p Note 371

VARIOUS TESTS ON FNAL PROTOTYPE STOCHASTIC COOLNG ELECTRODE ASSEMBLY

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Errata — Note #371

p. 2 Should read: We would like S_{11} to be greater than 13 dB at each frequency, which would be less than 5% reflected power.

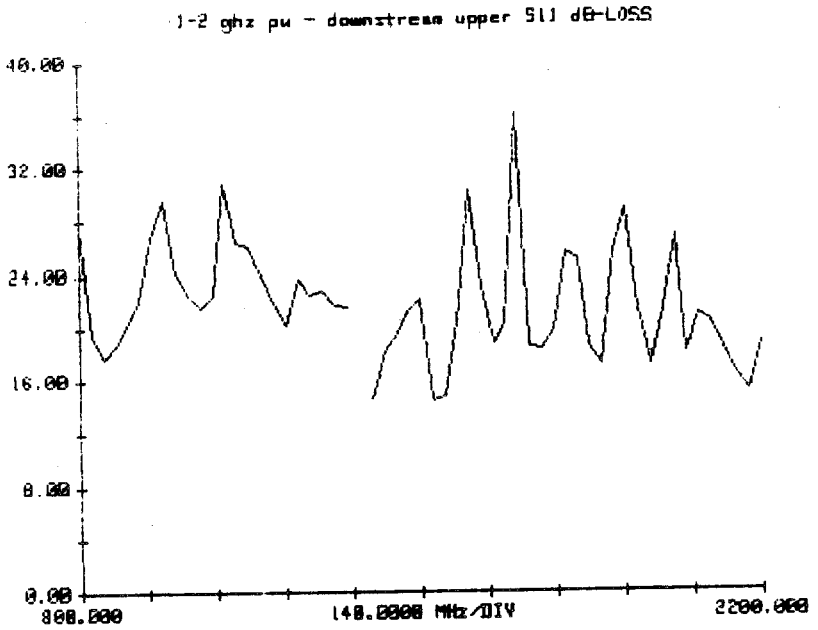
p. 12 Substitute "conductances" for "capacitances" at top and bottom of page.

We have performed a variety of tests on the 1-2 GHz stochastic cooling electrode assembly fabricated at Fermilab. The various tests which we performed and are discussed below are as follows: S parameter, vacuum, thermal, cryogenic, operation as kicker, operation as pickup in Argonne LINAC.

I. S Parameter Measurements

Using a network analyzer, we measured S_{11} at the four electrode ports: downstream upper, upstream upper, downstream lower, upstream lower, where the beam flows from upstream to downstream. Our results are shown in Figs. 1-1 to 1-4. We would like S_{11} to be greater than 20 dB at each frequency, which would be less than 1% reflected power. However, we found several troublesome data around 10dB in the 1-2 GHz range. We should try to improve this during the electrode production.

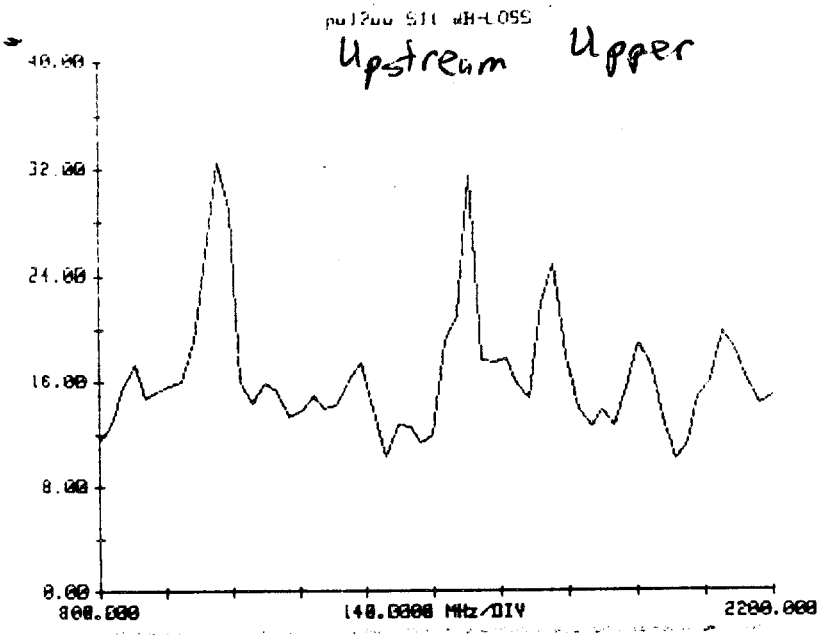
FIG. 1-1



1-2 ghz pu - downstream upper

FREQUENCY	RETURN LOSS-IN S11	
MHZ	DB	ANG
800.0000	27.79	-37.5
825.0000	19.31	-68.2
850.0000	17.73	-108.5
875.0000	18.76	-169.1
900.0000	20.14	61.3
925.0000	22.16	-85.6
950.0000	26.88	-172.4
975.0000	29.60	48.9
1000.0000	24.11	-32.8
1025.0000	22.35	-84.8
1050.0000	21.50	-123.8
1075.0000	22.44	171.0
1100.0000	30.73	40.2
1125.0000	26.43	-135.3
1150.0000	26.04	150.4
1175.0000	23.91	106.4
1200.0000	21.79	48.8
1225.0000	20.12	-44.4
1250.0000	23.55	149.4
1275.0000	22.37	42.3
1300.0000	22.69	-2.2
1325.0000	21.61	-13.8
1350.0000	21.50	-63.9
1375.0000	42.93	-73.4
1400.0000	14.58	-40.7
1425.0000	18.13	-89.9
1450.0000	19.47	-100.8
1475.0000	21.12	-113.2
1500.0000	22.10	-86.8
1525.0000	14.41	-110.9

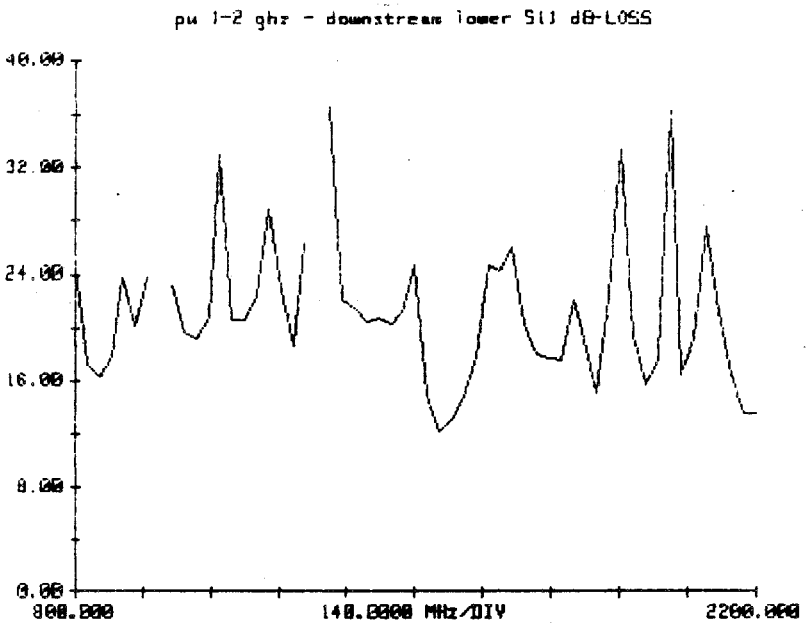
FIG. 1-2



pu12uu

FREQUENCY	RETURN LOSS-IN S11	
MHZ	DB	ANG
800.0000	11.38	-69.3
825.0000	12.72	-106.9
850.0000	15.69	-138.6
875.0000	17.32	158.6
900.0000	14.68	50.5
925.0000	15.21	-44.0
950.0000	15.67	-82.3
975.0000	16.03	-116.8
1000.0000	19.04	-157.1
1025.0000	25.65	-169.8
1050.0000	32.48	171.1
1075.0000	28.88	-4.3
1100.0000	15.78	-56.4
1125.0000	14.23	-116.5
1150.0000	15.75	-150.2
1175.0000	15.24	-178.7
1200.0000	13.20	133.5
1225.0000	13.71	41.8
1250.0000	14.87	-19.4
1275.0000	13.88	-79.8
1300.0000	14.13	-128.1
1325.0000	16.02	-171.8
1350.0000	17.31	155.4
1375.0000	13.62	92.7
1400.0000	10.18	-25.3
1425.0000	12.54	-90.0
1450.0000	12.52	-116.4
1475.0000	11.28	-147.0
1500.0000	11.78	168.7
1525.0000	18.87	141.8
1550.0000	20.84	135.2
1575.0000	31.45	-117.6

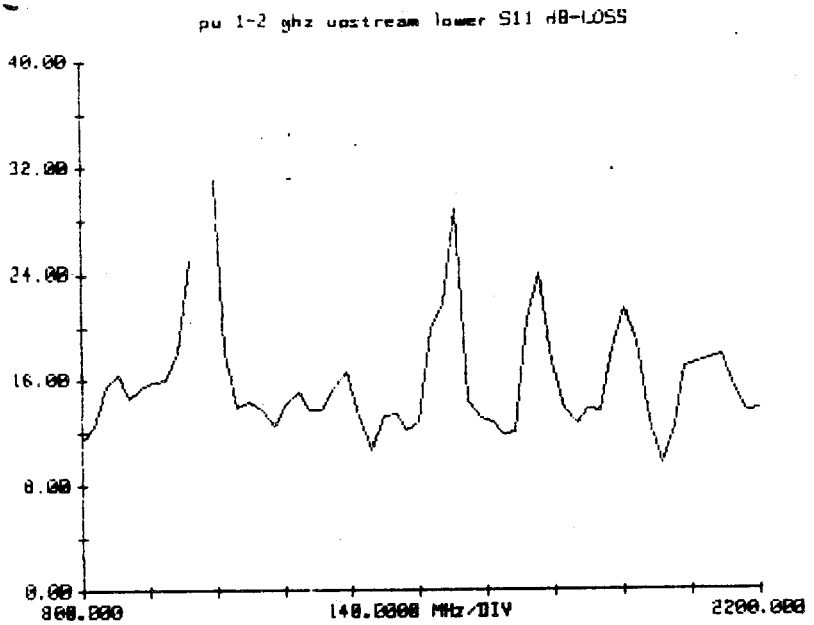
FIG. 1-3



pu 1-2 ghz - downstream lower

FREQUENCY	RETURN LOSS-IN S11	
MHZ	DB	ANG
800.0000	24.60	-52.7
825.0000	17.26	-74.4
850.0000	16.23	-109.9
875.0000	17.87	-156.7
900.0000	23.74	68.9
925.0000	20.14	-94.9
950.0000	23.81	-153.2
975.0000	48.01	56.6
1000.0000	23.16	-56.2
1025.0000	19.68	-96.5
1050.0000	19.22	-126.1
1075.0000	20.75	-159.6
1100.0000	32.90	-167.9
1125.0000	20.53	-126.2
1150.0000	20.49	-175.3
1175.0000	22.47	156.3
1200.0000	28.82	97.1
1225.0000	22.89	-85.2
1250.0000	18.51	174.1
1275.0000	26.39	107.4
1300.0000	43.40	-35.1
1325.0000	36.65	-64.8
1350.0000	22.12	-125.1
1375.0000	21.52	156.9
1400.0000	20.38	-56.9
1425.0000	20.79	-129.9
1450.0000	20.20	-145.1
1475.0000	21.24	-163.6
1500.0000	24.70	-145.2
1525.0000	14.87	-134.5
1550.0000	12.11	178.6
1575.0000	13.06	141.6
1600.0000	14.70	123.3
1625.0000	17.80	93.3

FIG. 1-4



pu 1-2 ghz upstream lower

FREQUENCY	RETURN LOSS-IN S11	
MHZ	DB	ANG
800.0000	11.32	-74.7
825.0000	12.41	-114.6
850.0000	15.49	-146.8
875.0000	16.39	153.1
900.0000	14.63	55.8
925.0000	15.37	-42.5
950.0000	15.79	-84.4
975.0000	16.00	-119.6
1000.0000	18.08	-160.9
1025.0000	24.99	159.4
1050.0000	40.50	-98.9
1075.0000	31.14	-54.1
1100.0000	18.11	-54.7
1125.0000	13.78	-109.3
1150.0000	14.24	-148.2
1175.0000	13.62	-180.0
1200.0000	12.52	130.8
1225.0000	14.13	47.1
1250.0000	15.01	-15.7
1275.0000	13.75	-82.5
1300,0000	13.66	-136.4
1325.0000	15.30	178.1
1350.0000	16.58	146.2
1375.0000	13.24	81.2
1400.0000	10.63	-36.3
1425.0000	13.28	-98.4
1450.0000	13.39	-122.8
1475.0000	12.15	-152.3
1500.0000	12.84	165.4
1525.0000	19.81	142.5
1550.0000	21.81	134.3
1575.0000	28.87	-60.4
1600.0000	14.28	-135.3
1625.0000	13.12	-177.0

II. Vacuum and Thermal Tests

We first tested the empty 18" (ID) x 64" (long) vacuum vessel (ie. without array). To the empty vacuum vessel we connected 1 turbo, 1 ion, and 3 sublimation pumps (Perkin-Elmer, Thermionics, Balzers) and pressure gauges.

After pumping for one day with the turbo pump we achieved 1.2×10^{-5} Torr at the pump and 6×10^{-5} Torr in the tank. During another half-day the pressures varied as follows:

TANK	TURBO
6×10^{-5} Torr	1.2×10^{-5} Torr
3×10^{-5}	5×10^{-6}
1.8×10^{-5}	2.8×10^{-6}
1.2×10^{-5}	2.2×10^{-6}.

To degas, the sublimation pumps were fired several times for 2 minute periods at current 50A. Before baking, the ion pump established a base pressure of 5×10^{-8} Torr. The prebake tank pressure with both ion and sublimation pumps reached 1.2×10^{-8} Torr.

The whole system was baked for 12 hours at 150°C. During bake, the turbo pressure was 2×10^{-6} Torr.

We found it convenient to degas the ion pump by turning on the sublimation pumps.

The system was cooled to room temperature and, after pumping with the ion pump, achieved a base pressure of 1.8×10^{-10} Torr. All 3 sublimation pumps were fired for 2 minutes at 50 A current. The pressure immediately rose to 1×10^{-8} Torr but eventually settled down at 4.5×10^{-11} Torr as shown in Fig. 2-1.

Next, we installed the 1-2 GHz Pickup Array and thermocouples. The system was roughed down overnight, and after pumping with the ion pumps, the pressure did not go below the

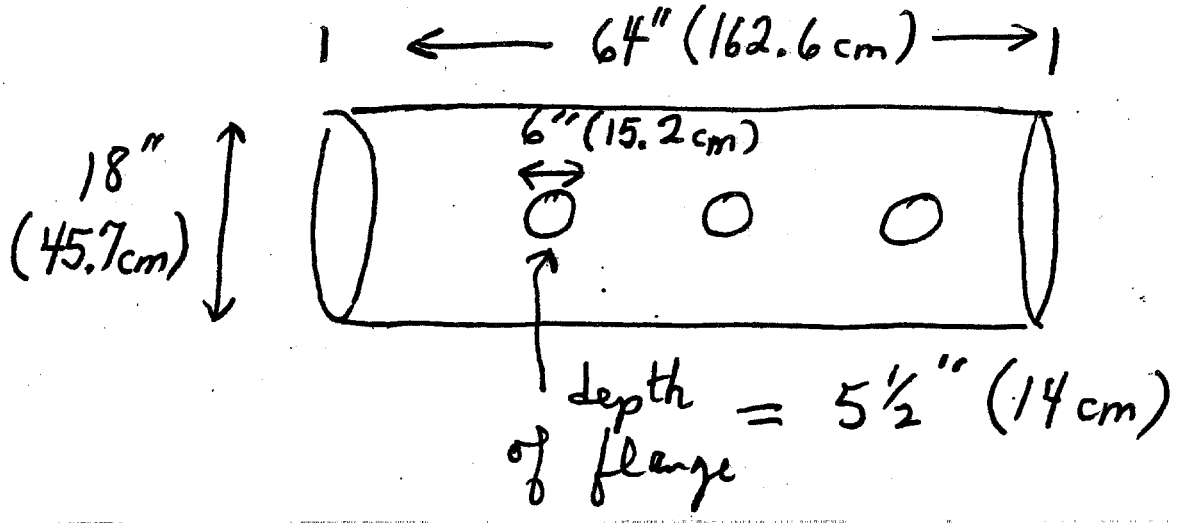
10^{-7} range (see Fig. 2-2). So we decided to go ahead and bake for 2 days. Some temperatures during bake were as follows:

TANK – 165°C
End flanges – 150°C
Ion Pump – 150°C
Array – 120°C.

The ion pump and sublimation pump filaments were degassed. After baking, the vacuum pressure was 1.2×10^{-5} Torr. With the ion pump we achieved 2.6×10^{-9} Torr (see Fig. 2-3). After firing all 3 sublimation pumps the pressure first increased to 6×10^{-7} Torr, but after 3 days and several firings of the sublimation pumps, the pressure reached

3.1×10^{-10} Torr, consistent with the design specification. This could only be improved by cooling.

We calculated the expected pumping speeds for the sublimation pumps. For an outline of a similar calculation, see $\bar{p}$ Note #294. For the present case we have a 16 loop pair array as opposed to the 32 loop pair considered in $\bar{p}$ Note #294. Also, at extremely low pressures (3×10^{-10} Torr), we assumed all pumping was done by the sublimation pumps. The vacuum vessel dimensions were



The capacitances (see p Note #294) were as follows:

	$C\ (l/s)$	$R\ (s/l)$
C_1	40.35	2.48×10^{-2}
C_2	62	1.61×10^{-2}
C_3	62	1.61×10^{-2}
C_4	40.35	2.48×10^{-2}
C_5	81	1.23×10^{-2}
C_6	81	1.23×10^{-2}
C_7	3327	3.01×10^{-4}
C_8	3351	2.98×10^{-4}

C_8 is the sum of the capacitances from the flanges of the sublimation pumps.

The gas loads were as follows:

V_1 & V_2 (see p Note #294)

Combiner Board	2.75×10^{-8} (Torr l/s)
Stainless Steel	1.22×10^{-8}
$i_2 = i_1 =$	3.97×10^{-8} Torr l/s

V_3

Resistors	$32 \times 5 \times 10^{-10} = 1.6 \times 10^{-8}$
Stainless Steel	4.68×10^{-8}
$i_3 =$	6.28×10^{-8} Torr l/s

V_4 & V_5

Pipe	4.67×10^{-8}
Array	4.29×10^{-8}
Wheels	6×10^{-9}
$i_4 = i_5 =$	9.56×10^{-8}

$$Q_{Total} = \sum_{j=1}^{5} i_j = 3.33 \times 10^{-7} \text{ Torr l/s}$$

Upon solving the electric circuit analogy, we get the following pressures (voltages V_i):

$$V_1 - V_6 = 6.84 \times 10^{-10} \text{ (Torr)}$$

$$V_2 - V_6 = 6.74 \times 10^{-10}$$

$$V_3 - V_6 = 4.08 \times 10^{-10}$$

$$V_4 - V_6 = 1.24 \times 10^{-10}$$

$$V_5 - V_6 = 9.94 \times 10^{-11}$$

But

$$V_4^{\text{measured}} = 3.1 \times 10^{-10} \text{ Torr}$$

so that

$$V_{\text{pump}} \equiv V_6 = 3.1 \times 10^{-10} - 1.24 \times 10^{-10}$$

$$= 1.86 \times 10^{-10} \text{ Torr}$$

Thus,

$$S_{\text{total}}^{\text{3 pumps}} = \frac{3.33 \times 10^{-7} \text{ Torr } \ell/s}{1.86 \times 10^{-10} \text{ Torr}} = 1790 \ \ell/s$$

And

$$S_{\substack{\text{each} \\ \text{pump}}} = 597 \text{ l/s}.$$

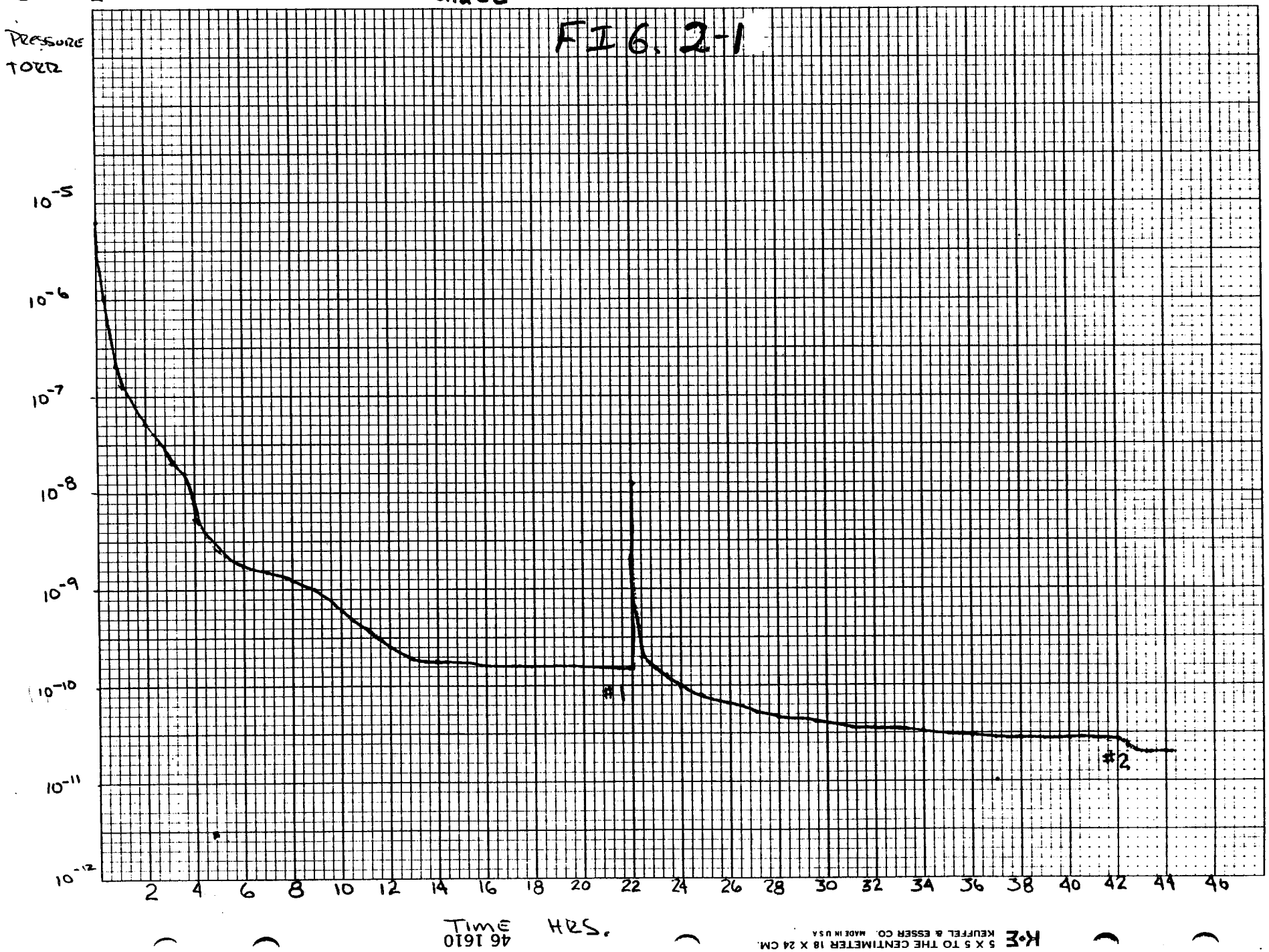
The effect of the ion pump would be to reduce this number slightly, so we estimate that each sublimation pump is pumping ~ 500 l/s.

#1 SUBLIMED All THREE PUMPS

#2 SHUT OFF PPA FILAMENT and 1 GAUGE

PUMP DOWN AFTER BAKE SYST. STILL 150°C AT 8×10^{-6} (AT START OF PLOT)

FIG. 2-1

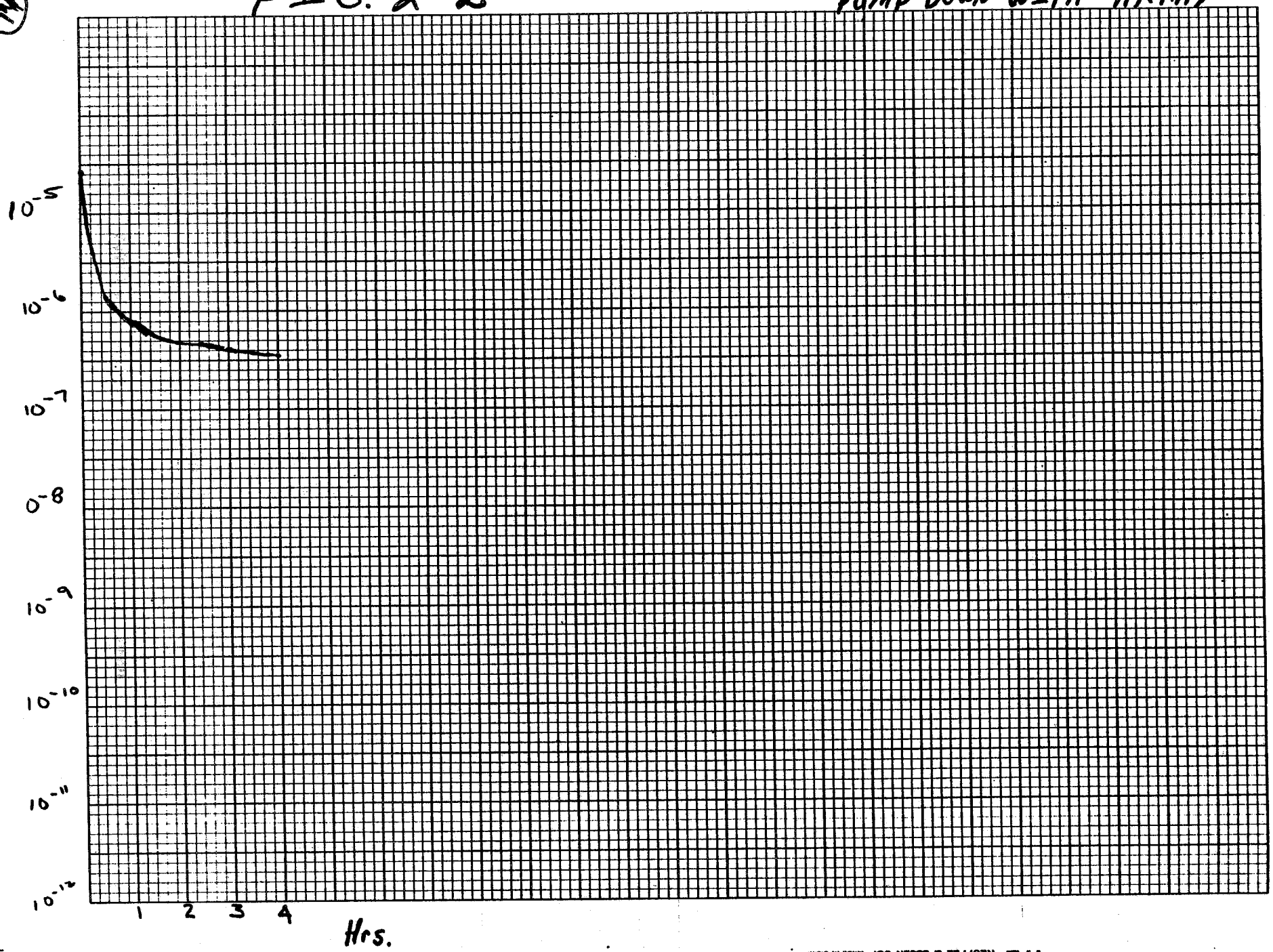


46 1610

K+E 5 X 5 TO THE CENTIMETER 18 X 24 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG. 2-2

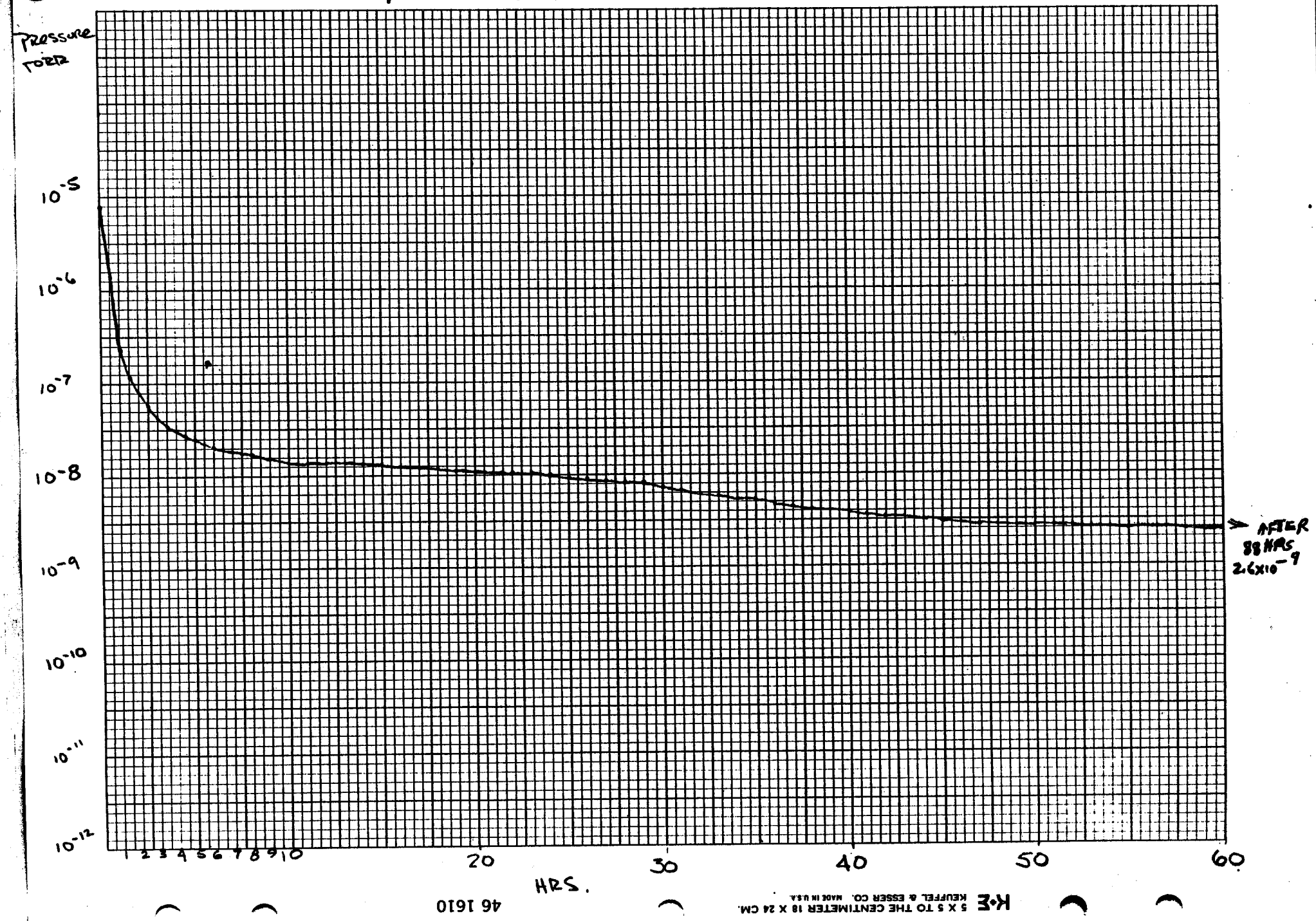
NO BAKE
PUMP DOWN WITH ARRAY



K&E 5 X 5 TO THE CENTIMETER 18 X 24 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1610

FIG. 2-3

Pump Down After Bake Left Up With Dry N_2 For 1 Hr. Then Re Pumped



K+E 5 X 5 TO THE CENTIMETER 18 X 24 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.
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III. Cryogenic Tests

A copper cryogenic shield was installed between the array and the vacuum vessel walls. Cooling tubes were soldered on and connected to liquid nitrogen (LN) dewars. Thermo-couple wires were secured by epoxy at various points throughout the system: electrodes, beam tube, shield, combiner board, etc. In Fig. 3-1, we show the temperature vs. time during bake-out of the system.

We then cooled the system with a liquid nitrogen flow rate of between 100 - 200 ft^3/hour. The shield, beam tube, and combiner board temperatures during cool-down are shown in Fig 3-2. The beam tube went down to -70°C.

We believe that this reading may not be accurate, but we should try to improve cooling tube contacts anyway to better achieve LN temperature.

Next, we pumped the system down to 3×10^{-10} Torr. Then we measured the resistor noise power at 78°K and compared it to that at 293°K. To do this the resistor output was connected to the input of an amplifier (MITEQ AFD 3-1020-3 #51313) from the stochastic cooling electronics lab and the amplifier output was sent to a spectrum analyzer. The amplifier was previously measured to have a room temperature noise figure

(NF) of 1.2 dB corresponding to $T_{AMP} = 92.3°K$, where

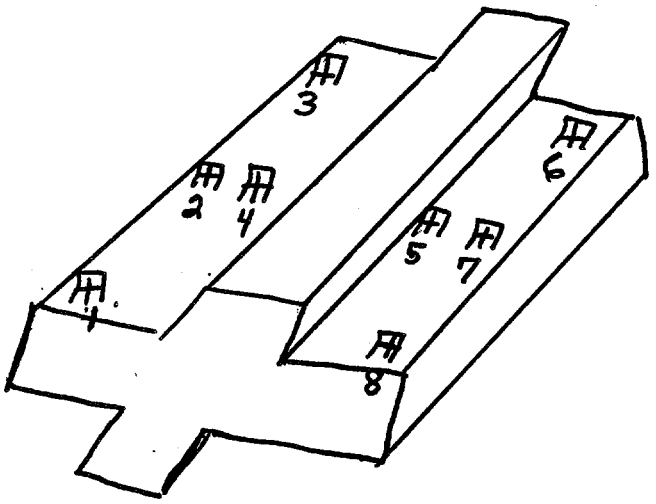
$$\frac{T_{AMP}}{290} = 10^{NF/10} - 1.$$

Thus, we would expect our measurement to give

$$Y = \frac{78° + 92.3°}{293° + 92.3°} = 0.44.$$

As shown in Fig. 3-3, we measure an average of 0.49, in fairly good agreement.

Next, surveyor's flags were positioned on the top (T) and bottom (B) beam tube surfaces as shown:

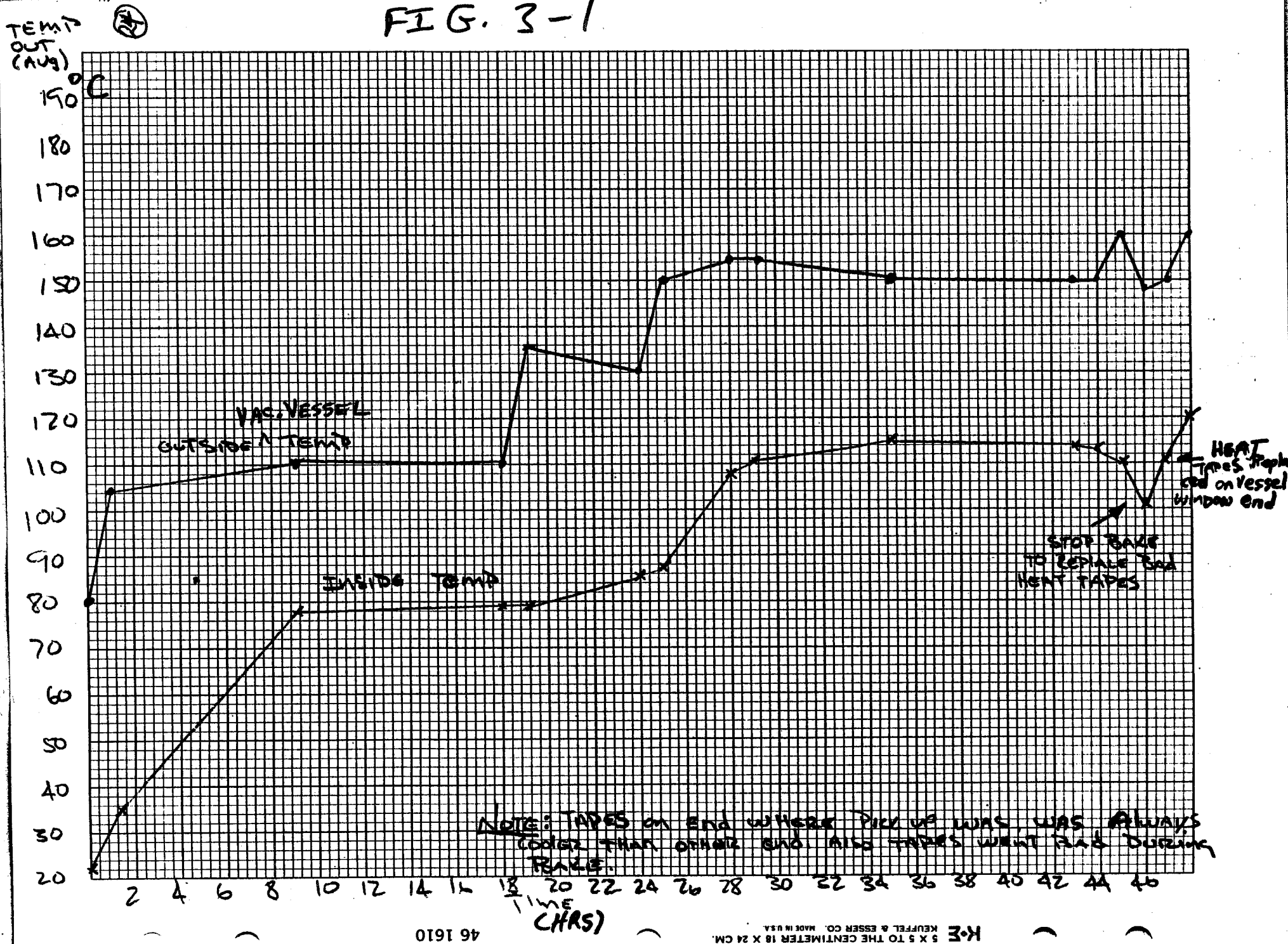


A reference datum was placed on the floor beneath the vacuum vessel. Surveyors measured the positions of the flags both at room temperature and after cooling according to Fig. 3-2. Horizontal relative distances before and after cooling are as follows:

Distance	Before (inches)	After (in.)	Δ(in.)
B1 – B8	6.860	6.855	−0.005
B2 – B4	3.141	3.143	−0.002
B5 – B7	1.672	1.669	−0.003
B4 – B5	3.894	3.891	−0.003
B3 – B6	9.641	9.645	+0.004
T1 – T8	6.846	6.842	−0.004
T2 – T4	2.964	2.964	0.000
T5 – T7	1.666	1.663	−0.003
T4 – T5	4.097	4.094	−0.003
T3 – T6	9.659	9.653	−0.006

Horizontal contractions were $\lesssim 0.005''$ while vertical contractions were $\lesssim 0.010''$. We did not see any serious distortions in the beam tube.

FIG. 3-1



K&E 5 X 5 TO THE CENTIMETER 18 X 24 CM.
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FIG. 3-2

(25)

K·E 5 X 5 TO THE CENTIMETER 18 X 24 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

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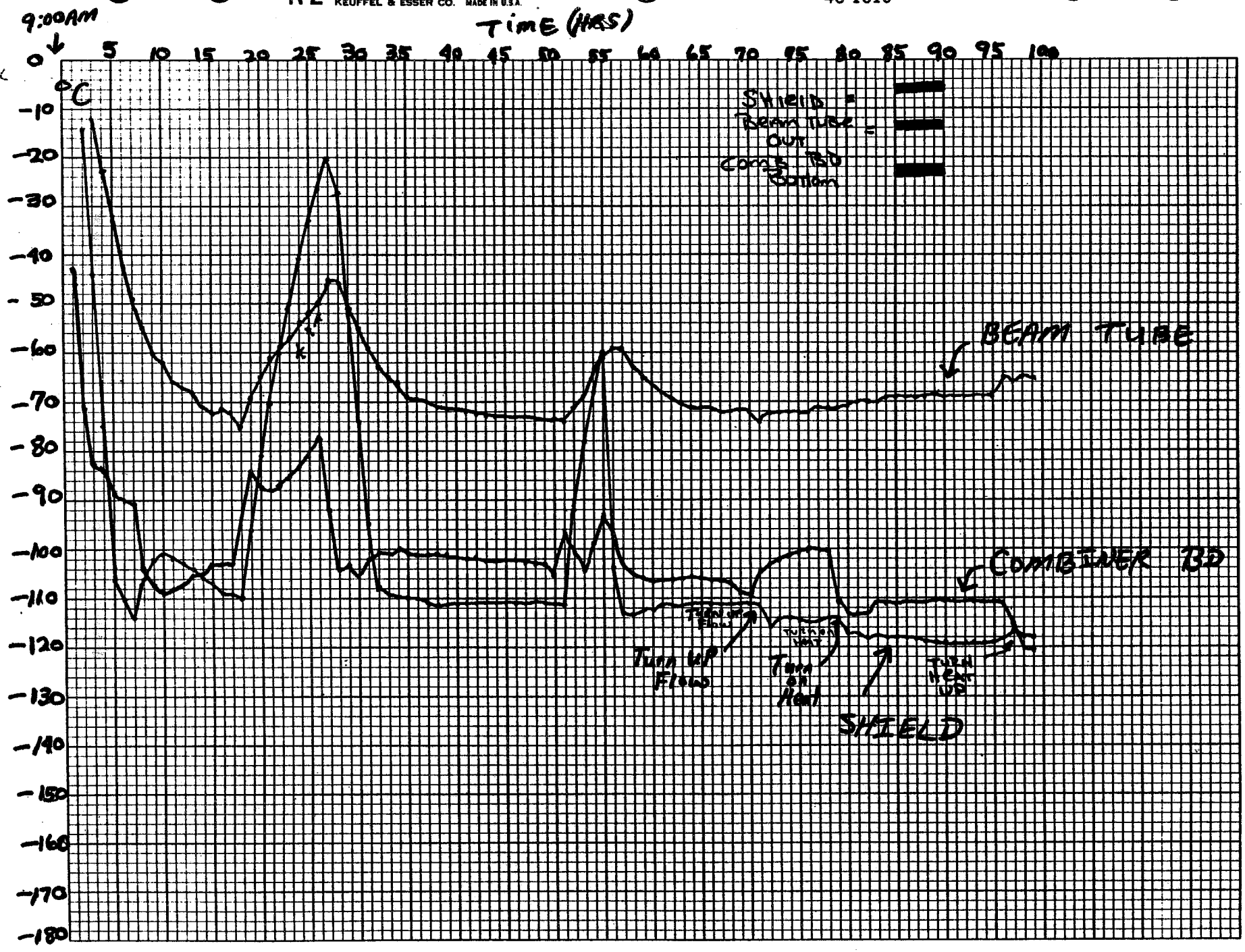
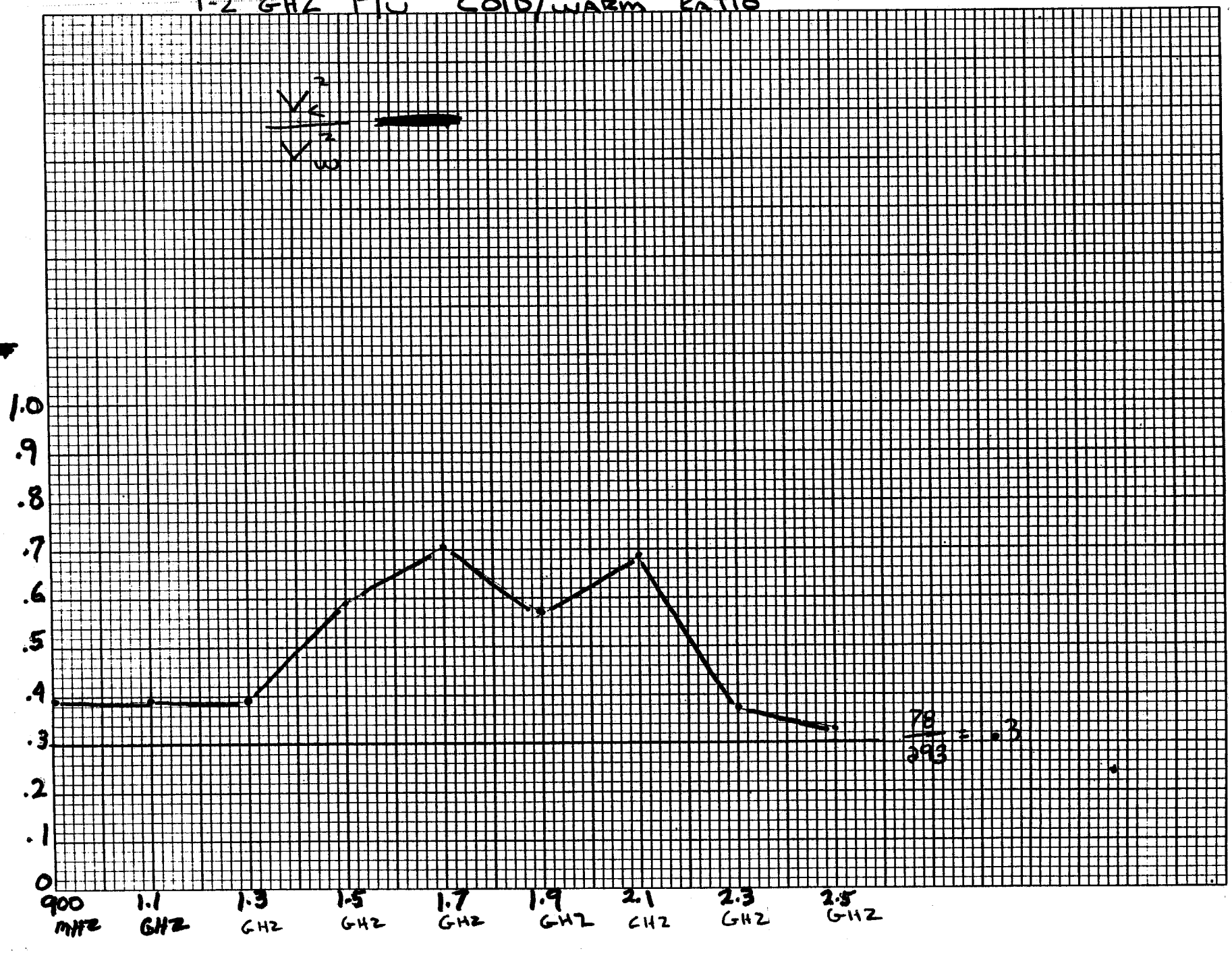


FIG 3-3

K·E 5 X 5 TO THE CENTIMETER 18 X 24 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1610

1-2 GHZ P/U COLD/WARM RATIO



IV. Array Operated as a Kicker

We operated the array as a kicker at various power levels. For these tests we cooled the array with chilled water. In the first test, we drove the array with 60 cycle AC power. Temperature and pressure curves are shown in Fig. 4-1. When driven with 5 watts (W) per resister the vacuum pressure degraded from 6×10^{-10} Torr to 9×10^{-10} Torr; however, the array had not yet reached thermal equilibrium and the vacuum pressure might have increased if we had run longer.

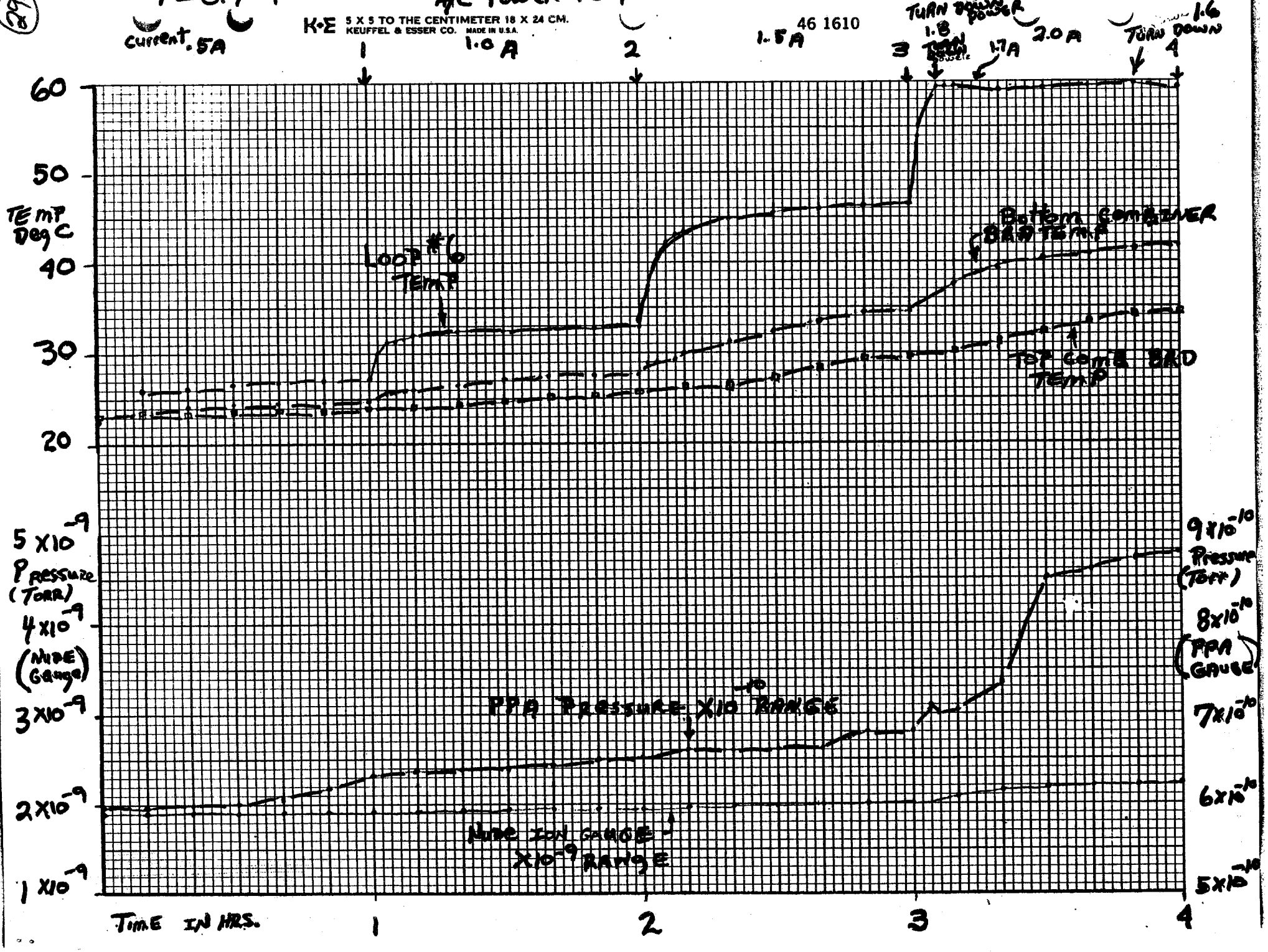
Next we drove half of the electrodes with traveling-wave-tube microwave power and the other half

with 60 cycle AC power. At 8 W/resistor, the pressure increased to 10^{-7} Torr as shown in Fig. 4-2, but came down in a few hours to approximately 2×10^{-9} Torr. More tests are needed.

FIG. 4-1

A/C POWER TEST

K+E 5 X 5 TO THE CENTIMETER 18 X 24 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1610



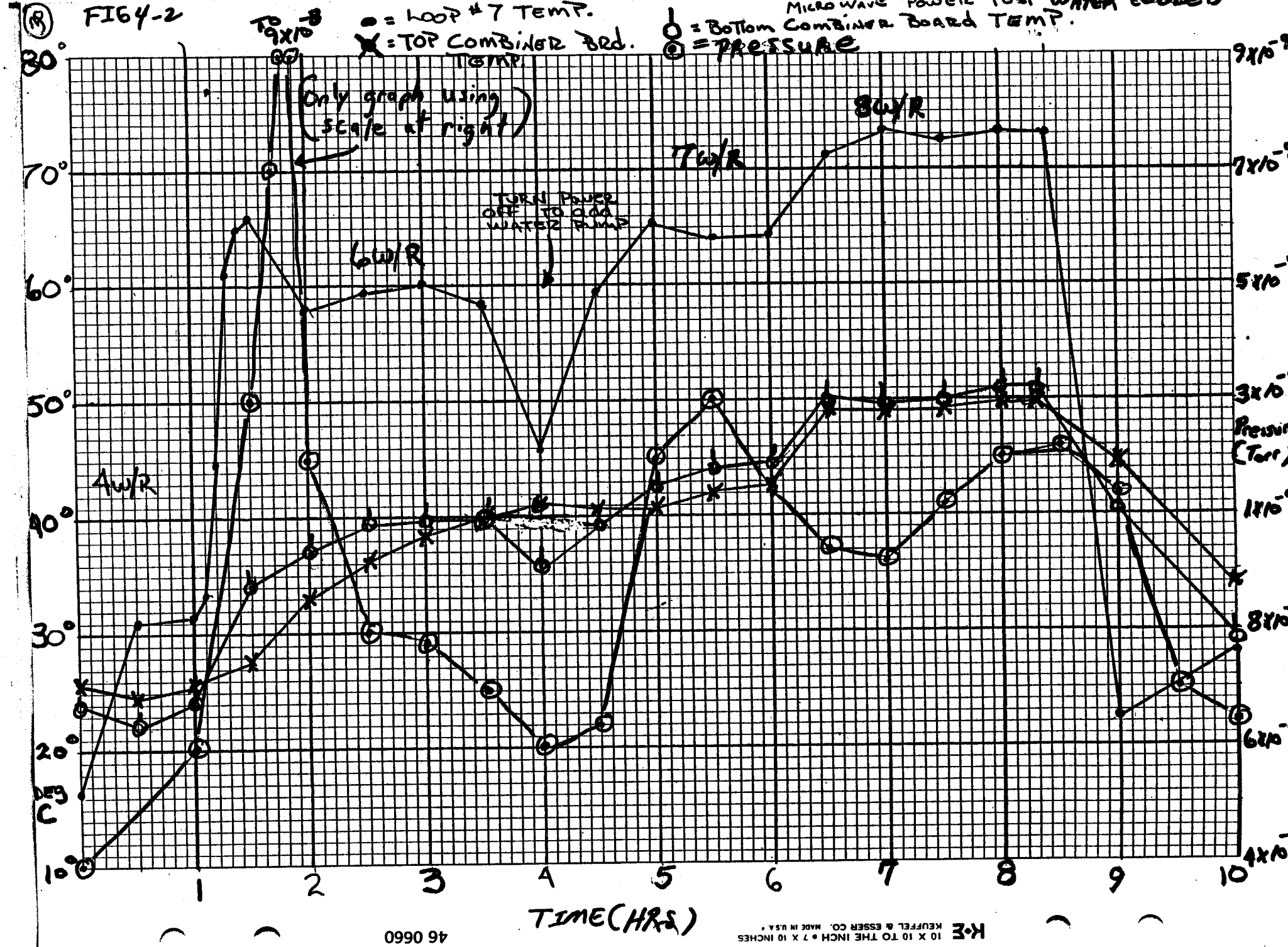


FIG 4-2
MICROWAVE POWER TEST WATER COOLED
● = LOOP #7 TEMP.
X = TOP COMBINER BRD. TEMP.
O = BOTTOM COMBINER BOARD TEMP.
⊙ = PRESSURE
TO 9x10^-8
(Only graph using scale at right)
TURN POWER OFF TO ADD WATER PUMP
4W/R
6W/R
7W/R
8W/R
80°
70°
60°
50°
40°
30°
20°
10°
DEG C
9x10^-9
7x10^-9
5x10^-9
3x10^-9
1x10^-9
8x10^-9
6x10^-9
4x10^-9
Pressure (Torr)
1
2
3
4
5
6
7
8
9
10
TIME (HRS)
46 0660
K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

V. Array Operated as a Pickup

To study the performance of the array as a pickup, we measured its coupling impedance $Z_{\substack{Sum \\ MODE}}$ at Argonne's 20 MeV electron LINAC. The results from the FNAL array and those from a similar LBL array are shown in Figs. 5-1 and 5-2. For the FNAL array, the 8 upstream and 8 downstream electrodes were measured separately, but the data are quite consistent as shown in Fig. 5-1. Note that the $Z \propto \sqrt{\#\text{ of loop pairs}}$ so that the 8 loop pair FNAL data has been adjusted upward to compare with the 16 loop pair LBL data. Fig. 5-3

shows that all the FNAL and LBL data are consistent with each other and are in good agreement with the theoretical curve.

* * * *

To conclude, in none of the above tests did we feel the array behaved terribly; however, more tests are recommended to gain more confidence in ~~its~~ performance.

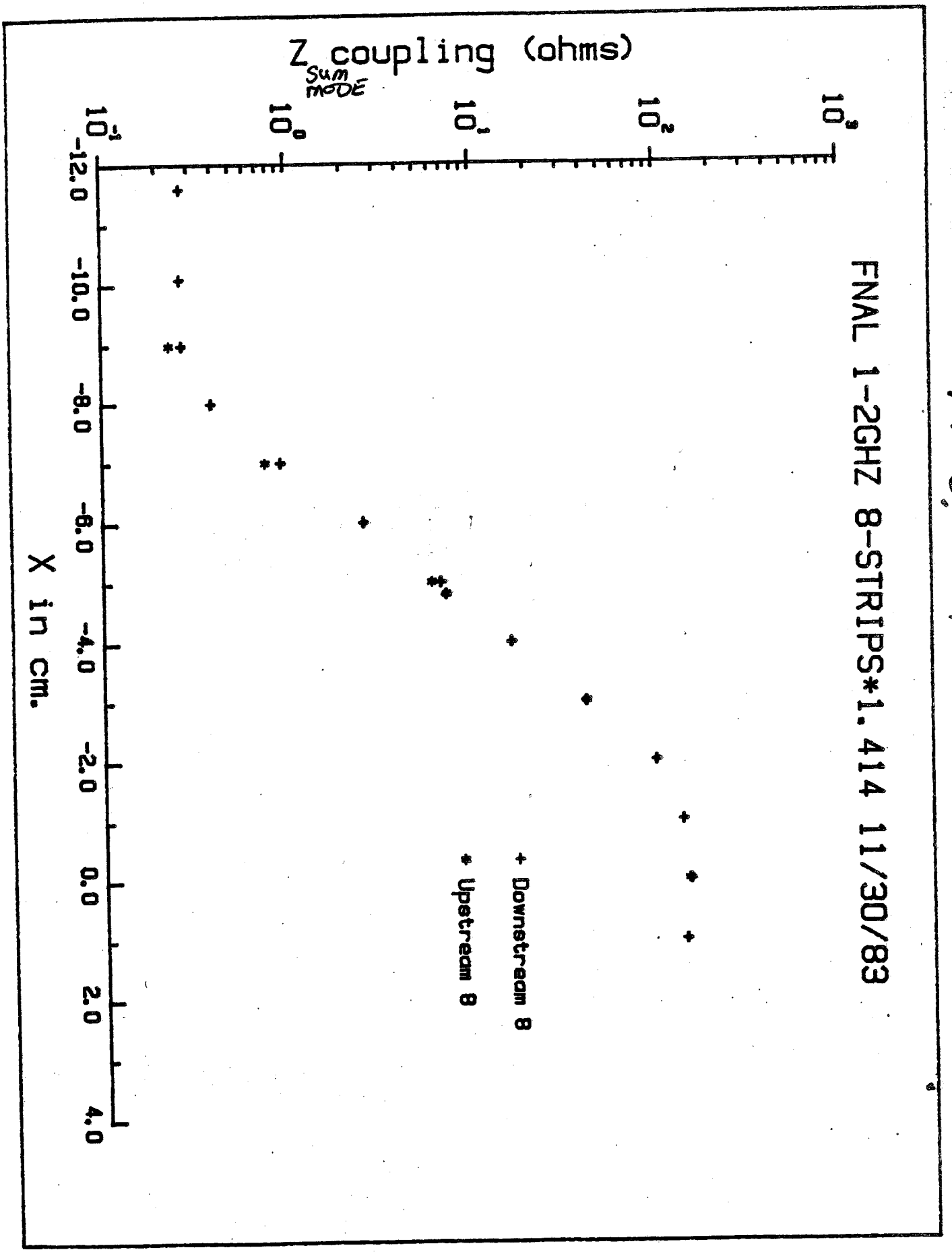

Z coupling (ohms)
SUM MODE
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
-12.0
-10.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
X in cm.
FNAL 1-2GHZ 8-STRIPS*1.414 11/30/83
+ Downstream 8
* Upstream 8

FIG. 5-1

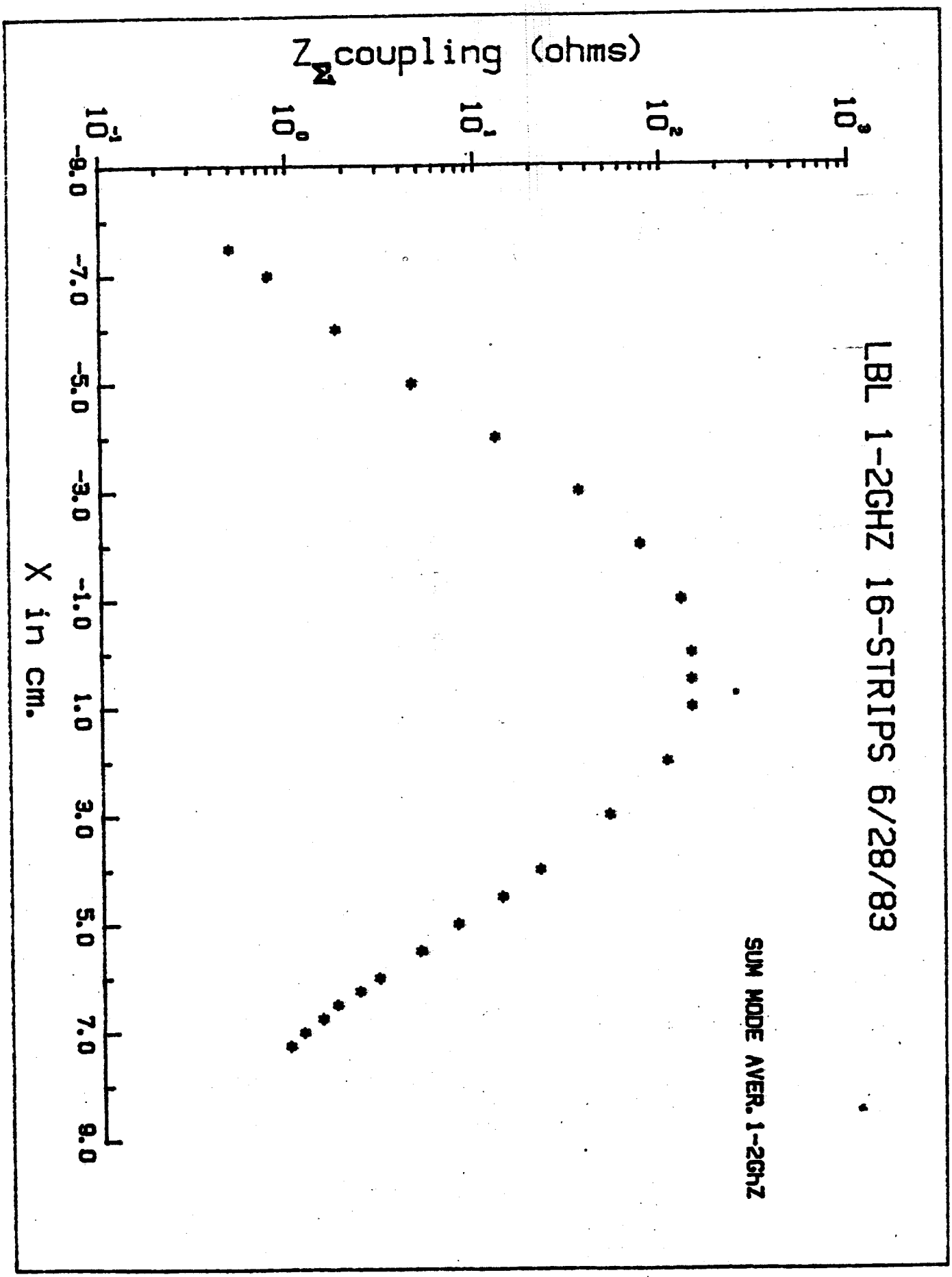
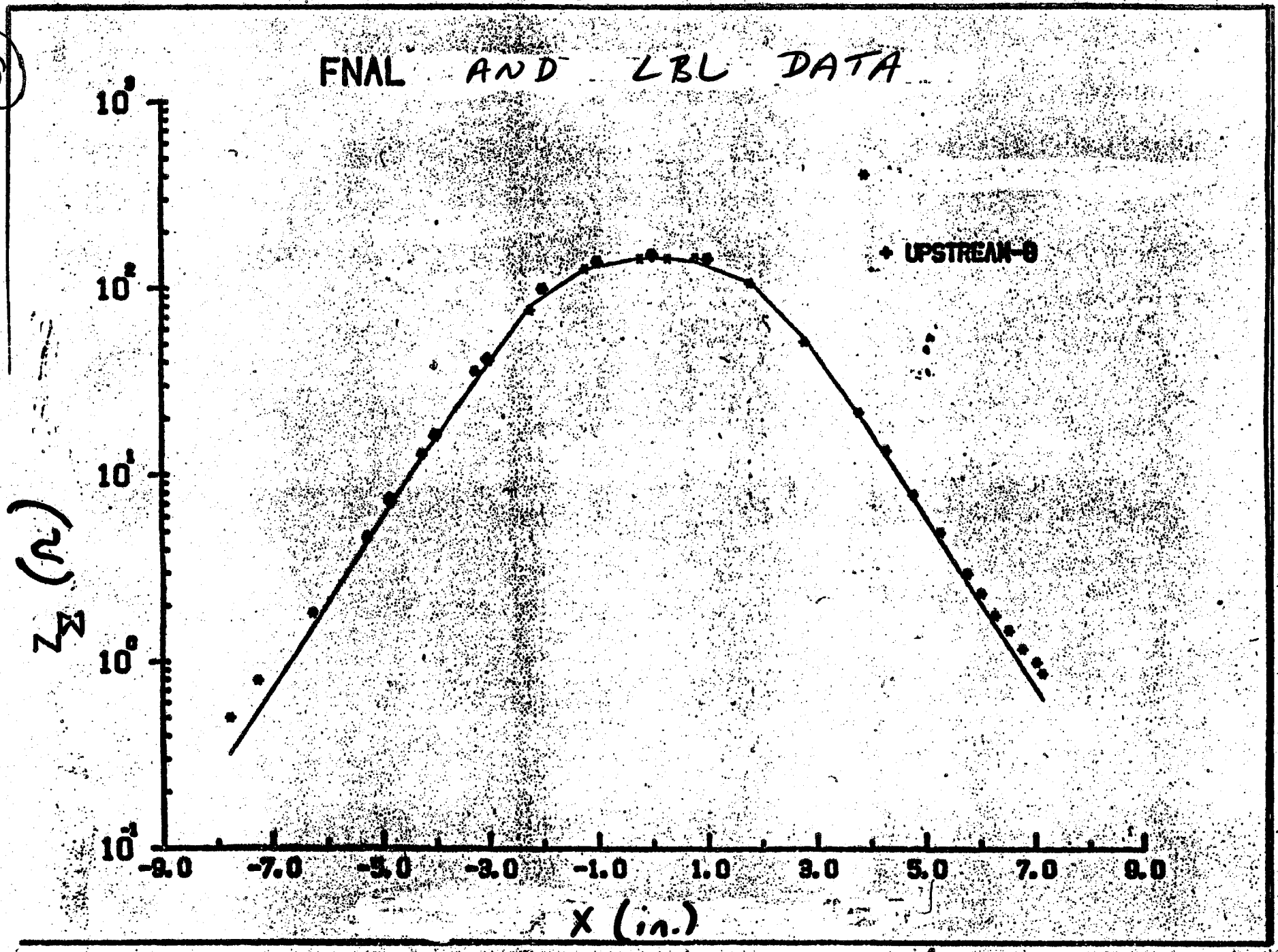

Z_Σ coupling (ohms)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
X in cm.
LBL 1-2GHZ 16-STRIPS 6/28/83
SUM MODE AVER. 1-2GhZ

FIG. 5-2

FIG 5-3


FNAL AND LBL DATA
UPSTREAM-B
10^3
10^2
10^1
10^0
Z_Σ (Ω)
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
X (in.)