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technical reprint

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gating of photomultipliers

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Gating of photomultipliers is a common technique in nuclear physics when it is required to observe nuclear phenomena as a result of intense irradiation. More recently applications of the laser to molecular physics and spectroscopy have given rise to more acute detector constraints in observing a weak incoherent light scattering process closely following an intense molecular excitation. In these cases it is desirable to cut off the photomultiplier for a certain period of time in order to prevent the dynode system from suffering temporary overload, and even permanent damage. (In situations where this is not a necessay condition a simpler approach using a switched, high speed unity gain buffer, has been described[11]. It is assumed that the light level is not so great as to cause damage to the semiconductor photocathode layer by heating or photochemical reaction. A more fundamental background limitation is discussed later.

Particular gating systems tend to relate to a particular type of photomultiplier, and important parameters such as speed of switching, cut-off ratio and signal to noise enhancement are often in conflict and any one may be relatively more important in a particular application. For these reasons it is not possible to recommend any one method of gating, but this paper discusses some of the techniques available and reviews relevant literature for further reference.

It is most convenient to consider the techniques under five headings:

1 pulsing overall high voltage supply
2 pulsing groups of dynodes
3 pulsing the photocathode
4 pulsing the first dynode
5 pulsing a focusing or gating electrode, if present

1 pulsing overall high voltage supply

A number of authors have discussed this technique [1,3,4,6]. One advantage claimed is that a higher signal to noise performance may be obtained, because higher gains are available under gated operation before saturation begins to occur, and the dark current background tends to be lower. A very high cut-off ratio of anode current under constant illumination in the 'on' and 'off' conditions is obviously available (e.g. 10^6). Unfortunately there are several practical problems. High voltage pulses are required, and their amplitude has to be maintained very precisely. In order to obtain reasonably fast switching a steep front to the pulse is required, and this necessitates a low resistance voltage divider (such as 50Ω total) and a low impedance voltage generator. Finally, very large spurious pulses (due to capacitive coupling to the anode) may be difficult to overcome.

2 pulsing groups of dynodes

This is most successful technique for side window type photomultipliers [4,10], and has also been applied to end window type devices [6,7,9]. In this case the problems described in section 1 are reduced proportionately, but at the expense of efficiency in cut-off. As a rough approximation, reversing the potential between adjacent dynodes such that secondaries are repelled by the succeeding dynode rather than accelerated will reduce the output signal by 30 to 100 times. Using two, three or more such reverse biased stages in the multiplier (not including d_1) it is possible to attain a cut-off ratio of 10^4, but this appears to be a practical limit. Care must be taken that maximum inter-stage voltages are not exceeded under these conditions.

For side window types it is advantageous to switch the central dynodes of the multiplier. For the early stages, the cut-off ratio is very dependent upon positional location of the excitation at the photocathode, and the latter stages are more difficult to switch due to the higher currents, and also there is an increased chance of inducing spurious signals at the anode. This latter consideration is contested by de Marco and Penco[6] for a linear focused photomultiplier. Their results indicated faster switching, less troublesome transients and a gain enhancement by pulsing the last two dynodes in preference to the early stages. However, the cut-off ratio is degraded. The speed of switching, in general, is determined by capacitances of dynodes and their secondary emissive layers, structural factors (for instance, ceramic supports) and circuitry limitations, but would normally be in the rage of 10-60 ns. It is reported that pulsing the last dynode of venetian blind dynode tubes gives a high cut-off ratio, but problems exist due to capacitive coupling to the anode.

3 pulsing the photocathode

Although this method is very efficient, it cannot normally be used due to the long time constant of switching (of order 20 µs) as a result of the intrinsic nature of the photocathode layer(1). However, this problem can be overcome by the use of a conductive sub-layer to the photocathode or, in some cases, a fine mesh applied externally to the photocathode window.

4 pulsing the first dynode

This technique has been successfully utilised in fast photomultipliers(5) and should be equally applicable in venetian blind types, especially where a separate focus element is incorporated. If the dynode is reverse biased (say 50 volts) with respect of the cathode, and pulsed positive for normal operation, a high cut-off ratio (such as 10^5) is possible, with a rise time dependent upon the capacitances associated with the first dynode, but of order 20 ns. The problems with this technique, and similarly with pulsing a unique focus element (see section 5) is that in the cut-off condition there may be a tendency to form a space charge in the cathode-d_1 region, consisting of photoelectrons excited by the main exposure. This space charge is either swept out as the tube returns to normal operation (producing a large negative transient) or it may cause a delay in attaining normal operation potentials and therefore full gain.

5 pulsing a focusing or gating electrode (if present)

This technique has been widely used in tubes normally incorporating a focus electrode (in the cathode-d_1 region) (2,7,8), and special tubes may be designed incorporating a further electrode specifically for gating purposes (see later). Essentially the advantages are the simplicity of switching circuit design and the speed of switching available, because the gating electrode has low capacitance to other tube electrodes. As in section 4 the electrode is biased negative with respect to the cathode for cut-off and pulsed positive for normal cooperation. Alternatively, the electrode may be held a the potential of d_2 and photoelectrons are then swept out by the more positive electrode with no space for charge accumulation(7). The cut-off efficiency is however reduced.

6 Electron Tubes Limited photomultipliers for gating

Any Electron Tubes photomultiplier may be gated by the variety of techniques described in this paper. However, certain tubes, incorporating particular features, have been specially designed for gating.

All tubes in the 9814 series (2" fast linear focused) are available in a gated variant that incorporates modified electron optics such that pulsing of the focus electrode may be achieved for fast switching but without the possibility of any build-up of space charge in the cathode-d1 space. The 9821 type (3" fast linear focused) is so modified in standard form. The following focus electrode voltages are recommended:-

tube type	**'On' condition**	**'Off' condition** (minimum negative with respect to cathode)
9814 series (special order)	d_1 potential	15 volts
9821 series	d_1 potential	50 volts

Other than these, special types may be requested with a further electrode incorporated to act as a gating control.

7 limitations

There are three fundamental limitations to the detection of weak signals during the gating period.

1 electrical pick up

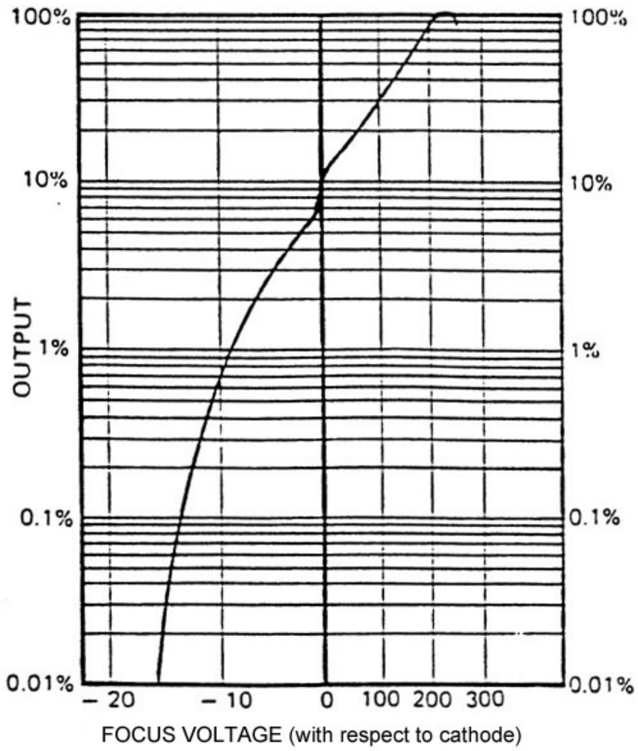
Switching pulses or their derivatives will almost certainly be detected at the anode due to the capacitive couplings through the photomultiplier and circuitry. This can only be minimised by careful electrical design.

2 after pulsing

All photomultipliers produce subsidiary pulses after the main pulse, mainly due to ionic feedback to the photocathode. These may be present from 50ns to 10 µs after the main excitation, and their magnitude and number (dependent upon cathode illumination level, k-d_1 voltage and other individual tube characteristics), have been minimised by the manufacturer by design. In general, the closer the gating occurs to the photocathode the less chance there will be of detecting troublesome after pulse effects.

3 photocathode states

The semiconductor layer that forms the photocathode may have been subjected to a very strong excitation, and it has been observed that immediately after such an excitation the dark count is temporarily increased. This is particularly noticeable with trialkali (S20) photocathodes, where the dark count enhancement may be several orders of magnitude, and decays exponentially for up to 500 µs.



output variation with focus voltage potential fo 9810 series, gated variant

This is a fundamental limitation of the photocathode layer, which appears to trap electrons in metastable states with a quite long decay times. The increased background level my be reduced by correspondingly reducing the inicident light level.

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