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A HIGH-RATE PHOTOTUBE BASE

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Abstract

A photomultiplier tube base designed to minimize voltage changes at the phototube's dynodes under high-rate conditions is described. Over 200 of these phototube bases are presently used on lead glass and other calorimeter phototubes in high energy physics experiments. Stiff voltage sources for dynodes are provided by making use of emitter follower characteristics of high beta, high voltage, video transistors.

Introduction

Phototube bases designed for high-rate applications have historically made use of voltage regulator tubes, large capacitor banks[1] and divider string currents $> 10^3$ times larger than the time-averaged dynode current.[2] Other techniques include the use of cathode followers,[3] zener diodes,[4] miniature on-board Cockcroft-Walton power sources,[5] and the so-called afterburner technique[6] where additional power supplies are needed to supply stiff voltage to the last few dynodes of a phototube. All of these techniques may find use where they nicely solve a problem; in this paper a new type of high-rate base will be discussed which doesn't have a high-current string and therefore works effectively from the present high voltage zener divider distribution panels available at Fermilab.[7] This base is designed to minimize voltage changes in a photobase that would cause gain instability.

Circuit Design

Although high-rate bases have been produced for a variety of phototube types, i.e. 56 AVP, 6342A, 6655A, 8055, the concept is generally applicable to any photomultiplier. Figure 1 is the schematic of a phototube base designed for the 8575 and will serve well to demonstrate the design under discussion here. The concept will work for either high plus or high minus voltages; high minus is shown. Stiff voltage sources for dynodes are provided by making use of emitter follower characteristics of high beta, high voltage, video transistors. This is an "intelligent" power saving voltage divider: as the tube current increases, current is diverted from string to tube; instead of using a high string current, the transistor's beta provides an improvement factor as if the string current were more than 100 times greater than it is. For example, with the base illustrated in Figs. 1 and 2, with -2 kV H.V. and an 8575 phototube giving a gain of 2×10^7, it was measured that the required current from the -2 kV supply did not vary, and also the tube gain was held constant, for counting rates from zero to 10 MHz. As the count rate was increased, to light levels equivalent to 100 times the regulation limit, the average anode current at first rose to about twice the limit at counting rates of 10 MHz, and then fell (i. e. anode current overload protection was demonstrated).

Over a group of transistors purchased there will be a spread of betas. The high-beta transistors (e.g. $\beta = 150$) were put in the latter stages to get the best overall performance from the active voltage divider. The technique provides a lightweight, small size and simple base design not requiring voluminous energy-storage capacitors. The only capacitors needed are the usual ones for high-frequency bypassing.

The diodes placed at the base-emitter junction of the transistors are to prevent overvoltaging the transistor junction in the inverse direction, an effect that does not normally happen but could occur under fault conditions or during the transient turn-on or turn-off periods.

Various different tapers for the voltage division are possible at will; these are achieved by the proper choice of resistors at each stage in the resistor string shown in Fig. 1. If a particular interstage voltage is too high for one transistor, use two in

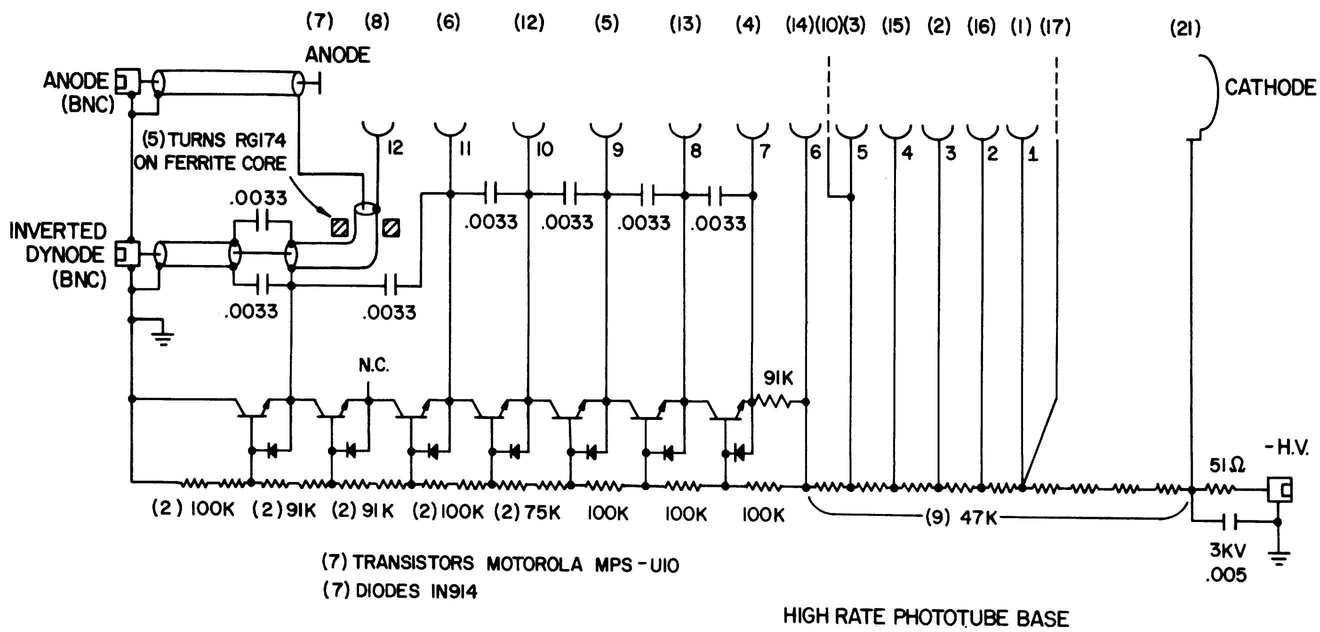

FIG. 1

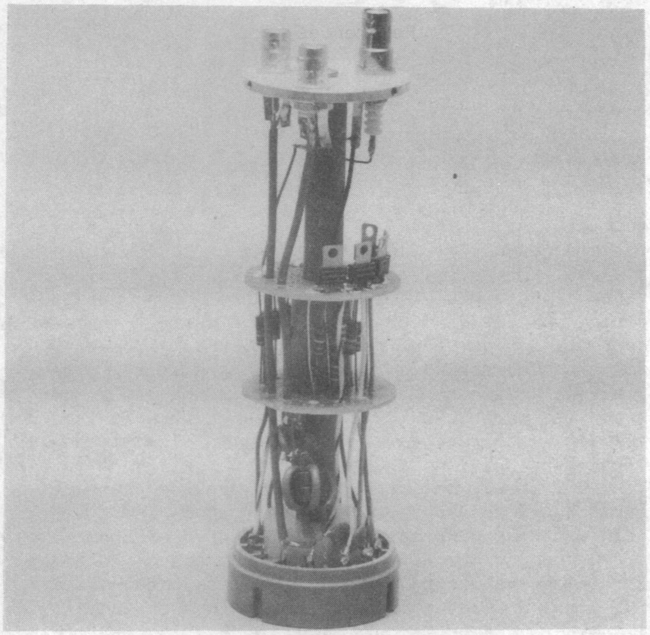

FIG. 2

series; Fig. 1 demonstrates (D_{11}-D_{12}) this principle, which can be extended at will to three, four, or --- transistors.

A feature of this base, not found in zener bases or after-burner systems, is worth mentioning. Suppose you wish to change the phototube voltage---the voltage division "tracks" over the whole voltage range with a single voltage adjustment, just like an ordinary simple resistive divider. With a zener base, of course, the voltage on some tube elements stays constant,while others vary in some fashion as the supply voltage is adjusted. With afterburners, one has at least two separate power supplies to adjust, plus extra cables and connectors to contend with. Another point is lower cost; even if 10 transistors were used in each base, the cost is less than just the extra connector used with the afterburner let alone the rest of the electronics used with such a design. (The transistors, MPS-U10, are less than a dollar each).

NPN vs. PNP Transistors

The negative high voltage base of Fig. 1 could be described as a solid-state, active voltage divider. The designer is faced with the choice of using either NPN or PNP transistors. One could make the base with either type, however, it appears that certain advantages favor the NPN. (When suitable F.E.T.'s appear on the market, they should be tried.)

1) The stiff voltage action of the NPN transistor only applies over a purposely limited current range. This helps prevent destruction of phototubes; a base capable of supplying unlimited current is a booby-trap because if a phototube is accidentally exposed to an excessive amount of light, it may be damaged by the resultant high current. This current-limiting action carries the terminology "fold-back current limiting", i.e. the voltage holds constant from zero current to some level; for greater current loading the voltage sags. This foldback protection is obtained "naturally" with the use of NPN's in this circuit, whereas PNP's turn "ON" harder with more load current, instead of turning "OFF".

2) One does not need a transistor for every dynode stage if NPN's are used, but one does need a transistor for every dynode if one uses PNP's. Typically, one saves 8 out of 14 transistors by going NPN with say a 56 AVP phototube.

Disadvantages

Solid-state devices are used in the phototube base, hence radiation damage eventually may occur. So far this has not been a problem. In the course of time, we will doubtless accumulate more experience on this. If it becomes a problem, the transistors can be replaced at less than one dollar each.

Bench Testing

Tests were made on a phototube and base assembly, making use of an enclosure (dark box) setup as indicated in Fig. 3. Both a fast pulsed light source and a DC light simultaneously illuminated the phototube to evaluate the adequacy of the base assembly to withstand high count rates. From the test setup diagram (Fig. 3) one sees that the phototube output is split into two components.

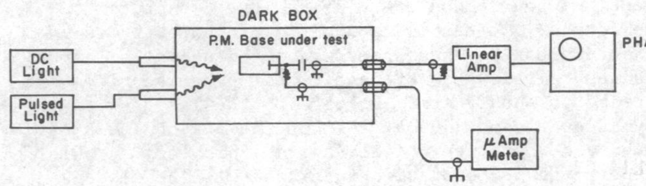

FIG. 3

The fast pulse component is capacitively coupled and terminated for monitoring pulse amplitude. The other component is directly coupled for monitoring the average anode current. Gain variation tests on various phototubes and base assemblies can be made with such a setup. Further details of this technique can be found in Ref. 8.

Experimental Applications

As indicated in the following table, a number of experiments here at Fermilab are presently using this high-rate phototube base.

Experiment	Tube Type	Application
E288/494	8575	Swimming pool Hadron Calorimeter
E288/494	56AVP	Beam Bucket Monitor
E456	8055	Lead glass
E456	6655A	Misc. trigger counters
E456	8575	Beam monitors
E456	56AVP	Trigger counters
E95	6342A	Lead glass
E290	8055	Lead glass
Meson Lab	56AVP	Beam line monitors

The E288/494 "bucket monitor" is of interest. A gas Čerenkov counter viewed with a 56AVP and high-rate base is used to give a measure of the proton intensity in each 1-2 ns wide RF bunch in the beam. These bunches are spaced by about 19 ns; each bunch contains from 1-1000 or so protons. The phototube's output enables the experimenters to reduce accidental coincidence rate problems by eliminating buckets with anomolously large numbers of protons; these excessively large bunches are digitized and veto the data-taking trigger. Figure 4 is a photograph showing the anode pulses from this tube operating at 53 MHz.

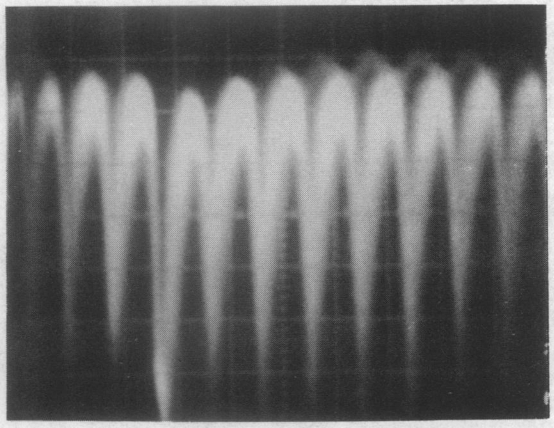

FIG. 4

A Parting Thought

This high rate base was designed to solve a particular problem given to me. While preparing references for this paper, I discovered a paper by H. Jung and M. Brullmann[9] with similar concepts. I suspect that there are still other independent discoverers and users of this idea; we have made sufficient use of it at Fermilab that I believed our experience will be useful to others.

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