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PLANAR DYNODE MULTIPLIERS
FOR
HIGH-SPEED COUNTING

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A new high-speed electron multiplier using a planar dynode configuration is discussed. This multiplier has a total transit time significantly shorter than available in conventional structures of equivalent gain. It also features rise-times generally less than three nanoseconds while providing the large sensitive area of an unfocussed configuration. Two basic types of planar dynodes are employed: transmission secondary emission thin films as the early multiplier stages and silver-magnesium modified mesh multipliers as the high current output stages. The relevant gain and pulse-response data for these two types of dynodes are presented. The structure is quite flexible and permits the number and types of dynodes to be easily tailored to a specific application. In particular it will be shown how the number of mesh-type dynodes may be altered to effect a trade-off between current handling capabilities and rise-time characteristics. Several possible combinations of these planar dynodes have been incorporated in photomultipliers whose gain, dark current, pulse response, and operating life are discussed.

Introduction

The ever increasing demands of high energy nuclear physicists for multiplier phototubes with improved pulse response characteristics have for the most part been met by making sophisticated refinements in the conventional focussed structures. These refinements, though achieving rise-times in the nanosecond region, have yet to reduce the total transit time below about 25 nanoseconds. In addition, experiments involving single photoelectrons indicate that these structures exhibit time jitter which is generally greater than five nanoseconds.[1] What has been needed is a compact, high voltage structure in which the path lengths for all electrons are essentially identical. A tube incorporating these features would be minimally affected by the initial velocity spread of photo and secondary electrons and would consequently be a very high speed structure.

Transmission secondary emission (TSE) dynodes, which have been developed primarily for image intensifier applications, lend themselves very well to a planar multiplier structure which may be operated at very high voltages. Cone and Alvarez[2] at the University of California were the first to experimentally investigate the feasibility of employing thin film TSE multipliers in high speed counting applications. Subsequent work by Sternglass, et al,[3] at the Westinghouse Research Laboratories led to the development of the present line of planar dynode photomultipliers specifically designed for short total transit time, short rise time, and low pulse jitter.

In the present paper two basically different types of planar dynodes will be described: the TSE multiplier which employs KCl as the secondary emitter, and the modified AgMg Weiss-type mesh multiplier. Two tubes, the WX 5009 and the WX 30006, will be discussed with emphasis on their basic design features and operating characteristics.

TSE Dynode Characteristics

The TSE dynodes used in the tubes discussed in the present report are self-supporting thin films mounted on their periphery to Kovar rings. They are mechanically rugged - able to withstand drumhead resonance vibration at 20 g's for at least five minutes. A typical TSE dynode gain curve is shown in Figure 1. Even though peak gains in excess of seven can be achieved at six kilovolts, these dynodes are generally operated between 3400 and 3800 volts in order to minimize effects arising from transmitted primaries.

It has been shown by Kanter[4] that the principal factor affecting the pulse response of a TSE dynode is the velocity spread of the emitted secondary electrons. Kanter assumes a spread in the axial component of the initial velocity corresponding to an energy spread of ±2 eV.[5] Using this assumption it is shown that the transit time spread in one stage of TSE multiplication is less than 3×10^{-11} seconds. Thus in a seven stage tube of the current design one can anticipate a rise time of the order of 1×10^{-10} seconds and a total transit time of approximately four nanoseconds.

Enthusiasm for thin film emitters of reasonable gain, particularly the alkali halide emitters, was somewhat damped by early reports of short life under small current loadings.[6,7,8] The various phenomena affecting loss of gain of these dynodes is only imperfectly understood. However, it has become evident that the life of these emitters is dependent not only on the energy and intensity of the incident beam, but also on the history of the film and its operating environment. For these reasons it was not surprising to find that in a properly processed tube the life of these dynodes is greater by at least an order of magnitude than has been previously reported. Recent life test results indicate that a 17% reduction in gain will occur for a single TSE film bombarded by 3 KeV electrons for 220 hours. During this time the current drawn from the film was maintained at 0.6 microamperes.

Encouraging as these recent life test results may be, they nonetheless indicate that TSE dynodes have yet to exhibit the current handling capabilities of other secondary emitters such as magnesium oxide.

Modified Weiss-Type Multipliers

Sternglass suggested using silver magnesium Weiss mesh dynodes for the high current output stages in order to extend the usefulness of the general tube design to applications which require a total charge of several coulombs to be drawn from the last dynode. The planar construction and large sensitive area of the Weiss multipliers complement the corresponding features of the TSE dynodes. In addition these mesh dynodes were known to have good pulse response characteristics in compact structures.

The one major drawback of the Weiss type multiplier is its relatively low yield under the very high field conditions desirable in high speed tubes. Sternglass proposed using a highly transmissive mesh as a screen grid which would immediately precede the AgMgO mesh emitter. By operating this screen grid at a potential 20% greater than that of the AgMgO mesh he was able to achieve an improvement in gain of 300% over the earlier design. If the grid were operated at the same potential as the AgMgO mesh an improvement of 250% was realized.

In the present design the screen grid is tied electrically to the secondary emitting mesh which it immediately precedes. In obtaining the gain characteristics of these dynodes (Figure 2) the collecting potential was adjusted so as to always be equal to the primary potential. This accurately reproduces the operating conditions of such a dynode in an actual tube.

At present, the pulse response characteristics of these dynodes, though quite acceptable, are not as good as those of the TSE dynodes. The factors affecting the pulse response for these mesh multipliers are the relatively low interstage voltages, the low field condition which exists between the AgMgO mesh and its associated screen grid, and the large number of transmitted primaries which generally define the leading edge of the pulse. The problems are identical to those of other unfocussed structures such as the venetian-blind designs. It superiority to these other unfocussed designs is due to the fact that its much finer structure results in very short electron trajectories in the low field regions.

The interstage transit time and transit time spread have been calculated to be one nanosecond and 1.1 x 10^{-9} seconds respectively. The transit time spread, which increases as the square root of the number of stages, has been measured experimentally in pulse response investigations on actual tubes and is in excellent agreement with the theoretical value.

Planar Dynode High-Speed Photomultipliers

By using the two types of planar dynodes just discussed a number of high-speed photomultipliers have been developed. The cathode to first dynode configurations were designed to retain the advantages of the plane parallel structure. The one inch diameter photocathode is deposited on a flat, transparent substrate which is parallel to the planar dynodes. This substrate may be recessed, as in the Westinghouse WX 30006 (Figures 3, 4) for optimum pulse response characteristics, or it may form the end-window of the tube as in the WX 5009 (Figures 3, 5) for better light collection efficiency. The remainder of this paper will be devoted to a detailed description of the basic design features and operating characteristics of these two tubes.

Briefly, the WX 30006 with the recessed photocathode incorporates seven thin film dynodes and has the best possible pulse response characteristics featuring a total transit time of less than four nanoseconds and a rise-time of less than 0.5 nanoseconds. The WX 5009 having an end-window photocathode, six thin film dynodes, and four silver-magnesium mesh dynodes is somewhat slower than the WX 30006 but has better light collection efficiency and longer life. Either tube can be supplied with a 50 ohm co-axial output.

WX-30006

The ultrafast 30006 incorporates thin film dynodes exclusively. It also has a very short photocathode to first dynode spacing of 0.75 inches which is made possible by use of the recessed photocathode configuration. The cathode is deposited on a glass disc which is then flipped over into the operating position (Figure 4). Because of the barrier established by the cathode disc, the alkali metals used in formation of the p.c. do not readily enter the dynode structure. The result is a high-speed multiplier phototube with very low dark current. Figure 6 shows a plot of the overall gain and dark current as a function of tube voltage for the 30006. Note that at 32 KV overall the electron gain is about 10^6 and the dark current is about 10^{-9} amps. In all of these investigations the photocathode was operated at negative high voltage.

The pulse response of the 30006 was determined by using a free-running spark in air as the light source and applying the output signal from the tube directly to the vertical deflection electrodes of a TWT oscilloscope. Using this technique rise-times of less than 0.5 nanoseconds were measured. Theoretically the rise time of this tube should be only a bit more than one tenth of a nanosecond. At the time of writing, the total transit time has not been measured experimentally, but a straight-forward calculation indicates that it should be approximately 3.8 nanoseconds.

Perhaps the one major objection to the all TSE design is that at present so little is known about the life of the KCl emitter when subjected to heavy current loadings. In early investigations current pulses of 30 mA to 60 mA amplitude and 10 nanosecond to 2 millisecond duration were repeatedly drawn from TSE dynodes with no apparent gain degradation. More recent life data on an all TSE tube operated at approximately 3 KV per stage with a constant output current of 0.6 microamperes indicated that after 220 hours of continuous operation, the gain had decreased to a relatively stable value value which was only 20% less than the initial gain. The sensitivity of the photocathode, which in this case was an S-24 deposited on the end-window, remained unchanged throughout the test. Indications are that the decay of dynode sensitivity is slightly greater for higher primary voltages and for heavier current loadings.

In any event, it is evident that the thin film dynodes may not be satisfactory for certain high current, large duty cycle applications. Consequently the WX 5009 was developed.

WX-5009

Tubes such as the 5009 (Figure 5) which incorporate both types of planar dynodes, that is, the thin film TSE dynodes as well as the silver magnesium mesh dynodes, have been somewhat indelicately referred to as "hybrid" photomultipliers. In the 5009 the bi-alkali or S-24 photocathode is on the end-window There are six TSE dynodes and four silver magnesium mesh dynodes. The tube gain and dark current characteristics of this tube are plotted as a function of overall voltage in Figure 7. The total transit time for this tube at 25 KV overall has been calculated to be approximately nine nanoseconds. Using a mercury capsule light source and a high-speed sampling scope, a rise-time of 2.3 nanoseconds has been measured (Figure 8). The time jitter for quantum input pulses should be less than 0.5 nanoseconds.

Life test data at this time are very incomplete but do indicate that the life of the 5009 should be considerably longer than that of the 30006 in applications requiring large time-average output currents from the tube.

Summary

The WX 30006 and WX 5009, whose characteristics are summarized in Table I, are just two representatives of a whole family of high-speed tubes which can be constructed using the building blocks at hand. Many trade offs are possible allowing one to design a tube tailored to a specific application. All tubes incorporating planar dynode multipliers have several features in common, some of which are enumerated below:

1. Uniform and close spacing of dynodes in a plane parallel geometry, combined with high voltage per stage, allowing a substantial reduction in transit time fluctuations as well as total transit time.

2. Absence of positive ion feedback (owing to the compartmentalized structure of the tube) resulting in virtual elimination of after pulses.

3. Ability to operate in the presence of relatively intense magnetic fields because of the close spacings, high voltages, and guard-ring effect of the kovar mounting flanges. All TSE tubes have operated effectively in axial fields in excess of 1200 gauss, and there is no reason to suspect that the gain would suffer appreciably even in axial fields of 20 Kilogauss.

There are, however, two possible limitations on the usefulness of these tubes which frankly require further investigation:

1. At present the life of these devices is only imperfectly understood.

2. The high voltage required for operating these tubes will in many cases pose problems which require some imagination for their solution.

The high voltage operation of these tubes actually presents few problems which have not already been satisfactorily solved by those working with multi-staged image intensifiers. In actual experiments, the tubes with their appropriate bleeder strings will be encapsulated in an insulating compound, greatly simplifying tube operation.

In summary, there are many special applications for which these tubes are particularly well suited. One might mention triggering spark chambers where very short transit times are a must, time of flight and other short-time resolution measurements requiring fast rise-times and negligible pulse jitter, and any applications where intense magnetic fields prohibit the use of conventional structures.

Acknowledgements

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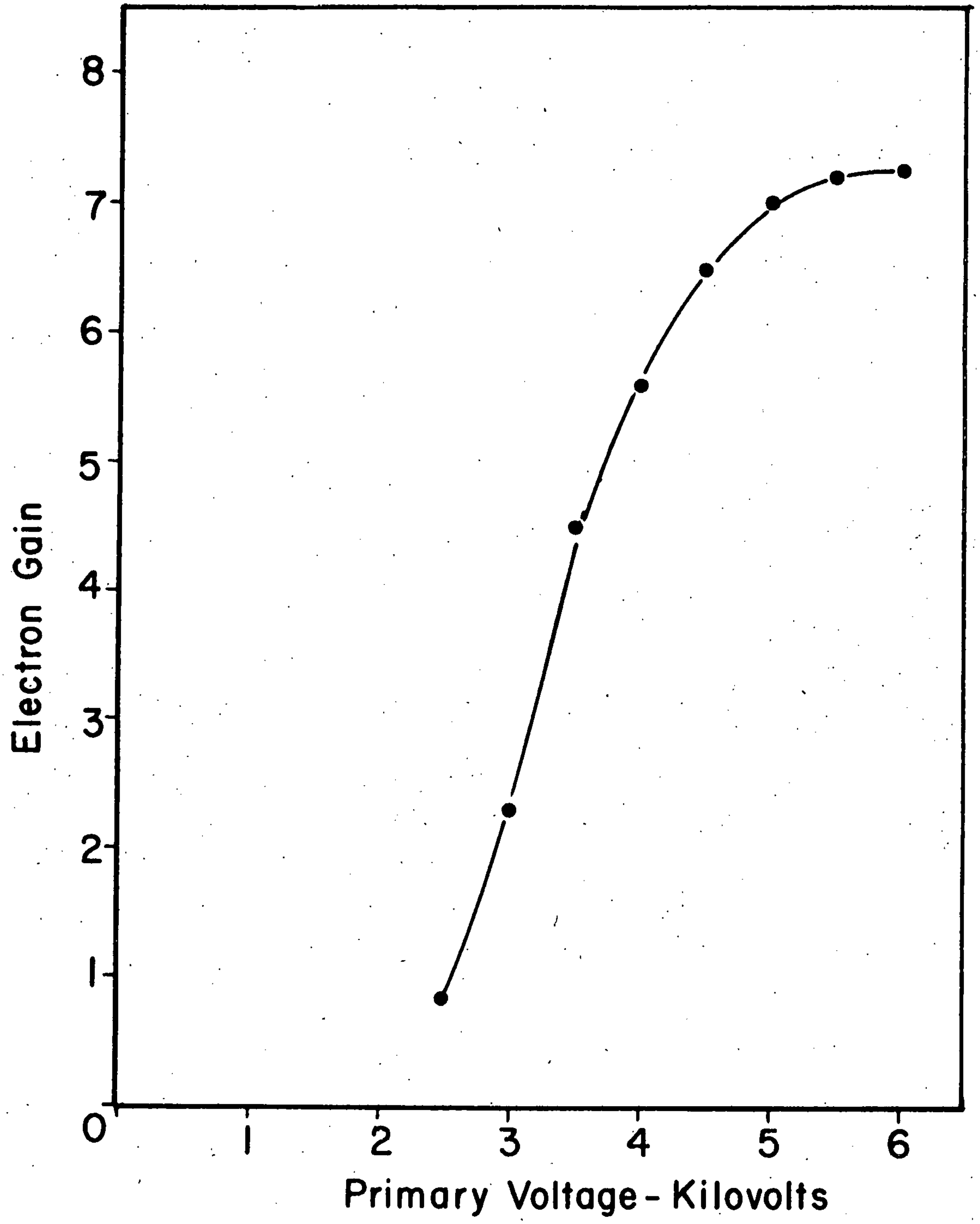
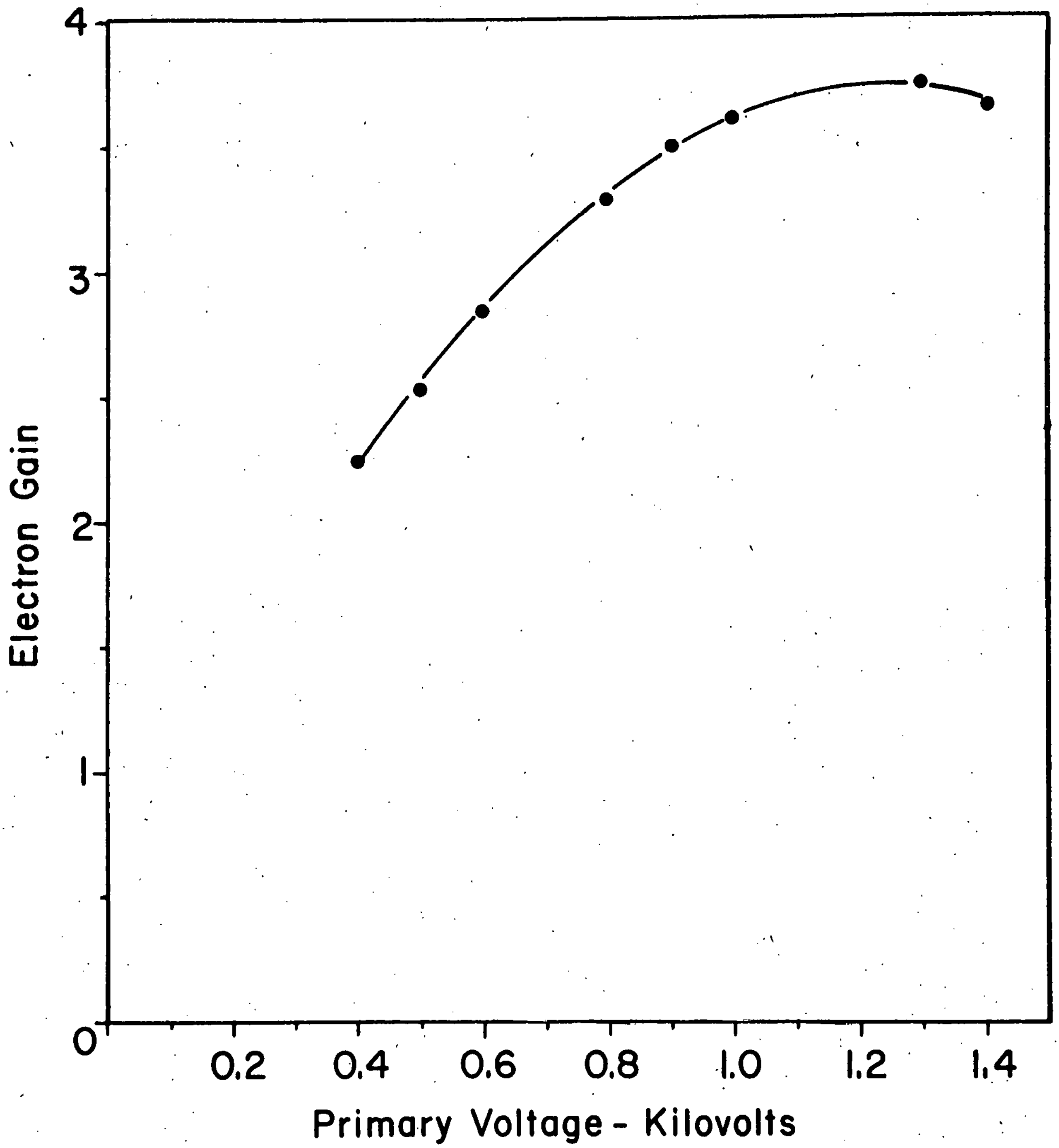


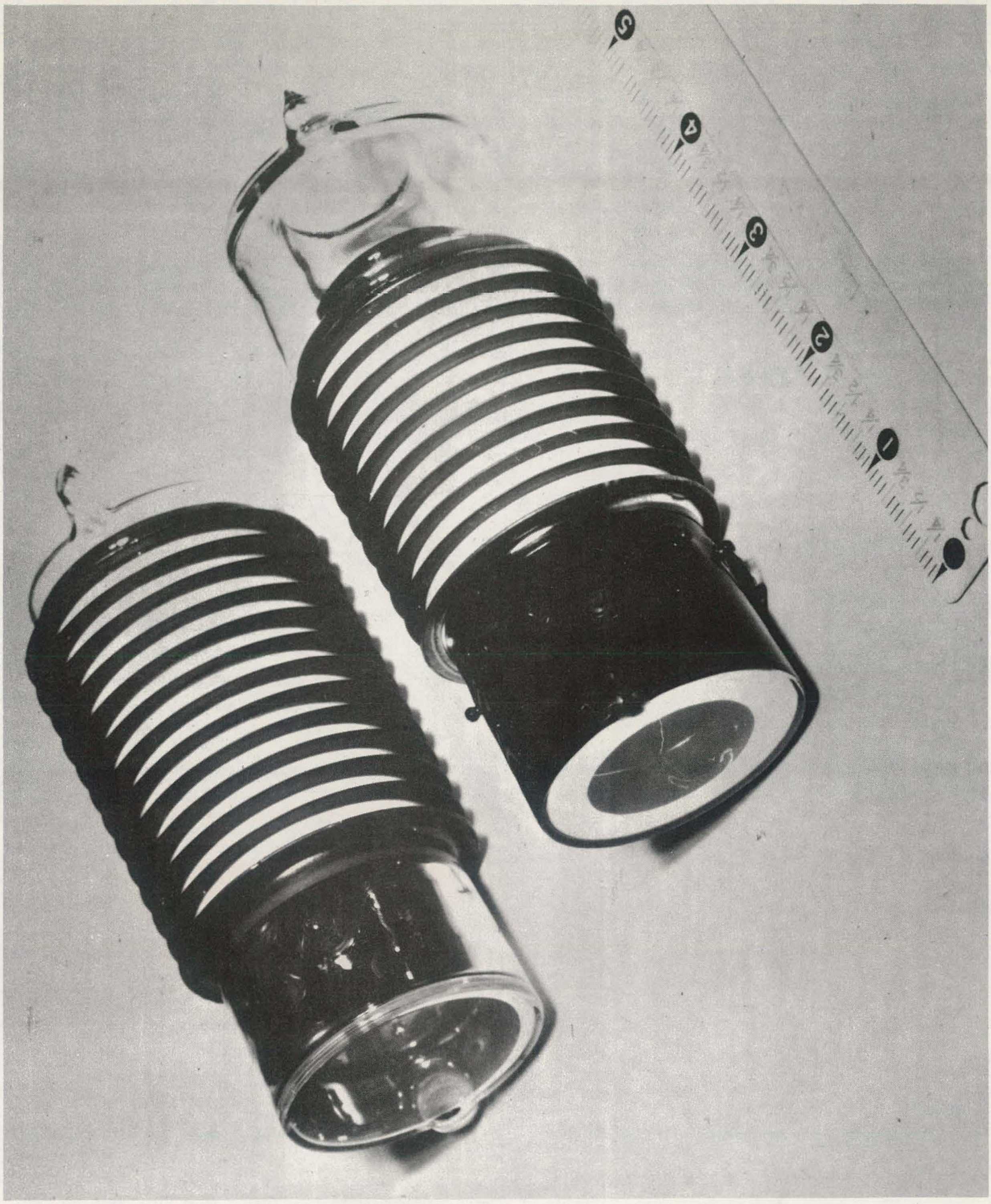
Electron Gain Versus Primary Voltage Curve for a Typical One Inch Diameter TSE Dynode

Figure I



Electron Gain Versus Primary Voltage Curve for a Typical Ag Mg Mesh Dynode

Figure 2



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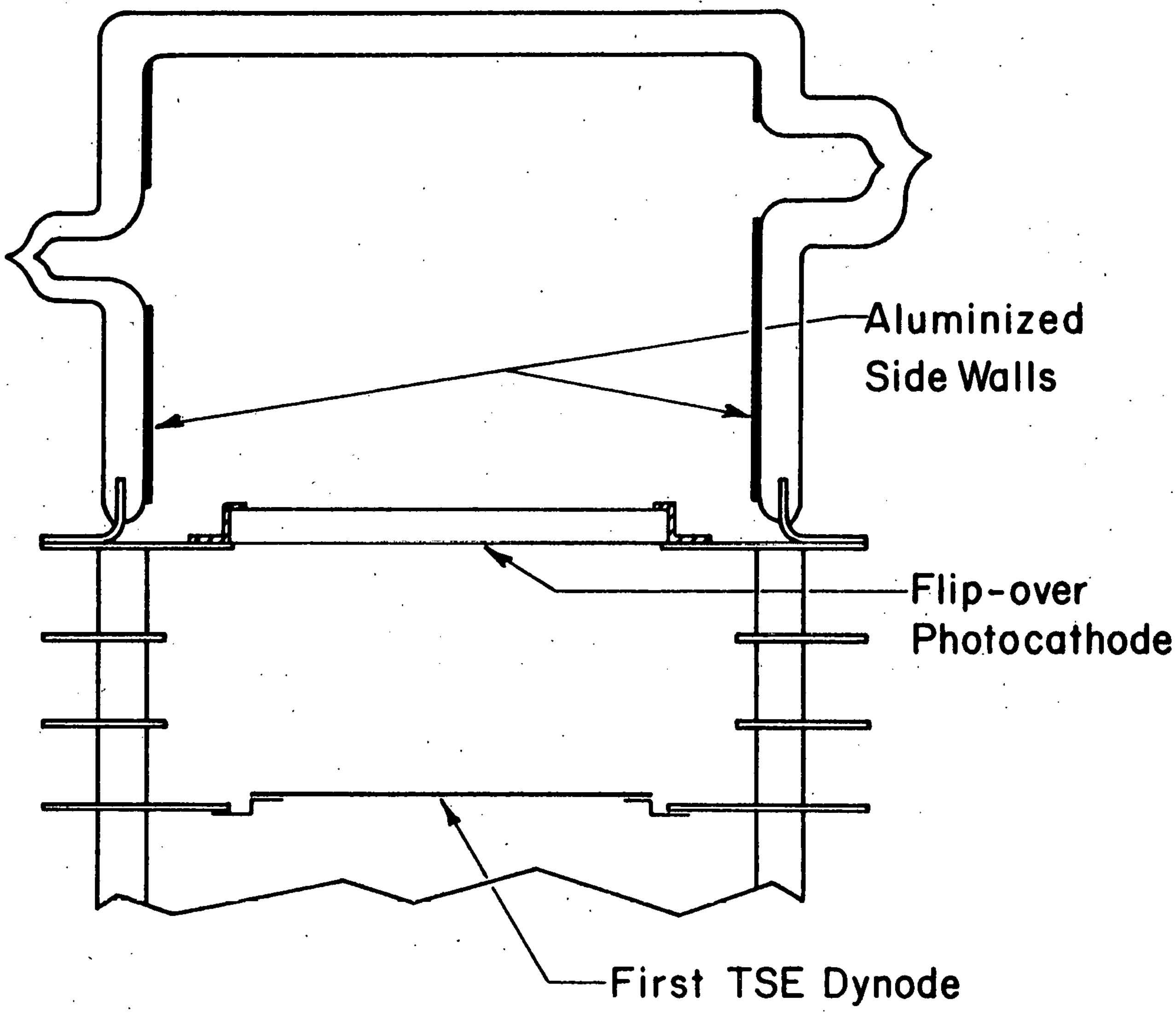
High Speed Photomultiplier Tubes

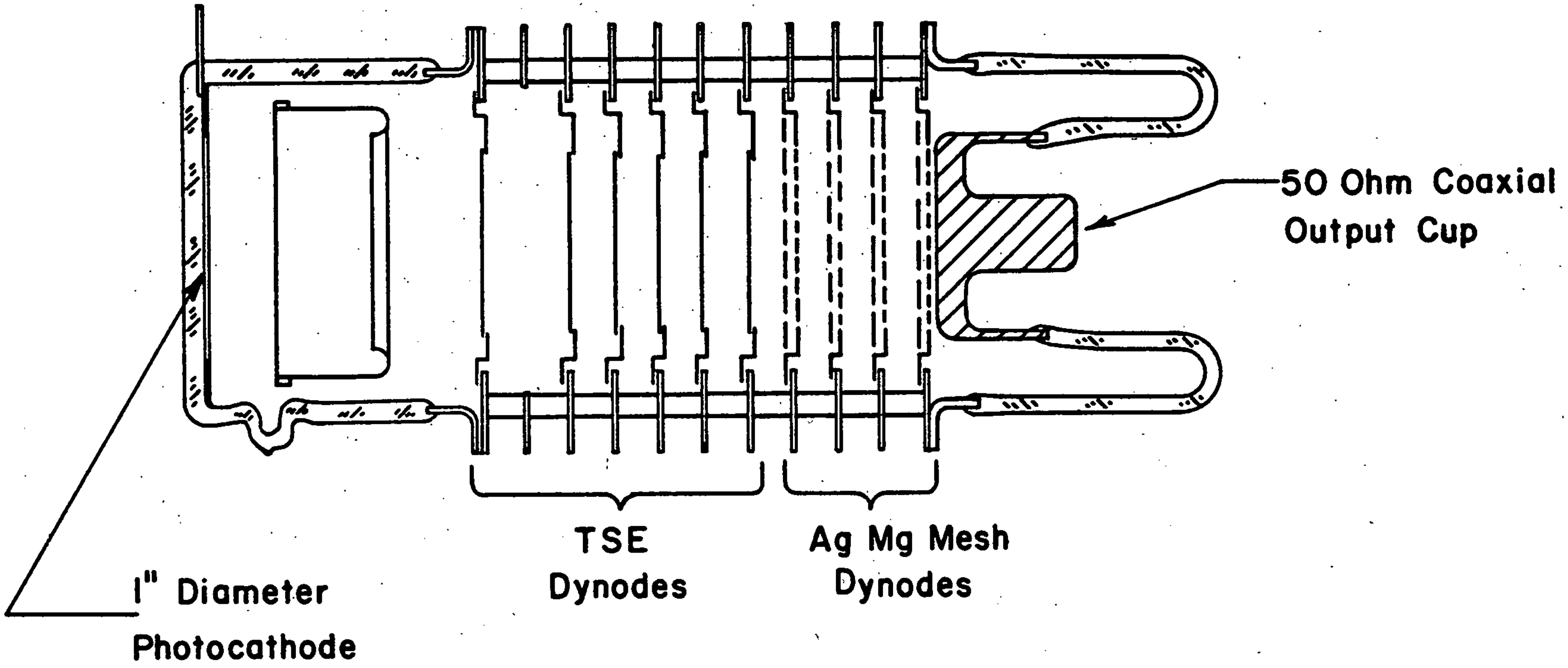
(a) WX 30006 (Flat Output)   (b) WX 5009

Figure 3



High Speed Photomultiplier Tube
Flip-over Photocathode Design

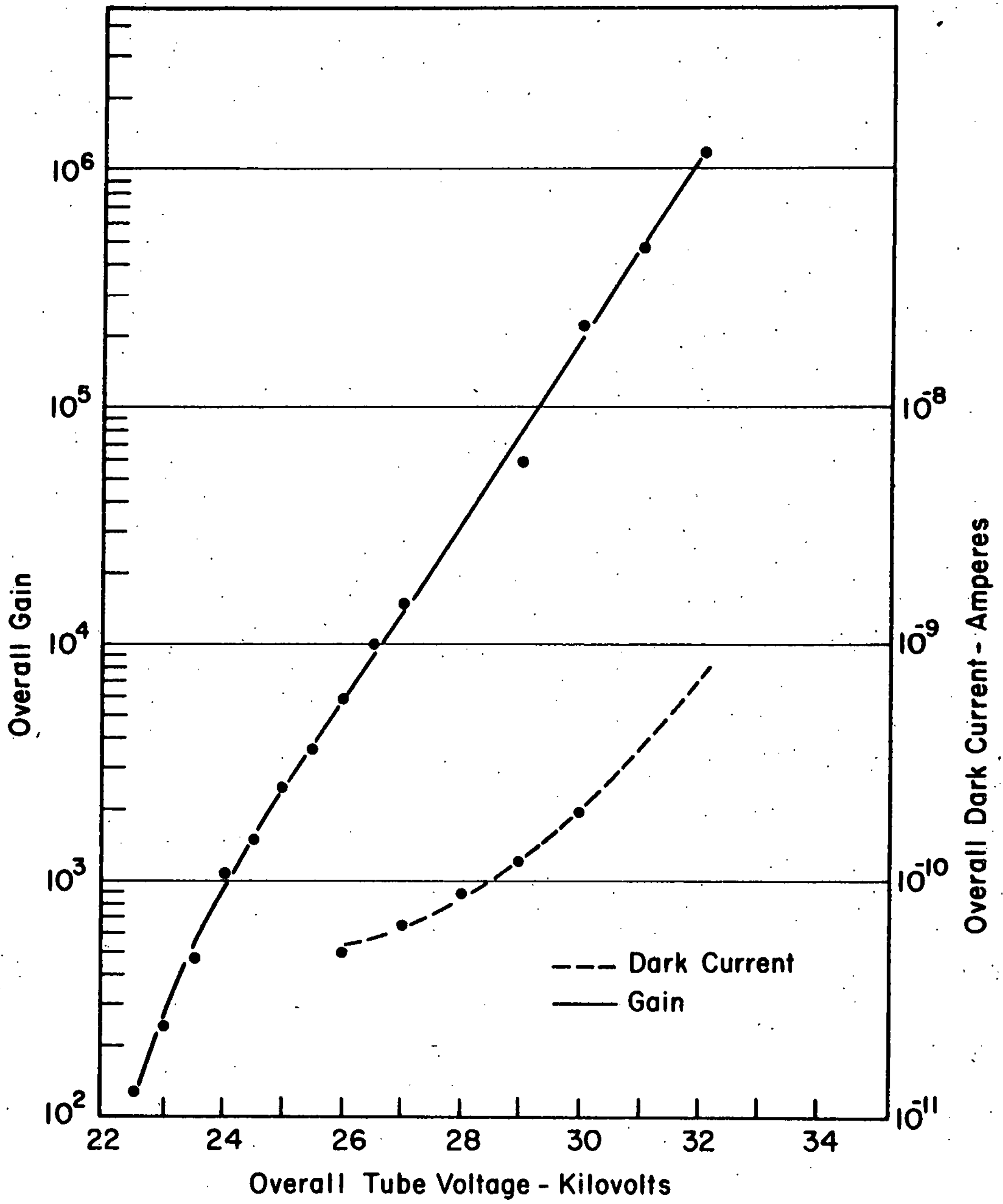
Figure 4



High Speed Photomultiplier Tube

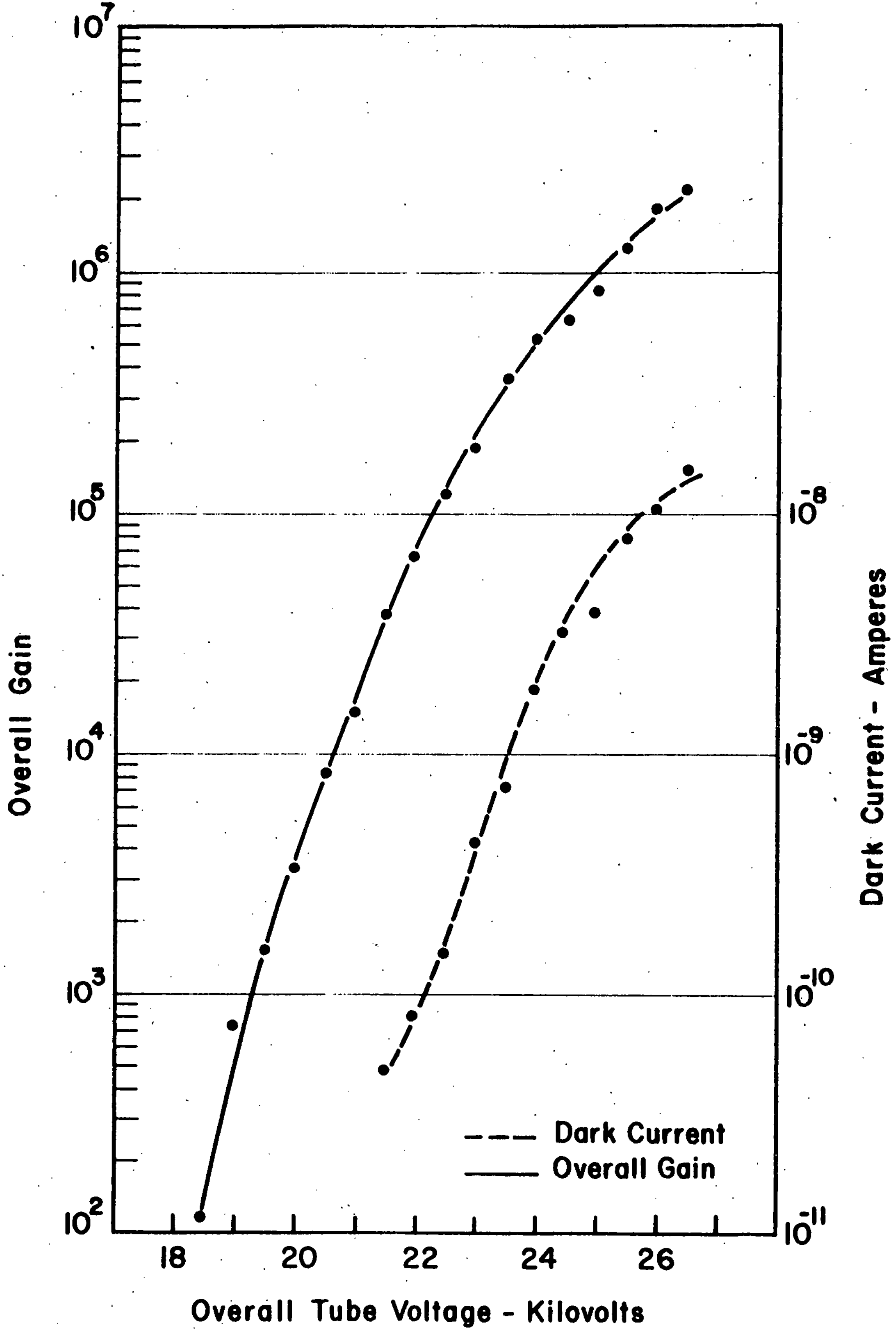
Type WX-5009

Figure 5



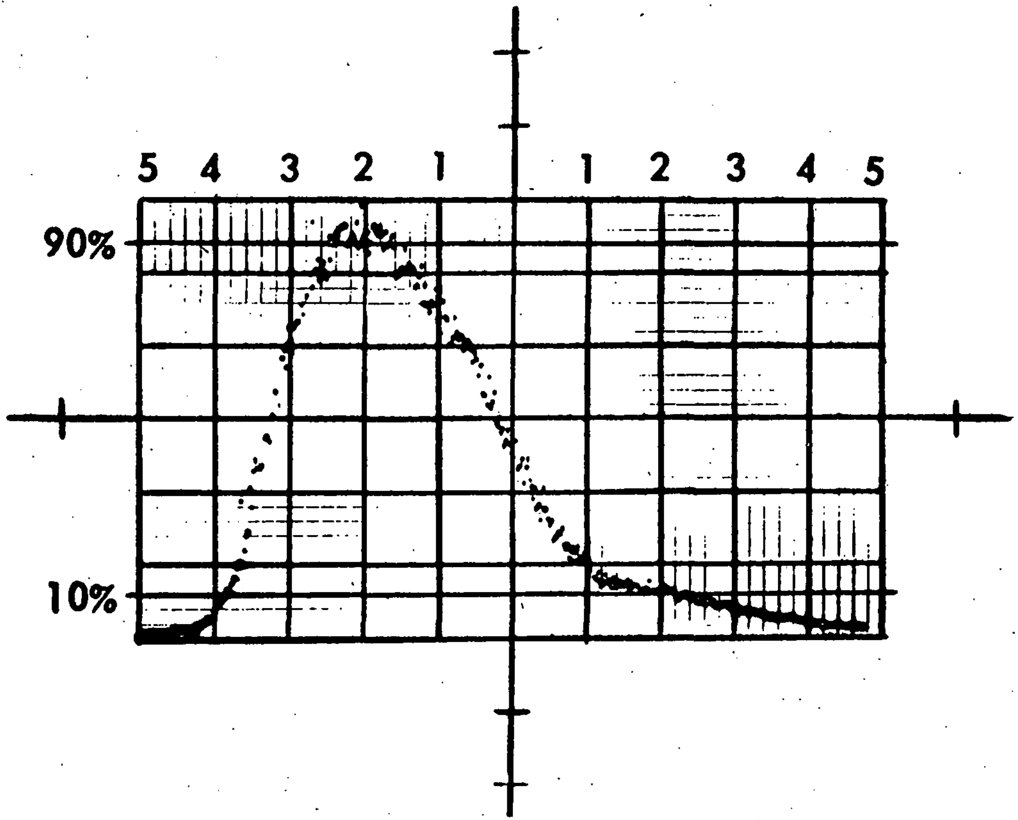
Overall Gain and Dark Current Characteristics
of MPT No. 6313104
(7 TSE, S-9)

Figure 6



Overall Gain and Dark Current Characteristics
for MPT No. 6404014
(6 TSE - 4 Ag Mg, S-24)

Figure 7



WX 5009

HIGH SPEED PHOTOMULTIPLIER RISE TIME PULSE
(2NS PER MAJOR DIVISION HORIZONTAL;
55 MV PER MAJOR DIVISION VERTICAL)

Figure 8

Tube Type	WX 30006	WX 5009
Dynodes	7 TSE + Screen Grid	6 TSE + 4 Ag Mg
Photocathode	Recessed S-9	End-Window S-24
Overall Tube Voltage	32 KV	25 KV
Current Amplification	1×10^6	1×10^6
Dark Current	$\sim 1 \times 10^{-9}$ amperes	6×10^{-9} amperes
Rise Time	$< 0.5 \times 10^{-9}$ seconds	$\sim 2.3 \times 10^{-9}$ seconds
Total Transit Time*	$\sim 3.8 \times 10^{-9}$ seconds	$\sim 9 \times 10^{-9}$ seconds
Time Jitter for Quantum Input Pulses*	$< 0.5 \times 10^{-9}$ seconds	$< 0.5 \times 10^{-9}$ seconds

*Values Calculated from Basic Principles

TABLE I