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PERFORMANCE EVALUATION OF POSITION-SENSITIVE PROPORTIONAL COUNTERS*

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Abstract

Engineering services, including a test facility and procedures, were established to evaluate the performance of RC-line encoded position-sensitive proportional counters (PSPCs) by measuring linearity, sensitivity, spatial resolution, and energy resolution. Engineering support and technical assistance are provided to an increasing number of users of these PSPCs, and, therefore, these services bridge the gap between the PSPC development engineer and the users of this new technology at ORNL.

Introduction

A specialized engineering and test service was established to evaluate the electronic performance of RC-line encoded, position-sensitive proportional counters (PSPCs)[1] at Oak Ridge National Laboratory (ORNL). With many PSPCs in use and more being developed at ORNL, there is a need for this on-call service to assist scientists using the PSPCs. This service provides PSPC users with specialized technical assistance, develops techniques and procedures for evaluation of PSPCs, both in the shop and on-site, and prepares reports of repair and performance evaluation results. It also provides assistance during installation and initial testing of the PSPC at the user's site.

The instrumentation for this service is used mainly for performance evaluation of PSPC. When a PSPC is received from the field for modifications or repair, the same test instruments and cabling used for a previous evaluation of the PSPC can be used again, thus enabling a continuity of standardized test equipment and procedures.

The facility can evaluate most RC-line encoded PSPCs; e.g., one- and two-dimension, flow-through, single- or double-chamber, and high- and low-pressure counters. PSPC performance is evaluated by measuring spatial linearity and sensitivity, spatial resolution, and energy resolution.

Line PSPC Signal Flow Description

Only a one-dimensional, RC-line encoded PSPC and its associated instrumentation will be described (Fig. 1), because any two-dimensional PSPC is equivalent to two, orthogonal, one-dimensional RC-line encoded PSPCs.[2]

An ionizing event at point "x" on the PSPC produces an output pulse at each end of the RC-line; these two pulses have different shapes. The right end of the PSPC, as viewed from the direction of the ionizing source, is arbitrarily selected as the START channel signal origin.

The pulse from the START end of the PSPC is routed through a preamplifier and a linear amplifier for pulse shaping and amplification and then to a timing single-channel analyzer, where its crossover time delay is adjusted to the timing single-channel analyzer minimum. A START pulse is generated and routed to the START signal input of the time-to-amplitude converter.

The pulse from the STOP end of the PSPC is routed through a preamplifier, linear amplifier, and timing single-channel analyzer, where its crossover time delay is adjusted to produce pulses that always occur after the START pulses. A STOP pulse is generated and routed to the STOP signal input of the time-to-amplitude converter.

The elapsed time between the arrival of the START and STOP pulses at the time-to-amplitude converter produces an output pulse. Each period of elapsed time is uniquely related to a location along the RC-line, thus locating the site of the ionizing phenomenon.

Preliminary Considerations

Before a new PSPC is connected to the measuring instrumentation, the original voltage levels, waveforms, and instrument control positions specified by the PSPC development engineers should be reviewed. If the PSPC had been removed from the site of an experiment for a special, "in-shop" evaluation, or after the PSPC has been repaired, the record of the previous test set-up and results should be reviewed.

A visit to the experiment site prior to the removal of a PSPC can provide important operational information, such as the type and flow rate of the gas used with a flow-through PSPC, the type and energy of the ionizing agent (photon, neutron, or charged particle), the types and run locations of the high-voltage, low-voltage, and signal cables, and the levels of all power supply operating voltages.

The front-panel, rear-panel, and inside switch positions on each signal conditioning module should be recorded. The type of each signal conditioning module should be included on a diagram that also indicates all the interconnecting cables from the PSPC output to the input of the experiment data acquisition system.

The preceding information noted is especially important for setting up and evaluating a PSPC that was in service prior to establishment of this evaluation service. The site visit information is also helpful when a request to assist with a PSPC field installation is received.

Preliminary Set-Up

The PSPC is positioned on a grid covered workbench (Fig. 2). The grid facilitates the accurate and repeatable placement of the PSPC, radioactive source, and collimator.

A large bottle of P-10 gas (90% argon-10% methane) equipped with metering valves supplies flow-through gas to PSPCs that require it. The gas output port of the PSPC is connected by rubber tubing to a bottle of glycerine through which the gas is allowed to bubble. The gas is allowed to flow through the PSPC (depending on the volume) for 6 to 24 hours prior to the performance of any measurements. The glycerine is a visual flow rate indicator of the slowly flowing gas; it also prevents escape of the gas and prevents air from entering the PSPC when the metering valves are closed.

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The PSPC, power supplies, signal conditioning modules, and readout devices are all interconnected with appropriate types and lengths of cables. The front-panel, rear-panel, and interior switches of the signal conditioning modules and the potentiometers are adjusted to their required positions.

The line PSPC is placed on its side at a convenient location on the grid. The radioactive source is positioned so that its output is in the same horizontal plane as the PSPC RC-line center line and perpendicular to the PSPC midpoint. The source should also be placed far enough from the PSPC so that the entire length of the RC-line is flooded with ionizing events.

Measuring Techniques

Spatial Sensitivity

The purpose of this measurement is to verify the estimated value of the spatial sensitivity, $S = R_o C_{gt}$ (sec/mm). A method for measuring the RC-line anode resistivity, $R_o = R_t/L$ (Ω/mm) is illustrated in Fig. 3a. The total capacitance, $C_{gt} = C_oL + 2C_\ell$, consists of the total capacitance C_oL of the anode-cathode combination (Fig. 3b) plus the load capacitance C_ℓ (connector and preamplifier input) at each end of the RC-line (Fig. 3c).

Spatial sensitivity of the PSPC is measured by using a finely collimated (50 μ) radioactive source. The bias voltage is adjusted to an estimated operating value. The PSPC cabling is configured (Fig. 1) to route the START channel output signal to its linear amplifier and timing single-channel analyzer, and to the START input connection of the time-to-amplitude converter. The STOP channel output signal is routed to its linear amplifier and timing single-channel analyzer, and STOP input connection of the time-to-amplitude converter.

The potentiometer delay values for the START and STOP timing single-channel analyzers are recorded for later reference.

The collimated source is placed flush against the face of the PSPC so that the horizontal centerline of the RC-line and the collimator slot are perpendicular to each other.

The RC-line midpoint is located, and the collimated source is positioned precisely 5 cm to the left of the midpoint. The multichannel pulse height analyzer is configured to acquire the output from the time-to-amplitude converter for a preset period of time. When the period of acquisition has elapsed, the channel number of the peak, as shown by the pulse height analyzer display, is recorded.

The collimated source is repositioned precisely 5 cm to the right of the midpoint. A peak is acquired with the pulse height analyzer, and the channel number is recorded.

The delay potentiometer in the STOP channel, timing single-channel analyzer is adjusted while the pulse height analyzer is in the acquire mode. The "right" peak is precisely positioned with the delay potentiometer until the peak is displayed in the same channel as that where the collimated source was 5 cm to the left of the RC-line midpoint. The reading of the adjusted delay potentiometer is recorded.

The adjusted STOP channel delay potentiometer reading is subtracted from the original potentiometer. The ratio of the difference value (in nanoseconds) to the number of channels that separate the two peaks is the measured PSPC spatial sensitivity: S = nsec/mm.

The setting of the delay potentiometer in the STOP channel, timing single-channel analyzer is returned to its original value.

Spatial Linearity

The purpose of this measurement is to ensure that the spatial sensitivity S is independent of position.

Spatial linearity is measured by stepping a coarsely collimated (1 mm) radioactive source over the length of the RC-line while recording the peaks at each step on a multichannel pulse height analyzer calibrated in nanoseconds per channel.

The RC-line length is divided in each direction from the midpoint into five or more equally divided points. The collimated source is aligned at the designated point on the left end of the RC-line. A peak is acquired for a preset period of time, after which the collimated source is moved to the next point to the right, and another peak is acquired. This procedure is repeated for all the points selected. The peak channel number and the linear position in millimeters are recorded for each peak. The results are plotted (Fig. 4).[3]

Spatial Resolution

The objective of this measurement is to certify that the spatial resolution X_r (mm) specified by the user can be met. An indication of achieving the proper operating gas multiplication level to produce the desired resolution is observed by a set-up shown in Fig. 5. As the bias voltage is increased, the measuring instrumentation system oscilloscope will display a pulse (Fig. 6) originating from one end of the PSPC. The slope Δt/ΔV of the displayed pulse, at the baseline crossover, is directly related to the RC-line spatial resolution. This relationship can be seen in a formula[2] developed for this measurement:

$$X_r = 2.35\ V_n\ (\text{volts, rms})\ \frac{\Delta t}{\Delta V}\left(\frac{\text{sec}}{\text{volts}}\right) \frac{E_s}{E}\left(\frac{\text{keV}}{\text{keV}}\right)\frac{1}{S}\left(\frac{\text{mm}}{\text{sec}}\right),$$

where X_r is the user specified spatial resolution value, in millimeters; V_n is the system noise, in volts (rms) as measured with an rms voltmeter; Δt/ΔV is the desired slope, in seconds per volt; E_s is the energy of the evaluation test source, in keV; E is the energy of the user ionization agent, in keV; and S is the spatial sensitivity, in seconds per millimeter as provided or previously measured. If the bias voltage can be increased to produce the desired Δt/ΔV without breakdown, this value is the PSPC operating bias voltage. If breakdown does occur, the PSPC must be repaired.

The instrumentation is connected as shown in Fig. 1 for the spatial resolution measurement.

A finely collimated (50 μ) radioactive source is positioned at locations 2 mm on each side of the PSPC midpoint. Peaks at each of the two locations are acquired by the multichannel pulse height analyzer (Fig. 7).[4] The product of the distance (in millimeters) between the two peaks and the number of channels under one (either) of the peaks at full-width, half-maximum (fwhm), divided by the number of channels separating the two peaks, represents the PSPC spatial resolution X_r:

$$X_r = \frac{(\text{mm})(\text{ch's})}{\text{ch's}} = \text{mm} .$$

Energy Resolution

The best energy resolution is obtained with the minimum bias voltage required to meet the user-specified spatial resolution.

Energy resolution ΔE is measured by using a multichannel pulse height analyzer (MCPHA) and the instrumentation and source configuration as shown in Fig. 8. The PSPC summed output signals are acquired by the analyzer and displayed. The energy spectrum of the radioactive source is accumulated for a period of time that will allow "good statistics." A precision pulser is connected to the input of the linear amplifier in place of the PSPC summed signal. Two calibration peaks are acquired and displayed (Fig. 9). The pulser voltage level V and 2V, corresponding to each of the two pulses, is noted, along with the channel number of each pulser peak.

The energy resolution ΔE at fwhm[2] is

$$\Delta E_{fwhm}(\text{keV}) = \frac{E}{N_0 - 2N_1 + N_2} \Delta N ,$$

where E is the energy of the ionizing events used during the test, N_1 and N_2 represent the channel numbers of the two calibration peaks which are used to establish the zero intercept of a "volts-per-channel" slope, N_0 is the channel number of the zero intercept, and ΔN is the number of channels under the energy peak at fwhm.

Concluding Remarks

In the past year, numerous requests for assistance were handled. PSPC malfunctions varied widely, such as contaminated gas, preamplifier failure, excessive electrical noise, NIM bin power failure, and signal conditioning module failure. PSPC users benefit from this new, specialized service by having their requests for assistance handled promptly and by having a better operating PSPC system resulting from the assistance received during installation, initial testings, and follow-up checks. Another benefit all PSPC users share is that there is feedback to the PSPC development engineers about failures and malfunctions, which can be studied to develop new ways to upgrade in-service units and to improve new designs.

Even though this specialized service can handle outside requests for assistance, it serves mainly as a model for users and "commercial" organizations outside ORNL that might wish to establish a similar specialized support group.

References

1. C. J. Borkowski and M. K. Kopp, *Rev. Sci. Instrum.* 46, 951 (1975).
2. Private consultation with M. K. Kopp.
3. C. J. Borkowski and M. K. Kopp, *Rev. Sci. Instrum.* 39, 1515 (1968).
4. C. J. Borkowski and M. K. Kopp, *IEEE Trans. Nucl. Sci.* NS-17(3), 340 (1970).

Figure Captions

Figure 1. System for the performance evaluation of a line PSPC.

Figure 2. PSPC performance evaluation instrumentation and workbench.

Figure 3a. Anode dc resistance (R_t) measurement.

Figure 3b. Anode-cathode capacitance (C_o) measurement.

Figure 3c. PSPC connectors and preamplifier input load capacitance (C_ℓ).

Figure 4. Typical linearity test results (from Borkowski and Kopp[3]).

Figure 5. Slope $\Delta t/\Delta V$ measuring instrumentation.

Figure 6. Energy pulse and noise signals from one linear amplifier output.

Figure 7. Spatial resolution X_r obtained with 1-mm-separated collimated x-ray beams (from Borkowski and Kopp[4]).

Figure 8. Energy resolution measurement instrumentation.

Figure 9. Energy spectrum of calibration source and pulser peaks for measuring energy resolution.

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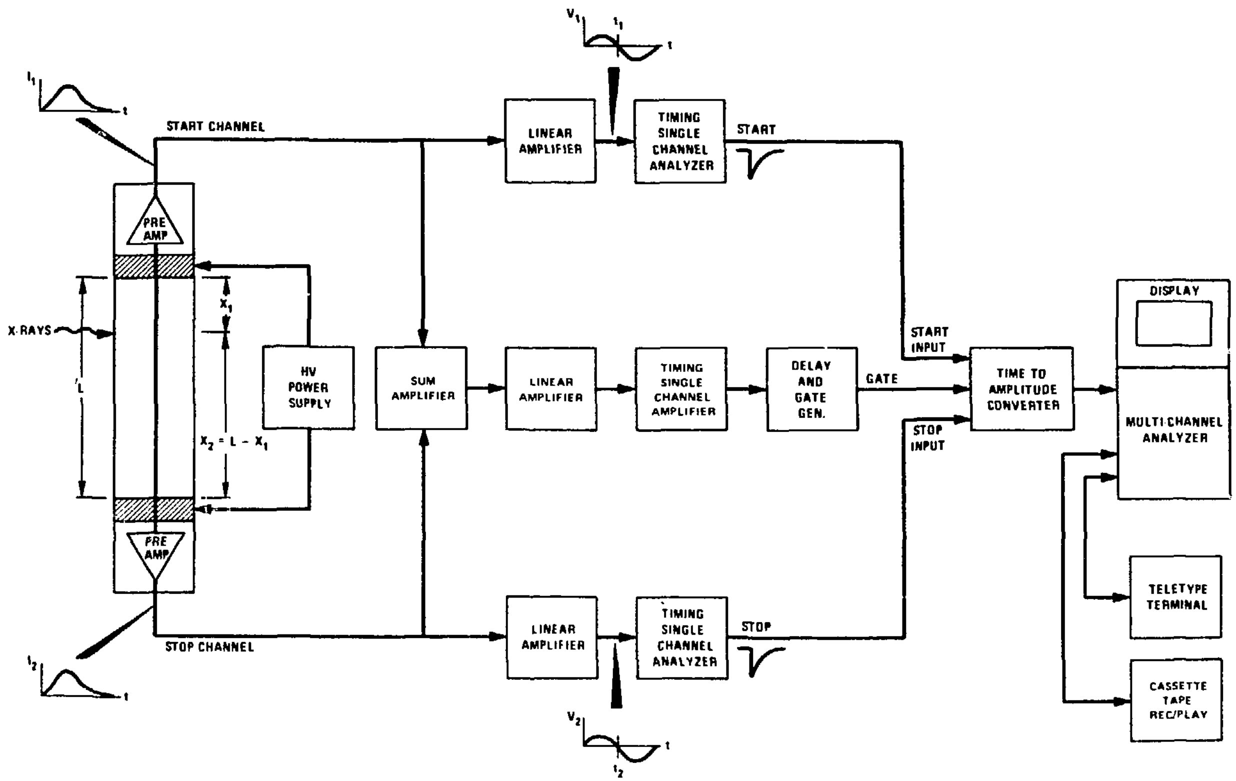

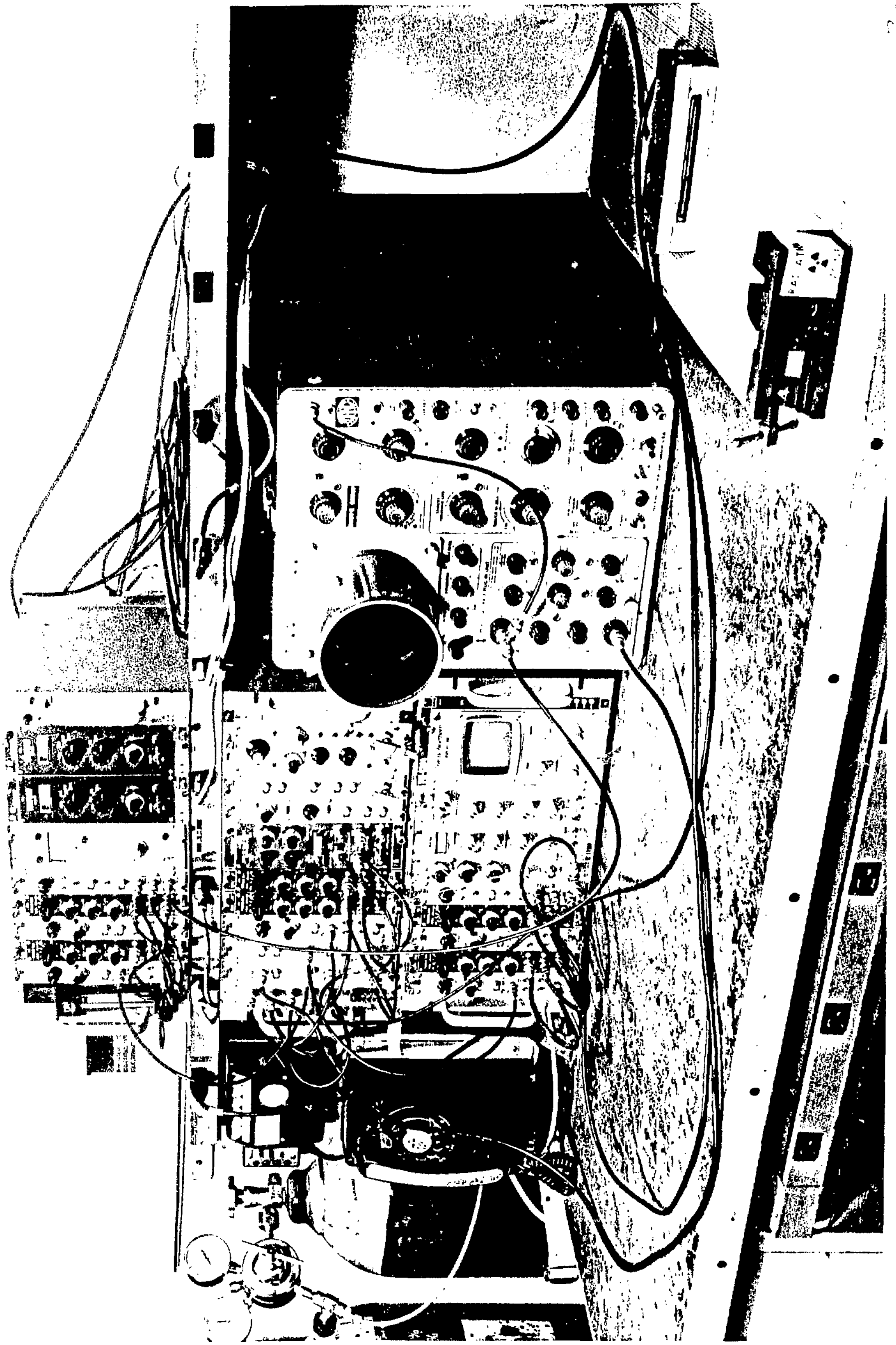

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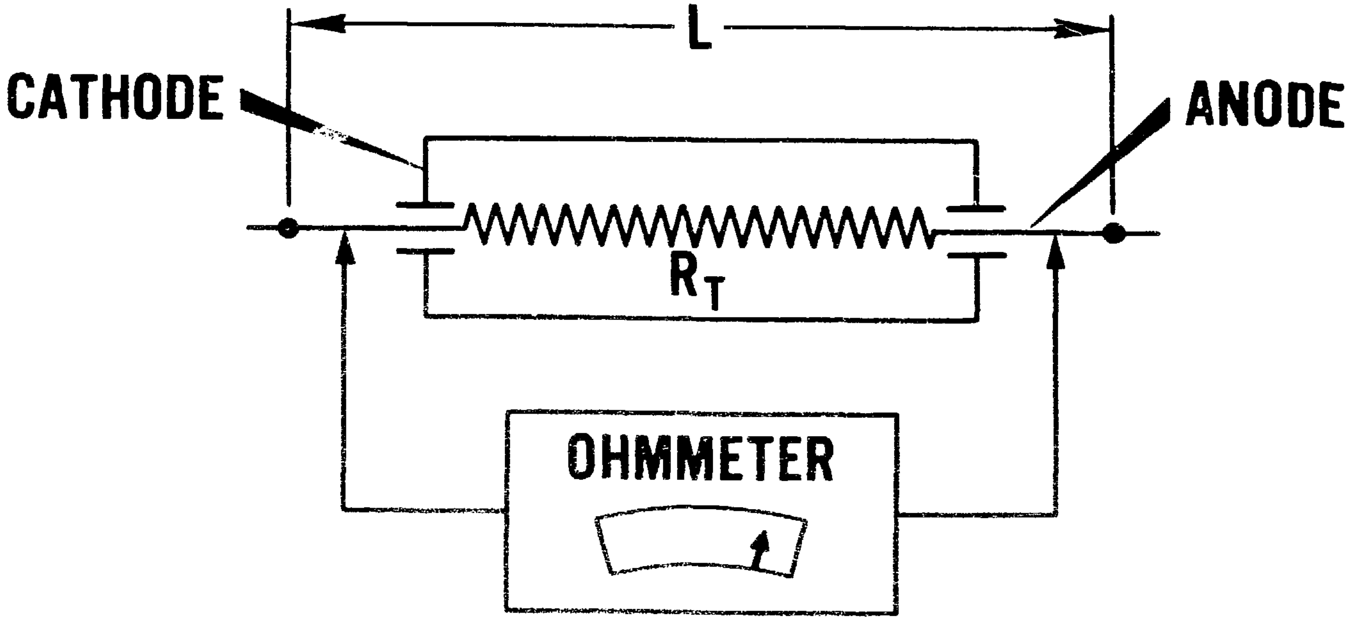

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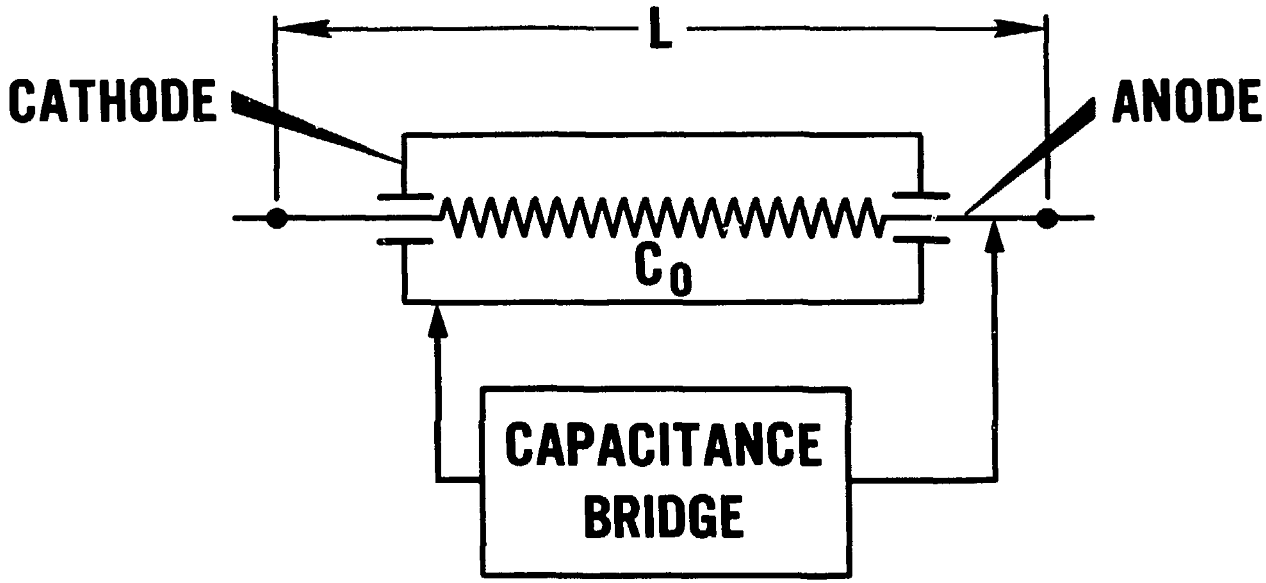

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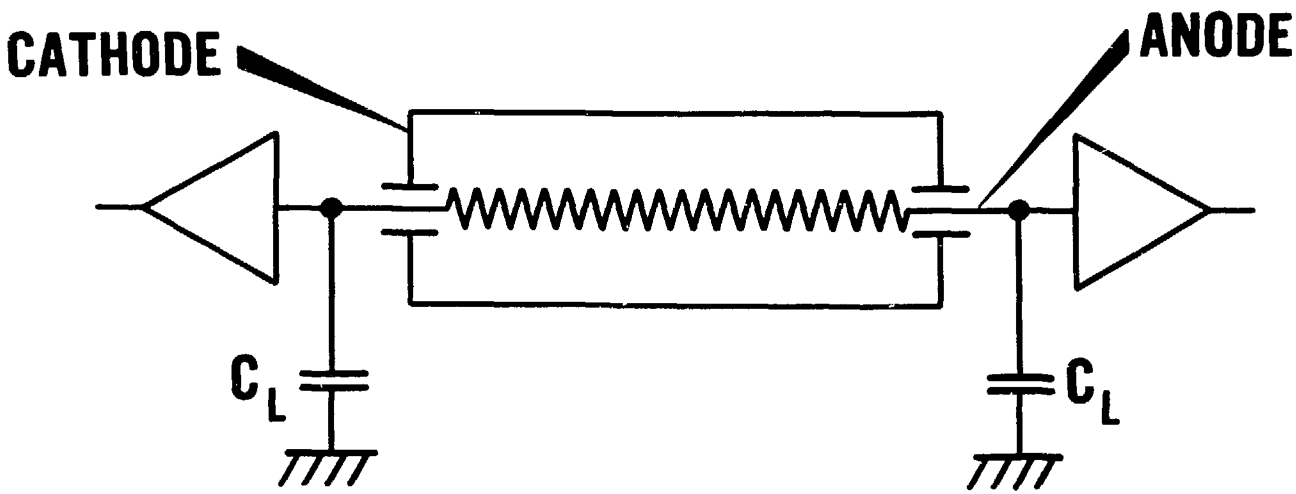

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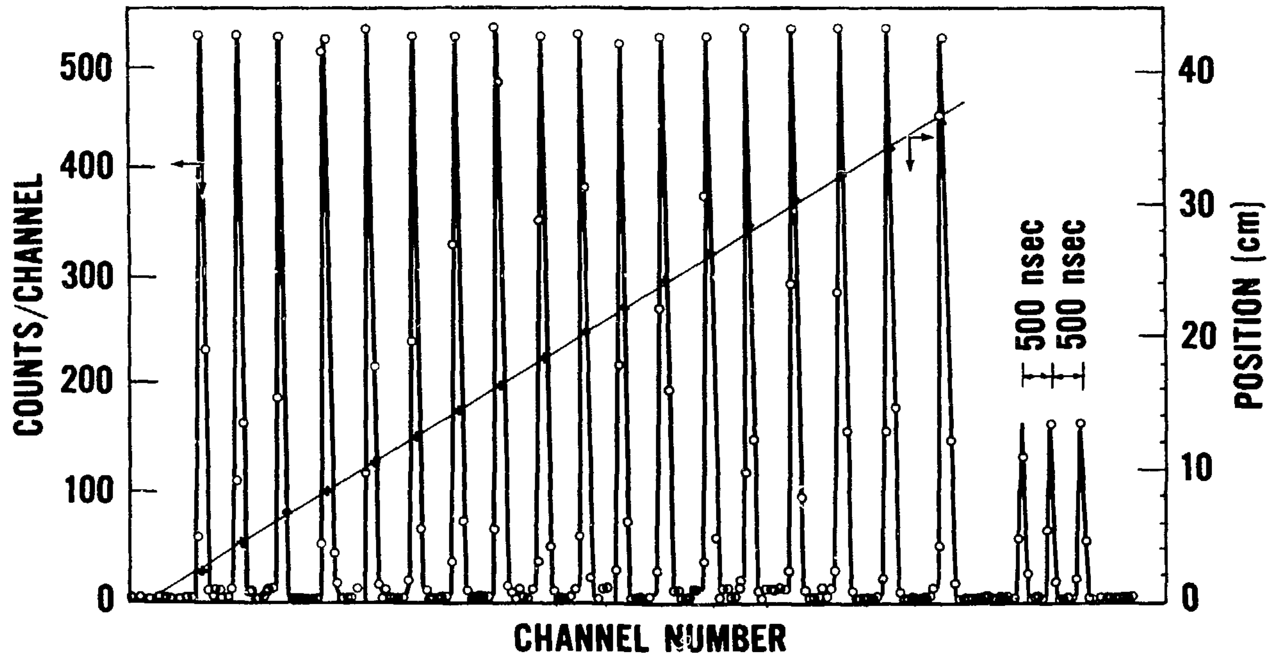

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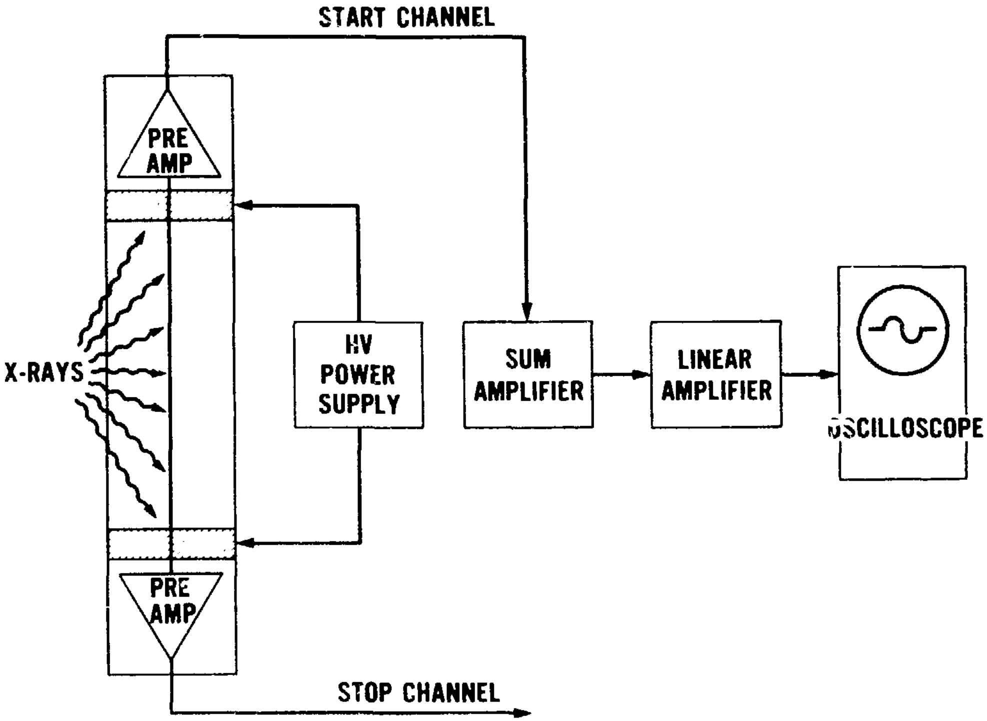

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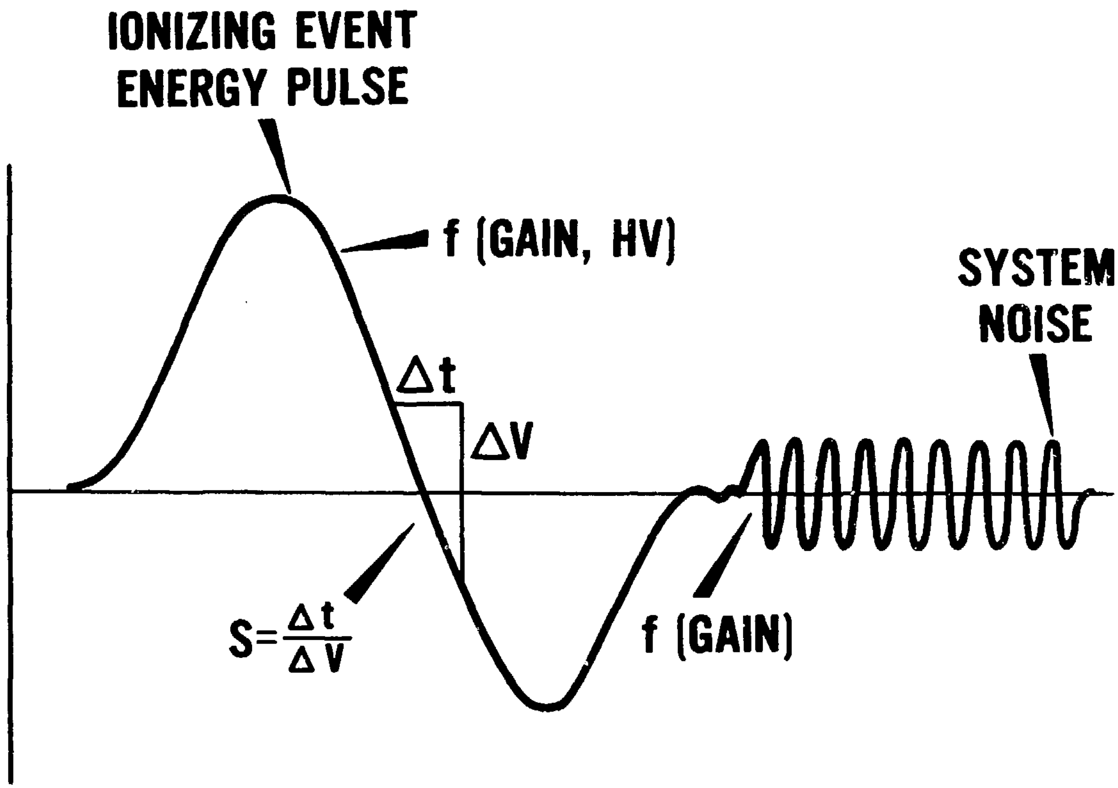

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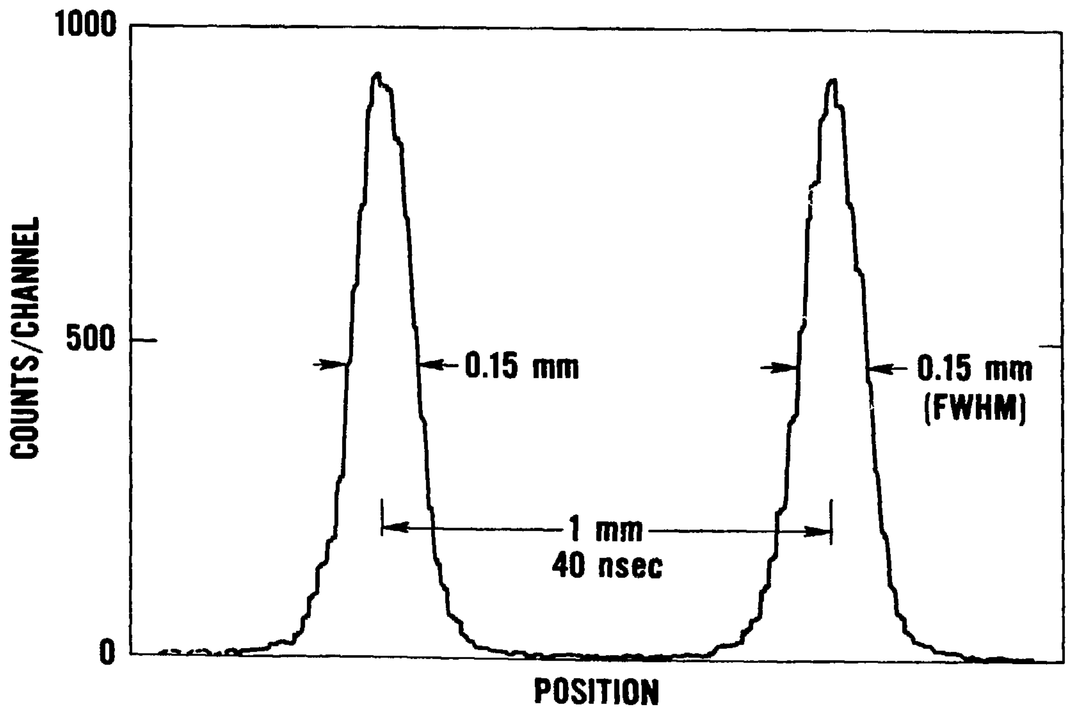

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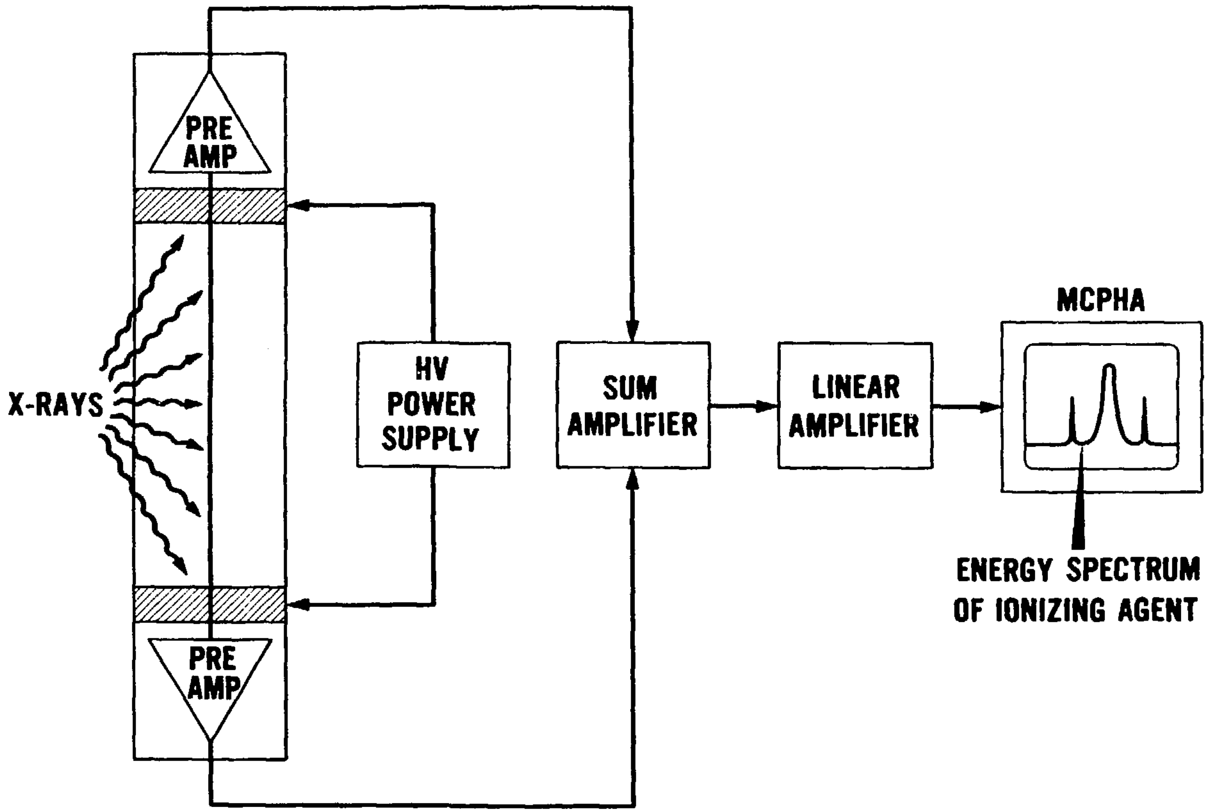

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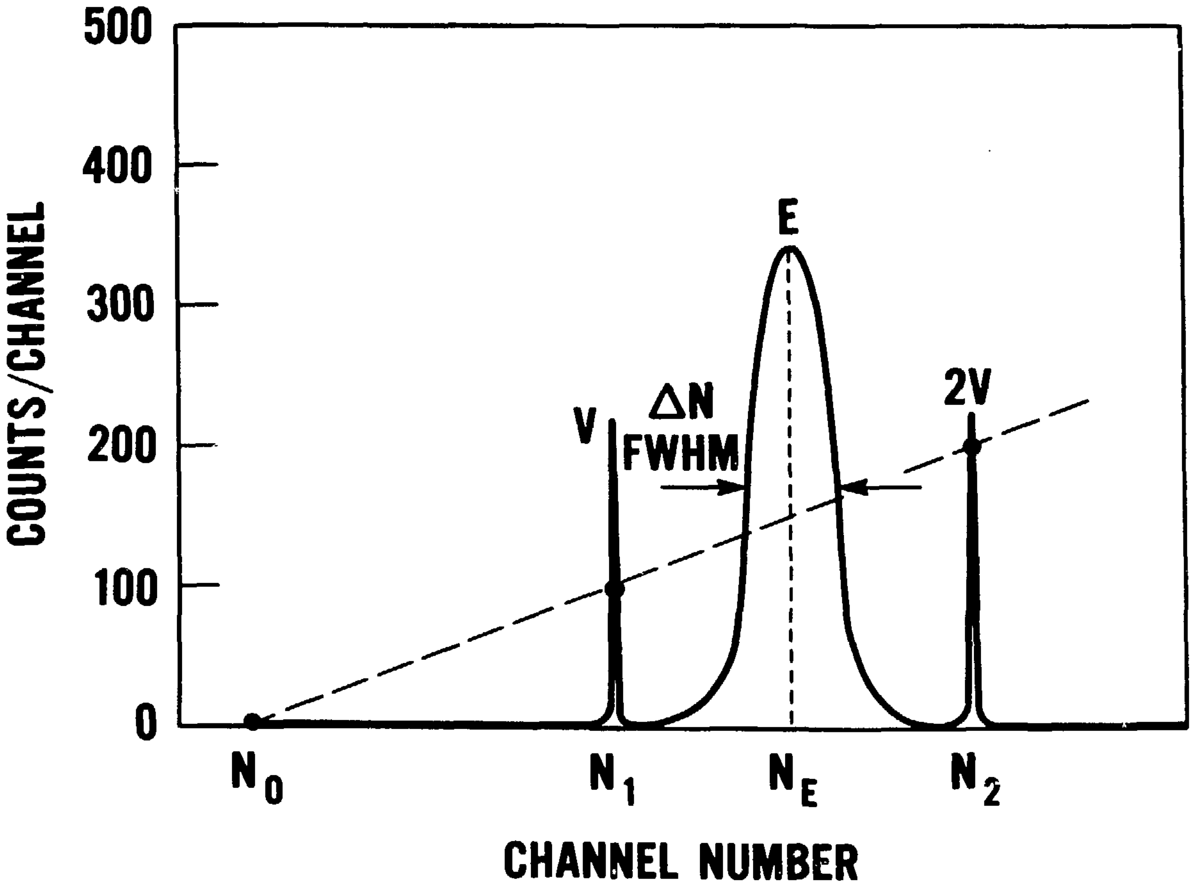

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