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MULTI-WIRE PROPORTIONAL CHAMBERS WITH UNIFORM GAIN

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ABSTRACT

A method is described for constructing and operating multi-wire proportional chambers having systematic gain variations of less than ± 2% rms over their entire active area.

I. INTRODUCTION

This paper describes a method of constructing and operating multi-wire proportional chambers with systematic gain variations of less than ± 2% rms over their entire active area. Under less favorable conditions these systematic variations, caused by irregularities in the wires and by unequal wire spacing, can be as large as ± 20% or more. The method consists in using highly uniform anode wires to reduce local fluctuations along individual wires and in compensating the separate anode voltages to hold the gain constant from wire to wire.

In addition to the systematic fluctuations, there are statistical fluctuations in the energy lost by an ionizing particle, in the number of ions per unit energy loss, and in the avalanche gain. These effects may dominate regardless of the systematic variations. The pulse-height spectrum obtained for 5.9-keV x-rays interacting in the chamber gas is shown in Fig. 1a. In this case the energy loss is fixed, and the resolution is determined mainly by the number of ions per unit energy loss and by the avalanche gain. The pulse-height spectra shown in Fig. 1b and Fig. 1c are for minimum-ionizing particles crossing one and two chambers, and in this case the Landau fluctuations in the energy loss dominate. When large energy losses occur, the related statistical fluctuations are correspondingly smaller. This is illustrated in Fig. 1d, which shows the response of a lead-plate shower detector using six proportional chambers with 9-GeV electrons and negative pions incident, equivalent to about 300 single tracks.

Other potential applications of proportional chambers with highly uniform gain may be found in medicine with the detection of fluorescent x-rays in the presence of low-energy backgrounds,[1] in astronomy with measurements of stellar x-rays, and in high-energy and cosmic-ray physics with the detection of transition radiation.

II. CONSTRUCTION

The chamber construction is conventional. The anode wires are 20 μ in diameter spaced 2 mm apart, and they form a plane with sensitive area 20 cm × 20 cm. Each anode plane is located between two cathode planes; the cathode wire diameter is 0.127 mm, and the gap between planes is 4 mm. The gas seal is made with sheets of aluminum foil 25 μ thick spaced 3 mm outside of the cathode planes and tied to the cathode potential through 20 MΩ resistors. The outer conducting surfaces are held at a fixed potential to prevent surface charging or discharging from changing the amplification. The 3-mm spacing is used to keep the capacity of the individual cathode-wires low so that induced pulses can be taken from them.

Guard planes are not needed since relatively low voltages are used (2 to 2.5 kV with 93% argon, 7% methane) to keep the chamber gain linear. Four wires of increasing diameter (30 μ, 45 μ, 60 μ, and 130 μ) replace the usual 20-μ anode wires on either edge of the anode planes. If space is limited it should be possible to avoid using these wires by changing the compensating voltage applied to the outer fine wires (see Sec. IV). The wire planes are supported by frames of Nema G10.

III. ANODE WIRES

The anode wires were made of stainless steel 20 μ in diameter.[2] Figure 2a is a photograph of such a wire viewed by a scanning electron microscope. A comparable photograph of 20 μ gold-plated tungsten wire is shown in Fig. 2b. The exceptional uniformity of the stainless-steel wire was achieved by drawing it through many dies that were closely spaced in diameter. The steel wire, being relatively free of surface imperfections, is also slightly stronger than the tungsten wire (elastic limit 70 g versus 55 to 60 g, breaking point 100 g versus 72 to 85 g)[3] even though the Handbook of Chemistry and Physics gives values indicating tungsten is three times stronger. The wires were wound at 50 g, were held in place with a bead of epoxy, and were then soldered to the circuit contacts.

The sensitivity of the response to small variations in wire diameter can be estimated by differentiating the amplification with respect to the wire radius r. The amplification is given by[4]

$$A = \exp\left\{2\left[\frac{arV}{\frac{\pi L}{s} - \ell n\,\frac{2\pi r}{s}}\right]^{\frac{1}{2}}\left[\left(\frac{V\lambda}{V_i r\left(\frac{\pi L}{s} - \ell n\,\frac{2\pi r}{s}\right)}\right)^{\frac{1}{2}} - 1\right]\right\} \qquad (1)$$

where V is the anode-cathode voltage, s is the wire spacing, L is the anode-cathode spacing, V_i is the ionization voltage, λ is the electron mean free path, and $a = 1/\left(\lambda_i\left(V - V_i\right)\right)$ is approximately constant. λ_i is the mean free path between ionizing collisions. A number of approximations have been made in the derivation[4] of Eq. (1), including the neglect of electron recoil velocity following collisions and of statistical fluctuations. The measured gain, shown in Fig. 3, has a somewhat steeper voltage dependence than is given by Eq. (1); however, the variation with wire radius is quite insensitive to changes in the values of the model parameters and is accurate enough to be a useful guide in designing chambers.

Differentiation of the amplification equation with respect to wire radius gives

$$\frac{dA}{A} = k_1 \frac{dr}{r} \qquad (2)$$

where for common chamber parameters, k_1 ranges from 5 to 20.[5] Actually, k_1 is approximately proportional to r so that

$$\frac{dA}{A} \simeq \frac{dr}{k_1'} \qquad (3)$$

where k_1' is about 1 μ for our chamber dimensions. The observed uniformity in gain of ± 2% thus implies, among other things, a wire uniformity of the order of ± 200 Å for at least the length of the individual chamber wires.

IV. VOLTAGE COMPENSATION

Gain variations from wire to wire can be due either to slow variations in r or to systematic variations in other chamber parameters such as the gap between wire planes and the wire-to-wire spacings. Differentiating Eq. (1) with respect to s and L, we obtain

$$\frac{dA}{A} = - k_2 \frac{ds}{s} \qquad (4)$$

and

$$\frac{dA}{A} = k_3 \frac{dL}{L} \, . \qquad (5)$$

Typical values of k_2 and k_3 range from 8 to 15.

The gain fluctuations resulting from changes in wire diameter r, gap spacing s, and wire-to-wire spacing L can be reduced by adjusting the gains of the individual wire amplifiers. However, this procedure is not satisfactory if a delay-line readout[6] is used since all wires go to the same amplifier. It is also unsatisfactory when pulse-height information from signals induced on the cathode lines is required since each cathode line receives signals from many individual anode wires. A more direct solution--keeping the gas gain constant--has, however, proved to be quite easy. Each anode wire is simply offset from ground potential by a small compensating voltage ΔV. Figure 4 shows the change in gain when the voltage is changed on an individual wire and on a group of wires. Values of ΔV of the order of ± 5 to ± 10 volts are usually adequate. The figure also indicates that a moderate change in high voltage (e.g., 200 V, a value sufficient to change the average gain by a factor of 4) does not change the relative dependence of the gain shift on ΔV.

Figure 5 shows the printed-circuit board that provides the compensation voltage. A 100-volt power supply provides the voltages through the resistor string and bus lines. A small piece of wire is inserted in the hole and soldered between the appropriate ΔV bus and the line going to each anode wire. Ten steps of about 1.5 to 2 volts are normally used between the 11 center bus lines, while two steps of about 10 volts are used on each side between the outer lines. The latter are connected to the outer anode wires, which need larger voltage shifts due to edge effects.

From Fig. 4 it is clear that the interaction between adjacent wires must be taken into account in determining the correct values of ΔV since ΔA/ΔV is larger when ΔV is applied to only one wire. This is most easily done by setting the voltages in groups of 20 wires with a 20 by 20 matrix switch[7] temporarily replacing the printed circuit board. The 5.9 keV x-ray from an Fe^{55} source and a pulse-height analyzer are used to measure the relative gains. Then, if a large ΔV should be needed on wire i, it is a simple matter to go back to wire i-1 to make and check the necessary compensating change in its ΔV. At most, only one or two such iterations should be necessary. Figure 5 shows the gain of a typical chamber, wire-by-wire, for the offset voltage supply on and off. With the supply on, the rms fluctuation is less than ± 1%. The rms fluctuations along individual wires may be as large as ± 2%.

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FIGURE CAPTIONS

1. (a) Pulse-height distribution on one wire from 5.9-keV Fe^{55} x-rays. The peak at channel 29 is caused by argon atoms that de-excite by emitting a 3-keV x-ray (which escapes) rather than an Auger electron. The full-width-at-half-maximum (FWHM) is 22%. The resolution in this case is determined mainly by fluctuations in the number of ions per unit energy loss and in the avalanche gain.

   (b) Pulse-height distributions from two chambers for perpendicular traversals of minimum-ionizing particles. The most probable energy loss is 2.6 keV, and the mean is 3.4 keV. The FWHM is 100%, dominated by Landau fluctuations in the energy lost by the original ionizing particles.

   (c) Same as (b) except that the signals from the two chambers have been attenuated by a factor of two and then added. The FWHM for the combined signal is 70%.

   (d) Combined signal from six proportional chambers in a lead-plate shower detector with 9-GeV electrons and negative pions incident. The shower in this configuration is equivalent to about 300 single tracks.

2. (a) Photomicrograph of 20-μ-diameter stainless steel wire.

   (b) Photomicrograph of 20-μ-diameter gold-plated tungsten wire. (The resolution of 2b is poorer than that of 2a because an optical microscope, rather than a scanning electron microscope, was used.)

3. Chamber gain versus high voltage.

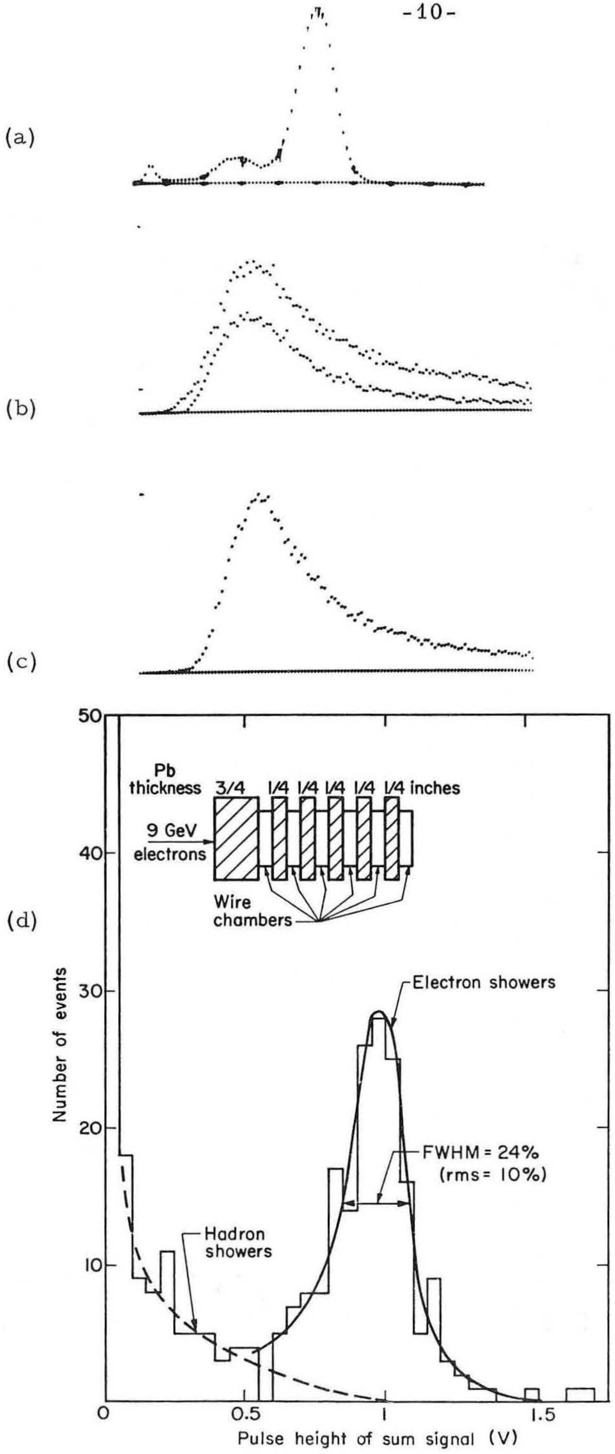
4. Relative gain changes versus compensating voltage applied to one wire when the high voltage is 2356 volts (●), one wire at 2135

volts (o), and 100 wires at 2135 volts (▽).

5. Photograph of △V board with delay line in place (delay-line clamps not shown). (a) Top. (b) Bottom.

6. (a) Relative chamber gain, wire by wire, for △V supply on and off.

   (b) The corresponding △V's.



XBB 715-1879

Fig. 1

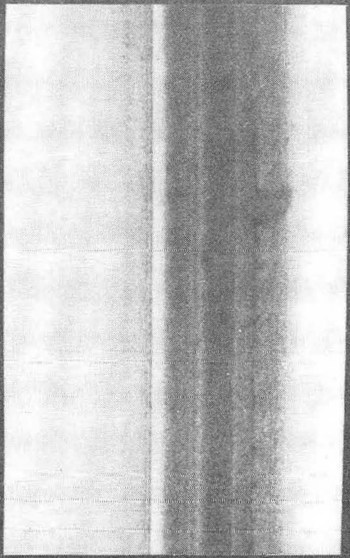


Fig. 2b

XBB 714-1268

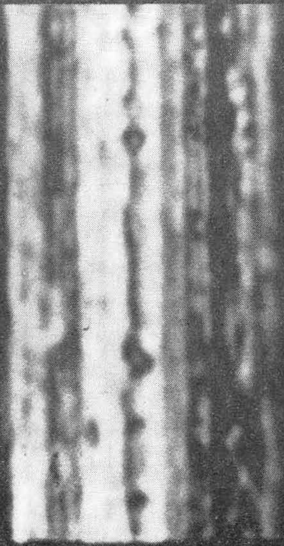
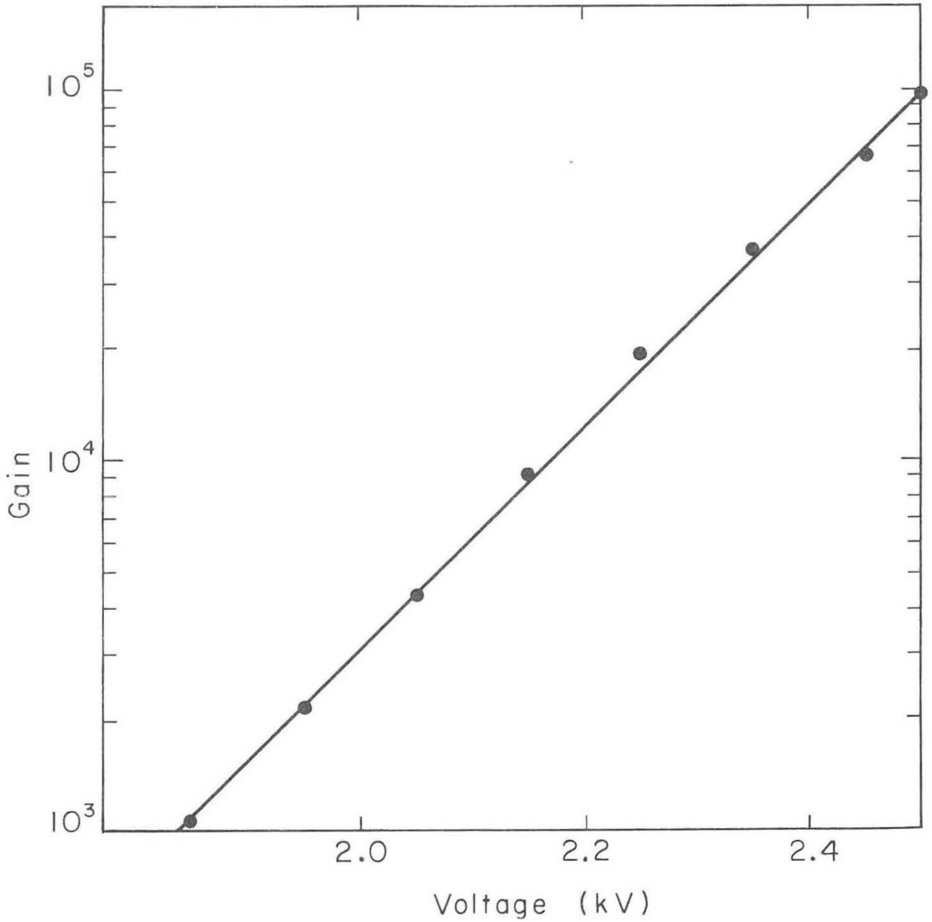


Fig. 2a



XBL715-3502

Fig. 3

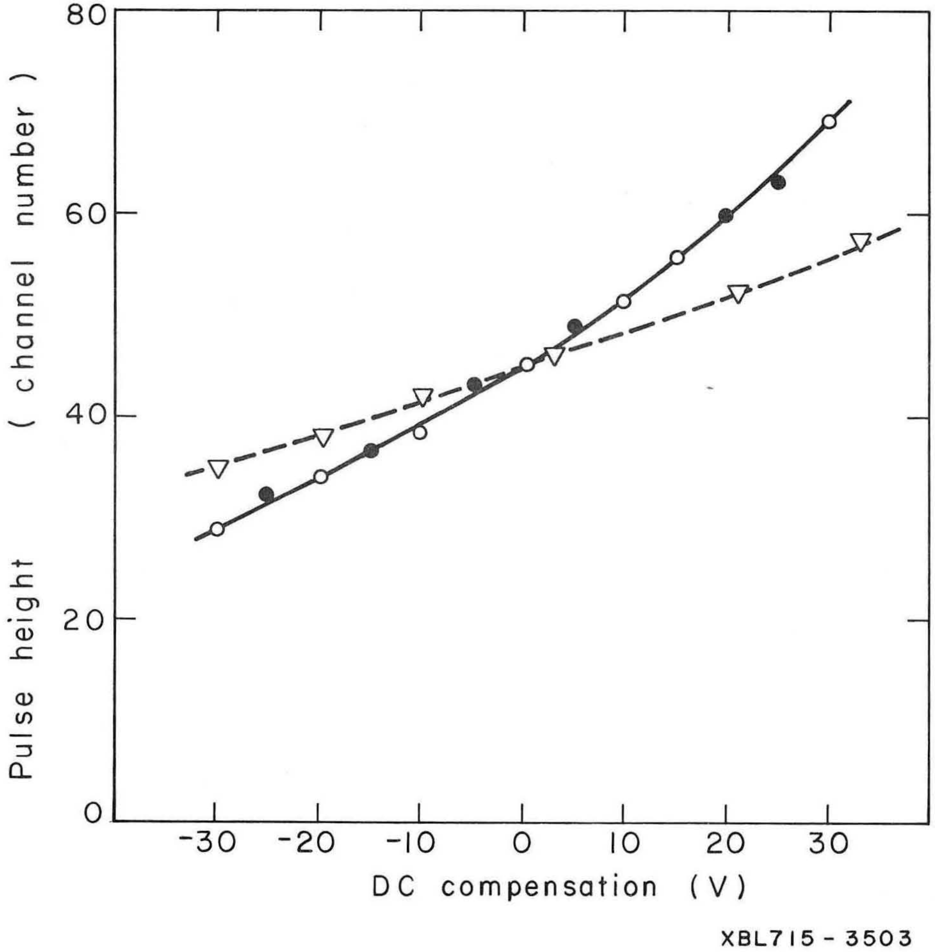


Fig. 4

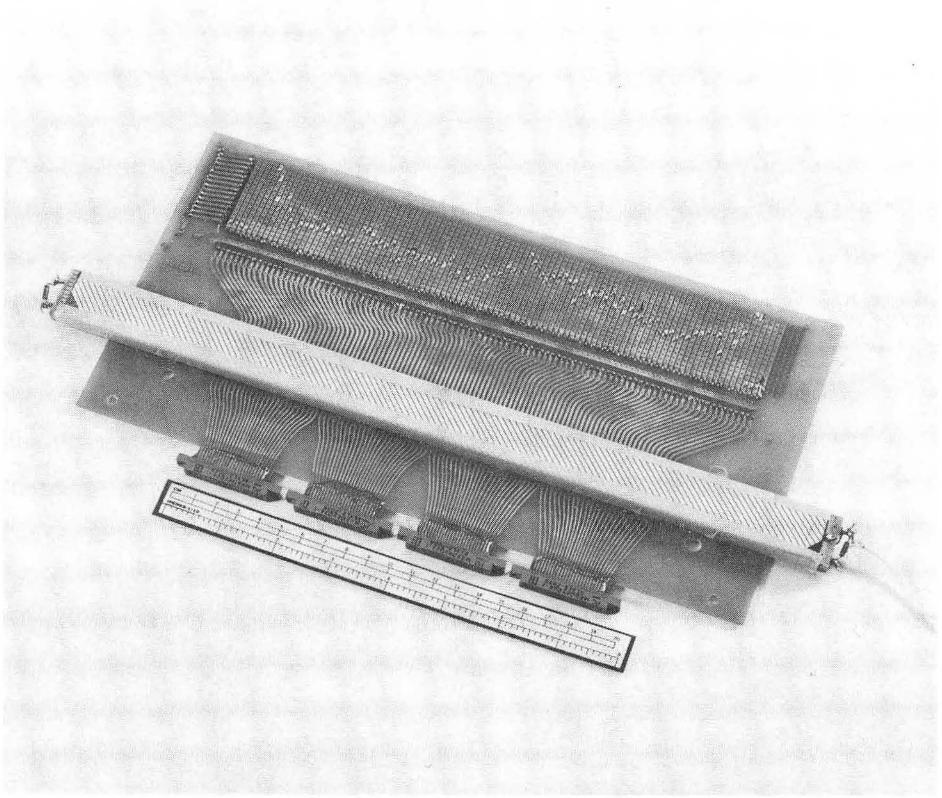

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Fig. 5a

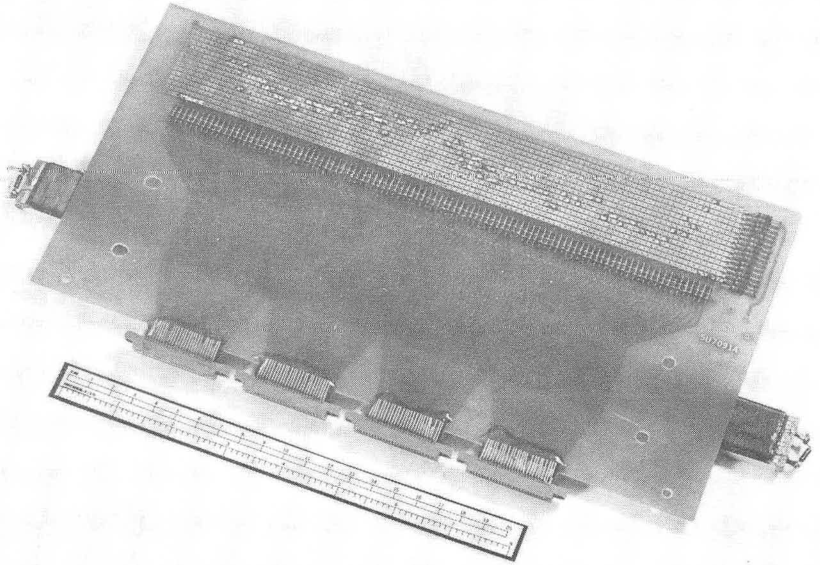

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Fig. 5b

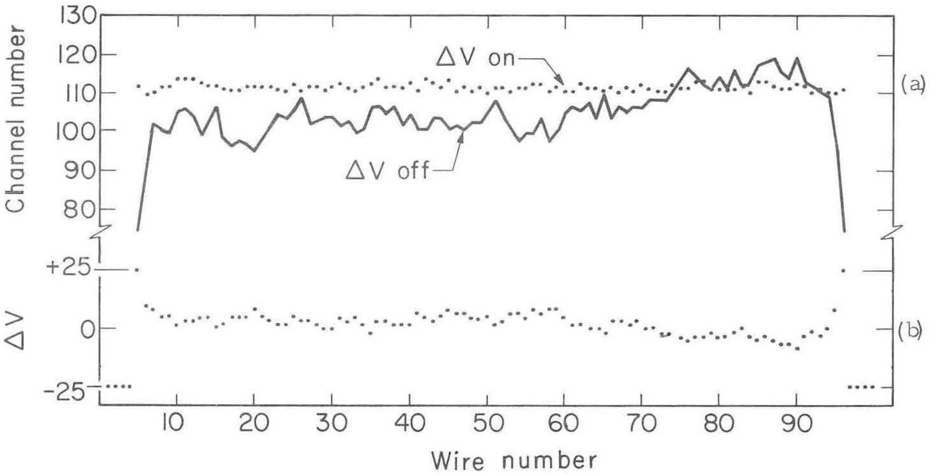

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Fig. 6

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