Low-Cost Scintillation Probe Based on a Surplus XP3312 PMT for Ludlum Ratemeters and the Prutchi CDV700-Pro Radiation Counter

David Prutchi, Ph.D. and Shanni R. Prutchi

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Abstract

This paper shows how to wire a surplus XP3312 photomultiplier tube (PMT) to be used in a low-cost, yet highly sensitive scintillation probe for Ludlum ratemeters. The probe can also be used with the do-it-yourself Prutchi CDV700-Pro radiation counter described in the book "Exploring Quantum Physics Through Hands on Projects" [1]. The probe is based on a Philips XP3312/SQ that is coupled to either an inorganic or organic scintillator.

Figure 1 – D.I.Y. low-cost, high sensitivity scintillation probe based on a surplus XP3312 PMT connected to a Ludlum Model 12 Ratemeter. A paint can makes a convenient, light-tight enclosure for the probe.

Introduction

Ludlum general-purpose ratemeters are professional-grade instruments that are available on the secondary market at affordable prices. They are compatible with a wide variety of probes, making them a great choice for educators, surveyors, and advanced amateur users. However, probes for Ludlum ratemeters are often as expensive as the meter instrument itself, making it worthwhile to build comparable versions from surplus components.

One of the most popular types of probes for these instruments is the scintillation probe. Depending on its materials and construction, this type of probe can be used for the detection of α, β, γ, and neutron radiation [2]. At the core of the probe is a scintillation crystal that produces a short flash of light when hit by ionizing radiation, and a sensitive light detector to translate the light flash into an electrical signal that can be read by the counting instrument.

The most common light detector in scintillation probes is the photomultiplier tube (PMT), and although expensive when new, a large number of new surplus units are available at very affordable prices in the secondary market. There are many types of PMTs, each with its own characteristics and specific supply/readout requirement. In addition, each radiation counter model has its own interface requirements, so a single schematic diagram does not suffice to show how to connect any PMT to a ratemeter. For this reason, we have selected the XP3312/SQ – a PMT that is currently widely available in the surplus market as the detector for our probe.

Lastly, the probe described in this paper can be used with other general-purpose radiation counters. For example, in our book "Exploring Quantum Physics Through Hands-On Projects"[1] we described a scintillation probe for our modified Civil Defense model 700 Geiger Counter – an Electro Neutronics Inc. (ENi) Civil Defense V-700 model 6b to which we made a number of changes, improvements, and additional features that turn it into a great instrument for lab use (Figure 57 in reference 1). We affectionately call our version the "CDV-700 Pro." Our version adds the following features to the stock CDV-700:

- Preamplifier to make it compatible with photomultiplier scintillation probes (Geiger-Müller tubes can still be used)
- Selectable, regulated bias voltage (900V or 1,200V) for connection to GM tubes and photomultiplier tubes. A blinking indicator warns of the high voltage selection.
- Noise-reduction circuitry eliminates hum.
- Internal piezo clicker.
- Power input jack saves batteries when powered from car or AC-operated power supply.
- 8-digit digital counter.

The XP3312/SQ PMT

In a photomultiplier tube, a single electron released from a photocathode by a single photon is accelerated towards another electrode in order to produce secondary electrons. Two or more electrons are then released when the accelerated photoelectron slams into the electrode. As shown in Figure 2, the same process can be repeated over and over again with the secondary electrons used to successively multiply the number of electrons released in a cascade. A much larger number of electrons finally reach the anode as the result of a single photon hitting the photocathode. Commercially-available photomultiplier tubes based on this principle produce as many as 10^6 to 10^7 secondary electrons at the anode for each photon that releases a photoelectron from the photocathode.

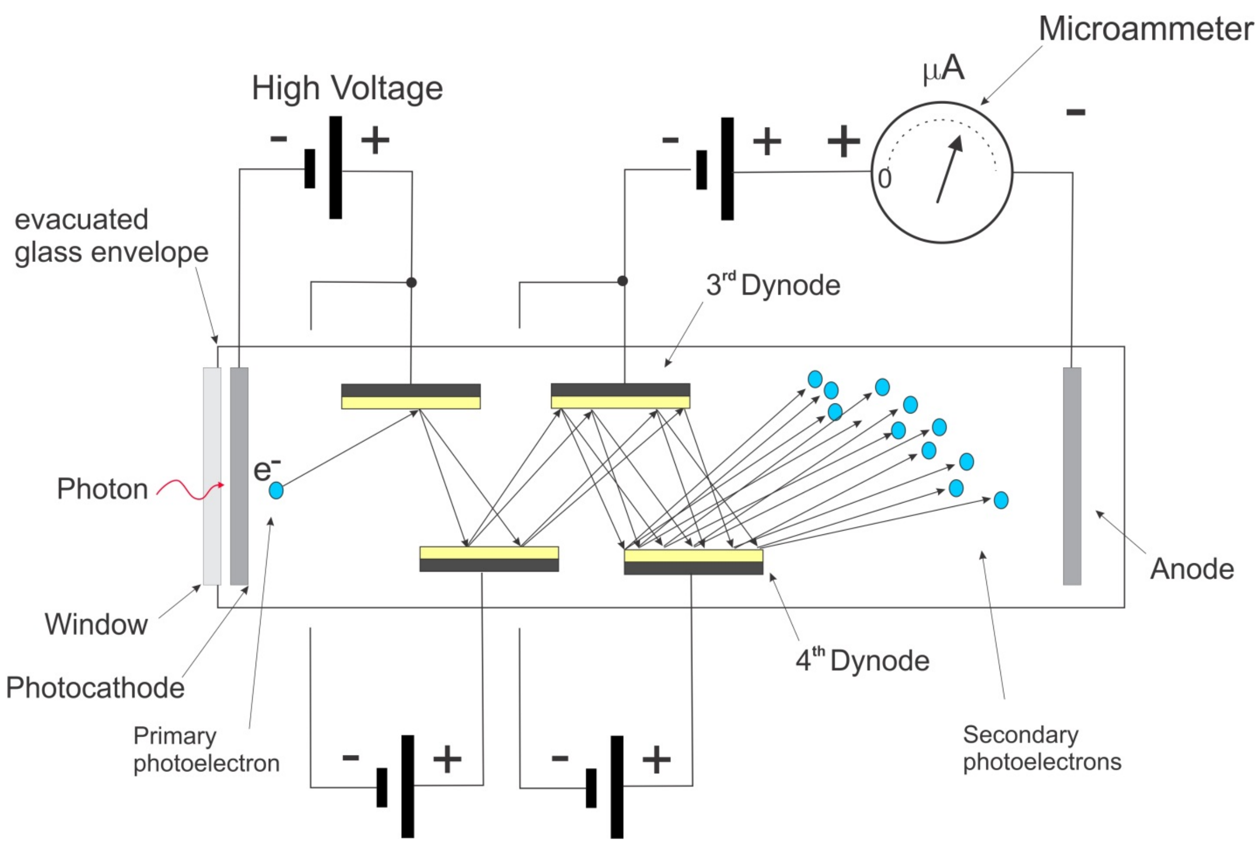

Figure 2 - Photomultiplier tubes (PMTs) are the workhorse detector of experimental Particle Physics. The photoelectrons released at the photocathode of a photomultiplier tube are accelerated toward an electrode (first dynode), and cause the release of two or more secondary electrons. Each of these causes the release of two or more electrons from the second dynode. The cascade continues until a very large number of electrons are available for detection at the anode. [Adapted from D. Prutchi and S.R. Prutchi, "Exploring Quantum Physics Through Hands-On Projects", J. Wiley & Sons, 2012].

The surplus availability of specific PMT models is very variable, so for the benefit of our readers, we decided to base this design on the XP3312/SQ – a PMT that is currently widely available in the surplus market, including eBay® and Sphere Research[1].

The XP3312/SQ PMT, like the one shown in Figure 3, was used by Philips Medical Systems in some of its gamma cameras and CAT scanners. It is an 8-stage round tube with a 3" diameter window. The PMT achieves a gain of around 2.3×10^5 at a bias voltage of 1,000 V. The PMT is sensitive to photons within

[1] Sphere Research Corporation, 3394 Sunnyside Road, West Kelowna, B.C., CANADA V1Z 2V4
URL: http://www.sphere.bc.ca, Phone: +1 (250) 769-1834, Fax: +1 (250) 769-4106

the 290 nm to 650 nm wavelength range, and its sensitivity peaks at 420 nm. The tube used by Philips has the flying-lead pinout shown in Figure 4.

Figure 3 – The Philips XP3312/SN is a high-gain, 8-stage photomultiplier tube with a 3" round face that was used in some Philips Medical gamma cameras. It is inexpensive and widely available in the surplus market.

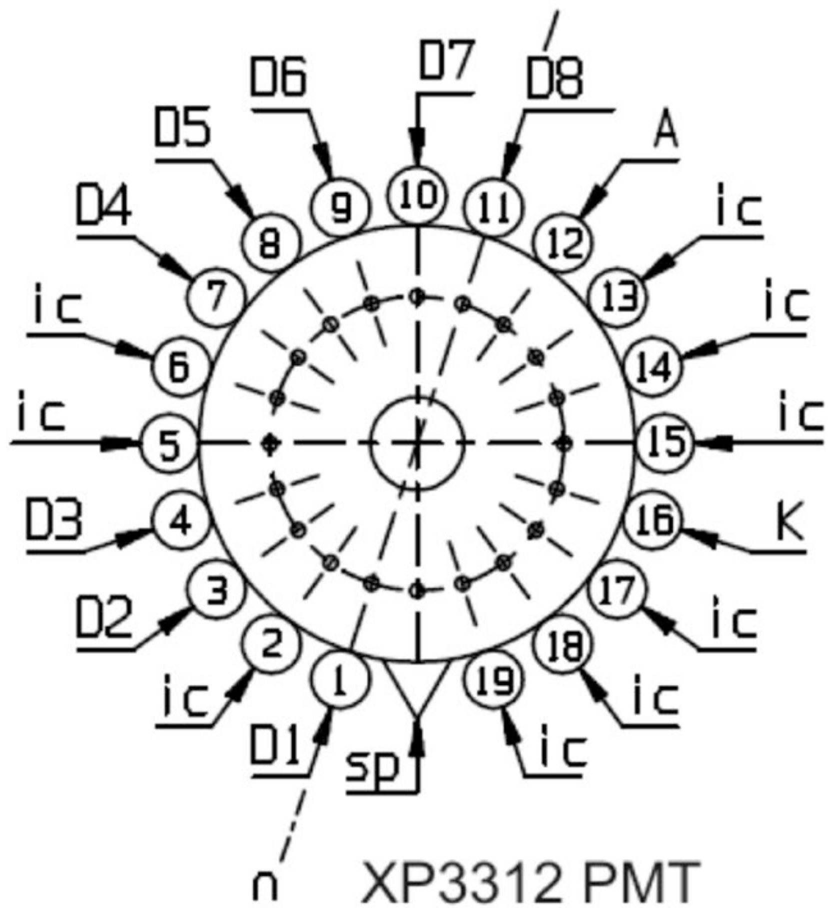

Figure 4 – Pinout of the XP3312 PMT [3]. The reference for numbering is one short pin (labeled "sp" in this figure) that barely protrudes from the plastic retainer.

Constructing the PMT Assembly

The original circuit board wired by Philips to the base of the tube is designed to use a voltage divider string comprising 2.2 MΩ resistors. However, the PCB needs to be clipped away because we need to use resistors of much larger value, since neither the Ludlum ratemeter nor the CDV-700 Pro power supplies can provide more than just a couple of μA. Before discarding the PCB, unsolder and keep the blue 4,700pF high-voltage capacitor since it can be reused when wiring the probe.

Figure 5 – The dynode voltage divider network can be wired directly onto the flying leads of the XP3312 PMT

As shown in Figure 5, assemble the voltage divider shown in the schematic diagram of Figure 6 directly onto the flying leads of the PMT.

Photomultiplier tubes are extremely sensitive to magnetic fields and exhibit output variations even from sources such as terrestrial magnetism. As such, if your application requires high gain stability, wrap the PMT with magnetic shielding foil (with a permeability of at least 10^5). We used a layer of NETIC and a layer of CONETIC from Magnetic Shielding (www.magnetic-shield.com) and held them in place using Gorilla tape as shown in Figure 7. The magnetic field intensity within the shield will be attenuated to approximately 1/1000 that outside the shield case, ensuring a stable output when operating in proximity to magnetic fields.

The PMT assembly can then be coupled directly to the scintillation crystal using index-coupling grease. This doesn't have to be the expensive gel sold for premium optical systems (e.g. Dow Corning Q2-3067 optical coupling compound at over $250 for a four ounce jar), but rather any low-cost, high-purity silicone grease such as Dow Corning 4. Use a tiny bead and let it squeeze between the PMT and the scintillator to form the thinnest possible interface between the two components. If you prefer not to use index-coupling grease, you may do so, but it will result in a 10 to 20% drop in sensitivity from your probe.

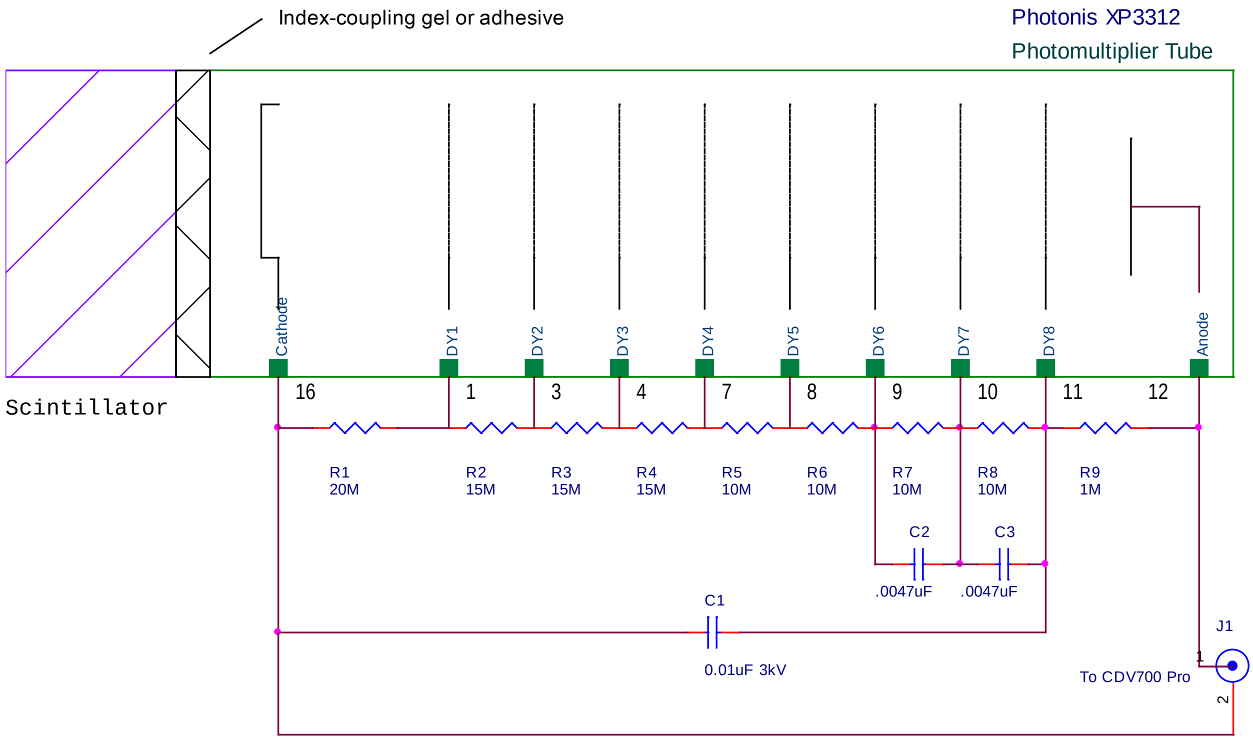

Figure 6 – Schematic diagram of scintillator probe. 20MΩ are two 10MΩ resistors in series. 15MΩ resistors are a 10MΩ resistor in series with a set of 10MΩ resistors in parallel.

Figure 7 – Optionally, a magnetic shield can be fashioned from NETIC and CONETIC foils wrapped around the PMT. We used Gorilla tape to hold the magnetic shielding against the tube.

Scintillators

Scintillators are materials that produce a short flash of light when hit by ionizing radiation. Purpose-grown inorganic crystals have been developed and are commonly used in physics labs. The most widely used is NaI(Tl) (sodium iodide doped with thallium). Chinese, Russian, and Ukrainian eBay® vendors list these for $100 to $200. Small surplus crystals in good condition sold by US eBay® vendors usually run in the $200 to $400 range.

Besides inorganic crystals, many organic liquids and solids exhibit scintillation. Easy-to-use plastic scintillators have been developed by incorporating organic scintillating substances within a transparent plastic. Plastic scintillators are widely used by experimenters because they are relatively inexpensive and are very easily shaped. Scintillation plastic is available from a number of eBay® vendors[2]. Expect to pay around $50 for a 3" × 3" × 2" piece.

Enclosures

Although any light-tight enclosure can be used, we prefer to use a paint can because of its low cost, wide availability, and assured light-tightness without any other sealing means. Our assembly is shown in Figure 1, and construction details for using a paint can as a scintillation probe enclosure can be found in reference 4.

The high sensitivity and convenient portability of this probe make it ideal for radioactive mineral surveying, as well as for "urban surveying" to find miscellaneous gamma-ray sources.

References

1. Prutchi D, Prutchi SR, *Exploring Quantum Physics Through Hands-On Projects*, J. Wiley & Sons, 2012.
2. Koontz PG, Keepin GR, *ZnS(Ag) Phosphor Mixtures for Neutron Scintillation Counting*, Los Alamos Scientific Laboratory of the University of California, 1954.
3. HZC Photonics, *XP23312 Datasheet*
4. Prutchi D, Prutchi SR, *A Low-Cost, Super-Sensitive Scintillation Probe for the Prutchi CDV700-Pro Counter using a Surplus Philips XP5312/SN PMT*, www.diyPhysics.com Technical Note 2013-1, January 2013.

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[2] George Dowell, eBay® user GeoElectronics has over 40,000 square inches of plastic scintillator (1 1/2" thick, lengths up to 7 feet long) available for sale.

