TP-133

Application Note

Fast Photomultiplier Tube Techniques

by
R. E. McHose
Phototube Product Development

Operation of photomultipliers as pulse detectors offers certain advantages over DC operation. In some applications, pulses of light are the only signals available. This note describes the advantages of and techniques used in the operation of a photomultiplier **(PMT)** in a pulsed mode. Methods of evaluating pulsed performance are also given.

Advantages of Pulsed Operation

The most important advantage of operating a PMT in a pulsed mode is that much higher peak currents can **be** obtained than in the DC mode. Furthermore, gain stability of the **PMT is much** better when the pulsed light source is adjusted to yield a high peak anode current while maintaining a low average anode current. By using this technique, a peak anode current of 100 mA or more can be obtained while keeping the average current well below 100 nA. If an attempt were made to draw 100 mA DC, the PMT dynodes would be severly fatigued, resulting in permanent damage to the PMT.

Because a PMT is a current source rather than a voltage source, it can be made to work readily into a low impedance load, such as 50 ohms. This advantage makes the PMT ideal for providing signals to timing gates, scaler-timers, counters, and many other digital modules, nearly all of which have low impedance inputs (usually 50 ohms). The PMT output needs little or no amplification for many pulsed applications, as a 100 mA signal into a 50 ohm load provides an easily detectable 5 volt signal. In addition, pulsed outputs are typically capacitively coupled which blocks ohmic leakage components of the PMT dark current and steady-state DC levels induced by an ambient light level.

Anode Coupling Techniques

A valuable characteristic of all photomultipliers is that they have very fast rise times when compared to most other types of light detectors. To take full advantage of this characteristic, however, it is necessary to use good socket wiring techniques (e.g., any charge storage capacitors used should be connected with short, direct leads), and, more important, to carefully couple the PMT output to the transmission line.

Most PMTs have wire leads or stiff pins for the output signal and therefore do not have a controlled output impedance that matches a typical coaxial cable. As a result, a fast rise signal will induce ringing on the fall of the output pulse. This can be minimized, however, by proper application of the signal line to the tube, either by direct connection to the wire leads with a supporting base standoff, or proper assembly of the socket in the case of tubes with stiff pin outputs. Tubes that have bases on them should have the bases removed and a supporting standoff applied to the stem for the transmission line and associated components. **Figure 1** illustrates an example of how to optimize the rise time and damp the ringing on the fall of the pulse.

Coaxial coupling accessories are made by many manufacturers in varying grades. When the fastest possible rise time is required, no compromise in quality should be made. For example, RG8/U (or RG213/U) cable rather than RG58 cable should be used for a50-ohm system to minimize skin effect and dielectric losses. BNC connectors should be avoided and high frequency connectors, such as the General Radio Type 874, should be used. The BNC type has an impedance discontinuity which will appear in the output of the PMT when excited with pulses of 1 ns rise times or less. The General Radio Type 874 (GR874) is specifically mentioned because several equipment manufacturers employ it in equipment useful for measuring PMT pulse performance. In addition, cables and many other coaxial accessories used in PMT pulse measurements are available with this connector. By using the GR874 connector exclusively, adapter transistions are eliminated and impedance mismatches caused by them are avoided. **Figure 2** shows a carefully arranged coaxial signal system used for PMT pulse testing.

PMT Time Response Parameters

Rise time is usually specified **by** PMT manufacturers as a measure of speed of response. This value is commonly the 10-90% rise time of the anode output pulse, and is generally measured with a sampling oscilloscope.

BURLE Electron Tubes

Another parameter that may be specified is full width at half maximum (FWHM) or the half amplitude width of the output pulse. This characteristic provides more information than rise time alone because fall time is necessarily measured. However, fall time should be specified to give a complete picture of the pulse response because many PMT's have an asymmetrical pulse characteristic with a fall time that is longer than the rise time. This extended fall time may not be included in the FWHM as the fall of the pulse can "stretch out" after it falls below the half amplitude point. This characteristic is commonly known as a "tail". Such a "tail" may be caused by ringing of the output pulse which limits the usefulness of a PMT for fast pulse detection. Many experimenters are interested in events that occur in the time period that could be obscured by ringing or a long tail.

Sampling Oscilloscope Techniques

Photomultiplier pulse output characteristics can be measured to a limited extent with real-time oscilloscopes. However, most real-time 'scopes with adequate sensitivity do not have sufficient bandwidth for measuring fast rise times. Real time 'scopes having adequate bandwidth require very large output signals from the PMT because they generally employ direct coupling of the PMT signal to the CRT vertical deflection system of the 'scope. Without amplification, signals of the order of 5 to 10 volts are required from the 50 ohm PMT source; and accordingly, 100 mA to 200 mA is required. Currents of this magnitude must be limited to a low duty cycle to keep the average PMT output current low. Resolution of fast real time 'scopes is marginal, and pulse detail cannot **be** easily observed. For these reasons, pulse testing of fast PMT's is done mostly with sampling 'scopes. **Figure 3** shows a complete sampling system used for PMT testing.

Sampling oscilloscopes have both the bandwidth and sensitivity required for a versatile pulse testing system. They are most useful for measurement of repetitive signals at rates of 50 Hz or greater.

Sampling 'scopes unfortunately can be damaged very easily by improper use. Usually the damage involves destruction of the sampling diodes in the vertical amplifier. These diodes are very damage prone because of their response time, which can be as fast as 25 ps. It is impossible to use a protection system that can shunt a large current transient fast enough to prevent destruction of the sampling diodes. This peculiarity of sampling 'scopes has been stressed because the type of damage described usually involves sending the 'scope back to the manufacturer for repair.

The best way to avoid sampling diode destruction is to monitor the PMT output with an electrometer before connecting the output signal to the 'scope. When PMT stability is found to be satisfactory, (e.g., no large current transients are present), only then should the signal be applied to the sampling 'scope. **Figure** 4 shows a diagram of a suggested system. Note that the 'scope is capacitively coupled. In this configuration, the electrometer must be left connected, or the 1 k-ohm resistor must be shorted to ground, in order to provide a DC discharge path for the anode.

Triggering and signal delay for sampling 'scopes also requires special consideration. **In** general, external triggering produces the best results for PMT testing. Internal trigger systems are available in sampling 'scopes, but they usually require high repetition rates. This discussion will assume that a trigger signal is available for external triggering. The most desirable trigger signal is supplied by a pulsed light source and coincides with the rise of the light pulse. Note that trigger inputs of sampling 'scope sweep units are also sensitive, so the operator must be sure not to exceed trigger input levels. Coaxial attenuators should be used in the trigger line if necessary.

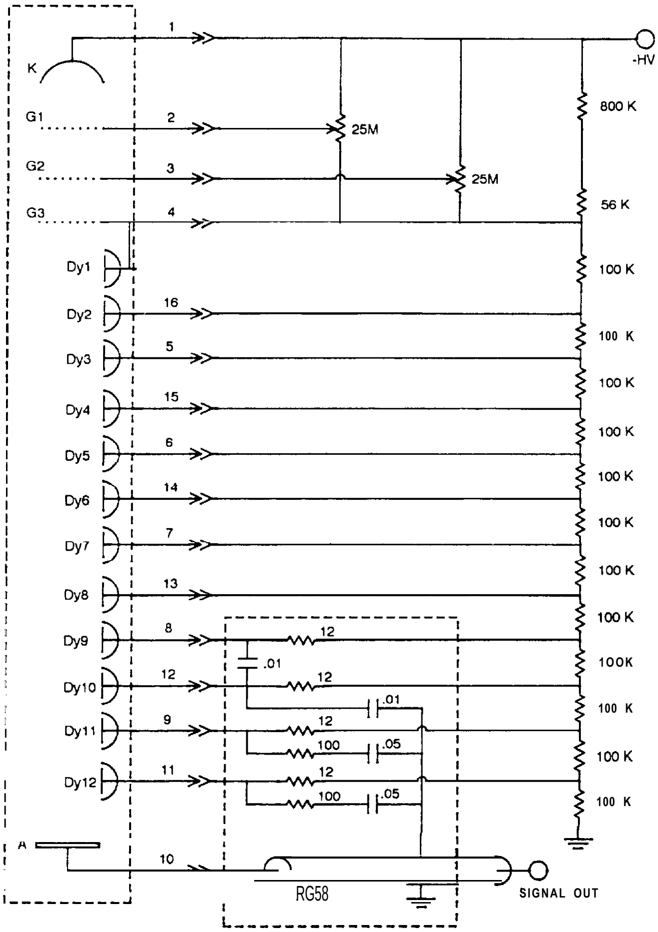
If no trigger signal is available from the light source, one can be created from the PMT output signal. A device that is particularly useful for this purpose is the Tektronix CT-3 signal pickoff. The CT-3 is **a** 50-ohm coaxial device that takes 1% of the signal and steps up the voltage so that the magnitude is equal to 10% of the PMT input signal. This step up generally provides enough amplitude to trigger a sampling time base. A simpler device that may be adequate is a coaxial "tee", such as that shown in **Figure** 2. The 1 k-ohm tap then serves as a trigger pickoff.

Signal delay is usually required for sampling 'scopes because the PMT output signal arrives at the vertical input too soon after the start of the sweep. Delay is almost always achieved by inserting a large coil of coaxial cable in the signal line between the PMT and 'scope input. A delay of 50 to 100 ns is common, and **a** fine delay adjustment is provided in the sampling time base to position the pulse accurately. It should be noted that when the PMT signal is used to derive a trigger signal, the trigger pickoff must be inserted before the delay line.

It is customary to display a single pulse on a sampling 'scope for detailed examination of the pulse characteristics. Because a sampling display is a series of dots, the sweep unit should be adjusted for maximum dot density to achieve the best resolution. The display is frequently photographed to assure accurate measurements of rise time, fall time, and FWHM of the pulse. Measurements are done with a scale directly on the photograph. If desired, a specially calibrated graticule can be superimposed on the screen that shows the 10 to 90% points of the pulse when the pulse is adjusted to preset amplitude limits. The rise and fall times can then be read directly from the display. **Figure 5a** shows a typical PMT pulse photograph taken from a sampling display; **Figure 5b** shows the same photograph ruled for a careful measurement of the 10-90% rise time, fall time, and FWHM.

Summary

Fast pulse techniques require care in selection and arrangement of components. Only high grade coaxial components should be used in the signal line. When using sampling oscilloscopes, remember that they are easily damaged -- do not be in a hurry to connect the PMT signal. After all inputs are ready, check out the system again before applying any signals. A little extra care will give a long life to a sampling 'scope. Keep in mind that manufacturers' specifications may not tell all one needs to know about a PMT; the user who is prepared to do his own pulse testing will be able to judge whether or not the pulse performance of a PMT meets his needs.



Note 1: Circuit componentsshown within the dashed lines should be mounted directly on the tube socket (AJ2144A or AJ2145A). However, care should be taken that the socket pins are free to move within their seats in the socket body. Otherwise, difficulty in tube insertion may lead to tube damage.

Note 2: This circuit arrangement includes concepts suggested by Los Alamos National Laboratory and is shown here with its permission.

Figure 1 -C83061E Output Network to Minimize Ringing.

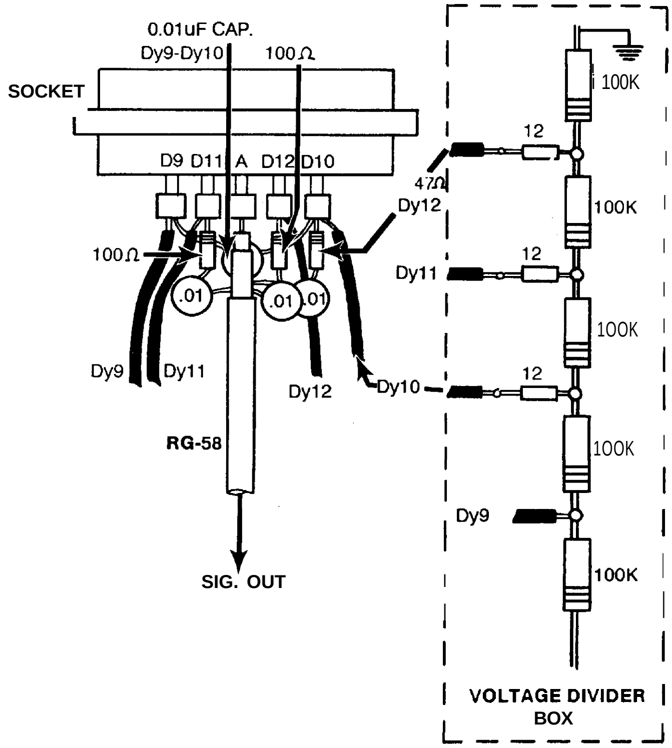
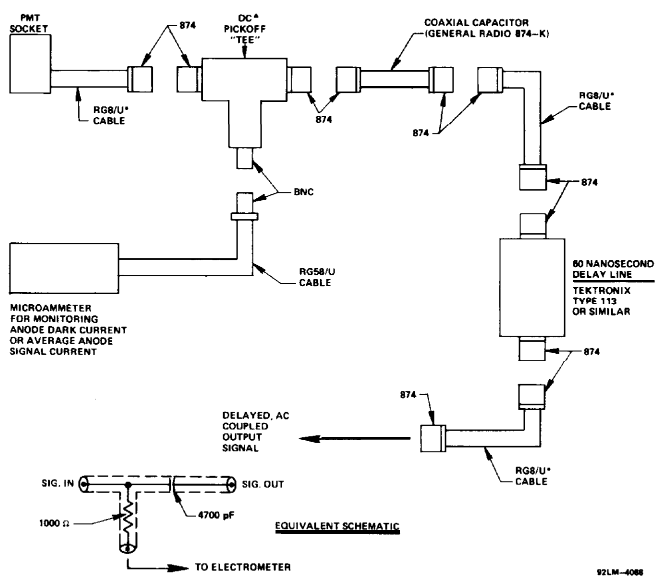


Figure 1 a - Physical Configuration



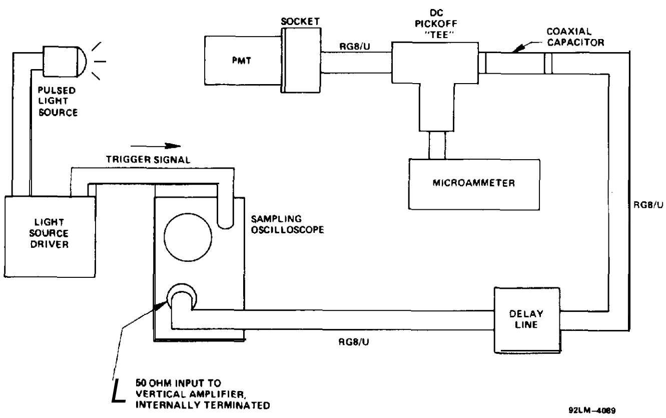
Notes

*Or RG213/U Cable

^ Thru signal chamber must maintain 50 ohm impedance; DC output branch should have noninductive connection to 1,000 ohm resistor.

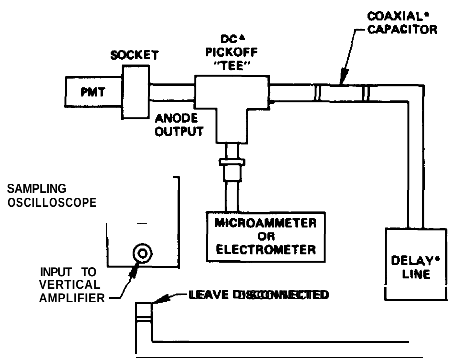
874 - All fittings marked refer to General Radio Type 874 coaxial connectors.

Figure 2 - A Carefully Arranged Coaxial Signal System

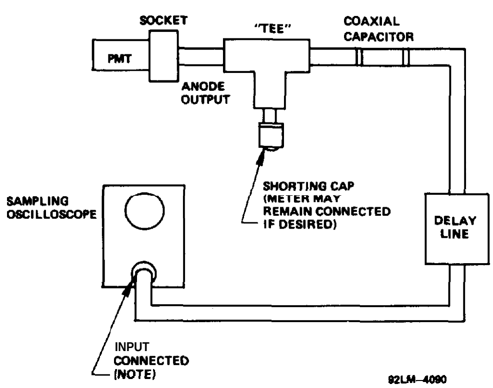


(See Figure 2 for more component details.)

Figure 3 -A Complete Sampling System Used for Measuring Photomultiplier Pulse Response



(Step 1)



(Step 2)

Note: An attenuator between the capacitor and 'scope input will prevent capacitive discharge transients from damaging the most sensitive sampling inputs -- usually not required.

Figure 4 **-Technique for Preventing Sampling Diode Damage**

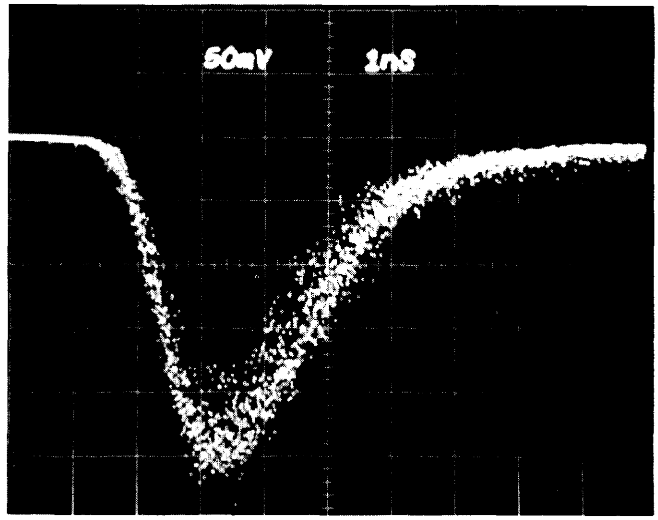


Figure 5a - Photograph from Sampling Oscilloscope

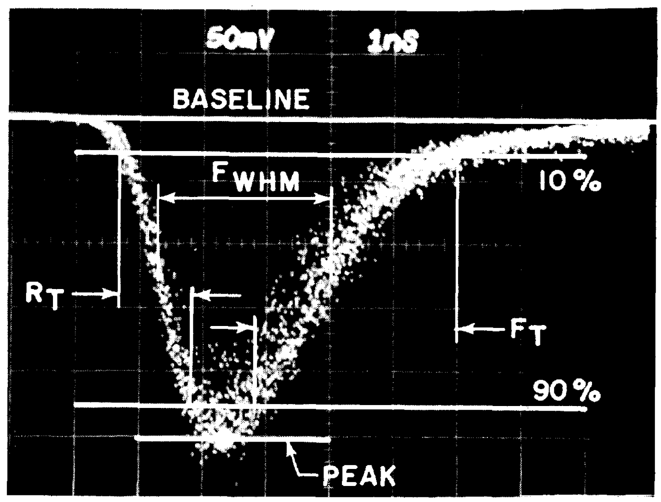


Figure 5b - Photograph Ruled for Time Response Measurement

1 Division = 1 ns (0.33" measured directly from photo)
FWHM = 0.9" = 2.73 ns
R_T = 0.38" = 1.15 ns
F_T = 1.04" = 3.15 ns

Figures 5a and 5b - Light Pulse from a Light-Emitting Diode Detected by a BURLE C31024 Photomultiplier