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technical reprint

R/P062

reducing noise from photomultipliers

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Noise may be defined as spurious signals, which are present at the output of a system.

In a typical system, in which a photomultiplier is used, the observer wishes to obtain information about a source. The output of the source is converted into an optical signal, which is converted into electricity at the photocathode and then amplified. The amplified signal is displayed to the observer. The observer needs to know, to a defined accuracy, the magnitude of the light signal falling on the photocathode in a particular period of time; in effect he is concerned with the signal/noise ratio. It is necessary to consider the whole system to minimise the noise which is displayed to the observer (**figure 1**).

Shot noise is the major consideration in most system employing photomultipliers. This can be looked at in two ways.

a) Systems with a defined sampling time:
If the mean current leaving the photocathode is I, the mean number of electrons leaving the photocathode in a time τ is:

$\frac{I\tau}{e}$ (where e is the electronic charge, 1.6022 x 10-19 coulombs).

Then the standard deviation of the number of electrons is:

$\sqrt{\frac{I\tau}{e}}$ (see **figure 2**)

One can also view this in terms of the charge emitted in a time (see figure 3).

b) Systems in the frequency domain: if the band width of a system is Δf Hertz and the response outside this frequency band is zero, the root mean square shot noise current is:

$\sqrt{2eI\Delta F}$ (see **figure 4**)

When considering the noise contribution of amplifiers, the noise current associated with a resistor (R ohms) is important. The r.m.s. value of this noise current is:

$$\frac{\sqrt{4kT\Delta f}}{R}$$

Where k is Boltzmann's constant and T is the temperature in °K. The amplifier voltage noise and amplifier current noise are also important and are normally specified for amplifiers intended for low noise applications.

In a system using a photomultiplier, it is clearly important to have an efficient input transducer which does not introduce noise into the light signal to the photomultipliers. One must also try to minimise the stray light coming from the transducer.

In a photomultiplier, the shot noise depends on the total number of electrons leaving the photocathode, so one must maximise the number of signal electrons and minimise the number of spurious electrons. The spurious electrons include electrons from thermionic emission, stray light and light generated by electrical breakdown in the photomultiplier or housing.

The number of signal electrons is proportional to the quantum efficiency, so photomultipliers which high quantum efficiency at the wavelength of interest are desirable. However, in order to increase the long wavelength cut-off, the work function of the photocathode must be reduced and this increases the thermionic emission. Fortunately the thermionic emission can be reduced by cooling the photomultiplier, although this may cause operational problems. The thermionic emission also depends on the area of the photocathode surface; so photomultipliers with small effective photocathodes may be suitable. This can be achieved by special design or using magnetic defocusing. This approach may not always be appropriate, because it may not be possible to focus the light on to a small area of photocathode.

Since thermionic noise increases very rapidly with temperature, photomultipliers should be kept cool. The gain is a sensitive function of temperature (the temperature coefficient is typically -½/°C); so photomultipliers should be kept at an even temperature to avoid drift.

Drift is present in almost any system. It may be considered as low frequency noise and is often called flicker of 1/f noise in amplifiers. Drift may be overcome by subtracting the spurious signals, or zeroing, at regular intervals or alternatively by chopping the light and amplifying the resulting a.c. signal at a frequency above the 1/f region.

The photomultiplier should normally be operated so that the noise from the amplifier is negligible compared to shot noise, except in the 1/f region, but this may not always be possible, for example if very wide dynamic range is required.

Displayed noise can be reduced by increasing the sampling time or restricting the bandwidth and this is the basis of most techniques for reducing the effect of noise. Filters with sharp cut-offs should be considered; for a single pole low pass filter the bandwidth is $\frac{\pi}{2}$x (d3B frequency).

The lock-in amplifier improves on these techniques for periodic signals. If the light is chopped, the signal is effectively being modulated by the chopping frequency and a very narrow bandwidth tuned amplifier is required to select out the bandwidth containing the signal in the immediate vicinity of the carrier without passing too much noise. The lock-in amplifier rejects noise on the basis of phase as well as frequency like the tuned amplifier. The modulated signal is multiplied by the reference waveform, (also obtained from the chopper), to give a full wave rectified output. This is then smoothed with a low pass filter. The carrier should not be a harmonic or subharmonic of line frequency.

If a signal is repeatable, though not necessarily periodic, it can be extracted from noise by signal averaging. This involves superimposing a number of signal traces by sampling and storing them by digital or analogue means. A synchronising pulse is required to initiate the sampling process.

The boxcar integrator is rather similar in that it is essentially a single channel signal averager. It consists of an analogue gate followed by a low pass filter. The gate is opened for a specific time after the trigger pulse. It has a number of modes of operation.

Correlation techniques are a powerful but rather complex method of signal to noise enhancement.

Digital techniques are improving and becoming more economic. Obviously photon counting is becoming very important. A particular advantage is apparent from the difference in shape of the dark noise and the single photoelectron spectra (**figure 5**). There is a maximum count rate limitation Ω 10^8 photons/sec. Digital lock-in amplifiers are available.

In summary, the two main techniques for reducing noise from photomultipliers are to minimise the stray light and minimise the bandwidth.

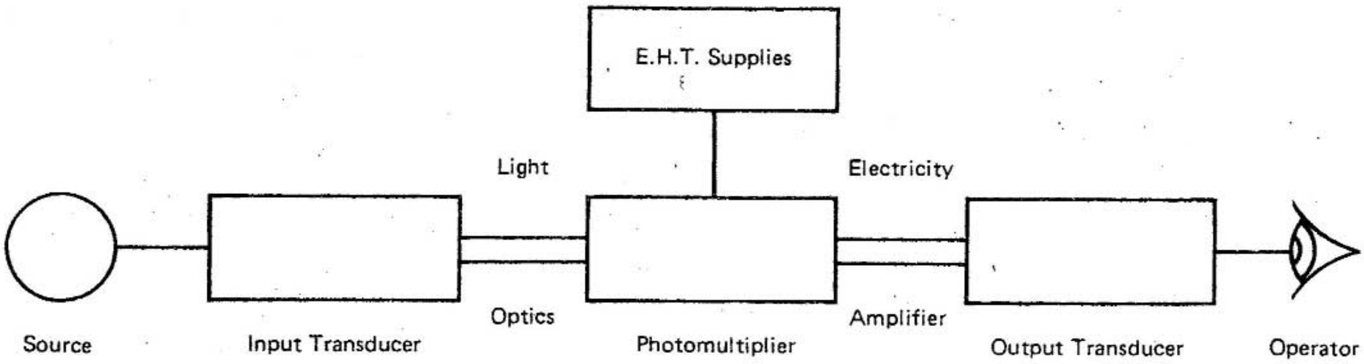
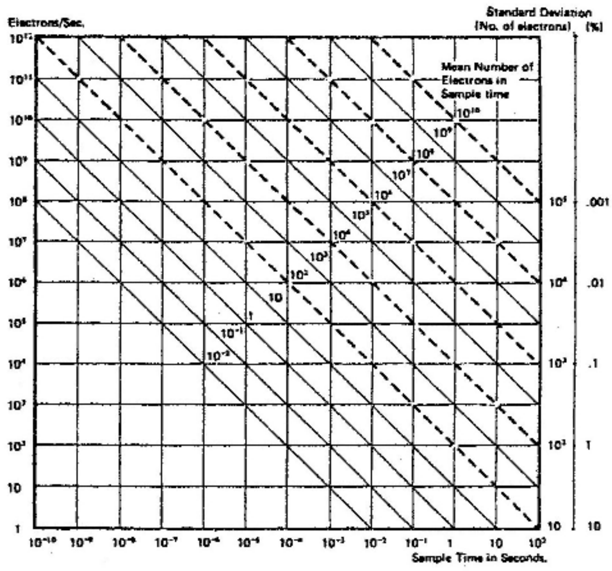
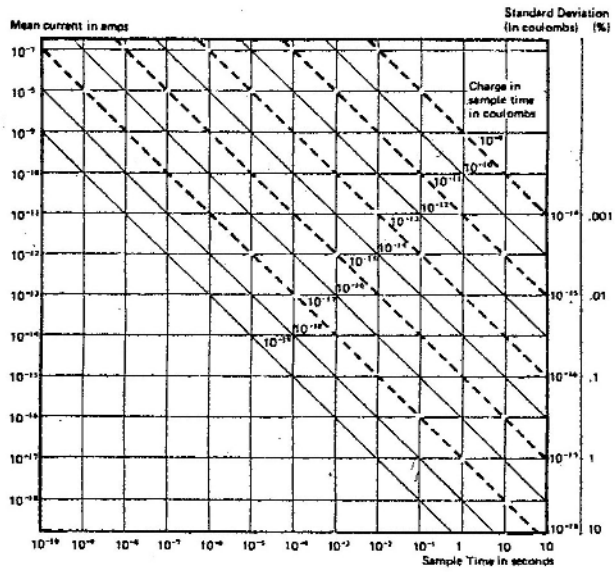


figure 1 typical system using a photomultiplier





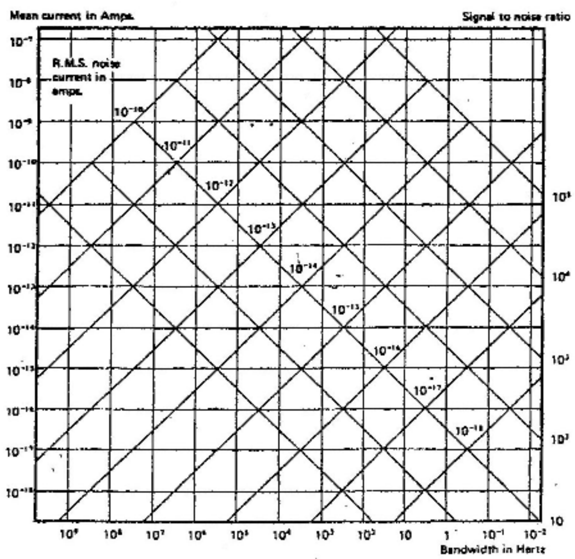


figure 2 (above left), **3** (above right) and **4** (left). Shot Noise

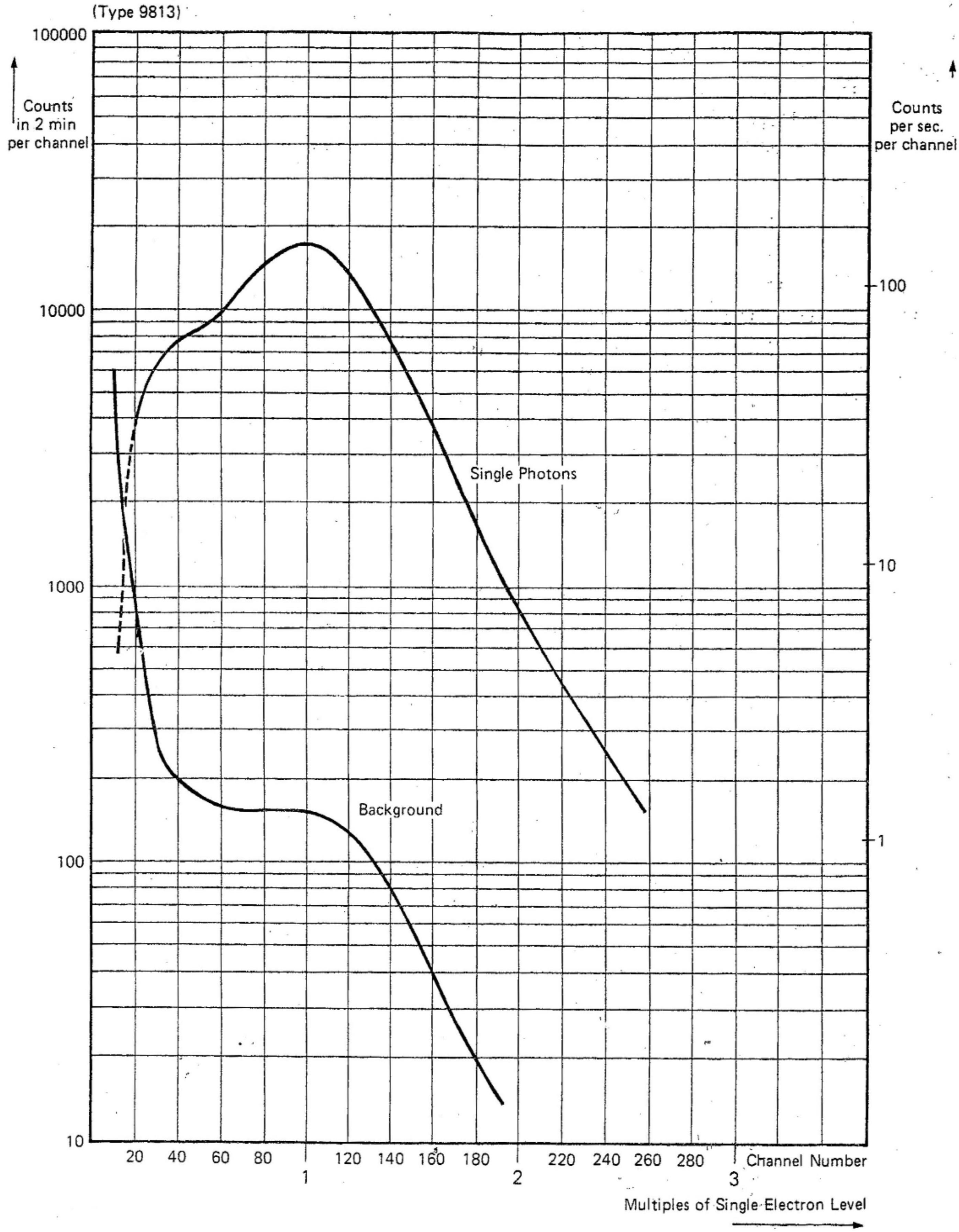


figure 5 differential pulse height distribution

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