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STUDY OF DEFECTIVE RCA 6810 MULTIPLIER PHOTOTUBES

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**STUDY OF DEFECTIVE RCA 6810 MULTIPLIER PHOTOTUBES**

**F. Kirsten**

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STUDY OF DEFECTIVE RCA TYPE 6810  
MULTIPLIER PHOTOTUBES

INTRODUCTION

Multiplier phototubes purchased by UCRL (Berkeley) are, at present, given a routine check for noise and sensitivity by use of a scintillator crystal and a source of radiation as a generator of standard light pulses. The amplitude and number of the noise pulses generated within the tube are compared with the amplitude and number of pulses from the standard scintillator. Of a recent group of about forty 6810 multiplier phototubes purchased by UCRL, approximately 25% failed to pass this routine check. An investigation was made to determine, if possible, (a) the basic causes of failure in the rejected tubes, and (b) improved methods of phototube testing. This note presents the methods and results of performing some of the tests. The work described was done by the Counting Research Group, supervised by Quentin Kerns.

TESTING TECHNIQUES

A. Interelectrode Impedance Checker

Inasmuch as the routine tests indicated that many of the rejected tubes 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 CRT beam, therefore, traces out the volt-ampere (v-i) characteristic of the electrode under test to all other electrodes sixty times a 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 observed as terminal A of Fig. 1 is connected to the various electrodes in turn can be interpreted in terms of impedances, as is indicated in the sketches of Fig. 2, where some

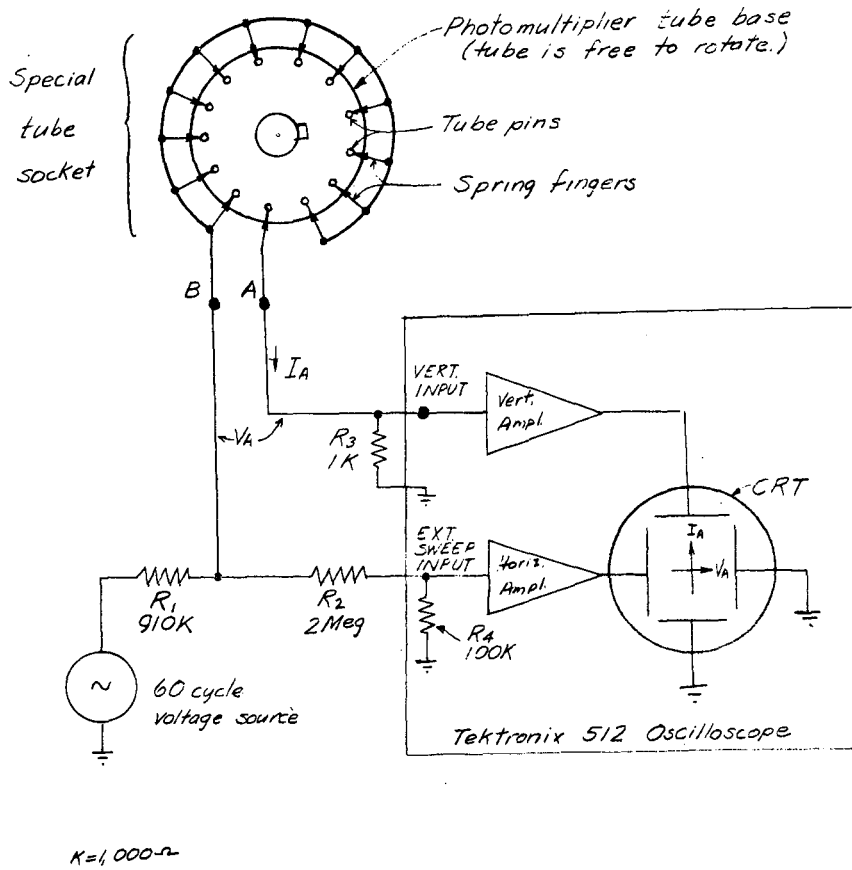
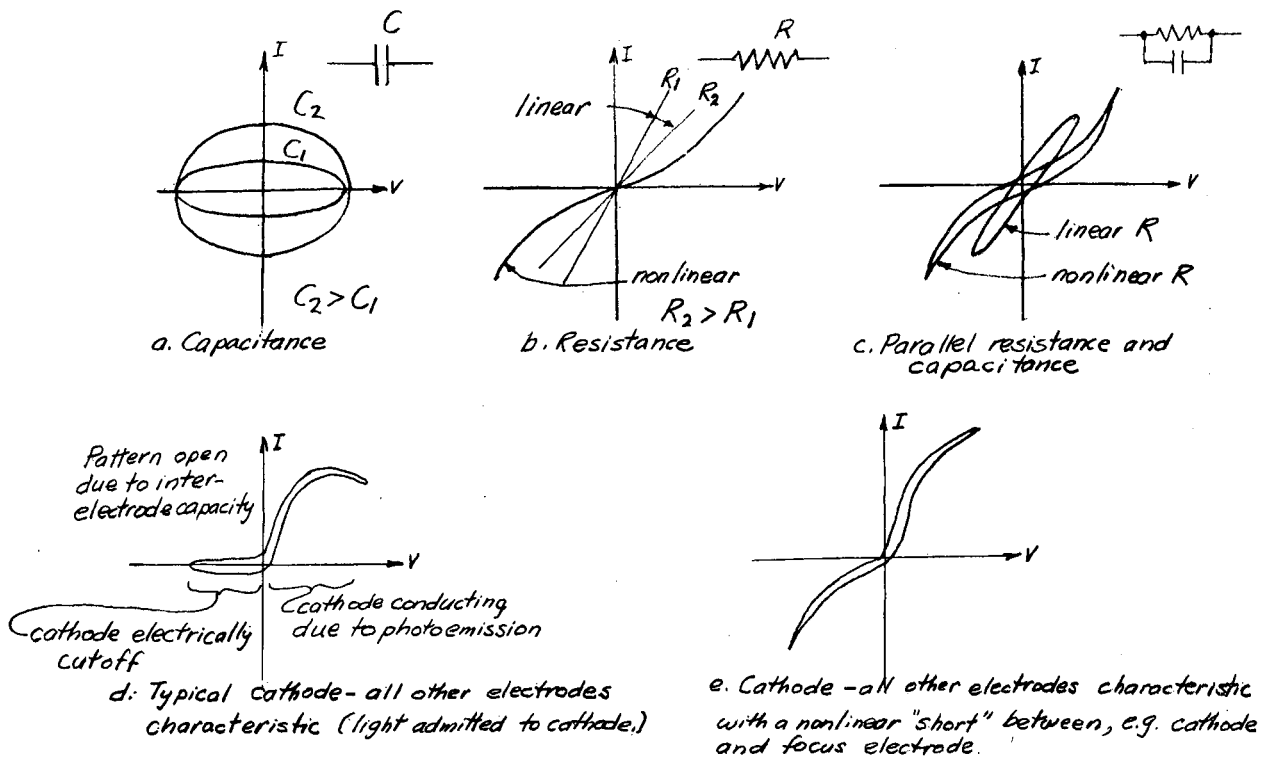


Fig. 1. Block diagram of equipment used to measure dynamic interelectrode impedances of multiplier phototubes.



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

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 built to facilitate making the impedance observations at each of the 20 base pins. The tube under test is free to rotate within the socket, which has a ring of spring fingers to make connections 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 it is easy to (a) detect an open lead in the tube under test (from capacity indication), (b) detect a "short" having from 0 to 100 megohms resistance, (c) determine if the "short" resistance is linear or nonlinear within the range of applied voltage, (d) estimate the relative cathode sensitivity (from response to room light). As shown in photo-No. 1, the values of capacities on the range of 5-50  $\mu\text{f}$ , and resistances in the range 100 meg to 100K can be estimated from the patterns on the cathode-ray tube. If the resistances of Fig. 1b are changed, lower resistances can be measured. After some experience, it is possible for an operator to check all the electrodes of a 6810 or other phototube for all the above-listed defects in a matter of 10 to 20 seconds. 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. Conditions under which the pictures were made are given below.

Photograph 1. Calibration of scope for conditions used in taking Photographs 2 through 7.

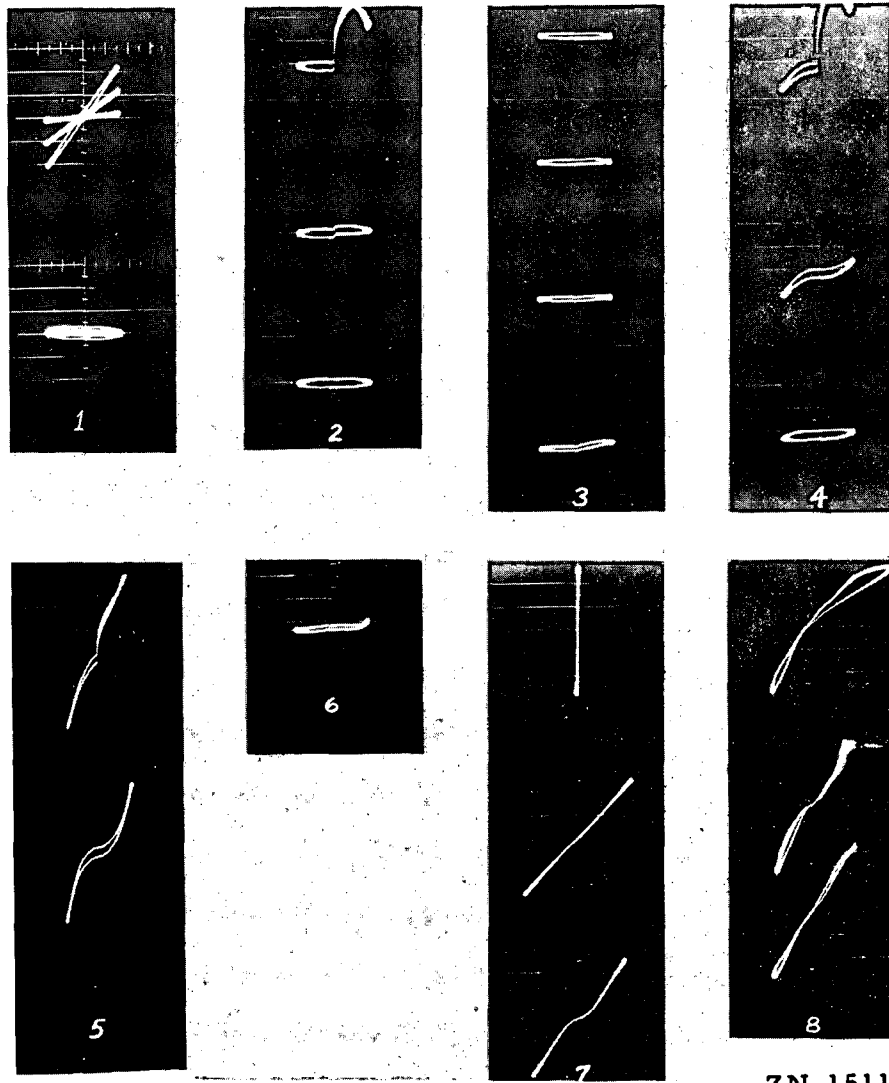
Top: The characteristics of three 0.5-watt resistors. A 100-megohm resistor gave the nearly horizontal trace; the others in counterclockwise order are 20 megohms and 10 megohms. The slight opening of the traces is owing to shunt capacity, most of which is contributed by the resistors themselves (cf.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

Lower: Three values of capacity--0, 10, 30  $\mu\text{f}$ ; the 30- $\mu\text{f}$  trace is the largest ellipse.

Photograph 2. All three traces are of the cathode-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.





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

Photographs 4 and 5. The cathode-X v-i characteristic of rejected 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 having been 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 inch. There were evidences of a deposit of some material within this gap. With the tube in a dark room and with 300 to 500 volts 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-X characteristic of tube 1-6-21. The upward tilt of the right-hand part of the trace indicates that conduction between dynode No. 1 and some other electrode takes place at the peak value (approx. 100 volts) of the applied voltage. In this tube, the clearance between the dynode No. 1 and dynode No. 3 support rods was rather small at the ceramic side insulators. In the darkroom, an application of dc voltage between dynodes Nos. 1 and 3 resulted in a bluish glow, visible to the dark-adapted eye, until the applied voltage was reduced below 200 volts. This glow was intense enough so that a clear photograph of it was obtained with an exposure at f 1.9 of 10 minutes, using a film with an ASA speed of 400.

Photograph 7.

Top: The dynode 1-X characteristic of tube 2-6-875, indicating a short of approximately 100 ohms between dynodes No. 1 and No. 3. In this tube also, the separation between the dynode No. 1 and No. 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, No. 7: The dynode 13-X characteristic of tube 10-5-29, showing a tap-sensitive short between dynode No. 13 and the anode. When the tube was tapped, the short was found to change from a linear resistance to a nonlinear resistance, as the pictures show.

Photograph 8. The dynode 1-X characteristic of tube Z-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 dynode No. 1 and No. 3 support rods. The three traces show the different volt-ampere 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

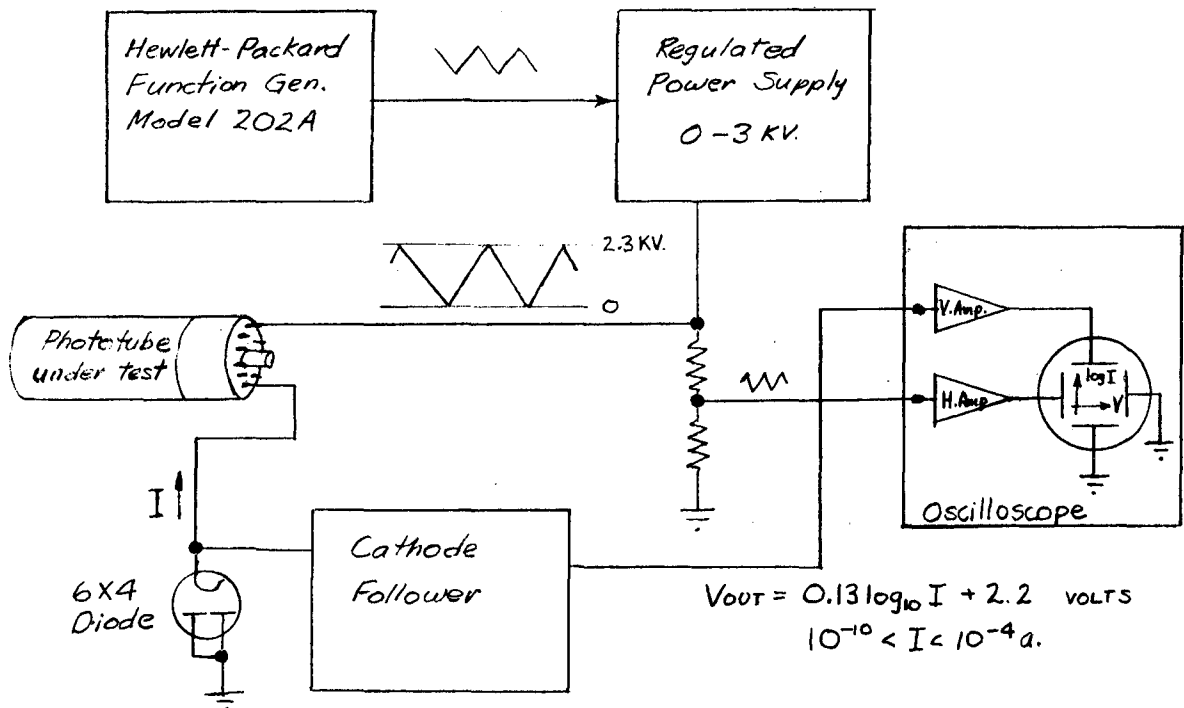
If allowed to reach the cathode, the light and ions produced by voltage breakdowns across the close spacings and semiconducting deposits observed in some of the rejected tubes could result in an increase in the dark current of the tube. To investigate this effect, an instrument was built to measure the dark current as the phototube supply voltage was varied slowly from zero to 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. 3. 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  $10^{-15}$  ampere 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 seconds. The output of the regulated power supply is an amplified version of the triangular wave, with a peak amplitude of 2300 volts.

A series of representative patterns of dark current observed with this equipment is shown in Photographs 9 through 12, as described below. The voltage calibration on all the pictures is 250 volts per horizontal centimeter. (the three vertical lines are at 0, 5, and 10 cm) with zero volts on the left, 2500 volts at the right, 1250 volts in the center. The calibration of the vertical current scale is shown in Photograph 9. Each photograph was exposed for 30 seconds, this time corresponding to one cycle of the triangular wave form of the anode supply voltage.

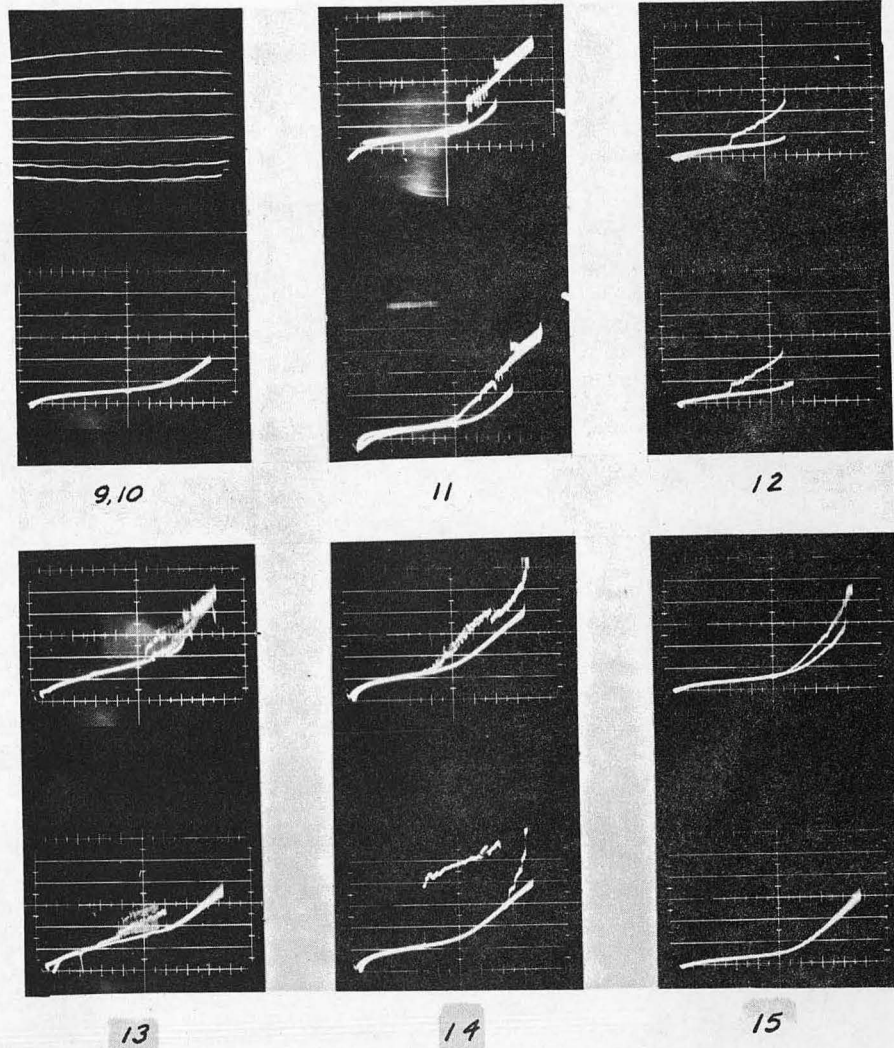
Photograph 9. Current calibration traces are shown. Top to bottom, they record currents of  $10^{-9}$ ,  $10^{-8}$ ,  $10^{-7}$ ,  $10^{-6}$ ,  $10^{-5}$ ,  $10^{-4}$ , and  $5 \times 10^{-3}$  amp. Note that the scale is nearly logarithmic from  $10^{-9}$  to  $10^{-4}$  amp.

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 waveform are coincident.



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Fig. 3. Block diagram of equipment used in the swept-voltage dark current test. (Photographs 9 through 15.)



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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 volts 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  $.5 \times 10^{-3}$ ,  $1 \times 10^{-4}$ ,  $10^{-5}$ ,  $10^{-6}$ ,  $10^{-7}$ ,  $10^{-8}$  and  $10^{-9}$  amperes.

Photograph 11, Tube 2-6-233.

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

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

For comparison purposes, dark currents measured with an RCA WV-84A Microammeter for Tube 2-6-233 as the supply voltage was increased manually are tabulated:

Anode-cathode supply voltage	Dark current (amperes)
600	$5 \times 10^{-10}$
800	$7 \times 10^{-10}$
1000	$9 \times 10^{-10}$
1200	$1.3 \times 10^{-9}$
1400	$8 \times 10^{-8}$
1600	$2.5 \times 10^{-7}$
1800	$1.5 \times 10^{-6}$
2000	$5 \times 10^{-6}$
2200	$2.2 \times 10^{-5}$
2400	$1.4 \times 10^{-4}$
2600	$8 \times 10^{-4}$

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

**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 volts, rose to more than 0.5 milliampere.

**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 volts.

### **C. Further Darkroom Observations**

As mentioned in Sec. II A, it has been observed that light is produced in parts of certain tubes. The light can come from at least two sources--voltage breakdown, and ionization of residual gas by space current.

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 have been observed to be due to small particles captive within the tube. 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 No. 1 and No. 3, a very poor place to have extraneous light produced because of the proximity to the photocathode. Glows have also been observed on sharp points on 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 Nos. 12-14. It is bright enough, with average anode currents of 0.1 ma and anode-cathode voltages of 2300V, 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.

SUMMARY

These were the defects found in the nine 6810 multiplier tubes rejected by UCRL and returned to RCA at Lancaster, Pennsylvania:

1-6-21. Intermittent high-resistance (megohms) shorts between cathode and focus electrode, and between dynodes Nos. 1 and 3. (Photographs 4, 5, and 6) In darkroom, glow visible between dynodes No. 1 and No. 3 support rods at ceramic insulator (photos of this were taken) with dynode No. 1 to No. 3 voltages down to 200V. Tube has small spacing between cathode-potential aluminium coating and focus-electrode support.

1-6-648. Intermittent operation observed. Small points of bluish light seen on ends of latter-dynode support rods. Observed to jump into condition of large dark current with 2 kv anode-cathode potential. (Photograph 14)

1-6-687. Dark current erratic. (Photograph 13)

2-6-233. Intermittent short of approximately 75K ohms between dynodes Nos. 1 and 3. As the voltage is raised, the dark current increases suddenly at 1000 to 1500 volts, decreases suddenly when the voltage is decreased to a lower value. Dark current is  $10^{-4}$  to  $10^{-3}$  amp at 2300v. (Photographs 11 and 12)

2-6-790. A short of about 10,000 ohms between dynodes Nos. 1 and 3. A short between anode and dynode No. 14, with resistance that varied from 15,000 down to 1 ohm when tapped. Very erratic and large dark current observed.

2-6-840. Short of a 5K ohms between dynodes Nos. 1 and 3. (Photograph 8) A small fragment was seen lodged between these two dynodes. The fragment later fell out when tube was tapped. Erratic dark current. (Photograph 15)

2-6-875. Intermittent short of approx. 100 ohms between dynodes Nos. 1 and 3. (Photograph 7) Upon first application of voltage of approximately 300 volts between these electrodes, a yellowish glow was seen between dynodes Nos. 1 and 3 at the ceramic side insulator.

12-5-392. Intermittent short between dynodes No. 1 and No. 3. In gain tests using pulsed light source, gain varies when tube is tapped.

12-5-657. Erratic operation observed.



## CONCLUSIONS

The following causes of tube failure were found in the nine 6810's 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 No. 1 and No. 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 described in the report. 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.

This work was done under the auspices of the U. S. Atomic Energy Commission.

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\* Some other multiplier phototube testing methods developed at UCRL are covered in:

Q. Kerns, F. Kirsten, Results of Preliminary Tests on Two RCA LE59 Photomultiplier Tubes. (After-pulsing measurements.)

F. Kirsten, Results of Transit-Time Measurements on Three C7187A Photomultiplier Tubes. (Transit time measurements.)

Q. Kerns. (A description of the mercury capsule light pulser, which gives light pulses having rise times of less than  $10^{-9}$  second at a rate of up to 5 kc, is in preparation.)