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Laboratory Session on: Drift Chamber Studies

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ICFA SCHOOL ON INSTRUMENTATION IN HEP

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LABORATORY SESSION ON : DRIFT CHAMBER STUDIES

INTRODUCTION:

PHYSICAL DESCRIPTION OF DRIFT CHAMBER

The drift chamber which you will use in this exercise is designed to illustrate some of the features of the Central Tracking Chamber of the Collider Detector at Fermilab. The CTC contains 6156 signal wires (and a total of approximately 36000 wires) organized into three kinds of drift cells which are in turn arranged in nine cylindrical "super layers" around the beam axis. Five of the super layers contain cells with twelve sense wires strung parallel to the beam axis. Two of the super layers contain cells with six sense wires strung at an angle of +3 degrees with respect to the beam axis, and the other two super layers contain six sense wires with a stereo angle of -3 degrees.

The drift chambers constructed for this lab contain one drift cell similar to the twelve sense wire CTC cells, although in our case only eight wires will be read out. The injection molded plastic parts which are used at the ends of the chambers are the same as those used in the CTC axial super layers. The white insert protects against edge breakdown at the ends of the chamber by making the potential path for breakdown extremely long. The black plastic part holds a fiberglass "pulltrusion" rod into which grooves have been precisely ground every five mm. The wires are positioned by these grooves. The wire tension is held by a .040" (outside diameter) 1.3" long crimp tube through which the wire is strung. The part of the black plastic block that the crimp tube bears on is manufactured from injection molded fiberglass.

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* The original manuscript was prepared by David Christian who was in charge of the Drift Chamber Laboratgory Session in the 1987 School

The drift cell is illustrated in Figure 1. The sense plane is centered between two cathode planes which are separated by 1.6". Each cathode plane contains thirty-one .005' diameter Cu-Be wires located on 5 mm centers. The cathode wires are tensioned to 300 gm. The sense plane contains twenty-three .005" diameter Cu-Be "field wires" and eight .001" diameter gold plated tungsten wires as shown in Figure 1. The sense wires are tensioned to 75 gm and the field wires to 300 gm. All the wires are 2 feet long and are inside a pipe, the pipe's outside diameter is 9" and its wall are 3/8" thick. The drift cells of the CTC axial super layers contain the same number of wires but are wedge shaped, as shown in Figure 2. In the CTC the cathode wires are connected to negative high voltage, the field wires are grounded, and the sense wires are connected to positive high voltage. The drift chamber constructed for this lab uses negative high voltage for the cathodes and for the field wires, and the sense wires are connected through the preamplifiers to ground. The outside pipe is also connected to ground. This allows the use of one dual high voltage power supply per chamber instead of two and means that no high voltage blocking capacitors are required.

READOUT SYSTEM

A block diagram of the readout system is provided in Figure 3. The sense wires are connected to preamplifiers mounted on the chamber. The circuit used is a three transistor preamplifier developed by V. Radeka (BNL) and is implemented on a hybrid chip. The signals travel from the preamps to an "amplifier-shaper-discriminator" which cancels most of the long time tail using a "pole zero" network, amplifies the signal again, and provides a time over threshold logic level output as well as an analog output. These circuits are essentially identical to the preamplifiers and ASD's used for the CDF CTC. The ECL logic output of the ASD is converted to a NIM logic signal and then input to a LECROY 2228A CAMAC TDC. The TDC's are read out through CAMAC into a PC. The TDC's used by the CDF group for the CTC are LECROY 1879 multihit FASTBUS TDC's which digitize both the leading and trailing edge of the time-over-threshold discriminator output. Circuit diagrams for the preamplifier and ASD are given in Figures 4 and 5.

ELECTROSTATICS

Like with any electrostatic problem to calculate the electric fields inside the chamber built for this lab. we have to solve Laplace's equation $\nabla^2 V = 0$. The boundary conditions are:

1) the anode wires and the pipe that surround the chamber are at zero voltage,
2) the field shaping wires are at V_F
3) the cathode wires are at V_c.

To solve the problem exactly is very complicated, but it can be solved easily if we make the following two approximations:

1) The wires and the pipe are infinitely long and
2) the field at the surface of a given wire is completely dominated by the charge at that wire.

The following examples will give you an idea on how good the approximations are. Example 1: a wire with a linear charge density q and diameter d in the middle of two wires with linear charge density Q at a distance S from the middle wire. At the surface of the middle wire the ratio of electric fields is greater than the ratio of the linear charges q/Q times 2 $(S/d)^2$. This last factor is at least 3100 for the "field wires" and 77500 for the anode wires. Example 2: if r is the distance to the wire half way between the extremes then the ratio of electric fields between a wire of length L and an infinitely long one is: $1\text{-}2\ (r/L)^2$. For the lab drift chambers L = 610 mm and r ranges from zero to 155 mm.

Using approximation 1, the field for one wire will be $E = Q/r$, where Q = linear charge density/$2\pi\varepsilon_0$. Using approximation 2, the equipotentials near the wires will be circles. So we can replace one of them by a conductor *(the real wire!)* and automatically satisfy the boundary conditions at the wire.

If we know the value of Q for all the wires, we can easily calculate the potential difference between any pair of wires. For example if we want the potential between wires 8 and 45, we integrate the total field from the surface of wire 8 to the surface of wire 45. After doing that for all needed pairs of wires we will end up with a linear system of equations. Each equation consists of a linear combination of the Qs equal to a voltage. In the real case we know the voltages not the Qs. **So all we have to do is to invert the problem inverting the matrix of the linear system!**

In the chambers built for this lab. there are 93 wires so we will have 93 Qs. From calculating voltages between pairs of wires we will get only 92 independent equations. Why? we can only pick up one wire and calculate the potential difference with all the other wires (but not with itself!). The inclusion of all the other pairs will not give linear independent equations. For example, if we know the potential $V_{2,4}$ (between wires 2 and 4) and $V_{2,6}$ (between wires 2 and 6) the potential between wires 4 and 6 is just $V_{2,4} - V_{2,6}$.

The extra equation comes from the boundary conditions outside the system of wires. For example, if we do not include the outside pipe, we put the requirement that the potential at infinity is zero which is the same as saying that the sum of all the Qs is equal to zero. If we have the outside pipe included in the calculation its potential will provide equation 93.

To include the pipe in the calculation we have to add image charges. Appendix B describes how to do that.

If you decide to go through these calculations yourself, do not forget that the pipe and the anode wires are at the same potential. If you do not have time now then Table 1 has the numbers that you will need to get the Qs knowing the potentials of the cathode and field shaping wires.

Figures 6 to 13 and 14 to 16 show the electric field for different values of V_f and V_c. These values were chosen along the line of constant charge

$$Q_a(4) = - 46.8\ V_c - 78.1\ /V_f = 278$$

For Figures 6 to 13 one field line is equal to Mod (Q/16.5, 4) (mod. (4) because we need four-fold symmetry). For Figures 13 to 16, the 16.5 was changed to 33 because the scale was also changed by a factor of 2.

MEASUREMENTS WITH AN OSCILLOSCOPE

DEPENDENCE OF GAIN ON APPLIED VOLTAGES

Set the scope up to look at the signal from one wire coming out of the preamp and also at the corresponding ASD analog output. Raise the two high voltages slowly, keeping the ratio between the cathode voltage and the field wire voltage between 2/1 and 3/2. Stop often & shine the Ru source through the chamber. When the signals from the Ru are easily seen, switch to the Fe source.

The Fe source emits a 5.9 KeV x-ray which, when it does anything in the chamber gas, deposits all of its energy in one cluster of primary electrons. Since the chamber is operating in the proportional mode, this results in a well defined pulse. Adjust the two high voltages slightly and observe the corresponding changes in gas gain.

ERTIES OF THE PREAMPLIFIER AND ASD

Since the iron x-ray yields only one cluster of primary ionization it is perfect for measuring the nse of the readout electronics to an impulse of charge. The width of the pulses visible on the scope ictly a function of the amplifying and pulse shaping circuitry. Observe the effect of the pole zero ellation by comparing the pulse which is input to the ASD with its analog output. Next, measure the onship between the applied discriminator threshold voltage and the actual discrimination level in ASD. This is done easiest by triggering the scope on the digital time-over-threshold signal and ng at the ASD analog output. Vary the gas gain by adjusting high voltages (or perhaps just V_f); now the threshold voltage at which the discriminator just does produce an output. Plot this voltage gainst the ASD analog output pulse height for three or four pairs of values.

EPARATE CONTROL OF GAS GAIN AND DRIFT FIELD

Next, find a set of values of V_f and V_c which yield the same gas gain. Choose a gas gain for which the iron x-ray pulses are large, but not saturated at either the preamp output or the ASD analog output. ary V_f in 100 volts step. At each step in V_f vary V_c until the pulse looks the same again The gain is a unction of the charge at the wire. So keeping the pulse the same means that one is moving along a curve n V_f, V_c space) of constant charge. From Table 1, you can get the slope of this curve and compare it with the results of your measurements. Measure the voltages V_f and V_c with a volt meter, the dial of the power supply is not accurate enough. You should go up and down in Vf until the chamber sparks at both ends. Repeat the same procedure for different anode wires.

ETECTING MINIMUM IONIZING PARTICLES

Relativistic charged particles ionize much less heavily than a low energy x-ray does. They also leave a trail of clusters of typically 1-3 primary electrons rather than a single much larger cluster. The end-point of the Ru e- spectrum is 3.54 MeV, which means that some of the electrons emitted behave like minimum ionizing particles. One can isolate the signals of these electrons by triggering on the signal from a scintillation counter placed on the opposite side of the drift chamber from the Ru source. At a higher level of analysis, one can also demand that a subset of the drift chamber points fit to a straight line with a low chisquare, indicating that the e- did not scatter through a large angle as it traversed the chamber.

Using the Ru source, trigger the scope on signals from a scintillation counter placed on the far side of the drift chamber and look at the preamp output and/or the ASD analog output. Adjust one or both high voltages to raise the gas gain until the very small pulses produced by the "high energy" electrons are visible. Note the difference in size and shape between these pulses and x-ray induced pulses. Can you see evidence of multiple avalanches resulting from more than one cluster of primary ionization?

Set the high voltages and discriminator threshold so that essentially all of the "minimum ionizing" pulses will yield logic pulses. Make sure that the discriminator threshold is not so low that the readout system oscillates.

ASUREMENTS WITH THE FULL READOUT SYSTEM

FFICIENCY PLATEAUS

Now you are ready to read out data into the PC and do something with it. If you are an experienced programmer, you may want to write some of the programs yourself. If not, a number of simple compiled BASIC routines are available. Even if you decide to write your own programs, you may want to look at the source code of the prepared routines. Appendix A contains a list of the available programs.

Shine the Ru source through the chamber. Provide a start signal to the CAMAC TDC using the signal from a scintillation counter placed on the othe· side of the drift chamber. Readout the TDC either with the BASIC program "COLDAT" or with a program of your own devising. If you choose to write your own program, consult the TDC manual and the CAMAC-PC interface manual or look at "COLDAT" to see how to communicate with the CAMAC TDC.

Measure efficiency plateaus as a function of the high voltages and discriminator threshold. This can be done either using the BASIC program "EFFS" or with your own program. To calculate the efficiencies, you might require wires 1, 2, 7 and 8 to be ON. This way you make sure that you have a track. Select one of the remaining wires, its efficiercy is the number of times the wire is ON divided by the total number of time you look at the wire (ON + OFF).

TIME TO DISTANCE RELATIONSHIP

Choose a set of operating voltages. Determine the relationship between the measured drift time and the distance of closest approach to the sense wire of the track. You can either use the Ru source or set up a coincidence between two scintillation counters, one placed on either side of the chamber, and use cosmic rays. If the Ru source is used, you can shine the source through either set of holes in the aluminum wall of the chamber. This means that tracks from the source can intersect the cell close to parallel to the planes of wires, or at approximately a 20 degree angle with respect to the planes of wires. The counters may be set up to trigger on cosmics which traverse the cell at any angle. If cosmics are used, it will probably be necessary to leave the setup on overnight to collect a large enough data sample to infer a time to distance relationship. The BASIC program "COLDAT" may be used to collect data; "TPLOT" may be used to plot raw time distributions.

The time to distance relationship will be close to linear; compare the drift velocity that you infer assuming a linear relationship (ie constant drift velocity over the entire drift distance) with the drift velocity read off of Figure 17.

One foolproof method of finding the time to distance relationship is to isolate a set of time measurements that you are sure come from part cles which uniformly populate the drift cell. The resulting time distributions can then simply be integrated. The BASIC program "TIMEDIST" may be used with cosmic ray data to produce time to distance relationships using this method.

POSITION RESOLUTION

Once the time to distance relationship is determined, you are ready to find and fit tracks. The time measurement made by each wire could either have been caused by a track passing to the left of the wire or by a track passing to the right of the wire. It is not hard to reduce the measurement ambiguity to an overall left-right ambiguity for the group of eight wires. Once the individual wire left-right ambiguity has been resolved, a least squares fit to a straight line can be performed. Leave one wire out of the fit, and then calculate the residual at this wire. The residual is defined as the difference between the position measured by the wire that was left out of the fit and the prediction of the fit for that measurement. The BASIC program "LINEFT" may be used or you may write your own. Recall the formula for a least squares fit to a straight line:

$y = a + bx$ (y measured at known x values)

$a = (\Sigma x_i^2 \Sigma y_i - \Sigma x_i \Sigma x_i y_i)/\Delta$

$b = (N\Sigma x_i y_i - \Sigma x_i \Sigma y_i)/\Delta$

$\Delta = N\Sigma x_i^2 - (\Sigma x_i)^2$ N = Number of measurements

POSSIBLE MEASUREMENTS

...re Drift Velocity as a Function of Drift Field

... ...te Resolution (Choose HV's & threshold)

... ...e Chamber Performance with 90% Ar - 10% CO^2

... ... "Expected" Gas Gain & Compare with Measurements

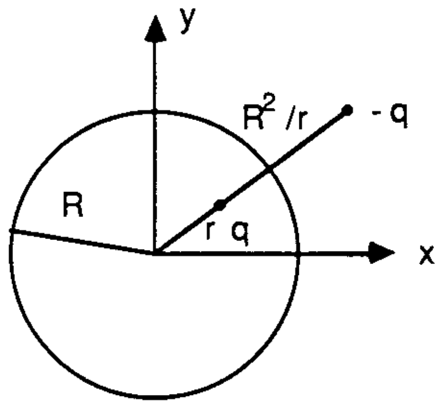
Calculate "Expected" Resolution and Compare with Measurements

Appendix A

The following BASIC programs are available for use:

COLDAT	Reads out TDC and writes data to a file
DISPLAY	Reads the data written by COLDAT and displays the results
EFFS	Reads out TDC and calculates efficiency for each wire
LINEFT	Calculates straight lines using N of the 8 wires. Cuts on chisquared, and plot residuals for the wires ex cluded from the fits.
TPLOT	Reads data from file and pl... ...C distributions.
TIMEDIST	Reads data from file 1 and ... time-to-distance relationships for each wire; ... ...s time-dist. relationships to file 2.

Appendix B



If we have the above configuration of charges in two dimension then the surface of the cylinder of radius R is at constant potential.

$$V = q\ln\left|\vec{x} - \vec{r}\right| - q\ln\left|\vec{x} - \frac{R^2}{r^2}\vec{r}\right|$$

for |**x**| = R, we get (**u** and **n** are unit vectors in the direction of **x** and **r** respectively).

$$V(R) = q\ln\left|R\vec{u} - r\vec{n}\right| - q\ln\left|R\vec{u} - \frac{R^2}{r}\vec{n}\right| = q\ln(r/R)$$

TABLE 1

Definitions:

Qc(I) = charge per unit lenght / 2 pi epsilon0 for cathode wire I.
Qf(I) = charge per unit lenght / 2 pi epsilon0 for field shaping wire I.
Qa(I) = charge per unit lenght / 2 pi epsilon0 for anode wire I.

Vc = cathode wires potential in KV.
Vf = field shaping wires potential in KV.
The anodes and the outside pipe are at zero volts.

The wires are numbered from top to bottom. The "charges" are linear combinatios of the potentials. For example:

Qc(3) = 54.5 Vc - 25.8 Vf

	Qc(1)	Qc(2)	Qc(3)	Qc(4)	Qc(5)	Qc(6)	Qc(7)	Qc(8)	Qc(9)	Qc(10)	Qc(11)	Qc(12)	Qc(13)	Qc(14)	Qc(15)	Qc(16)
Vc coef. =	89.9	64.4	54.5	49.4	46.3	44.3	42.8	41.7	40.8	40.2	39.7	39.3	39.1	38.9	38.8	38.8
Vf coef. =	-26.1	-25.0	-25.8	-26.3	-26.3	-25.7	-24.4	-22.7	-21.0	-19.5	-18.5	-17.8	-17.3	-17.1	-17.0	-16.9

	Qc(31)	Qc(30)	Qc(29)	Qc(28)	Qc(27)	Qc(26)	Qc(25)	Qc(24)	Qc(23)	Qc(22)	Qc(21)	Qc(20)	Qc(19)	Qc(18)	Qc(17)
Vc coef. =	89.9	64.4	54.5	49.4	46.3	44.3	42.8	41.7	40.8	40.2	39.7	39.3	39.1	38.9	38.8
Vf coef. =	-26.1	-25.0	-25.8	-26.3	-26.3	-25.7	-24.4	-22.7	-21.0	-19.5	-18.5	-17.8	-17.3	-17.1	-17.0

	Qf(1)	Qf(2)	Qf(3)	Qf(4)	Qf(5)	Qf(6)	Qf(7)	Qf(8)	Qf(9)	Qf(10)	Qf(11)	Qf(12)
Vc coef. =	-53.9	-51.4	-53.1	-55.0	-56.5	-57.7	-59.0	-61.6	-65.0	-65.8	-66.0	-66.1
Vf coef. =	103.2	77.9	69.5	66.5	66.3	68.9	76.7	102.7	137.6	143.5	145.0	145.3

	Qf(23)	Qf(22)	Qf(21)	Qf(20)	Qf(19)	Qf(18)	Qf(17)	Qf(16)	Qf(15)	Qf(14)	Qf(13)
Vc coef. =	-53.9	-51.4	-53.1	-55.0	-56.5	-57.7	-59.0	-61.6	-65.0	-65.8	-66.0
Vf coef. =	103.2	77.9	69.5	66.5	66.3	68.9	76.7	102.7	137.6	143.5	145.0

	Qa(1)	Qa(2)	Qa(3)	Qa(4)	Qa(5)	Qa(6)	Qa(7)	Qa(8)
Vc coef. =	-45.43	-46.42	-46.71	-46.80	-46.80	-46.71	-46.42	-45.43
Vf coef. =	-89.67	-80.73	-78.64	-78.09	-78.09	-78.64	-80.73	-89.67

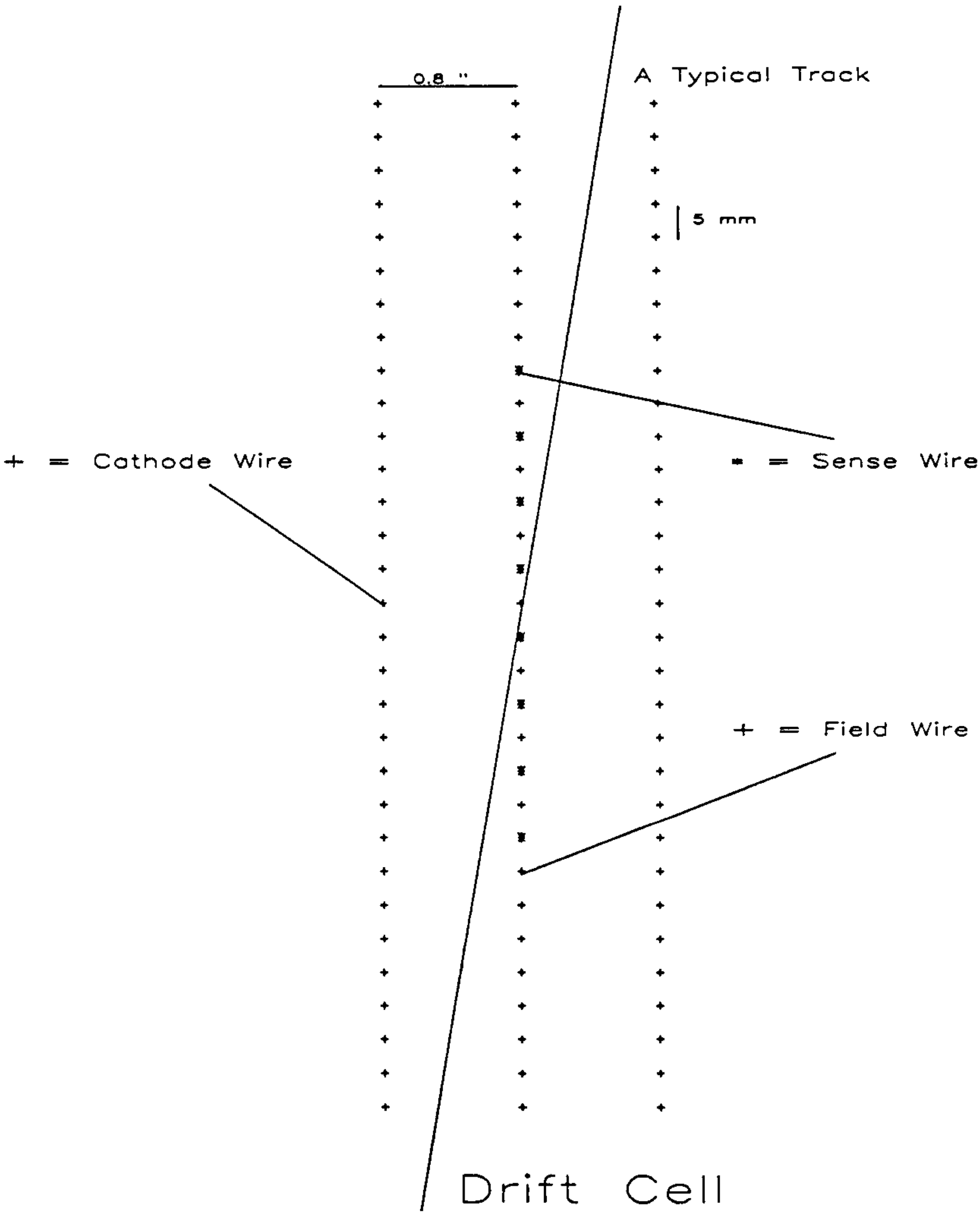
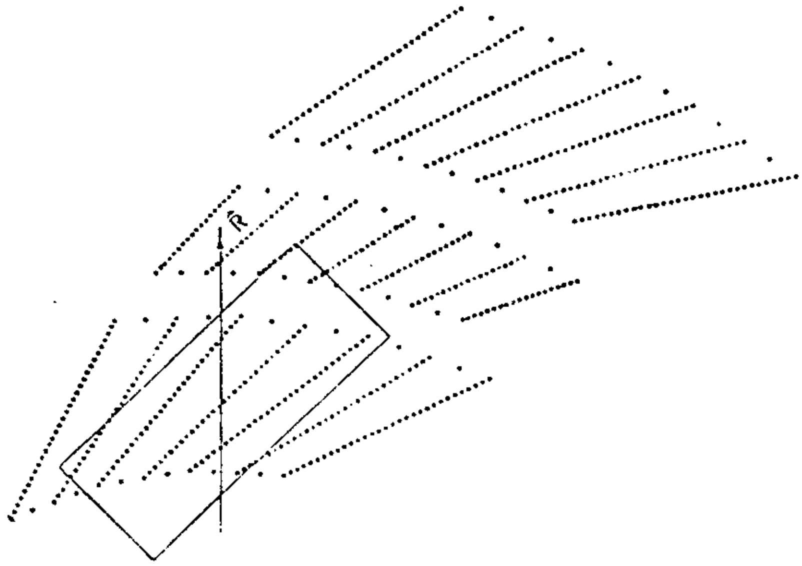

0.8 "
A Typical Track
5 mm
+ = Cathode Wire
= Sense Wire
+ = Field Wire
Drift Cell

Figure 1



(AXIAL CELL)

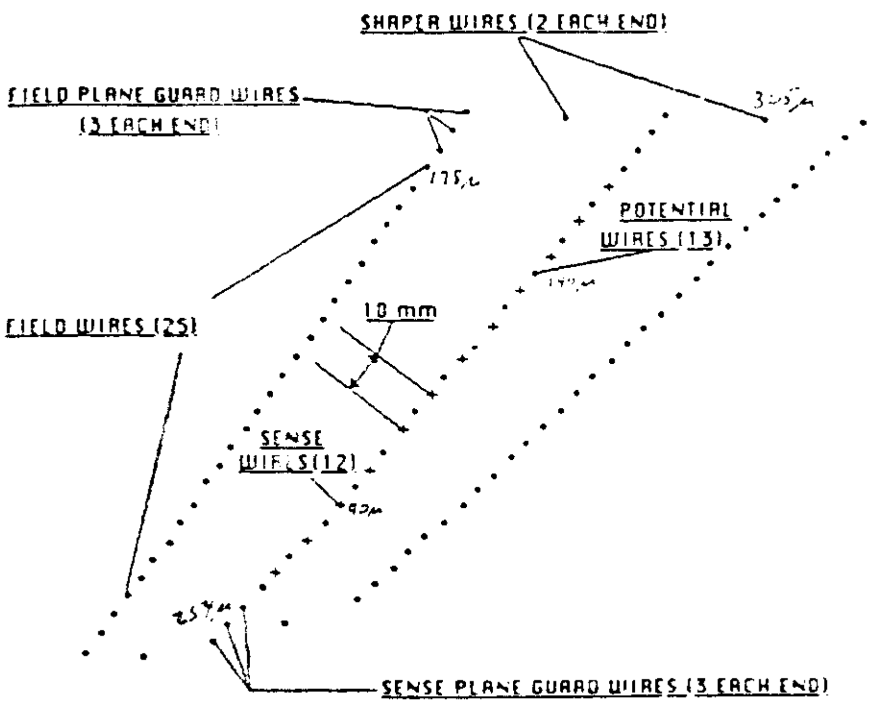


FIGURE 2 (CDF CTC)

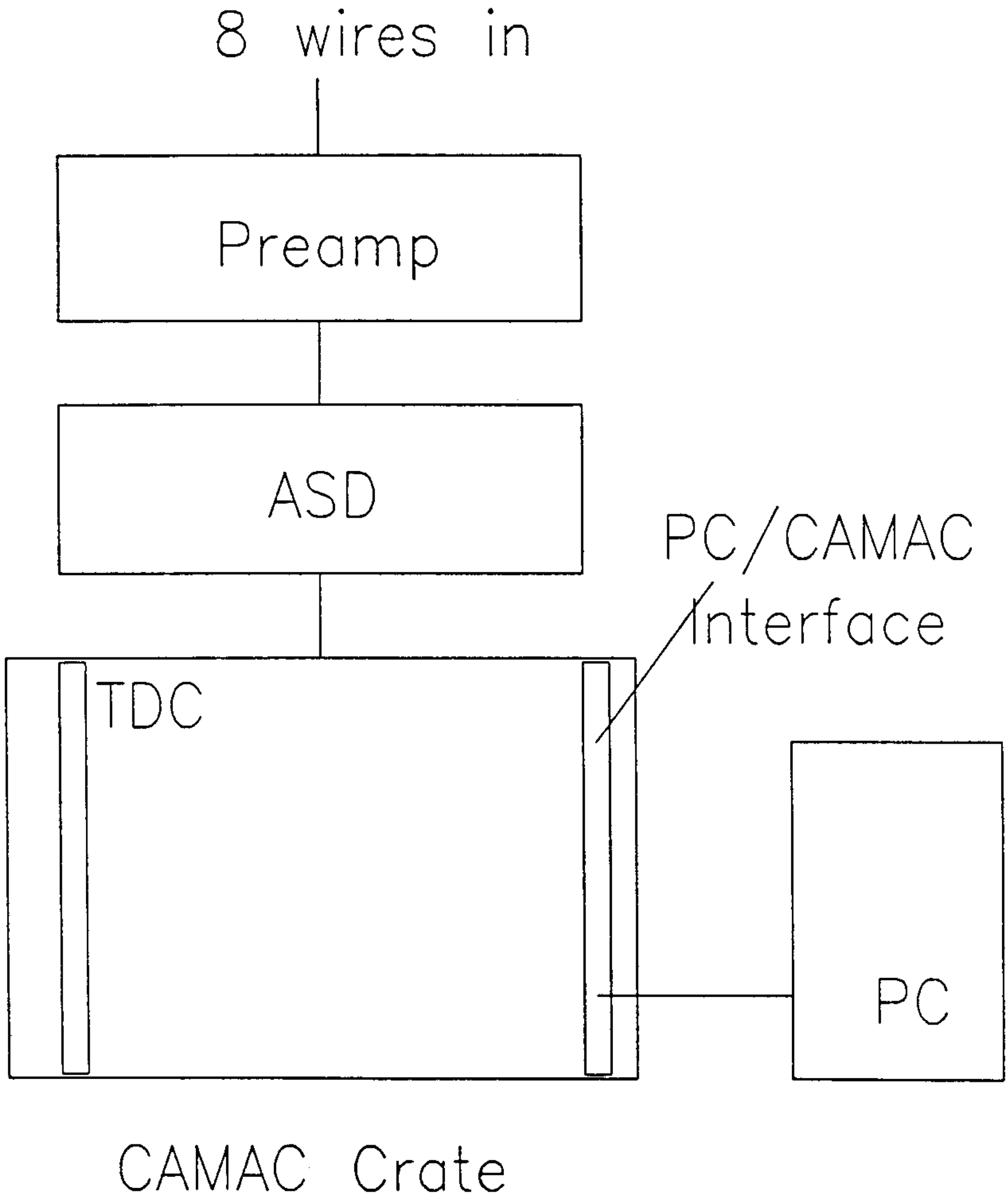
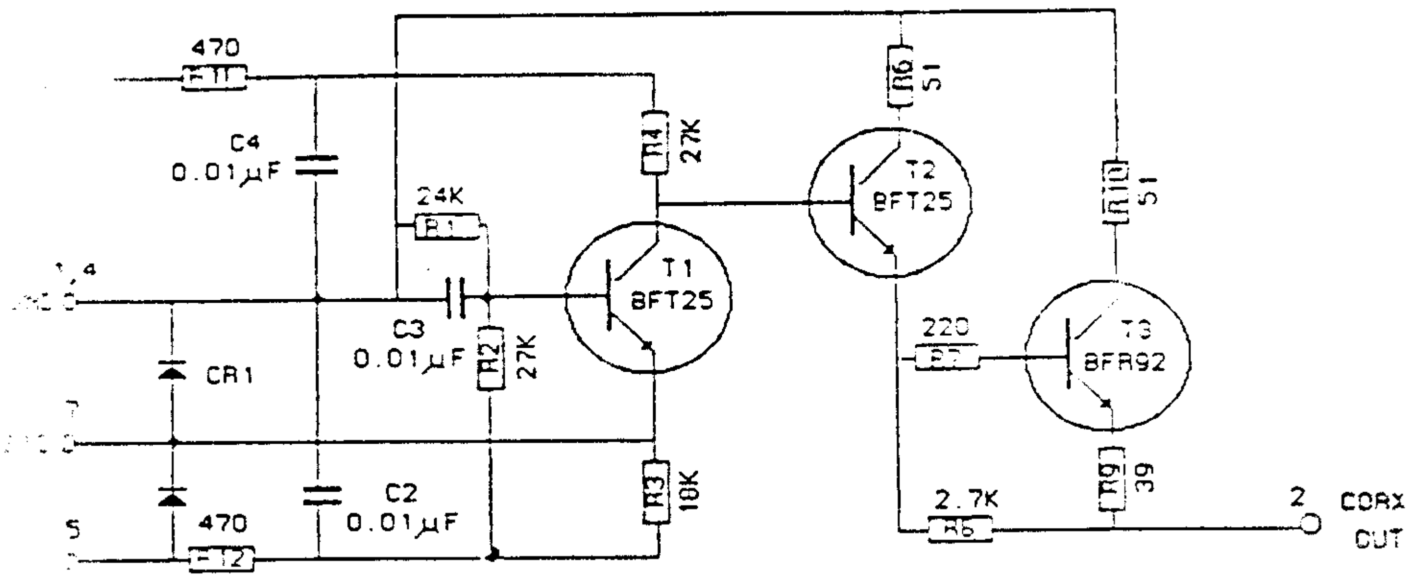


Figure 3

<u>FIGURE 14: IO 354 HYBRID PREAMP</u>



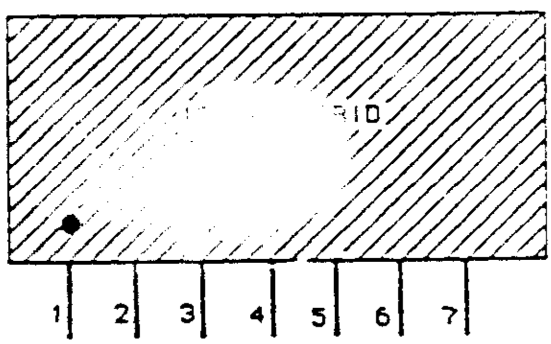


Figure 4

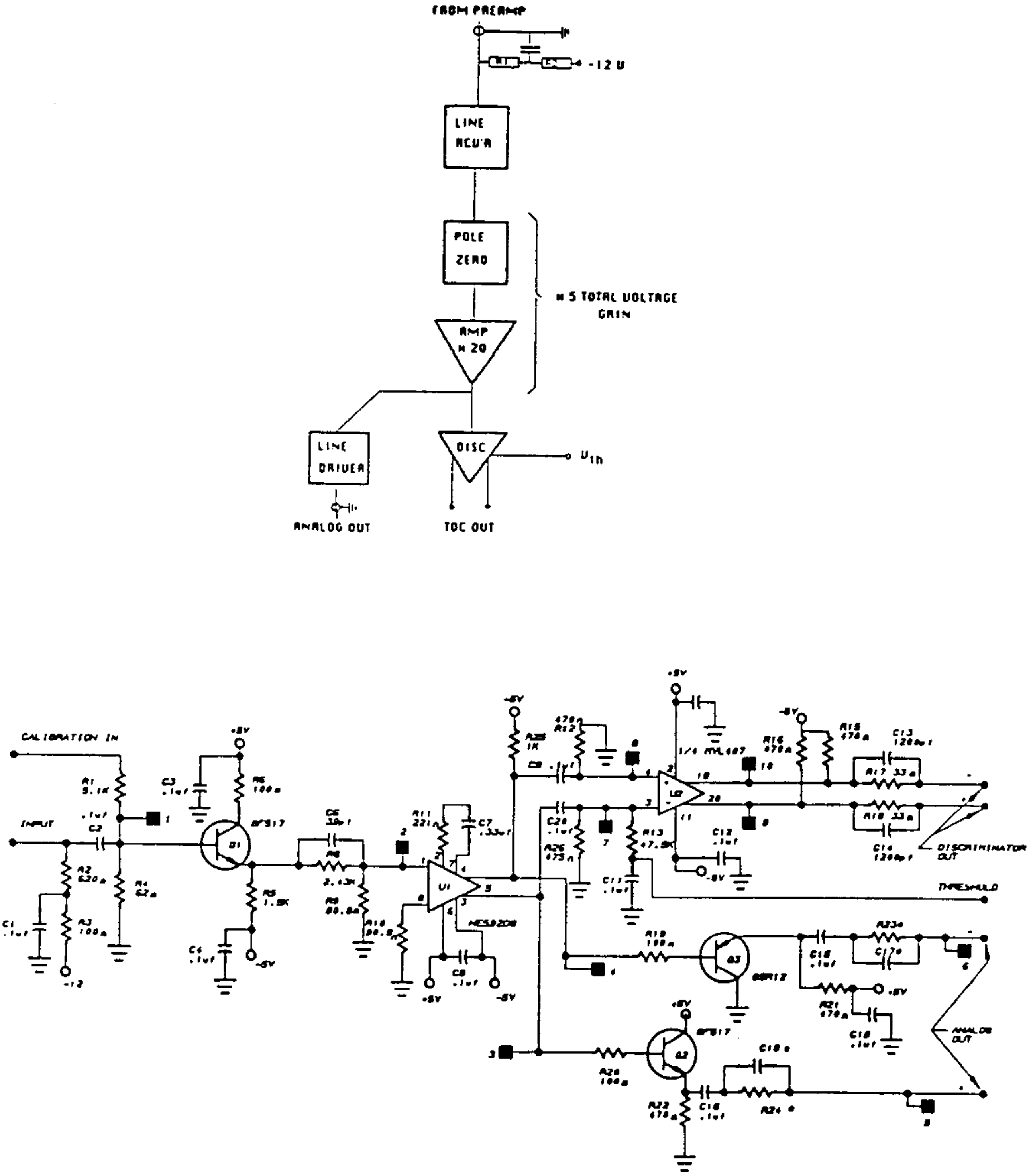

FROM PREAMP
-12 V
LINE RCV'R
POLE ZERO
X 5 TOTAL VOLTAGE GAIN
AMP X 20
LINE DRIVER
DISC
ANALOG OUT
TDC OUT
CALIBRATION IN
INPUT
THRESHOLD
DISCRIMINATOR OUT
ANALOG OUT

Figure 5 ASD

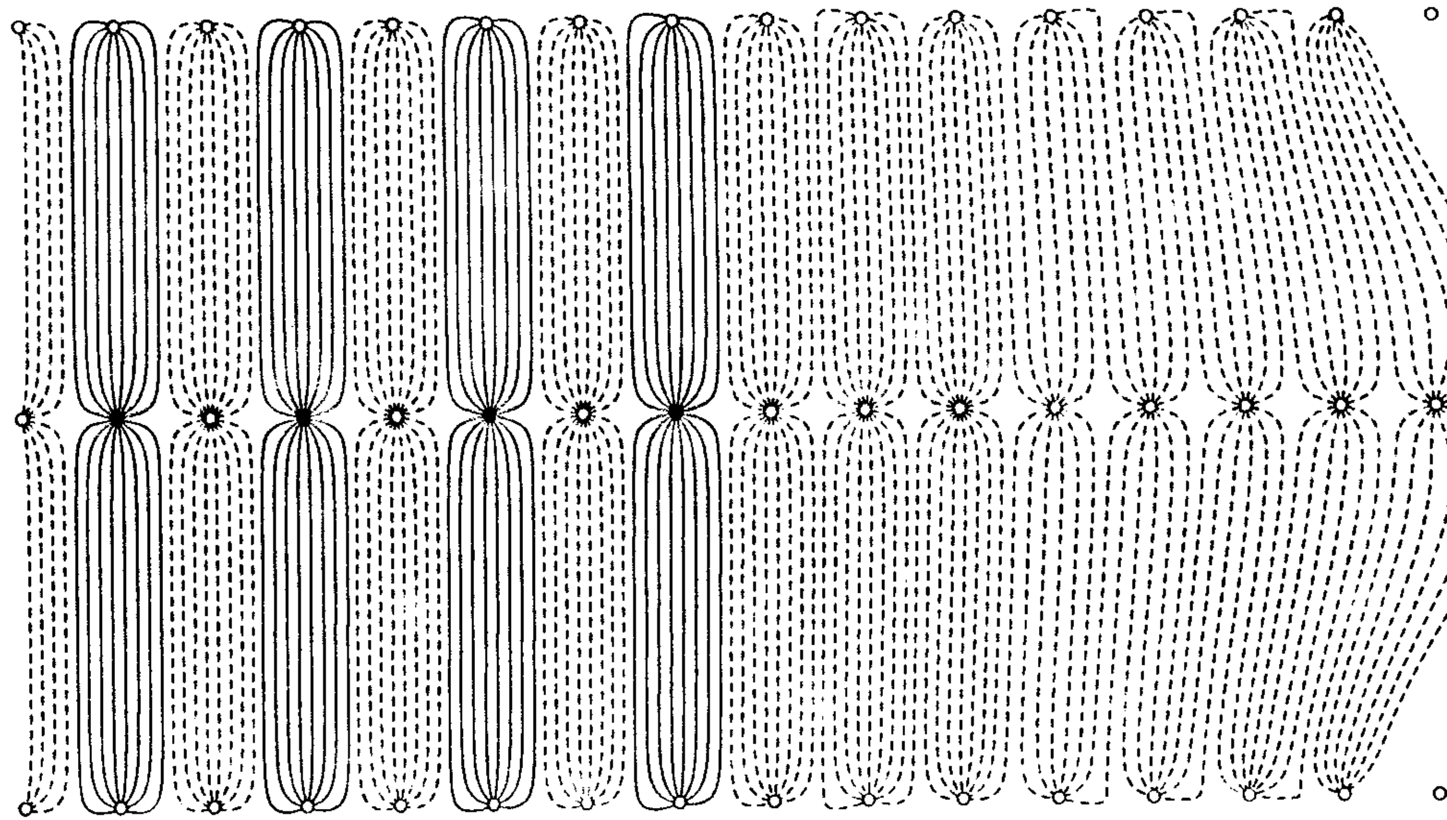


FIG. 6 : $V_c = -5.11$ $V_F = -0.50$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

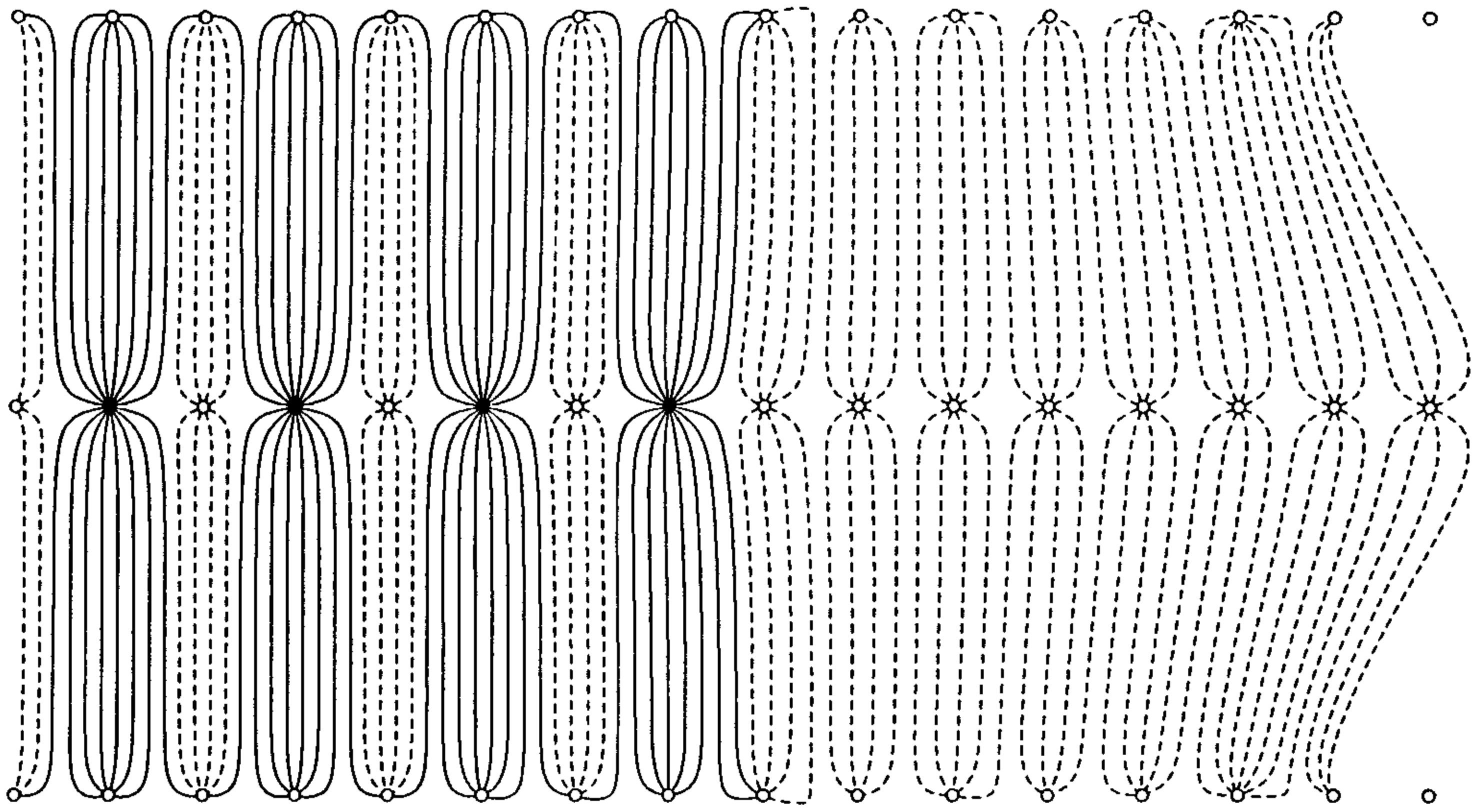


FIG. 7 : $V_c = -4.27$ $V_F = -1.00$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

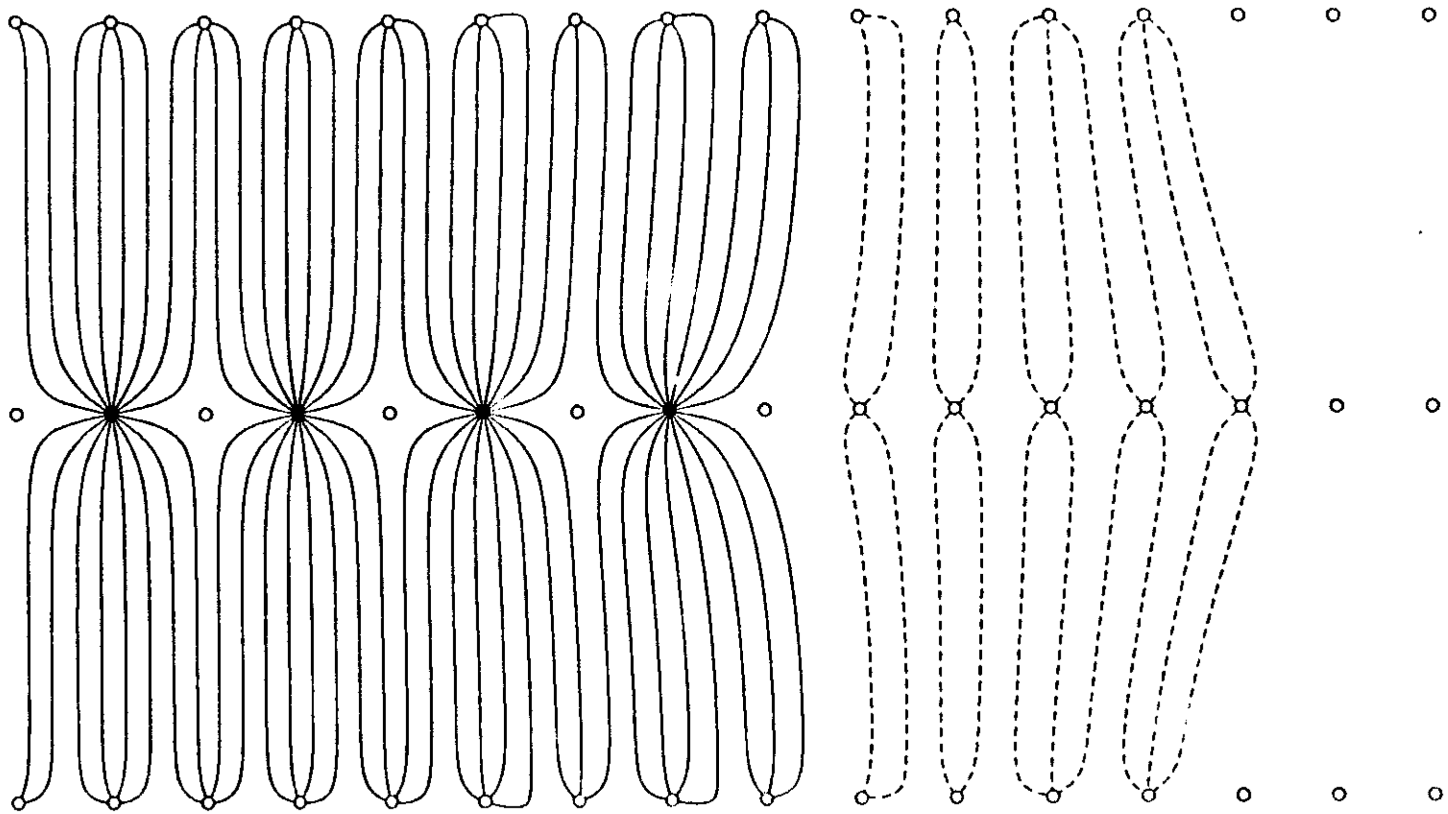


FIG. 8 : $V_c = -3.37$ $V_F = -1.54$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

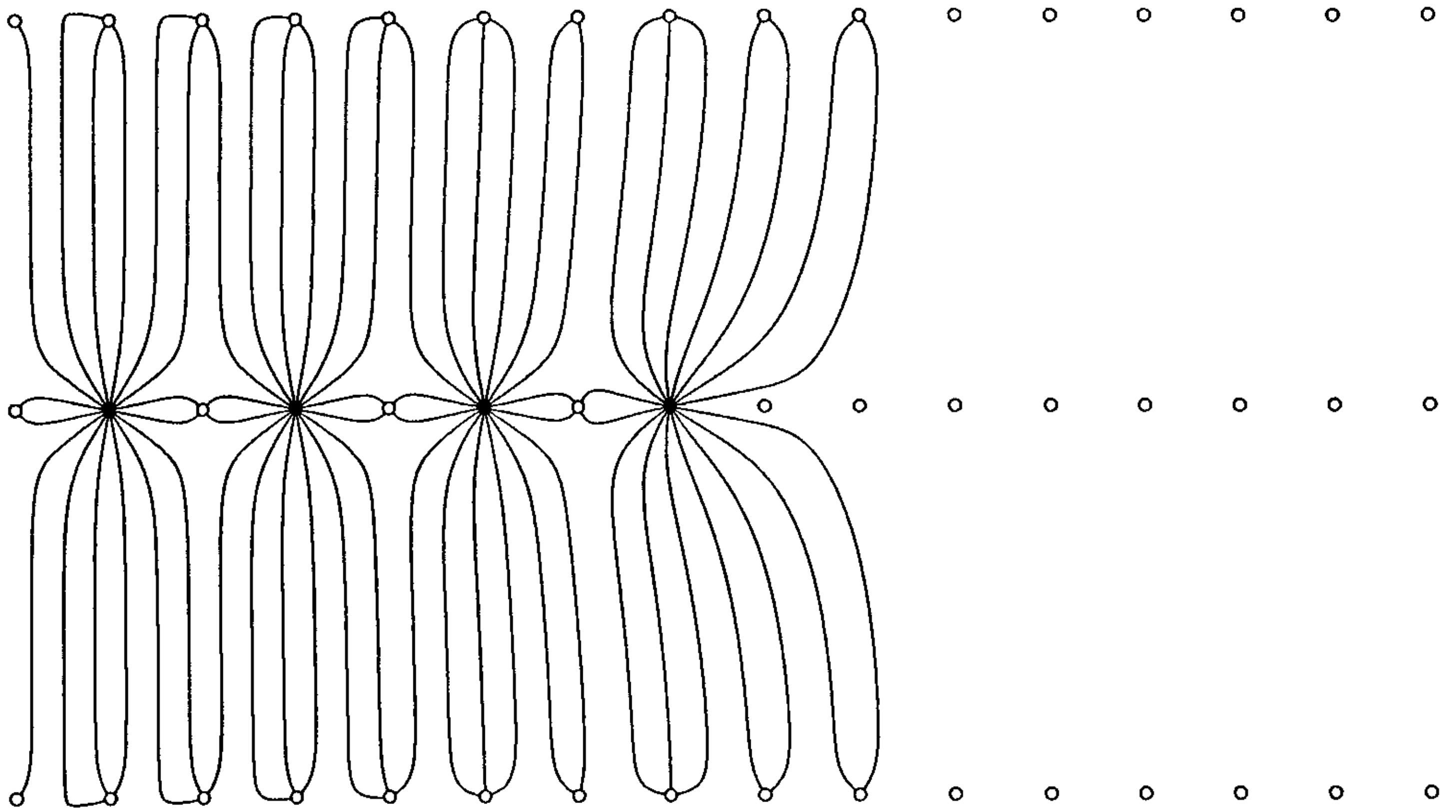


FIG. 9 : $V_c = -2.93$ $V_f = -1.80$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

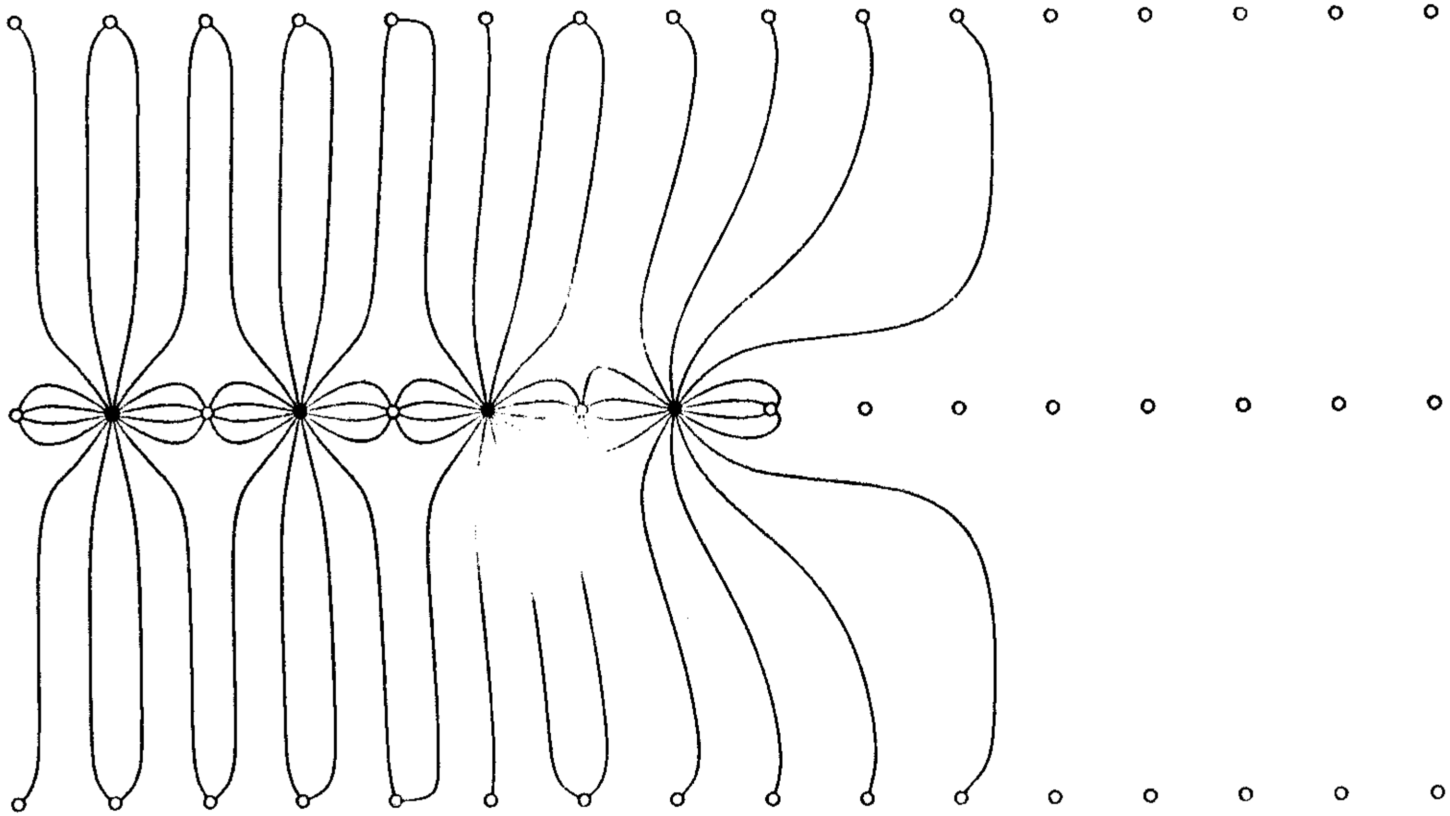


FIG. 10 : $V_c = -2.43 \quad V_F = -2.10$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

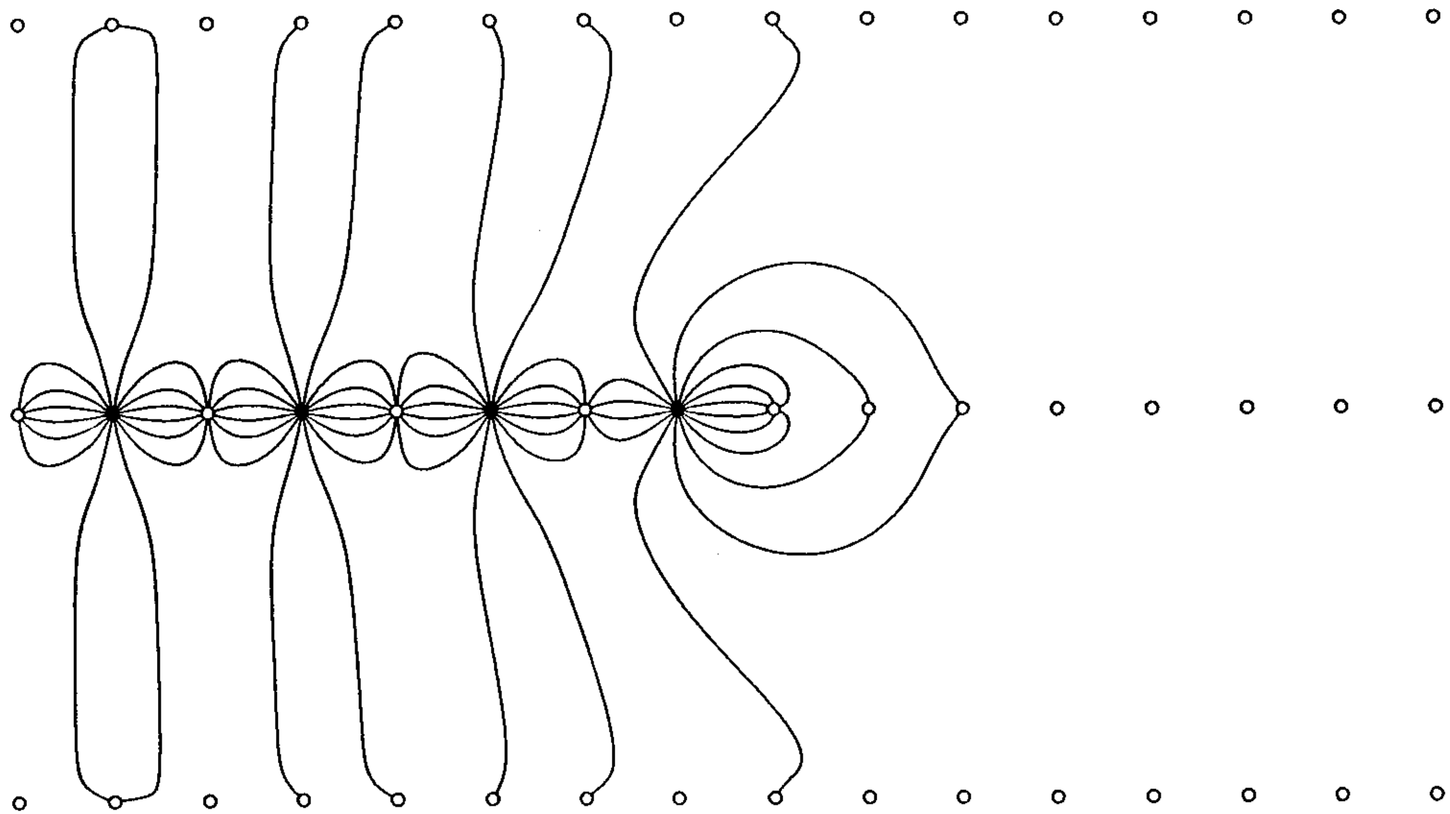


FIG. 11 : $V_c = -2.10$ $V_f = -2.30$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

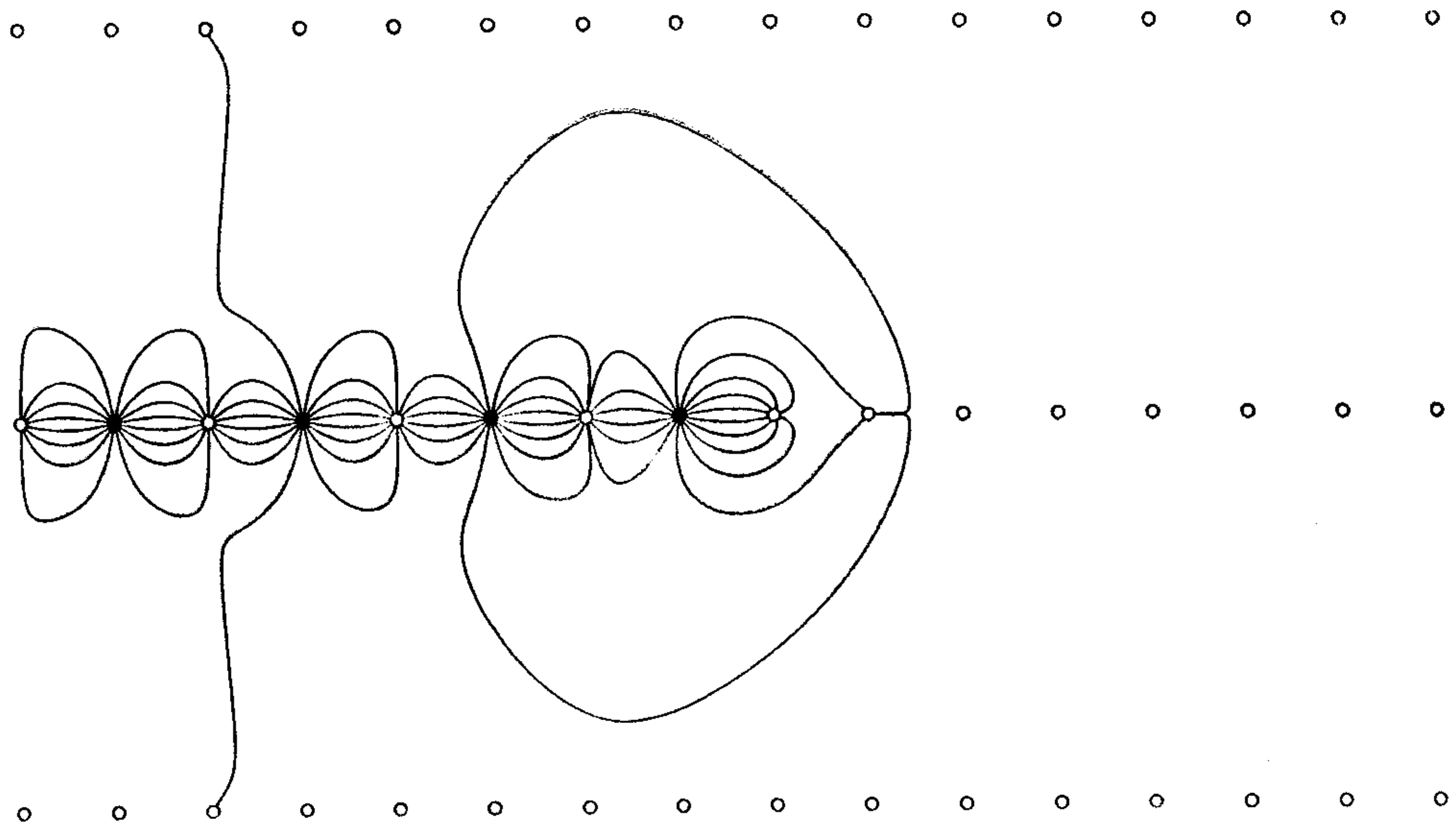


FIG. 12 : $V_c = -1.76 \quad V_F = -2.50$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

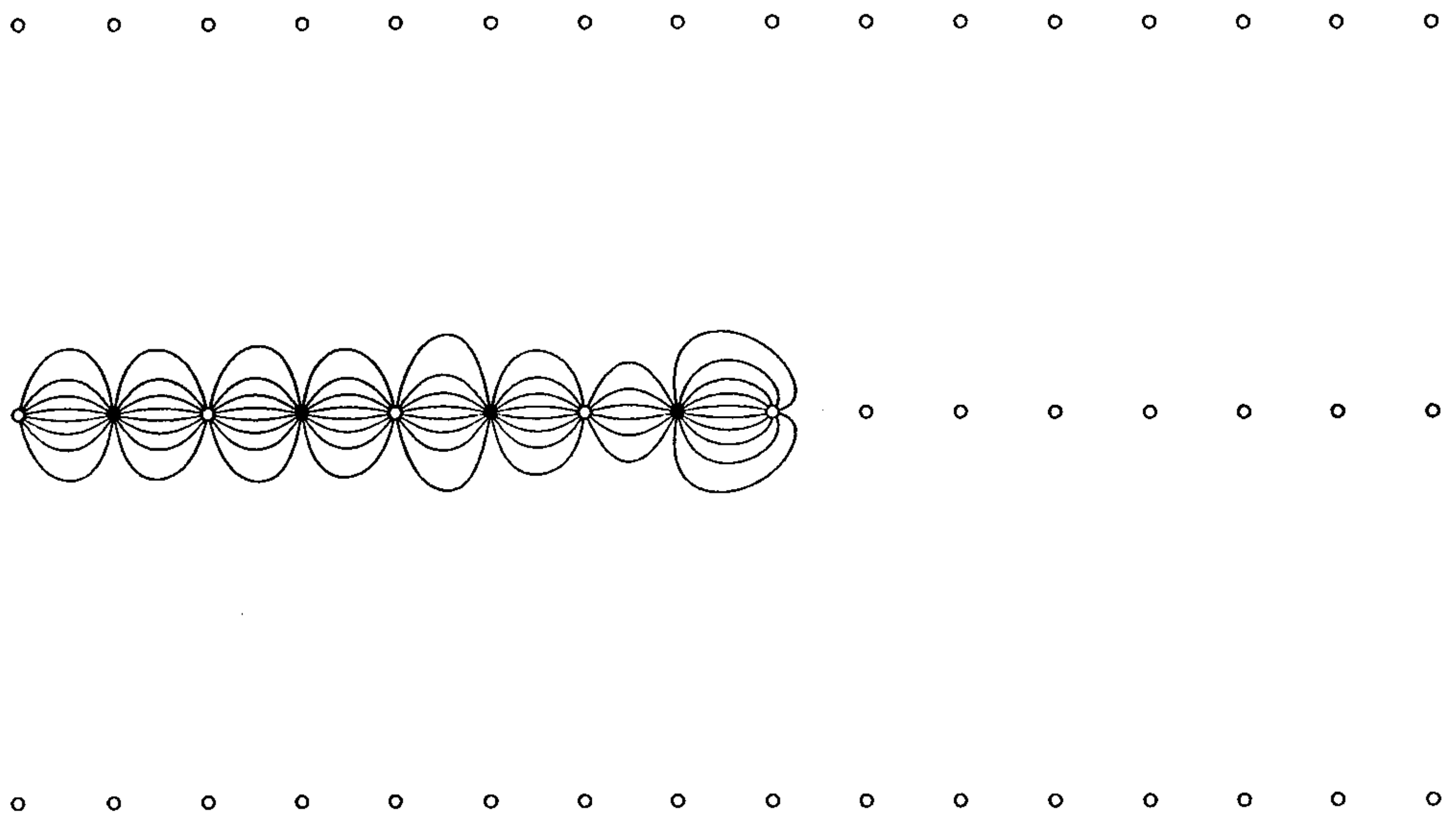


FIG. 13 : $V_c = -1.43 \quad V_F = -2.70$

The field lines start only from wires with positive charge. The continuous(dashed) lines start from the anode(field shaping) wires. The number of field lines is proportional (mod(4)) to the charge in the wires.

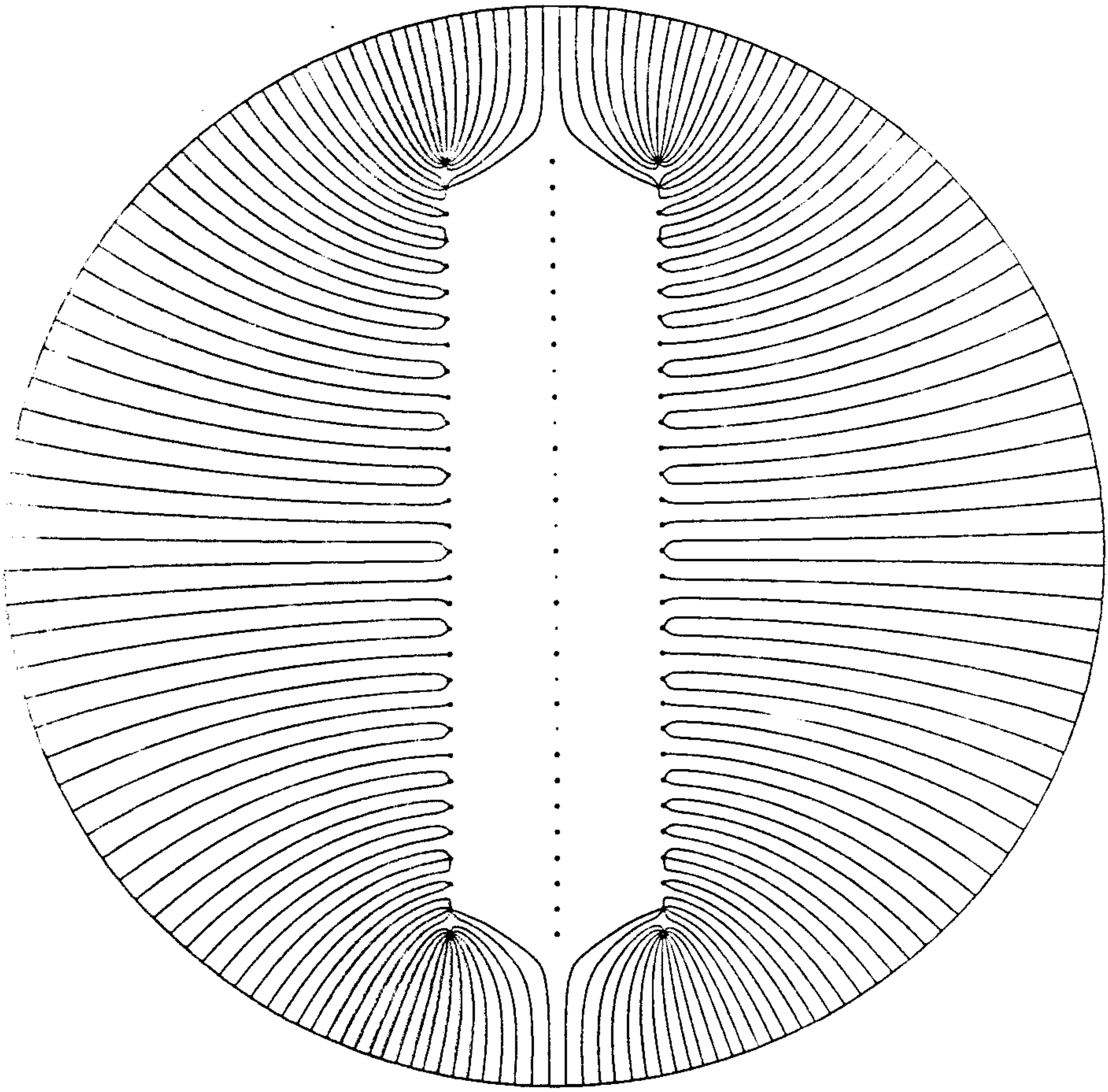


FIG. 14 : $V_c = -4.27$ $V_F = -1.00$

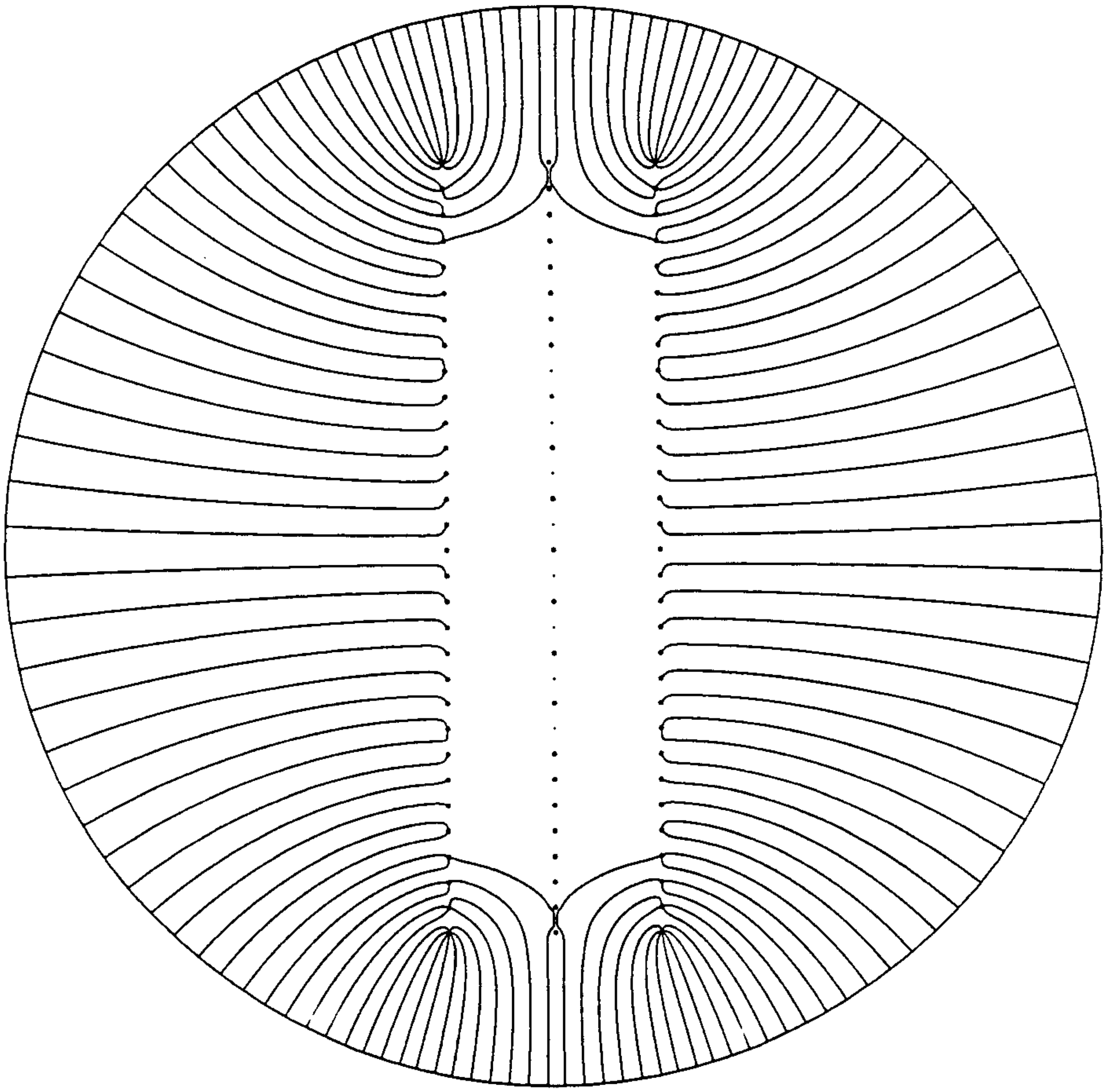


FIG. 15 : $V_c = -2.93 \quad V_F = -1.80$

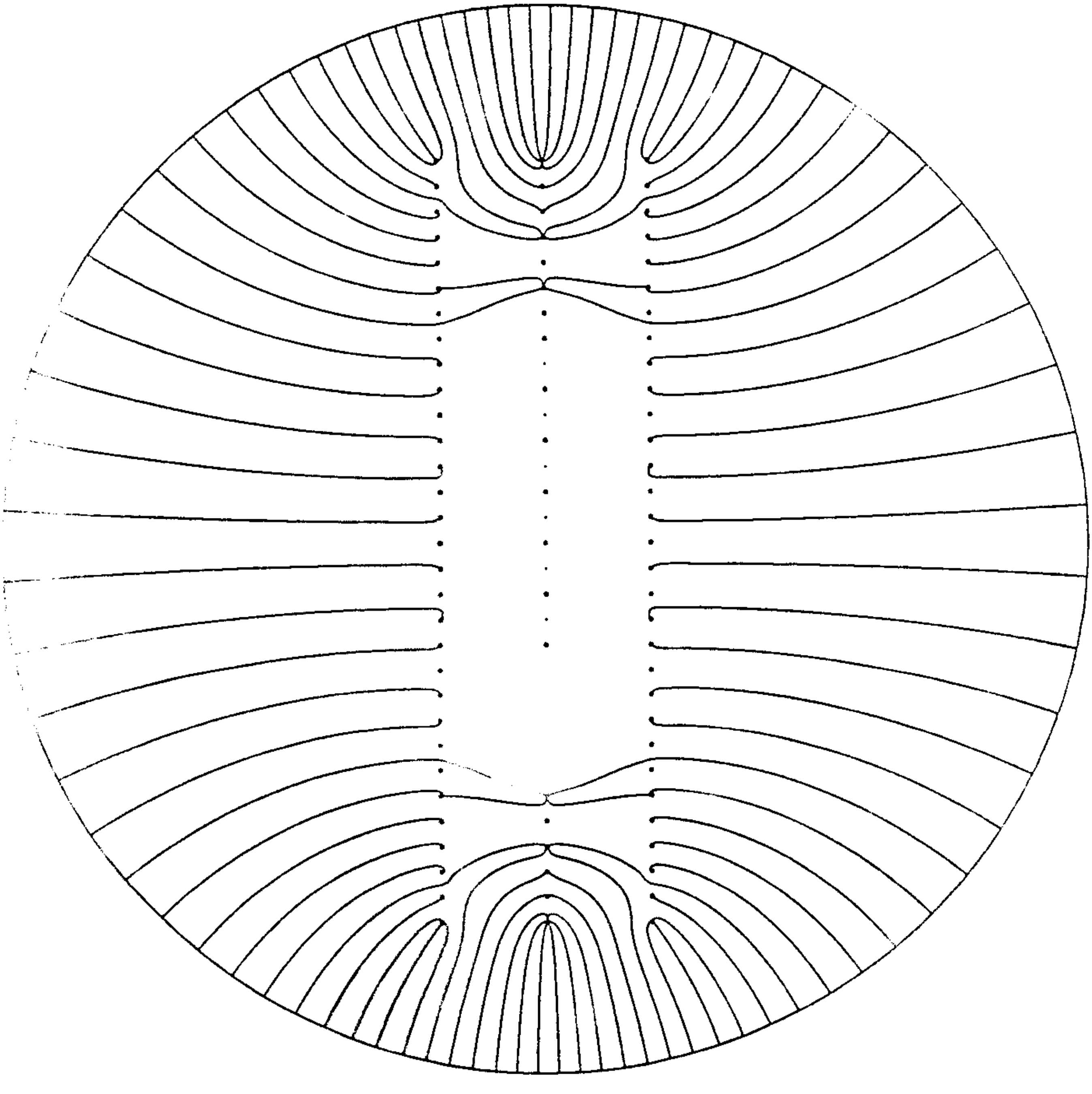


FIG. 16 : $V_c = -1.76$ $V_r = -2.50$

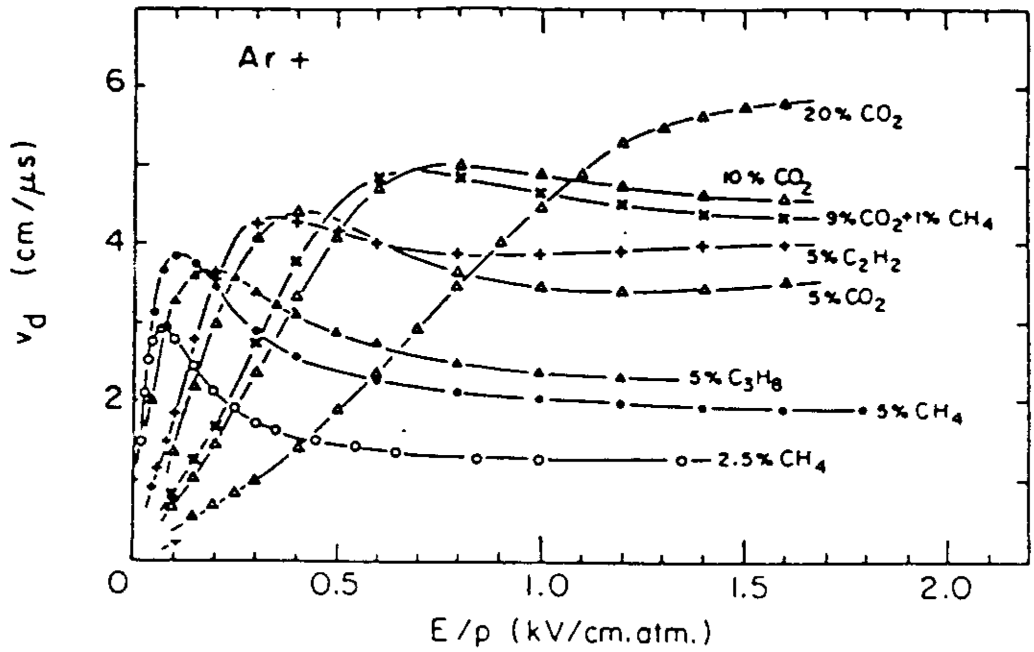


Fig. 63 Lehraus et al. (1983)

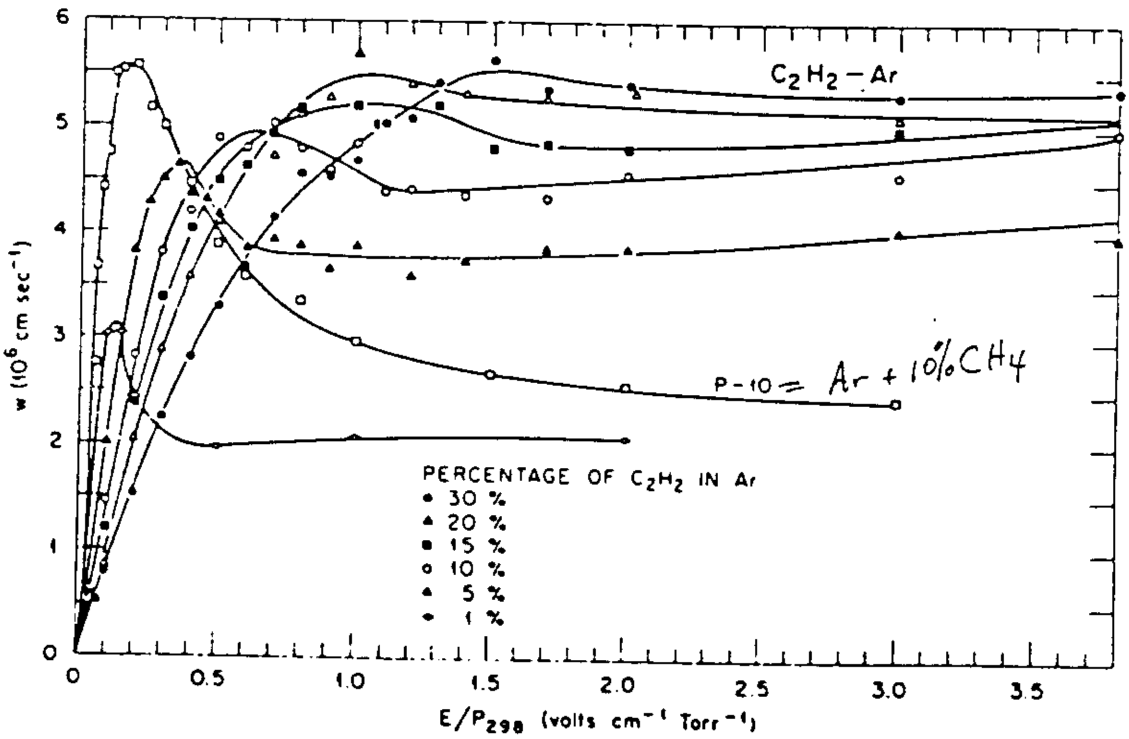


Fig. 79 Christophorou et al. (1979)

Figure 17