124
2-21-78

Lh. 1852

LA-7022-MS
Informal Report

UC-34c
Issued: February 1978

MASTER

Calibration of a Detector for Pulsed Neutron Sources

L. R. Veeser
A. Hemmendinger*
E. R. Shunk

*Consultant.

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

CALIBRATION OF A DETECTOR FOR PULSED NEUTRON SOURCES

by

L. R. Veeser, A. Hemmendinger, and E. R. Shunk

ABSTRACT

A scintillator detector for measuring the strength of a pulsed neutron source is described and the problems of calibration and discrimination against x-ray background for both pulsed and steady-state detectors are discussed.

I. INTRODUCTION

Some recent investigations required measurement of the number of neutrons from a point source following a burst of x rays that preceded the neutron pulse by one or more microseconds. The neutron pulse lasted a few nanoseconds. This is longer than the response time of a liquid or solid scintillator, but comparable to that of fast, 127-mm photomultipliers.

Let us assume that the maximum usable sensitivity for counting neutrons from a central 14-MeV source corresponds to 20 n falling on a scintillator. Although 1 n may make a detectable pulse, we know from experience that with 10 n interacting in the detector the uncertainty is about ±50%. Therefore, we can predict that the smallest measurable isotropic source is about 2.5×10^4 for a 10^4-mm^2 fluor at a distance of 1 m. We found that for a nearly coincident x-ray pulse such a detector system was so overloaded by the x rays that the system was inoperative during the neutron pulse. In this report we describe the techniques for using and calibrating a pulsed detector that has low sensitivity during the x-ray pulse, but normal sensitivity during the neutron pulse.

II. INSTRUMENTATION

A. Scintillator

We used a plastic scintillator detector similar to one that the Los Alamos Scientific Laboratory (LASL) has used for several years to measure neutron yields. It is a 15-cm-diam by 13-cm-long cylinder of Pilot-F plastic mounted on an RCA-4522 photomultiplier. One face of the fluor was spherical to fit the glass envelope of the photomultiplier. An aluminum case with a 6.4-mm wall fit loosely over the fluor. The fluor was painted with magnesium oxide suspended in lacquer to increase reflectivity at its surface. The small gap between the photomultiplier and fluor was filled with optical coupling compound. A rubber boot light-sealed the photomultiplier at the base.

B. Tube Sockets

We provided the photomultiplier with either a gated or an ungated negative high-voltage tube base. Circuit details of the tube sockets are given in the Appendix. The standard (ungated) tube base, similar to that described by RCA[1] as appropriate for "high-peak current applications," was modified to permit measurement of the signals on dynodes 10 and 14. Although the dynode signals were not used for general recording of data, they were used for preliminary diagnostic and calibration work.

For a 1-ns radiation pulse, the detector signals had risetimes of about 5 ns and widths (FWHM) of 20 ns, fast enough to separate x-ray and 14-MeV-neutron signals (16.7 ns/m different) in distances of a few meters.

C. Calibration

We used an indirect calibration because we had no calibrated pulsed source of 14-MeV neutrons. We exposed a detector to neutron beams from a Cockcroft-Walton accelerator, monitored absolutely by counting the associated alpha particles, and recorded the pulse height distribution. Using the same amplifier gain, we compared this distribution with that produced by ^{60}Co gamma rays so that we would have a convenient reference in the field. We then calculated the efficiency for 14-MeV neutrons,

$$\epsilon = \frac{\text{total number of counts(n)}}{\text{total number of neutrons on detector (N)}} ,$$

and $\bar{p}$, the average pulse height in the neutron-induced pulse distribution. The average pulse height per incident neutron is then $\eta = \epsilon\bar{p}$. The quantity η is relatively insensitive to changes in the setting of the lower pulse limit (bias) of the pulse distribution. A bias is essential to discriminate against noise, but in a single pulse measurement of a strong source, the average noise is zero and the smaller neutron pulses add only a small amount to the measured signal. Therefore, the error in η introduced by extrapolating the neutron pulse height distribution to zero is small even though both ϵ and $\bar{p}$ are sensitive to errors in the extrapolation.

Figure 1 shows the measured pulse height spectra for 14.2- and 2.45-MeV neutrons and for ^{60}Co gamma rays. The unit pulse height was chosen to be the pulse height of the upper side of the ^{60}Co peak where the intensity has dropped to half that of the peak intensity. We refer to this pulse height as the Compton edge. For 14-MeV neutrons, $\bar{p} = 1.98$ pulse height units and $\epsilon = 0.51$; for 2.45-MeV neutrons, $\bar{p}$

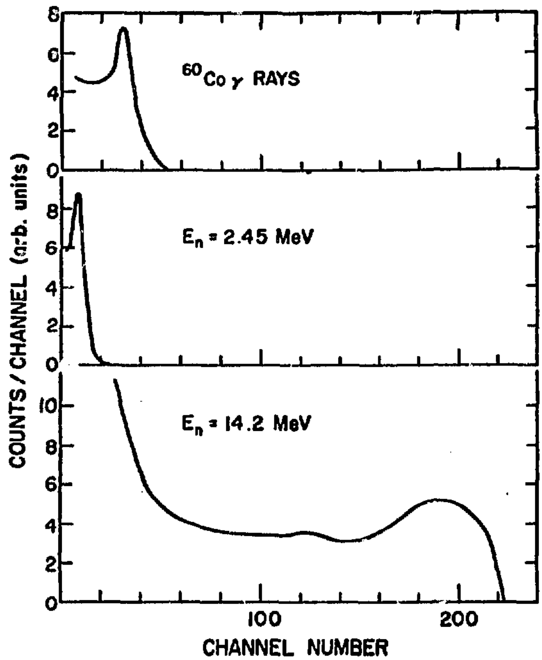


Fig. 1.

Pulse height distributions of ^{60}Co gamma rays and 2.45- and 14.2-MeV neutrons.

$= 0.227$ and $\epsilon = 0.56$. Thus, $\eta = 1.01$ at 14 MeV and 0.127 at 2.45 MeV.

Because η depends mainly on a detector's composition and geometry, rather than on operating conditions, we were able to recalibrate our detectors in the field by using a ^{60}Co source to define the unit pulse height. By using the same material and geometry for all detectors, we avoided having to calibrate each detector at the Cockcroft-Walton accelerator.

Because the detectors, at 1200 V, could measure only several thousand neutrons per pulse resolution time without being saturated, the source-to-detector distance was determined by the expected output and duration of the neutron yield. Source-to-detector distances >50 m were physically unmanageable, so we often had to reduce the gain even further (when a large neutron output was expected) by placing neutral density filters between the scintillator and photomultiplier. Filters with a gain reduction of more than a factor of about 10 gave such a poor resolution of the ^{60}Co spectrum that it was difficult to use the source for calibration; such detectors had to be calibrated relative to a detector with no filter by pulsing them with an accelerator, and the advantages of field calibration with a gamma-ray source were lost.

To cover a large sensitivity range, we operated the photomultipliers at 1200 and 1800 V. We measured the gain change for each photomultiplier and tube base by flashing a light-emitting diode (LED) that was inside the detector. Signals were recorded as a function of high voltage for identical LED outputs. A typical photomultiplier gain was about 150 times larger at 1800 V than at 1200 V.

The LED was also used to measure tube linearity. More useful in linearity measurements, however, was a xenon light flasher, whose output was large enough to be monitored with a photodiode. A set of neutral density filters was used to change the intensity of light reaching the detector. A typical detector, with its output terminated by 50 Ω and a high-voltage setting of 1200 V, was linear for anode signals ≲250 mV, but it became increasingly saturated for larger outputs. By measuring each detector's response curve before using it, we could obtain useful data even if the detector was saturated somewhat during the measurement. Figure 2 shows a set of response measurements. The points are

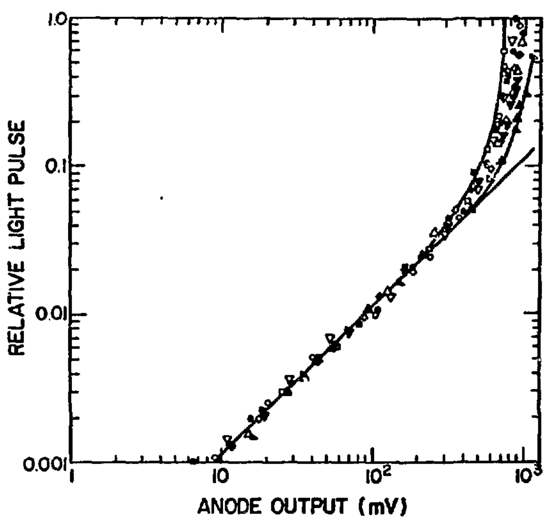


Fig. 2.
Photomultiplier response curves showing linearity range for 11 RCA-4522 tubes.

measurements for various detectors, and the curves show the linearity range.

The photomultiplier tube bases were designed to produce the largest possible signal without saturating. The output signal was taken directly from the anode, without a coupling capacitor, to minimize the detector's response time and to allow it to recover from the source x-ray signal in time to measure the neutrons.

III. PROCEDURE

A. Low Background

Calibrations were made by photographing on Polaroid film many oscilloscope traces from ^{60}Co. Neutron measurements were recorded by photographing oscilloscope traces of 2- to 5-μs duration. To cover a wide signal range, we used several traces for each detector. Although a signal could not be >250 mV without some saturation, we extended coverage up to 1 V, with the intention of correcting the results should the neutron output be that large. Because noise levels were typically a few millivolts, we did not use sensitivities >5 div/mV.

To learn whether satisfactory measurements could be made with fewer oscilloscopes, we recorded signals from one experiment using a LASL Model 50 logarithmic amplifier.[3] Although these results were more difficult to analyze, they agreed with the unamplified results.

B. High Background

Measurements of neutron fluxes in the presence of x-ray backgrounds were much more difficult to record than those without background. In one experiment neutrons were produced about 1 μs after the x-ray pulse, and the x-ray signals were usually about 60 times larger than the neutron signal. The continuously active detector described in Sec. II.A would work only if placed far from the source and shielded with several centimeters of lead. Even then the photomultiplier was so saturated by the x-ray pulse that it would not recover within 1 μs, and the resultant neutron signal had to be corrected for attenuation caused by tube saturation. For experiments where a low expected yield required that we place the detector closer to the source, the detector was too saturated to be of any use.

We partially solved the detector saturation problems by using Fullwood's[9] direct-coupled, negative high-voltage version of a gated tube base. The gated base can be turned on with a risetime of 20 ns; when gated off, its gain is >1000 times smaller than when gated on. The base is gated off by inverting the potential differences between several pairs of dynodes early in the chain. By this means the electron beam is defocused before it becomes very large, and the photomultiplier does not have the large currents that normally result from a large scintillator light pulse.

The gate was timed to turn the tube on during the 1-μs period between the x-ray pulse and the neutron output. To allow the scattered radiation and the scintillator output to decay, we would gate the tube on as late as possible after the x-ray pulse while still allowing enough time for the tube to turn on completely before the earliest possible neutron signal.

Before running an experiment, we measured the amount of attenuation that the neutron signal would suffer from the nonrecovery of the tube by using a pulsed 14-MeV neutron source (zipper) to simulate the expected signal. The zipper was placed near enough to the detector to produce a signal about as large as that expected from the experiment, and it was timed to give a signal at the same time after the x-ray pulse as the expected neutrons. Measurements of the zipper neutron pulses (which were assumed to be identical) with and without an x-ray pulse gave the attenuation factor.

The amount of attenuation depended on the x-ray intensity in the detector and on the time between the x-ray pulse and the neutron pulse. When the neutron pulse occurred 1 μs after the x-ray pulse, we turned on the photomultiplier gate midway between the two signals. Detectors placed 90° to the x-ray axis about 5 and 15 m from the x-ray source were shielded with 10 cm of lead around the sides and 5 cm in front. Immediately after turn-on, the detector 5 m from the source had a residual signal of 600 mV with an exponential decay time of 1.5 μs, and the neutron pulse was completely obscured. When we delayed the zipper neutrons an additional 0.5 μs, we could barely see their pulse; a delay of 2.0 μs after the x rays gave a neutron pulse about four times smaller than without x rays. For the detector 15 m from the source, the residual pulse height at turn-on 0.5 μs after x rays was 250 mV, and the attenuation of the neutron pulse 1 μs after x rays was <20%.

IV. ANALYSIS OF RESULTS

We analyzed the film recording of an oscilloscope trace by enlarging the photograph and using a planimeter to measure the area below the trace between the time limits of interest. For the ^{60}Co signals, we integrated in the same way a trace that went slightly higher than those in the most intense part of the peak to approximate the upper edge of the Compton peak, which provided the scale for calibration of the detector at the Cockcroft-Walton accelerator. Both integration results were measured in millivolt-nanoseconds.

The number of neutrons emitted by the source was

$$N_o = \frac{S_n G}{S_\gamma \eta} \times \frac{4\pi}{\Omega} ,$$

where S_n is the area under the neutron peak, S_γ is the area under the ^{60}Co trace representing the Compton edge, G is the ratio of the detector gain at 1800 V to that at 1200 V (or at whatever detector voltages were used in the measurements), η is the pulse height per incident neutron (in units of the ^{60}Co Compton edge) for the neutron energy of interest, and Ω is the solid angle subtended by the detector. We also had to correct N_o to account for any loss of neutrons from scattering in the air in the flight path, and from scattering in the shielding, if any, in front of the detector. This correction was at most 20%.

Systematic errors associated with calibration of the detector include measurements of the output per neutron, dependence of gain on high voltage, and linearity of the detector. Random errors arise from (a) statistical fluctuations in the number of neutrons interacting with the detector and in the energies of the particles the neutrons produce, (b) errors in measuring the areas under the curves and the solid angle subtended by the detector, and (c) drifts in the gain of the detectors.

Systematic uncertainties in the measurement are estimated to be ±20%. The largest uncertainty is that resulting from measuring the detector efficiency and response at the Cockcroft-Walton accelerator. Verbinski et al.[4] made similar measurements for a 5-cm-long by 5-cm-diam cylindrical scintillator of NE-213 liquid. By adjusting their 14-MeV results for the different size and composition of the detectors, we were able to estimate the quantity $\bar{\rho}$ for our detector; this estimate agreed with our measurement within ±10%.

Random errors from integrating the oscilloscope photographs depend on the quality of the recordings and on the background under the neutron peak. These errors are estimated to range from 2 to 20%. Effects of gain drifts in the detector system and errors in measuring the detector solid angle were assumed negligible.

To estimate the statistical uncertainties, suppose that the (normalized) response ρ of a detector with efficiency ϵ to a neutron of energy E_o has a probability distribution $\epsilon\phi(\rho,E_o)$. The average output per detected neutron is $\bar{\rho} = \int_0^\infty \rho\phi(\rho,E_o)d\rho$. For an ideal proton recoil detector the response function is

$$\phi(\rho,E_o) = \begin{cases} 1/\rho_o \text{ for } 0 \leqslant \rho \leqslant \rho_o \\ 0 \text{ otherwise} \end{cases} ,$$

and the output per detected neutron in the ideal detector is $\bar{\rho} = \rho_o/2$, where ρ_o is the response to a proton recoiling with energy E_o. If a detector subtending a solid angle Ω observes a burst of N_o neutrons of energy E_o, the mean number of neutrons that will strike the detector will be $N = N_o\Omega/4\pi$. The probability that n neutrons will interact in the detector is $W(n) = (\epsilon N)^n e^{-\epsilon N}/n!$, the Poisson distribution. The total detector output is

$$\rho_T = \sum_{n=o}^{\infty} \int_0^\infty \rho\phi(\rho,E_o)d\rho \; n\,W(n) = \epsilon N\bar{\rho} = N\eta \quad .$$

The fluctuation in the number of neutrons that interact in the detector contributes to the variance in ρ_T

$$\sigma_N{}^2 = \sum_{n=o}^{\infty} (n\bar{\rho} - \rho_T)^2 W(n) = \epsilon N\bar{\rho}^2 \quad .$$

(For the familiar case, such as charged-particle detection, where $\epsilon = 1$ and the size of the signal is $\rho = \bar{\rho}$ for each incident particle, $\Delta\rho_T = \sigma_N = \bar{\rho}\sqrt{N}$ and $\Delta\rho_T/\rho_T = 1/\sqrt{N}$.) The contribution to the variance by the range in possible detector output for a given detected neutron is

$$\sigma_\rho{}^2 = \int_0^\infty \left[\sum_{n=o}^{\infty} (\rho - \bar{\rho})^2 \phi(\rho,E_o) n W(n) \right] d\rho$$

$$= \epsilon N \int_0^\infty (\rho - \bar{\rho})^2 \phi(\rho,E_o) d\rho \quad .$$

For the ideal detector, $\sigma_\rho^2 = \epsilon N\bar{\rho}^2/3$ and $\sigma_N^2 + \sigma_\rho^2 = 4\epsilon N\bar{\rho}^2/3$. Thus, to first approximation, $\Delta\rho_T/\rho_T = \sqrt{4/3\epsilon N}$ for the ideal detector.

Because of nonlinearity of the light output as a function of the energy deposited, combined with multiple scattering of neutrons, neutron interactions with carbon atoms, recoil protons leaving the edges of the scintillator, and energy resolution of the detector, the response of the real detector differs from that of the ideal detector. In estimating uncertainties we assume that η, the pulse height per incident neutron, is the same for the real detector as for some ideal detector of unknown geometry and efficiency. We know from the response function of the real detector (see Fig. 1) that $\bar{\rho} < \rho_o/2$. Thus, to calculate the uncertainty, we substitute the quantity $\epsilon' = 2\epsilon\bar{\rho}/\rho_o \cong 0.40$ for the 14-MeV efficiency ϵ. The resultant relative uncertainty in the signal is $\Delta\rho_T/\rho_T = \sqrt{4/3\epsilon' N} \cong \sqrt{10/3N}$ for this particular detector at 14 MeV. For 20 n falling on the scintillator, $\Delta\rho_T/\rho_T = 41\%$, which is expected (see Sec. I). Optimally we would arrange to have enough neutrons to make the statistical uncertainty in a measurement $\lesssim 3\%$.

V. CONCLUSION

We have measured the number of neutrons from point sources, both in a background-free environment and in a nearly coincident x-ray background. The upper sensitivity limit is set by the requirement that 20 n fall on the scintillator. The lower sensitivity limit is defined by saturation of the photomultiplier, typically at 5 mA into a 50-Ω load. The allowed detector distance defines the r^{-2} attenuation, and the use of a neutral density filter to attenuate light falling on the photomultiplier is limited to an attenuation of 10. A factor of 150 decrease in photomultiplier gain is achieved by decreasing the high voltage applied to the tube.

With the detector described here, we could measure a source of 10^{12} n at 50 m. For slower pulse measurements, the upper source strength limit can be increased by observing one of the dynode signals, with suitable smoothing, instead of the anode signal.

REFERENCES

1. RCA Tube Handbook HB-3, Photosensitive Device Section, Type 4522, Data 5, Radio Corporation of America, Commercial Tube Division, Harrison, New Jersey (1968).

2. Los Alamos Scientific Laboratory, "Fast Bipolar Log Amplifier, Model 50," Drawing No. 4Y-89787 (1972).

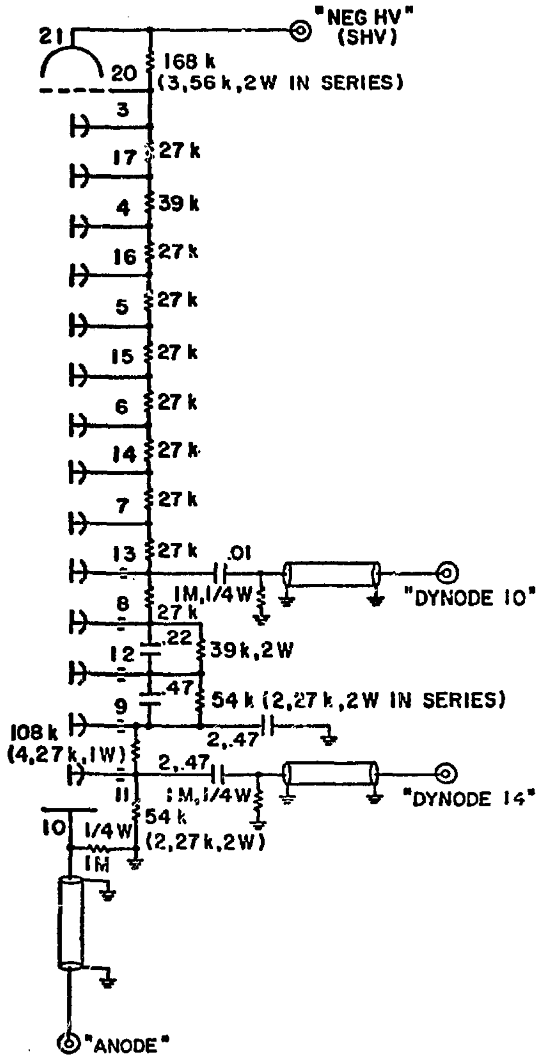
3. R. R. Fullwood, "A Bistable Symmetrical Photomultiplier Gate Using Integrated Circuits," Nucl. Instrum. Methods 95, 509 (1971).

4. V. V. Verbinski, W. R. Burrus, T. A. Love, W. Zobel, N. W. Hill, and R. Textor, "Calibration of an Organic Scintillator," Nucl. Instrum. Methods 65, 8 (1968).

APPENDIX

CIRCUIT DETAILS OF TUBE SOCKETS

The ungated tube base, arranged for high-peak currents and provided with 10 and 14 dynode signal outputs,[1] is shown in Fig. A-1. The gated tube base, similar to that described by Fullwood[3] except with direct-coupled output, is shown in Fig. A-2.



ALL RESISTOR 1W 5% COMPOSITION UNLESS INDICATED.

Fig. A-1.
Ungated tube base for RCA-4522 photomultiplier with direct-coupled output.

D1-4, 7, 8	*1N645*		*Q5, 6*	*2N3904*
D5, 6	*1N4729A*	*3.6 V Zener*	*T1, 2*	*Technitrol 11 NGB*
D9, 10	*1N4372A*	*3.0 V Zener*	*I.C.1, 2*	*MC810G (Motorola)*
D15-17	*1N4764A*		*R1, 2*	*200 kΩ*
Q1, 2	*2N3645*	*PNP*	▭	*Ferrite sleeve*
Q3, 4	*2N3643*	*NPN*		

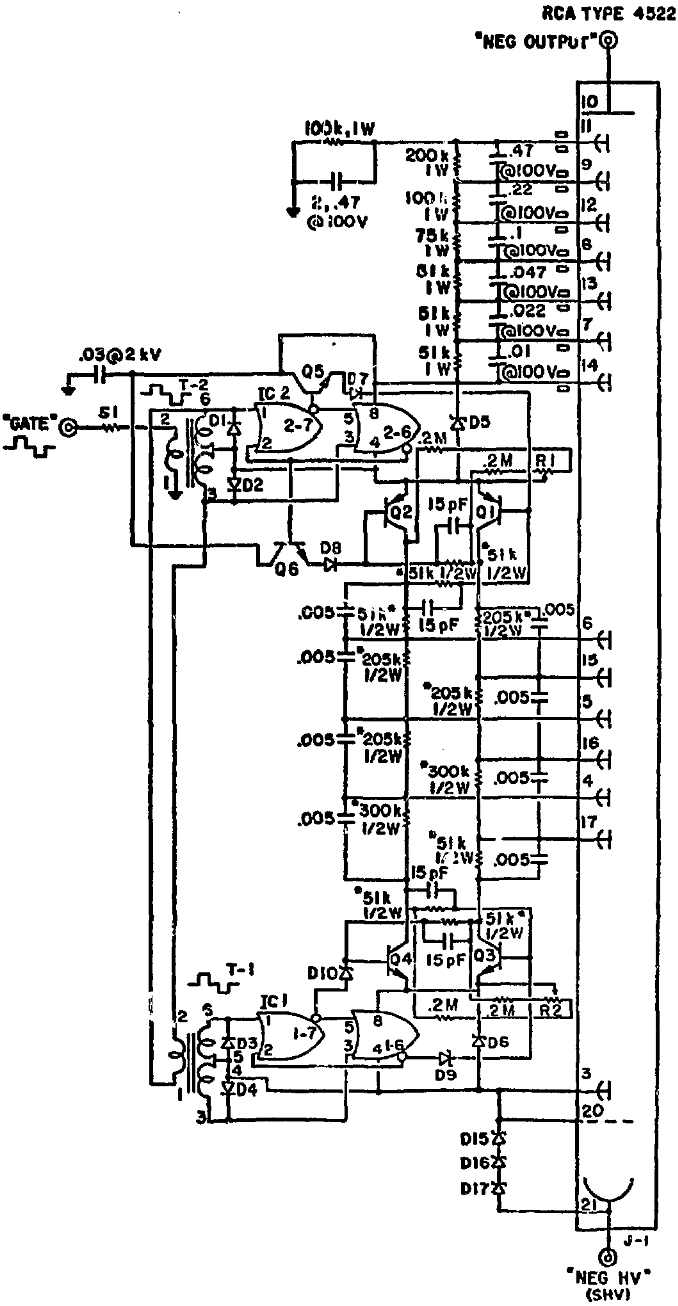


Fig. A-2.
Gated tube base.