DUKE UNIVERSITY

RESOLUTION IMPROVEMENT FOR FLYING SPOT DIGITIZER

L. R. Fortney

Department of Physics

Duke University

Durham, North Carolina 27706, U. S. A.

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L. R. Fortney

Physics Department, Duke University, Durham, N. C. 27706, U.S.A.

Abstract

A modification to the standard hit detection electronics, used on most flying spot digitizers, has been developed for the RIPPLE system. The new electronics has made a dramatic improvement in the ability of RIPPLE to resolve closely spaced tracks. Design features and operational results are presented.

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Introduction

The RIPPLE, a unique flying spot bubble chamber film measurement device using a CRT, was first described at the Cambridge Conference in 1970. The system is currently being used to measure very complex events in a hydrogen-neon mixture in the SLAC 82" bubble chamber. A serious problem throughout this measuring effort has been the ability to resolve complex track topologies on the digitized display. In the absence of this information, even the intervention of an operator does not result in reliable measurements of complex events. The hardware changes described in this paper have made it possible to measure multiprong events (14 prong at primary vertex) and e-pairs from gamma conversion within the chamber.

History of the problem

When RIPPLE was first designed, careful attention was given to the ability to digitize nearby tracks. It was anticipated that the device would be used on high momentum hydrogen interactions with high multiplicities of forward going tracks. These forward tracks are often very close together over a large fraction of their path length. Since the RIPPLE, like other flying spot devices, must digitize each bubble encountered during a sweep, it is essential that the digital part of the system be able to respond to bursts of sequential hits. While the use of gates, roads, or short sweep lengths might reduce the incidence of these bursts, the general problem would remain and still be apparent during area scan or track acquisition operations.

With 10 MHz electronics used throughout the controller, the only real speed problem occurs at the interface between the hard wired controller and the computer. The multiplexer channel speed of the SIGMA-5 computer we are using is fairly typical at about five microseconds per word. This presented a severe mismatch with RIPPLE where it was estimated hits could occur as close together as 200 nanoseconds. This mismatch was softened with the aid of a series of eight hardware word buffers arranged in a cascade.

The cascade accepts data words at the top spaced as close as 100 ns apart and makes them available at the bottom at whatever rate the computer channel can manage, as shown in Figure 1.

It was assumed that this device would permit the detection of close spaced hits since the maximum sweep speed for RIPPLE is 6 μ/100 ns. However, operational experience quickly showed that RIPPLE could not digitize tracks closer together than about 60 μ, and a check of the digital electronics failed to show any bug. Because of other factors this problem was ignored until recently.

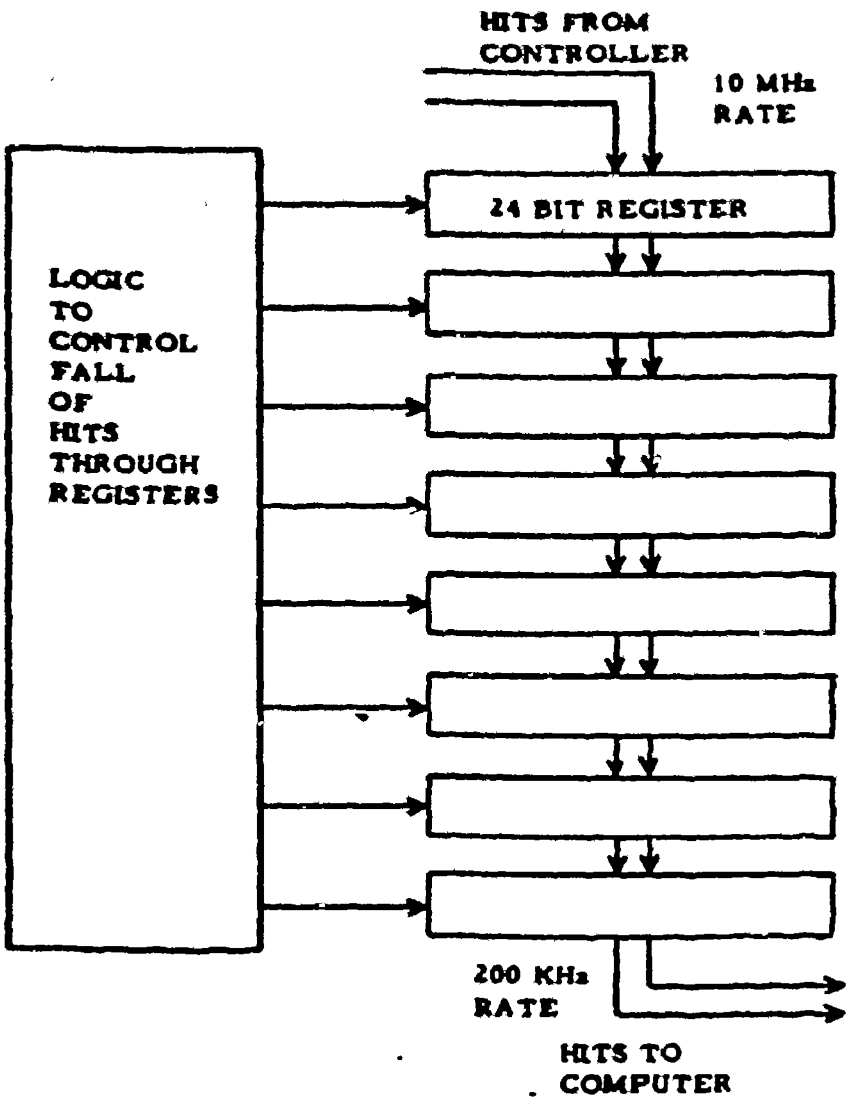


Fig. 1. Eight word buffer cascade is used between controller and computer to improve acquisition of closely spaced bubble hits.

Cause

Inspired by difficulties encountered while trying to measure events in the H-Ne mixture, the source of this residual digitization problem was finally recognized to be at the analog-digital interface. Consider a spot of 30 μ diameter sweeping over a random collection of 30 μ diameter bubbles. Some bubbles will be hit squarely such that the spot is covered, Case A. Others will be hit so that the spot is partially covered, Case B. More complex cases occur when the spot encounters a second bubble before moving clear of the first. Several distinct possibilities exist: Case C, both bubbles are hit squarely; Case D, both are only partially covered; the general Case E in which one is hit squarely and the other partially. A typical analog signal (PHOTO) from the photo multiplier amplifier is displayed in Figure 2a for the above cases. Each of the cases described is represented on the figure by a lettered peak. Note that the operational RIPPLE system described here has a spot size of 30 μ. This implies that the bubble centers for Case C must be 60 μ apart before the valley returns to the background level.

Following common practice, the RIPPLE uses a fast analog comparator circuit which sets at a specified threshold voltage on the leading edge of a bubble, and then resets at approximately the same voltage on the trailing edge. The hit position is determined as being midway between these digital leading and trailing edges. In RIPPLE this threshold level is set as a fraction of the distance between the local average background level and the maximum pulse height. Figures 2a and 2b show examples of the digitized pulses obtained for a 30 percent threshold level and a 70 percent threshold level.

As can be seen from the figure, the 30 percent level digitizes only bubbles A and B correctly while the 70 percent level gets A, both parts of C, and the last part of E. Normal practice was to run near a 50 percent threshold, producing a result only marginally better than those shown.

Simply stated the dilemma is as follows: to get all of the bubbles digitized, including partial hits, it is necessary to digitize with a lower threshold; to obtain high resolution of close bubbles, it is necessary to digitize with a high threshold; actually, the best setting is near the top of any particular hit pulse.

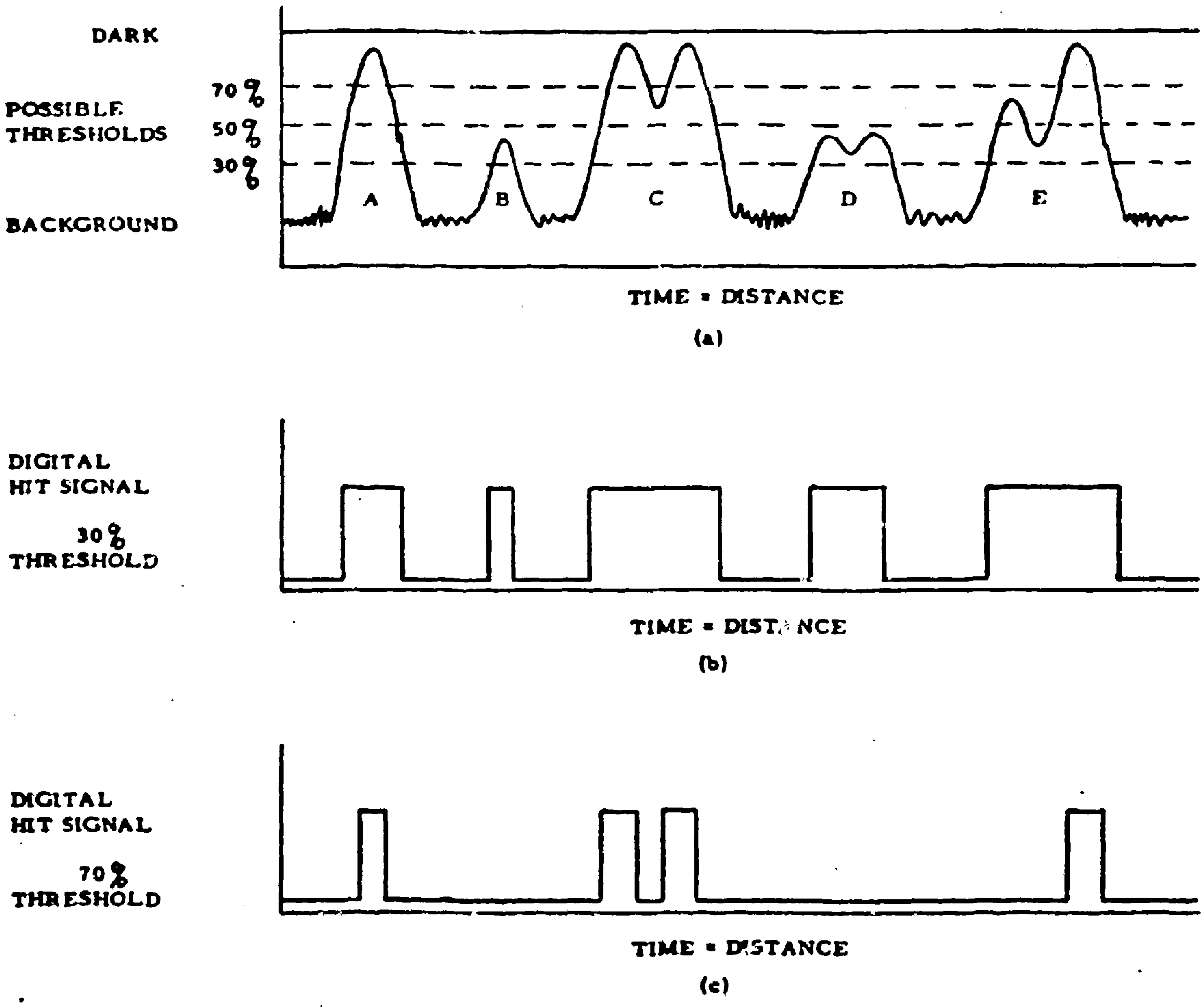


Fig. 2. Representative PHOTO signals resulting from various bubble configurations are shown (a) together with the corresponding digital output from a fast comparator set at a 30 percent threshold (b) and at a 70 percent threshold (c).

Solution

The requirement that each bubble pulse be digitized based on information obtained only near its peak is a difficult one. Because of the variable bubble pulse heights the single threshold method described above must be ruled out. A method which would work in principle is peak detection by finding zeros in the differentiated PHOTO signal. This method was quickly discarded for two reasons. First, the PHOTO signal is noisy and bubble hits are sometimes flat topped; and second, the method is difficult to implement within the existing RIPPLE digital hit logic. All that remains is some general scheme to vary the threshold so it is high for high pulses and low for low pulses. An analog method of varying the threshold was tried but abandoned because of failure on cases like E in Figure 2a. Finally, the simple method of four separate threshold levels equally spaced between a programmable minimum and the "dark" level was implemented. Each PHOTO bubble pulse is digitized by the highest threshold level crossed. Referring back to Figure 2, and simplifying to only two threshold levels, this scheme would accept as the best digital hit signal for pulse A, the hit signal of 2c; for B, the hit in 2b; for both parts of C, the hits in 2c; for D, the incorrect hit of 2b, and for E, the correct but incomplete hit in 2c. The result is still not perfect, but is a major improvement over either threshold separately.

Details

The scheme was easily implemented within the framework of the existing hit detection system. A diagram of the multi-level system is shown in Figure 3; the digital portion has been simplified for clarity. It should be noted that in the system shown, PHOTO is a negative signal rising toward 0 volts for a hit. Also, the signal PSHFTC is the original threshold signal used in the old one level system; it is also a negative signal riding at a programmable fraction of distance between the background and the highest PHOTO pulse.

The essentials of the digital mechanization are as follows. When the PHOTO signal crosses one of the comparator levels A, B, C, or D, the corresponding PH flip-flop is set by the master clock signal 10 MHz. On the next clock cycle the corresponding H flip-flop sets. The signal $PH \cdot \overline{H}$ then becomes a 100 ns leading edge pulse. Similar signals from each threshold are OR'ed together to form HITLP which can be used to transfer the contents of the sweep position scalar to a half speed scalar. Each bubble pulse may produce up to to four such transfers; later transfers to the half speed scalar must correctly overwrite earlier ones. A similar AND/OR circuit (not shown) for $\overline{PH} \cdot H$ will generate a trailing edge pulse HITTP. The first of these HITTP pulses following a HITLP is used to stop and save the half speed scalar as a HIT position, thereby accomplishing the desired result.

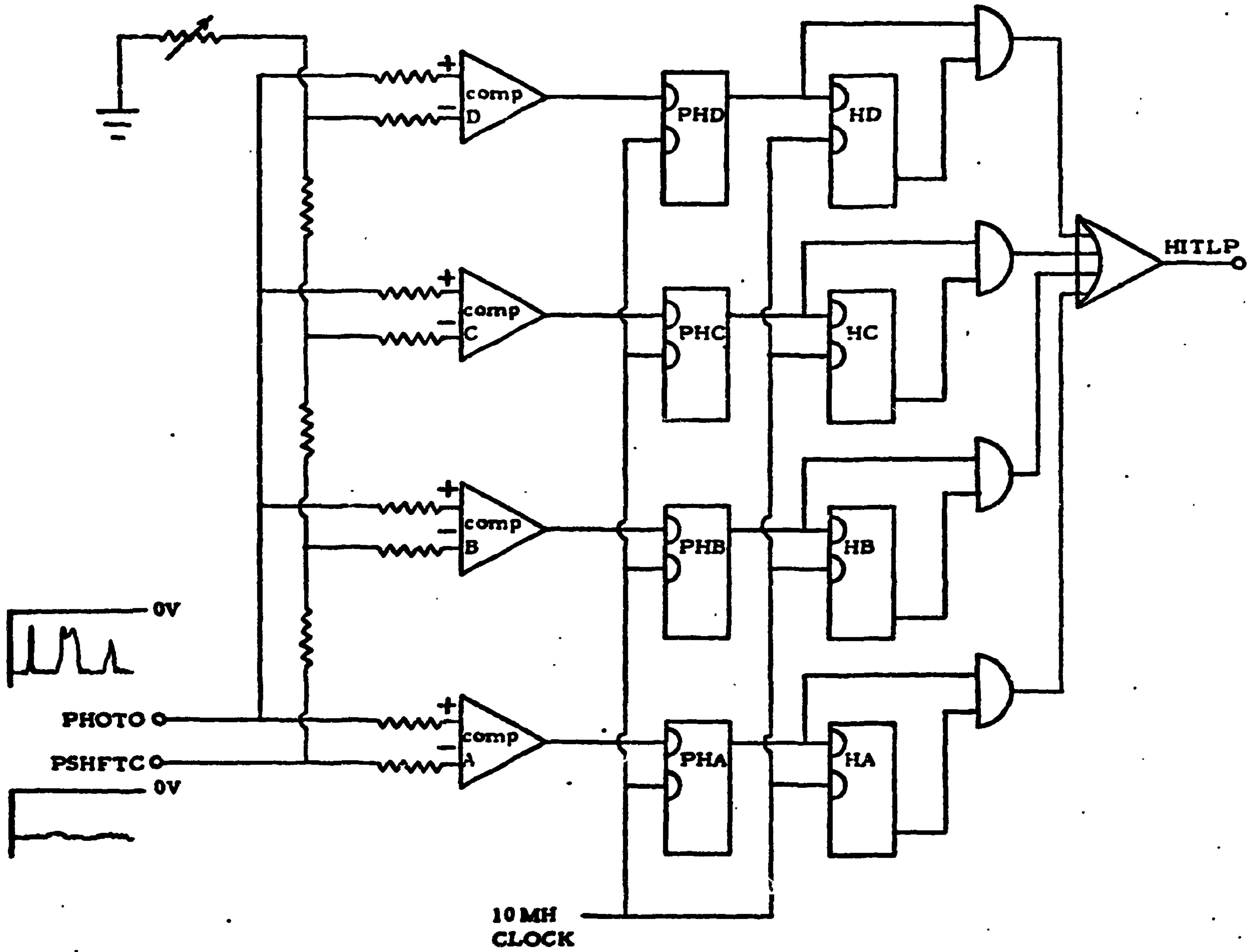


Fig. 3. Schematic shows essential features of four level threshold circuit. Portions of the digital circuit have been removed for clarity. The leading edge output HITLP will produce a 100 ns pulse as the analog signal PHOTO crosses the threshold on each of the four comparators.

The oscilloscope traces shown on the lower half of Figure 4 show a typical PHOTO signal and the HITLP and HITTP pulses generated by the digital logic shown on Figure 3. The PHOTO signal shown is the result of the flying spot crossing a two or three bubble cluster. Note that the PHOTO signal generates two HITLP pulses as it sets comparators A and B while rising to the first broad peak. As PHOTO falls into the shallow valley it recrosses threshold B generating a HITTP pulse and a digitized bubble. As PHOTO rises again to the narrower peak, it again sets comparator B yielding a single HITLP pulse. As comparator B resets on the trailing edge, a second HITTP pulse digitizes the second peak. Comparator A resets later on this trailing edge but the corresponding HITTP pulse is suppressed by digital electronics (not shown on Figure 3) which requires that at least one HITLP pulse separates HITTP pulses. A single level system would most likely generate a single hit for the whole peak and would yield a digitized point near the valley between the peaks.

Operational results

The threshold system outlined above has been in routine use for some three months. It is difficult to quote any percentage improvement in measuring rate or quality as a result of the changeover to this threshold system because nearly simultaneous changes to the software occurred. However, the visual effect of this system can be rather dramatic as is shown on the upper half of Figure 4. These "before and after" pictures were taken from a routine display and request for operator assistance during the measurement of an event vertex. The beam track extends toward the right in both pictures but is cut off by the display. Hardware and software conditions were unchanged between the two displays except that the single level threshold was used on the left display while the new system was used on the right. (The lack of a cursor on the left display is of no significance.) These pictures were taken within a few minutes of each other since the new electronics can be easily reduced back to a one level system by holding off flip-flops PHB, PHC, and PHD on Figure 3.

Two features of these displays are most prominent. First, it can be seen that the three forward tracks radiating out toward the left are resolved much better in the right hand display. Second, the right display shows two stubs approximately 200 microns long on the film, while the left display shows only one. The scan comment 2STUB shown at the bottom of each display confirms the added detail shown by the four level system.

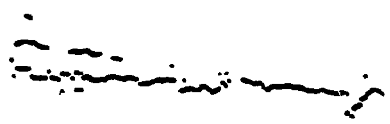
Conclusion

This multi-level threshold system has made a significant improvement in the ability of RIPPLE to resolve closely spaced tracks. Since an older generation cathode ray tube with a 30 micron spot is currently used on RIPPLE, the positive effect of this system is somewhat exaggerated. However, even with a 15 micron spot available on the newer tubes the technique should still provide a noticeable improvement in resolution.

Fig. 4. Upper pair of this composit shows a before and after display of a vertex with three forward tracks and two stubs; the beam track is to the right and has been cut off by the display. The stubs are about 200 μ long on the film. These otherwise identical sweeps are taken with the single threshold on the left set equal to the lowest of the four thresholds used on the right.

The lower trace shows some bubble pulses on a typical PHOTO signal and the corresponding leading edge pulses HITLP and trailing edge pulses HITTP. Each HITTP pulse shown on the lower trace indicates the acquisition of a digitized bubble by the four level threshold electronics.

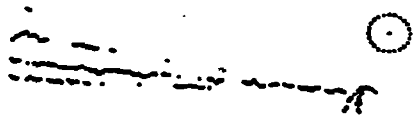
FRAME 290 VIEW 1



ZSTUB =

X= 5827.6
Y= 1661.0

FRAME 290 VIEW 1



ZSTUB =

X= 5827.6
Y= 1661.0