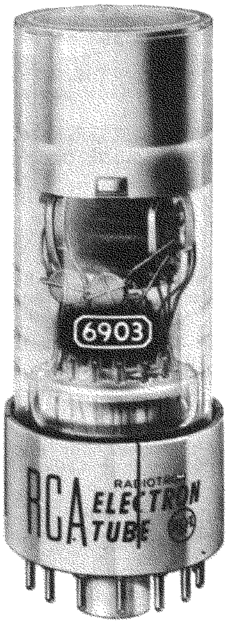
6903

MULTIPLIER PHOTOTUBE

1-5/8" Dia. Flat Face	**10-Stage Head-On Type**	**6-9/16" Max. Length**
Semitransparent Cathode	**S-13 Response**	**2-5/16" Max. Diameter**

TENTATIVE DATA

RCA-6903 is a head-on type of multiplier phototube intended especially for the detection and measurement of ultraviolet radiation, and in other applications involving low-level radiation sources. It is constructed with a fused-silica faceplate which transmits radiant energy in the ultraviolet region down to and below 2000 angstroms. The response below 2000 angstroms is limited only by the transmission of the faceplate. The 6903 may also be used in scintillation counters for the detection and measurement of nuclear radiation.



The spectral response of the 6903 covers the range from about 2000 to 6500 angstroms, as shown in Fig. I. Maximum response occurs at approximately 4400 angstroms. The 6903, therefore, has high sensitivity to blue-rich light and negligible sensitivity to red radiation.

Because of its spectral response, the 6903 is well suited for use with organic phosphors such as anthracene as well as with inorganic materials such as thallium-activated sodium iodide.

Design features of the 6903 include a semitransparent cathode having a minimum diameter of 1-5/8 inches on the inner surface of the face end of the bulb; ten electrostatically focused multiplying (dynode) stages; and a focusing electrode with external connection for shaping the field which directs photoelectrons from the cathode onto the first dynode.

The 6903 is capable of multiplying feeble photoelectric current produced at the cathode by a median value of 400,000 times when operated with a supply voltage of 1000 volts. The output current of the 6903 is a linear function of the exciting energy under normal operating conditions.

The electrode configuration of the 6903 is designed to provide minimum spread in electron transit time. As a result, the 6903 has very short time-resolution capability, i.e., in the order of 1 millimicrosecond. For an input pulse having a duration of 1 millimicrosecond or less, the time spread of the pulse at the anode is about 8 millimicroseconds measured at 50 per cent of the maximum pulse height.

The various features of the 6903 commend its use in applications involving measurement of ultraviolet radiation and also in the design of a scintillation counter with high efficiency and a resolving time of only a small fraction of a microsecond.

DATA

General:

Spectral Response	S-13	
Wavelength of Maximum Response	4400 ± 500	angstroms
Cathode, Semitransparent:		
Shape	Circular	
Window:		
Area	2.0	sq. in.
Minimum diameter	1-5/8	in.
Index of refraction at 2000 angstroms	1.50	
Direct Interelectrode Capacitances (Approx.):		
Anode to dynode No.10	4.4	μμf
Anode to all other electrodes	7.0	μμf
Maximum Overall Length	6-9/16"	
Seated Length	5-5/8" ± 3/16"	
Maximum Diameter	2-5/16"	
Bulb	T-16	
Faceplate	Fused Silica	
Maximum Thickness	0.150"	
Base	Medium-Shell Diheptal 14-Pin, Non-hygroscopic (JETEC No.B14-38)	
Mounting Position	Any	
Weight (Approx.)	7	oz

Maximum Ratings, *Absolute Values:*

ANODE-SUPPLY VOLTAGE (DC or Peak AC)	1250 max.	volts
SUPPLY VOLTAGE BETWEEN DYNODE No.10 AND ANODE (DC or Peak AC)	250 max.	volts
DYNODE-No.1 SUPPLY VOLTAGE (DC or Peak AC)	300 max.	volts
FOCUSING-ELECTRODE VOLTAGE (DC or Peak AC)	300 max.	volts
AVERAGE ANODE CURRENT●	0.75 max.	ma
AMBIENT TEMPERATURE	75 max.	°C

Characteristics Range Values for Equipment Design:

Under conditions with supply voltage (E) across voltage divider providing 1/6 of E between cathode and dynode No.1: 1/12 of E for each succeeding dynode stage; and 1/12 of E between dynode No.10 and anode.

With E = 1000 volts (except as noted) and Focusing Electrode* connected to Dynode No.1 at socket

	Min.	*Median*	*Max.*	
Sensitivity:				
Radiant, at 4400 angstroms	–	19000	–	μamp/μwatt
Cathode radiant, at 4400 angstroms. . .	–	0.047	–	μamp/μwatt
Luminous:♦				
At 0 cps . . .	8	24	240	amp/lumen
With dynode No.10 as output electrode**. . .	–	14	–	amp/lumen
Cathode Luminous:				
With tungsten light source▲	40	60	–	μamp/lumen
With blue light source (See Fig.2)⊕	0.04	–	–	μamp
Current Amplification. .	–	400000	–	
Equivalent Anode-Dark Current Input✠□.	–	1×10^{-9}	3×10^{-9}	lumen
Equivalent Noise Input:				
Luminous★. . . .	–	6.7×10^{-12}	–	lumen
Ultraviolet† . .	–	1.6×10^{-14}	–	watt
Dark Current to Any Electrode Except Anode (At 25°C). . . .	–	–	0.75	μamp

With E = 750 volts (except as noted) and Focusing Electrode* connected to Dynode No.1 at socket

	Min.	*Median*	*Max.*	
Sensitivity:				
Radiant, at 4400 angstroms	–	1650	–	μamp/μwatt
Cathode radiant, at 4400 angstroms. . .	–	0.047	–	μamp/μwatt
Luminous:♦				
At 0 cps . . .	–	2.1	–	amp/lumen
With dynode No.10 as output electrode**.	–	1.0	–	amp/lumen
Cathode Luminous:				
With tungsten light source▲. . .	40	60	–	μamp/lumen
With blue light source (See Fig.2)⊕	0.04	–	–	μamp
Current Amplification.	–	35000	–	

● Averaged over any interval of 30 seconds maximum.

* In general, the focusing electrode is connected to dynode No.1 at the socket and operated at the same fixed potential as dynode No.1. However, in applications critical as to magnitude, uniformity, or speed of the response, the focusing electrode may be connected to the adjustable arm of a potentiometer between cathode and dynode No.1 in the voltage divider, and operated at an optimum potential within a range of 10 to 60 per cent of the dynode-No.1 potential.

♦ For conditions where the light source is a tungsten-filament lamp operated at a color temperature of 2870°K. A light input of 10 microlumens is used. The load resistor has a value of 0.01 megohm.

** An output current of opposite polarity to that obtained at the anode may be provided by using dynode No.10 as the output electrode. With this arrangement, the load is connected in the dynode-No.10 circuit and the anode serves only as collector.

▲ For conditions the same as shown under (♦) except that the value of light flux is 0.01 lumen and 150 volts are applied between cathode and all other electrodes connected together as anode.

⊕ Under the following conditions: Light incident on the cathode is transmitted through a blue filter (Corning Glass Code No.5113 polished to 1/2 stock thickness) from a tungsten-filament lamp operated at a color temperature of 2870°K. The value of light flux on the filter is 0.01 lumen. The load resistor has a value of 0.01 megohm, and 150 volts are applied between cathode and all other electrodes connected together as anode.

✠ Measured at a tube temperature of 25°C and with the supply voltage (E) adjusted to give a luminous sensitivity of 20 amperes per lumen. Dark current caused by thermionic emission and ion feedback may be reduced by the use of a refrigerant.

□ For maximum signal-to-noise ratio, operation with a supply voltage (E) below 1000 volts is recommended.

★ Under the following conditions: Supply voltage (E) 1000 volts, 25°C tube temperature, ac-amplifier bandwidth of 1 cycle per second, tungsten light source at color temperature of 2870°K interrupted at a low audio frequency to produce incident radiation pulses alternating between zero and the value stated. The "on" period of the pulse is equal to the "off" period. The output current is measured through a filter which passes only the fundamental frequency of the pulses.

† Determined under the same conditions as shown under (★) except that use is made of monochromatic source having radiation of 2537 angstroms.

DEFINITIONS

Radiant Sensitivity. The quotient of output current by incident radiant power of a given wavelength, at constant electrode voltages.

Cathode Radiant Sensitivity. The quotient of current leaving the photocathode by incident radiant power of a given wavelength.

Luminous Sensitivity. The quotient of output current by incident luminous flux, at constant electrode voltages.

Cathode Luminous Sensitivity. The quotient of current leaving the photocathode by the incident luminous flux.

Current Amplification. Ratio of the output current to the photocathode current, at constant electrode voltages.

Equivalent Anode-Dark-Current Input. The quotient of the anode dark current by the luminous sensitivity.

Equivalent Noise Input. That value of incident luminous flux or incident radiant power which when modulated in a stated manner produces an rms output current equal to the rms noise current within a specified bandwidth.

GENERAL CONSIDERATIONS

The 6903 is a phototube incorporating an electron multiplier. An electron multiplier utilizes the phenomenon of secondary emission to amplify signals composed of electron streams. In the 6903 multiplier phototube, represented in Fig.3, the electrons emitted from the irradiated cathode are directed by fixed electrostatic fields to the first dynode (secondary emitter). The electrons impinging on the dynode surface produce many other electrons, the number depending on the energy of the impinging electrons. These secondary electrons are then directed by fixed electrostatic fields along curved paths to the second dynode where they produce more new electrons. This multiplying process is repeated in each successive stage, with an ever-increasing stream of electrons, until those emitted from the last dynode (dynode No.10) are collected by the anode and constitute the current utilized in the output circuit.

Dynode No.10 is so shaped as to enclose partially the anode and to serve as a shield for it in order to prevent the fluctuating potential of the anode from interfering with electron focusing in the interdynode region. Actually the anode consists of a grating which allows the electrons from dynode No.9 to pass through it to dynode No.10. Spacing between dynode No.10 and anode creates a collecting field such that all the electrons emitted by dynode No.10 are collected by the anode. Hence, the output current is substantially independent of the instantaneous positive anode potential over a wide range. As a result of this characteristic, the 6903 can be coupled to any practical load impedance.

The shield which extends between dynode No.1 and the anode shields dynode No.1 and the cathode from the anode and prevents ion feedback. If positive ions produced in the high-current region

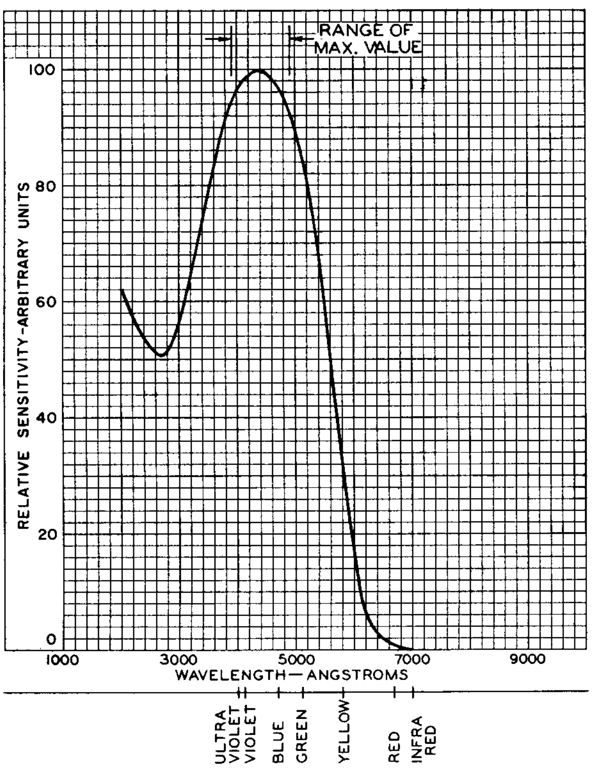


Fig.1 - Tentative Spectral Sensitivity Characteristic of Type 6903 which has S-13 Response. Curve is shown for Equal Values of Radiant Flux at All Wavelengths.

near the anode were allowed to reach the cathode or the initial dynode stages, they would cause the emission of spurious electrons which after multiplication would produce undesirable and often uncontrollable regeneration. The metallic coating on the inner side wall of the glass bulb is connected to the cathode, and serves to direct the electrons from the cathode toward dynode No.1.

The grill through which the electrons reach dynode No.1, is connected to dynode No.1 and

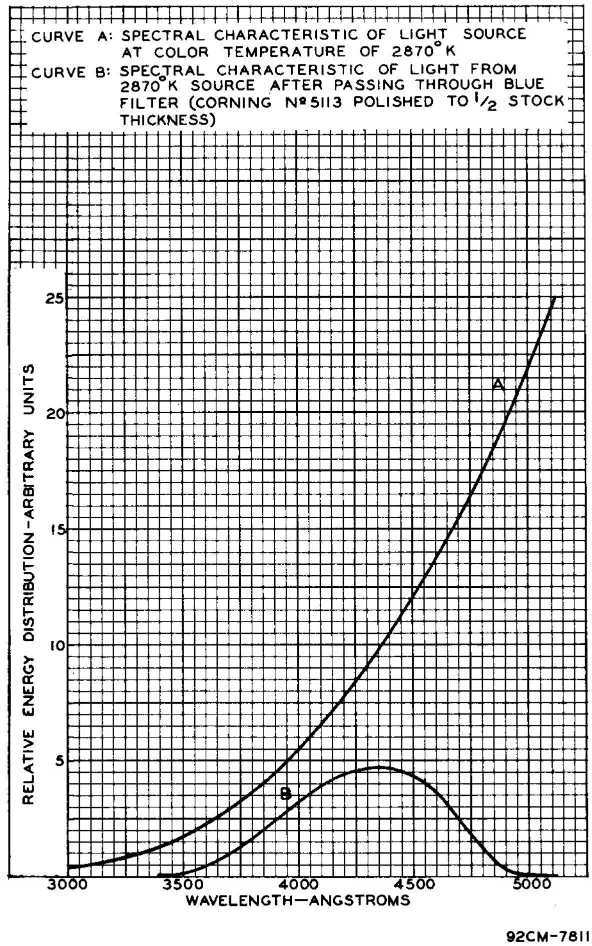


Fig.2 - Spectral Characteristic of 2870°K Light Source, and Spectral Characteristic of Light from 2870°K after Passing through Indicated Filter.

serves along with accelerating electrode as an electrostatic shield for the open side of the electrode structure.

The focusing electrode shapes the field which directs photoelectrons from the cathode onto dynode No.1.

INSTALLATION and APPLICATION

The *maximum ratings* in the tabulated data are limiting values above which the serviceability of the 6903 may be impaired from the viewpoint of life and satisfactory performance. Therefore, in order not to exceed these absolute ratings, the equipment designer has the responsibility of determining an average design value for each rating below the absolute value of that rating by an amount such that the absolute values will never be exceeded under any usual condition of supply-voltage variation, load variation, or manufacturing variation in the equipment itself.

The *maximum ambient temperature* as shown in the tabulated data is a tube rating which is to be observed in the same manner as other ratings. This rating should not be exceeded because too high a bulb temperature may cause the volatile cathode surface and dynode surfaces to evaporate with consequent decrease in the life and sensitivity of the tube.

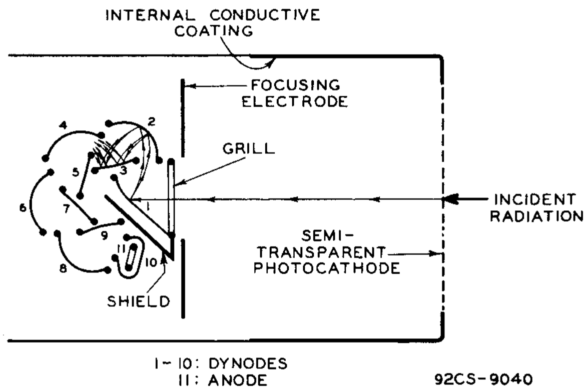


Fig.3 - Schematic Arrangement of Type 6903 Structure.

The *base pins* of the 6903 fit the medium diheptal 14-contact socket. The socket should be made of high-grade, low-leakage material, and should be installed so that the incident radiation falls on the face end of the tube.

In general, the *operating voltages* for the 6903 are as follows. The cathode-to-dynode-No.1 potential is about twice the potential applied between the successive dynodes. The steps for the successive stages are generally chosen as 75 to 125 volts. The voltage between dynode No.10 and anode should be kept as low as will permit operation with anode-current saturation. Referring to the anode characteristic curves, shown in Fig.4, it will be seen that saturation occurs in the approximate range of 50 to 100 volts. Low operating voltage between dynode No.10 and anode reduces the dark current. To obtain the indicated operating voltage between dynode No.10 and anode, it will be necessary to increase the supply voltage between these electrodes above the operating voltage by an amount to allow for the signal-output voltage desired.

In applications where it is desired to keep the statistical fluctuations to a minimum, e.g., as in nuclear radiation spectroscopy, the potential between cathode and dynode No.1 may be increased to the rated maximum value of 300 volts.

The *focusing-electrode potential* may be adjusted between that of the photocathode and that of dynode No.1 to optimize the magnitude, uniformity, or speed of the response. When the focusing electrode is operated at dynode-No.1 potential, the smallest possible spread in transit time of the photoelectrons as well as good

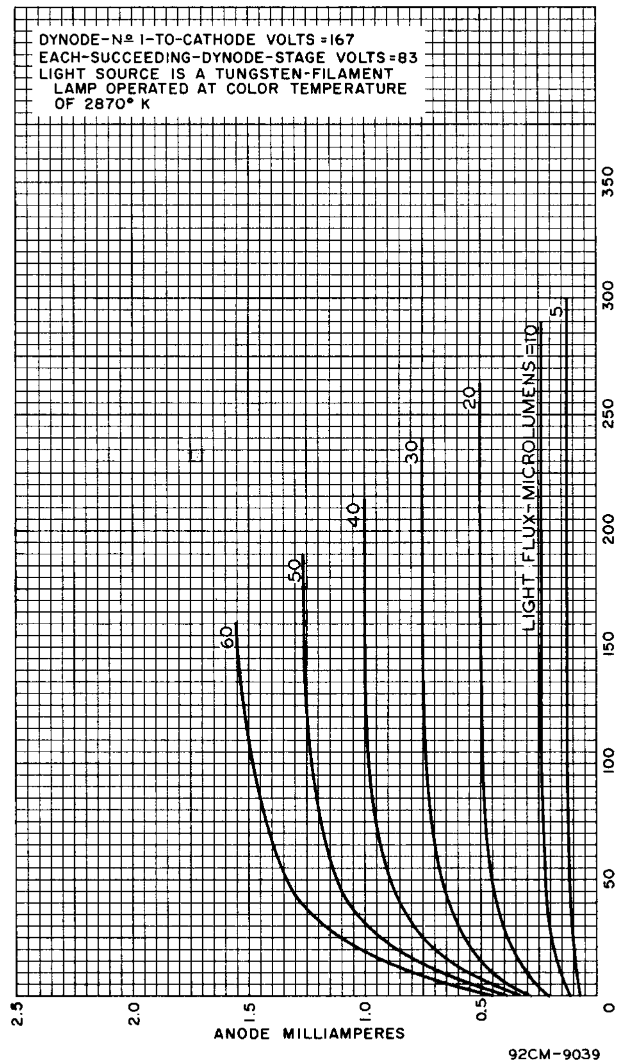


Fig.4 - Average Anode Characteristics of Type 6903.

uniformity of response over the entire cathode area is obtained. As the potential of the focusing electrode is decreased toward that of the cathode, all other electrode potentials remaining constant, it will be noticed that the anode current generally passes through a maximum which occurs when the value of focusing-electrode potential is 10 to 60 per cent of that between cathode and dynode No.1. Operation with the focusing electrode at a potential near that of the cathode is characterized by optimum signal magnitude with some increase in transit-time spread and some decrease in uniformity of response over the cathode area. Such operation may offer an advantage in some applications where the increased number of collected photoelectrons is the primary consideration.

diation on the cathode can not be detected. Dark current may be kept at a minimum by storing tubes in light-proof containers.

When the application utilizes *continuous luminous excitation and dc anode current* and it is desired to have a high ratio of signal output to dark current, it is recommended that the oper-

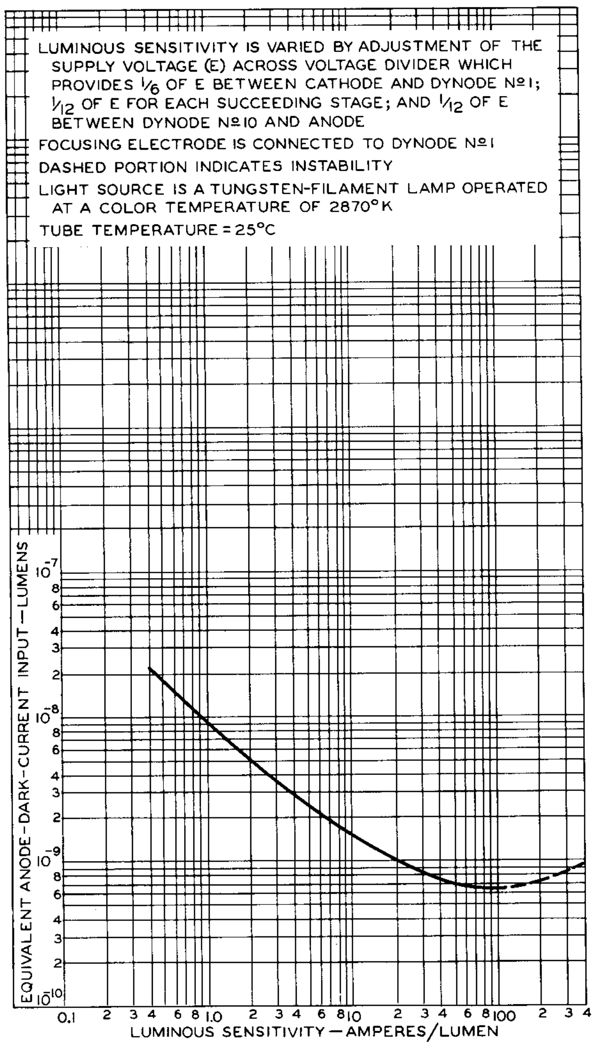


Fig.5 - Typical Anode-Dark-Current Characteristic for Type 6903.

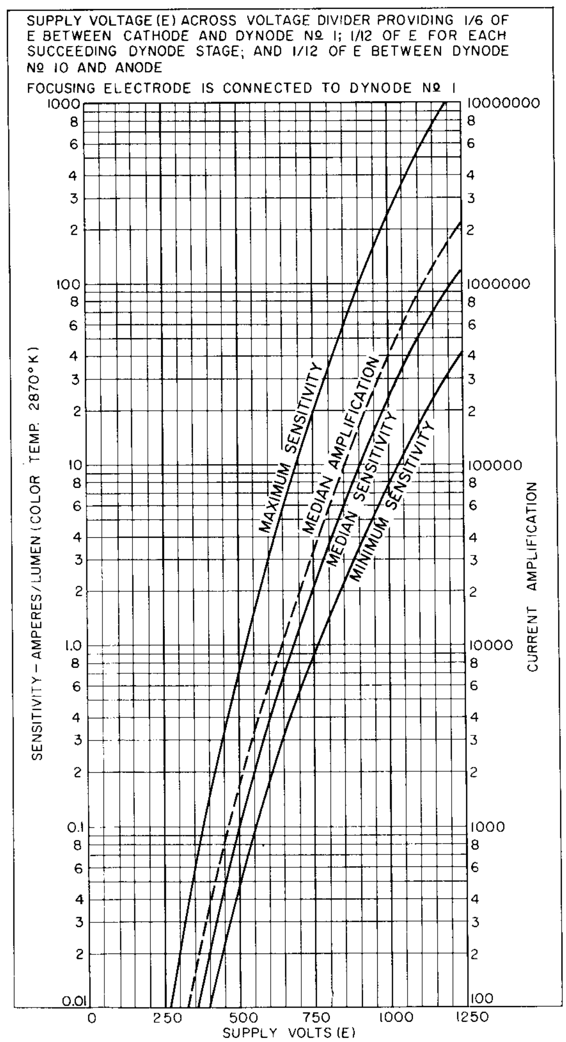


Fig.6 - Characteristics of Type 6903.

A very small *dark current* is observed when voltage is applied to the electrodes of the 6903 in complete darkness. This current has a component caused by leakage, and a component consisting of pulses produced by electrons thermionically released from the cathode, by secondary electrons released by ionic bombardment of the dynodes or cathode, or by cold emission from the electrodes. The magnitude of the dark current establishes a limit below which the exciting ra-

ating supply voltage (E) be determined with reference to the curve in Fig.5 which shows the equivalent anode-dark-current input as a function of luminous sensitivity for the 6903, and the curves in Fig.6 which show luminous sensitivity as a function of the supply voltage. The voltage between dynode No.10 and the anode should be kept as low as will permit operation at a point just giving anode-current saturation. This point on the anode characteristic curves, shown in Fig.4, occurs in the approximate range of 50 to 100 volts.

In applications involving *pulsed excitation and ac coupling at the anode*, the best signal-to-noise ratio is obtained with a supply voltage (E) in the range from 750 to 1000 volts. Within this range, the noise at the anode is produced primarily by the statistical release of thermal electrons, and the noise power spectrum is essentially flat up to about 50 megacycles per second. At voltages above 1000 volts, regenerative phenomena usually contribute to the noise.

The noise spectrum of the 6903 is such that the threshold of pulse detection depends on the associated circuitry. The bandpass filter should be designed to pass only the frequency range of the exciting signal in order to eliminate as much noise as possible.

In either dc or ac applications where maximum gain with unusually low dark current is required, the *use of a refrigerant*, such as dry ice or liquid air, to cool the bulb of the 6903 is recommended. The refrigerant reduces the thermionic emission, and thereby lowers the detection threshold to give improved operation. The curve in

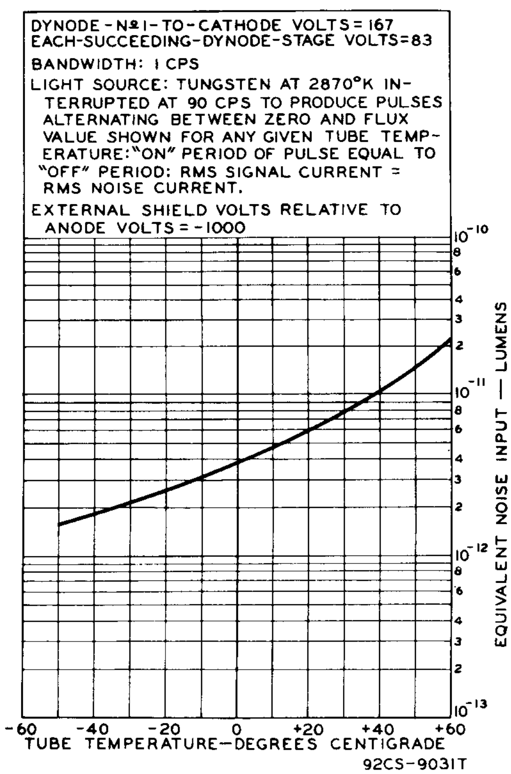


Fig.7 - Equivalent Noise-Input Characteristic of Type 6903.

Fig.7 shows the equivalent noise input as a function of the temperature of the 6903.

Exposing the 6903 to strong ultraviolet radiation may cause an increase in anode dark current. After cessation of such irradiation, dark current drops rapidly.

The *operating stability* of the 6903 is dependent on the magnitude of the anode current and its

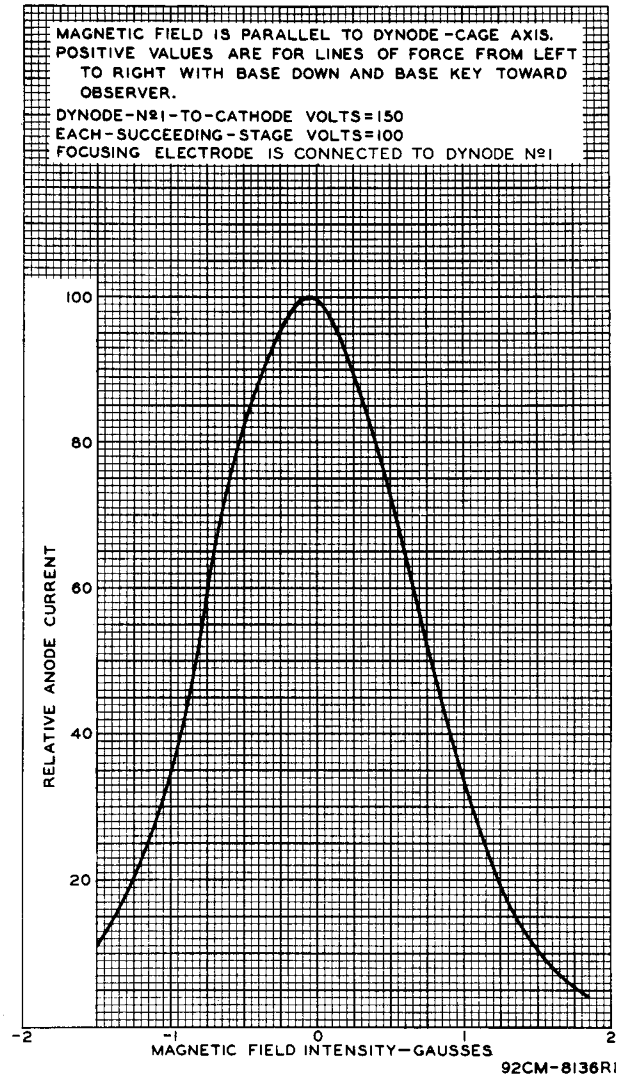


Fig.8 - Effect of Magnetic Field on Anode Current of Type 6903.

duration. When the 6903 is operated at high values of anode current, a drop in sensitivity (sometimes called fatigue) may be expected. The extent of the drop below the tabulated sensitivity values depends on the severity of the operating conditions. After a period of idleness, the 6903 usually recovers a substantial percentage of such loss in sensitivity.

The use of an average anode current well below the maximum rated value of 0.75 milliampere is recommended when stability of operation is important. When maximum stability is required, the anode current should not exceed 100 microamperes.

The *range of sensitivity* values is dependent on the respective amplification of each dynode stage. Hence large variations in sensitivity can be expected between individual tubes of a given type. The overall amplification of a multiplier phototube is equal to the average amplification per stage raised to the *n*th power, where *n* is the number of stages. Thus, very small variations in amplification per stage produce very large changes in overall tube amplification.

Because these overall changes are very large, it is advisable for designers to provide adequate adjustment of the supply voltage per stage so as to be able to adjust the amplification of individual tubes to the desired design value. The voltage-adjustment range required to take care of variations between individual tubes may be determined from Fig.6. For example, if a sensitivity of 2 amperes per lumen is desired, it will be observed that this value on the "minimum" sensitivity curve corresponds to a supply voltage of about 840 volts, and on the "maximum" sensitivity curve to a supply voltage of 570 volts. Therefore, provision should be made to adjust the supply voltage over the range from 570 to 840 volts.

Electrostatic and/or magnetic shielding of the 6903 may be necessary. The metallic coating on the inner side wall of the glass bulb acts as an electrostatic shield to prevent the coated portion of the bulb wall from charging to a positive potential. However, the uncoated area of the bulb wall tends to charge to a potential near that of the anode, especially when the 6903 is operated at voltages near the maximum, with the result that an internal discharge phenomenon may occur and cause an increase in noise. To prevent this possibility, it is suggested that a shield be closely fitted over the uncoated area and be connected as a safety precaution (see below), through a high impedance in the order of 10 megohms to a potential near that of the cathode. The shield may consist of a conductive coating painted on the clear portion of the bulb above the base, or metallic foil wrapped around the clear area.

With certain orientations of the 6903, it will be observed that the earth's magnetic field is sufficient to cause a noticeable decrease in the response of the tube. The curve in Fig.8 shows the effect on anode current of variation in magnetic-field strength under the conditions indicated. With increase in voltage above 100 volts between cathode and dynode No.1, the effect of the magnetic field will cause less decrease in anode current.

To prevent such decrease in response of the tube, magnetic shielding should be provided. When connected to cathode potential, this shielding may closely fit the bulb and serves the dual purpose of providing both magnetic and electrostatic shielding. When connected to anode potential, this shielding should be spaced at least 1/2 inch from the bulb wall to prevent the internal discharge phenomenon described above.

It is to be noted that the use of an external magnetic and/or electrostatic shield at high negative potential presents a safety hazard unless the shield is connected through a high impedance in the order of 10 megohms to the potential. If the shield is not so connected, *extreme care should be observed in providing adequate safeguards to prevent personnel from coming in contact with the high potential of the shield.*

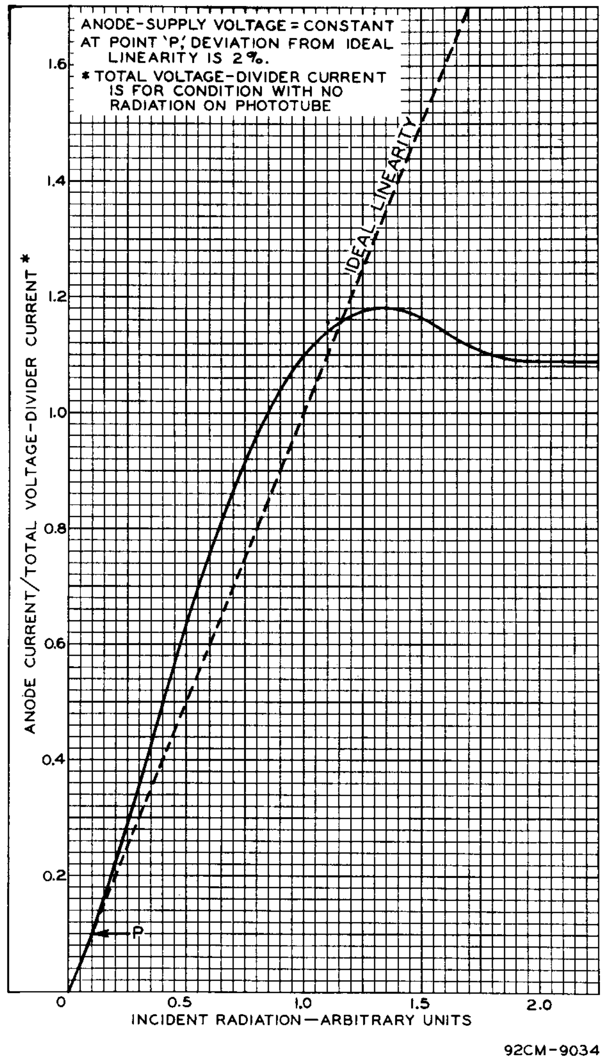
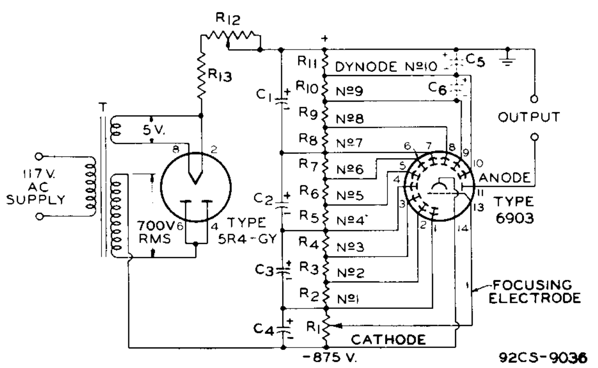


Fig.9 - Linearity Characteristic of Type 6903 as Affected by Ratio of Anode Current to Total Divider Current.

Adequate *light and ultraviolet-radiation shielding* should be provided to prevent extraneous radiation from reaching any part of the 6903. Although the metallic coating on the inner side wall of the glass bulb serves to reduce the amount of extraneous radiation reaching the electrodes, it is inadequate to shield completely the entire structure from extraneous radiation.

Whenever frequency response is important, the leads from the 6903 to the amplifier should be short so as to minimize capacitance shunting of the phototube load.

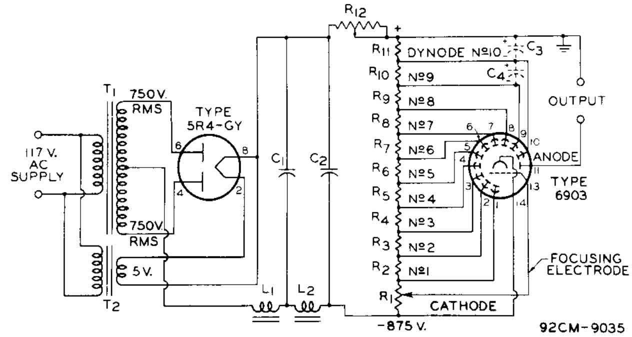
The *dc supply voltages* for the electrodes can be obtained conveniently from a high-voltage, vacuum-tube rectifier. The voltage for each dynode and for the anode can be supplied by spaced taps on a voltage divider across the rectified power supply. The current through the voltage divider will depend on the voltage regulation required by the application. In general, the current in the divider should be about 10 times the maximum value of total dynode current flowing through the divider. Such a value will prevent variations of the dynode potentials by the signal current. Because of the relatively large divider current required for good regulation, the use of a rectifier of the full-wave type is recommended. Sufficient filtering will ordinarily be provided by a well-designed, two-section filter of the capacitor-input type. A choke-input filter may be desirable for certain applications to provide better regulation. Due to critical dependence of the gain of the 6903 on voltage, rapid changes in the voltage resulting from insufficient filtering of the power supply will introduce hum modulation; and slow shifts in the line voltage due to poor regulation will cause a change in the level of the output. When the dc supply voltage is provided by means of a rectifier, satisfactory regulation can be obtained by the use of a vacuum-tube regulator circuit of the mu-bridge type.



C1 C2 C3 C4: 16 μf, electrolytic, 450 volts (dc working)
C5 C6: 8 μf, electrolytic, 150 volts (dc working)
Required only if high peak currents are drawn.
R1 R12: 100000 ohms, 2 watts, adjustable
R2 R3 R4 R5 R6 R7 R8 R9 R10: 50000 ohms, 1 watt
R11: 33000 ohms, 1 watt
R13: 100000 ohms, 2 watts
T: United Transformer Corp. No.R-2, or equivalent.

Fig. 10 - Simple Half-Wave Rectifier Power-Supply Circuit with Voltage Divider for Supplying DC Voltages to Type 6903.

The relationship between the ratio of anode current-to-voltage-divider current and incident radiation is shown in Fig.9. For operation along the *ideal linearity* curve of Fig.9, the anode current-to-voltage-divider current ratio should be less than 0.1.



C1 C2: 2 μf, 1000 volts (dc working)
C3 C4: 8 μf, electrolytic, 150 volts (dc working)
Required only if high peak currents are drawn.
L1 L2: United Transformer Corp. No.R-17, or equivalent
R1: 50000 ohms, 5 watts, adjustable (General Radio Co. Type 314-A or equivalent)
R2 R3 R4 R5 R6 R7 R8 R9 R10: 18000 ohms, 2 watts
R11: 12000 ohms, 2 watts
R12: 100000 ohms, 10 watts, adjustable (General Radio Type 471-A, or equivalent)
T1: United Transformer Corp. No.S-45, or equivalent
T2: United Transformer Corp. No.FT-6, or equivalent

Fig. 11 - Full-Wave Rectifier Power-Supply Circuit with Voltage Divider for Supplying DC Voltages to Type 6903 in Applications Critical as to Hum Modulation.

In most applications, it is recommended that the positive high-voltage terminal be grounded in order that the output signal will be produced between anode and ground. This method prevents power-supply fluctuations from being coupled directly into the signal-output circuit.

The high voltages at which the 6903 is operated are very dangerous. Care should be taken in the design of apparatus to prevent the operator from coming in contact with these high voltages. Precautions should include the enclosure of high-potential terminals and the use of interlock switches to break the primary circuit of the high-voltage power supply when access to the apparatus is required.

In the use of the 6903 as with other tubes requiring high voltages, it should always be remembered that these high voltages may appear at points in the circuit which are normally at low potential, because of defective circuit parts or incorrect circuit connections. Therefore, before any part of the circuit is touched, the power-supply switch should be turned off and both terminals of any capacitors grounded.

Typical power-supply circuits for the 6903 are shown in Figs.10 and 11. The circuit in Fig.10 utilizes a half-wave rectifier to provide the dc power for the 6903. In applications where excellent regulation particularly for wide variation in output current of the 6903 is required and where minimum hum modulation is essential, the circuit of Fig.11 may be used.

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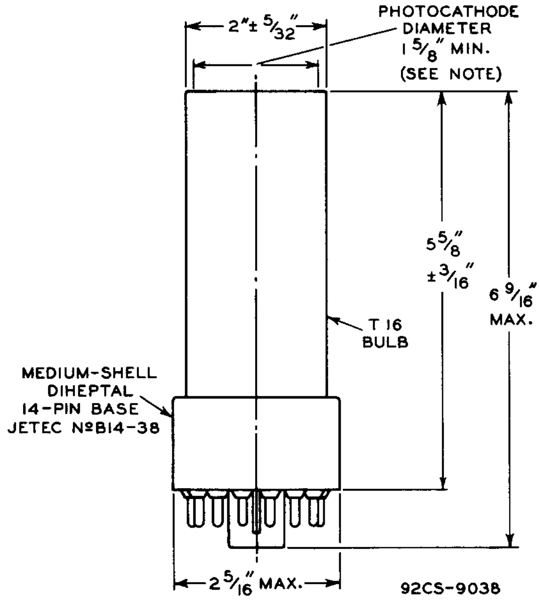
R. F. Post and N. S. Shiren, *"Performance of Pulsed Photomultiplier Scintillation Counters,"* Physical Review, Vol.78, page 81, April, 1950.

DIMENSIONAL OUTLINE

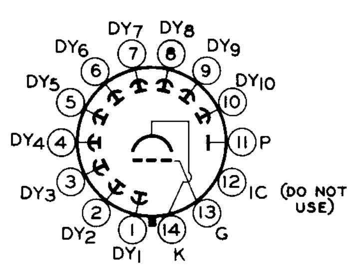


℄ OF BULB WILL NOT DEVIATE MORE THAT 3° IN ANY DIRECTION FROM THE PERPENDICULAR ERECTED AT THE CENTER OF BOTTOM OF THE BASE.

NOTE: WITHIN MINIMUM DIAMETER, DEVIATION FROM FLATNESS WILL NOT EXCEED 0.010" FROM PEAK TO VALLEY.

SOCKET CONNECTIONS
Bottom View

PIN 1: DYNODE No.1
PIN 2: DYNODE No.2
PIN 3: DYNODE No.3
PIN 4: DYNODE No.4
PIN 5: DYNODE No.5
PIN 6: DYNODE No.6
PIN 7: DYNODE No.7
PIN 8: DYNODE No.8



DIRECTION OF LIGHT: INTO END OF BULB

14AA

PIN 9: DYNODE No.9
PIN 10: DYNODE No.10
PIN 11: ANODE
PIN 12: INTERNAL CONNECTION—DO NOT USE
PIN 13: FOCUSING ELECTRODE
PIN 14: CATHODE