# Introduction

Bases, Voltage Dividers, and Preamplifiers Accessories for Scintillation Detectors

Voltage dividers and voltage divider/preamplifiers allow you to supply the proper operating high voltage distribution to the photomultiplier tubes (PMTs) and to get the signal from them to your system electronics. These devices can be plugged onto or hard-wired to PMTs.

Voltage dividers used by Saint-Gobain Crystals are resistive (or transistorized) devices specially designed to accelerate electrons from the cathode to the anode of a phototube. Or, to say this in another way, a resistive voltage divider is a chain of resistors linked end to end (in series). One end of the chain or string of resistors is attached to a voltage source and the other end attached to the voltage source return (ground) so that a complete circuit or loop is formed. The connection points between resistors in the string are attached to the elements of a phototube to cause electrons to be accelerated from the cathode to the anode.

Model P-1410

Model PA-1410 with 10' supplied cable with multi-pin connector

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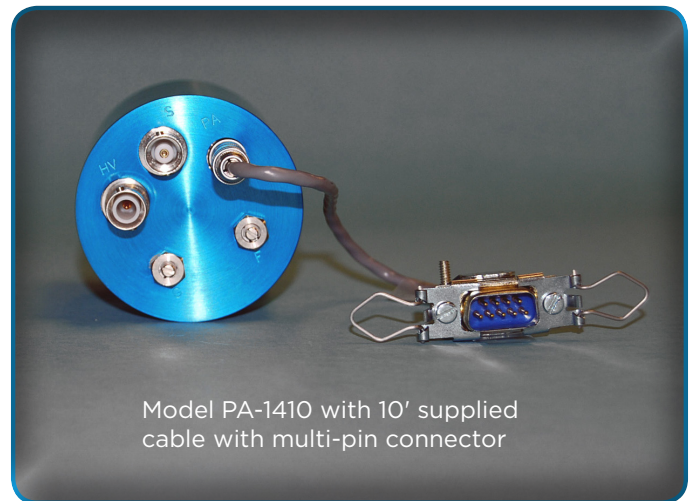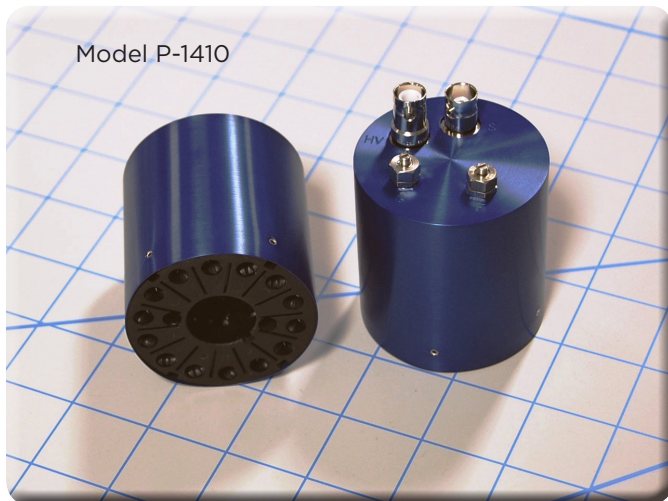
Voltage Divider Design Considerations

In order for electrons to be accelerated through a phototube, each element must be more positive in voltage than the element that immediately precedes it. See Figure 1 for a typical resistive voltage divider and phototube circuit.
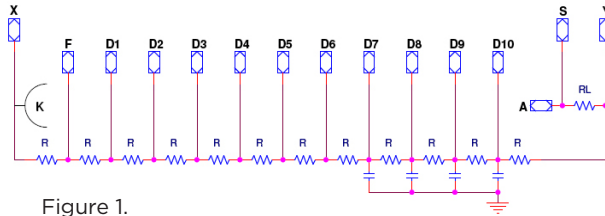

Figure 1.

The circuit in Figure 1 is typical for either a positive or negative high voltage system. Note that in this circuit there are points at the ends of the string labeled X and Y and S. Connections to these three labeled points make the phototube operate at positive or negative high voltage with direct or capacitive coupling to the preamp. We will review operation at positive high voltage first and then go on to negative high voltage. To use positive high voltage with a gain adjustment potentiometer, make connections to points X, Y and S as shown in Figure 2.
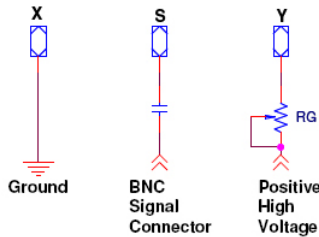

Figure 2. Connections to points X, Y and S of Figure 1 for operation with positive HV

As an example, we will now go through this positive high voltage circuit (Figure 1 and Figure 2) to show the following:

A. The voltage becomes more positive as we move from K to F to D_1 ... to A.
B. The approximate range of gain adjustment made possible by the use of R_G .
C. The change in voltage at the BNC signal connector when ^{137}Cs gamma ray is detected.
D. The reason for the capacitors on D9 and D10.
E. An average phototube current and the voltage divider current.

First, we assign some reasonable values to the various circuit elements.

Let :

H.V.	=	+1200 volts
R_G	=	1.2 M
R	=	0.1 M
R_L	=	0.1 M
C	=	0.01 µF
C_C	=	0.001 µF

A. The voltage becomes more positive as we move from K to F to D_1 to A.
If the wiper of R_G is set to point Y, then 1200 volts is applied between points Y and X. This 1200 volts is applied across 12R; therefore, each R drops 100 volts. Starting with the cathode at ground or 0, F is at 100 volts. D1 is 200 volts, D2 at 300 volts, etc. Each element is 100 volts more positive than the preceding element.

To help in looking at some of the other characteristics of this positive divider string, an equivalent circuit combining Figures 1 and 2 is shown in Figure 3.
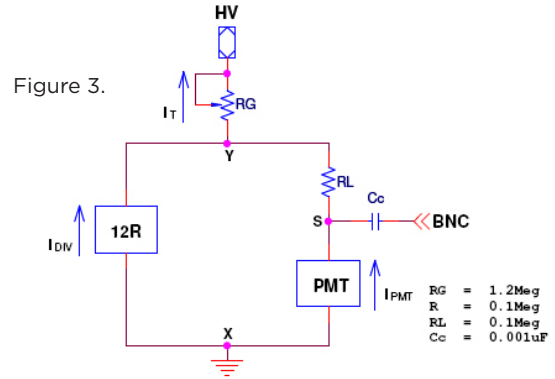

Figure 3.

B. The approximate range of gain adjustment made possible by the use of R_G. If we assume that the resistance of the phototube is much greater than 12R, then the resistance of the parallel current paths shown by I_{PMT}* and I_{DIV} is approximately equal to 12R. The applied HV is then dropped across the series combination of R_G plus 12R and I_{DIV} is equal to I_T. A simple ratio can be derived to show how much of the applied HV can be dropped across R_G. For every change of 100 volts across the phototube (volts dropped across R_G), the gain changes by approximately a factor of 2. We can calculate the range of gain adjustment made possible by the use of R_G. The voltage dropped across the gain pot is equal to the applied high voltage times the resistance of the gain pot divided by the voltage divider resistance plus the gain pot resistance.

$$V(\text{gain pot}) = V(\text{applied}) \ \times \ \frac{R_{\text{Gain Pot}}}{R_{\text{Divider}} + R_{\text{Gain Pot}}}$$

In the example:

$$V(\text{gain pot}) = 1200 \ \times \ \frac{1.2}{1.2 + 1.2} \ = \ 600 \text{ volts}$$

The gain pot in this circuit can change the phototube gain by a factor of approximately 64. This large gain adjustment range may be desirable when trying to match the gain for a group of phototubes, but it is not a good design practice. As a rule, the gain pot resistance should be less than or equal to one half the voltage divider resistance. Look at the values used in the SG standard P-1410:

Gain Pot Resistance = 1 Mohms

Voltage Divider Resistance = 4.3 Mohms

$V(\text{gain pot}) = 1000 \ \times \ \dfrac{1}{5.3} \ = \ 188.7$ volts

Using our standard P-1410, the phototube gain can be changed by a factor of approximately 3.77. Notice the range of gain adjustment changes as the applied voltage changes.

The initial assumption that the resistance of the phototube is much, much greater than 12R, can be checked as follows:

$$R_{PMT} = \frac{V(\text{Applied})}{I(\text{Dark Current})} = \frac{1200}{1 \times 10^{-9}} = 1.2 \times 10^{12} \text{ ohms}$$

and 1.2×10^{12} ohms is much, much greater than 12R(C1.2 Mohms).

* Current here is defined to be the flow of electrons.
 This is contrary to the normal definition of current.

Voltage Divider Design Considerations

C. The change in voltage at point S when ^{137}Cs gamma ray is detected.

When no signal is present, the voltage at point S (the anode) is equal to the applied high voltage minus the voltage across the gain pot. The coupling capacitor keeps this voltage from being present on the BNC signal connector. The voltage change at point S caused by the total absorption of a ^{137}Cs gamma photon can be calculated as follows.

For a photomultiplier tube, a typical bialkali photocathode generates about 8 photoelectrons per keV of nuclear photon energy deposited when coupled to a good quality NaI(Tl) scintillator.

Therefore, the total charge at the PMT anode corresponding to a ^{137}Cs gamma photon is calculated by the following formula:

$$Q = N \times E \times G \times Ce$$

where
N = Number of photoelectrons/keV: 8
E = Energy of Gamma Photon: 662 keV for ^{137}Cs
G = Photomultiplier Gain: 5 X 10^5 typical
Ce = Charge per electron: 1.6×10^{-19} coulomb

therefore
$Q = 8 \times 662 \times (5 \times 10^5) \times (1.6 \times 10^{-19}) = 4.24 \times 10^{-10}$ C

This is the total charge transferred from the PMT anode to the load. To calculate the anode current per pulse, the value of charge needs to be divided by the time interval. Since the natural decay time constant of NaI(Tl) is 250nsec, the anode current per pulse (I_a) is:

$I_a = Q/T = 4.24 \times 10^{-10} / 250 \times 10^{-9} = 1.7mA$

Case 1.

If the anode is connected through the coupling capacitor to a transmission line terminated in 50 ohms, then the voltage developed across this 50 ohm load is given by:

$$V_{out} = I \times R = (1.7 \times 10^{-3}) \times 50 = 85mV$$

Case 2.

If the output signal is connected to the input of a charge sensitive preamplifier through a coupling capacitor, the equivalent circuit is shown in Figure 4. (Note that R1 and C1 correspond to RL and Cc in Figures 1, 2 and 3.)
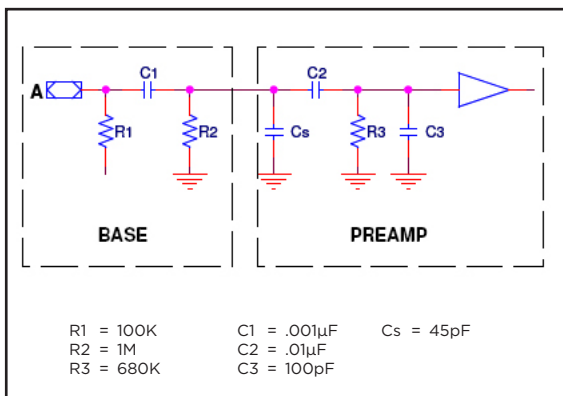

Figure 4.

The charge developed at the phototube anode will be integrated on C3 and CS provided that the coupling capacitors C1 and C2 are much larger than C3 and CS. In this case, the peak voltage developed at the preamp input will be:

$$V = \frac{Q}{C} = \frac{4.24 \times 10^{-10}}{1.45 \times 10^{-10}} = 2.92V$$

where C is the parallel combination of C3 and CS.

This voltage will decay with a time constant of:

$$T = CR = (1.45 \times 10^{-10})(8 \times 10^4) = 12 \ \mu sec$$

where R is the parallel combination of R1, R2 and R3.

Note 1:

The general purpose main amplifiers designed for nuclear instruments include pulse shaping and pole-zero correction functions. Typically, these functions require a minimum of 50μsec input pulse decay time constant.

In Case 2 of the above example, the pulse decay time constant is 12μsec which is too short for the input requirements of a main amplifier. As a result, the pole-zero function will not be effective. To correct this situation, the decay time constant of the output pulse in Case 2 should be increased to a minimum of 50μsec. One simple way to achieve this is to increase the values of R1 and R2. If we choose to use 2.2 Mohm for both R1 and R2, the net effective resistance would be the parallel combination of R1, R2 and R3 which is 420 kohm and the value of the time constant would be:

$$T = (145 \times 10^{-12}) (420 \times 10^{-3}) = 61\mu sec$$

This value is well within the range of the pole-zero correction function of the main amplifier.

Note 2.

The count rate capability of the divider/preamp combination is affected by the selection of the pulse decay time constant which is a function of the anode load resistor values. Additionally, the gain pot setting will affect the decay time constant in systems which are designed with a gain pot.

Note 3.

The coupling capacitor (C1) in this voltage divider is not very large compared to the preamp input capacitance. This coupling capacitor will charge to a significant fraction of the input charge and will reduce the signal amplitude available at the preamp input. A suitable value for the coupling capacitor would be 0.01μF.

Note 4.

The amplitude of the output pulse in the above example is dependent on the PMT anode load. A phototube can be made to deliver output pulses of amplitude equal to the voltage difference between the last dynode and the anode.

Voltage Divider Design Considerations

D. The reason for the capacitors to ground on Dynodes 9 and 10.

In Figure 1, bypass capacitors are used between D9 and D10 to ground. (For high rate applications, other dynodes may be bypassed also, i.g., D7 and D8 in Figure 1.) In our application, a pulse of light generated in the NaI(Tl) crystal strikes the photocathode and causes a pulse of photoelectrons to be emitted. This electron pulse is amplified as it travels through the dynode structure and will reach a very high peak value at the last few dynodes. The peak pulse current will be much greater than the voltage divider current and must, therefore, be provided by a secondary current source. The bypass capacitors are the secondary current source. If the capacitors were eliminated from the circuit, the last few dynodes would have to draw from the voltage divider current, causing a change in the interdynode voltages, which causes the tube gain to shift. In the majority of divider circuits used, the divider current is much lower than the peak pulse current so that, without the capacitors, the tube linearity would also be affected.

In our standard voltage divider, we use .01 microfarad bypass capacitors. During the peak current pulse, these capacitors discharge through the dynode structure and anode load resistor with a time constant of one millisecond. This time constant is very large compared to the peak pulse duration, therefore, the voltage on the bypassed dynodes does not change. Good wiring practice requires that these capacitors be grounded using the shortest possible wire to the ground side of the signal connector.

E. An average phototube current and the voltage divider current.

Using the component values shown in Figure 3, a count rate of 10,000 per second for ^{137}Cs (assuming that 10,000 gamma photons are totally absorbed in NaI(Tl) per second), and an assumed phototube gain of 5×10^5, we can calculate the divider current and an average phototube anode current.

$$\text{Divider Current} = I_{DIV} = \frac{HV}{12R + R_G}$$
$$= \frac{1200}{2400000} = 5 \times 10^{-4}\ A$$
$$= 500\ mA$$

The divider current increases to 1.0 mA as the wiper of R_G is moved to point Y.

Calculation of the average phototube anode current:

The average phototube anode current is the product of the anode charge per pulse as calculated in section C and the pulse rate (which is the same as count rate).

Average Phototube current is: $I_{PMT} = Q*R$

As shown above, $Q = N \times E \times G \times Ce$

where

N = Number of photoelectrons/keV: 8
E = Energy of Gamma Photon: 662 keV for ^{137}Cs
G = Photomultiplier Gain: 5×10^5 typical
Ce = Charge per electron: 1.6×10^{-19} coulomb; and
R = Count rate: 10000 c/s

therefore,
$$I_{PMT} = 4.24 \times 10^{-10} \times 10000$$
$$= 4.24 \times 10^{-6}A = 4.24\ \mu A$$

For good phototube gain stability and linearity, the divider current should be at least 50 times the average phototube anode current. In this example,

$$\frac{I_{Div}}{I_{PMT}} = \frac{500\mu A}{4.24\mu A} = 118$$

which is a good ratio for PMT gain and linearity operation.

Important!!   Negative High Voltage

The basic voltage divider circuit of Figure 1 can be wired for negative high voltage operation by making the connections shown in Figure 5.

The coupling capacitor has been removed and an electrostatic shield in close contact with the glass bulb of the phototube has been added. Connections to points X and Y are the reverse of the positive high voltage system. The 10M resistor is simply a current limiter that is operative in the event of accidental grounding of the shield which is at cathode potential.

All of the calculations and information given previously apply equally well to a negative high voltage divider.
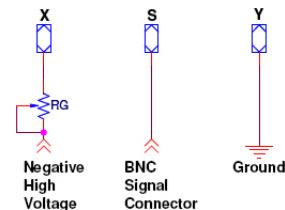
Figure 5. Connections to points X, Y and S of Figure 1 for operation with negative HV.

Fast Timing Considerations:

For fast timing applications, the R_L may be changed to 50 ohms. Some users make R_L=0. This can present a hazard to a preamplifier if it is connected when the PMT is operating and a large potential has built up on the anode. Instead of R_L=0, a large value bleeder resistor is recommended. Gauging applications do not use the 50 ohm resistor, but should use a large value bleeder resistor also.

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