ZENER DIODE PHOTOMULTIPLIER TUBE BASE

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ABSTRACT

One would like to keep the gain of a photomultiplier reasonably constant when it is subject to short bursts of high counting rates. When a high resistive divider string is used to supply the voltages for the dynodes, the voltage distribution changes when the tube begins to draw appreciable current. This change in voltage affects a) the gain of the tube, b) the maximum output current of the tube. For stable operation, therefore, one must maintain the dynode voltages constant. A particular design which utilizes zener diodes is discussed.

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I. INTRODUCTION

Various methods have been used to stabilize the gain of a photomultiplier during bursts of high counting rates. These methods fall roughly into three classes:

A) The tubes can be operated in such a way as to minimize the output current of the photomultiplier. They can be used at low gain and followed by amplifiers and sensitive circuits to compensate for the lower gain. The scintillator size can sometimes be reduced to keep out unwanted counting rates; counters can sometimes be shielded from background radiations.

B) The gain can be measured by means of a light pulser and maintained constant by means of a feedback loop. For example, if the gain as measured by a light pulser is seen to decrease, the high voltage on the photomultiplier tube could be increased to compensate.

C) The dynode voltages can be stabilized. Several methods have been used, for example:

C1. Condensers of high capacity can be used in conjunction with a resistive divider to supply charge during beam ON time. They are recharged during beam OFF time.

C2. High voltage batteries can be placed directly between the dynodes. In this case a resistive divider is not used and one takes advantage of the low impedance of the batteries.

C3. A separate high voltage supply can be used for the last few dynodes. This supply should be of low impedance so that the extra current drawn by the photomultiplier during beam ON will not change the voltage appreciably.

C4. The use of active elements instead of resistors in the divider string. They could be, for example, voltage regulator tubes, a string of cathode followers, zener diodes, etc. The current in the divider string is essentially shunted to the photomultiplier while maintaining a constant voltage distribution. This method obviously
fails when the current in the first dynode of the photo-
multiplier approaches the current in the divider. Again,
additional current can be supplied for the last few stages.

C5. A Cockcroft-Walton type of voltage doubling to produce the
d.c. voltage for each dynode separately. Low impedance
can be provided for the first few stages.

II. DESIGN OF A ZENER-DIODE TUBE BASE

Combinations of the above ideas are generally used to maintain
a constant gain. We report here on the use of zener diodes as active
elements in the divider string.

The use of zener diodes is advantageous in that they are small,
inexpensive and presently available in high voltage ranges. They do not
oscillate when a condenser is placed across them, a trouble which afflicts
voltage regulator (V.R.) tubes. Also they regulate current at smaller
current values and hence have a larger useful dynamic range than V.R. tubes.
They are quite free of noise, and are two-terminal devices, which lends to
simplicity.

Let us take, as an example for design purposes, a 6810 A photo-
multiplier. Suppose we place zener diodes across the last three stages
and use a resistive divider for the remaining stages. The rated maximum
d.c. current of the 6810 A is 2 mA. The zener diodes will supply essentially
the total current in the divider string before the voltages will change
significantly. Let us therefore design the resistor string so that it will
carry 2 mA of current at 2,000 V. Thus the design will be capable of operat-
ing the photomultiplier at its maximum rated d.c. current at 2,000 V.

For the 180 V zener diode which we used (Intermetall ZL 180),
the maximum rated current is 46 mA if they are placed in a good heat sink;
their a.c. impedance is about 150 Ω. For the 2 mA maximum change of
current for the 6810 A, this would give a voltage change of 0.3 V, or
less than 0.2%.

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The current in the first unstabilized dynode (dynode number 4) can be calculated to be

\[ I_4 = g^{-3}(1 - g^{-1})I_0 \]

where \( I_4 \) is the current in dynode No. 4, \( I_0 \) is the anode current and \( g \) is the gain per stage assumed to be the same for all stages. For a 68 K A at 2,000 V, \( g \) is about 3.5. For \( I_0 = 2 \) mA, from the above equation \( I_4 \) is 0.034 mA. In a 68 K resistor, this will produce a voltage change of 2.3 V, which is near the maximum change in voltage that one could tolerate. It is interesting to note that for a small decrease in the absolute voltage for dynode 4 (and a corresponding increase in voltage across dynodes 5, 6, 7, etc.) the gain is slightly increased. (This is a high order effect, but has been observed when operating a tube near 10 mA of anode current.) At any rate, to operate the tube at more than 2 mA (for short bursts so that the average does not exceed the rated maximum), one should probably use more than three stages of zener diodes.

A disc ceramic condenser of 0.02 \( \mu F \) is conveniently small in physical size and has low inductance. The time duration for which such a condenser could maintain 2 mA of current and have a voltage change of less than 2 V is 20 \( \mu \)sec. This time is sufficiently long so that the zener diodes do not need to be placed right at the tube base but can be mounted in a heat sink connected thermally to the metal housing which forms the base.

Operating data has been obtained for the tube base shown in Fig. 1. A diagram of the test arrangement is given in Fig. 2. The slow neon lamp light pulser is ON for 0.3 seconds every 2 seconds, and was used to simulate the high d.c. current of a beam pulse from the PS. The fast light pulser was used to simulate a single light signal of constant amplitude. By observing this fast pulse during beam OFF and beam ON conditions (as simulated by the slow neon light pulser) any change in gain could be observed.
We also tested the 6810 A with three stages of zener diodes with an additional 4.30 V high voltage supply connected to the top of the zener diode string. For the test described below, 20 mA of current was flowing through the zener diodes.

By increasing the light output of the neon tube and observing the d.c. output of the anode of the 6810 A during the 0.3 seconds that the neon lamp was ON, the tube saturated at 11 mA. If the light level was increased still further, the d.c. current dropped to ~ 5 mA. With neon lamp intensities set to give anode currents of 0, 1, 2 and 3 mA (during the 0.3 sec. ON time) no observable gain changes were observed for the fast pulse (observational accuracy was limited to about 10% due to pulser jitter). At 4 mA the gain increased by 10% ± 10%, at 6 mA the gain increased by 15% ± 10%. At 8, 9, 10 and 11 mA the trace on the fast oscilloscope (517 A Tektronix) became so noisy that the gain of the signal from the fast light pulser was hard to estimate. Perhaps it was unchanged to ± 30% accuracy at 11 mA d.c. current. As mentioned above, the d.c. current was reduced sharply to 5 mA when the neon light intensity was increased still further; the fast light pulse was at the same time attenuated by a factor of 4. Therefore, we feel that with three stages of zener diodes, one should not operate the tube above 4 mA of d.c. current in the anode during beam ON time. Additional stages of zeners should be used if higher currents are encountered as the voltage changes on dynode No. 4 become large (~ 5 V at 4 mA in the anode).

These bases have been used during initial tune-up of the q$_3$ and m$_4$ beams. A similar design was used in a pion charge exchange experiment in Berkeley with beam intensities up to 10$^6$ per beam pulse.

**III. GAIN VERSUS HIGH VOLTAGE**

Figure 3 plots the gain of the 6810 A as a function of the high voltage applied across the tube. The two solid curves are measured with the zener diode base indicated in Fig. 1. The dashed curve is the gain
of a 6810 A with a resistive divider string with equal voltages across each dynode stage; it has been arbitrarily normalized. The solid curve labelled PULSE OUTPUT VOLTAGE plots the peak voltage output of the photomultiplier when using the fast mercury light pulser as a constant source of light. The curve labelled d.c. CURRENT GAIN IN MILLIAMPS plots the average d.c. output of the 6810 A when using the neon lamp as a constant source of light. The latter two curves agree closely and the curve for PULSE OUTPUT VOLTAGE FOR LINEAR RESISTIVE CHAIN is expected to be different since this represents a different distribution of voltage among the dynodes.
6810A PHOTOMULTIPLIER BASE

Photo Cathode I15 2.0

1 114 2 68K
2 113 17 68K
3 112 3 68K
4 111 16 68K
5 110 4 68K
6 109 15 68K
7 108 5 68K
8 107 14 68K
9 106 6 68K
10 115 13 68K
11 114 7 68K
12 113 12 68K
13 112 8 68K
14 111 11 68 \mu F

Anode I6 10

OUTPUT SIGNAL IS ON BERKELEY TYPE 125 \Omega CONNECTORS HIGH VOLTAGE, INPUTS ARE ON HIGH VOLTAGE BNC TYPE CONNECTORS.
CONDENSORS IN 10^{-12} FARADS; RESISTORS ARE 1/2 WATT (UNLESS SPECIFIED)
Test arrangement to measure the gain of the photomultiplier with high counting rate simulation.