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R.Z. Fuzesy, N.J. Hadley, and P.R. Robrish

October 1983

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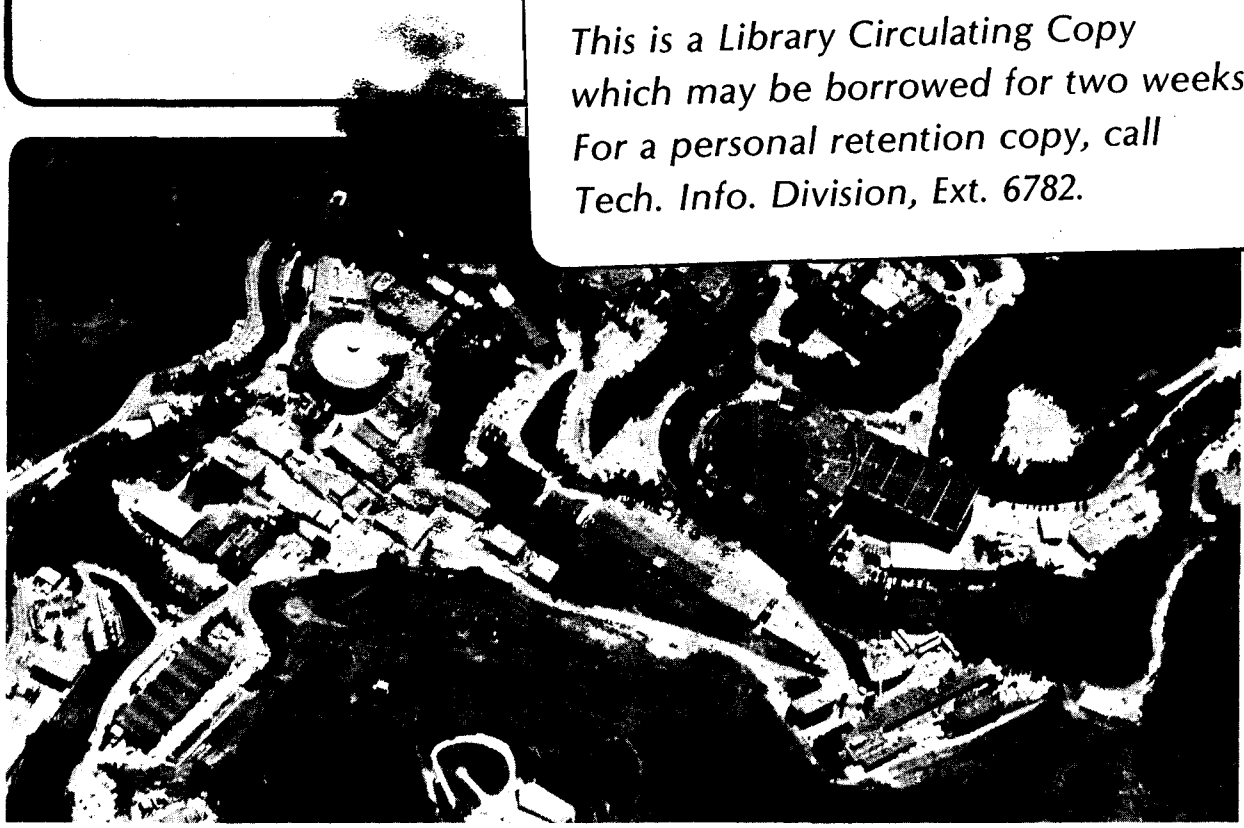

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# Design of the Multiwire Proportional Detectors for the PEP-4 Time Projection Chamber

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## Abstract

We present the essential features of the design of the multiwire proportional detectors used in the PEP-4 Time Projection Chamber.

## §1 Introduction

The central tracking device in the PEP-4 facility at SLAC is a Time Projection Chamber[1]. In this paper, we will report on the design of the multiwire proportional detectors for the TPC. We will first discuss the desired characteristics of the PEP-4 TPC and their implications for the design of its detectors. Next, we will present the major features of their design and fabrication. Finally, we will discuss the performance of these multiwire proportional detectors.

The Time Projection Chamber is a large-volume pressurized drift chamber which is designed to operate within a solenoidal magnetic field, with the magnetic field lines aligned with the electric drift field. In this configuration, it is possible to drift ionization electrons over long distances (1 meter for PEP-4) without track distortion as long as the electric and magnetic fields are sufficiently uniform and the gas has a very low level of electronegative impurities. At the end of their drift, the ionization electrons are detected by one of twelve multiwire proportional chambers which we call sectors. The TPC was envisioned as a device which would provide sufficient information to reconstruct charged particle tracks accurately in order to measure their momenta, while simultaneously determining their identity by measuring the energy loss distribution of each track. The results obtained with a prototype indicated that, at least on a small scale, the concept was sound. Energy loss distributions were measured to better than 3% with 192 samples of 4 mm track length at 10 atm, and track positions were measured with

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100 $\mu$m accuracy by segmenting the cathode of the multiwire proportional chamber detector and making use of the pulses induced on the segmented cathode by the avalanches on the few wires above the segments[2].

The requirement that the detector be able to measure energy loss distributions accurately was a driving element in the subsequent design of a full scale detector. Much of our effort was directed to minimizing systematic variations in proportional gain along each of the sector sense wires. Since the gain of a wire depends on the characteristics of the wire, its position relative to the other electrodes in the chamber, and the local gas density, we had to try to control all of these factors. Because the TPC contains twelve sectors which are also structural members of the device, and is located in a region of the PEP-4 facility with limited access, the sector design philosophy emphasized ruggedness, reliability and interchangeability. Finally, we sought to minimize the dead space between sectors by careful attention to the design of wire attachments.

## §2 Mechanical Design and Fabrication

The cell structure of a sector is shown in Fig. 1. There are two planar arrays of wires located 4 and 8 mm above a cathode ground plane. The array at 4 mm consists of 20-$\mu$m-diameter gold-coated tungsten sense wires spaced by 4 mm from each other and spaced 2 mm from 75-$\mu$m-diameter gold-coated beryllium-copper field wires. The array of wires at 8 mm contains 75-$\mu$m-diameter grid wires spaced 1 mm apart. Sense wires were tensioned at 55 gr, field wires at 250 gr and grid wires at 300–350 gr (depending on length).

Since the objective of the PEP-4 TPC was to make energy loss measurements with a resolution of $\sim$3%, we set, as our design goal, a limit of 1% in systematic gain variation within a sector. Electrostatic calculations[3] based on the cell structure shown in Fig. 1 indicated that this limit translated into a requirement that the ground plane of a sector be flat to 20 $\mu$m, and that each plane of wires be parallel to the ground plane to a similar tolerance. Subsequent measurements of the gain variation along a wire in an early prototype and of the position of the ground plane relative to the plane of the sense wires confirmed the calculations. This comparison is shown in Fig. 2.

In order to maintain the flatness of the ground plane and to provide a structure which could support the wire loading, the preamps and thermal control system for the chamber, and which could also provide a structural member for the TPC itself, a rib structure was designed to form, with the ground plane, a very rigid box. The

structure may be seen in Fig. 3 which shows a rear view of a sector, with its full complement of electronics and its thermal control system. The 6-mm-thick ground plane was cut from a piece of copper-clad NEMA G-10. The ribs which were glued to the ground plane to form the box were made from 4-mm-thick G-10. The ground plane and the side ribs have etched printed circuit artwork to provide signal paths to the electronics. The side of the ground plane facing the drift volume has rows of etched square pads $7.5 \times 7.5$ mm$^2$ which pick up induced signals from avalanches on the wires above the pad rows and allow a determination of the position of the avalanche along the wire by a weighted average of the induced signals on several pads. In addition to the ribs, there are four aluminum brackets which were glued to the ribs, forming connections between some of them, and providing the means to attach each sector to the cylinders which form the rest of the TPC.

The box structure was fabricated using a fixture built on a flat granite table. The surface of the granite table had small grooves cut into it in the shape of the ground plane and forming a waffle pattern within this outline. These grooves allowed the space between the ground plane and the flat granite to be evacuated so that the ground plane was held against a known flat surface during the subsequent gluing operations. Each ground plane had two precision holes drilled through it which provided reference for machining the ground plane shape. These holes oriented the ground plane with respect to the printed circuit artwork and also with respect to the gluing fixture, which was provided with pins to mate with the holes. All the aluminum brackets were pinned to the fixture with known orientation with respect to the ground plane reference holes during gluing, and the ribs were also held in place by appropriate fixturing. This fabrication procedure allowed twelve mechanically interchangeable units to be made.

The sector box structure served as a base of support for wire attachment pieces. A cross sectional view of the wire attachment pieces is shown in Fig. 4. The wire attachment pieces for the sense wire plane were glued directly to the sector. The surface to which the wires were to be attached was positioned a few mils below the desired position of the wire plane. In subsequent gluing of the wires to the frame, these pieces were not used to determine the position of the wire plane. They merely served as a foundation for the epoxy which held the wires in place. After the wire attachments were in place, flexible copper-clad Kapton artwork was glued along the sides of the wire attachments and ribs of the sector in order to bring signals from the wires to the high voltage blocking capacitors shown in the figure. After the wires were glued to the wire attachments, they were bent through 90° and soldered to the artwork. Sense wires were attached to artwork on one side of a sector, and field wires on the

other side. On the sense wire side, field wires were cut where they emerged from the epoxy and the cuts were covered with a small dab of epoxy to prevent breakdown. A complementary procedure was carried out on the field wire side.

After the sense wire attachments were glued to the sector but before wires were attached, the grid wire attachment pieces were positioned with a fixture so that they were a few mils below the desired grid plane position. Mounting screw holes and positioning pin holes were then drilled through the grid wire attachment pieces and into the sector side ribs, so that the grid attachments could be remounted after the sense wire plane was in place. Since a sector has a kite shape, two grid attachment pieces were required for each side of the sector. These pieces were aligned so that they met at a position which would be between two adjacent grid wires. When the grid was glued to the attachments, we took care not to glue the attachment pieces together. We are, therefore, able to remove the grid from a sector by loosening its attachment screws to release the grid wire tension. Figure 5 shows the two sections of a grid as they look when removed from a sector. When a grid is re-attached to a sector, the array of screw holes and $\frac{3}{16}''$ dowel pin holes previously drilled allows precise realignment and retensioning of the grid plane. Grid plane electrical artwork was done on flexible copper-clad Kapton glued to the side of the attachment piece. Grid wires were attached to the artwork as described for the sense and field wires. This design led to a dead space between sectors of about 2 cm.

The wire arrays were wound on aluminum transfer frames using a facility designed by one of us (RZF). Each transfer frame held four precision machined grooved bars which provide the pitch reference for all wires. Wire arrays for two sectors were wound on each frame. The grooved bars were aligned parallel, in pairs, on a flat table and glued to the transfer frame. The bars used for the sense-field wire plane had grooves which alternated in depth to account for the different sense and field wire diameters, assuring that the sense and field wire arrays were in the same plane.

In order to attach the wires accurately to a sector, we placed it on a flat table and measured the position of the sector ground plane relative to the flat table. The deviations from parallelism were small due to the way in which the sectors had been constructed. Using the measurements, we positioned the sense wire plane 4 mm above and parallel to the ground plane. The transfer frame was held in place by adjustable supports, and the position of the wire plane above the flat table was determined by micrometers. Alignment of the wires with respect to the

ground plane artwork was accomplished optically, using crosshairs which defined a line parallel to that defined by the two reference holes in the sector ground plane. A wire plane, when properly positioned, rested a few mils above, but not touching, its wire attachment piece. An epoxy bead was then applied which flowed between the wires and wetted the top of the attachment piece. The setup was left in place for a 24-hour cure in a warm dry room. After completion of the cure, the wires were cut from the frame and soldered to pre-tinned artwork. High voltage blocking capacitor packages were then loaded into the artwork, and sense and field wire high voltage connections to the electronics area of the sector were made. We then aligned the grid attachment pieces by means of their matched pin holes and screwed them in place. The grid wires were aligned 8 mm above the ground plane, glued in place using the technique described above, and soldered to the grid artwork. Before and during these operations, scrupulous attention was paid to the cleanliness of all surfaces on the active side of the chamber.

## §3 Electronics, Thermal Control System, and Calibration Sources

In this design, both the sense and field wires have voltage on them while the grid plane is grounded. Each sense and field wire is connected to its appropriate high voltage bus through a 20 megohm resistor in order to prevent direct signal coupling between wires. In addition, each pair of field wires is capacitively shunted to ground through 400 pF to prevent cross-talk between neighboring cells caused by pickup on the field wires. The sense wires are capacitively coupled to the input of charge sensitive preamplifiers through 200-pF blocking capacitors. These capacitors were made up by joining two 400-pF 5KV rated capacitors in series. We chose to do this since the capacitors are located in a region of the sector which is difficult to access, and, therefore, the capacitors must operate reliably for a long period of time. Capacitors and resistors servicing 16 wires were mounted in a single package. These packages were inserted into sockets in the artwork on the side of a sector in the space beneath the grid wire attachment piece as shown in Fig. 4. This location assured that there was no exposed high voltage on the back of the sector. For the sense wires, the bus bars supplying the first 80 wires were joined together and brought to one high voltage connector in the back of the sector. The rest of the wires were serviced by a second connector, allowing us the option to run wires at the inner radius of the TPC at lower gain if background proved too much of a problem. The high voltage connectors located on the chamber for both sense and field wires were attached to low-pass filters to shunt any noise coming in from the power supplies away from the preamp inputs.

The details of the electronic design of the charge sensitive preamplifiers used for the wires and pads are available elsewhere[4]. Individual preamps were inserted into sockets on motherboards. These motherboards provided connectors to external signal processing electronics and preamp power. They also provided pins which connected the preamp inputs to sockets mounted in the backplane of a sector. The sockets were connected by artwork and plated-through holes to either the pads or the low voltage side of the wire blocking-capacitor packages. After all preamps were mounted on a motherboard, an aluminum cover was placed over the preamps and screwed to the motherboard so as to make good thermal contact with each of the preamps. When the motherboard was inserted into the sockets in a sector, this cover was attached with screws to aluminum bars which were part of the thermal control system for the sector. This attachment provided a path to shunt preamp heat away from the sector backplane and into the water of the thermal control system. It also provided a firm mechanical attachment for the motherboards. Figure 6 shows a sketch of the arrangement.

The design philosophy of the thermal control system was that it should provide a heat shield between the preamps, which were a non-uniform source of heat behind a sector, and the sense wires, whose gain at constant pressure was a sensitive function of the gas temperature at a wire. Since we were trying to keep systematic gain variations along a wire to less than 1% , we found that we needed to keep systematic temperature variations to less than $\frac{1}{3}$°C. In order to do this, the system shown in Fig. 7 was used. It consists of $\frac{1}{2}''$ thick aluminum bars which cover all of a sector back plane except those areas needed for sector ribbing, motherboard insertion, and source actuators. Each bar had a hole drilled along its long axis to permit water to flow through it. The bars were joined by aluminum tubes which were brazed to the bars to form two series water systems, each of which served one side of a sector. The two systems were joined by fittings to a water return line. The bars of the system were mounted to the sector back plane with screws, with care taken to assure good uniform thermal contact. When the bars make good uniform contact, then the combination of bars and back plane provides good thermal shielding between the preamps and the gas around the wire. The bars incidentally provide cooling for the preamps, but their primary purpose is to form part of the heat shield.

The final elements of the endplane system are the calibration sources and their actuators. These $Fe^{55}$ sources allow the overall gain of each wire in the detector to be calibrated with a known energy deposition. For most wires in a chamber, there are three sources which can illuminate a wire at points well spaced along its length

to check for systematic gain shifts due to changing thermal conditions within the TPC gas volume. The sources illuminate the wires through 1-mm-diameter holes drilled in the ground planes. These holes form three lines in the ground plane, as can be seen in Fig. 8. The lines are at 60°, 90°, and 75° with respect to the wires. Dots of $Fe^{55}$ were put on each of three brass rods with spacings appropriate to the rod location in a sector. The rods were $1.5 \times 3$ mm$^2$ in cross section. A buried slot to contain a rod was formed in the 6-mm-thick ground plane by milling to within 2 mm of the front surface, and inlaying a 2-mm-thick piece of copper clad NEMA G-10 to reform the back plane. A rod placed in this slot could illuminate the wires when its source dots were aligned with the holes in the ground plane and could be shut off by sliding the rod about 2 mm in the slot. The rod had to be held at +200 volts so that the electric field from the sense wires would not penetrate to the source rod and scavenge ionization produced near the rod. The movement of each rod was accomplished by means of a gas pressure operated actuator which coupled to the rod through a short slot milled into the backplane. Gas pressure of about 25 psi above TPC pressure is sufficient to move the sources to their ON position. With the pressure reduced to TPC pressure, a return spring holds the source rods in their OFF position.

## §4 Sector Performance

There are three criteria by which one may judge the performance of the TPC sectors in the light of the design philosophy. The first is the chamber "plateau," or in our case, the range of voltages above the design operating point for which these chambers are electrostatically stable. The second is the chamber gain uniformity along any wire, particularly when the total design philosophy, including proper thermal control, is implemented. Finally, one must judge the design by its performance in the operating environment.

The sense wires are maintained in place against electrostatic forces by wire tension. As the sense wire potential is raised relative to the surrounding electrodes, a voltage is eventually reached at which the restoring force due to the tension is insufficient to prevent the wires from moving in the electrostatic field. At this point the wires move, and the chamber usually sparks. In order to determine an appropriate operating point for the sectors, we varied the field wire voltage, with the grid plane grounded, and determined the maximum gain which could be obtained from the sector before it became electrostatically unstable. Figure 9 shows the results of those measurements. By decreasing the potential difference between sense and field wires, we attained a larger gain before a sense wire moved toward an adjacent field wire. For large values of field wire potential, however, the sense wires

must be brought to such large voltages to get any gain that they are more attracted to the grid or ground planes, and go unstable in those directions. There is, therefore, an optimum field wire potential for maximum "plateau" of a sector. Since the sectors are operated at gains of order $10^3$, we have at least an order of magnitude in gain latitude. With our design electronics, the chambers were normally tested at 10 atm pressure with field voltage of +700 volts and sense voltage of +3850 volts, but were required to reach a sense voltage of 4400 volts without going electrostatically unstable.

Sector gain uniformity was checked using an $Fe^{55}$ line source which could be swept across the entire front surface of the sector above a thin conductively coated membrane. This membrane was held at negative potential to establish an appropriate drift field for a drift distance of a few centimeters. The line source was pivoted at one end, and its angular position was controlled by a stepping motor activated by commands from a PDP 11/20 computer. Pulse height spectra from wires selected by a multiplexing system were measured using a LeCroy QVT multichannel analyzer and read into the computer. A quick determination of the peak position was made by the 11/20, but the entire spectra could be output to tape and analyzed later on a VAX 11-780. This system was used to make archival pedigree maps of all production sectors.

Figure 10a,b show equi-angular scans of one wire in a sector. These scans were taken before and after careful attention was paid to all elements of the thermal control system. Figure 10a shows the situation which can occur if the system is merely fastened together without checking whether adequate mating of all heat transfer surfaces has been achieved. The bump at around $-20°$ corresponds to the position of the wire preamps along one edge of the sector. These wire preamps constitute the major thermal non-uniformity on the sector. Figure 10b shows that the situation can be substantially improved by proper attention to the mating of the elements of the system. The figure shows that thermal non-uniformities caused by the non-uniform electronic heat load can be controlled to the level of a few percent by proper application of the design philosophy. One can also see that large scale systematic variations, due to mis-alignment of the wire planes with respect to one another or to the ground plane, are absent at the level of about one percent.

The twelve sectors installed in the PEP-4 TPC have been operating now for approximately a year and a half of PEP running. While they are regularly ramped to zero voltage during beam fills, they have been subjected to numerous unscheduled beam dumps with no apparent ill effect. At this time, with the beam off, their quiescent

currents at operating voltage (at 8.5 atm) are all less than 10 nA. Measurements taken during the spring of 1982 show that the chambers yield dE/dx resolutions of about 4% with no corrections to the data other than those for electron capture, relative electronic gain and relative wire gain[5].

## §5 Acknowledgements

We appreciate the careful and dedicated work of the many members of the technical staff at LBL who helped with the design and fabrication of the sectors. In particular, we would like to acknowledge V. Resnick for mechanical design of the sector structure, J. Hodges, S. Klingler, and W. Lee for their work on our precision alignment and fixturing, and F. Witharm for her extra effort on the printed circuit artwork. We would also like to thank E. Edwards for superb work in fabricating the aluminum thermal control systems and M. Cepeda for careful gluing of the sector frames. In addition, we appreciate the efforts of C. Peters and R. Armer in mechanical design. We thank H. Hilke, R. Majka, P. Martin, and M. Shapiro for their help during various stages of the prototyping and design work, and O. Chamberlain and K. Mirk for critical support during the later stages of the work. We appreciate the programming help of G. Shapiro and J. Wissmar. We acknowledge the efforts of P. Delpierre, B. Gabioud, P. Nemethy, and P. Oddone in data taking for the production sectors, and D. Nygren and the PEP-4 collaboration for their encouragement of this work.

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3. H.J. Hilke, TPC Note, TPC-LBL-78-50, using a computer program developed by J. Bowlby.

4. D. Landis et al., IEEE Trans. Nucl. Sci. **NS-29**, 573 (1982).

5. G.R. Lynch and N.J. Hadley, International Conference on Instrumentation for Colliding Beam Physics, SLAC PUB-250, 85 (1982). H. Aihara et al., IEEE Trans Nucl. Sci. **NS-30**, 63 (1982).

## Figure Captions

1. TPC Endplane Cell Structure
2. Gain and Cathode Ground Plane Position versus Source Position along a Wire
3. Rear View of TPC Sector Showing Rib Structure, Assembled Electronic Packaging and Thermal Control System
4. TPC Sector Wire Attachments
5. TPC Sector Grid Wires after Removal from Sector
6. Schematic of Thermal Control System Design
7. Brazed Aluminum Water System for TPC Sector
8. Front View of TPC Sector Showing Wires, Pads, and $Fe^{55}$ Source Holes
9. Maximum Stable Sector Gain versus Field Wire Voltage
10. Gain Profiles of TPC Sector Wire Showing Influence of Thermal Control System

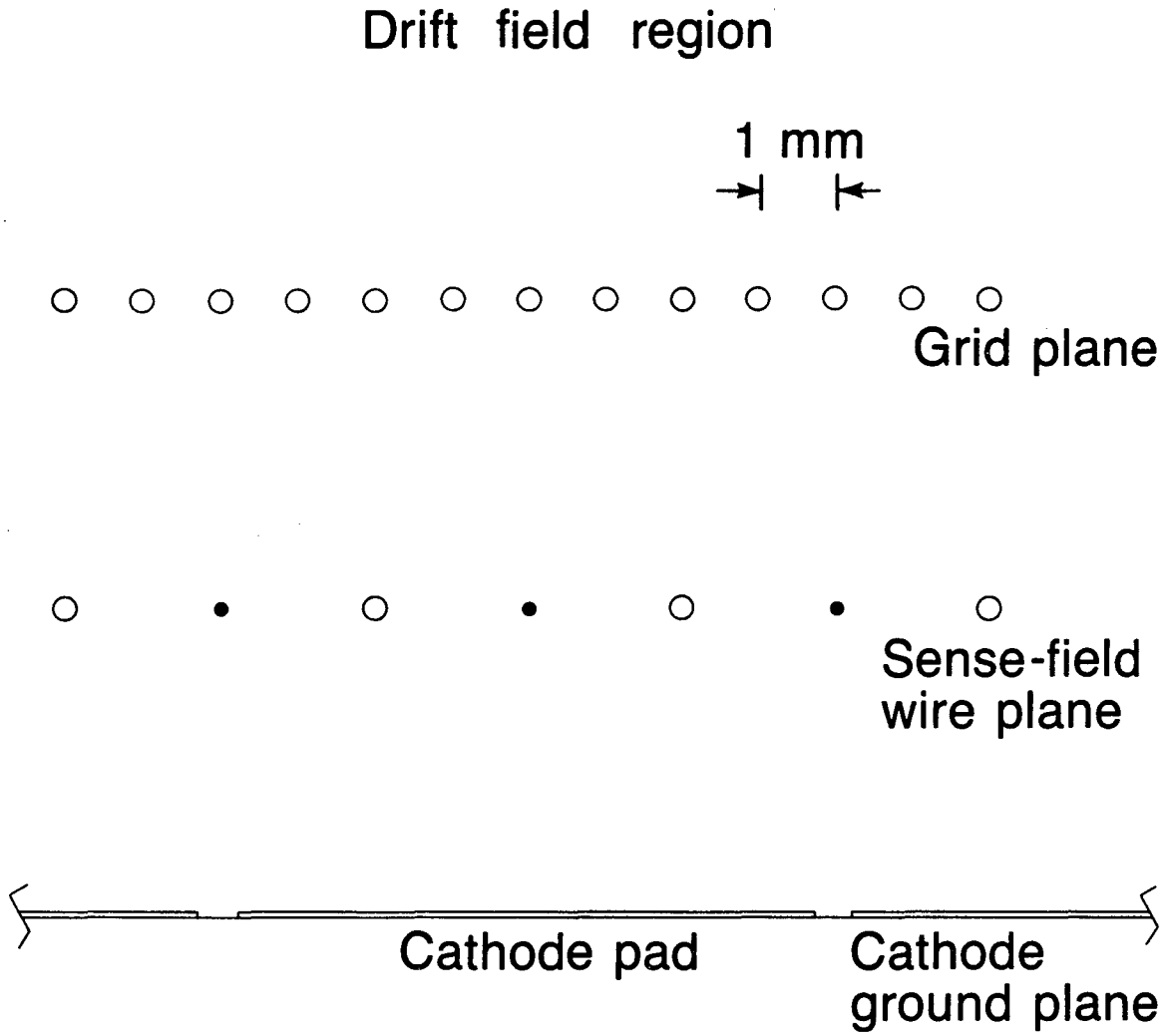
Drift field region
1 mm
Grid plane
Sense-field wire plane
Cathode pad
Cathode ground plane
○ 75 micron Au coated Be-Cu wire
• 20 micron Au coated W wire
XBL 839-3256

Fig. 1

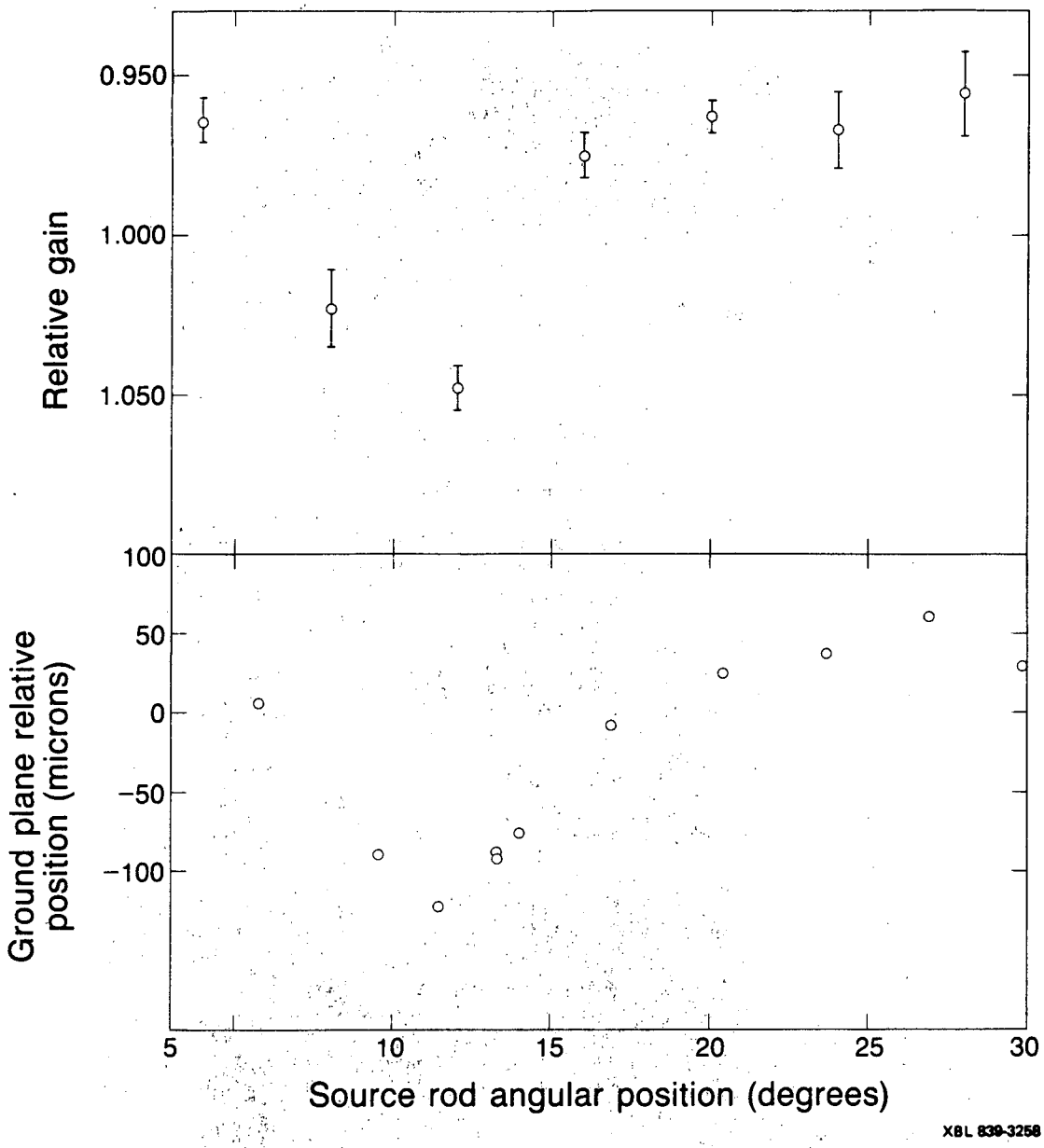
0.950
1.000
1.050
Relative gain
100
50
0
−50
−100
Ground plane relative position (microns)
5
10
15
20
25
30
Source rod angular position (degrees)
XBL 839-3258

Fig. 2

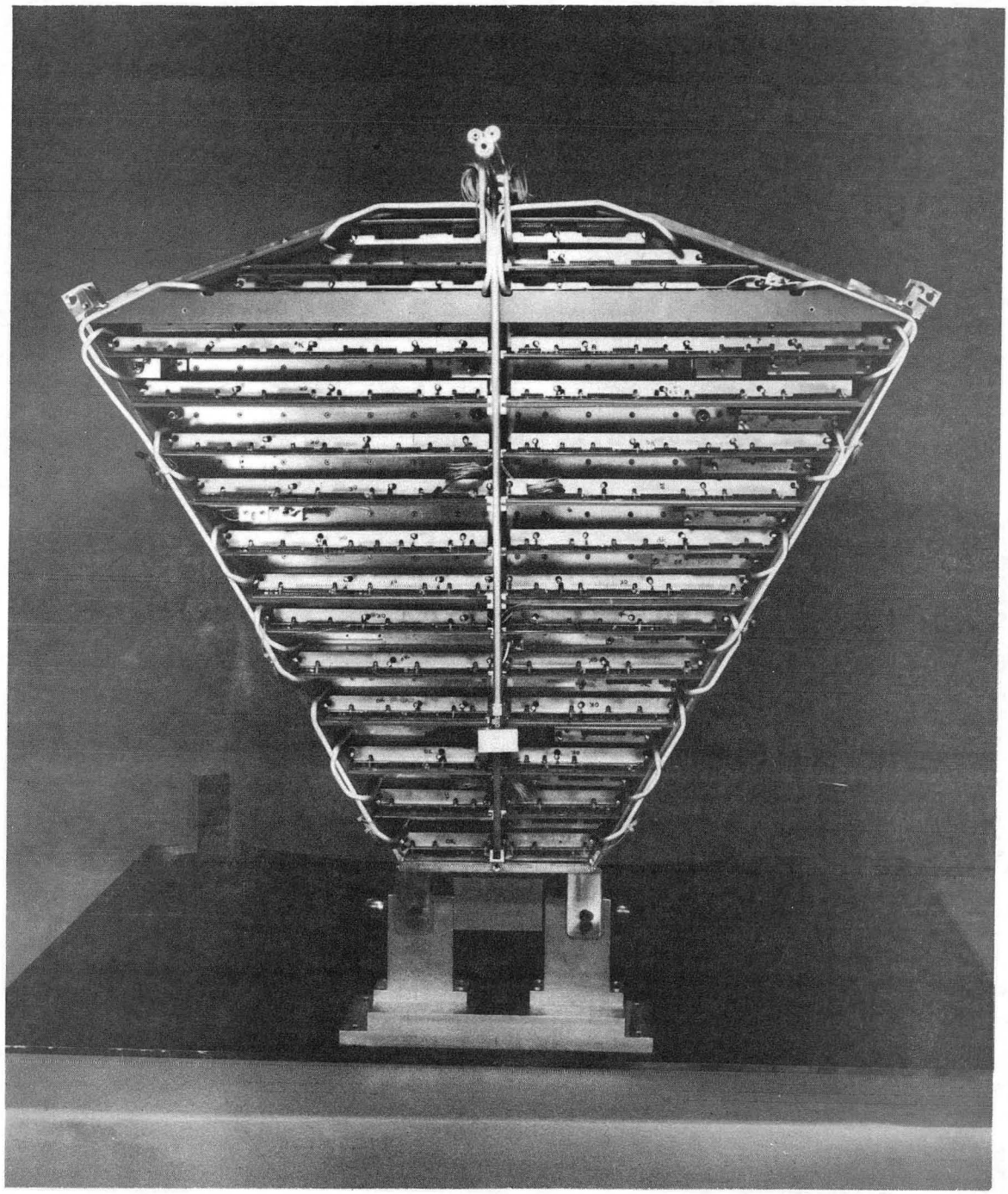

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Fig. 3

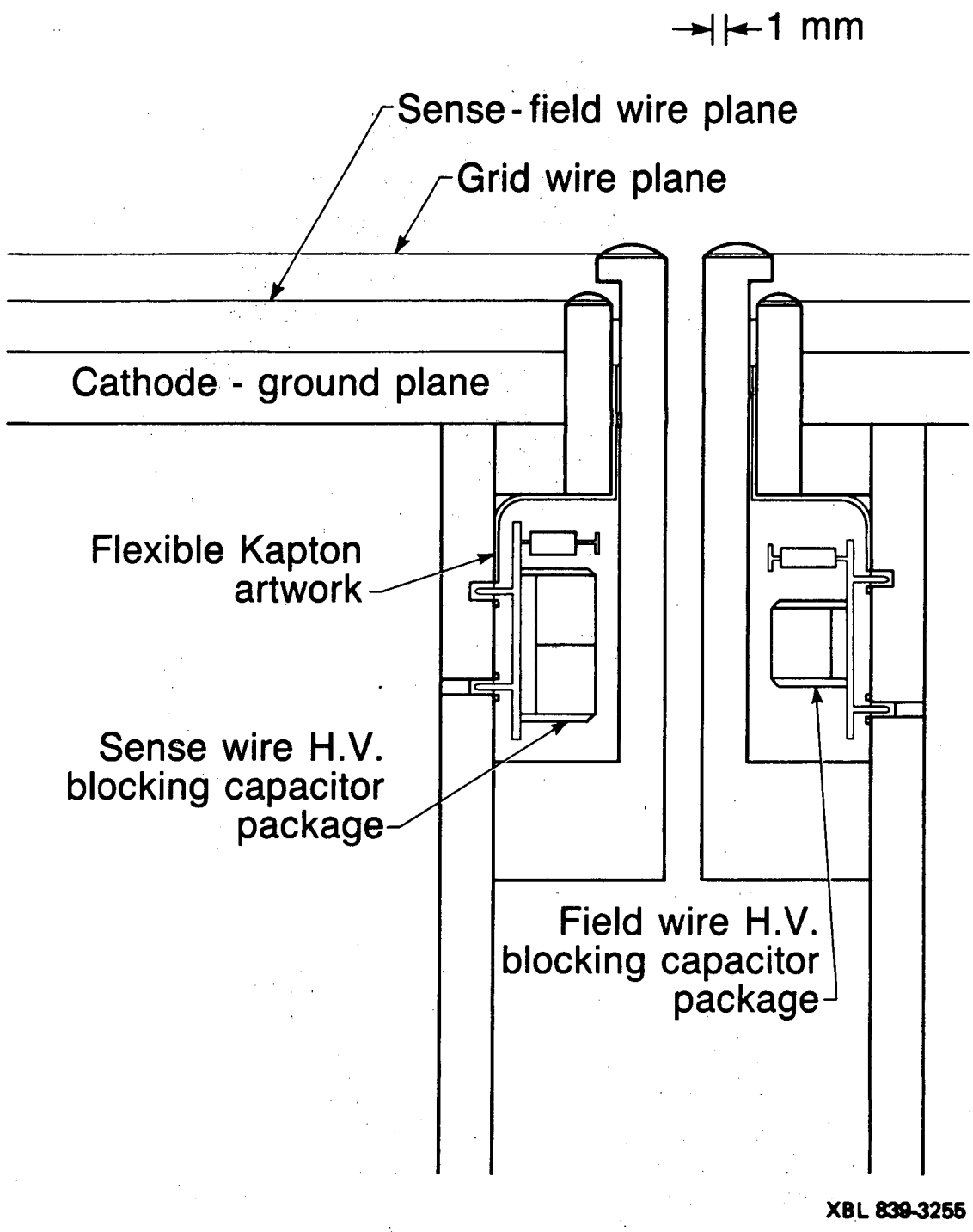
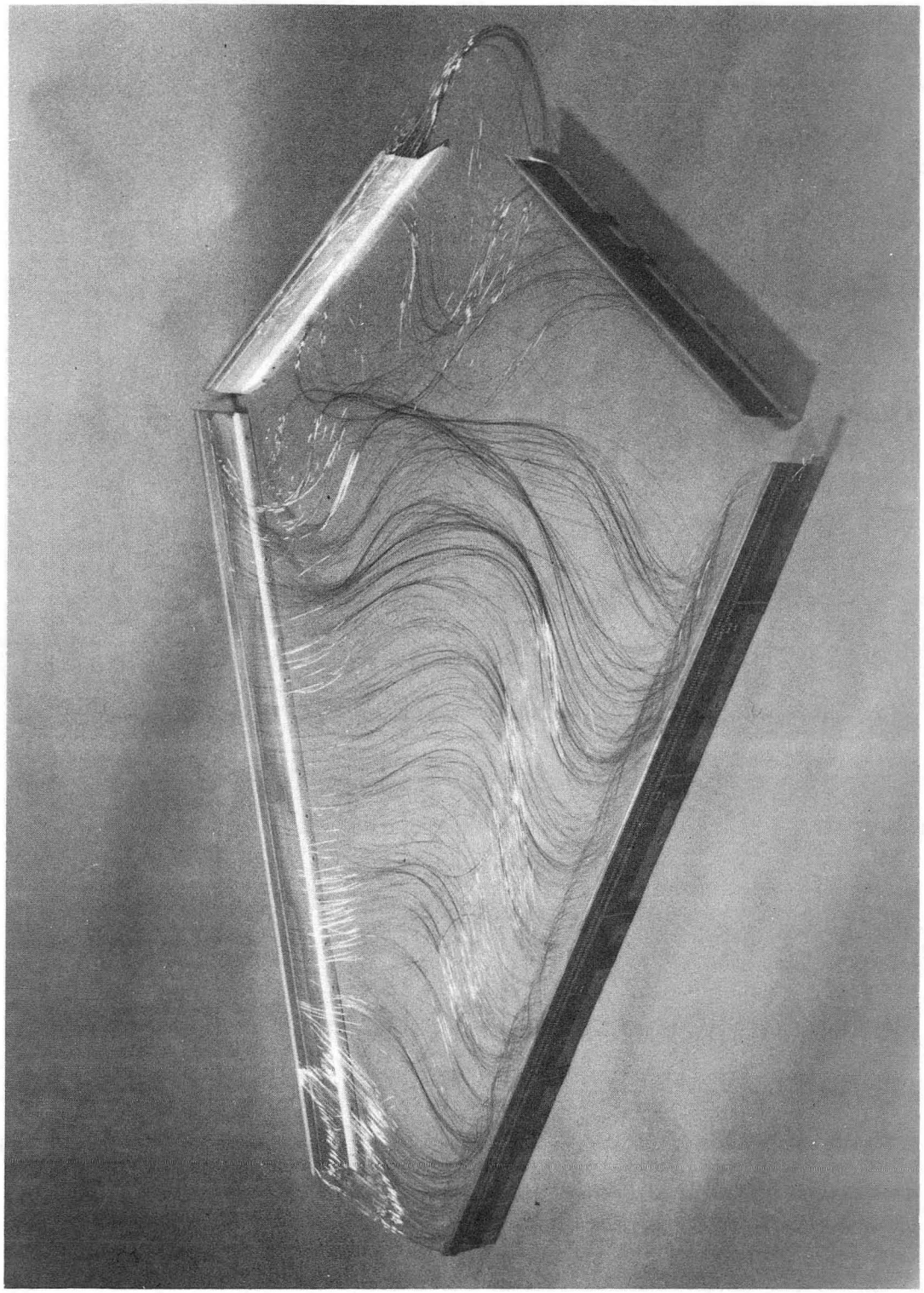

1 mm
Sense-field wire plane
Grid wire plane
Cathode - ground plane
Flexible Kapton artwork
Sense wire H.V. blocking capacitor package
Field wire H.V. blocking capacitor package
XBL 839-3255

Fig. 4



CBB 813-2224

Fig. 5

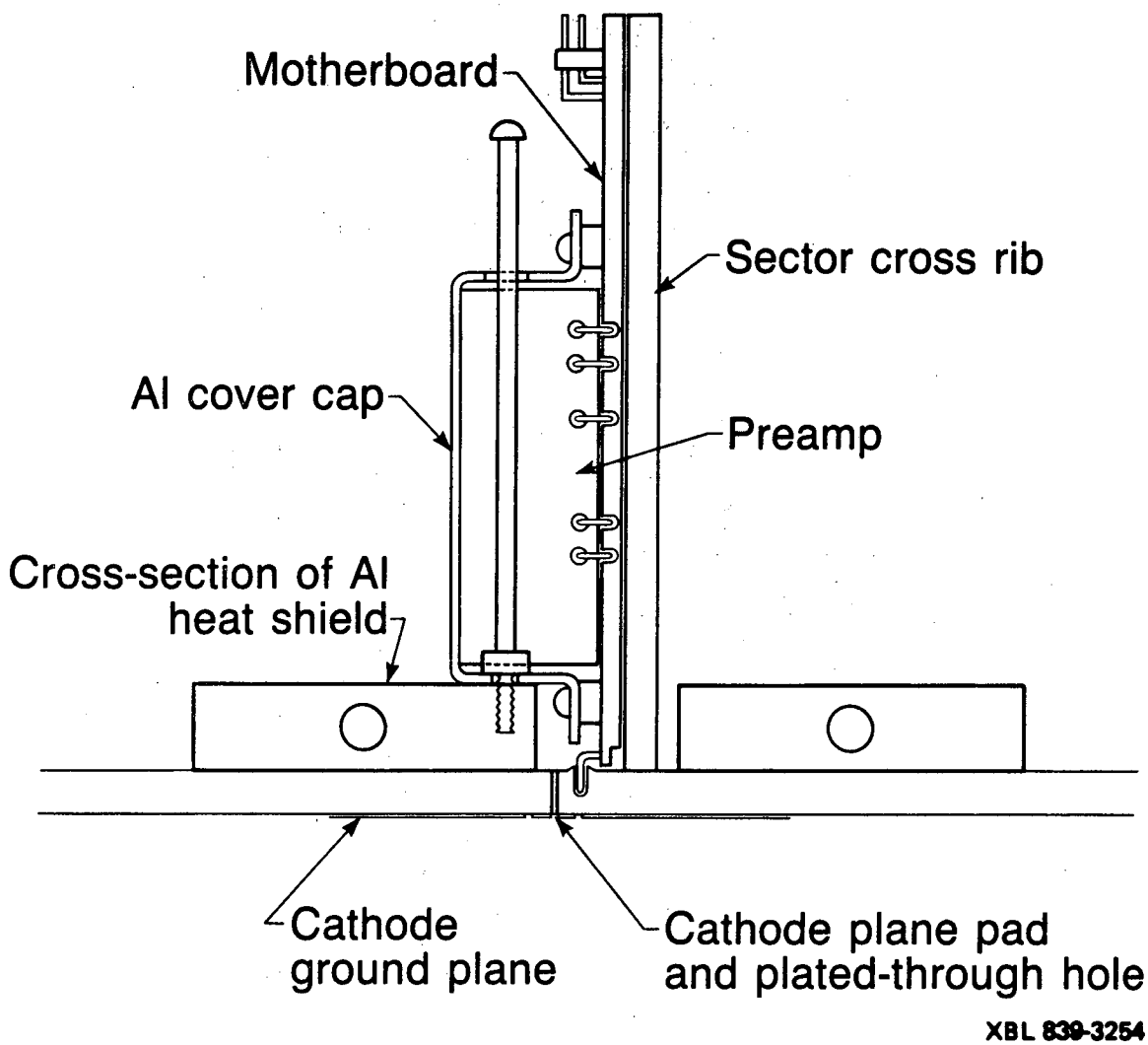
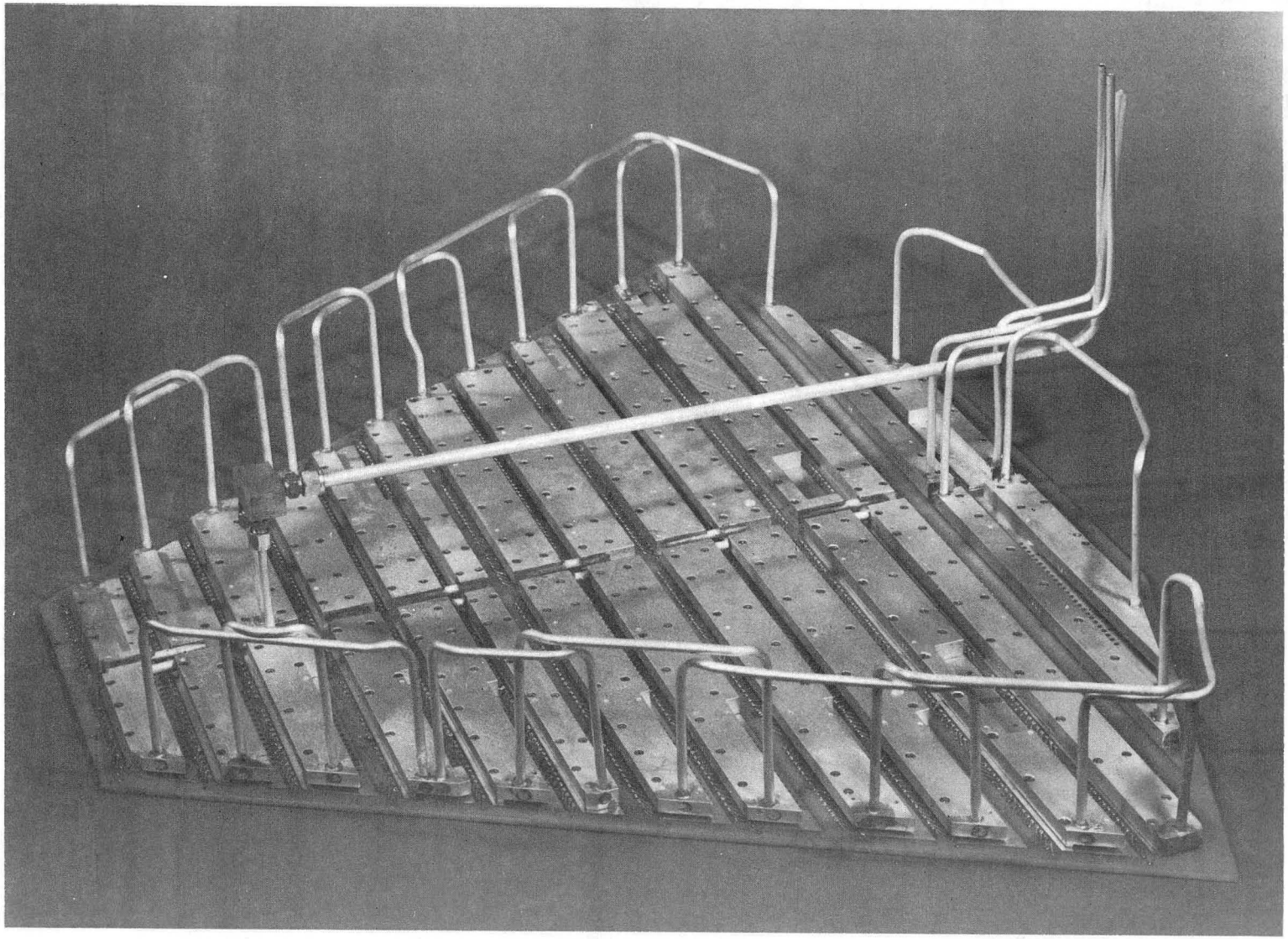
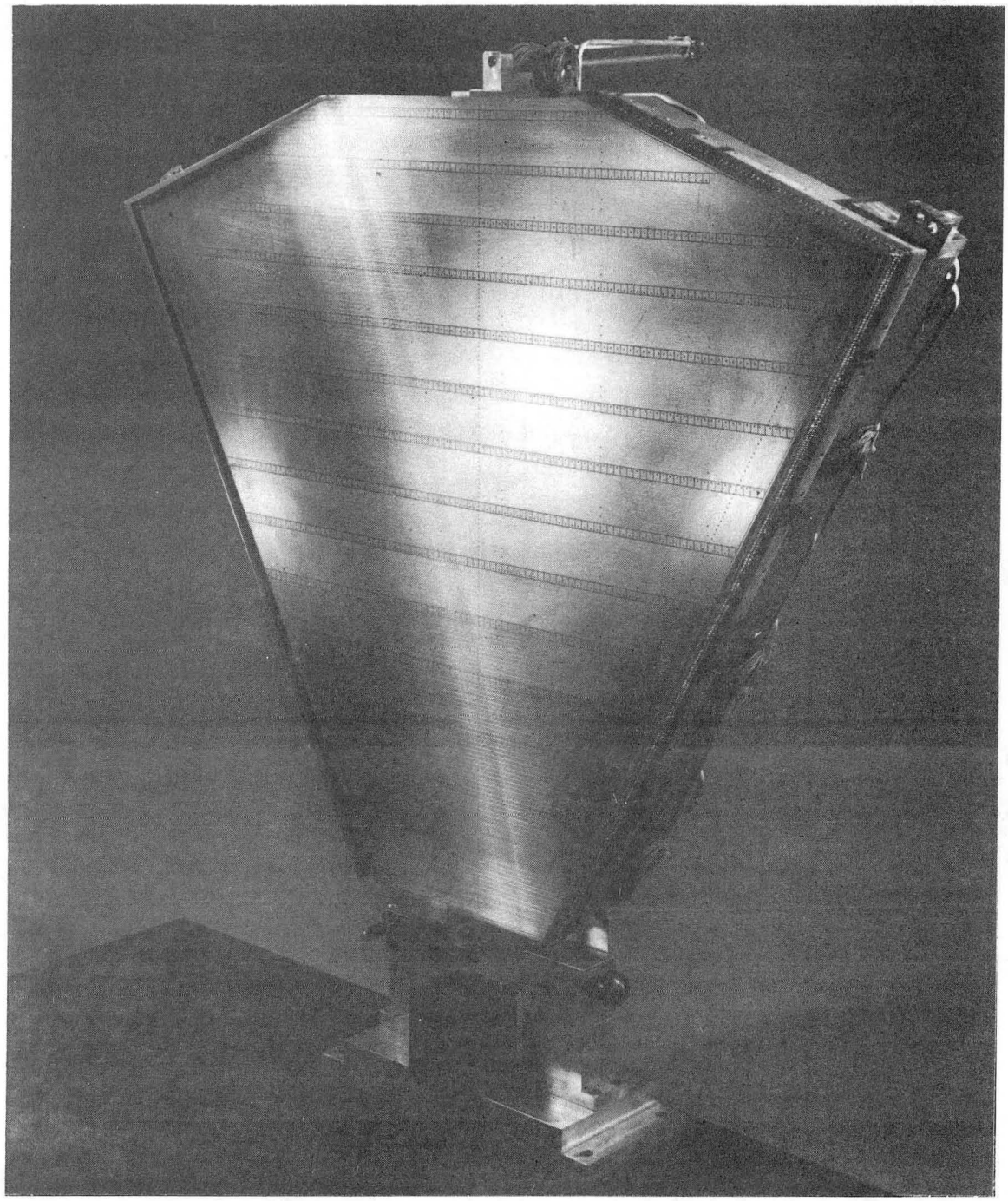

Motherboard
Sector cross rib
Al cover cap
Preamp
Cross-section of Al
heat shield
Cathode
ground plane
Cathode plane pad
and plated-through hole
XBL 839-3254

Fig. 6



CBB 813-3034

Fig. 7



CBB 817-6456

Fig. 8

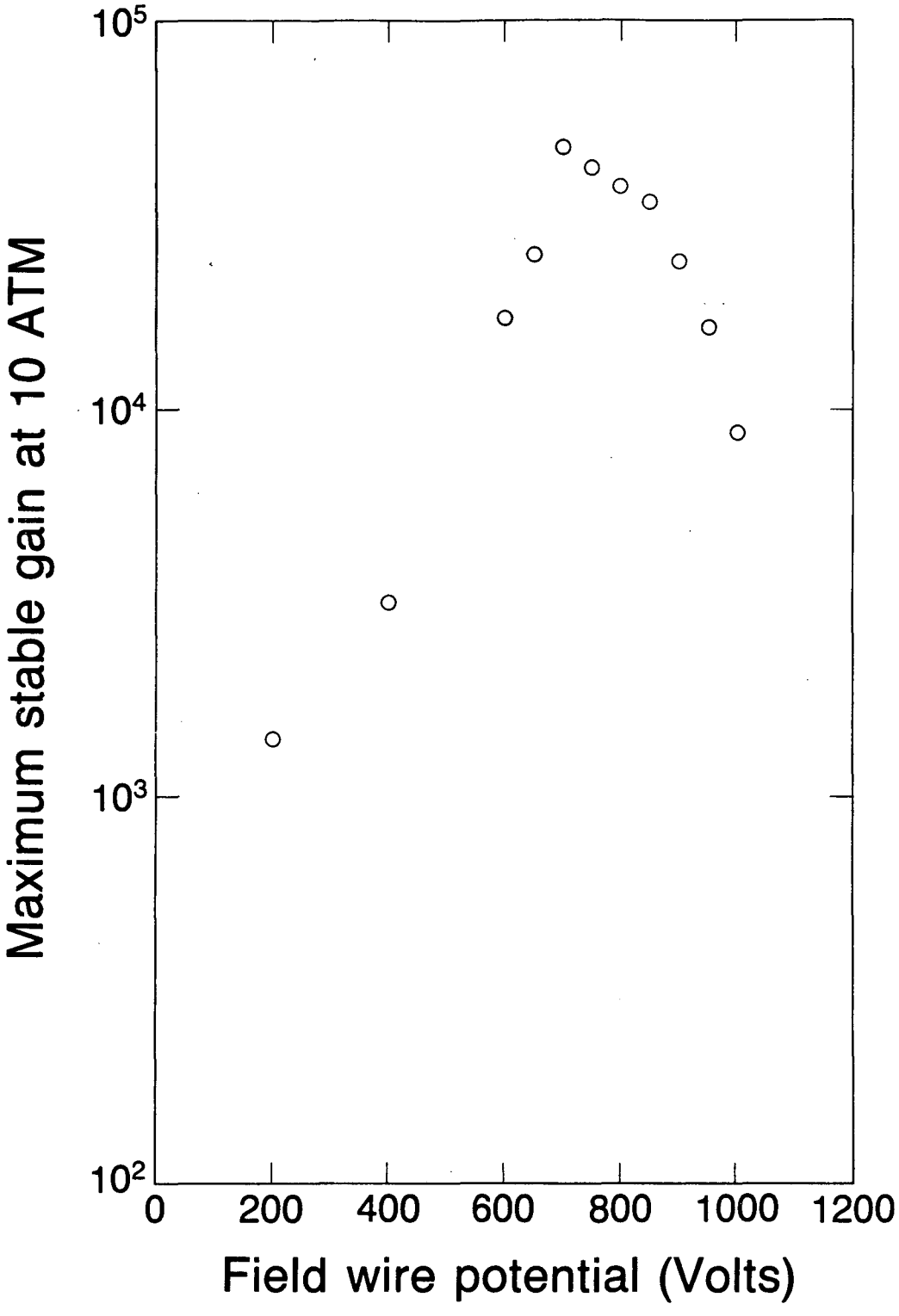
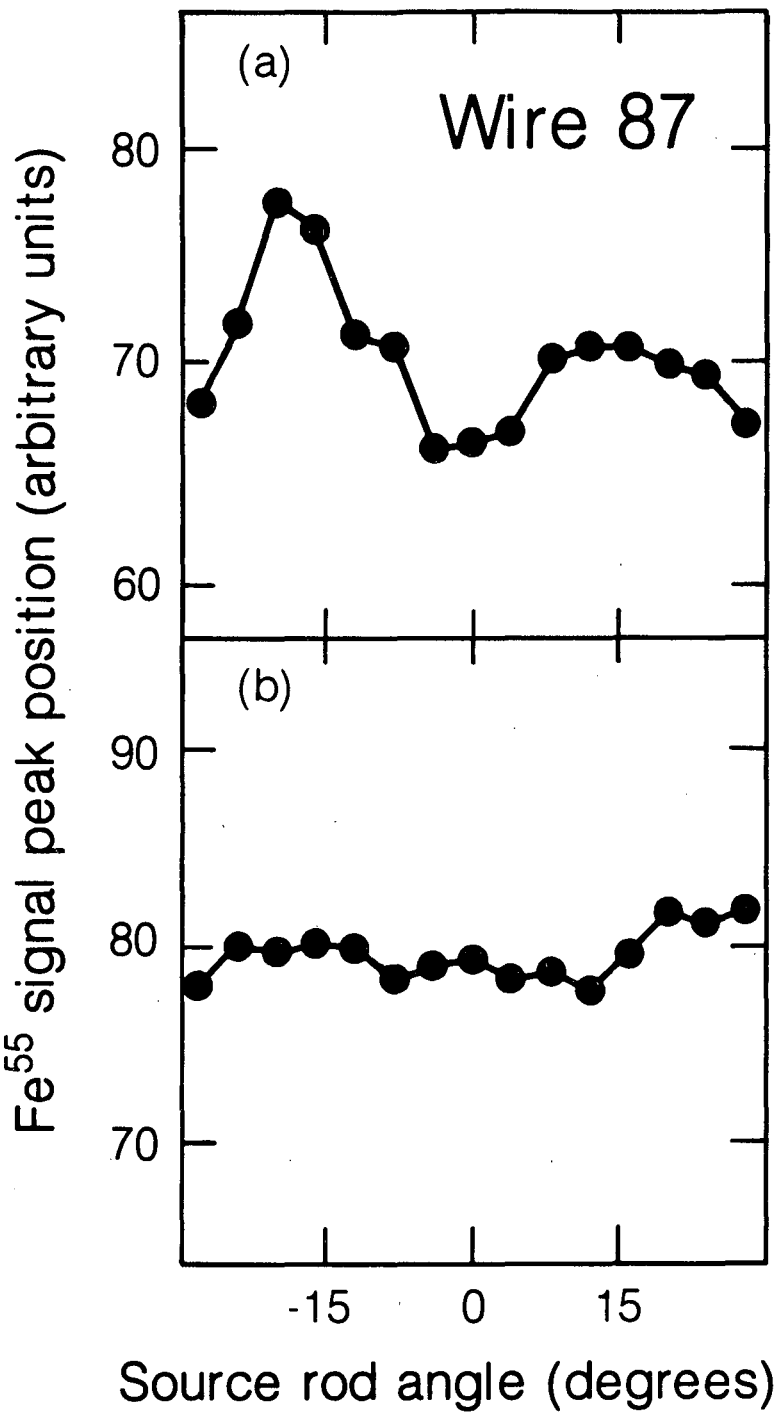

Maximum stable gain at 10 ATM
$10^5$
$10^4$
$10^3$
$10^2$
0
200
400
600
800
1000
1200
Field wire potential (Volts)
XBL 839-3257

Fig. 9




XBL 8310-585

Fig. 10

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