before reporting to the host computer. The result is provided to the nearest four counts. Also, note that, since the pre-scaler is not cleared during the read cycle, single counts are not lost; they will appear in the very next 10 millisecond Integration period.

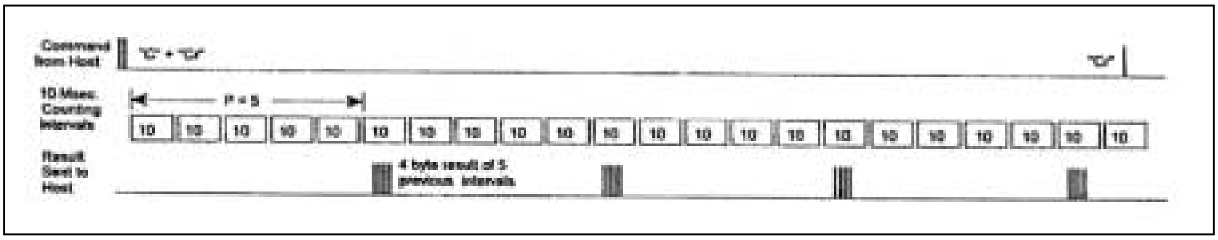
The pre-scaled pulses are then sent to the counters. To determine the count rate, the counters must be gated for a precisely defined time interval. For the H9319 Series, the time interval is set to 10 milliseconds. Any integration period desired by the user must be an integer multiple of this basic time block. The 10 millisecond time block is derived from a programmable timer circuit in the microcontroller which in turn is based on a very accurate crystal-controlled oscillator. The first of the two, 4-bit counters Is gated on by the microcontroller when the data is to be taken, it is gated off briefly (17 microseconds) while the count is read by the microcontroller's parallel port, freezing the subsequent counters as well. The output of the first counter is sent to the second 4-bit counter. The output of the second counter is fed to a 8-bit counter internal to the microcontroller, giving a total of 16 bite of counting.

With only 16 bits of counting, the maximum count that can be measured is 65,535 counts times the pre-scale factor, or 262,140 counts. However, the counters are read and cleared every 10 milliseconds, giving an extra two decades of range in counts per second. The overall result is a maximum count of 26.2 million counts per second (before correction for linearity).

CONTROLLED BY HOST PROGRAM -- CONTINUOUS READING

This mode of operation lets the host collect data continuously after sending a start command, "C". The rate that the data is returned is set by the value of "P". To stop the measurement process, the host can send a stop command, "Cr" the carriage return. This mode is convenient for displaying the count rate data for an arbitrary time interval or for a time to be determined by some program condition that is to be decided while the reading is in progress. It may also be useful in case the host is triggered by an external event and must, in turn, start and stop the H9319. A potential disadvantage is the uncertainty about when the integration of the light signal actually begins. The time between an event recognized by the host and sending out the command may vary unexpectedly. The time between receipt of "C" + "Cr" and the beginning of integration in the microcontroller is approximately 185 microseconds.

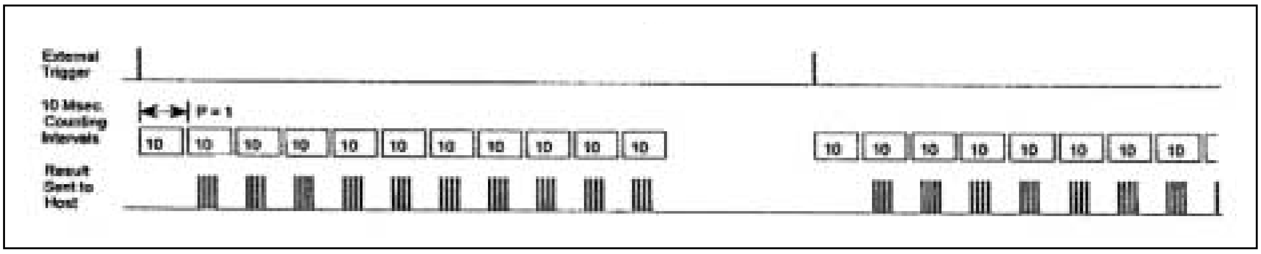
In the schematic below, the P value has been set for 50 millisecond integration periods between each report of the count rate. That is, the reading rate is 20 readings per second. Note that the timing of the stop command occurs asynchronously with the timing of the microcontroller. The last two readings (10 milliseconds each) will be abandoned to let the microcontroller return as soon as possible to the command processor. In figuring the count rate, the time should be taken as the product of the number of results received times the integration time. Use of the time between start and stop commands from the host would be in error because of the truncation.



CONTROLLED BY HOST PROGRAM -- FIXED SET OF READINGS

In this mode of operation, the host prepares the H9319 to take a fixed set of "R" readings every time the start command, "S" is issued. The integration time is set, as described above, with the "P" setting. "R" ranges over 1 to 255. This command is most useful when it is desirable to have the microcontroller determine an exact integration time that is longer than one second or when a carefully timed sequence of readings is needed for small values of "P".

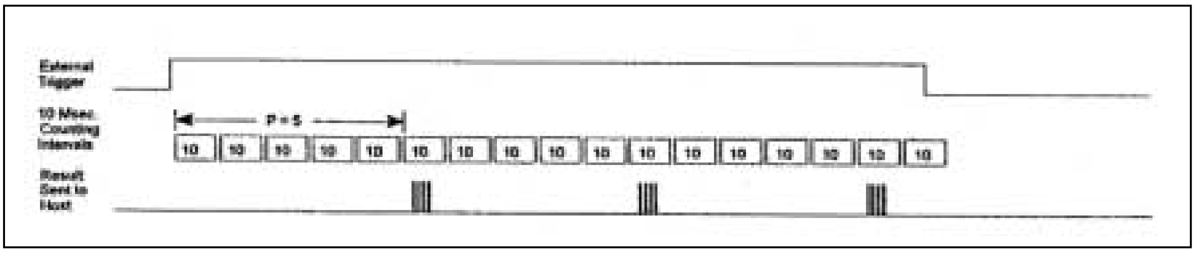
The example shows the result for P set to 3 and R set to 6. Once the reading is in progress, the timing is very accurate. However, the exact time of the beginning of the set of readings will still have some uncertainty as described above. The time between receipt of "S" + "Cr" and the beginning of integration in the microcontroller is approximately 185 microseconds.



CONTROLLED BY EXTERNAL TRIGGER -- READ WHILE TTL INPUT IS HIGH

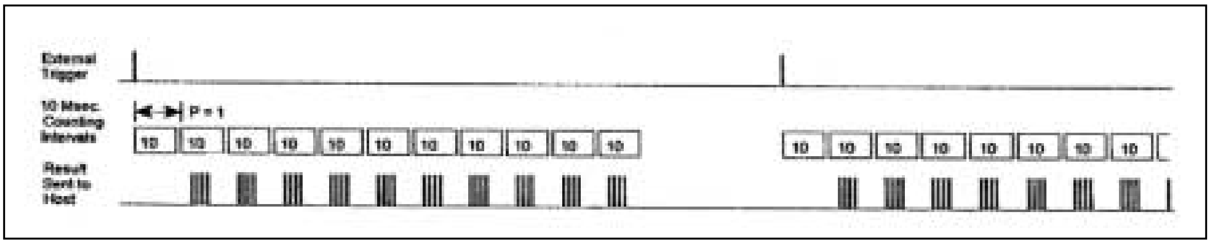
The microcontroller can be placed in an external trigger mode where readings are taken as long as the trigger input is a logic one. To enter this mode, the host should send the command "L" + "Cr". The reading rate is set by the value of P. In this case, "R" is not assigned any meaning; in fact it is always set to one. The beginning of the integration is 75 microseconds after the control line goes high. There is no uncertainty about when the measurement starts due to the host. The reading is stopped when the control line goes low. Truncation of the last 10 millisecond periods that occur after the receipt of the stop command happens as noted above. If the control line goes high again, the readings will begin again with the rate set by P. To return back to the command mode, the host should send "Cr".

The example schematic: below shows the sequence of readings resulting from the external triggering when the P value is set to 5.



CONTROLLED BY EXTERNAL TRIGGER -- FIXED SET OF READINGS PER PULSE

The reading sequence can be initiated externally by the rising edge of a pulse, which results in a fixed set of "R" readings for each pulse. To enter this mode, the host should send the command "E" +"Cr". The reading rate is set, as usual, by the value of P, The example below shows sets of 10 readings for each trigger pulse, where the reading rate is 100 readings per second.



Again, the host will not cause any uncertainty about when the start of the readings actually begins.

PROGRAMMING

The H9319 detector series has a variety of programmable features that are selected by simple commands. To help users to study these features easily, a Qbasic program has been written to exercise all of the basic functions of the module. In this way, the user cart take data and evaluate the detector in the actual application without having to write code. The Qbasic program will let the user get a feel for how the detector works and how to best adapt it to their application. Additionally, if external triggering is needed, the setup can be built up and debugged without having to write detailed software.

A step by step instruction for using the Qbasic Evaluation program is presented including tips on the handling of the module. A discussion of the module's commands is next, including their meaning and how they are used in an application. And finally, there is a discussion of the software to drive the module centered on Basic Language with some advice on the structure of the program to insure reliability of the overall system.

STEP BY STEP INSTRUCTION FOR THE QBASIC EVALUATION PROGRAM --VERSION 4.0

PRELIMINARY

POWER SUPPLY Select a regulated low voltage power supply with good voltage stability to use with the H9319 detector module. Measure the output voltage to be sure that it outputs +5 volts, plus or minus 0.25 volts, if the supply is adjustable by a front panel control, it is particularly important to be sure of the adjustment. The module can be easily damaged by overvoltage. Then, make electrical connections to the supply.
Connect the Black wire from the detector to the ground side of the power supply. Connect the Yellow wire from the detector to the +5 terminal of the power supply. These connections are important as well. If the wires are reversed, damage to the module will result.

EXTERNAL TRIGGER If you intend to use external triggering of the readings, connect the trigger source to the white wire with the purple stripe. The trigger source should be TTL compatible or zero to +5 volts. The trigger source must not exceed +5 or go below ground. If you intend to use the digital output, connect the white wire with the orange stripe to the TTL compatible device. Be careful to avoid letting the wire come into contact with a TTL output, ground, or other voltage source.

DISKETTE BACKUP COPIES Make a backup copy of the 3.5 inch diskette or the 5.25 inch diskette -- whichever is appropriate for your computer. You may also want to copy the diskette contents to a directory on your hard drive for ease of use.

DETECTOR MODULE PREPARATION Pull the black protective cap off the detector module. Place the detector in a way that allows light from your source to fall on the window of the detector. Then exclude all other light. At photon counting light levels, this is normally very difficult. But, it is still essential. Failure to protect the detector from even dim light may cause damage to the detector module, if the high voltage is on and if allowed to persist for more than 10 or 20 seconds, If you need the lowest possible background or if you are planning to qualify the detector against it's specified performance, allow at least 12 hours in darkness. Of course, for most measurements this waiting time is unnecessary. There is no problem about using the detector right away.

HOST COMPUTER Prepare the IBM computer (or IBM compatible) for use. Locate the Serial I/O port and determine which COM port number it is -- either 1 or 2. Plug in the serial connector from the detector module using the 25 pin to 9 pin adapter if necessary.

(Note that some computers may not be fast enough to read and display data at the highest rate. At 100 readings per second, *286 computers tend to fail to keep up with the influx of data. A communication buffer overflow occurs. Most *386 computers are able to keep up. If you are testing with a slower machine, limiting the data rate to 50 readings per second should not result in errors.)

STEP ONE

STARTING THE PROGRAM Turn on the computer and the +5 volt power supply. Either insert the diskette containing the evaluation program into the changeable drive and change to that drive OR switch to the drive and directory that you have copied the files to. Then start the program in any of the following ways.

type EVAL40 and hit enter if you are using the floppy disc drive
type EVAL40 and hft enter if you are at the DOS prompt and in the directory that contains the previously copied evaluation files.

Or use the RUN mode in the FILE menu of the WINDOWS Program Manager and type the path and file name in the Command Line Box, For example; A;EVAL40. Then click on OK.

STEP TWO

SERIAL COMMUNICATIONS The program starts by asking you which serial port you have decided to use for the detector module. Simply answer with "1" or "2" depending on which port of the computer you plugged the serial cable of the module into. If you answer incorrectly, the screen will show "Communication Breakdown! " No harm-just try the other number. If you still get the breakdown response, be sure the +5 was switched on, check the wiring, and check to be sure that you have plugged in correctly to an unused serial port. If all goes well, you will get a menu of setup selections and you can go to step three. If not, refer to the advice in the troubleshooting section.

STEP THREE

READING RATE AND SEQUENCE The module can be programmed to change the rate at which readings are taken so as to follow variations in the light signal. This is done by selecting the number of individual, 10 millisecond periods in which the microcontroller collects the photon count data. The number, "P", times 10 milliseconds gives the total integration time for each reported reading. This is the same as the time between readings. And the reading rate can be found from:

readings per second =100 / P where 1 <=P <= 100

For example, if P Is set to 20, the detector will provide 5 readings per second.

The module can also be programmed to perform a sequence of "R" readings to be taken at the rate set by "P". For example, if "R" is set to 10 while "P" had been set to 100, the module will provide 10 readings at the rate of one per second.

Use the menu options "3" and "4" to select and adjust the settings for "P" and " R". The easy choice is to skip step three and use the default values of "P" = 100 and "R" =1.

STEP FOUR

SET THE HIGH VOLTAGE ON Select the menu choice "7" or "D" to turn on the high voltage. You need not know the value (it is actually the value at the plateau), because the proper value has been pre-programmed into the permanent memory of the module.

IMPORTANT !!! MAKE SURE THAT THE MODULE IS SAFE FROM STRONG LIGHT WHENEVER THE HIGH VOLTAGE IS ON !!! With the high voltage turned on, you are ready to take measurements. But, even though the module is not providing readings, it is active and is susceptible to damage from more than 100 picowatts of light.

Light leaks must be controlled and the signal light should be off, if possible, especially if it's level is unknown. If adjustments to the light source are needed, set the high voltage to zero with the voltage adjust first (number "6" or "V" menu choice) or turn off the +5 supply.

STEP FIVE

SELECT TRIGGER SOURCE The timing of the readings can be selected by either using the keyboard to Initiate the reading or by using an external TTL signal to start the readings.

If you want to use the keyboard, select menu option 1 and go to the next step.

If you want to use the external trigger, select menu option 2 and go to step 7.

STEP SIX

KEYBOARD MODE Step six assumes you have selected "1" from the main menu and want to use the keyboard to start and stop the reading process. You still have another option regarding how the readings are taken. Selecting the sequence mode (menu option "1") continues with the previously defined " R" readings and 100/P reading rate. But you may opt for continuous readings at the rate of 100/P by selecting menu option "2". The continuous mode is good for taking the data directly from the screen.

After making your choice, you have the option to save the data to a file. If you choose yes, answer with the drive, filename and extension. For example: A:TEST01.DAT. The last affirmative will immediately start the reading process so turn on the light signal and then press the key. If you hit any key (thereby answering no to saving to a file), the reading process will start immediately. Again, turn on the light source first, and then hit the key.

If you selected the reading sequence mode, the screen displays the count for each "R" value and freezes with the last value on the screen. Hit any key to return to the sub-menu. If you selected the continuous, the reading process continues indefinitely (10,000 data point limit if saving to a file). It is stopped by pressing the F1 key.

In either case, you may notice a response other than the numbers you are expecting, if your light is too strong, the warning "OVERFLOW!!!." is displayed. You should either tower the light into the detector or shut off the +5 and start again with tower light levels. If the excess light condition persists for more than 5 seconds, the host computer will beep letting you know that the high voltage has been set to zero to protect the detector. You must reduce the light level to avoid damage to the detector and to get usable readings, Remember, whenever the high voltage is on whether it is providing readings or not ---the detector can be damaged from excess light.

Once the readings are taken, the sub-menu choice "3" gets you back to the main menu. Turn off the high voltage with "6" or " V" and selecting "0" for the voltage. This is a must if you are going to make adjustments to the optical arrangement where strong light may enter the detector.

STEP SEVEN

EXTERNAL MODE Step seven assumes you want to use the external trigger signal as the method to control the starting and stopping of the reading process. After selecting "2" of the main menu, you have two options with regard to the external trigger, level and edge. These options, "L" and "E", appear on the sub-menu.

The first option, level trigger, assumes you want readings to be taken as long as the trigger input is at a high level, a logical one. The reading rate is set by the value of "P" as discussed above. The second option, edge trigger, assumes you want a reading sequence to start with the rising edge of a trigger pulse. The sequence will consist of "R" readings for each trigger pulse and will have a reading rate as defined by 100/P. You cannot allow a new trigger pulse until the readings in progress have finished. If a pulse does occur too soon, it will be Ignored. For example, if "P" is set to 1 and "R" is set to 10, and the trigger pulse has a repetition rate of 1 second, then 10 readings will occur every second with each reading having an integration time of 10 milliseconds.

After making your choice, you have the option to save the data to a file. If you choose yes, answer with the drive and filename and extension. For example: A:TEST01.DAT. Once the file choice is decided, the screen changes to display the data. Turn on the signal light and then initiate the external trigger to start the data taking.

If an "OVERFLOW" condition is displayed, you must reduce the light signal, or turn off the high voltage or turn off the +5 volt supply. Since the photomultiplier is stilt active white the high voltage is on, it is insufficient to just stop the reading process.

To stop the external trigger mode, hit the "F1" key. The counting process stops. Then hit any key to get to the sub menu. If adjustments to the optical system are to be made, turn off the high voltage first Go to the main menu by selecting "3" and select "6" or 'V and then answer the question with "0" to set the high voltage to zero.

While the reading process is in progress in any mode, hitting the "F1" key will stop the readings. The hit any key to show the sub-menu. Stopping the readings does not turn off the high voltage - continue to protect the tube from strong light until the high voltage is off.

When using the save-to-file feature, the maximum number of readings allowed is 10,000. Thus, the program will not run indefinitely in the continuous mode or the external level trigger mode, while saving data. Otherwise, EVAL40 can read indefinitely.

If saving to a file is selected, the save operation occurs immediately after the last reading is taken. The screen displays a message when the save is in progress.

TROUBLESHOOTING

PROBLEMS WHEN USING THE EVALUATION PROGRAM -- EVAL40

1.) COMMUNICATION BREAKDOWN IS DISPLAYED AT THE START OF THE PROGRAM

The EVAL40 program checks the serial port before displaying the main menu, it asks the user to enter the number of the COM port, which must be either "1" or "2". The program then issues an open statement using that port number. Then, the program sends a test character and waits for the proper response from the H9319. There are a number of ways for things to go wrong:

A) Check to be sure the +5 votts supply is turned on and reads +5 volts within 0.25 volts.
B) Check the wiring of the Yellow and Black leads as well as the connection of the RS-232-C interface cable.
C) The COM port may be incorrectly assigned. PC's that use a serial mouse, fax card and printer could very easily be configured with no free serial port and interrupt request. Due to the variety of available hardware, we can only suggest that you refer to the computer's manual for advice. The free port must be configured as "1" or "2" and must not share the interrupt assigned to it.
D) Measure the +5 volt supply to be sure it was not excessive. If it exceeds +6, disconnect the unit from the power supply and computer and do a resistance check on the Yellow to Black leads. It should read one to five k-ohms in both directions. If it reads open, the fuse has been blown. Return the unit for service.

2.) OVERFLOW

When the message "OVERFLOW!!!" is displayed on the output screen, the incident light flux entering the detector is beyond the counting capability of the counters. Reduce the light signal level or check for light leakage. Overexposure of the detector may cause damage to the photomultiplier tube inside. The EVAL40 program was written to beep after five seconds of overflow condition and to set the high voltage to zero. This wilt protect the tube only if the unit is in a counting mode. The assembly is susceptable to damage any time the high voltage is on.

3.) PROGRAM TERMINATES AFTER TAKING A FEW READINGS

If the reading rate has been set to maxim, 100 readings per second, ("P" =1) and the program terminates after a few tens of readings have been made, the communication buffer has probably overflowed. The failure is caused by the host computer being unable to keep up with the influx of data and the consequent calculations before displaying it. The problem usually occurs with *286 based computers or slower. However some laptops using higher level processors may also fail to keep up.

The alternatives are;

A) Reduce the reading rate to 50 readings per second. If that "fixes" the problem, then the difficulty is certainly processor power.
B) Edit the EVAL40 to run faster by eliminating the screen display for example. You may also benefit by specifying a larger buffer size in the open statement. This is especially true if the number of readings can be limited
C) Select a faster host for the highset speed measurements.

4.) PROGRAM RUNS BUT NO COUNTS REGISTER

The most common problem is that the high voltage was inadvertently left at zero. The detector sets the high voltage to zero at start-up as a protection. The user must turn on the high voltage and then be very careful to avoid excessive light from then on. Or at least, until it is turned off. To set the high voltage on, select "D" from the main menu. To set the high voltage off, select "V" from the main menu and program the voltage to "0".

5.) HIGH BACKGROUND COUNT

The H9319-01 should show 120 counts per second in the dark, typically. The H9319-02 will show approximately 10,000 counts per second in the dark. For levels much higher than, this that are not due to light leakage, check:

A) The detector was recently exposed to room light, even though the high voltage was turned off. The dark count level will drop slowly on it's own over the next 30 minutes. Full recovery may take several hours. Avoid exposure to room light if optimum sensitivity Is needed without delay.

B) The detector was exposed to damaging light with the high voltage turned on. The detector may improve with storage in darkness for one or two days. If not permanent damage occurred. Consider return of the unit for replacement of the photomultiplier tube.

C) Be sure that the plateau voltage is being used and not a higher value. The plateau voltage setting has already been programmed into the assembly and can be accessed by selecting "D" from the main menu.

6.) NEITHER EXTERNAL TRIGGER MODE FUNCTIONS

If the external trigger mode is selected, and the response is always "BAD COMMAND", regardless of the selection of pulse or level, then the trigger level is already high (at logic one) before entry into the mode. To use the external mode, the "trigger off level" must be low (at logic zero). The readings will start when the trigger goes high.

7.) NO DATA RETURNED IN LEVEL TRIGGER MODE

If external triggering with level control has been selected, but no data is returned, the level trigger is probably returning to zero too soon. For example, suppose that "P" has been set to 100 for 1 second integration time. The detector will start to integrate the light signal as soon as a logic one is detected on the trigger control line, But if the control line returns to zero before 100 of the 10 milliseconds intervals have been read, then the whole reading process is abandoned. The micorcontroller returns to the command module without any result sent out. Be sure that the duration of the level trigger signal exceeds the product of the number of readings needed times the Integration time for each reading.

8.) DATA IS NOT RETURNED FOR EACH TRIGGER PULSE IN EDGE TRIGGER MODE

A sequence of " R" readings will be returned for each trigger pulse, starting with the rising edge of the trigger. But, if a new trigger is received by the microcontroller before the current reading in progress is finished, the micorcontroller Ignores that trigger. Make sure that no new trigger pulses are made before completion of a given reading.

9.) PROGRAM STOPS WHILE READING DATA

When the H9319 is operated with a host computer in a network, the computer may not be able to read all of the data sent by the detector because it is busy with network tasks. The detector expects the serial port to always be ready to receive data. For multi-tasking environments, care must be used to insure that requests for a reading are not made when other tasks might take over. Programming methods to avoid this conflict are not implemented in EVAL40.

PROBLEMS WHEN WRITING NEW PROGRAMS

In general, EVAL40 should be used to isolate the problem to the new program. This approach will save a lot of time in troubleshooting because the detector module can be eliminated as the cause of the problem.

1.) COMMUNICATION BREAKDOWN

Test with EVAL40 and repeat with the new program and the same port. Then look for.

A) Be sure that the commands are sent as upper case letters and are followed by carriage returns.

B) Double check that the port was opened with the proper communication specification; 9600 baud, no parity, 8 data bite, and 1 stop bit

2.) NO DATA-DATA ALWAYS ZERO

Make sure that the program has sent out a valid "D" command to turn on the high voltage.

3.) RESULT DATA IS EXTREMELY LARGE NUMBER

If the number is large and fluctuates, most likely the bytes are being processed in reverse order by the new program. Note that the microcontroller sends out the highest order byte first and the lowest order byte last .If the number is very large and does not fluctuate, the cause is probably due to overflow. Check to see if the condition is light sensitive. If the returned data is overflow, the data is invalid and should be discarded as a measure of the light level. Of course, some action should be taken to protect the detector from continued exposure.

4.) BUFFER OVERFLOW

At the highest reading rates for incoming data, it may be difficult for the host computer to get all of the necessary calculations done. If the host falls behind, the communication buffer may overflow. To check to be sure of the cause of the problem, try slowing down the reading rate, if the problem is cleared, try to streamline the program steps performed while the data is streaming in. It may also be possible to limit the maximum number of readings to stop the overflow or increase the size of the communication buffer.

5.) "BC" ISSUED WHEN ENTERING AN EXTERNAL TRIGGER COMMAND

"BC" is returned if the control line is high (a logic one) when the external trigger command is sent. This is true for either "L" + "Cr" or "E" + "Cr".