RCA
Electronic Components

Photodetector
Application Note
AN-4884

Time Characteristics of Photomultipliers - Some General Observations

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Introduction

Photomultipliers (PMT's) are excellent detectors for measuring the time characteristics of very weak and extremely short-duration light pulses. Not only can state-of-the-art photomultipliers readily measure radiant flux inputs of femtowatt intensity but they can also detect sub-nanosecond pulses that occur at rates exceeding one gigahertz. Even the lowest cost PMT's are capable of detecting pulses occurring at rates from tens to hundreds of megahertz. Photomultipliers may be considered true broad-band detectors as nearly all can be operated from DC to their upper frequency limit.

Photomultiplier Pulse Response Characteristics

Anode Pulse Rise Time, Full-Width-at-Half Maximum (FWHM), and **Anode Pulse Fall Time** are normally measured using a delta-function light pulse to excite the PMT photocathode. A delta function light source, by definition, is a light source whose rise time, fall time, and FWHM are no more than one-third of the corresponding parameters of the photomultiplier's output pulse. Practical delta function light sources include light emitting diodes (LED's), mode-locked lasers, and spark sources.

Anode Pulse Rise Time is the most commonly specified time response characteristic of the PMT. This characteristic is defined as the elapsed time between the 10% and 90% amplitude points of the leading edge of the anode current pulse with the photocathode fully illuminated.

Full-Width-at-Half-Maximum is also often quoted as a measure of the PMT's time response. This characteristic is the period of the anode current pulse width at its half amplitude points.

Anode Pulse Fall Time is of importance in some applications because the fall time is generally longer than the rise time. This characteristic is defined as the elapsed time between the 90% and 10% points of the trailing edge of the anode current pulse.

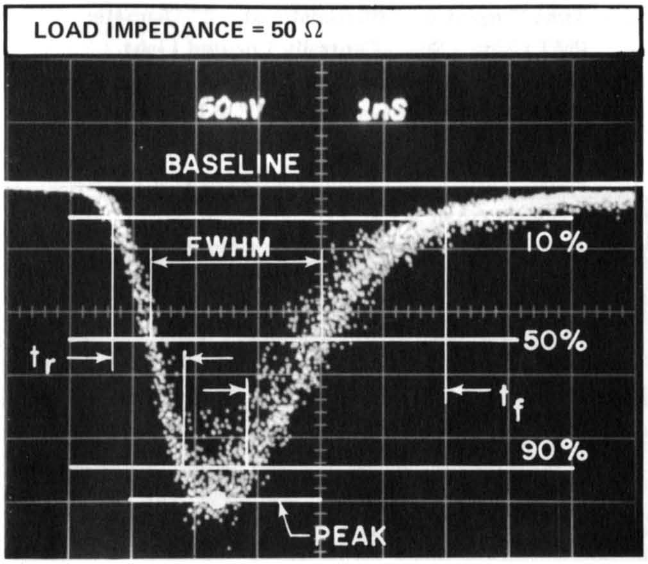

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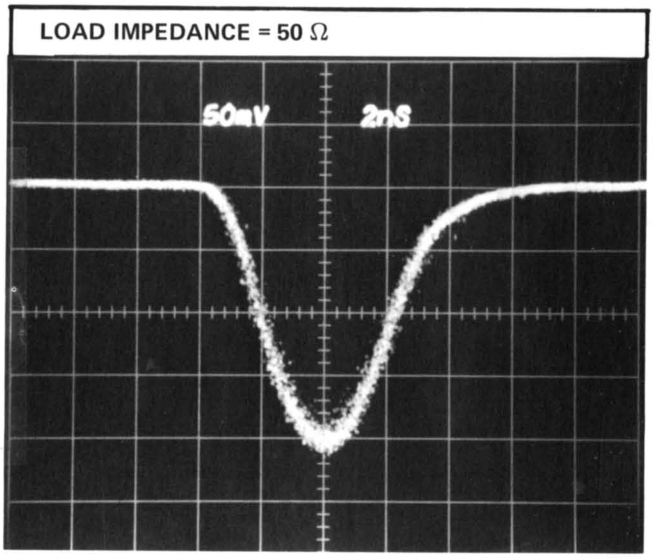
Figure 1 — **Reproduction of a Photograph Showing the Relationship Between Rise Time (t_r), Fall Time (t_f), and Full Width at Half Maximum Points (FWHM)**

Figure 1, which is a photograph of a sampling oscilloscope display of an anode current pulse obtained using a delta-function light source, illustrates these three PMT time response characteristics.



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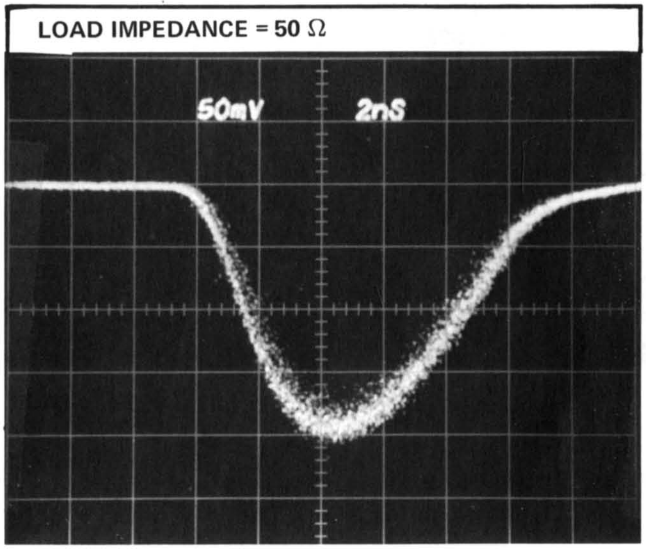
(a) – Time Response Characteristic of a 2″-Diameter PMT Using a Small Centrally Located Light Spot on the Photocathode. The Light Spot Diameter is Approximately 1/4″ in Diameter.



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(b) – Time Response Characteristic of the Same 2″-Diameter PMT with its Photocathode Fully Illuminated

Figure 2 – Variation of Time Response as a Function of Illuminated Photocathode Area for a 2″-Diameter PMT. Tube Operating Conditions, Except for Light Spot Size, are Identical. The Light Source is a Pulsed LED.

Operating Conditions Affecting PMT Pulse Response Characteristics

Although photomultiplier time characteristics are primarily a function of applied operating voltage, other operating conditions can affect the time response.

A decrease in anode pulse rise time can be obtained by illuminating a small central area of the photocathode rather than the entire photocathode. This effect is shown in the photographs of **Figure 2** where the time response characteristics obtained using a fully illuminated photocathode and those obtained using a small beam spot (approximately 1/4″ in diameter) centrally focused on the photocathode are compared.

Another factor affecting PMT time characteristics is the amplitude of the anode current pulse; as the amplitude increases, the rise time increases. The time increase is attributed to space charge limitations in the latter stages of the tube. However, if the peak linear anode current rating of the tube is not exceeded, the increase is usually less than a factor of 2. This effect is shown in **Figure 3** where the peak anode current pulse level is almost doubled.

A steady-state background light level is still another factor which can affect PMT time characteristics because extraneous light can produce a high direct current output level. While it is possible to detect pulses in this DC current, the dynamic range is reduced in proportion to the DC level. Because the output of the PMT is often AC-coupled to following circuitry, i.e., through a blocking capacitor, this condition is not always readily apparent. To obviate this effect, as much ambient light as possible should be excluded from the PMT.

Excessively high dark current levels caused by high ambient temperature or extraneous electric fields near the tube also tend to increase rise time. This effect is similar to that caused by background light but the source of current differs. Operation of the tube above its maximum ratings can produce a dark current level that approaches an unstable state due to regenerative effects in the tube.

Single Electron Rise Time

When the fastest possible time response must be obtained from the PMT, it is advisable to measure the **Single Electron Rise Time (SERT).** This measurement is made using a very weak DC light to illuminate the photocathode. The intensity of the light is adjusted so that single photoelectrons are emitted from the photocathode. Part of the PMT output signal is used to provide a trigger signal for a sampling oscilloscope while the larger part of the signal flows through a delay line to the vertical amplifier of the oscilloscope. **Figure 4** shows a typical display obtained using this measurement technique.

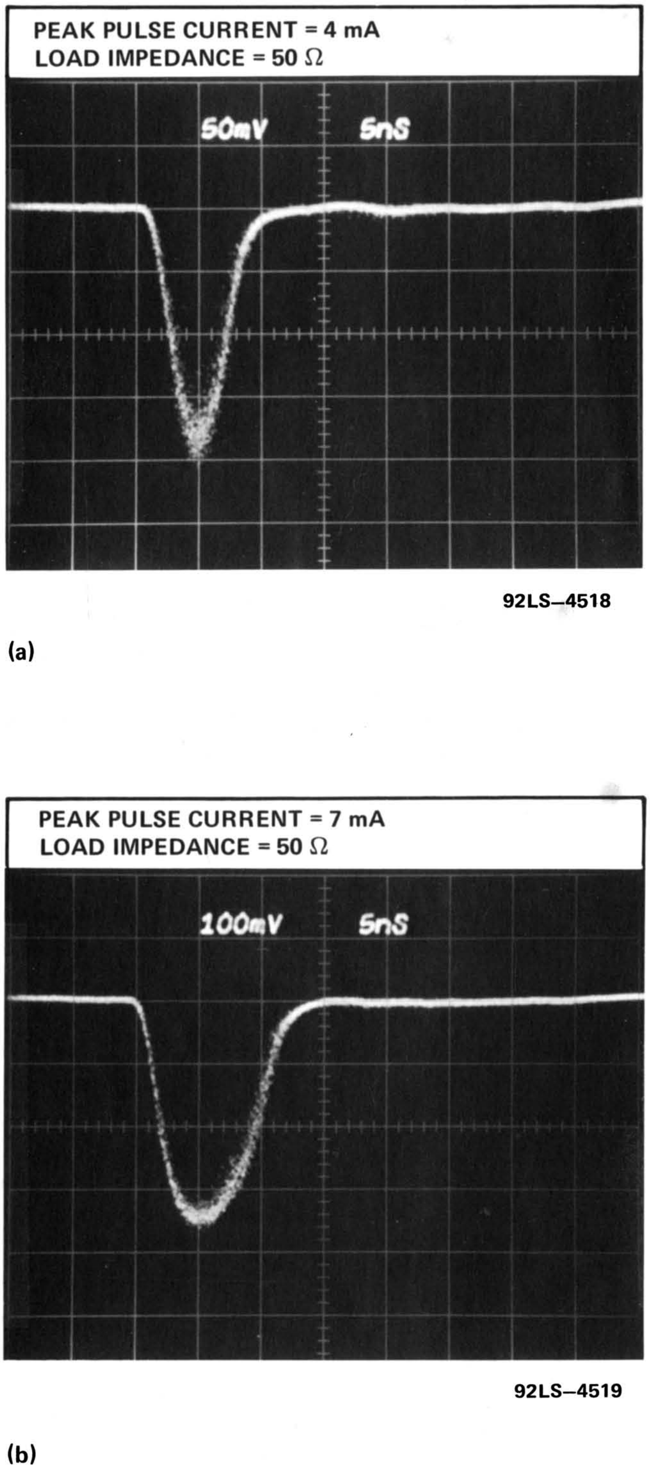


Figure 3 – Variation of Time Response as a Function of Peak Pulse Current for a 2″-Diameter PMT. Tube Operating Conditions are Identical Except the Light Pulse Intensity was Increased in (b).

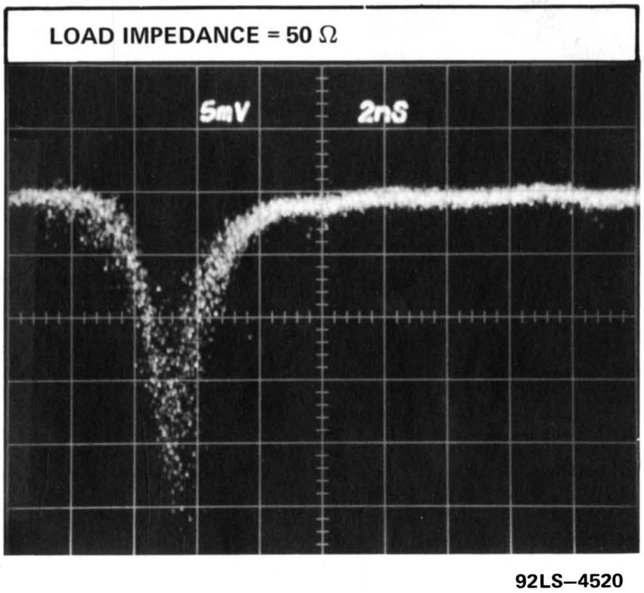


Figure 4 – Single Electron Time Characteristic for a 2″-Diameter PMT. The Time Characteristics Shown Here Represent the Fastest Possible Time Response of a PMT.

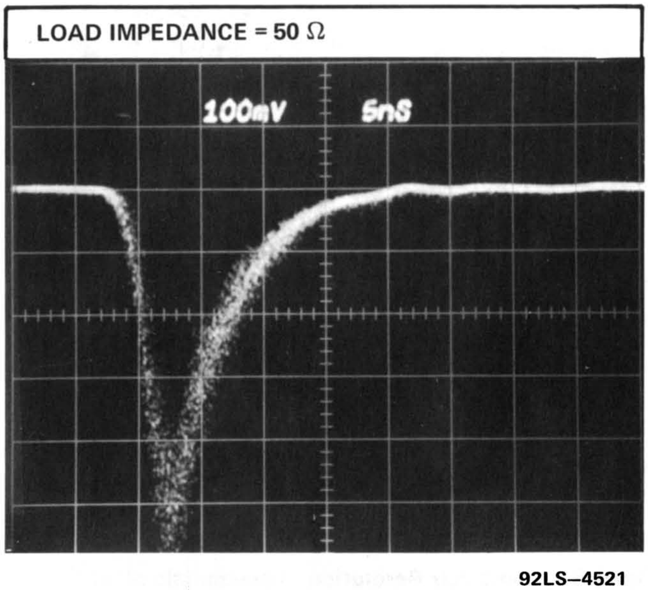
Single Photoelectron and Multiple Photoelectron Time Characteristics

The time characteristics of a PMT excited by single photon and multiple photon events are shown in **Figure 5.** The fall time of the anode current pulse characteristic for the multiple electron pulse appears to be a monotonically decreasing function while the fall time for the single electron pulse reveals the "ringing" characteristic.

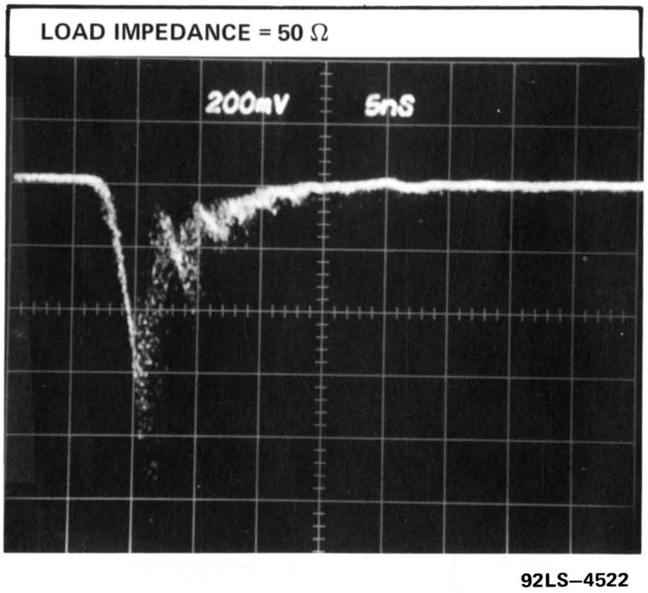
Step Function Response Characteristics

Photomultiplier time response to a step function light pulse is not predictable from the time characteristics obtained using a delta function light pulse. The reason for non-predictability has not been determined but the end result is that the rise time is considerably longer when a step function is used.

When a step function is used rather than a delta function light source, the design of the voltage-divider network becomes important. Under this input light condition, the obtainable peak pulse currents are dependent on the current available from the voltage divider. As pulse width is increased, a point is eventually reached where the voltage divider requirements approach those of DC circuits. The use of charge-storage capacitors between adjacent dynodes of the latter stages of the PMT help to prevent pulse droop. See **Figure 6.**



(a) – Time Characteristic of a 2″-Diameter PMT Excited by Multiple Photoelectron Events. Note the Absence of Ringing.



(b) – Time Characteristic of a 2″-Diameter PMT Excited by Single Photoelectron Events. Note the Introduction of Ringing.

Figure 5 – Time Characteristics of a 2″-Diameter PMT Excited by Single and Multiple Photoelectron Events. Tube Operating Conditions, Except for the Excitation, are Identical. The Light Source is a Pulsed LED.

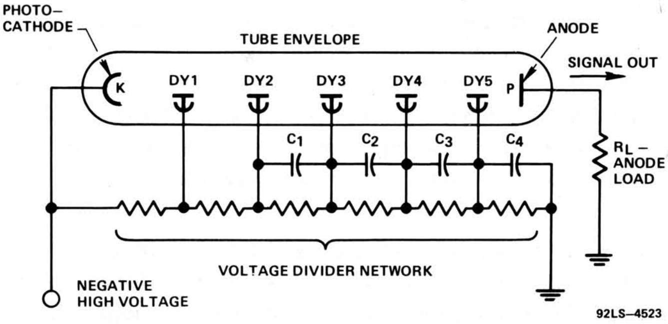


Figure 6 – Voltage-Divider Network for a 2″-Diameter PMT for Wide Signal Pulse Widths

Sine-Wave Response Characteristics

Photomultiplier response characteristics are seldom specified in terminology common to radio equipment simply because of the lack of sine-wave light sources capable of operating at high frequencies. A commonly used rule-of-thumb for converting pulse rise time (t_r) into sine-wave response is

f_o (3 dB point) = $0.35/t_r$

However, preliminary investigations with frequency spectrum analyzers indicate that this rule-of-thumb is not strictly valid. High frequency roll-off begins at frequencies considerably lower than those calculated from the delta-function rise time. **Figure 7** shows the display of a noise spectrum of a fast PMT coupled to a frequency spectrum analyzer.

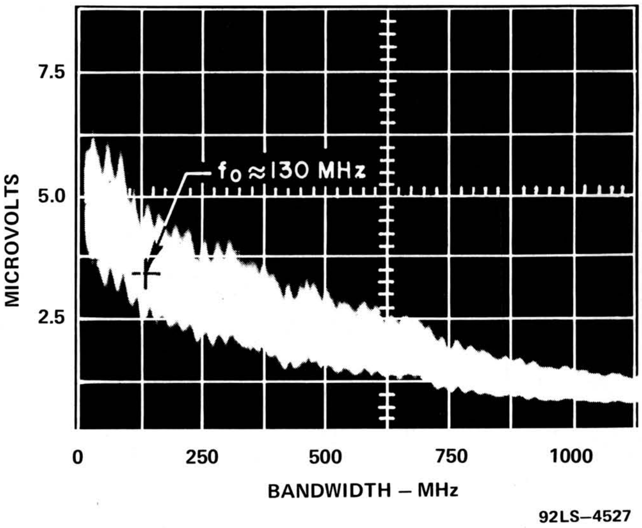


Figure 7 – Noise Frequency Spectrum Analysis of a 2″-Diameter PMT. The PMT is Coupled to a Spectrum Analyzer Having a 50-ohm Input and a Bandwidth of 1250 MHz. The Comb Structure is a Result of Reflections from the Input of the Spectrum Analyzer. Although the 3 dB Point (f_o) Shown on this Illustration is only 130 MHz, the Useful Bandwidth Extends to Almost 500 MHz.

Sine-wave response information, or its equivalent, is becoming important because of the increased activity in optical communication systems. Because of the lack of satisfactory light modulation equipment, characteristics such as pulse-pair resolution and maximum pulse repetition rates are usually measured in lieu of sine-wave response.

A mode-locked Nd:YAG laser emitting at 1.06 μm (sometimes doubled to 532 nm) is generally used for obtaining this information. Repetition rate is varied by adjusting the cavity length and modulation frequency while pulse-pair spacing is varied by an optical delay line. Gas lasers with double-pulsing capabilities can also be employed. A sampling oscilloscope is used to measure the performance of the optical receiver. To date, receivers have been demonstrated that function to beyond 1 gigahertz. **Figure 8** shows a pulse-pair resolution characteristic obtained with a double-pulse argon laser.

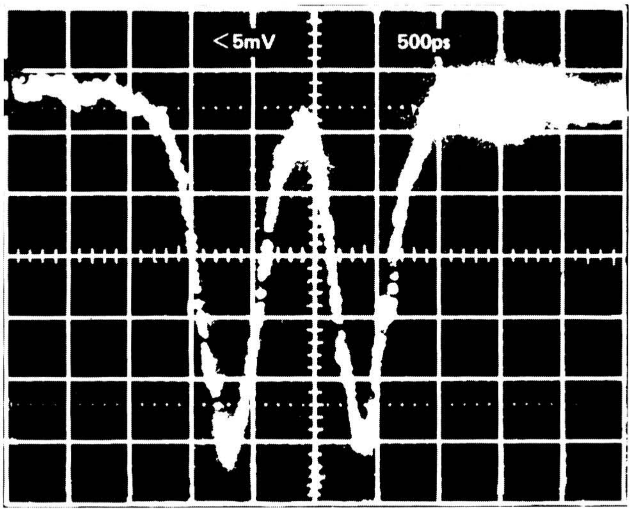


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Figure 8 — Pulse-Pair Resolution Characteristic of an Optical Communications Receiver

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