Presented at the IEEE Nuclear Science Symposium, Nuclear Instrumentation for Research and Development, San Francisco, California. November 14-16, 1973.

LBL-2420
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November 1973

Prepared for the U. S. Atomic Energy Commission under Contract W-7405-ENG-48

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RECENT DEVELOPMENTS IN DELAY LINE READOUT OF MULTIWIRE PROPORTIONAL CHAMBERS*

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Abstract

The application of electromagnetic delay line readout methods for determining the track positions of ionizing particles in multiwire proportional chambers is described. Construction techniques for large area chambers, which allow the use of all three planes for track position measurements are given. The construction and characteristics of electromagnetic delay lines optimized for wire chamber readout are discussed.

Introduction

The electromagnetic delay line method for the readout of the position coordinates of charged particles in MWPC has been in use at our Laboratory, and elsewhere, during the last three years in a number of particle physics[1] and biomedical applications.[2] Although in general, the construction of the chambers, the delay lines and the readout electronics is similar in all of these various applications, the requirements for particle physics are the most demanding. In this paper we shall confine ourselves to a description of the various components as optimized for particle physics work.

Description of Delay Line Readout MWPC

The basic electrical connections for a delay line readout is illustrated in fig. 1. The chamber consists of three planes with the central wire plane at a positive high voltage relative to the outside ones which are at ground or close to ground potential. We have been making the anode plane--on which the avalanches occur--of polished stainless steel or gold-plated tungsten of diameter ranging from 15 to 25 microns. The wire spacing has been between 1 and 5 mm depending on the desired accuracy and size of the chambers. The cathode wires are isolated from a fixed potential through resistors of 250 KΩ to 5 MΩ in order to allow a voltage signal to appear on them which is communicated to the delay lines by a capacitative coupling. The simplest position determination of the trajectory of a charged particle can be made by connecting all the anode wires together to give a zero time signal and measuring the X and Y coordinates by the delayed pulse appearing at one end of each of the delay lines coupled to the cathode planes. The anode pulse is proportional to the ionization energy, ΔE, deposited in the chamber gap by the particle if a chamber gas is used which has no electronegative contamination and the chamber is operated in the proportional region. This configuration is suitable for biomedical and other applications in which only one particle track occurs per event.

In particle physics applications the number of ionizing tracks per event can often be larger than one. For those cases it is desirable to use the maximum amount of information obtainable from the anode and two cathode planes of the chamber. Thus if any two planes have wires oriented at 90° to each other, the third plane can have its wires oriented at some intermediate angle--typically 45°. With a delay line coupled to each plane, three coordinates are then read out, X, Y, U, from the 0°, 90°, 45° planes which is sufficient, if the accuracy is good enough, and the pulses do not merge, to solve for the coordinates of the n tracks in a multiple track event when n is not too large. Some further redundancy in solving for n tracks and a factor of two improvement in position accuracy is obtained by timing the arrival of the pulses to both ends of the delay lines. With delay lines coupled to all three planes, the zero time of the event, i.e., when the avalanche is formed, can be obtained by coupling the ground plane of any one delay line through a low input impedance amplifier to ground and obtaining a prompt signal from it which starts the counting period and which can provide, in addition, the pulse height information for the ΔE measurement. The 7-channel readout electronics for such chambers is described elsewhere.[3]

We have made a number of delay line readout chambers of various sizes up to 50 cm using cathode planes made of wires.[4] For these chambers, even when filled with a high-drift velocity gas mixture (i.e., 30% CO_2, 70% Ar), it is necessary to place a bias potential of a few hundred volts between the cathode planes and the aluminized mylar windows which form the

* Research supported by the U. S. Atomic Energy Commission.

external gas envelope when charged particle tracks are to be detected. This prevents electrons produced in the cathode-to-window drift regions from being collected in the avalanche region between cathode and anode planes. These drift electrons, if not eliminated, tend to produce pulses with rise times appreciably slower than 100 nsec and thus affect adversely the timing accuracy on the delay line and the ensuing position measurement.

Larger delay line readout chambers with sensitive areas of 1m × 1m have been made in our Laboratory as part of an External Muon Identifier[5] for the 15 ft. bubble chamber at the National Accelerator Laboratory. These chambers have been designed with cathode planes made of copper strips on a mylar backing which is epoxied on to a flat Hexcel[6] honeycomb plastic backing which is flat to ±200 microns. Since the whole detector will consist of more than 20 chambers of this size, the main emphasis here was on achieving the desired active area for the lowest cost, both in the construction and in the readout electronics, consistent with the desired accuracy. With this in mind, the anode wire spacings were chosen to be 5mm, the anode-to-cathode spacing 8mm, and the cathode plane strips 2mm wide with 0.5mm spacing. The U plane is one of the cathode planes with copper platings at 45° relative to the chamber rims; this plane is read out by two delay lines on opposite edges of the plane. The 0° and 90° planes are the anode plane (wire) and the second cathode plane (copper strips on mylar). The digitizing electronics operates at 25 MHz which gives an accuracy of 1 count = 4mm which is the final accuracy of the system since it is larger than any other error.

In the following section we give descriptions of our latest modifications to the delay lines and to large area chamber construction.

Electromagnetic Delay Lines

All the forms of continuously wound delay lines that we have used in MWPC readout have been capacitatively coupled to the chamber wires. They have all been built with some form of phase compensation in order to minimize the inherent dispersion and to provide well-shaped pulses optimized for timing purposes. Except for our initial work,[7] we have used rectangular cross section delay lines with distributed capacity phase compensation.[8] In fig. 2, we show the construction of a delay line and in fig. 3 we show it mounted on a ½m cathode plane. Figure 4 shows a partially assembled 1 meter chamber.

Various modifications have been made to these rectangular cross section delay lines. The criteria that we have used are as follows:

a. The bandwidth of the delay line should be approximately matched to the risetime of the proportional chamber pulses.

   Typically the chamber pulses have a risetime of ~100 ns for minimum ionizing particles traversing a 0.5 cm gap in 90% Argon - 10% Methane at one atmosphere pressure. The 1m chambers with their wider gaps (8mm + 8mm) have rise times closer to 200 ns, and their delay lines have rise times that range from 200 to 500 ns for a pulse travelling their full length. (Their delays are about 25 to 30 times the corresponding rise times.)

b. The coupling to the chamber should be simple and the coupling efficiency should be high. The lines are made with a large area rectangular cross section and the desired coupling efficiency is obtained by placing the line on a flat surface of plated metallic bands which are connected to the chamber wires.

c. The impedance should be high to allow good coupling without loading the chamber pulse.

d. There should be uniform delay dependence with delay line length.

e. The delay per unit length should be ~50 to 100 ns/cm so that timing electronics with a minimum time jitter of 1 ns is sufficient to localize the pulse origin to a fraction of a millimeter.

f. The attenuation should be moderate for a line $\lesssim$ 1m.

g. The two pulse resolution should be as good as possible.

All of the above criteria are not independent. The delay per unit length is given by $\sqrt{LC}$; the impedance is given by $\sqrt{L/C}$; the bandwidth is proportional to $\sqrt{1/LC}$ and can be further limited by the ohmic resistance of the windings. Here L is the inductance per unit length and C is the capacitance per unit length. In practice the delay per unit length is made as large as is possible without causing unacceptable attentuation of the signals due to the decrease in bandwidth. The desired high impedance is obtained by making L relatively large and C relatively small. The best overall performance is obtained when the minimum rise time of the delay line is approximately equal to the rise time of the chamber pulses.

The changes described below were made in order to increase the high frequency response of the lines and to increase the coupling efficiency to the chamber.

First the thickness of the line was made smaller. This increases the effective number of sections, since the distributed delay lines can be considered as consisting of a number of sections with the section length determined by the thickness of the lines.[9] A well-known property of lumped-section delay lines[10] is that the delay-to-risetime ratio increases as $n^{2/3}$ where n is the number of sections. In order to maintain the delay per unit length at the desired value of 50 to 100 ns/cm, the quantity $\sqrt{LC}$ has to be maintained at the desired value. This was done by increasing the width of the line as well as the number of turns/cm of the helical winding.

Eddy current losses in the distributed ground strip were reduced by making it of copper-plated lines on Mylar or Kapton with strips of 1mm or less in width. The eddy current losses in the compensation pads were minimized by making them of aluminum plated Mylar with thin enough platings so that the resistance is of the order of 1Ω/square.

Dielectric losses in the distributed capacitance of the delay line were minimized by making the plastic former of Nema G-7 (a glass-fiber plastic impregnated with low-loss silicone resin) and the dielectric spacer between the ground plane and the helical winding of Polyethylene.

The coupling efficiency of the delay line to the chamber wires was increased primarily by raising the characteristic impedance of the line as well as by increasing the coupling capacity between the line and

wire pads; this latter increase occurs primarily from the increased width.

That these changes produce better coupling can be seen as follows. Define a coupling capacity C_c between the metallic strip and the delay line. Then for signals of a given frequency (typically 3 MHz) the capacity acts as an impedance given by $Z_c = 1/2\pi f C_c$ where f is the frequency. This impedance is in series with one half of the delay line impedance since a signal coupled to midpoint of the line sees the characteristic impedance of both sections in parallel. The coupling capacity and delay line behave as a voltage divider and the fraction of the input voltage transmitted in each direction is given by $(Z_d/2)/(Z_c+Z_d/2)$ or $Z_d/(2Z_c+Z_d)$ where Z_d is the line characteristic impedance. From this expression it is evident that both the increased coupling capacity and the increased characteristic impedance improve the coupling efficiency. For example, take C_c = 80 pf, f = 3 MHz and Z_d = 1500 Ω. Then Z_c = 662 Ω and $Z_d/(2Z_c+Z_d)$ = .53. These numbers are typical for our recent delay lines. Note however that further increases in C_c do not produce comparable increases in the delay line signal amplitude obtained from a chamber. This is because the chambers are current limited sources, and increasing the coupling efficiency merely loads the signal on the chamber producing only slight gains in the output signal from the delay line. Schemes in which the chamber wires are directly coupled to the delay line can increase the amplitude of the output signal by at most about 50%.

The tight coupling of the delay lines to the chamber planes means a wave travelling along the delay lines is accompanied by one travelling from strip to strip (or wire to wire) along the chamber planes. For large chambers, the strip-to-strip capacity must be allowed for in designing the delay line frequency compensation.[11] Also some care must be taken to prevent cross-coupling between delay lines.

The electrical characteristics, from measurements described below, are given in Table 1. For comparison, the characteristics of the old line[8] are included also.

Table 1

Mechanical and Electrical Parameters of the Delay Lines

Parameter	New Line	Old Line
Length	51 cm	51 cm
Width	3.2 cm	2.6 cm
Thickness	.33 cm	.9 cm
Windings (#38 wire)	78 turns/cm	34 turns/cm
Ground Strip Width	2.5 cm	3.4 cm
Compensation Strip Width (45°)	≈ 1 cm	1.8 cm
Inductance	77 μh/cm	30 μh/cm
Capacity	36 pf/cm	49 pf/cm
Impedance	1500 Ω	750 Ω
Delay	52 ns/cm	39 ns/cm
Voltage Coupling Efficiency	18%	5%
Attenuation	5 db/m	6.5 db/m
Band Pass	-3 db @ 3 MHz	-3 db @ 2.5 MHz
Delay-Risetime	30:1	15:1
D. C. Resistance	590 Ω	300 Ω

From the table, taking the delay-to-risetime ratio as a figure of merit, it is seen that the new line with a value of 30 is appreciably better in its overall frequency response than the previously described line. The voltage coupling efficiency and attenuation are determined by measuring the output voltage response of the line to a 100 ns rise time step function input from a voltage source. The signal is capacitively coupled to the delay line using a printed circuit board with 5 strips/cm of the same type as is used on the wire chambers. Typical pulses are seen in fig. 5a. The delay-to-risetime ratio is obtained by coupling directly a 20 ns step function in one end of the line and measuring the time delay and risetime (10% - 90%) of the step function at the other end. To measure the corresponding two-pulse resolution, two equal amplitude pulses are simultaneously entered on the line via a coupling board as described above, again using step functions with a 100 ns rise time. The two pulses are said to be resolved when the dip between the two peaks is a quarter of the peak amplitude. Some pulses showing the line response versus the two pulse separation at a distance of 25 cm from the end of the line are shown in fig. 5b. The effect of this non-resolution on a chamber readout for multi-track events is shown schematically in fig. 6. The heavy lines indicate the regions in which two or more pulses are not resolved. In fig. 6a we assume that two pulses originate simultaneously at two different positions, X_1 and X_2. In fig. 6b we plot the case for two pulses originating at times t_1 and t_2 and show how the non-resolvable region propagates in time to the end of the delay line. In both cases, if a third pulse occurs anywhere on the shaded band, part of the coordinate information will be lost. Note however that enough redundant information is available so that the particle track can still be reconstructed in the computer so long as the pulse does not come in a triple crossing region where A (delay line left end), B (right end), and C (prompt) signals all intersect. Also, of course, it is not necessary in general to wait for a delay line to "clear" before accepting later events.

The width of this non-resolvable band can be decreased considerably by making full use of the redundant timing information to both ends of the delay lines. This is accomplished by using constant fraction timing discriminators in place of zero cross discriminators. The former operate on the leading edges of the merged pulse; thus, by recording the time intervals from the zero time of the event to the arrival times of the leading edges of the pulses at both ends of the delay lines separately, each half of the merged pulse can be identified, giving the positions of the two events. The situation that occurs when a few pulses merge together may be the most difficult to unfold. Another simple situation occurs, however, in the case of electron showers where often the required information is the position of the centroid of the shower and the energy deposited in the chamber gap. Both of these quantities can be conveniently obtained by use of integrating discriminators which can be designed to give both of these numbers.[1] Figure 7 shows a block diagram of the readout electronics. In practice, two delay lines on opposite sides of the chamber are used for the U coordinate. A prompt pulse (not shown in the figure) can also be obtained from any delay line ground strip.

Conclusion

Delay line readout of the track coordinates produced by ionizing particles in MWPC's is a convenient, accurate and simple method to use. The simplicity of the readout allows the use of all three planes

in the chamber for coordinate information with some degree of redundancy. This redundancy is useful in providing more accurate position determination for single track events and for allowing the unambiguous recording of multi-track events in a single chamber.

Last, but not least, since the amount of electronics required is minimal, the cost of this readout scheme is considerably less than that for the amplifier per wire method.

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Figure Captions

Fig. 1. Schematic of a chamber with delay line readout.

a. Side view showing wire planes and drift regions.

b. Top view showing X, Y, U planes and delay lines coupled to X and Y planes.

Fig. 2. Schematic of delay line construction showing helical winding, ground plane and distributed compensating capacity.

Fig. 3. Picture of delay line coupled to chamber plane made of plastic film with metallic plated strips.

Fig. 4. Picture of a partially assembled 1m chamber. On the right side, a mylar cathode plane is visible; on the bottom a delay line placed over circuit strips that connect to the anode plane; on the left a pressure pad used in clamping the other delay lines to their corresponding cathode planes.

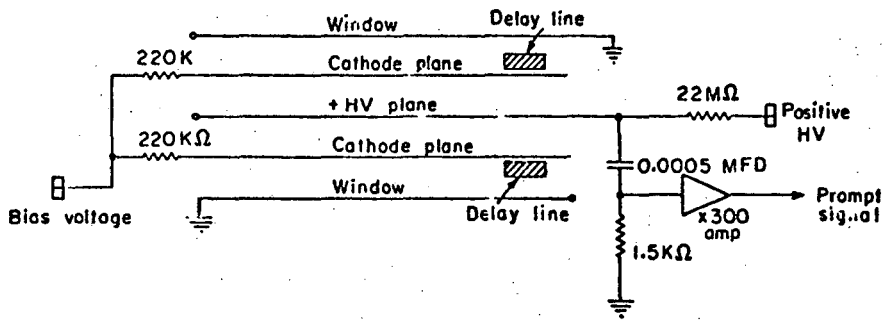
Fig. 5. Photographs of delay line pulses

a. Single pulses at 10 and 40 cms distance from one end of delay line.

b. Output of delay line produced by two equal amplitude pulses occuring at the same time but at different positions in chamber.

Fig. 6. Position-time plots indicating propagation of a pair of delay line pulses.

Fig. 7. Block diagram of readout electronics.



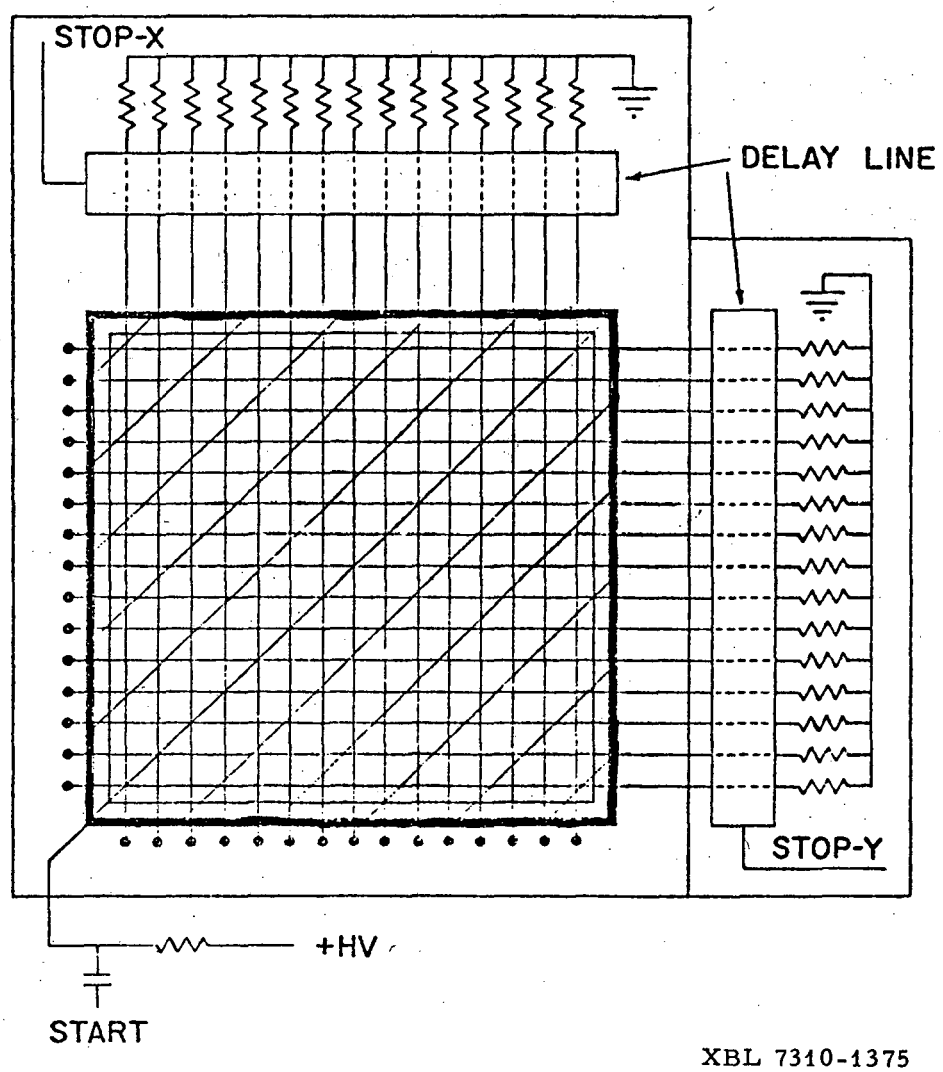


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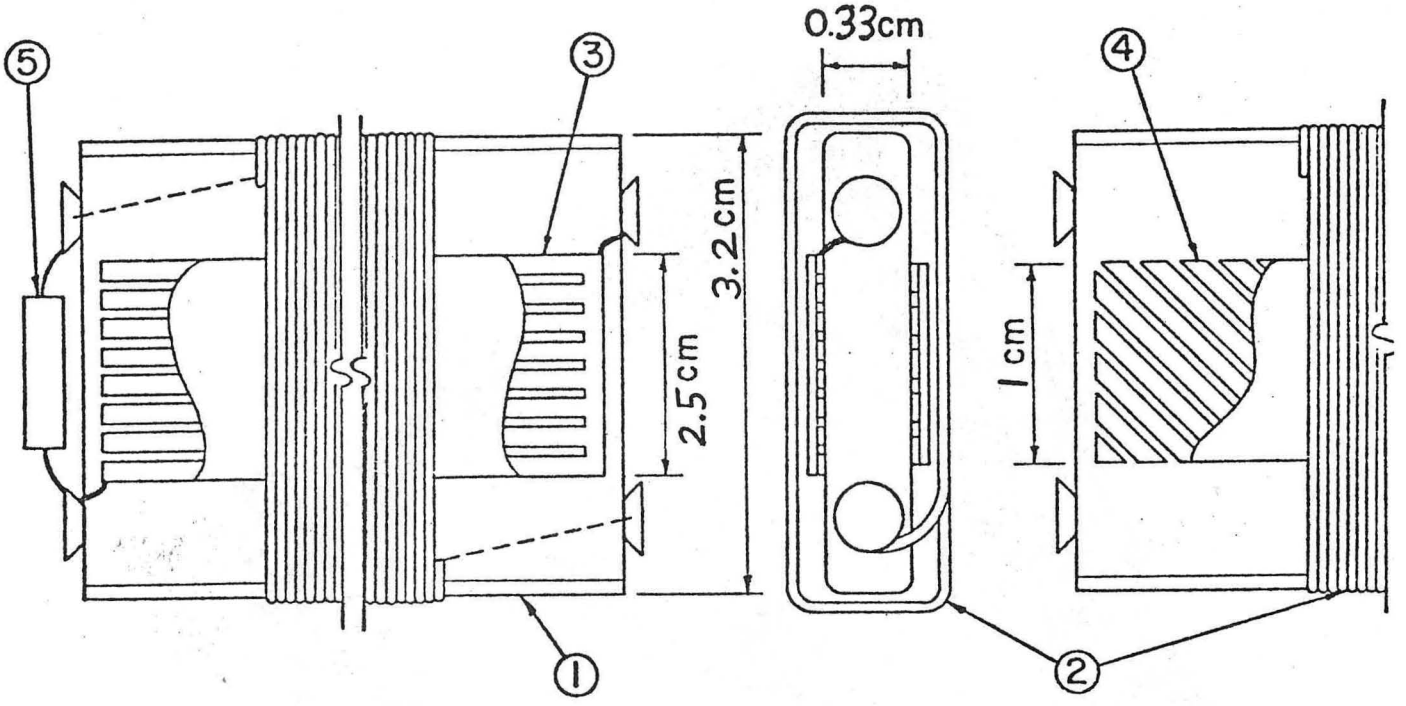
Fig. 1



1. G-7 Fiberglas core (silicone resin binder).

2. Winding (#38 wire, 8 turns/mm).

3. Ground Strips (10 strips/cm of 25 μm Cu. Strip width = 0.5 mm, gap width = 0.5 mm).

4. Compensating Strips (metalized strips on plastic).

5. Terminating Resistor.

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Fig. 2

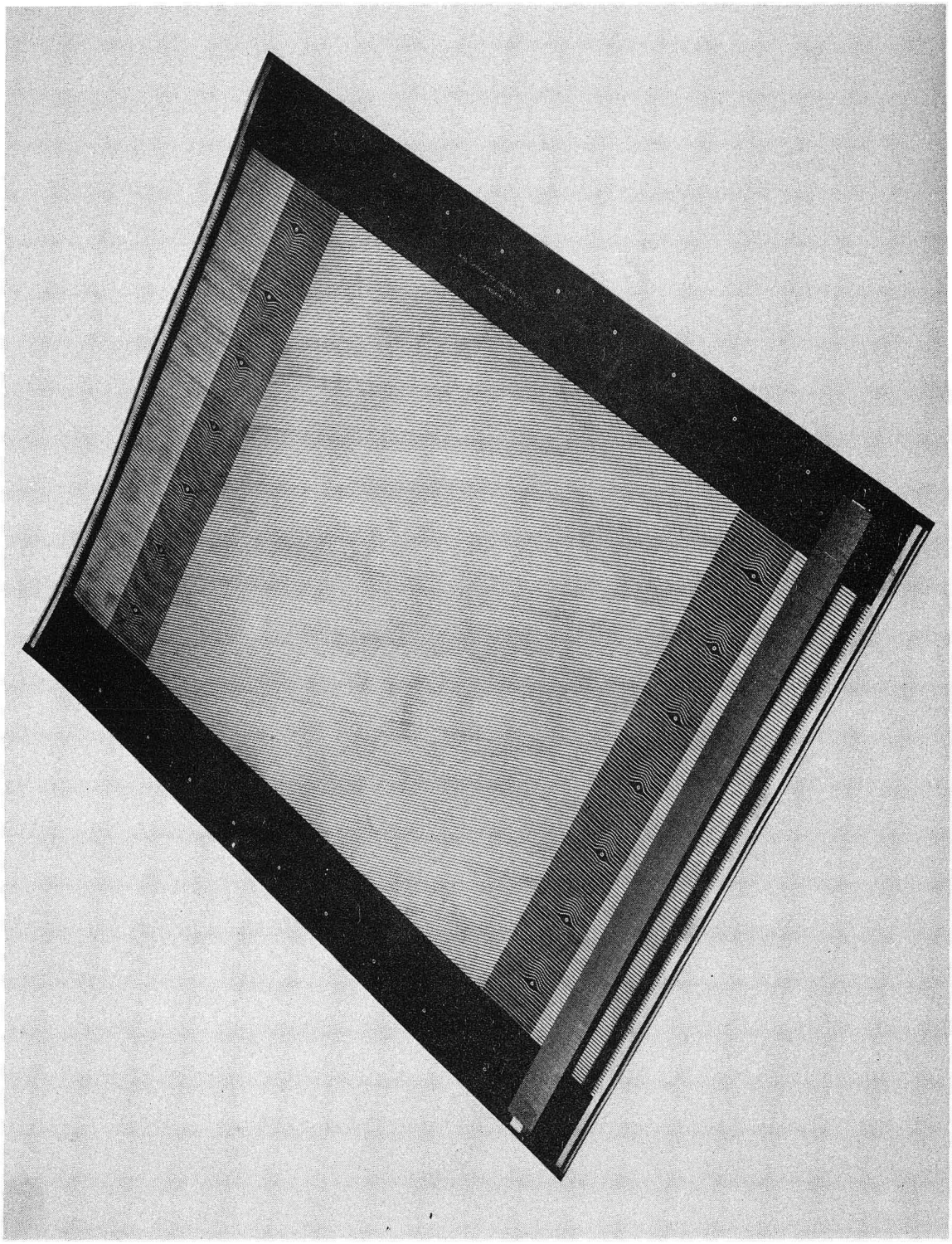

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Fig. 3

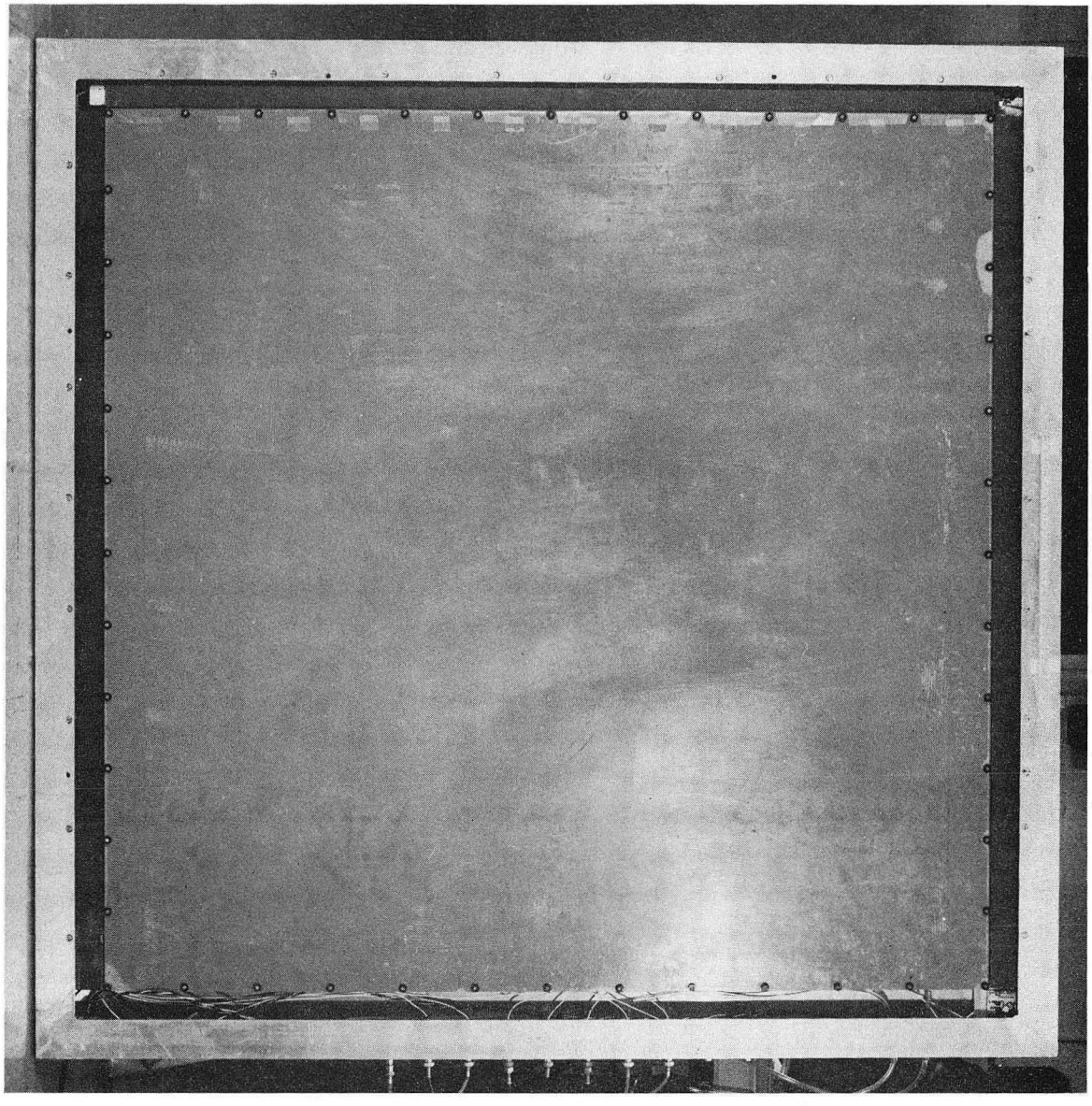

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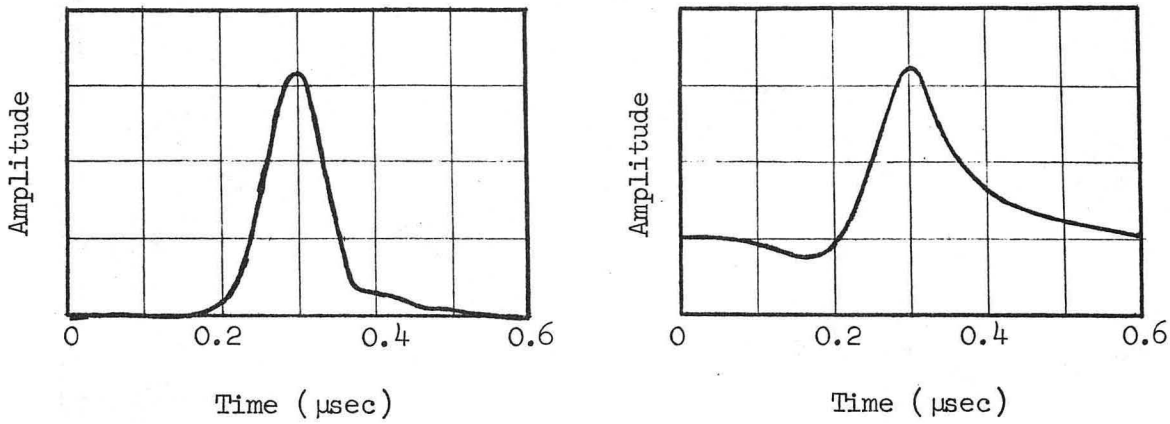
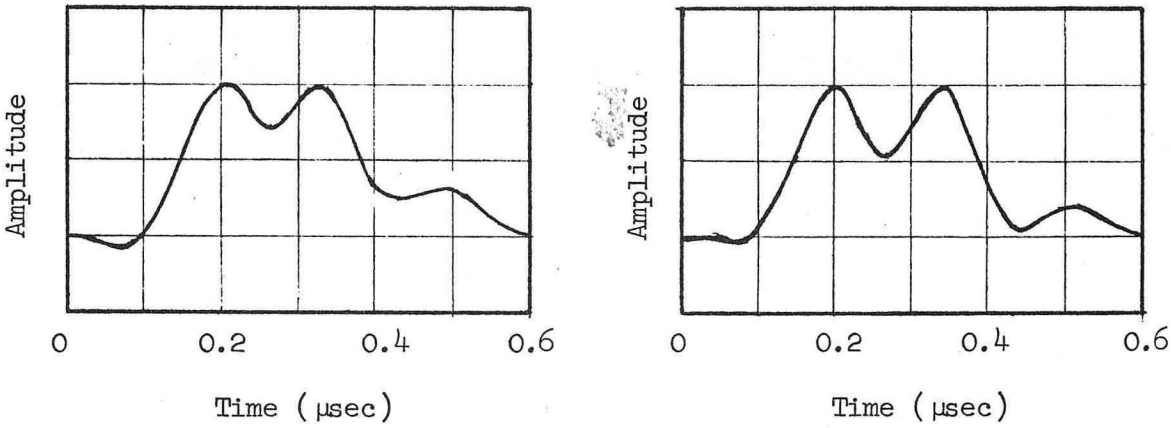
Fig. 4

DELAY LINE PULSES



Output Pulses from Delay Line
(10 cm down line) (40 cm down line)

DELAY LINE PULSES FOR TWO SIMULTANEOUS EQUAL-AMPLITUDE INPUT PULSES



Input Pulse Separation

(2 cm) (2.5 cm)

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Fig. 5

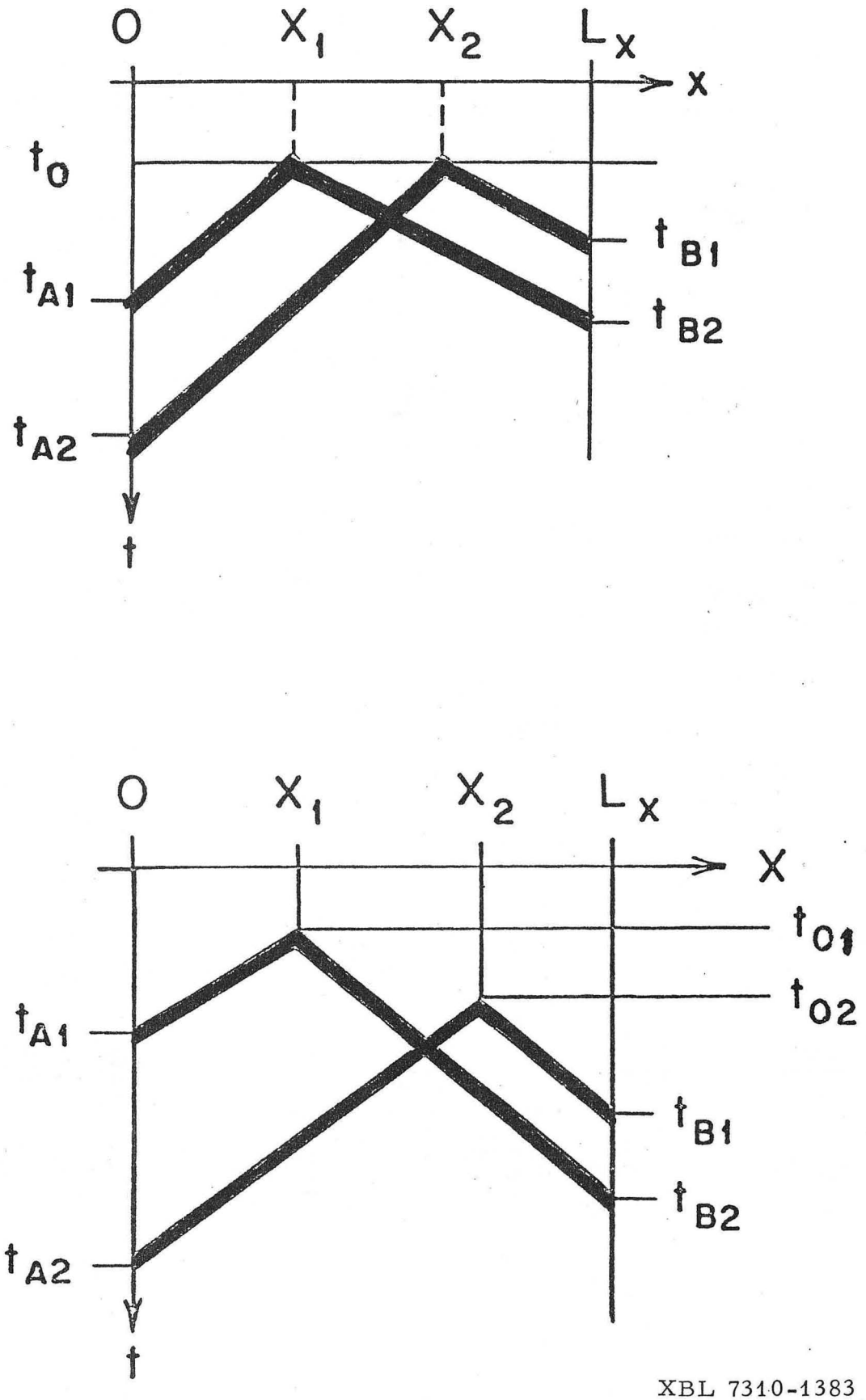

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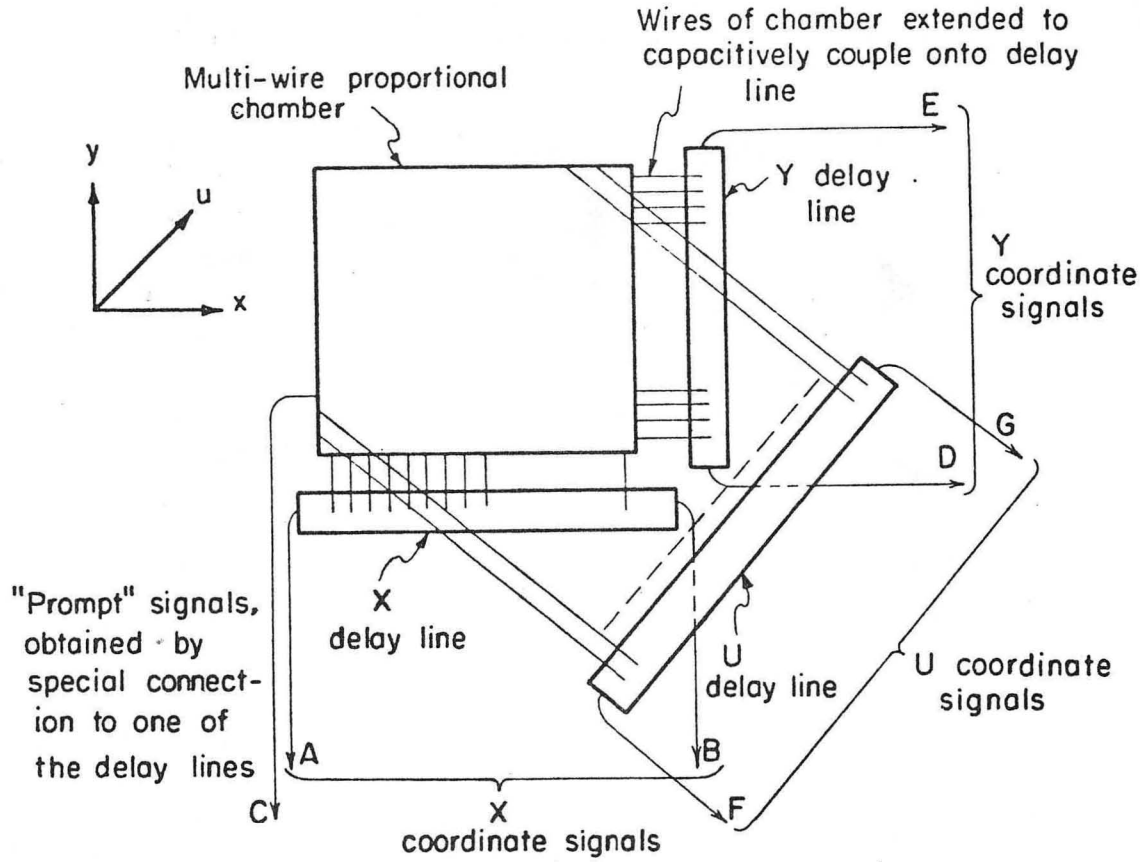
Fig. 6



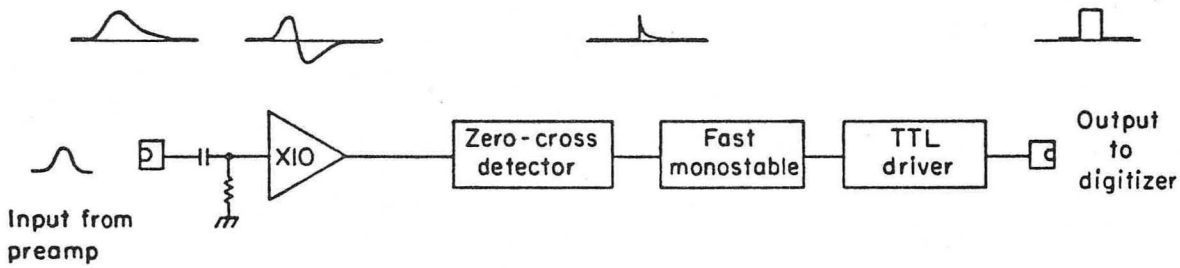


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Fig. 7

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