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Instrumentation for a Large Area Fast Neutron Spectrometer

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INSTRUMENTATION FOR A LARGE AREA FAST NEUTRON SPECTROMETER.*

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The development of large area detector instrumentation is described for use with a fast neutron time-of-flight spectrometer. A mean-timer module and a linear summing module have been built and tested in conjunction with a prototype large area detector.

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1. Introduction.

A previous report (1) described the development of a fast neutron time-of-flight spectrometer. This report describes the work now being done to increase the resolution of the spectrometer by increasing the flight path and by using a large area detector with associated electronic modules.

For a fixed intrinsic time resolution of a time-of-flight spectrometer the energy resolution can be increased simply by increasing the flight path, but the count rate decreases with the square of the distance due to the reduced solid angle at the detector. To compensate for this effect a large area detector is often used at the end of the long flight path.

The large area detector (LAD) has to provide a precise timing signal indicating the end of the neutron flight time. The size of the detector scintillator introduces a timing uncertainty due to the variations in the transit times of photons traveling from the scintillation event to the photocathode of the photomultiplier tube (PMT). This can be of the order of 4ns for a 1 m long scintillator. To remove this timing error the mean-timing technique is used. This depends on the fact that the average of the photon transit times from the scintillation event to the two ends of a long scintillator is independent of the position of that event. A mean-timer (MT) circuit, which produces an output pulse time related to the average of the times of two input pulses derived from two ends of the large area detector, is therefore required.

For extracting pulse height information from the PMT anode signals it is important that the pulse height is also position insensitive. For one PMT the amplitude of the anode signal suffers from light attenuation within the scintillator material, depending on the distance from the scintillation event to the photocathode. By linearly summing the two anode signals from each end of the scintillator, a signal can be obtained which is much less dependent of the position of the event. To do this a fast linear summing module (LSM) is required.

A block diagram of the LAD and its associated electronic modules is shown in fig. 1. A program has been initiated to develop a large area detector. A small prototype LAD has been built and tested and a larger one will eventually be constructed. The MT and LSM modules have been built based on designs by the Kent State nuclear group (2,3). These are all described in detail below.

2. Large area detector.

A prototype LAD has been constructed from a 4.5 cm diam. by 28 cm long pyrex tube and filled with BC 501 scintillator (Bicron Corp.). Oxygen was removed by slowly bubbling high purity nitrogen gas through the scintillator. Fig. 2 shows the oxygen

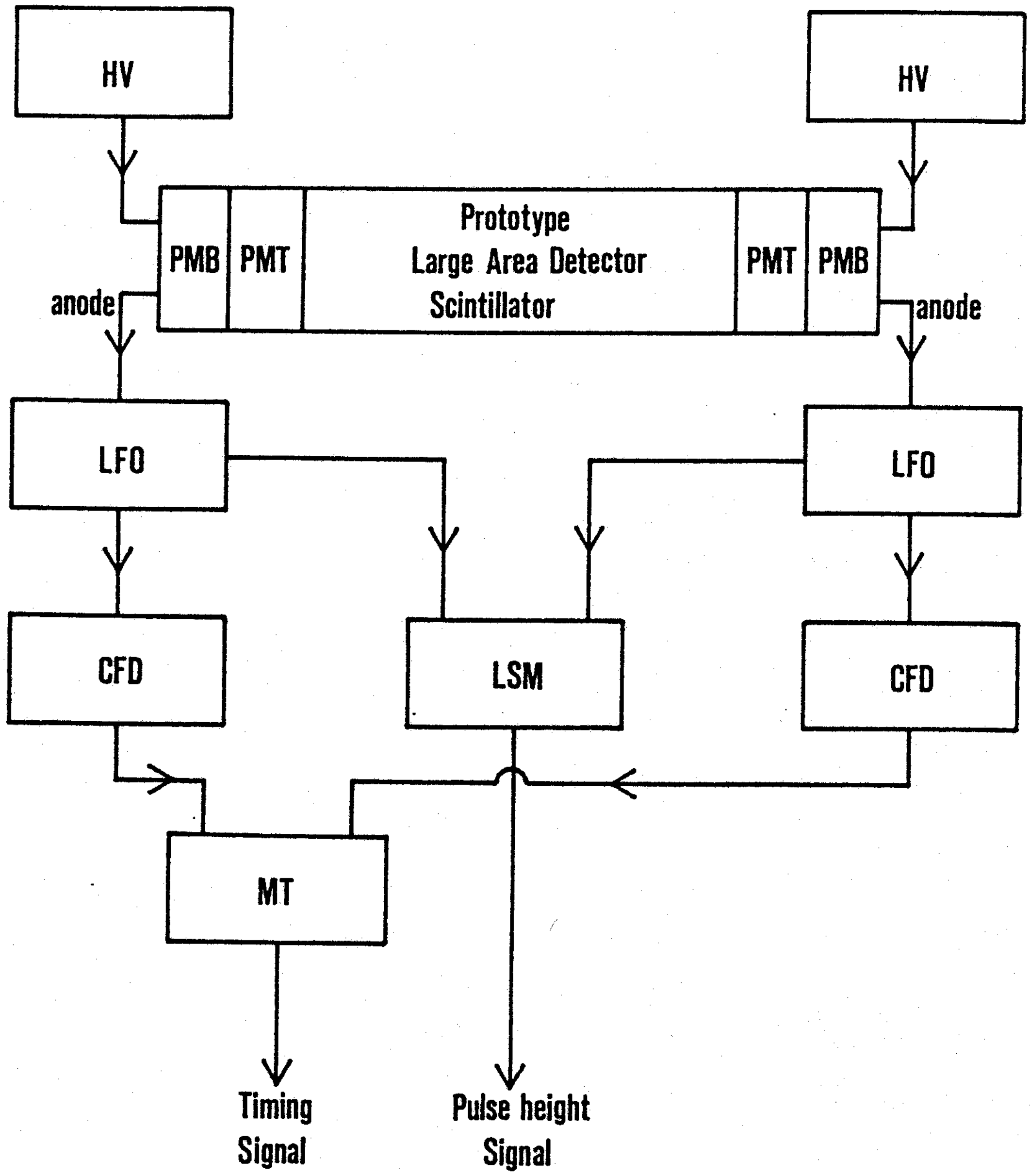

Fig.1 LAD and associated electronic modules.

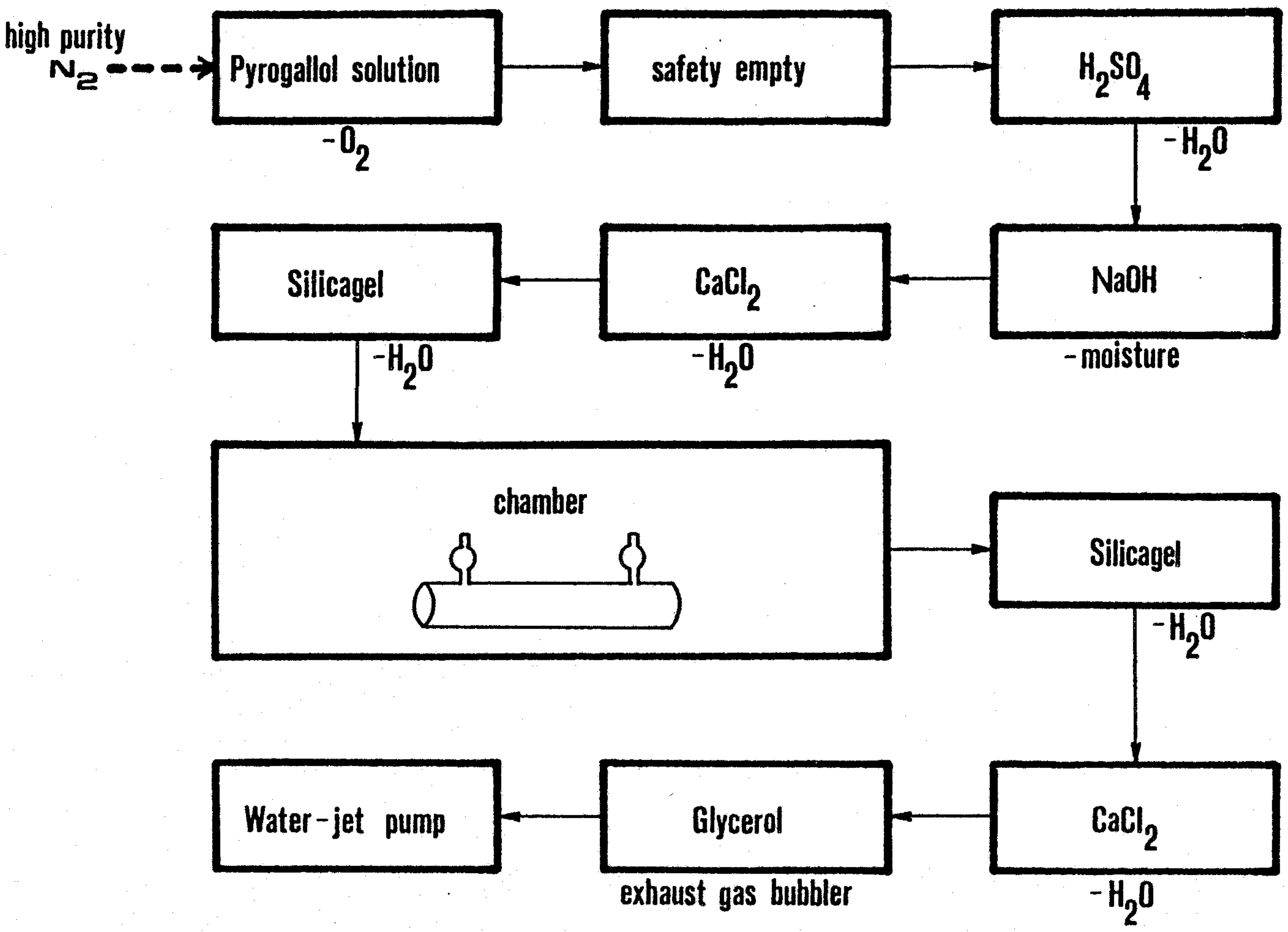

Fig.2 LAD oxygen removal facility.

removal facility. The detector is covered with white paper and light sealed with black tape. It is viewed from both ends with RCA 8575 photomultiplier tubes.

3. Mean-timer module.

The function of the mean-timer (MT) is to create an output signal whose timing is related to the average of the times of arrival of its two input signals which are derived from the anodes of the PMT's connected one to each end of the large area detector.

The block diagram of the mean-timer is shown in fig. 3. An input at A sets the A latch and turns on the corresponding constant current generator creating a linear ramping voltage across the integrating capacitor C. A further input at B would likewise enable the B constant current generator, doubling the slope of the ramping voltage across C. The level discriminator compares the voltage across C with a reference voltage Vth. At the time when the ramping voltage exceeds Vth, the level discriminator simultaneously produces an output signal via the output driver, discharges C and resets the A and B latches. As the latches reset they terminate the output signal to keep its width down to about 10ns.

Let ta and tb be the turn on times of the A and B current sources, and tp be the time of the mean-timer output pulse. The first current source starts at a time ta and stops at time tp, generating a voltage V1 across C:

$$V1 = I/C\int_{ta}^{tp} dt = I\ (tp - ta)/C \qquad (1)$$

The second current source starts at a time tb and stops at a time tp generating an additional voltage V2 across C:

$$V2 = I/C\int_{tb}^{tp} dt = I\ (tp - ta)/C \qquad (2)$$

The level discriminator produces the mean-timer output pulse at time tp when the total voltage across C equals the reference threshold voltage Vth:

$$Vth = V1 + V2 = I\ (2tp - ta - tp)/C \qquad (3)$$

Solving this equation for the time of the output pulse tp gives:

$$tp = CVth/2I + (ta + tb)/2 \qquad (4)$$

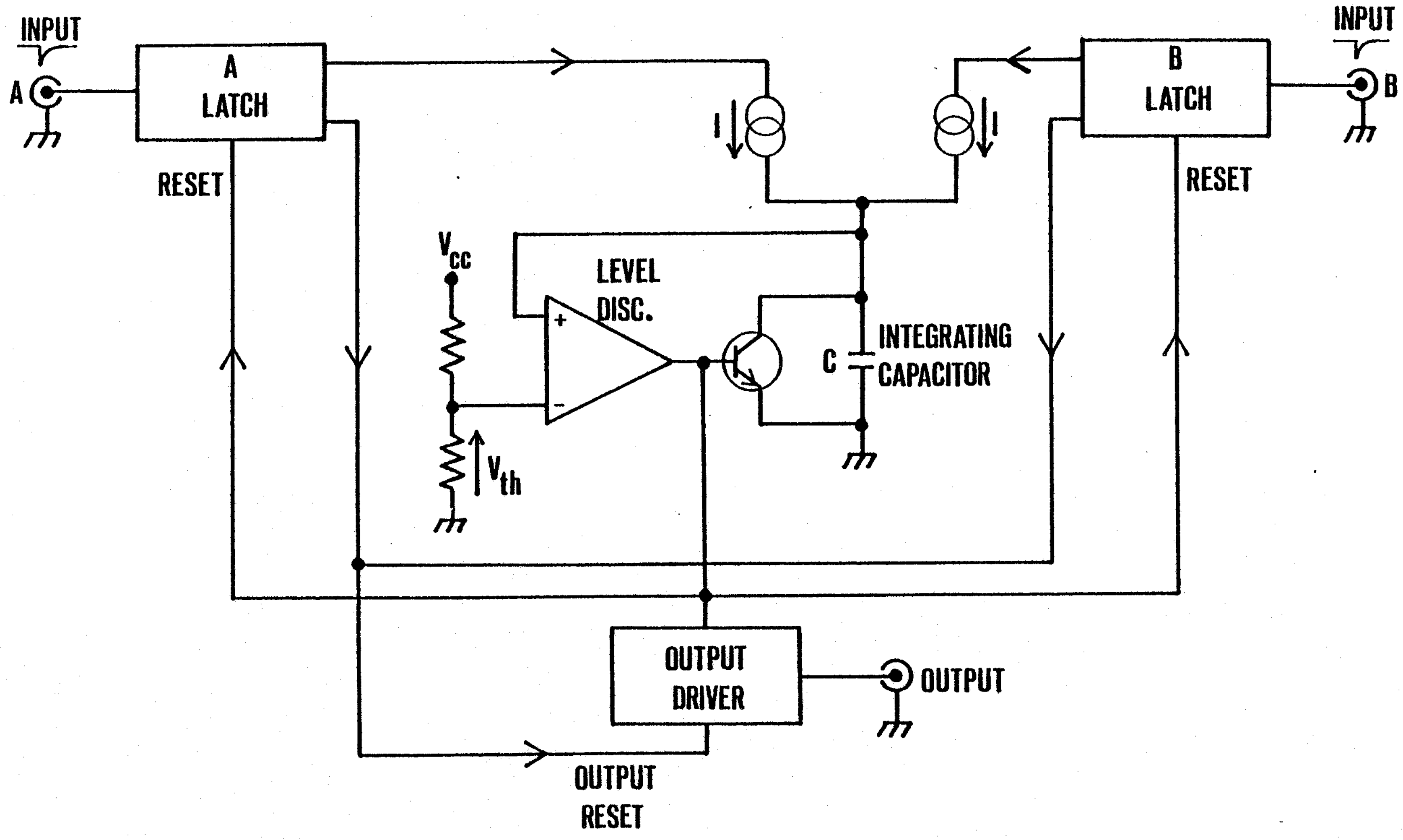

Fig.3 Mean-timer block diagram.

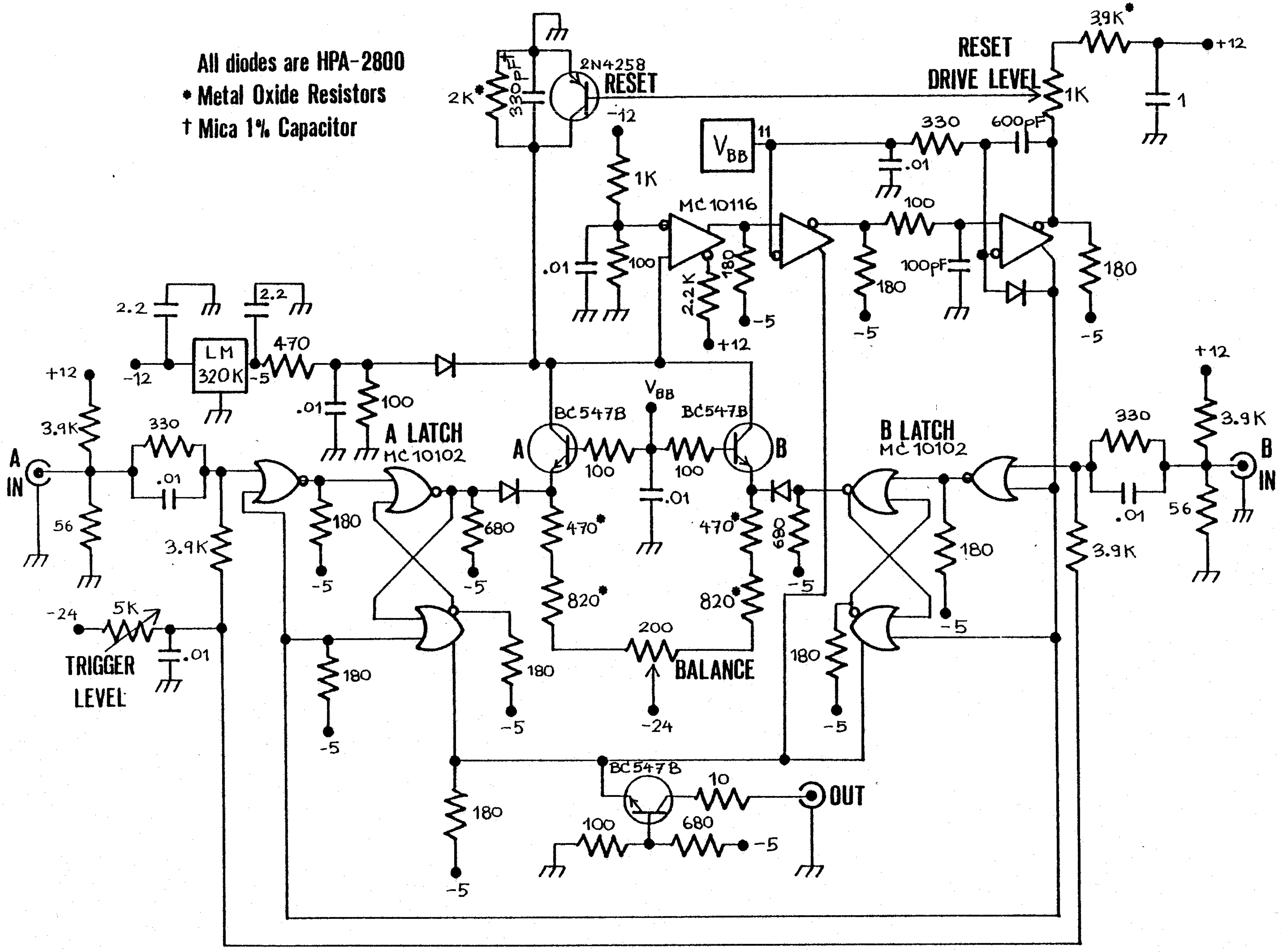

Fig.4 Mean-timer circuit diagram.

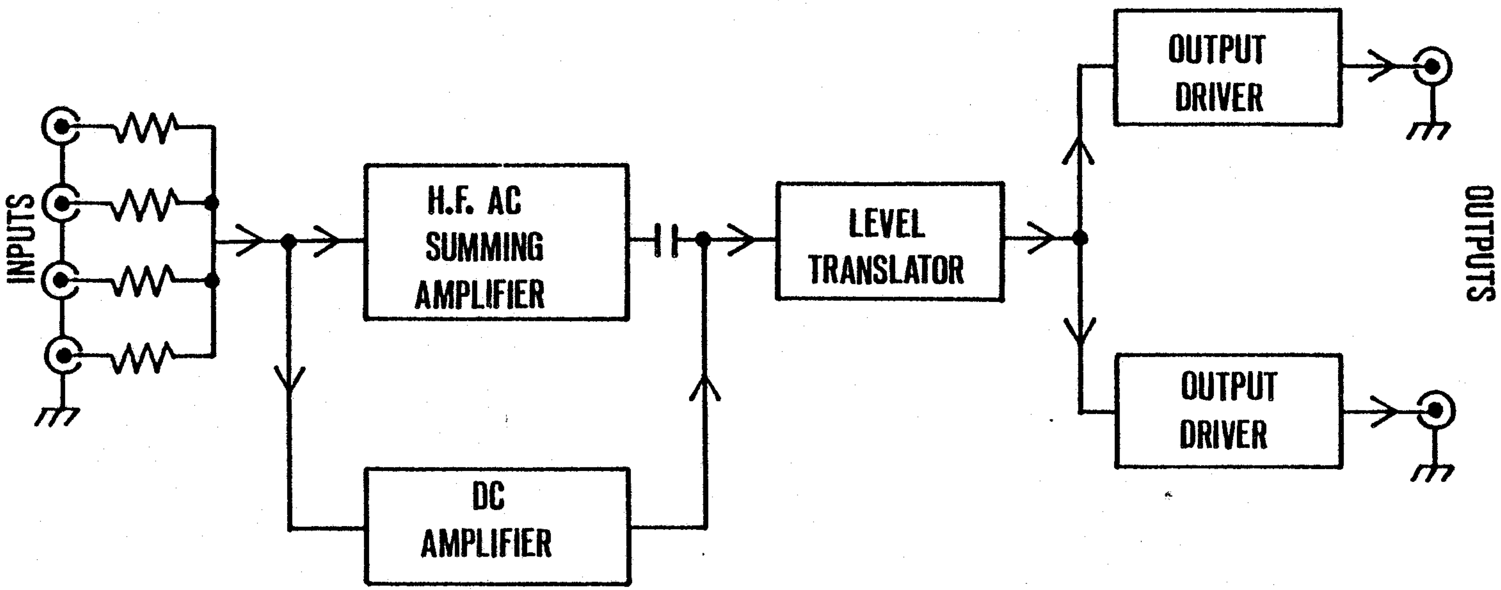

Fig.5 Linear Summing Module block diagram.

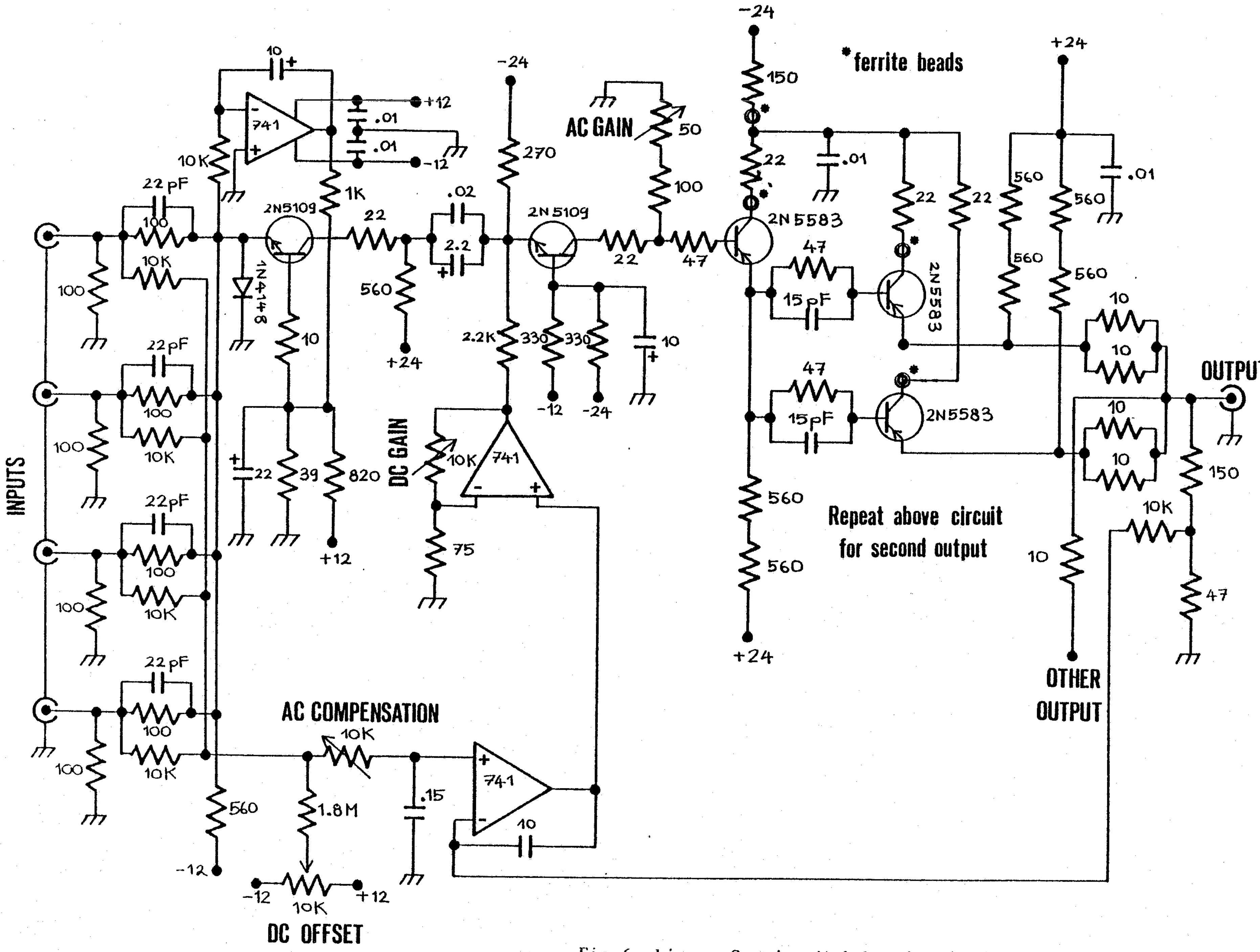

Fig.6 Linear Summing Module circuit diagram.

where (ta + tb)/2 is the mean-time of the input pulses and CVth/2I is a constant propagation time through the circuit. The time of the output pulse then represents a true analog computation of the mean-time of arrival of the two input pulses.

A detailed circuit diagram of the mean-timer is shown in fig. 4. It is essentially the same as that of Baldwin and Madey (2) except that the more common two input NOR gates, MC10102's, have been used instead of the three input MC10105's, and that we used BC547B instead of 2N4275 transistors which we found had insufficient current gain.

4. Linear Summing Module.

The Linear Summing Module (LSM) is a unity gain high frequency amplifier capable of providing two identical outputs from a single input or the sum of from two to four analog or digital signals. The amplifier will drive two 50 ohm loads at levels up to 10 volts (negative) with a 3dB bandwidth of 100MHz.

The block diagram of the linear summing module is shown in fig. 5. Up to four separate fast signals are current summed at the input of the high frequency summing amplifier, which is at virtual ground. The high frequency components of the summed signal are ac coupled to the level translator. The dc to low frequency components of the summed signal are handled by the dc amplifier which is temperature stabilized. Thus the high frequency amplifier does not need to be temperature stabilized to handle dc components.

The level translator combines the lf and hf signals and translates the dc levels to drive the outputs at zero volts. The output driver stages are two separate emitter follower amplifiers each capable of supplying 0.2 A into a 50 ohm load on a pulse basis.

A detailed circuit diagram of the LSM is shown in fig. 6.

5. Tests.

Fig. 7 shows the circuit used for testing the mean-timer and linear summing module with the large area detector. The collimator allows the LAD to be illuminated at specific points along its length and test for position sensitive effects. Fig. 9 shows the test results of the MT. It can be seen that the timing errors, introduced by the transit time of the photons, for each individual PMT are effectively removed by the MT module. The intrinsic time resolution was measured at 0.8ns FWHM, about the same as the original spectrometer (1) without the LAD.

Fig. 8 shows the pulse height variation as a function of the location of the incident radiation. For a single PMT, except for the region near the PMT, the light attenuation is about a

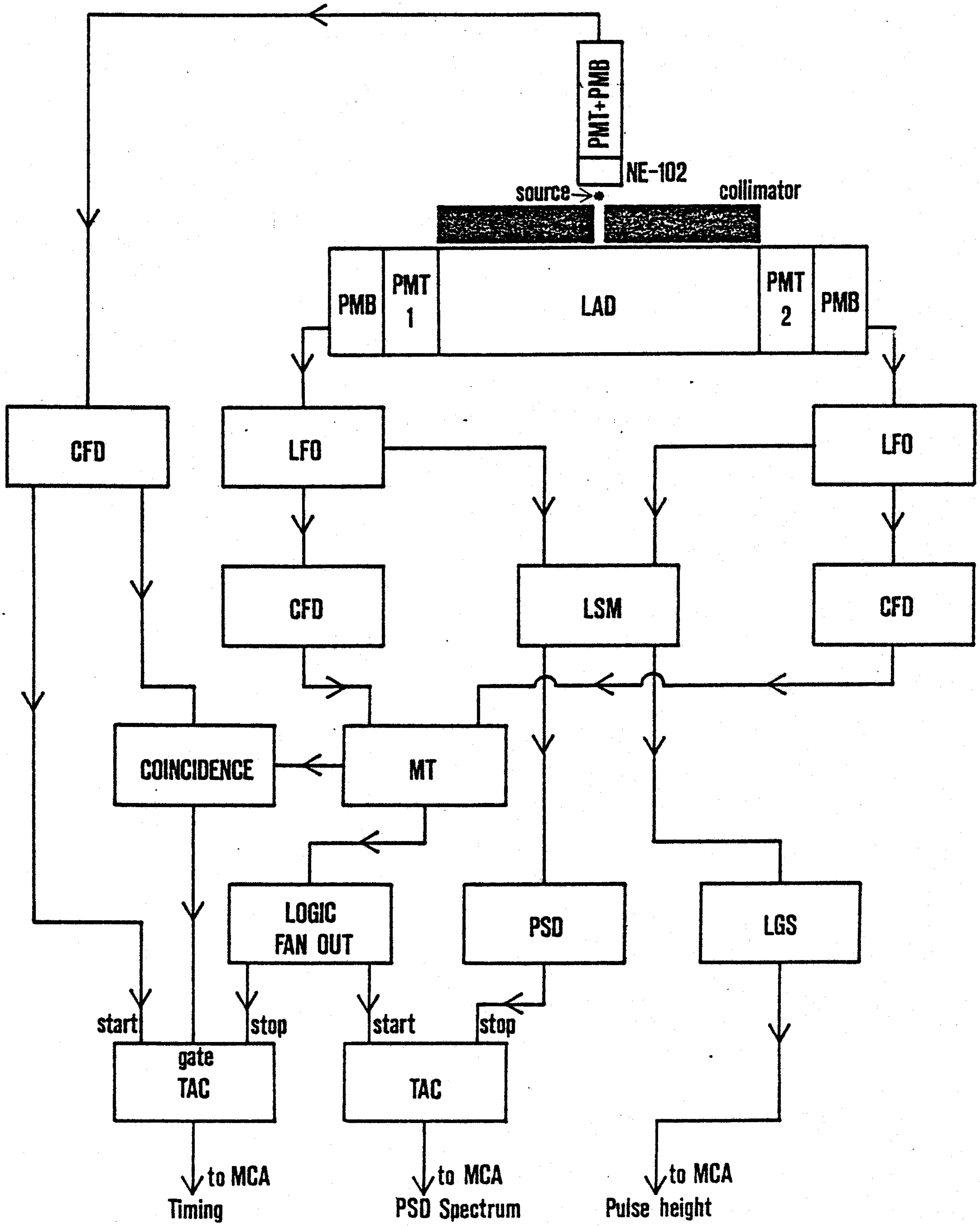

Fig.7 Test circuit.

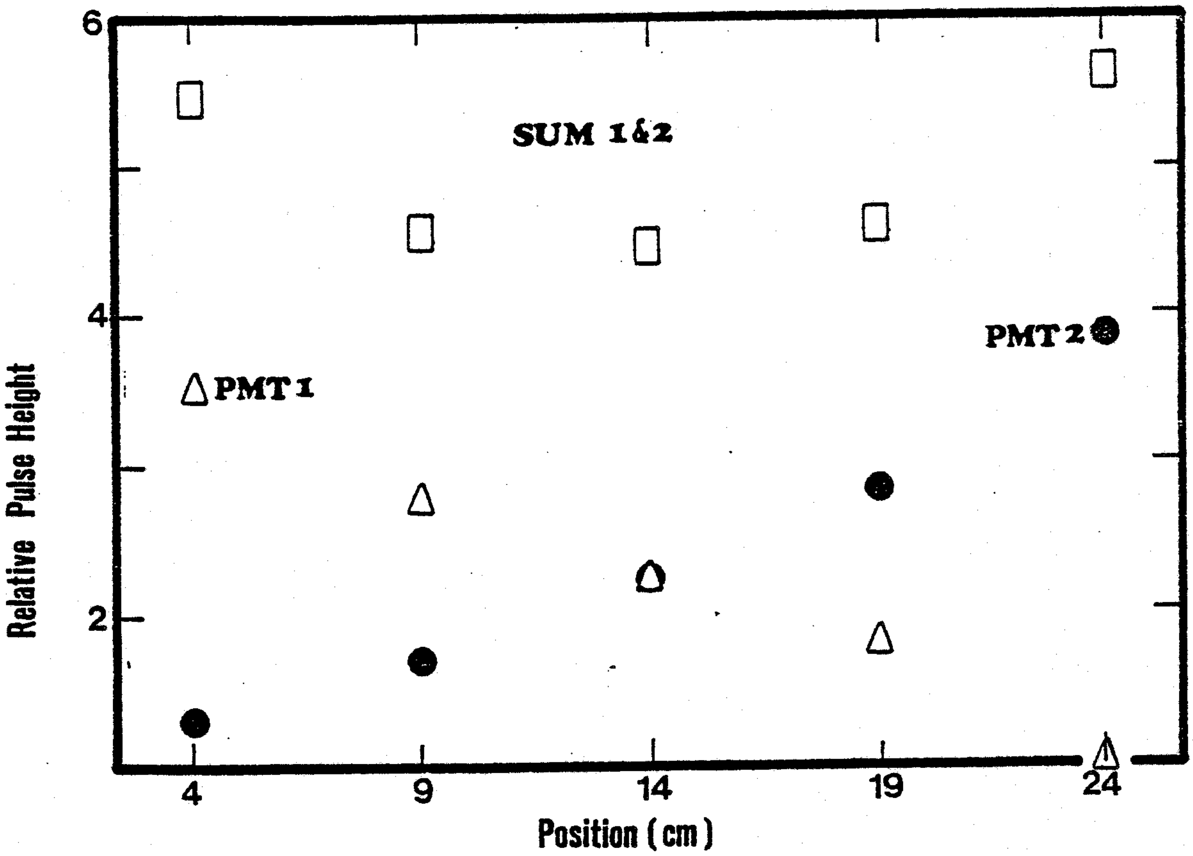

Fig.8 Pulse height variation within the LAD scintillator.

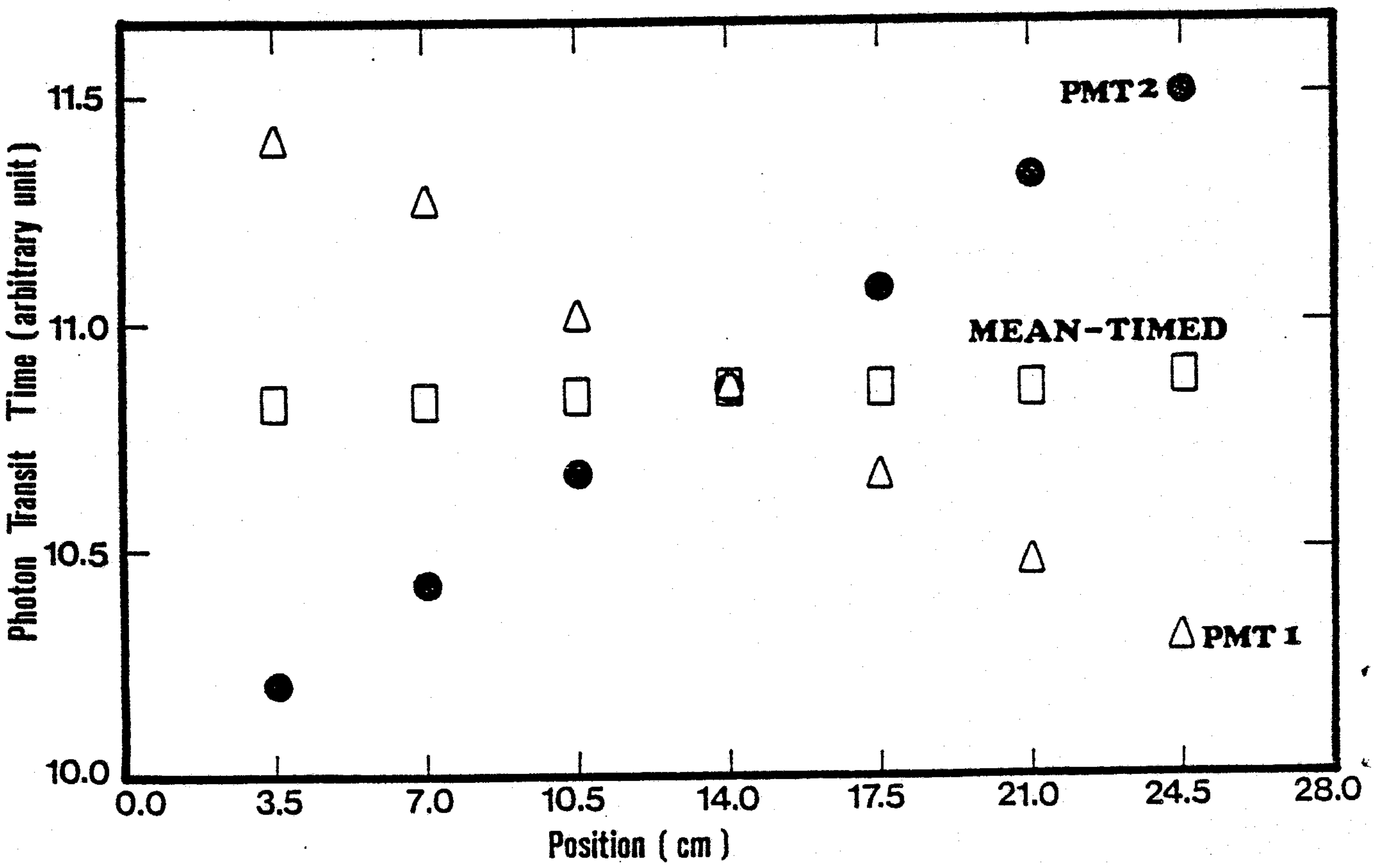

Fig.9 Transit time of photons within the LAD scintillator.

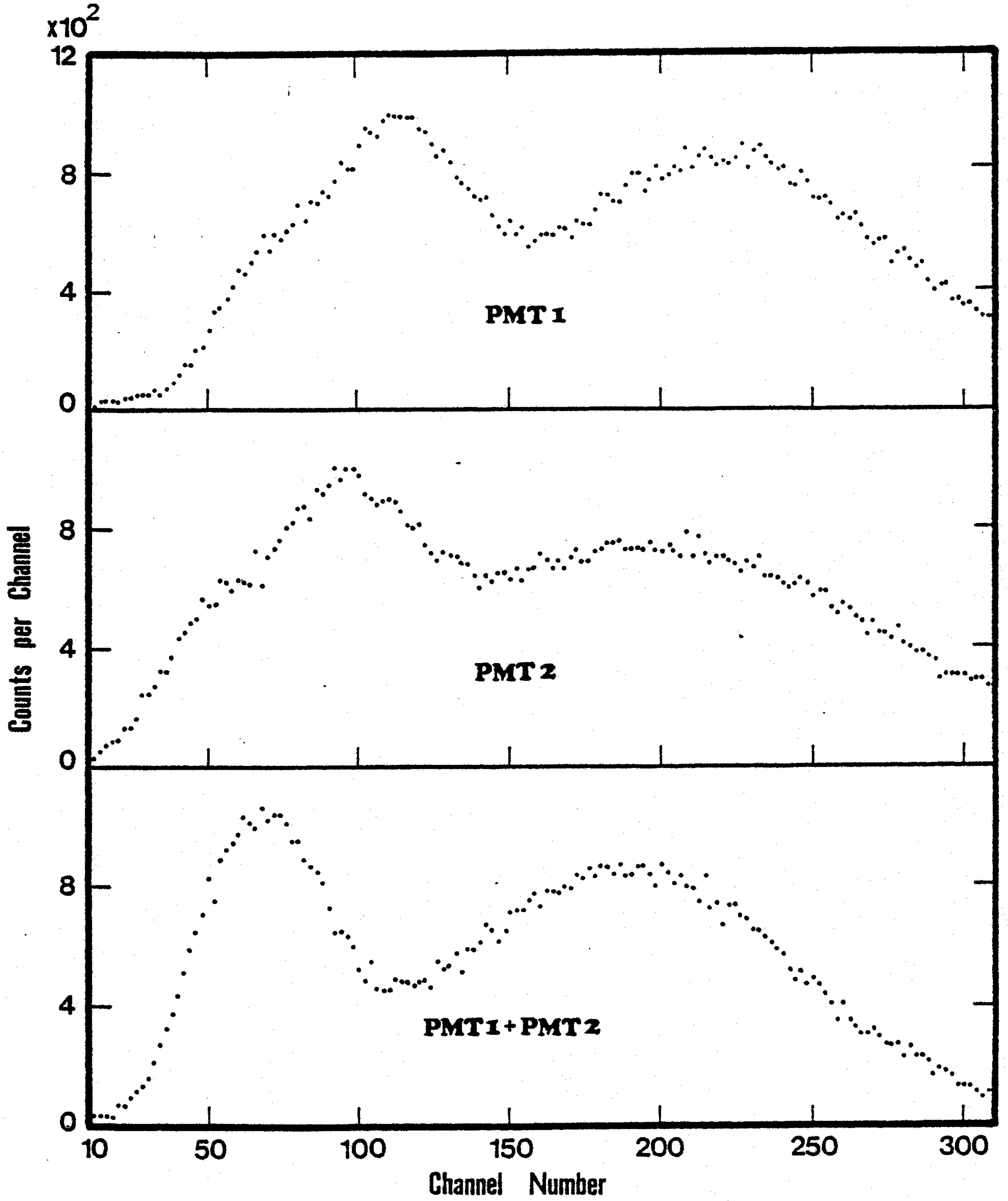

Fig.10 PSD spectra using an Am-Be source with the threshold set at half the height of a ^{60}Co peak.

factor of 3 over the entire scintillator length. The sum of the light outputs of two PMT's using the LSM is practically constant over the region far from the PMT's. A pulse height variation of about 20% is observed over the whole scintillator length.

We also checked the neutron-gamma pulse shape discriminating properties of the detector using an Am-Be source. As shown in fig. 10 optimum discrimination was obtained when using the sum of the anode signals to feed the pulse shape discriminator (PSD) module. This confirms the findings of Carlson et al. (4).

6. Conclusion and further work.

The mean-timer and linear summing module have been seen to operate satisfactorily with the prototype large area detector. Work will soon begin on a larger 80cm x 20cm x 5cm detector.

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