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SECOND QUARTERLY REPORT
RESEARCH IN THE DEVELOPMENT EFFORT OF AN IMPROVED MULTIPLIER PHOTOTUBE

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APPLICATIONS NOTE E4

COOLING CHARACTERISTICS OF ITTIL MULTIPLIER PHOTOTUBES

The appreciable contribution of thermionic emission from the photocathode to the anode dark current observed in some multiplier phototubes makes possible a reduction in this current and consequently in the dark noise of these tubes by cooling. Figure 1 Curve (a) shows the measured decrease in anode DC dark current, I_{DC}, in an ITTIL FW-118 multiplier phototube (S-1 type) down to photocathode temperatures of about -20 degrees C. The sharply falling dark current, approximately following a Richardson type law, substantiates the predominance of thermionic emission from the photocathode in this tube at these temperatures. A decrease of about an order of magnitude for each 10 degrees C of cooling is observed.

Figure 1 Curve (b) shows the corresponding decrease in the equivalent noise input (ENI)[1] as a function of temperature, compared to the published[2] ENI characteristic Curve (c) for a competitive type tube. The FW-118 starts with a lower ENI characteristic at room temperature (at least partially because of its smaller effective photocathode area) and improves about twice as fast as the competitive detector with temperature.

At anode dark current levels below about 10^{-10} amperes, reliable and significant cooling characteristics can only be observed with difficulty in many multiplier phototubes because of the erratic and nonreproducible contribution of leakage currents (in the tube stem and base and internal parts), external pickup effects, and other low current measurement difficulties. For example, a resistance of 10^{13} ohms across the surface of nominally insulating internal anode pin support (an entirely reasonable value in view of the chemically reactive cathode materials present) can contribute 10^{-10} amperes in the typical operating range of 10^3 volts. This difficulty may be further aggravated when cooling a complete tube envelope if condensation of water vapor across various tube stem and basing lead connections occurs. Noise from this latter source can be particularly troublesome if the condensation occurs between the tube stem and base, where moisture may be trapped in the base cementing process. To avoid this, ITTIL recommends the use of unbased tubes (flying lead construction) or photocathode-only cooling.

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[1] Defined and measured according to IRE publication No. 62IRE7.S1.

[2] RCA tube manual, 7102 tube type.

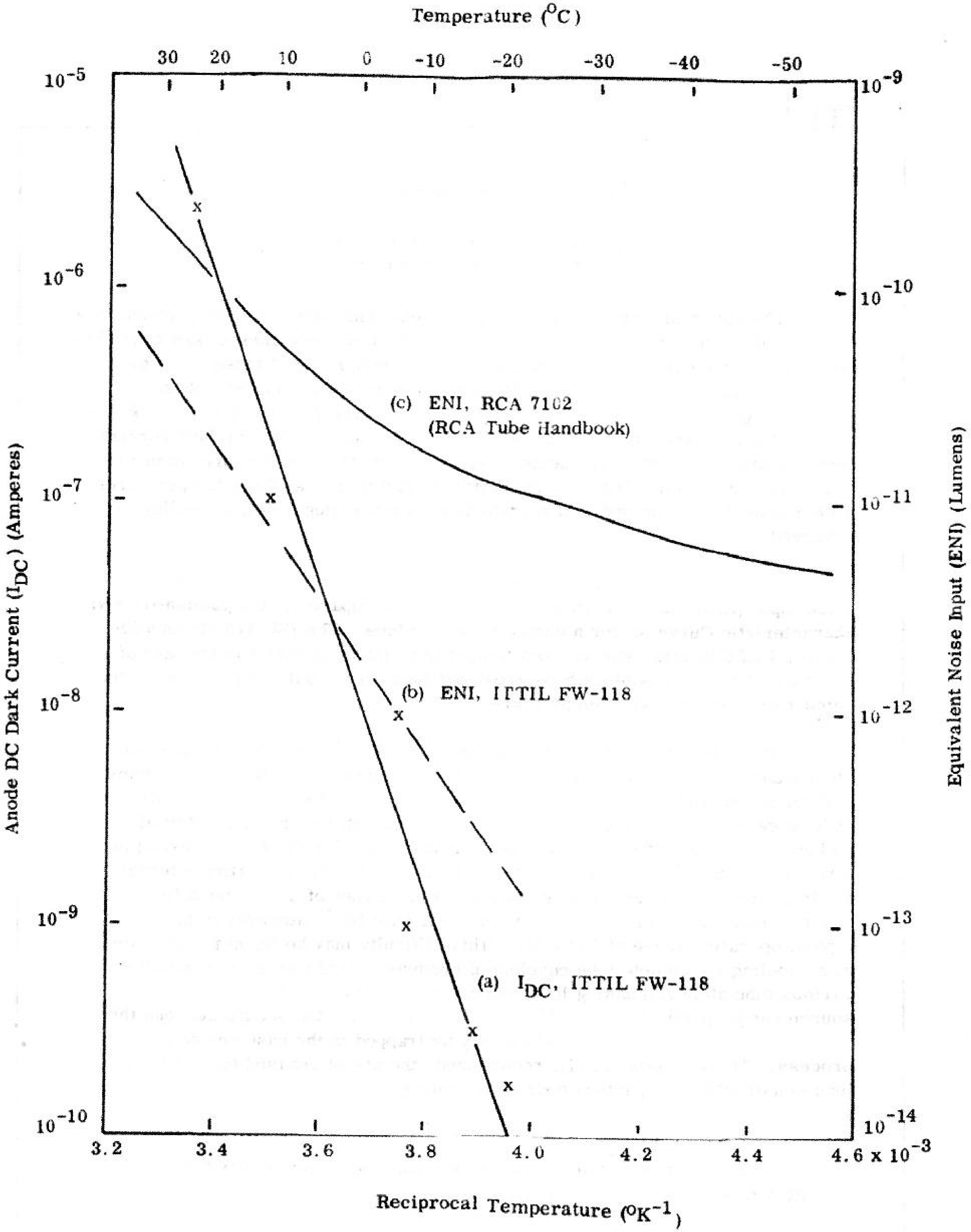

Figure 1 Anode DC Dark Current and ENI Vs Temperature for S-1 Type Multiplier Phototubes

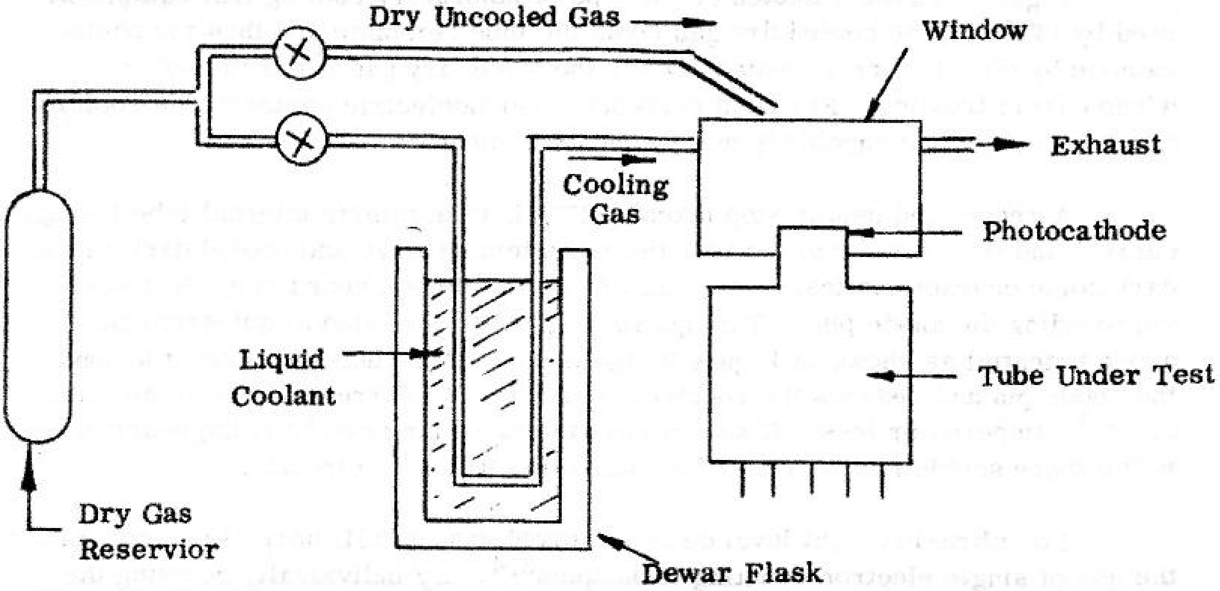

Figure 2 ITTIL Cooling Configuration

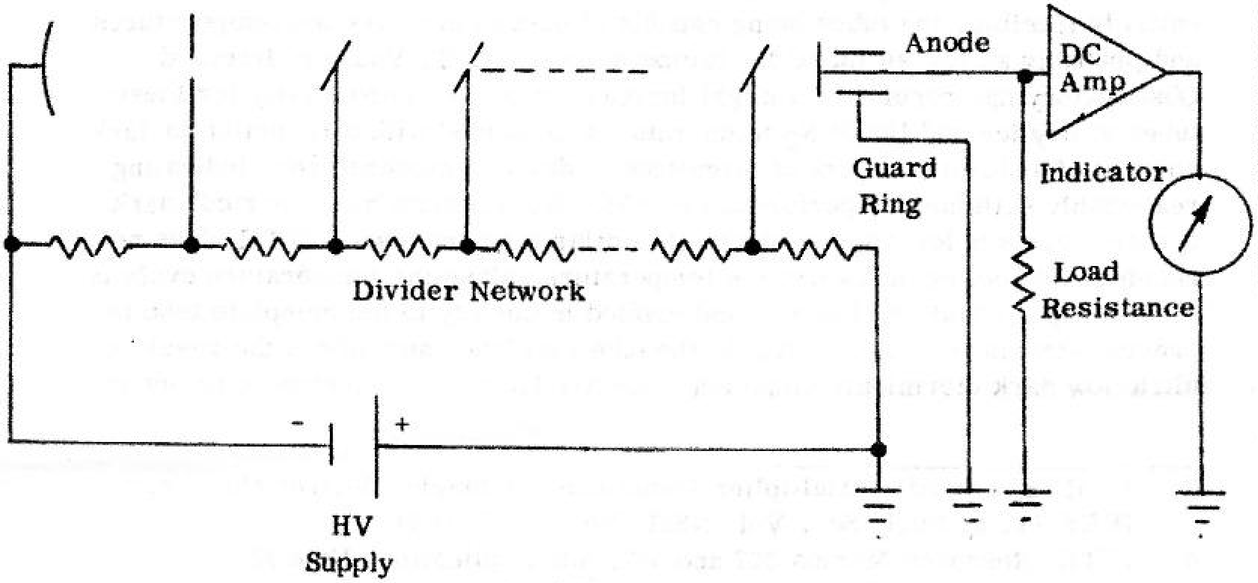

Figure 3 Typical Multiplier Phototube Circuit Using Guard Ring Electrode

Figure 2 shows a sketch of one type of laboratory cooling test equipment used by ITTIL. The cooled dry gas cools the tube faceplate and thus the photocathode by direct thermal contact, while the warm dry gas keeps the outer window from frosting. For field purposes, thermoelectric photocathode coolers of moderate cooling capability may be entirely adequate.

A recent and unique step taken by ITTIL to minimize internal tube leakage current and therefore improve both the room temperature and cooled dark current-dark noise characteristics, is the addition of an internal guard ring electrode surrounding the anode pin. This guard ring, when operated at quiescent DC anode potential as shown in Figure 3, bypasses surface leakage current around the anode pin and reduces the resultant minimum DC current levels to the order of 10^{-12} amperes or less. If so desired this guard ring can be voltage-driven in the more sophisticated types of feedback electrometer circuits.

For ultra-low light level detection problems, ITTIL normally recommends the use of single electron counting techniques[3,4]. By individually counting the comparatively large pulses produced in the anode circuit of multiplier phototubes resulting from single photoelectrons from the photocathode and biasing off the smaller pulses resulting from leakage current, dynode emission, etc., maximum differentiation between signal and dark noise can be achieved.

Further cooling of ITTIL tubes below the levels shown in Figure 1 is entirely feasible, the tubes being capable of operation at dry ice temperatures and probably as low as liquid N_2 temperatures. A. T. Young of Harvard Observatory has reported[5] a slight increase in over-all sensitivity for these tubes at dry ice and liquid N_2 temperatures combined with a reduction in dark current of at least 5 orders of magnitude at dry ice temperatures, indicating reasonably satisfactory performance, while W. A. Baum has reported[6] dark counting rates below 10 per minute at similar temperatures. ITTIL does not recommend cooling below dry ice temperature unless the temperature cycle is slow enough (a matter of hours) and applied uniformly to the complete tube to prevent strains from developing in the tube envelope, and unless the resultant ultra-low dark thermionic emission rates are known to be desirable (in many

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[3] E. H. Eberhardt, "Multiplier Phototubes for Single Electron Counting", IEEE Tr. of Nucl. Sc., Vol. NS11, No. 2, 48, 1964.

[4] ITTIL Research Memos 367 and 387, and Applications Note E5.

[5] A. T. Young, Applied Optics, Vol. 2, 51 (1963).

[6] W. A. Baum, Vol. II, Astronomical Techniques, U. of Chicago Press, 1962, page 28.

applications, background light flux, present on the photocathode in the absence of the signal flux to be detected, radioactive content of the tube parts, and other dark noise sources may normally cause much more noise than photocathode thermionic emission).

The example reported by Baum in which a cooled ITTIL 16 PMI (predecessor of the present FW-118) was operated at a dark counting rate of less than 10 electrons/minute is particularly interesting. Referred to the anode circuit, under the assumption of a gain of 10^6 in the electron multiplier, this is equivalent to less than 3×10^{-14} amperes, a value well below the expected anode leakage current limits. If these 10 dark counts/minute were randomly distributed, as expected, the statistical uncertainty for a one minute observation time would have been $\sqrt{10} \cong 3$ photoelectrons, equivalent to about 13 input photons/second or a total of 750 photons in 1 minute for a peak quantum efficiency of 0.4 percent in the corresponding S-1 photocathode at 8000 Å. The ability to detect flux levels of this magnitude (approximately 3×10^{-18} watts) using single electron counting techniques with a cooled FW-118 multiplier phototube demonstrates the unique capabilities of this detector.

Cooling characteristics of S-11 and S-20 type multiplier phototubes (such as the ITTIL FW-129 and FW-130 types), are not shown in Figures 1 and 2 because of the difficulty in making reliable measurements at the dark emission rates involved. For example, a total thermionic dark count rate of only 30 electrons/second at room temperature was observed[3] in one sample ITTIL FW-129 tube. This magnitude is believed to be typical of present S-11 and S-20 tubes. Based on tentative experimental measurements it is believed that these thermionic emission dark current count rates will also fall rapidly with cooling.