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TESTING TECHNIQUES USED IN THE QUALITY SELECTION OF RCA 6810 MULTIPLIER
PHOTOTUBES

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ABSTRACT

Some new methods for testing multiplier phototubes intended for scintillation or Cerenkov counting are described. These methods were developed to facilitate finding some of the more commonly occurring defects that would impair the usefulness of the phototubes. Such defects include open leads, shorts having linear and nonlinear resistances, and sources of light within the tube.

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INTRODUCTION

Multiplier phototubes are presently a vital part of most high-energy nuclear physics experiments. It is necessary to impose rather strict standards when selecting multiplier phototubes for such service. Rather large numbers of phototubes are involved in some experiments, and operating time is expensive on high-energy particle accelerators.

This report describes some testing techniques developed to aid in selecting tubes. The RCA 6810 multiplier phototube has assumed an important role in particle-counting techniques, hence the tests described here were developed primarily for this tube. However, the techniques are applicable to most of the multiplier phototube types now used. Some of the basic causes of tube failures as determined during this investigation are enumerated.

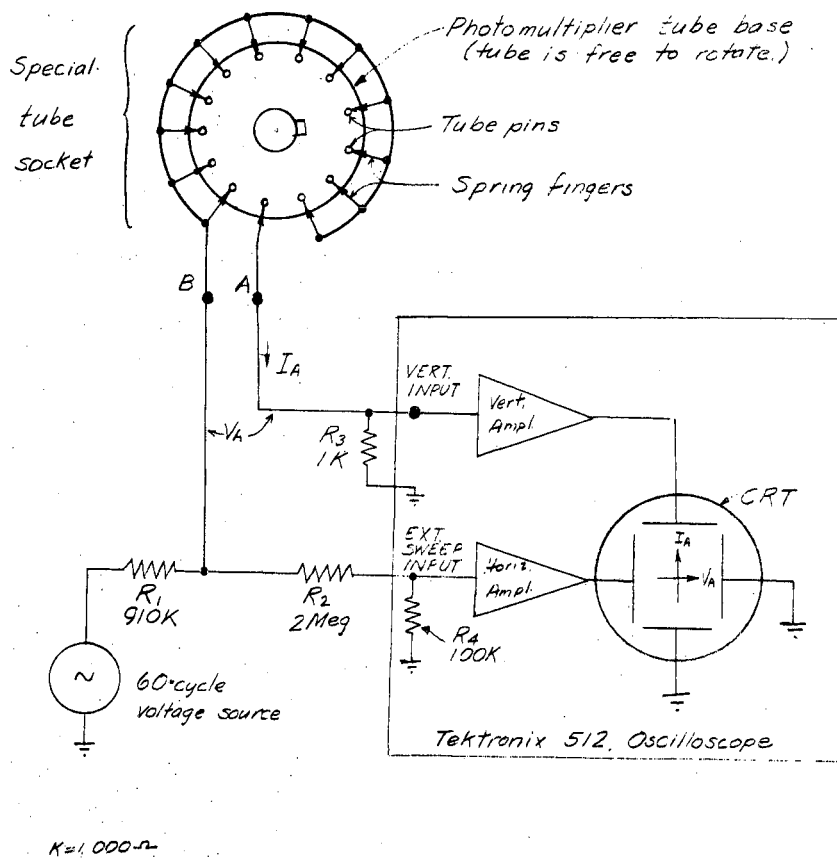
TESTING TECHNIQUES

A. Interelectrode-Impedance Checker

Because it was found that some of the tubes examined suffered from erratic or intermittent operation, a device was constructed to aid in finding the specific electrodes contributing to the intermittent condition. This device, referred to as an "interelectrode impedance checker," is similar in nature to the interelectrode short tester on a commercial tube tester, but is capable of indicating much more about the nature of the tube defects encountered. As shown on the block diagram of the instrument in Fig. 1, a 60-cycle alternating voltage, V_A , is applied between one of the electrodes (connected to terminal A) and all other electrodes (terminal B). As a result of the applied voltage, a current I_A flows through the impedance existing between the electrode connected to terminal A and all other electrodes. The voltage $I_A R_3$ is amplified and impressed on the vertical deflection plates, causing a deflection of the cathode-ray tube beam proportional to I_A . The horizontal deflection is proportional to V_A . The cathode-ray tube beam, therefore, traces out the volt-ampere (v-i) characteristic of the electrode under test to all other electrodes 60 times per second. (For convenience, "all other electrodes" is abbreviated as X in this note. Thus, the v-i characteristic existing between Dynode 1 and all other electrodes is called the Dynode 1-X characteristic.) The patterns that are observed as terminal A of Fig. 1 is connected in turn to the various electrodes can be interpreted in terms of impedances, as is indicated in the sketches of Fig. 2, where some sample patterns and their interpretations are given. Note that it is possible to differentiate between linear and nonlinear resistances; the latter are typical of semiconductors.

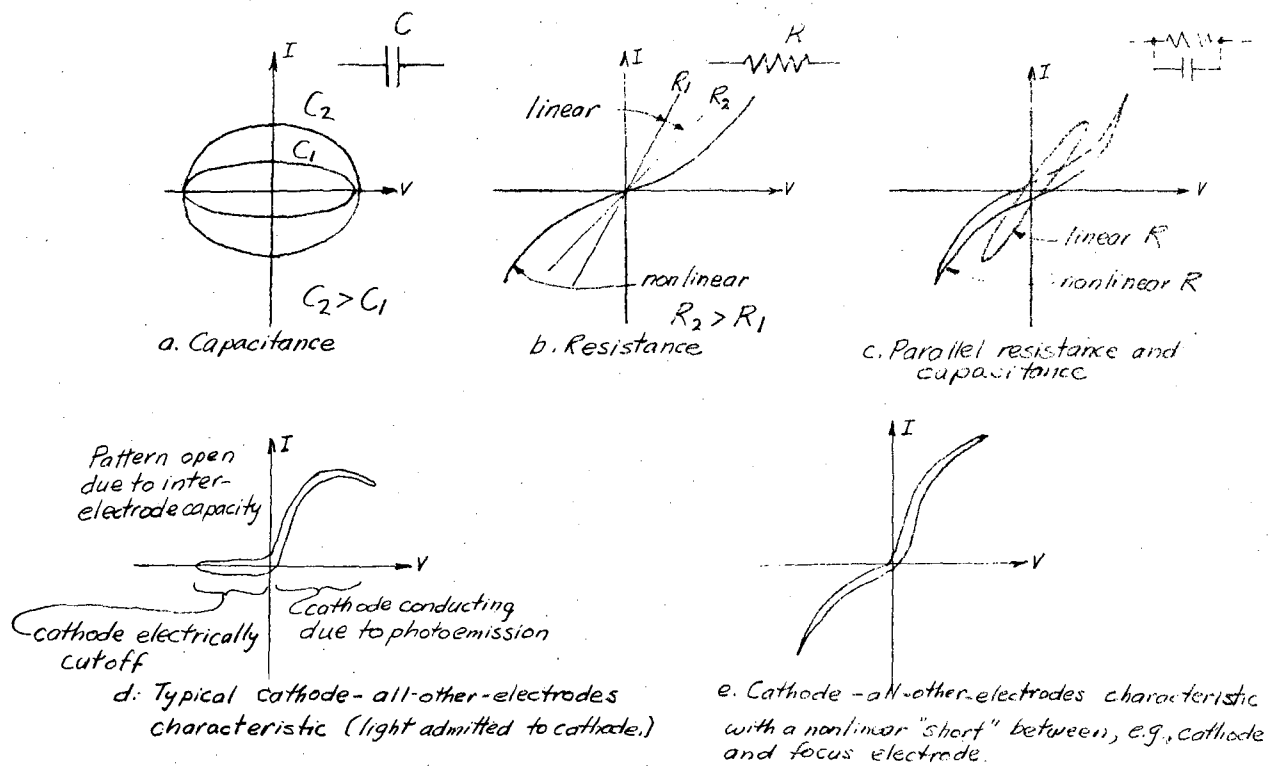
A special tube socket was constructed to facilitate making the impedance observations at each of the 20 base pins (Fig. 3). The tube under test is free to rotate within the socket, which has a ring of spring fingers to connect the checker circuit to the base pins. The contact fingers are arranged so that all but one of the base pins are connected to terminal B, the remaining pin to terminal A. As the tube is rotated in the socket, each base pin in turn is connected to terminal A.

The sensitivity of the instrument is such that one can (a) detect an open lead in the tube under test (from capacity indication), (b) detect a short circuit having from 0 to 100 meg resistance, (c) determine if the resistance



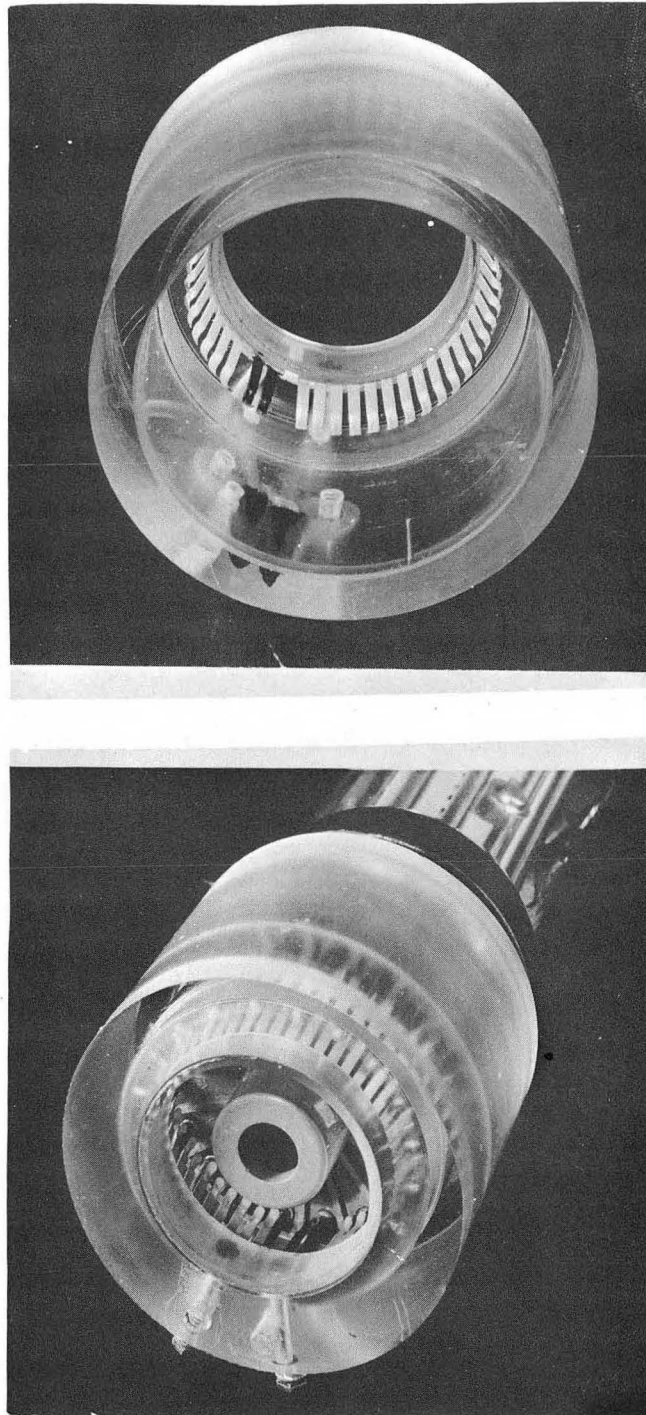
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Fig. 1. Block diagram of equipment used to measure dynamic interelectrode impedances of multiplier phototubes.



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Fig. 2. Volt-ampere characteristics of certain electrical elements. These are included to aid in interpreting Photographs 1 through 8.



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Fig. 3. Two views of the special socket constructed for the inter-electrode impedance checker. The lower view shows a phototube inserted in the socket and ready for testing. In use, the socket may be held in the hand. The two spring fingers comprising terminal A are painted black.

of the short is linear or nonlinear within the range of applied voltage, (d) estimate the relative cathode sensitivity (from response to room light). After some experience, it is possible for an operator to check all of the electrodes of a 6810 or other phototube for all of the above-listed characteristics in a matter of 10 to 20 sec. The contact fingers are stiff enough so that the tube may be tapped to look for vibration-sensitive defects without getting false indications.

Photographs of some of the patterns observed on the cathode-ray tube are shown in Fig. 4. Conditions under which the pictures were made are given below.

Photograph 1. Calibration of scope for conditions used in taking photographs 2 through 7. Photograph 1 was taken with the oscilloscope amplifier gains set so that phototube interelectrode capacities as low as 5 μf and interelectrode resistances as high as 100 meg could easily be detected. The range of capacitance and resistance indication can be changed by operating the oscilloscope gain controls or by changing R_1 , R_2 , and R_3 of Fig. 1.

Top: The characteristics of three 0.5-w resistors. A 100-meg resistor gave the nearly horizontal trace; the others in counterclockwise order are 20 meg and 10 meg. The slight opening of the traces is owing to shunt capacity, most of which is contributed by the resistors themselves (cf. Fig. 2c).

Lower: Three values of capacity--0, 10, and 30 μf ; the 30- μf trace is the largest ellipse. The 0 and 10 μf traces are indiscriminate.

Photograph 2. All three traces are of the cathode-to-X characteristic of a good tube. The amount of light admitted to the cathode decreases in order from full room light for the top trace to zero light for the bottom trace.

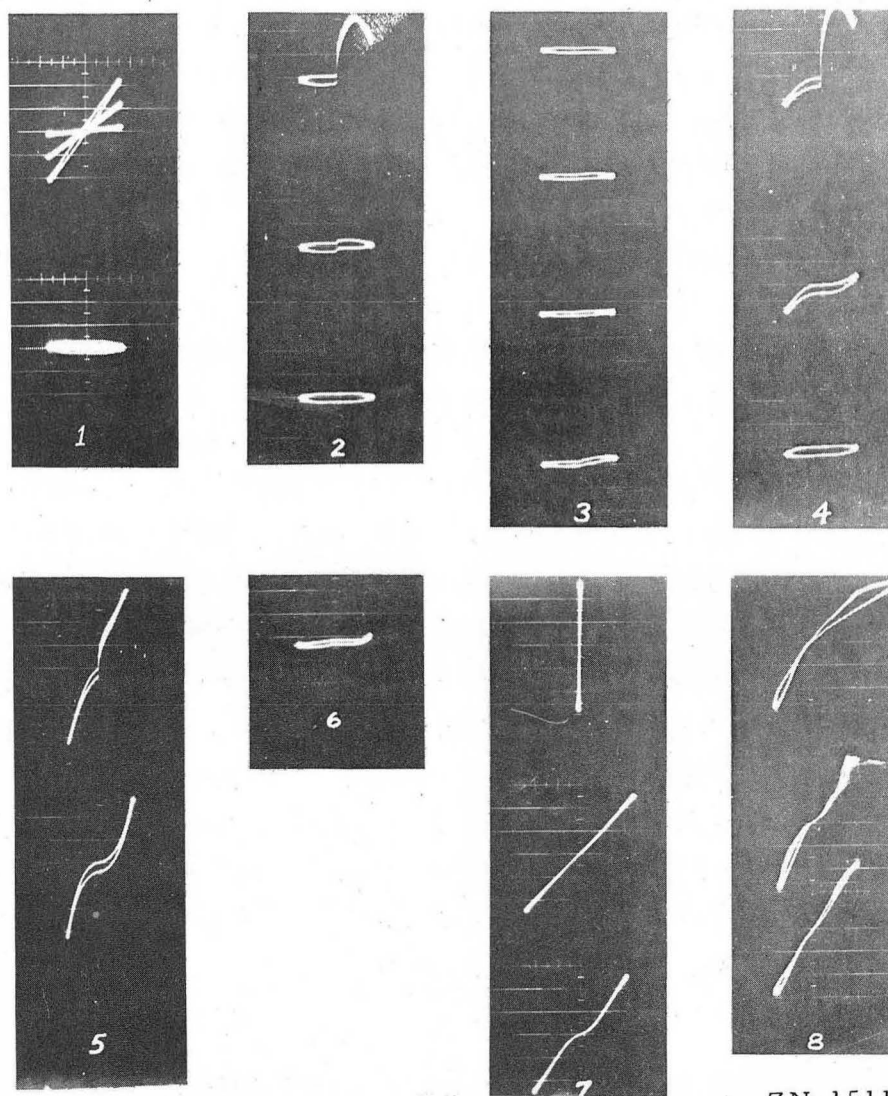
Photograph 3. The same (good) tube as in Photograph 2; the v-i characteristics between all other electrodes and dynodes Nos. 4, 3, 2, 1 from top to bottom, with the tube exposed to room light. Note that some of the cathode current flows to dynode No. 1, less to dynode No. 2., etc.

Photographs 4 and 5. The cathode-to-X v-i characteristic of tube 1-6-21.

Top, No. 4: Room light admitted to cathode.

Middle, No. 4: No light admitted to cathode,

Bottom, No. 4: No light admitted to cathode, but the tube had been



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Fig. 4. Photographs 1 through 8 show interelectrode volt-ampere characteristics of some 6810 multiplier phototubes. Details are given in Section IIA.

shaken since the middle picture was made.

Top No. 5. Light on cathode, tube shaken again.

Bottom No. 5: Same as Top No. 5, light blocked from cathode.

These pictures indicate the presence of a variable-resistance, vibration-sensitive semiconducting short between the cathode and some other electrode, in this case the focus electrode (shield between cathode and dynode structure). The short was found on the inner surface of the glass envelope between the extension on the internal aluminized shield, which is also used as the cathode lead, and one of the four focus-electrode supports. The gap between the support and the aluminizing is abnormally small at this point--approximately 0.1 in. There were evidences of a deposit of some material within this gap. With the tube in a dark room and with 300 to 500 v applied between cathode and focus electrode, small bluish sparks could be seen in this gap when the tube was tapped.

Photograph 6. The Dynode 1-to-X characteristic of tube 1-6-21. The upward tilt of the right-hand part of the trace indicates that conduction between Dynode 1 and some other electrode takes place at the peak value (approx. 100 v) of the applied voltage. In this tube, the clearance between the support rods of Dynode 1 and Dynode 3 was rather small at the ceramic side insulators. In the darkroom, an application of dc voltage between Dynodes 1 and 3 resulted in a bluish glow, visible to the dark-adapted eye, until the applied voltage was reduced below 200 v. This glow was intense enough so that a clear photograph of it was obtained with an exposure of 1.9 for 10 minutes, using a film with an ASA speed of 400.

Photograph 7.

Top: The Dynode 1-to-X characteristic of tube 2-6-875, indicating a short of approximately 100 ohms between dynodes 1 and 3. In this tube also, the separation between the dynode-1 and-3 support rods was small. Application of voltage between these electrodes resulted at first in a yellowish glow between the support rods at the ceramic side insulator. This glow later disappeared, but a bluish discharge appeared at this point when the tube was tapped.

Middle and Bottom: The dynode 13 to X characteristic of tube 10-5-29, showing a tap-sensitive short between dynode 13 and the anode. When the

tube was tapped, the short was found to change from a linear resistance (middle) to a nonlinear resistance (bottom).

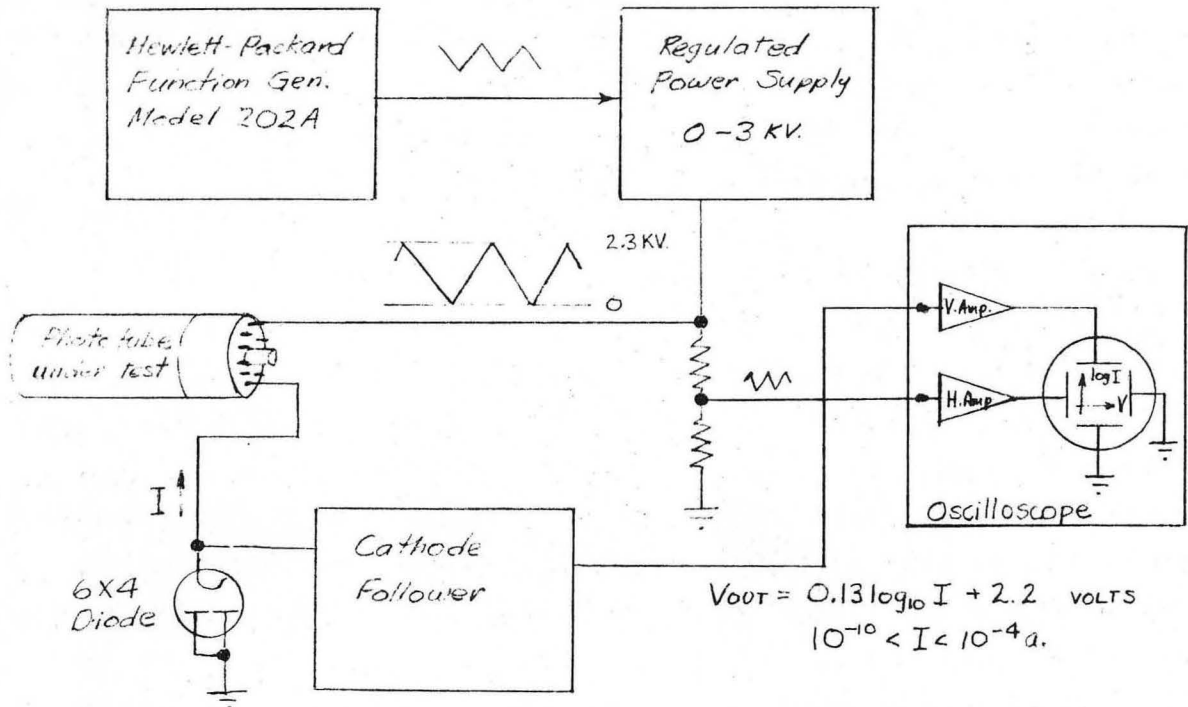
Photograph 8. The Dynode 1-to-X characteristic of tube 2-6-840, with different scale factors than for Photographs 1 through 7. These three traces show an average slope corresponding to about 10,000 ohms. In this tube a small fragment of matter was seen lodged between the support rods of Dynodes 1 and 3. The three traces show the different v-i characteristics assumed as the fragment was moved by tapping the tube. The tube was held stationary while each trace was photographed, but the middle trace shows that the v-i characteristic varied spontaneously.

B. Dark-Current Swept-Voltage Test

If allowed to reach the cathode, the light and ions produced by voltage breakdowns across the close spacings and semiconducting deposits observed in some of the rejected tubes could result in an increase in the dark current of the tube. To investigate this effect, an instrument was built to measure the dark current as the phototube supply voltage was varied slowly from zero to the rated voltage. It was expected that at the supply voltage at which the glow first appeared there would be a sharp increase in dark current. This expectation was borne out, as is described below.

A block diagram of the equipment used in this test is shown in Fig. 5. An oscilloscope is used to obtain a plot of dark current vs voltage. A fraction of the supply voltage is impressed on the horizontal input of the scope, and a voltage proportional to the logarithm of the phototube anode current is impressed on the vertical input. This latter voltage is generated by passing the anode current through the nonlinear plate resistance of a thermionic diode. A cathode follower with grid current known to be less than 10^{-13} amp is used to measure the voltage developed across the diode. The signal generator is used to generate a triangular wave, the period of which can be made as long as 10 sec. The output of the regulated power supply is an amplified version of the triangular wave, with a peak amplitude of 2300 v.

A series of representative patterns of dark current observed with this equipment is shown in Photographs 9 through 12 of Fig. 6. The voltage calibration on all the pictures is 250 v per horizontal cm (the three vertical



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Fig. 5. Block diagram of equipment used in the swept-voltage dark current test. (Photographs 9 through 15.)

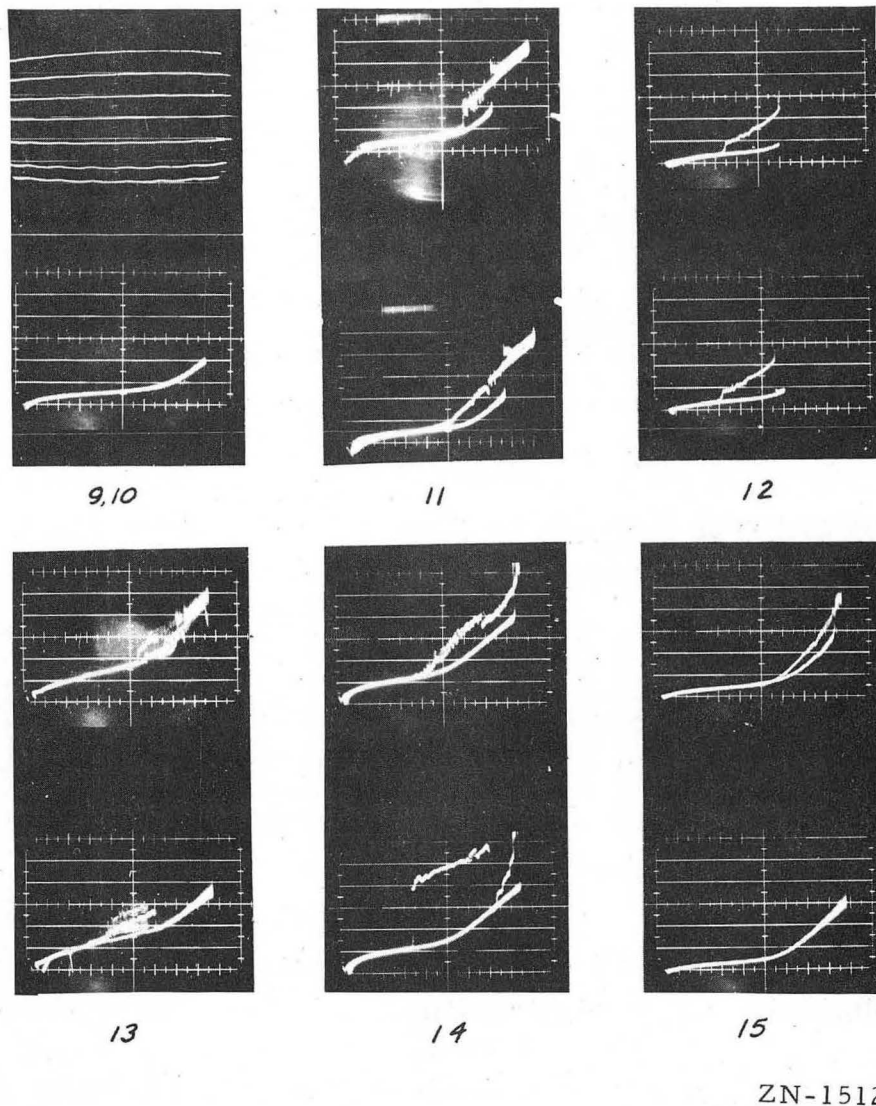


Fig. 6. Photographs 9 through 15 show the relation between anode dark current and anode-cathode voltage of several 6810 multiplier phototubes. Voltage is plotted with a linear scale on the horizontal axis, zero volts on the left, 2500 on the right side of the graticule. The current calibration is shown in Photograph 9, where, from top to bottom, the traces shown correspond to 5×10^{-4} , 1×10^{-4} , 10^{-5} , 10^{-6} , 10^{-7} , 10^{-8} , and 10^{-9} amp.

lines are at 0, 5, and 10 cm) with zero volts on the left, 2500 v at the right, 1250 v in the center. The calibration of the vertical current scale is shown in Photograph 9. Each photograph was exposed for 30 sec, this time corresponding to one cycle of the triangular wave form of the anode supply voltage.

Photograph 9. Current-calibration traces are shown. Top to bottom they record currents of 5×10^{-4} , 1×10^{-4} , 10^{-5} , 10^{-6} , 10^{-7} , 10^{-8} , and 10^{-9} amp. Note that the scale is nearly logarithmic from 10^{-4} to 10^{-9} amp.

Photograph 10, Tube 1-6-643. The dark-current characteristic typical of a good tube. Note that the curve is smooth and that the portions for the increasing and decreasing parts of the triangular-anode-supply-voltage wave form are coincident.

Photograph 11, Tube 2-6-233.

Top: As the supply voltage is raised, the dark current suddenly increases at 1800 v by an order of magnitude. For decreasing supply voltages, the dark current suddenly decreases at 1500 v. This hysteresis is typical of many discharge phenomena.

Bottom: The dark-current characteristic is slightly different each time the anode supply voltage is cycled. This exposure shows the characteristic observed several cycles after the top picture was taken.

Table I shows, for comparison purposes, the dark current values measured with an RCA WV-84A microammeter for Tube 2-6-233 as the supply voltage was increased manually.

Photograph 12, Tube 2-6-233. Supply voltage cycled between limits of 0 and 1500 v.

Top: Dark-current jump occurred at the highest supply voltage.

Bottom: Dark current jumped after supply voltage had reached its peak and had started to decrease.

Photograph 13, Tube 1-6-687. Two very noisy traces. When the dark current is in its higher state, the instantaneous amplitude fluctuates rapidly.

Photograph 14, Tube 1-6-648.

Top: Dark-current jumps occurred when supply voltage reached 2300 v, and rose to more than 0.5 ma.

Table I

Variation in dark-current values with increasing anode-to-cathode supply voltage	
Anode to cathode supply voltage	Dark current (amp)
600	5×10^{-10}
800	7×10^{-10}
1000	9×10^{-10}
1200	1.3×10^{-9}
1400	8×10^{-8}
1600	2.5×10^{-7}
1800	1.5×10^{-6}
2000	5×10^{-6}
2200	2.2×10^{-5}
2400	1.4×10^{-4}
2600	8×10^{-4}

Bottom: After the tube was tapped, the dark-current characteristic changed slightly.

Photograph 15, Tube 2-6-840.

Bottom: This is the dark current observed for the first cycle of the triangular wave form of supply voltage when first turned on.

Top: After several cycles, the dark-current jumps occurred at about 2100 v.

C. Further Darkroom Observations

It was found during this investigation that light is emitted by certain parts of some tubes. When normal voltages are applied to a tube, light can be produced because of incandescence of metallic or semiconducting shorts or by voltage breakdown at points of high voltage gradient. Intermittent shorts due to small particles captive within the tube have been observed. These particles may move about within the tube and become lodged in such a spot as to cause an electrical short. They can often be dislodged by vibrating the tube, or may be burned out by passing a heavy enough current through them. They are the cause of many intermittent tube failures.

Voltage breakdowns within the tube can occur when sharp points on electrodes or their supports or excessively small spacings between electrodes are built into the tube. A large percentage of such breakdowns observed have been between Dynodes 1 and 3, an unfavorable place to have extraneous light produced because of the proximity to the photocathode. Glows have also been observed on sharp points on the ends of some of the latter-dynode support rods. A high gradient is set up at some of these points by the voltage between the rod and near-by leads going to the cathode and early dynodes.

Light is also produced when the residual gas in the tube is ionized by space current. This glow occurs predominantly in the higher-current section of the tube--i. e., Dynodes 12 to 14. It is bright enough, with average anode currents of 0.1 ma and anode-cathode voltages of 2300 v, that the dark-adapted eye can see it leaking between the dynode structure and the ceramic side supports. Photographs were made of this glow in an early model of the C7187, which has transparent mica side supports. The photographs indicated that the glow was distributed within the space contained by the latter dynodes in accordance with the density of electron flow.

CONCLUSIONS

The following causes of tube failure were found in the 6810 multiplier phototubes examined:

1. Intermittent interelectrode shorts due to particles captive within the tube.
2. Intermittent shorts due to voltage breakdown at points of high electrical stress.
3. Erratic dark currents, of up to saturation amplitudes, caused in part by light and ions generated within the tube by voltage breakdowns and by space current.

Too small a spacing between, and sharp points on, the support rods of Dynodes 1 and 3 were the cause of many of the above defects. Point 3 above emphasizes the need for a good vacuum in the tube and an efficient light shield between the photocathode and multiplier structure.

The two testing methods described, * namely the interelectrode-impedance test and the swept-voltage dark-current test, are believed to be valuable for quickly checking multiplier phototubes for the apparently common defects listed above. Some of the shorts detected by the impedance test have nonlinear characteristics that tend to defy detection at the low voltages employed in conventional ohmmeters.

* Some other multiplier phototube testing methods developed at UCRL are covered in the following notes issued by the UCRL counting research group:

Q. Kerns, F. Kirsten, Results of Preliminary Tests on Two RCA LE59 Photomultiplier Tubes, CRG-2, Aug. 1955.

F. Kirsten, Results of Transit-Time Measurements on Three C7187A Photomultiplier Tubes, CRG-3, Dec. 1955.

Q. Kerns, A Generator of Fast-Rising Light Pulses for Phototube Testing, CRG-6, in preparation.

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