Title

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CHARACTERISTICS OF MULTIWIRE PROPORTIONAL COUNTERS WITH DELAY LINE READOUT FOR MINIMUM IONIZING PARTICLES

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Abstract

We have investigated the effect of gas mixture and chamber thickness on the gain and pulse shape of a multiwire proportional counter with delay line readout. We were primarily concerned with optimizing the position accuracy for high-energy particle physics applications. Our best results, both from the point of view of chamber gain and the risetime and uniformity of the delay line pulses were obtained with a 4 mm gap chamber run on a mixture of 30.2% carbon dioxide, 69.2% argon and 0.6% freon. When using gas mixtures with no electronegative components, we found it necessary to bias the outer grids negative with respect to ground to prevent electrons in the drift regions from migrating into the multiplication region and spoiling the delay-line pulse shape.

I. Introduction

We present here some measurements on the gain of the chamber and the shape of the delay line pulses that are relevant to particle physics applications in which an energetic, charged particle traverses

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the chamber with small energy loss; the shape and amplitude of the proportional signal vary substantially from event to event, and the chamber parameters must be optimized carefully to maintain the spatial resolution. This is a more difficult case than other applications in which low energy gamma rays convert in the chamber producing a small region of ionization and uniform, easily localizable pulses.[1]

We have studied chamber performance as a function of three parameters: (1) voltage gradient, (2) gas mixture, and (3) gap spacing. In addition, we have experimented with "drift regions" located between the outer grids and the grounded aluminum windows, which constitute the gas envelope of the chamber. Our criteria for satisfactory chamber performance are (1) the signal from the chamber should be as large as possible to overwhelm the noise inherent in the input stage of the delay line amplifiers.[2] (2) The gain should be stable without leakage, breakdown, or "regenerative feedback" leading to uncontrolled amplification of the signals. (3) The delay line signals should be fast, narrow, symmetric, and vary in shape as little as possible from pulse to pulse.

Each of these items is discussed in turn in Section III.

II. Chamber Description.

These tests were made with two different multiwire proportional counters, which are essentially identical except for the gap spacing, 9.5 mm between anode and cathode in the thick chamber and 4.1 mm in the thin chamber. The construction is shown schematically in fig. 1. The chambers are double gapped with the central plane at positive high voltage and the two outside grids near ground potential. A "prompt" signal is extracted from the anode, and the delay lines are coupled to the two cathode planes, which give an X and Y readout. The mechanical parameters of the chambers are summarized in Table I. The construction of the delay lines is described in references 3 and 4.

Table I - Chamber Construction

Plane Spacing	9.5 mm or 4.1 mm
Central Plane	20 μ stainless wound 5/cm.
Ground Plane	80 μ stainless wound 10/cm.
Chamber Area	50×25 cm^2
Windows	0.5 mil mylar, 0.5 mil aluminum
Delay Lines	40 cm and 60 cm long impedance 1.3 K ohms 6.5 nsec/mm propagation time
Spacing between ground planes and windows	8 mm

These chambers were designed for a series of cyclotron and Bevatron experiments involving high energy protons and alpha particles. They were the final elements of a magnet spectrometer system, consequently spatial resolution was at a premium. No attempt was made, however, to use dE/dx or pulse height information from the chambers, and the start time signal was obtained from a system of scintillators and fast logic. Hence we are not concerned with the properties of the signal from the central plane but only from the delay lines. It is often convenient to use the central plane signal to start the digitizing electronics, but no loss of positioning accuracy is involved in using a start time signal generated independently of the chamber so long as the pulses from both ends of the delay lines are digitized and the position obtained by subtracting the two delays.[2]

III. Results

The gain of the chambers was measured as a function of voltage by observing the pulse height on the central plane due to 22 keV gamma rays from Cd^{109} converting in the chamber. A scope picture of these pulses is shown in fig. 2. The gain curves are plotted for six different gas mixtures in figs. 3,4. These graphs were made with the thin chamber. Comparable curves could be made with the thick chamber but poor chamber insulation and excessive leakage prevented us from extending the voltage over 5800 volts.

The gain curves in figs. 3,4 extend from the voltage at which the signal was just large enough to distinquish clearly from the amplifier noise to what we regard as the maximum usable gain. It is an important point that this limitation on the maximum gain comes about differently for different gas mixtures:

a) 7% CH_4, 93% Ar. Above 2600 volts the pulse begins to widen and develop subsidiary peaks. As the voltage is increased an orderly succession of "saw-teeth" spread out from the initial pulse.

b) 30% CH_4, 70% Ar. At maximum gain the chamber begins to spark. Even with a 22 MΩ protection resistor in series with the high voltage one can hear distinct sparks as the chamber capacitance is discharged.

c) 7% CO_2, 93% Ar. The gain is limited by a regenerative feedback mechanism, which causes the pulses to grow erratically in amplitude and length. At slightly higher voltage the discharges become self sustaining.

d) 30.4% CO_2, 69.6% Ar. As the gain is increased the chamber loses pulse height resolution and the well-defined band of pulses from gamma conversion disappears entirely.

e) 29.7% CO_2, 70.0% Ar, 0.3% freon (13-B1). This is the same freon used in the magic gas mixtures.[5] There is a decreased pulse height resolution compared to (d). Other than the fact that the rise time of the pulses is appreciably faster --40 ns-- than in (d), there is little difference between both mixtures.

f) 30.2% CO_2, 69.2% Ar, 0.6% freon. This mixture gives a factor of 3 - 4 more gain before the pulse shape deteriorates prior to breakdown than the corresponding mixture in (d). The increased amount of the electronegative component --0.6% freon-- further sharpens the rise time of the pulse to 30 ns or less.

An important advantage of all the CO_2 mixtures is that the discharges in the chamber are self limiting; i.e., they draw sufficient current through our protection resistor to reduce the chamber voltage and thus they tend to prevent sparks. We have no evidence that the sparks that occur in methane mixtures do any real damage, but in the case of larger chambers with more capacity or accidental overvoltage the sparks could easily break the thin central wires.

Of the gas mixtures tested without electronegative additives, the 30% CO_2 clearly provides the highest gain for both the thin and thick chambers. Gain curves for a number of intermediate CO_2 concentrations and similar chambers are presented in ref. 6. These curves suggest that the optimum concentration of CO_2 is at least 25% for 4 mm gap spacing and about 20% for 8 mm spacing, i.e., the thinner the gap the more CO_2 needed to achieve optimum gain. The maximum attainable gain remains roughly constant as the CO_2 concentration is increased but the voltage necessary to reach it continues to rise. One eventually exceeds the limitations of the chamber insulation. For example, we were unable to run our thick chamber over 5.8 kV because of excessive leakage, but at this voltage the 30% CO_2 gain curve had not reached its maximum.

In addition to the gain, the pulse shape from the delay lines is extremely important in maintaining adequate resolution. The pulse width, after all, is at least 200 ns or about 4 cm in spatial extent. So to match the spatial resolution inherent in the chamber, the discriminator must find the center of the delay line pulse accurately to within a few percent of the pulse width. To mitigate this task we try to optimize the chamber to produce pulses that are as narrow and symmetric as possible.

The pulse shape measurements reported here were all made with a cosmic ray counter telescope, which insured that a minimum ionizing particle traversed the chamber within a small area ($\sim 5 \times 5$ cm^2) and within a small cone of angles ($\sim \pm 20°$) to the perpendicular.

One mechanism that seriously deteriorates pulse shape is the diffusion of electrons from outside the gap, through the cathode grids and into the multiplication region. Even when there is no potential difference between the grounded aluminum windows and the cathode many electrons produced in this "drift region" find their way into the central gap. This process is slow enough that the latecomers spoil the trailing edge of the delay line pulse producing multiple peaks. We have been able to eliminate this effect by biasing the outer planes negative with respect to the grounded windows, 300 volts in the case of the thin chamber and 600 volts for the thick chamber. We had originally intended to collect the electrons from these drift regions by biasing the cathode grids positive with respect to ground, thus accelerating the electrons into the multiplication region and increasing the effective thickness of the chamber. Even with very large biasing voltage, however, the pulses produced in this way were unacceptably broad and irregular. The situation is quite different when low energy gamma rays convert in the drift region. Because the recoil photoelectrons have such a short range in the gas the ionization electrons drift "in step" with each other into the multiplication region and produce a standard pulse shape. Thus the drift regions, which seem useless for high-energy work, are very practical in x-ray imaging applications.[1]

Another parameter that affects the delay line pulse shape is the thickness of the central gaps. Quite reasonable, the thicker the gap the broader the pulse, not only because of the increased electron collection time but also because of the spreading of the field lines going from anode to the cathode. We observe about 30% to 50% increase in pulse width depending on gas mixture between the thick and thin chambers. This increase comes about without appreciable deterioration of rise time, rather the pulses become broader and flatter on top. These trapezoid-like pulses are especially undesirable for use with zero-cross discriminators because the cross-over point of the differentiated pulse is not very well defined.[7] For this reason we have tried to keep the pulses as short and triangular as possible, and from this point of view the thinner chamber is definitely preferable.

These conclusions apply only to the gas mixtures without the Freon. When the Freon is added, we find that, as expected, there is no need for a drift voltage since the electrons which form the avalanche originate in a small region around the central plane wires.

From our measurements of the effect of gas mixture on the chamber pulses we can make the following observations:

1. Both the amplitude and the shape of the pulses vary substantially from event to event if the gas mixture does not contain Freon. The amplitude fluctuations have a full width at half maximum of about 50% and are consistent with the expected Landau fluctuations in dE/dx in the chamber gas.

The variations in pulse shape affect the risetime and the pulse width. They are presumably due to statistical fluctuations in ionization density along the track and are exacerbated by the differentiation in the chamber-delay line coupling. These fluctuations contribute to the error in pulse timing. They can be minimized by optimum choice of chamber thickness and gas mixture.

2. The risetimes of the signals on the central plane are more indicative of the collection times in the chamber gas than the output

of the delay lines because there is no differentiation. These risetimes observed near maximum gain are given in the next table.

Table II. Risetimes on the Central Plane for Various Gas Mixtures.

	7%	30%
Ar - CH_4	180 ns	140 ns
Ar - CO_2	125 ns	100 ns
Ar - CO_2	--	40 ns (0.3% Freon)
Ar - CO_2	--	30 ns (0.6% Freon)

The risetimes of the central plane and delay lines are qualitatively consistent if one takes into account the differentiation characteristics of the delay lines.

3. The risetime and hence the width of the delay line pulses is determined both by the characteristics of the delay line and of the gas when using gas mixtures without the Freon. For gas mixtures containing Freon (or any other suitable electronegative gas) both the risetime and width of the pulses will be determined mostly by the delay line since its frequency response is the limiting factor.

These results, which were obtained by photographing oscilloscope traces, are shown in the following tables.

Table III. Risetimes of Delay Line Pulses with Various Gas Mixtures.

	7%	30%
Ar - CH_4	r = 130 ns σ = 80 ns	r = 110 ns σ = 30 ns
Ar - CO_2	r = 100 ns σ = 25 ns	r = 90 ns σ = 15 ns
Ar - CO_2	---	r = 90 ns (0.3% Freon and σ = 15 ns 0.6% Freon)

Table IV. Delay Line Pulse Width

	7%	30%
Ar - CH_4	260 ns	215 ns
	σ = 80 ns	σ = 30 ns
Ar - CO_2	220 ns	180 ns
	σ = 60 ns	σ = 10 ns
Ar - CO_2	---	180 ns (0.3% Freon) σ = 10 ns
Ar - CO_2	---	180 ns (0.6% Freon) σ = 10 ns

As in all other respects the 30% CO_2 mixture with or without Freon is clearly superior. The pulses are almost symmetric with rise time equal to fall time and the timing jitter is minimal. (See figs. 5 and 6)

4. The results on pulse shapes are qualitatively similar for the thicker chamber if the pulse widths and the σ's are scaled up by roughly 50% for the gas mixtures without the Freon. The main point is that even with the reduced Landau fluctuations in the thick chamber, the timing jitter (discounting possible slewing effects in the discriminators) is less with the thin chamber.

Summary

We have investigated the effect of gas mixture and chamber thickness on the gain and pulse shape of a multiwire proportional counter with delay line readout. We were primarily concerned with optimizing the position accuracy for high-energy particle physics applications. Our results can be summarized as follows:

1. Of the two chambers tested, one with a 4.1 mm and the other with a 9.5 mm gap, the thinner chamber produced superior delay line signals with narrower pulses and less jitter in rise time and pulse width.

2. Four gas mixtures with no electronegative additives and two with 0.3% and 0.6% Freon were tried. The Ar-30% CO_2 mixture was the best of the first group in all respects, yielding higher maximum gain and faster pulses with less jitter. However, if one wishes to sacrifice linearity of response even further, the Ar-30% CO_2-0.6% Freon gives higher gain and considerably narrower pulses.

3. When using gas mixtures without electronegative additives, the outer chamber grids had to be biased so that free electrons in the drift regions between the cathode and the grounded chamber windows

could not be drawn into the multiplication region. Our attempt to increase the effective thickness of the chamber by accelerating electrons from the drift region into the central gap was unsuccessful because of the unacceptably broad and irregular pulses produced.

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Notes and References

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3. R. Grove, I. Ko, B. Leskovar, V. Perez-Mendez, "Phase Compensated Delay Lines for Wire Chamber Readout". Nuclear Instruments and Methods 99, p. 381 (1972).

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7. Discriminators that find the centroid of a pulse by integrating over the area and dividing by two would be quite useful for such pulses.

List of Illustrations

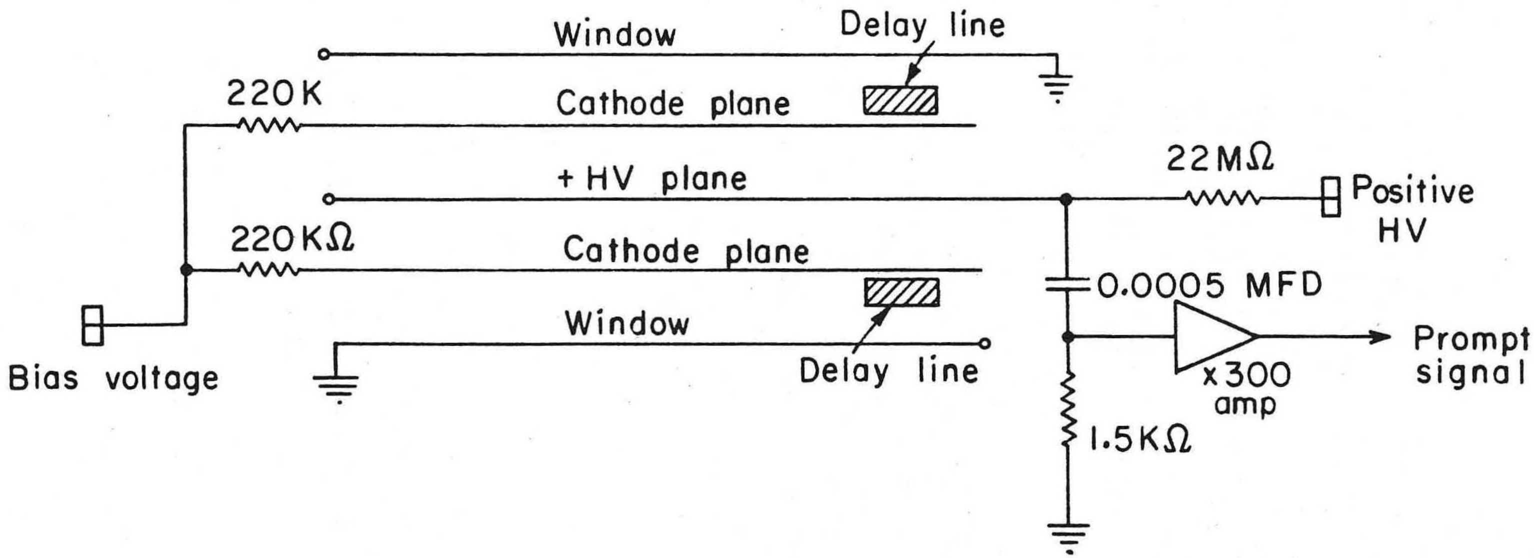
Window
Delay line
220K
Cathode plane
+HV plane
22MΩ
Positive HV
220KΩ
Cathode plane
0.0005 MFD
Window
Bias voltage
Delay line
x300 amp
Prompt signal
1.5KΩ
XBL737-3571

Fig. 1

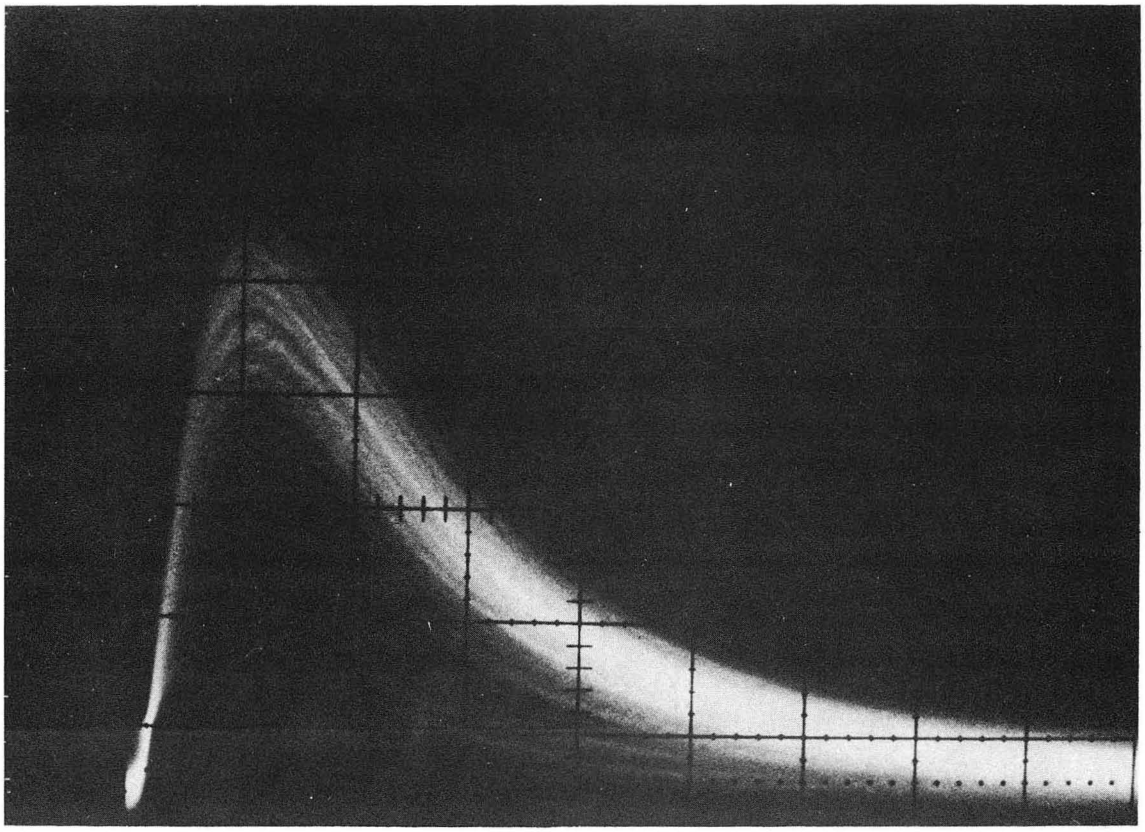

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Fig. 2

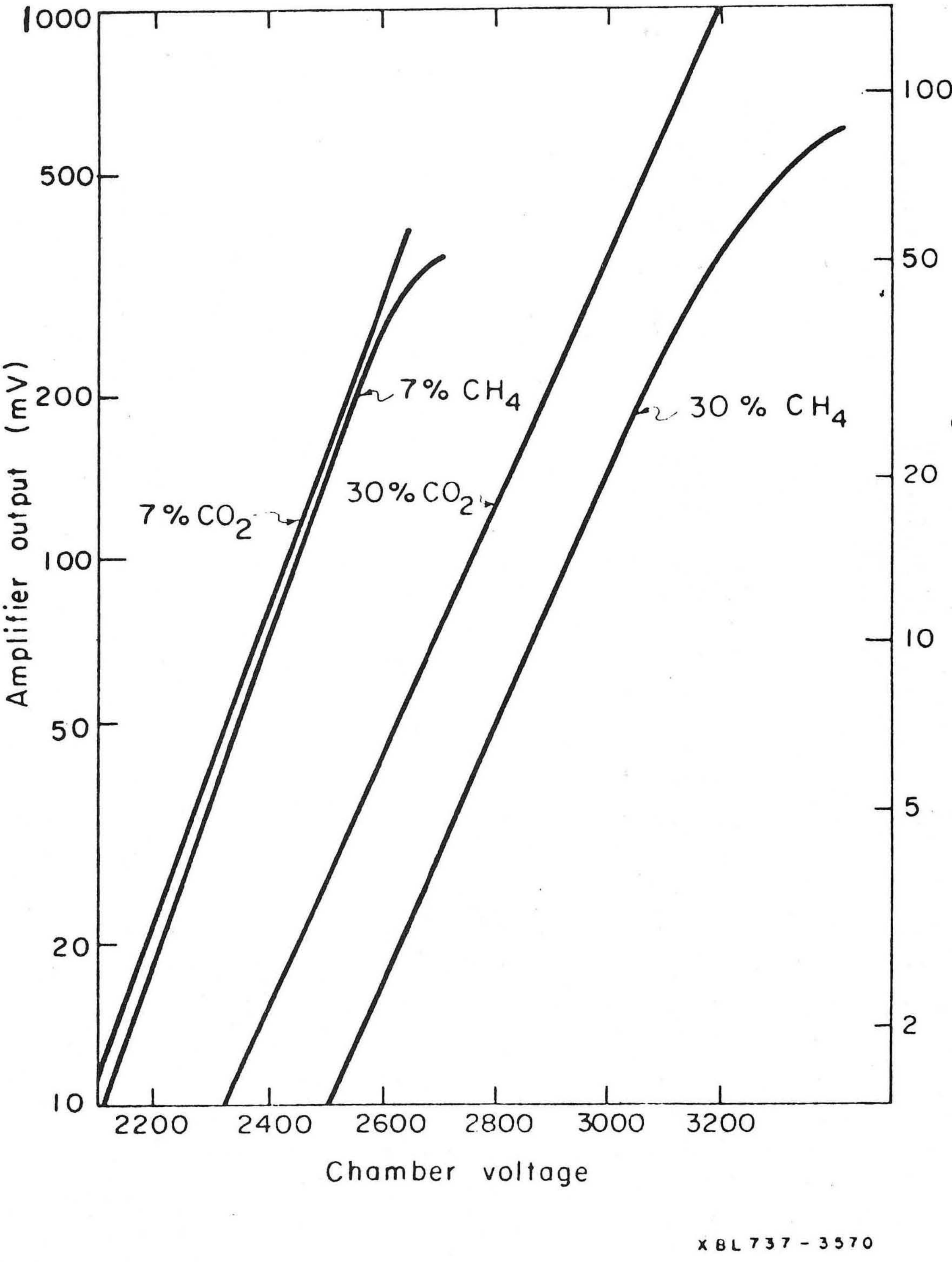
1000
500
200
100
50
20
10
100
50
20
10
5
2
2200
2400
2600
2800
3000
3200
Chamber voltage
Amplifier output (mV)
Gain x 10^{-2}
7% CH_4
30 % CH_4
7% CO_2
30% CO_2
XBL 737-3570

Fig. 3

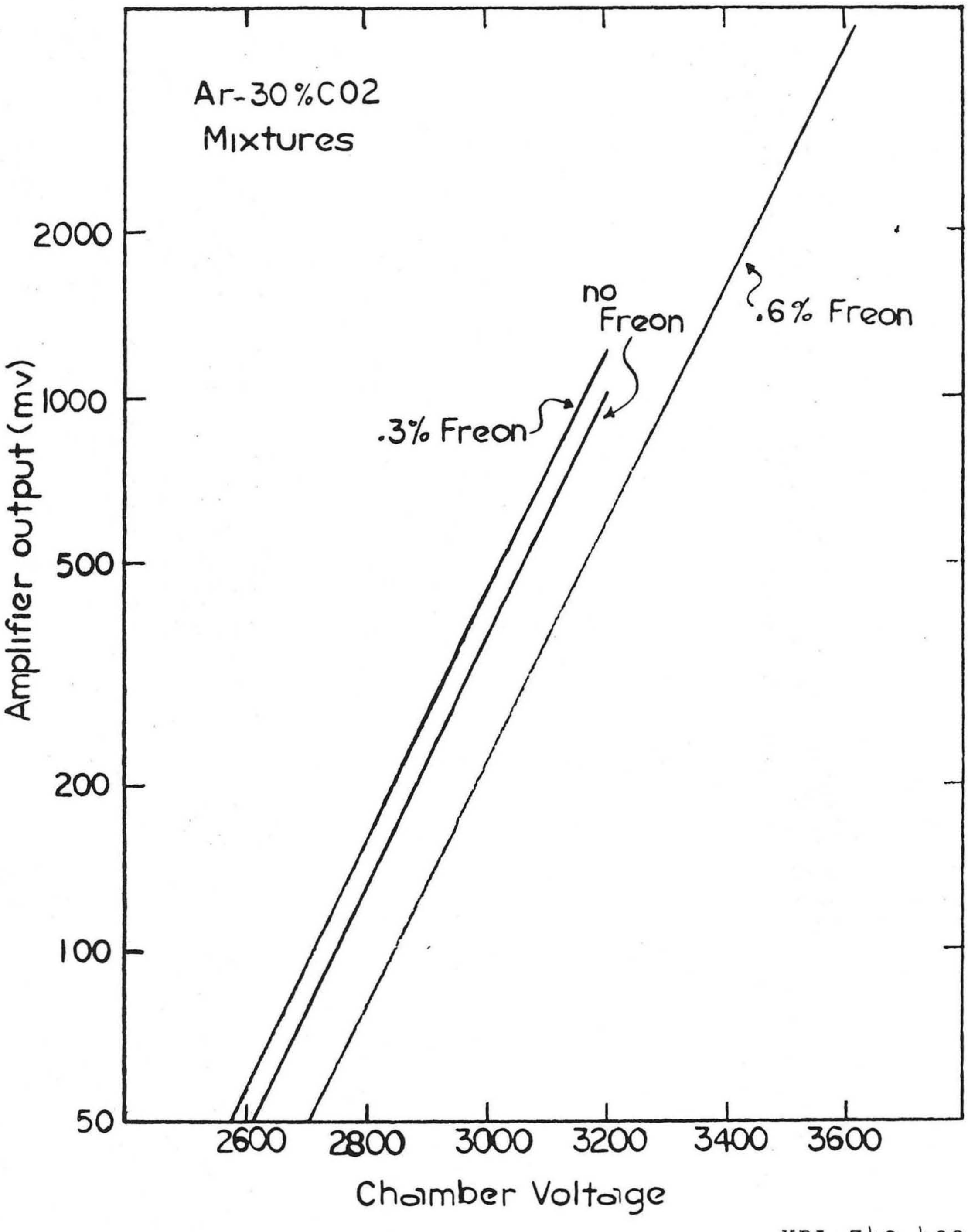

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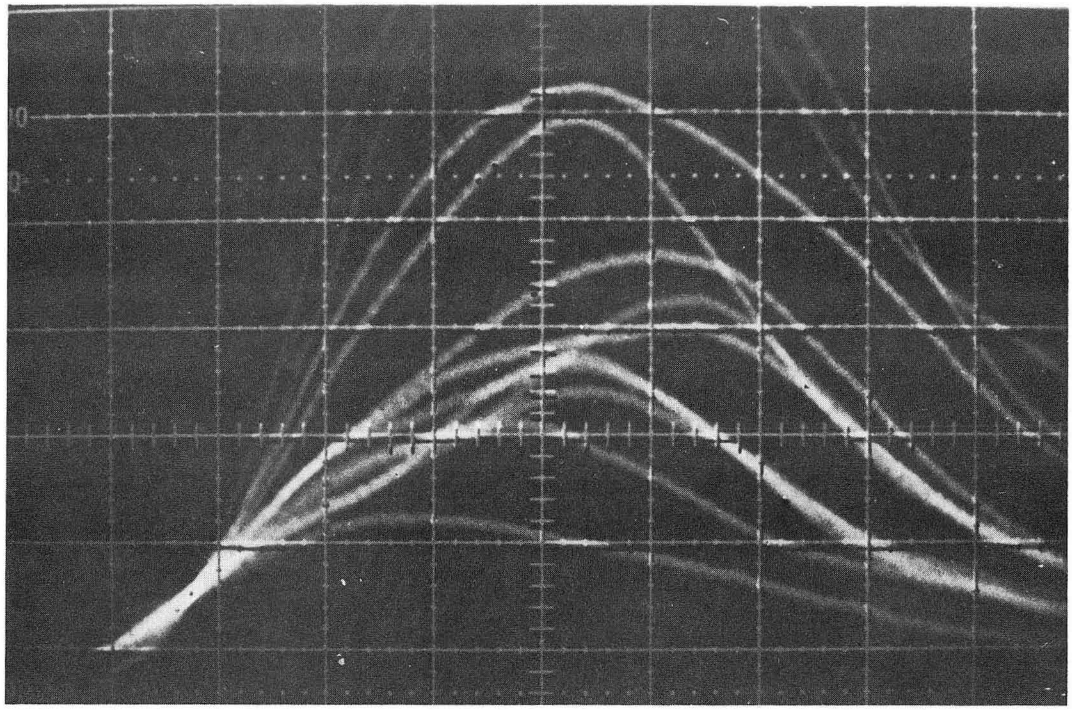
Fig. 4



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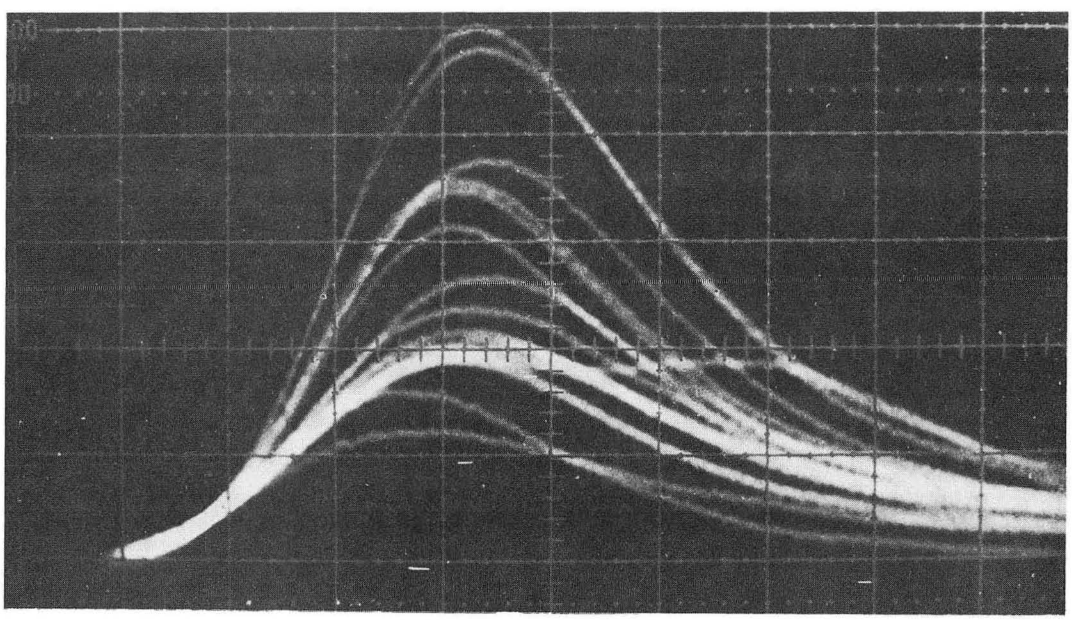

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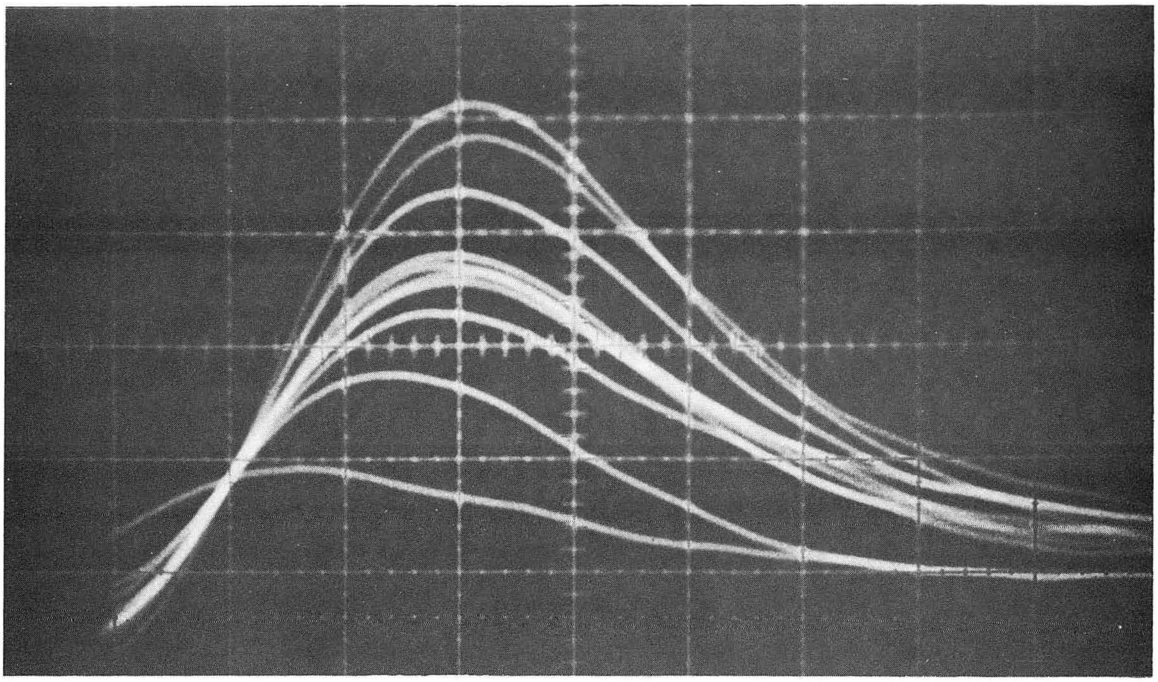
XBB 737-4164

Fig. 5



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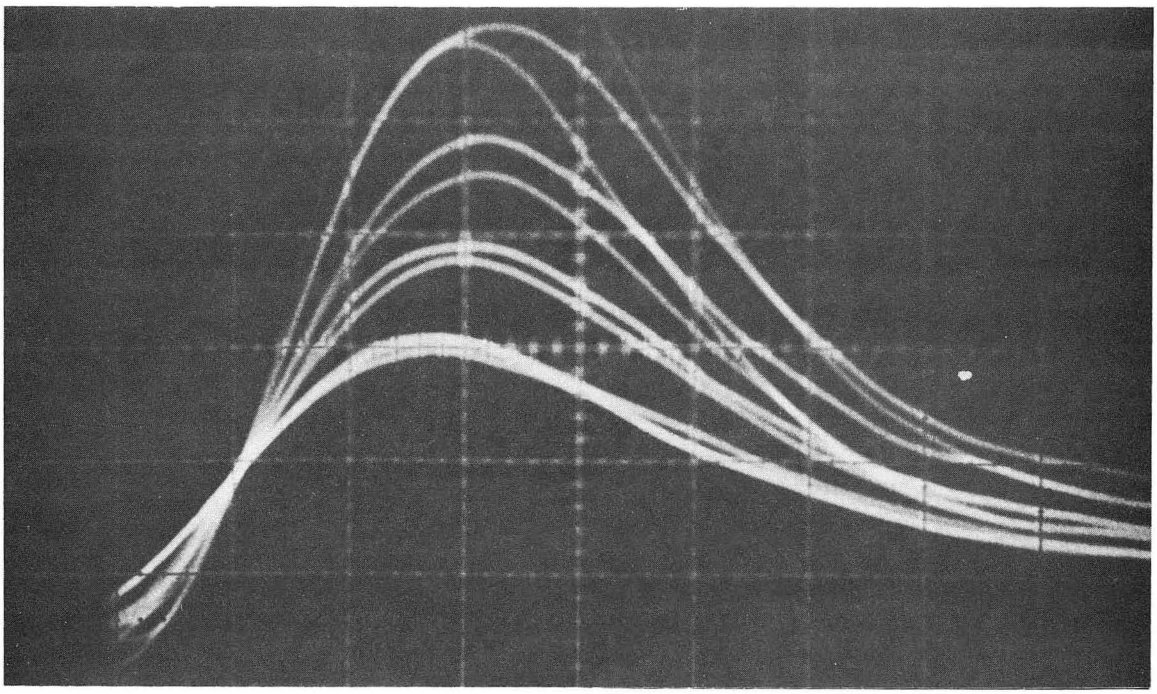

b

XBB 743-1659

Fig. 6

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