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Photomultiplier Tube Socket Assemblies

Hamamatsu provides a wide variety of socket assemblies specifically designed for simple and reliable operation of photomultiplier tubes (often abbreviated as PMTs). These socket assemblies consist primarily of a high quality socket and voltage divider circuit integrated into a compact case. Variant types are available with internal current-to-voltage conversion amplifiers, gate circuits and high voltage power supply circuits.

Types of Socket Assemblies

The circuit elements used in Hamamatsu socket assemblies are represented by the three letters below. The socket assembly types are grouped according to the combination of these letters.

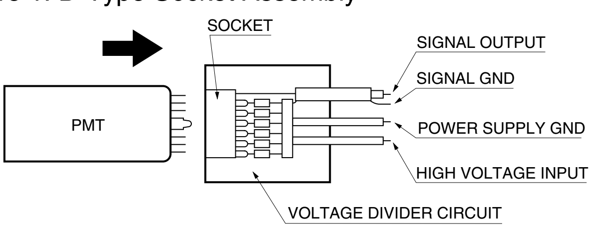
D : Voltage Divider
A : Amplifier
P : High Voltage Power Supply

D-Type Socket Assemblies (E717, E990 Series, etc.)

The D-type socket assemblies contain a voltage divider circuit along with a socket in a compact metallic or plastic case. Plastic case types are potted with silicone compound to ensure high environmental resistance.

Refer to page 88 for the selection guide to D-type socket assemblies.

Figure 1: D-Type Socket Assembly



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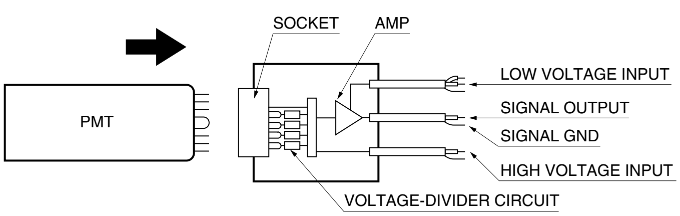
DA-Type Socket Assemblies (C7246, C7247 Series)

In addition to the circuit elements of the D-type socket assemblies, the DA-type socket assemblies include an amplifier that converts the low-level, high-impedance current output of a photomultiplier tube into a low-impedance voltage output. Possible problems from noise induction are eliminated since the high-impedance output of the photomultiplier tube is connected to the amplifier at the minimum distance.

Figure 2: DA-Type Socket Assembly



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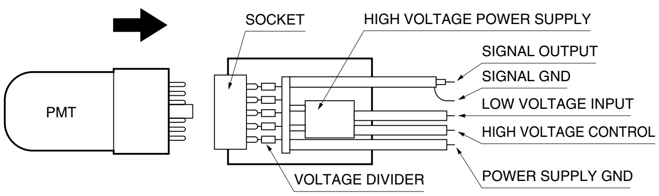
DP-Type Socket Assemblies (C6270, C8991, etc.)

DP-type socket assemblies comprise a built-in high-voltage power supply circuit added to a D-type socket assembly.

Figure 3: DP-Type Socket Assembly



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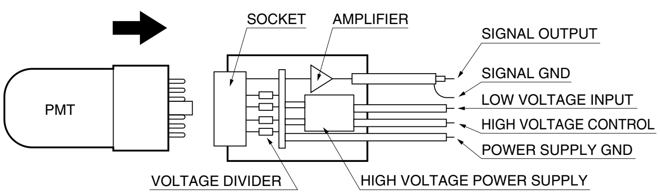
DAP-Type Socket Assemblies (C6271, C7950, C7950-01)

This type of socket assembly has a current-to-voltage conversion amplifier and a high voltage power supply, efficiently added to the circuit components of the D-type socket assembly.

Figure 4: DAP-Type Socket Assembly



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Basics of Voltage Dividers

The following information describes voltage divider circuits which are basic to all types of socket assemblies. Refer to this section for information on proper use of the socket assemblies.

Voltage Divider Circuits

To operate a photomultiplier tube, a high voltage of 500 volts to 2000 volts is usually supplied between the photocathode (K) and the anode (P), with a proper voltage gradient set up along the photoelectron focusing electrode (F) or grid (G), secondary electron multiplier electrodes or dynodes (Dy) and, depending on photomultiplier tube type, an accelerating electrode (Acc). Figure 5 shows a schematic representation of photomultiplier tube operation using independent multiple power supplies, but this is not a practical method. Instead, a voltage divider circuit is commonly used to divide, by means of resistors, a high voltage supplied from a single power supply.

Figure 5: Schematic Representation of Photomultiplier Tube Operation

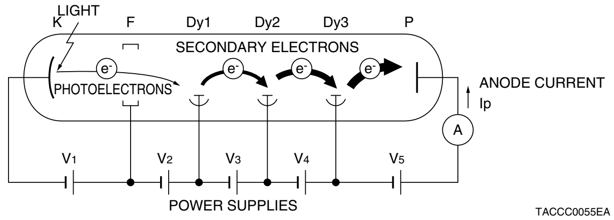
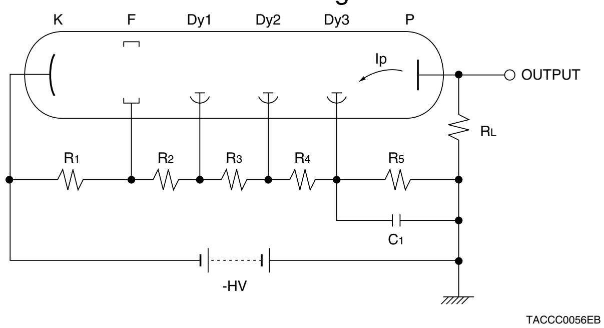


Figure 6 shows a typical voltage divider circuit using resistors, with the anode side grounded. The capacitor C_1 connected in parallel to the resistor R_5 in the circuit is called a storage capacitor and improves the output linearity when the photomultiplier tube is used in pulse operation, and not necessarily used in providing DC output. In some applications, transistors or Zener diodes may be used in place of these resistors.

Figure 6: Anode Grounded Voltage Divider Circuit

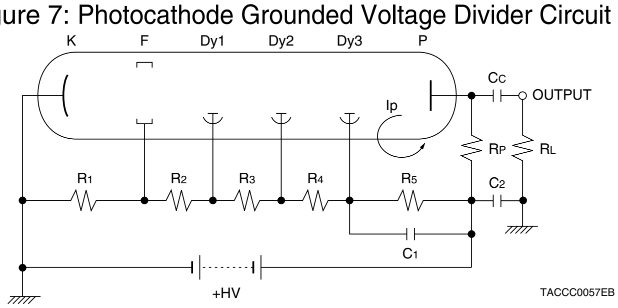


Anode Grounding and Photocathode Grounding

In order to eliminate the potential difference between the photomultiplier tube anode and external circuits such as an ammeter, and to facilitate the connection, the generally used technique for voltage divider circuits is to ground the anode and supply a high negative voltage (-HV) to the photocathode, as shown in Figure 6. This scheme provides the signal output in both DC and pulse operations, and is therefore used in a wide range of applications.

In photon counting and scintillation counting applications, however, the photomultiplier tube is often operated with the photocathode grounded and a high positive voltage (+HV) supplied to the anode mainly for purposes of noise reduction. This photocathode grounding scheme is shown in Figure 7, along with the coupling capacitor Cc for isolating the high voltage from the output circuit. Accordingly, this setup cannot provide a DC signal output and is only used in pulse output applications. The resistor R_P is used to give a proper potential to the anode. The resistor R_L is placed as a load resistor, but the actual load resistance will be the combination of R_P and R_L.

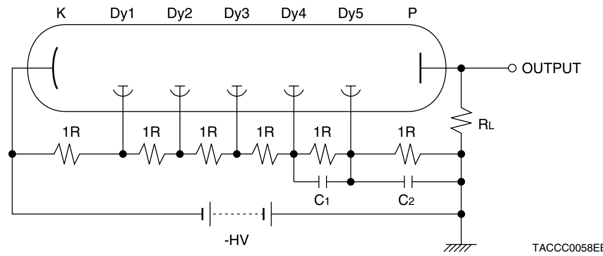
Figure 7: Photocathode Grounded Voltage Divider Circuit



Standard Voltage Divider Circuits

Basically, the voltage divider circuits of socket assemblies listed in this catalog are designed for standard voltage distribution ratios which are suited for constant light measurement. Socket assemblies for side-on photomultiplier tubes in particular mostly use a voltage divider circuit with equal interstage voltages allowing high gain.

Figure 8: Equally Divided Voltage Divider Circuit



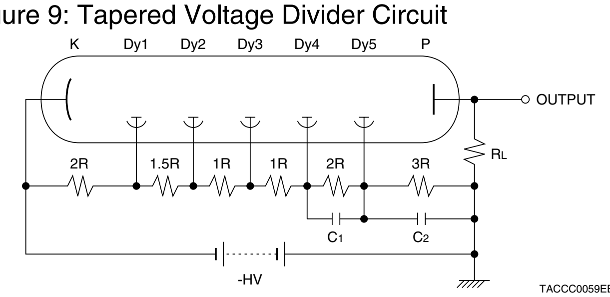
Tapered Voltage Divider Circuits

In most pulsed light measurement applications, it is often necessary to enhance the voltage gradient at the first and/or last few stages of the voltage divider circuit, by using larger resistances as shown in Figure 9. This is called a tapered voltage divider circuit and is effective in improving various characteristics. However it should be noted that the overall gain decreases as the voltage gradient becomes greater. In addition, care is required regarding the interstage voltage tolerance of the photomultiplier tube as higher voltage is supplied. The tapered voltage circuit types and their suitable applications are listed below.

Tapered circuit at the first few stages (resistance: large → small)
- Photon counting (improvement in pulse height distribution)
- Low-light-level detection (S/N ratio enhancement)
- High-speed pulsed light detection (improvement in timing properties)
- Other applications requiring better magnetic characteristics and uniformity

Tapered circuit at the last few stages (resistance: small → large)
- High pulsed light detection (improvement in output linearity)
- High-speed pulsed light detection (improvement in timing properties)
- Other applications requiring high output across the load resistor

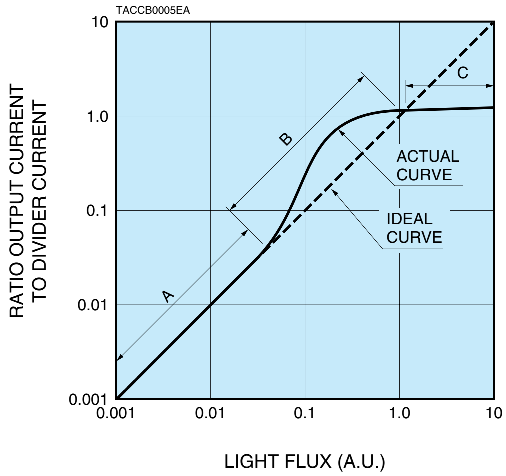
Figure 9: Tapered Voltage Divider Circuit



Voltage Divider Circuit and Photomultiplier Tube Output Linearity

In both DC and pulse operations, when the light incident on the photocathode increases to a certain level, the relationship between the incident light level and the output current begins to deviate from the ideal linearity. As can be seen from Figure 10, region A maintains good linearity, and region B is the so-called overlinearity range in which the output increase is larger than the ideal level. In region C, the output goes into saturation and becomes smaller than the ideal level. When accurate measurement with good linearity is essential, the maximum output current must be within region A. In contrast, the lower limit of the output current is determined by the dark current and noise of the photomultiplier tube as well as the leakage current and noise of the external circuit.

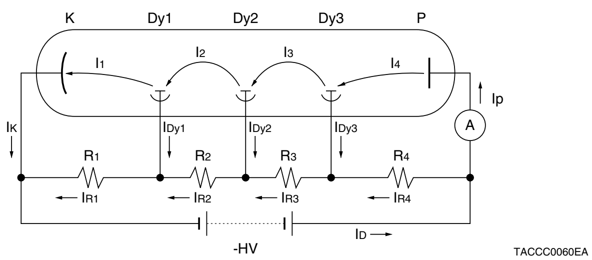
Figure 10: Output Linearity of Photomultiplier Tube



Output Linearity in DC Mode

Figure 11 is a simplified representation showing photomultiplier tube operation in the DC output mode, with three stages of dynodes and four dividing resistors R_1 through R_4 having the same resistance value.

Figure 11: Basic Operation of Photomultiplier Tube and Voltage Divider Circuit



[When light is not incident on the tube]

In dark state operation where a high voltage is supplied to a photomultiplier tube without incident light, the current components flowing through the voltage divider circuit will be similar to those shown in Figure 12 (if we ignore the photomultiplier tube dark current). The relation of current and voltage through each component is given below

Interelectrode current of photomultiplier tube

$$I_1=I_2=I_3=I_4 \ (= 0\ A)$$

Electrode current of photomultiplier tube

$$I_K=I_{Dy1}=I_{Dy2}=I_{Dy3}=I_P \ (= 0\ A)$$

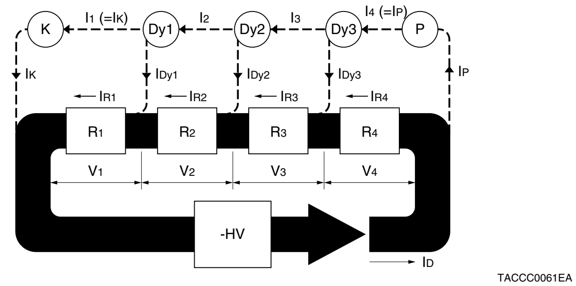
Voltage divider circuit current

$$I_{R1}=I_{R2}=I_{R3}=I_{R4}=I_D= (HV/\sum_{n=1}^{4} R_n)$$

Voltage divider circuit voltage

$$V_1=V_2=V_3=V_4=I_D \bullet R_n \ (= HV/4)$$

Figure 12: Operation without Light Input



[When light is incident on the tube]

When light is allowed to strike the photomultiplier tube under the conditions in Figure 12, the resulting currents can be considered to flow through the photomultiplier tube and the voltage divider circuit as schematically illustrated in Figure 13. Here, all symbols used to represent the current and voltage are expressed with a prime ('), to distinguish them from those in dark state operation.

The voltage divider circuit current I_D' is the sum of the voltage divider circuit current I_D in dark state operation and the current flowing through the photomultiplier tube ΔI_D (equal to average interelectrode current). The current flowing through each dividing resistor Rn becomes as follows:

$$I_{Rn}' = I_D' - I_n'$$

Where In' is the interelectrode current which has the following relation:

$$I_1' < I_2' < I_3' < I_4'$$

Thus, the interstage voltage V_n' ($=I_{Rn}' \bullet R_n$) becomes smaller at the latter stages, as follows:

$$V_1' > V_2' > V_3' > V_4'$$

Figure 13: Operation with Light Input

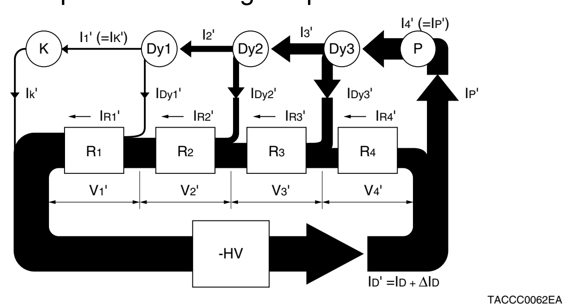
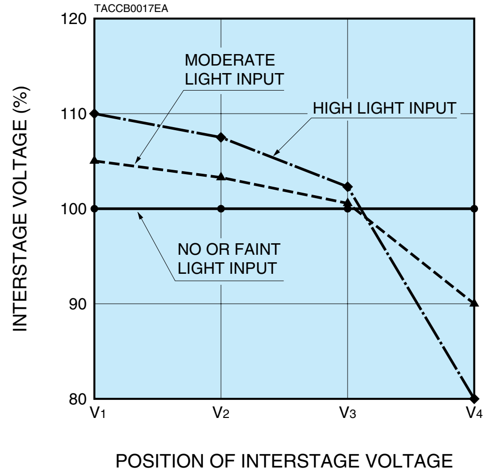


Figure 14 shows changes in the interstage voltages as the incident light level varies. The interstage voltage V_4' with light input drops significantly compared to V_4 in dark state operation. This voltage loss is redistributed to the other stages, resulting an increases in V_1', V_2' and V_3' which are higher than those in dark state operation. The interstage voltage V_4' is only required to collect the secondary electrons emitted from the last dynode to the anode, so it has little effect on the anode current even if dropped to 20 or 30 volts. In contrast, the increases in V_1', V_2' and V_3' directly raise the secondary emission ratios (δ_1, δ_2 and δ_3) at the dynodes Dy1, Dy2 and Dy3, and thus boost the overall gain m ($= \delta_1 \bullet \delta_2 \bullet \delta_3$). This is the cause of overlinearity in region B in Figure 10. As the incident light level further increases so that V4' approaches 0 volts, output saturation occurs in region C.

Figure 14: Changes in Interstage Voltages at Different Incident Light Levels



Linearity Improvement in DC Output Mode

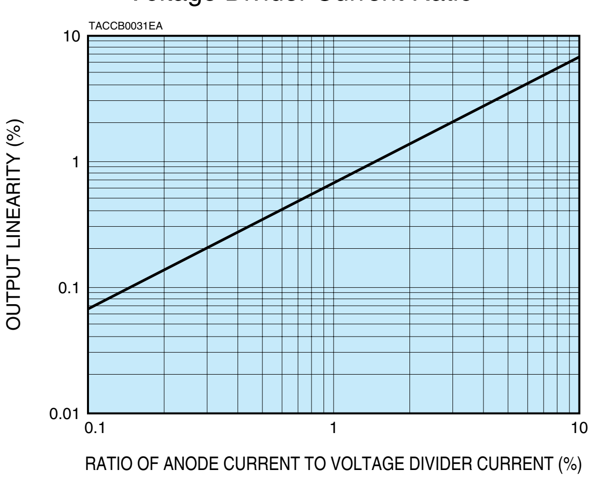
To improve the linearity in DC output mode, it is important to minimize the changes in the interstage voltage when photocurrent flows through the photomultiplier tube. There are several specific methods for improving the linearity, as discussed below.

①Increasing the voltage divider current

Figure 15 shows the relationship between the output linearity of a 28 mm (1-1/8") diameter side-on photomultiplier tube and the ratio of anode current to voltage divider current. For example, to obtain an output linearity of 1 %, it can be seen from the figure that the anode current should be set approximately 1.4 % of the divider circuit current. However, this is a calculated plot, so actual data may differ from tube to tube even for the same type of photomultiplier tube, depending on the supply voltage and individual dynode gains. To ensure high photometric accuracy, it is recommended that the voltage divider current be maintained at least twice the value obtained from this figure.

The maximum linear output in DC mode listed for the D-type socket assemblies in this catalog indicates the anode current equal to 1/20 of the voltage divider current. The output linearity at this point can be maintained within ±3 % to ±5 %.

Figure 15: Output Linearity vs. Anode Current to Voltage Divider Current Ratio

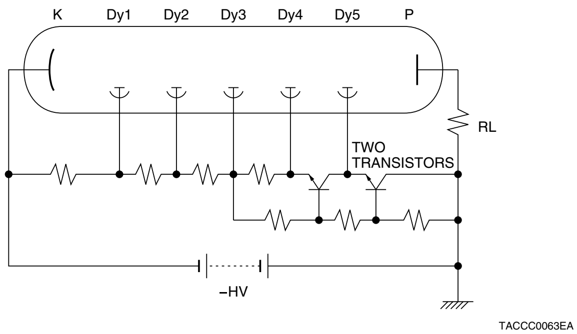


As stated above, good output linearity can be obtained simply by increasing the voltage divider current. However, this is accompanied by heat emanating from the voltage divider. If this heat is conducted to the photomultiplier tube, it may cause problems such as an increase in the dark current, and variation in the output.

②Using the active voltage divider circuit

Use of a voltage divider circuit having transistors in place of the dividing resistors in last few stages (for example, Hamamatsu E6270 series using FETs) is effective in improving the output linearity. This type of voltage divider circuit ensures good linearity up to an output current equal to 60 % to 70 % of the voltage divider current, since the interstage voltage is not affected by the interelectrode current inside the photomultiplier tube. A typical active voltage divider circuit is shown in Figure 16.

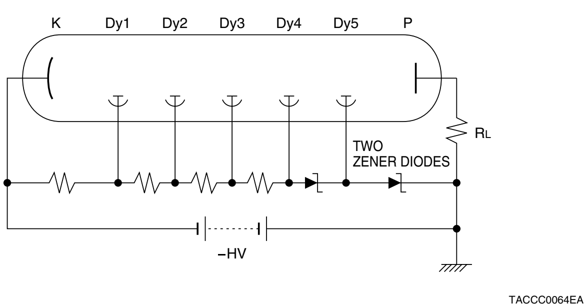
Figure 16: Active Voltage Divider Circuit



③Using Zener Diodes

The output linearity can be improved by using Zener diodes in place of the dividing resistors in the last few stages, because the Zener diodes serve to maintain the interstage voltages at a constant level. However, if the supply voltage is greatly varied, the voltage distribution may be imbalanced compared to other interstage voltages, thus limiting the adjustable range of the voltage with this technique. In addition, if the supply voltage is reduced or if the current flowing through the Zener diodes becomes insufficient due to an increase in the anode current, noise may be generated from the Zener diodes. Precautions should be taken when using this type of voltage divider circuit. Figure 17 shows a typical voltage divider circuit using Zener diodes.

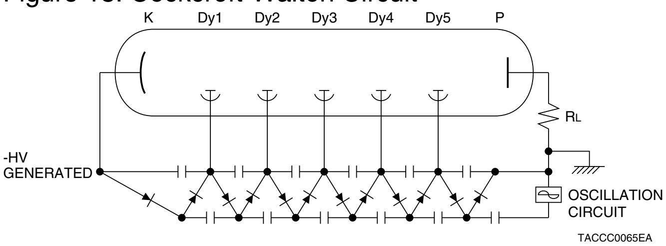
Figure 17: Voltage Divider Circuit Using Zener Diodes



④Using Cockcroft-Walton Circuit

When a Cockcroft-Walton circuit as shown in Figure 18 is used to operate a 28 mm (1-1/8") diameter side-on photomultiplier tube with a supply voltage of 1000 volts, good DC linearity can be obtained up to 200 µA and even higher. Since a high voltage is generated by supplying a low voltage to the oscillator circuit, there is no need for using a high voltage power supply.
This Cockcroft-Walton circuit achieves superior DC output linearity as well as low current consumption.

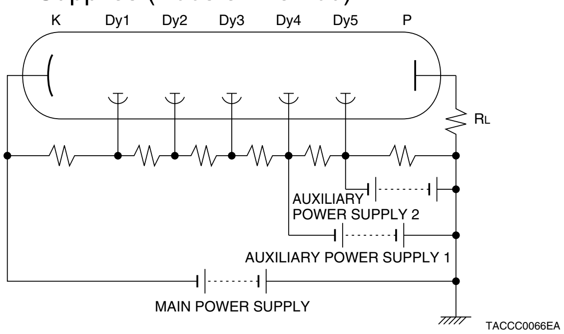
Figure 18: Cockcroft-Walton Circuit



⑤Using multiple high voltage power supplies

As shown in Figure 19, this technique uses multiple power supplies to directly supply voltages to the last few stages near the anode. This is sometimes called the booster method, and is used for high pulse and high count rate applications in high energy physics experiments.

Figure 19: Voltage Divider Circuit Using Multiple Power Supplies (Booster Method)



Output Linearity in Pulsed Mode

In applications such as scintillation counting where the incident light is in the form of pulses, individual pulses may range from a few to over 100 milliamperes even though the average anode current is small at low count rates. In this pulsed output mode, the peak current in extreme cases may reach a level hundreds of times higher than the voltage divider current. If this happens, it is not possible to supply interelectrode currents from the voltage divider circuit to the last few stages of the photomultiplier tube, thus leading to degradation in the output linearity.

Improving Linearity in Pulsed Output Mode

①Using storage capacitors

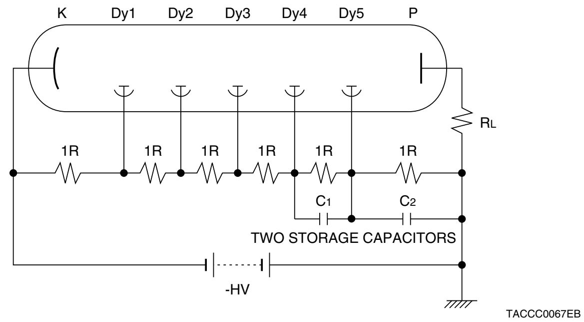
Using multiple power supplies mentioned above is not popular in view of the cost. The most commonly used technique is to supply the interelectrode current by using storage capacitors as shown in Figure 20. There are two methods for connecting these storage capacitors: the serial method and the parallel method. As Figures 20 and 21 show, the serial method is more widely used since it requires lower tolerance voltages of the capacitors. The capacitance value C (farads) of the storage capacitor between the last dynode and the anode should be at least 100 times the output charge as follows:

$$C > 100 \cdot Q/V$$

where Q is the charge of one output pulse (coulombs) and V is the voltage (volts) across the last dynode and the anode.

Since this method directly supplies the pulse current with electrical charges from the capacitors, if the count rate is increased and the resulting duty factor becomes larger, the electrical charge will be insufficient. Therefore, in order to maintain good linearity, the capacitance value obtained from the above equation must be increased according to the duty factor, so that the voltage divider current is kept at least 50 times larger than the average anode current just as with the DC output mode.
The active voltage divider circuit and the booster method using multiple power supplies discussed previously, provide superior pulse output linearity even at a higher duty factor.

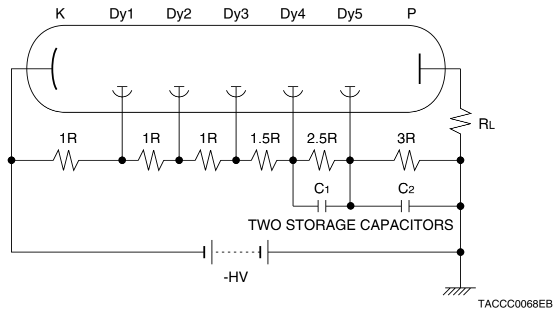
Figure 20: Equally Divided Voltage Divider Circuit and Storage Capacitors



②Using tapered voltage divider circuit with storage capacitors

Use of the above voltage divider circuit having storage capacitors is effective in improving pulse linearity. However, when the pulse current increases further, the electron density also increases, particularly in last stages. This may cause a space charge effect which prevents interelectrode current from flowing adequately and leading to output saturation. A commonly used technique for extracting a higher pulse current is the tapered voltage divider circuit in which the voltage distribution ratios in the latter stages are enhanced as shown in Figure 21. Care should be taken in this case regarding loss of the gain and the breakdown voltages between electrodes.
Since use of a tapered voltage divider circuit allows an increase in the voltage between the last dynode and the anode, it is possible to raise the voltage across the load resistor when it is connected to the anode. It should be noted however, that if the output voltage becomes excessively high, the voltage between the last dynode and the anode may drop, causing a degradation in output linearity.

Figure 21: Tapered Voltage Divider Circuit Using Storage Capacitors



D-Type Socket Assemblies

The D-type socket assemblies are grouped as follows:

(a) For DC output (-HV supply)
Available only upon request

(b) For DC or pulsed output (-HV supply)
ex. E717-63

(c) For pulsed output (+HV supply)
ex. E990-08

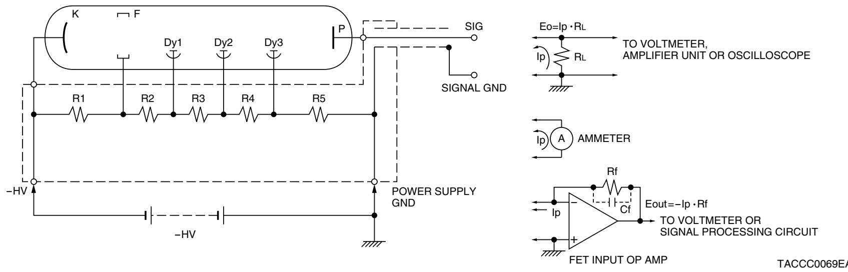
(d) For DC or pulsed output (-HV supply), or pulsed output (+HV supply)
ex. E717-74

Connection of D-Type Socket Assemblies to External Circuits

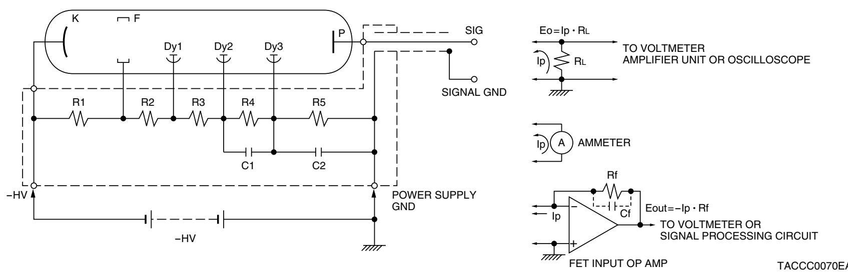
Figure 22 shows typical examples of connecting various D-type socket assemblies to external circuits.

Figure 22: Connection of D-Type Socket Assemblies to Extrernal Circuits

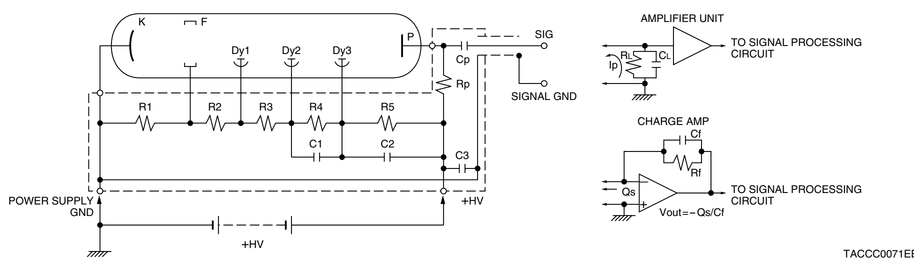
(a) For DC output (-HV supply)



(b) For DC or pulsed output (-HV supply)



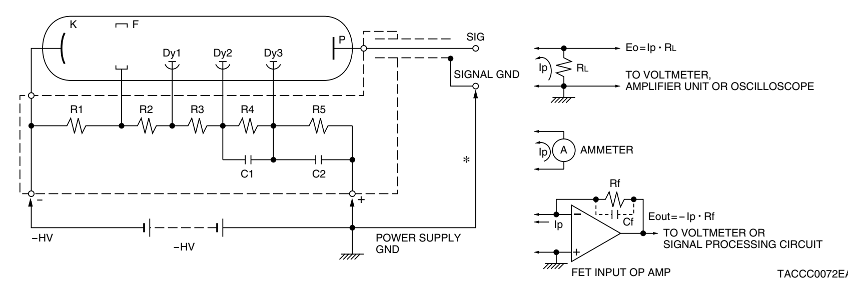
(c) For pulsed output (+HV supply)



(d) For DC or pulsed output (-HV supply), or pulsed output (+HV supply)

d-1. For DC or pulsed output (-HV supply)

* GND should be connected externaly.



d-2. For pulsed output/+HV supply

For general scintillation counting and photon counting applications, recommended values for C_P and R_P are 0.001 µF to 0.005 µF and 10 kΩ to 1 MΩ. Since a high voltage is supplied to these parts, care must be taken when handling this circuit.

* GND and C_B should be connected externally.