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October 11, 1968

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ABSTRACT

We describe methods by which large wire spark chambers can be constructed and read out with uniform efficiency and accuracy over their entire length. The high uniform efficiency for registering multiple tracks is obtained by the use of auxiliary conducting planes which serve to charge the chamber capacity with a low impedance transmission-line characteristic. The magnetostrictive readout is improved by the use of torsional pulses in the sense wire which provide a greater degree of linearity than the longitudinal pulses used previously.

I. INTRODUCTION

In many spectrometer-type experiments in which wire chambers with magnetostrictive readout have been used, the simple arrangement shown schematically in fig. 1 has given excellent results[1].

The success of this technique has prompted us to develop it further for use in large chambers capable of detecting multiple tracks with a uniform high efficiency. As regards the stereo ambiguity problems, we have found that these are essentially resolved by making the chambers in modules of two gaps, with each gap forming an independent set of coordinates.

These wire plane arrangements, however, have the difficulty that direct pulsing of the chambers does not produce a very uniform efficiency over the

entire sensitive area, due to the large distributed inductances of the wire planes. To resolve this difficulty, we build the chambers with additional thin aluminum planes, which are used to charge the capacity of the chamber gap with a characteristic approximating that of a transmission line.

A second difficulty that occurs in the readout when the chambers become large enough in any one dimension (more than 2 or 3 meters) is that the longitudinal-mode magnetostrictive readout has dispersive characteristics which affect the shape of the acoustic pulses and require linearity corrections in order to achieve maximum accuracy[2]. To overcome this difficulty, we have investigated the characteristics of lowest-mode torsional pulses in the magnetostrictive sense wire and find that they can be used with advantage in large chambers.

II. TRANSMISSION LINE PULSING AND EFFICIENCY CHARACTERISTICS

The configuration of crossed-wire planes shown in fig. 1 results in a chamber whose efficiency is liable to vary appreciably over its sensitive surface, because the inductance of the wires produces a nonuniform electric field in the gap when a high-voltage pulse is applied through the bus bars of each plane. Arrangements in which either the two wire planes have wires parallel to each other, or one of the planes is made of a solid conducting sheet improve the pulse characteristics appreciably. However, both of these methods have the obvious disadvantage that they require a larger number of gaps in order to obtain the same information on track coordinates that the crossed-wire-plane gaps achieve. As mentioned above, the solution that we have adopted is to retain crossed-wire configurations for the readout, but to charge the chamber capacity through thin aluminum planes placed close to the wire planes[3].

Two alternative arrangements that we have used are shown schematically in fig. 2. The arrangement of fig. 2a provides for a decoupling of the two gaps by having separate conductors for the central planes. Figure 2b is the arrangement used in some of our sparkostrictive (nonmagnetic readout) chambers[4] in which the decoupling is not necessary, since we draw smaller currents during the spark. These charging planes are made conveniently of aluminized Mylar (0.2-mm Mylar; 0.01-mm aluminum) which is quite strong and provides a minimum amount of material in the way of the beam particles. For the magnetostrictive case, these charging planes are electrically connected along their entire length to the bus bars of their corresponding wire planes.

Since the impedance of a parallel-plate transmission line in air is $Z_0 = 377(a/b)$, where a is the width of the gap, and b is the width of the plane, the impedance of the chambers will usually be of the order of a few ohms. The low-impedance termination at the far end insures that electrical reflections are well-damped, and hence that the electric field in the gap is uniform during the build-up of the spark. Furthermore, since this impedance is small compared to the spark impedance during its formation phase, it tends to minimize voltage changes that would otherwise occur if the current load on the voltage source varied appreciably due to different numbers of sparks in each event.

The total current drawn by the sparks can be limited by the use of a 'quenching' gas such as ethyl or methyl alcohol. In fig. 3a we plot the relative currents drawn by sparks under the same external conditions but with different amounts of quenching gas. In fig. 3b we show the effect on the threshold voltage on the chamber for 100% efficiency as a function of the quenching-gas concentration. These concentrations can be obtained easily by

bubbling the normal Ne-He mixture through the appropriate organic liquid maintained at a specific temperature.

Since the sparks appear to be very clean and narrow although with a much-diminished brightness relative to the pure Ne-He gas, it is feasible and convenient to limit spark currents by this method. The reduction in threshold potential as a function of quenching-gas concentration is due to the Penning effect[5]. A side effect of the diminution of the spark current is that the recovery time of the spark chambers is decreased appreciably[6].

The voltage pulse on the chambers can be provided by discharging a delay line of the same characteristic impedance as the chamber. Such a delay line can be made of course by paralleling a number of coaxial cables to give the necessary impedance. In practice, we have found that the voltage pulses appearing on the chamber can be made satisfactorily by discharging 2 or 3 sections of an artificial delay line. Such an arrangement is shown in fig. 4, where the inductance between the condensers is provided by a short piece of 50-Ω cable.

The data given below were obtained from a pair of chambers consisting of two gaps each in which the two ground planes had wires oriented vertically and horizontally, while the two high-voltage planes in the middle had wires oriented at ±30 deg relative to the vertical direction. The gap widths were 1 cm, and the external dimensions of the chamber were 1.5 m wide and 2 m long. Figure 5a & b shows the shape of the voltage pulse at the input and at the terminated end of these chambers; fig. 5c shows the corresponding voltage pulse shapes in the sparkostrictive chambers in which the wire planes have a smaller coupling to the aluminized Mylar planes.

The multiple-track efficiency shown in fig. 6 was obtained from the

two magnetostrictive chambers, discussed above, which have been used in an experiment at SLAC[7]. Multiple-track events were generated by electron-positron background pairs traversing the chambers during the 1.5-μsec beam spill of the accelerator.

III. TORSIONAL-PULSE MAGNETOSTRICTIVE READOUT

The magnetostrictive-delay-line readout method that we have been using for the smaller chambers uses longitudinal pulses in the sense wire. As is well known from acoustic theory, this type of pulse transmission has dispersive propagation properties and hence poses some practical limitations on the length of the sense wire that can be used. Some of the properties of longitudinal pulses and lowest-order torsional pulses are listed in Table 1.

Table 1

Properties of Longitudinal and Torsional Pulses in Wires[8]

	Longitudinal	Torsional
Pulse generation	Joule effect	Wiedemann effect
Pulse detection	Inverse Joule (Villari) effect	Inverse Wiedemann effect
Longitudinal phase velocity in infinite medium	$C_L = \left(\frac{E_L}{\rho}\right)^{\frac{1}{2}} = \left(\frac{\lambda + 2\mu}{\rho}\right)^{\frac{1}{2}}$ *	$C_T = \left(\frac{\mu}{\rho}\right)^{\frac{1}{2}}$ = velocity of transverse waves
Phase velocity V in wire of radius Ω, wave length Λ	$V_L \approx C_L \left(1 - \frac{\pi^2 \sigma^2 r^2}{\Lambda^2}\right)$ **	$V_T = C_T$ (for lowest mode)
Wire radius r for useful pulse propagation	$r < 0.1$	$r < \frac{5.14\ V_T}{2\pi f_c}$ (for lowest mode)

* λ, μ = Lame constants, E_L = Young's modulus of elasticity, ρ = density of material.

** $\sigma = \frac{\lambda}{2(\lambda + \mu)} = \frac{\text{lateral contraction}}{\text{longitudinal extension}}$ = Poisson's ratio.

From the table we see that the dispersive effects can be minimized by choosing a sense-wire diameter small compared to the mean effective wave length of the pulse. In practice we have used 0.15-mm-diam Vacoflux[9] Fe-Co wire, which is a suitable compromise between a satisfactory degree of dispersion and signal strength. As can be seen from fig. 7, there is a noticeable degradation in the pulse shape at distances greater than 2 meters. Thus for larger chambers the use of torsional pulses becomes worthwhile, since the lowest-mode pulses have no dispersion and they can be generated in wire chambers in the same configuration as used for longitudinal pulses.

The method of generating torsional pulses in wire chambers involves the use of the Wiedemann effect as shown in fig. 8. The torsional pulses are generated by a combination of a steady-state azimuthal magnetic field through the wire and a local pulsed longitudinal field. The superposition of these two fields produces a local pulsed helical field which generates a torsional pulse provided that H_θ is greater than H_L[10]. Since the component H_θ is generated by a uniform current passing through the wire, it is maximum at the surface and decreases to zero at the center. Thus there will be a region of the wire where H_θ is less than H_L, and in this region a longitudinal pulse will be generated. This simultaneous generation of torsional and longitudinal pulses poses no difficulty, since the detector can be made to pick up one or the other uniquely. The mode-converter arrangement shown in fig. 9a, which can be made quite easily by soldering a short piece of nickel wire or ribbon at the end of the sense wire, detects only torsional pulses with a high degree of discrimination against longitudinal pulses. Alternatively (fig. 9b), the coil pickup arrangement commonly used for detection of longitudinal pulses can

be used also. If the coil is biased by a longitudinal dc magnetic field, it detects the longitudinal pulse; if there is no dc component of magnetic field in the portion of sense wire in the vicinity of the coil (i.e., no bias magnet) the longitudinal pulses are not detected, whereas the torsional pulses are detected by the inverse Wiedemann effect[11]. This inverse effect is the generation of a voltage signal by a time-varying helical magnetic field.

In reality, various torsional pulse modes may be excited by the pulsed helical field. However, the lowest mode can always be selected by choosing the wire diameter so it is the only one that will propagate with slight attenuation.

This condition is that[12]

$$r < \frac{5.14\ V_T}{2\ f_c} ,$$

where $V_T = \left(\frac{\mu}{\rho}\right)^{\frac{1}{2}}$, and f_c is the limiting upper frequency for the lowest torsional mode.

When this condition is satisfied for a given frequency f_c, the higher modes will be strongly attenuated by a factor

$$\alpha = \frac{R_n}{r}\left[1 - \left(\frac{f}{f_c}\right)^2\right]^{\frac{1}{2}} ,$$

where A is in nepers/cm, and R_n are the roots of a characteristic equation and have the values

$$R_1 = 5.14;\quad R_2 = 8.42;\ R_3 = 11.62;\ \text{etc.}$$

For our sense wire we used hard-drawn Elinvar Extra[13] (an alloy of iron, nickel, chromium, and titanium used in commercial delay lines.)

Figure 10 shows the attenuation and distortion of the pulse shape as a function of distance. Although these pulses are slightly wider than the corresponding longitudinal-mode pulses, the two-spark resolution is not impaired since their velocity is approximately two-thirds the velocity of the longitudinal ones.

CONCLUSIONS

Large wire chambers can be built with uniform, high multiple-track efficiency by charging the capacity of the chamber through aluminum backing plates and terminating the chamber in its characteristic impedance. Since this is of the order of a few ohms, the effect of the spark currents on the voltage wave form is small, and hence there is a uniform efficiency for multiple tracks. The use of torsional pulses on the readout line permits a high accuracy of spark position location along the chamber's entire length.

FOOTNOTE AND REFERENCES

* This work was done under the auspices of the U. S. Atomic Energy Commission.

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8) Warren P. Mason, Physical Acoustics and the Properties of Solids (D. Van Nostrand & Co., Princeton, N. J., 1958), Chap. 2.

9) Vacoflux, an Fe-Co alloy manufactured by Vacuumschmelze Aktiengesellschaft, Hanau, West Germany.

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11) R. M. Bozorth, Ferromagnetism (D. Van Nostrand & Co., Princeton, N. J., 1951), Chap. 13, p. 628.

12) See reference 8, Chap. 2, p. 48.

13) Elinvar Extra, a Ni-Cr-Ti alloy manufactured by Hamilton Precision Metals, Lancaster, Pennsylvania.

FIGURE LEGENDS

Fig. 1. Crossed-wire arrangement for small chambers.

Fig. 2. (a) Magnetostrictive chamber with independent gaps.
(b) Sparkostrictive chamber with common high-voltage plane.

Fig. 3. (a) Relative spark current and (b) sparking efficiency threshold in 90% Ne - 10% He vs. ethanol concentration.

Fig. 4. Artificial charging line schematic.

Fig. 5. Magnetostrictive chamber high-voltage pulses at (a) terminating point and (b) driving point. (c) Sparkostrictive chamber pulse with and without sparks (superimposed).

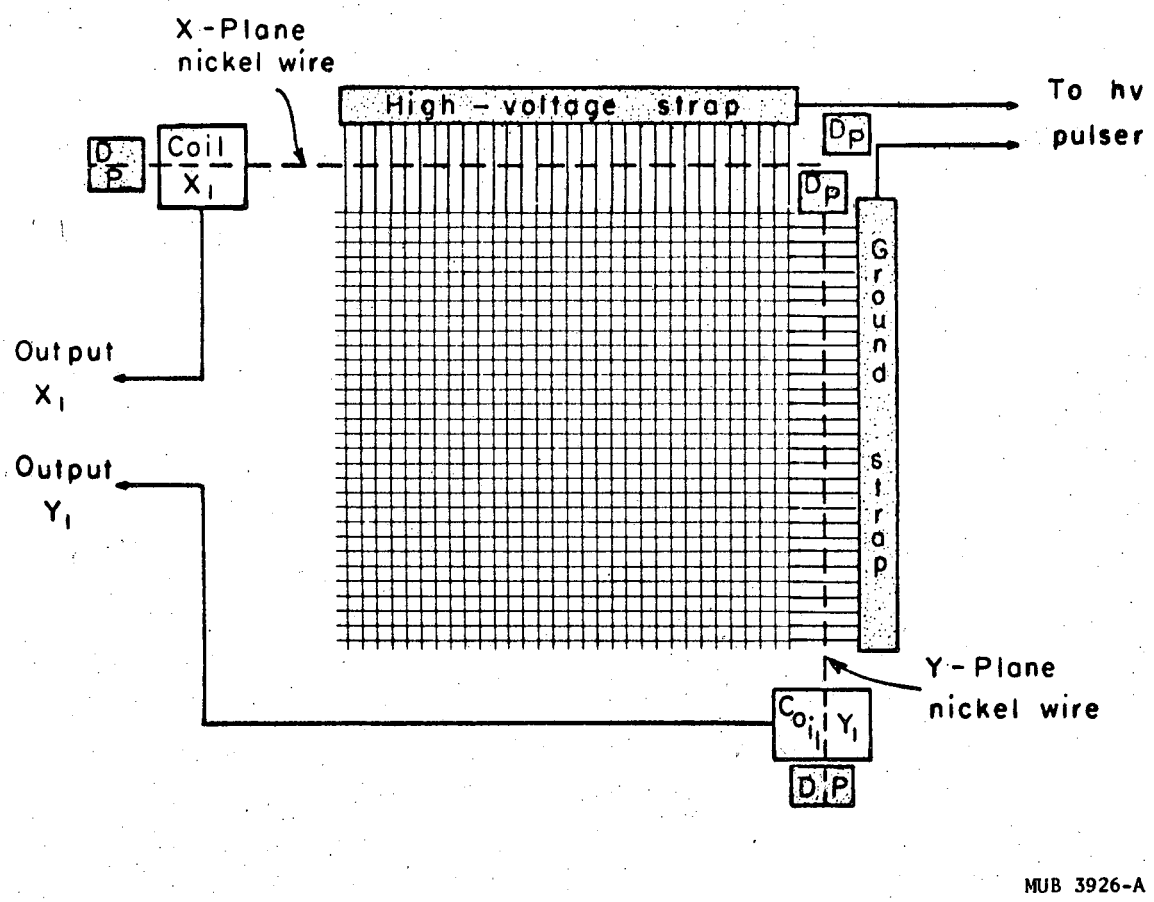
Fig. 6. Efficiency of SLAC magnetostrictive chambers as a function of number of recorded tracks.

Fig. 7. Longitudinal pulse shapes for 0.15-mm-diam Vacoflux wire in (a) air and (b) in Teflon tubing as used in the chambers.

Fig. 8. Generation of torsional pulse by summation of steady-state azimuthal field $[H_\theta]$ and pulsed longitudinal magnetic field $[H_L]$.

Fig. 9. Detection of torsional pulses. (a) Mode converter; (b) nonbiased coil.

Fig. 10. Torsional pulse shapes for 0.020-in.-diam Elinvar Extra wire in (a) air and (b) in Teflon tubing, as used in the chambers.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nickel wire
High - voltage strap
To hv
pulser
D
P
Coil
X1
Dp
Dp
Ground
strap
Output
X1
Output
Y1
Y-Plane
nickel wire
Coil
Y1
D P
MUB 3926-A

Fig. 1

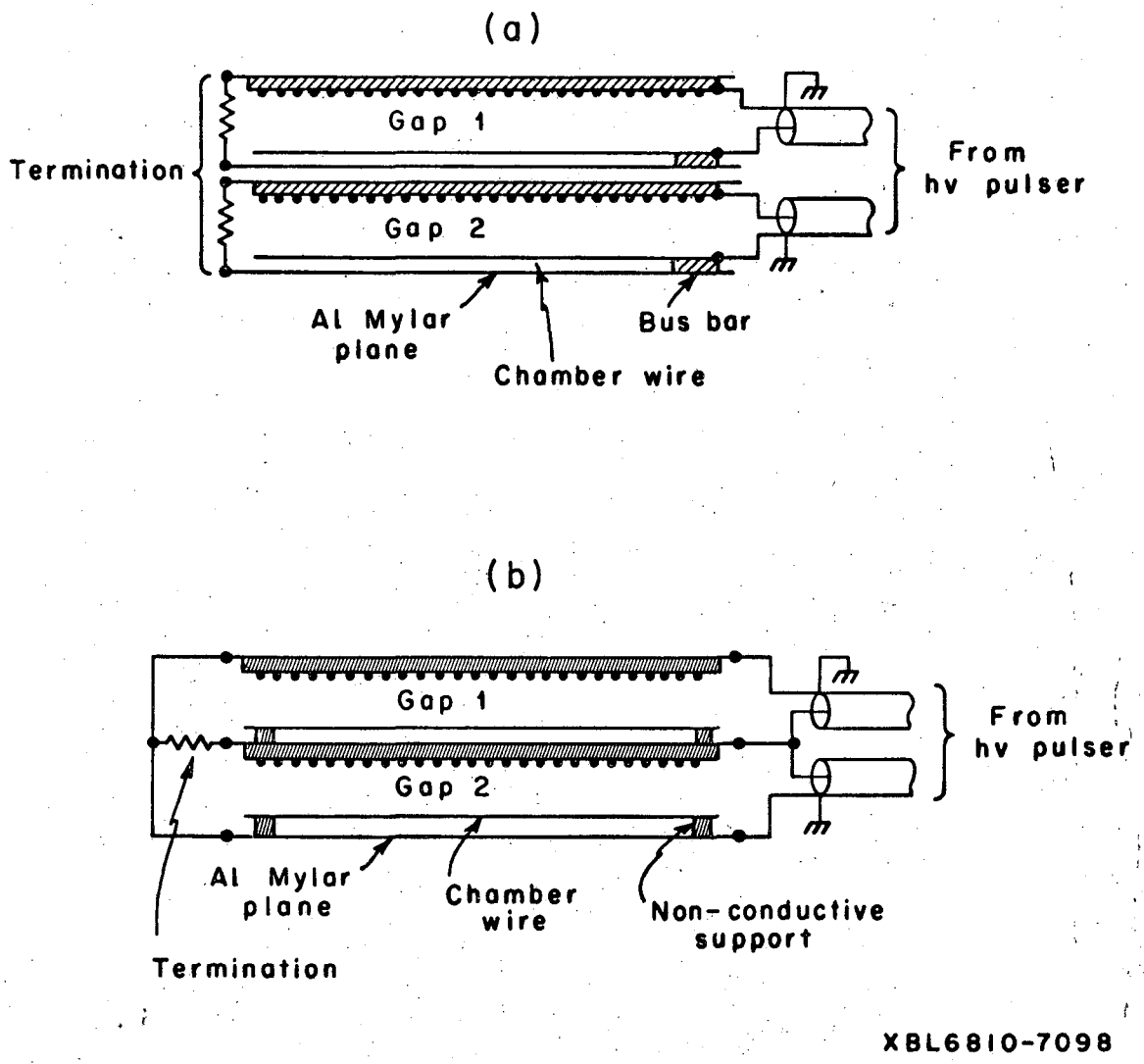
(a)
Gap 1
Gap 2
Termination
From
hv pulser
Al Mylar
plane
Chamber wire
Bus bar
(b)
Gap 1
Gap 2
From
hv pulser
Al Mylar
plane
Chamber
wire
Non-conductive
support
Termination
XBL6810-7098

Fig. 2

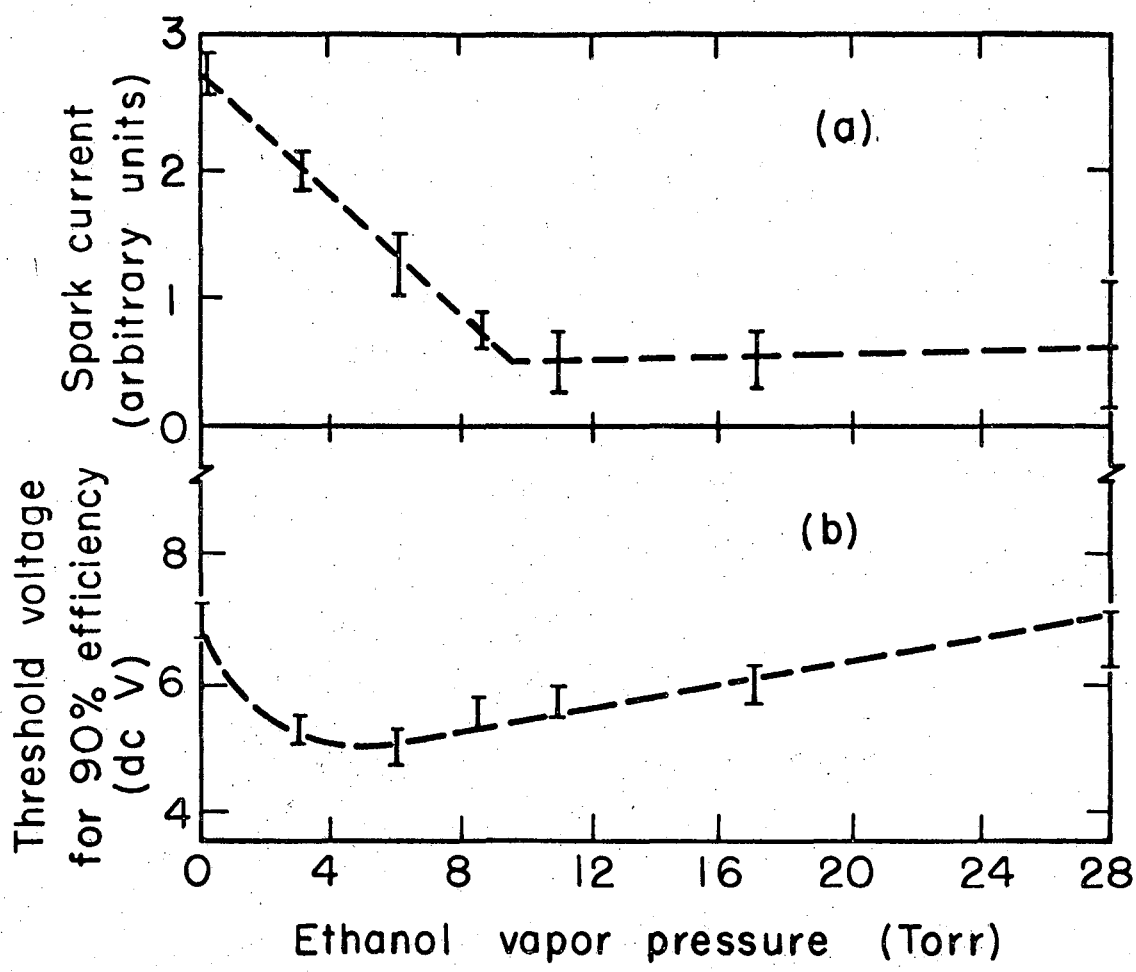

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Fig. 3

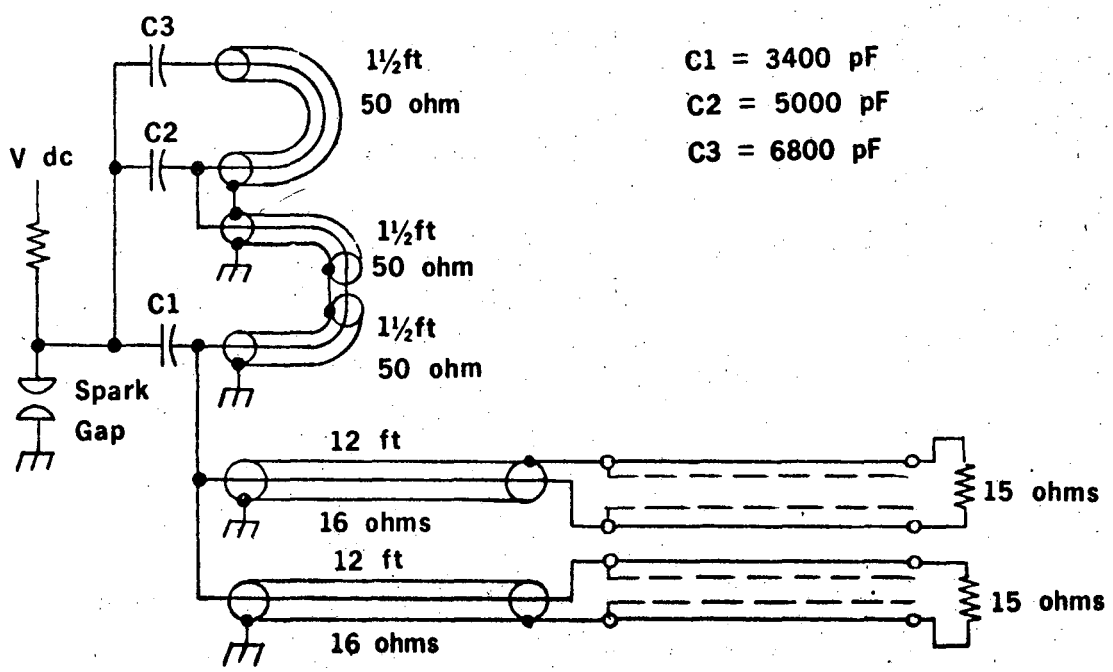

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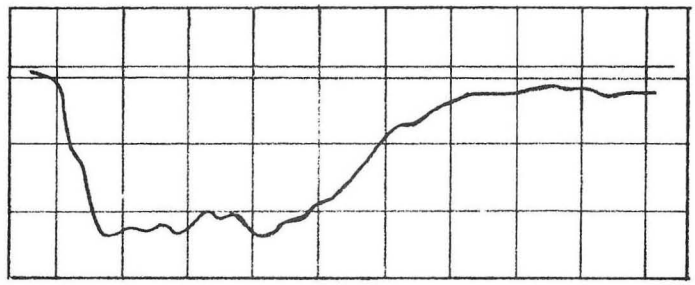
Fig. 4

(a) Terminating Point



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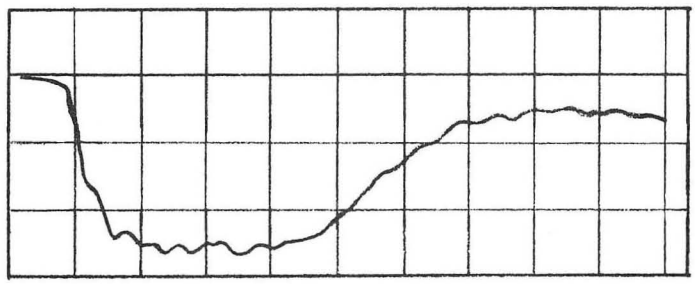
(b) Driving Point



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(c) Terminating Point

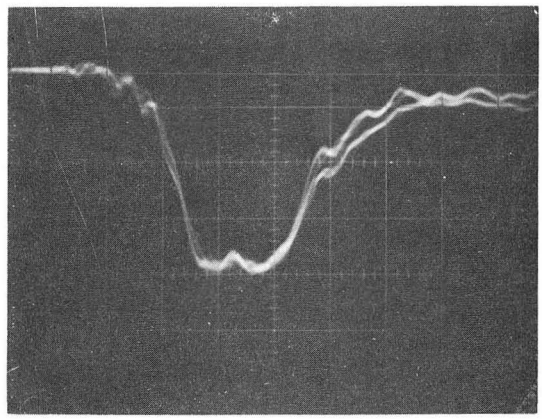

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Fig. 5

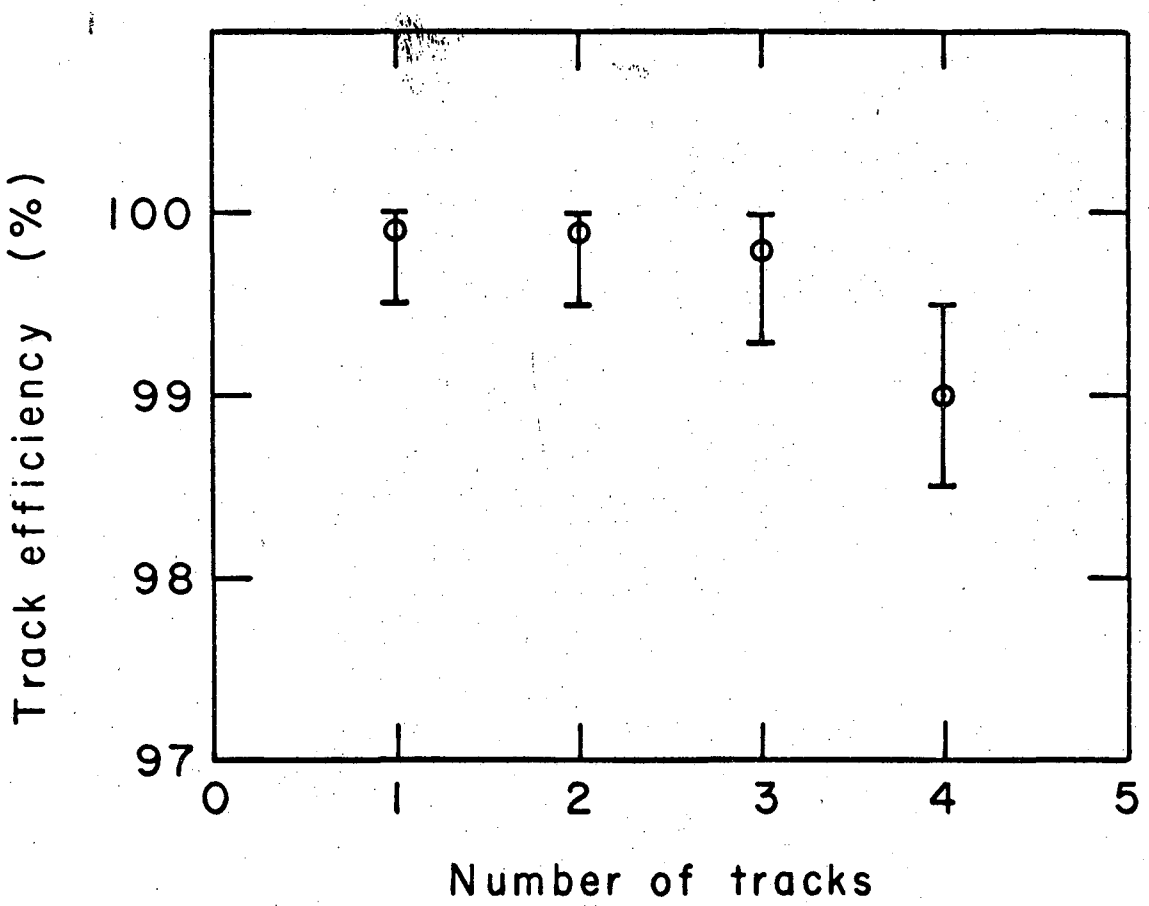

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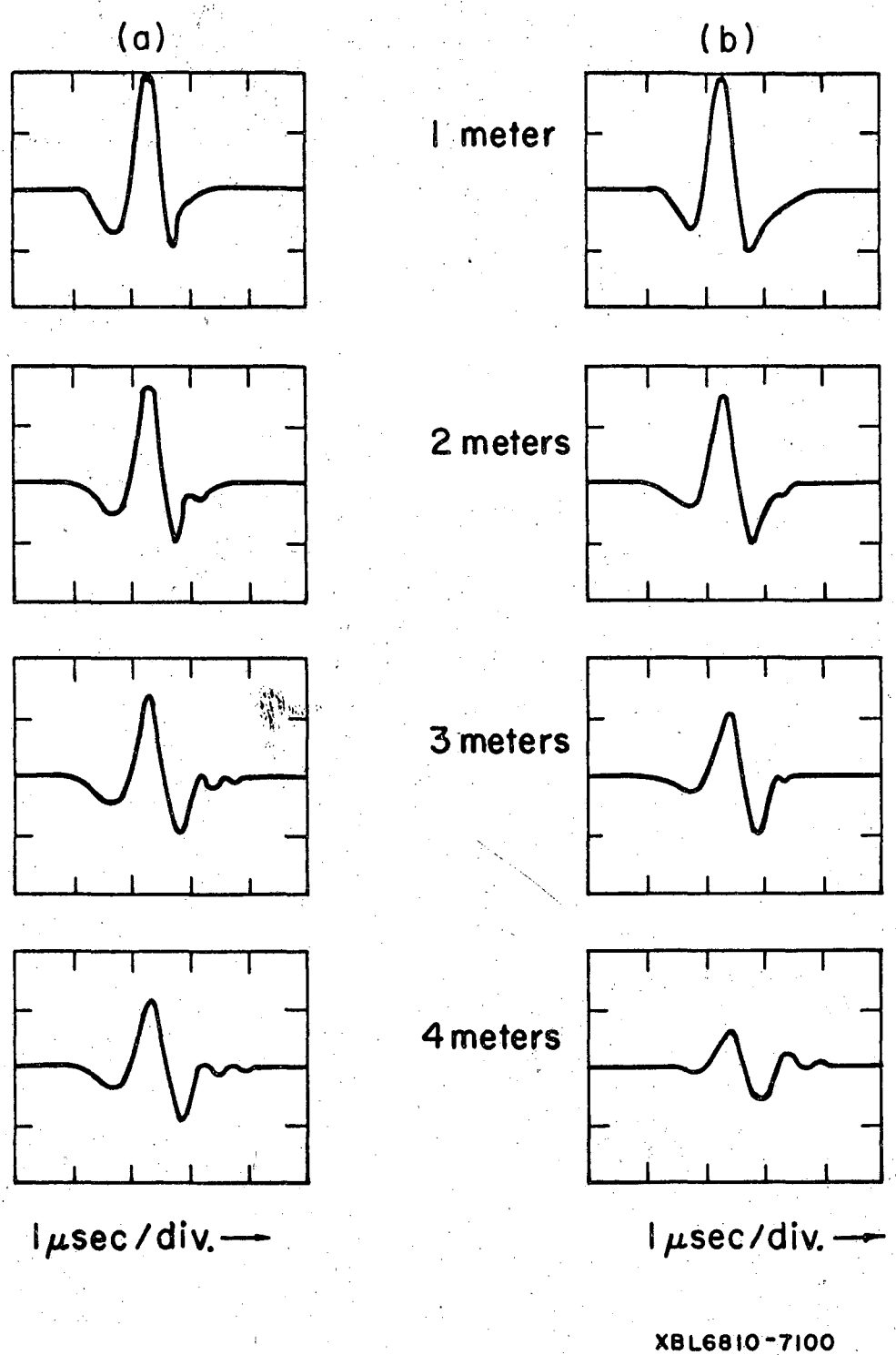
Fig. 6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(b)
1 meter
2 meters
3 meters
4 meters
1 μsec/div.
1 μsec/div.
XBL6810-7100

Fig. 7

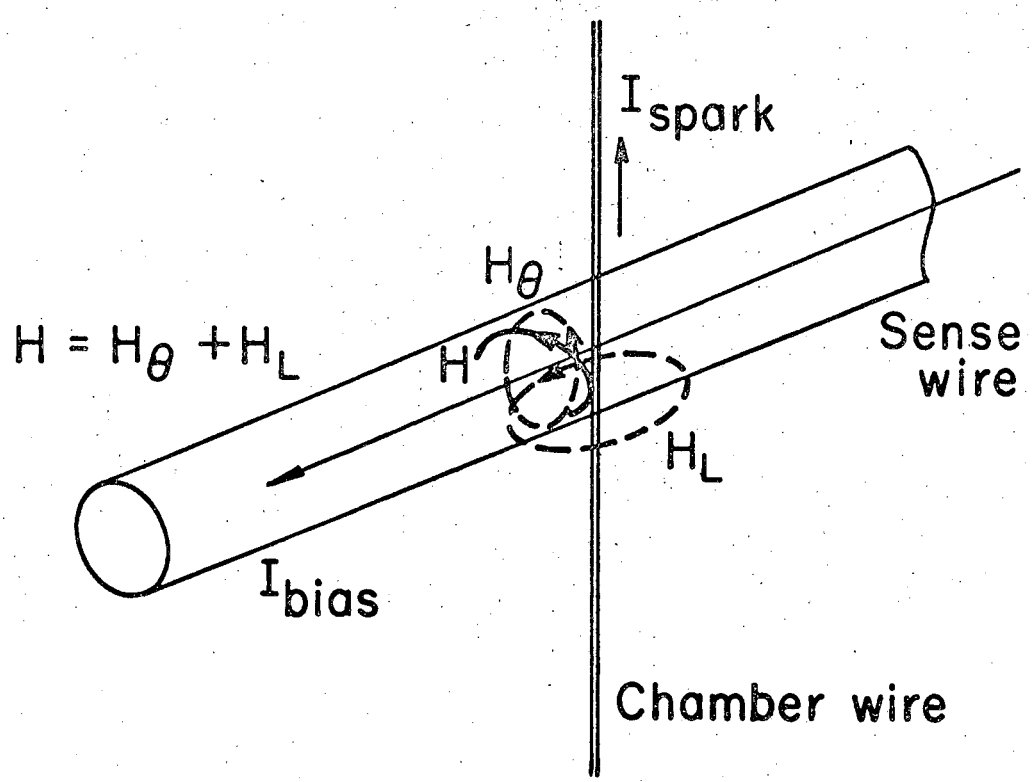

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Fig. 8

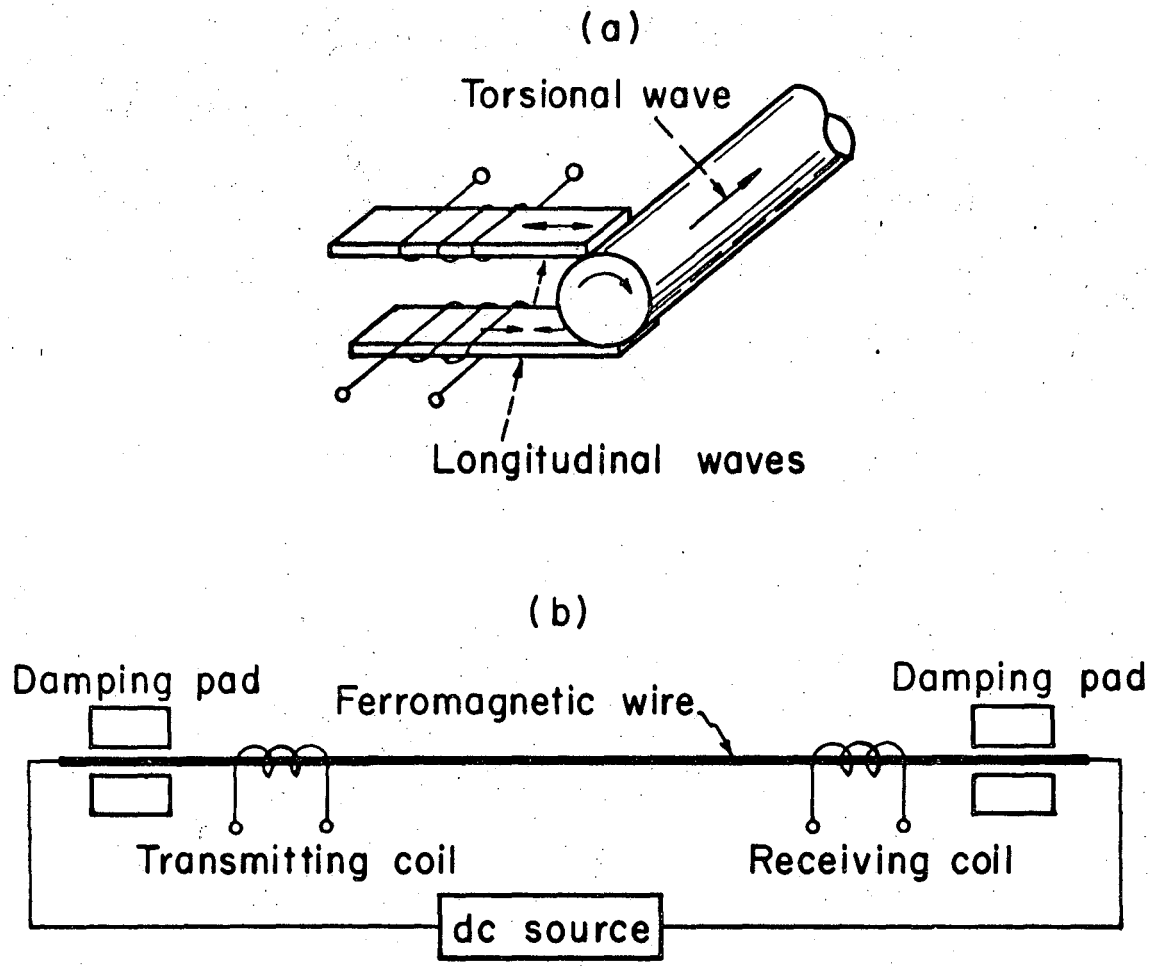

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Fig. 9

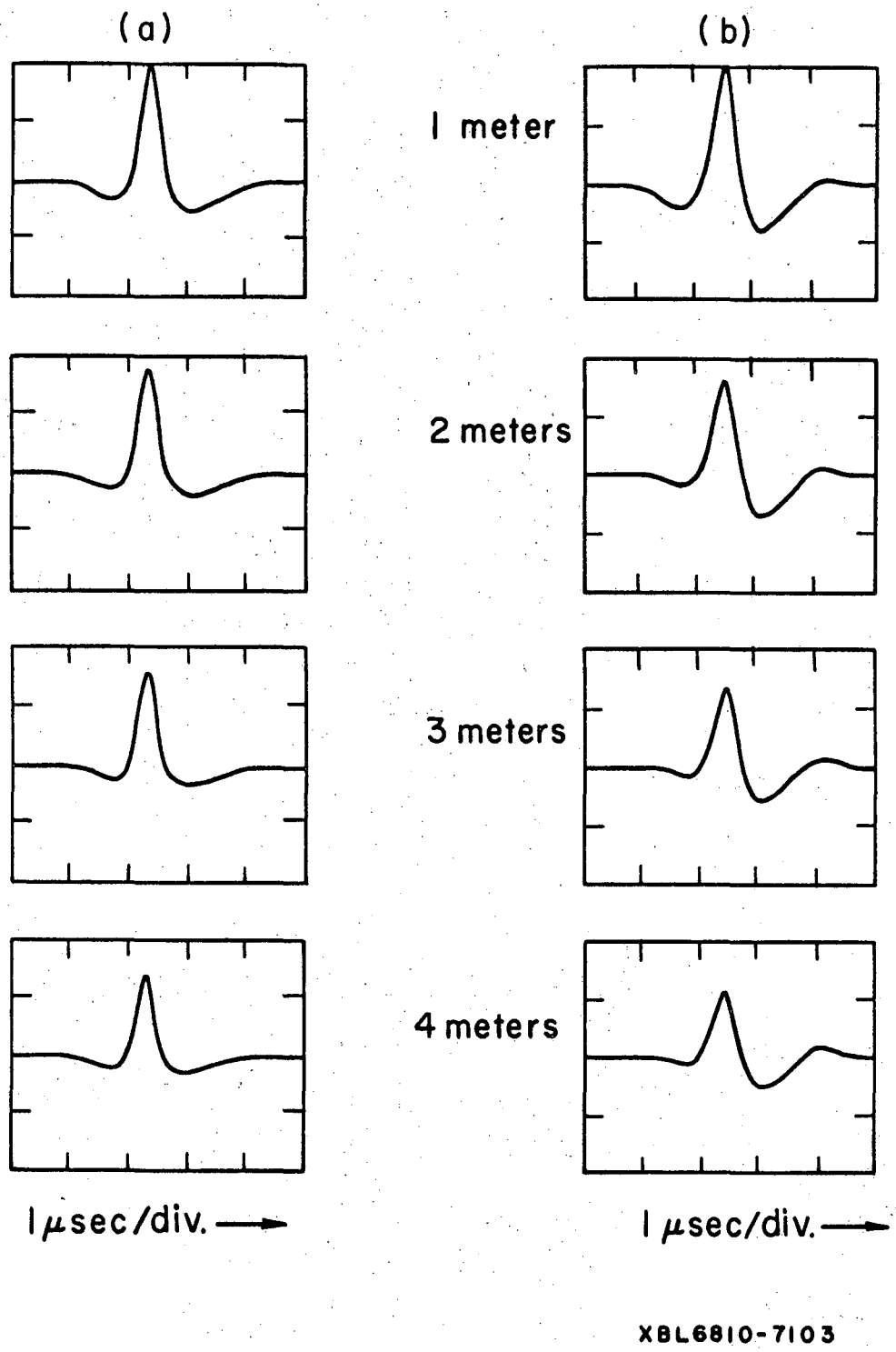
(a)
(b)
1 meter
2 meters
3 meters
4 meters
1 μsec/div.
1 μsec/div.
XBL6810-7103

Fig. 10

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