from RTMA release #378D, Aug. 31, 1950

1P28

MULTIPLIER PHOTOTUBE

9-Stage Type with S-5 Response

RCA-1P28 is a high-vacuum, multiplier phototube constructed with a special glass bulb which transmits radiant energy in the ultraviolet region down to about 2000 angstroms. It is especially suited for scientific research and specialized applications involving very low ultraviolet radiation levels because it features a combination of high photosensitivity, high secondary-emission amplification, very small dc dark current, and an ultraviolet equivalent noise input of 6×10^{-15} watt at 25°C.

The spectral response of the 1P28 covers the range from about 2000 to 6000 angstroms, as shown in Fig. 1. Maximum response occurs at approximately 3400 angstroms.

The 1P28 is capable of multiplying feeble photoelectric current produced at the cathode by an average value of 1,000,000 times when operated at 100 volts per stage. The output current of the 1P28 is a linear function of the exciting energy under normal operating conditions.

The frequency response of the 1P28 is flat up to a frequency of about 100 megacycles per second above which the variation in electron transit time becomes the limiting factor.

Having small size, rugged construction, high sensitivity, extremely low equivalent noise input, and freedom from distortion, the 1P28 is recommended for use in spectrophotometry, in scintillation counters, in scientific research, and in other specialized applications.

DATA

General:

Spectral Response		S-5
Wavelength of Maximum Response	3400 ± 500	angstroms
Cathode:		
Minimum Projected Length*		15/16"
Minimum Projected Width*		5/16"
Direct Interelectrode Capacitances (Approx.):		
Anode to Dynode No.9	4	μμf
Anode to All Other Electrodes	6.5	μμf
Maximum Overall Length		3-11/16"
Maximum Seated Length		3-1/8"
Length from Base Seat to Center of Useful Cathode Area		1-15/16" ± 3/32"
Maximum Diameter		1-5/16"
Bulb		T-9
Base		Small-Shell Submagnal 11-Pin, Non-hygroscopic
Mounting Position		Any

Maximum Ratings, ***Absolute Values:***

ANODE-SUPPLY VOLTAGE (DC or Peak AC)□	1250 max.	volts
SUPPLY VOLTAGE BETWEEN DYNODE No.9 AND ANODE (DC or Peak AC)	250 max.	volts
PEAK ANODE CURRENT	5 max.	ma
AVERAGE ANODE CURRENT○	0.5 max.	ma
AMBIENT TEMPERATURE	75 max.	°C

Characteristics:

With 100 volts per dynode stage and 100 volts between dynode No.9 and anode

	Min.	*Av.*	*Max.*	
DC Anode Dark Current#●	–	–	0.1	μamp
Sensitivity:				
At 3400 angstroms	–	22600	–	μamp/μwatt
Luminous:				
Cathode§	–	20	–	μamp/lumen
Anode▲:				
At 0 cps	4.5	20	300	amp/lumen
At 100 Mc.	–	19	–	amp/lumen
Current Amplification■	–	1000000	–	
Luminous Equivalent Noise Input★	–	7×10^{-12}	–	lumen
Ultraviolet Equivalent Noise Input †	–	6×10^{-15}	–	watt

With 75 volts per dynode stage and 50 volts between dynode No.9 and anode

	Av.	
Sensitivity:		
At 3400 angstroms	3400	μamp/μwatt
Luminous:		
Cathode§	20	μamp/lumen
Anode▲, at 0 cps	3	amp/lumen
Current Amplification■	150000	

---

* On plane perpendicular to the indicated direction of incident radiation.

□ Referred to cathode.

○ Averaged over any interval of 30 seconds maximum.

\# Dark current due to thermionic emission and ion feedback may be reduced by the use of refrigerants.

● For maximum signal-to-noise ratio, operation below 1000 volts is recommended.

§ For conditions the same as shown under Anode Luminous Sensitivity except that the value of light flux is 0.01 lumen and that 100 volts are applied between cathode and all other electrodes connected together as an anode.

▲ For conditions where a tungsten lamp operated at a filament color temperature of 2870°K is used as a light source. A light flux of 10 microlumens from a rectangular aperture approximately 0.8" long and 0.2" wide is projected normal to the center of the cathode. The load resistor has a value of 0.01 megohm. The applied voltages are as indicated.

■ Ratio of anode sensitivity to cathode sensitivity.

★ Defined as the value where the rms output current is equal to the rms noise current determined under the following conditions: 100 volts per dynode stage, 25°C tube temperature, ac-amplifier bandwidth of 1 cycle per second, tungsten light source 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.

† Defined the same as Luminous Equivalent Noise Input except that use is made of a monochromatic source having radiation at 2537 angstroms.

GENERAL CONSIDERATIONS

An *electron multiplier* is a vacuum tube which utilizes the phenomenon of secondary emission to amplify signals composed of electron streams. In the 1P28 multiplier phototube, represented in

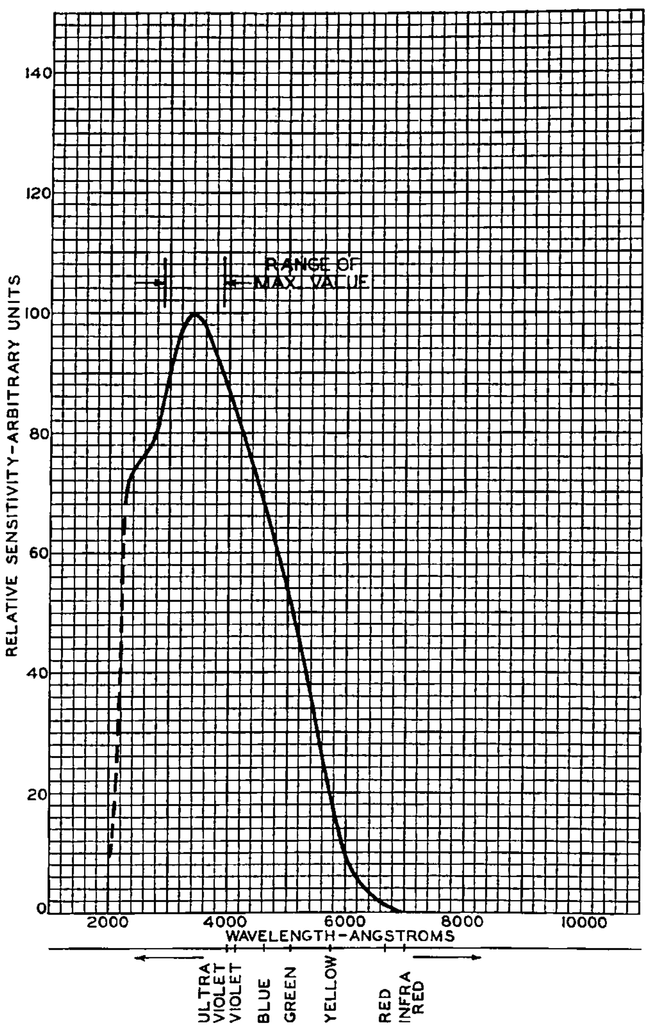


Fig. 1 - Spectral Sensitivity Characteristic of Type 1P28 which has S-5 Response. Curve is taken for Equal Values of Radiant Flux at all Wavelengths.

Fig. 2, the electrons emitted from the illuminated 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.9) are collected by the anode and constitute the current utilized in the output circuit.

Dynode No.9 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 grid which allows the electrons from dynode No.8 to pass through it to dynode No.9. Spacing between dynode No.9 and anode creates a collecting field such that all the electrons it emits 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 1P28 can be coupled to any practical load impedance.

The shield which extends between the photocathode and the anode shields the photocathode from the anode and prevents ion feedback. If positive ions produced in the high-current region near the anode were allowed to reach the photocathode or the initial dynode stages, they would cause the emission of spurious electrons which after multiplication would produce undesirable and often uncontrollable regeneration.

The grill through which the incident radiation reaches the photocathode, is connected to the photocathode and serves as an electrostatic shield for the open side of the electrode structure.

The successive stages of the 1P28 are operated at voltages increasing in equal steps from the photocathode to the 9th dynode, and are generally chosen as 75 to 90 volts per stage. The voltage between dynode No.9 and the anode should be kept as low as will permit of operation at a point just giving anode-current saturation. This point on the anode characteristic curves corresponds to a voltage of about 50 volts. Low operating voltage between dynode No.9 and anode reduces the dark current due to leakage paths and also reduces the ion bombardment of the dynodes. As a result, the operating stability of the 1P28 is improved without sacrifice in sensitivity. It is to be noted that the supply voltage required to give an operating voltage of 50 volts between dynode No.9 and anode will, of course, be contingent on the load impedance used and the signal output voltage desired.

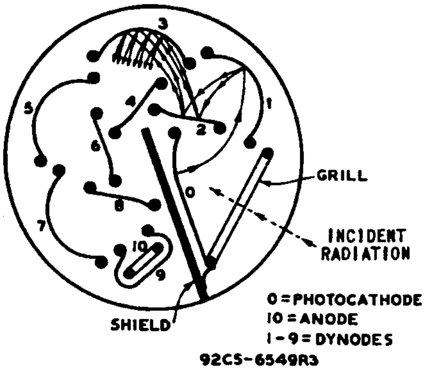


Fig. 2 - Schematic Arrangement of Type 1P28 Structure.

INSTALLATION and APPLICATION

The *maximum ratings* shown in the tabulated data are limiting values above which the serviceability of the IP28 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.

The *operating stability* of the IP28 is dependent on the magnitude of the anode current and its duration. When the IP28 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 IP28 usually recovers a substantial percentage of such loss in sensitivity.

The use of an average anode current well below the maximum rated value of 0.5 milliampere is recommended when stability of operation is important. When maximum stability is required, the anode current should not exceed 10 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. It is suggested that an overall voltage-adjustment range of 2 to 1 be provided. When the output current can be controlled by change in the radiant energy incident on the photocathode of the multiplier phototube, the required range of adjustment in the voltage per stage can be reduced.

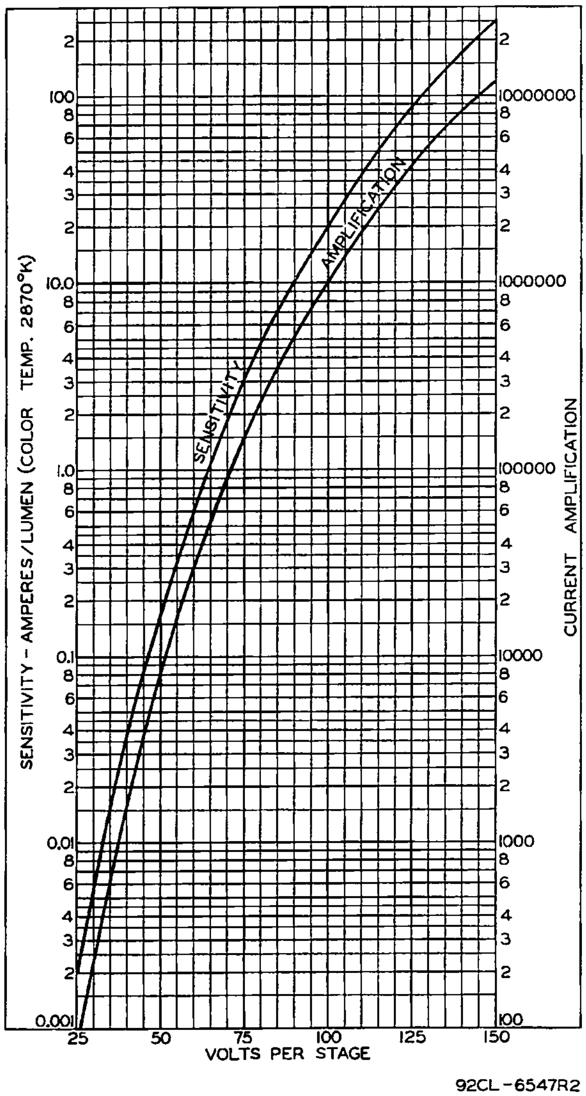


Fig. 3 - Average Characteristics of Type 1P28.

Fig. 3 shows sensitivity and current amplification versus the dc voltage per stage.

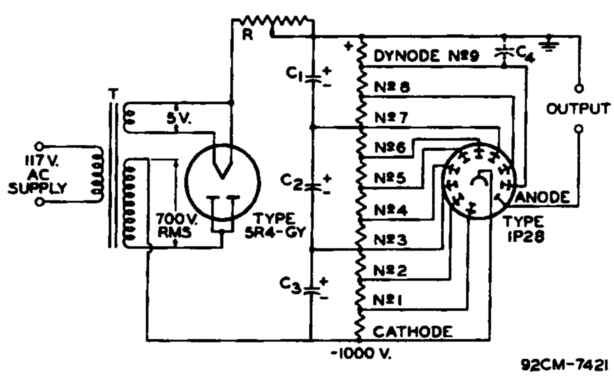
The *base pins* of the IP28 fit the submagnal II-contact socket designed for a pin-circle diameter of 0.75 inch. The socket should be made of high-grade, low-leakage material, and should be installed so that the base key of the tube faces the incident radiation.

Magnetic shielding of the 1P28 is necessary if it is operated in the presence of strong magnetic fields.

Adequate *light shielding* should be provided to prevent extraneous light from reaching any part of the 1P28.

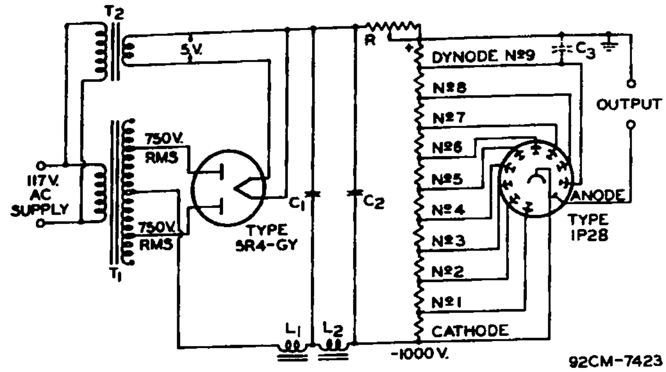
Whenever frequency response is important, the leads from the 1P28 to the amplifier should be short so as to minimize capacitance shunting of the phototube load.

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 equally 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 several times the value of the total average dynode current flowing through the divider. The value should be adequate to prevent variations of the dynode potentials by the signal currents. 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. Inasmuch as the gain of the 1P28 is critically dependent 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 produced by 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: 16 µf, 450 volts (dc working), electrolytic
C4: 8 µf, 150 volts (dc working), electrolytic.
Required only if high peak currents are drawn.
R: 100000 ohms, 1 watt, variable (Centralab A122, or equivalent)
T: United Transformer Corp. No.R-2, or equivalent
VOLTAGE DIVIDER: 10 Resistors, each 50000 ohms, 1/2 watt

Fig. 4 - Simple Half-Wave Rectifier Power-Supply Circuit with Voltage Divider for Supplying DC Voltages to Type 1P28.



C1 C2: 2 µf, 1000 volts (dc working)
C3: 8 µf, 150 volts (dc working), electrolytic
Required only if high peak currents are drawn.
L1 L2: United Transformer Corp. No.R-17, or equivalent
R: 200000 ohms, 12 watts, variable (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
VOLTAGE DIVIDER: 10 Resistors, each 20000 ohms, 1 watt

Fig. 5 - Full-Wave Rectifier Power-Supply Circuit with Voltage Divider for Supplying DC Voltages to Type 1P28 in Applications Critical as to Hum Modulation.

In most applications, it is recommended that the positive high-voltage terminal be grounded rather than the negative terminal. With this method, which places the cathode at a high negative potential with respect to ground, the dangerous voltages can more easily be made inaccessible.

The high voltages at which the 1P28 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 1P28, 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 to incorrect circuit connections. Therefore, before any part of the circuit is touched, the power supply switch should be turned off, the plug removed from the outlet, and both terminals of any capacitors grounded. Also, the use of a protective resistor having a minimum value of 10,000 ohms in the output circuit is recommended as a desirable procedure to prevent possible damage to component parts during adjustment.

Typical power-supply circuits for the 1P28 are shown in Figs. 4 and 5. The circuit in Fig. 4 utilizes a half-wave rectifier to provide the dc power for the 1P28. In applications where excellent regulation particularly for wide variation in the output current of the 1P28 is required and where minimum hum modulation is essential, the circuit in Fig. 5 may be used.

The *anode family* for the 1P28 is shown in Fig. 6.

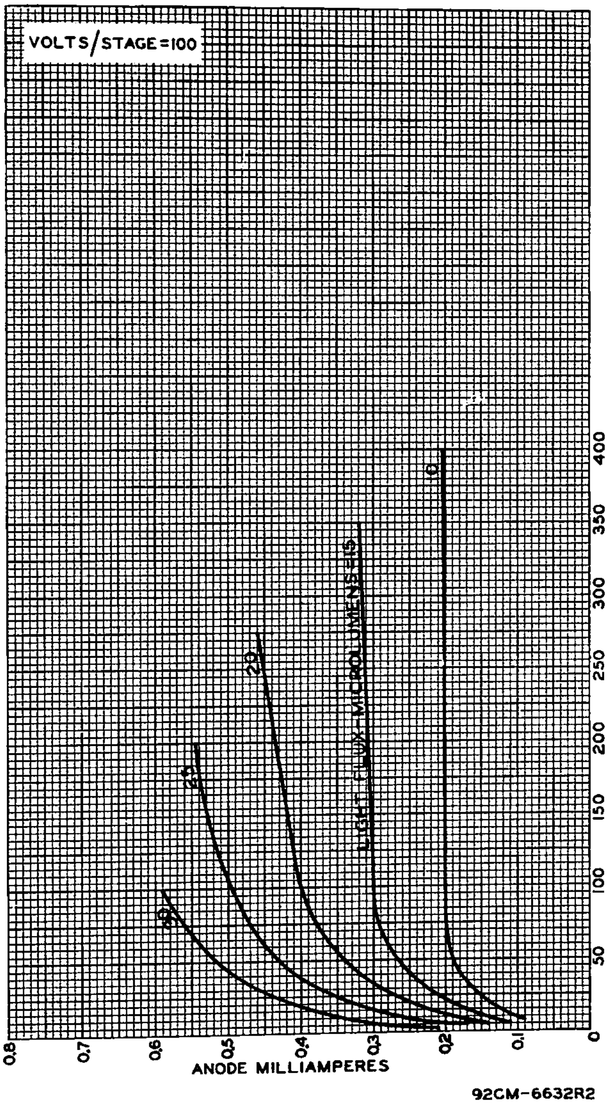


Fig. 6 - Average Anode Characteristics of Type 1P28.

The *use of a refrigerant*, such as dry ice or liquid air, to cool the 1P28 is recommended in those applications where maximum gain with unusually low dark current is required.

An *external electrostatic shield* in contact with the sides of the glass envelope and connected to a negative dc potential essentially the same as that of the photocathode, should be employed in those applications where it is desired to reduce the luminous equivalent noise input of the 1P28 to a minimum. Since the shield is at a dangerous potential, extreme care should be exercised to provide adequate protection for the operator, as described under *high voltages*.

The *luminous equivalent noise input as a function of the temperature* of the 1P28 is shown in Fig. 7.

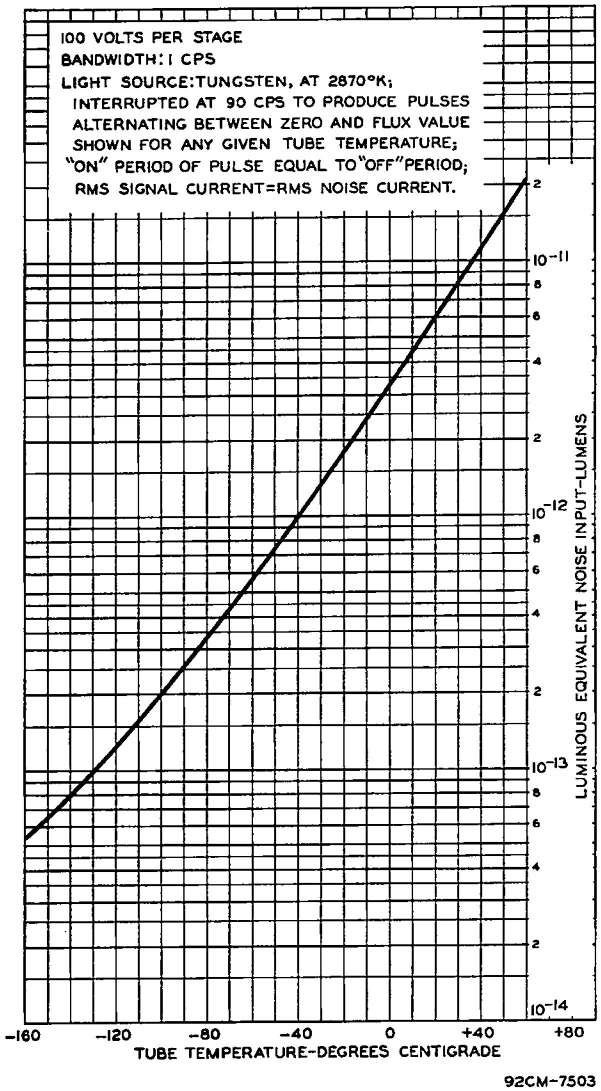


Fig. 7 - Equivalent Noise Input Characteristic of Type 1P28.

REFERENCES

E. A. Boettner and G. P. Brewington, *"The Application of Multiplier Photo-Tubes to Quantitative Spectrochemical Analysis"*, Journal of the Optical Society of America, Vol. 34, pp. 6-11, January, 1944.

G. H. Dieke and H. M. Crosswhite, *"Direct Intensity Measurement of Spectrum Lines with Photo-Multiplier Tubes"*, Journal of the Optical Society of America, Vol. 35, pp. 471-480, July, 1945.

M. F. Hasler and H. W. Dietert, *"Direct Reading Instrument for Spectrochemical Analysis"*, Journal of the Optical Society of America, Vol.34, pp. 751-758, December, 1944.

R. B. Janes and A. M. Glover, *"Recent Developments in Photo-Tubes"*, RCA Review, Vol.6, No.1, pp. 43-54, July, 1941.

D. H. Rank, R. J. Pfister, and H. H. Grimm, *"A Method for Determining Depolarization Factors in Raman Spectra"*, Journal of the Optical Society of America, Vol. 33, pp. 31-35, January, 1943.

G. A. Morton and K. W. Robinson, *"A Coincidence Scintillation Counter"*, Nucleonics, Vol. 4, No.2, pp. 25-29, February, 1949.

F. V. Hunt and R. W. Hickman, *"On Electronic Voltage Stabilizers"*, Review of Scientific Instruments, Vol. 10, pp. 6-21, January, 1939.

J. W. Coltman, *"The Scintillation Counter"*, Proc. of the Institute of Radio Engineers, Vol. 37, No.6, pp. 671-682, June, 1949.

W. H. Jordan and P. R. Bell, *"Scintillation Counters"*, Nucleonics, Vol. 5, No.4, October, 1949.

H. H. Goldsmith, *"Bibliography on Radiation Detection"*, Nucleonics, Vol. 4, No.5, May, 1949.

M. Deutsch, *"Naphthalene Counters for Beta and Gamma Rays"*, Nucleonics, Vol. 2, No.3, March, 1948.

Ralph W. Engstrom, *"Multiplier Phototube Characteristics; Application to Low Light Levels"*, Journal of the Optical Society of America, Vol.37, pp. 420-431, June, 1947.

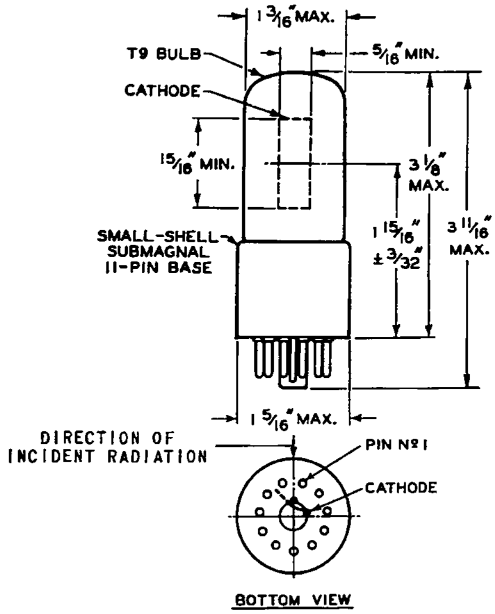
J. S. Allen, *"Recent Applications of Electron Multiplier Tubes"*, Proc. of the Institute of Radio Engineers, Vol. 38, No.4, pp.346-358, April, 1950.

L. Dunkelman and C. Lock, *"Ultraviolet Spectral Sensitivity Characteristics of Photomultipliers Having Quartz and Glass Envelopes"*, Journal of the Optical Society of America, Vol. 40, No.4, p. 264 (Abstract), April, 1950.

Robert Hofstadter, *"The Detection of Gamma Rays with Thallium-Activated Sodium-Iodide Crystals"*, Physical Review, Vol. 75, No.5, pp. 796-810, March, 1949.

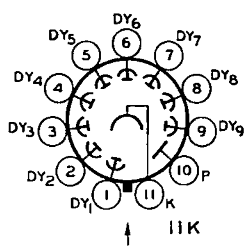
"Properties of Scintillation Materials", Nucleonics, Vol. 6, No.5, pp. 70-72, May, 1950.

DIMENSIONAL OUTLINE



₵ OF BULB WILL NOT DEVIATE MORE THAN 2° IN ANY DIRECTION FROM THE PERPENDICULAR ERECTED AT CENTER OF BOTTOM OF BASE.

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
PIN 9: DYNODE NO.9
PIN 10: ANODE
PIN 11: CATHODE