NASA CR-145137

FINAL TECHNICAL REPORT

MONITORING AIR POLLUTION FROM SATELLITES (MAPS)

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APPENDICES

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CONTENTS

APPENDIX A

DESIGN ANALYSIS REPORT, SIGNAL PROCESSING CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides design analysis documentation for the signal processing circuitry of the MAPS breadboard electronics.

2.0 CIRCUIT REQUIREMENTS

The signal processing circuit implementation is per the block diagram, figure 1 with the individual block requirements as delineated below:

2.1 Input Buffers

Each of 3 composite scene and balance reference signals from the sensor head shall be received via a shielded twisted pair with a differential buffer stage.

- Buffer gain = 0.5 ± 2%
- Dynamic range = ± 10 volts
- $(S_1 + R_1)$ and $(S_3 + R_3)$ buffer shall be non-inverting and the $(S_2 + R_2)$ buffer shall be inverting.

2.2 AGC Attenuators

Per the block diagram, 2 analog multipliers shall be used as AGC attenuators to control the gain over a range of ± 25% around unity gain. The gain control voltage is the ± 10 volt output of the AGC control integrator.

The transfer function shall be:

$$e_o/e_{in} = 1 + K_{ATT} V_C$$

where V_c = AGC integrator control voltage

K_{ATT} = Attenuator scaling constant

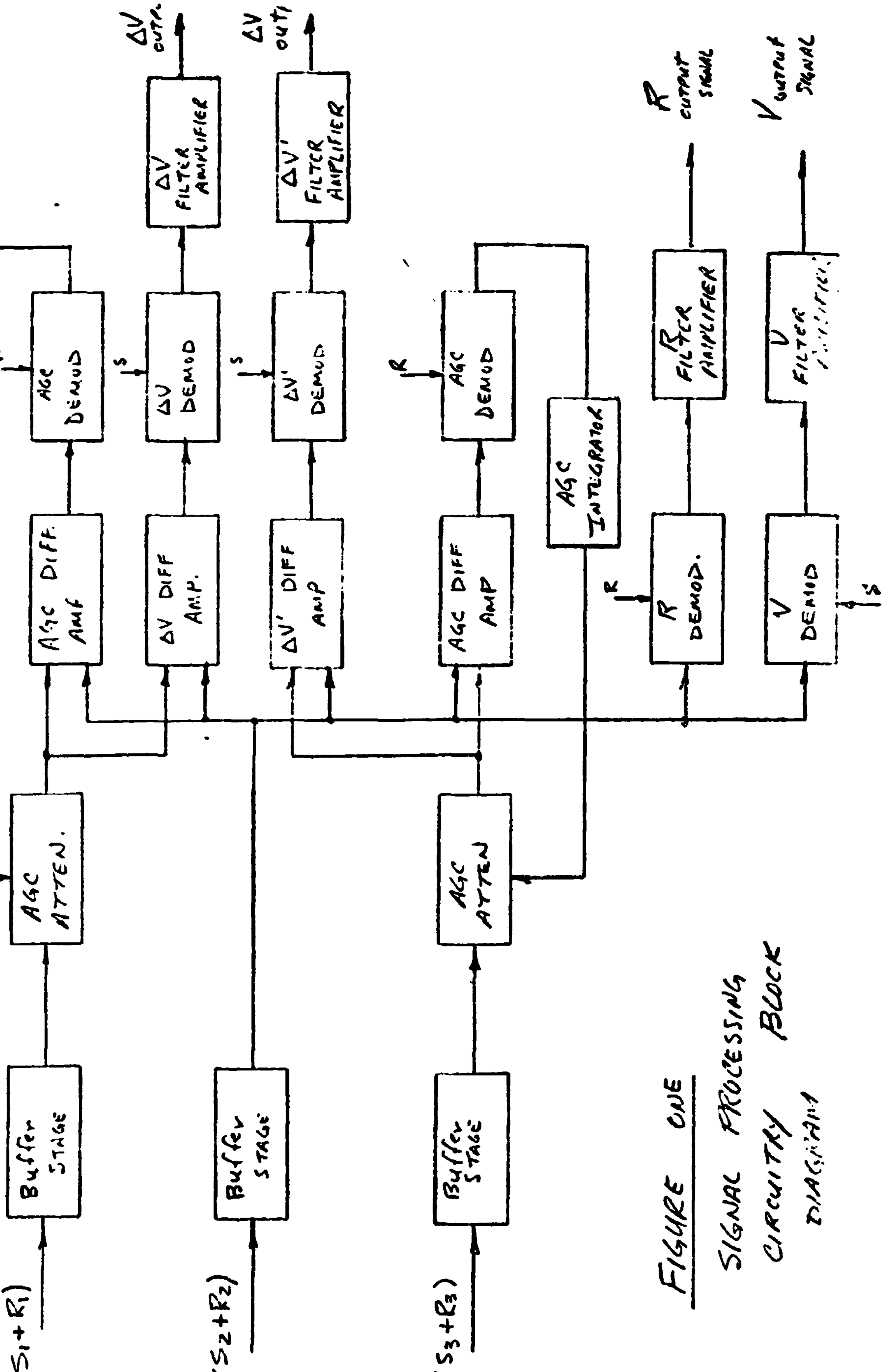

FIGURE ONE
SIGNAL PROCESSING BLOCK
CIRCUITRY
DIAGRAM

2.3 AGC Loop Scaling

The AGC loops shall have a difference amplifier, a R timed synchronous demodulator and an op-amp integrator. The total AGC loop gain and integrator time constant shall be such that the AGC loop time constant is 20 seconds when the R component of the buffer amplifier input signal is one volt peak to peak.

2.4 R Output Signal Scaling

The R component of the $(S_2 + R_2)$ signal shall be demodulated, amplified and filtered as the R output signal. Gain scaling shall be such that the d.c. output is 2.5 volts per volt peak to peak square wave input to the $(S_2 + R_2)$ buffer stage.

The output shall be filtered by an amplifier having 2 single order lags at 0.2Hz.

2.5 V Output Signal Scaling

The S component of the $(S_2 + R_2)$ signal shall be demodulated, amplified and filtered as the V output signal. Gain scaling shall be such that the dc output is 1.0 volts dc per volt peak to peak square wave input to the $(S_2 + R_2)$ buffer stage.

The output shall be filtered by 2 single order lags at 0.2 Hz.

2.6 ΔV and $\Delta V'$ Signal Scaling

The difference in the gain adjusted S_1 and S_2 signal components shall be obtained, demodulated, amplified and filtered as the ΔV output signal. The difference in the gain adjusted S_3 and S_2 signals provides the $\Delta V'$ output.

The gain scaling for each signal shall be such that the dc output is 22.5 volts dc per volt peak to peak signal difference referred to the buffer amplifier inputs.

The outputs shall be filtered by 2 single order lags at 0.2 Hz

3.0 CIRCUIT DESCRIPTION AND ANALYSIS RESULTS

Each of the individual circuits is described briefly below. The attached circuit analyses provide an assessment of circuit performance. The circuits are also shown on sketch schematics SK-MAPS-BB-102 and 103.

3.1 Input Buffer Stages

This stage consists of a HA2-2700 operational amplifier with a gain of ± 0.5 depending upon which input is used as the high side.

The feedback resistance is shunted with a selectable rolloff capacitor which is used to adjust the phase delays between the S_2 and S_1 or S_3 channel.

3.2 AGC Attenuator Stages

The AGC attenuation function is implemented with an integrated circuit analog multiplier. (Analog Devices AD 530L).

The AGC control input is fed both a +10 volt reference voltage and the output of the AGC integrator stage through a resistive summing network. Hence the nominal gain with no AGC integrator voltage is unity.

3.3 Difference Amplifier Stages

Each of the four differencing amplifiers uses a low power Harris HA2-2700 IC operational amplifier.

The AGC loop balance signal difference gain is 10. The ΔV and $\Delta V'$ signal difference gain is 15.

Small (0-50 ohn) selectable series resistors in the ΔV and $\Delta V'$ stage input circuits are used to match these difference circuits to the AGC balance loop. Resistor values are selected in test to provide a maximum reduction in the effect of the V signal upon the ΔV and $\Delta V'$ outputs.

3.4 Demodulator

All six of the signal processing demodulator circuits employ an identical circuit Topology.

The gain of a LM108A op-amp is switched between ± 1 by a DG129 FET switch integrated circuit which is driven from the appropriate drive reference signal (S or R). Pages 5 thru 8 of analysis attachment A review the demodulator performance characteristics.

3.5 AGC Loop Integrators

Each of the 2 AGC balance loops utilize an operational amplifier type RC integrator.

The operational amplifier consists of a 2N5196 dual FET stage followed by a LM108A IC op-amp.

The RC integration time constant is set by a 845K resistor and a 2.2 μfd mylar feedback capacitor.

Analysis pages 9 thru 13 cover the AGC integrator performance.

3.6 Output Filter Amplifiers

Each of the output filter amplifiers uses a LM108A IC op-amp in an active filter circuit to provide two single order lags at 0.2 Hz while providing the necessary gain.

Analysis pages, 14 thru 25, provide a complete performance analysis of the R, V, ΔV, and ΔV' output filter amplifier performance.

3.7 OVERALL PERFORMANCE

The analysis results in attachment B show how an overall AGC loop time constant of 20 seconds is achieved and reviews the various output scale factors, offsets and scale factor stabilities.

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ATTACHMENT A - 25 PAGES

SIGNAL PROCESSING CIRCUITS

- INPUT Buffer
- AGC ATTENUATOR (ANALOG MULTIPLIER)
- Difference Amplifiers
- Demodulators
- AGC INTEGRATORS
- output FILTER Amplifiers

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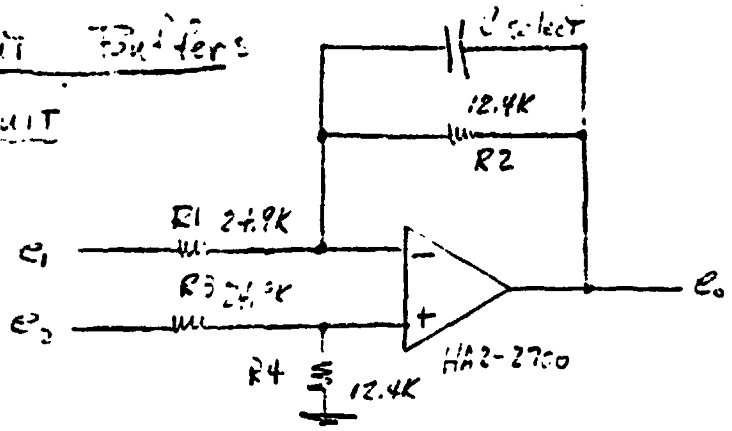
PROJECT A APS	SUBJECT SIGNAL PROCESSING CIRCUITS	DATE		OF

INPUT Buffers

CIRCUIT



$$\text{GAIN TO } e_1 = -\frac{R_2}{R_1} = -0.5$$

$$\text{GAIN TO } e_2 = \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right) = (1.5)\left(\frac{1}{3}\right) = +.5$$

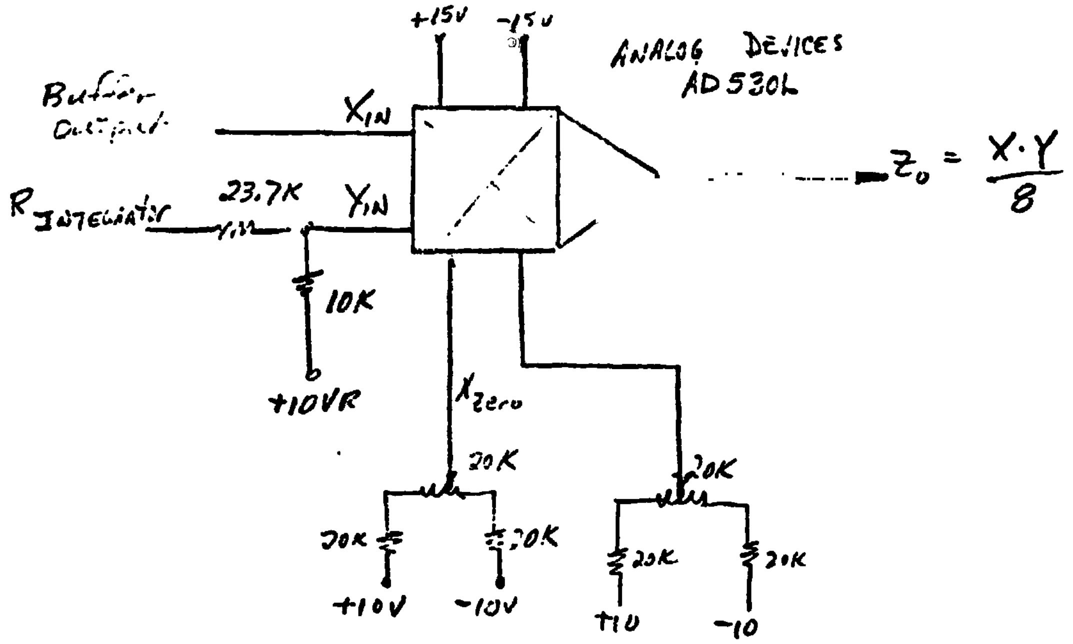
- For (S_1+R_1) AND (S_3+R_3) inputs, SIGNAL IS fed to NON-INVERTING input.
- For (S_2+R_2) input, SIGNAL is fed to inverting input.
- Response Rolloff CAPACITOR is Selectable To Adjust SIGNAL Phase delay.

  Typical VALUE = 100pf

  So $f_{Rolloff} = \dfrac{1590\times10^{-4}}{12.4K\times100\times10^{-12}} = 128Kc$

ANALOG MULTIPLIER — ATTENUATOR STAGE

1) Circuit



2) MAXIMUM X_{INPUT} = ±10V TO Buffer Amp
= ±5V To Multiplier.

3) GAIN CONTROL — Y_{INPUT} VOLTAGE:

- For Unity GAIN, Y_{INPUT} needs to be +3 Volts.
- For GAIN of 0.75, Y_{INPUT} needs to be +6 Volts.
- For GAIN of 1.25, Y_{INPUT} needs to be +10 Volts.

So Dynamic Range of AGC Integrator Voltage is found from:

$$Y_{IN} = \left(\frac{23.7}{33.7}\right)\cdot 10 + \left(\frac{10}{33.7}\right)\cdot V_{INT}$$

So

$$V_{INT} = \frac{33.7}{10}\left[Y_{IN} - \left(\frac{23.7}{33.7}\right)\cdot 10\right] = \left(\frac{33.7}{10}\right) Y_{IN} - 23.7$$

So The Required V_{INTEG} Range = −3.5V To +10V.

[illegible] AGC Integrator

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PROJECT [illegible]	SUBJECT Signal Processing Circuits	PREPARED BY: [illegible] DATE	ATTACHMENT	PAGE [illegible] OF

Analog Multiplier - AGC Attenuator Stage Cont.

3) output offset - dc voltage

Trimmed to zero initially

Varies 1mV/°C max per AD530L Spec Sheet

∴ over ±25°C Temp range, $e_{o_{dc}} = \pm 25\,mV$

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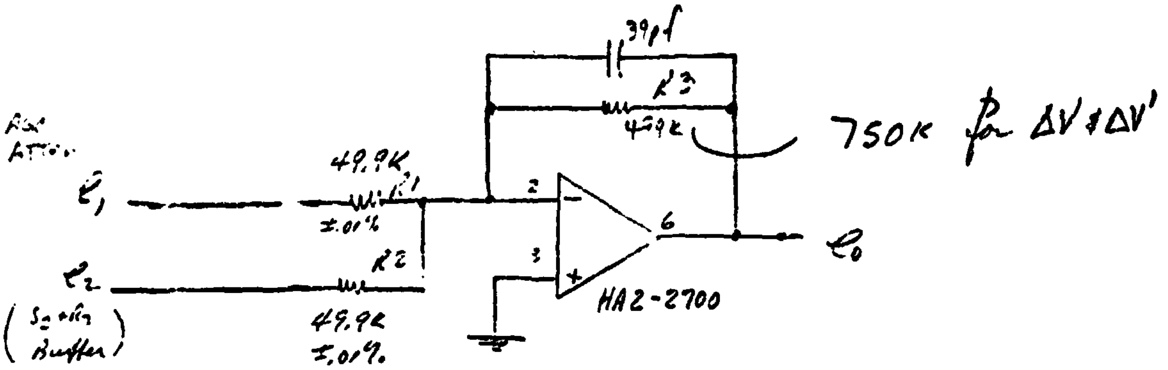
AGC & ΔV Difference Amplifiers



$$e_0 = -\frac{R_3}{R_1}e_1 - \frac{R_3}{R_2}e_2 = -R_3\left(\frac{e_1}{R_1} - \frac{e_2}{R_2}\right)$$

$$= -10(e_1 - e_2) \text{ for AGC}$$
$$= -15(e_1 - e_2) \text{ for } \Delta V \,\&\, \Delta V'$$

RATIO of R_1 TO R_2 DETERMINES DIFFERENCING ACCURACY.

Both are RBR 56L Resistors with .01% initial Tolerances.

ΔV & ΔV' Differencing is further trimmed with small (0-50Ω) Series Resistors for optimum initial balance

Average Temp Coeff. of Resistance = ±10ppm/°C

So Differencing Accuracy is:

$$= \pm.001\%/°C$$
$$= \pm\underline{.025\%} \text{ over } \pm25°C \text{ Temp Range}$$

High freq Rolloff ≅ 8.2kc

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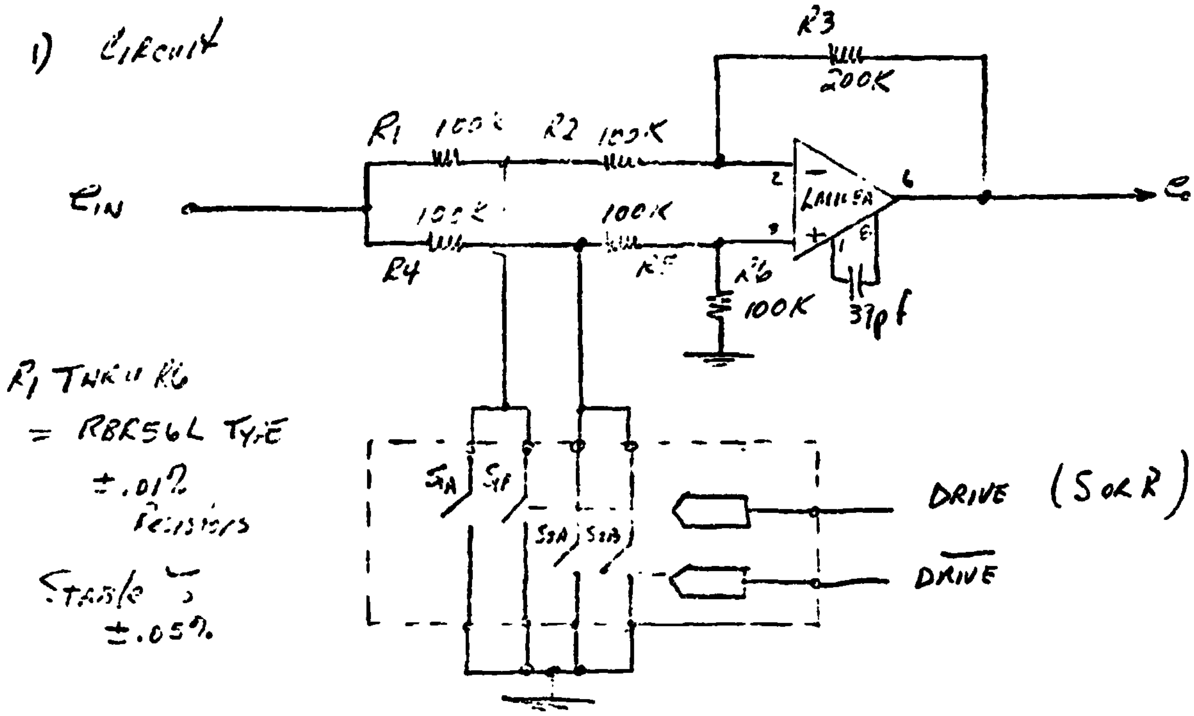
MAPS	Signal Processing Circuits	DKE DATE		5 OF

Full Wave Demodulator Circuit for V, R, ΔV, $\Delta V'$ and AGC ...

1) Circuit



R_1 THRU R_6
= RBR56L TYPE
±.01%
Resistors

Stable to
±.05%

Gain is alternately switched between +1 and −1

2) "IDEAL SWITCH" GAIN EQUATIONS:

for inverting case $S1$ is off, $S2$ is on

$$e_o/e_{IN} = \frac{-R_3}{R_1+R_2} = -1$$

For non-inverting case, S_1 on, $S2$ off
Then

$$e_o/e_{IN} = \left(1+\frac{R_3}{R_2}\right)\left(\frac{R_6}{R_4+R_5+R_6}\right) = (1+2)\left(\frac{1}{3}\right)$$
$$= +1$$

So a 1Vpp input will give +0,5V out.

DEMODULATORS CONTINUED

3) Effects of non-ideal switches

Two switches in Parallel

Assume: $\overline{R_{ON}} = \frac{50\Omega}{2} = 25\Omega$

$R_{off} = \frac{5V}{10nA} = 500\ \text{Megohm}$

So inverting GAIN IS:

$$\frac{e_0}{e_{IN}} = -\left(\frac{R_{off}}{R_1 + R_{off}}\right)\left(-\frac{R_3}{R_2 + R_1 \| R_{off}}\right) + \left(1 + \frac{R_3}{R_1 + R_2}\right)\left(\frac{R_6}{R_5 + R_6}\right)\left(\frac{R_{ON}}{R_4 + R_{ON}}\right)$$

$$= -(.9998)\left(\frac{200K}{100K + 100K}\right) + (2)(.5)\left(\frac{25}{100025}\right)$$

$$= -.9998 + .00025$$

$$= -.99955 \quad \text{or } -.045\% \text{ GAIN Change}$$

AND NON-INVERTING GAIN IS:

$$\frac{e_0}{e_{IN}} = -\left(\frac{R_3}{R_2}\right)\left(\frac{R_{ON}}{R_1 + R_{ON}}\right) + \left(1 + \frac{R3}{R_2}\right)\left(\frac{R_6}{R_5 + R_6 + R_4 \| R_{off}}\right)\left(\frac{R_{\ldots}}{R_{\ldots}}\right)$$

$$= -2\left(\frac{25}{100{,}025}\right) + (3)\left(\frac{1}{3}\right)\left(\frac{500\,Meg}{500M + .1Meg}\right)$$

$$= -4.99 \times 10^{-4} + .9998 = .9993 \quad \text{or } -.07\% \text{ GAIN Change}$$

Note That since the parameter change Effects both ± GAIN ONLY Differences in switch RESISTANCES CAUSE offset in output.

4) Effect of mis-matched Resistors

OVER Temperature & Environment $\frac{\Delta R}{R} = \pm .05\%$

for .01% initial tolerance

Effect on −GAIN:

$$\frac{\Delta G_-}{G_{-ss}} = \left[\pm\left(\frac{\Delta R_3}{R_3}\right)^2 \pm \left(\frac{R_1}{R_1+R_2}\right)^2\left(\frac{\Delta R_1}{R_1}\right)^2 + \left(\frac{R_2}{R_1+R_2}\right)^2\left(\frac{\Delta R_2}{R_2}\right)^2 \right]$$

$$= \left[\pm(.05)^2 \pm (.025)^2 \pm (.025)^2 \right]^{1/2} = \pm .06\%$$

Effect on +GAIN:

$$\frac{\Delta G_+}{G_{+ss}} = \left\{ \pm\left(\frac{R_3/R_2}{1+\frac{R_3}{R_2}}\right)^2\left(\frac{\Delta R_3}{R_3}\right)^2 \pm \left(\frac{R_3/R_2}{1+R_3/R_2}\right)^2\left(\frac{\Delta R_2}{R_2}\right)^2 \right.$$

$$\left. \pm\left(\frac{R_4+R_5}{R_4+R_5+R_6}\right)^2\left(\frac{\Delta R_6}{R_6}\right)^2 \pm \left(\frac{R_4}{R_4+R_5+R_6}\right)^2\left(\frac{\Delta R_4}{R_4}\right)^2 \pm \left(\frac{R_5}{R_4+R_5+R_6}\right)^2\left(\frac{\Delta R_5}{R_5}\right) \right]^{1/2}$$

$$\frac{\Delta G_+}{G_{+ss}} = \left\{ \pm(.033)^2 \pm (.133)^2 \pm (.033)^2 \pm(.0167)^2 \pm(.0167)^2 \right]^{1/2}$$

$$= \pm .06\%$$

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Demodulators Cont

Effective output offset

- Due To op-amp offsets
- Due to mismatched GAIN Response To dc input:

max. dc input = 15 × ±25mv = ± 375mv

15: diff Amp Gain

±25mv: multiplier offset

- LM108A $e_{os} = \pm .5mv$ $\Delta e_{os} = 5\mu v/°c$ = ±.65mv max

  $i_b = 3nA$ max $i_{os} = .4nA$

  $e_{os}\big|_{i_{os}} = .4nA \times 100K = .04mv$ insignificant.

- MAX output offset due to LM108A offset

  = .65mv × 3 = ±1.95mv MAX

  MAX VARIATION = (.15 + .04)(3) = ±.57mv

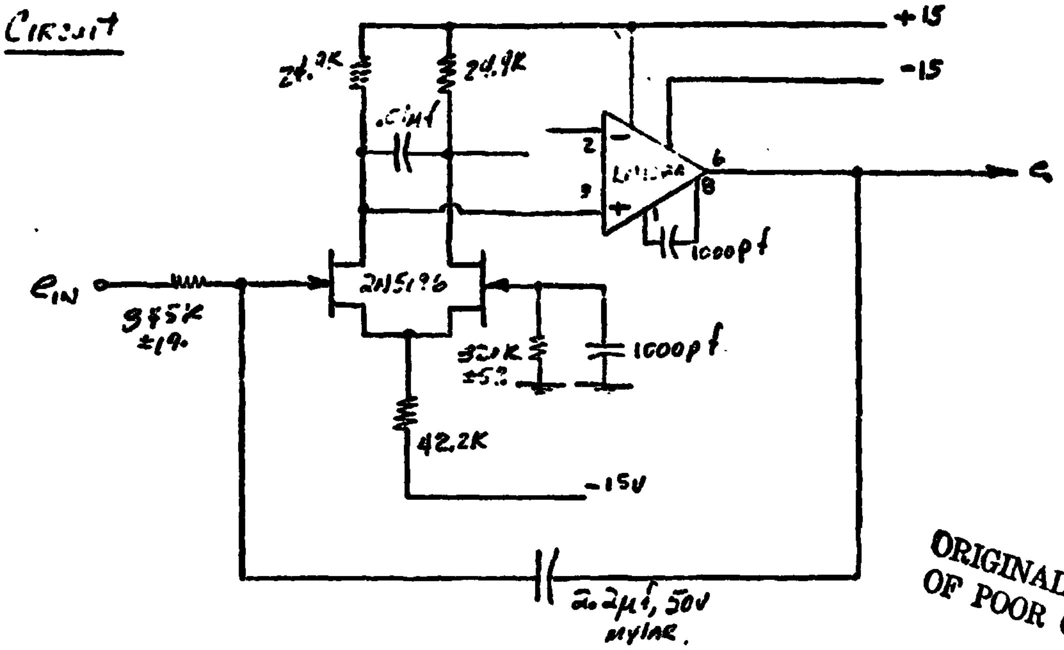
MIS-MATCHED GAIN RESPONSE To ± 375mv dc input IS: ±.06% × 3 × ±.375mv = ±0.68 mv

So TOTAL output offset VARIATION

$$rss = \left[(\pm.68mv)^2 + (\pm.57mv)^2\right]^{1/2} = \pm.\text{[illegible]}$$

AGC LOOP INTEGRATORS

1) CIRCUIT



2) FET BIASING —

a) For V_p of 2N5196 ≈ 2V, $V_{R_3} = 17V$

$I_{R_3} = .4ma$ ∴ I_D (each side) = 200μamps

b) $V_{drain} = V_{cc} - I_D R_1 = 15 - .2ma \times 24.9k = 10V$

c) Fet Stage GAIN ≈ $g_m R_L = 1000 \times 10^{-6} \times 25 \times 10^3$
$\doteq 25$

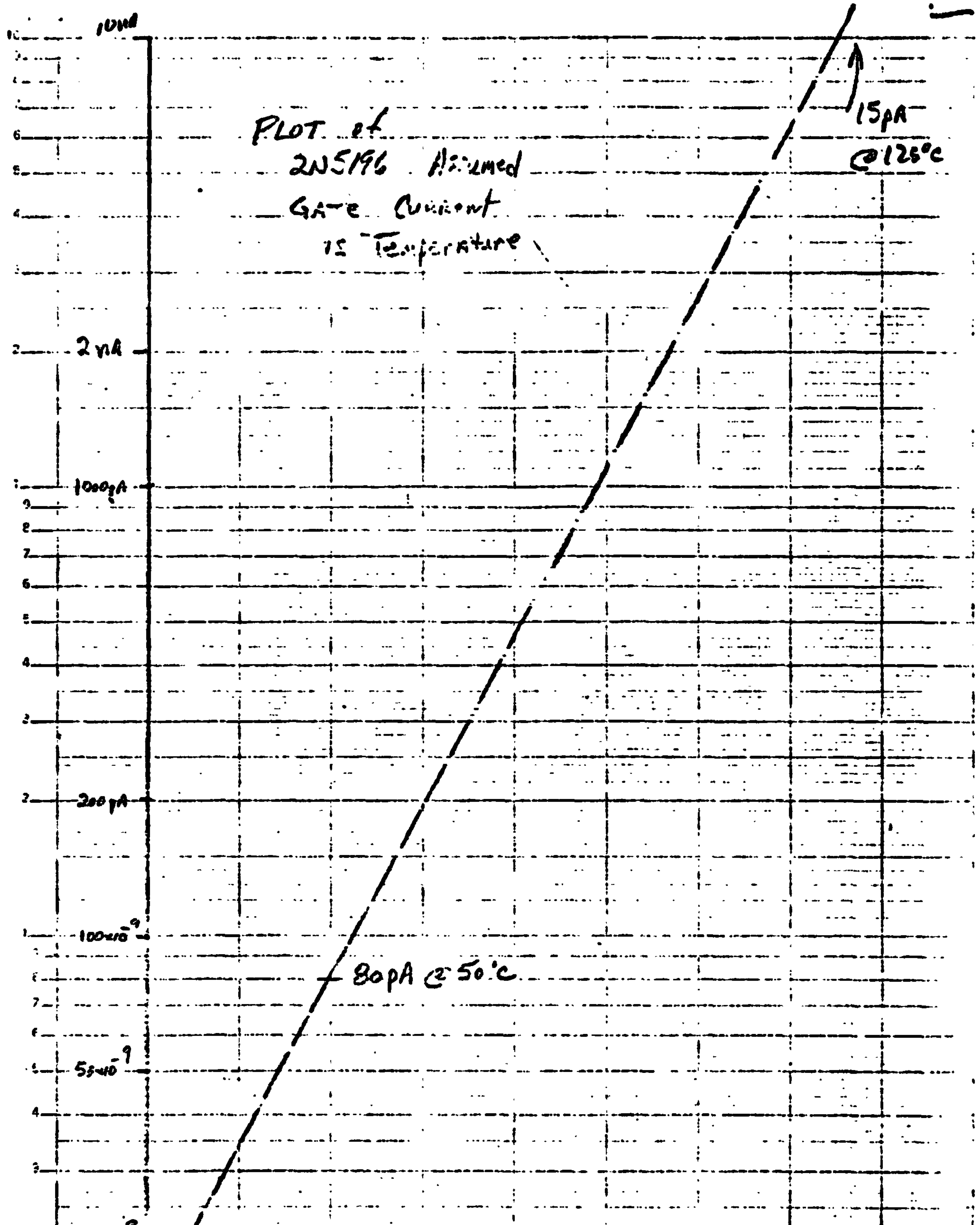
3) Input offsets — for 2N5196 dual fet

$\Delta V_{GS} = \pm 5mV$ $\frac{\Delta V_{GS}}{\Delta T} = \pm 5\mu V/°C$

$$\left.\begin{aligned} I_G &= 15pA @ 25°C \\ &= 15nA @ 125°C \end{aligned}\right\}$$ from this we get 80pf @ 50°c (See GRAPH PAGE 2)

we will assume

$|I_{GS_1} - I_{GS_2}| = \frac{1}{3} I_G = \underline{27pA}$


PLOT of
2N5196 Assumed
Gate Current
vs Temperature
10nA
2nA
1000pA
200pA
100×10^{-9}
55×10^{-9}
20×10^{-9}
15pA
@125°C
80pA @ 50°C
25
50
75
100
125
Temp °C

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AGC Integrators Continued

3) Therefore the fixed initial offsets are:

$$e_{os}\Big|_{rss} = \Big\{ \underbrace{(\pm 5mv)^2}_{e_{os}} + \underbrace{(80pA \times 649K)^2}_{I_G \times Z_{IN}} \Big\}^{1/2}$$

$$= \underline{\underline{5mv}}$$

Variations in input offset over ±25°C Temp Range

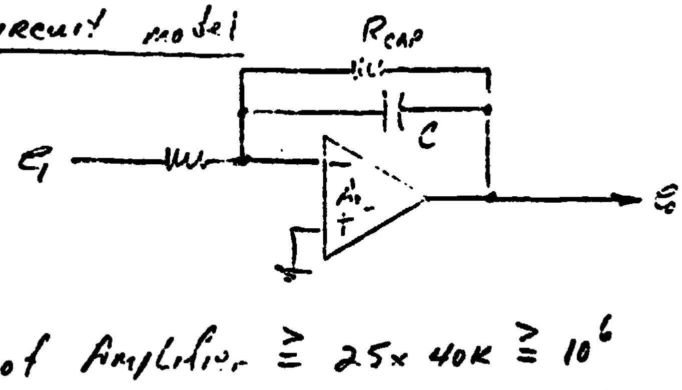
- Δe_{os} of fet $= 5\mu v/°c \times \pm 25°c = \pm .125mv$
- Δe_{os} due to I_{os}

$$= .65meg \times \pm 27pA = .02mv$$

$$rss\ Total = \left[(.125)^2 + (.02)^2\right]^{1/2} = \underline{\underline{\pm .127mv}}$$

4) Integrator Transfer Function

circuit model

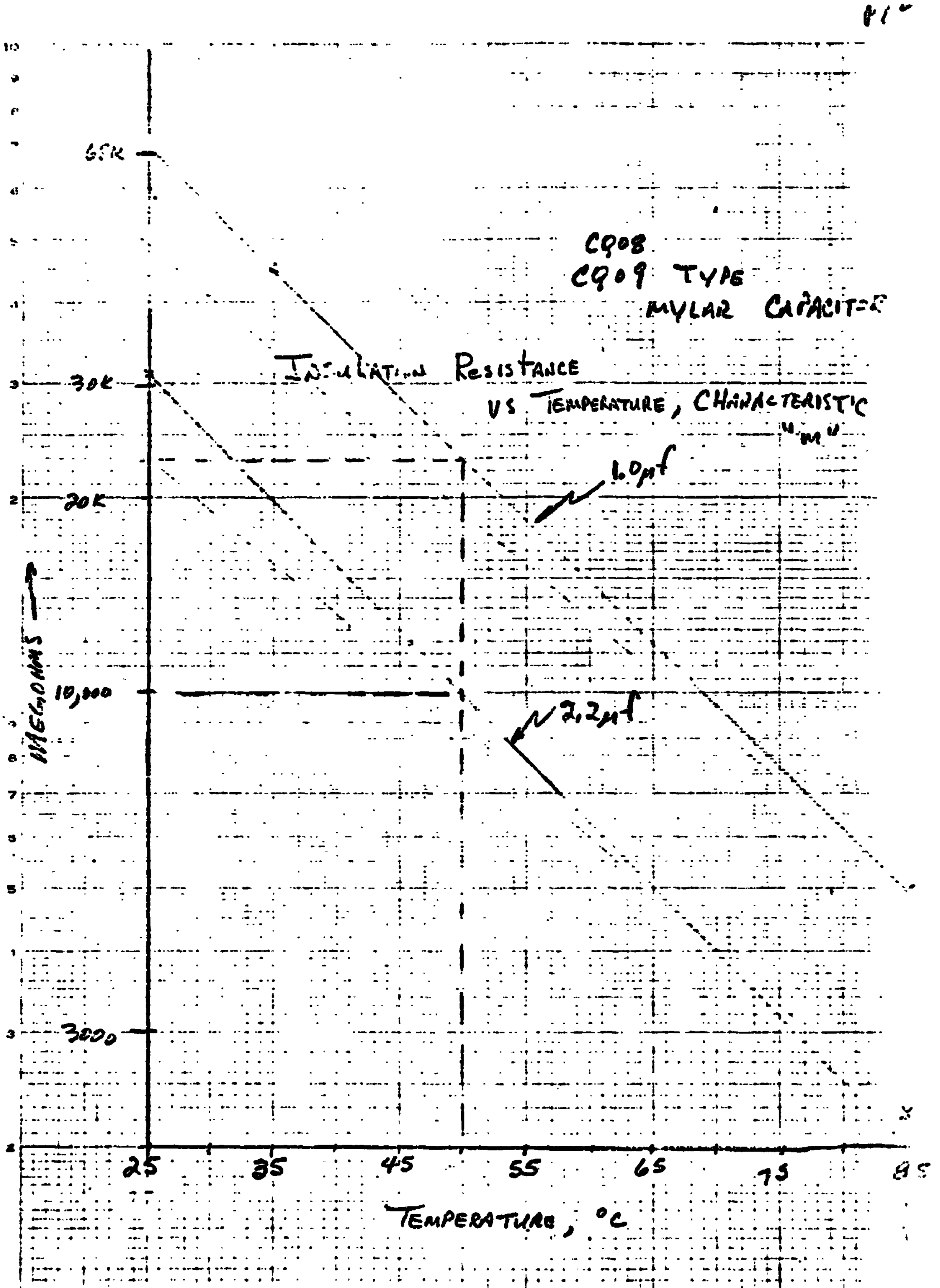


- A_{oL} of Amplifier $\geqq 25 \times 40K \geqq 10^6$
- Z_{IN} of Fet Stage $\geq \frac{10v}{80pA} \geq 10^4 meg$
- Mylar Cap Insulation Resistance (See graph)

  $\geqq$ 68Kmeg µf @ 25°c

  $\geq$ 5Kmeg µf @ 85°c

  Extrapolation gives $\geq$ 23Kmeg µf @ 50°c


CQ08
CQ09 TYPE
MYLAR CAPACITOR
INSULATION RESISTANCE
VS TEMPERATURE, CHARACTERISTIC "M"
1.0μf
2.2μf
65K
30K
20K
10,000
3000
MEGOHMS
25
35
45
55
65
75
85
TEMPERATURE, °C

A.S.C. Integrating Ckt.

4) Integrator Transfer Function Cont.

Mylar Cap Insulation Resistance Cont.

So 2.2μf feedback Capacitor

$IR \geq 30.9K\,\text{Meg} \;@\; 25°C$

$\geq 20.5K\,\text{meg} \;@\; 35°C$

$\geq 10.5K\,\text{meg} \;@\; 50°C$

So MAX. DC GAIN

$$= \frac{30.9K\text{meg}}{.85\text{meg}} = \underline{36k} \ll A_{OL} \text{ of } 10^6$$

AND $R_{IN} \gg R_1$

Therefore Transfer function Basically Determined by feedback Components AS

$$G(s) = \frac{R_c}{R_{IN}}\left(\frac{1}{sR_cC+1}\right) = \frac{1}{R_1C}\left(\frac{R_cC}{sR_cC+1}\right)$$

$$= \frac{1}{R_1C}\left(\frac{(R_c/R_1)(R_1C)}{s\left(\frac{R_c}{R_1}\right)R_1C+1}\right) = \frac{1}{\tau_1}\left(\frac{A_0\tau_1}{sA_0\tau_1+1}\right)$$

where: $A_0 = (R_c/R_1)$ & $\tau_1 = 1/R_1C$

minimum Value of A_0 is @ 50°C

$$A_0 = \frac{10.5K\text{meg}}{.85\text{Meg}} = \underline{\underline{12,350}}$$

and $\tau_1 = .845^{M} \times 2.2\mu f = \underline{1.86 \text{ seconds}}.$

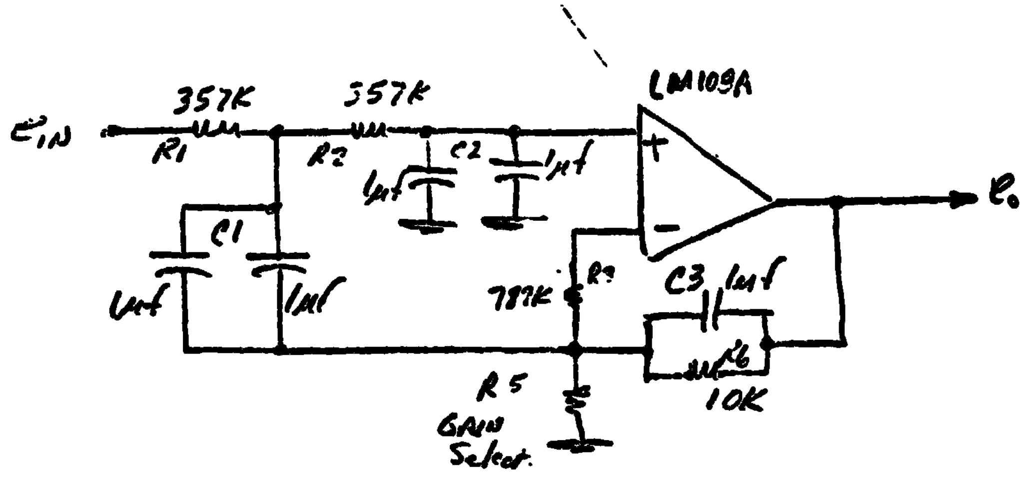
and $$\frac{\Delta\tau_1}{\tau_1} = \sqrt{(\pm 1\%)^2 + (\pm 1.5)^2} = \underline{\underline{\pm 1.63}}$$

OUTPUT FILTER AMPLIFIERS

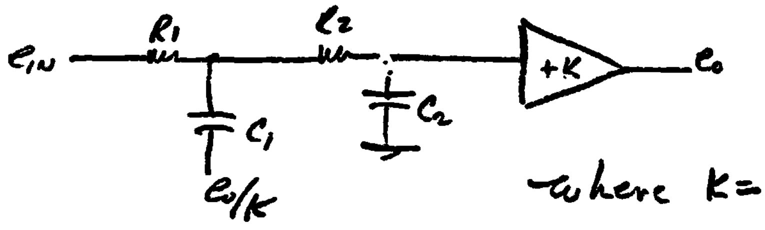
1) FUNCTION

GAIN SCALE & RIPPLE filter

2) General Topology



3) Approximate AC. Response Circuit·



where $K = \frac{R_5 + R_6}{R_5}$

THUS

$$e_o = K \left\{ \frac{(sR_1C_1e_o/k + e_1)}{sR_2C_2(sR_1C_1+1) + (sR_1C_1+1) + sR_1C_2} \right\}$$

Solving for e_o:

$$e_o = \frac{K e_1}{s^2R_1R_2C_1C_2 + sR_2C_2 + sR_1C_2 + 1} = \frac{Ke_1}{(sR_1C_1+1)(sR_2C_2+1)}$$

if $\underline{C_1 = C_2}$

ORIGINATOR

DATE

TITLE
OUTPUT FILTER
Amplifiers

APPROX. AC Response

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SK

SHEET 14 OF

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CHG LTR

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CHG LTR

SK

∴ FILTER ACTS AS A Double LAG with BREAK freq = $\frac{1}{2\pi R_1 C_1}$

with 357K & 2μf we get

$f = \underline{0.223 HZ}$ NOMINAL

Additional Capacitor C3 in Parallel with R6 Continues Roll off past 10HZ. See exact ANALYSIS.

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OF POOR QUALITY

ORIGINATOR [illegible]

DATE

MJO

TITLE Output Filter Amplifiers

Approx. AC Response

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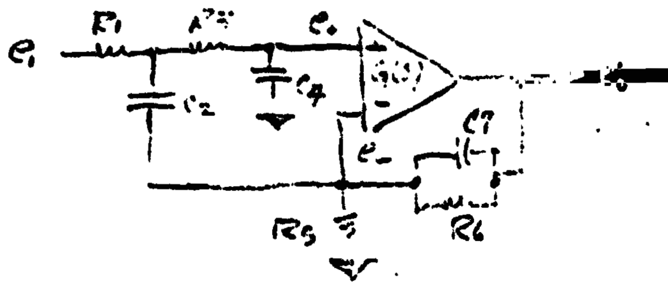
1. Circuit



$$e_0 = G(s)[e_+ - e_-]$$

1) Defining Variables for [illegible] Program

Let A0 = OP AMP GAIN = 3×10^5

A1 = R1

A2 = C2

A3 = R3

A4 = C4

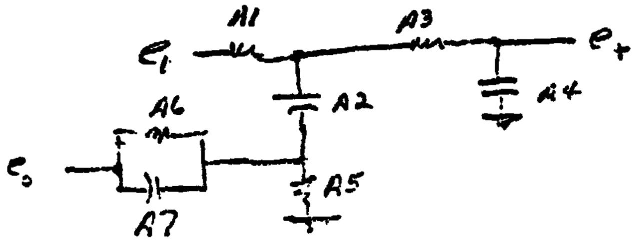
A5 = R5

A6 = R6

A7 = C7

A8 = T1 = OP-AMP Low freq Corner ≈ .15 Sec

2) Then At Non-inv. input we have:



Define Complex impedances

* 3001 Z1 = CMPLX(0, −1/(w*A2))

* 3002 Z2 = CMPLX(0, −1/w*A4)

* 3003 Z3 = CMPLX(0, −1/w*A7)

Then

* 3004 Z4 = A6*Z3/((A6+Z3)

ORIGINATOR AHS	DATE	TITLE Output Filter Amplifiers EXACT GAIN/frequency Response ANALYSIS	ENGINEERING SKETCH TRW ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
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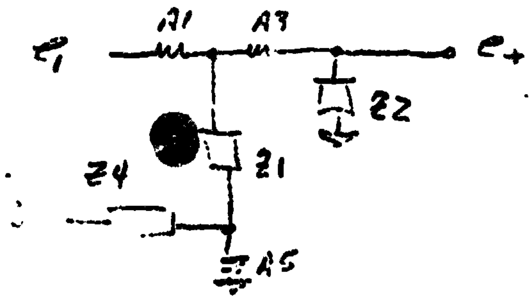
So AT NON-INV INPUT WE HAVE

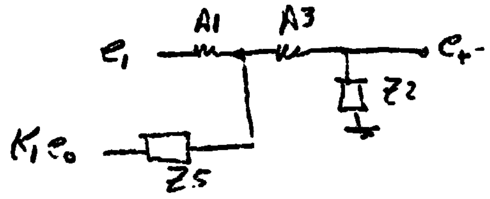


Define The following:

* 3005 $K1 = A5/(A5+Z4)$

* 3006 $Z5 = Z1 + Z4 * A5/(A5+Z4)$

THEN WE have:



So

$$e_+ = \frac{Z2}{Z2+A3+\frac{A_1 Z5}{A1+Z5}}\left[e_1 \times \frac{Z5}{A1+Z5} + \frac{K_1 e_0 \; A1}{Z5+A1}\right]$$

AGAIN WE define new VARIABLES AS follows

* 3010 $K_2 = (Z2 * Z5)/(Z5 * A1 + A1*(Z2+A3) + Z5*(Z2+A3))$

* 3015 $K_3 = (K_1 * Z2 * A1)/(Z2*(A1+Z5) + A3*(A1+Z5) + A1*Z5)$

THUS WE HAVE:

$$e_+ = K_2 e_1 + K_3 e_0$$

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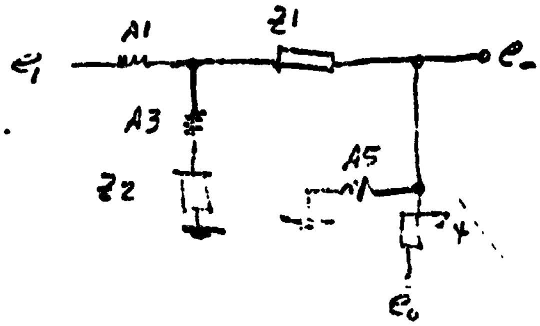
ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
PTE		OUTPUT FILTER AMPLIFIERS (EXACT AC RESPONSE)	TRW ONE SPACE PARK · REDONDO BEACH, CALIFORNIA
			SK
MJO MAPS BB			SHEET 17 OF

SK

CHG LTR

SYSTEMS 528 REV. 8-67

3) At the inverting input we have

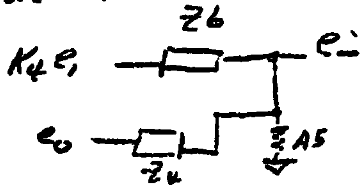


Define the following:

* 3020 Z6 = Z1 + A1*(A3+Z2)/((A1+A3+Z2)

* 3025 K4 = A3+Z2)/(A1+A3+Z2)

Then we have



So by Superposition:

$$e_- = \frac{K_4 e_1 (A5 \parallel Z4)}{(A5 \parallel Z4) + Z6} + \frac{e_0 * (A5 \parallel Z6)}{(A5 \parallel Z6) + Z4}$$

So define new constants

* 3030 K_5 = (K_4 * A5 * Z4)/(A5 * Z4 + Z6(A5 + Z4))

* 3035 K_6 = (A5 * Z6)/((A5 * Z6 + Z4 * (A5 + Z6))

Then

$$e_- = K_5 e_1 + K_6 e_0$$

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ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
A.H.F.E		Output filter Amplifiers (Exact AC Response)	TRW ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
			SK
MJO			SHEET [illegible] OF

4) AT output $e_0 = K_7(s)\left[e_+ - e_-\right]$

Define $K_7 = \dfrac{A_0}{\tau_1 S + 1}$ where A_0 = open loop gain

τ_1 = main pole of op-amp

So

```
* 3010   K7 = A0/(CMPLX(1, W*A8)
```

Substituting e_+ & e_- we have

$$e_0 = K_7\left[K_2 e_1 + K_3 e_0 - K_5 e_1 - K_6 e_0\right]$$

$$= K_7\left[(K_2 - K_5)e_1 + (K_3 - K_6)e_0\right]$$

OR:

$$e_0\left[1 + K_7(K_6 - K_3)\right] = K_7(K_2 - K_5)e_1$$

FINALLY

$$e_0/e_1 = \text{GAIN} = \frac{K_7(K_2 - K_5)}{1 + K_7(K_6 - K_3)}$$

So for PROGRAM

```
* 3200   X = K7*(K2-K5)/(1+ K7*(K6-K3))
```

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
		Output filter Amplifiers (Exact AC Response)	TRW ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
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SK

R5SWC1 Test Computer Program is Then:

```
LIST,FLTAMP

500 FOR F =.001,.01,.02,.05,.08,.1,.2,.4,.8,1,2,4,8,10,20,40
2000 DATA 225,2.75E3,2E-6,2.57E3,2E-6,1.1E3,1E4,1E-6,.159
2100 DATA 30,2,20,2,20,2,2,20,20
2200 DATA A0,A1,A2,A3,A4,A5,A6,A7,T1
2300 DATA "OUTPUT FILTER AMPLIFER"
3001 Z1=CMPLX(0,-1/(W*A2))
3002 Z2=CMPLX(0,-1/(W*A4))
3003 Z3=CMPLX(0,-1/(W*A7))
3004 Z4=A6*Z3/(A6+Z3)
3005 K1=A5/(A5+Z4)
3006 Z5=Z1+(Z4*A5)/(A5+Z4)
3010 K2=(Z2*Z5)/(Z5*A1+A1*(Z2+A3)+Z5*(Z2+A3))
3015 K3=(K1*Z2*A1)/(Z2*(A1+Z5)+A3*(A1+Z5)+A1*Z5)
3020 Z6=Z1+A1*(A3+Z2)/(A1+A3+Z2)
3025 K4=(A3+Z2)/(A1+A3+Z2)
3030 K5=(K4*A5*Z4)/(A5*Z4+Z6*(A5+Z4))
3035 K6=(A5*Z6)/(A5*Z6+Z4*(A5+Z6))
3040 K7=A0/CMPLX(1,W*A8)
3200 X=K7*(K2-K5)/(1+K7*(K6-K3))
```

where data on line 2000 is for the R output filter amplifier.

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ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
		Output Filter Amplifiers Exact AC Response	TRW SPACE PARK • REDONDO BEACH, CALIFORNIA
MJO			SK SHEET 20 OF

SK

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SYSTEMS 520 REV. 8-67

Balance Signal (R) Filter Amp. Run

```
  FREQ            GAIN-DB          +TOL.   -TOL.-DB     PHASE      TOL-DEG

 1.00000E-03     2.00701E+01       .219     -.224       -.517        .103
 1.00000E-02     2.00209E+01       .219     -.224      -5.170       1.027
 2.00000E-02     2.00085E+01       .223     -.229     -10.319       2.029
 5.00000E-02     1.96511E+01       .330     -.340     -25.448       4.679
 8.00000E-02     1.86229E+01       .591     -.635     -39.746       6.529
 1.00000E-01     1.84902E+01       .793     -.672     -48.649       7.293
 2.00000E-01     1.49372E+01      1.511    -1.830     -84.449       8.143
 4.00000E-01     7.24420E+00      1.580    -2.371    -123.040       7.821
 8.00000E-01    -2.47527E+00      1.994    -2.592    -151.464       5.557
 1.00000E+00    -5.96208E+00      1.996    -2.595    -158.127       4.704
 2.00000E+00    -1.64611E+01      1.801    -2.275    -173.864       2.840
 4.00000E+00    -2.48247E+01      1.229    -1.432     173.018       2.903
 8.00000E+00    -2.96970E+01       .653     -.706     157.117       4.557
 1.00000E+01    -3.10736E+01       .630     -.679     150.940       5.115
 2.00000E+01    -3.47918E+01      1.022    -1.159     130.078       5.556
 4.00000E+01    -3.96037E+01      1.392    -1.658     112.477       3.924

THE ARGUMENTS AND TOLERANCES ARE:

R0          A0   300000     20          R5          A5   1100         2
R1          A1   357000     2           R6          A6   10000        2
C2          A2   .2E-05     20          C7          A7   .1E-05       10
R3          A3   357000     2           T1          A8   .159E+00     20
C4          A4   .2E-05     20

PROGRAM: OUTPUT FILTER AMPLIFER
07/22/75.        07.44.04.
```

DC GAIN = 20db or 10

See Graph of Response Plot.

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ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
		output Filter Amps	TRW ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
MJO		R Signal Amp AC Response	SK SHEET 21 OF

SYSTEMS 520 REV. 8-67

Common Scene(S) Signal Filter Amp Run

$R_5 = 3.32K$

```
AC ANALYSIS     Output Filter Amp
-----------

FREQ              GAIN(DB)          +TOL.   -TOL.(DB)      PHASE      TOL(DEG)

1.00000E-03      1.20870E+01        .182      -.186        -.517         .103
1.00000E-02      1.20499E+01        .183      -.187       -5.164        1.027
2.00000E-02      1.19980E+01        .187      -.192      -10.308        2.029
5.00000E-02      1.16438E+01        .308      -.319      -25.421        4.679
8.00000E-02      1.10227E+01        .579      -.621      -39.702        6.529
1.00000E-01      1.04825E+01        .783      -.861      -48.595        7.293
2.00000E-01      6.98546E+00       1.502     -1.818      -84.341        8.143
4.00000E-01     -2.48868E-01       1.834     -2.328     -122.830        7.821
8.00000E-01     -1.00424E+01       1.898     -2.432     -151.080        5.560
1.00000E+00     -1.33034E+01       1.856     -2.363     -157.677        4.709
2.00000E+00     -2.23487E+01       1.440     -1.727     -173.296        2.847
4.00000E+00     -2.81488E+01        .759      -.832      173.373        2.884
8.00000E+00     -3.11223E+01        .468      -.494      157.219        4.545
1.00000E+01     -3.19056E+01        .542      -.578      151.002        5.108
2.00000E+01     -3.50168E+01       1.018     -1.154      130.095        5.557
4.00000E+01     -3.96594E+01       1.392     -1.658      112.484        3.926

THE ARGUMENTS AND TOLERANCES ARE:

R0           A0   300000      30        R5          A5   3320          2
R1           A1   357000      2         R6          A6   10000         2
C2           A2   .2E-05      20        C7          A7   .1E-05        20
R3           A3   357000      2         T1          A8   .159E+00      20
C4           A4   .2E-05      20

 PROGRAM: OUTPUT FILTER AMPLIFER
 07/23/75.      07.51.48.
```

DC GAIN = 12db = 4

See Graph of Response Plot

ORIGINATOR	DATE	TITLE
		output Filter Amps
		VSignal Amplifier
MJO		

ENGINEERING SKETCH

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SHEET 22 OF

SK

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SYSTEMS 828 REV. 8-67

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SK

ΔV & ΔV' Signal Filter Amplifiers

R_5 = 2.00K

```
RSS ANALYSIS
```

ΔV & ΔV', output Filter Amp

```
FREQ          GAIN(DB)          +TOL.  -TOL.(DB)     PHASE     TOL(DEC

1.00000E-03   1.55627E+01        .202    -.207        -.517       .10
1.00000E-02   1.55455E+01        .203    -.207      -5.167      1.027
2.00000E-02   1.54935E+01        .207    -.212     -10.314      2.02
5.00000E-02   1.51284E+01        .320    -.332     -25.436      4.67
8.00000E-02   1.45155E+01        .586    -.628     -39.726      6.52
1.00000E-01   1.39781E+01        .788    -.867     -48.624      7.29
2.00000E-01   1.04650E+01       1.507   -1.824     -84.400      8.14
4.00000E-01   3.18315E+00       1.848   -2.351    -122.945      7.821
8.00000E-01  -6.78885E+00       1.950   -2.518    -151.286      5.558
1.00000E+00  -1.01702E+01       1.920   -2.485    -157.916      4.704
2.00000E+00  -1.99565E+01       1.618   -1.990    -173.573      2.83
4.00000E+00  -2.69162E+01        .956   -1.074     173.226      2.88
8.00000E+00  -3.07023E+01        .526    -.559     157.183      4.54
1.00000E+01  -3.18247E+01        .566    -.606     150.981      5.11
2.00000E+01  -3.49425E+01       1.019   -1.155     130.089      5.55
4.00000E+01  -3.96411E+01       1.392   -1.658     112.482      3.926.

THE ARGUMENTS AND TOLERANCES ARE:

R0          A0   300000      20          R5          A5   2000        2
R1          A1   357000      2           R6          A6   10000       2
C2          A2   .2E-05      20          C7          A7   .1E-05      20
R3          A3   357000      2           T1          A8   .159E+00    20
C4          A4   .2E-05      20

 PROGRAM: OUTPUT FILTER AMPLIFER
 07/23/75.        07.49.41.
```

DC Gain = 15.53 db or 6.0

See graph for Response Plot

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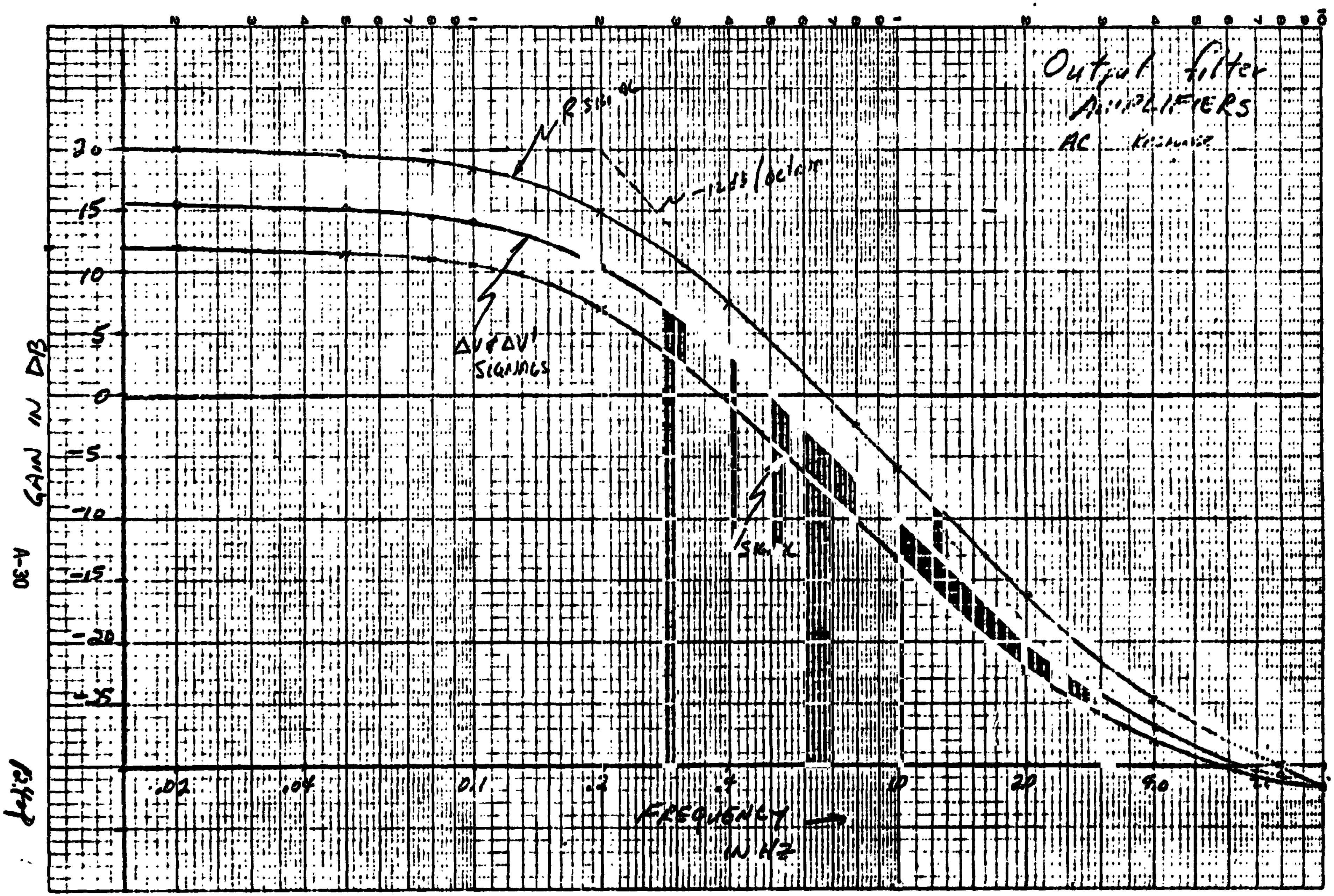
ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
		Output Filter Amps ΔV, ΔV' Amplifiers	TRW ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
MJO			SK SHEET 3 OF

SYSTEMS 529 REV. 8-67

NO. 341-L310 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.



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OUTPUT FILTER AMPLIFIERS

DC offset

LM108A e_{os} = ±.5mv ± 5μv/°C = ±.5mv + .15mv for ±30°C Temp

Bias Current = 3nA max/over temp = ±.65mv

offset Current = 0.4nA

Here input Resistances are matched & Ceramic Cap leakage can be ignored

$\therefore$ e_{os} (Total) = $\pm e_{os} \pm i_{os} \times R$

@input $= \pm 0.65mv \pm .4\times10^{-9} \times .787\times10^{6}$

$= \pm .65mv \pm .31mv = \pm .91mv$

GIVEN VARIOUS GAINS, THE MAX. wc offset AND offset VARIATION IS

AMPLIFIER	GAIN	MAX wc output offset	max VARIATION in output offset
R	10	9.1mv	4.6mv
V	4	3.64mv	1.84mv
ΔV	6	5.5mv	2.8mv
ΔV'	6	5.5mv	2.8mv

ORIGINATOR DFE

DATE

TITLE Output Filter AMPLIFIERS (DC offset)

MJO

ENGINEERING SKETCH

TRW

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SK

SHEET 5 OF

SYSTEMS 929 REV. 9-67

Attachment B

Overall Signal Processing

- AGC Loop Time Constant
- Output Scale factors
- ΔV, $\Delta V'$ offsets
- ΔV, V, & R Gain Stability

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
MAPS	SIGNAL PROCESSING CIRCUITS	DATE		1 OF

AGC LOOP TIME CONSTANT

1) Per FARRENKOPH ANALYSIS, Time Constant

$$\tau = \frac{\pi}{2 K_1 K_f A_1}$$

where: $K_1 A_1 =$ peak amplitude of R component @ ANALOG MULTIPLIER input.

AND $\frac{2K_f}{\pi} =$ loop GAIN IN $(V_{OLT_{pp}} Sec)^{-1}$

2) Input Signal

$K_1 A_1$ WAS ASSUMED TO be 1.0Vpp @ SIGNAL PROCESSING INPUT. with Buffer GAIN of 0.5, $K_1 A_1$ at multiplier input IS 0.5Vpp or 0.25Vp.

3) Loop Gain

$$= \begin{pmatrix}\text{MULTIPLIER}\\ \text{GAIN}\\ V_{dc}^{-1}\end{pmatrix} \times \begin{pmatrix}\text{Diff. AMP}\\ \text{GAIN}\\ V/V\end{pmatrix} \times \begin{pmatrix}\text{Demod}\\ \text{GAIN}\\ V_{dc}/V_p\end{pmatrix} \begin{pmatrix}\text{INTEG}\\ \text{GAIN}\\ V/V\,Sec\end{pmatrix} \times \begin{pmatrix}\text{Feedback}\\ \text{ATTEN}\\ V/V\end{pmatrix}$$

$$= (M_G \times D.A._G \times Demod_G \times Int_G \times ATT_G)(Volts_{peak} \cdot Sec)^{-1}$$

$$= (1/8)(10V/V)(1V_{dc}/V_{peak})\left(\frac{1}{1.86}\right)\left(\frac{10K}{33.7K}\right)$$

$$= 0.20 (V_p Sec)^{-1}$$

MULTIPLIER GAIN CAN HAVE INITIAL VALUE from (1/7) TO (1/9) MAKING LOOP GAIN VARY from .23 TO .18 IN INITIAL VALUE.

AGC Loop Time Constant Cont.

So Loop Time Constant for $R = 1V_{pp}$ is

$$\tau = \frac{1}{.25V_p \times \frac{.2}{V_p Sec^{-1}}} = 20 \text{ Sec}$$

or for Loop Gain of .18 To .23

$$\tau = 17.4 \text{ To } 22.2 \text{ Seconds.}$$

@ An R Component of $1.5V_{pp}$, input To Multiplier is $.375V_{peak}$ So Loop Time Constant is

$$\tau = \frac{1}{.375 \times .2} = 13.3 \text{ Seconds.}$$

Stability of The Loop Time Constant At A Given Value of R depends on Stability of Loop Gain

RSS: Variation in Loop Gain is

$$\frac{\Delta L.G}{L.G.} = \left\{ \underbrace{(\pm 1\%)^2}_{\text{MULTIPLIER}} + \underbrace{(\pm 1\%)^2}_{\text{Diff Amp}} + \underbrace{(\pm .1\%)^2}_{\text{Demod}} \pm \underbrace{(1.6\%)^2}_{\text{Integ.}} \pm \underbrace{(1.4\ )^2}_{\text{AGC feedback ATT.}} \right\}^{1/2}$$

$$= \pm \underline{2.6\%} \text{ r.s.s.}$$

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PROJECT: MAPS
SUBJECT: SIGNAL PROCESSING CIRCUITS
PREPARED BY:
DATE
ATTACHMENT
PAGE 4 OF

ΔV, ΔV' TOTAL offset ERRORS

Per Demod ANALYSIS demod offset VARIATION = ±.9mv

Per output Amp Analysis

ΔV, ΔV' GAIN = 6, MAX offset Variation = 2.8mV

So Total ΔV, ΔV' offset Variation, rss,

$$= \left[(6 \times .9)^2 + (2.8)^2\right]^{1/2}$$

$$= \pm \underline{6.1 \text{mv}} \text{ rss}$$

Gain Stability of ΔV, ΔV' CHANNEL

Demod Gain Stability = ±.06%
Error Amp St. = ±.01%
Diff. Amp Stability = ±1.1%

So rss total = ±1.11%

APPENDIX B

DESIGN ANALYSIS REPORT, PYROELECTRIC DETECTOR GAIN CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides the design and analysis documentation for the pyroelectric detector preamplifier and second amplifier gain stages.

2.0 CIRCUIT REQUIREMENTS

Each of 3 pyroelectric detectors (PIN 8D008) shall interface with a preamplifier and 2nd amplifier which have the following characteristics.

2.1 Detector Interface

- Source Load Impedance - 68.1K ± 1% to - 12V
- Bias Voltage = - 6.0V ± 2% from ≤ 500K dc impedance

2.2 Preamplifier

The preamplifier shall have a gain characteristic which rises at 6db per octane from 0.32Hz to 160 Hz.

The gain at 39 Hz shall be 248 ± 10 percent. The preamplifier equivalent input noise with the input terminated in 10K ohms shall not exceed 30 NV rms in a 0.2 Hz bandwidth centered at the scene chopping frequency of 25 Hz.

2.3 Second Amplifier

The preamplifier shall be followed by a second gain stage which raises the detector signal level to the ± 5 volt range. This stage shall have its low frequency response at less than 2.5 Hz and its high frequency rolloff at greater than 500 Hz. The gain shall be adjustable by resistor selection and/or potentiometer adjustment from 10 to 40.

3.0 CIRCUIT DESCRIPTION AND ANALYSIS RESULTS

3.1 Preamplifier

A schematic of the preamplifier circuit is shown on page #1 of the attached analysis. It is also shown on sketch schematic SK-MAPS-BB-105.

The circuit consists of a low noise differential FET stage followed by a LM108A operational amplifier. The feedback network around the amplifier then provides the required frequency response.

Pages 1 thru 5 of the attached analysis covers the FET stage biasing and show an adequate phase margin to provide closed loop stability.

Pages 6 and 7 provide a tabulation of the expected closed loop response. Page 15 is a plot of measured preamplifier response.

Analysis pages 9 thru 12 provide a simplified calculation of the preamplifier equivalent input noise and presents test data which shows fairly close agreement. In all cases the preamplifier noise contribution is significantly less than that of the detector.

Pages 13 and 14 of the analysis compute the ratio of the preamplifier gains at 23.5 Hz and 39 Hz (old operating frequencies) as a function of component variations. For the component tolerances used, the rss variation in the gain ratio was 0.1 percent.

3.2 Second Amplifier

The second amplifier consists of an integrated circuit operational amplifier, AR2(HA2-2700) and its feedback network components as shown in sketch schematic SK MAPS-BB-105.

Attached analysis pages 16 and 17 cover the performance of the amplifier. Potentiometer R7 is used to set the overall gain to match a particular detector responsivity.

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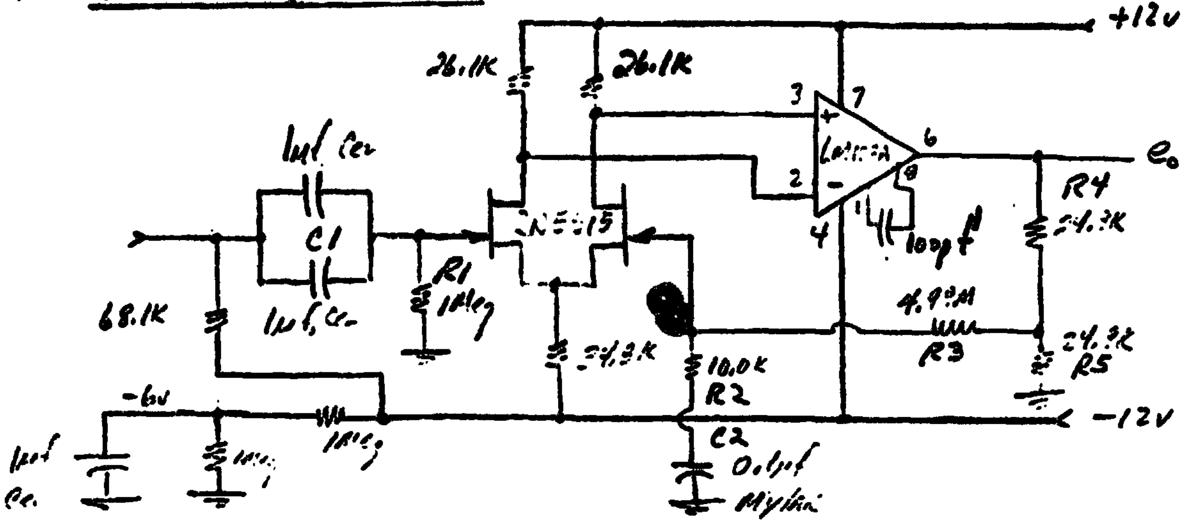
PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE 1 OF
	PYRO-DETECTOR PREAMPLIFIER	DATE 5/29/75		

1.0 CIRCUIT SCHEMATIC



2.0 FET INPUT STAGE

- **Fet Biasing**

Fet Drain Current $= I_D = \frac{1}{2}\left(\frac{12+V_{gs}}{R_D}\right) = \frac{1}{2}\left(\frac{12+2}{34.8K}\right)$

$$\leq \underline{200 \mu A}$$

$\therefore V_d$ (Each Fet) $= 12 - .2ma \times 26.1K = \underline{\underline{6.8V}}$

$\therefore V_{DS} \geq \underline{\underline{4.8V}}$

- **Fet Stage Gain**

$$GAIN \cong g_m R_L \cong 500\mu mhos \times 26.1K = 13$$

- **Fet Stage Break Frequency**

$C_{rss} = 5pf$ @ 20V V_{GD}

$$C_{gd} \cong C_{rss} \times \sqrt[3]{\frac{V_{GD}}{V_{gd}}} + C_{PACKAGE} = 5pf\sqrt[3]{\frac{20}{5}} + .5$$

$$\cong 8pf$$

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SYSTEMS GROUP

PREPARED BY: WAE
ATTACHMENT
PAGE 2 OF

PROJECT MAPS
SUBJECT Pyro-detector PREAMPLIFIER
DATE 5/29/75

2. Fet input stage continued

• Fet Stage Break freq. Cont.

$$f_{\text{alloff}} \cong \frac{1}{2\pi C_{gd} \times 2R_D \cdot G} = \frac{.159}{8pf \times 26.1k \times 2 \times 15}$$

$$\cong 25.5kc$$

$$\therefore \tau_1 = 6.3\mu sec$$

and Transfer function of Fet Stage

$$K_1 = \frac{A_1}{\tau_1 s + 1}$$ where we Assume $A_1 = 15 \pm 30\%$
$\tau_1 = 6.3\mu sec \pm 50\%$

3. LM103A STAGE

with $C_{PIN\,1-8} = 30pf$, $f_{\text{UNITY GAIN}} \approx 750\,KHZ$

$\therefore$ with $C_{1-8} = 100pf$, $f_{UG} = 225Kc$

FOR DC GAIN $\approx 3 \times 10^5 = 109.54\,db$

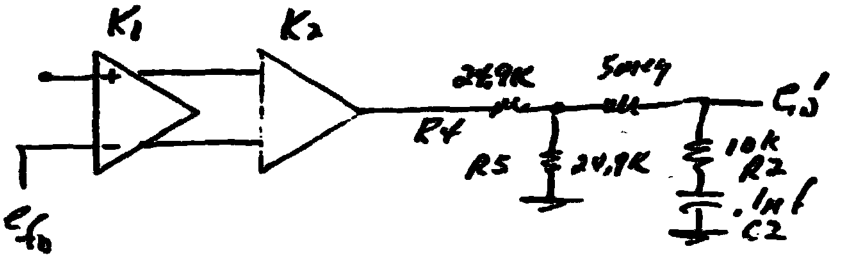
$\therefore$ LM108 Stage Transfer function is Assumed to be

$$K_2 = \frac{A_2}{\tau_2 s + 1}$$ where $A_2 = 3 \times 10^5 \pm 30\%$
$f_{\text{BREAK}} = 0.75\,HZ$
$\tau_2 = .212 sec \pm 30\%$

4.0 AMPLIFIER STABILITY (GAIN/PHASE MARGIN)

TO ESTABLISH CLOSED LOOP FREQ STABILITY WE CONSIDER OPEN LOOP GAIN PLOT AS FOLLOWS:

LOOP GAIN:



∴ LOOP GAIN IS

$$= K1K2 \times \left(\frac{R5}{R4+R5}\right)\left(\frac{Z2}{R_4 \| R_5 + R_3 + Z_2}\right)$$

where $Z_2 = \left(R_2 + \frac{1}{sC_2}\right)$

DATA INPUT TO RSSWCI PROGRAM IS THEN:
(VARIABLE ASSIGNMENTS ARE SHOWN IN PRINTOUT)

```
500 FOR F =.1,1,10,20,40,100,200,400,1E3,2E3,4E3,1E4,2E4,5E4,1E5,2E5
2000 DATA 15,6.2E-6,3E5,.212,24900,24900
2001 DATA 5E6,1E4,.1E-6,1E6,2E-6
2100 DATA 30,50,30,30,2,2
2101 DATA 2,2,5,2,20
2200 DATA A0,T1,A2,T2,R4,R5
2201 DATA R3,R2,C2,R1,C1
2300 DATA "PYRO-PREAMP RESPONSE"
3000 K1=A0/CMPLX(1,A1*W)
3010 K2=A2/CMPLX(1,A3*W)
3020 Z1=(A4*A5)/(A4+A5)
3030 Z2= CMPLX(A7,-1/(W*A8))
3035 Z3= CMPLX(0,W*B0*A9)/CMPLX(1,W*B0*A9)
3040 B=(A5/(A5+A4))*(Z2/(Z2+A6+Z1))
3050 T1=K1*K2*B
5300 [illegible] 1
```

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PROJECT	SUBJECT	PREPARED BY:	DATE	ATTACHMENT	PAGE
MAPS	PYRO-DETECTOR PREAMPLIFIER	WKR	5/29/75		4 OF

4 AMPLIFIER STABILITY Cont.

RESULTANT Computer Run. (GAIN IN V/V)

```
FREQ             GAIN(V/V)        TOL.(%)     PHASE          TOL(DEG) .

1.00000E-01      2.12691E+06      42.456       -25.0657        2.417
1.00000E+00      4.08074E+05      46.840      -125.1628        8.296
1.00000E+01      5.34550E+03      52.158      -170.3187        1.289
2.00000E+01      1.34758E+03      52.225      -169.8248         .729
4.00000E+01      3.44875E+02      52.223      -164.4524         .780
1.00000E+02      6.32131E+01      52.143      -147.4696        1.392
2.00000E+02      2.14698E+01      52.067      -128.6524        1.517
4.00000E+02      9.04796E+00      52.350      -112.4368        1.148
1.00000E+03      3.40293E+00      52.054      -101.2128        1.213
2.00000E+03      1.68181E+00      52.056       -98.9743        2.232
4.00000E+03      8.31429E-01      52.069      -101.1200        4.360
1.00000E+04      3.13420E-01      52.471      -112.1895        9.690
2.00000E+04      1.32655E-01      55.376      -128.3756       13.889
5.00000E+04      3.07213E-02      65.366      -153.0051       11.639
1.00000E+05      8.36224E-03      70.070      -165.6935        6.899
2.00000E+05      2.14078E-03      71.616      -172.7313        3.617

THE ARGUMENTS AND TOLERANCES ARE:

A1          A0    15          30        R3        A6    5000000      2
T1          A1    .62E-05     50        R2        A7    10000        2
A2          A2    390000      30        C2        A8    .1E-06       5
T2          A3    .212E+00    30        P1        A9    1000000      2
R4          A4    24900       2         C1        B0    .2E-05       20
R5          A5    24900       2

 PROGRAM: PYRO-PREAMP RESPONSE
 05/30/75.       09.16.23.
```

From The Above Data we See PHASE MARGIN NOMINALLY GREATER THAN 79° INSURING ADEQUATE CLOSED LOOP STABILITY.

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE OF
MAPS	PYRO-DETECTOR PREAMPLIFIER	DATE 5/29/75		

4. AMPLIFIER STABILITY CONTINUED

RESULTANT COMPUTER RUN, (GAIN IN DB)

```
AC ANALYSIS
-------------



FREQ            GAIN(DB)          +TOL.  -TOL.(DB)     PHASE      TOL(DEG)

1.00000E-01     1.26555E+02       3.474    -4.830      -25.066      2.417
1.00000E+00     1.12215E+02       3.337    -5.486     -125.163      2.298
1.00000E+01     7.45598E+01       3.646    -6.404     -170.319      1.239
2.00000E+01     6.25911E+01       3.650    -6.416     -169.825       .729
4.00000E+01     5.07532E+01       3.650    -6.416     -164.452       .780
1.00000E+02     3.601615E+01      3.645    -6.401     -147.470      1.392
2.00000E+02     2.66446E+01       3.641    -6.387     -128.652      1.317
4.00000E+02     1.91310E+01       3.640    -6.384     -112.437      1.148
1.00000E+03     1.05371E+01       3.640    -6.385     -101.213      1.211
2.00000E+03     4.51556E+00       3.640    -6.385      -98.974      2.232
4.00000E+03    -1.60350E+00       3.641    -6.388     -101.120      4.360
1.00000E+04    -1.00775E+01       3.664    -6.461     -112.189      9.690
2.00000E+04    -1.75455E+01       3.826    -7.009     -128.576     13.385
5.00000E+04    -3.02512E+01       4.370    -9.215     -153.005     11.635
1.00000E+05    -4.15535E+01       4.613   -10.478     -165.694      6.899
2.00000E+05    -5.33826E+01       4.691   -10.939     -172.751      3.617


THE ARGUMENTS AND TOLERANCES ARE:

A1          A0   15            30       R3          A6   5000000     2
T1          A1   .62E-05       50       R2          A7   10000       2
A2          A2   300000        30       C2          A8   .1E-06      5
T2          A3   .212E+00      30       R1          A9   1000000     2
R4          A4   24900         2        C1          B0   .2E-05      20
R5          A5   24900         2


 PROGRAM: PYRO-PREAMP RESPONSE
 05/30/75.        08.16.19.
```

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PROJECT MAPS | SUBJECT PYRO-DETECTOR PREAMPLIFIER | PREPARED BY: | DATE 5/29/75 | ATTACHMENT | PAGE 6 OF

5. CLOSED LOOP GAIN RESPONSE:

USING THE OPEN-LOOP GAIN EQUATIONS THE Closed Loop Response is: (including input Coupling network K)

$$G = \left(\frac{1}{\beta}\right)\left(\frac{K_1K_2\beta}{1+K_1K_2\beta}\right)\times K_3$$

where:

$$\beta = \left(\frac{R5}{R4+R5}\right)\left(\frac{Z_2}{R_4 \| R_5 + R_3 + Z_2}\right)$$

where $Z_2 = R_2 + \frac{1}{sC_2}$

$$K_1 = \frac{A_1}{\tau_1 s+1}, \quad K_2 = \frac{A_2}{\tau_2 s+1}, \quad K_3 = \left(\frac{sR_1C_1}{sR_1C_1+1}\right)$$

RSSWC1 Computer input DATA CHANGES ARE THEN:

```
$ 2300 DATA "PYRO-PREAMP CLOSED LOOP RESPONSE"
$ 3200 X= Z3*(1/B)*(X1/(X1+1))
```

CLOSED LOOP GAIN RUN IN DB:

```
FREQ            GAIN(DB)         +TOL.   -TOL.(DB)     PHASE      TOL(DEG)

1.00000E-01     4.30233E+00       .663     -.718       55.990        5.680
1.00000E+00     1.63905E+01       .431     -.454       76.607        1.260
1.00000E+01     3.59911E+01       .469     -.495       85.044         .151
2.00000E+01     4.19624E+01       .465     -.491       82.150         .344
4.00000E+01     4.78022E+01       .450     -.474       75.508         .713
1.00000E+02     5.46738E+01       .380     -.397       57.228        1.439
2.00000E+02     5.81585E+01       .317     -.329       36.300        1.945
4.00000E+02     5.97259E+01       .306     -.318       15.575        3.459
1.00000E+03     6.00533E+01       .299     -.310       -7.970        8.851
2.00000E+03     5.93369E+01       .985    -1.112      -23.374       15.007
4.00000E+03     5.70595E+01      2.417    -3.360      -54.669       18.016
1.00000E+04     5.06078E+01      3.704    -6.592      -93.059       15.057
2.00000E+04     4.31842E+01      4.003    -7.647     -121.455       16.664
5.00000E+04     3.00279E+01      4.452    -9.617     -152.002       12.306
1.00000E+05     1.65560E+01      4.637   -10.619     -165.463        7.012
2.00000E+05     6.66881E+00      4.695   -10.964     -172.670        3.6[illegible]
```

PROJECT [illegible]
SUBJECT PYRO-DETECTOR PREAMPLIFIER
PREPARED BY: CF
DATE 5/30/75
ATTACHMENT
PAGE 7 OF

5. CLOSED LOOP RESPONSE
RSS DATA IN V/V.

```
RSS ANALYSIS
------------


 FREQ           GAIN(V/V)        TOL.(%)     PHASE         TOL(DEG)

 1.00000E-01    1.64103E+00       7.935      55.9560        5.680
 1.00000E+00    6.59972E+00       5.093      76.6070        1.260
 1.00000E+01    6.30310E+01       5.543      85.0438         .151
 2.00000E+01    1.25349E+02       5.498      82.1503         .344
 4.00000E+01    2.45535E+02       5.316      75.5976         .713
 1.00000E+02    5.41613E+02       4.473      57.2281        1.439
 2.00000E+02    8.08955E+02       3.714      36.3004        1.945
 4.00000E+02    9.66932E+02       3.591      15.5751        3.459
 1.00000E+03    1.02615E+03       3.507      -7.9702        8.851
 2.00000E+03    9.26501E+02      12.012     -22.3744       15.007
 4.00000E+03    7.12815E+02      32.060     -54.5695       18.018
 1.00000E+04    3.39149E+02      53.184     -93.0589       15.037
 2.00000E+04    1.44281E+02      58.540    -121.4546       16.664
 5.00000E+04    3.17244E+01      66.953    -152.0915       12.306
 1.00000E+05    8.46838E+00      70.554    -165.4831        7.012
 2.00000E+05    2.15497E+00      71.698    -172.6702        3.632

THE ARGUMENTS AND TOLERANCES ARE:

A1          A0   15          30         P3         A6   5000000     2
T1          A1   .62E-05     50         R2         A7   10000       2
A2          A2   300000      30         C2         A8   .1E-06      5
T2          A3   .212E+00    30         R1         A9   1000000     2
P4          A4   24900       2          C1         B0   .2E-05      20
P5          A5   24900       2

 PROGRAM: PYRO-PREAMP CLOSED LOOP RESPONSE
 05/30/75.       08.22.28.
```

6. OUTPUT DC Q POINT

- AMPLIFIER DC GAIN = $1 + \frac{R5+R6}{R_5} = \underline{\underline{3}}$

- INPUT OFFSET VOLTAGE

e_{os} (fet pair) = 5mv initial
$+ 5 \mu v/{}^\circ c \pm 20^\circ c$ = 5mv±.1mv
= 5.1mv TOTAL

i_{bias} of fet pair = 100pA @ 25°C
≤ 600pA @ 50°C

So $e_{os}\Big|_{\text{due to } i_b}$ = .6nA × 5meg = 3mv

∴ TOTAL INPUT offset = ±8.1mv
and @ output = 3×8.1 = ± $\underline{\underline{24mv}}$

7) PREAMP EQUIVALENT INPUT NOISE @ 20HZ

a) NOISE SOURCES

1) $\overline{e}_n$ of each Fet ≦ 30nv/√Hz @ 10Hz
ASSUME $\overline{e}_n$ = 20nv/√Hz @ 20 Hz
(1/f effect)

2) i_g(fet) ≦ 600pA @ 50°C
∴ $\overline{i}_s = (2q\,I_g)^{1/2} = 1.4 \times 10^{-14}$ AMP/√Hz

3) JOHNSON NOISE OF INPUT RESISTANCE AT INVERTING & NON-INVERTING INPUTS.

7. [illegible]

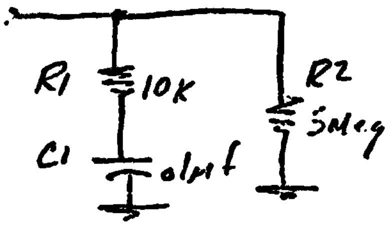
B) So total EQ input noise is:

$$\overline{e_{IN}}^2 = \overline{e_{n_{fet}}}^2(\text{N.INV}) + \overline{e_{n_{fet}}}^2(\text{INV}) + I_{n_{fet\,INV}}^2 \times |Z_{IN}|^2_{INV}$$

$$+ I_{n_{fet\,N.INV}}^2 \times |Z_{IN}|^2_{N.INV} + \overline{e_n}^2_{\text{eq Resistance Noise @ INV}} + \overline{e_n}^2 \ldots$$

C) Z_{IN} (Non-INV) = 10KΩ (Detector Z_0 Basically)

d) Z_{IN} (inverting) =



$$= \frac{R_2(1+j\omega C_1R_1)}{1+j\omega(R_1+R_2)C_1} = \frac{5\times10^6(1+j\,2\pi\times20\times.1\times10^{-6}\times10^4)}{(1+j\,2\pi\times20\times5.01\times.1)}$$

$|Z| = 80K$ @ 20HZ

So I_n of fet is developed across 8.1K

e) Johnson Noise of R_1 & R_2 = ?

Johnson noise of R1 all seen at input

Johnson noise of R_2 shunted by R1 & C1

can model as current noise $\frac{4KT\Delta f}{R_2}$

Applied to the 80K impedance

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PROJECT [illegible] | SUBJECT [illegible] [illegible] AMPLIFIER | PREPARED BY: [illegible] | DATE [illegible] | ATTACHMENT | PAGE 11 OF

7) Noise Calculation Cont.

Summary of Mean Sq Noise Sources:

a) $\overline{e_{n\,fet}}^{2} = \left(20\ nV/\sqrt{Hz}\right)^{2}$ for both N.I & INV inputs @20Hz

b) $\overline{I_{n_{fet}} \times 80k}^{\,2} = \left(1.4\times10^{-14}\ \frac{Amp}{\sqrt{Hz}}\right)^{2}\left(8\times10^{4}\right)^{2} = \left(1.12\ nV/\sqrt{Hz}\right)^{2}$

c) $\overline{I_{n\,fet} \times 10k}^{\,2} = \left(1.4\times10^{-14}\ Amp/\sqrt{Hz}\right)^{2}\times\left(10^{4}\right)^{2} = \left(0.14\ nV/\sqrt{Hz}\right)^{2}$

d) $\overline{e_{n\,R_1}}^{2} = 4KTR\ V^{2}/Hz = \left(13.4\ nV/\sqrt{Hz}\right)^{2}$

10K @ NON-INV. INPUT

e) $\overline{e_{nR_1}}^{2} = \left(13.4\ nV/\sqrt{Hz}\right)^{2}$

10K @ INV INPUT

f) $\overline{e_{nR_2}}^{2}_{\text{AS SHUNTED}} = \left(\frac{4KT\Delta f}{R}\right)\times 180K^{2}$

$$= \frac{1.27\times10^{-20}}{5\times10^{6}}\times 64\times10^{8} = 16.26\times10^{-18} = \left(4\ nV/\sqrt{Hz}\right)^{2}$$

Therefore Total Noise @ 20HZ

$$\overline{e_T} = \left\{(20)^2+(20)^2+(1.12)^2+(.14)^2+(13.4)^2+(13.4)^2+(4)^2\right\}^{1/2} nV/\sqrt{Hz}$$

$= 34.8\ nV/\sqrt{Hz}$ Noise density @ <u>20Hz</u>

∴ Measured 20HZ Noise with HP 302 WAVE ANALYZER

$\cong 30\ nV/\sqrt{Hz}$

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PROJECT	SUBJECT	PREPARED BY:	DATE	ATTACHMENT	PAGE
[illegible]	[illegible]-Detector Preamplifier		6/5/75		12 OF

7. Noise data — Measured with HP 302 wave analyzer (assuming 6Hz noise BW)
Measured noise performance was as follows

freq	GAIN	output noise with HP 302	Eq input noise (6Hz BW)	Eq input noise (1Hz BW)	With Barnes BB Detector: output noise	Eq input noise
20Hz	2660	0.2mV	7.5×10^{-8} V rms	31nV/√Hz	2mV	306 nV/√Hz
40Hz	5281	0.35mV	6.6×10^{-8} V rms	27nV/√Hz	2mV	155 nV/√Hz
100Hz	11416	0.6mV	5.26×10^{-8}	21.5nV/√Hz	2mV	71.5nV/√Hz
200Hz	16191	0.7mV	4.32×10^{-8}	17.7nV/√Hz	1.8mV	45.4 nV/√Hz
400 Hz	16792	0.7mV	4.17×10^{-8}	17.0 nV/√Hz	1.5mV	36.5nV/√Hz

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SYSTEMS 1489 REV. 2-68

8) Ratio of Gains at Ref. freq & Scene frequency

Scene freq = f_1 = 23.5HZ

Ref Balance freq = f_2 = 1.67×f_1 = 39HZ

∴ Taking the closed loop response equations of P6 & solving @ f_1 & f_2 and finding the gain ratio with RSSWP1 program we have:

Revised Program:

```
[ LIST,PAMP1

500 FOR F=5 TO 40 BY5
2000 DATA 15,6.2E-6,3E5,.212,24900,24900
2001 DATA 5E6,1E4,.1E-6,1E6,2E-6
2100 DATA 30,50,30,30,2,2
2101 DATA 2,2,5,2,20
2200 DATA A1,T1,A2,T2,R4,R5
2201 DATA R3,R2,C2,R1,C1
2300 DATA 'PYPD-PREAMP GAIN RATIO"
3000 K1=A0/CMPLX(1,A1*W)
3010 K2=A2/CMPLX(1,A3*W)
3020 Z1= (A4*A5)/(A4+A5)
3030 Z2= CMPLX(A7,-1/(W*A6))
3035 Z3= CMPLX(0,W*B0*A9)/CMPLX(1,W*B0*A9)
3040 B= (A5/(A5+A4))*(Z2/(Z2+A6+Z1))
3050 X1=K1*K2*B
3100 X2=Z3*(1/B)*(X1/(X1+1))
3105 K3=A0/CMPLX(1,A1*W*1.67)
3110 K4=A2/CMPLX(1,A3*W*1.67)
3120 Z4=CMPLX(A7,-1/(1.67*W*A6))
3125 Z5=CMPLX(0,W*B0*A9*1.67)/CMPLX(1,1.67*W*B0*A9)
3130 A=(A5/(A5+A4))*(Z4/(Z4+A6+Z1))
3140 X3=K3*K4*A
3150 X4=Z5*(1/A)*(X3/(X3+1))
3200 Y=X4/X2
```

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PROJECT: [illegible] SUBJECT: Pyro-detector Preamplifier	DATE: 6/13/75		

8) GAIN RATIO

Using ±1% Resistance & ±3% Capacitor Tolerance, Results are

SCENE

$\frac{G(f_2)}{G(f_1)}$

```
•II ANALYSIS
------------

FREQ           GAIN(V V)        TOL.(%)     PHASE          TOL(DEG)

5.00000E+00    1.66666E+00      .007         -.11[444HHHFFF.110
1.00000E+01    1.66420E+00      .026        -1.8529           .103
1.50000E+01    1.65798E+00      .059        -3.2061           .126
2.00000E+01    1.64919E+00      .104        -4.4369           .153
2.50000E+01    1.63818E+00      .158        -5.5907           .179
3.00000E+01    1.62521E+00      .219        -6.6780           .202
3.50000E+01    1.61057E+00      .287        -7.7004           .222
4.00000E+01    1.59452E+00      .357        -8.6569           .240

THE ARGUMENTS AND TOLERANCES ARE:

A1          A0   15          30      P3          A6   5000000     1
T1          A1   .62E-05     50      R2          A7   10000       1
A2          A2   300000      30      C2          A8   .1E-06      3
T2          A3   .212E+00    30      R1          A9   1000000     1
R4          A4   24900       2       C1          B0   .2E-05      20
R5          A5   24900       2

 PROGRAM: PYRO-PREAMP GAIN RATIO
 06.13.75.      08.23.29.
```

So CHANGE IN GAIN RATIO (rss) IS ≈ 0.1% WITH COMPONENT VALUE TOLERANCES LISTED.

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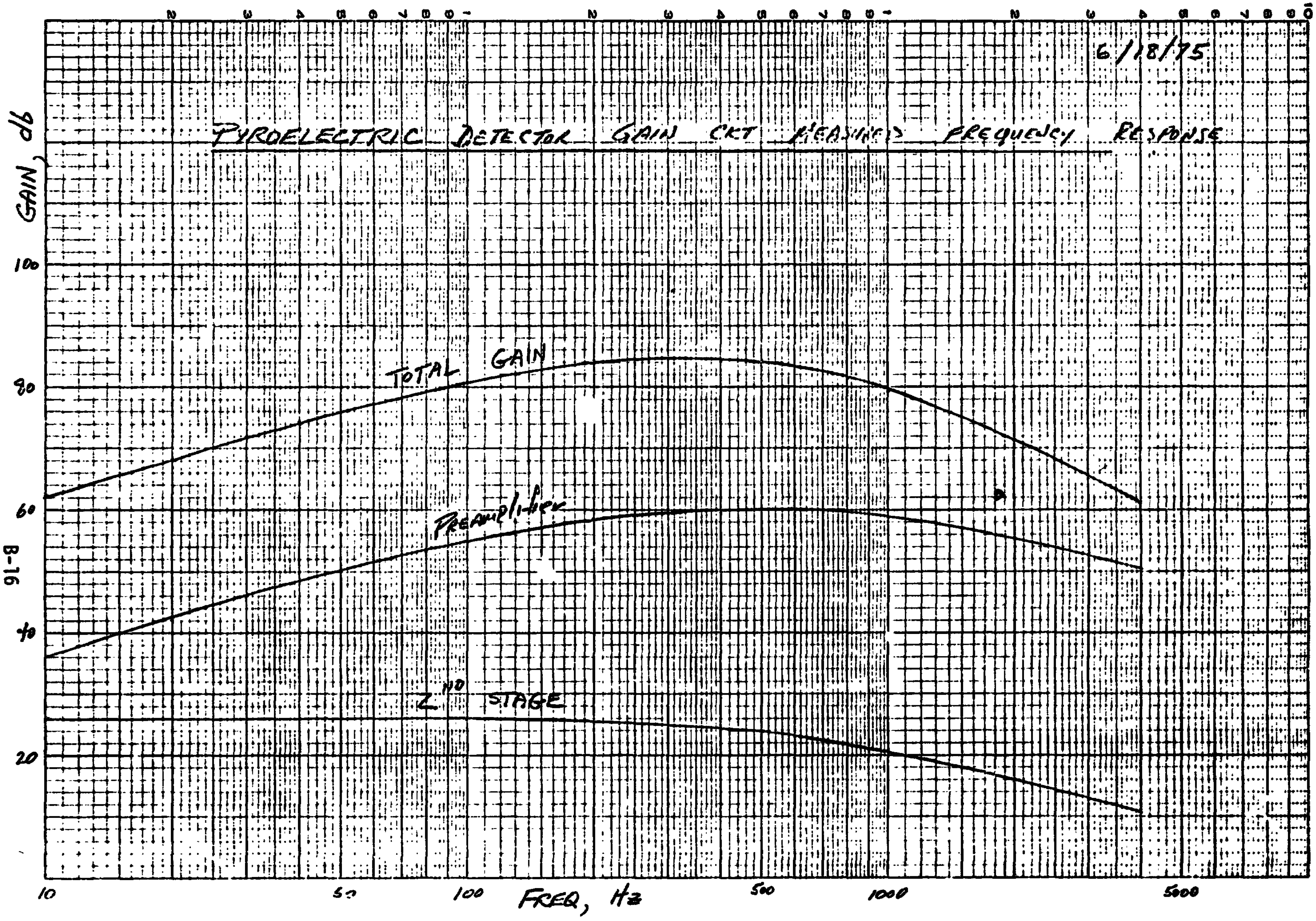

PYROELECTRIC DETECTOR GAIN CKT MEASURED FREQUENCY RESPONSE

6/18/75

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PROJECT: [illegible]
SUBJECT: PYRO-DETECTOR 2nd Amplifier
PREPARED BY: [illegible]
DATE:
ATTACHMENT:
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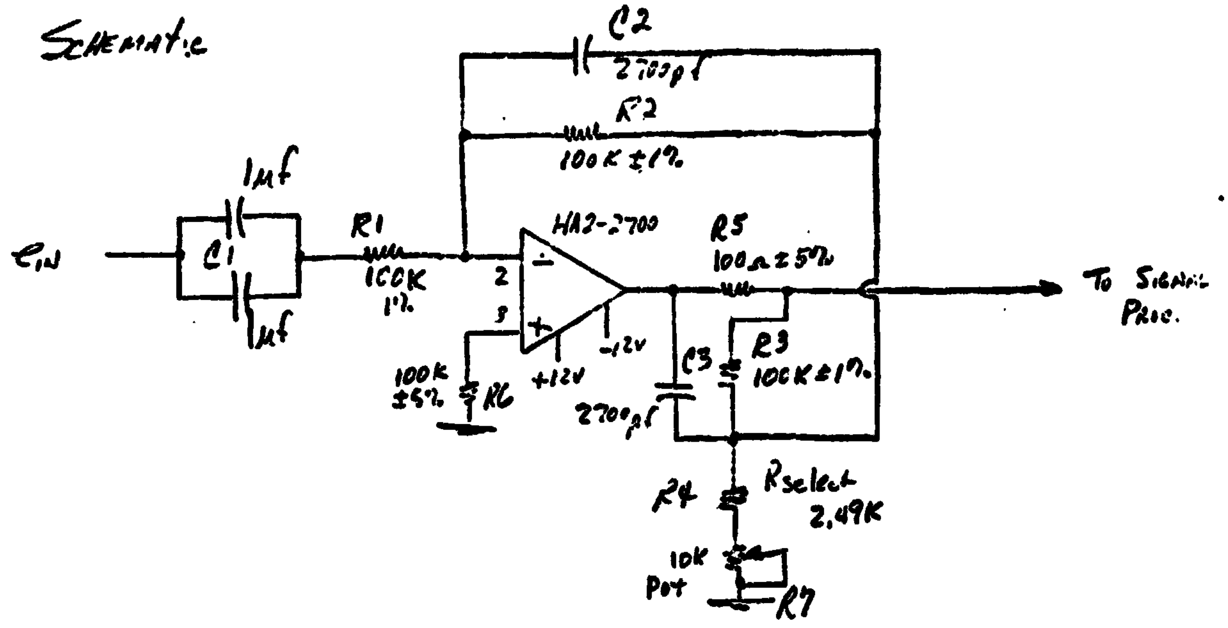
Schematic



1) Input Coupling network 3db freq.

$$f_c = \frac{.159}{2\times10^{-6} \times 10^5} = 0.8Hz, \quad \left(\text{min input freq} = 25Hz\right)$$

2) <u>MIDBAND GAIN</u> with $R4 = 2.49K$
$R7 = 10K$ Pot

$$G = -\left(\frac{R_2}{R_1}\right)\left(1 + \frac{R_3}{R_2 \,//\, (R_4+R_7)}\right)$$

AND $R_4+R_7 = 2.49K$ min, $7.49K$ nom, $12.49K$ max

$\therefore$ $R_2 // (R_4+R_7) = 2.43K$ min, $6.97k$ nom, $11.1K$ max

AND THUS GAIN RANGE IS

$G_{MIN} = \underline{10.1}$
$G_{NOM} = \underline{15.3}$
$G_{MAX} = \underline{42.1}$
$\Big\}$ per Pot adjustment

SYSTEMS 1400 REV. 2-68

3) <u>GAIN STABILITY</u> -

At these Low Gains, Gain Stability is that of feedback network Components.

ie 4 ±1% Resistors & 1-3% Pot

So rss Gain Stability over Environment

$$= \sqrt{4(1\%)^2 + (3\%)^2} = \sqrt{13} = \pm 3.6\%$$

4) <u>High frequency Rolloff</u>

Set by $R_2 C_2$ AND $R_3 C_3$ Time Constants

$$f_{HIGH} = \frac{.159}{2700\times10^{-12}\times10^{5}} = \frac{1590\times10^{-4}}{2700\times10^{-4}} = \underline{589\text{ Hz}}$$

5) <u>CABLE Capacity Loading</u>

100Ω Resistor R5 effectively Decouples Load CABLE Capacity at High frequency assuring only unity feedback @ Hi frequencies

APPENDIX C

DESIGN ANALYSIS REPORT, LEAD SELENIDE DETECTOR GAIN CIRCUITS FOR THE MAPS BREADBOARD

1.0 SCOPE

This report provides the design and analysis documentation for the cooled lead selenide detector preamplifier and 2nd amplifier gain stages.

2.0 Circuit Requirements

Each of 3 lead selenide detectors (FIN 8D007) shall interface with a preamplifier and second amplifier gain stage having the following characteristics.

2.1 Detector Interface

The preamplifier shall be a.c. coupled to a detector which is biased from a 100 volt bias and is terminated in a 1 megohm load resistance.

2.2 Preamplifier

The preamplifier shall provide a constant gain of 50 ± 5% over the frequency range of 10 Hz to 3 KHz.

The equivalent input noise shall not exceed 56 nanovolts rms in a 0.2 Hz bandwidth centered at the scene chopping frequency of 177 Hz.

2.3 Second Amplifier

The preamplifier shall be followed by a second gain stage which raises the detector signal level to the ± 5 volt range. This stage shall have its low frequency response at less than 10 Hz and its high frequency rolloff at greater than 5 K hz. The gain shall be adjustable by resistor selection and/or potentiometer adjustment from 10 to 20.

3.0 CIRCUIT DESCRIPTION AND ANALYSIS

3.1 Preamplifier

A schematic of the preamplifier is shown on sketch schematic SK-MAPS-BB-105.

The circuit consists of a low noise differential FET stage followed by a LM108 A operational amplifier.

Pages 1 thru 8 of the attached analysis covers the preamplifier performance. Adequate biasing, closed loop stability and noise performance is shown.

3.2 Second Amplifier

The second amplifier consists of a HA-2-2700 IC operational amplifier and the gain control feedback network. The key performance parameters are given on Page 9 of the attached analysis.

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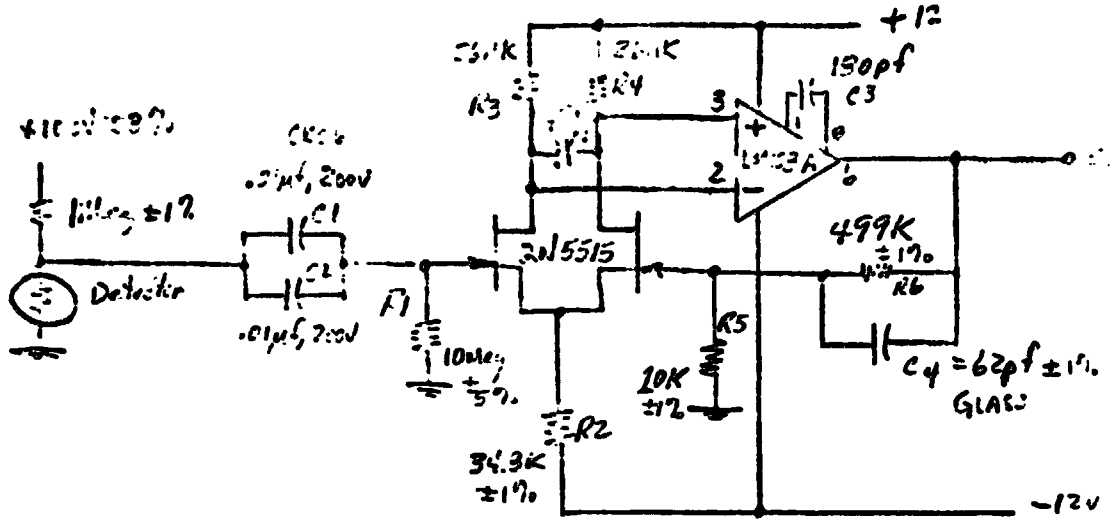
ATTACHMENT

PAGE 1 OF

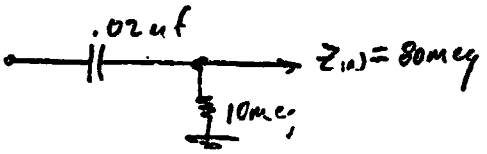
PROJECT

SUBJECT [illegible] Detector [illegible] Ckt.

DATE



1) INPUT COUPLING NETWORK



$$f_c = \frac{159\times10^{-3}}{.02\times10^{-6}\times\left(\frac{10\times80}{90}\right)\times10^{6}} = 0.894\,HZ$$

MINIMUM CHOPPING freq = 171.5HZ

2) FET BIASING

$$\text{FET DRAIN Current} = I_D = \tfrac{1}{2}\left(\frac{12+V_{GS}}{R_D}\right)$$

$$= \tfrac{1}{2}\left(\frac{12+.2}{34.3K}\right) = 0.2ma$$

$$\therefore\ V_D = +12v - I_D R_D$$

$$= +12v - .2ma\times26.1K = 6.8V$$

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PROJECT MAPS · SUBJECT P[illegible] Detector Preamp Circuit	DATE		

3) Amplifier Gain

$$= \left(1 + \frac{R6}{R5}\right) = \left(1 + \frac{499K}{10K}\right) = \underline{50.9}$$

4) High freq rolloff

$$f_c = \frac{.159}{.499 \times 10^6 \times 62pf} = \underline{5.14Kc}$$

Highest Chopping freq = 265HZ

5) Equivalent input offset Voltage

e_{os} of fet pair = 5mV initial

+ $5\mu v/°C \times \pm 20°C = \pm 0.1mV$

i_b of fet pair = 100pA @ 25°C

≅ 600pA @ 50°C

$\therefore e_{os}\Big|_{\text{DUE TO } I_b} = .6nA \times 10meg = 6mV$

So TOTAL DC offset $= \pm 11.1mV$ WC

$e_{output} = \pm 11.1mV \times 51 = \pm 566mV = \pm .6$ VOLTS

MAXIMUM SIGNAL SWING @ PREAMP OUTPUT

$$= \frac{\pm 5V}{2nd\ amp\ GAIN} = \frac{\pm 5V}{2.5\ (\text{MINIMUM GAIN})} = \pm 2V$$

So ±9V DYNAMIC RANGE IS MORE THAN ADEQUATE.

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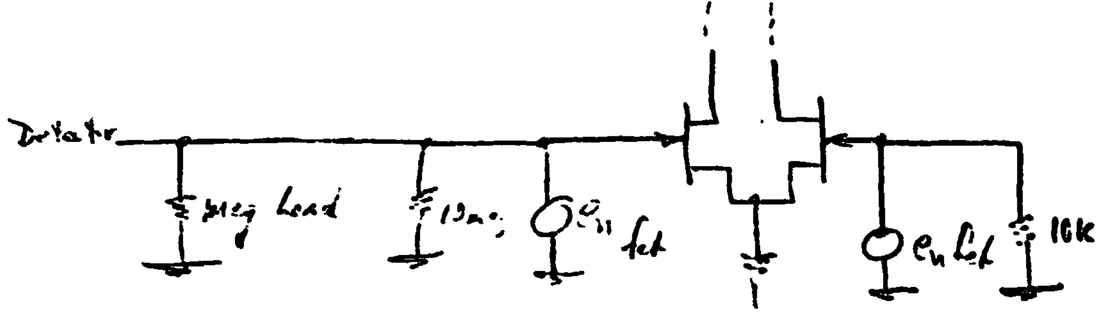
PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
ARPS	Lead Selenide Preamplifier Circuit	DATE		3 OF

b) Equivalent input Noise

in Passband



NOISE SOURCES

a) Fet $\bar{e}_n$ = 10nv/√Hz @ ≥100Hz per Data Sheet

b) $I_G \leq$ 600fA MAX @ 50°c

$$\therefore \bar{i}_s = (2qI_G)^{1/2} = (2\times1.6\times10^{-19}\times.6\times10^{-9})^{1/2}$$

$$\bar{i}_s = 1.4\times10^{-14} \text{ Amp}/\text{Hz}^{1/2}$$

So with 1Meg R_s, Noise due to i_s =

$$\bar{e}_n\big|_{is} = 1.4\times10^{-14}\times1\times10^{6} \text{ Volts}/\sqrt{\text{Hz}} = 14\text{nv}/\sqrt{\text{Hz}}$$

c) @ inverting input (10k, R_s)

$$\bar{e}_n\big|_{is} = 1.4\times10^{-14}\times10^{4} = 0.14\text{nv}/\sqrt{\text{Hz}}$$

d) Input Resistors @ non-inv. input ≤ 1Meg

@ inverting ≤ 10k

$$\text{So } \bar{e}_{n_{1meg}} = (4KTR)^{1/2} \text{V}/\sqrt{\text{Hz}} = 1.34\times10^{-7} \text{V}/\sqrt{\text{Hz}}$$

$$= 134\text{nV}/\sqrt{\text{Hz}} \text{ @ } 50°\text{c}$$

$$\bar{e}_n\big|_{10k} = (4KTR)^{1/2} \text{V}/\sqrt{\text{Hz}} = 13.4\text{nv}/\sqrt{\text{Hz}} \text{ @ } 50°\text{c}$$

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PROGRAM	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
MEPS	Lens Solenoid Preamplifier Circuit	NE DATE		1 OF

cont

Finally Total input noise = rss combination of all sources

$$= \left[(10nV)^2 + (10nV)^2 + (14nV)^2 + (.14nV)^2 + (134nV)^2 + (13.4nV)^2\right]^{1/2}$$

$e_{n_{C_1}}$ $e_{n_{fet}}$ $i_{n_{fet}}$ $i_{n_{fet}}$ R_{in} R_{oR}

$= \underline{\underline{136\ nV/\sqrt{Hz}}}$ ie almost all due to R_L (1meg)

IN 0.2HZ $\overset{\text{NOISE EQ.}}{\wedge}$ BANDWIDTH @ 17HZ

THE EQ. INPUT NOISE (PREAMP ONLY) IS THEN

$$\frac{136nV}{\sqrt{Hz}} \times \sqrt{.2}\sqrt{Hz} = \underline{\underline{61\ nV}}\ \text{rms} @ 50°C$$

Noise ≅ $\underline{\underline{57nV}}$ rms @ 25°C

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PROJECT [illegible]
SUBJECT Cooled Detector Gain Stage
PREPARED BY: [illegible]
DATE 5/14/75
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PAGE 4A OF

MEASURED NOISE Performance

Input Terminated in 1Meg

f	e_0 (HP302 with 6Hz Noise BW)
30Hz	200μv
60Hz	"
100Hz	"
200Hz	"
500Hz	"

Expected 1meg Resistor Noise:

$$= 1.27\times10^{-4}\sqrt{R\Delta f} =$$

$$= 1.27\times10^{-4}\sqrt{1meg \parallel 10meg}\times\sqrt{\Delta f}$$

$$= 1.27\times10^{-4}\times\sqrt{.91\times10^{6}}\times\sqrt{\Delta f}$$

$$= 121.2\,nv\times\sqrt{\Delta f}$$

$$= 121.2\,nv\times\sqrt{6} = \underline{297\,nv}\ rms$$

Measured noise referred to input

$$= \frac{200\,\mu v}{650} = \underline{308}\ nv\ rms$$

OR 125.7 nv/$\sqrt{Hz}$

Noise with input shorted

$$\cong \frac{25\,\mu v}{650} = 38.5\,nv \text{ in 6HZ BW}$$

So noise density $\simeq \dfrac{38.5}{\sqrt{6}}\ nv/\sqrt{Hz}$

$$\cong \underline{\underline{15.7\,nv}}/\sqrt{Hz}$$

which compares with Fet. Data sheets result.

TRW SYSTEMS GROUP		PREPARED BY:	ATTACHMENT	PAGE 5 OF
PROJECT FAPS	SUBJECT PbSe Detector Preamplifier	DATE 5/31/75		

7. AMPLIFIER STABILITY (GAIN/PHASE MARGIN)

a) FIRST STAGE RESPONSE

$$GAIN = g_m R_L \approx 15$$

$$\text{Rolloff freq} = \frac{1}{2\pi \times 2R_D \times C} = \frac{.159}{2 \times 26.1k \times 470pf}$$

$$= 6.48Kc$$

So

$$K_1 = \frac{15}{(24.5 \times 10^{-6})S + 1}$$

b) For LM108A OP-AMP WITH 100pf Compensation

$$A_{DC} = 3 \times 10^5$$

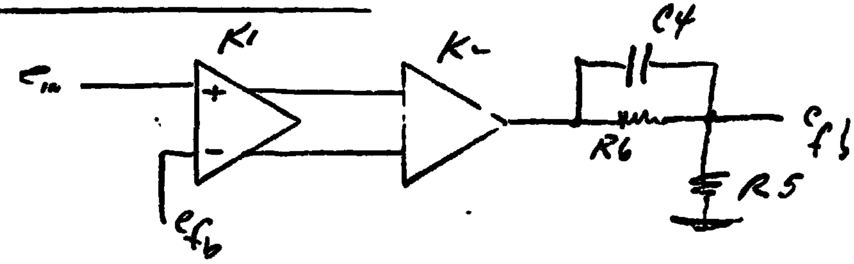
$$f_T \equiv 750Kc \text{ WITH } C_{comp} = 30pf$$

$$\therefore f_T = 225kc \quad C = 100pf$$

$$\therefore -3db\ f = .75HZ$$

$$\text{So Transfer function} = \frac{A_2}{T_2 S + 1} = \frac{3 \times 10^5}{.212 S + 1}$$

LOOP GAIN IS THEN :



7 Cont

RSSave Program for open Loop Response is Then:

```
LIST,PAMP2

500 FOR F=1,10,20,40,100,200,400,1E3,2E3,4E3,1E4,2E4,4E4
2000 DATA 15,24.3E-6,3E5,.212,484E3
2001 DATA 1E4,62E-12,10E6,.02E-6
2100 DATA 20,30,30,30,2
2101 DATA 2,2,20,20
2200 DATA A1,T1,A2,T2,F3
2201 DATA F2,C3,F1,C1
2300 DATA "PBSE PREAMP RESPONSE"
3000 K1= A0/CMPLX(1,A1*W)
3010 K2=A2/CMPLX(1,A3*W)
3015 Z1= A4/CMPLX(1,W*A4*A6)
3020 B=A5/(A5+Z1)
3030 Z2=CMPLX(0,W*A7*A9)/CMPLX(1,W*A7*A8)
3040 X1=K1*K2*B
3050 X2=Z2*(1/B)*(X1/(X1+1))
3200 X=X2
```

NOTE: LINE 3700
X= X1 for open Loop Response
X= X2 for Closed Loop Response

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7 cont.
Open Loop Response Data:

```
-.S ANALYSIS
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 FREQ              GAIN(DB)          +TOL.  -TOL.(DB)     PHASE     TOL(DEG)

 1.00000E+00       9.44990E+01       2.980    -4.574     -53.101       8.252
 1.00000E+01       7.64152E+01       3.339    -5.494     -85.686       1.293
 2.00000E+01       7.04129E+01       3.344    -5.507     -87.806        .646
 4.00000E+01       6.43969E+01       3.345    -5.511     -88.641        .340
 1.00000E+02       5.64339E+01       3.345    -5.512     -89.360        .296
 2.00000E+02       5.04214E+01       3.345    -5.512     -89.366        .536
 4.00000E+02       4.44081E+01       3.345    -5.512     -89.057       1.062
 1.00000E+03       3.64489E+01       3.346    -5.512     -87.927       2.602
 2.00000E+03       3.06367E+01       3.349    -5.522     -86.283       4.364
 4.00000E+03       2.50549E+01       3.387    -5.627     -84.620       7.713
 1.00000E+04       1.79505E+01       3.608    -6.284     -86.397       7.877
 2.00000E+04       1.22629E+01       3.765    -6.793     -90.796       5.061
 4.00000E+04       6.28891E+00       3.825    -7.000     -96.788       2.728
 1.00000E+05      -2.12199E+00       3.844    -7.064    -110.130       1.218
 2.00000E+05      -9.55212E+00       3.845    -7.069    -126.986        .937

THE ARGUMENTS AND TOLERANCES ARE:

A1          A0   15          20        R2          A5   10000       2
T1          A1   .245E-04    30        C3          A6   .62E-10     2
A2          A2   300000      30        R1          A7   10000000    20
T2          A3   .212E+00    30        C1          A8   .2E-07      20
R3          A4   499000      2

 PROGRAM: PBCM PREAMP RESPONSE
 05 30 75.     08.36.10.
```

So we see phase margin exceeds 70°
& adequate stability is insured.

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PROJECT	SUBJECT		PREPARED BY:	ATTACHMENT	PAGE
MMPS	PBCE	PREAMPLIFIER	DATE 5/30/75		OF

8 Closed Loop Response Data

```
AC ANALYSIS
------------


 FREQ           GAIN(V/V)           TOL.(%)     PHASE         TOL(DEG)

 1.00000E+00    3.98277E+01         11.311      38.5001          7.895
 1.00000E+01    5.07324E+01          2.778       4.4320          1.281
 2.00000E+01    5.08538E+01          2.773       2.0429           .644
 4.00000E+01    5.08878E+01          2.773        .6684           .383
 1.00000E+02    5.08879E+01          2.772       -.7221           .139
 2.00000E+02    5.08593E+01          2.770      -2.1273           .122
 4.00000E+02    5.07408E+01          2.763      -4.5894           .209
 1.00000E+03    4.99325E+01          2.718     -11.5924           .509
 2.00000E+03    4.73317E+01          2.603     -22.4612           .965
 4.00000E+03    3.99165E+01          2.513     -40.1462          1.701
 1.00000E+04    2.29578E+01          2.993.    -67.7312          3.735
 2.00000E+04    1.23546E+01          3.641     -84.9447          7.339
 4.00000E+04    6.20434E+00          8.188    -101.0533         13.867

THE ARGUMENTS AND TOLERANCES ARE:

A1          A0   15          20        P2         A5   10000       2
T1          A1   .245E-04    30        C3         A6   .62E-10     2
A2          A2   300000      30        P1         A7   10000000    20
T2          A3   .212E+00    30        C1         A8   .2E-07      20
P3          A4   495000      2


 PROGRAM: PBCN PREAMP RESPONSE
 05 30 75.      08.22.06.
```

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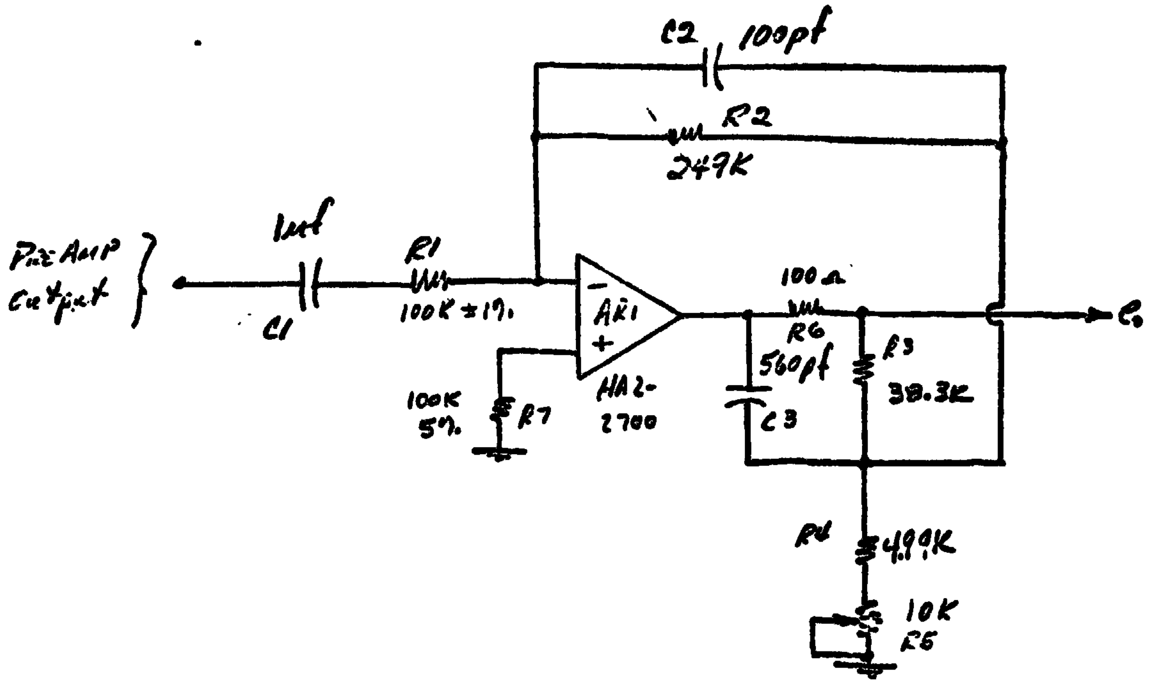

1] INPUT COUPLING NETWORK.

$$f_{Low} = \frac{.159}{1\mu f \times 100K} = 1.59HZ$$

(MIN. Chopping freq = [illegible]

2]. MID-BAND GAIN

$$= \left(\frac{R_2}{R_1}\right)\left(\frac{R_3+R_4+R_5}{R_4+R_5}\right) = 2.49\left(\frac{48.3}{9.99}\right) = 12.04$$

NOMINAL

$$= 2.49(3.56) = 8.85 \text{ MINIMUM}$$

$$= 2.49(8.68) = 21.6 \text{ MAX.}$$

3] HIGH FREQUENCY Rolloff — Set by R_2C_2 and R_3C_3 time Constants.

$$f = \frac{.159}{249\times10^{3}\times100\times10^{-12}} = \frac{.15900\times10^{-5}}{2.49\times10^{-5}} = 6.4Kc$$

APPENDIX D

DESIGN ANALYSIS REPORT, CHOPPER MOTOR DRIVE AND PICKOFF CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides design and analysis documentation for the chopper motor drive and pickoff circuits of the MAPS Breadboard.

2.0 CIRCUIT REQUIREMENTS

The function of these circuits is to provide a variable voltage, variable frequency 2-phase square wave voltage drive to a synchronous motor and to provide the S and R demodulation timing signals.

a) Internal Oscillator

Provide an internal clock oscillator which will provide three different switch selectable motor operating speeds. The basic oscillator operating frequencies shall be 125HZ, 458HZ, and 916HZ.

Provision shall also be made to accept an external clock input.

b) Two-Phase Drive Logic

Provide two square wave logic signals with a 90 degree phase relationship which have an output frequency which is one-fourth that of the clock oscillator.

c) Motor Drivers

Two separate ØA and ØB motor drive circuits shall be provided which have the following characteristics:

- Low impedance square wave output
- Output voltage - within ± 1 volt of the supply voltage for a range of supply voltages from ± 16 volts to ± 60 volts.
- Drive capability - must drive synchronous motor with characteristics per specification 2B006.

d) Pickoff Circuits

The chopper disc pickoff circuits shall provide wheel timing signals as follows:

- Lamp bias networks - Each of 2 light emitting diodes shall be provided with a bias current adequate to give sufficient detector signals.
- Pickoff Amplifier - The outputs of 2 separate phototransistors shall be sensed and a 0 to + 5 volt square wave developed by the use of a zero crossing detector.
- Timing Adjustment delay circuit - a delay circuit shall be provided for each pickoff signal which allows an adjustable delay of the square wave signal by up to 1 percent of its period.

3.0 CIRCUIT DESCRIPTION AND ANALYSIS RESULTS

The motor drive circuitry is shown on sketch schematic SK-MAPS-BB-101 and the pickoff circuitry is shown on sketch schematic SK-MAPS-BB-103.

The attached circuit analyses sheets provide an assessment of circuit performance.

3.1 Motor Drive Circuits

The basic motor drive clock signal is obtained from an SE555 timing IC which is connected as a free running square wave oscillator.

The two 90° phase related drive signals are then obtained from a cross connected 2 bit shift register. (See analysis page 2.)

The drive signals are increased to 15 volts peak-to-peak by a 2N2222 stage and then ac coupled to the output drivers. AC coupling is used so that the loss of the clock signal or external sync will result in the removal of all motor voltages.

The output stage consists of a complementary pair of transistor switches which alternately switch one side of the motor winding between the plus and minus supply voltage. Clamp diodes (IN4944's) across the switches provide current paths for transient inductive motor currents.

3.2 Scene and Reference Pickoff Circuits

Two phototransistor and light emitting diode pairs provide the pickup of the S and R timing signals. As is shown on analysis page 5, a HA2-2700 IC operational amplifier is connected as a voltage comparator with positive feedback to develop a square wave output from the phototransistor signal. The phototransistor output is AC coupled so the circuit switches only on zero crossings and is immune to steady state light level responses of the phototransistor.

Analysis pages 6 and 7 show the timing of the adjustable delay circuit which provides an overall timing signal delay. The delay equals the period of the one shot circuit using the 2N2222 transistor.

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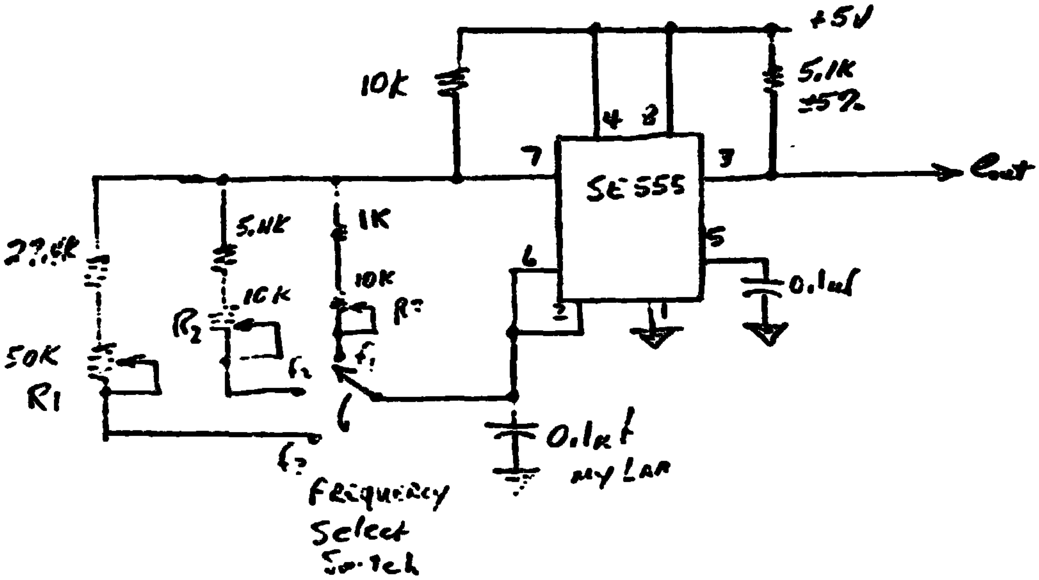
PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
[illegible]	[illegible] MOTOR DRIVE CIRCUIT	[illegible]		1
		DATE 6/1/75		OF

i) INTERNAL CLOCK OSCILLATOR

A) CIRCUIT



OSCILLATOR = SE555 CONNECTED AS ASTABLE MULTIVIBRATOR.

$$f_{osc} = \frac{1.44}{(R_2 + 2R_3)C}$$

where R_2 = resistance from pin 7 to +

R_3 = resistance from pin 7 to pin 6

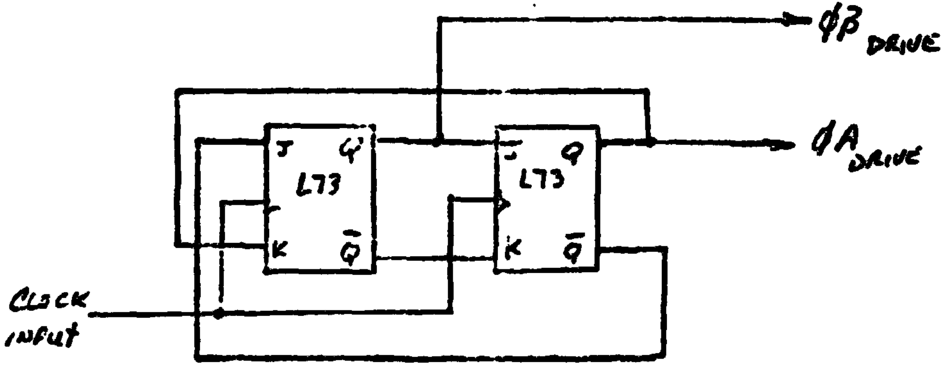
C = Capacitance, pin 6 to ground

POTS R1, R2 & R3 set 3 separate frequencies of 125HZ, 458HZ, and 916HZ.

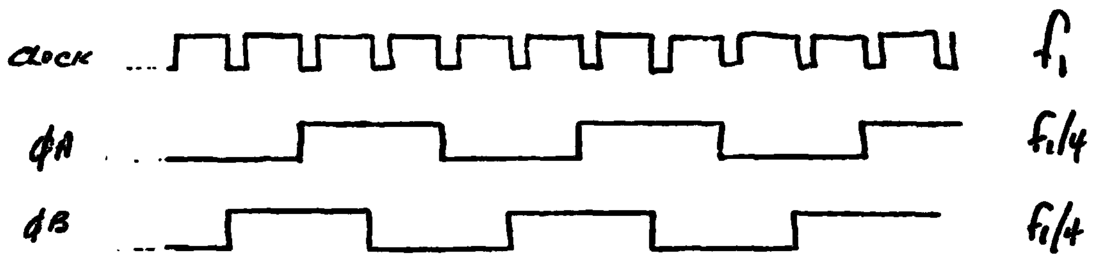
2) 90° PHASE SHIFT NETWORK

2 Bit Shift Reg. Provides ØA & ØB Clock Waveforms

a) Circuit



b) Timing Waveforms



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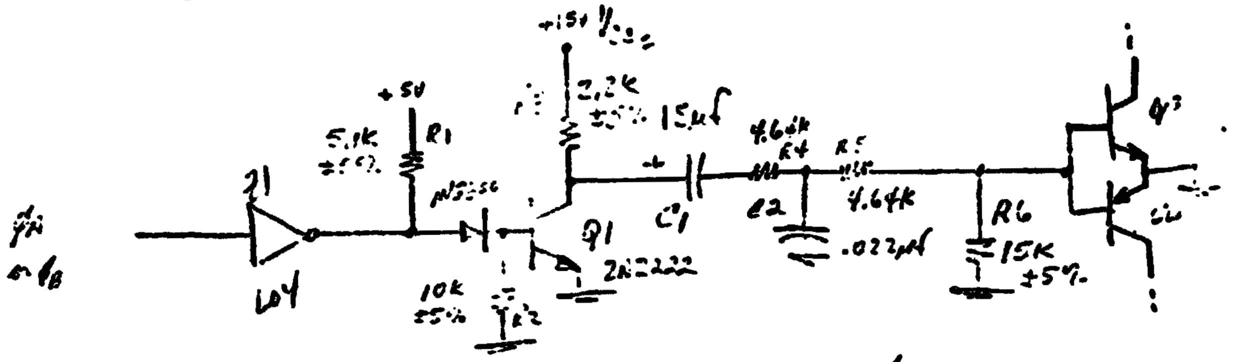
3) DRIVER STAGE



Voltage To output Swing = ± V_{BE}(Q3 & Q4)

(a) output drive
BASE CURRENT

$$= \frac{\frac{1}{2}(V_{CC_2} - V_{BE})}{R_3 + R_4 + R_5} - \frac{V_{BE}}{R6} = \frac{\frac{1}{2}(15-.75)}{(2.2K+2\times4.64K)} - \frac{.75}{15K}$$

$= 0.57$ ma Nominal

(b) minimum output BASE DRIVE

$$= \frac{1}{2}\left(\frac{14.75-.85}{2.2K(1.2)+2(4.64K)(1.03)}\right) - \frac{.85}{15K(.8)} = \underline{\underline{0.53\ ma}}$$

(c) MAX Collector Current Q1

$$= \frac{15.25V}{2.2K(.8)} = 9.66\,ma$$

(d) minimum BASE DRIVE, Q1 $= \dfrac{4.75 - V_{BE} - V_d}{R_1} - \dfrac{V_{BE}}{R2}$

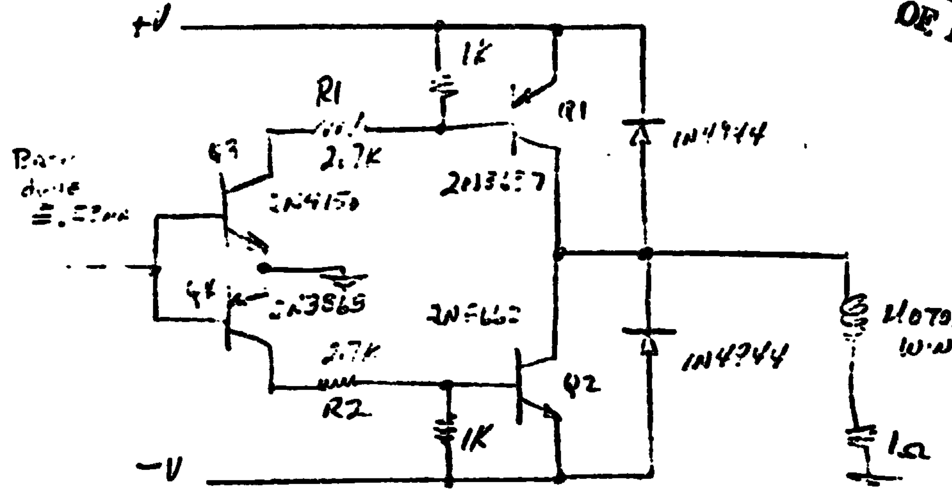
$$= \frac{4.75-.85-.75}{5.1K(1.2)} - \frac{.85}{10K(.8)} = 0.41\,ma$$

$\therefore \beta \geq \frac{8.66}{.41} \geq 21.2$ is Required

e) MAX CURRENT SINK By Z1 IS $\frac{5.25}{5.1K(.8)} = 1.3$ma.

LO4 CAN SINK $\underline{\underline{2.0ma}}$ ∴ DRIVE IS OK.

4) OUTPUT STAGE



(a) CASE I, $V_{cc} = \pm 28V$, Low freq.

Load Current

@ Low freq & ±28V is Determined by Motor R of 265Ω

$$I_{peak} = \frac{28V}{265\Omega} = 106ma$$

$$I_B(Q1 \text{ or } Q2) = \frac{V_{cc} - V_{BE} - V_{SAT}(Q3 \text{ or } Q4)}{R1 \text{ or } R2} - \frac{V_{BE}}{1K}$$

$$\geq \frac{28 - .8 - .3}{2.7k(1.2)} - \frac{.8}{1k(.8)} \geq 7.3ma$$

$$\therefore \beta(Q1 \text{ or } Q2) \geq \frac{106}{7.3} \geq 14.5 \text{ is needed}$$

(b) Q3 & Q4 DRIVE

$$I_{c\,max}(Q3 \text{ or } Q4) = \frac{28V - .15 - .1}{2.7k(.8)} = 12.62ma$$

$$\therefore \beta(Q3 \text{ or } Q4) \geq \frac{12.62}{.53} \overset{>}{=} 23.8 \text{ is required.}$$

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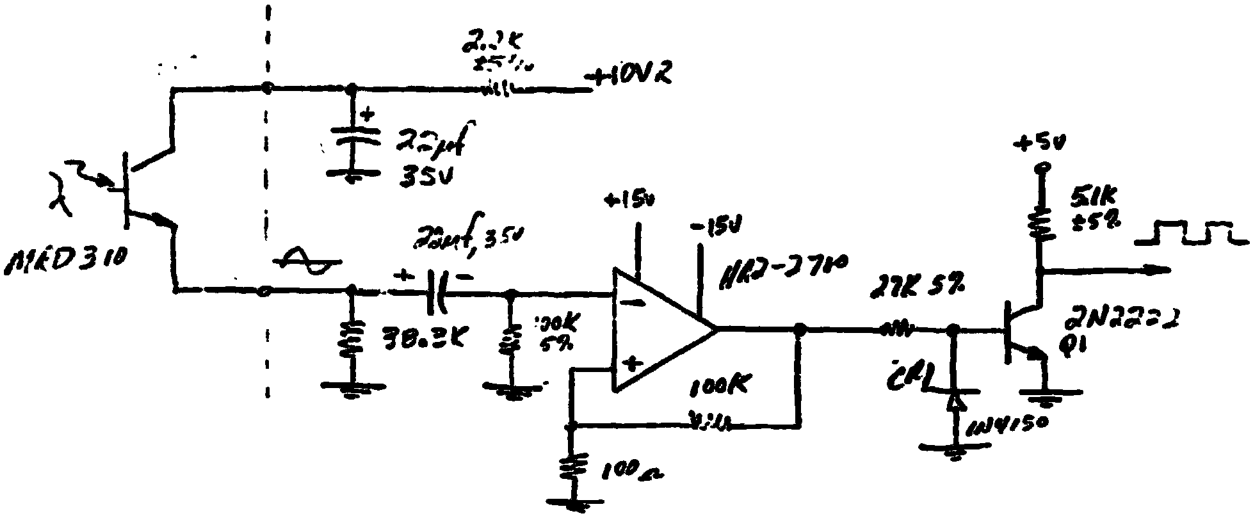
ATTACHMENT
PAGE 5 **OF**
PROJECT MAPS
SUBJECT SIGNAL PROCESSING Pickoff Ckts.
DATE

S + R Pickoff Amplifiers



1) HA2-2700 ACTS AS Zero Crossing Squaring Amplifier To AC SIGNALS.

2) Positive feedback

$$= \pm 14v \times \frac{100}{10^5} = \pm \underline{14 \text{ MILLIVOLTS}}$$

3) BASE DRIVE To Q1

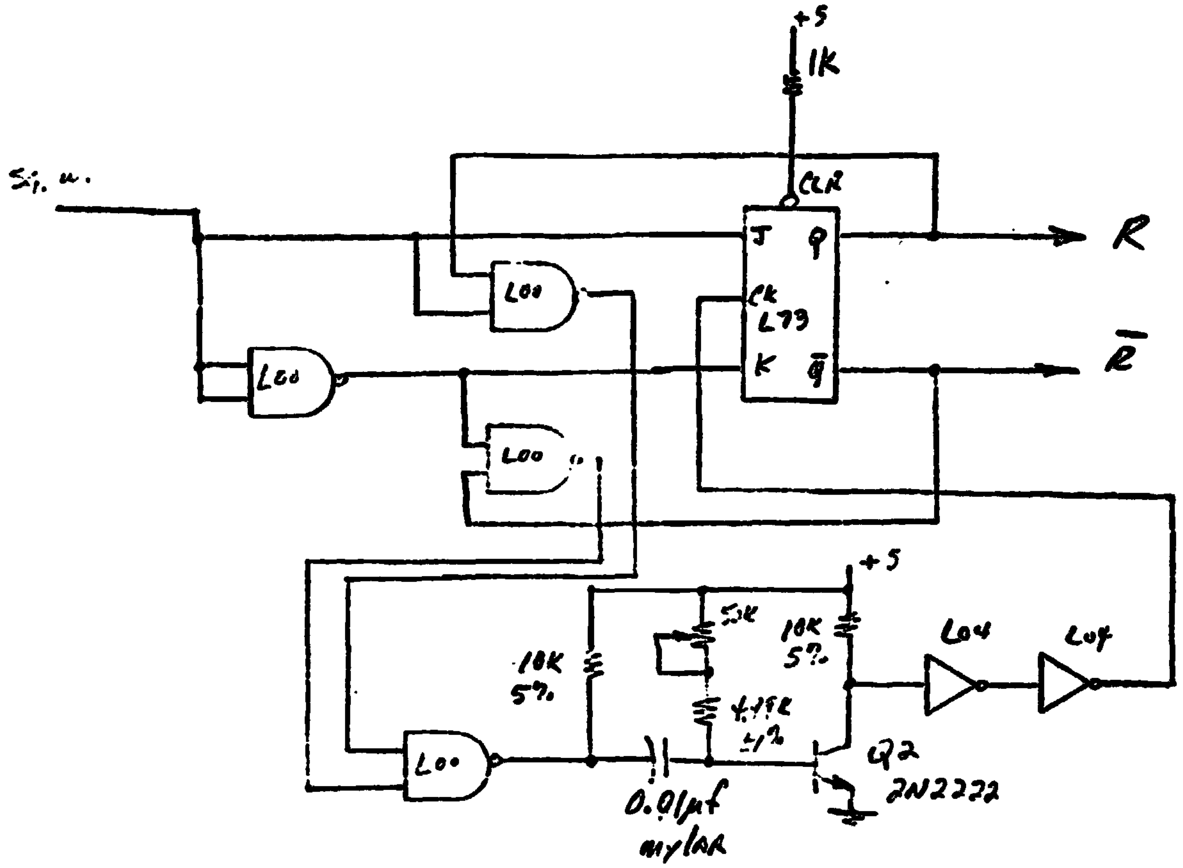
$$\geq \frac{12V}{27K} \geq .44ma$$

Q1 Collector Current ≅ 1.5ma including Logic loads

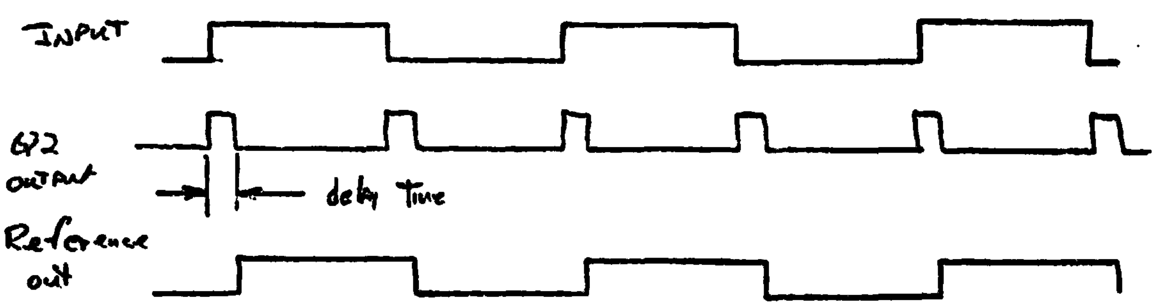
∴ Q1 operates at forced Beta of <10.

4) Diode CR1 PROVIDES Reverse Bias when Q1 is off.

S & R Reference Delay Circuits



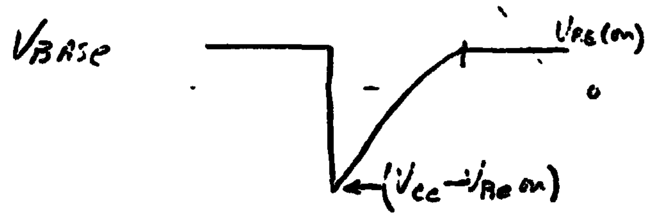
1) CIRCUIT TIMING



Delay is set by one-shot ckt.

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
[illegible]	Signal Processing Pickoff Circuits	DATE		7 OF

ONE SHOT TIME Delay



$$\text{So } V_B = -(V_{cc}-V_{Be}) + [(V_{cc}-V_{Low}) + (V_{cc}-V_{Be})]\,e^{-t/\tau}$$

where τ = RC

V_{Low} = Low State Voltage of 400 GAT.

$$\therefore\ t_p = RC\,\ln\left[\frac{2V_{cc}-V_{SAT}-V_{Be}}{V_{cc}}\right]$$

WITH Pot at MID Range of 25K

$$\text{nominal } t_p = 30\times10^3\times.01\times10^{-6}\,\ln\left[\frac{10-.05-.75}{5}\right]$$

$$= \underline{0.183\text{ milliseconds}}$$

Period of 5 Reference = 20MS

So Delay ≅ 0.9% Nominal

Stability of t_p

$$t_p = 30K(1.05)(.01\times10^{-6})(1.03)\,\ln\left[\frac{10(1.05)-.02-.6}{5(1.05)}\right]$$

$$= 0.205\text{ millisec MAX}$$

$$t_p = 30K(.95)(.01\times10^{-6})(.97)\,\ln\left[\frac{10(.95)-.2-.85}{5(.95)}\right]$$

$$= \underline{0.159\text{MS}}\text{ MIN}$$

= ±13% W.C.

If total delay is only 1% of Period, Then 13% Variation is only ±.13% of timing interval

APPENDIX E

DESIGN ANALYSIS REPORT TEMPERATURE SENSING AND CONTROL CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides the design analysis documentation for the three blackbody temperature sensing circuits, for the three detector temperature sensing and control circuits and for the on-off temperature controller circuit.

2.0 CIRCUIT REQUIREMENTS

2.1 Room Temperature Blackbodies

For each of 2 unheated blackbodies, provide an analog voltage proportional to temperature over a minimum range of 7°C to 37°C. The output signal range shall be ±5 volts with a measurement accuracy of ±0.25°C.

2.2 Heated Blackbody

For the heated blackbody, provide the analog output over a minimum temperature range of 67°C to 87°C with an accuracy of ±0.25°C. The output signal range shall be ±5V nominal.

2.3 Cooled Detectors

For each of 3 cooled detectors, an analog voltage output shall be generated using the thermistor internal to the detector (per PIN 8D007). The measurement range shall be a minimum of -65°C to -90°C with a measurement accuracy of ±3°C with individual thermistor calibration.

In addition, the temperature readout voltage shall be compared with a set point voltage and the difference signal used to control the voltage applied to each detector thermoelectric cooler to maintain a constant detector temperature.

2.4 On/Off Blackbody Heater Driver

An on/off temperature controller shall be provided which switches 28V, 10 watts max, to the blackbody heater.

The set point temperature shall be adjustable from 72 to 80°C.

The switching point dead zone shall be as required for ±3°C temperature control.

3.0 CIRCUIT DESCRIPTIONS

3.1 Temperature Sensing Circuits

The six temperature sensing circuits are shown on sketch schematic SK-MAPS-BB-104. The circuits are identical in the sense that a thermistor-resistor bridge circuit and a gain scaling isolation amplifier are used in all cases.

The three blackbody sensing circuits use YSI precision thermistors which provide matched interchangeable temperature/resistance characteristics to within ±0.5 percent.

The three cooled detector circuits use the thermistors internal to the detector. Because of the wide variation in thermistor characteristics from detector to detector, a selectable shunt resistance is placed across the thermistor in each case. Individual circuit calibration is still necessary however.

3.2 Blackbody Heater Drive

The blackbody heater drive circuitry and the 3 detector T.E. cooler control circuits are shown on sketch schematic SK-MAPS-BB-101.

Transistors Q12 (2N2222) and Q13 (2N5153) comprise the heater on/off voltage switch. A Harris 2700 operational amplifier is used as a voltage comparator to drive the voltage switch. The blackbody temperature voltage is then compared with a set point voltage at the input of the voltage comparator to provide the control action. Positive feedback around the comparator sets up the switching dead zone.

3.3 Thermoelectric Cooler Controllers

The T.E. cooler drive and control circuits are shown on sketch schematic SK-MAPS-BB-101. Each T.E. cooler is provided with a low impedance drive voltage from a darlington connected emitter follower circuit. The emitter follower is driven by a gain of 100 control amplifier which uses an LM108A I.C. operational amplifier.

The control amplifier compares a temperature set point voltage from a potentiometer voltage divider with the output of the detector temperature sensing circuit and amplifies the difference voltage to provide temperature control.

4.0 CIRCUIT ANALYSIS

The attached sketch sheets provide supporting circuit performance analyses.

Pages 1 through 4 of the attached analysis show a rss uncertainty in the unheated blackbody temperature measurements of ±37.2 millivolts or ±0.14°C at a nominal temperature of 22°C.

Pages 5 through 7 give the program results for the heated blackbody. The rss uncertainty in readout at 77°C is ±0.2°C.

Pages 8 and 9 cover the cooled detector temperature sensing circuits using data from opto-electronics detector S/N 005. As the data shows a thermistor shunt resistor must be selected for each detector and a separate output calibration curve will be needed because of the differences in the detector thermistors.

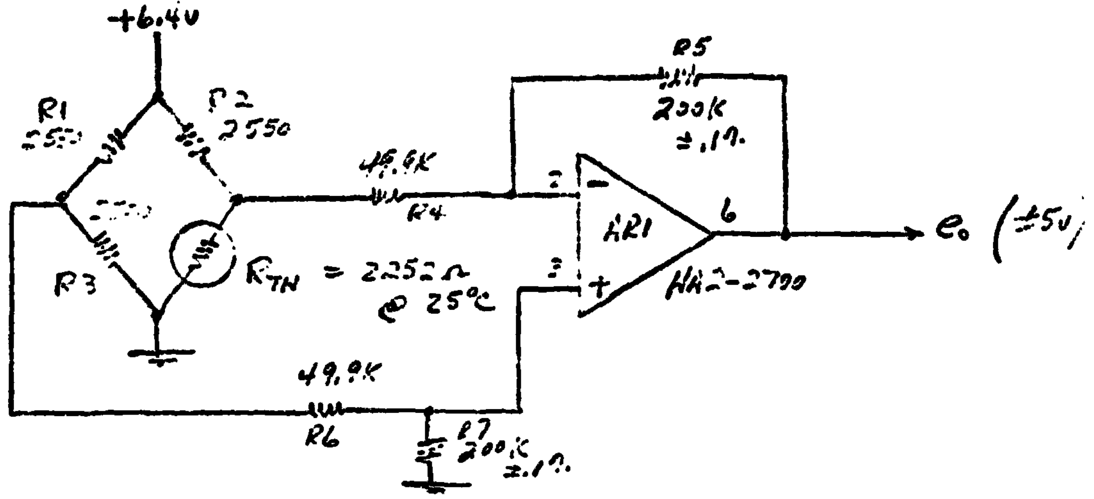
Page 10 shows the thermoelectric cooler drive circuitry and feedback control amplifier.

Analysis pages 11 through 14 cover the temperature controller circuit.

An adequate drive capability is shown along with an adequate set point adjustment range and dead zone.

ROOM TEMP BB TEMP SENSE AMPLIFIER

1. CIRCUIT



THERMISTOR CHARACTERISTICS PER YSI # 44033

RSSWC1 PROGRAM INPUT

```
LIST,TEMP1

500 FOR I=1 TO 16
2000 DATA 7155,5719,5183,4486,3529,3226,2814
2001 DATA 2572,2252,2064,1915,1657,1471,1355,1200,983.8
2010 DATA 6.4,2550,2550,2550,49.9E3,2E5,49.9E3,2E5
2050 DATA 50E-3,50E-3
2100 DATA .5,.5,.5,.5,.5,.5,.5
2101 DATA .5,.5,.5,.5,.5,.5,.5,.5,.5
2110 DATA .25,.05,.05,.05,.05,.05,.05,.05
2120 DATA 0,10
2200 DATA F0,F5,F7,F10,F15,F17,F20
2201 DATA F22,F25,F27,F30,F32,F35,F37,F40,F45
[illegible] [illegible],F1,F2,F3,F4,F5,F6,F7
[illegible]
[illegible] DATA "TEMP SENSE AMPLIFIER"
[illegible] DATA 0,50,70,100,150,170,200,220,250,270,300,320,350,370,400,450
[illegible] Z1=[illegible]
[illegible] Z2=[illegible]
[illegible] V1=[illegible]
[illegible] V2=[illegible]
[illegible] -V1*(C1+C0*Z1)*(C1+C0*Z1[illegible]
[illegible]
```

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TRW
SYSTEMS GROUP

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
MARS	Temp Sense & Control Circuits			OF
		DATE		

Program Output for 22°C ± 15°C

```
PCI ANALYSIS
......................

Temp                    Voltage
 X-AXIS                  OUTPUT               TOL.       -LIM.            +LIM.

0C                     -5.96394E+00           .58     -5.99855E+00     -5.92934E+00
5C                     -4.72339E+00           .75     -4.75871E+00     -4.68808E+00
7C  min. Temp          -4.20094E+00           .65     -4.22656E+00     -4.16531E+00
10C                    -3.39530E+00          1.06     -3.43137E+00     -3.35922E+00
15C                    -2.01284E+00          1.82     -2.04956E+00     -1.97611E+00
17C                    -1.45200E+00          2.54     -1.48892E+00     -1.41508E+00
20C                    -6.11639E-01          6.07     -6.48770E-01     -5.74507E-01
22C                    -5.34378E-02         69.64     -9.06498E-02     -1.62258E-02
25C                     7.73354E-01          4.82      7.36112E-01      8.10595E-01
27C                     1.31405E+00          2.83      1.27635E+00      1.35125E+00
30C                     2.10398E+00          1.76      2.06591E+00      2.14104E+00
32C                     2.61903E+00          1.41      2.58210E+00      2.65596E+00
35C                     3.36134E+00          1.09      3.32466E+00      3.39802E+00
37C max Temp            3.83692E+00           .95      3.80043E+00      3.87341E+00
40C                     4.51988E+00           .80      4.48371E+00      4.55606E+00
45C                     5.57621E+00           .64      5.54055E+00      5.61188E+00


THE ARGUMENTS AND TOLERANCES ARE:

R0          A0   7255          .5E+00   R37        B3    1355          .5E+00
R5          A1   5719          .5E+00   R40        B4    1200          .5E+00
R7          A2   5183          .5E+00   R45        B5    983.8         .5E+00
R10         A3   4422          .5E+00   VB         B6    6.4           .25E+00
R15         A4   3539          .5E+00   R1         B7    2550          .5E-01
R17         A5   3226          .5E+00   R2         B8    2550          .5E-01
R20         A6   2814          .5E+00   R3         B9    2550          .5E-01
R22         A7   2572          .5E+00   R4         C0    49900         .5E-01
R25         A8   2252          .5E+00   R5         C1    200000        .5E-01
R27         A9   2064          .5E+00   R6         C2    49900         .5E-01
R30         B0   1815          .5E+00   R7         C3    200000        .5E-01
R32         B1   1667          .5E+00   E1         C4    .5E-01        0
R35         B2   1471          .5E+00   E2         C5    .5E-01        10


 PROGRAM: TEMP SENSE AMPLIFIER
 05/07/75.       08.28.13.
```

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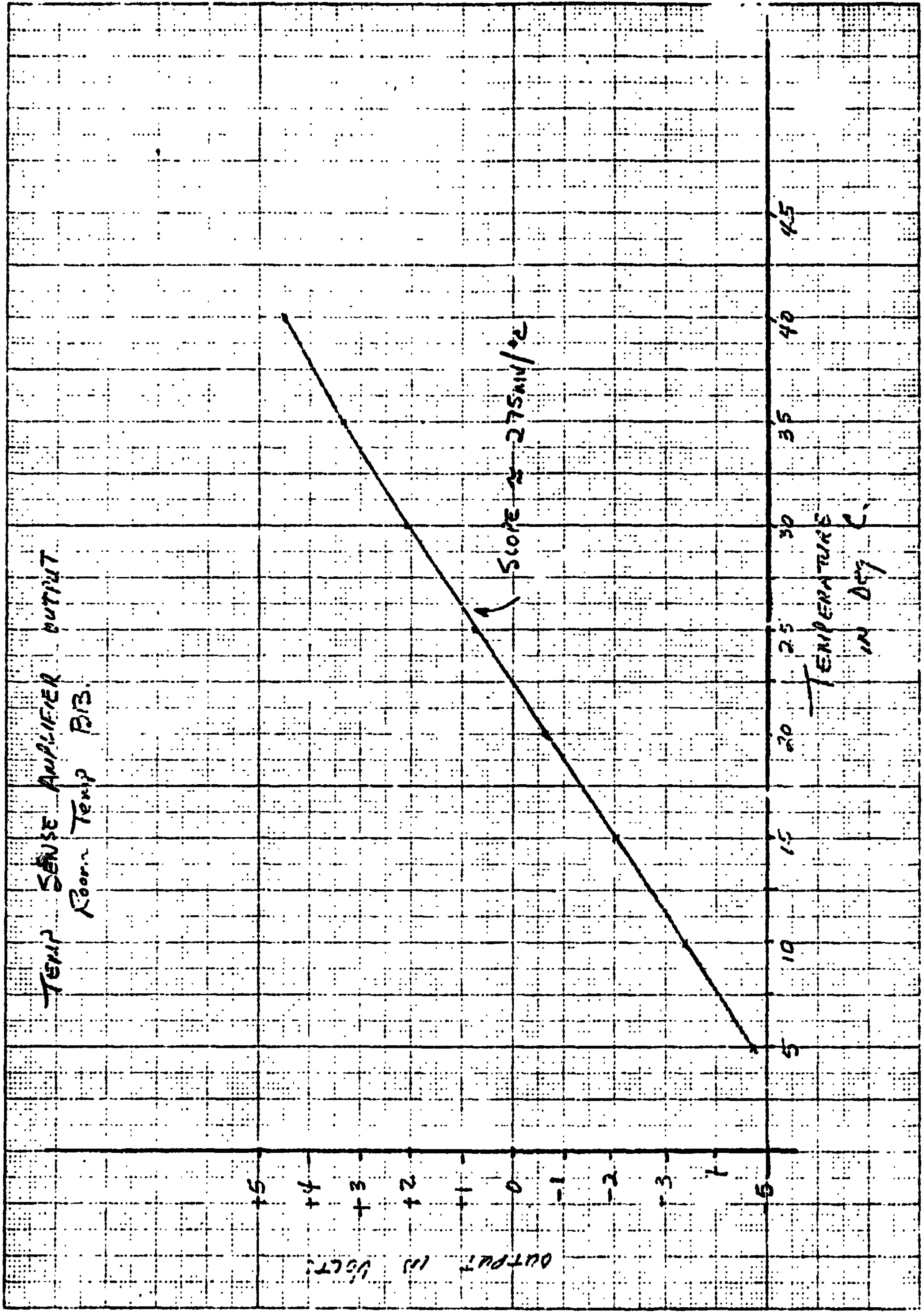
P3


TEMP SENSE AMPLIFIER OUTPUT
Room Temp BB.
SLOPE ≈ 275mV/°C
TEMPERATURE IN DEG C.
5
10
15
20
25
30
35
40
45
OUTPUT IN VOLTS
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5

TRW
SYSTEMS GROUP

PROJECT: MAPS

SUBJECT: TEMP Sense of Control Circuits

PREPARED BY:

DATE:

ATTACHMENT:

PAGE: 4 OF

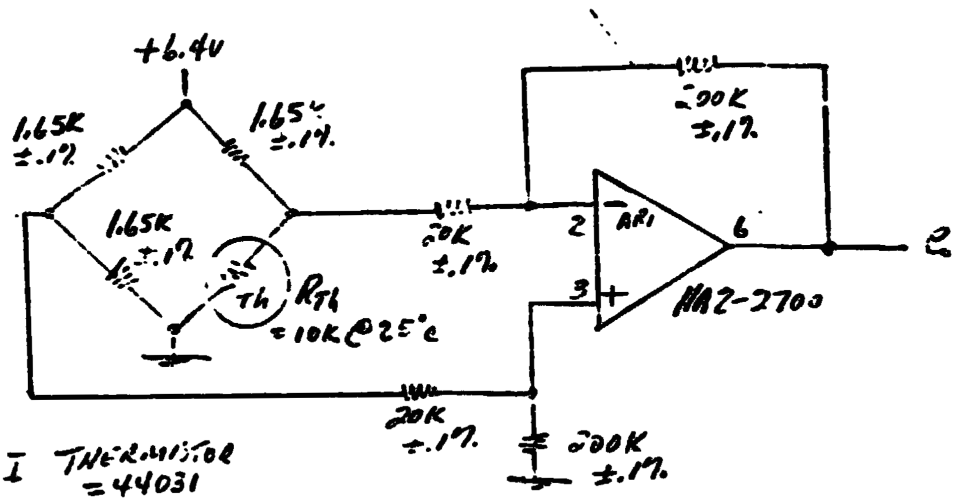
PER PLOTTED DATA

SLOPE of OUTPUT ≅ 275 mv/°C

UNCERTAINTY IN VOLTAGE OUTPUT @ 22°C = ±37.2 mv.

which is ±0.14 °C

HOT SB TEMP SENSE AMPLIFIER



YSI THERMISTOR
=44031
R_{Th}= 1598Ω @77°C

RSSWC1 PROGRAM INPUT

```
LIST,TEMP2

500 FOR T=1 TO 16
2000 DATA 2669,2447,2339,2191,2055,1928,1810
2001 DATA 1700,1598,1503,1414,1332,1255,1163,1116,1053
2010 DATA 6.4,1650,1650,1650,2E4,2E5,2E4,2E5
2020 DATA 50E-3,50E-3
2100 DATA .5,.5,.5,.5,.5,.5,.5
2101 DATA .5,.5,.5,.5,.5,.5,.5,.5,.5
2110 DATA .25,.05,.05,.05,.05,.05,.05,.05
2120 DATA 0,10
2200 DATA R61,R63,R65,R67,R69,R71,R73
2201 DATA R75,R77,R79,R81,R83,R85,R87,R89,R91
2210 DATA VB,R1,R2,R3,R4,R5,R6,R7
2215 DATA E1,E2
2300 DATA "HOT SE TEMP SENSE AMPLIFIER"
2400 DATA 610,630,650,670,690,710,730,750
2401 DATA 770,790,810,830,850,870,890,910
3000 Z1=R3*R(T)/(R2+R(T))
3010 Z2=R7*R4/(R7+R4)
3020 V1=R6*R(T)/(R3+R(T))
3030 V2=R6*R4/(R7+R5)
4000 X= V2*(C3/(C3+C2+Z2))*(1+C1/(C0+Z1))-V1*(C1/(C0+Z1))+(C1/(C0+Z1))*
+ (C4-C5)
```

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Program output for 77°C ± 10°C

```
   - HARDWARE
-------------

TEMPERATURE    VOLTAGE
DEG.C          OUTPUT              TOL.         -LIM.              +LIM.

61C            -7.15683E+00        1.24     -7.24536E+00       -7.06826E+00
63C            -6.20324E+00        1.44     -6.29233E+00       -6.11417E+00
65C            -5.25246E+00        1.71     -5.34202E+00       -5.16290E+00
67C  min       -4.28850E+00        2.10     -4.37852E+00       -4.19849E+00
69C            -3.33242E+00        2.71     -3.42283E+00       -3.24201E+00
71C            -2.37159E+00        3.83     -2.46235E+00       -2.28083E+00
73C            -1.41325E+00        6.44     -1.50430E+00       -1.32220E+00
75C            -4.56707E-01       19.99     -5.47993E-01       -3.65421E-01
77C  nom        4.90492E-01       18.65      3.99032E-01        5.81952E-01
79C             1.42760E+00        6.59      1.33352E+00        1.52167E+00
81C             2.36548E+00        3.87      2.27385E+00        2.45712E+00
83C             3.27889E+00        2.79      3.18726E+00        3.37053E+00
85C             4.18565E+00        2.19      4.09403E+00        4.27727E+00
87C  MAX        5.08025E+00        1.80      4.98876E+00        5.17175E+00
89C             5.95652E+00        1.53      5.86517E+00        6.04788E+00
91C             6.82204E+00        1.34      6.73086E+00        6.91322E+00


THE ARGUMENTS AND TOLERANCES ARE.

R61         A0   2669          .5E+00   R87        B3   1183           .5E+00
R63         A1   2497          .5E+00   R89        B4   1116           .5E+00
R65         A2   2339          .5E+00   R91        B5   1053           .5E+00
R67         A3   2191          .5E+00   VR         B6   6.4            .25E+00
R69         A4   2055          .5E+00   P1         B7   1650           .5E-01
R71         A5   1928          .5E+00   P2         B8   1650           .5E-01
R73         A6   1810          .5E+00   P3         B9   1650           .5E-01
R75         A7   1700          .5E+00   P4         C0   20000          .5E-01
R77         A8   1598          .5E+00   R5         C1   200000         .5E-01
R79         A9   1503          .5E+00   P6         C2   20000          .5E-01
R81         B0   1414          .5E+00   R7         C3   200000         .5E-01
R83         B1   1332          .5E+00   E1         C4   .5E-01         0
R85         B2   1255          .5E+00   E2         C5   .5E-01         10


 PROGRAM: HUF 12 TEMP SENSE AMPLIFIER
 05/29/75.     08.01.15.
```

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PROJECT MAPS

SUBJECT Temp Sense & Control Circuits

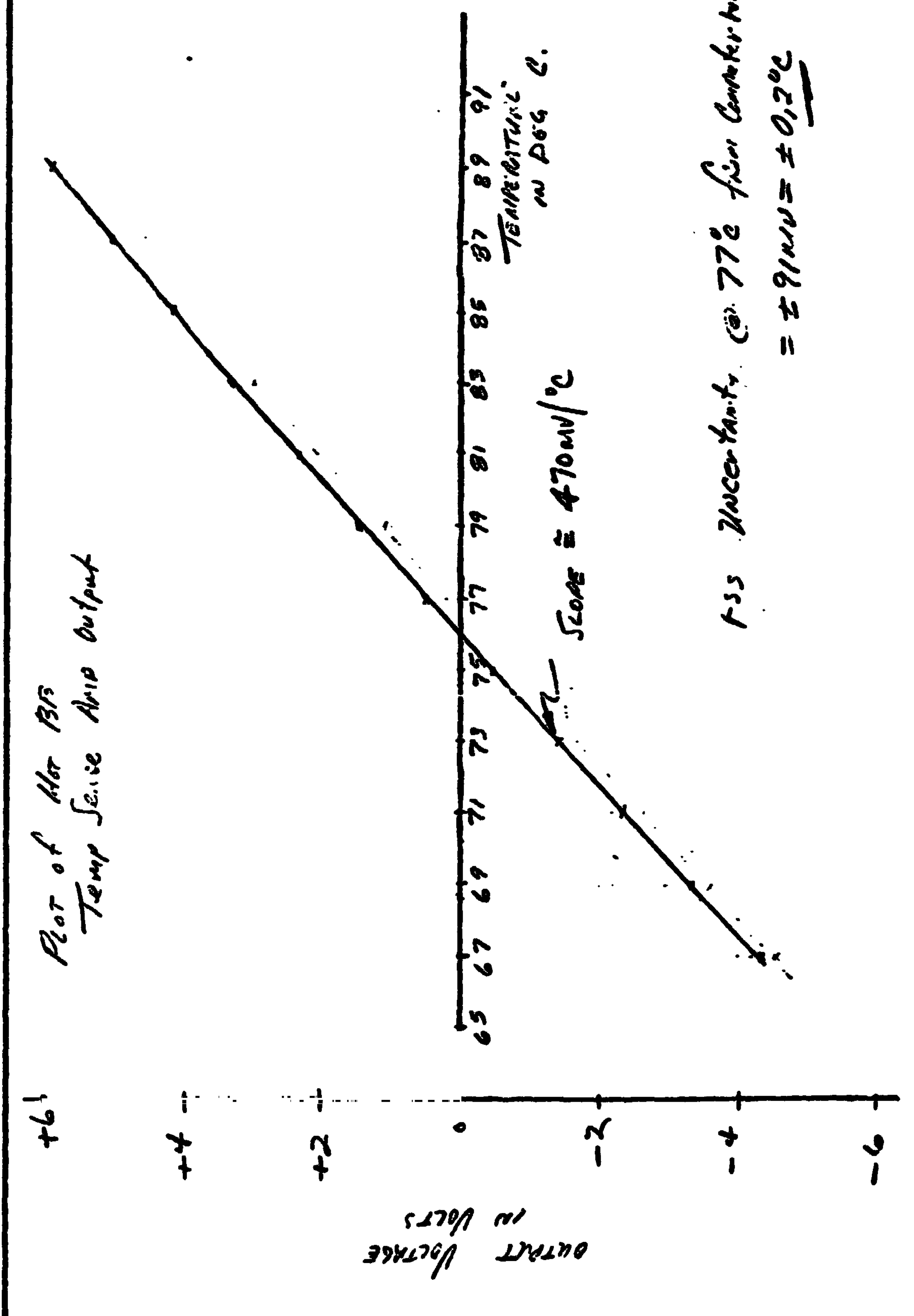
PREPARED BY: NFE

DATE

ATTACHMENT

PAGE 7 OF

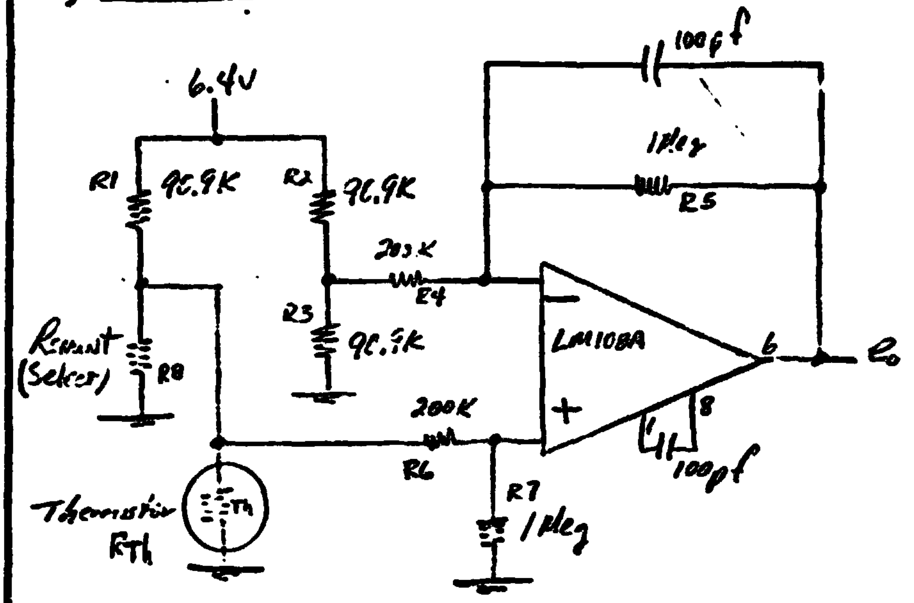
Plot of Hot BB Temp Sense Amp Output



TRW
SYSTEMS GROUP

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
MAPS	Cooled detector Temperature Readout	JHE DATE 10/9/75		2 OF

1) Circuit



2) Thermistor Shunt

Because of a wide range of variation in thermistor resistance vs temperature, a selectable paralleling shunt resistance is used to null the bridge at ≃ −75°C.

3) THERMISTOR CHARACTERISTICS

3 Typical Thermistors from Opto-Electronics data are show below

Temperature	Resistance S/N 005	Resistance S/N 004	Resistance S/N 006
-40C	31.3K	34K	
-45C	38K	40.5K	
-50C	47K	54K	37K
-55C	59K	71K	48K
-60C	75K	100K	62K
-65C	97K	145K	84K
-70C	129K	385K	110K
-80C	250K	710K	210K
-85C	378K		300K

TRW
SYSTEMS GROUP

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE OF
MAPS	Cooled detector Readout	DLE DATE 10/9/75		

4) OUTPUT CHARACTERISTICS

FOR CKT SHOWN:

$$e_o = \left(\frac{-R_5}{R_4 + R_2 \| R_3}\right)\left(\frac{6.4\, R_3}{R_1 + R_3}\right) + \left(1 + \frac{R_5}{R_4 + R_2 \| R_3}\right)\left(\frac{6.4\, R_x}{R_1 + R_x}\right)\left(\frac{R_7}{R_6 + \cdots R_x}\right)$$

— where

$$R_x = R_{Th} \| R_8 = \frac{R_{Th}\, R_8}{R_{Th} + R_8}$$

Putting in Component Values

$$e_o = -13.037 + \left(\frac{32.47\, R_x}{R_1 + R_x}\right)\left(\frac{R_7}{R_6 + R_7 + R_1 \| R_x}\right)$$

So for Typical Case — S/N 005 AND 215K Shunt — we GET

Temp	R_{Th}	e_o
−40°C	31.3K	−6.89V
−45C	37K	−6.08V
−50C	47K	−5.15V
−55C	59K	−4.14V
−60C	75K	−3.06V
−65C	97K	−1.93V
−70C	128K	−0.79V
−75C	175K	+0.37V
−80C	250K	+1.49V
−85C	378K	+2.52V

So output Slope at null

$$= \frac{\Delta V}{\Delta T} \cong -.23\,V/°C$$

TRW SYSTEMS GROUP

PROJECT NMPS | SUBJECT T.E. Cooler Controller

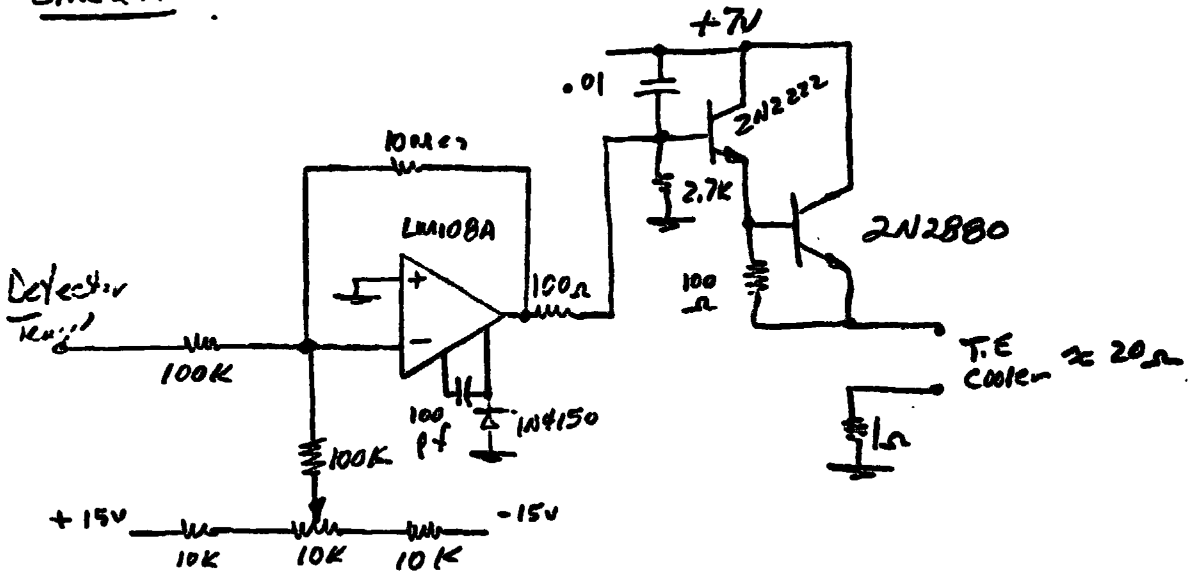
PREPARED BY: KAE

DATE

ATTACHMENT

PAGE 10 OF

CIRCUIT



T.E. Cooler Drive

V_0 (@ -70°c) Typically = 5.5V

So $I_L = \frac{5.5}{20} = 280$ ma

ω forced Beta of 10 for 2N2880
AND 15 for 2N2222

Current from LM108A needed is $\frac{280}{150} = 1.83$ ma.

So DRIVE CAPABILITY IS ADEQUATE.

VOLTAGE Comparison Amplifier

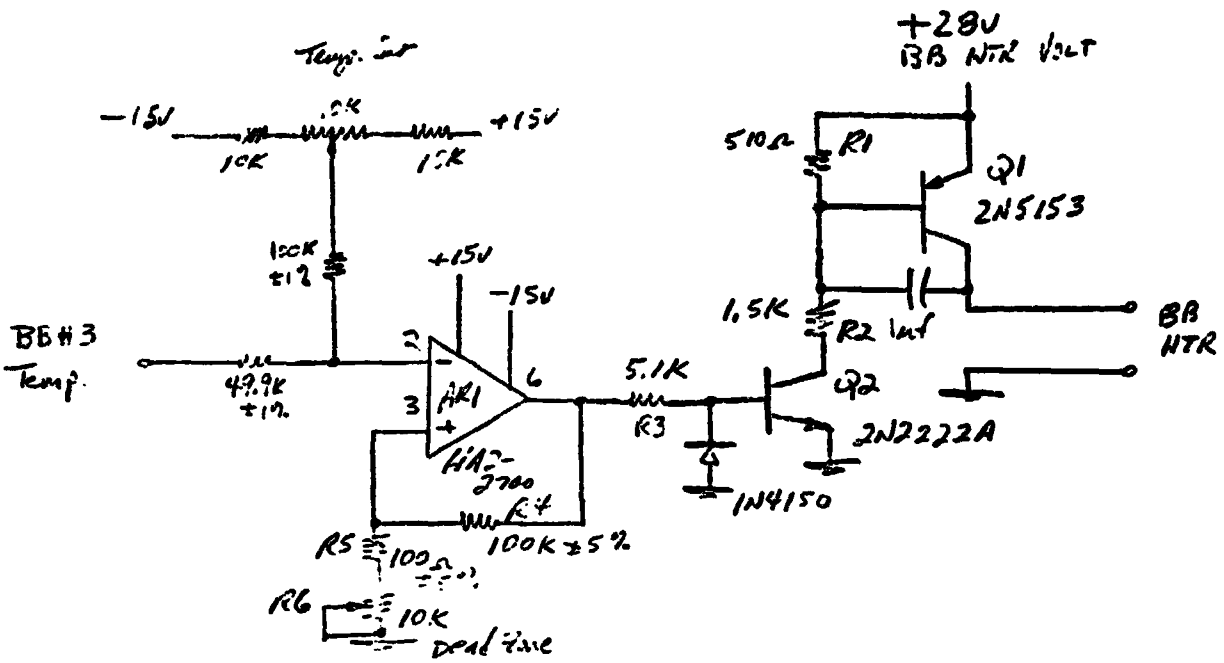
$$V_{TE_{cooler}} = 100(V_{Setpoint} - V_{\substack{Detector\\Temp}})$$

Since full Scale drive is ≈ 6V
Difference of Setpoint Voltage & Det. Voltage
is .06 volts which is ≈ 0.25°C

SYSTEMS 1489 REV. 2-66

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
MAPS	BB Temp. Controller Circuit	DATE		11 OF

1. CIRCUIT



2) HEATER REQ'MTS

Power = 2watts Max in Vacuum, EST. [illegible] ≈ 5w in Rm Amb.

Heater Resistance = 78 OHMS

So with 28V Supply

Power To Load = $\frac{E^2}{R}$ = 10watts

So controller Should operate at ≈ 50% duty cycle.

3) OUTPUT DRIVER CIRCUIT

$$I_{LOAD} = \frac{28v}{78\Omega} = 360ma$$

$$I_B(Q1) = \frac{28v - V_{BE}(Q1) - V_{sat}(Q2)}{R2} = \frac{28 - .9 - .25}{1.5(1.25)}$$

$$I_B = 14.32ma$$

$\therefore \beta(Q1) \geq \frac{360}{14.32} \geq 25$ is Required for Saturation of Q1.

4) 2N2222 DRIVE

$$I_C = \frac{28 - V_{CE}(Q1) - V_{SAT}}{1.5K(.85)} = \frac{28-.7-.05}{1.5K(.85)} = 21.37ma$$

$$I_B(Q2) = \frac{V_0(AR1) - V_{BE}(Q2)}{R3} = \frac{13-.85}{5.1K(1.25)} = 1.91ma$$

$$\therefore \beta(Q2) \geq \frac{21.37}{1.91} \geqq 11.21$$ is Required from Q2.

5) MAX. AR1 OUTPUT

$$I = \frac{15V-.6}{5.1K(.85)} \leq 3.32ma$$ WHICH THE HA2-2700 OP-AMP CAN SUPPLY.

(6) Temperature Sense Comparator

(a) TRIP POINT = Zero ± Hysteresis feedback

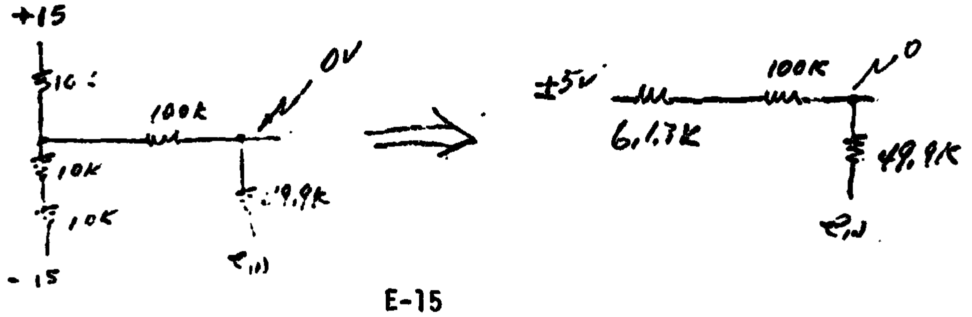
(b) $$\text{Hysteresis} = \pm V_c \times \left(\frac{R5+R6}{R4+R5+R6}\right)$$

$$\text{Max} = \pm 14 \times \frac{10.1K}{110.1K} = \pm 1.28 \text{ VOLTS}$$

$$\text{Min.} = \frac{\pm 14 \times .1K}{100.1K} = \pm 14 \text{ millivolts}$$

(c) MINIMUM/MAXIMUM e_{IN} Required for Zero for Different Setpoint Voltage

Case #1



TRW SYSTEMS GROUP

PROJECT	SUBJECT	PREPARED BY: / DATE	ATTACHMENT	PAGE 13 OF
MAPS	BB TEMP. Controller Circuit	DATE 10/8/75		

(c) Continued

e_{IN} needed for Zero Volts at Comparator

$$\frac{\pm 5}{106.67K} = \frac{e_{IN}}{49.9K} \quad , \quad e_{IN} = \underline{\pm 2.34 \text{ VOLTS}}$$

Since Temp Ckt output Slope is ≈ 470mv/°C,

This ≈ ±5°C Adjustment Range.

(d) minimum Amplitude of Dead Zone refered to input

$$\pm 14\text{mv} \times \frac{156K}{106K} = \pm 20.6\text{mv}$$

$$= \frac{20.6}{470} = \pm \underline{.05}\,°C \quad \text{OR} \quad 0.1°C \text{ dead Zone minimum}$$

SYSTEMS 1400 REV. 2-66

APPENDIX F

GROUND SUPPORT UNIT (G.S.U.)

GROUND SUPPORT UNIT (G.S.U.)
FINAL REPORT

PREPARED BY

W. MORROW
T. V. WARD
BARRINGER RESEARCH LIMITED
304 CARLINGVIEW DRIVE
REXDALE, ONTARIO, CANADA

PREPARED FOR
T.R.W. SYSTEMS INC.
ONE SPACE PARK
LOS ANGELES, CALIFORNIA

OUR REF: TR75-255

OCTOBER 1975

CONTENTS

GROUND SUPPORT UNIT DESIGN AND FABRICATION

INTRODUCTION

The Ground Support Unit (GSU) was designed to serve as the radiometric calibration standard for the MAPS instrument and provides a capability for simulating a broad range of source temperatures and pollutant concentrations. It allows a complete end-to-end checkout and calibration of each MAPS channel. It was designed for use in the performance evaluation of the BRL brassboard interfaced with the TRW signal processor and prior to the redirection of the contract it had been intended to be used in the performance evaluation of all models through to the flight model. The GSU consists of a blackbody radiation source and absorption gas cell which may be adjusted over the temperature range 240°K to 320°K and placed between the target source and each individual MAPS channel.

COMPONENT DESIGN FEATURES

Blackbody Target Source

A blackbody source with a minimum clear aperture of 12 cms. was purchased from Eppley Laboratories. The source has an operating range of 240°K to 350°K, the lower temperature being achieved by a thermoelectric cooler backed by a Lauda Brinkmann refrigerator. The source is complete with five platinum resistance thermometer sensors which are capable of monitoring the uniformity and accuracy of the source to ± 0.1°C.

Absorption Gas Cell

The absorption gas cell consists of a type 304 stainless steel double walled cylinder of ½ metre length between germanium windows. The cell has four ports, two for cell windows and one each for pressure and temperature feedthroughs, and pump and manifold couplings. Multiple circular baffles are located between the double walls of the cell to restrict the coolant fluid flow, reduce any dead spaces within the volume, and remove any thermal non-uniformities within the cell. Nine copper-constantan thermocouples are located within the cell, three at each end and three located in the centre of the cell to measure thermal uniformity of the gas within the cell.

Cell Windows

Cell window material is germanium. Ge has transmission properties with broadband A.R. coatings > 90 percent required per window in each of the required spectral regions to achieve a cell transmission > 80 percent. It is also chemically compatible to small concentrations of the proposed test gases and its absorption coefficient does not change significantly over the temperature test range. The entrance window clear aperture is 12 cm. x 0.5 cm. thick and the exit window clear aperture is 9 cms. x 0.3 cm. thick. The A.R. coatings used have a vapour pressure < 10^{-3} Torr.

Pressure Transducer

An M.K.S. pressure transducer with a 0 to 1000 Torr head was initially installed in the absorption cell to act as the absolute standard for gas concentration measurements. However after delivery it was found that the M.K.S. capacitance manometer had insufficient accuracy and also suffered from considerable drift and could not be used as the absolute standard in the region 10^{-3} Torr - 1 Torr. To overcome this difficulty an NRC-801 thermocouple gauge was installed in the absorption cell and on the manifold to measure ultimate vacuum and leak rates. The calibration of the thermocouple gauges should be verified at regular intervals.

Vacuum Pump

A double stage rotary pump with a pumping speed of 100 litres/minute is used to evacuate the cell and manifold. With this pump in series with a molecular sieve trap an ultimate vacuum of 1 x 10^{-3} Torr was achieved in the absorption cell.

Heat Exchanger

An F.T.S. model FC-50-40 compressor with a Model P40 probe is used to provide the cooling capability to the circulating fluid between the cell walls. This combination with the probe immersed in an insulated, well stirred, open topped dewar containing 8 litres of ~~methanol~~ coolant and a room ambient of 24°C has a cooling capacity of ≈ 1200 Watts. A proportional thermocouple temperature controller with a 1.2 kw heater proportions power to the heater to achieve control accuracy of the fluid in the dewar of 0.1°C.

Thermocouple Readout

The nine thermocouples located within the absorption cell are read out on a Doric multi-channel digital thermometer with a resolution of 0.1°K.

Test Gas Specifications

Research grade test gases with certified analysis are used and introduced to the cell manifold via high purity stainless steel single stage regulators which have been helium leak tested.

The gases provided are as follows:

1. Matheson purity nitrogen with analysis for hydrocarbons and dew point.

2. 0.03 percent ammonia in nitrogen to a certified standard.

3. 0.3 percent carbon monoxide in nitrogen to a primary standard contained in an aged cylinder.

Insulation

The absorption cell is insulated with three inches of polyurethane foam to reduce the effect of conductive and convective heat losses wher operating the cell at temperatures below ambient.

G.S.U. SUBSYSTEM TESTS

1. Inner Cell Leak Test July 8 to 14 -- see Figure 1A, 1B, 1C.

1.1 The G.S.U. gas cell minus outer covering, port flanges and end flanges was leak tested with dummy flanges and ports. The cell pressure was monitored with a Varian 801 thermocouple gauge with 531 thermocouple head. Preliminary tests were carried out with the cell in the same condition as it was delivered from the welder, that is with the welding blemishes from the attachment of the circulation baffles. These tests indicated that the cell leak plus outgassing rate was 7 ± 1 μ/minute. In addition negative results were obtained (indicating no leaks) when the cell welds were sprayed with acetone.

1.2 After this test the decision was made to grind out the weld blemishes since they obstructed the placement of the T.C. rack and were potential sources of outgassing. After the welds were ground out the cell was cleaned of any loose metal and flushed with tetrachloroethylene until no residue appeared on a clean kimwipe used to scrub the inner cell wall.

1.3 The second inner cell vacuum test proceeded as the first. The leak plus outgassing rate was approximately 3 μ/minute and the acetone spray gave negative results. The leak and outgassing rate was approximately .4 that of the preceeding test (1.1). This indicated that cleaning the cell inner walls and/or removing the weld blemishes reduced outgassing. The cell exceeded the leak specifications (20 μ/minute) by a factor of 7 times and was cleared for welding the flanges, ports and outer shell.

2. Checkout of the MKS Capacitance Manometer. May 30 to June 3.

2.1 In order to test the MKS system, the pressure head was attached to a rotary pump vacuum system to which a Varian thermocouple head and Vacustat McLeod gauge were also attached. Pressure readings were taken with the pump valve closed so that all gauges were at the same pressure during the test. Two sets of measurements were made; one set was made three hours after switching on the electronics and the second was made three days after switch on (the latter set was taken to ensure that measurements were taken after the system had adequate time to thermally stabilize).

2.2 Friday Observation (May 30) -- see Figure 2.

The MKS capacitance manometer system exhibited zero drift that exceeded the absolute pressure accuracy specification of 10^{-5} of full range which was 1,000 Torr. The drift observed was positive and exceeded 1.0 Torr/hour. The drift measurements were made after the manometer and associated electronics had warmed up for two hours (with the manometer thermal regulator on). The quad setting had been minimized and the null and full scale calibrations had been set. The system pressure was verified not to drift by checking with a McLeod gauge and a Varian thermocouple gauge, both of which gave the same absolute pressure to within ± 5 μ with no indication of pressure drift.

2.3 Monday and Tuesday Observation (June 2 and 3) -- see Figure 3.

The MKS manometer was run on the vacuum system over the weekend (the system pressure was unchanged Monday morning at 40 μ. The MKS zero was set at 40 μ and the pressure monitored for 24 hours. The manometer showed an initial drift of -.02 Torr/hour which was reasonably linear. In addition the MKS pressure reading fell to -.57 Torr overnight (net rate of 0.1 Torr/ hour.

2.4 On the basis of these measurements the MKS head was returned for replacement.

3. Checkout of Replacement MKS Head and Pressure System (July 14)

3.1 After receipt of the MKS replacement head a second calibration test was carried out. MKS again had not supplied a calibration for the head in the 0 to 1000 Torr region (as requested by BRL). Communication with MKS indicated that no systematic calibration in the region had been taken and time constraints did not allow the head to be returned to MKS for calibration.

3.2 The MKS head was attached to the Alcatel vacuum pump and pumped down. The DVM (170 - M - 25) readout for the MKS head read 12 V overload with the electronic setting on null (0.0 V output), F.S. (10.0 V output) and with the DVM inputs noted. Operation of the MKS head and electronics (minus the DVM) was verified with an AVO meter. A replacement DVM was requested (shipped from MKS on July 14). The rest of the MKS system was checked out with an H.P. DVM and with a McLeod and Varian pressure head to calibrate the MKS head.

3.3 After the system pressure had stablized (both on the Varian thermocouple and the McLeod) the MKS showed a negative pressure drift. The MKS, Varian and McLeod pressure readings were monitored for a 15 hour period. The Varian and McLeod readings remained stable at 50μ and 40μ respectively during the 15 hour interval. The MKS pressure reading decayed from 1450μ to -200μ during the same interval falling most rapidly in the first two hours (e.g. 1450 to 135μ). See Figure 4.

3.4 Communication with MKS indicated that the system performance was generally measured after stabilization for at least 3 hours. The "absolute" accuracy statements in the MKS literature were concluded to be valid for only short term measurements. Our test indicated absolute pressure measurements have an accuracy no greater than ± 2 Torr unless calibrated with another absolute pressure head.

4. Vacuum Pump Checkout (July 13)

The McLeod pressure gauge was connected directly to the Alcatel vacuum pump. The ultimate vacuum obtained for the pump (without the molecular sieve) was measured at 1.4μ. McLeod gauges of this type have absolute accuracies of ± 3μ[*] (Ref. Edwards vacuum components catalogue pp. 111, 112).

(* at pressure from 10μ to 0μ)

5. Checkout of Varian TC Gauge (July 16)

5.1 The Varian TC gauge and the McLeod gauge were attached to the Alcatel vacuum pump (with molecular sieve). One half hour after the pump down the Varian thermocouple gauge read 30μ while the McLeod gauge read 5μ. The Varian thermocouple pressure reading then slowly fell while the McLeod remained at 5μ. After about 10 hours the Varian stabilized at 10μ (McLeod read 5μ). The Varian gauge reading remained at 10μ for about 5 hours (until the system was pressurized).

Subsequent measurements with the Varian thermocouple gauge confirmed their zero drift. In order to obtain an accurate pressure zero with the Varian pressure gauge it should be held at a vacuum that is better than 10μ for at least 10 hours.

6. Checkout of Blackbody System (July 22). See Figure 5, 6.

6.1 The blackbody system was interconnected per the Eppley instructions. Operation of the Doric platinum resistance thermometer was verified at room temperature. The platinum resistance thermometers read room temperature to within .2°C (no control on BB temperature).

6.2 The Lauda Brinkman cooler was set at -10°C and the compressor was switched on. After 1 hour 45 minutes the temperature of the bath (with circulation pump off and no thermal load) read +10°C. The circulation pump was switched on and the blackbody T.E. cooler was set at 1,000 (low range). The BB temperature fell to -40° and then began to rise. The coolant temperature rose from 10°C to 25°C. It was apparent that the T.E. cooler was thermally overloading the Lauda Brinkman cooler.

6.3 The test was repeated with the T.E. cooler at a setting of 2,500. In this test the BB temperature reached -20°C then began to rise when the coolant temperature went from +14.5°C to about 35°C.

6.4 It was concluded that the Lauda Brinkman cooler could not handle the 150 watt maximum thermal load of the blackbody T.E. cooler. The rated cooling power of the Super K2R cooler was 250 watts. Consequently, efforts were made to have the refrigerator unit repaired or replaced.

7. Vacuum Test of the Completed Cell (July 23 to July 25. See Figure 7.

7.1 The completed cell (with end flanges, port flanges and outer shell) was connected to the Alcatel vacuum pump with molecular sieve. The Varian thermocouple, McLeod, and MKS pressure gauge were connected to the inlet of the pump upstream of the gate valve with a "Tee" coupling. The upper flange was sealed with the doubler flange, germanium window, and window retaining ring (per assembly drawing). The lower flange was sealed with a flat plate and "O" ring.

7.2 The system was pumped down and the pressure read on the Varian thermocouple and the McLeod gauges. The cell pumped to 10µ in about 5 minutes and to about 5µ in one hour.

7.3 The main gate valve was closed and the pressure monitored with time. The Leak plus outgassing rate with the McLeod was 3.1µ/minute, with the Varian thermocouple, 13µ/minute and with the MKS, 3.8µ/minute. The MKS rate was measured by the decrease in pressure when the system was pumped out (after being closed off 10 minutes). In this way the drift of the MKS did not affect the reading because the pump out occurred in less than 10 seconds.

The difference in readings between the McLeod, MKS and the Varian indicated that the Varian was more sensitive to an outgassed component than either of the displacement type gauges. This is not unusual since the Varian is sensitive to the thermal conductivity of the medium surrounding the gauge, which changes with molecular weight as well as pressure.

7.4 All welds on the cell were sprayed with acetone while the system was under vacuum (gate valve closed) and no leaks were detected.

8. <u>Vacuum Test of Completed Cell Coolant Chamber. July 28. See Figure 8.</u>

The coolant chamber was connected to the vacuum pump with flexible teflon tubing. The inner chamber was pressurized and the window was removed. The outer chamber pumped down to 30μ on the McLeod gauge. All welds on the outside and the inside of the cell were tested by spraying with acetone. No leaks were detected in the coolant chamber.

9. Checkout of Brinkman Lauda Cooler after "Repair"

The Lauda Brinkman cooler was set at -20°C and the compressor switched on. The temperature of the coolant in the bath was monitored (circulator on, T.E. cooler off) with time. The temperature of the bath fell to +15°C (from 27°C) in 31 minutes, then began to rise. The thermal overload relay on the compressor motor began switching at the point in time that the bath began to warm up. The problem was diagnosed as either a faulty thermal overload switch or a faulty compressor motor that caused the system to overheat. Communications were resumed with Brinkman and Eppley in order to have the system replaced or repaired.

10. Checkout of the FTS Temperature Control System

The FTS bath was filled with methanol and water solution and the compressor, pump and stirrer were hooked up. The stirrer and pump operations were verified. The compressor motor operated intermittently when connected to the mains with an extension cord. Checking the voltage across the cord indicated that the starting current of the compressor caused an 18V drop when the compressor was switched on. The compressor operated satisfactorily when connected directly to the mains through its own power cord. The system achieved a bath temperature of -32.5° in 1½ hours when the ambient temperature was +32.22 ($\Delta T = 64.7^{\circ}C$).

11. GSU Debugging and Calibration

11.1 Calibration of Gas Cell Thermocouple

The nine Omega thermocouples to be used in the gas cell were interconnected with the Doric Digital Thermocouple readout per Doric instructions. The ends of the thermocouple were sheathed in plastic and attached to the Lauda Brinkman cooler bath thermometer, near the bulb. After a preliminary calibration run the Doric zero and span controls were set so that the Doric readout corresponded to the Lauda Brinkman thermometer. The bath was then cycled from -5.4°C to +49.2°C in a one hour period. Readings were taken for all nine thermocouples at eight temperatures. See Table 1. At the highest temperature the potential across thermocouple #5 and #6 (#6 in water ice bath) was measured. Thermocouple #5 was supplied with an absolute calibration carried out by Orenda. The voltage across these thermocouples corresponded to 54.33°C compared to an average reading of 54.41°C for the rest of the thermocouples. Thus the maximum error in absolute temperature (at 54.40) is estimated at .08°C.

L.B. Thermometer	T/C 1	T/C 2	T/C 3	T/C 4	T/C 5	T/C 6	T/C 7	T/C 8	T/C 9	
-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	°C
-1.1	-1.1	-1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	"
+2.8	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.7	2.7	"
+10.8	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.6	10.6	"
24.1	24.0	24.0	24.0	24.0	23.9	24.0	24.0	24.0	23.9	"
25.3	25.2	25.2	25.2	25.2	25.2	25.2	25.3	25.3	25.2	"
36.5	36.5	36.5	36.5	36.4	36.4	36.5	36.5	36.5	36.5	"
49.2	49.3	49.3	49.2	49.2	49.2	49.2	49.3	49.2	49.2	"

TABLE 1.

11.2 Debugging Vacuum System

The assembled vacuum system was tested in the following sequence:

1. Vacuum pump to ACG valve and ½" shroud and manifold pumpline
2. Vacuum pump to manifold and shroud gate valve
3. Manifold
4. Shroud pumpline
5. Gas cell
5. Black Body shroud

Each subsystem was tested by spraying couplings, joints and valves with acetone. In addition ultimate vacuums and leak plus outgassing rates were measured (where possible). Only minor leaks were detected and these were eliminated by tightening the vacuum couplings. The molecular sieve filter was found to outgass but this was remedied by replacing the charge of the molecular sieve. The vacuum pumpline (1) (2) pumped down to 6μ in 15 minutes and fell to about 2μ in three hours. The manifold and shroud pumpline (3) (4) had a leak plus outgassing rate of 2μ/minute and pumped down to 25μ (on the manifold thermocouple pressure gauge) after 16 hours. The gas cell had an outgassing rate (after 48 hours of continuous pumping) of 1.5μ/minute and an ultimate vacuum (by thermocouple pressure gauge) of 1.3μ. The blackbody shroud reached 280μ in about three hours.

11.3 Debugging Cell Fluid Circulating System

The Cell circulation chamber was filled with fluid by venting with the plug at the top of the cell with the FTS circulation pump running. The fluid level of the bath was monitored for 72 hours after this to detect any leaks into the fluid circuit (cell, pipeline, pipeline connections) which would have resulted in an increase in the bath level. No increase of the bath level was detected.

11.4 Debugging Replacement Blackbody Cooler

The replacement Lauda Brinkman cooler was connected to the blackbody. The bath was charged with methanol and the compressor run (with the

11.4 (Continued)

the circulation pump off) until the bath temperature was -20°C (1½ ho The circulator was then switched on. The Black Body temperature fell to -12°C in about one hour. The Temptonic T.E. control was set at 2,000 and switched on. The Black Body temperature fell to -41°C in 8 minutes. The T.E. control was reset to 2,350 and the BB temperature stabilized at 40.0° ± .1°C for two hours. In this time the coolant temperature rose to about -9.5°C. See Table II.

Table II

Elapsed time after TE cooler switched on (minutes)	°C Black Body Temperature	°C Coolant Temperature
0	-12	-19
2	-26	-17.5
5	-36	-15
8	-41	-13.5
13*	-40	-13.0
43	-39.9	-12
114	-40.06	-10
133	-40.10	-9.5
*reset TE control to 2,350		

ACCEPTANCE TESTS

Formal Acceptance Tests were carried out on the G.S.U. at BRL premises on September 4th and 5h, 1975. These tests were carried out in the presence of BRL Q.A. personnel and a TRW representative. The test data recorded are included.

SHIPPING

A copy of the shipping order for the G.S.U. is included. A BRL representative was on hand at TRW to assemble the GSU after receipt of shipment at TRW. This was accomplished and all systems checked out to TRW satisfaction.

QUALITY ASSURANCE

The document package assembled by Quality Assurance for 196-11 GSU is on file, and is to all intents and purposes structured in the following manner.

1. The Receiving Function

Copies of Purchase Orders, Packaging Slips, Drill Certificates, Test Result Sheets, Certificates of Compliance and all related correspondence together with BRL Accept, Test and/or Reject Tags are cross referenced completely and recorded in an "Incoming Materials Log", such log allocating R/L (Release Numbers) that act as common demonimations to individual incoming occurrences.

2. Assembly and Internal Manufacture

All work tasks performanced internally are qualified by Q.A. acceptance tags, all such tags having been retrieved and assembled in the Q.A. files.

3. Correspondence BRL/TRW

Copies of all correspondence by BRL and by TRW related to Quality Assurance remain on Q.A. files.

4. GSU Acceptance

Copies of all acceptance test and test data information are on Q.A. files, as yet we still await return from TRW signed copies of the formal acceptance test document and the IR 501108 that will "buy off" the deviations from specifica

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BARRINGER RESEARCH

BARRINGER RESEARCH LIMITED
304 CARLINGVIEW DRIVE
METROPOLITAN TORONTO
REXDALE, ONTARIO
CANADA M9W 5G2
PHONE. 416-677-2491
CABLE BARESEARCH
TELEX 06-968743

TEST DATA SHEET

1 / 2

JOB NO. 196-11

DRG: 5805800 REV'n Orig. DESCRIPTION G. S. U.

CHARACTERISTIC	SPECIFICATION	ACTUAL MEASURED	TIME etc.	REMARKS
PARA. 1.1.1.	≤5x10^{-3} TORR	5 MICRONS.		
1.1.2.	20TORR±2TORR	✓		
1.1.3.	100 TORR ± 5 TORR	✓		
1.1.4.	1000 TORR ± 20 TORR	✓		
PARA. 1.2.1.	5 x 10-3TORR in ≤ 10 Min.	4 MINUTES.	4-32-15 4-36-15	BASED ON McLEOD GAUGE READING.
PARA. 1.3.1.	2 x 10-2 TORR/Minute	.65 x 10^{-2} TORR/MIN.		
PARA. 1.4.1.	≤240° K	248°K.		OUT OF SPEC. SEE INSPECTION REPORT I.R. 50110
1.4.2.	≥320° K	324.25°K.		
PARA. 1.5.3.	<100 Minutes			NOT CARRIED OUT DUE TO TIME RESTRICTION.
1.5.5.	<100 Minutes			
1.5.7.	in <100 Min.			
PARA 1.6.3.	320° K ±5° K	324.25°K.		
1.6.4.	≤ ±1° K	✓		

TEST SPEC./PROC:	TESTED BY	DATE	ACCEPTED by Q.A.	DATE
BRL C012 Rev: A	T.V. Ward	SEPT 5/75.	BA'L / T.K.W	SEPT 5/75.

BARRINGER RESEARCH

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PHONE: 415 677 7491
CABLE BARESEARCH
TELEX: 06-963743

TEST DATA SHEET

2 / 2

JOB NO. 196-11

DRG: 5805800 REV'n Orig. DESCRIPTION G. S. U.

CHARACTERISTIC	SPECIFICATION	ACTUAL MEASURED	TIME etc.	REMARKS
PARA. 1.7.4.	≤±2.5°K	✓		
PARA. 1.8.2	50cm ± 0.1cm	50.10.cm		
PARA. 1.9.2.	≤2 x 10^{-2} TORR/Min.	0.43 x 10^{-2} TORR/MIN.		
PARA. 1.10.2.	Maintain ≤1 TORR	✓		
PARA. 2.1.1.	≤240° K	232°K		STABILITY MEASURED LESS THAN ±1° IN 15 MINS.
2.1.2.	≥350° K	353-8°K		
PARA. 2.2.4.	≤±0.1°K	±0.08°K		
PARA. 2.3.4.	≤± 0.1° K	✓		
PARA. 2.4.3.	<60 Minutes	279.15°K. 13 MINUTES.	09.32 09.45	
PARA. 2.5.2.	Maintain ≤1 TORR			NEGATED - SHROUD TEST. AT 1.10.2. WITH BLACK BOD IN PLACE.

TEST SPEC. PROC:	TESTED BY	DATE	ACCEPTED by Q.A.	DATE
BRL 6012 Rev: A		SEPT 5/75	BRL. / T.R.W.	SEPT 5/75.

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BARRINGER RESEARCH LIMITED,
TORONTO, ONT., CANADA

INSPECTION REPORT

I.R. 501108.
DATE SEPT 5th/75

JOB NO.
DWG/PART NO. 196-11.
P.O. SUFFIX N/A.

DWG/PART NO.	DESCRIPTION	~~VENDOR~~/INTERNAL
5805800.	G.S.U. ACCEPTANCE TEST	Q.A. ACCEPTANCE TEST.

QTY. ACCEPT	QTY. MADE	DISCREPANCY
/	1	

Ⓐ CHARACTERISTIC AT PARA. 1.4.1. DOES NOT MEET SPEC^N
ACTUAL MEASURED 248°K. SPEC^N = ≤ 240°K.
Ⓑ TESTS AT PARA'S 1.5.3. – 1.5.5. & 1.5.7. NOT COMPLETED.

STAMP

1 REJECT QUANTITY

INSPECTOR

ACTION: BRL recommend (based on TRW Customer discussions) That this unit be shipped "AS IS". BRL will supply two gaskets which should aid in meeting 1.4.1 during future tests at TRW.

STAMP

SCRAP / ACCEPT AFTER REWORK

INSPECTOR

QTY.

SPECIAL INSTRUCTIONS:

M.R.B. APPROVAL.

SIGNING AUTHORITY		QTY.
PRODUCTION SUP'V'R.	JH Davies	
PROJECT SUP'V'R		
Q.A. SUP'V'R		
CUSTOMER REP.		1

TOTAL SCRAP

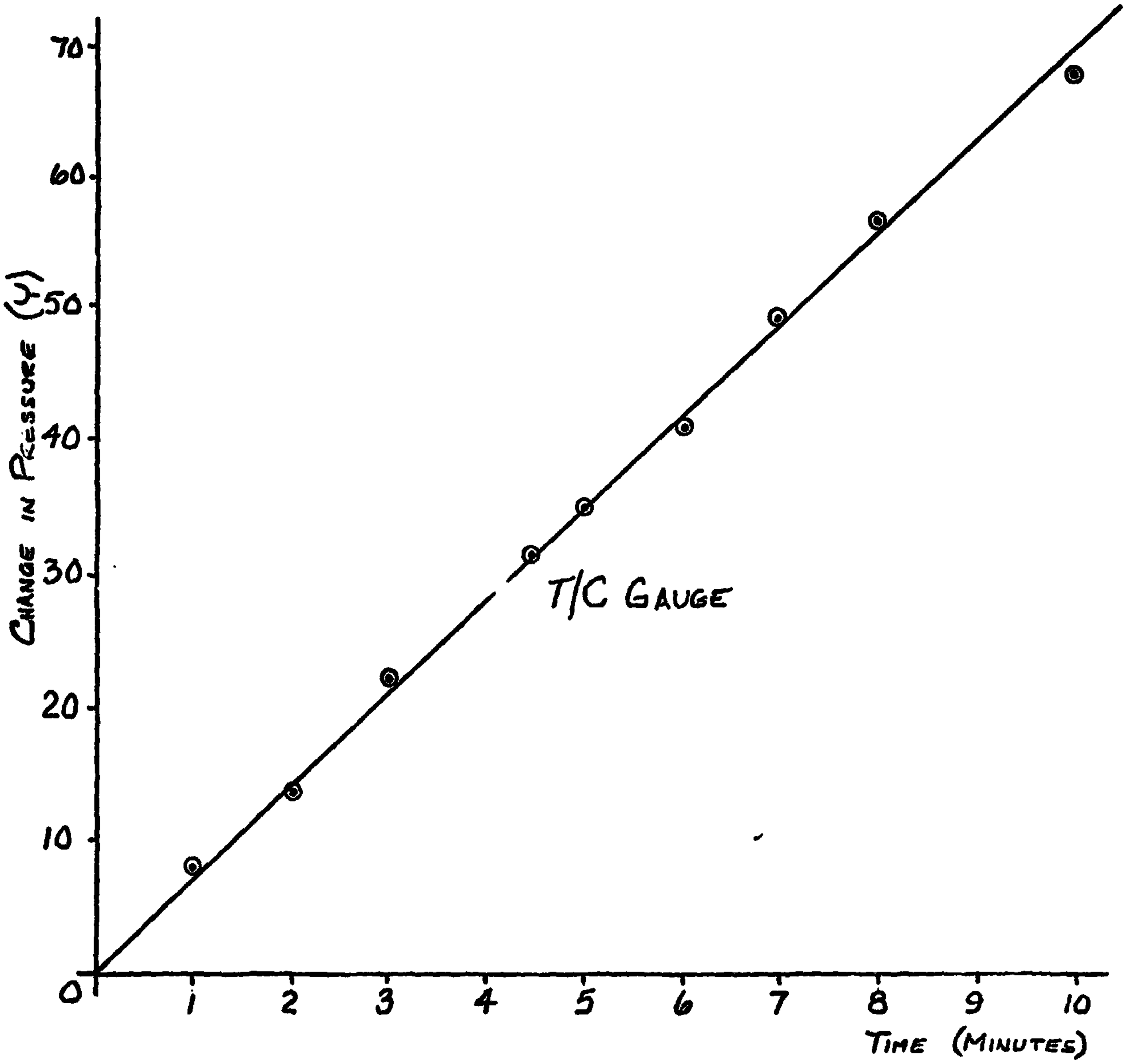
~~TRANSPORTATION DRAWING.~~
REF: BRL 6012. REV. A

TOTAL ACCEPT 1

OPERATIONAL MANUALS

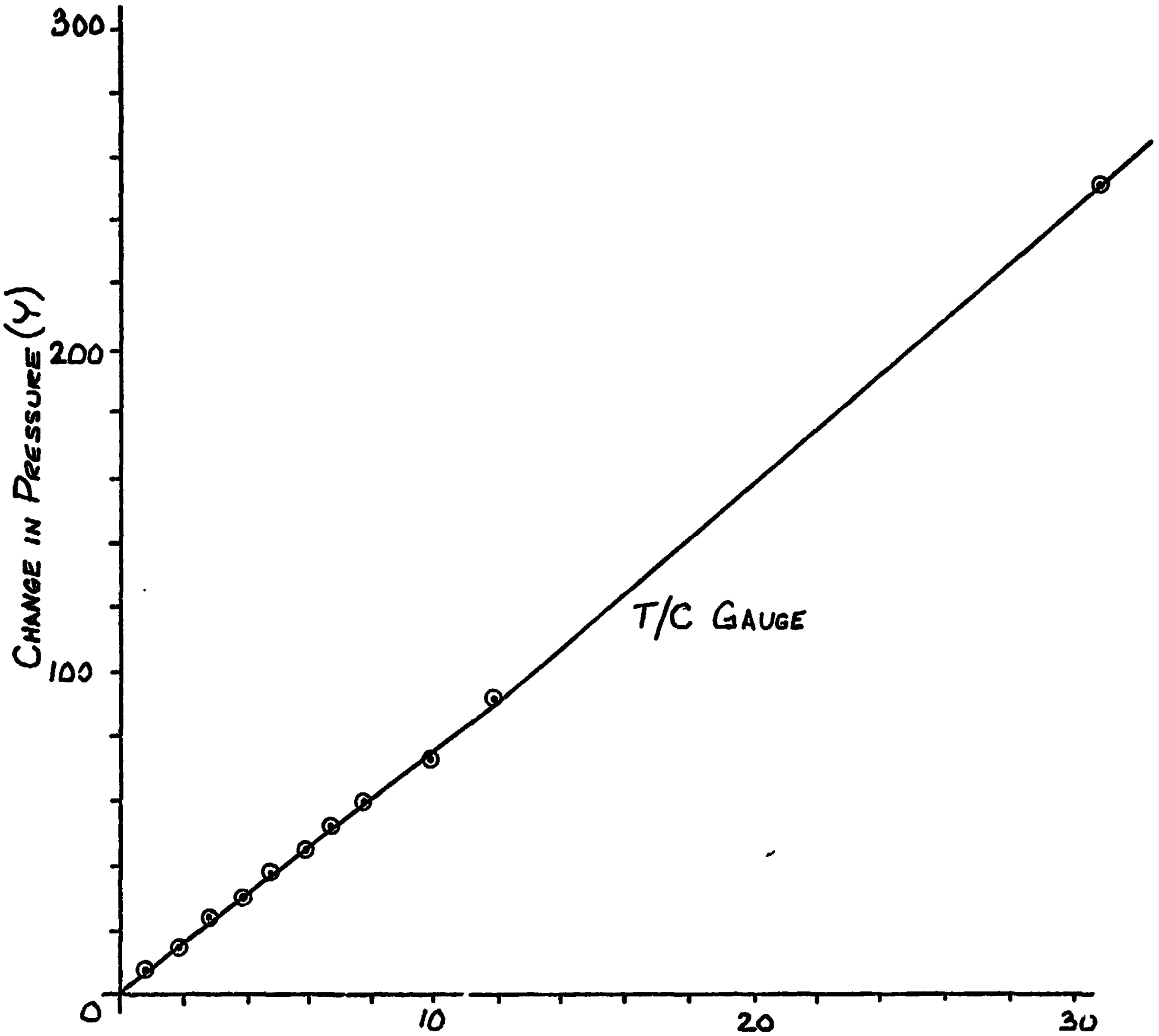
1. Eppley - delivered to TRW with GSU
2. Lauda - included in this package
3. MKS - delivered to TRW with GSU
4. NRC - included in this package
5. FTS - delivered to TRW with GSU
6. Doric - delivered to TRW with GSU
7. BRL - included in this package

Fig. 1A



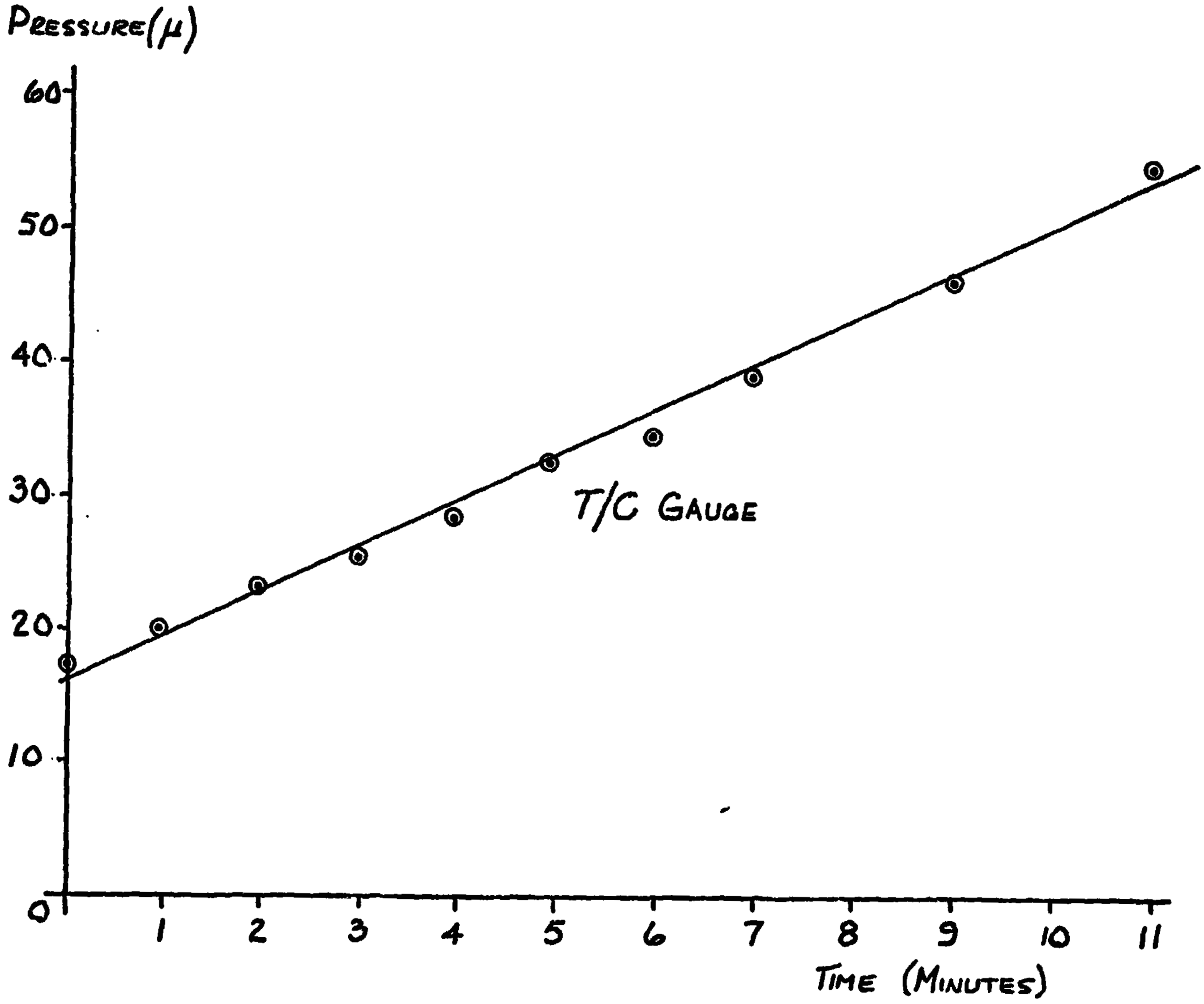
GSU Inner Cell Vacuum Leak Test
(Prior To Cell Clearout)
July 8th 1975
Pressure Rise At 7μ/Min

Fig. 1B



GSU Inner Cell Vacuum Leak Test
(Prior To Cell Clearout)
July 8th 1975

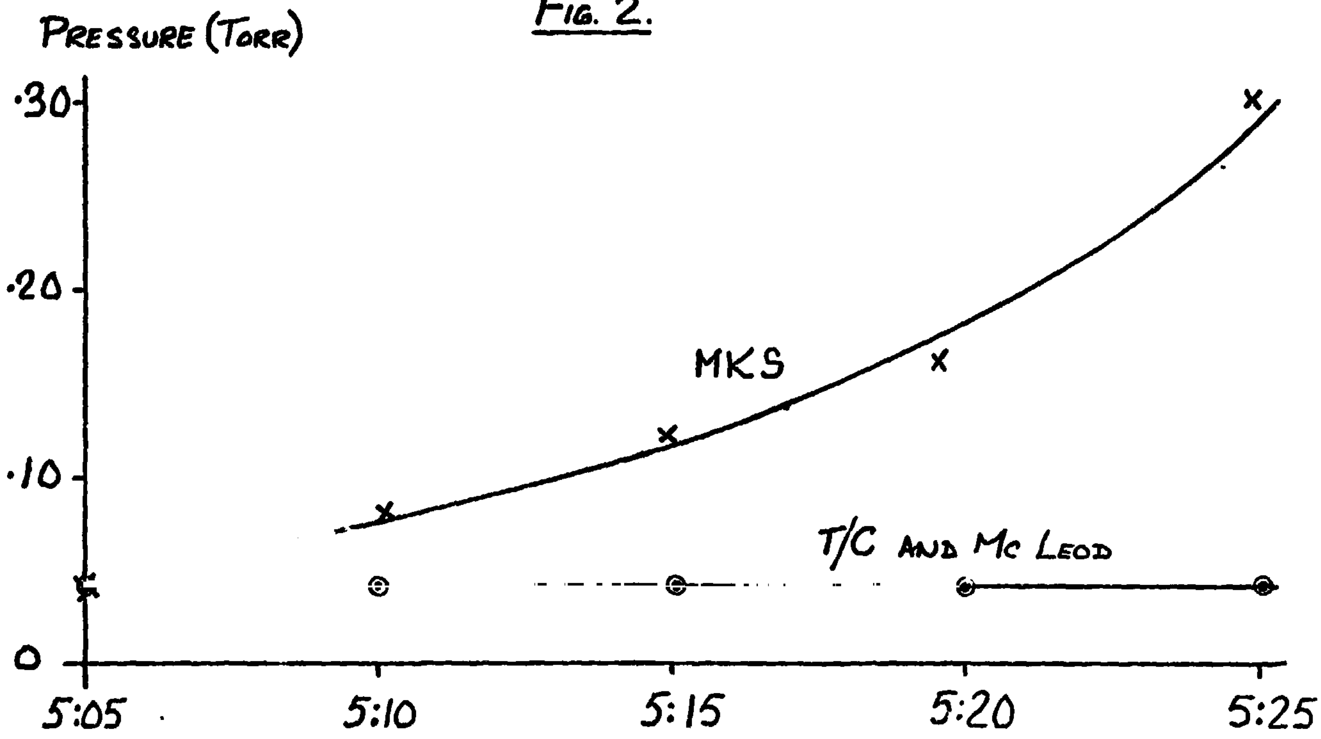
FIG. 1C



GSU INNER CELL VACUUM LEAK TEST
(AFTER CELL CLEAROUT)

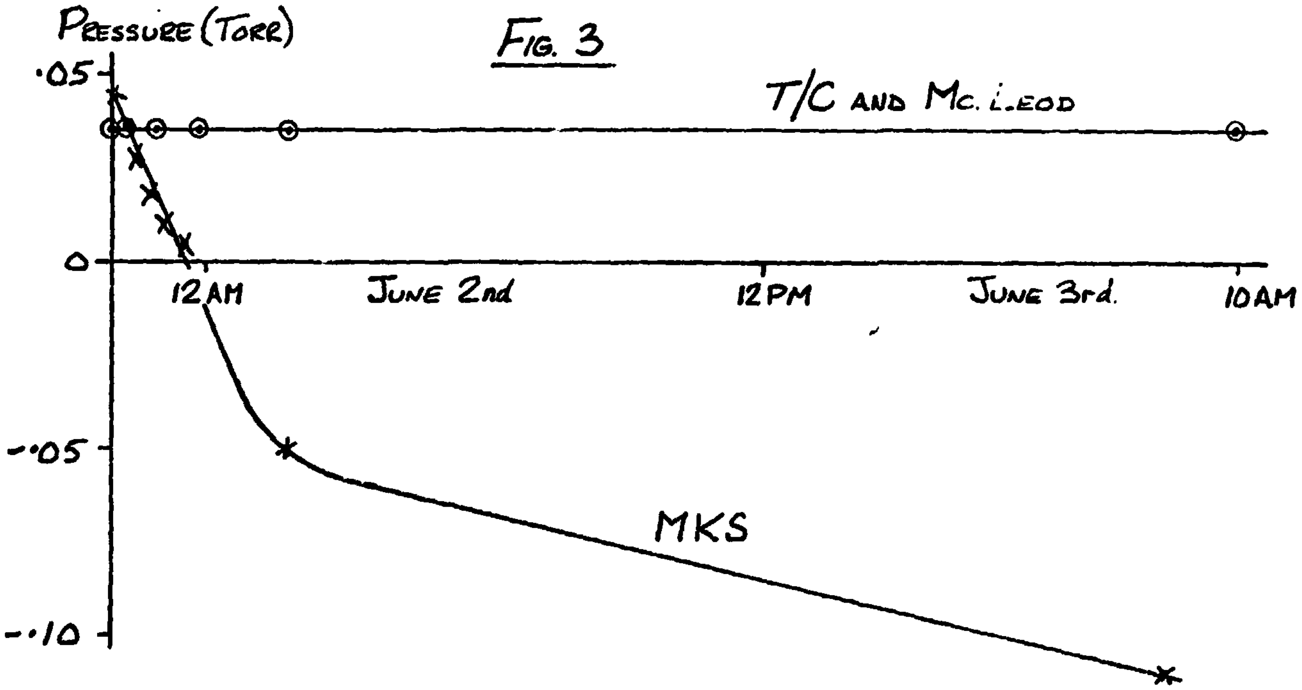
PRESSURE RISE 3.3 μ/MIN

FIG. 2.



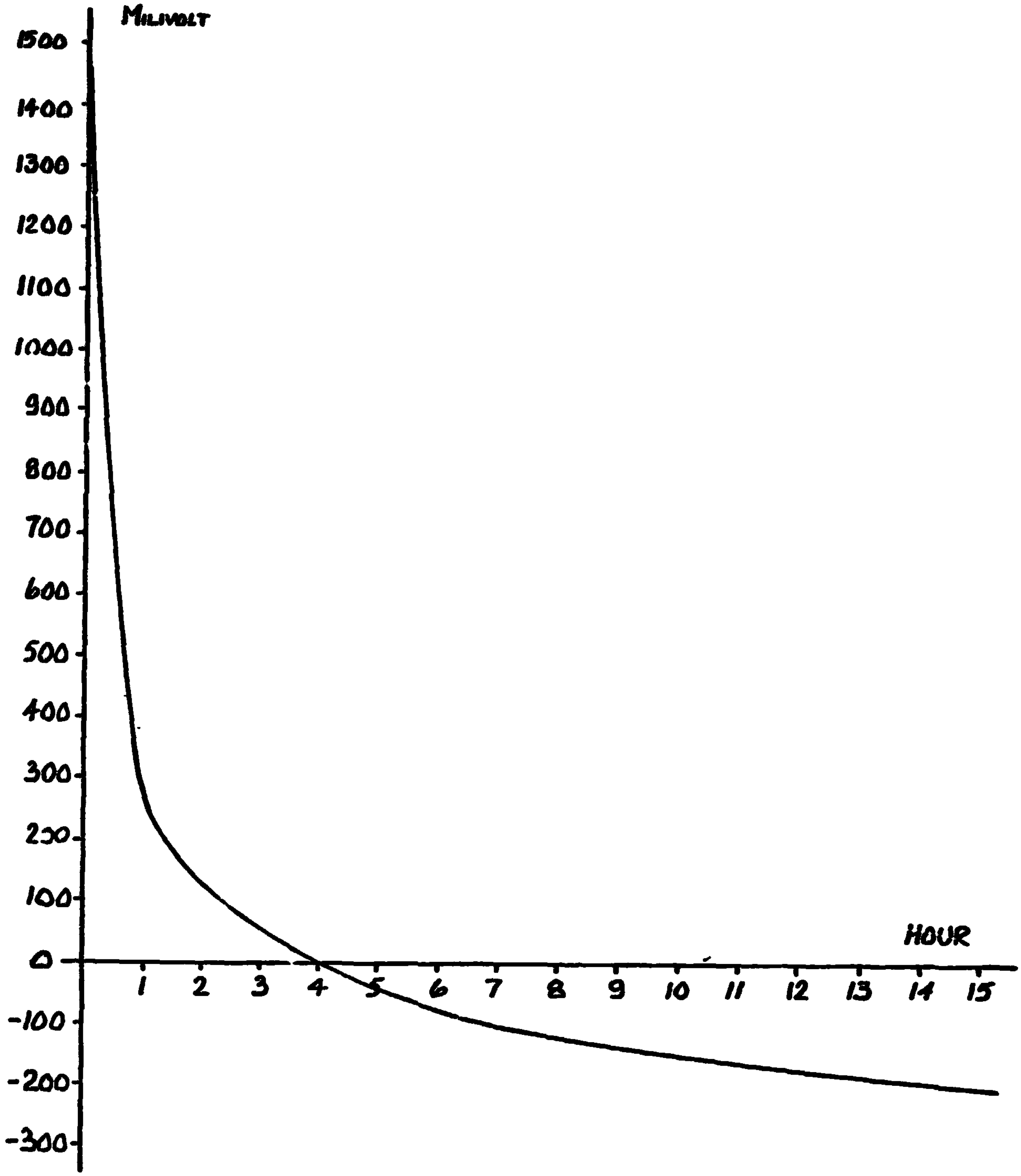
ZERO DRIFT ON MKS PRESSURE TRANSDUCER
AFTER 3Hr WARM UP

FIG. 3



ZERO DRIFT ON MKS PRESSURE TRANSDUCER
AFTER 3 DAY WARM UP

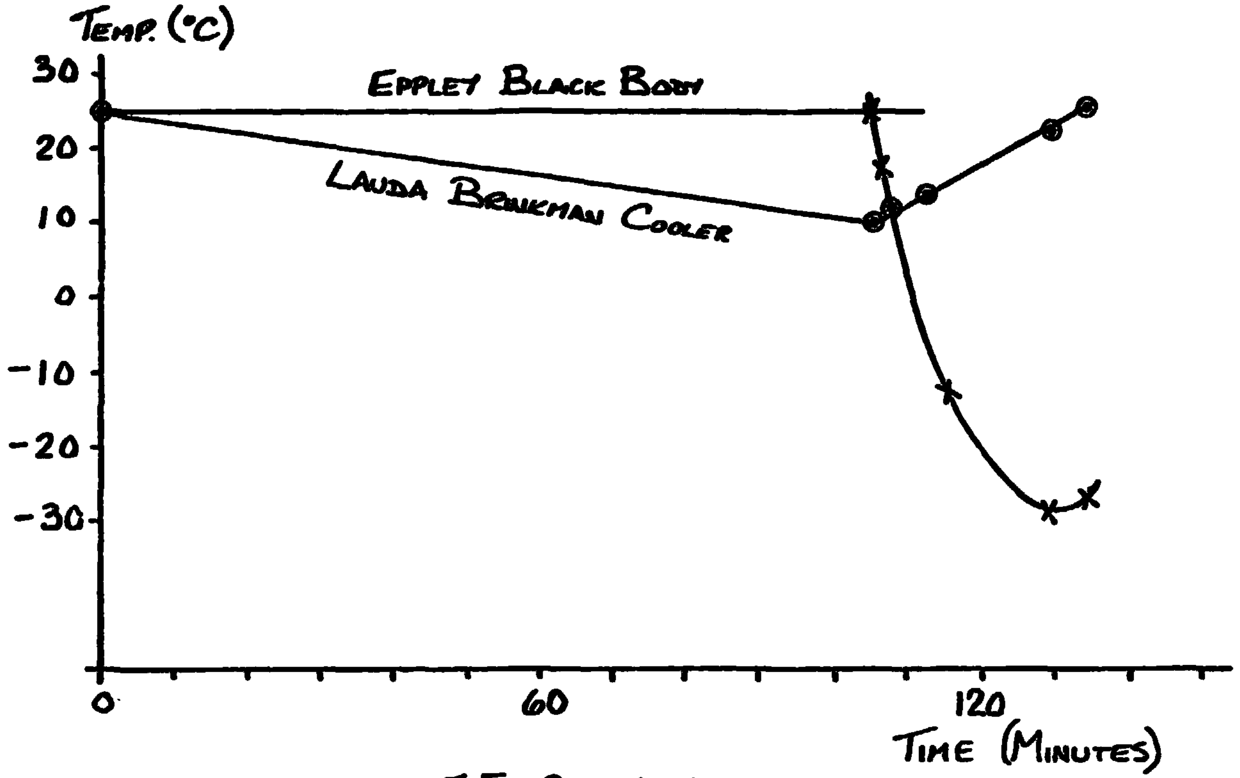
Fig. 4



1000 mV = 1 Torr

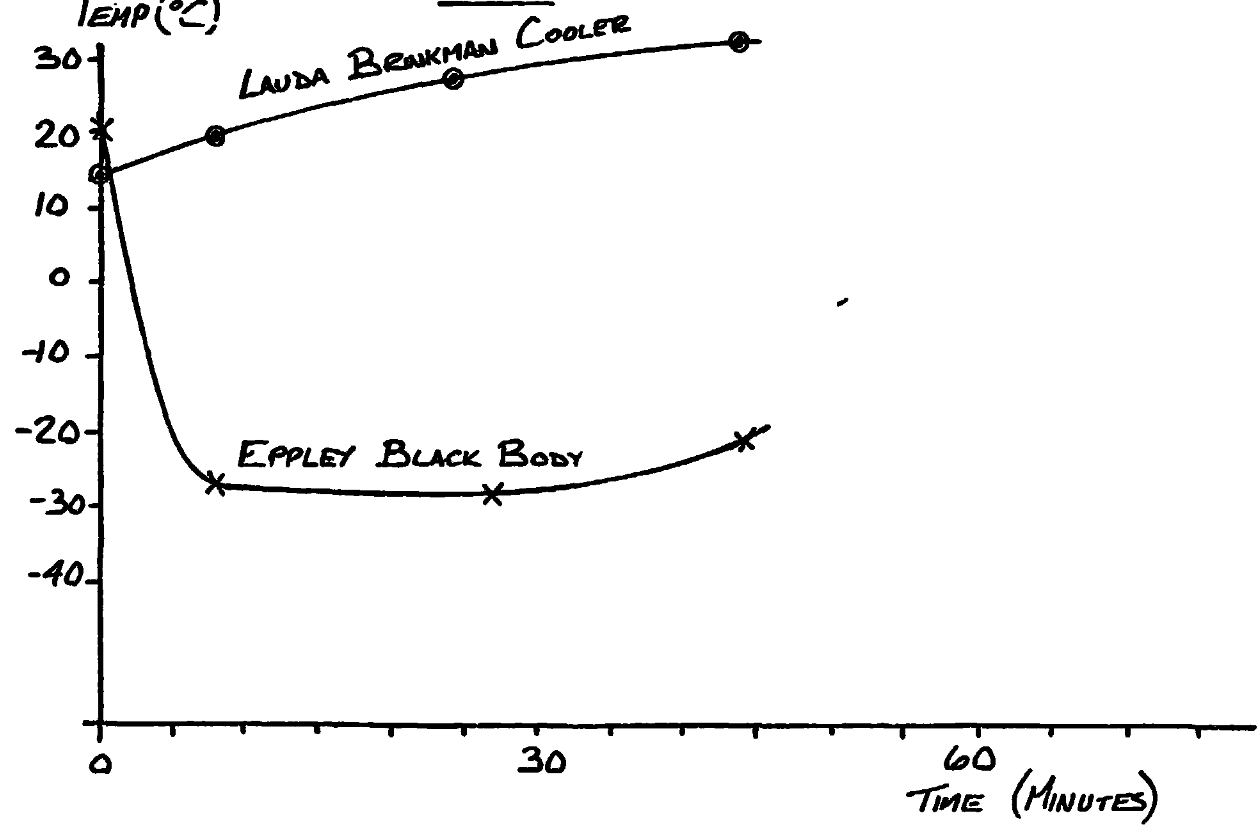
MKS Sensor Head
Type 310 BHS-1000 Ser. No. 13426
Zero Drift

Fig. 5



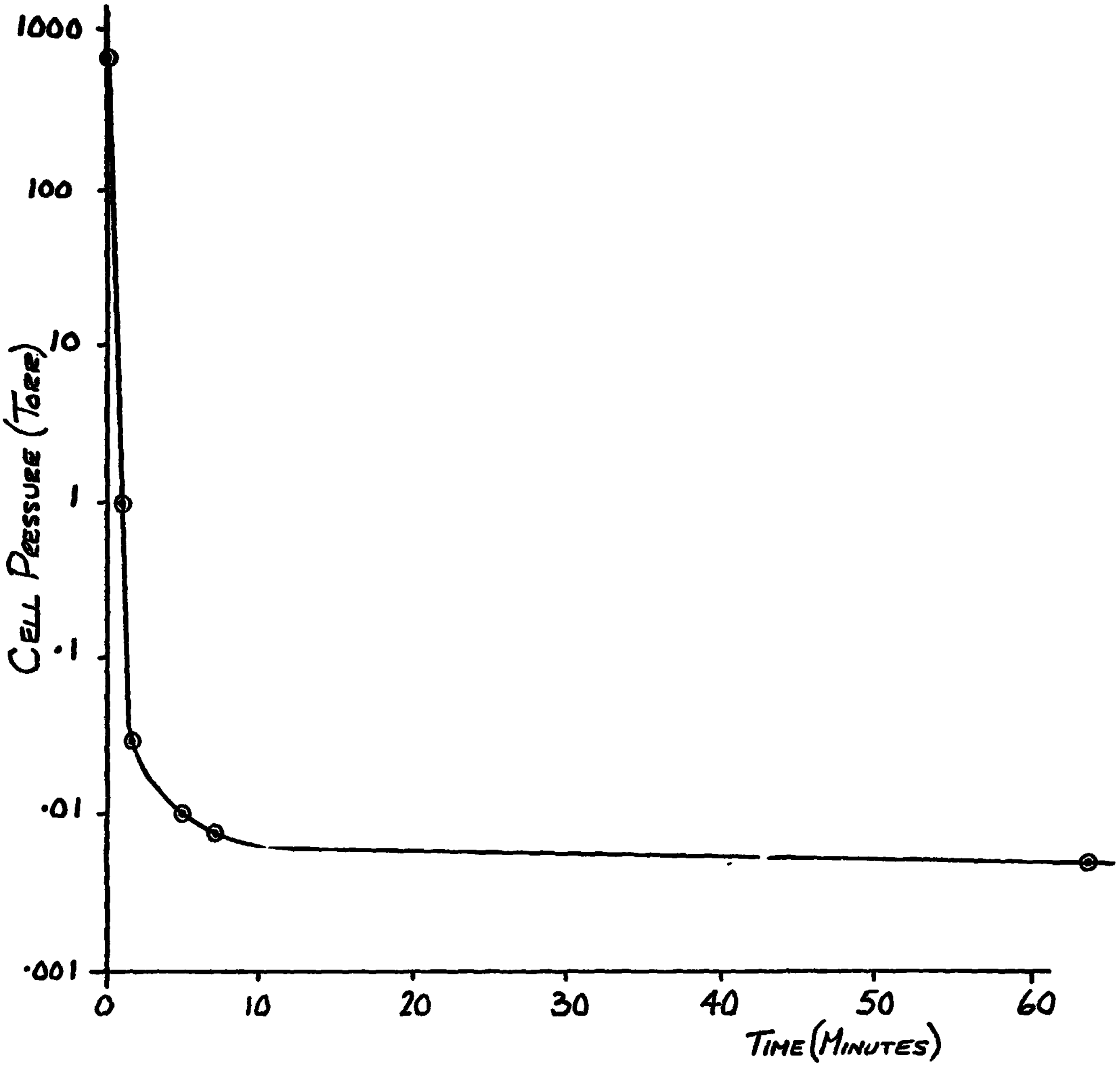
T.E. Set At 1,000

Fig. 6



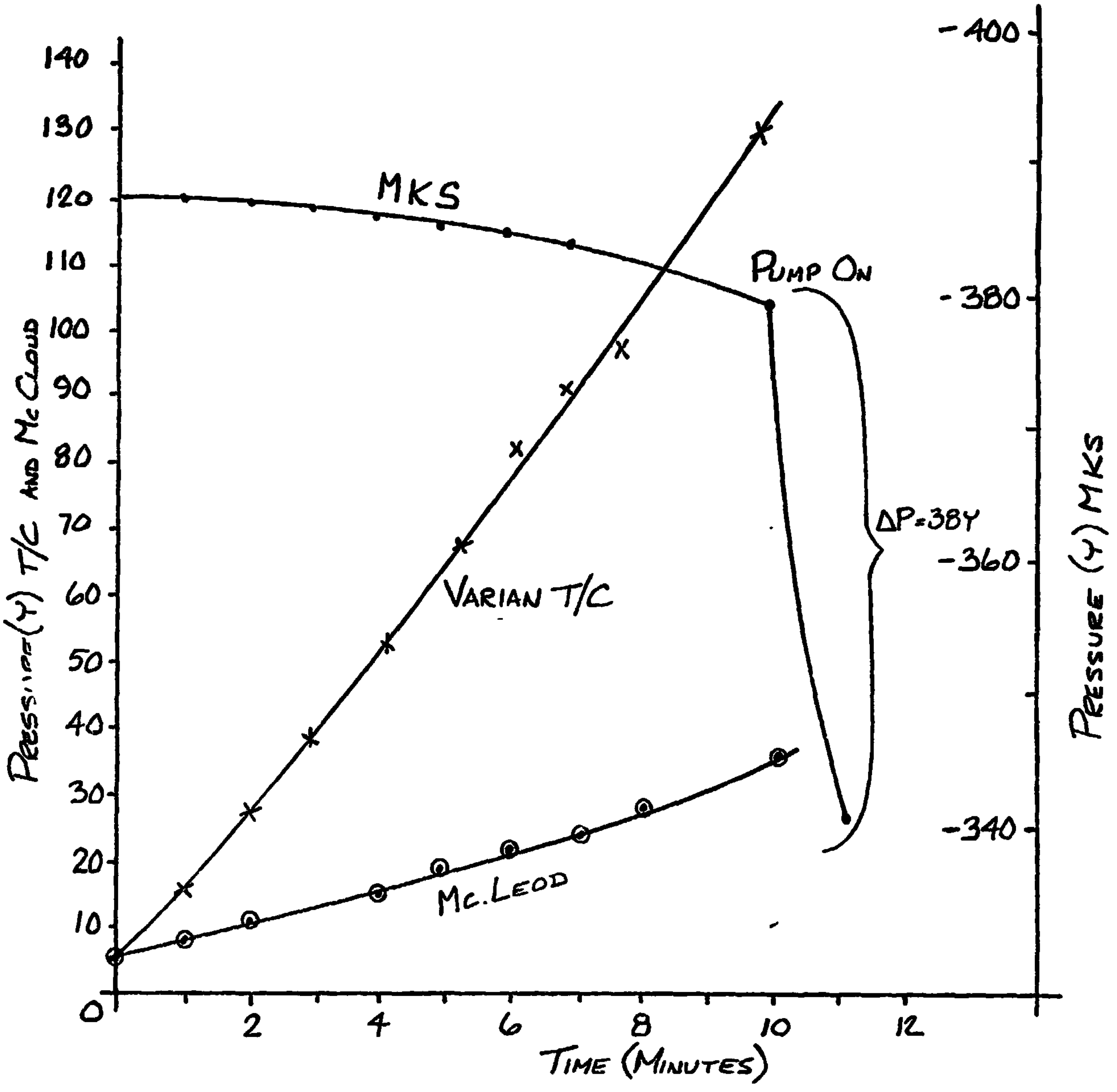
T.E. Set At 2,500

Fig. 7

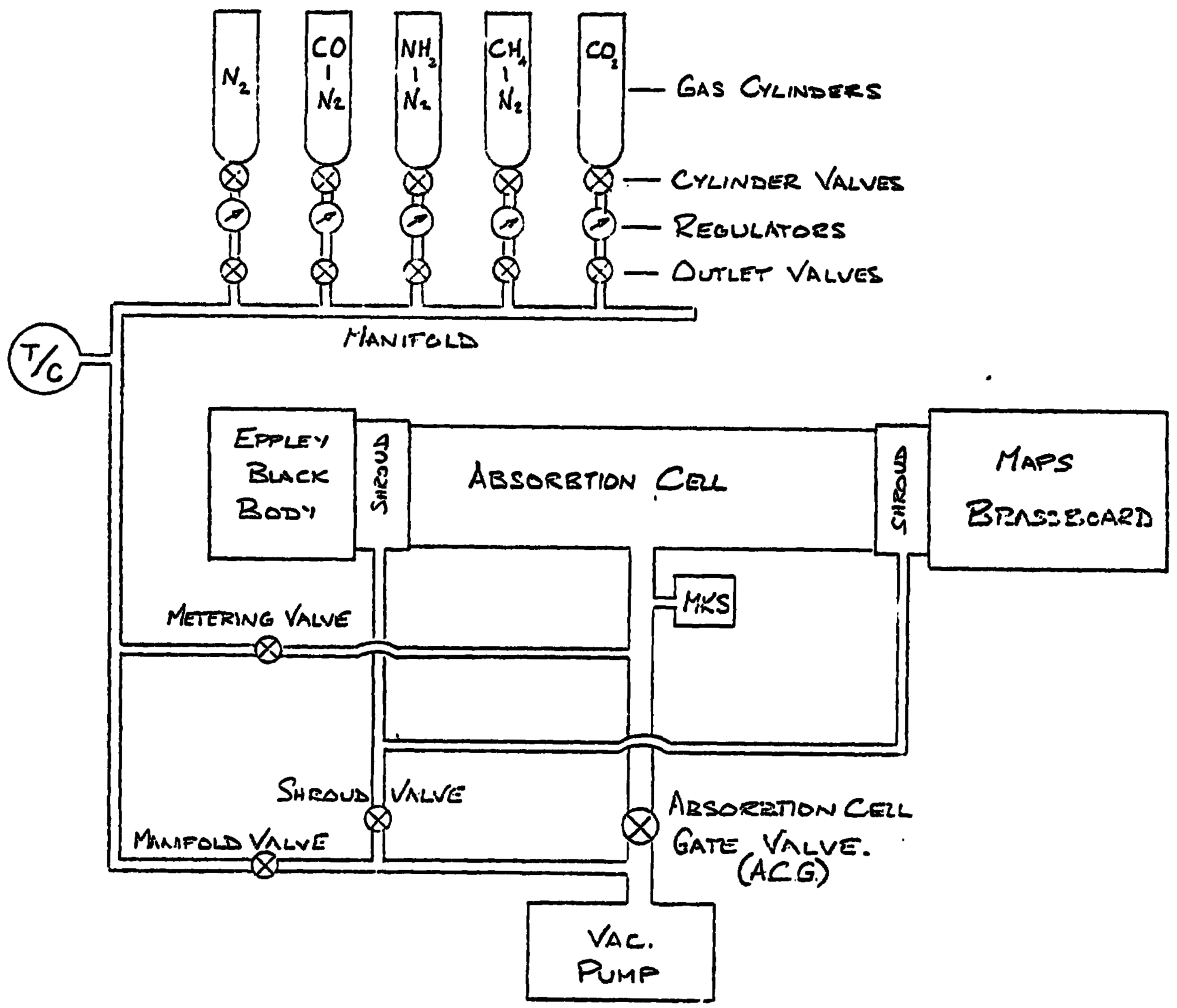


GSU Cell
Pump Down Tests (MKS Guage)
July 25th 1975

FIG. 8



GAS CELL LEAK TEST



G.S.U. SCHEMATIC

☐ Shipping, after shipment to ☐ Cost Accounting
☐ Shipping File
☐ Open Shipping Order File
☐ Cost Accounting

SHIPPING ORDER/REPORT NO: 8815 USA

Cross References
Job No: 196-11
Job Order No:
Receiving Report No:

hip to T.R.W. Systems Group.
~~T.R.W. Inc.~~
~~3001 Aviation Rd.~~
Manhattan Beach.
Cal. M.S.B.
att C SCHIMPF Traffic Mgr.

ia Emerican 213-535-0796

Bill to

for ☒ Sale, ☐ rental, ☐ loan, ☐ testing, ☐ return after repa ☐ other (explain)

from ☐ Stock-Material ☐ Stock-Finished Goods ☒ Contract ☐ Our Equipment ☐ Other (explain)

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off premises insurance yes ☐ no ☐

m	Quantity	DESCRIPTION	Serial No.	Unit Price	
1 of 2		Auxilary equipment ground Support Unit		50,000.00	
2 of 2		C.S.V Unit		50,000.00	
		freight chg. 276.00			
		[illegible] Cost 150.00			
		Contract # NAS-I-13695			
		Sub Cont. D39260 R DBS (75-1985-RA-076)			
					1200.
		Custom Clearance by			
		Pacific Int. Brokers			
		11207 South La Cienega BLVD.			
		L.A. Cal.		Packaging approved [illegible]	[illegible] Sept 1974

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APPENDIX G

MAPS ELECTRONICS BREADBOARD TEST PROCEDURE

TEST DATA COPY

Revision A
August 11, 1975

MAPS ELECTRONICS
BREADBOARD TEST PROCEDURE

1.0 SCOPE

This procedure covers the final performance testing of the MAPS Electronics breadboard exclusive of the circuitry contained in the opto-mechanical head assembly.

2.0 TEST CONDITIONS

2.1 Test Article

The MAPS electronics breadboard consists of a chassis assembly containing 4 breadboard circuit assemblies whose sketch schematic identification is as follows:

Bd. #1 - SK-MAPS-BB-101, Temperature Control and Motor Drive
Bd. #2 - SK-MAPS-BB-102, Signal Processing - A
Bd. #3 - SK-MAPS-BB-103, Signal Processing - B
Bd. #4 - SK-MAPS-BB-104, Temperature Sense and Bias Regulators

Breadboard input/output connections are delineated in sketch # SK-MAPS-BB-107.

2.2 Test Equipment

Testing of the breadboard will be performed using the special power supply panel to provide the various secondary voltages. Inputs simulating signals from the opto-mechanical sensing head will be provided from a special head simulating kludge box.

Simulation of various thermistor inputs will be provided by decade resistance boxes. The motor, heater, and T. E. Cooler loads will be represented by a set of load resistors.

In addition to the above mentioned special items, the following additional test equipment is needed:

2.2 Test Equipment - continued

- Function Generator, Wavetek
- Oscilloscope, Tektronix
- W Type, Plug-in for Tektronix Scope
- DVM, DC and rms AC
- Counter, frequency
- Strip Chart Recorder, Sanborn
- Data Translator Box, TRW Special to interface DVM to an HP9100 Calculator
- HP9100 Calculator
- VOM

2.2.1 Test Equipment Description

2.2.1.1 Sensing Head Simulator

This unit provides the S and R timing inputs as well as the 3 simulated radiance input signals denoted $(S_1 + R_1)$, $(S_2 + R_2)$ and $(S_3 + R_3)$. Potentiometers on the simulator allow the adjustment of the balance signal level (R), the common scene signal level (S) and the addition of a small scene signal component to the $(S_1 + R_1)$ and $(S_3 + R_3)$ signals (simulating the ΔV and $\Delta V'$ signals).

In addition, the relative amplitudes of the $(S_1 + R_1)$ or $(S_3 + R_3)$ signals may be adjusted without changing the ratio of scene signal to balance signal. (This simulates individual channel gain variations.)

2.2.1.2 Load Simulator

The chopper motor, the BB heater, and the 3 T. E. Coolers are simulated by a set of load resistors as follows:

- 2-Motor Coils - 1000 ohms each (represents 60V case only)
- 1-BB Heater - 82.5 ohms
- 3-TE Coolers - 21.5 ohms each

2.2.1.3 Data Reduction Unit

This unit accepts data from the Digital Voltmeter and formats it for readout to a HP9100 calculator. The calculator is then programmed to provide the mean and standard deviation of a selected number of DVM readings.

3.0 PROCEDURE

3.1 Procedure Performance

The step-by-step procedure for the functional testing is given below. The test sequence given is not mandatory. Test results should be recorded in the spaces provided in the body of the procedure.

3.2 Test Setup and Preliminary Checks

Interconnect the MAPS breadboard and the power switching unit. Connect the head simulator to the breadboard via a breakout box to head connector J3. Connect the dummy loads to head connector J2.

Switch on the electronics and measure and record the following input and bias voltages:

(a) Inputs

- +15V IN @ pin 1 of J1 = +14.99V
- -15V IN @ pin 2 of J1 = −15.05V
- + 5V IN @ pin 3 of J1 = +4.98V

(b) Regulated ±12V Outputs

- +12V-1 @ pin 7 of J3 = +12.01V
- +12V-2 @ pin 8 of J3 = +12.01V
- +12V-3 @ pin 9 of J3 = +12.01V
- -12V-1 @ pin 10 of J3 = −12.01V
- -12V-2 @ pin 11 of J3 = −12.01V
- -12V-3 @ pin 12 of J3 = −12.01V

(c) Internal ±10V Bias Voltages

- +10V @ pin 6 of AR7, Board 3 = +9.992V
- -10V @ pin 6 of AR8, Board 3 = −9.992V

(d) Regulated +100V Output

Switch on the +130 volt input and measure the following voltages:

- +130V input @ pin 7 of J1 = +120.5V
- 100V-1 @ pin 38 of J3 = 100.18V
- 100V-2 @ pin 39 of J3 = 100.18V
- 100V-3 @ pin 40 of J3 = 100.18V

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3.3 Motor Driver Tests

The purpose of these tests is to check out the 2 phase synchronous motor drive electronics.

The circuit can operate at 3 selectable frequencies using an internal clock or can use an external clock. The motor drive voltage also has three selectable values as determined by a switch on the unit power panel. The test sequence is as follows:

(a) Set the breadboard clock frequency switch in the low position and the clock select switch in the internal position.

(b) Put the motor voltage switch on the power panel into the 20 volt position.

(c) Turn on the motor voltage and check the ϕA and ϕB motor drive signal at pins 9 and 11 of J2.

(d) Verify that square wave outputs are present with an oscilloscope. Measure and record the peak to peak amplitude and verify that a 90° phase relationship exists. Also measure the drive signal frequency. Record the results below:

- PP voltage, ϕA = 32VPP
- PP voltage, ϕB = 32VPP
- 90° phasing = ✓
- Drive frequency = 30.56 Hz

(e) Switch the frequency select switch to the mid and high positions and record the drive frequency.

- Mid position 113 Hz.
- Hi position 225 Hz.

3.3 Motor Driver Tests - continued

(f) Return the frequency select switch to the low position and switch the motor voltage switch to the 40 volt position. Measure the peak to peak drive outputs.

- PP voltage, ϕA = 72vpp
- PP voltage, ϕB = 72vpp

(g) Put the motor voltage switch in the 60 volt position and repeat step (f).

- PP voltage, ϕA = 120vpp
- PP voltage, ϕB = 120vpp

(h) Put the clock select switch in the external position. Verify that the ϕA and ϕB outputs go to zero.

Outputs zero, ✓ Check to verify

(i) Connect a square wave function generator to the external clock input and adjust for a 100 Hz square wave output of 5 volts peak to peak about zero. Check the ϕA and ϕB outputs and verify that the output drive is at one-fourth of the input frequency.

✓ Check to verify

3.4 Thermoelectric Cooler Drive Tests

The purpose of these tests is to verify the correct operation of the 3 emitter followers which supply constant voltage drive to the thermoelectric coolers.

The test sequency is as follows:

(a) Turn on the T.E. cooler voltage at the power panel and measure the dc voltage into the unit on pin 16 of J1.

T.E. Cooler Input Voltage = 6.905 volts.

3.[illegible] <u>Thermoelectric Cooler Drive Tests</u> - continued

(b) Connect the DVM across the load resistor connected to pins 1 and [illegible] of J2 to monitor the drive voltage. Adjust potentiometer R51 on Board #2 to vary the output voltage to the load. Measure and record the minimum and maximum output capability and set the pot for 3.5 volts out. Record results below.

T.E. Cooler #1

- Minimum voltage = 1.729v, (≤ 2V)
- Maximum voltage = 5.76v, (> 5.5V)
- Set point voltage = 3.5v, (3.5V)

(c) Repeat step (b) for T.E. Cooler #2 adjusting R52.

T.E. Cooler #2

- Minimum voltage = 1.65v, (≤ 2V)
- Maximum voltage = 5.67v, (> 5.5V)
- Set point voltage = 3.5v (3.5V)

(d) Repeat step (b) for T.E. Cooler #3 adjusting R53.

T.E. Cooler #3

- Minimum voltage = 1.68v, (≤ 2V)
- Maximum voltage = 5.75v, (> 5.5V)
- Set point voltage = 3.5v, (3.5V)

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3.5 Temperature Sensing Circuit Tests

These tests check the operation of the six temperature readout circuits on Board #4 (schematic SK-MAPS BB-104). A variable resistance box is to be used to simulate the variable resistance of the sensing thermistor. Measure and record the bridge bias voltage at the emitter of Q4 on Board #4.

6.408 volts (requirement = 6.4V ±.02 V)

3.5.1 Blackbody #1 Temperature Sense Circuit

Connect a variable resistance box to pins 22 and 23 of J3. For each of the resistance box settings given below, measure and record the voltage at the BB#1 temperature output (pin 5 of J4).

Simulated Temperature	BB#1 Thermistor Resistance (Ohms)	BB#1 Temperature Voltage (Volts)
0°C	7355	-5.961
5°C	5719	-4.724
7°C	5183	-4.201
10°C	4482	-3.354
15°C	3539	-2.010
17°C	3226	-1.448
20°C	2814	-0.107
22°C	2572	-0.048
25°C	2252	+.775
27°C	2064	+1.321
30°C	1815	+2.112
32°C	1667	+2.627
35°C	1471	+3.371
37°C	1355	+3.847
40°C	1200	+4.531
45°C	984	+5.538

3.5.2 Blackbody #2 Temperature Sense Circuit

Repeat the test of paragraph 3.5.1 for blackbody #2. Connect the resistance box to pins 24 and 25 of J3. Read the output at pin 6 of J4. Record results below:

Simulated Temperature	BB#2 Thermistor Resistance (Ohms)	BB#2 Temperature Voltage (Volts)
0°C	7355	-5.970
5°C	5719	-4.727
7°C	5183	-4.204
10°C	4482	-3.528
15°C	3539	-2.813
17°C	3226	-1.452
20°C	2814	-0.610
22°C	2572	-0.051
25°C	2252	+.776
27°C	2064	+1.317
30°C	1815	+2.108
32°C	1667	+2.624
35°C	1471	+3.367
37°C	1355	+3.944
40°C	1200	+4.527
45°C	984	+5.584

3.5.3 Blackbody #3 Temperature Sense Circuit

Repeat the test of paragraph 3.5.1 for blackbody #3. Connect the variable resistance box to pins 26 and 27 of J3. Monitor the voltage at pin 7 of J4. Record the voltage for the following resistance values.

Simulated Temperature	BB#3 Thermistor Resistance (Ohms)	BB#3 Temperature Voltage (Volts)
61°C	2669	-7.187
63°C	2497	-6.234
65°C	2339	-5.283
67°C	2191	-4.307
69°C	2055	-3.360
71°C	1928	-2.378
73°C	1810	-1.438
75°C	1700	-0.471
77°C	1598	+.467
79°C	1503	+1.407
81°C	1414	+2.344
83°C	1332	+3.258
85°C	1255	+4.166
87°C	1183	+5.062
89°C	1116	+5.939
91°C	1053	+6.806

3.5.4 Detector Temperature Sense Circuit Tests

Each of the 3 detector thermistor bridge circuits must be matched to the characteristics of the detector thermistor by the selection of a fixed resistance to be placed in parallel with the thermistor.

Values selected for these tests were picked to match detector vendor thermistor data on the 3 detectors delivered for brassboard use.

3.5.4 Detector Temperature Sense Circuit Tests - continued

(a) Detector #1 Test

Install a 124K ±1% shunt as R68 on Board #4. Connect the variable resistance box to pins 16 and 17 of J3. Read the output on pin 8 of J4.

Simulated Temperature	Thermistor Resistance	Voltage
-65°C	145K	+1.96v
-67°C	175K	+1.429v
-70°C	230K	+0.757v
-73°C	310K	+0.154v
-75°C	390K	-.224v
-80°C	710K	-.934v

(b) Detector #2 Test

Install a 210K shunt as R69 on Board #4. Connect the variable resistance box to pins 18 and 19 of J3. Read the output on pin 9 of J4.

Simulated Temperature	Thermistor Resistance	Voltage
-60°C	75K	+3.215v
-65°C	92K	+2.033v
-70°C	128K	+.867v
-75°C	174K	-.262
-80°C	250K	-1.365
-85°C	380K	-2.344
-90°C	600K	-3.109

3.5.4 Detector Temperature Sense Circuit Tests - continued

(c) Detector #3 Test

Install a 261K ±1% shunt as R70 on Board #4. Connect the variable resistance box to pins 20 and 21 of J3. Read the voltage at pin 10 of J4.

Simulated Temperature	Thermistor Resistance	Voltage
-60°C	62K	+3.855
-65°C	84K	+2.364
-70°C	112K	0.955
-75°C	150K	-0.271
-80°C	208K	-1.447
-85°C	300K	-2.517
-90°C	420K	-3.242

3.6 Blackbody Temperature Control Circuit Tests

The purpose of these tests is to check the operation of the on-off temperature control circuitry of Board #1.

(a) Adjust R39 on Board #1 so that the center arm voltage (junction of the pot and R37) is zero ±10 millivolts.

(b) Connect a decade resistance box to simulate BB #3 thermistor (pins '6 and 27 of J3).

(c) Set dead zone potentiometer R66 to the center of its adjustment range.

(d) Connect a DVM across the Heater load at pin 7 and 8 of J2.

(e) Set the decade resistance box to 2055Ω, turn on the Heater voltage supply and measure the voltage across the heater load.

Load voltage 27.7, (28V)

(f) Set the decade resistance box to 1503 ohms and measure the load voltage.

Load voltage 0, (0 V)

(g) Slowly increase value of resistance until load voltage goes on. Note resistance. Slowly decrease the resistance until the load voltage goes off. Repeat the above procedure several times to determine the equivalent on-off switching points and hysteresis.

Switch on Resistance = 1648 ohms (≈76°C)
Switch off Resistance = 1587 ohms.

(h) Turn the temperature set point potentiometer R39 fully clockwise and repeat step (g).

Switch on Resistance = 1424 ohms (≈52°C)
Switch off Resistance = 1365 ohms.

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3.. Blackbody Temperature Control Circuit Tests - continued

(i) Turn the set point control R39 fully ccw and repeat step (g).

Switch on Resistance = 1896 ohms (≃ 72°C)

Switch off Resistance = 1817 ohms.

Return R39 to the center of its control range.

(j) Adjust dead zone control R66 fully clockwise and repeat the test of step (g). Note R39 should be in the mid-range position per step (g).

Switch on Resistance = 1151 ohms

Switch off Resistance = 1649 ohms.

(k) Adjust dead zone control R66 fully counterclockwise and repeat the test of step (g).

Switch on Resistance = 1651 ohms

Switch off Resistance = 1576 ohms.

(l) Return R66 to its mid-range position and R39 to the center set point position.

3.7 Signal Processing Circuit Tests

The sequence of signal processing tests are to be performed at both the low and the high chopping frequencies. The pick off phase adjustments for the S and R demodulators must be adjusted separately for each operating frequency.

In addition, the ΔV and ΔV' difference amplifier trim resistors (R29, R33, R37, and R38) must be separately selected for minimum V signal feedthrough at each chopping frequency.

3.7.1 Low Chopping Frequency Tests (NH_3 Mode)

For the tests which follow, the head simulator is set in the low frequency mode (25 Hz scene, 50 Hz balance) and the bandwidth limit switch is to be placed in the low position.

The demodulator phasing should be adjusted and the ΔV and ΔV' difference amplifier trimming should be made before proceeding. Record the trim resistor values below.

For ΔV, R29 = 0, R33 = 0

For ΔV', R37 = 43Ω, R38 = 0

3.7.1.1 V Signal Gain and Linearity

The purpose of this test is to check the gain and linearity of the V output as the common scene input is varied. For this test the output is measured with a DVM at pin 2 of J4.

A composite (S + R) test signal from the head simulator shall be fed into the $S_2 + R_2$ input (J3, pin 3). The R component shall be set to zero and the peak to peak S value shall be accurately set to the values listed below through the use of an oscilloscope with a W type plug-in.

Also measure and record the rms ac input with a DVM. (DANA 4530 or equivalent).

8/13/75

S Input PP	S Input AC RMS	V Signal Output
0 Vpp	0	-.3mv
+2 Vpp	1.07v	1.96v
+4 Vpp	2.14v	3.94v
+6 Vpp	3.24v	5.94v
+8 Vpp	4.31v	7.91v
+10 Vpp	5.37v	9.87v

The expected gain is 1 volt dc per volt pp ac with a perfect square wave input.

3.7.1.2 R Signal Gain and Linearity

The purpose of this test is to check the gain and linearity of the R output as the balance signal level is varied. The input connections are the same as paragraph 3.7.1.2. The scene component shall be set to zero and the R component shall be varied using a W type plug-in to set the pp level. The R output shall be measured at pin 1 of J4.

8/13/75

R Input PP	R Input AC RMS	R Signal Output
0 Vpp	0	+0.04V
0.5 Vpp	.267V	1.07V
1.0 Vpp	.53V	2.09V
1.5 Vpp	.796	3.12V
2.0 Vpp	1.06V	4.16V

The expected gain is 2.5 Vdc per volt pp ac with a perfect square wave input.

3.7.1.3 ΔV, ΔV' Signal Gain and Linearity

The purpose of these tests is to check the gain and linearity of the ΔV and ΔV' output as the S_1 and S_3 signals are varied relative to the S_2 signal level.

For this test, all 3 simulated radiance inputs are required as follows:

- $(S_1 + R_1)$ to J3, pin 1
- $(S_2 + R_2)$ to J3, pin 3
- $(S_3 + R_3)$ to J3, pin 5

Set the common scene level and the ΔV level pots on the simulator to zero. Adjust the balance level pot until the R output is 2.50 volts ±.01 volts.

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The S component of the $S_1 + R_1$ and $S_3 + R_3$ inputs is then varied with the ΔV level control. The ΔV component of the inputs should be very accurately set up using a Tektronix oscilloscope with a W type plug-in. Record the data as listed below:

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(a) ΔV Test

S Component of $S_1 + R_1$	AC RMS $S_1 + R_1$ Voltage	ΔV Output
0 Vpp	.6344v	+7mv
0.05 Vpp	.6345v	1.07v
0.1 Vpp	.6346	2.24v
0.30 Vpp	.635[illegible]	[illegible]
0.40 Vpp	.6368v	9.06v

The expected gain is 22.5 volts dc/volt pp ac with a square wave input.

(b) ΔV' Test

8/13/75

S Component of $S_3 + R_3$	AC RMS $S_3 + R_3$ Voltage	ΔV' Output
0 Vpp	.6354v	+9mv
0.05 Vpp	.6356v	1.08v
0.1 Vpp	.6356v	2.23v
0.15 Vpp	.6357v	3.40v
0.20 Vpp	.6358v	4.54v
0.25 Vpp	.6360v	5.67v
0.30 Vpp	.6364✓	6.76v
0.40 Vpp	.6374v	9.16v

The expected gain is 22.5 volts dc/volt pp ac with a square wave input.

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3.7.1.4 AGC Balance Loop Time Constant Check

The purpose of these tests is to check the ΔV and ΔV' automatic gain balance loop time constants.

For these tests all 3 simulated radiance inputs are needed as per paragraph 3.7.1.3.

3.7.1.4.1 ΔV Channel Balance Time Constant Check

(a) Adjust the scene and balance level controls for an R output of 2.5 volts and a V output of 5.0 volts. The ΔV control should be at zero.

(b) Adjust the simulator gain dials to make the R component of the $(S_1 + R_1)$ signal equal to 1V pp and the R component of the $(S_3 + R_3)$ signal equal to 1.5 volts pp.

(c) Feed the $(S_1 + R_1)$ and $(S_3 + R_3)$ simulated radiance signals to a selector switch and feed the switch output to the $(S_1 + R_1)$ input of the unit (pin 1 of J3).

(d) Set up the Sanborn strip chart recorder to monitor the ΔV AGC integrator voltage. (Pin 6 of AR13 on Board #2)

(e) By switching the $(S_1 + R_1)$ input selector switch back and forth between the $(S_1 + R_1)$ and $(S_3 + R_3)$ signal, an expotentia change in the integrator output voltage will be observed.

(f) Use the Sanborn Recorder to record the voltage and measure the time for the voltage to change 63% of the total change value when the selector switch is changed from the $S_3 + R_3$ to the $S_1 + R_1$ position. Repeat going from S_1 + to $S_3 + R_3$ switch position.

3.7.1.4.1 <u>ΔV Channel Balance Time Constant Check</u> - continued

(g) Record the measured time constant and other data as outlined below:

- R output = 2.500 Volts
- V output = 5.000 Volts
- $(S_1 + R_1)$ Signal- Total pp value = 5.25 Vpp
  - R component = 1.0 Vpp
  - S component = 4.30 Vpp
- $(S_3 + R_3)$ Signal- Total pp value = 7.7 Vpp
  - R component = 1.5 Vpp
  - S component = 6.3 Vpp
- Time Constant going from $(S_3 + R_3)$ to $(S_1 + R_1)$ = 19.2 ~~16~~ Seconds
- Time Constant going from $(S_1 + R_1)$ to $(S_3 + R_3)$ = 11.5 ~~[illegible]~~ Seconds

3.7.1.4.2 <u>ΔV' Channel Balance Time Constant Check</u>

Repeat paragraph 3.7.1.4.1 for the ΔV' Channel. Feed the switch selected signal into the $S_3 + R_3$ input (pin 5 of J3). Connect the Sanborn recorder to pin 6 of AR15 on Board #2.

Record the following data:

- R output = 2.5 Volts
- V output = 5.001 Volts
- $S_1 + R_1$ Signal = 5.25 Vpp
  - S component = 4.3 Vpp
  - R component = 1.0 Vpp
- $S_3 + R_3$ Signal
  - Total = 7.7 Vpp
  - S component = 6.3 Vpp
  - R component = 1.5 Vpp
- Time Constant going from $(S_3 + R_3)$ to $(S_1 + R_1)$ = 19.2 ~~[illegible]~~ Seconds
- Time Constant going from $(S_1 + R_1)$ to $(S_3 + R_3)$ = 12.4 ~~[illegible]~~ Seconds

3.7.1.5 Effects of Common V Signal on the ΔV, ΔV' and R Outputs.

The purpose of these tests is to determine the effects of the large common scene signal upon the ΔV and ΔV' outputs and upon the R output.

Set up the input simulator to supply all 3 inputs. Set the $(S_1 + R_1)$ and $(S_3 + R_3)$ gain controls to the 500 dial setting.

Set the ΔV level to zero and the balance level for a 2.5V R signal.

For various ΔV output levels, vary the scene level to obtain the V signals shown below and record the values of ΔV and ΔV' output. When measuring the ΔV and ΔV' outputs, use the HP9100A calculator to obtain 100 sample mean and standard deviation values. Wait 5 minutes after each V signal level change to allow the AGC loops to stabilize.

(a) Run #1 ΔV Set to Zero

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V Output	R Output	ΔV Output		ΔV' Output	
(Volts dc)	(Volts dc)	Mean	Std Dev	Mean	Std Dev
0V	2.418V	+.1mV	—	+3mV	—
2V	2.500V	+3.9	±1.5mV	+0.2mV	±1.2mV
4V	2.50	+3.1mV	±4mV	+3.6mV	±2.6mV
6V	2.504	+7.9mV	±2.9mV	+13.1mV	±2.5mV
8V	2.487	+16.9mV	±9.7mV	+25.3mV	±4.4mV

(b) Run #2 ΔV Set to +2V when V = 0

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V Output	R Output	ΔV Output		ΔV' Output	
(Volts dc)	(Volts dc)	Mean	Std Dev	Mean	Std Dev
0V	2.498V	2.002V	—	2.031V	—
2V	2.500V	1.998V	±2.9mV	2.028V	±1.5V
4V	2.502V	1.995V	±4.3mV	2.029V	±2.5V
6V	2.504V	2.001V	±7.4mV	2.034V	±3.9V
8V	2.481V	2.006V	±12.6mV	2.053V	±5.7mV

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3.7.1.5 Effects of Common V Signal on the ΔV, ΔV' and R Outputs - continued

(c) Run #3 ΔV Set to 4V when V = 0

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V Output	R Output	ΔV Output		ΔV' Output	
(Volts dc)	(Volts dc)	Mean	Std Dev	Mean	Std Dev
0V	2.498V	4.000V	—	4.162V	—
2V	2.500V	3.994V	±2.5mV	4.058V	±2.9mV
4V	2.503V	3.993V	±6.7mV	4.058V	±3.3mV
6V	2.505V	3.995V	±8.3mV	4.064V	±3.8mV
8V	2.479V	4.003	±7.2mV	4.081V	±7.0mV

(d) Run #4 ΔV Set to 6V when V = 0

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V Output	R Output	ΔV Output		ΔV' Output	
(Volts dc)	(Volts dc)	Mean	Std Dev	Mean	Std Dev
0V	2.498V	6.000V	—	6.094V	—
2V	2.500V	5.996V	±2.4mV	6.094V	±2.3mV
4V	2.503V	5.997V	±5.5mV	6.095V	±4.9mV
6V	2.504V	5.995V	±5.8mV	6.101V	±6.9mV
8V	2.476V	6.005V	±6.9mV	6.117V	±6.[illegible]mV

3.7.1.6 Effects of Channel Gain Variation Upon the ΔV and ΔV' Outputs

The purpose of this test is to measure the effect of changes in the optical path, detectors and preamplifiers, which cause a common reduction in both the S and R component of the input to the signal processing circuits.

This effect is simulated by the $(S_1 + R_1)$ and $(S_3 + R_3)$ gain controls on the head simulator. With the gain pots set to the mid-range position (dial reading of 500), adjust the scene level for a 4 volt V output. Adjust the balance level for a 2.5 volt R output. Adjust the ΔV control for a 2 volt ΔV output.

With an ac reading DVM, measure and record the $(S_1 + R_1)$, $(S_2 + R_2)$, and $(S_3 + R_3)$ input voltages. Record in the table below. Then adjust the gain pot settings to obtain ±10 percent and ±25% changes in the $(S_1 + R_1)$ and $(S_3 + R_3)$ ac voltage readings. After making each gain setting, allow at least 15 minutes for the AGC loop to react and reach its final value before recording data.

The ΔV and ΔV' readings should be in the mean of 100 samples using the HP9100 calculator.

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Gain Balance	$S_1 + R_1$ RMS	$S_2 + R_2$ RMS	$S_3 + P_3$ RMS	V Volts, dc	ΔV Volts, dc	ΔV' Volts, dc	R Volts, dc
Equal	2.223V	2.175V	2.223V	4.003V	2.006V	2.039V	2.500V
+10%	2.445V	2.175V	2.445V	4.003V	2.006V	2.039V	2.501V
+25%	2.778V	2.175V	2.778V	4.002V	2.003V	2.039V	2.501V
-10%	2.000V	2.175V	2.000V	4.002V	2.003V	2.039V	2.501V
-25%	1.667V	2.175V	1.667V	4.002V	2.002V	2.038V	2.501V
Equal	2.223V	2.175V	2.223V	4.002V	2.004V	2.039V	2.501V

3.7.2 High Chopping Frequency Tests (CO Mode)

These tests are very nearly a repeat of the tests of paragraph 3.7.1 at the 172/34[illegible] hertz chopping rate.

Put the head simulator in the high frequency mode and put the bandwidth limit switch in the high position.

Demodulator phasing adjustments and the ΔV and ΔV' difference amplifier trimming should be made before proceeding. Record the trim resistor values below:

For ΔV, R29 = 0, R33 = 20Ω
For ΔV', R37 = 51Ω, R38 = 0

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3.7.2.1 V Signal Gain and Linearity

Repeat paragraph 3.7.1.1 at the high chopping frequency. Record the data below:

S Input PP	S Input AC RMS	V Signal Output
0 Vpp	0	+2mV
+2 Vpp	1.084v	1.97v
+4 Vpp	2.17v	3.95v
+6 Vpp	3.27v	5.94v
+8 Vpp	4.34v	7.89v
+10 Vpp	5.38v	9.79v

The expected gain is 1.0 volts dc per volt pp ac for a square wave input.

3.7.2.2 R Signal Gain and Linearity

Repeat paragraph 3.7.1.2 at the high chopping frequency. Record the data below:

R Input PP	R Input AC RMS	R Signal Output
0 Vpp	0	+.04v
0.5 Vpp	.263v	1.07v
1.0 Vpp	0.528V.	2.10v
1.5 Vpp	0.796v	3.15v
2.0 Vpp	1.06v	4.16v
2.5 Vpp	1.32v	5.18v
3.0 Vpp	1.58v	6.19v

The expected gain is 2.5V dc per volt pp ac with a square wave input.

3.7.2.3 ΔV and ΔV' Signal Gain and Linearity

Repeat paragraph 3.7.1.3 at the high chopping frequency. Record the data as listed below:

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(a) ΔV Test

S Component of $S_1 + R_1$	AC RMS S_1 + R1 Voltage	ΔV Output
0 Vpp	.6315v	+ 4mv
0.05 Vpp	.6317v	+1.08v
0.1 Vpp	.6319v	+2.18V
0.15 Vpp	.6321V	+ 3.36v
[illegible]	[illegible]	+4.42V
0.40 Vpp	[illegible]	[illegible]

(b) ΔV' Test

S Component of $S_3 + R_2$	AC RMS $S_3 + R_3$ Voltage	ΔV Output
0 Vpp	.6309V	+.003V
0.05 Vpp	.6310V	+ 1.09V
0.1 Vpp	.6312V	+2.23V
0.15 Vpp	.6318V	+3.33V
0.20 Vpp	.6321V	+ 4.49V
0.25 Vpp	.6324V	+ 5.57V
0.30 Vpp	.6327V	+6.63V
0.40 Vpp	.6330V	+9.05V

3.7.2.4 AGC Balance Loop Time Constant Check

Repeat the first 3 runs of paragraph 3.7.1.4 at the high chopping frequency.

(a) (a) ΔV Channel-Test per paragraph 3.7.1.4.1 and record data below:

- R output = 2.533 Volts
- V output = 5.013 Volts
- $(S_1 + R_1)$ Signal- Total pp value = 5.25 Vpp
  - R component = 1.0 Vpp
  - S component = 4.25 Vpp
- $(S_3 + R_3)$ Signal- Total pp value = 7.7 Vpp
  - R component = 1.48 Vpp
  - S component = 6.3 Vpp
- Time Constant going from $(S_3 + R_3)$ to $(S_1 + R_1)$ = 20.5 ~~[illegible]~~ Seconds
- Time Constant going from $(S_1 + R_1)$ to $(S_3 + R_3)$ = 12 ~~[illegible]~~ Seconds

(b) ΔV' Channel - Test per paragraph 3.7.1.4.2 and record data below:

- R output = 2.533 Volts
- V output = 5.013 Volts
- $S_1 + R_1$ Signal = 5.25 Vpp
  - S component = 4.3 Vpp
  - R component = 1.0 Vpp
- $S_3 + R_3$ Signal
  - Total = 7.7 Vpp
  - S component = 6.3 Vpp
  - R component = 1.5 Vpp
- Time Constant going from $(S_3 + R_3)$ to $(S_1 + R_1)$ = 18.5 ~~[illegible]~~ Seconds
- Time Constant going from $(S_1 + R_1)$ to $(S_3 + R_3)$ = 12.2 ~~[illegible]~~ Seconds

3.7.2.5 Effects of Common V Signal on the ΔV, ΔV', and R Outputs

Repeat the tests of paragraph 3.7.1.3 at the high chopping frequency. Record the test results below:

(a) Run #1 ΔV Set to Zero

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		ΔV' Output	
		Mean	Std Dev	Mean	Std Dev
0V	2.50V	4mV	0	-6mV	0
2V	2.514V	+10mV	0	-4mV	0
4V	2.526V	+18.4mV	±1.6mV	-1.2mV	±1.4mV
6V	2.524V	+30.2mV	±1.5mV	+6.3mV	±2.1mV
8V	2.533V	+45.3mV	±5.4mV	+19.5mV	±2.3mV

(b) Run #2 ΔV Set to +2V when V = 0

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		ΔV' Output	
		Mean	Std Dev	Mean	Std Dev
0V	2.50V	2.002V	0	2.024V	0
2V	2.514V	1.998V	±1.9mV	2.016V	±0.8mV
4V	2.527V	1.998V	±1.4mV	2.009V	±3mV
6V	2.524V	2.001V	±3.4mV	2.007V	±3.4mV
8V	2.533V	2.005V	±13.1mV	2.010V	±7.1mV

3.7.2.5 Effects of Common V signal on the ΔV, ΔV', and R Outputs - continued

(c) Run #3 ΔV Set to 4V when V = 0

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		ΔV' Output	
		Mean	Std Dev	Mean	Std Dev
0V	2.500V	3.997V	—	4.051V	—
2V	2.514V	3.990V	± 2.2mV	4.040V	± 3.3mV
4V	2.527V	3.985V	± 2.7mV	4.032V	± 5.7mV
6V	2.526V	3.97[illegible]V	± 8.3mV	4.025V	± 8.3mV
8V	2.534V	3.978V	± 4.2mV	4.025V	± 12.8mV

3.7.2.6 Effects of Channel Gain Variation Upon the ΔV and ΔV' Outputs

Repeat the tests of paragraph 3.7.1.6 at the high chopping frequency. Record the test results below:

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Gain Balance	$S_1 + R_1$ RMS	$S_2 + R_2$ RMS	$S_3 + R_3$ RMS	V Volts, dc	ΔV Volts, dc	ΔV' Volts, dc	R Volts, dc
Equal	2.258V	2.206V	2.256V	4.000V	2.002V	2.013V	2.499V
+10%	2.484V	2.206V	2.484V	4.000V	2.001V	2.012V	2.500V
+25%	2.813V	2.206V	2.823V	4.001V	1.998V	2.006V	2.500V
-10%	2.032V	2.206V	2.032V	4.000V	2.003V	2.017V	2.500V
-25%	1.693V	2.206V	1.693V	4.000V	2.002V	2.020V	2.500V
Equal	2.256V	2.206V	2.256V	3.999V	2.006V	2.016V	2.500V

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3.8 *Power Consumption Test*

The purpose of this test is to determine the overall power consumed by the electronics under various operating conditions.

Using a VOM, measure and record the +15, -15, and +5 volt line current into the breadboard under the following test conditons.

(a) Electronics on Only, R = 2.5V, V = 4V, ΔV = 4V

+5V line = 44.5 ma 19ma when Heater Thermistor is Shorted
+15V line = 60 ma
-15V line = 37 ma

(b) Same as step (a) with the T.E. Cooler power, Motor drive power, and the BB heater power on.

+5V line = 44.5 ma 14ma when Heater Thermistor is Shorted.
+15V line = 60 ma
-15V line = 37 ma

3.9 Phase Sensitivity Test

The purpose of this test is to evaluate the units performance with misaligned timing signals to the S and R synchronous demodulators.

The timing signals are developed by the chopper wheel pickoff circuits of signal processing Board B. Potentiometers R58 and R63 on this board allow adjustment of the S and R demodulator drive signals.

At each of the two chopping frequencies these pots are normally adjusted for maximum R and V outputs. For these tests they will be purposely misaligned to cause a ±3% phase error.

3.9.1 Low Frequency Phase Sensitivity Test

(a) Set up the test situation of paragraph 3.7.1.3. Adjust the balance input for a 2.5 volt R signal, the Scene level for a 4.0V V signal and the ΔV level for a ΔV signal of 2.0 volts.

(b) Check the timing of V signal and R signals relative to the demodulator switching signals and adjust R63 and R58 if necessary.

(c) Readjust the inputs for the correct output levels if necessary. Record the readings in the table below as the baseline data:

(d) Sync an oscilloscope on the R pickoff signal (pin 34 of J3) and monitor the R demodulator drive signal (pin 9 of Z2 on Board #2). Note the phase relationship of the R demodulator drive signal to the R pickoff signal and adjust R58 to delay the demodulator drive by 0.2 milliseconds (1%). Repeat the baseline readings, recording the data below.

(e) Repeat step (d), only this time advance the demodulator drive by -0.2 milliseconds.

(f) Return the R demodulator timing to the original R58 setting. Repeat the baseline data readings and record below.

(g) Sync an oscilloscope on the S pickoff signal (pin 28 of J3) and monitor the V demodulator drive signal (pin 13 of Z1 of Board #3). Note the phase relationship of the V demodulator drive signal to the sync signal and adjust R63 to delay the demodulator drive signal by 0.4 milliseconds. Repeat the baseline data readings and record in the table below.

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3.9.1 Low Frequency Phase Sensitivity Test - continued

(h) Repeat step (g) advancing the demodulator drive by 0.4 milliseconds.

(i) Return the V demodulator timing to the original R63 setting and repeat the baseline data readings. Record results in the table below.

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Low Frequency Phase Sensitivity Results

Test Case	R Signal	V Signal	ΔV Signal	ΔV' Signal
Initial Baseline	2.503V	4.000V	2.004V	2.037V
R, 1% delay	2.508V	4.000V	2.011V	2.046V
R, 1% advance	2.419V	4.000V	1.999V	2.031V
Baseline Repeat	2.501V	4.000V	2.003V	2.035V
V, 1% delay	2.500V.	3.985V	1.920V	1.947V
V, 1% advance	2.500V.	3.847V	1.940V	1.980V
Final Baseline	2.500V	4.001V	2.005V	2.037V

3.9.2 High Frequency Phase Sensitivity Tests

Repeat the tests of paragraph 3.9.1 using the high chopping frequency inputs. Peak the R and V readings prior to recording the baseline data of step (c).

For steps (d) and (e) adjust R58 for a timing change of 0.03 milliseconds.

For steps (g) and (h) adjust the R63 for a timing change of 0.16 milliseconds.

Record all the data in the table below:

3.9.2 High Frequency Phase Sensitivity Tests - continued

High Frequency Phase Sensitivity Results 8/14/75

Test Case	R Signal	V Signal	ΔV Signal	ΔV' Signal
Initital Baseline	2.502V	3.999V	2.015V	2.037V
R, 1% delay	2.473V	3.999V	2.008V	2.047V
R, 1% advance	2.458V	3.999V	1.986V	2.019V
Baseline Repeat	2.501V	3.999V	2.008V	2.034
V, 1% delay	2.501V	3.920V	1.948V	1.965V
V, 1% advance	2.500V	3.891V	1.957V	2.005V
Final Basline	2.501V	3.999V	2.003V	2.035V

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3.10 Temperature Tests

The purpose of these tests is to evaluate the performance of the signal processing circuitry over a temperature environment.

The breadboard electronics shall be installed in a temperature chamber and interconnected with the sensing head simulator, the load simulator, and the necessary output cabling.

3.10.1 Ambient Temperature Baseline Data - Low Frequency Mode

(a) Set up the test simulator in the low frequency mode. Install the difference amplifier trim resistors called out in paragraph 3.7.1.

(b) Adjust the input signal levels for a 2.5 volt R signal and a 2.0 volt ΔV signal with zero scene level. Then vary the scene level to give V signals of 2 and 4 volts. The (S_1+R_1) and (S_2+R_2) gain pots should be in the 500 setting. Record all test data below allowing adequate time for readings to stabilize.

BASELINE DATA - Room Temperature

V Output	R Output	ΔV Output		ΔV' Output	
		Mean	Std Dev.	Mean	Std Dev.
0	2.500	2.001	± .1	2.029	±.5
2	2.502	1.997	± .4	2028	±.8
4	2.505	1.995	± .5	2.039	±.7

3.10 Temperature Tests - continued

(c) With the same conditions as step (b) and with the scene level set for a V signal of 4 volts, vary the (S_1+R_1) and (S_3+R_3) gain pots as shown in the table below and record the test data.

BASELINE DATA - Room Temperature

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	2,128	2,175	2,128	4,002	2,506	1,994	2,028
+25%	[illegible]	2,174	2.66	4,002	2,506	1.994	2,028
-25%	1.[illegible]	2,174	1.593	4.002	2.506	1,994	2,028
Equal	2,128	2,174	2,128	4,002	2,506	1,995	2,029

3.10.2 High Temperature Data - Low Frequency Mode

(a) Raise the temperature chamber to a temperature of +100°F, allow to stabilize and repeat the tests of paragraph 3.10.1 recording the data below:

(b) High Temperature Test Data

V Output	R Output	ΔV Output		ΔV' Output	
		Mean	Std. Dev.	Mean	Std. Dev.
0	2,498	2002	±.3	2,030	±.5
2	2.500	1,997	±.3	2,028	±1.2
4	2.502	1,994	±.4	2,031	±1.8

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3.10.2 High Temperature Data - Low Frequency Mode - continued

(c) High Temperature Test Data

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	2,130	2,177	2,130	4.002	2.502	1.994	2030
+25%	2,661	2,177	2.661	4.002	2.502	1.994	2028
-25%	1.597	2,177	1.597	4.002	2.502	1.993	2029
Equal	2,130	2177	2130	4.002	2502	1995	2031

3.10.3 . Temperature Data - Low Frequency Mode

(a) Lower the temperature chamber temperature to 50°F, allow to stabilize and repeat the tests of paragraph 3.10.1, recording the data below:

(b) Low Temperature Test Data

pot. setting	V Output	R Output	ΔV Output		ΔV' Output	
			Mean	Std. Dev.	Mean	Std. Dev.
0	0	2.507	[illegible]	0	2027	±.6
71.5	2	2.509	[illegible]	±.3	2025	±1.0
173.2	4	2.511	1.994	[illegible]	2.025	±2.0

3.10.3 Low Temperature Data - Low Frequency Mode - continued

(c) Low Temperature Test Data

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	2.128	2.177	2.128	4.009	2.511	1.994	2.026
+25%	2.66	2.177	2.66	4009	2.511	1.992	2.024
-25%	1.596	2.177	1.596	4009	2.511	1.993	2.025
Equal	2128	2.177	2.128	4009	2.511	1.994	2026

3.10.4 Ambient Temperature Baseline Data - High Frequency Mode

(a) Set up the test simulator in the high frequency mode. Install the difference amplifier trim resistors called out in paragraph 3.7.2. Repeat the tests of paragraph 3.10.1 at room ambient temperature. Record the data below.

(b) Room Temperature Test Data

74°F 84.1

	V Output	R Output	ΔV Output		ΔV' Output	
			Mean	Std. Dev.	Mean	Std. Dev.
	0	2.500	2001	.2	2024	.0
71.2	2	2.513	1.998	.5	2011	± .3
172.5	4	2.527	1.997	.5	2002	± .7

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3.10.4 Ambient Temperature Baseline Data - High Frequency Mode - continued

(c) Room Temperature Test Data

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	2,157	2,205	2,157	3,999	2,526	1,996	2,002
+25%	2696	2,205	2696	4.006	2,526	1,997	1,999
-25%	1,618	2,206	1,618	4.000	2,526	1,990	2,004
Equal	2,157	2,205	2157	4.000	2,526	1,997	2,003

3.10.5 High Temperature Data - High Frequency Mode

(a) Raise the chamber to +100°F, allow to stabilize, and repeat the tests of paragraph 3.10.1 Record the test data below.

V Output	R Output	Mean	Std. Dev.	Mean	Std. Dev.
0	2,497	2.000	0	2,023	.3
2	2,510	1,995	.5	2012	.9
4	2,523	1,992	.5	2,003	2.1

(c) High Temperature Test Data

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	2,158	2,207	2,158	3,997	2,523	1,992	2,003
+25%	2696	2,207	2,696	3,996	2,523	1,993	2,001
-25%	1,618	2,207	1,618	3,990	2,523	1,984	2,004
Equal	2,158	2,207	2,158	3,995	2,523	1,993	2,004

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3.10.6 Low Temperature Data - High Frequency Mode

(a) Lower the chamber temperature to +50°F, allow to stabilize, and repeat the tests of paragraph 3.10.1. Record the test data below:

(b) Low Temperature Test Data

V Output	R Output	ΔV Output		ΔV' Output	
		Mean	Std. Dev.	Mean	Std. Dev.
0	2501	1997	0	2017	.5
2	2514	1992	.4	2003	.7
4	2527	1.989	.6	1991	1.4

(c) Low Temperature Test Data

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	2.157	2.206	2.157	4.000	2.528	1.989	1.992
+25%	2.696	2.206	2.696	4.000	2.528	1.992	1.991
-25%	1.618	2.206	1.613	4.000	2.528	1.978	1.987
Equal	2.157	2.206	2.157	4.000	2.528	1.989	1.992

(d) Return the test chamber to room ambient temperature and remove the unit.

APPENDIX H

MAPS BRASSBOARD FINAL REPORT

MAPS BRASSBOARD FINAL REPORT

PREPARED FOR

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TR75-255

September 1975

TABLE OF CONTENTS

1.0 INTRODUCTION

This report describes work done by Barringer Research Limited (BRL) towards the development of the measurement of air pollution from space experiments (MAPS), initially intended to be flown on the Nimbus G space satellite.

This is the final report on work done under Subcontract A39260 RABS to TRW Systems, and under NASA Prime Contract NAS-1-13695. The BRL programme began in December of 1974 with a Phase I conceptual design which ended in March, 1975 with the BRL conceptual design report TR75-250.

The conceptual design arrived at a baseline design approach and the main findings and baseline will be briefly described.

Phase II of the BRL effort was directed towards the detailed engineering design, fabrication, assembly and testing of a brassboard version of the opto-mechanical head of the MAPS sensor.

Phase III of the BRL effort was directed towards the design, fabrication and acceptance testing of a Ground Support Unit (GSU) intended to provide the radiometric stimulus and calibration optical signals for calibrating the brassboard and all MAPS sensor hardware.

Phase IV of the BRL programme is to provide "follow-on" support activity to aid TRW in data evaluation and brassboard and GSU hardware help.

This report will include the test results obtained in assessing the performance characteristic of the brassboard.

During the course of the programme some changes were made to the original work statement which resulted in less brassboard testing at BRL then initially planned. In addition, there were a number of changes in hardware design, i.e., chopper disc changes, an extra mounting plate for operating the GSU-brassboard independent of the GSU gas cell, etc.

2.0 BRASSBOARD DESIGN AND FABRICATION

2.1 Introduction

The MAPS brassboard optical design layout is shown in Figure 1. Source radiance enters the sensor via objective lens L1. The size of the objective is determined by the desired sensor field of view (4.5 degrees in this case). Radiance from a distant source is imaged in the objective focal plane where a field stop common to all detectors is located. A 45 degree reflective chopper is located adjacent to the field stop.

A relay lens L2 images the objective lens at the aperture stop. L2 also images the sensor field stop through the interference filter IF and the gas cells onto the field lenses L4, L5 and L6 via the beamsplitters BS1 and BS2. The field lenses image the aperture stop and the objective onto the detectors thus avoiding imaging any scene "hot spots" onto the detectors. A second relay lens L3 images via beam recombiner BR1, the reference stop onto the field lenses, coincident with the sensor field stop.

Reference radiation originating at the hot and cold blackbody pair set is chopped at a frequency f_R by the same chopper disc which modulates the scene at frequency f_S. The reflective chopper disc accomplishes this by means of a double annular set of chopping apertures.

2.2 Special Design Features

2.2.1 Balanced Chopper

The chopper disc at chopping frequency f_S alternately introduces radiation to the detectors from the scene and the reflective blackbody. The reflective blackbody radiance was chosen so as to minimize the difference in radiance from the two radiation sources. When the scene radiance and the reflective blackbody radiance are equal the chopper is "balanced" and the electronic signal amplitude is zero.

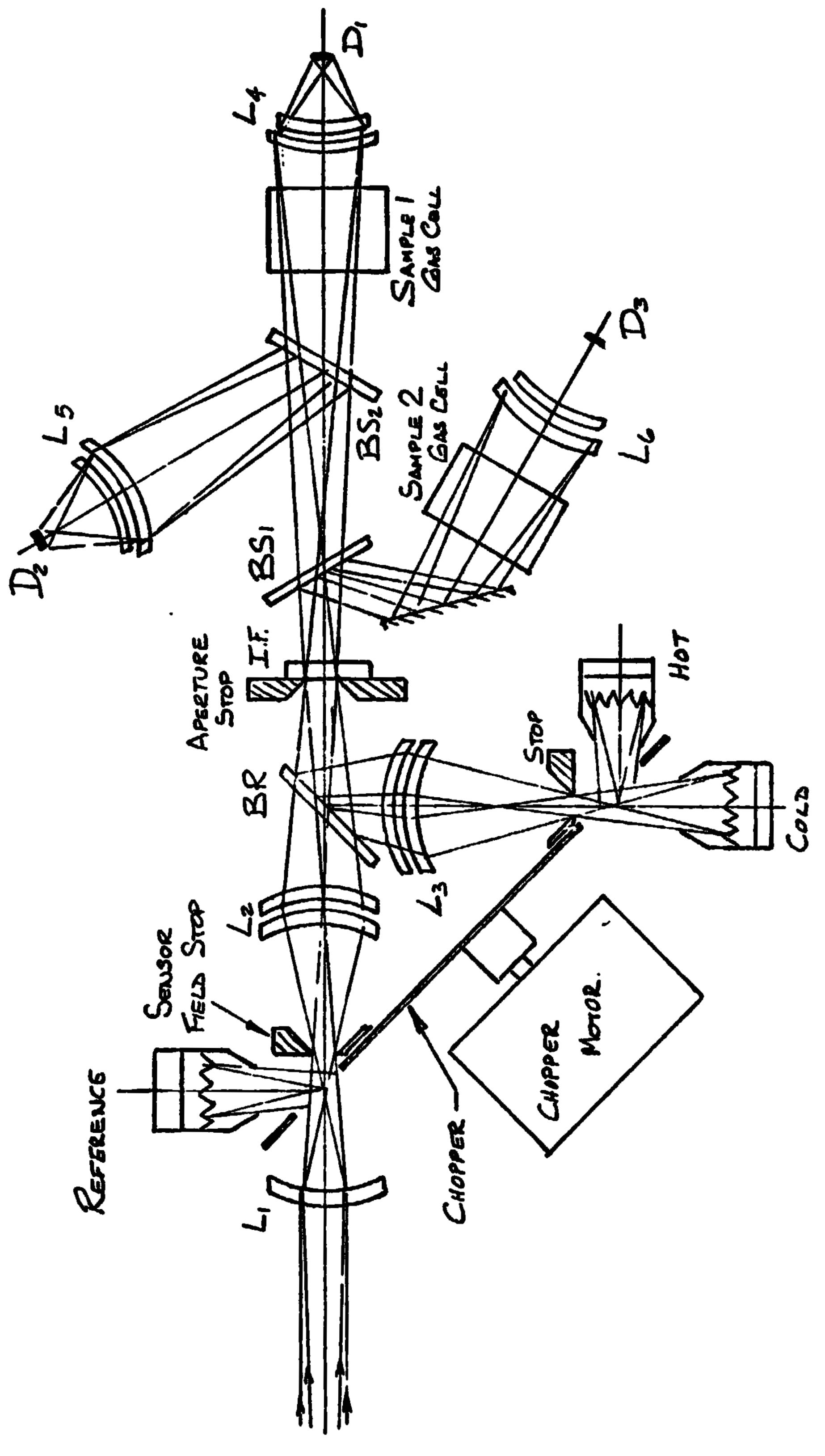

Reference
Sensor Field Stop
L1
L2
Chopper
Chopper Motor
L3
BR
Stop
Cold
Hot
Aperture Stop
I.F.
BS1
D2
L5
Sample 2 Gas Cell
BS2
L6
D3
Sample 1 Gas Cell
L4
D1

FIGURE 1

(Nevertheless the signal is still developed due to the correlation of incoming target gas with the internal target gas cell).

2.2.2 Reference Blackbodies

The reference blackbodies generate at frequency f_r, an optical signal which is used in an electronic feedback loop to gain control pairs of electro-optical arms (detector pairs 1 and 2 and detector pairs 3 and 2). The optical signal was computed to be adequate when the hot blackbody was at $70^{\circ}C$ and the cold at $20^{\circ}C$.

2.2.3 Common Field Stop

The use of a common scene field stop for all three detector arms ensures that each and every detector simultaneously receives energy from a hot or cold spot passing through the sensor field of view.

2.2.4 Beamsplitters and Beam Recombiners

The conceptual design study on beamsplitters and beam recombiners indicated that the spectral and spatial uniformity of the beam recombiner was not critical. However if the beam recombiner was polarizing it was found that the geometricl arrangement of the two beamsplitters would cause the sensor to be polarization sensitive. Thus the beam recombiner was required to be non-polarizing.

The beamsplitters were analysed and it was shown that the spatial and spectral uniformity quality of these were critical. In addition so as to avoid spurious noise due to incident radiation of changing polarization, two possible solutions were analysed:

(a) two uncoated ZnSe beamsplitters at opposing 30° angles.

(b) two Ge beamsplitters AR coated on one side and operating one at 20° with the second at 25° in the opposite direction.

2.2.5 Chopper Disc

The chopper disc was chosen to be an aluminum substrate with an overcoat of gold for high reflectivity.

2.2.6 Blackbody Design

Although in the sensor design, spatial uniformity of the source is not critical, the blackbody design attempts to achieve a uniformly high emissivity cavity whose temperature is precisely known.

The shape of the cavity is adjusted to achieve a high effective emissivity. Common shapes which have been used are spherical, conical, cylindrical, grooves, overlapping cones, and honeycombed walled arrays. Because of the difficulty in making high precision radiometry measurements, heavy reliance is placed upon computed emissivity values. Computer calculation techniques to predict cavity emissivities have been developed. Unfortunately, most real blackbodies do not have simple shapes such as those used in computations. Computations have been extended to blackbodies with lids even for nonisothermal cases. Work shows the importance of the cavity length to diameter ratio, being > 2, the importance of the cavity lid, and the relative insensitivity to the lid emissivity and to the cavity wall emissivity, and the tolerance of the effective emissivity to thermal gradients from the cavity base to the lid entrance. Good thermal contact of the housing lid to the base and heater source assures minimum thermal gradients.

To achieve a uniform temperature cavity surface, a high thermal conductivity wall material is used. Copper has a thermal conductivity about twice that of aluminum, but the difficulty in machining plus the more troublesome special preparation requirement of the surface prior to painting suggests aluminum as being the most suitable material.

The cavity is insulated for operation so as to minimize convective or conductive heat loss which would cause thermal gradients. Measurement of the cavity temperature must be done with good quality precision thermistors embedded in the cavity walls. Good thermal contact between the thermistors and the cavity is achieved by means of conductive greases of low vapour pressure.

The heat source or sink used for thermal control of the cavity should make good thermal contact over a large surface area of the cavity. A low vapour pressure thermally conductive grease coupling between the cavity and the cavity heat source is used.

The thermal time constant of the cavity is determined by the cavity mass and specific heat, and by the rate of heat input. Proportional temperature control plus a high specific heat material such as copper or aluminum of minimum mass should result in time constants of the order of a few minutes.

TABLE 1

BRASSBOARD LENS PARAMETERS

LENS	MATERIAL	DIAMETER (mm) ± 1 mm.	CENTRE THICKNESS (mm) ± 0.1 mm.	RADII OF CURV. (IN.) ± 0.1%	A.R. COATING
L1 Objective	Ge	50	3.5	2,602, 3.870	OCLI wideband multilayer, 6048005
L2 relay (a)	Ge	35	2.5	1,373, 1.228	ii
lens pair (b)	Ge	35	3.0	2,000, 4.744	
(L3 same)					
L4, L5, L6					
Field lens (a)	Ge	28	2.5	1.199, 1.625	ii
pair (b)	Ge	23	2.0	0.550, 0.573	

NOTES -- 80 - 50 scratch and dig

-- sphericity to 4 fringes overall, 1 fringe irregularity

-- uniformity stressed by manufacturing in planetary double rotation and masking techniques, and in the case of the field lens a special on-axis rotation used and all carried out in a common coating batch lot

-- 1 mm. of edge used for mounting

3.0 OPTO-MECHANICAL DESCRIPTION

This section is intended as a collection and summary of the specification parameters of the opto-mechanical section of the MAPS brassboard. The mechanical specifications of the various components are not described except in general terms, as these components are well specified in the attached engineering drawing set.

3.1 Optical Lens

The brassboard lenses were procured from OCLI. They are Germanium lenses whose radii of curvature were optimized for best imaging under the distance constraints shown in the mechanical drawings. The actual radii of curvature are given in Table I. Also shown are the diameters, thickness at center, and notes as to scratch and dig, sphericity and AR coatings.

3.2 Beamsplitter Parameters

The four beamsplitters for the brassboard are all Ge, AR coated on one side. One set of two beamsplitters were AR coated to peak at 4.6 microns at 20 degrees angle of incidence, while the other set of two were AR coated for 11.2 microns and 20 degrees angle of incidence.

3.3 Beam Recombiner

A single beam recombiner was designed for operation at both the 4.6 and 11.2 micron operating wavelengths. This beam recombiner, as stated earlier, needed to be non-polarizing. The beam recombiner is a 2 mm thick Germanium substrate, AR coated on both sides with a broadband coating, and in addition, one side overcoated with a polka dot pattern of gold dots so as to achieve a dot area to clear area ratio of 15/85. The beamsplitter parameters are also summarized in Table II.

3.4 Interference Filters

The interference filters were specified by NASA and the parameters for the OCLI filters supplied to BRL for the brassboard tests at 4.6 and 11.2 microns are specified in Table III.

TABLE II

BEAMSPLITTER PARAMETERS

BEAMSPLITTER	MATERIAL	DIAMETER mm. ± .1	THICKNESS mm. ± .1	SURFACE FINISH
4 beamsplitters	Ge	35	1	A.R. coated (for 22° operation) on one side only (1) one set of 2 A.R. coating peaked at 4.6 microns (2) one set of 2 A.R. coatings peaked at 11.2 microns
1 beam recombiner	Ge	40	2	Aluminized with a "polkadot" array of 0.61 ± .80 mm. radius for a net aluminized area of 15%. The dots being in linear rows and in a pattern so as to give isosceles triangles of 3 mm. sides. Both sides A.R. coated with wideband OCLI multilayer 6040005

NOTE: -- wedge angles $\leq$ 3 minutes of arc

-- 80 - 50 scratch and dig

-- 4 fringe flatness, 1 fringe inequality

-- 1 mm. of edge used for mounting

TABLE III

INTERFERENCE FILTER PARAMETERS

FILTER	λ PEAK	HALF BANDWIDTH (μ) (H.BW)	SLOPE	AVERAGE TRANS. OVER HBW	THICKNESS	MATERIAL
CO	4.671μ	0.151μ	0.766% 0.858%	70%	.0382"	Silicon
NH_3	11.132μ	1.028μ	0.98% 0.73%	60%	.040" .040"	BLKR-ZNS B.P.-G.e.

3.5 Gas Cells

The CO and NH_3 gas cells were provided to BRL by TRW. The brassboard required two different cells of each gas. The CO gas cell used 1 mm thick sapphire windows for 4.6 micron transmission while the Ammonia cells used 1 mm Ge windows for 11.2 micron transmission. The cells were assembled according to a gold bonding technique of attaching the windows to the body of the cell.

The cell parameters for the cells used in the brassboard tests at BRL are given in Table IV.

3.6 Detectors

The PbSe thermoelectrically cooled detectors for CO detection and the pyroelectric detectors for NH_3 detection are specified later in the results section as these parameters are used to reduce the data.

3.7 Optical Efficiency Budget

The overall optical transmissions of the MAPS sensor depend on all of the individual components in the optical path. These components are illustrated schematically in Figure 3.1. The optical efficiency of each detector arm is different. The summary of the transmission factors for the individual components, and the net transmission for each arm are given in Table V. The individual component transmissions are taken from vendor supplied data on the components, or witness pieces.

3.8 Mechanical Mounts

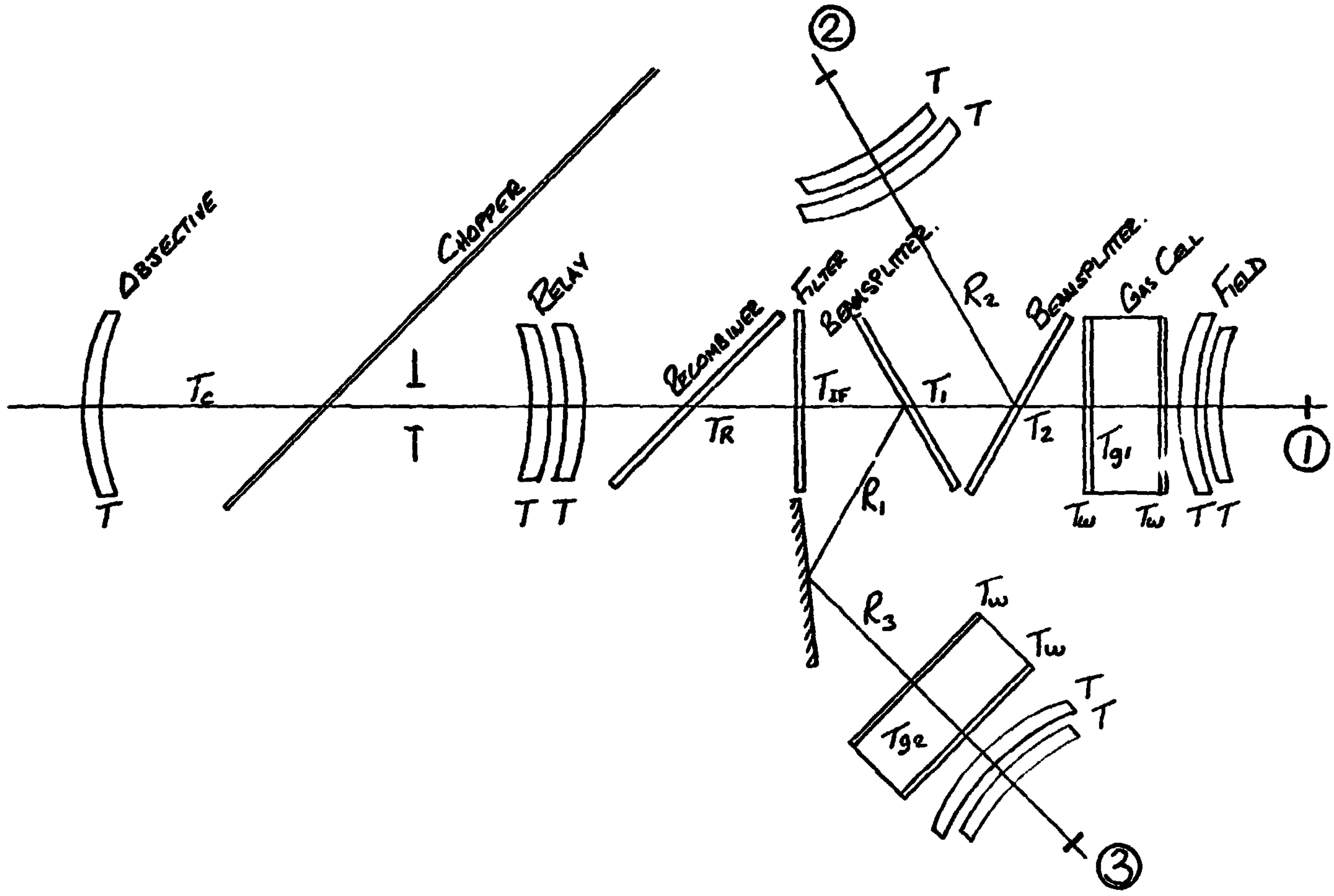
The individual optical components were attached to a flat aluminum baseplate by means of individual component mounts. This design allowed a good deal of flexibility for testing each component. The included drawing set details the design of each of the

TABLE IV

GAS CELL PARAMETERS

GAS	CONCENTRATIONS	WINDOW THICKNESS	WINDOW MATERIAL	AVERAGE TRANSMISSION
CO	HIGH	1.0	Sapphire	.62
CO	LOW	1.0	Sapphire	.68
NH_3	HIGH	1.0	Ge	.41
NH_3	LOW	1.0	Ge	.47

TRANSMISSION BUDGET NOMENCLATURE



SYSTEM TRANSMISSION

① $K_1 = T^5 T_C T_R T_{IF} T_1 T_2 T_w^2 T_{g1}$

② $K_2 = T^5 T_C T_R T_{IF} T_1 R_2$

③ $K_3 = T^5 T_C T_R T_{IF} R_1 R_3 T_w^2 T_{g2}$

FIGURE 3.1

TABLE V

OPTICAL TRANSMISSION BUDGET

COMPONENT	TRANSMISSION (11μ)	TRANSMISSION (4.6μ)
T	0.96	0.97
T_C	0.96	0.96
T_R	0.91 x 0.85	0.90 x 0.85
T_I	0.65	0.70
R_1	0.38	0.35
T_1	0.61	0.63
T_2	T_1	T_1
R_2	R_1	R_1
R_{3_2}	0.95	0.95
T_{W_1}	0.48	0.75
T_{g_2}	0.85	0.83
T_g	0.97	0.91
Efficiency		
T_1	.070	.109
T_2	.091	.097
T_3	.068	.091

mounts. The detector mounts are integral with the field lens mount. The adjustment mechanism that was finally built and is shown in the drawing set was modified at TRW request from the original design submitted to TRW.

3.9 Electronic Components

The MAPS brassboard was taken through a set of tests at BRL prior to delivery to TRW. To perform these tests a set of laboratory electronic equipment was used. A list of this equipment is given in Table VI.

TABLE VI

ELECTRONIC EQUIPMENT LIST

1. Tetronix Oscilliscope Model 502 with camera.
2. Wavetec Waveform Generator, Model 112
3. PAR Lock-in Amplifier Model HR-8
4. PAR Differential Amplifier Model 114
5. 12 Volt Battery.
6. 90 Volt Battery.
7. ± 15 Volt Power Supply.
8. Anakek 28 Volt Power Supply Model BRM 40-10C
9. Honeywell Chart Recorder Model Electronik 194

4. Brassboard Tests

4.1 OPTICAL ALIGNMENT, IMAGING AND THROUGHPUT OPTIMISATION

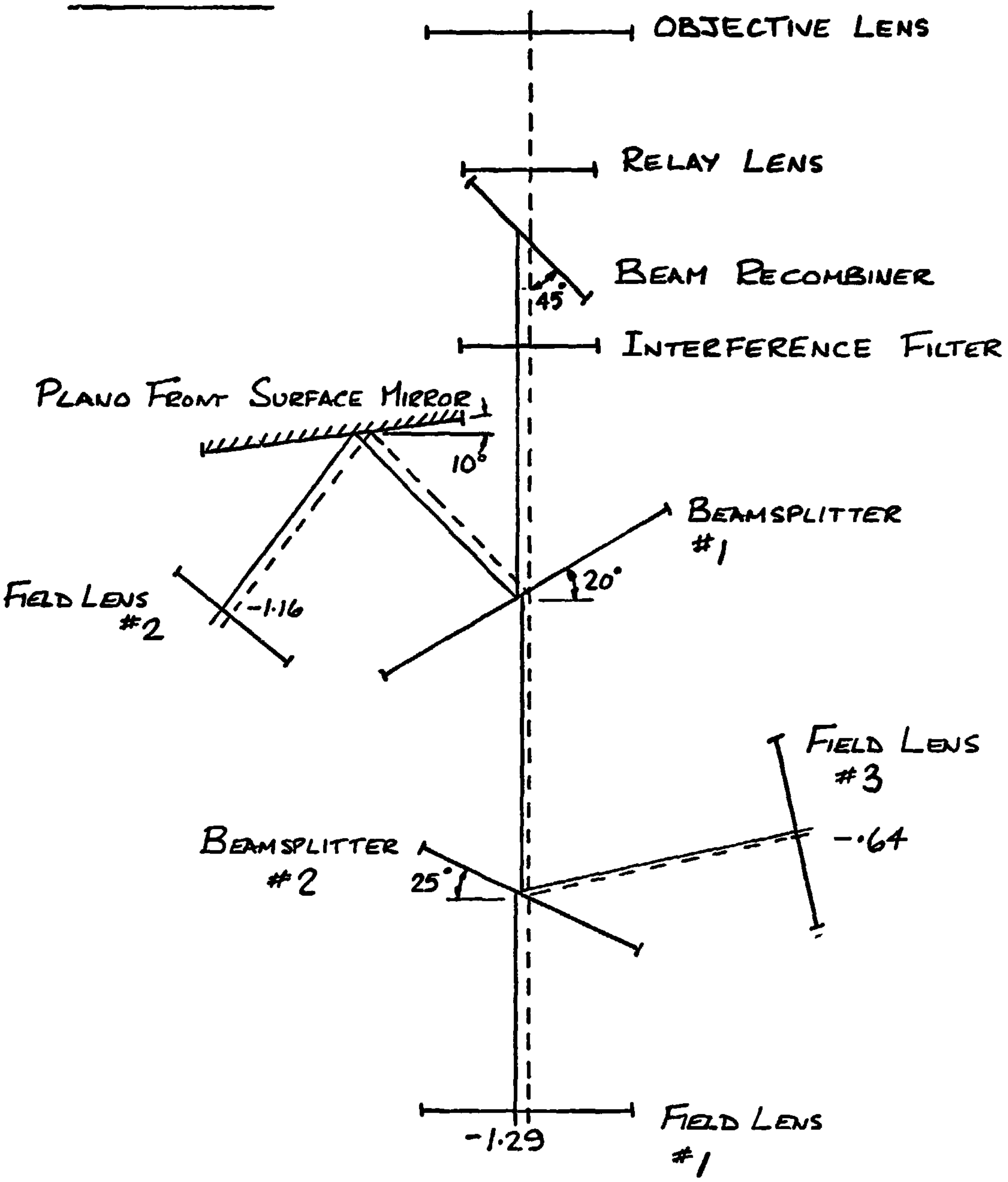
(a) Optical Alignment

Optical alignment of the brassboard was carried out using an He-Ne laser mounted on an adjustable holder (two co-ordinates variable) approximately 10 feet in front of the objective lens holder. The laser beam was aligned such that it was directed along the brassboard optical axis defined to be obtained when the laser beam passes centrally through .010" diameter holes located at the centre of the objective mount and field stop. Orthogonality was assured at the objective and field stop mounts by locating a plano front surface mirror at both mounts respectively and ensuring that the reflected laser beam was coincident with the transmitted beam. The relay lens mount which is an integral part of the field stop mount was considered aligned when the field stop had been aligned. The axial location of the interference filter and aperture stop was found taking into consideration the optical axis displacement due to the beam recombiner. Computed and measured displacements with tolerances for all the optical mounts are shown in Table 4.1. Figure 4.1 shows the computed displacements of the optical alignment. Field lens #1 axial position was found at its calculated axial displacement by measurement from a pinhole located at the centre of the field lens aperture. This displacement was due to the absence of the beam recombiner and two beam splitters. A front surface plano mirror placed at the field lens mount ensured orthogonality of the mount.

The location of the 25° beam splitter mount was obtained using a 25° aluminum jig referenced to a baseline parallel to the optical axis and located on the brassboard base plate. The axial location of field lens #2 was obtained by replacing beam splitter #2 with a front surface plano mirror and adjusting the field lens mount until the laser beam struck the field lens aperture at a location coincident with the computed axial displacement. This location was found by measurement from a pinhole located at the centre of the field lens aperture.

OPTICAL ALIGNMENT CALCULATED DISPLACEMENTS

PLAN VIEW



VERTICAL DISPLACEMENT = 0

SOLID LINE DENOTES LINEAR DISPLACEMENT FROM RAY AXIS (LASER BEAM) i.e. TRUE LOCATION OF OPTICAL AXIS

FIGURE 4.1

COMPARISON OF COMPUTED AND MEASURED AXIAL AND ANGULAR DISPLACEMENTS

LOCATION	COMPUTED DISPLACEMENT IN		MEASURED DISPLACEMENT
Field Lens No. 1	Horizontal	-1.29	-1.25 ± .25 mm
	Vertical	0	<± 0.3 mm
	Angle	normal	0° ± 1°
Beamsplitter No. 1	Horizontal	-1.24	-1.0 ± 0.3 mm
	Vertical	0	<± .3 mm
	Angle	65°	65° ± 0.3°
Field Lens No. 3	Horizontal	-.64	-0.6 ± 0.1 mm
	Vertical	0	0 ± 0.2 mm
	Angle	normal	0 ± 0.3°
Beamsplitter No. 2	Horizontal		-1.2 ± 0.2 mm
	Vertical	0	0 ± 0.2 mm
	Angle	70°	70° ± 0.3°
Front Surface Mirror	Horizontal	-1.	-1.3 ± 0.3 mm
	Vertical	0	0 ± 0.3 mm
	Angle	10°	10° ± 0.3°
Field Lens No. 2	Horizontal	-1.16	-1.3 ± 0.3 mm
	Vertical	0	0 ± 0.3 mm
	Angle	Normal	0 ± 0.3°
Aperture Stop	Horizontal	-1.16	-1.15 ± 0.3mm
	Vertical	0	0 ± 0.3 mm
	Angle	normal	0° ± 0.3°
Beam Recombiner	Horizontal	0	0.0 ± 0.3 mm
	Vertical	0	0.0 ± 0.3 mm
	Angle	45°	45° ± 0.3°

Table 4.1

Orthogonality of this field lens mount was again ensured by having the reflected laser beam at the field lens coincident with the transmitted beam. Beamsplitter #1 was installed using a 20° jig again referred to the base plate reference. A front surface plano mirror was then mounted on this beamsplitter mount in order to align the third field lens. The front surface mirror in this arm was located using a 10° jig. The axial position and orthogonality of field lens #3 was found in a similar fashion to #1 and #2.

The beam recombiner mount was located in position at 45° to the laser beam using a 45° jig.

The reference blackbodies were aligned by rotating the brassboard through 180° and aligning the laser beam in such a manner that it was orthogonal to and was transmitted through a .010" pin hole located .045" off the optical axis in the horizontal plane at the aperture stop. The hot and cold blackbodies were aligned by adjusting their respective mounts until the laser beam reflected at 45° by a front surface mirror located at the beam recombiner was coincident with pin holes located at the centres of the blackbody apertures in one instance directly (hot blackbody) and in the second instance after reflection at the chopper disc. Orthogonality of both blackbodies was found as before.

The reflective blackbody was aligned by introducing a .010" pinhole located at relay lens L2 and aligning the laser beam until it was orthogonal to this pinhole. The laser beam reflected from the chopper disc was then used to align the blackbody.

On completion of the optical alignment all mounts were drilled and pinned, prior to removal of the mounts in order to install the optical components and facilitate relocation.

(b) Imaging and Verification of Ray Trace

Field stop Focus

After mounting the objective lens in its mount and relocating mount on brassboard base plate and installation of the chopper disc and cover, the field stop focus was determined using a 3/8 inch diameter, 1/2 inch long hot silicon carbide resistor, located 10 feet on axis in front of the objective lens as the source. The location of the image was obtained using a 0.010 inch pin hole located in front of an InAs detector with the capability of scanning along and perpendicular to the optical axis. Figures 4.2 and 4.3 show the data obtained perpendicular to and along the optical axis. When compared to the optical ray trace the field stop image was found to be 0.6 mm on the beam recombiner side of the field stop physic location. This was initially left "as is". The image depth was found to be ≈ ±0.5 mm and the width ≈ ±0.2 mm.

Aperture Stop Focus

The relay lenses, beam recombiner and field stop were mounted on the base plate and the scanning InAs detector and pin hole were relocated at the aperture stop location. The objective lens was removed and the SiC resistor source was placed behind a 0.040 inch axially located stop at the objective lens position. Directions perpendicular to and along the optical axis were scanned and the data recorded in figures 4.4 and 4.5. The image of this source located in the objective plane was found to be ≈ 1 mm toward the field lens from the aperture stop. This was left "as is". The image depth was found to be ≈ ±0.5 mm and the width ≈ ±0.2 mm.

Field Lens Focus

The InAs detector and pin hole were relocated at the image location of the field stop, i.e., at the field lens #1 position. The hot source was relocated as for the field stop focussing and the objective lens remounted. The results of scanning the 0.010 inch aperture perpendicular to and along the optical axis are recorded in figures 4.6 and 4.7. The various curves in 4.6 are for different settings of the axial co-ordinate. The irregularities of the families of curves show the difficulty in aligning the X-Y scanner on the optical axis. Similar data were recorded for the locations of field lenses #2 and #3.

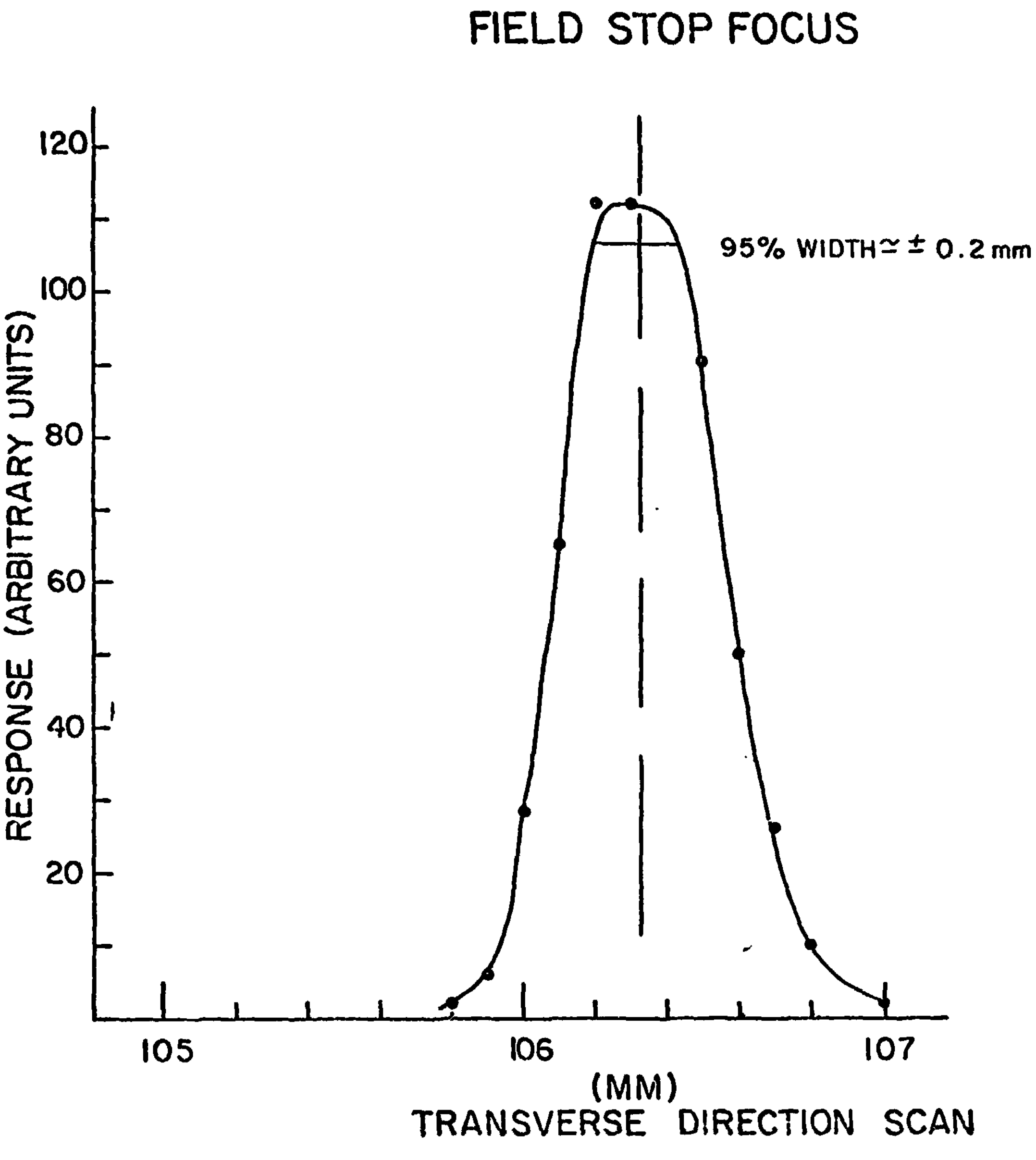
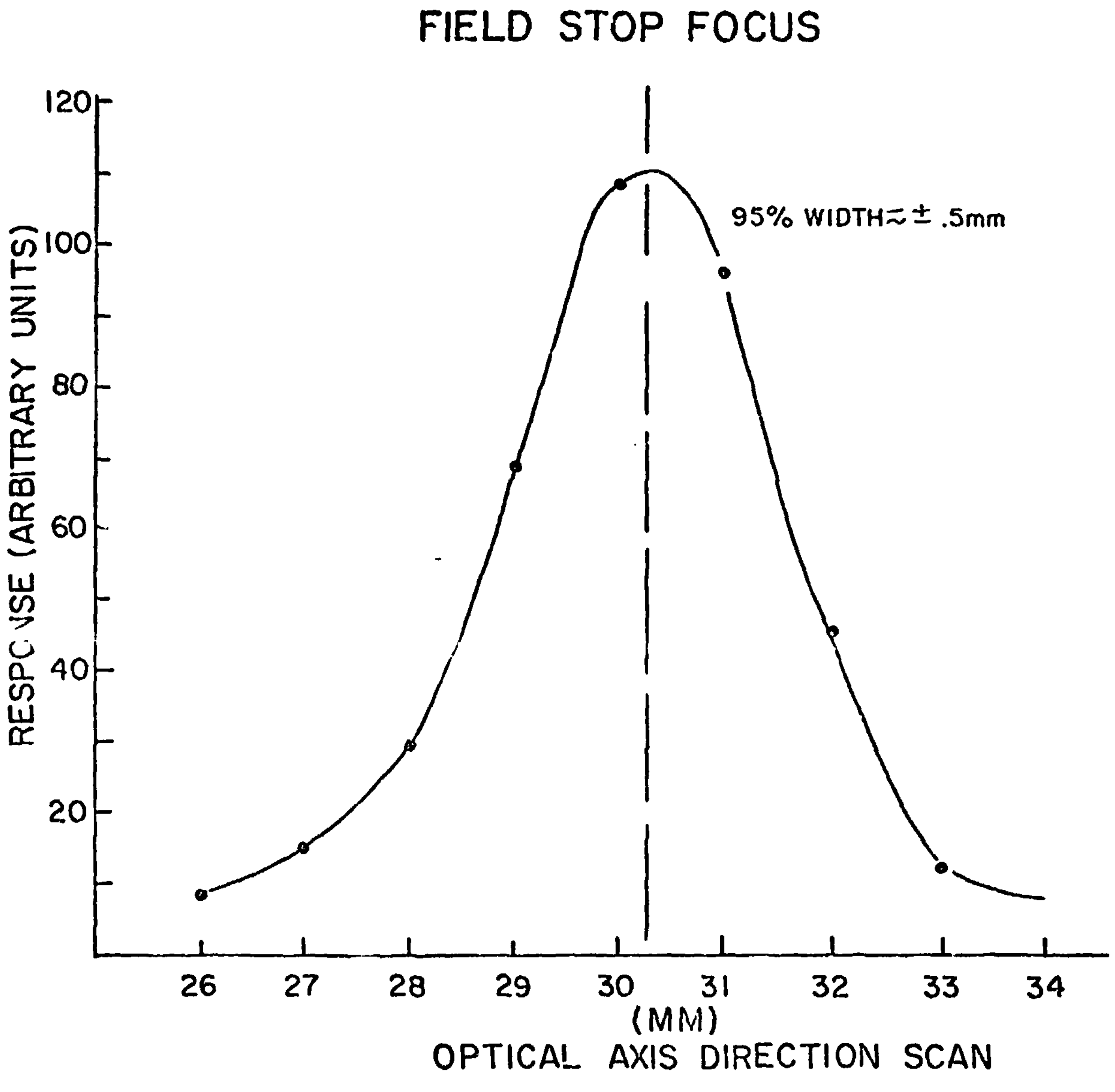


Fig. 4.2

Data obtained using a 0.010 inch scanning pinhole moving perpendicular to the optical axis. The source was a 3/8 inch diameter, 1/2 inch long hot SiC resistor located 10 feet on axis in front of the objective lens.



FIELD STOP FOCUS

Fig. 4.3

A 0.010 inch scanning aperture moving in the direction of the optical axis at the field stop focus. The source was as in Fig 4.1

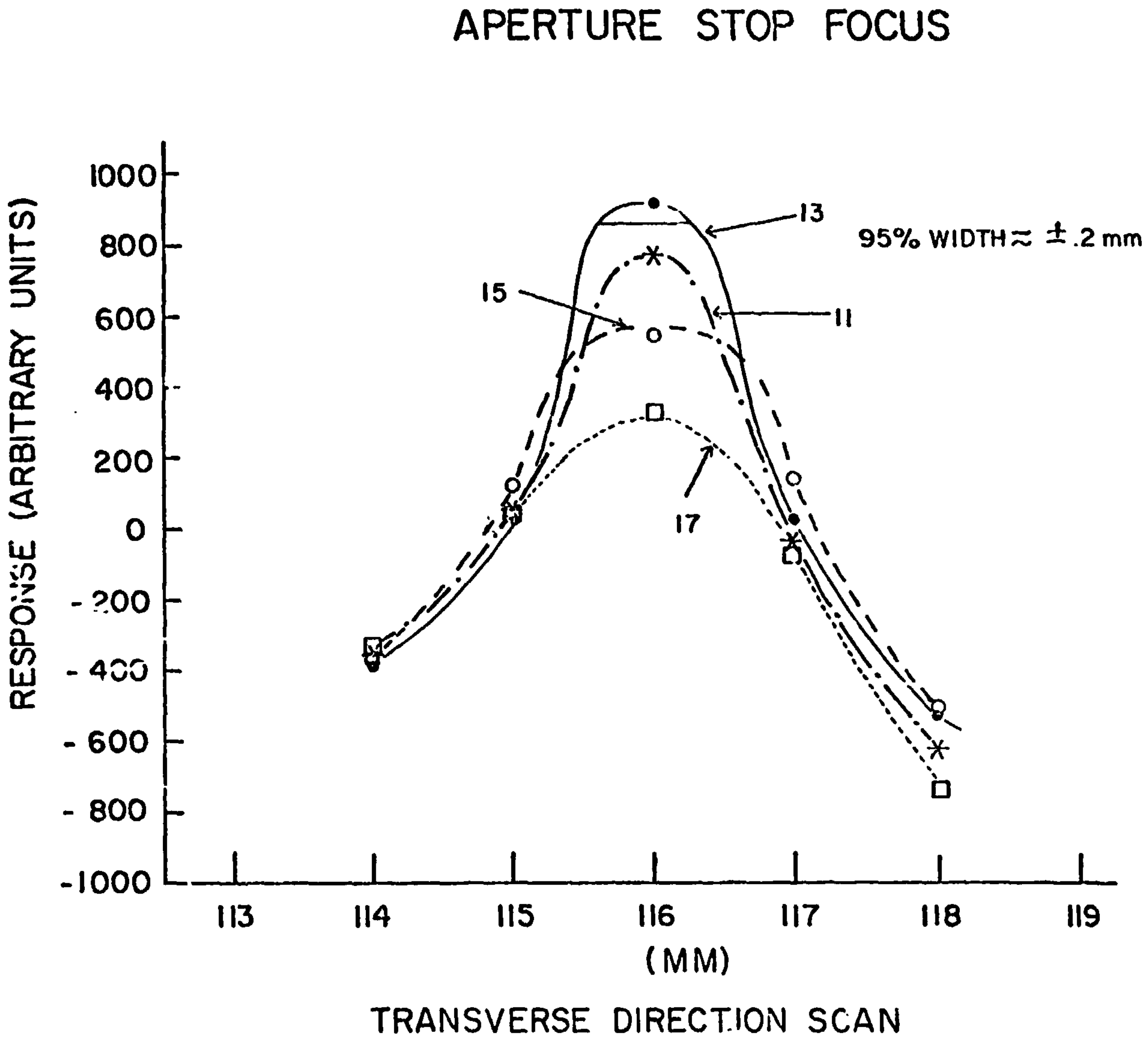


Fig 4.4

Results of pinhole aperture scans at the aperture stop location. The SiC resistor source was located behind a 0.040 inch axially located stop at the position of the objective lens. The X-Y microscope stage mount was scanned in the Transverse direction for a set of values (in mm) for the axial locations.

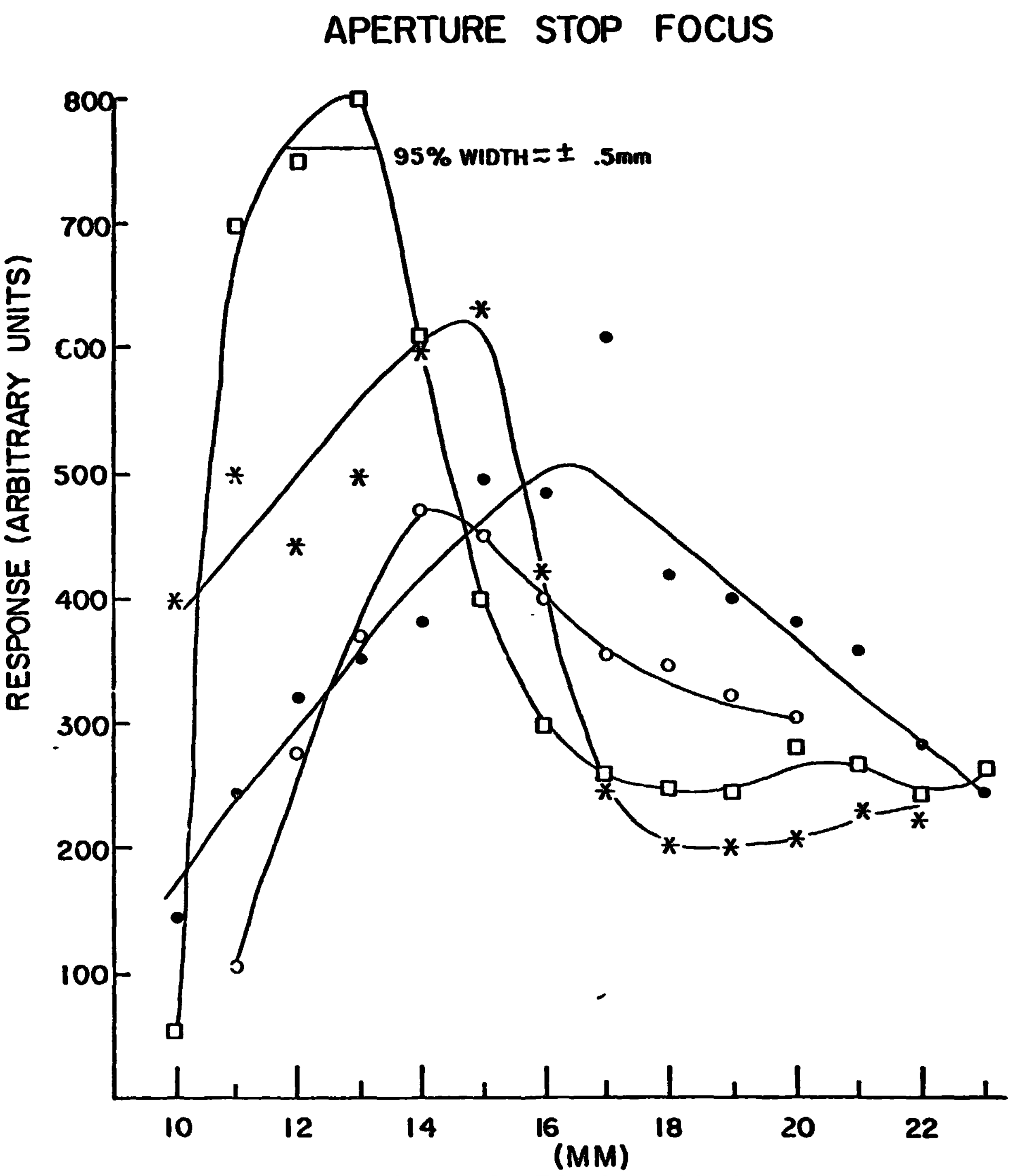


Fig 4.5

Scans of the 0.010 inch pinhole moving in the axial direction at the aperture stop. The source is as for Fig 4.3. The axial scans are for various lateral positions (shown in mm)

C·3

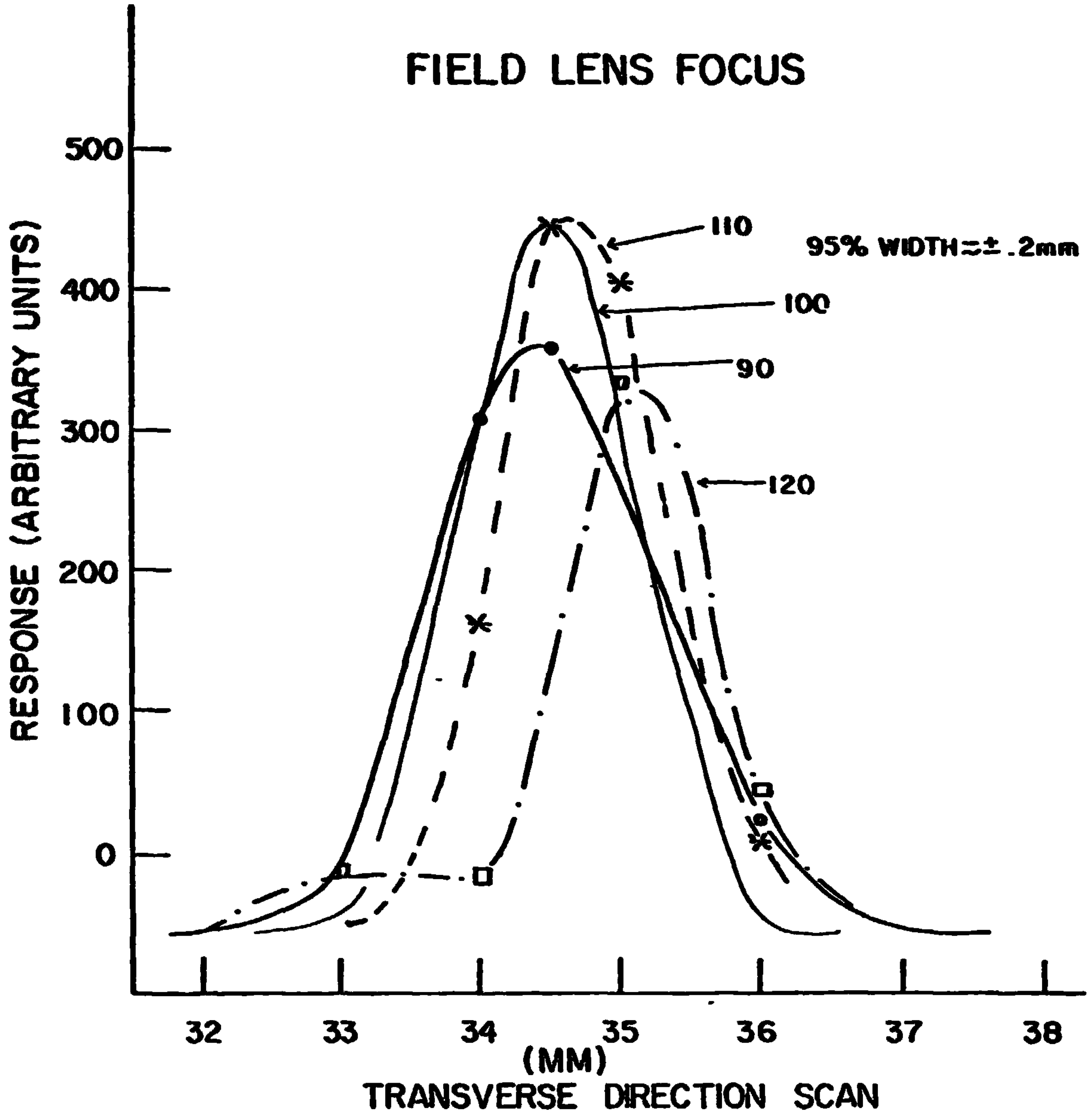


Fig 4.6
Results of scanning the 0.010 inch aperture through the field lens focus position. The source was the SiC resistor located axially 10 feet in front of the objective lens. Thus the focus is a reimaging of the first image located at the field stop. The various curves are for different (in mm) settings of the axial co-ordinate.

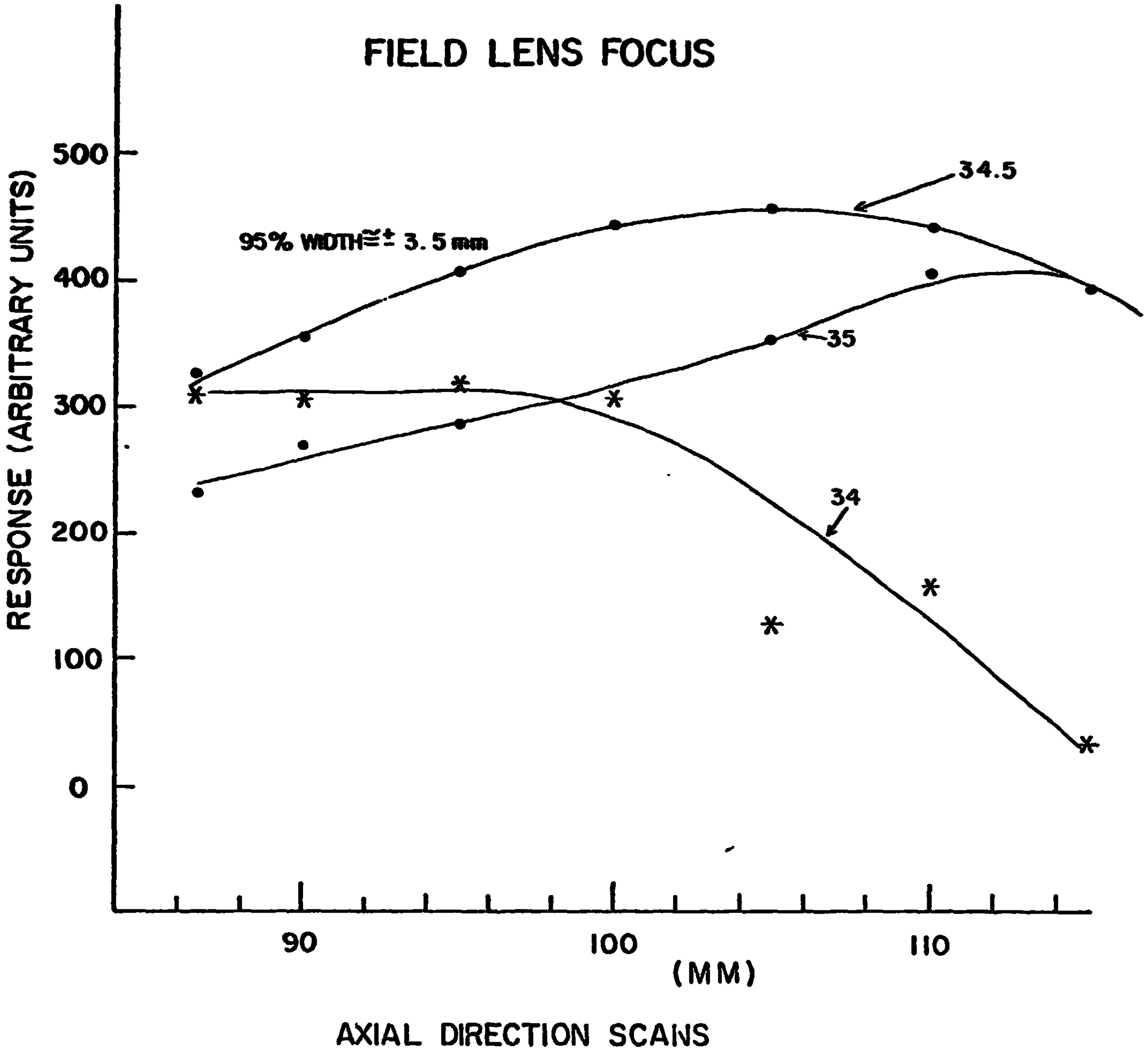


Fig 4.7

Results of the 0.010 inch aperture scans moving in the axial direction for several settings (indicated in mm) of the transverse co-ordinate. The families of curves are not regular because of the difficulty in aligning the X-Y scanner precisely on the optical axis.

(c) Detector Alignment

After locating filed lens positions, all optical components were reassembled and positioned on the brassboard baseplate. Initially, the Pb.Se detectors were installed in threir holders and after positioning the CO and N_2 gas cells in their respective optic arms, optimisation of each detector output was attempted. It was not found possible to go through a maximum for any PbSe detector in the direction of the optic axis, however, it was found possible to maximise the detector response in the two directions orthogonal to the optical axis. The detectors were demounted and the mounts modified by removing 0.120" from the rear surface of each, thus enabling the detector to be located closer to the field lens and allowing a maximum position to be found. After discussions with T.R.W. personnel, it was discovered that the PbSe manufacturers' drawings showing the location of the detector flake, were in error, and the detector flake was actually ≈ .100 inch closer to the detector base then had been expected.

A similiar procedure was carried out for the pyroelectric detectors and again it was found necessary to remove .040" from the rear face of each detector mount in order to locate the optimum position where each detector output was found to be able to go through a maximum in all three directions. On location of these positions all detector adjustable mounts were locked to enable relocation on the field lens mount when the PbSe and pyroelectric detectors were interchanged.

The field image was found with no interference filter or gas cells in the brassboard. This image was located at 195.7mm from the rear relay lens surface. The image depth was found to be ± 3.5mm and the width ≈ ±0.2mm. When taking the I.F. and gas cell windows into consideration the field image to relay lens distance would be ≈ 198mm, considered too far out of design tolerance. The objective lens was moved ≈0.6mm away from the field stop and the field lens image found to be relocated at 190.2mm (excluding I.F. and gas cell windows). The field lens surface is located at 193.7mm from the relay lens. (verification of ray trace) When all the optics are included the field image will be at 192.5mm i.e. the field image will be 1.2 mm ahead of the field lens surface.

4.2 PbSe COOLER TESTS

When the PbSe detectors were received from Opto-electronics it was not found possible to reproduce the cooler temperatures recorded by Opto with the power specified. It was also found that the ambient thermistor resistance values did not correlate with manufacturers data.

Most of the cooling capability was recovered after the detecor getters were fired and the variance in the ambient thermistor resistance was later found to be due to the fact that at Opto the thermistor resistance values were recorded with 100 V bias on the detecor, resulting in some internal heating.

Gettering was accomplished by passing 5½ Amp. A.C. derived from a variable transformer with a transformer acting as a choke to limit the current. The voltage on the Variac was 33 volts and the getters were fired 3 times for 10 seconds each, with a dead period of 3 minutes between each firing.

The time history of each PbSe detector coolers' operating efficiency during testing at BRL is shown in Figures 4.8 - 4.11.

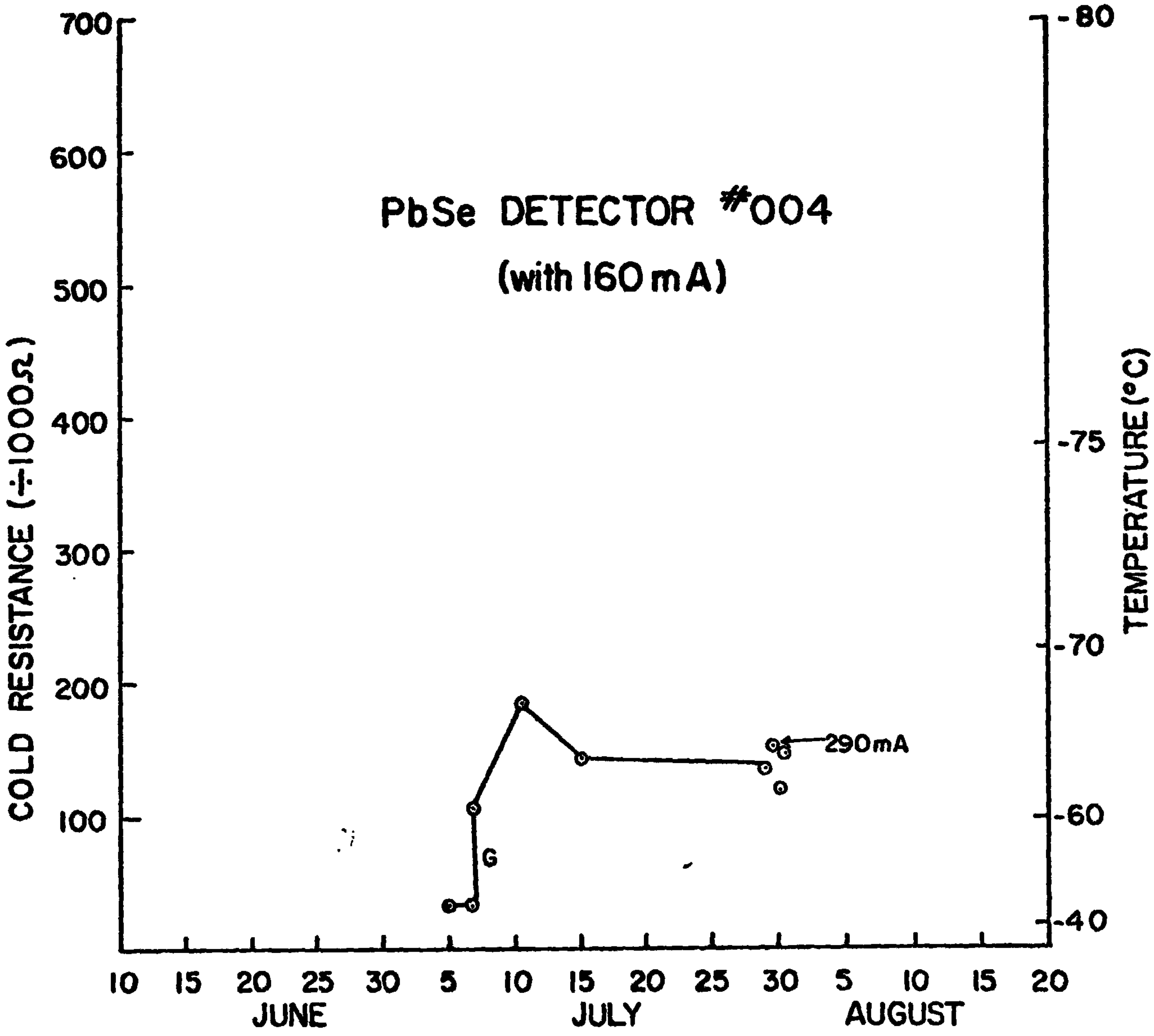


Fig 4.8
The time history of the PbSe detector No.004 cooler, operating efficiency during testing at BRL. Values for the cold resistance of the thermistor were taken for a variety of operating conditions, but the values shown here are for 160 mA of cooler current, unless otherwise shown. The "G" indicates firing the Getters.

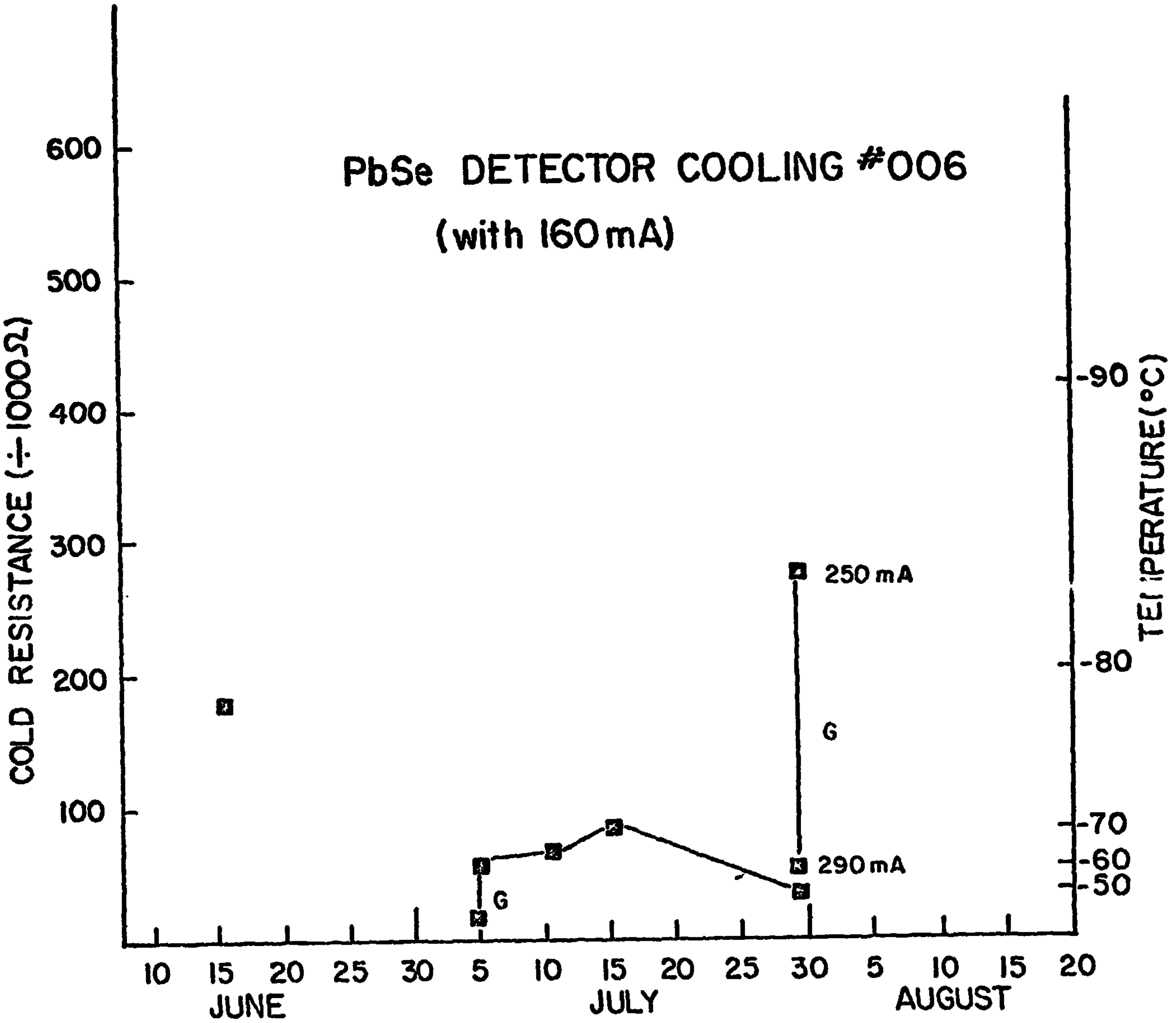


Fig 4.9

The time history of the PBSe detector No. 006 cooler, operating efficiency during testing at BRL. Values for the cold resistance of the thermistor were taken for a variety of operating conditions, but the values shown here are for 160 mA of cooler current, unless otherwise shown. The "G" indicates firing the Getters.

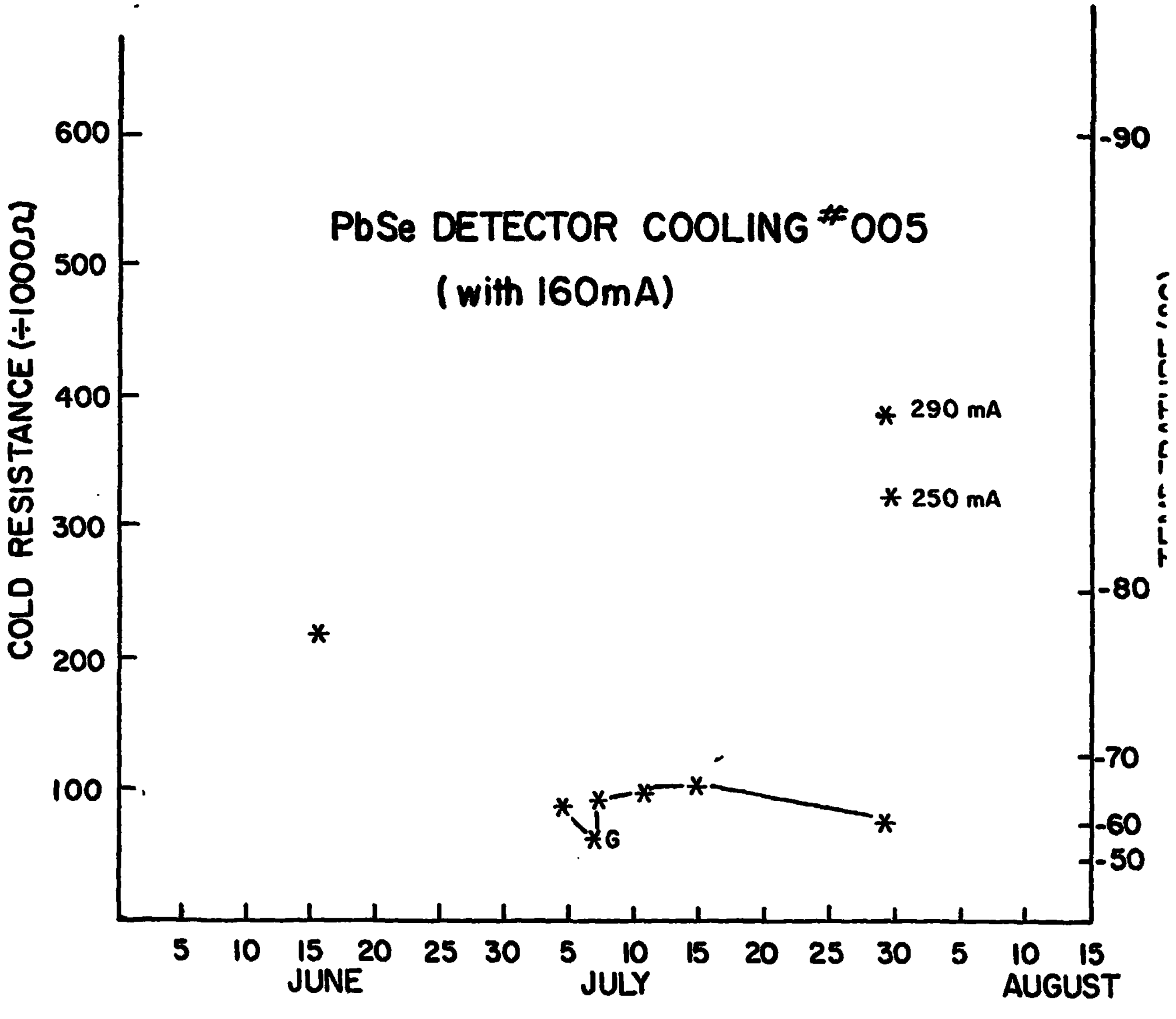


Fig 4.10
The time history of the PbSe detector No.005 cooler, operating efficiency during testing at BRL. Values for the cold resistance of the thermistor were taken for a variety of operating conditions, but the values shown here are for 160 mA of cooler current, unless otherwise shown. The "G" indicates firing the Getters.

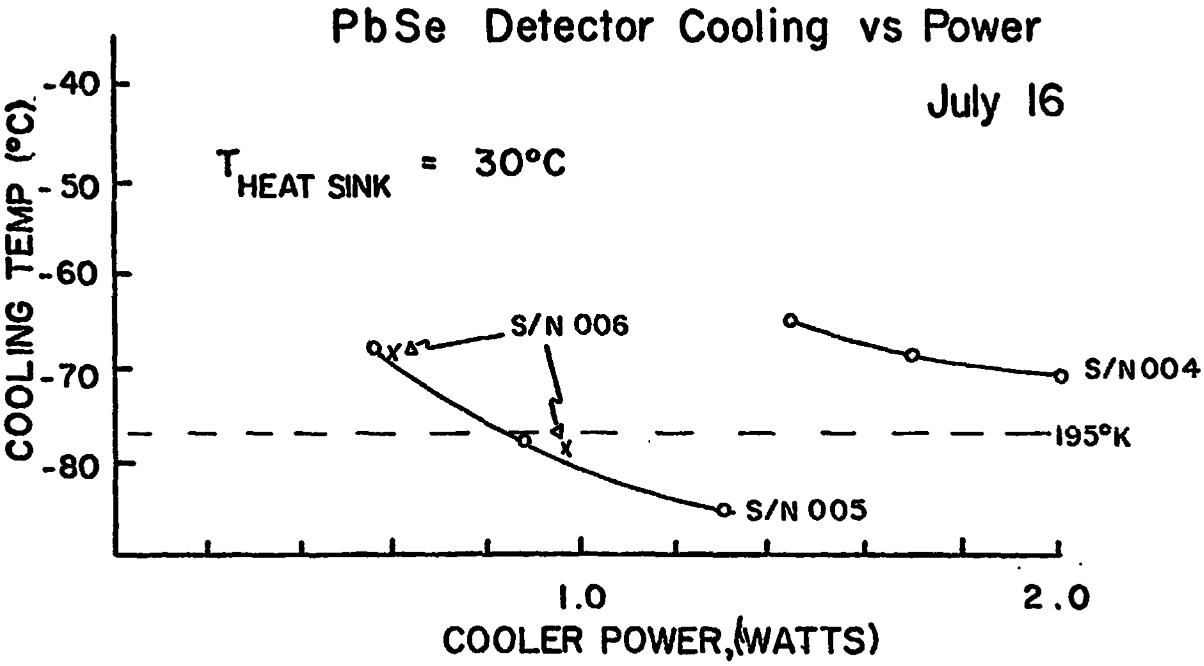


Fig 4.11

PbSe detector cooling efficiency versus power applied to the Thermoelectric heat exchangers. Curves are obtained for a detector heat sink at 30°C.

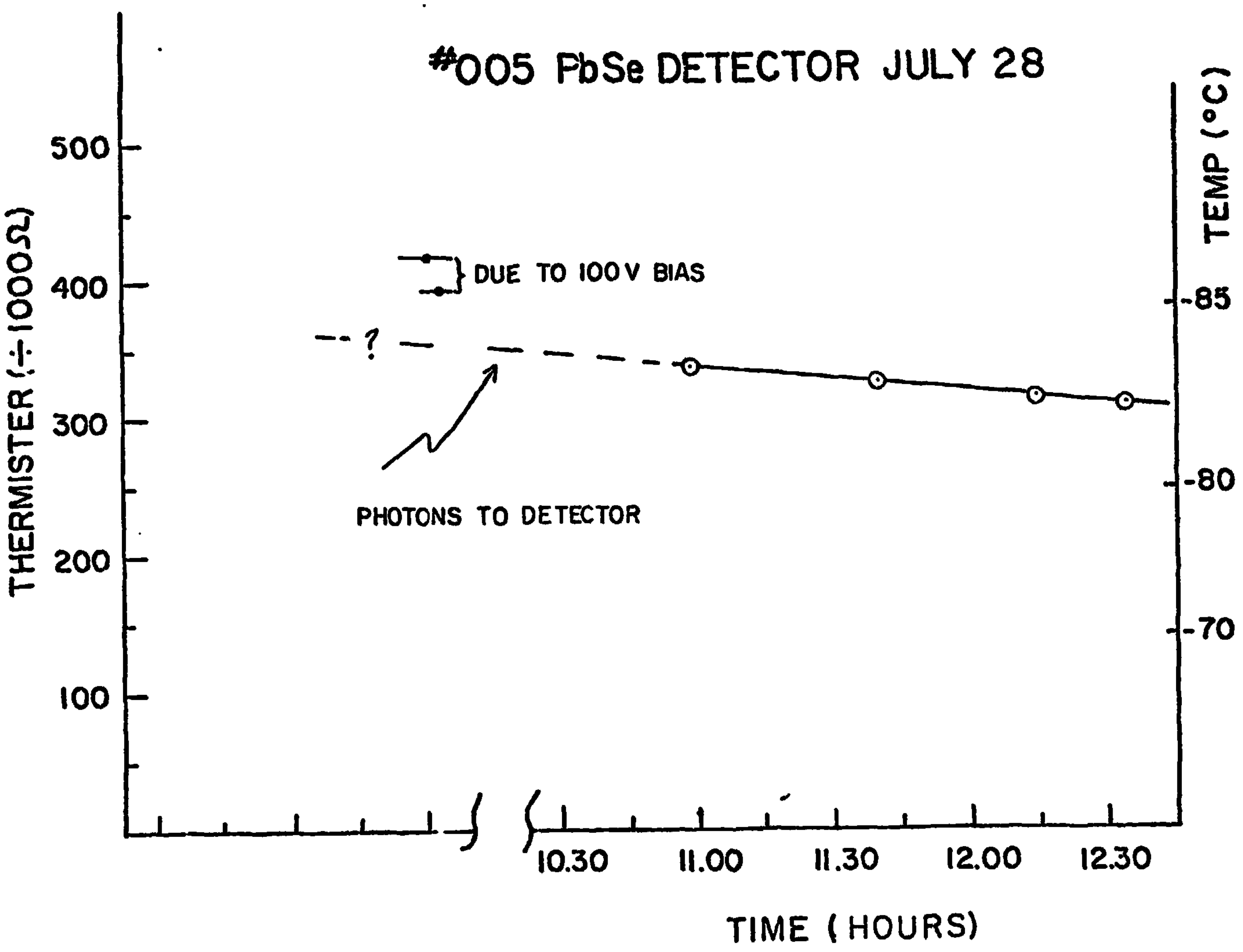


Fig 4.12

PbSe thermoelectric cooler performance versus time. The application of the 100V bias changes the indicated temperature by less than 1°C, and the application of increased photon flux from the blackbody source gave no discernable change in indicated temperature.

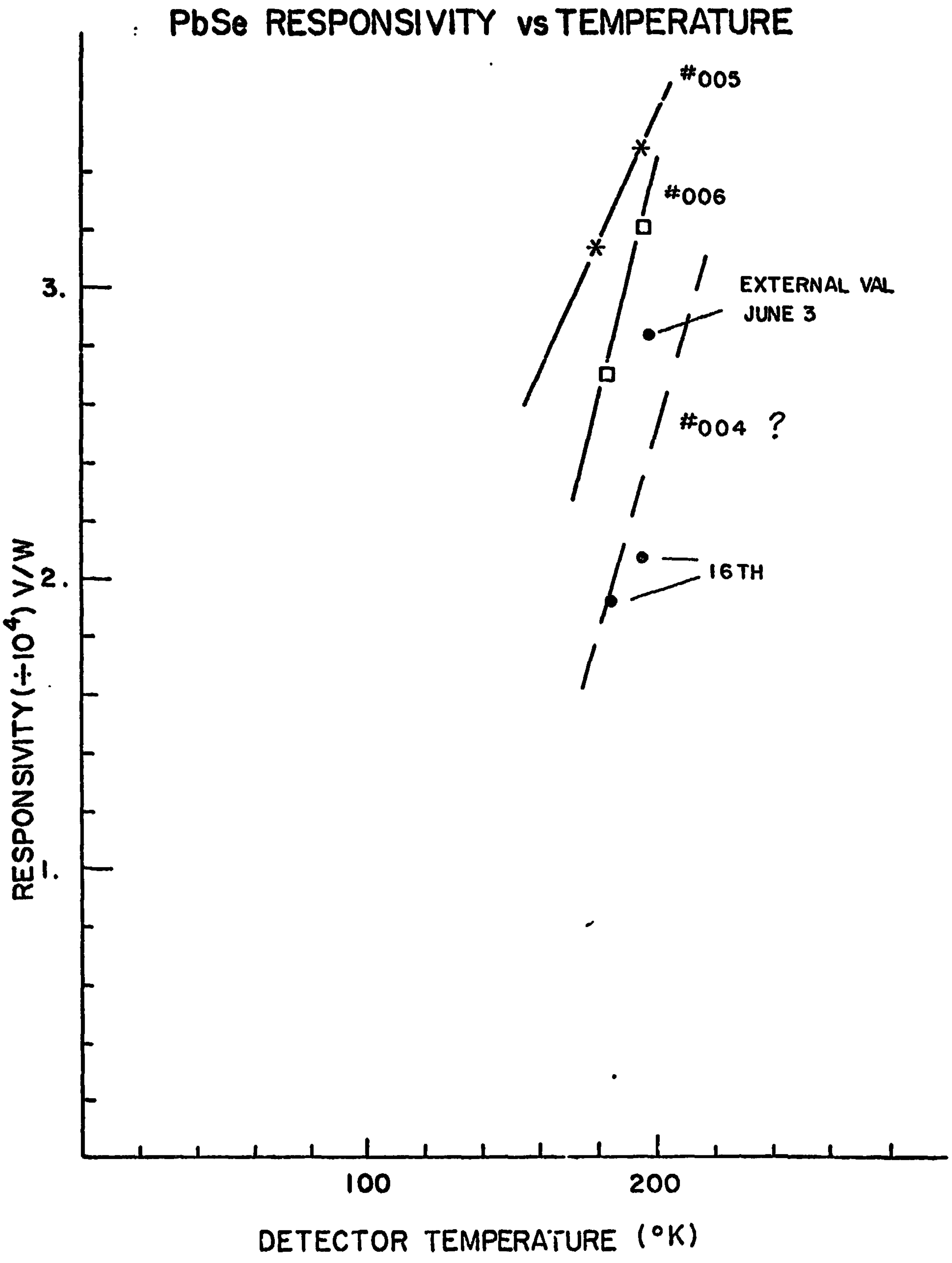


Fig 4.13

Responsivity versus Temperature for the PbSe detectors (data supplied by Opto-electronics).

4.3 HEAT SINKING EFFICIENCY TESTS

The efficiency of the detector heat sinking was evaluated with and without the heat sink strap connected. No. 44033, YSI thermistors were used to monitor the detector base, baseplate and ambient temperatures.

The temperature drift of the baseplate and detector base with the heat sink strap connected was found to correlate with ambient temperature. The detector base without the heat sink strap connected was found to be ≈2.5° C hotter than the base with the strap connected. The difference in the detector cold temperature with and without the heat sink strap was found to be only 0.7° C. Figure 4.14 shows the results obtained during the heat sink efficiency tests.

It would appear that although the heat sink straps do provide an increase in heat sinking efficiency the detectors would operate quite adequately without them. This is not really surprising when one considers that only 2 watts max. has to be dissipated and that the thermal contact between the detector base and mount is very good.

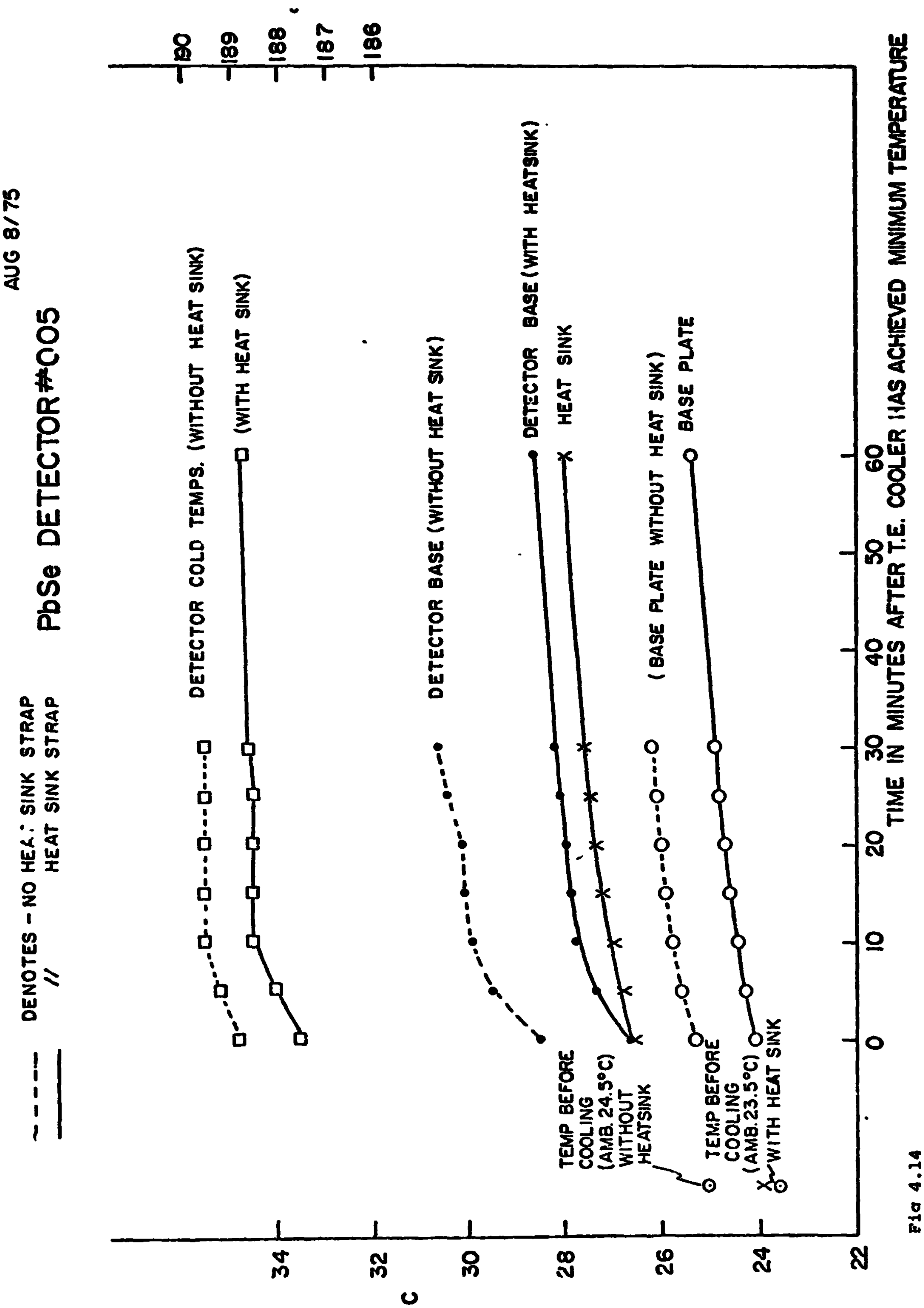

AUG 8/75
PbSe DETECTOR #005
DENOTES - NO HEAT SINK STRAP
" HEAT SINK STRAP
DETECTOR COLD TEMPS. (WITHOUT HEAT SINK)
(WITH HEAT SINK)
DETECTOR BASE (WITHOUT HEAT SINK)
DETECTOR BASE (WITH HEATSINK)
HEAT SINK
(BASE PLATE WITHOUT HEAT SINK)
BASE PLATE
TEMP BEFORE COOLING (AMB. 24.5°C) WITHOUT HEATSINK
TEMP BEFORE COOLING (AMB. 23.5°C) WITH HEAT SINK
°C
22
24
26
28
30
32
34
190
189
188
187
186
0
10
20
30
40
50
60
TIME IN MINUTES AFTER T.E. COOLER HAS ACHIEVED MINIMUM TEMPERATURE

Fig 4.14

4.4 BLACKBODY FABRICATION AND TESTING

The blackbodies were assembled by inserting the body consisting of the machined pyramids in liquid nitrogen and then pressing the body into the cover.

To ensure high emissivity, 3M black paint and appropriate primer were used to paint the blackbodies. Two different techniques were employed, one consisting of swilling the primer followed by the 3M paint around in the blackbody and then suspending the body upside down to allow all excess paint to drip out. The blackbodies were then baked at 275°F for = 30 minutes. When the baking was completed it was found that excess paint which had not been removed from the cavity had partially filled in the base of the pyramids non-black cavity. The second method which was found to give much better results consisted of spraying both the primer and paint on the blackbody and allowing the paint to cure overnight. It is felt that the best approach to take in future would be to spray the blackbody prior to assembling them in their covers, when it will be ensured that the spray carries paint to all sides of the pyramids.

In initial testing of the blackbody with the Tayco heater it was found that the additional heat load provided by the aluminium retaining ring was sufficient to ensure that the thermistor imbedded within the blackbody did not see a temperature greater than 50°C when maximum power (10 watts) was applied to the heater. A teflon ring was fabricated to replace the aluminium retaining ring and heating curves for the blackbody were obtained as a function of time for various fixed levels of heating power. It was found that for maximum heating power a temperature in excess of 100°C could be obtained in less than 20 minutes. Fig. 4.15

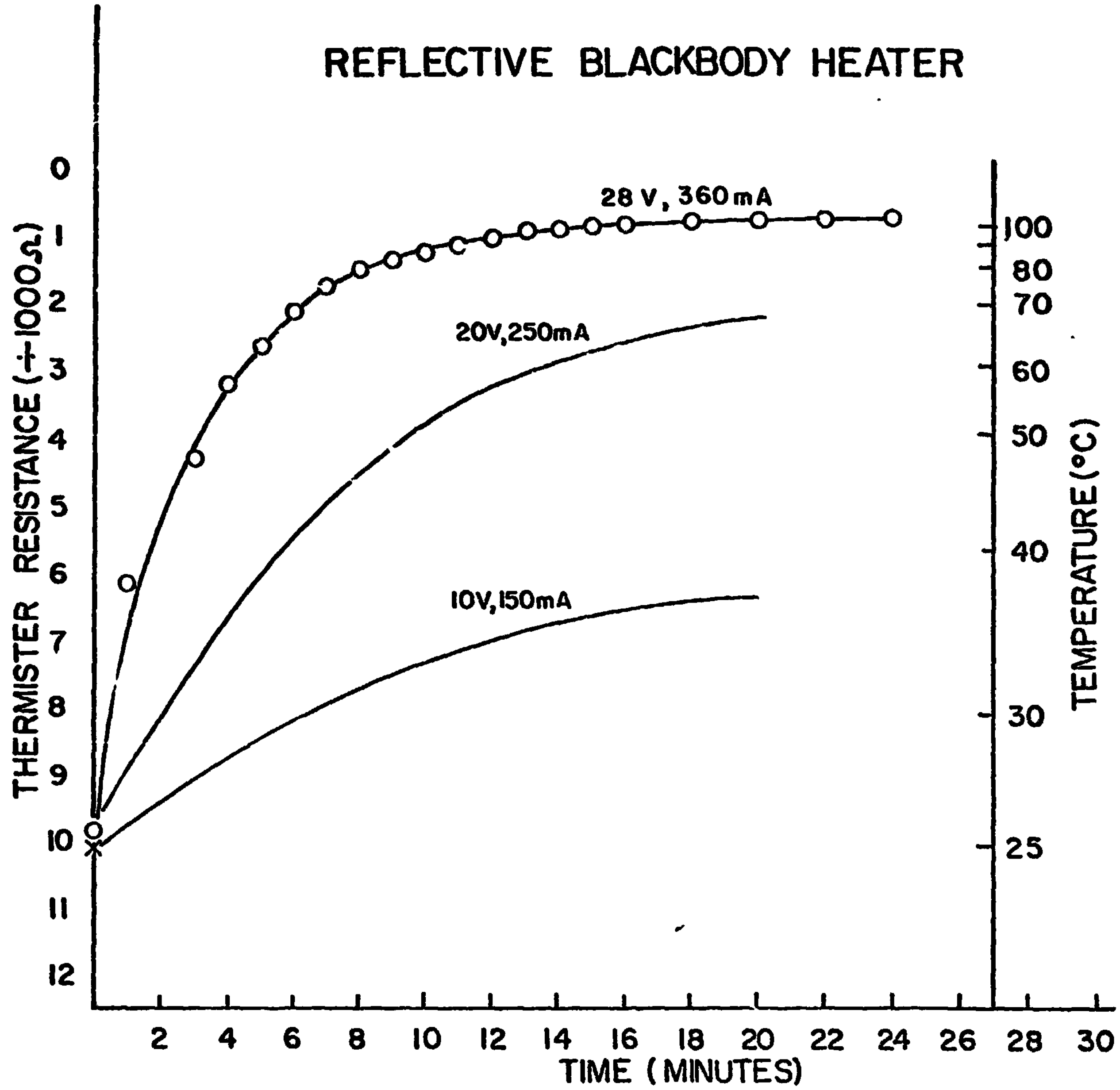


Fig 4.15

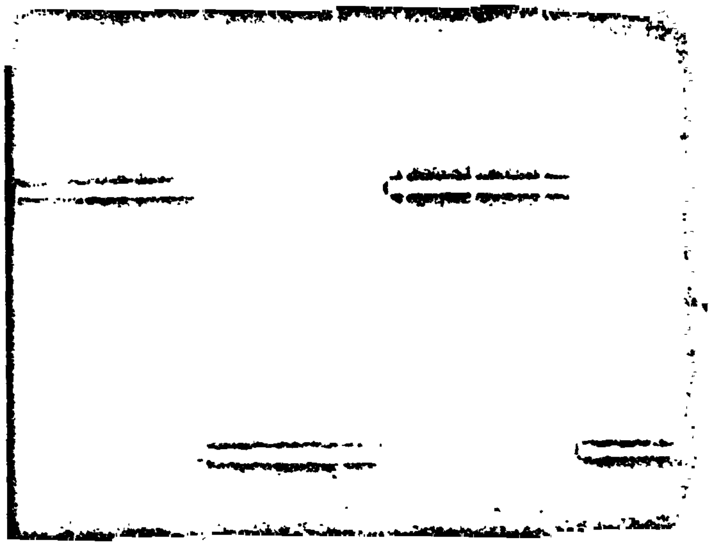
Heating curves for the hot blackbody. The curves are obtained as a function of time for various fixed levels of heating power applied to the Tayco heating element.

4.5 LED - Phototransistor Tests

L.E.D. - phototransistor tests were carried out for both the reference and signal frequency pick-offs. The L.E.D. used was a G.E. L.E.D. 56 and the phototransistor was an MRD 310. + 10 volts was applied through a 100 Ω resistance to the anode of the L.E.D. and + 20 volts was applied to the collector of the phototransistor. The output signal was picked off across a 100 Ω load resistor.

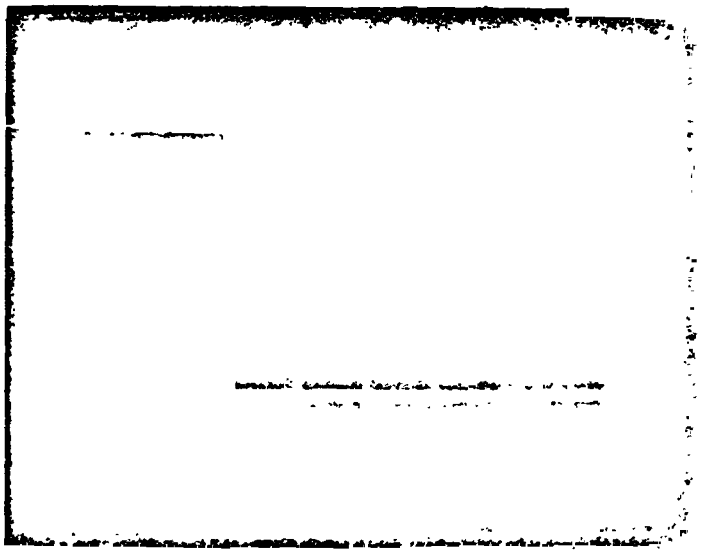
Oscilliscope records of the outputs of the phototransistors from the L.E.D. phototransistor pairs located on the chopper disc cover are shown in Figures 4.16 and 4.17. Fig 4.16 shows the waveforms for the pair synchronous with the source chopping frequency and Fig 4.17 shows the waveform for the reference blackbody chopping frequency. These records will be of use in evaluating the chopper disc waveforms.

MAPS SYNCHRONOUS SIGNAL WAVEFORM JULY 8, 1975



20 mV/cm.

2 mSec/cm.



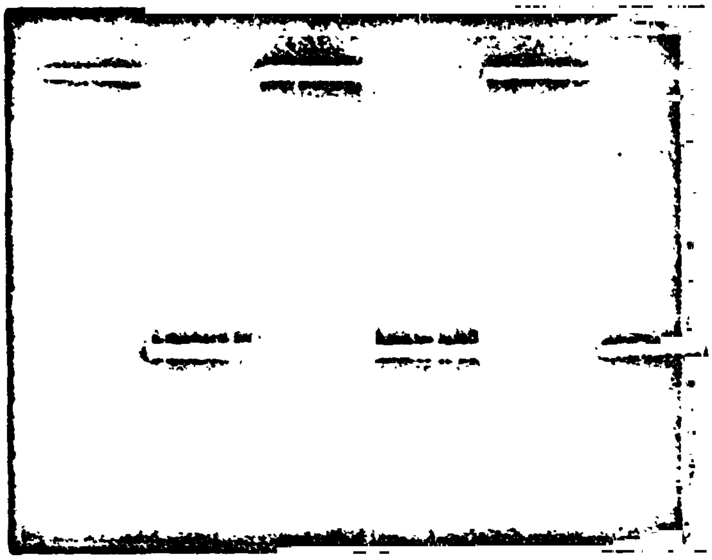
20 mV/cm.

1 mSec/cm.

Oscilliscope records of the outputs from the phototransistors of the LED - phototransistor pairs located on the chopper disc. These records are for the pair synchronous with the source chopping frequency. The records are to be used in evaluating chopper waveforms. The LED's had 10 volts applied and the phototransistors had 20 V on the collector.

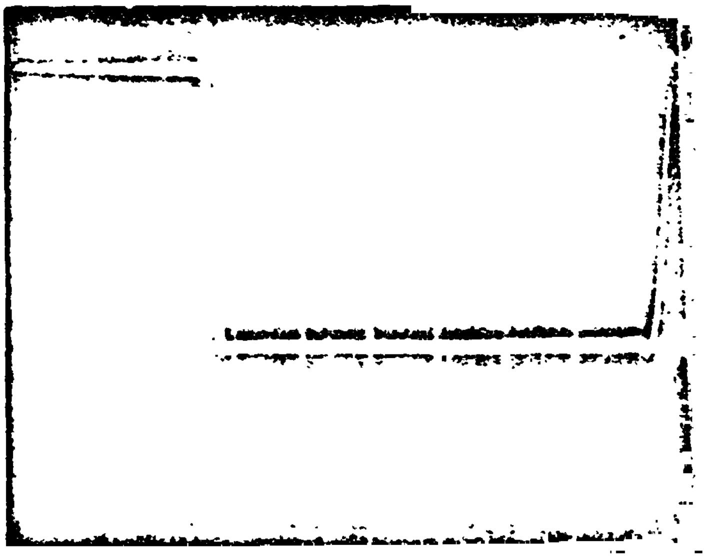
FIGURE 4.16

MAPS SYCNRHONOUS REFERENCE WAVEFORM **JULY 8, 1975**



20 mV/cm.

2 mSec/cm.



20 mV/cm.

0.5 mSec/cm.

Oscilliscope records of the LED - phototransistor chopper waveforms for the reference blackbody chopping frequency. The LED - phototransistor conditions are as for Figure 4.18.

FIGURE 4.17

4.6 Scene and Reference Signal Evaluation

The PbSe and pyroelectric detector and preamplifier output waveforms were examined using the Eppley blackbody as the scene target. From Figures 4.18 and 4.19 the outputs of the PbSe detector and preamplifier and pyroelectric detector and preamplifier at the scene frequency, for source and reflective blackbody temperatures as noted may be evaluated and the respective chopping efficiency determined through the bandpass of the preamplifier. Figures 4.20 and 4.21 show the composite detector waveforms, source and reference frequencies, for the source temperatures noted.

Optical crosstalk between the scene and reference frequencies was evaluated by monitoring the differential output from preamplifiers #1 and #2 via a P.A.R. differential amplifier and lock-in amplifier with the output $V_1 - V_2$ balanced at zero. $V_1 - V_2$ was recorded via a Honeywell chart recorder.

With the Eppley blackbody set at 33.41°C Av. for the five platinum resistance thermometers the output $V_1 - V_2$ at the scene frequency was monitored while the temperature of the hot reference blackbody was cycled to 64°C and allowed to cool down to ambient 31°C.

No optical crosstalk was apparent on the output at the scene frequency while the amplitude of the reference frequency was varied. Similarly while monitoring the differential reference signal with the hot reference blackbody at 51.5°C and cycling the scene amplitude from 33.41°C to 84.11°C and down again no crosstalk was apparent between the scene and reference frequencies.

PbSe DETECTOR SIGNAL WAVEFORMS **AUGUST 8TH, 1975**

#005

1 mSec/cm.
100 mV/cm.

Source 30.81°C
Reflective B. Board
27.95°C

2 mSec/cm.
50 mV/cm.

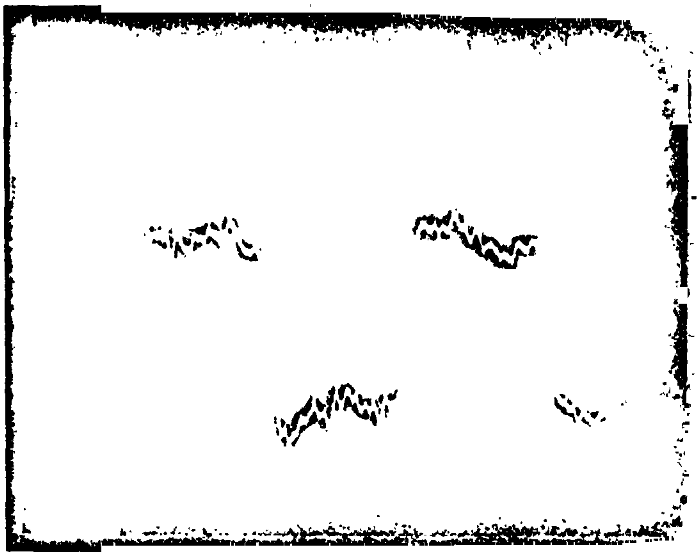
Source 30.7°C
Reflective B. Board
28.0°C

FIGURE 4.18

PYROELECTRIC WAVEFORM DETECTORS **AUGUST 7TH, 1975**

#12243

10 mS/cm.
200 mV/cm.



SIGNAL WAVEFORM
Source 36.54°C
Reflective B. Body
27.74°C

5 mS/cm.
200 mV/cm.

SIGNAL WAVEFORM
Source 45.73°C
Reflective B. Body
26.3°C

100 mS/cm.
200 mV/cm.

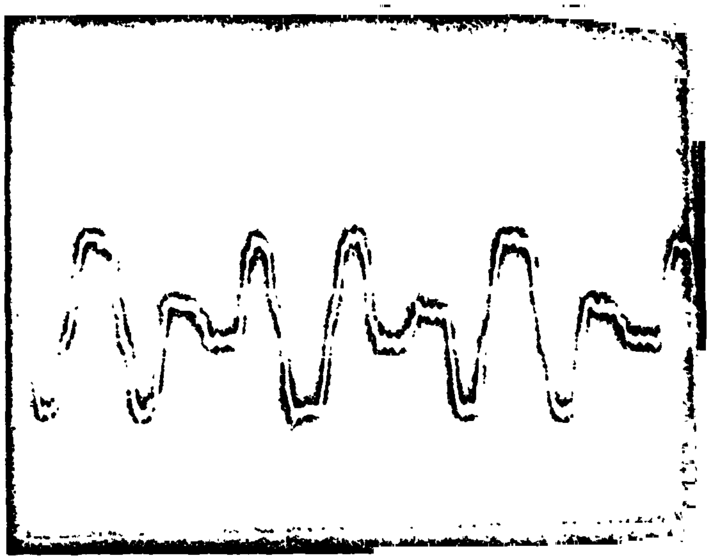
REFERENCE WAVEFORM
Cold B. Body 28°C
Hot B. Body 74.81°C

FIGURE 4.19

PYROELECTRIC DETECTOR COMPOSITE WAVEFORMS

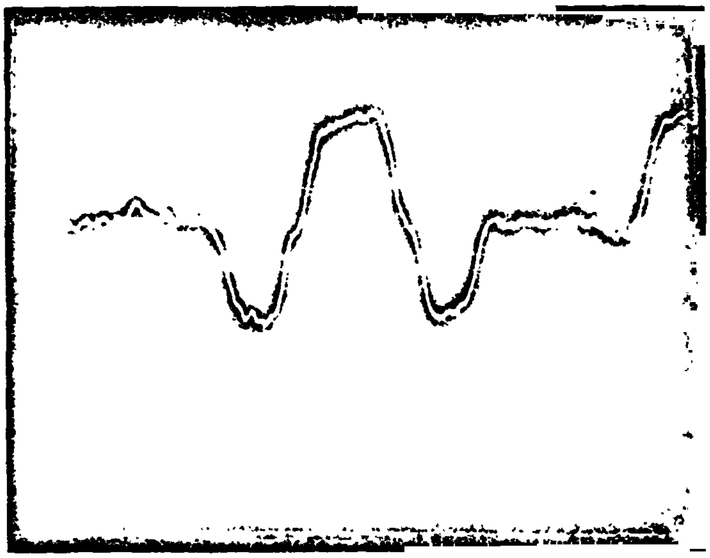
AUGUST 7, 1975

20 mSec/cm.
500 mV/cm.



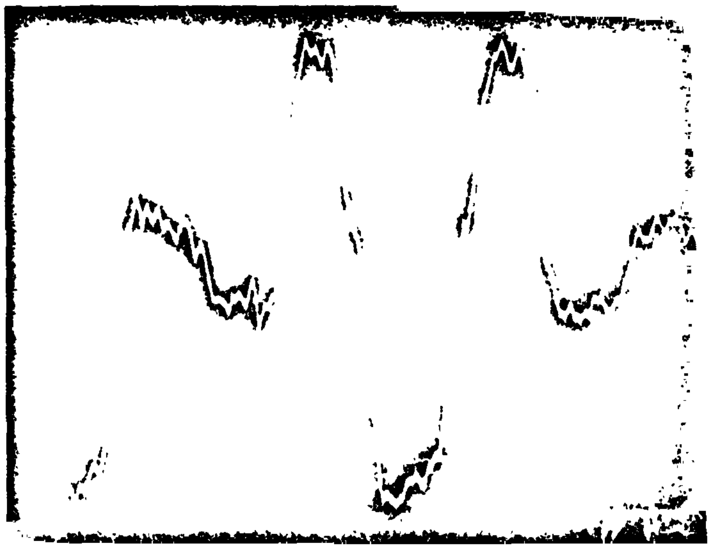
Source 36.52°C
Reflective B. Body
28°C
Cold B. Body
28.2°C
Hot B. Body
74.81°C

100 mSec/cm.
500 mV/cm.



Source 39.4°C
Reflective B. Body
27.6°C
Cold B. Body
27.74°C
Hot B. Body
74.81°C

100 mSec/cm.
200 mV/cm.



Source 36.53°C
Reflective B. Body
28°C
Cold B. Body
28°C
Hot B. Body
75°C

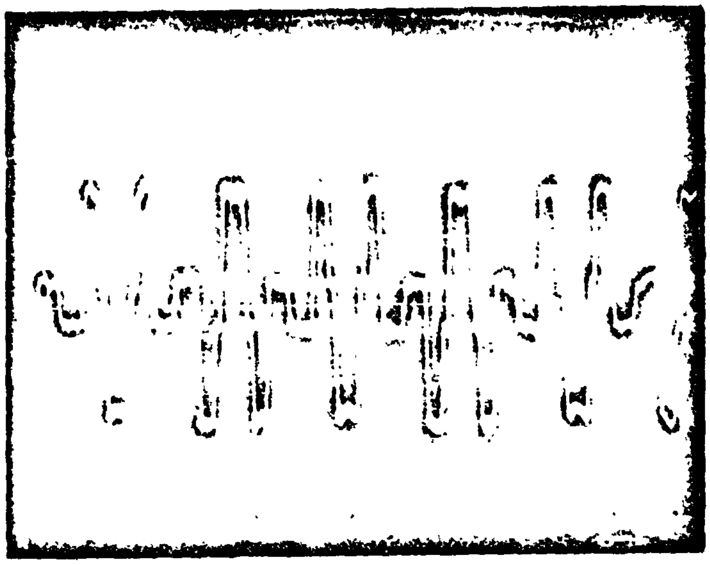
FIGURE 4.20

PbSe DETECTOR COMPOSITE WAVEFORMS

AUGUST 8TH, 1975

#005

5 mSec/cm.
200 mV/cm.

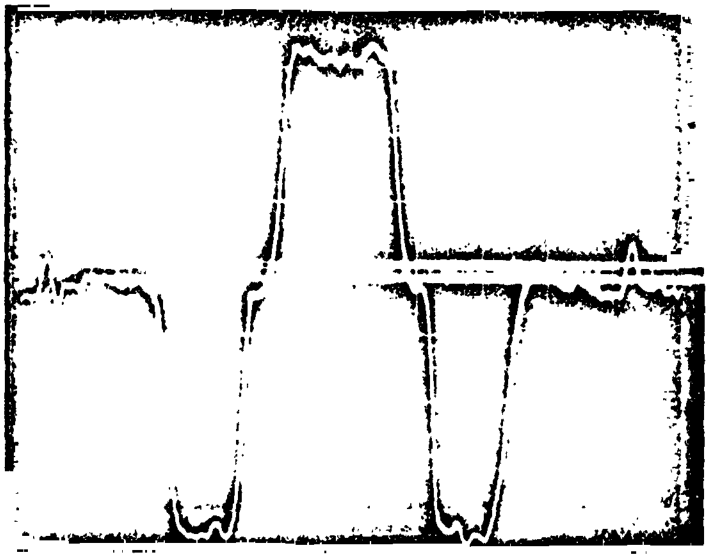


Source 31.17°C
Reflective B. Body
27.9°C
Cold B. Body
27.9°C
Hot B. Body
46.9°C

1 mSec/cm.
100 mV/cm.

Source 30.97°C
Reflective B. Body
27.95°C
Cold B. Body
27.95°C
Hot B. Body
47°C

1 mSec/cm.
100 mV/cm.



Source 31.88°C
Reflective B. Body
27.7°C
Cold B. Body
2P 25°C
Hot B. Body
45.9°C

FIGURE 4.21

4.7 Preamplifier Check-out

The TRW supplied PbSe and pyroelectric preamplifiers were consecutively installed on the brassboard connected to their respective detectors and pre-amplifier outputs evaluated. On the PbSe preamplifiers it was discovered that a large amount of pick-up was apparent due to the thermistor ground and T.E. cooler ground being connected at the output of the preamplifier rather than the input. This modification was carried out when the pick-up was found to disappear. Two of the pyroelectric preamplifiers were found to be wired incorrectly. The -6 V bias on the detector was absent due to lack of a connection between R_1 and R_2 on the preamplifier (see schematic). When these modifications had been carried out, all preamplifier detector combinations were found to operate satisfactorily. The value of the ferrous preamplifier covers was evaluated and while on one pyroelectric preamplifier, high frequency spikes were evident the presence or absence of the covers did not affect the coherent output of the detector and preamplifier.

PERFORMANCE EQUATIONS

$$\text{Detector noise voltage} = (\text{Out p-p noise}) \times \frac{1}{\text{Crest Factor}} \times \frac{1}{\text{Gain}} \times \Delta f^{\frac{1}{2}}$$

$$(V_{rms}\ \text{Hz}^{\frac{1}{2}}) \qquad (1)$$

$$\text{System efficiency } \tau_o\ \tau_e = \frac{\text{Signal response} \times 2 \times \frac{1}{\text{Gain}}}{\Delta N_\lambda \times \text{responsivity} \times \Delta\lambda \times A\Omega} \qquad (2)$$

$$\text{NEP} = \frac{\text{noise voltage}}{\text{responsivity}} \qquad (\text{watts}) \qquad (3)$$

$$\text{NEN} = \frac{\text{NEP}}{A\Omega\ \tau_o \tau_e} \qquad (\text{W cm}^{-2}\ \text{sr}^{-1}) \qquad (4)$$

$$\text{AF} = \frac{1}{A_v^2} \int_0^\infty \left[A_v(f)\right]^2 df$$

$$= \pi/2\ .\ f_2 \text{ for 6 db/octave filter} \qquad (5)$$

D* =

$$D^* = \frac{(\text{Ad}\ \Delta f)^{\frac{1}{2}}}{\text{NEP}} \quad \text{Cm Hz}^{\frac{1}{2}}\ \text{W}^{-1} \qquad (6)$$

4.8 NOISE VOLTAGE MEASUREMENTS

Noise voltages were determined for each detector preamplifier combination with modulated energy derived from the Eppley blackbody falling on the detectors. The output from each preamp was taken in turn via a PAR lock-in amplifier to a chart recorder and the peak-to-peak noise voltage determined when all modulated energy was removed from the detectors by blocking each optical arm in turn.

Noise voltages referred to each detector were obtained using equation (1). The peak-to-peak noise was measured from the chart record where the time period considered was $\approx$ 100 x PAR time constant. In this case the time constant was 1 second and thus peak-to-peak noise over periods of 100 seconds were taken and an average value derived over 5 such periods. Noise from all of the detectors was assumed to be Gaussian and the appropriate crest factor obtained from figure 4.22.

The gain of each preamp was determined by introducing a square wave of known amplitude at the signal frequency into each preamp input and recording the preamp output.

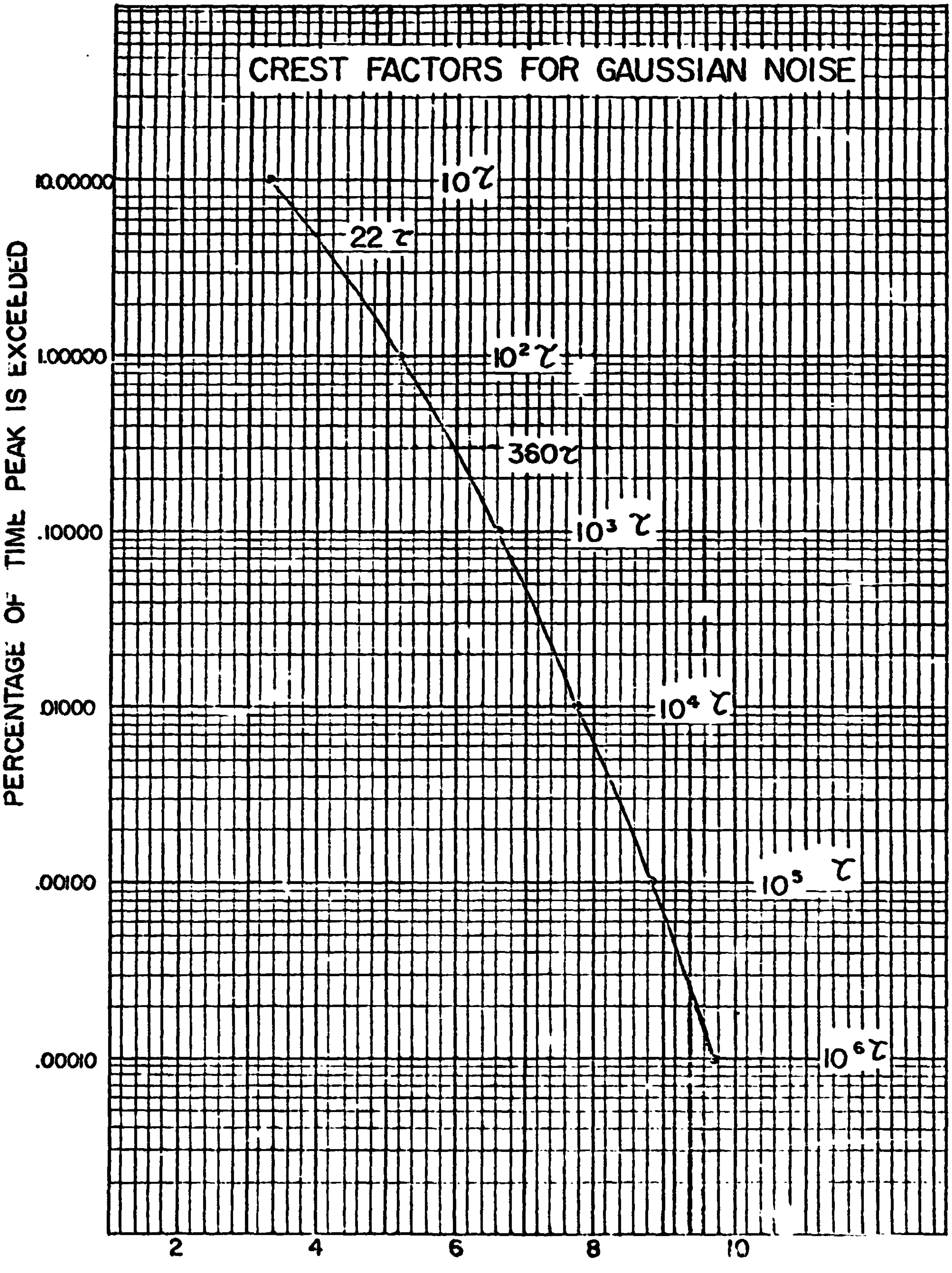
$$\text{Then preamp gain} = \frac{\text{Square wave p-p volts out}}{\text{Square wave p-p volts in}}$$

The gain of the PAR lock-in and chart recorder was obtained by fixing the PAR internal reference at the desired signal frequency and with a square wave of known amplitude, derived from a signal generator, at the signal input, sweeping the generator to obtain the beat frequency at the chart recorder output.

$$\text{Then PAR gain} = \frac{\text{Sine wave p-p volts out}}{\text{Sine wave p-p volts in}}$$

The noise bandwidth Δf was obtained from equation (5). Detector noise voltages thus obtained were compared with those obtained from the detector manufacturers as shown in Tables 4.4, 4.6, 4.10 and 4.12.

AUGUST 6/75



$\frac{V_{p-p}}{V_{rms}}$ Ratio of peak-to-peak voltage and RMS voltage.

FIGURE 4.22

4.9 SYSTEM EFFICIENCY

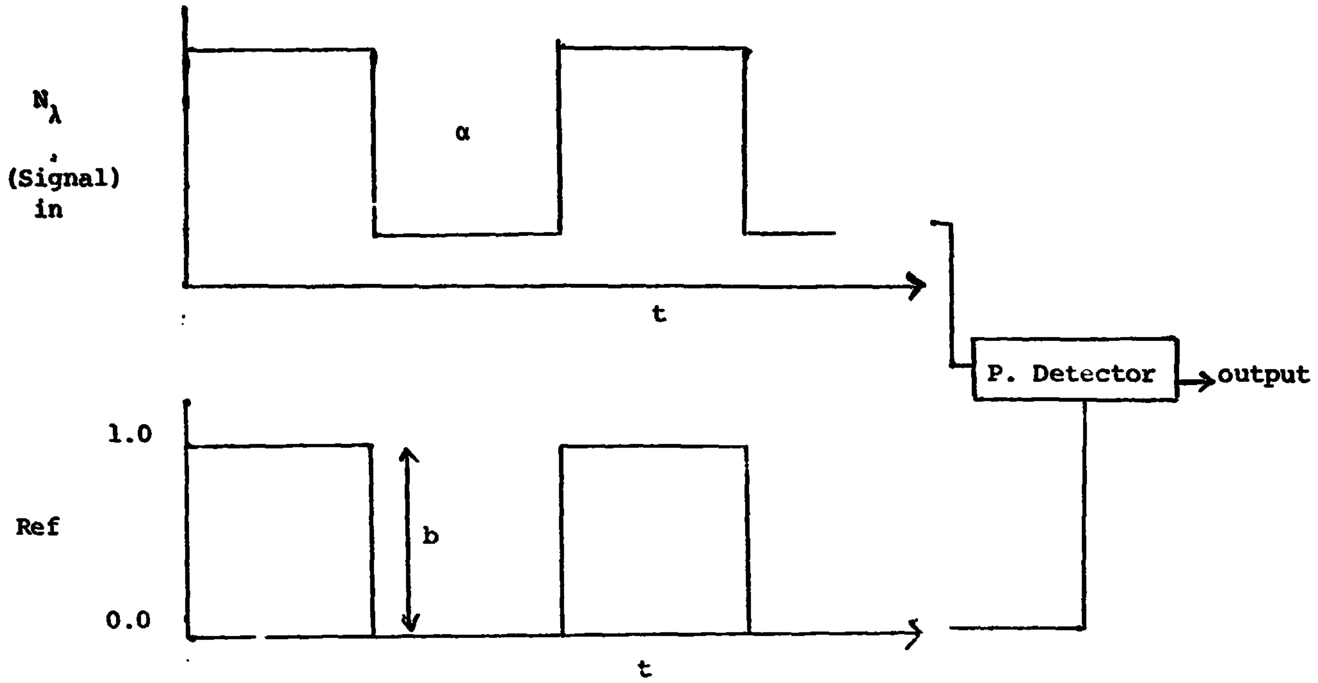
System thruput or total optical and electronic efficiency was derived in a similar fashion as the noise voltages. Using the Eppley blackbody as the radiant source and with a known temperature at the reflective blackbody the coherent signal on each detector was displayed on the chart recorder as an average voltage output. System efficiency $\tau_o\tau_e$ was then obtained from equation 2. The d.c. signal response was related to the peak-to-peak square wave radiant input as shown in Figure 4.23 System gain was derived as in section 4.8. The differential ΔN_λ radiance was computed from the known temperatures of the source and reflective blackbody. Manufacturers data for responsivity and $\Delta\lambda$ were assumed and $A\Omega$ was calculated from design data. The magnitude of the response from each detector was obtained by consecutively allowing the radiant energy in each arm to be completely blocked, to obtain a baseline and then removing the blocker. Measured values for $\tau_o\tau_e$ were then compared with the predicted design data as shown in Tables 4.7 and 4. 13.

Noise equivalent radiances (NEN) were then calculated from the noise voltage data using $\tau_o\tau_e$ as shown in equation (4). These NEN's were again compared with the design data as shown in Tables 4.7 and 4.13 .

4.10 GAIN BALANCING

The gains of two of the preamps for both the PbSe and pyroelectric detectors were adjusted to give identical outputs to a fixed Eppley blackbody source. This was accomplished by using the outputs from two of the preamplifiers and coupling them via the PAR differential amplifier and lock-in amplifier to obtain zero output by adjusting the gain of the preamp with the largest signal at its output through a potentiometer located on the preamplifier. The output from the third preamplifier was then coupled with one of the first two outputs through the differential amplifier and lock-in amplifier and the gain of the third preamplifier adjusted to again obtain zero output. In each instance the differential output $V_1 - V_2$ and $V_1 - V_3$ were recorded and the noise voltages after being differentially coupled.

Fig. 4.23



$$\text{output} = \int_T a\Delta \text{ in wt . b } \rho\text{in wt dt}$$

$$= \int_T (\tfrac{1}{2} \text{ ab co } 2\text{wt} - \tfrac{1}{2} \text{ ab cos } (\text{w}-\text{w})\text{t})\text{dt}$$

$$= -\int_T \tfrac{1}{2} \text{ ab dt} + \int_T \tfrac{1}{2} \text{ ab cos 2 wt dt}$$

after filtering (integration)

$$= - \tfrac{1}{2} \text{ a b}$$

4.11 ΔV GAS SIGNAL

Initially it had been intended to monitor the differential output from arms 1 and 2 to evaluate $V_1 - V_2$ as a function of gas signal input for the PbSe detectors. This required the use of the G.S.U. target source and absorption cell. Unfortunately due to scheduling problems only the target source was available and thus it was not possible to perform preliminary gas response tests. However it was found possible to place a 1 Cm x 1 1/2 inch diameter cell with sapphire windows containing 60 TORR CO backfilled with N_2 to a total pressure of 760 TORR. between the objective lens and the chopper disc and record the response. This test verifies that the brassboard was in fact capable of seeing 2 x 10^{-3}atm. cms. CO with a target source temperature of 33.4° C with an S/N (RMS) =1.

COMPARISON OF DETECTOR MANUFACTURER'S DATA & MEASURED DATA

Tables 4.4, 4.5, 4.6, 4.10, 4.11 and 4.12 give a comparison of the detector manufacturer's noise voltage data with that obtained on the brassboard, measured as outlined in section 4.8 for both PbSe and pyroelectric detectors.

Measured values for noise voltages were obtained under the following set of conditions in each case referred to the detector.

$$\text{Detector noise voltage} = (\text{Output p-p noise}) \times \frac{1}{\text{Crest factor}} \times \frac{1}{\text{Gain}} \times \Delta f^{-\frac{1}{2}}$$

$$(V_{RMS}\ Hz^{-\frac{1}{2}})$$

Crest Factor = 5.2

Noise bandwidth = 0.25 Hz

Output p-p noise was obtained from the chart record.
V_{AV} was also obtained from chart record

NEN CALCULATIONS

NEN values were calculated for each arm of the brassboard at 4.6 microns and 11.2 microns as described in section 4.9. These values along with optical efficiency and throughput values were then compared with design values in Tables 4.7 & 4.13.

PYROELECTRIC DETECTORS

		12117	12142	12243
ROOM TEMP.	Area (cm)	.0404	.0402	.0402
	Responsivity (V/W)	725	762	725
	D* (cm $Hz^{\frac{1}{2}}$ W^{-1})	7.7×10^{8}	9.5×10^{8}	5.9×10^{8}
	NEP (W)	2.56×10^{-10}	2.087×10^{-10}	3.38×10^{-10}

7°C	Responsivity	627	725	650
	D*	4.7×10^{8}	6.9×10^{8}	3.9×10^{8}

Table 4.2

Detector performance data supplied by manufacturer

ARM DETECTOR	3 No. 12117	2 No. 12142	1 No.12243
Black Body Temps (^{o}C)	25.5	25.1	26.8
" " Radiance (WCm^{-2}Sr$^{-1}\mu^{-1}$)	9.44 x 10^{-4}	9.385 x 10^{-4}	9-25 x 10^{-4}
Source Temps (^{O}C)	30.45	30.34	30.74
" Radiance (WCm^{-2}Sr$^{-1}\mu^{-1}$)	1.015 x 10^{-3}	1.013 x 10^{-3}	1.019 x 10^{-3}
Δ Radiance (WCm^{-2}Sr$^{-1}\mu^{-1}$)	7.09 x 10^{-5}	7.45 x 10^{-5}	5.65 x 10^{-5}
P.A.R. GAIN	39.5	43.45	43.45
Noise Bandwidth (Hz)	.25	.25	.25
Pre-amp gain	3 x 10^{3}	1.92 x 10^{3}	2.38 x 10^{3}
V_{AV} Signal (V)	3.15	7.8	5.6
V_{p-p} Noise (V)	90 x 10^{-3}	37.5 x 10^{-3}	90 x 10^{-3}
Crest Factor	5.2	5.2	5.2
Noise Voltage (V_{rms} Hz$^{-\frac{1}{2}}$)	2.65 x 10^{-7}	1.72 x 10^{-7}	3.34 x 10^{-7}
$\tau_o\tau_e$	.045	.073	.058
N.E.P. (W)	3.66 x 10^{-10}	2.25 x 10^{-10}	4.6 x 10^{8}
D* Cm Hz W^{-1}	5.46 x 10^{8}	8.89 x 10^{8}	4.34 x 10^{8}
NEN (WCm^{-2}Sr^{-1})	8.19 x 10^{-7}	3.18 x 10^{-8}	8.19 x 10^{-8}

Table No. 4.3

Pyroelectric detector measured data

PYRO NO. 12117

	MANUFACTURER'S DATA	MEASURED DATA
D* $Cm^{'}Hz^{\frac{1}{2}}W^{-1}$	7.7×10^{8}	5.46×10^{8}
NOISE VOLTAGE (Vrms $Hz^{-\frac{1}{2}}$)	1.86×10^{-7}	2.65×10^{-7}

Table 4.4

Comparison of manufacturer's and measured data

PYRO NO. 12443

	MANUFACTURER'S DATA	MEASURED DATA
D* ($Cm\ Hz^{\frac{1}{2}}\ W^{-1}$)	5.9×10^{8}	4.34×10^{8}
NOISE VOLTAGE ($Vrms\ Hz^{-\frac{1}{2}}$)	2.45×10^{-7}	3.34×10^{-7}

Table 4.5

Comparison of manufacturer's and measured data

PYRO NO. 12142

	MANUFACTURER'S DATA	MEASURED DATA
D* (Cm $Hz^{\frac{1}{2}}$ W^{-1})	9.5×10^{8}	8.89×10^{8}
NOISE VOLTAGE Vrms $Hz^{-\frac{1}{2}}$	1.59×10^{-7}	1.72×10^{-7}

Table 4.6

Comparison of manufacturer's and measured data

COMPARISON OF DESIGN & MEASURED BRASSBOARD

PERFORMANCE [NH_3]

		DESIGN (D)	MEASURED (M)
AΩ (Cm^2 Sr)		3.88×10^{-2}	4.85×10^{-2}
Δf (Hz)		0.1	0.25
D* ($Cm\ Hz^{\frac{1}{2}}\ W^{-1}$)	No. 1	5×10^{8}	4.34×10^{8}
	No. 2	5×10^{8}	8.89×10^{8}
	No. 3	5×10^{8}	5.46×10^{8}
$\tau_o\tau_e$	No. 1	.062	.058
	No. 2	.056	.073
	No. 3	.091	.045
NEN ($WCm^{-2}Sr^{-1}$)	No. 1	5.26×10^{-8}	8.19×10^{-8}
	No. 2	5.82×10^{-8}	3.18×10^{-8}
	No. 3	3.58×10^{-8}	8.39×10^{-8}

Table No. 4.7

PbSe DETECTORS

(195°K performance)

	Detector 004	Detector 005	Detector 006
Area (Cm^2)	.04	.04	.04
Responsivity (V/W)	2.04×10^4	3.49×10^4	3.21×10^4
D* (4.7y, 172 Hz) (CmHz$^{\frac{1}{2}}$ W^{-1})	1.05×10^{10}	9.59×10^9	1.25×10^{10}

TEMP	185°K	180°K	192°K
Responsivity (V/W)	1.91×10^4	3.15×10^4	2.71×10^4
D*	1.08×10^{10}	1.39×10^{10}	1.48×10^{10}
	197°K		
R.	2.85×10^4		
D*	1.29×10^{10}		

Table No. 4.8

PbSe detector performance data supplied by Opto Electronics.

ARM	1	2	3
Detector	No. 005	No. 004	No. 006
Black Body Temps ($^{\circ}$C)	26.	26.5	26.65
" " Radiance (WCm^{-2}Sr$^{-1}\mu^{-1}$)	1.807×10^{-4}	1.839×10^{-4}	1.848×10^{-4}
Source Temps ($^{\circ}$C)	30.57	30.65	30.68
" Radiance (WCm^{-2}Sr$^{-1}\mu^{-1}$)	2.11×10	2.116×10^{-4}	2.118×10^{-4}
Δ Radiance (WCm^{-2}Sr$^{-1}\mu^{-1}$)	3.03×10^{-5}	2.77×10^{-5}	2.7×10^{-5}
Detector Temps ($^{\circ}$K)	191	193	189
P.A.R. GAIN	43.5	39.55	43.5
Noise bandwidth (Hz)	.25	.25	.25
Pre-amp gain	473	773	555
Vav Signal (V)	3.35	2.05	2.3
Vp-p Noise (V)	46×10^{-3}	61×10^{-3}	35.3×10^{-3}
Crest Factor	5.2	5.2	5.2
Noise Voltage (Vrms Hz$^{-\frac{1}{2}}$)	8.6×10^{-7}	7.7×10^{-7}	5.6×10^{-7}
$\tau_o \tau_e$	.101	.082	.084
N.E.P. (W)	2.46×10^{-11}	3.77×10^{-11}	1.77×10^{-11}
D* (Cm Hz$^{\frac{1}{2}}$ W^{-1})	8.11×10^{9}	5.3×10^{9}	1.12×10^{10}
NEN (WCm^{-2}Sr^{-1})	2.51×10^{-9}	4.71×10^{-9}	2.17×10^{-9}

Table No. 4.9

PbSe detector measured data

PbSe No. 005

	MANUFACTURER'S DATA	MEASURED DATA
D* 4.7μ (Cm $Hz^{\frac{1}{2}}$ W^{-1})	9.59 x 10^{9} at 195°K 1.387 x 10^{10} " 180°K	8.11 x 10^{9} at 191°K
NOISE VOLTAGE (Vrms $Hz^{-\frac{1}{2}}$)	7.27 x 10^{-7} at 195°K 4.54 x 10^{-7} " 180°K	8.6 x 10^{-7} at 191°K

Table 4.10

Comparison of manufacturer's and measured data

PbSe No. 004

	MANUFACTURER'S DATA	MEASURED DATA
D* 4.7μ (Cm $Hz^{\frac{1}{2}}$ W^{-1})	1.046×10^{10} at 195°K 9.99×10^{9} " 195°K 1.077×10^{10} " 185°K 8.87×10^{10} " 195°K 1.29×10^{10} " 197.5°K	5.3×10^{9} at 193°K
NOISE VOLTAGE Vrms $Hz^{-\frac{1}{2}}$	3.9×10^{-7} at 195°K 4.0×10^{-7} " 195°K 3.55×10^{-7} " 185°K 4.57×10^{-7} " 195°K 4.4×10^{-7} " 197.5°K	7.7×10^{-7} at 193°K

Table 4.11

Comparison of manufacturer's and measured data

PbSe No. 006

	MANUFACTURER'S DATA	MEASURED DATA
$D^*_{4.7\mu}$ (Cm $Hz^{\frac{1}{2}}$ W^{-1})	1.25×10^{10} at 195°K 1.48×10^{10} " 182°K	1 12 x 10^{10} at 189°K
NOISE VOLTAGE (Vrms $Hz^{-\frac{1}{2}}$)	5.13×10^{-7} at 195°K 3.66×10^{-7} " 182°K	5.6×10^{-7} at 189°K

Table 4.12

Comparison of manufacturer's and measured data

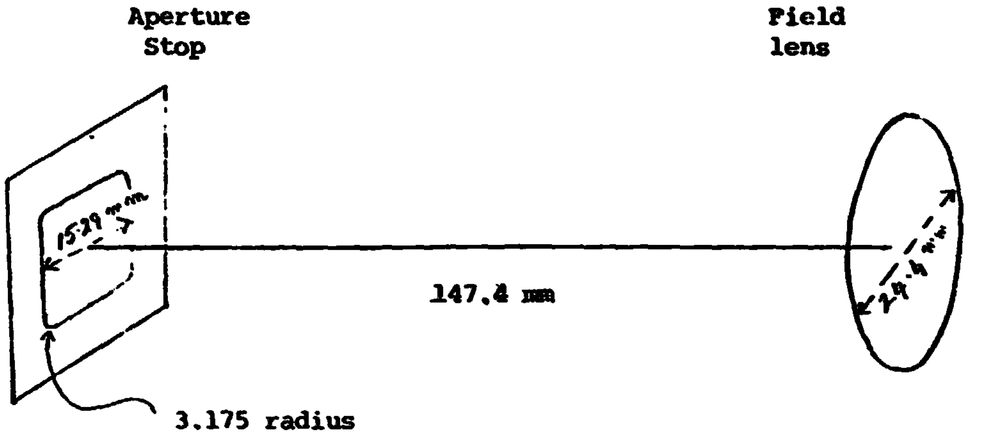
COMPARISON OF DESIGN & MEASURED BRASSBOARD

PERFORMANCE [CO]

	DESIGN (D)	MEASURED (M)
A Ω (Cm^2Sr)	3.88×10^{-2}	4.85×10^{-2}
Δ f (Hz)	0.1	0.25
D* ($Cm\ Hz^{\frac{1}{2}}W^{-1}$) No. 1	1.2×10^{10}	8.11×10^{9}
No. 2	1.2×10^{10}	5.3×10^{9}
No. 3	1.2×10^{10}	1.12×10^{9} ·10
$\tau_o \tau_e$ No. 1	.091	0.101
No. 2	.109	0.082
No. 3	.097	0.084
NEN ($WCm^{-2}Sr^{-1}$) No. 1	1.49×10^{-9}	2.51×10^{-9}
No. 2	1.25×10^{-9}	4.71×10^{-9}
No. 3	1.40×10^{-9}	2.17×10^{-9}

Table 4.13

A Ω CALCULATION



$$A\Omega = \frac{A_{AS} \cdot A_{FL}}{d^2}$$

$$A_{AS} = (15.29)^2 - \left((3.125 \times 2)^2 - \Pi\,(3.125)^2\right)$$

$$= 225.4 \text{ mm}^2$$

$$A_{FL} = \left[\Pi \frac{(24.4)^2}{4}\right]$$

$$= 467.6 \text{ mm}^2$$

$$A\ \Omega = \frac{225.4 \times 457.6}{(147.4)^2}$$

$$= \underline{\underline{0.0485 \text{ cm}^2 \text{ sr}}}$$

APPENDIX I

MAPS GAS CELLS CHEMICAL COMPATIBILITY LIFE TEST

TRW
SYSTEMS GROUP

INTEROFFICE CORRESPONDENCE

4341.AC.76-118

TO P. Hutchings

CC: E. A. Burns
C. Flegal
W. Massey
L. Peterson
R. Jones

DATE: 6-9-76

SUBJECT MAPS Gas Cells
Chemical Compatibility
Life Test

FROM: L.E. Ryan L. E. Ryan

BLDG	MAIL STA.	EXT.
01	2030	62451

Reference 1: 4341.AC.75-165, Chemical Compatibility Study of MAPS Gas Cell, To: W. Massey, From: L.E. Ryan, 7-24-75

Reference 2: Monitoring of Air Pollution by Satellites (MAPS) Phase 1 Report, Science Applications Incorporated.

Reference 3: 4341.AC.76-062, Report on MAPS Gas Cell Filling and Recommendations for Future Modifications to Fill Station, To: P. Hutchings, From: L.E. Ryan, 3-19-76

Introduction

The design objective of the MAPS gas cell effort was to produce a chemically stable gas reference cell for the operational lifetime of the instrument. Chemical changes were of primary concern because reactions which would deplete the reference gases or introduce absorptive species into the band pass would effect instrument response. Theoretically the cell design maintains an interior which is inert to the carbon monoxide, and ammonia fill gases. However, a life test was conducted to verify that the stability of these cells met the design criteria of a maximum 1% signal change over a two year period.

Test Sequence

Initially the windows used for these life test MAPS cells were characterized by an optical microscopic inspection. This inspection was conducted to look for any flaws. These windows were also scanned in the infrared (2.5-15 microns). These preparation tests were conducted to provide a baseline reference for each window in the event a life test failure indicated that the window materials were involved.

The cells for life test were processed and filled according to established MAPS procedures, reference 3. They were then leak checked to verify vacuum integrity, infrared scanned, and exposed to 85°C for 400 hours to simulate 3 years of life at 25°C (Determined from Arrhenius Equations - Influence of Temperature on the Rate of Reaction). After this exposure infrared scans were conducted to verify that changes had not taken place. Life test cell S/N 112, 5% NH_3 was cross sectioned in half at the end of these tests and the windows were reexamined and window #3 rescanned in the infrared.

The life test cells are identified below:

Table I: Life test Cell Assignments

Cell S/N	Fill Gas	Windows
108	35% CO	288517B, #3 and #4
110	10% CO	288517B, #8 and #9
109	20% NH_3	288517A, #5 and #6
112	5% NH_3	288517A, #3 and #4

Life Test Data

1. Window Characterization

The sapphire windows appeared to be free of defects. Cell S/N 108 had been constructed with windows #3 and #4 and Cell S/N 110 with windows #8 and #9.

The germanium windows were free of defects in appearance on the uncoated side. The antireflectance coating, however, was uneven on all the windows inspected. It appeared to be spotted with noncoated areas present (Window numbers #2, #3, #4, #5, #6 and #7)*. Photograph #1 shows a 500X magnification of window #3 which was used on life test cell S/N112.

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*Windows #2 and #7 were used on retrofit cell S/N114.

Photograph 1: Window #3, germanium, two areas at 500X of anti-reflectance coating defects, used on S/N112.

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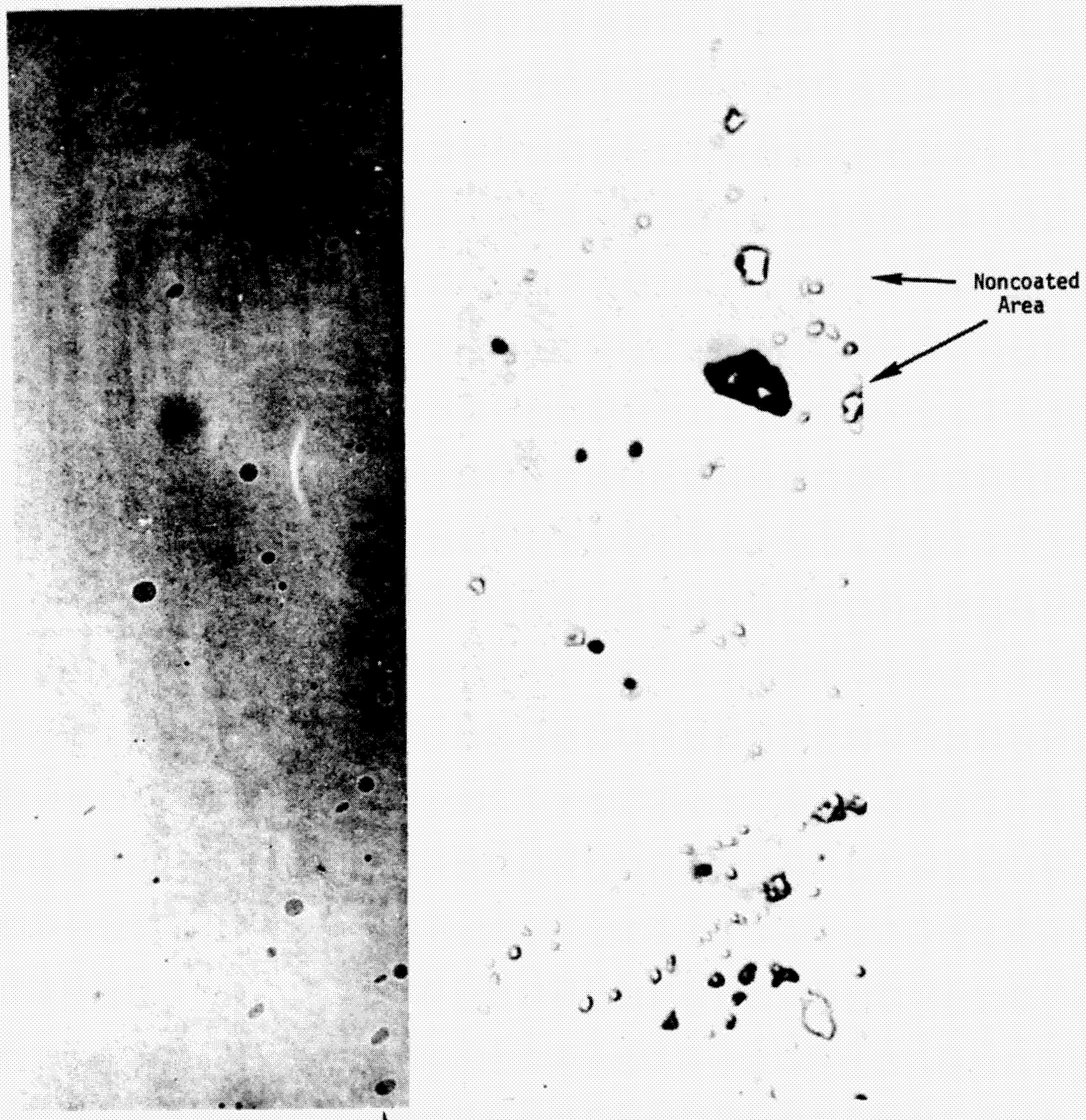
6-9-76



Area #1

Area #2

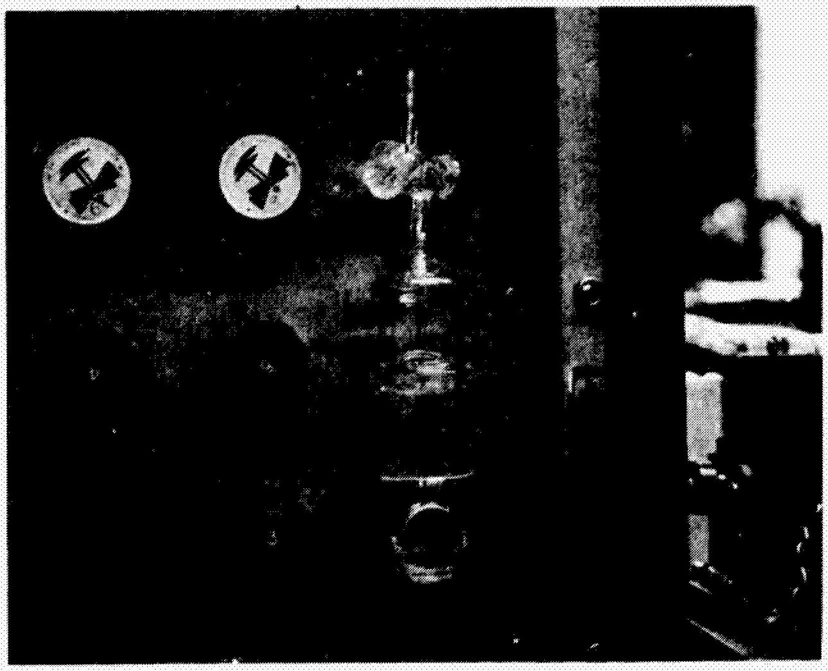
Cell S/N 112 had been constructed with windows #3 and #4 and life test cell S/N 109 with #5 and #6.

The windows from S/N 112 were carefully inspected after the life test and changes were not detected on the surface in contact with the NH_3.

Infrared transmittance scans were conducted on all these windows before cell construction. The initial scan of the germanium #3, S/N 112 cell, window is attached, scan #1. This same window was rescanned after cross sectioning and is also attached, scan #2. The transmittance characteristics were uneffected by contact with the NH_3.

2. Vacuum Integrity

These cells were scanned in the infrared just prior to vacuum exposure, scans #3, 4, 5, and 6. The vacuum exposure was conducted in a bell jar attached to the inlet system of a Hitachi/Perkin Elmer Mass Spectrometer, RMU-6, Photograph 2.



Photograph 2
MAPS
gas cell
S/N 109 during
Vacuum
Integrity
Analysis

After the bell jar was evacuated to approximately 5 x 10 $^{-8}$ torr., the bell jar was valved-off from the rest of the system. The cell, with approximately 1 atm. of fill gas, was then allowed to equilibrate with the vacuum environment of the bell jar for one hour. (If a leak were present the fill gas would tend to escape into the bell jar). Upon reventing into the mass spectrometer the increase in pressure was recorded and a mass scan was conducted of the contents of the bell jar. The data from these tests are recorded below:

Table II: Vacuum Exposure Mass Spectrophotometer Data

Sample/Cell	Mass Scan Data
Standard Helium leak, 8.8x10^{-10} attached to bell jar vent.	Helium detected strongly after one hour, a 5 unit peak height at lowest sensitivity. A trace of air also present. 5.8x10^{-8} torr. final pressure.
Background of bell jar, no cell present.	Air detected along with outgassing of silicone grease used on ground glass joint and vent valve. 8.0x10^{-8} torr. final pressure.
S/N 108 S/N 109 S/N 110 S/N 112	Same as background materials. Neon was not detected. Change in pressure less than change in helium standard leak.

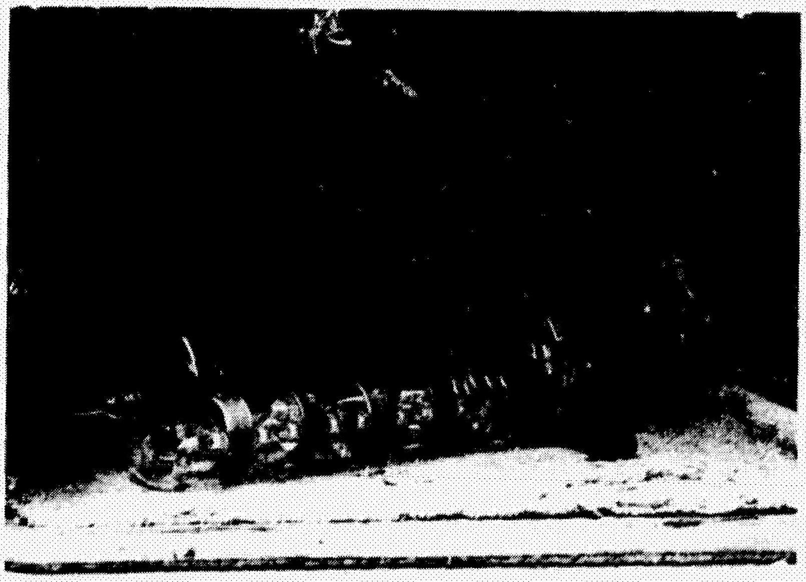
Leaks were not detected in any of these cells. They were again scanned in the infrared and these scans were compared with those conducted before the vacuum exposure, scans #7,8,9, and 10. The intensities of the absorptions peaks had not changed indicating again that no loss of gas had taken place during vacuum exposure. It should be noted that differences in these scans and those just after filling and tip-off are due to instrumental differences in the spectrophotometers. The Beckman I.R. 20A was the only instrument available at the time the vacuum exposure tests were conducted.

Table III: Infrared Peak Intensities, Before and After Vacuum Exposure

Cell	Peak measurement in inches from base line, CO at 2150cm^{-1} and NH$_3$ at 970 cm^{-1}*	
	Before Exposure 3-18-76	After Exposure 3-22-76
S/N 108	0.875	0.900, Slight increase due to instrumental variations
S/N 109	1.63	1.75, Slight increase due to instrumental variations
S/N 110	0.49	0.49, No change
S/N 112	0.93	0.93, No change

3. Thermal Exposure

The thermal exposure was conducted in a quartz chamber, Photograph 3. This was designed to provide a constant purge of heated (85°C) dry nitrogen on the exterior of the cells and also provide handling protection for them during testing.



Photograph 3: Thermal Exposure Chamber, from left to right. S/N 112, S/N 110 S/N 109, and S/N 108

---

* Conducted on Beckman IR 20A.

After 400 hours of exposure at 85°C the cells were removed from the test chamber and inspected under an optical microscope. The two shapphire windowed cells S/N 108 and S/N 110 provided a clear view of the gold plated cell walls, where discoloration that could be attributed to titanium diffusion could be observed if present. Discoloration was not observed up to 400X magnification. The germanium windows were carefully inspected for change in the antireflectance coating at the elevated temperature. Again changes were not observed.

Infrared scans on the cells were then conducted and compared with the post fill scans (approximately 2 months prior).

Table IV: Infrared Peak Intensities, Post Fill and Post Life Test

Cell	Peak measurement in transmittance units from base line, CO at 2150 cm^{-1} and NH_3 at 970 cm^{-1}*	
	Post Fill 2-13-76/2-20-76	Post Life Test 4-9-76
S/N 108	20, Ref. 3	21, scan #11
S/N 109	45, Ref. 3	45, scan #12
S/N 110	12, Ref. 3	12, scan #13
S/N 112	39, Ref. 3	0, scan #14

The only detectable change occured in cell S/N 112, 5% NH_3 where the absorption peaks attributed to NH_3 were not detectable.

4. Failure Analysis of S/N 112

There were three possible mechanisms for NH_3 loss in S/N 112:

1) absorption of NH_3 on cell wall
2) escape of the fill gas, and
3) degradation to a nonabsorbing species.

To investigate NH_3 absorption on the cell wall. The NH_3 cell was placed in a cell holder in the optical path of the Perkin Elmer 521.

---

* Conducted on Perkin Elmer 521.

The outside circumference of the cell body was wrapped in heating tape and elevated to 110°C ± 10°C. This should have been sufficient to drive any absorbed NH_3 into the optical path. Scans were run after 1/2 hour, 3 hours and overnight. The scan after 3 hours is attached scan #15, and shows that NH_3 was not vaporized.

It had been verified by the vacuum integrity test that a leak was not present. However, the existence of stress in the cell with exposure to 85°C could have propagated a fracture in the pryex. The cell was first very carefully reexamined using an optical microscope to verify that an observable defect was not present. The cell was found to be intact and the fill-tube stub was free of defects.

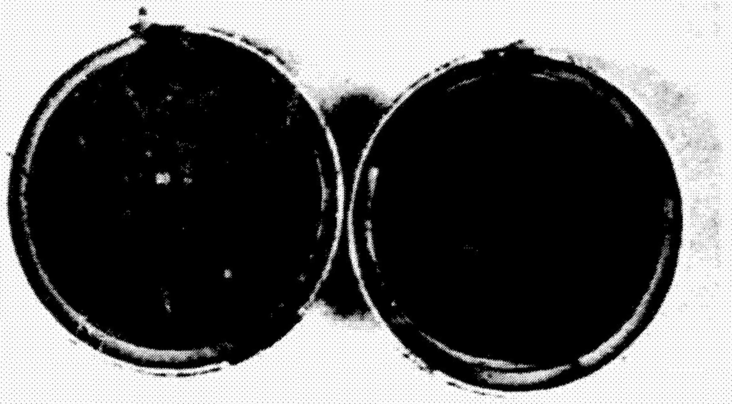
This cell was then placed in leak check bell jar, evacuated to 1×10^{-6} torr., back-filled with NH_3 gas to 1 1/2 atm., and placed in the 85°C oven for approximately 3 hrs. This was attempted to force the NH_3 back into the cell through any fissure that may have been present at the elevated temperature. When the apparatus was removed from the oven there was still a positive pressure of NH_3. The cell was then rescanned, scan #16, and NH_3 was not found. (Note: I.R. scan shows that the exterior of the cell was contaminated with outgassing from the silicone grease). A similar exposure test was also conducted at the elevated temperature with the cell immersed in Freon 113. Again gas had not entered the cell. The general conclusions of these tests were that there was no leak present through which the gas escaped. However, a recommendation was made to conduct a hermeticity inspection based on an incoming component evaluation test procedure. The test chosen was a "radaflow" inspection test. This consisted of exposing the cell to radioactive Krypton in an automated testing apparatus, which evacuates, back-fills with Krupton, and then counts any Krypton leaking from the device being tested. At the completion of this test, the cell was found with the fill tube stub broken off. In fact, the fill tube stub was found outside of the beaker in which the cell had been placed, indicating that the cell received a substantial shock. The cell was, therefore, lost to testing of the last mechanism (gas degradation to a nonabsorbing species).

Ammonia theoretically can be decomposed at an elevated temperature to nitrogen and oxygen in the presences of a transition metal catalyst. Therefore, if nickel or titanium were in contact with the fill gas under the 85°C life test condition the 5% ammonia would become the infrared nonabsorbing species of nitrogen and oxygen. The presence of nickel in the interior of the cells had been noted in the past. Even though inspection procedures were established during this phase of cell manufacturing to eliminate this problem, the carbon monoxide cells S/N 101 and S/N 102 after 2 months of storage contained nickel tetracarbonyl absorptions, scans #17 and #18. Two steps were taken to verify that gas degradation had indeed taken place:

1) verification that at 85°C and with nickel present, the ammonia would decompose and
2) examination of cell S/N 112 for nickel.

The 5% ammonia fill gas was first analyzed using the mass spectrometer for impurities. It was free from contaminants. A nickel body, 5 cm, standard infrared gas cell was then fill, scanned (scan #19), placed in the 85°C exposure for 24 hours. This cell was then rescanned and the absorption spectrum for ammonia was not detected (scan #20). The gas was then vented into the mass spectrometer. Nitrogen, hydrogen and the neon tracer were detected. The cell was also heated to approximately 110°C, to verify that the ammonia had not absorbed on the cell walls, no change was detected in the mass spectroscopic data. This test was repeated at a 48 hour time period and the same results were obtained.

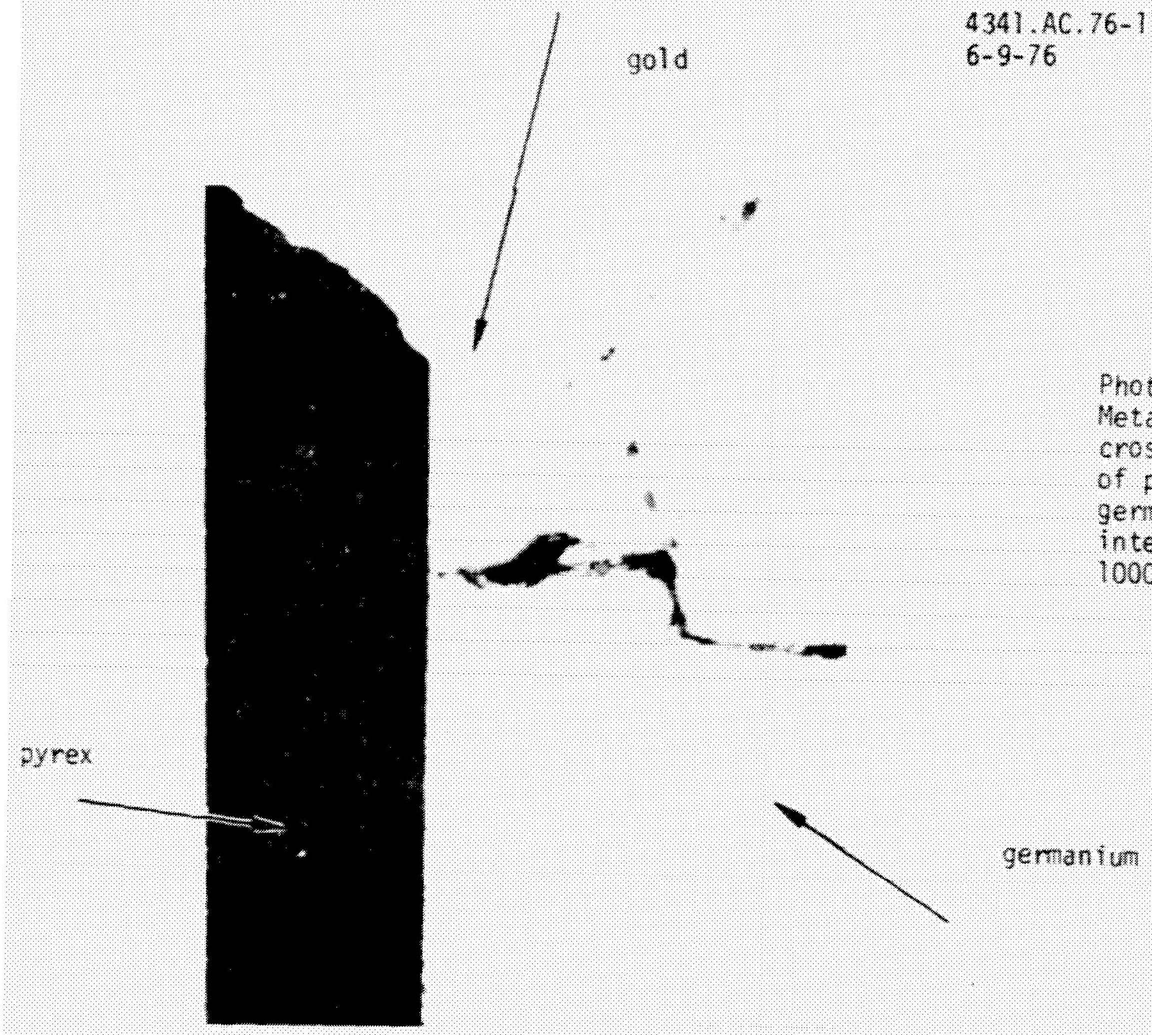
The cell was then cross sectioned by cutting through the cell body to allow for inspection of the window to body interface, Photograph 4. One window, #3, appeared to be completely sealed, an obvious ring of gold could be observed at the window/pyrex interface.



Photograph 4:
Cell S/N 112
Cross Sectioned

The other window, #4, appeared to have this gold seal missing from approximately one-half its circumference (the half opposite the fill tube aperture). Metallurgical examinations were made at four points on this section. Two showed there were unmetallized gaps between the pyrex/germanium interface, Photograph #5, and at two other points there was obviously gold, Photograph #6.

Photograph #5
Metallurgical
Cross Section
of Pyrex/
germanium
Interface at
1000X



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6-9-76

Photograph #6
Metallurgical
cross section
of pyrex/
germanium
interface at
1000X

It appears that areas along this lower half did not become sealed by gold and contact with the catalytic nickel took place. However, it also appears to be a random occurrence and may be very difficult to inspect for or control during manufacturing.

Conclusions

The MAPS gas cell, as designed, is a chemically stable means of containment for the reference pollutant gases. Loss of signal in either NH_3 or CO cells can only occur when improper processing produces a pyrex/window interface contaminated with nickel.

4341.AC.76-118
6-9-76

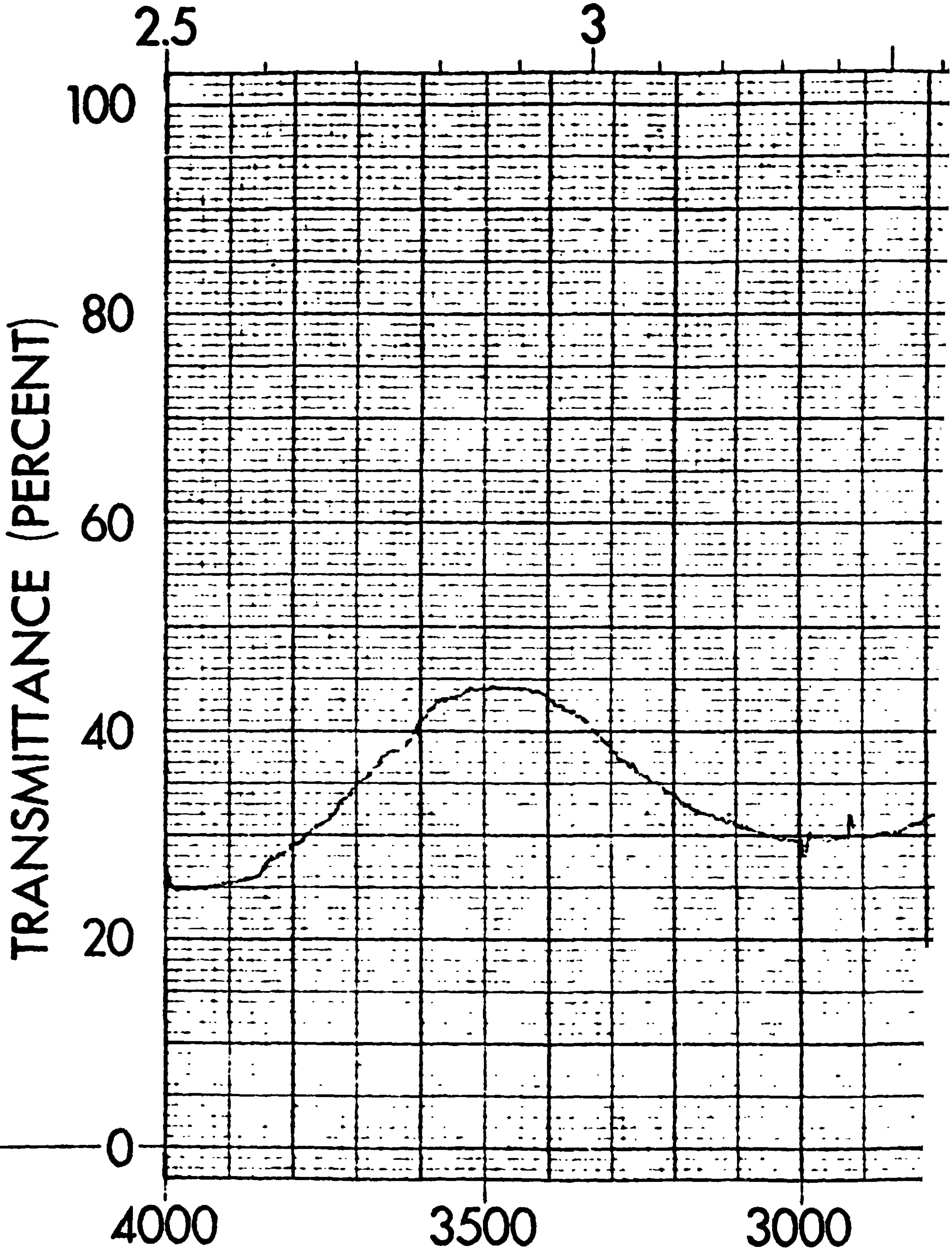
Current scans, 6-9-76, of cells S/N 108, 190 and 110 are attached and show no detectable differences from those obtained after cell tip-off on 2-20-76.

Approved: A Grant
A. Grant, Section Head
Analytical Chemistry

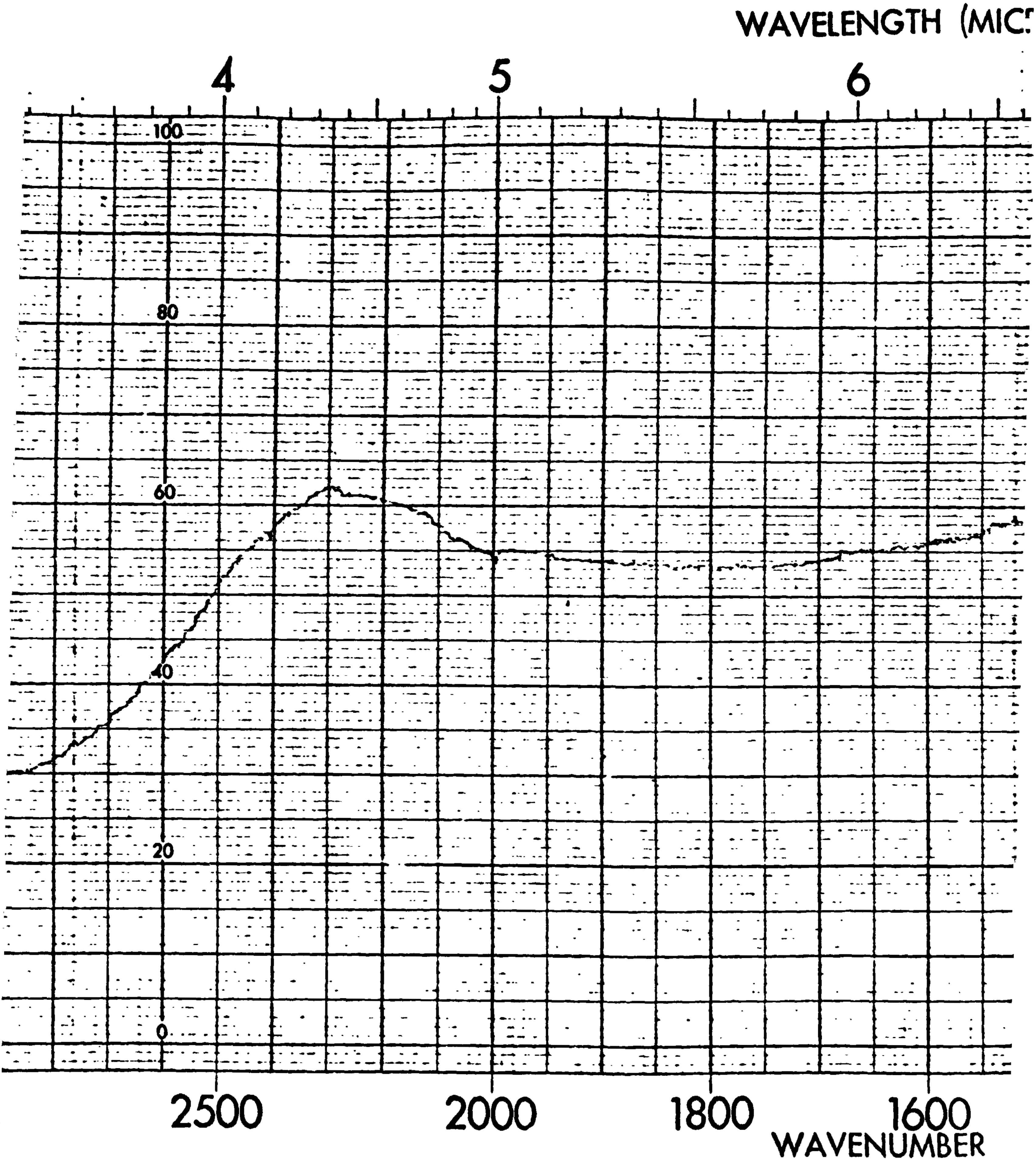
Infrared Scans

1. Germanium window, S/N 288517A, #3 before cell manufacturing.
2. Germanium window, S/n 288517A, #3 after life test.
3. S/N 108, before vacuum integrity test.
4. S/N 109, before vacuum integrity test.
5. S/N 110, before vacuum integrity test.
6. S/N 112, before vacuum integrity test.
7. S/N 108, after vacuum integrity test.
8. S/N 108, after vacuum integrity test.
9. S/N 110, after vacuum integrity test.
10. S/N 112, after vacuum integrity test.
11. S/N 108, after life test.
12. S/N 109, after life test.
13. S/N 110, after life test.
14. S/N 112, after life test.
15, S/N 112, cell wall heated for 3 hours.
16. S/N 112, cell exposed to NH_3
17. S/N 101, after 2 months storage.
18. S/N 102, after 2 months storage.
19. 5 cm Test Cell, 5% NH_3 filled
20. 5 cm Test Cell, after 24 hours at 85°C
21. S/N 108, Scanned on 6-9-76
22. S/N 109, Scanned on 6-9-76
23. S/N 110, Scanned on 6-9-76

SAMPLE



FOLDOUT FRAME 1



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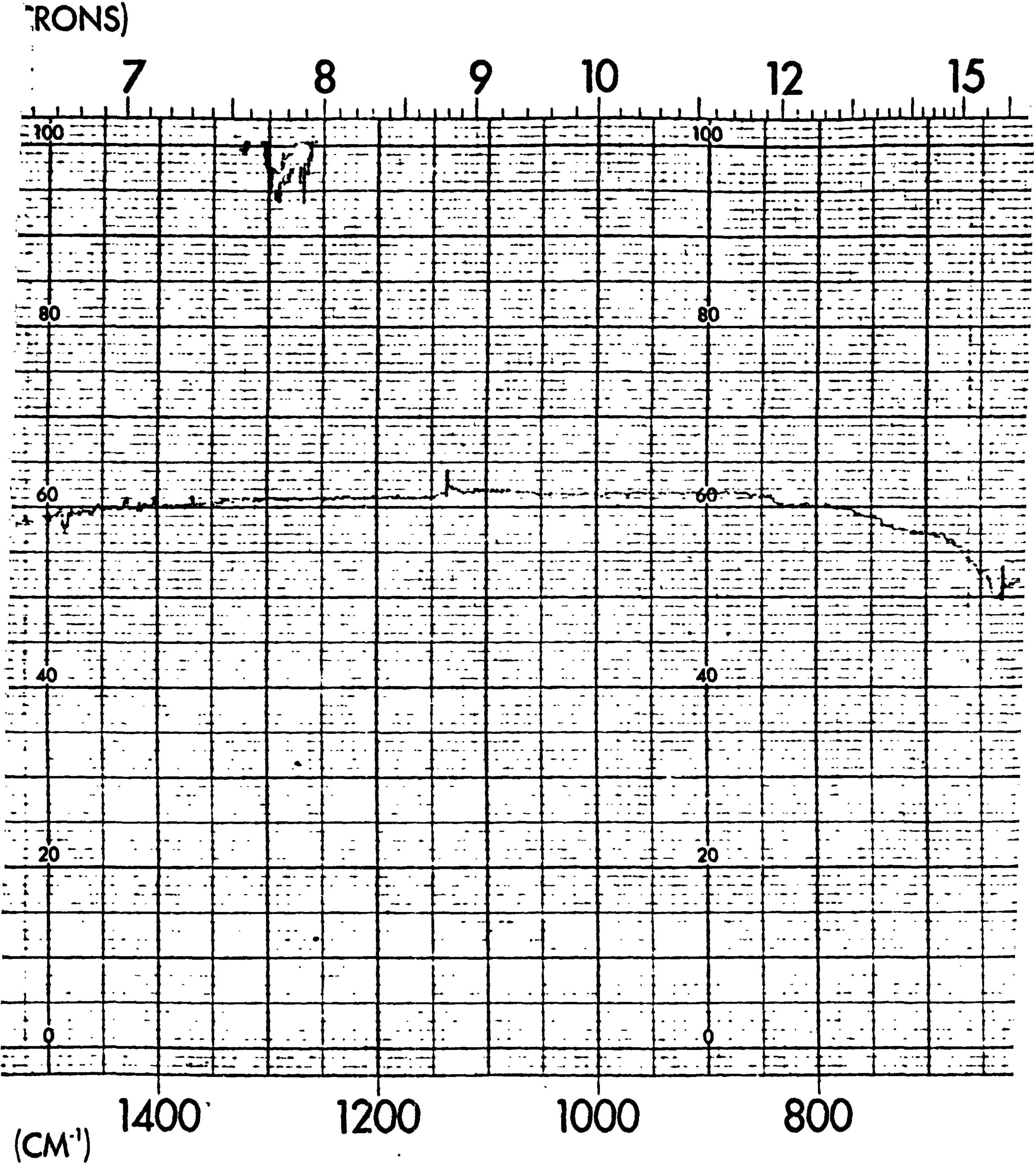
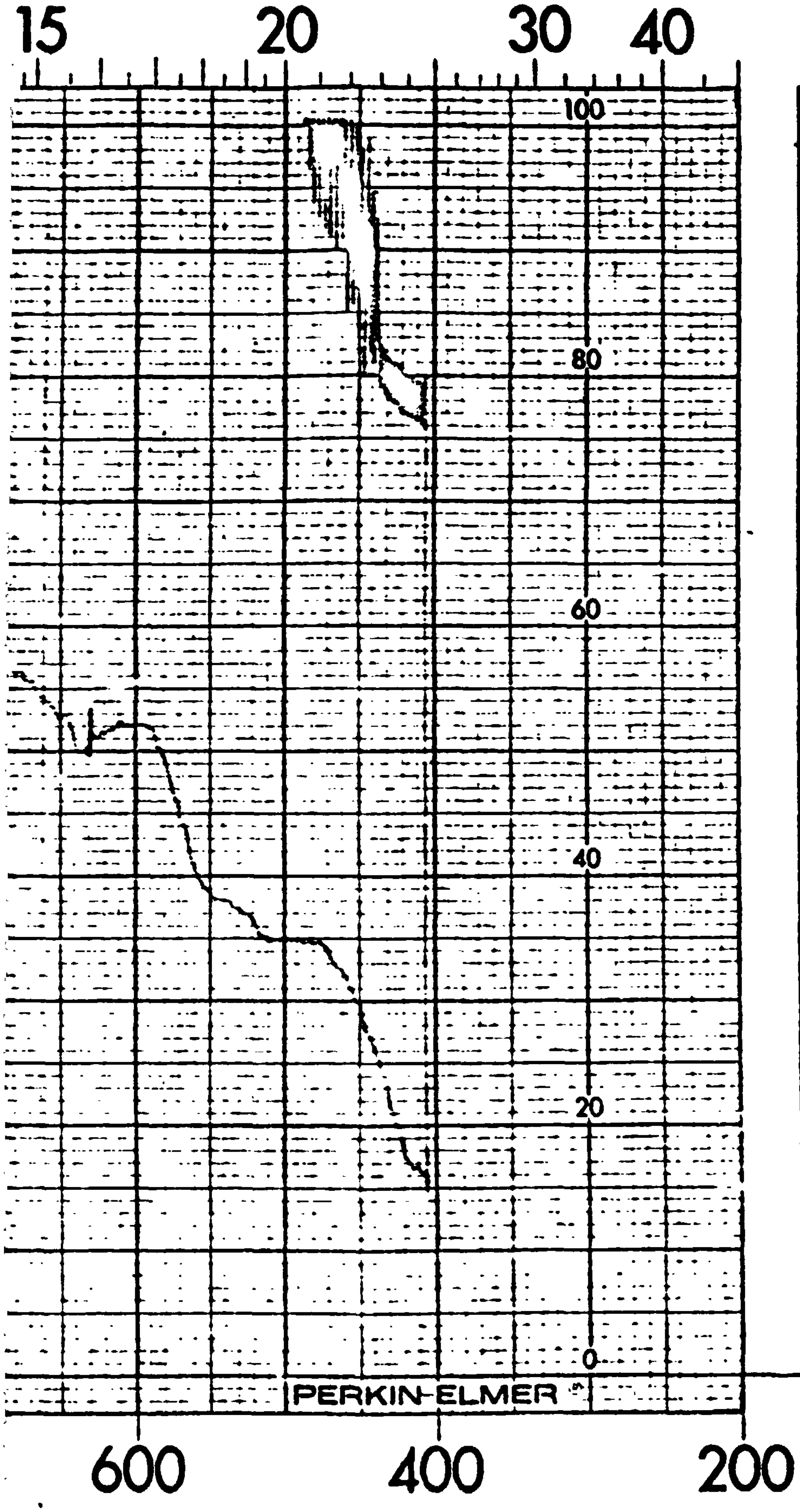

RONS)
7
8
9
10
12
15
100
80
60
40
20
0
100
80
60
40
20
0
1400
1200
1000
800
(CM-1)

DOUT FRAME 2



SPECTRUM NO. B-02703

SAMPLE X 288518A #3
1012 - 174

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 12/5/75

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

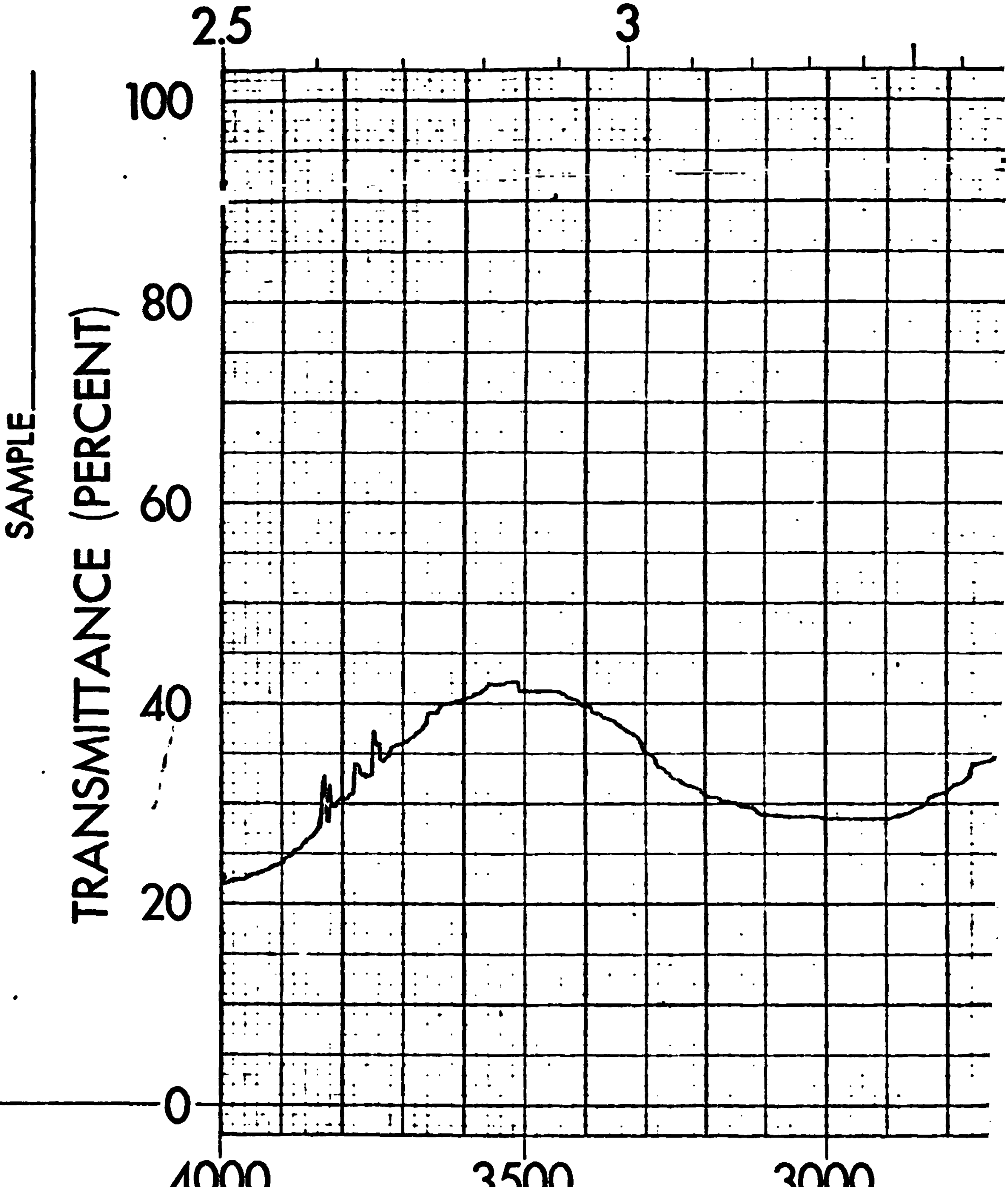
SCAN TIME

SUPPRESSION

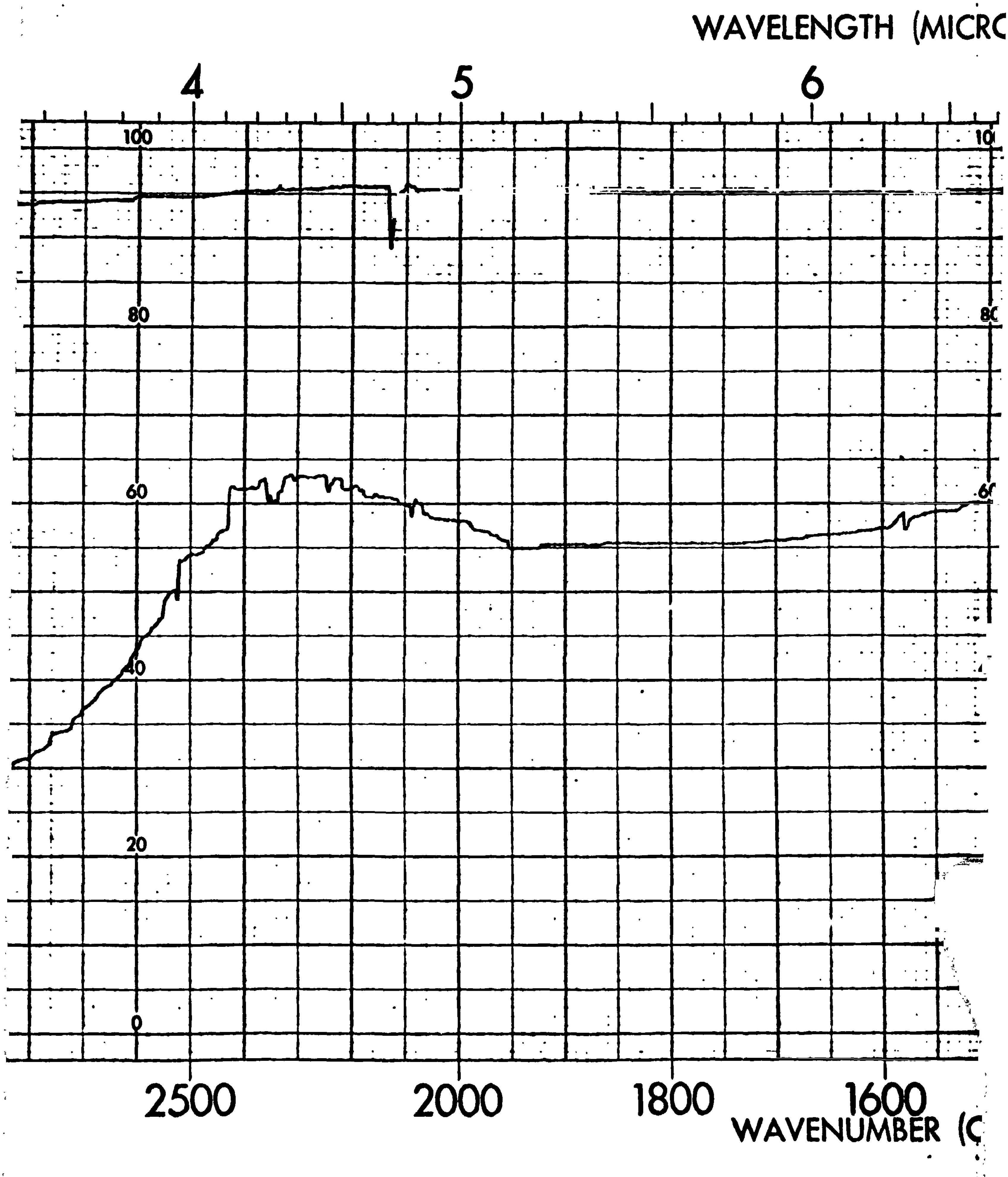
SCALE EXPANSION

SOURCE CURRENT

NO. 221-1607



FOLDOUT FRAME |



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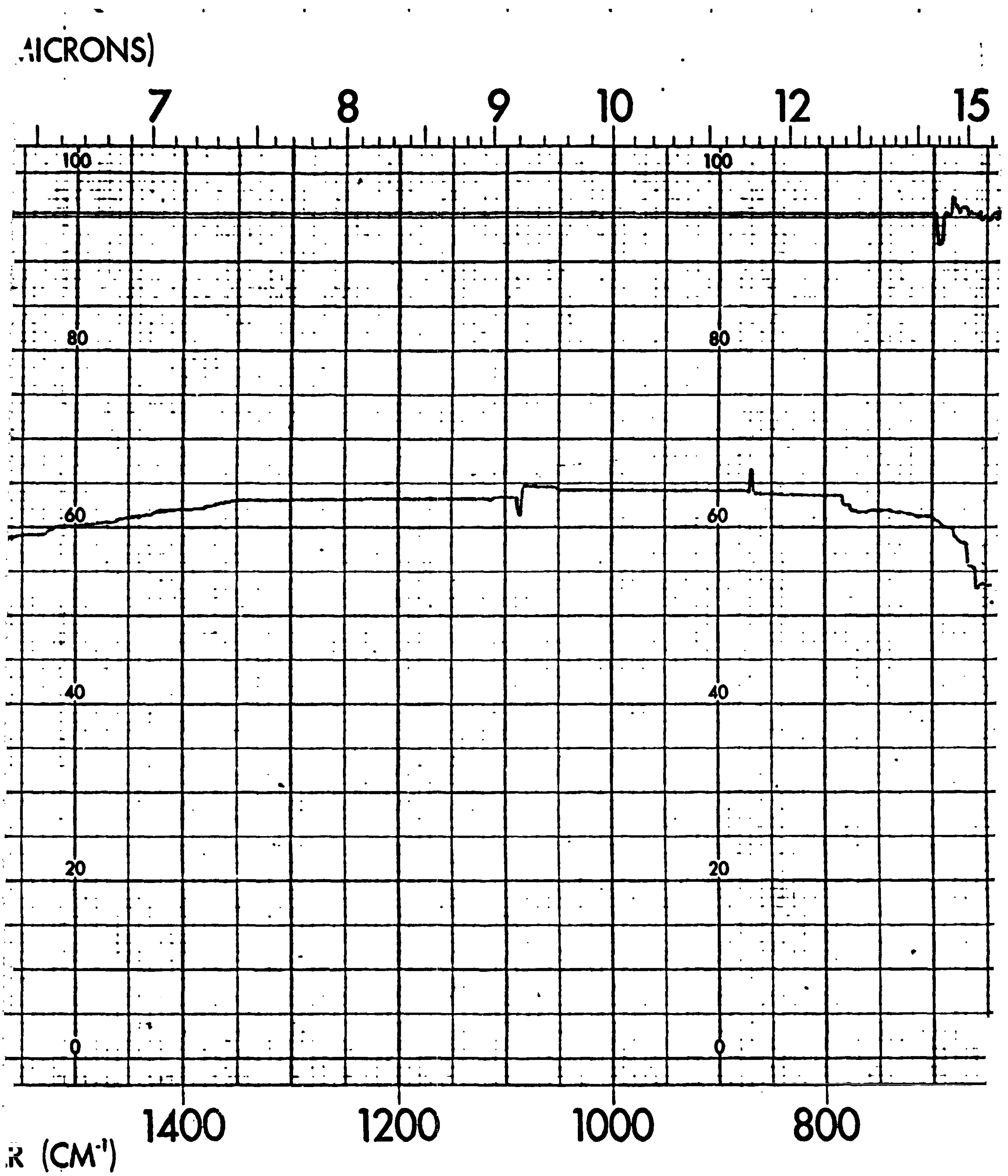

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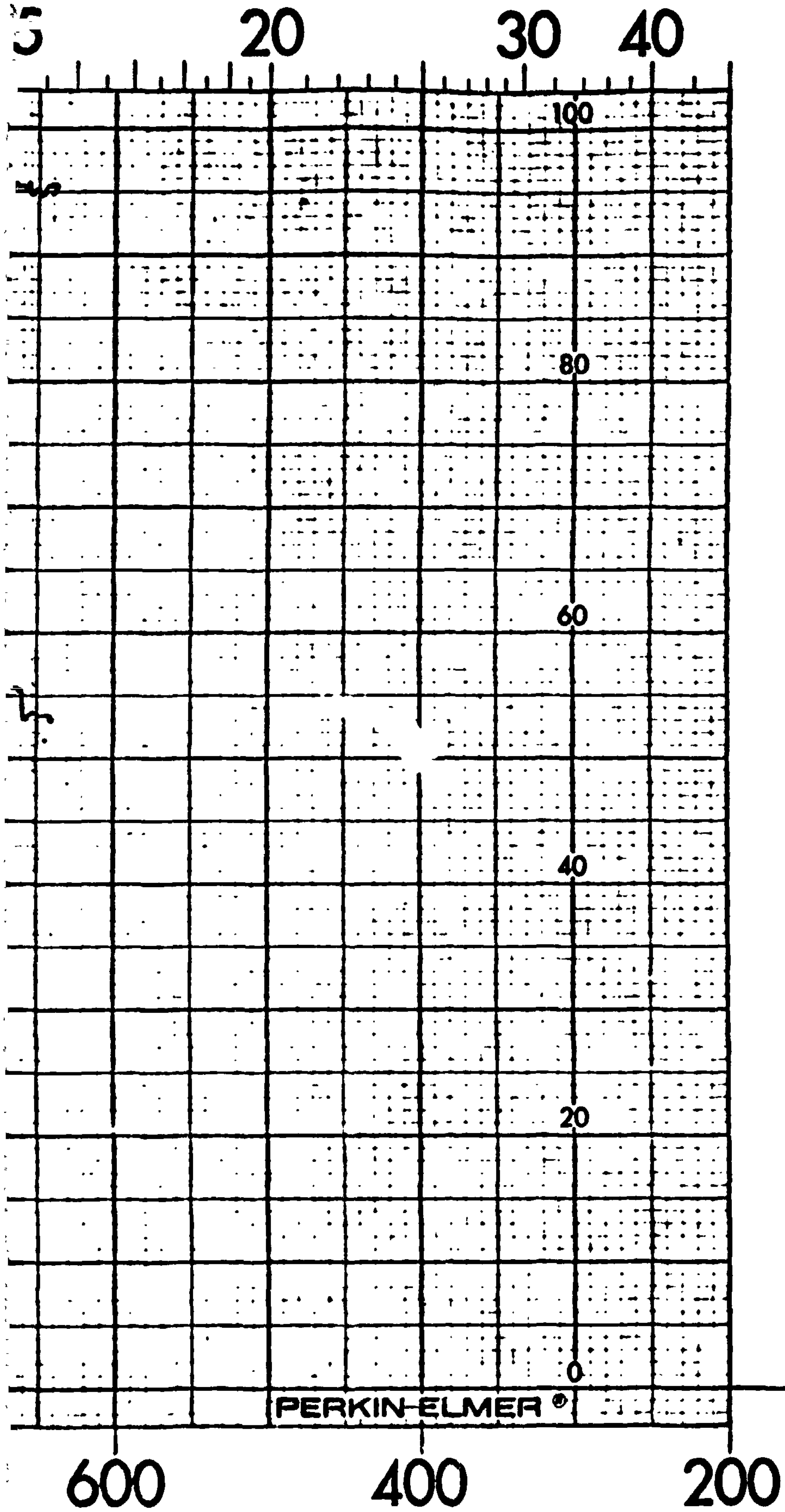


SPECTRUM NO. B-03266

SAMPLE GERMANIUM #3

GAS CELL S/N 112

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 6/7/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

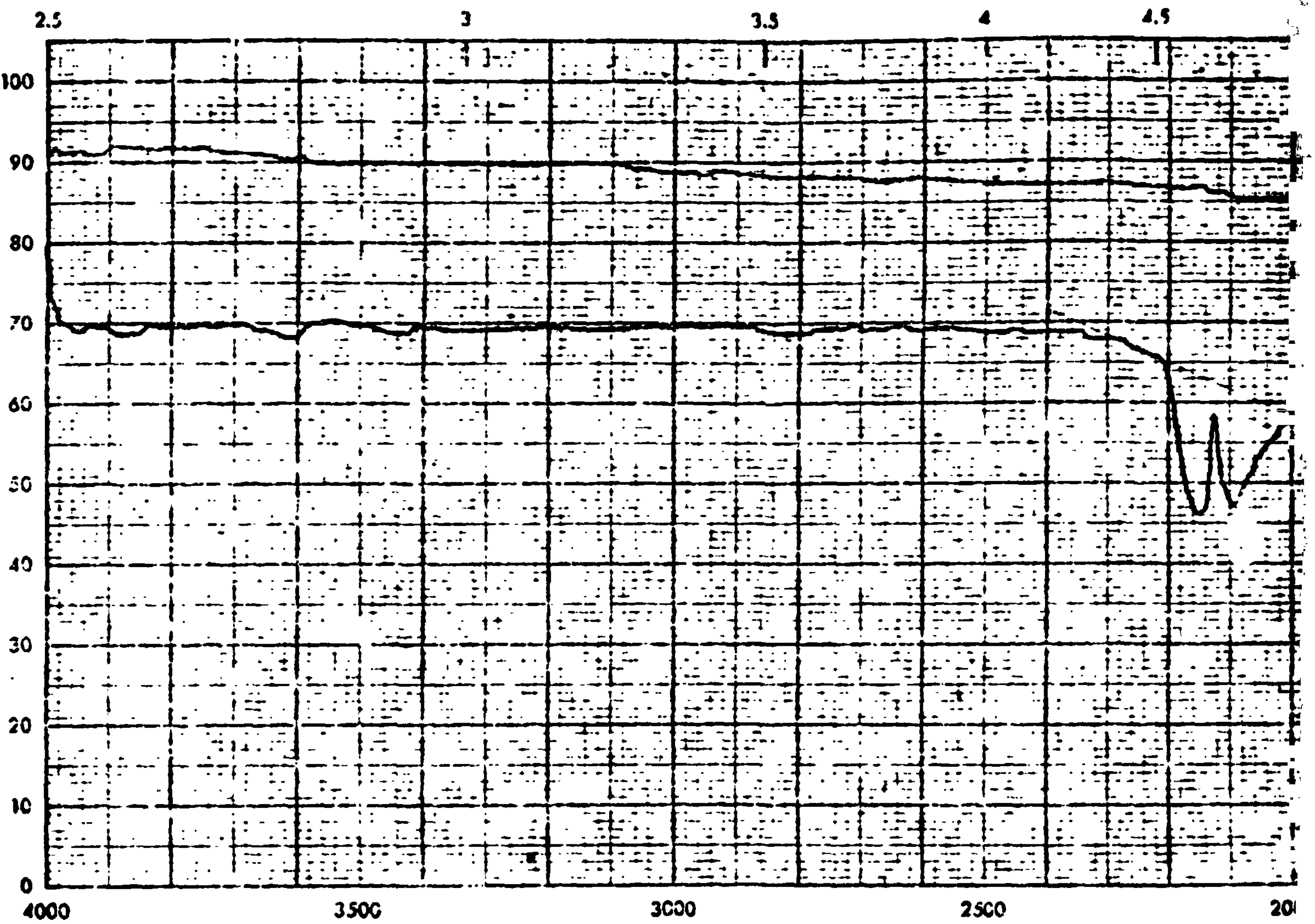
SUPPRESSION

SCALE EXPANSION

SOURCE CURRENT

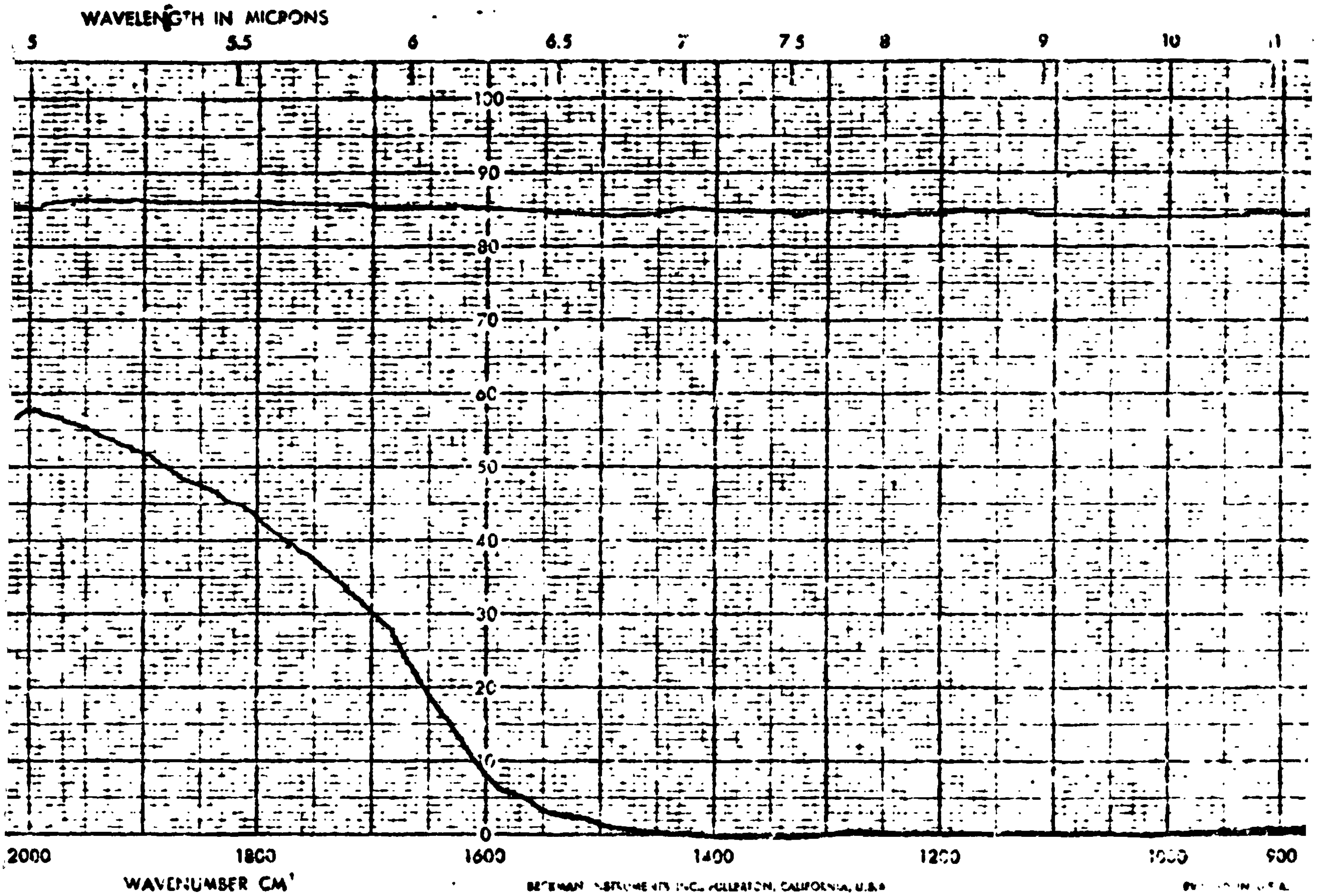
NO. 221-1607

#3

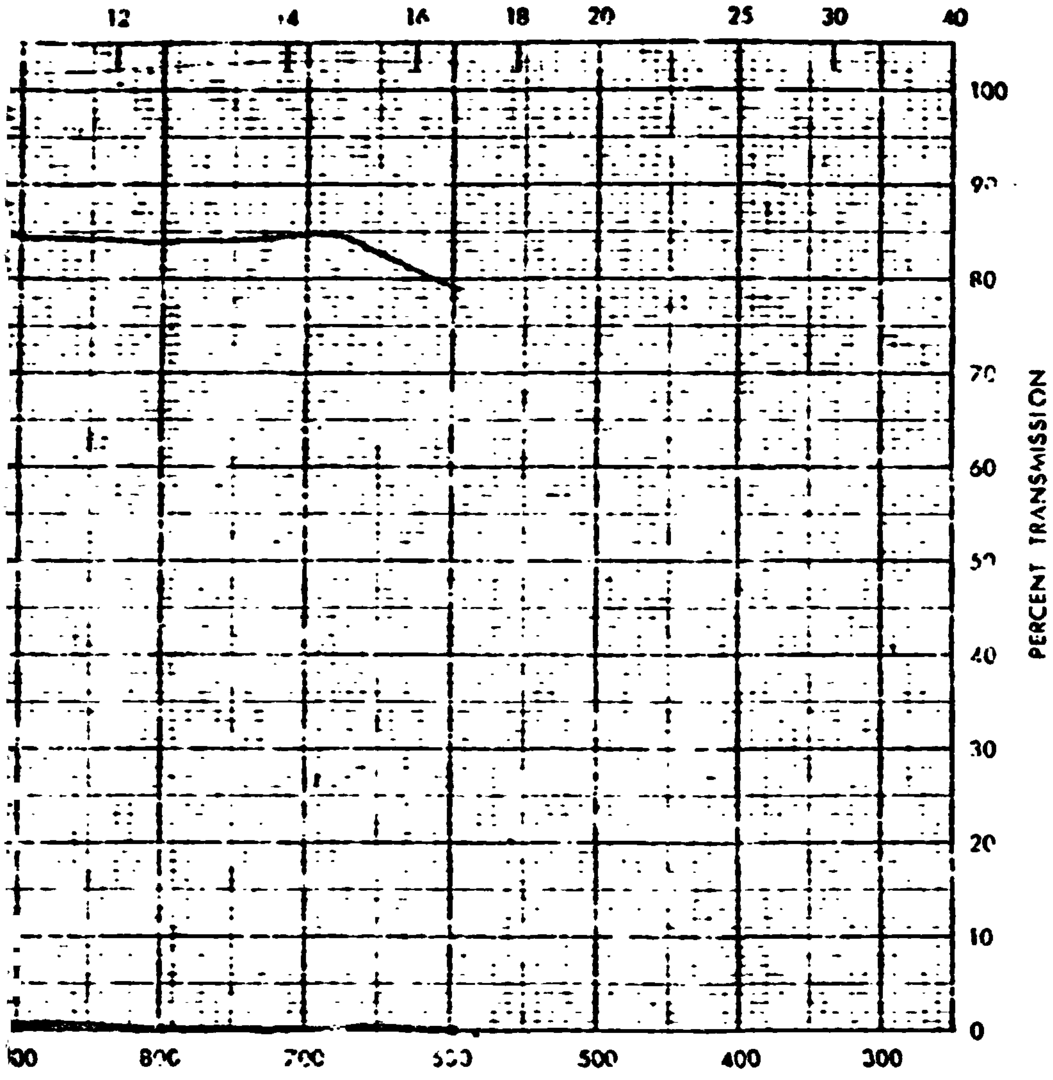


WHEN REORDERING SPECIFY CHART NO. S. .C.50

FOLDOUT FRAME |


WAVELENGTH IN MICRONS
5
5.5
6
6.5
7
7.5
8
9
10
11
100
90
80
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
900
WAVENUMBER CM⁻¹
BECKMAN INSTRUMENTS INC., FULLERTON, CALIFORNIA, U.S.A.

DOUT FRAME 2



SPECTRUM NO. B-02971

DATE 3/18/76

SAMPLE GAS CELL S/N 108

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

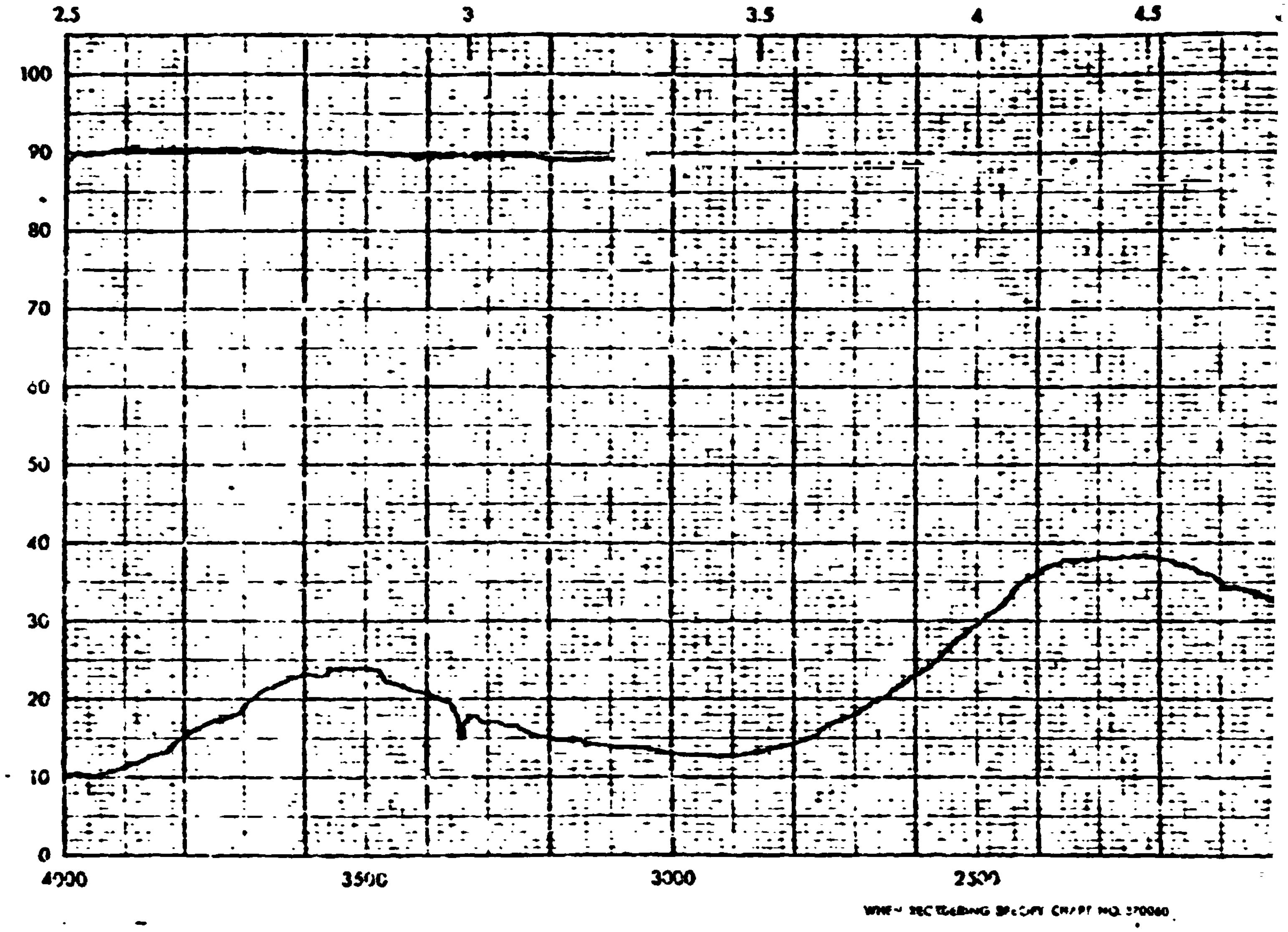
PHASE

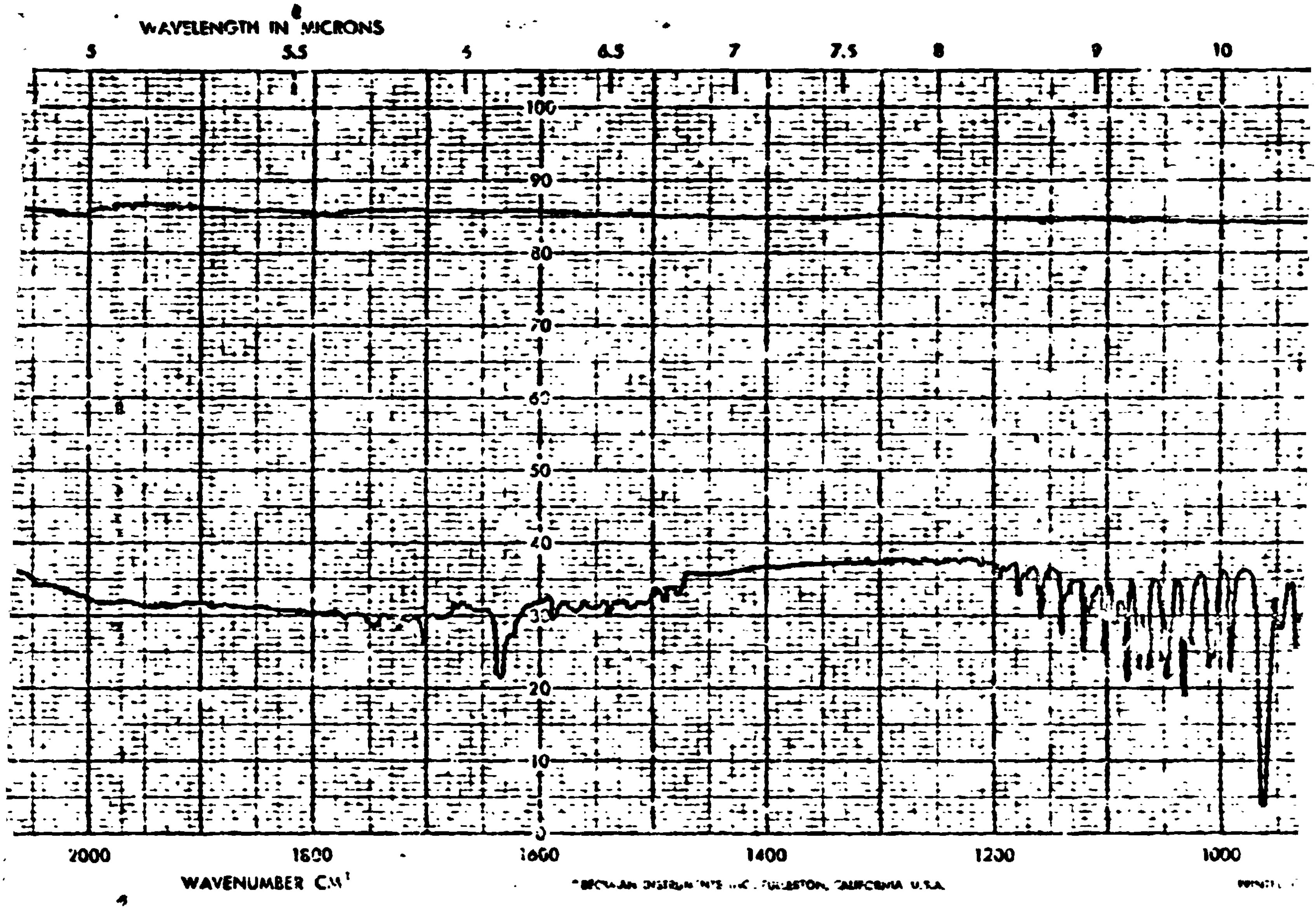
COMMENTS [illegible]

ANALYST KENNEDY

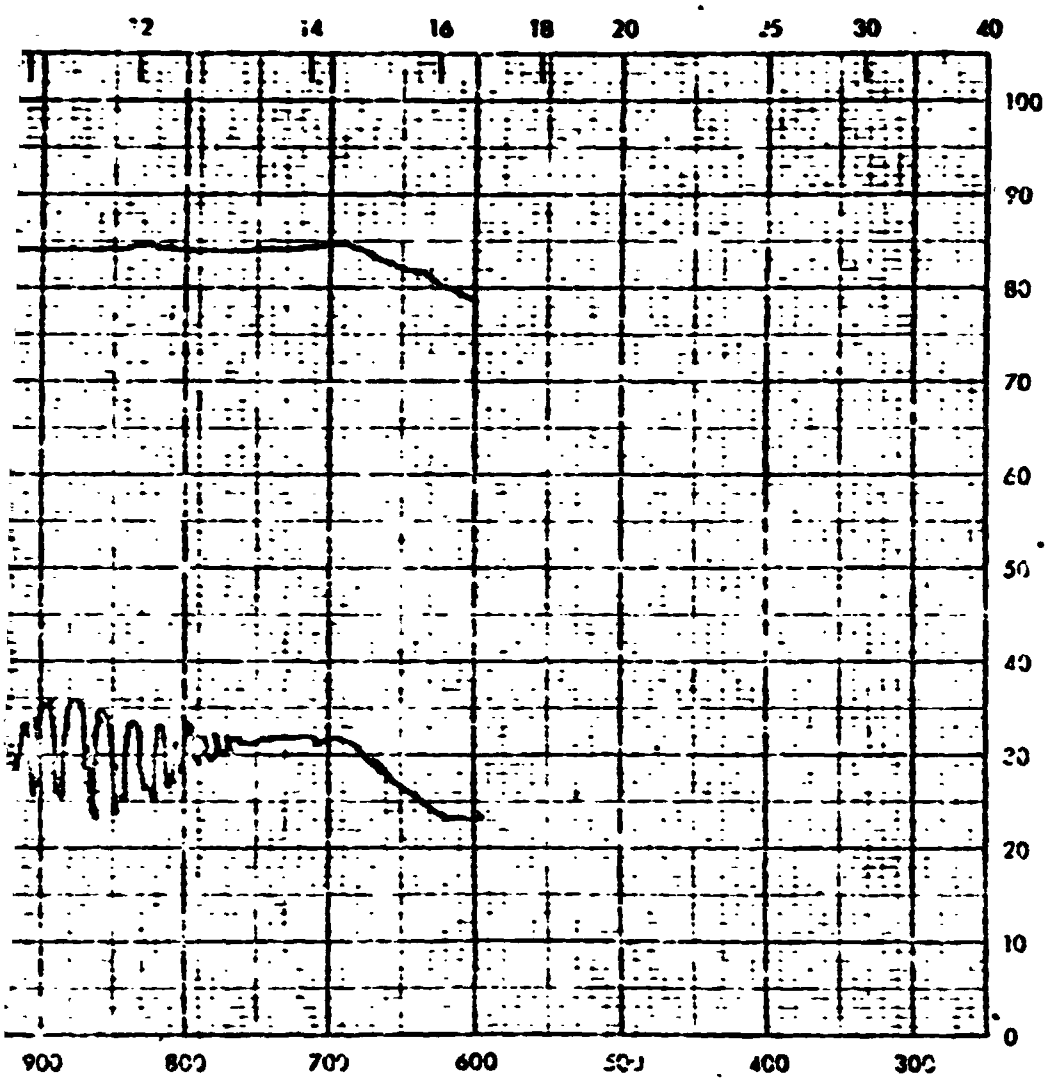
Beckman

INFRARED
SPECTROPHOTOMETER


2.5
3
3.5
4
4.5
100
90
80
70
60
50
40
30
20
10
0
PERCENT TRANSMISSION
4000
3500
3000
2500
WHEN REORDERING SPECIFY CHART NO. 370060



OLDOUT FRAME 2



SPECTRUM NO. B-02972

DATE 3/18/76

SAMPLE GAS CELL S/N 109

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

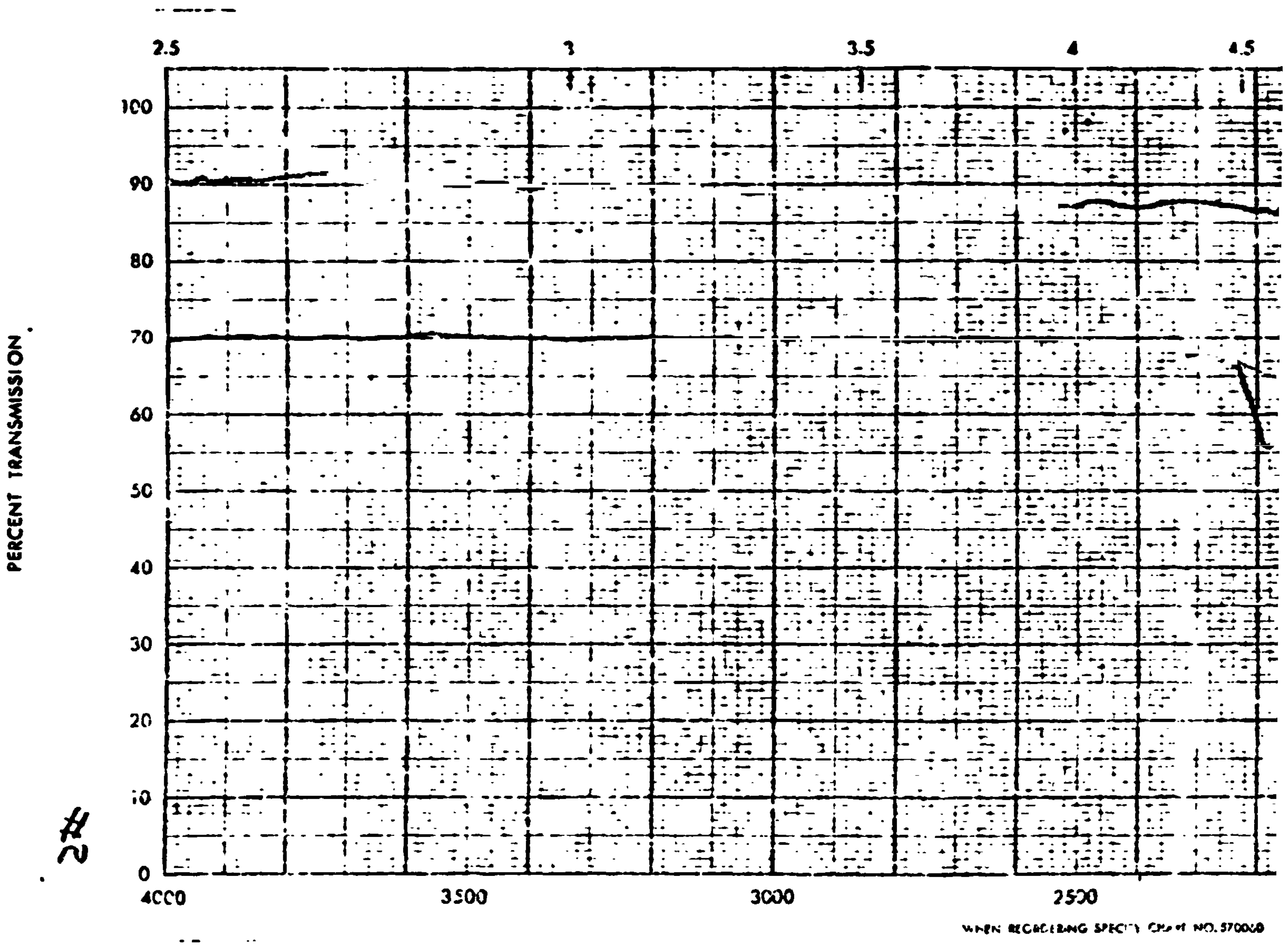
[illegible] 990 cm^{-1}

ANALYST KENNEDY

Beckman®

INFRARED
SPECTROPHOTOMETER

FOLDOUT FRAME



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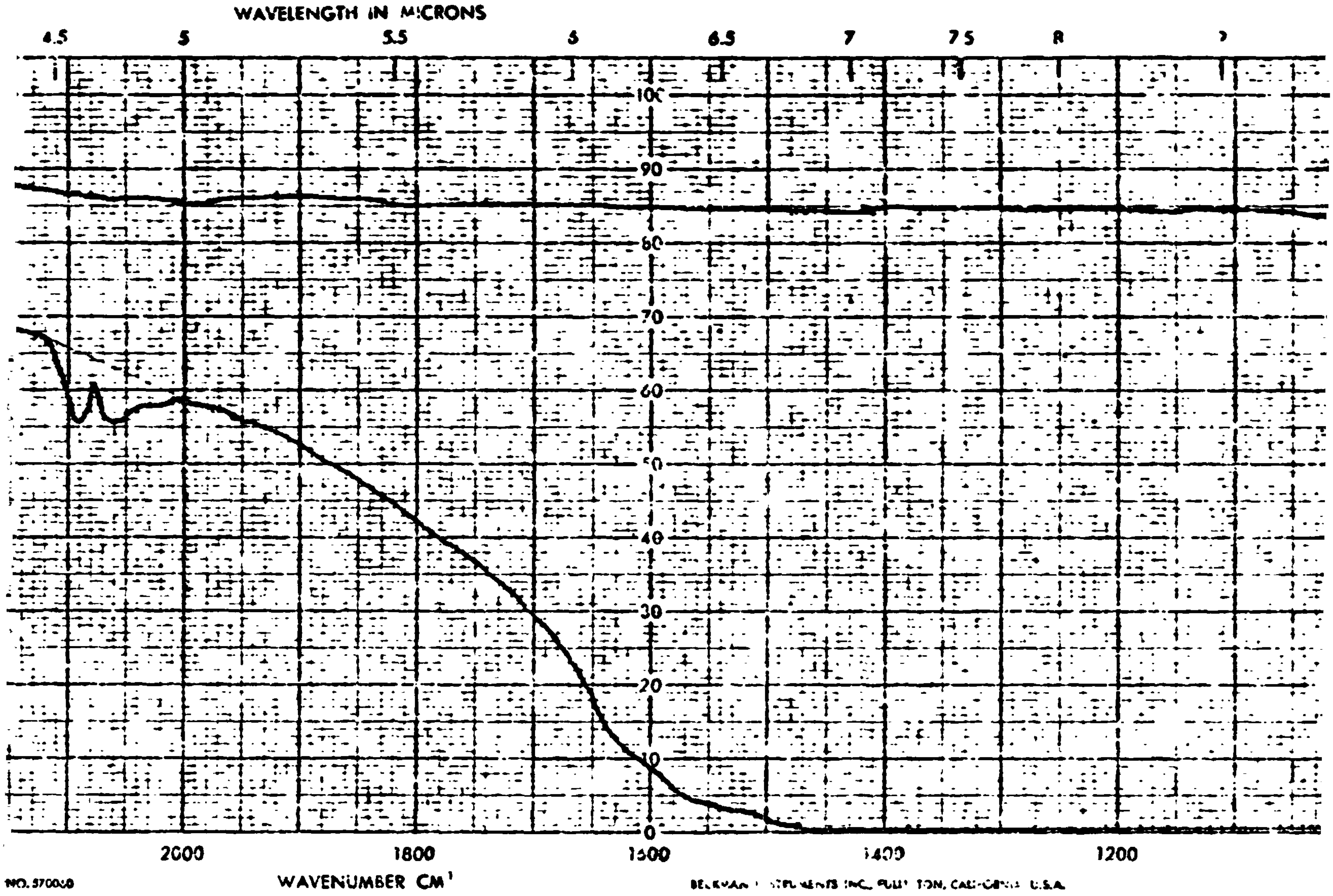
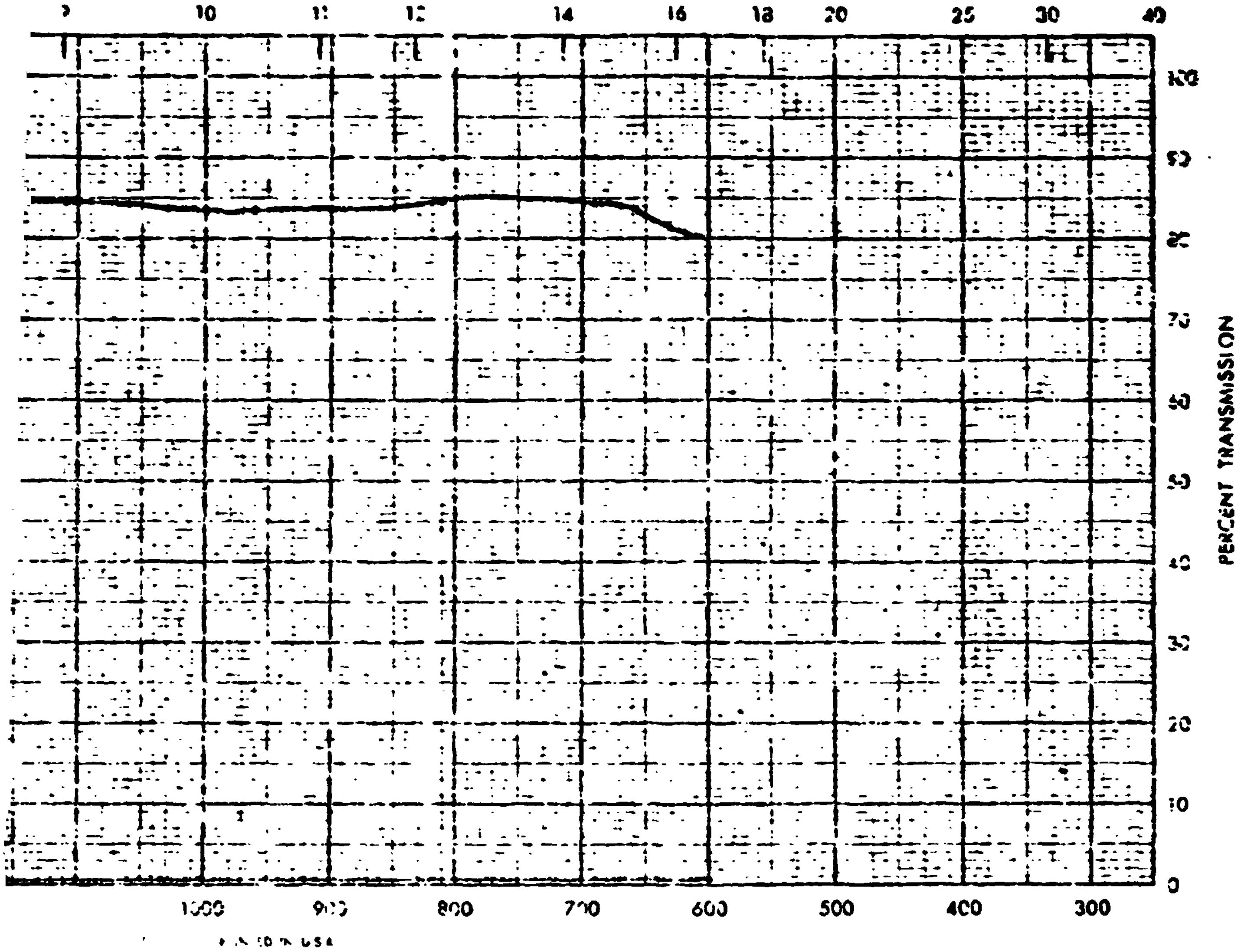
FOLDOUT FRAME (



FOLDOUT FRAME 2



SPECTR

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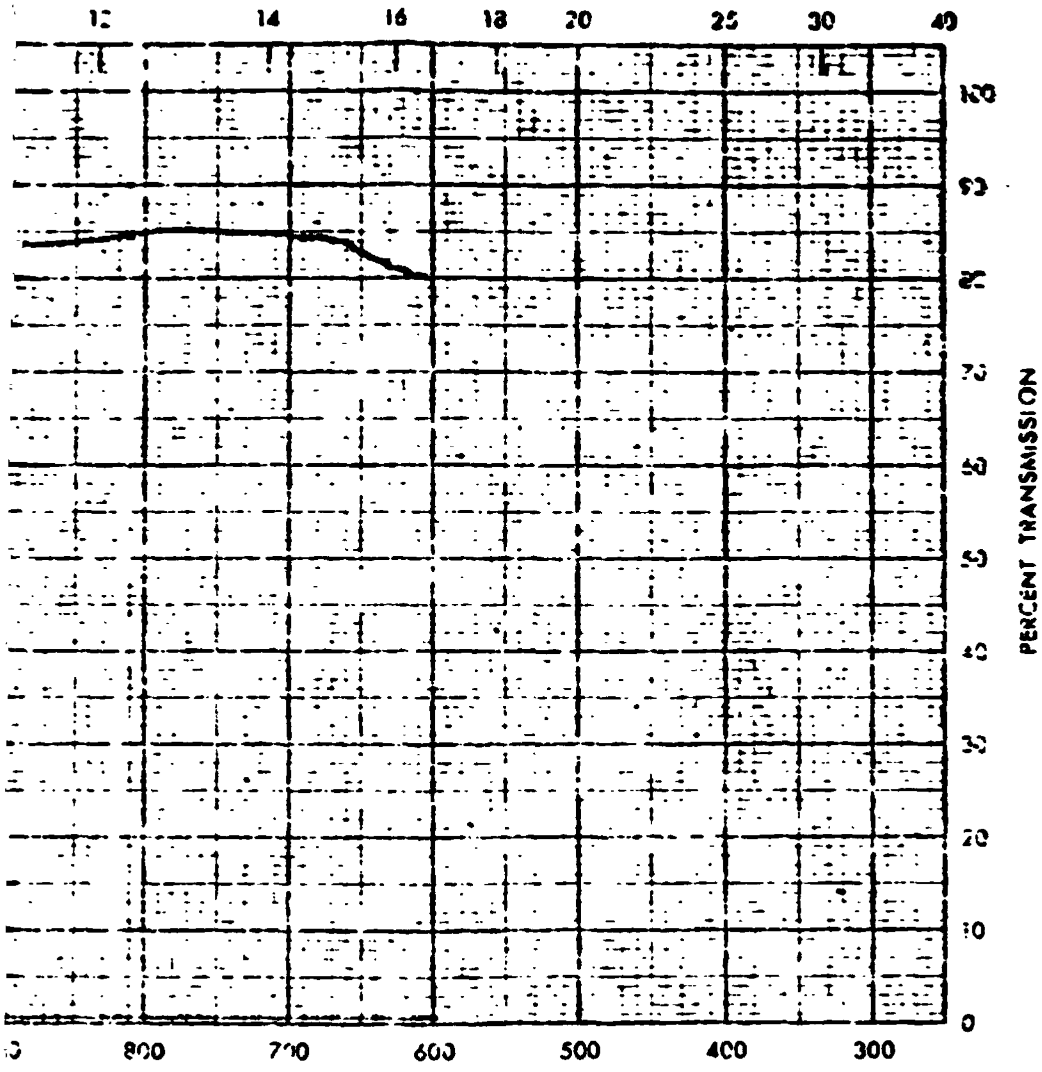
FOLDOUT FRAME 3



SPECTRUM NO. B-02973

DATE 3/18/76

SAMPLE GAS CELL 3/18 110

SOURCE

STRUCTURE

PATH ___ mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS

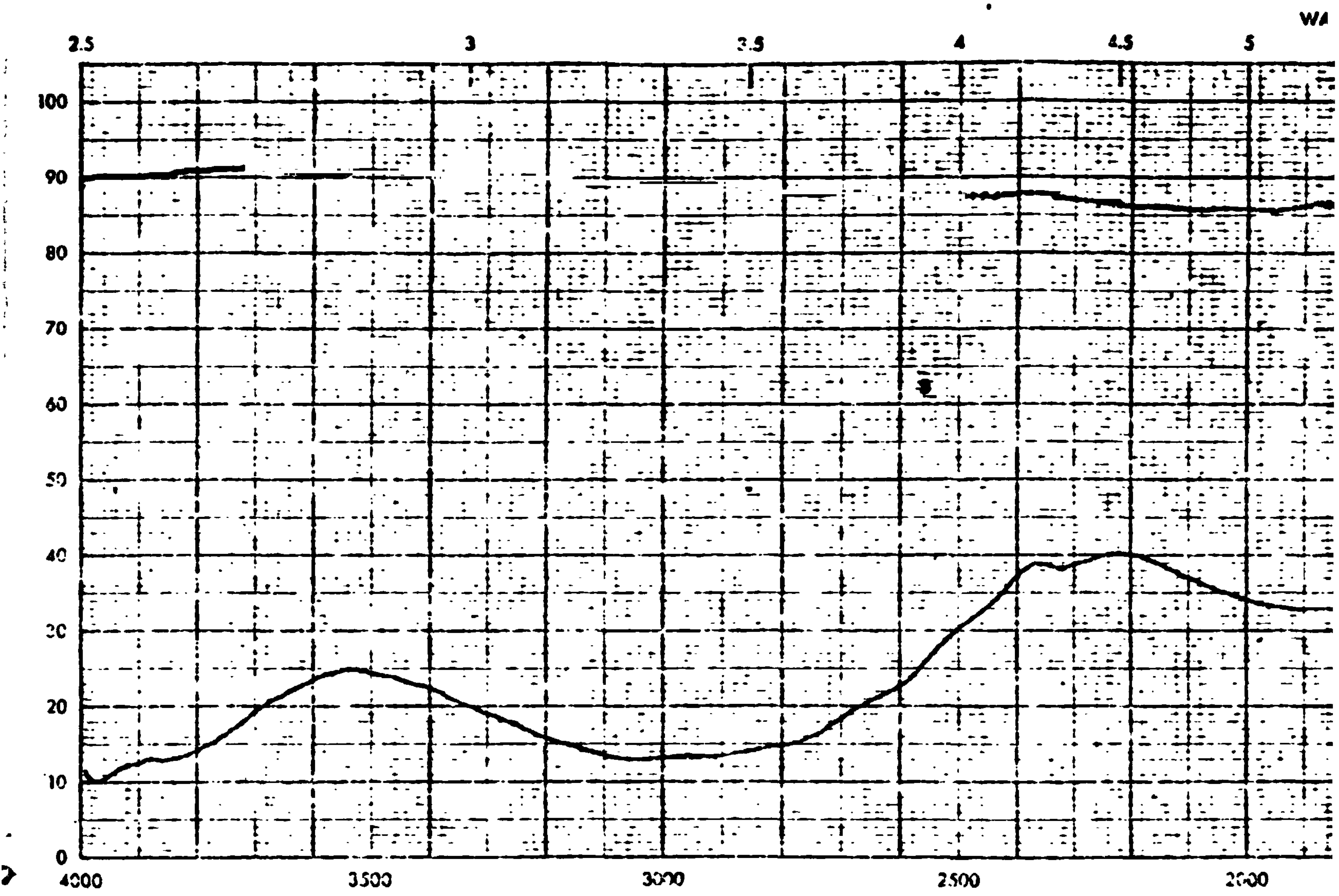
[illegible]

ANALYST KENNEDY

Beckman®

INFRARED SPECTROPHOTOMETER

FOLDOUT FRAME 4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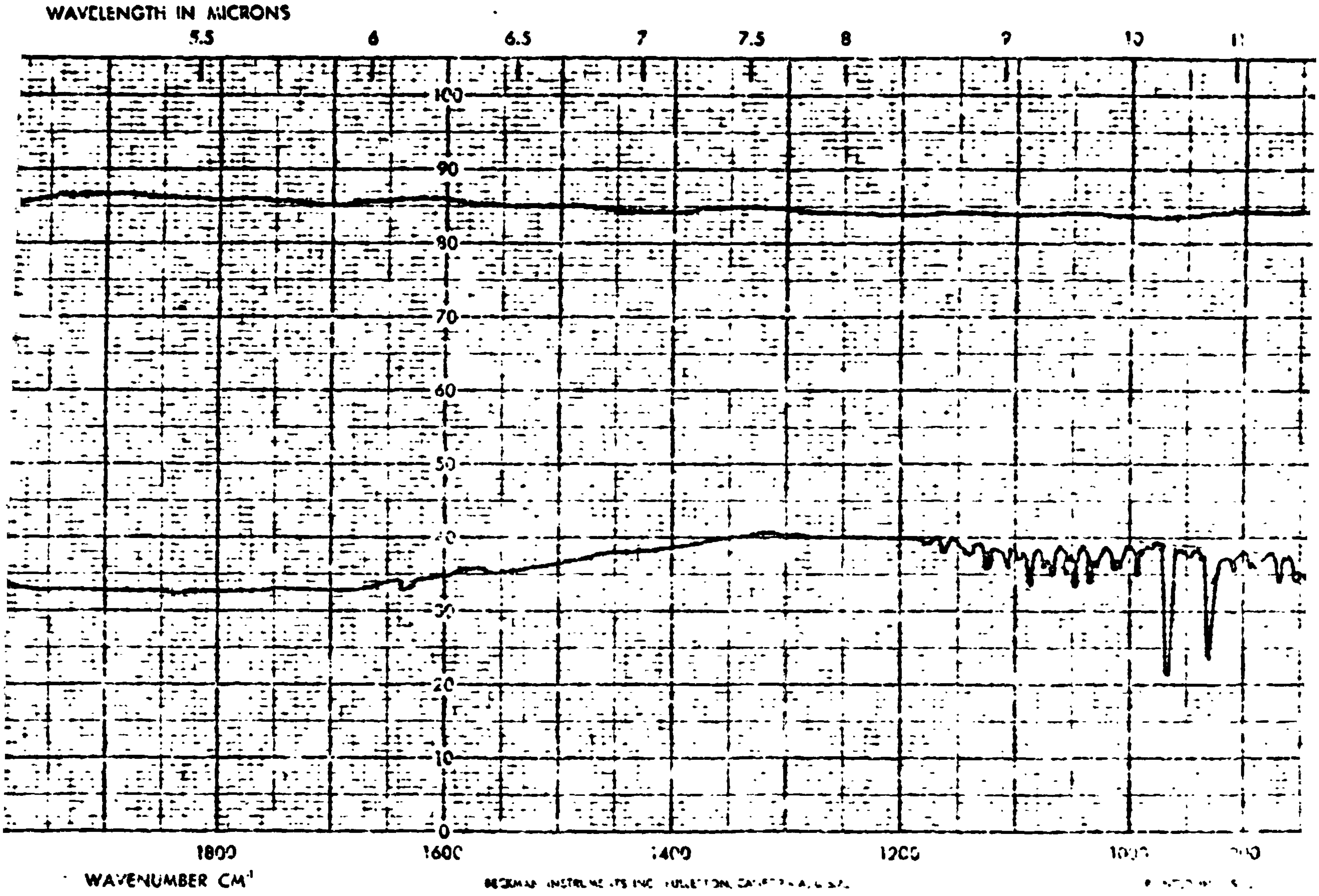
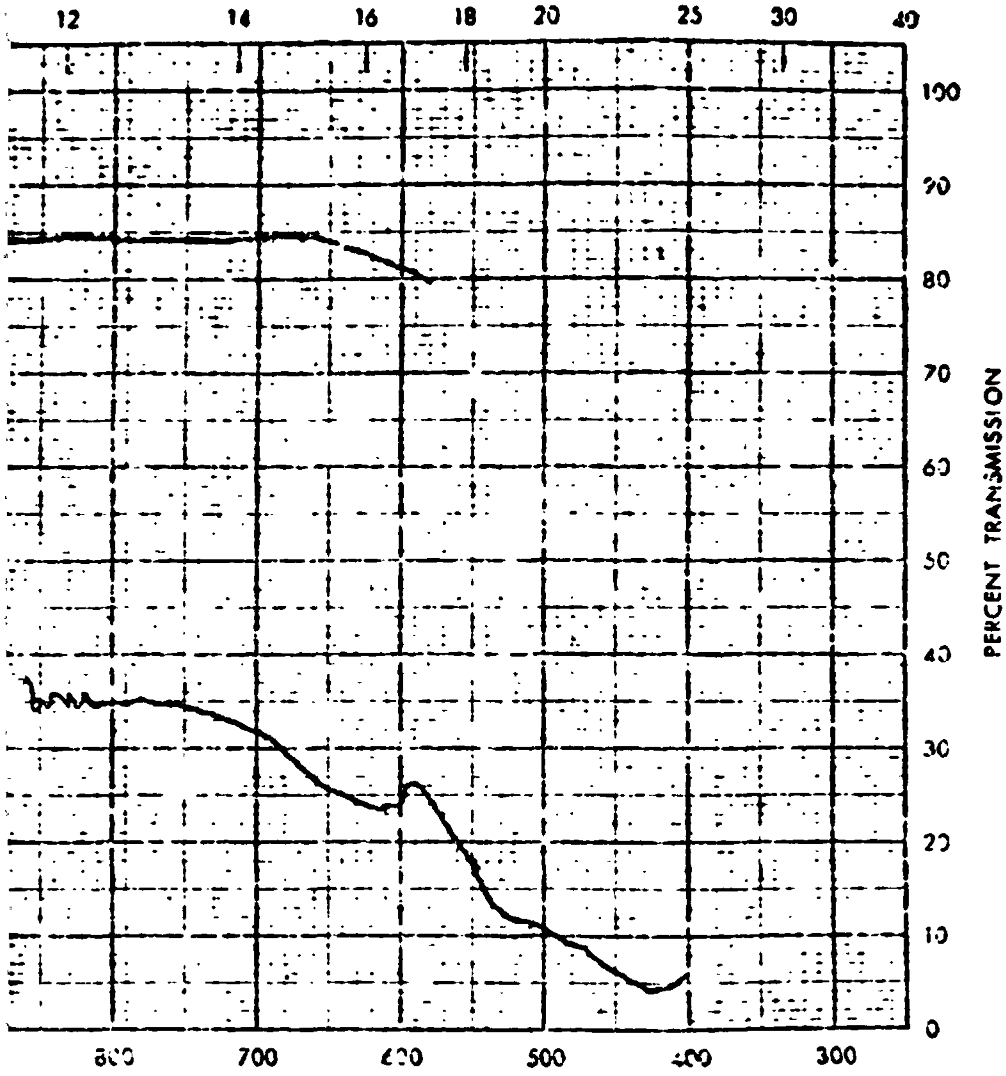


OLDOUT FRAME 2



SPECTRUM NO. B-0 2974

DATE 3/18/76

SAMPLE GAS CELL S/N 112

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

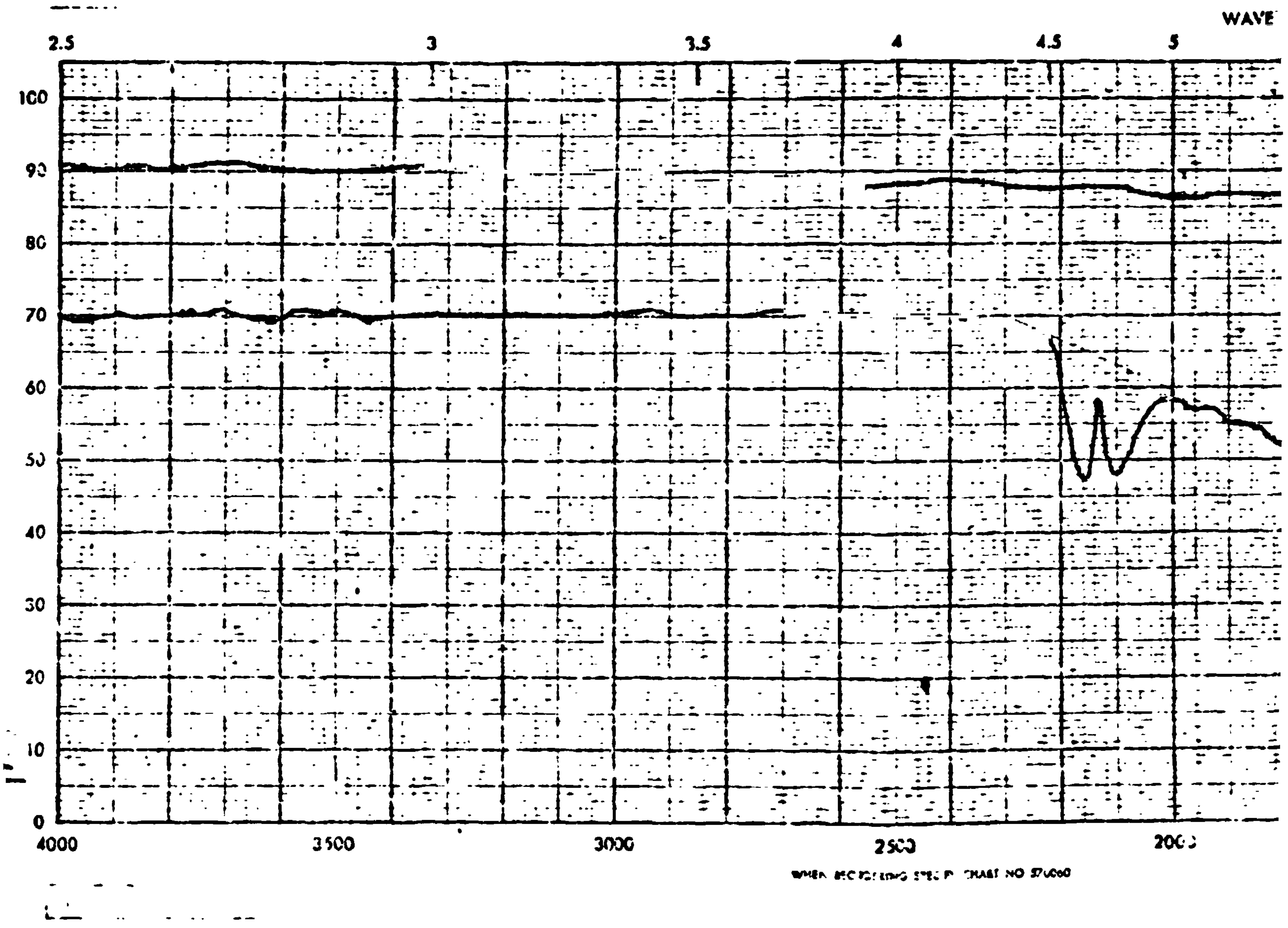
COMMENTS

.33

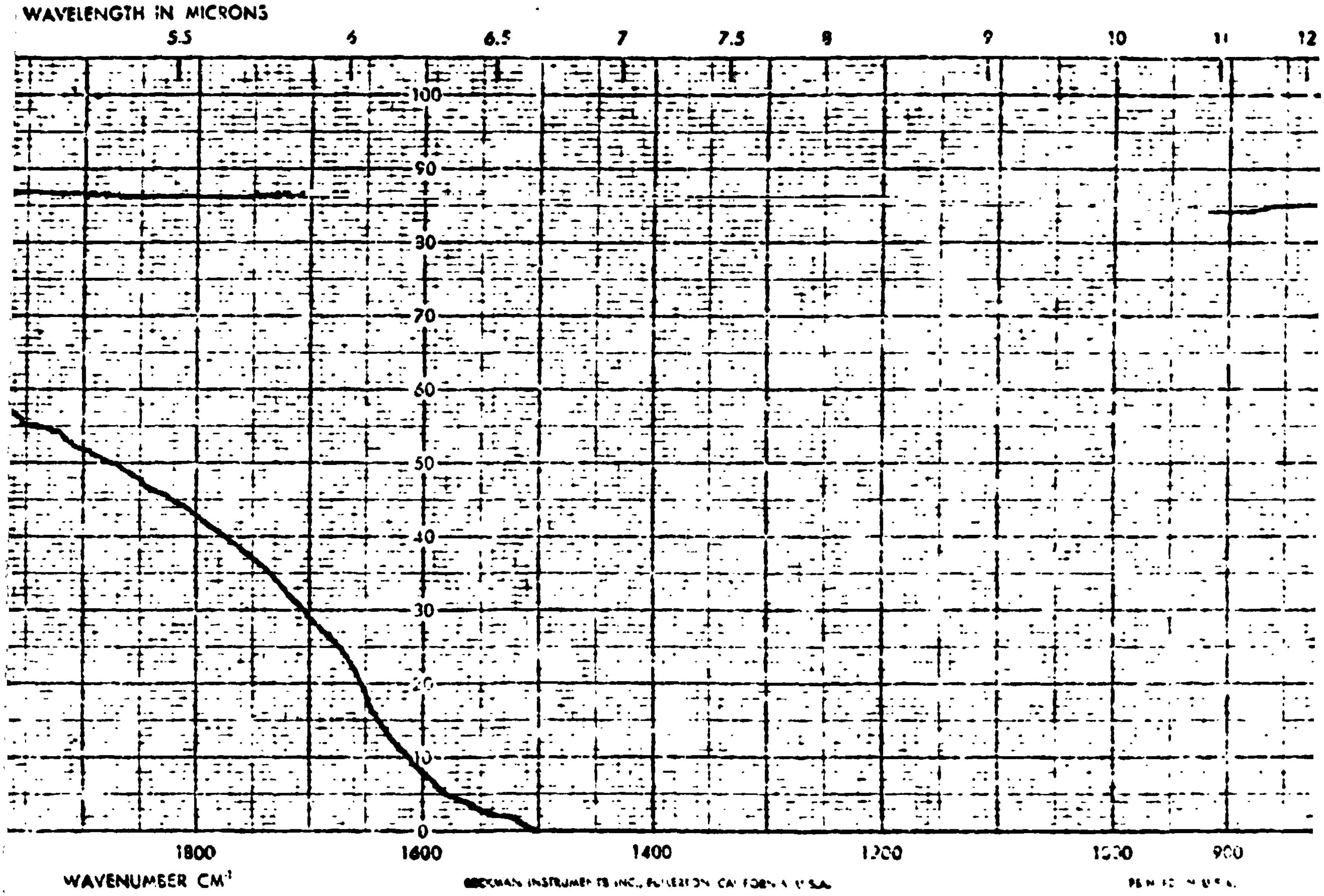
ANALYST KENNEDY

Beckman®

INFRARED SPECTROPHOTOMETER



OLDOUT FRAME


WAVELENGTH IN MICRONS
5.5
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7.5
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11
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100
90
80
70
60
50
40
30
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1800
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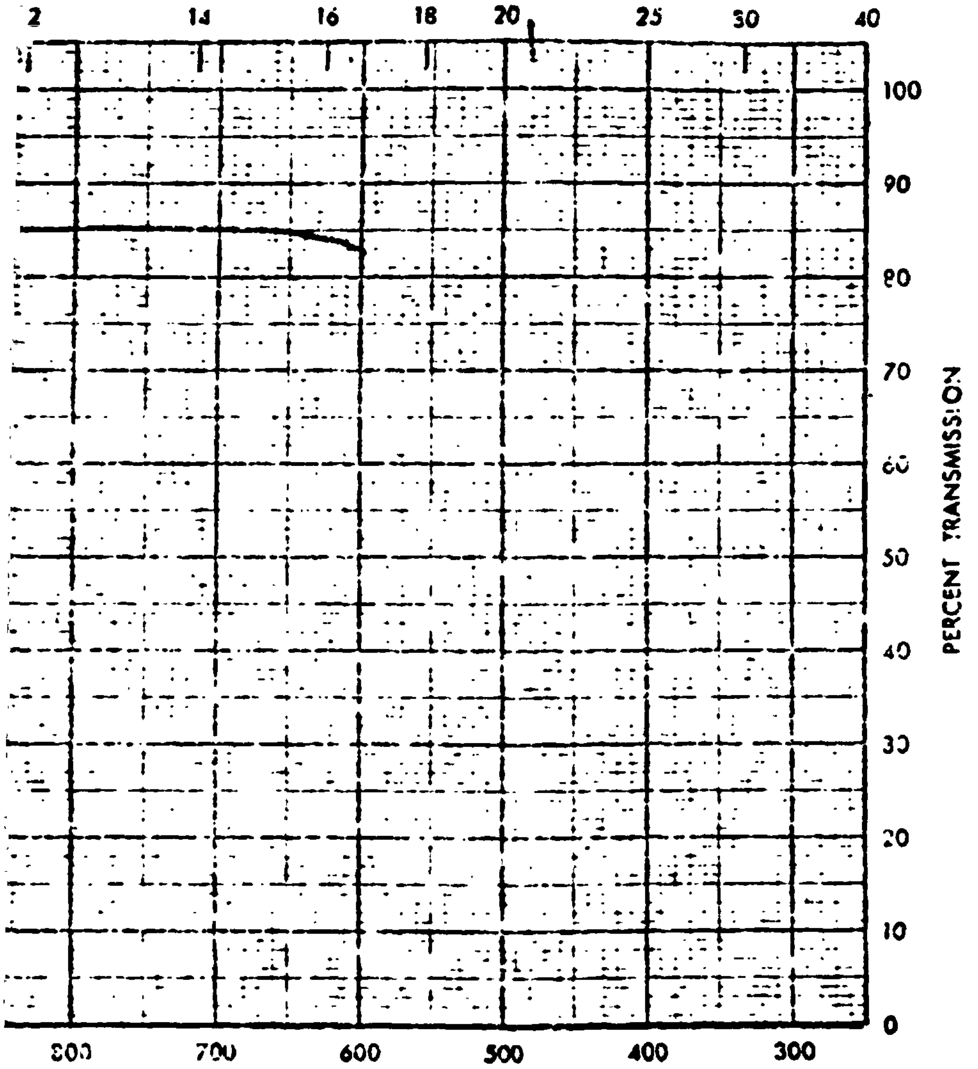
900
WAVENUMBER CM⁻¹
BECKMAN INSTRUMENTS INC., FULLERTON, CALIFORNIA U.S.A.

DOUT FRAME 2



SPECTRUM NO. B-02981

DATE 3/22/76

SAMPLE GAS CELL S/N 108

SOURCE

STRUCTURE

PATH mm.

SOLVENT

CONCENTRATION

PHASE

COMMENTS AFTER LEAK

CHECK/G .30 [illegible]

VACUUM EXPOSURE

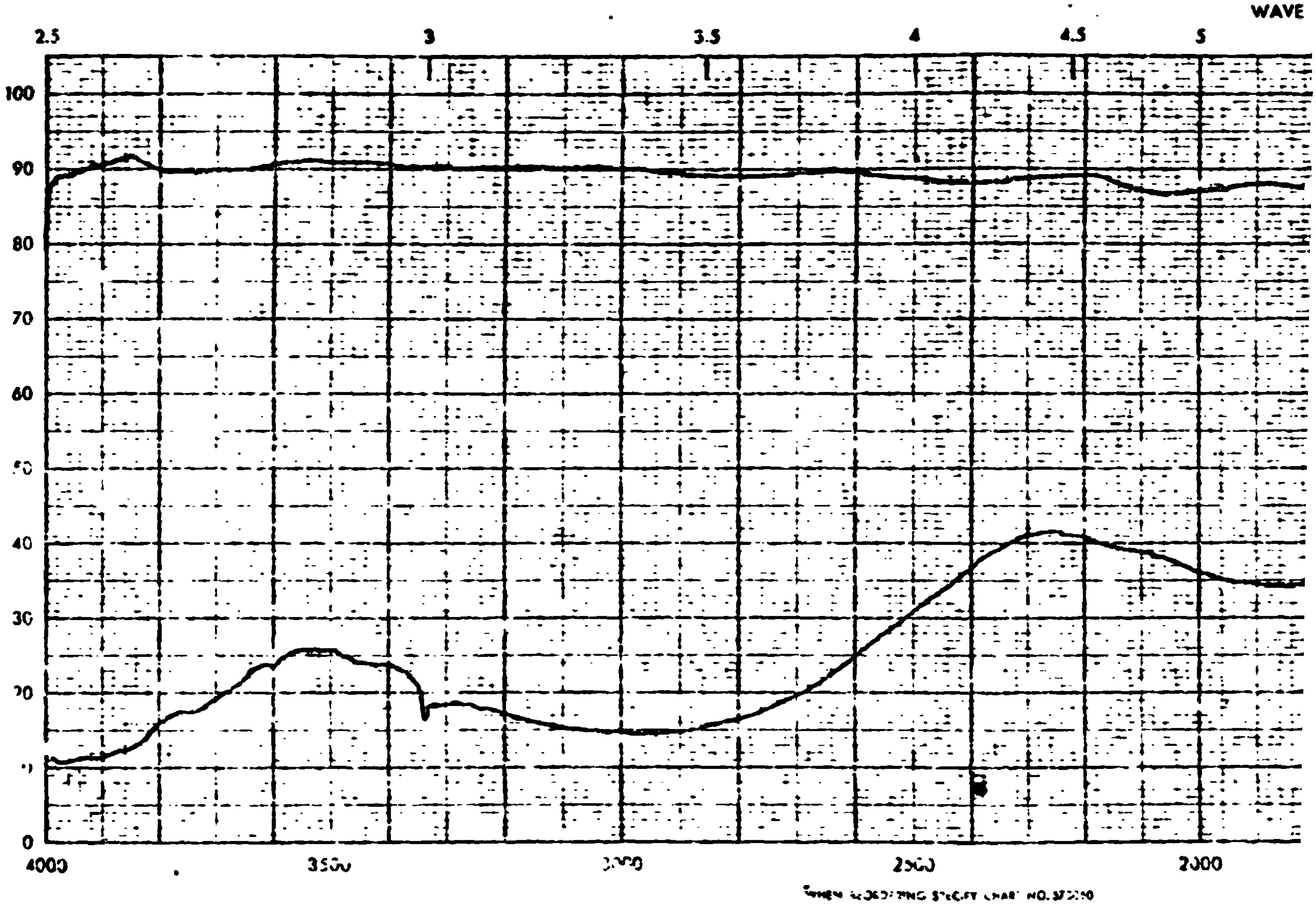
TEST

ANALYST KENNEDY

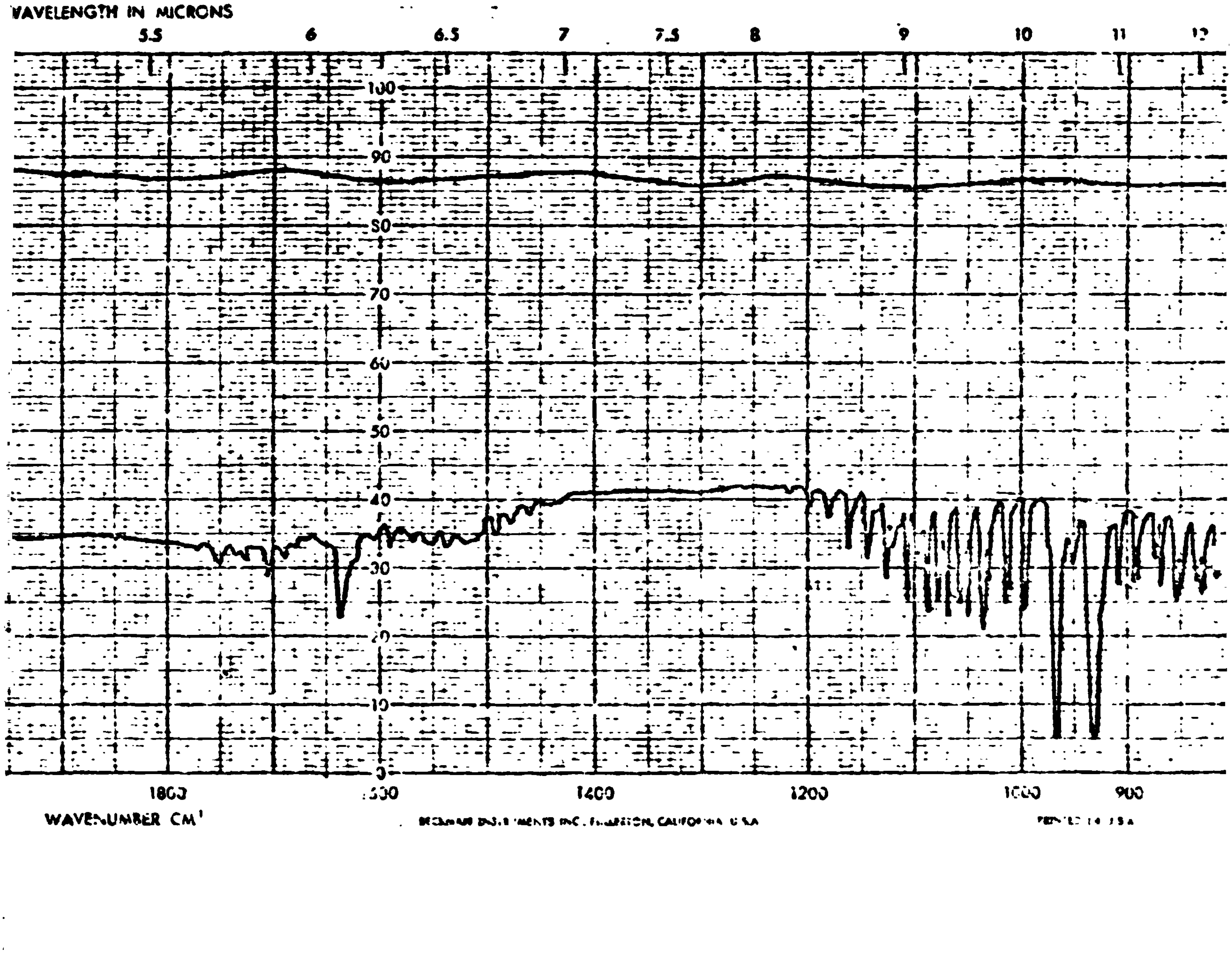
Beckman®

INFRARED
SPECTROPHOTOMETER

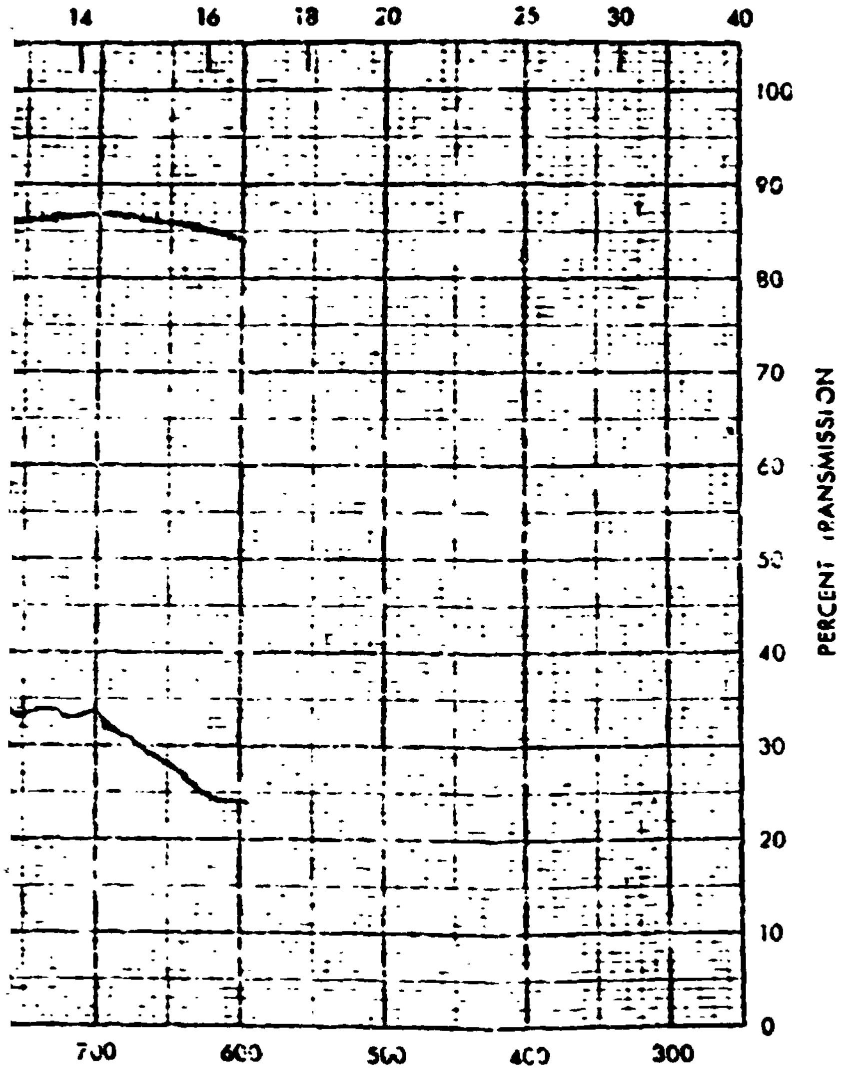
ORIGINAL PAGE IS
OF POOR QUALITY



FOLDOUT FRAME



FOLDOUT FRAME 2



SPECTRUM NO. B-02985
DATE 3/22/76
SAMPLE GAS CELL S/N 109

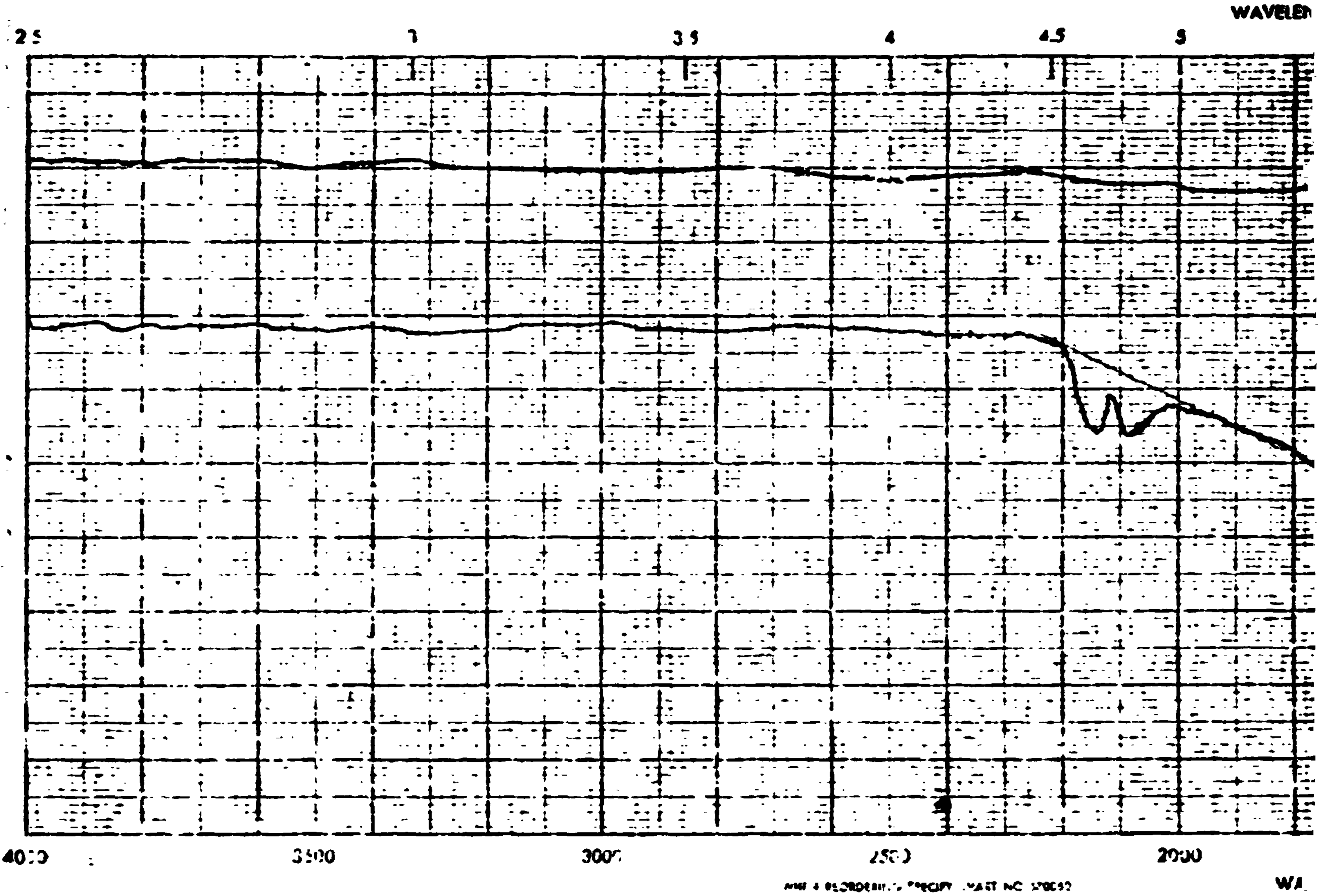
SOURCE
STRUCTURE

PATH m
SOLVENT
CONCENTRATION
PHASE
COMMENTS AFTER LEAK CHECK/VACUUM EXPOSURE 1.75 @ 97 in

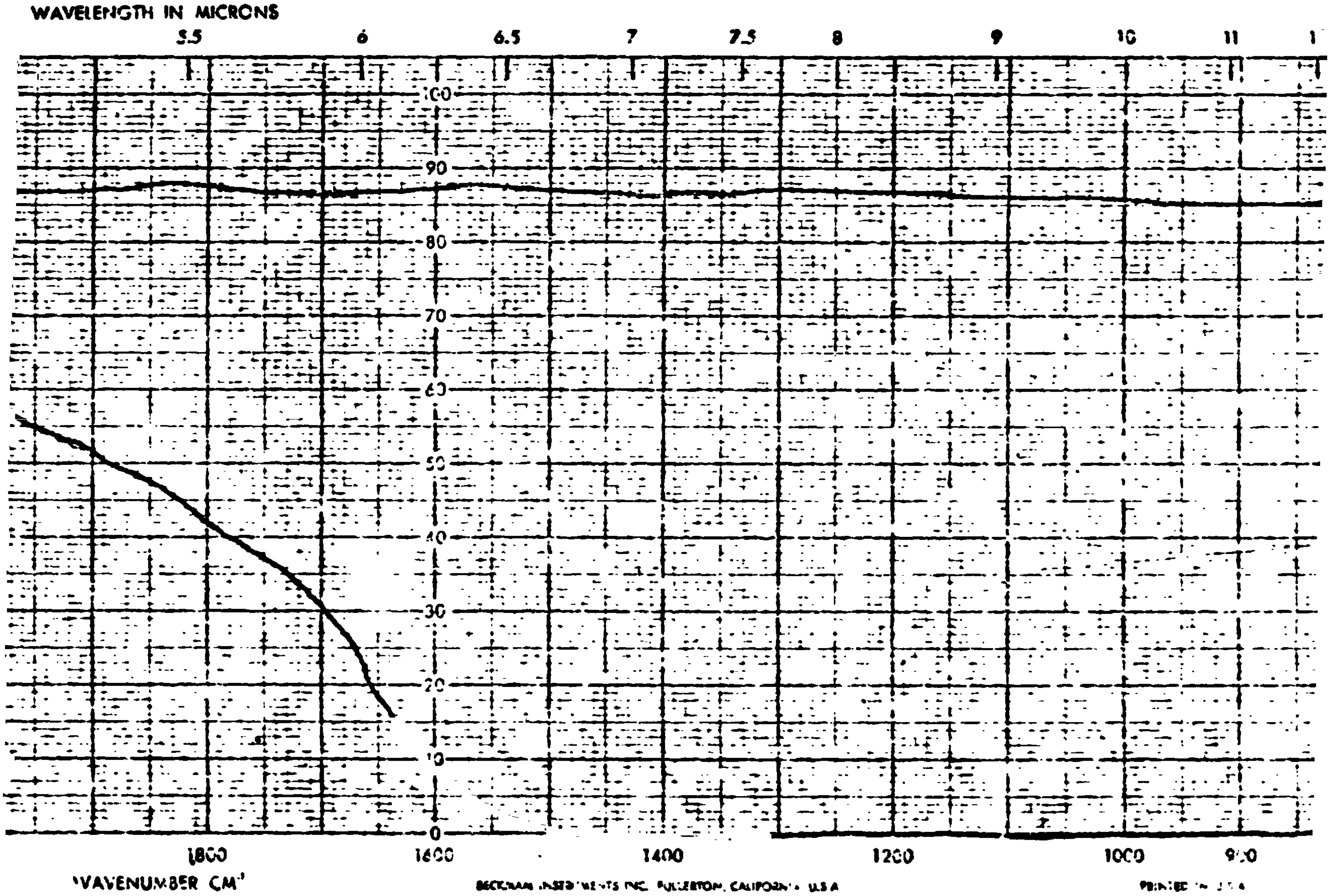
ANALYST KENNEDY

Beckman®

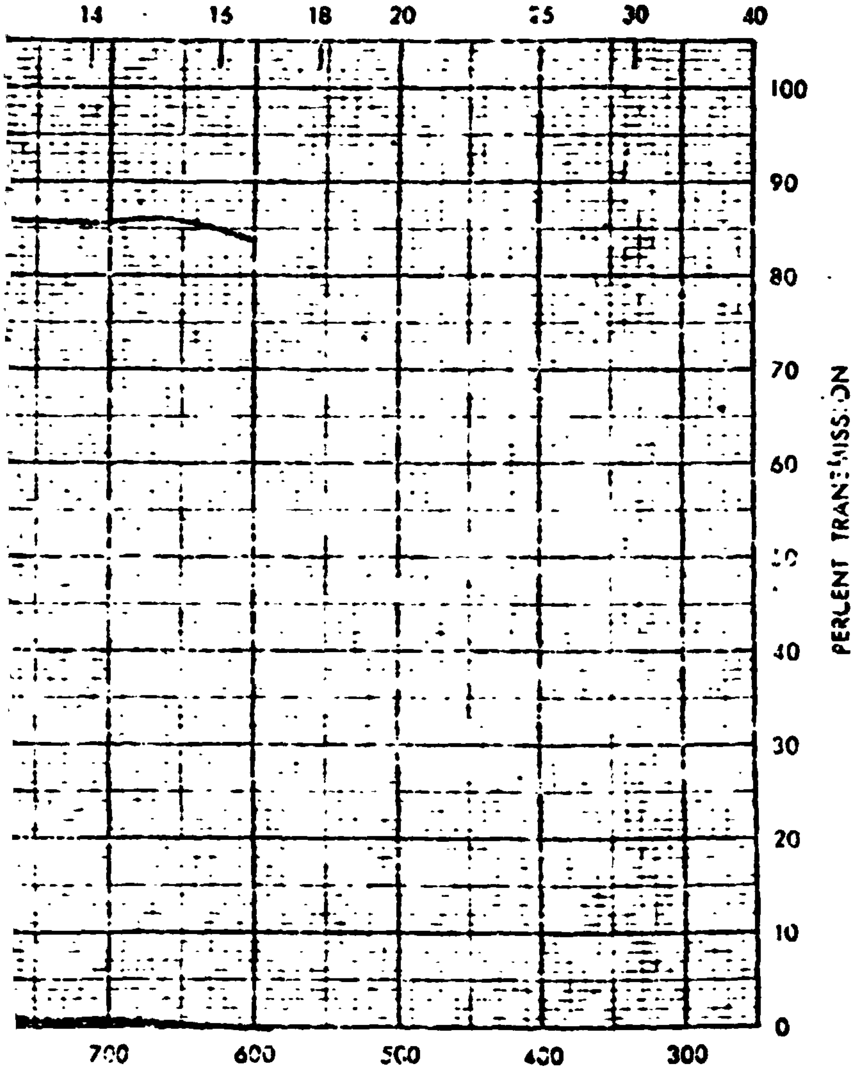
INFRARED SPECTROPHOTOMETER



FOLDOUT FRAME



FOLDOUT FRAME 2



SPECTRUM NO. B-02986

DATE 3/22/76

SAMPLE GAS CELL S/N 110

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

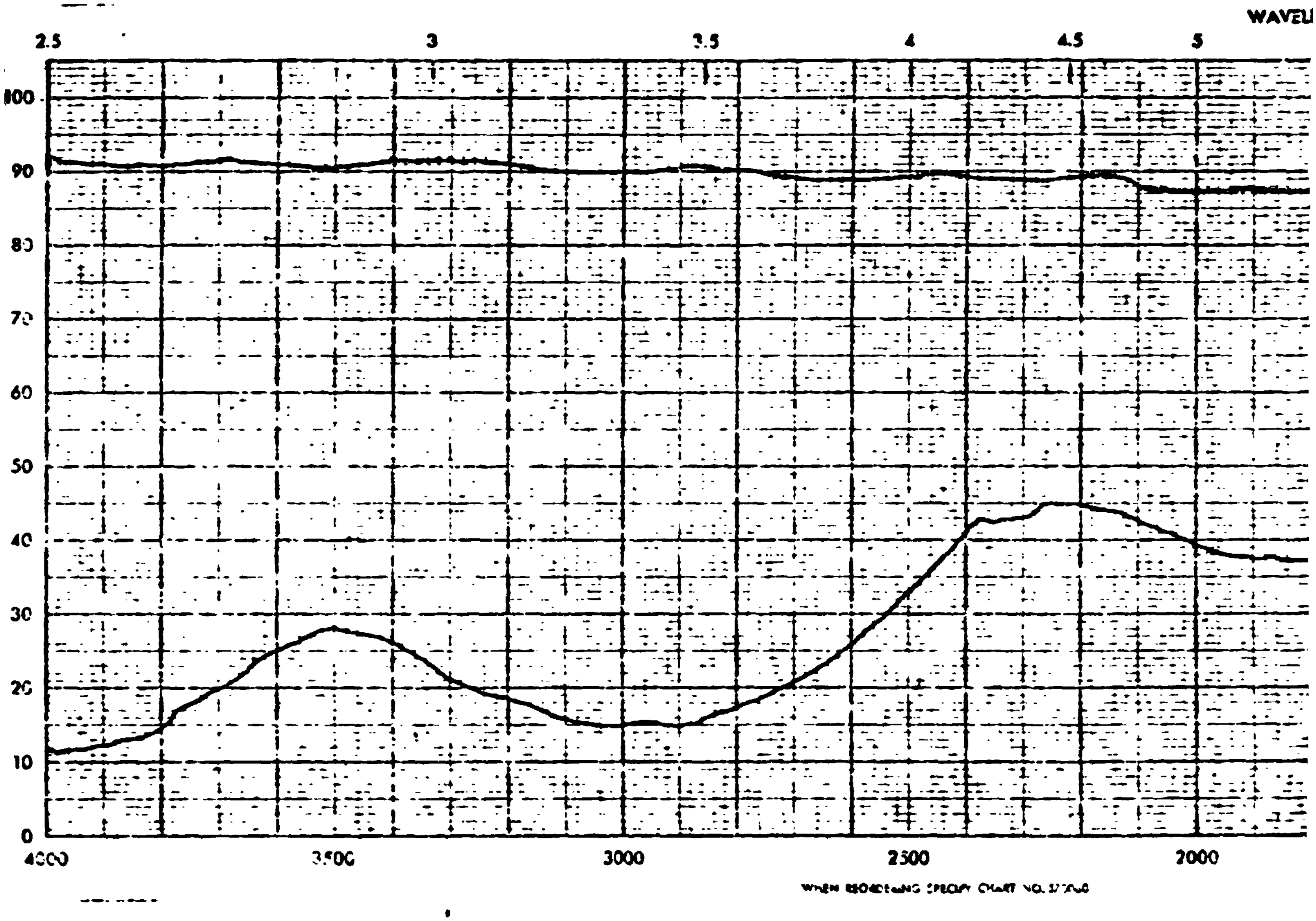
COMMENTS AFTER LEAK CHECK/VACUUM EXPOSURE 49 @ 2150

ANALYST KENNEDY

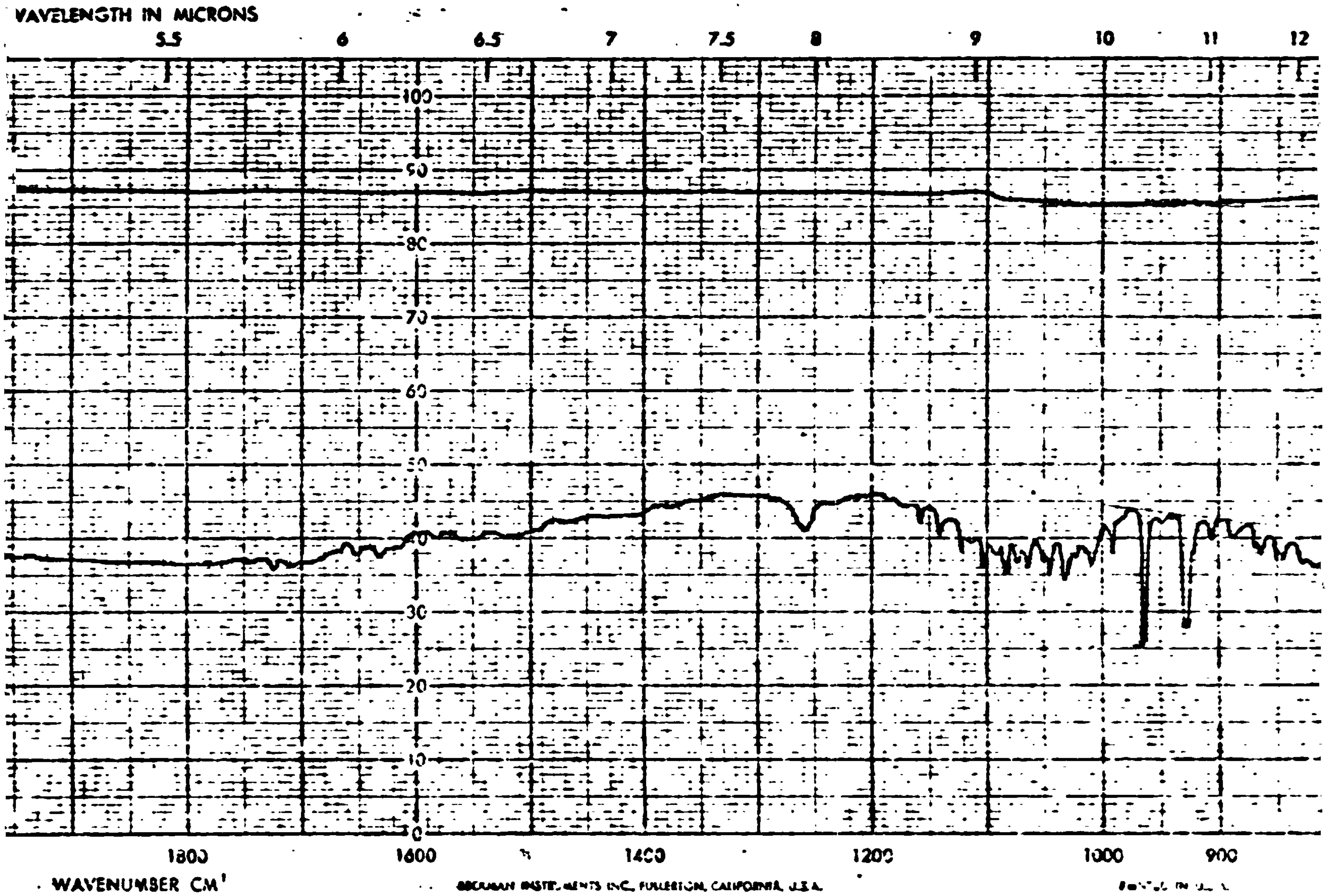
Beckman®

INFRARED SPECTROPHOTOMETER

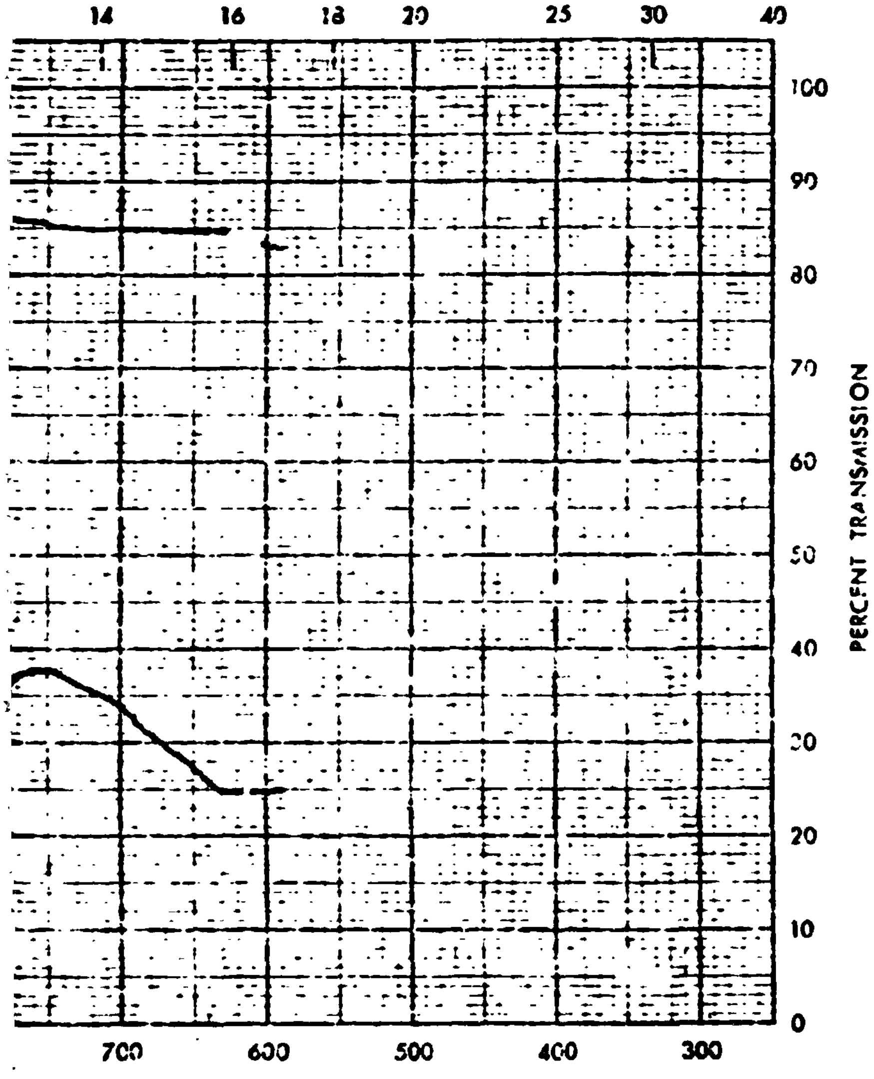
ORIGINAL PAGE IS
OF POOR QUALITY



FOLDOUT FRAME



LDOUT FRAME 2



SPECTRUM NO. B-02987

DATE 3/22/76

SAMPLE GAS CELL S/N 112

SOURCE

STRUCTURE

PATH mm

SOLVENT

CONCENTRATION

PHASE

COMMENTS AFTER LEAK CHECK/VACUUM EXPOSURE

.93

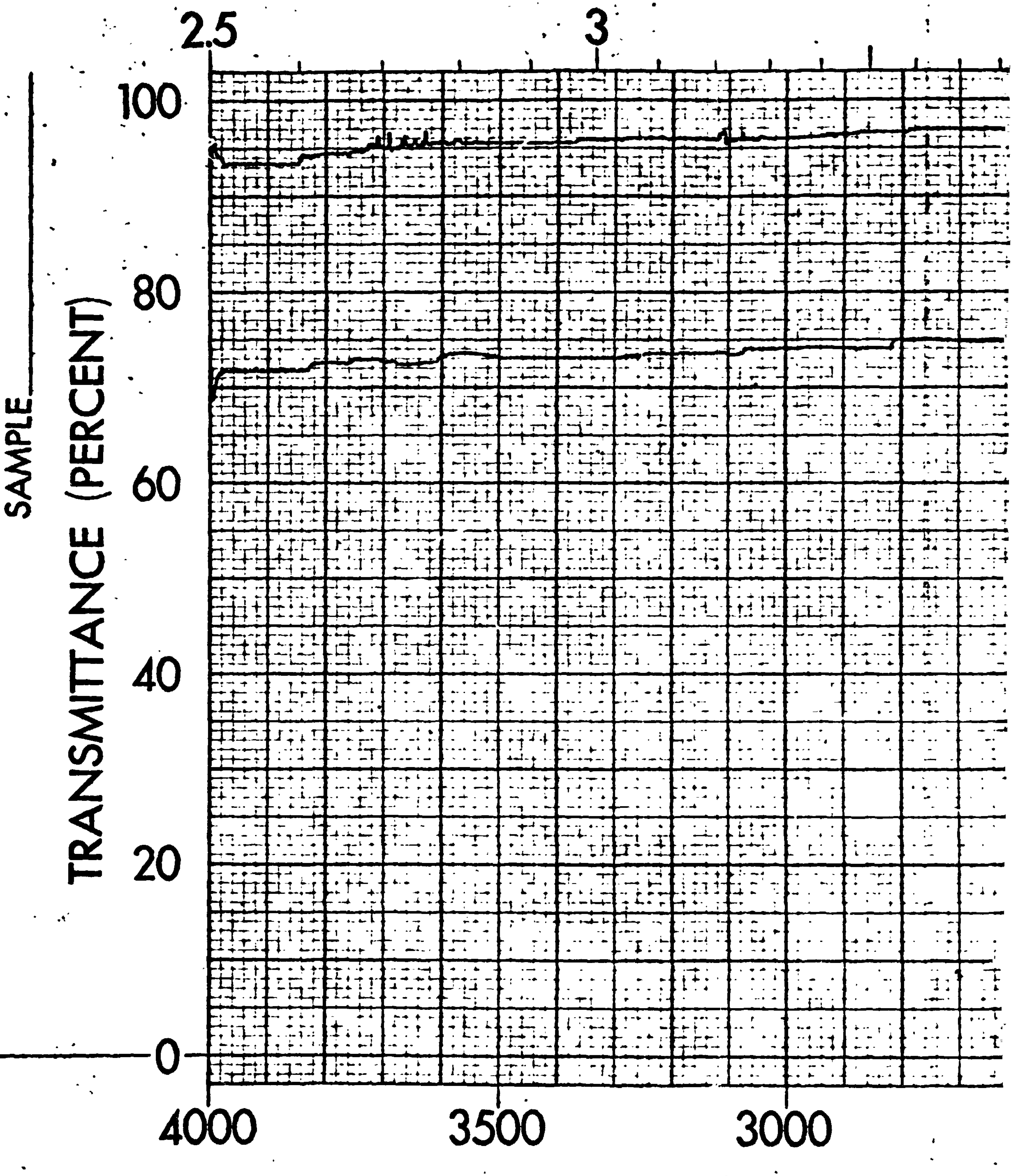
ANALYST KENNEDY

Beckman®

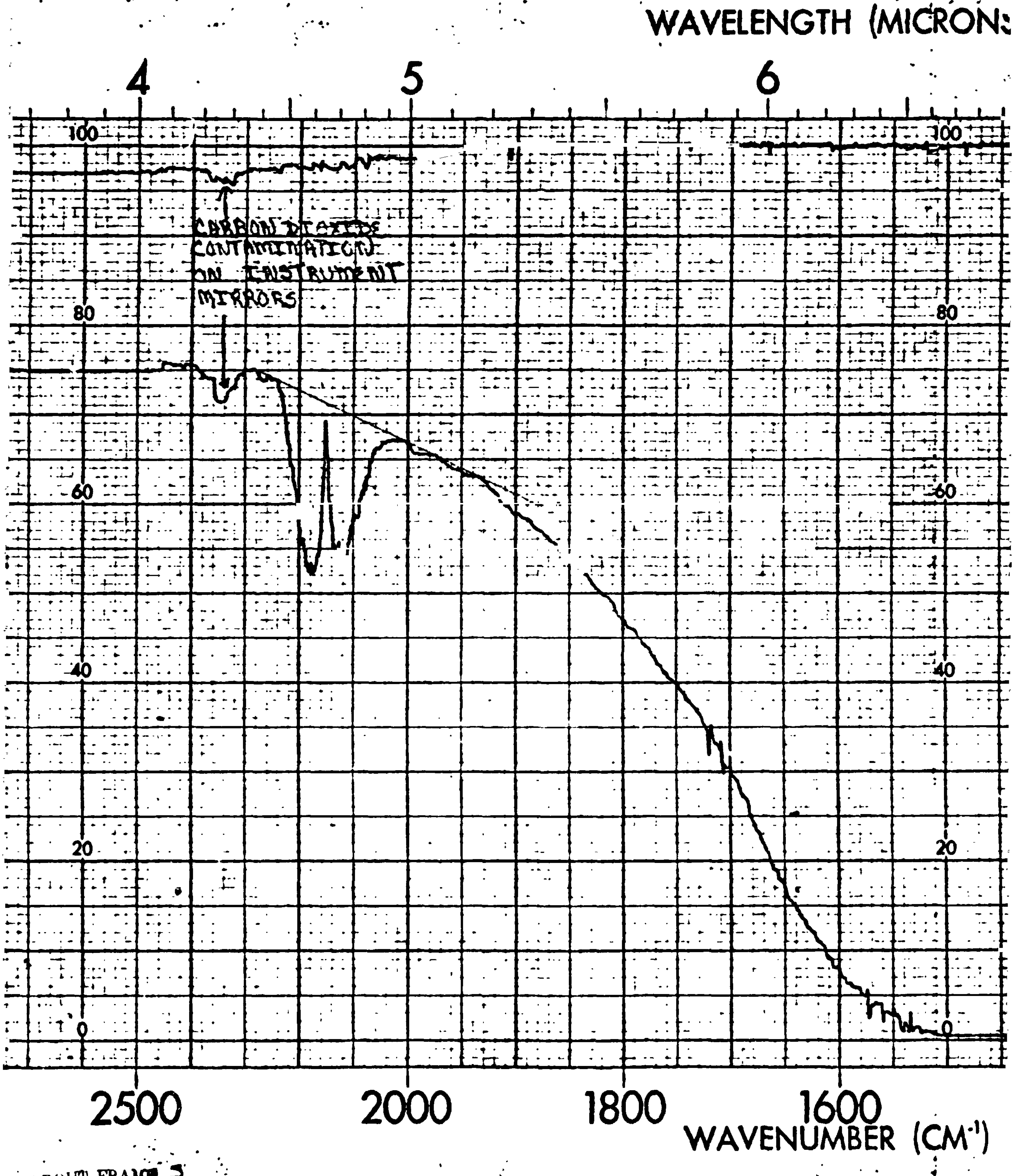
INFRARED SPECTROPHOTOMETER

11#

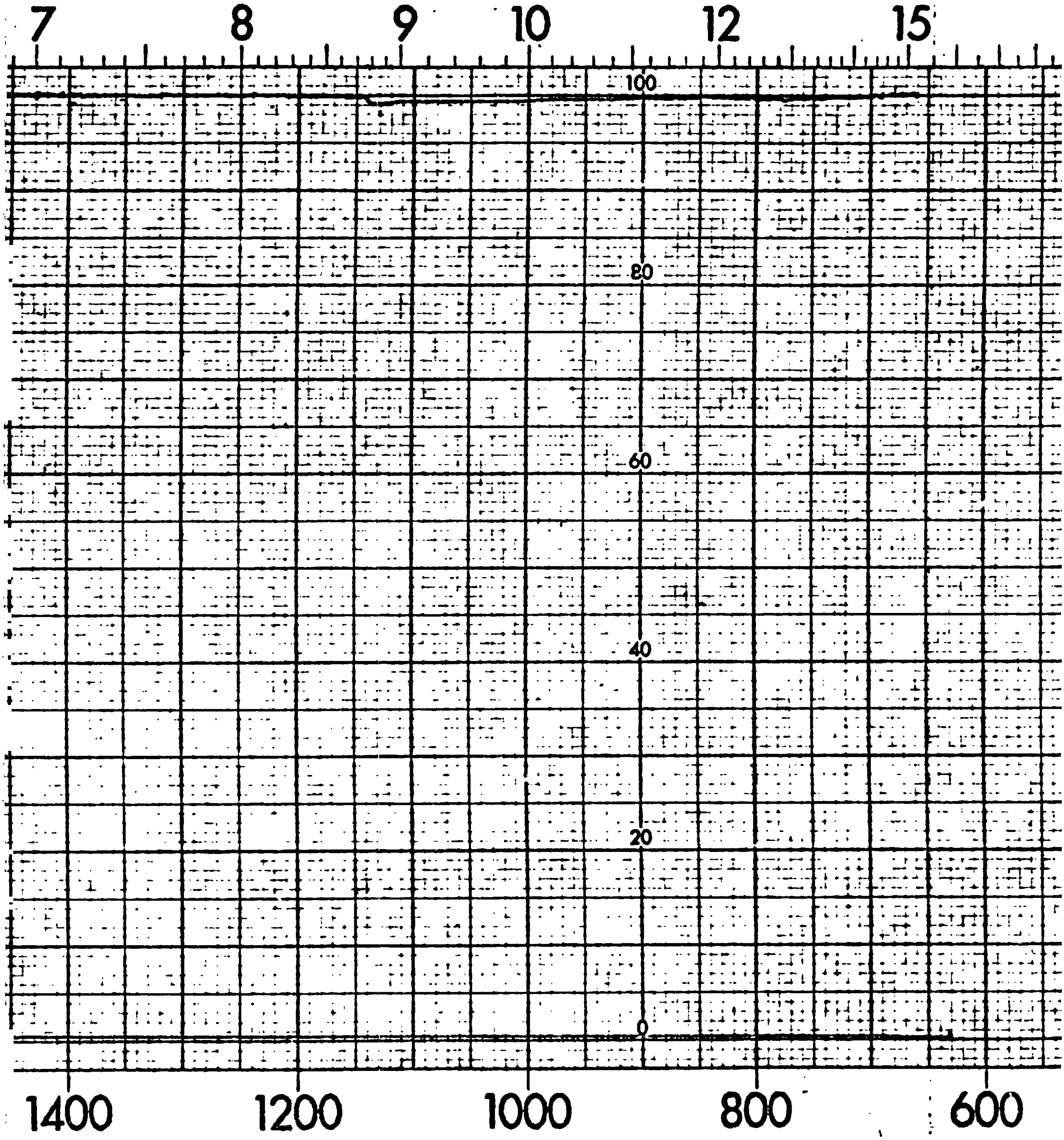
ORIGINAL PAGE IS
OF POOR QUALITY



OLDOUT FRAME /



CARBON DIOXIDE CONTAMINATION ON INSTRUMENT MIRRORS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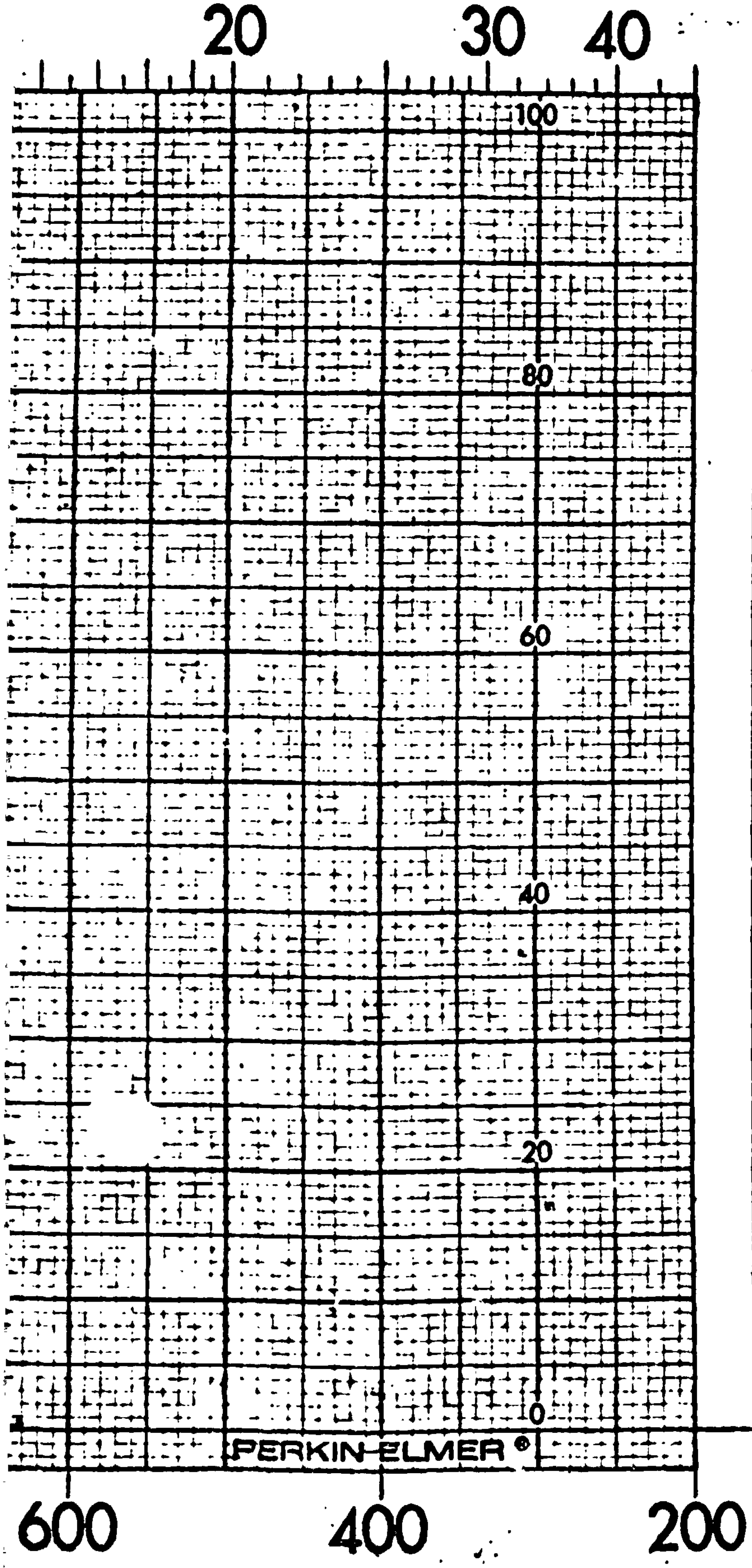


SPECTRUM NO.

SAMPLE Gas Cell S/N 108

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 8/9/76

OPERATOR

REMARKS AFTER LIFE TEST

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

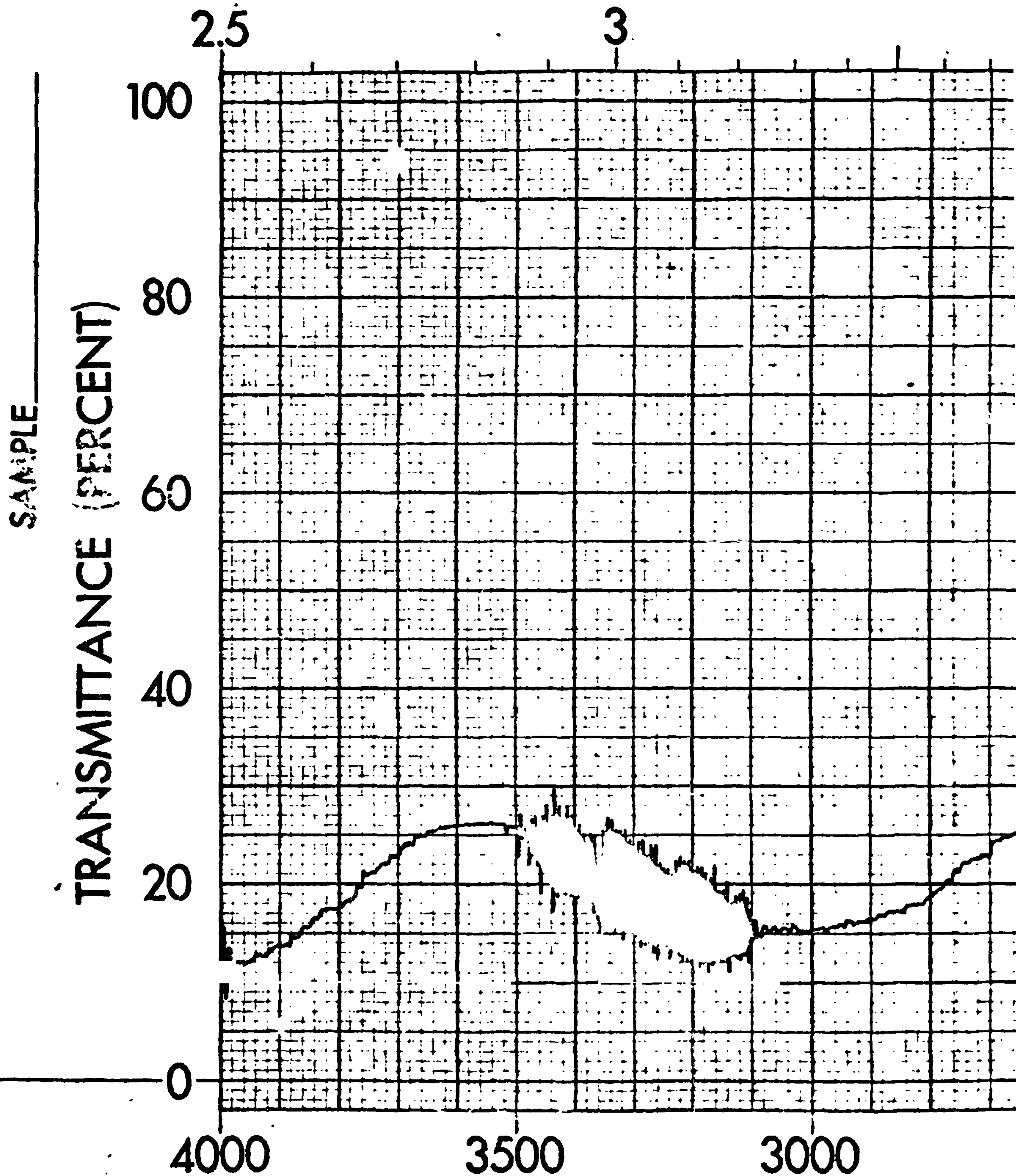
SUPPRESSION

SCALE EXPANSION

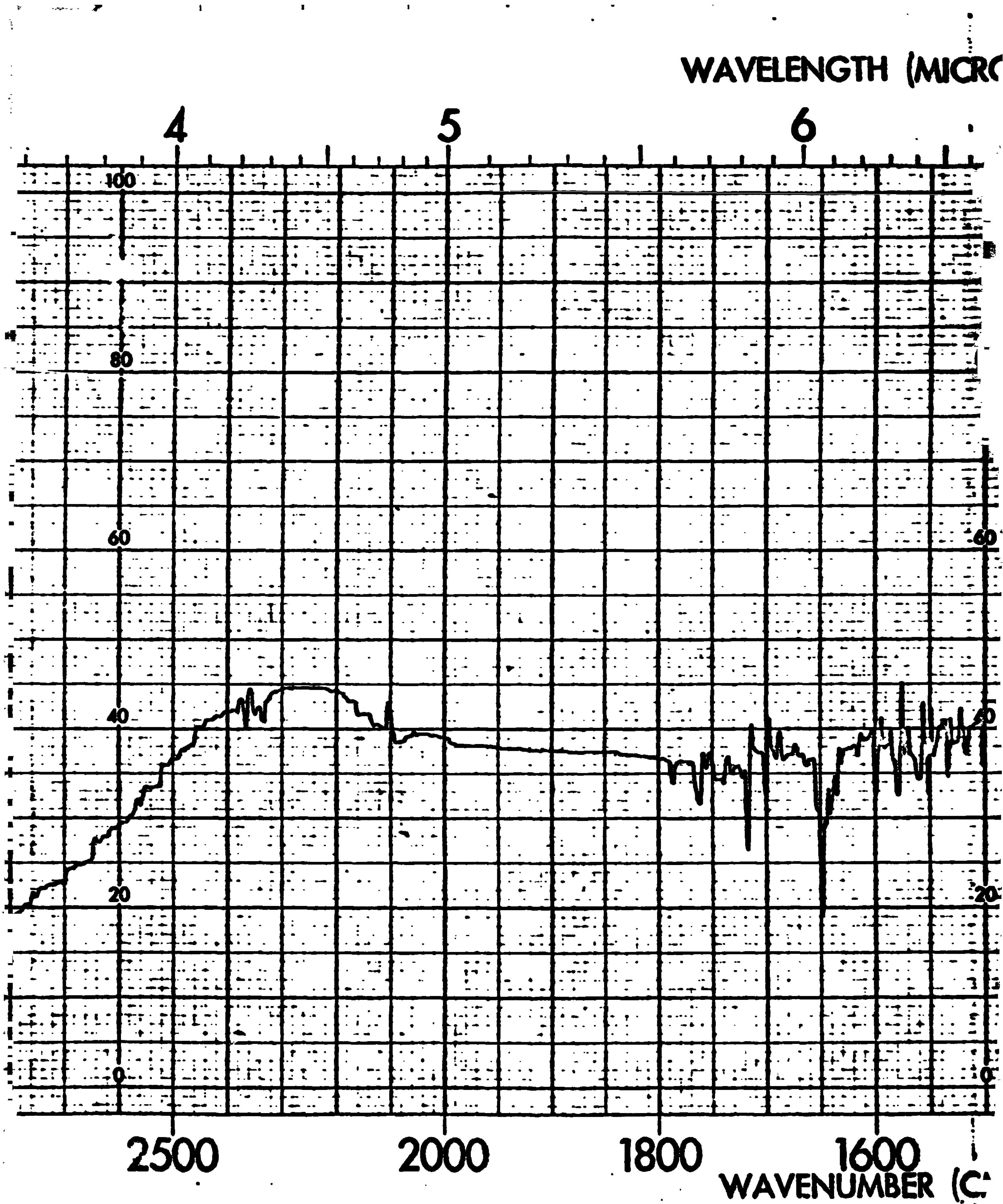
SOURCE CURRENT

NO. 221-1607

#2



FOLDOUT FRAME /


WAVELENGTH (MICR
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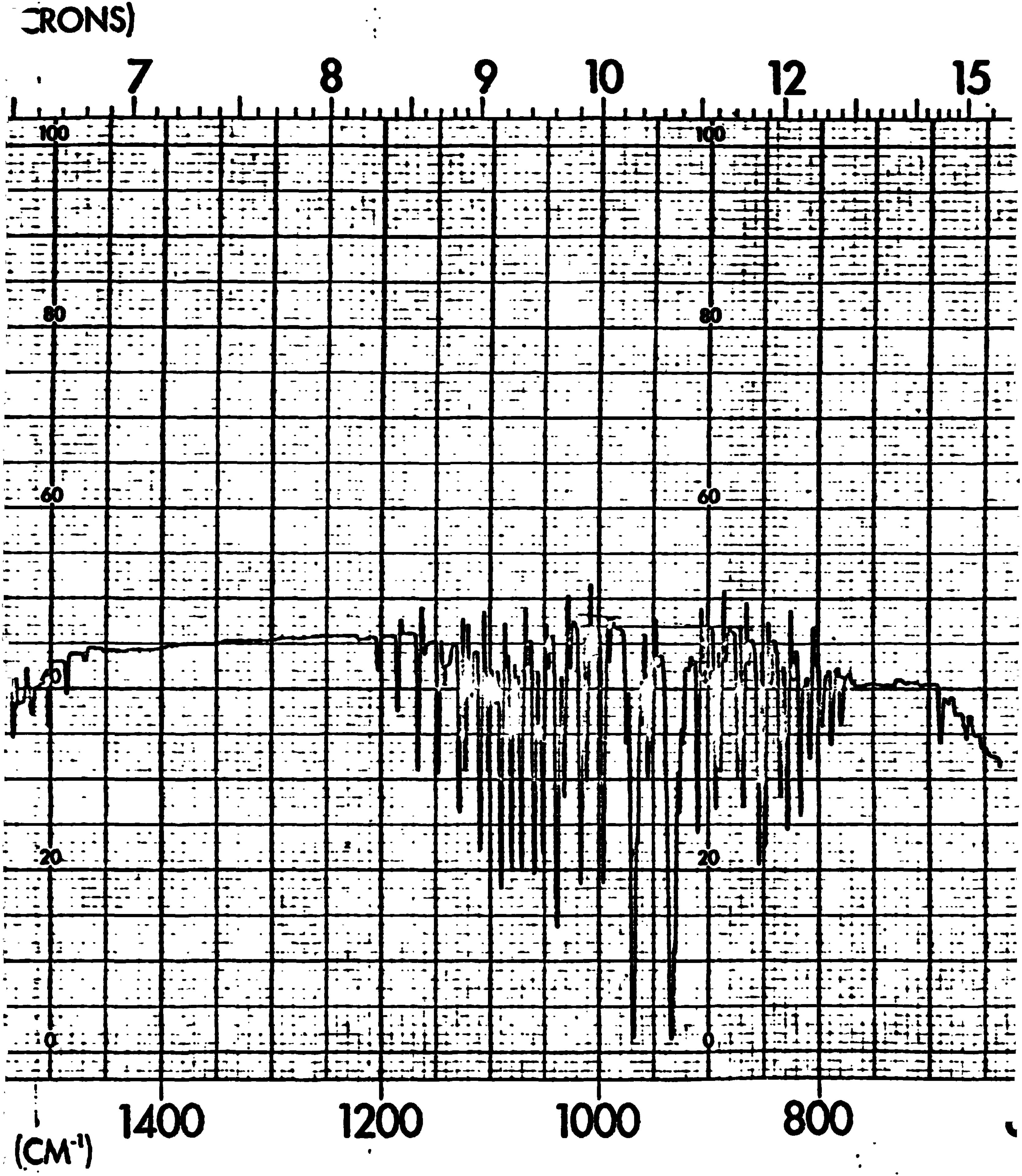
WAVENUMBER (C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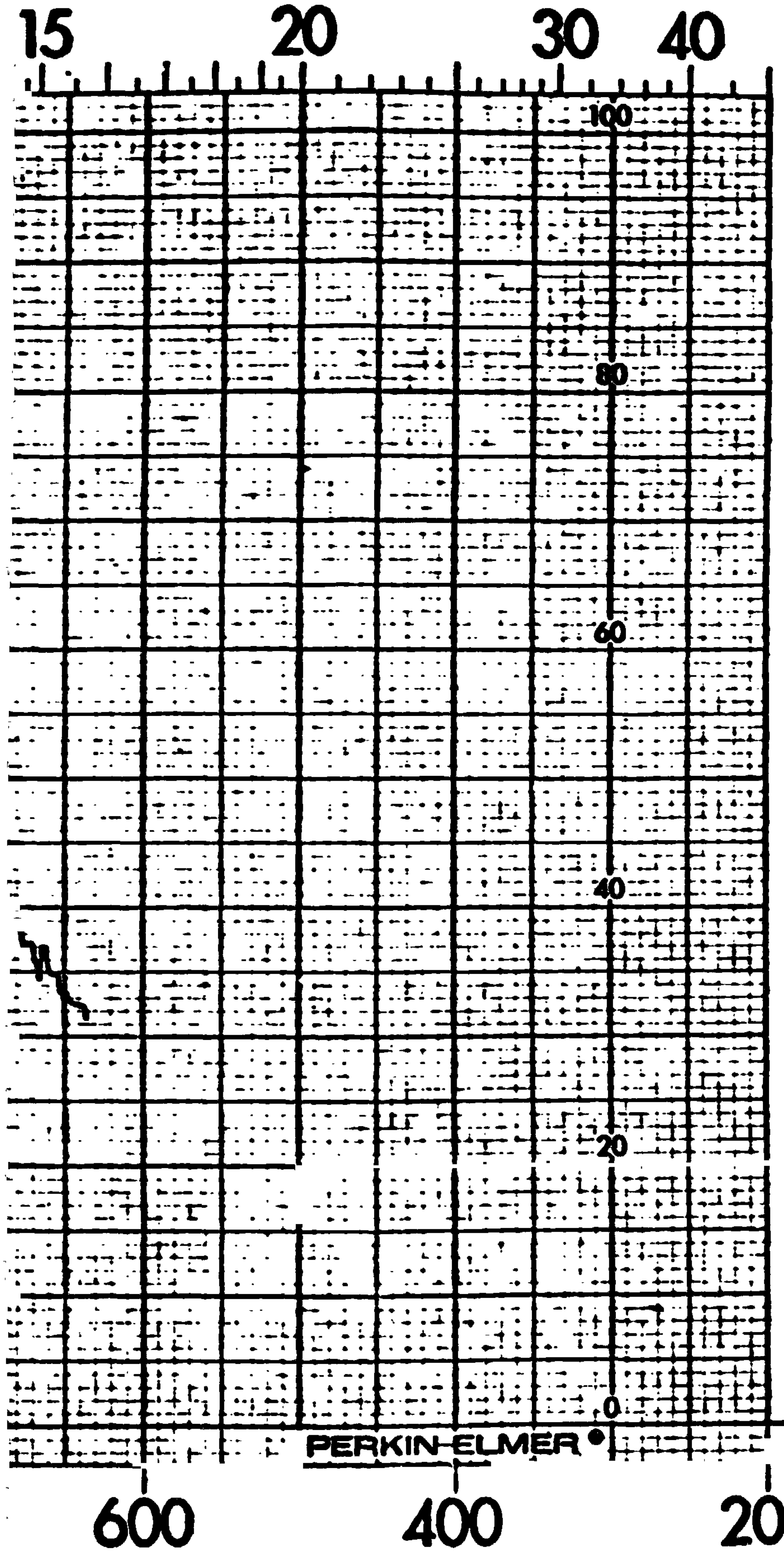


SPECTRUM NO.

SAMPLE GAS CELL S/N 109

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 4/9/76

OPERATOR

REMARKS AFTER LTFL TEST

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

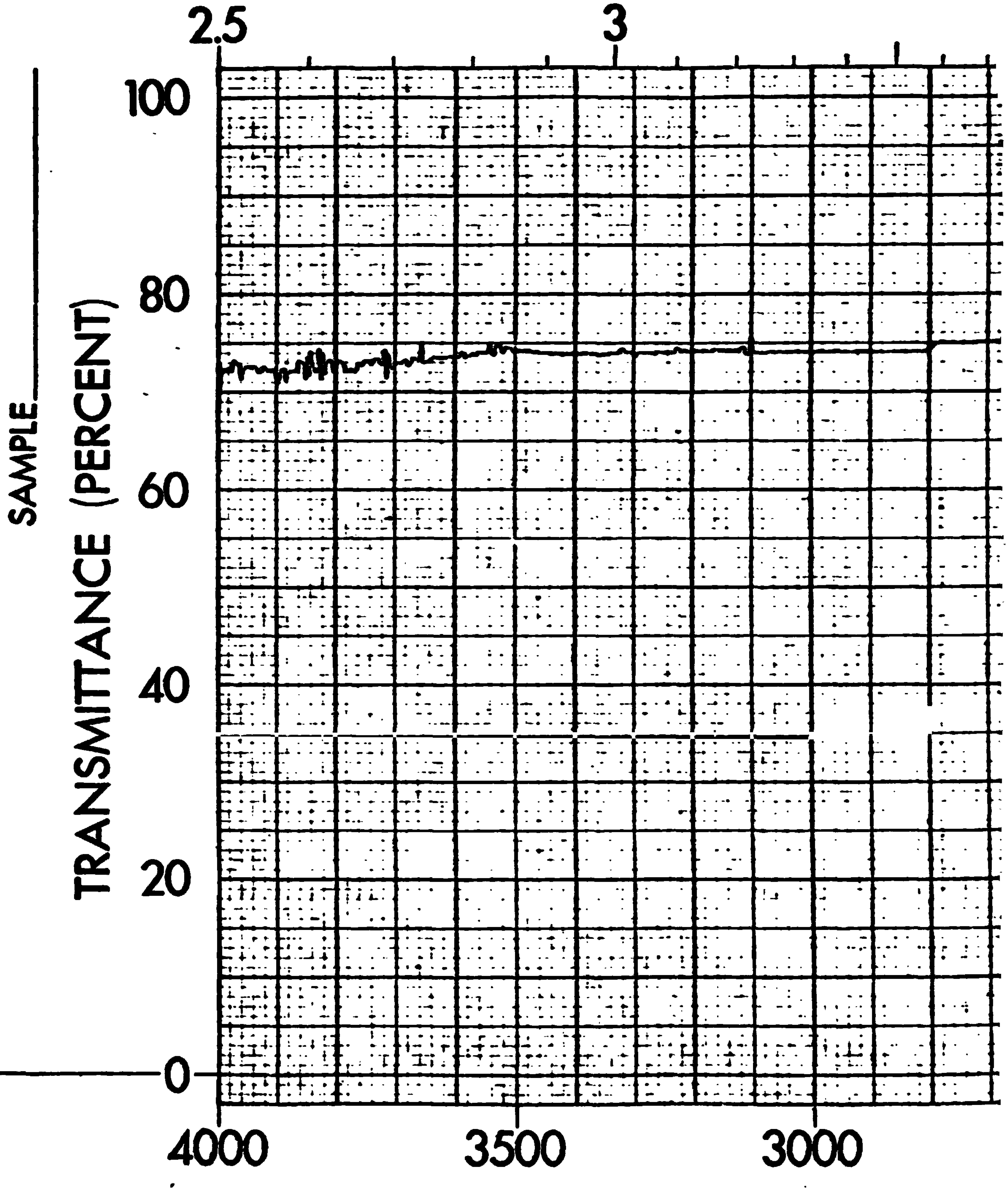
SUPPRESSION

SCALE EXPANSION

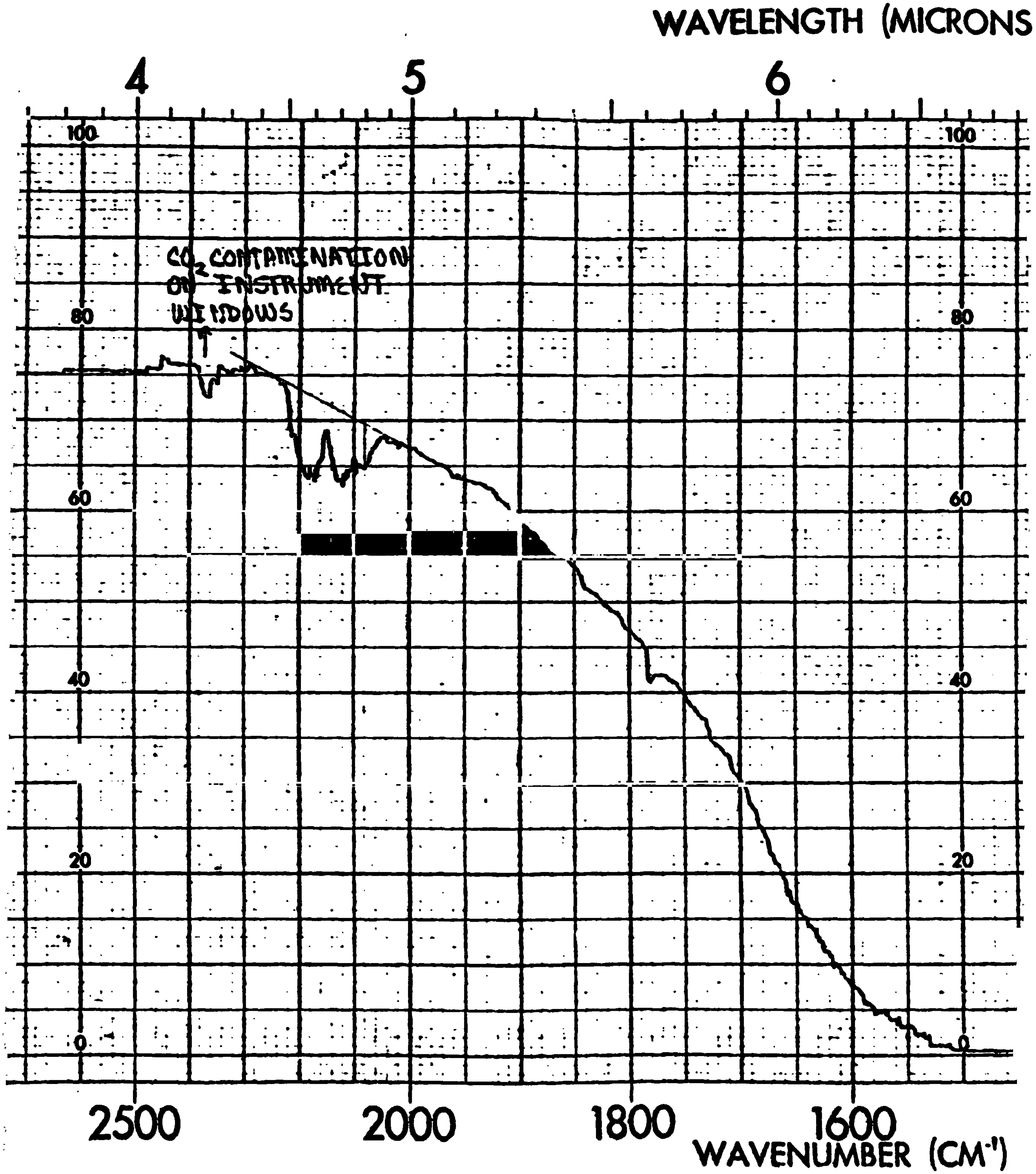
SOURCE CURRENT

NO. 221-1607

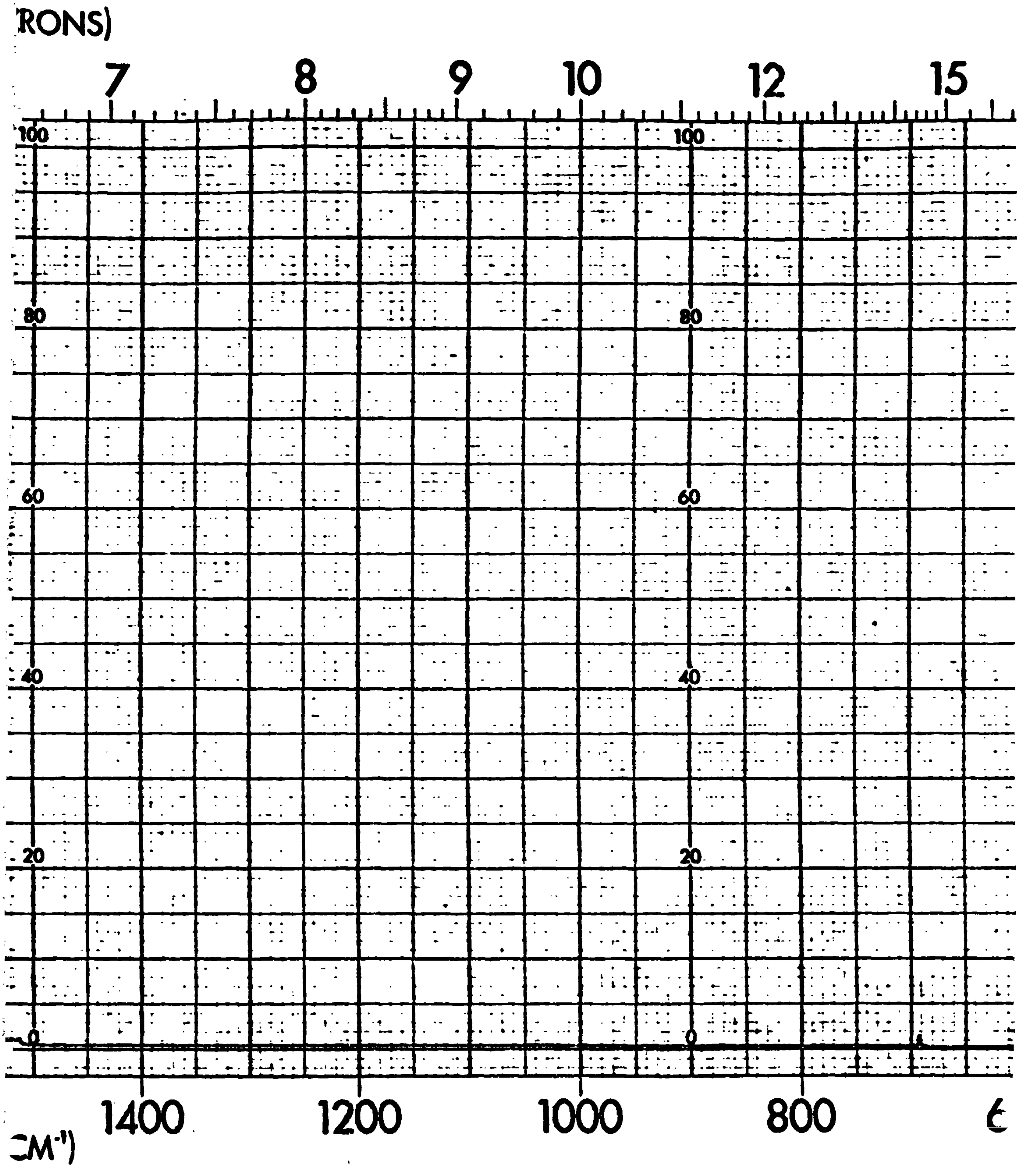
#13



FO'DOUT FRAME



CO₂ CONTAMINATION ON INSTRUMENT WINDOWS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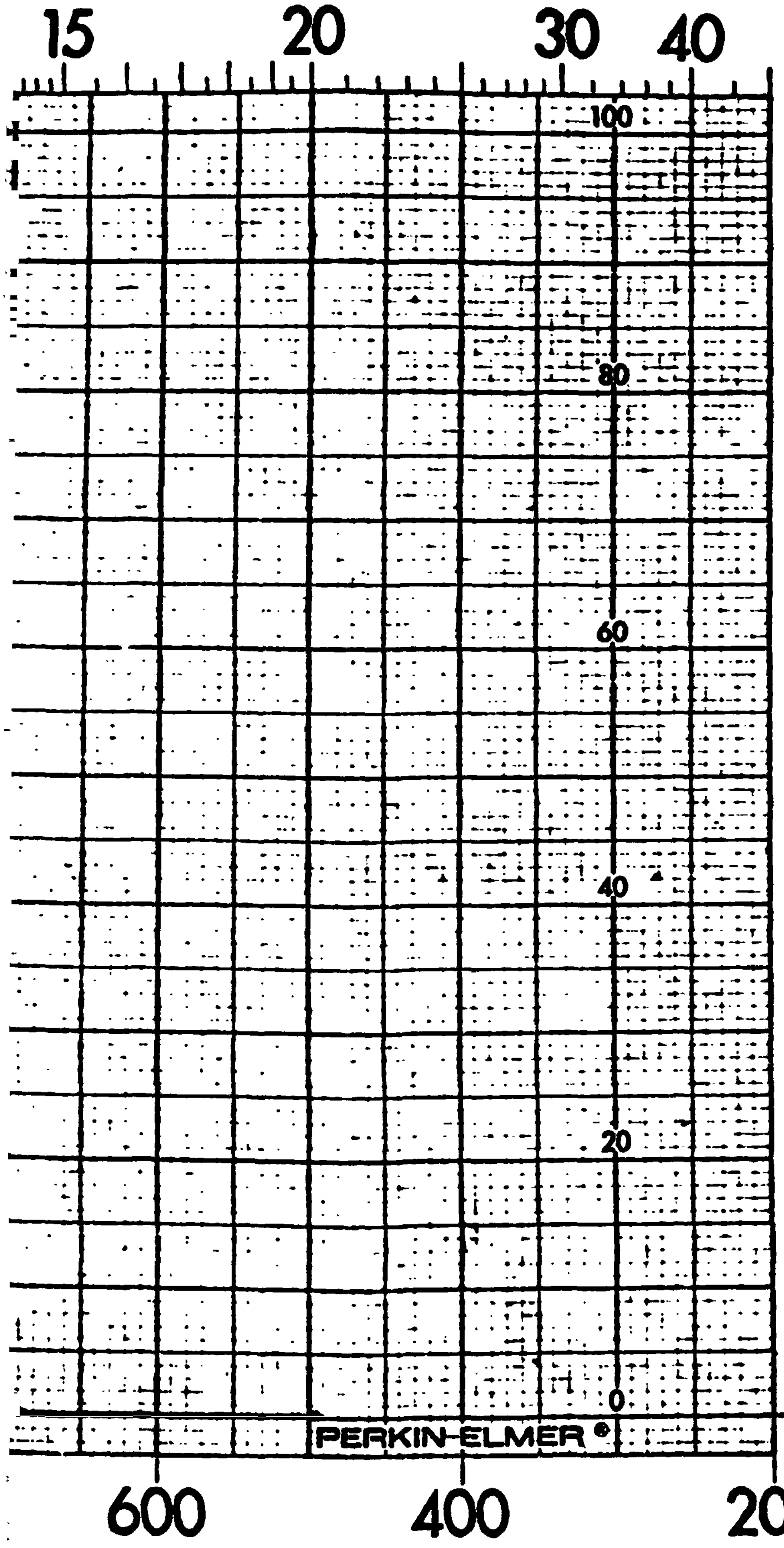


SPECTRUM NO.________

SAMPLE GAS CELL S/N 110

ORIGIN________

PURITY________

PHASE________

THICKNESS________

1.________

2.________

3.________

DATE 4/9/76

OPERATOR________

REMARKS AFTER LIFE TEST

MODEL 521 2:1 SCALE CHANGE________

SLIT PROGRAM________

GAIN________

ATTENUATOR SPEED________

SCAN TIME________

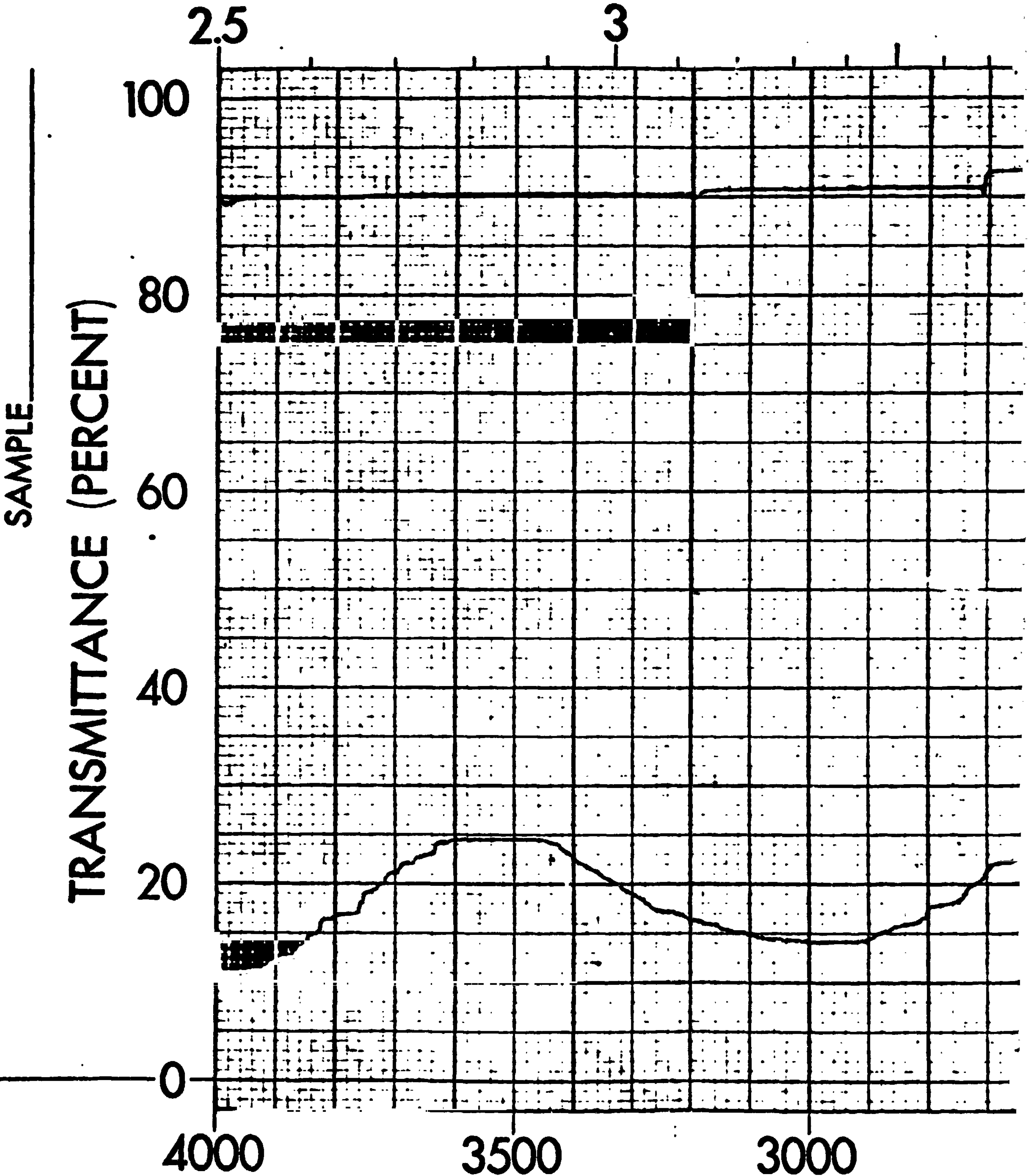
SUPPRESSION________

SCALE EXPANSION________

SOURCE CURRENT________

NO. 221-1607

#12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SAMPLE
TRANSMITTANCE (PERCENT)
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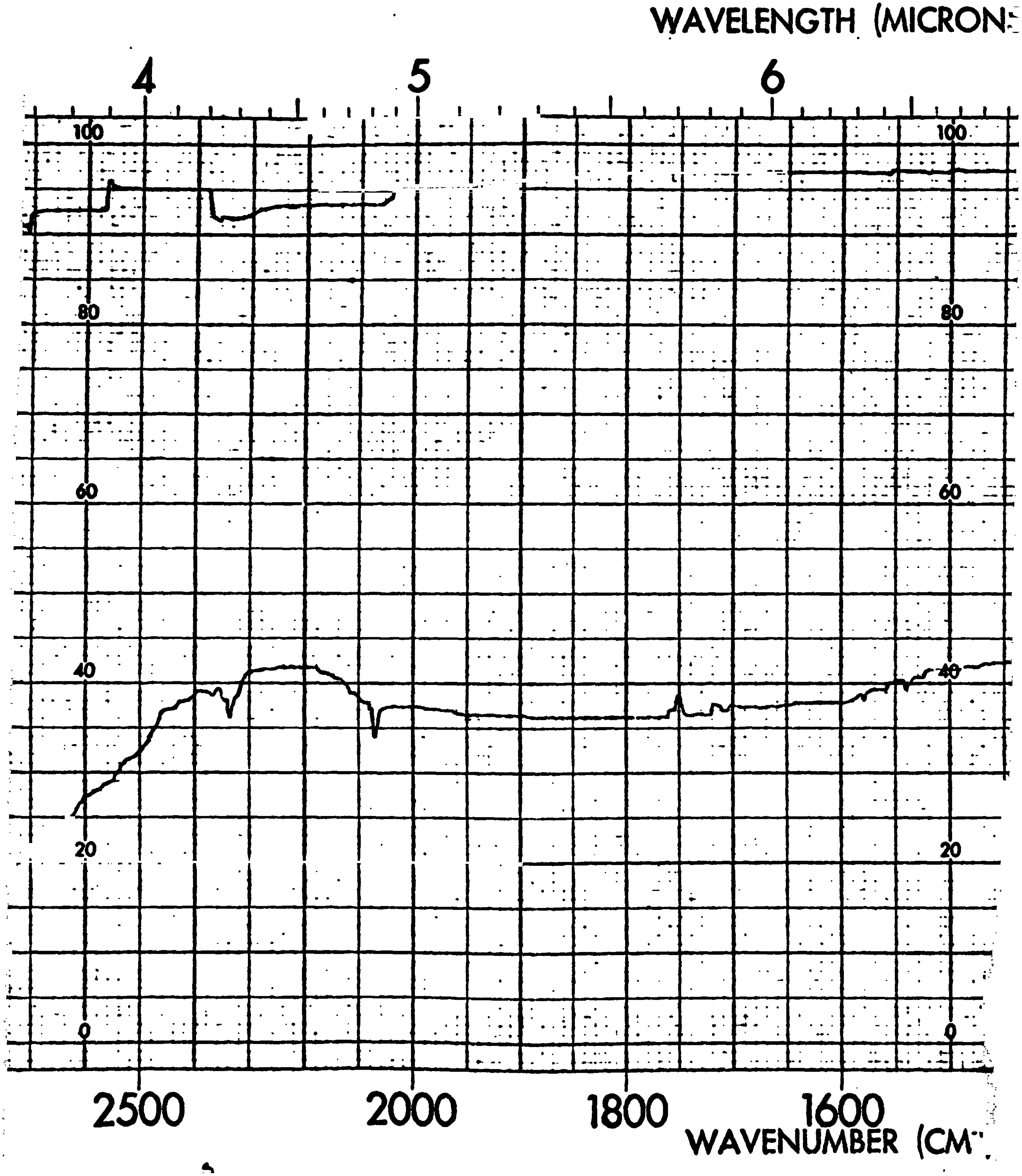
3500
3000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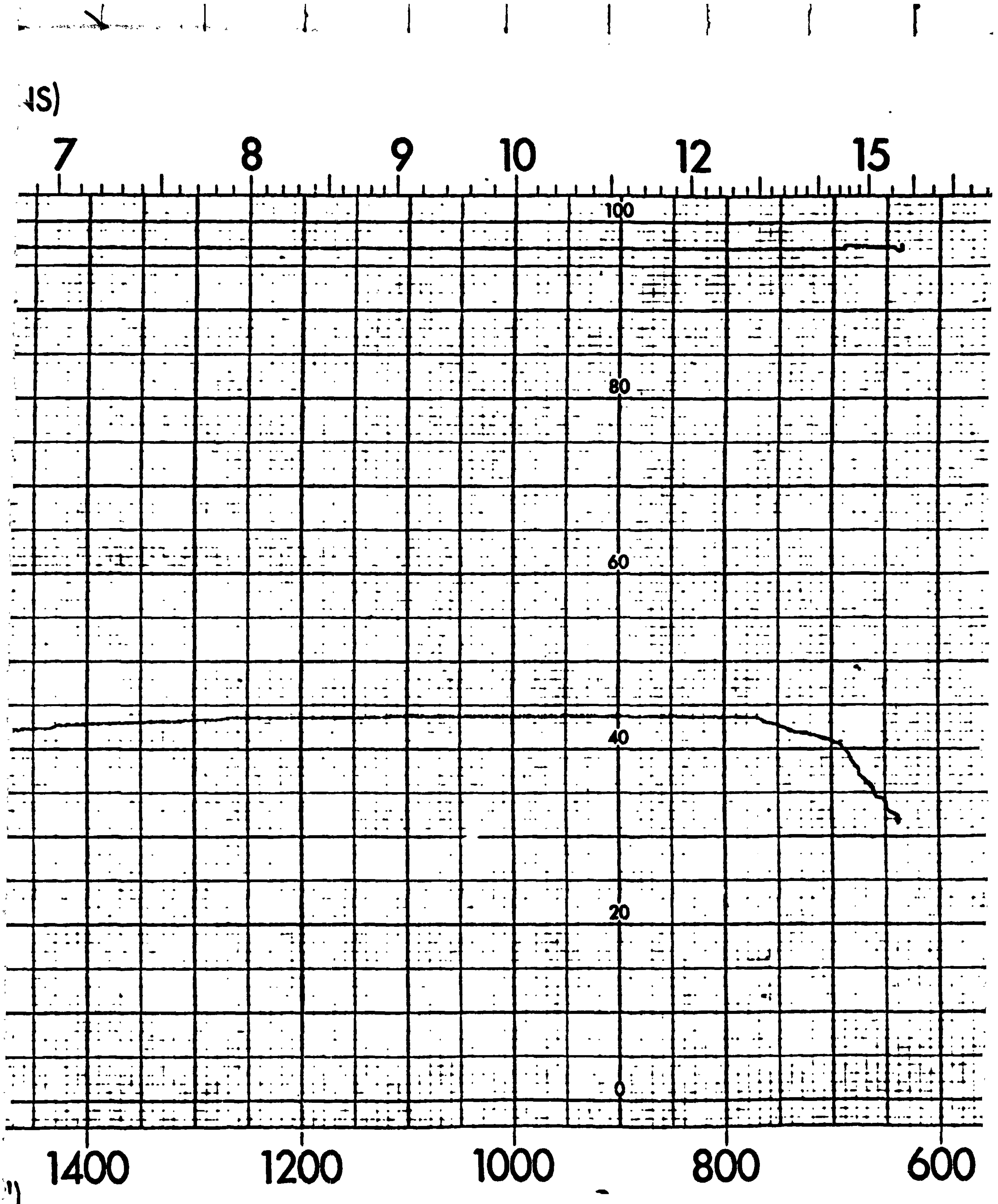
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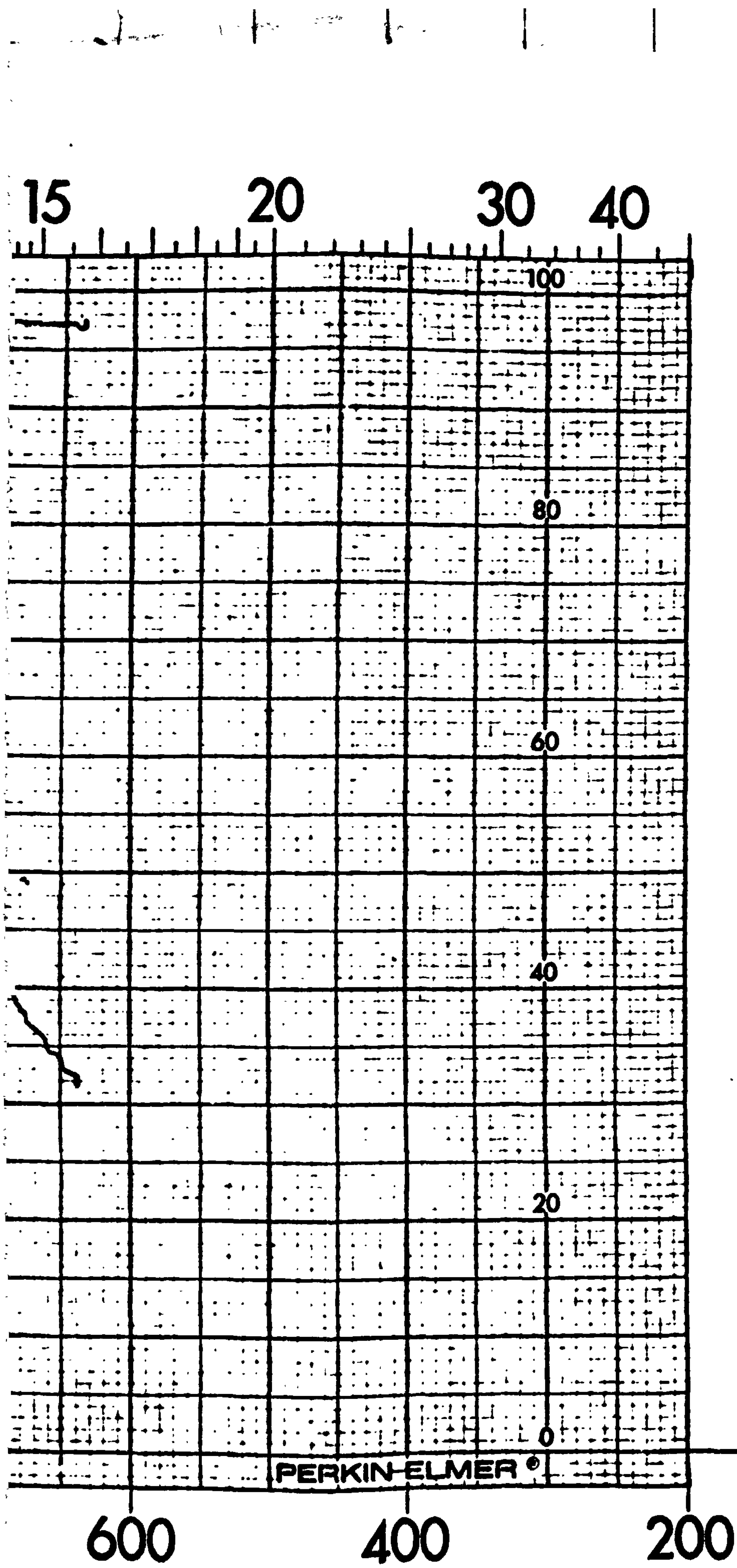


SPECTRUM NO. B-03069

SAMPLE Gas Cell S/N 112

After Being in 85°C Oven

ORIGIN With N2 Purge For 400 Hrs.

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 4/9/76

OPERATOR Kennedy

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

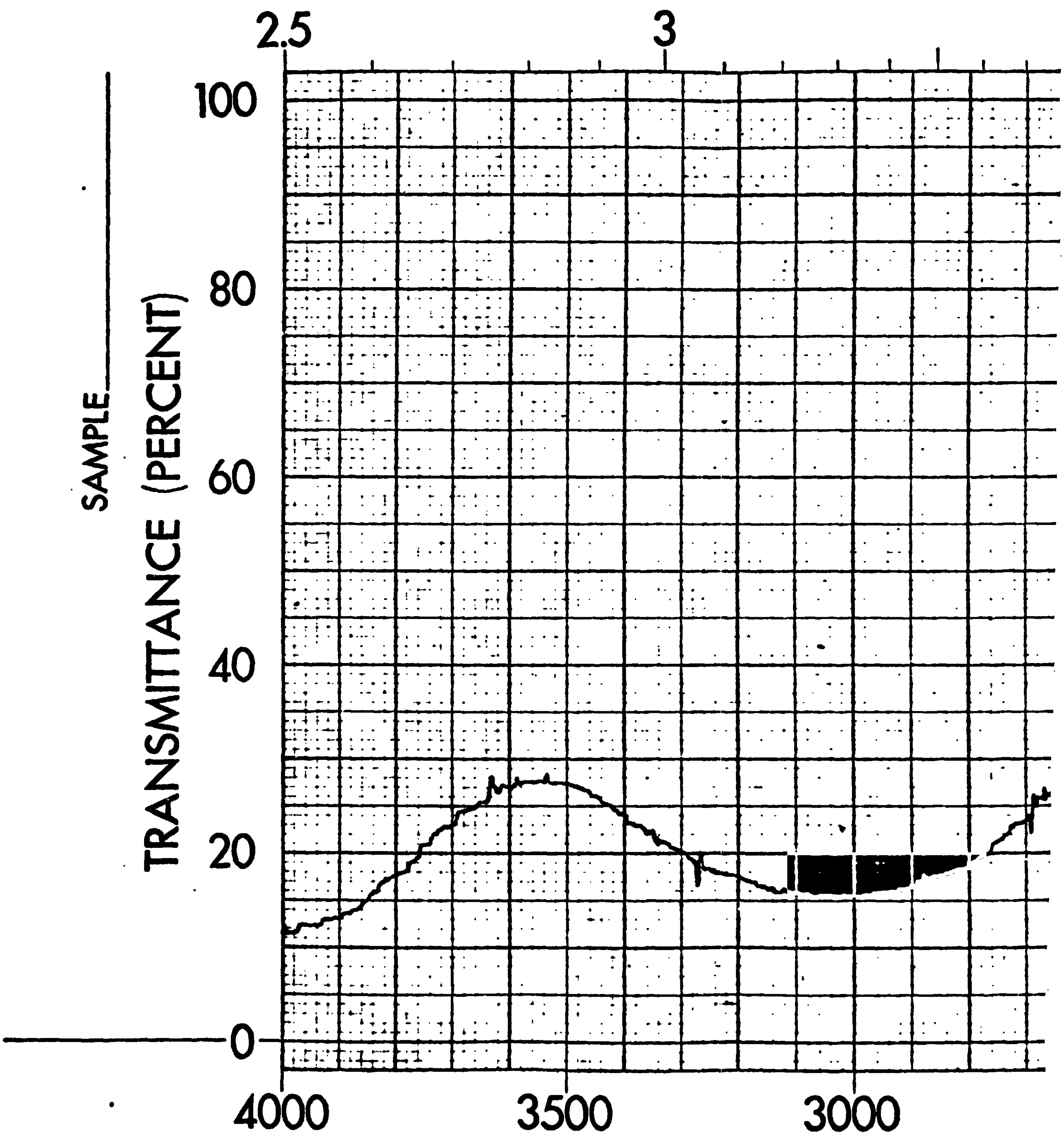
SUPPRESSION

SCALE EXPANSION

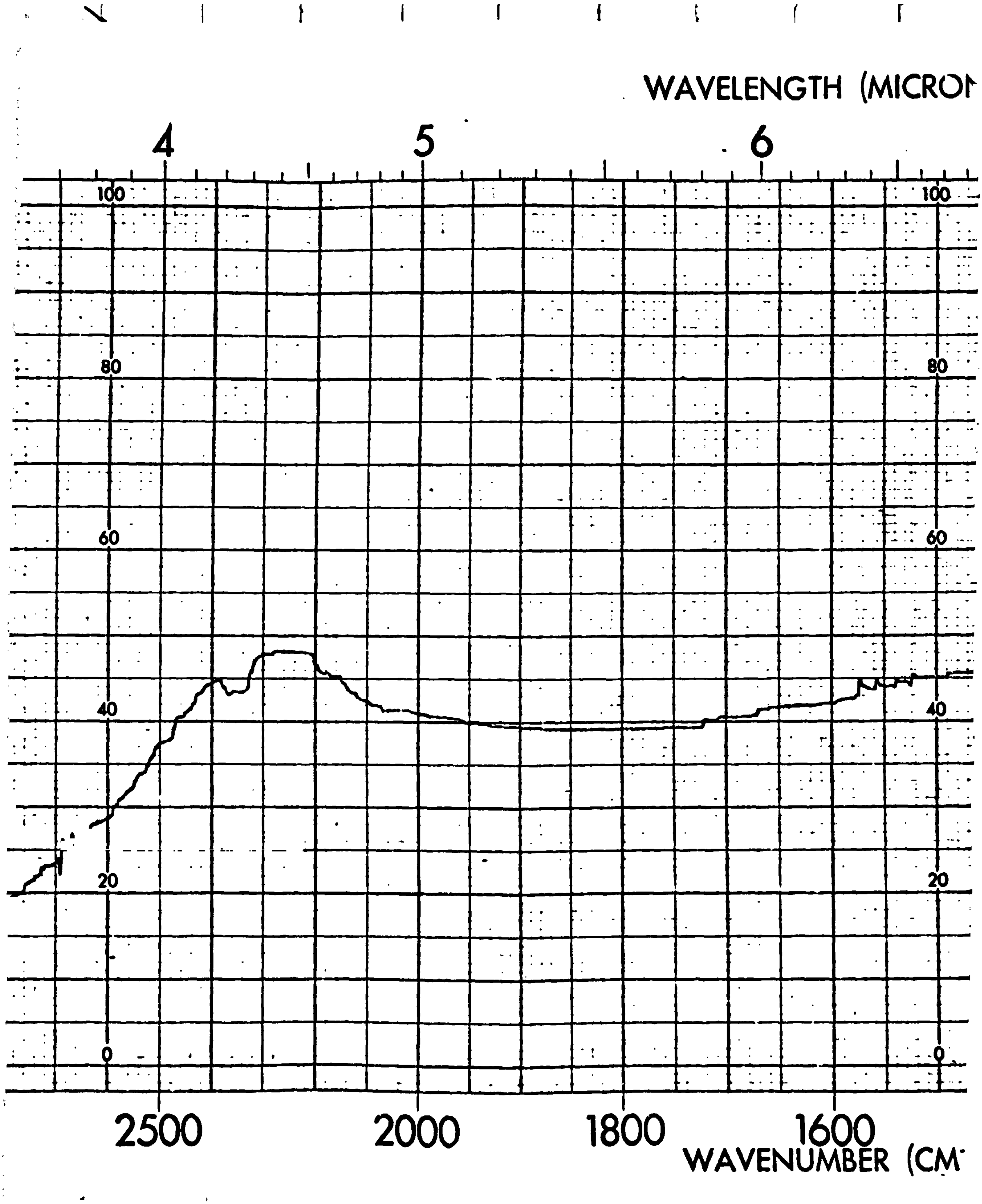
SOURCE CURRENT

NO. 221-1607

FOLDOUT FRAME



OLDOUT FRAME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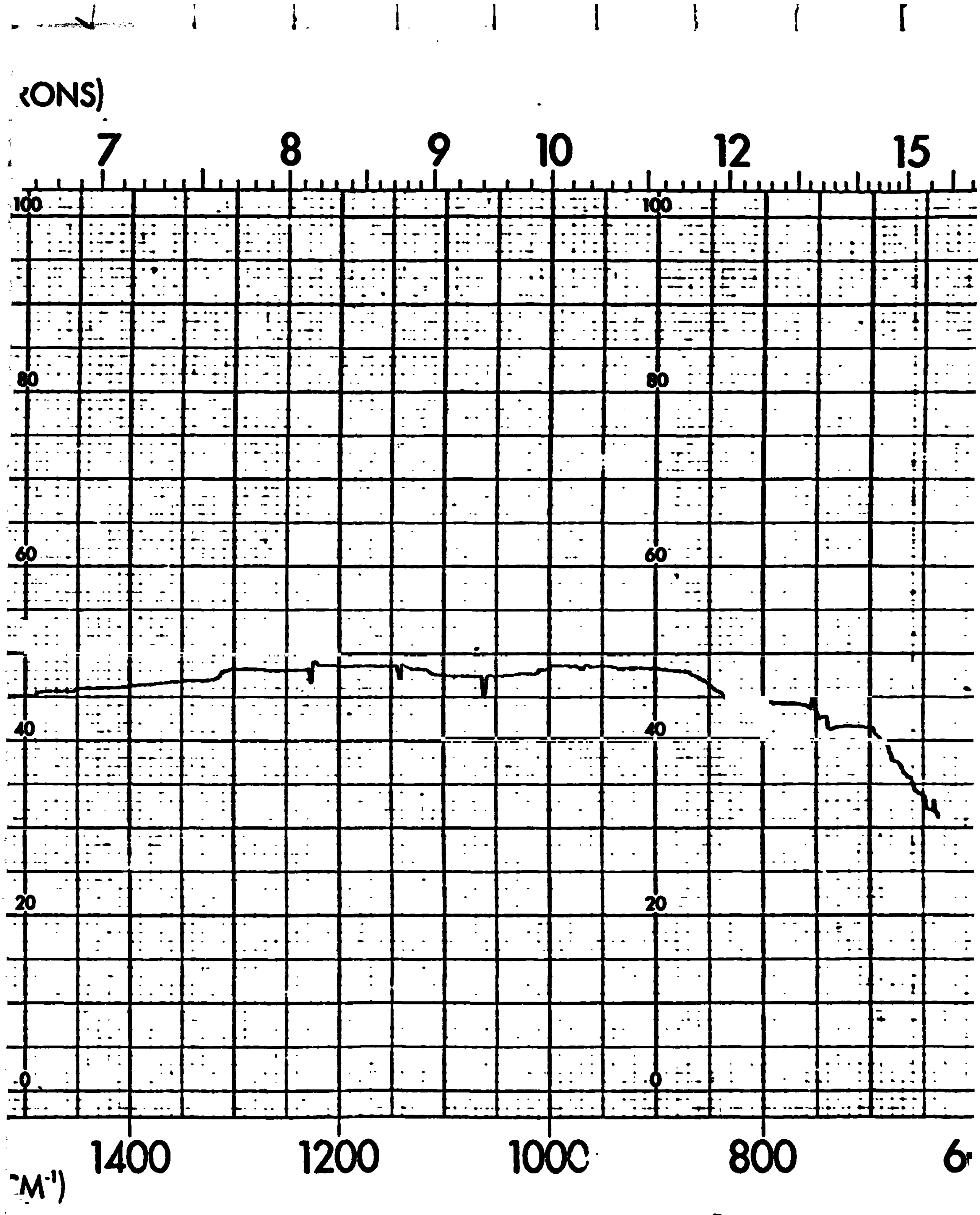
WAVENUMBER (CM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M-1)

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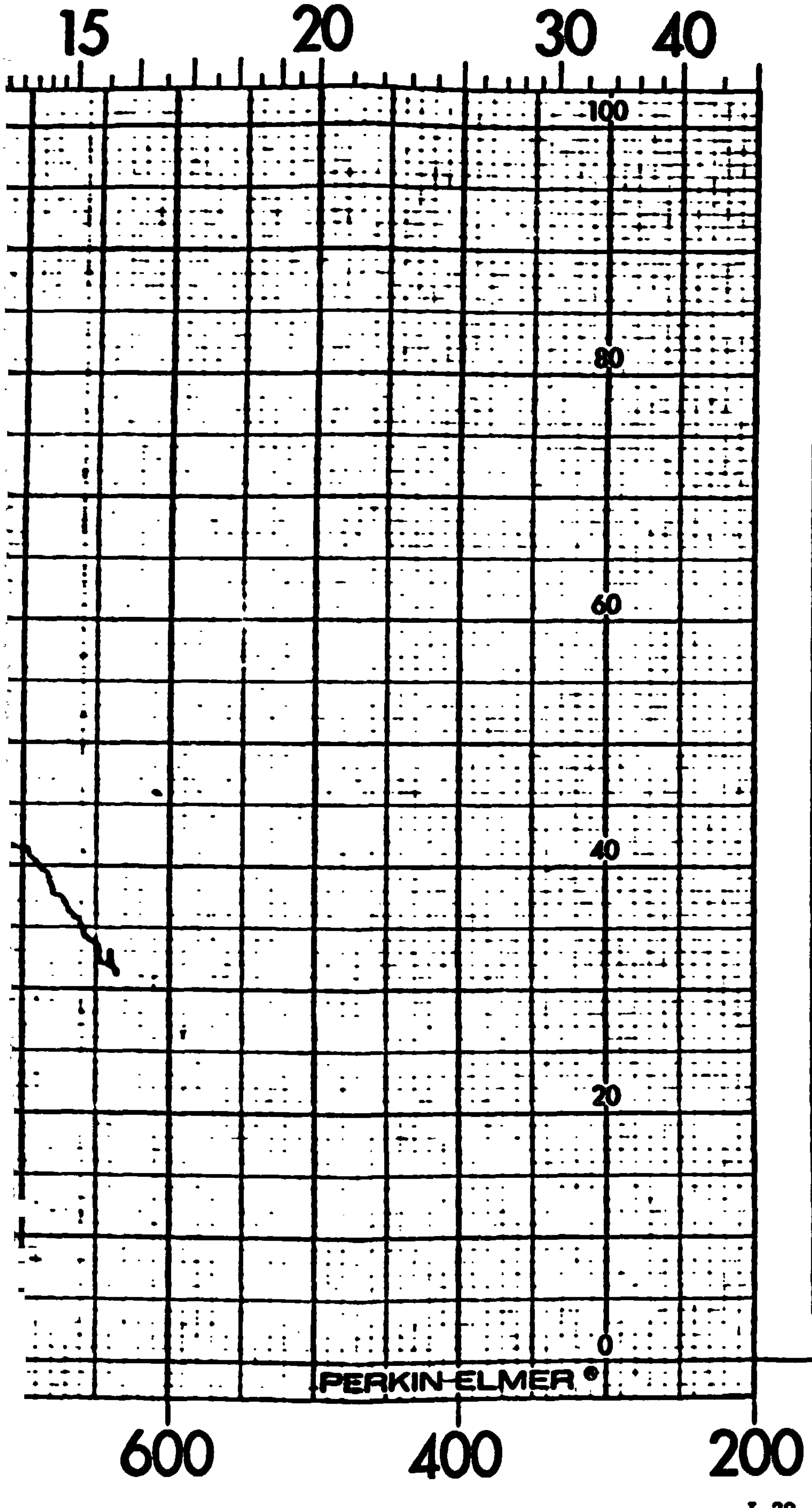


SPECTRUM NO. B-03137

SAMPLE SHI 112 After heating 3hrs. at 110°C

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 4/28/96

OPFRATOR

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

AT:ENUATOR SPEED

SCAN TIME

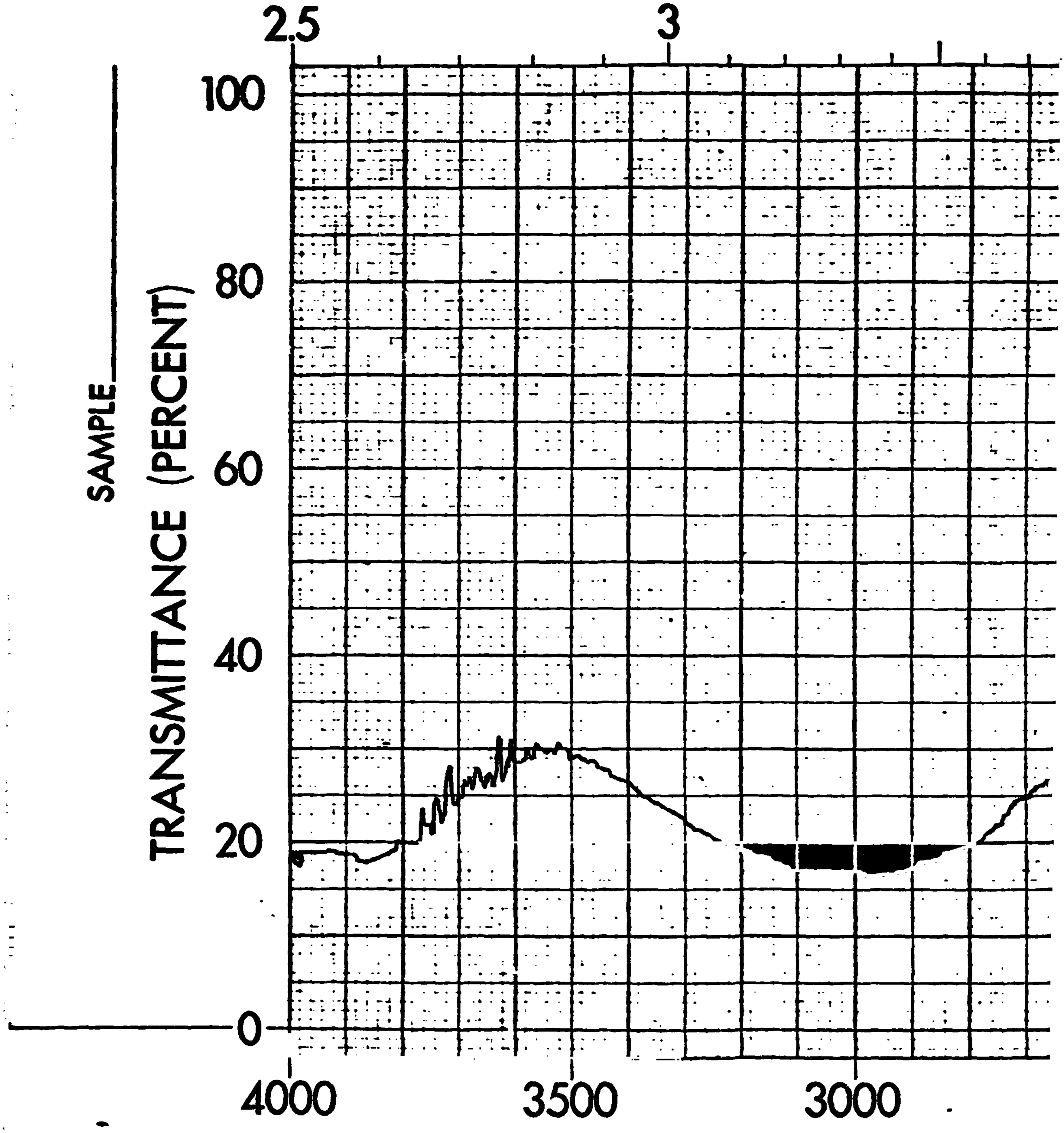
SUPPRESSION

SCALE EXPANSION

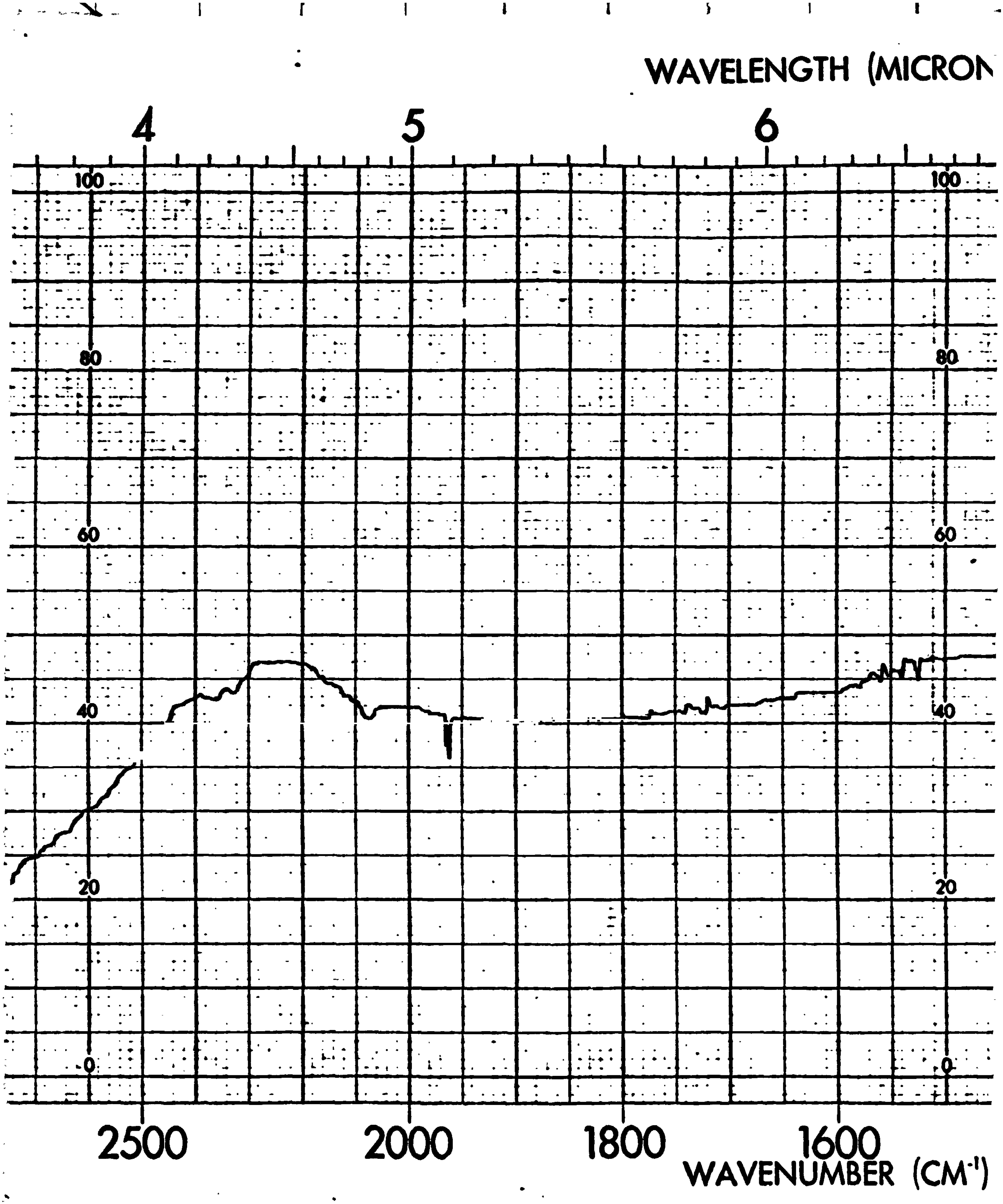
SOURCE CURRENT

NO. 221-1607

[illegible] 9

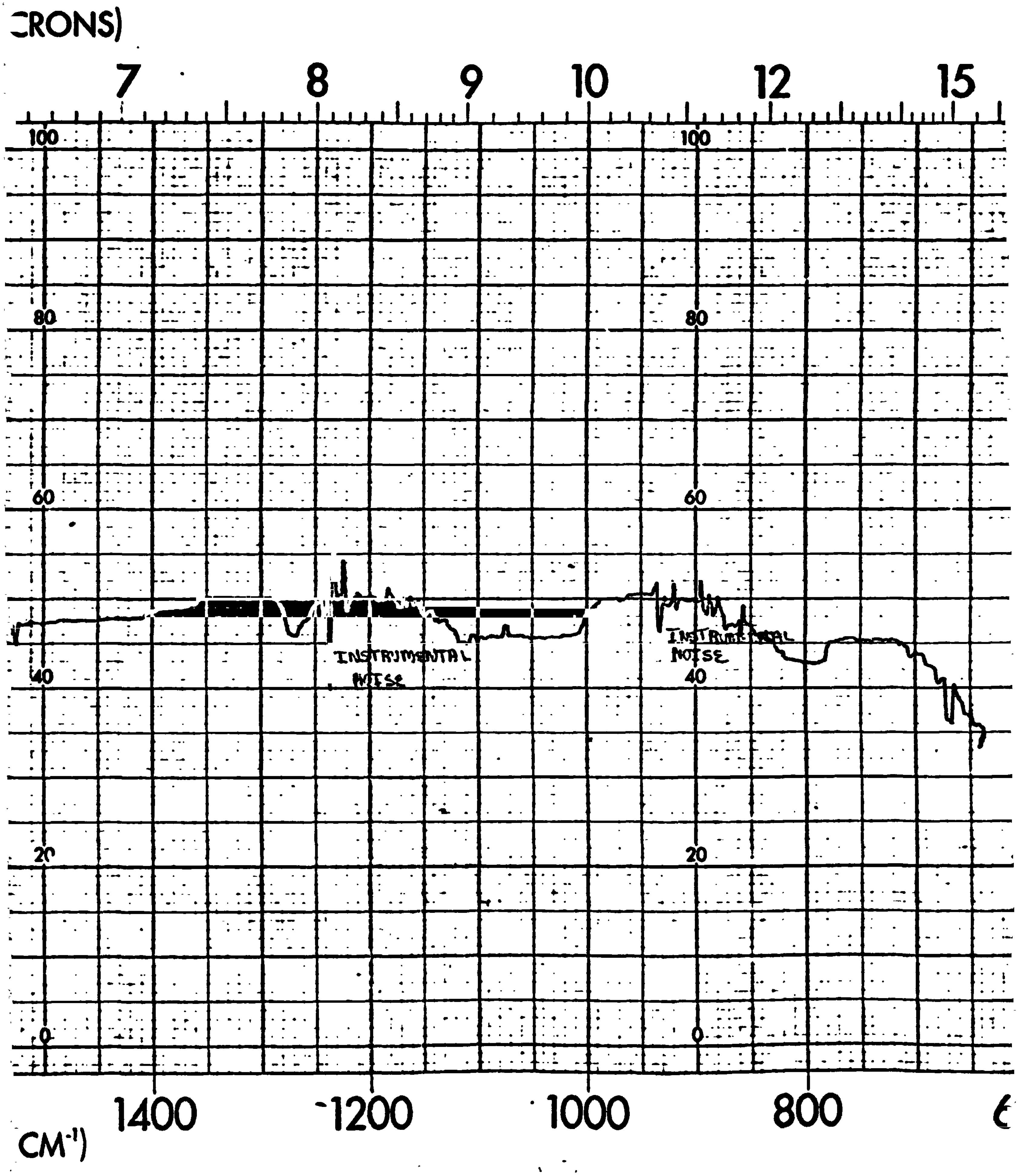


FOLDOUT FRAME

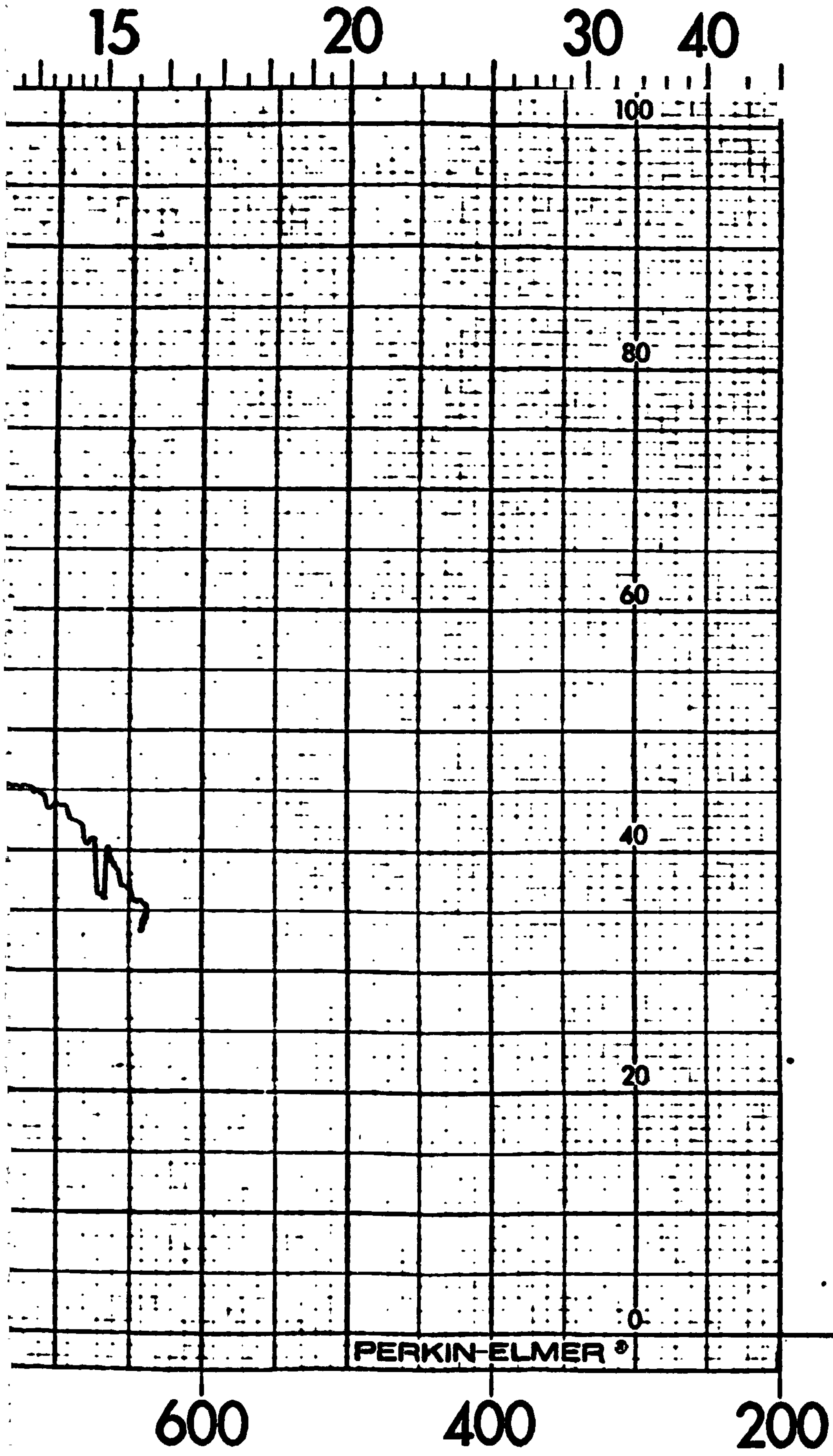


FOLDOUT FRAME 2

FC



FOLDOUT FRAME 3



SPECTRUM NO. B-03161

SAMPLE GAS CELL S/N 112

ORIGIN

PURITY

PHASE

THICKNESS CELL EXPOSED TO

1. NH_3 IN 80°C OVEN FOR 4 HR.

2.

3.

DATE 5/3/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

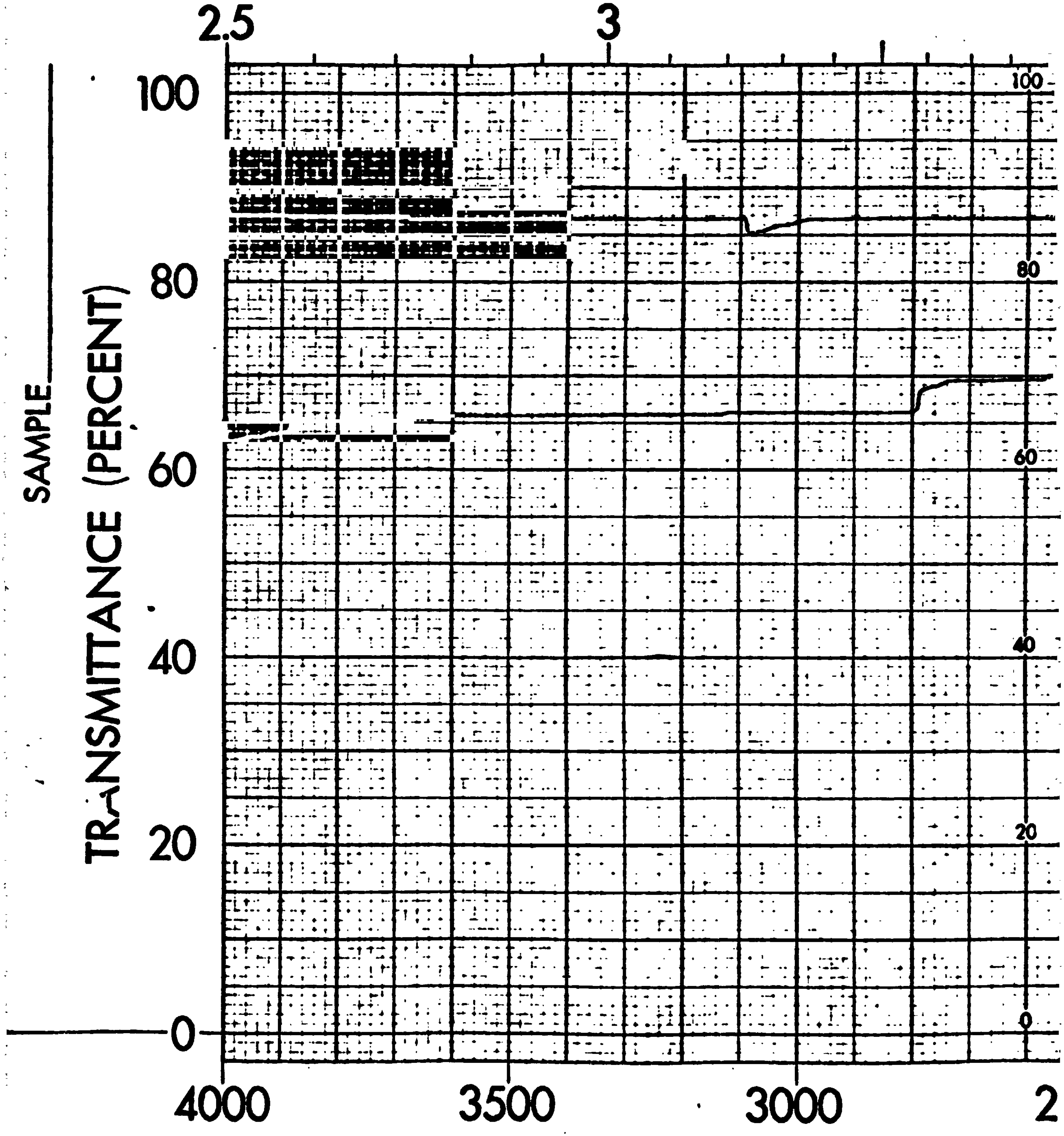
SCAN TIME

SUPPRESSION

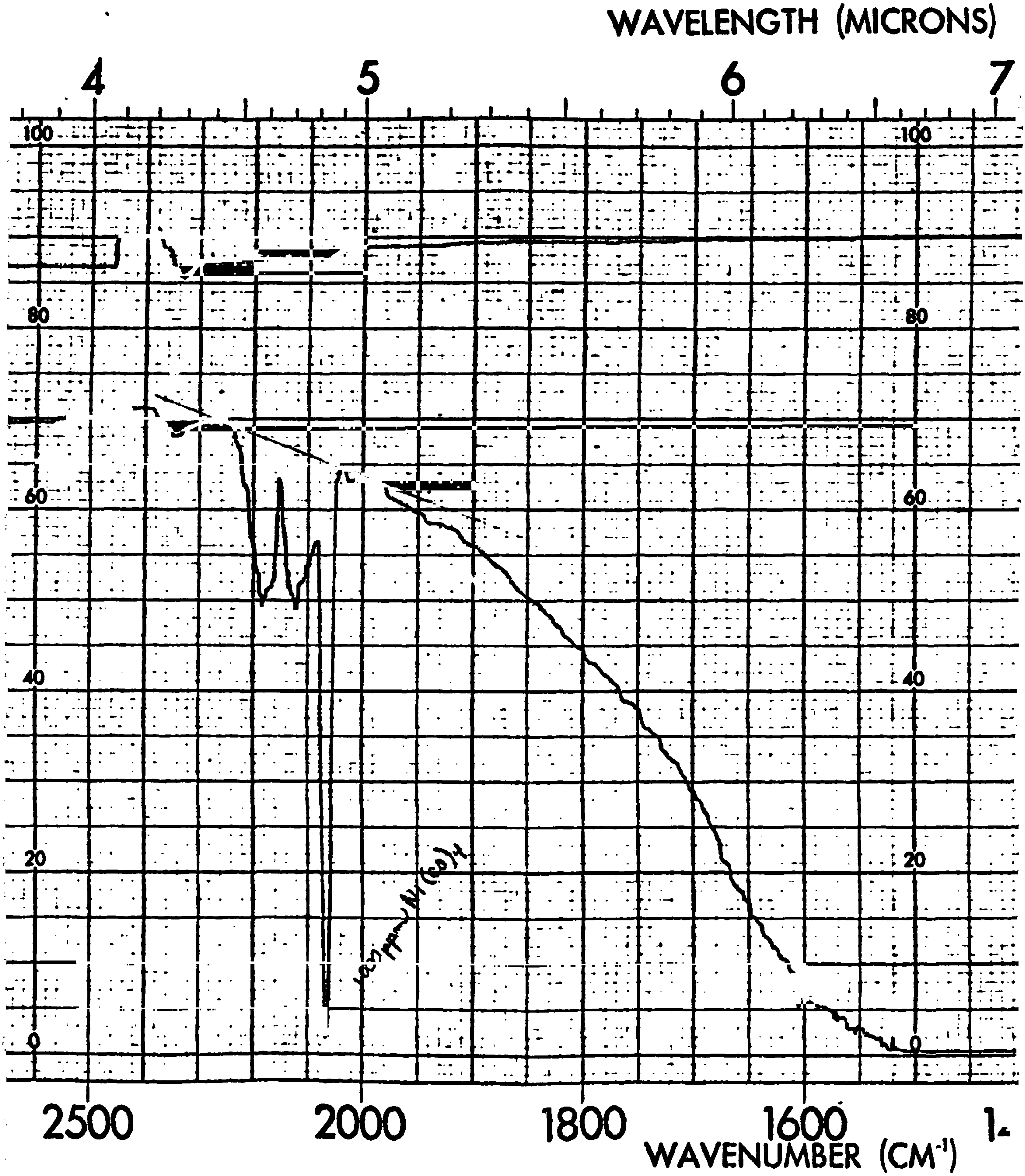
SCALE EXPANSION 1X

SOURCE CURRENT

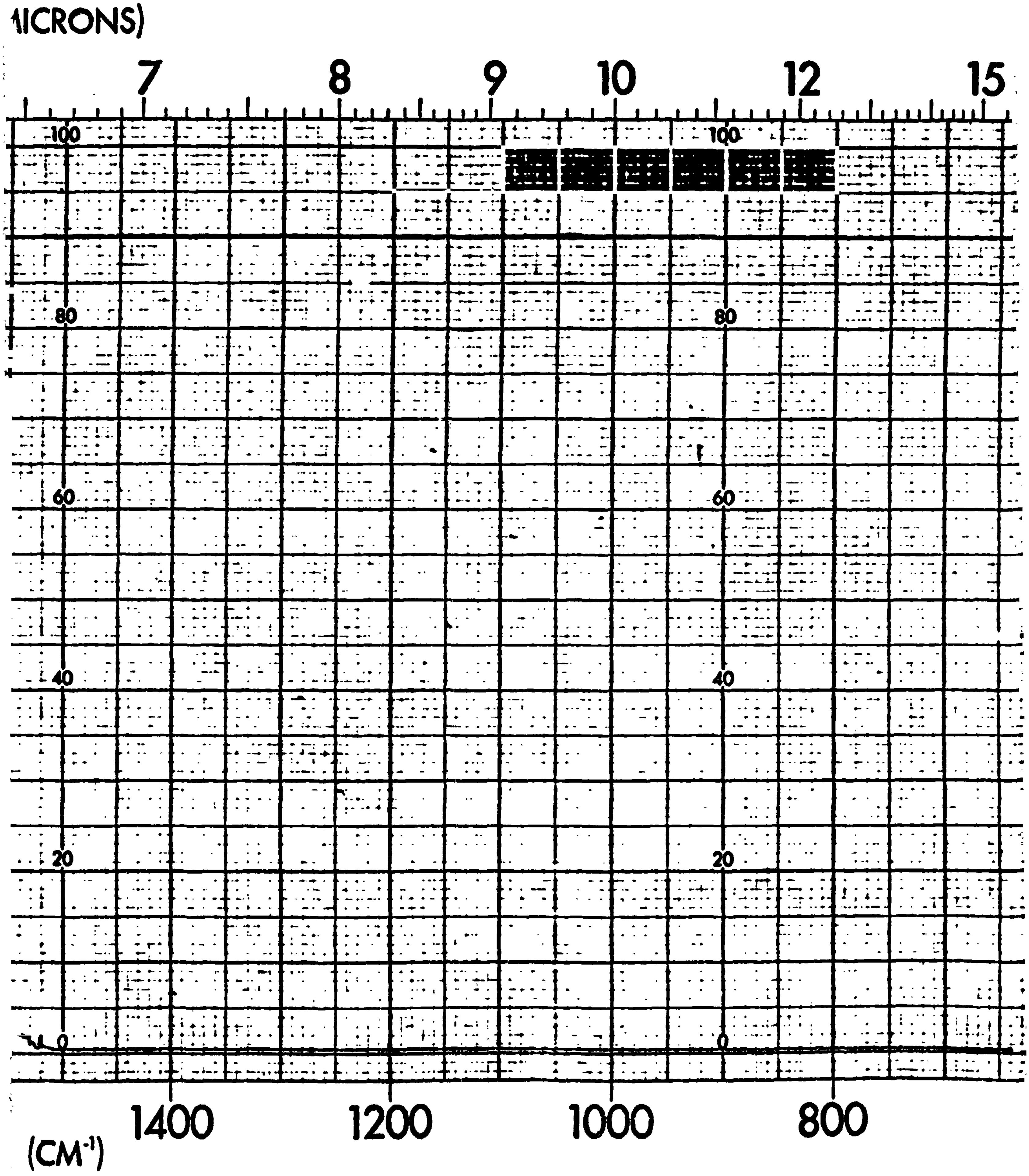
NO. 221-1607



FOLDOUT FRAME (

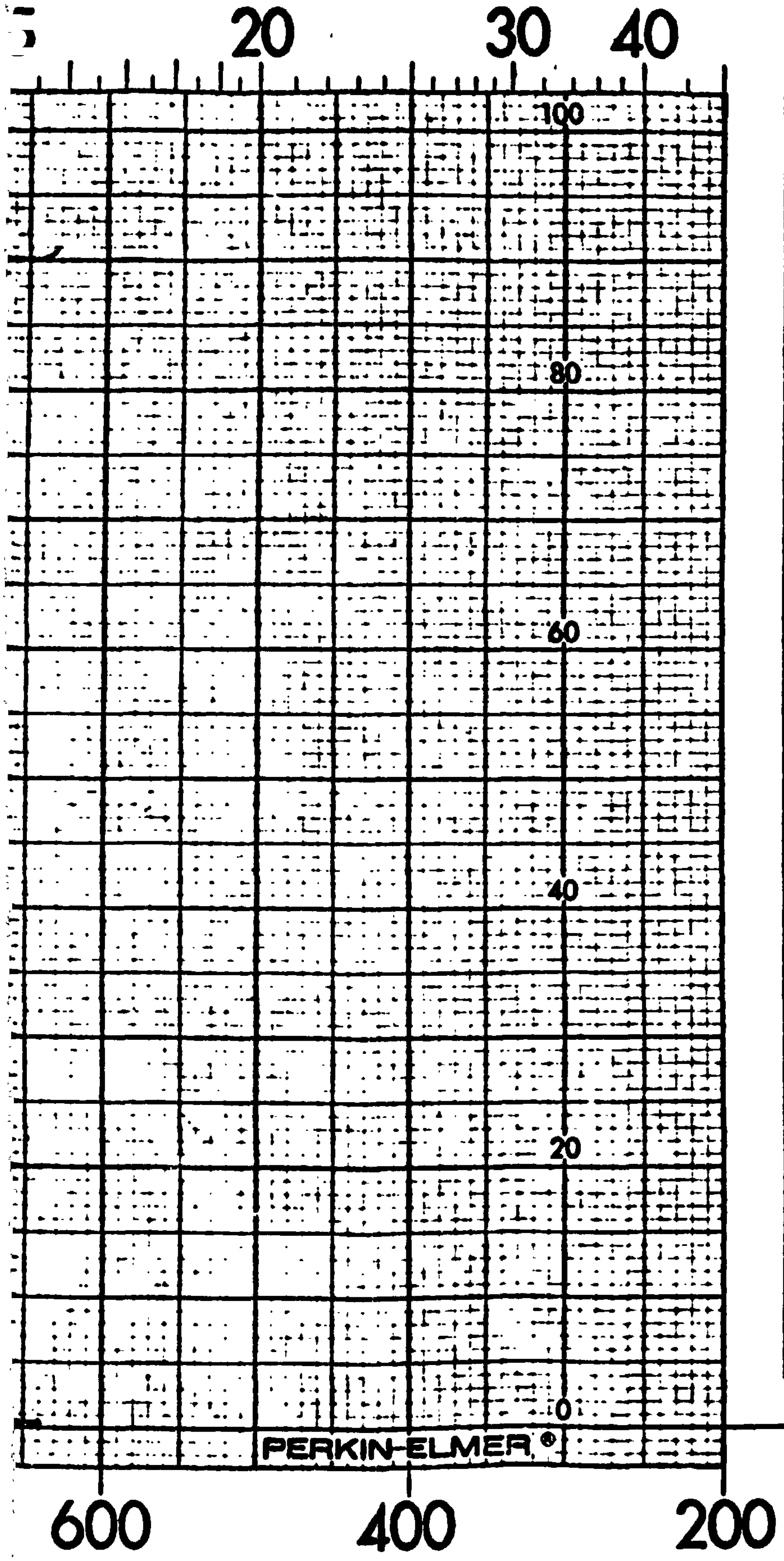


FOLDOUT FRAME 2



FOLDOUT FRAME

#17



SPECTRUM NO. B-03073

SAMPLE GAS CELL S/N 101

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 4/12/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

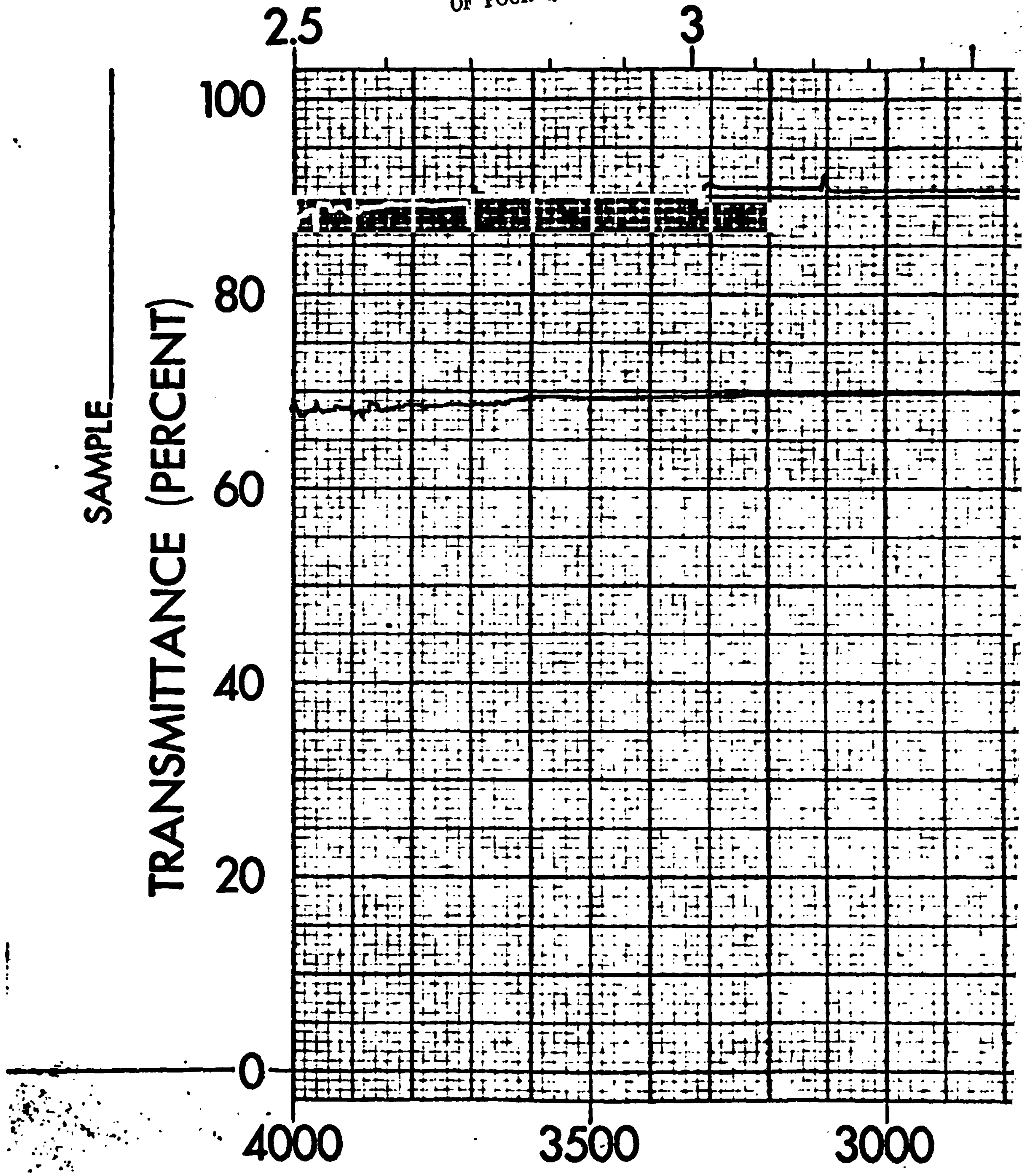
SUPPRESSION

SCALE EXPANSION

SOURCE CURRENT

NO. 221-1607

#18



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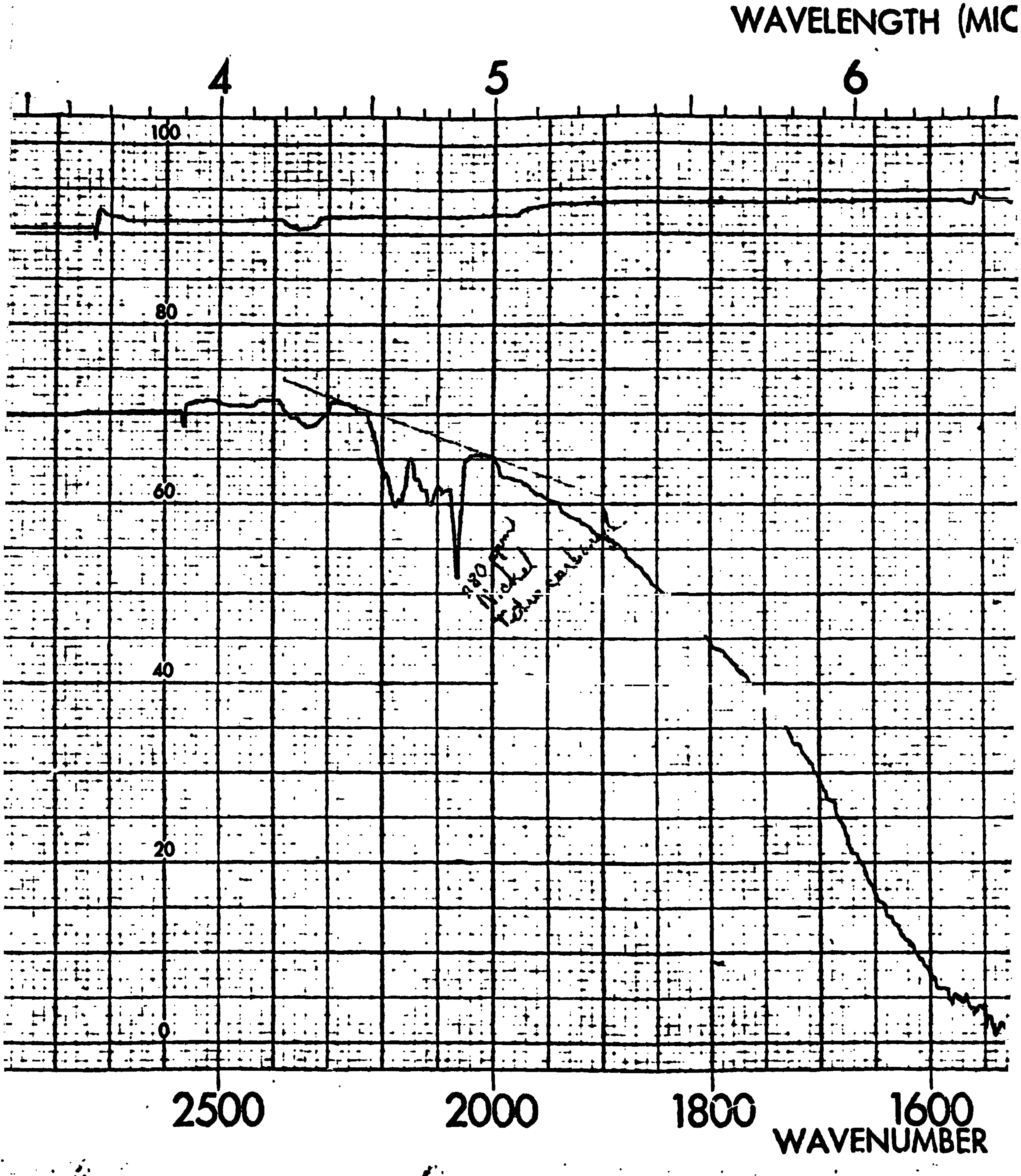

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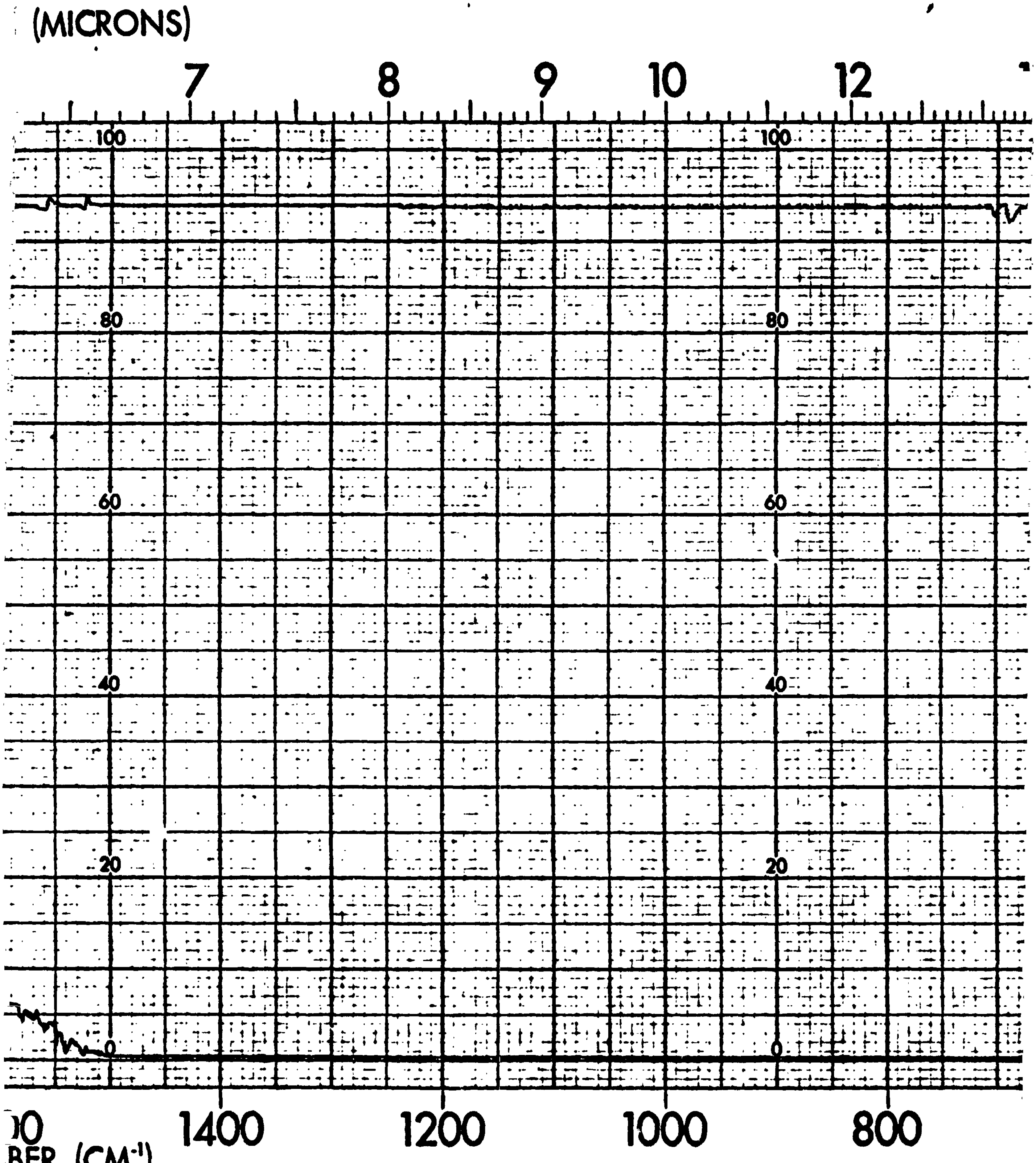

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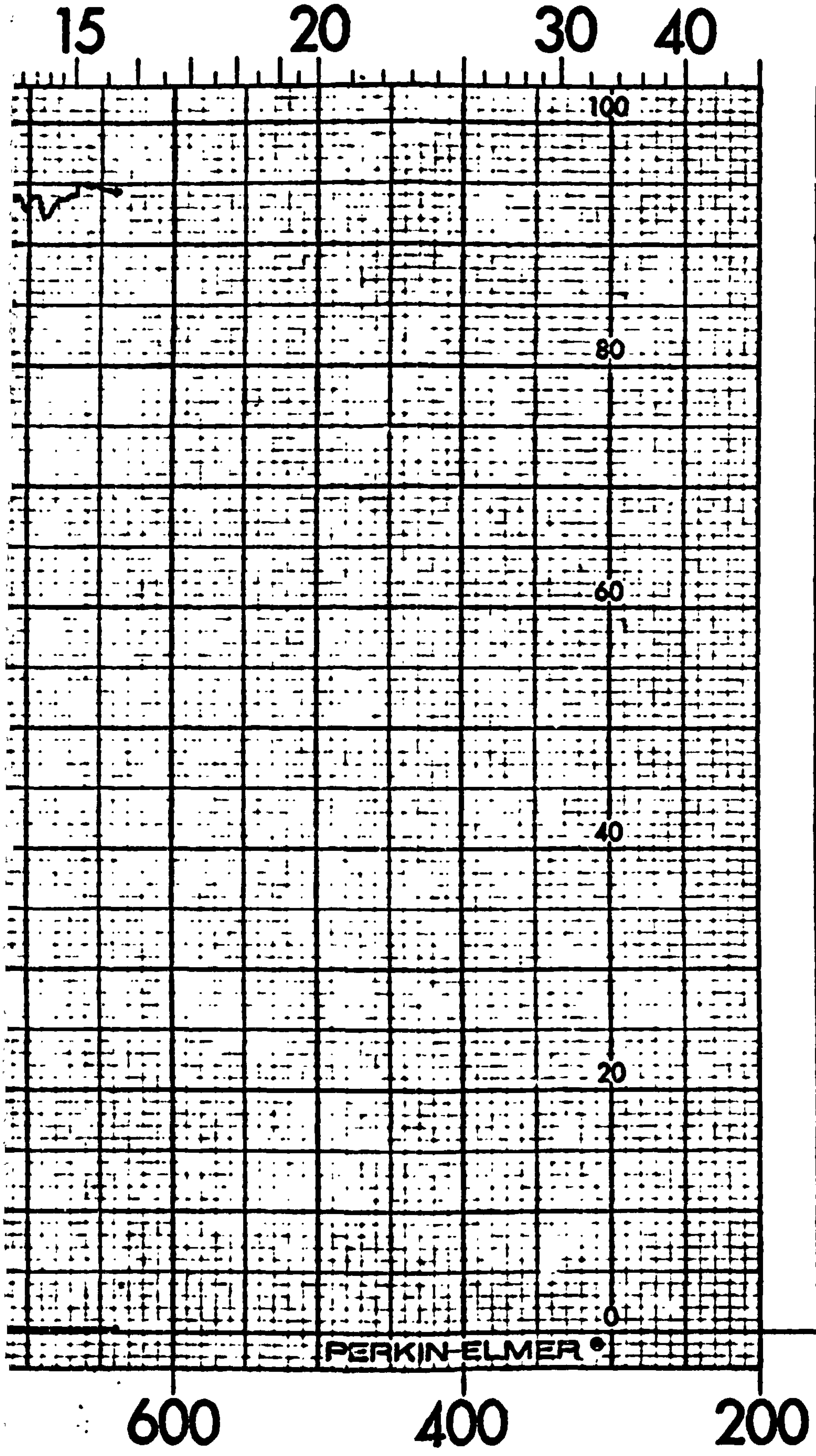


SPECTRUM NO. B-03074

SAMPLE Gas Cell S/N 102

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 4/12/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

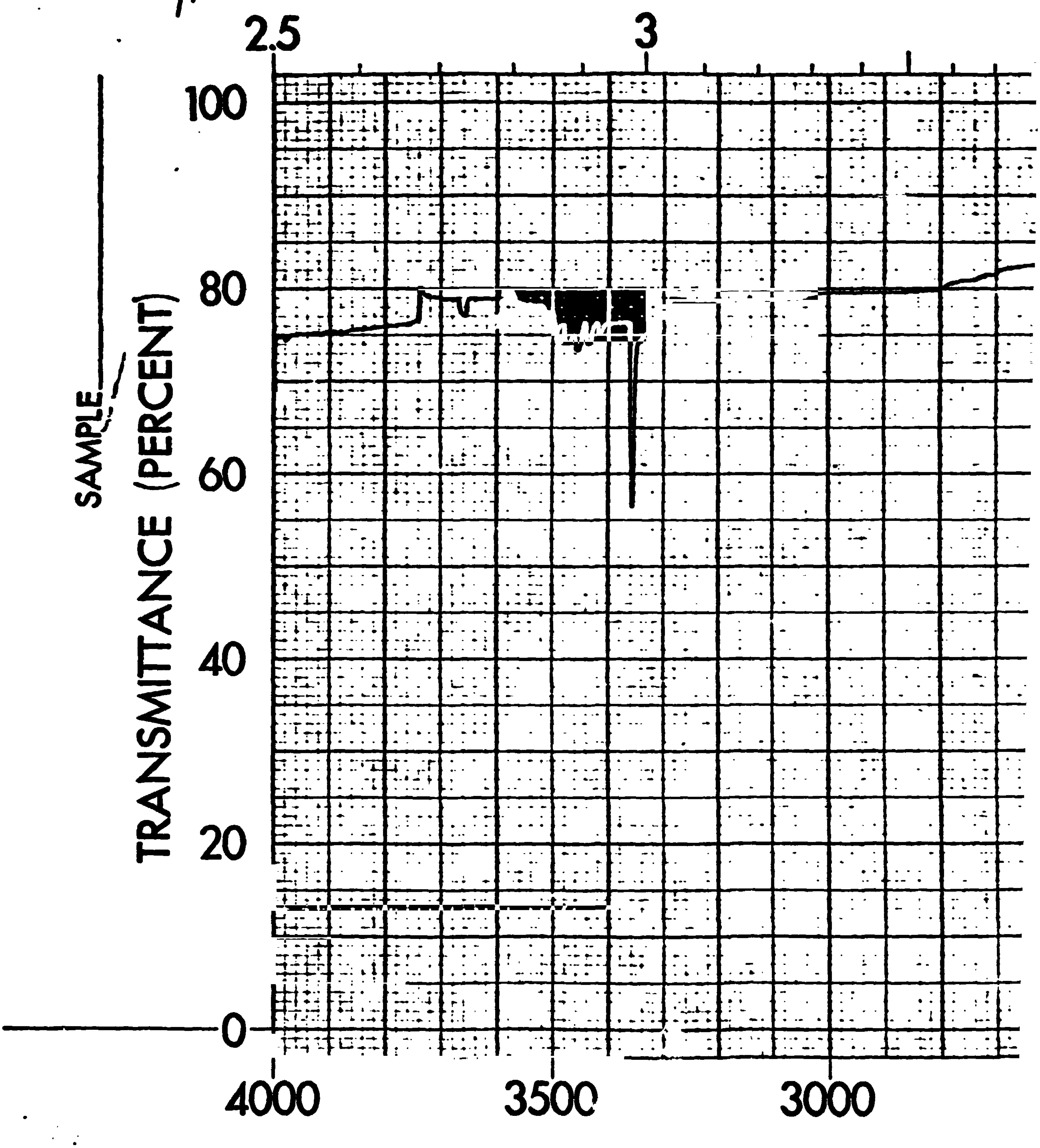
SUPPRESSION

SCALE EXPANSION

SOURCE CURRENT

NO. 221-1607

pl#



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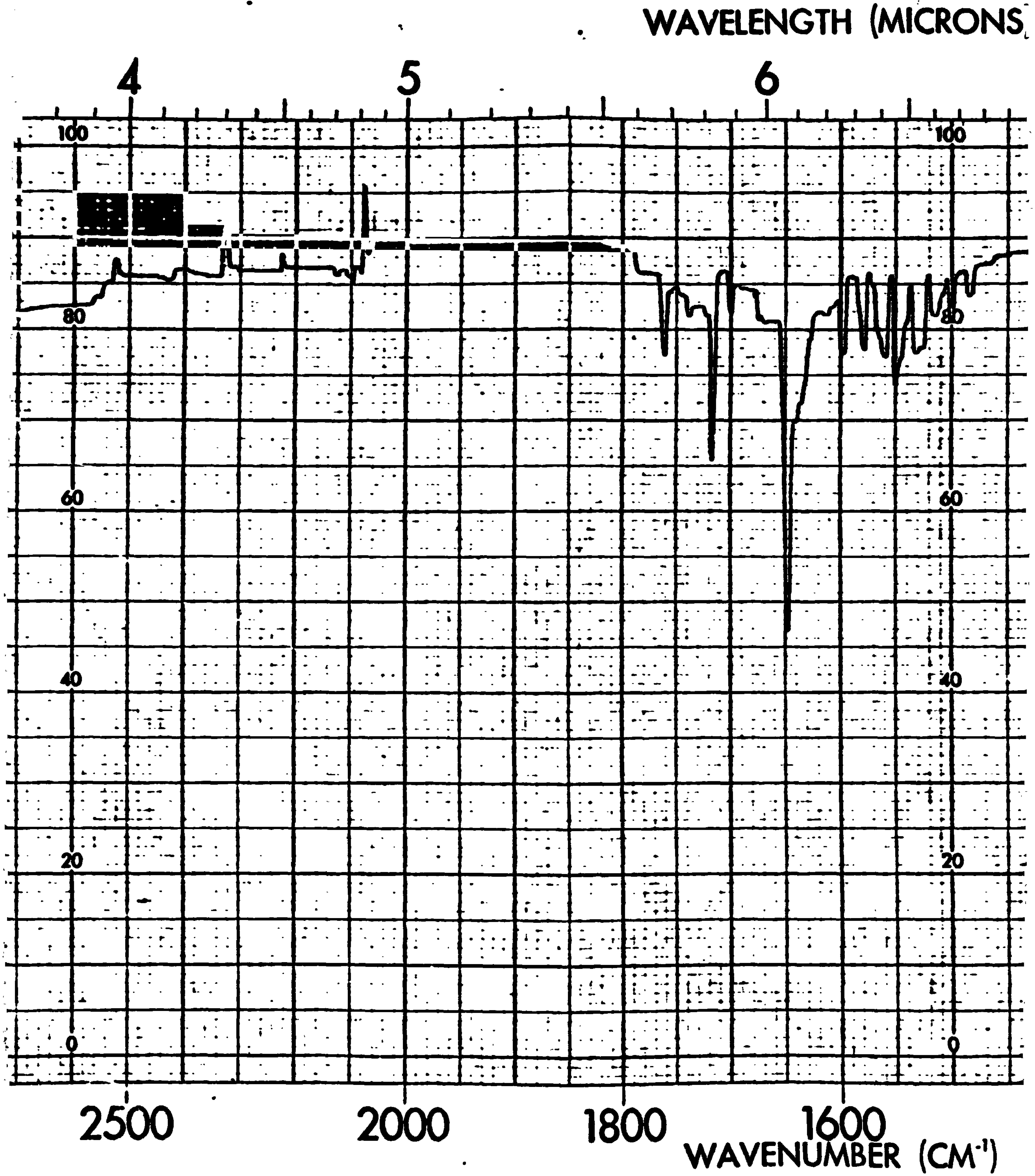
WAVELENGTH (MICRONS)
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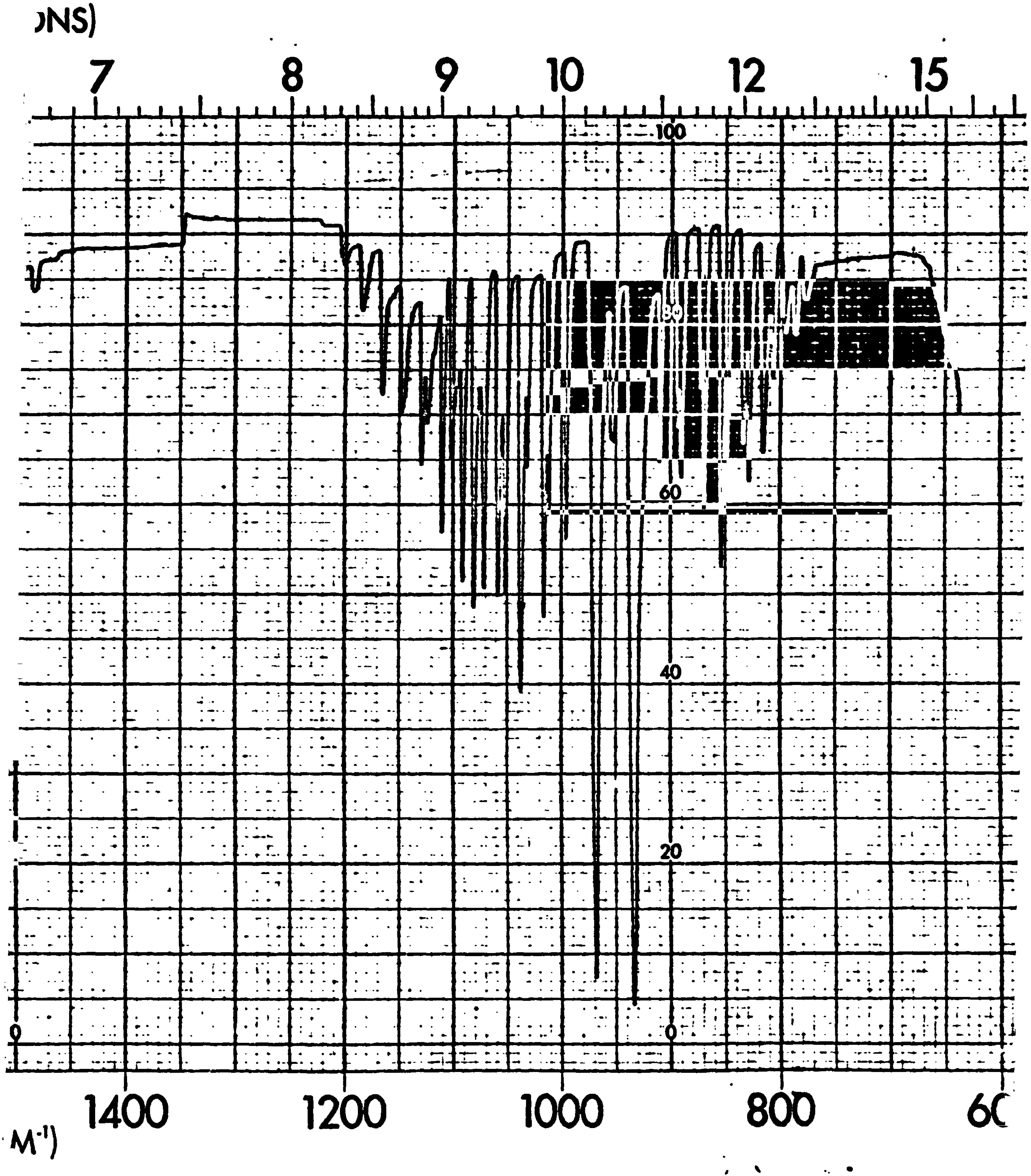
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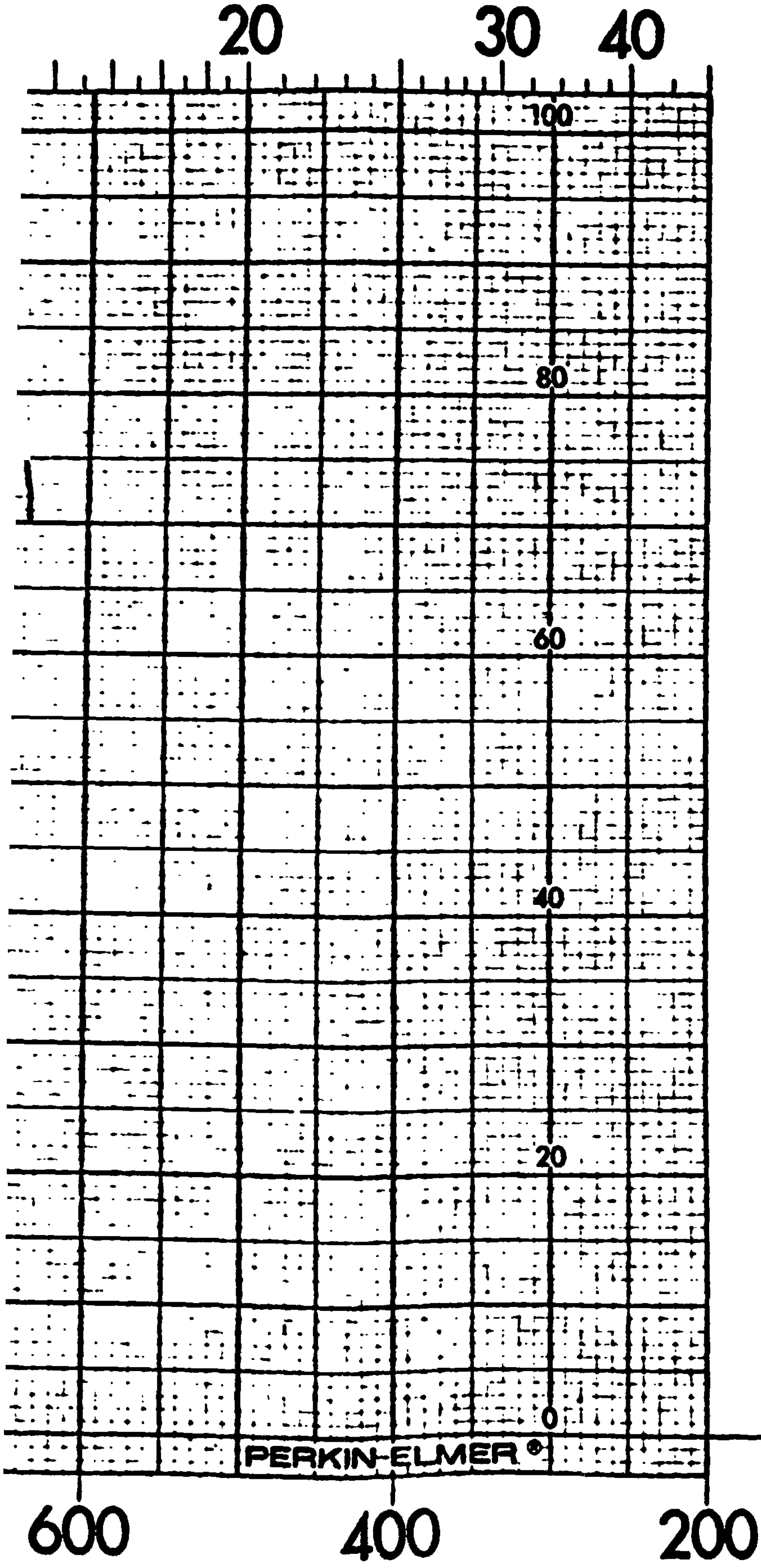


SPECTRUM NO. B-03210

SAMPLE 5 cm Gas Cell with NH3

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 5/17/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

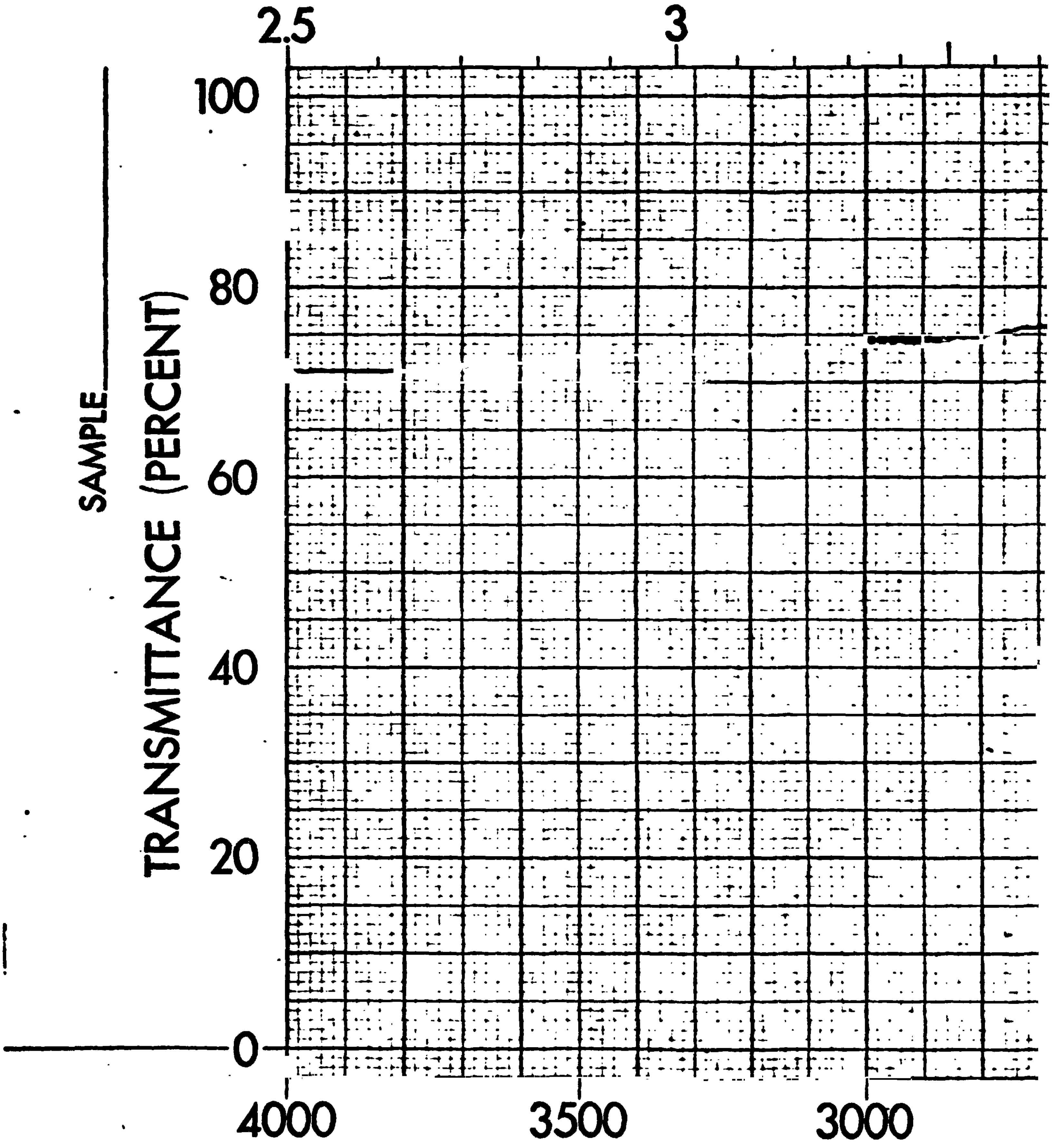
SUPPRESSION

SCALE EXPANSION 1X

SOURCE CURRENT

NO. 221-1607

#20



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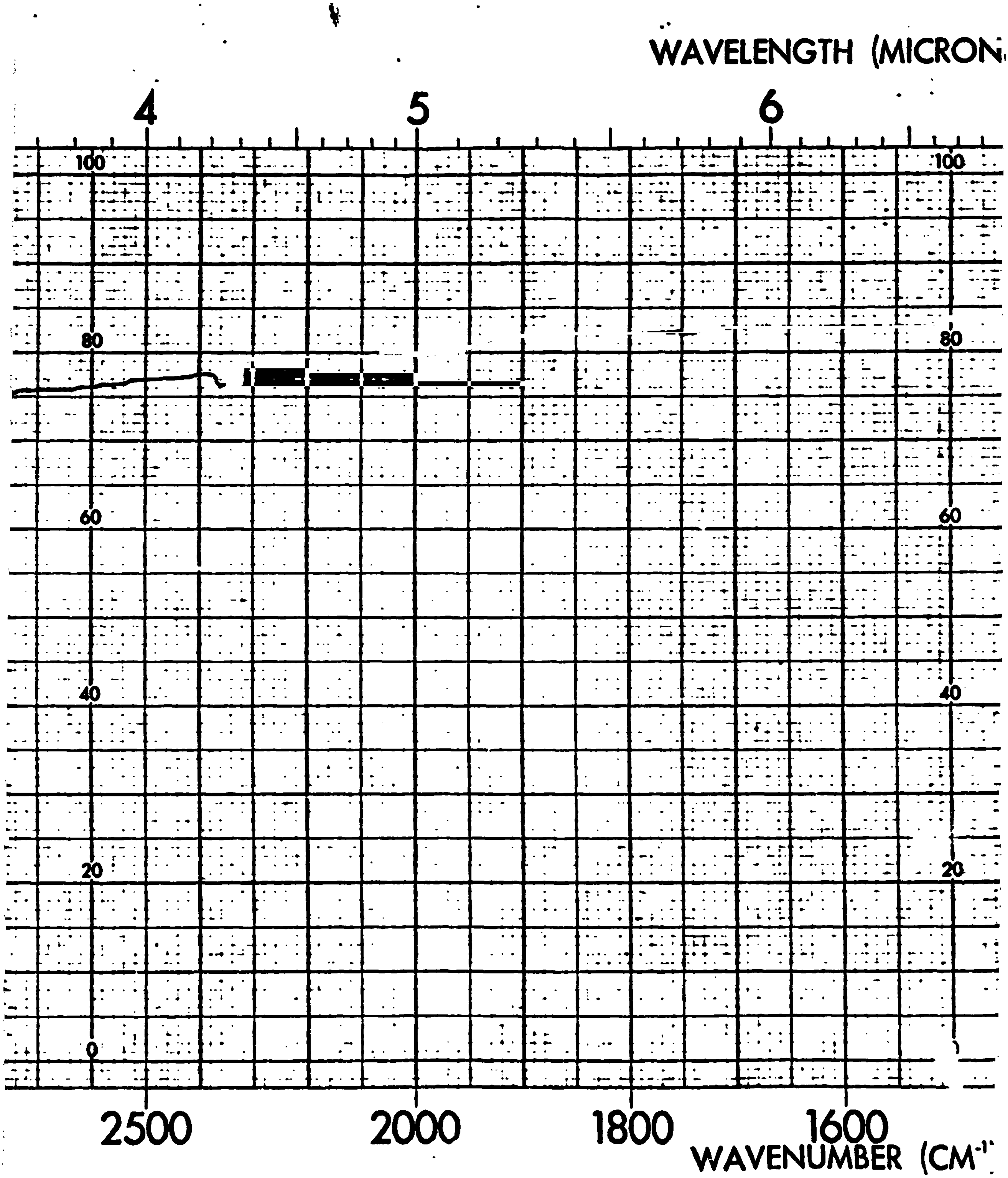
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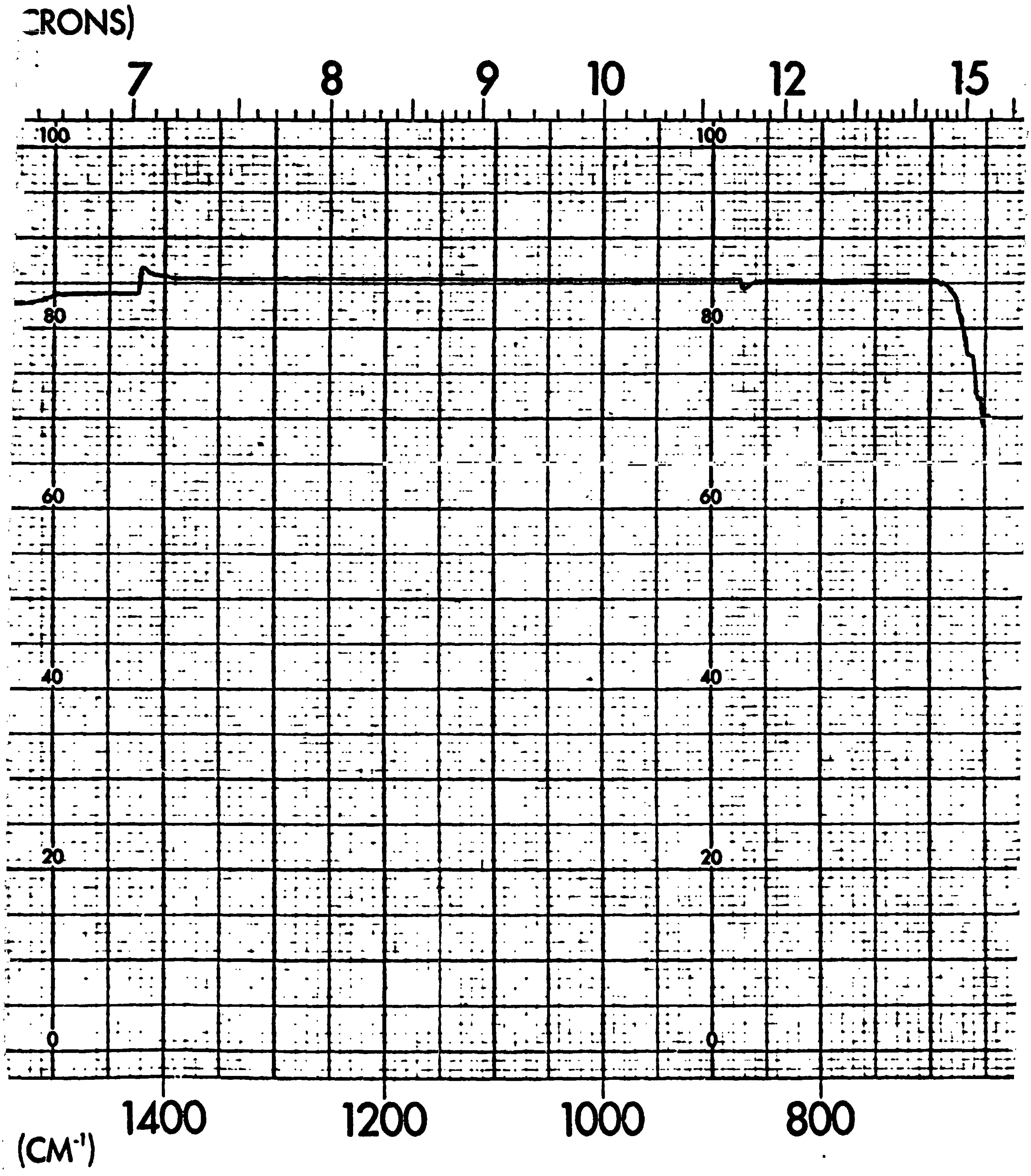
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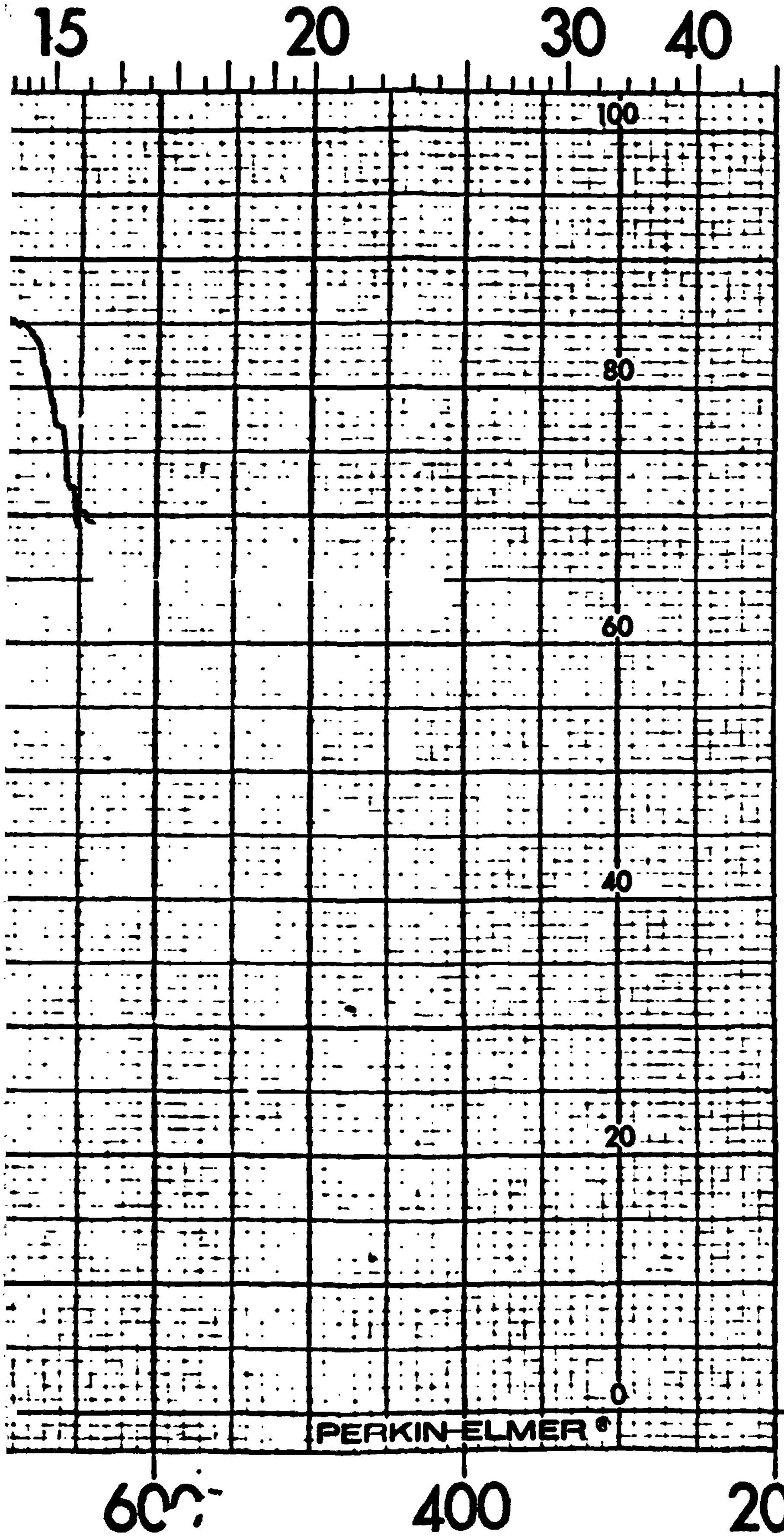


SPECTRUM NO. B-03217

SAMPLE 5 Cm. Gas Cell with NH3 After Being in 85°C oven For

ORIGIN 24 Hrs

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 5/18/76

OPERATOR Kennedy

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

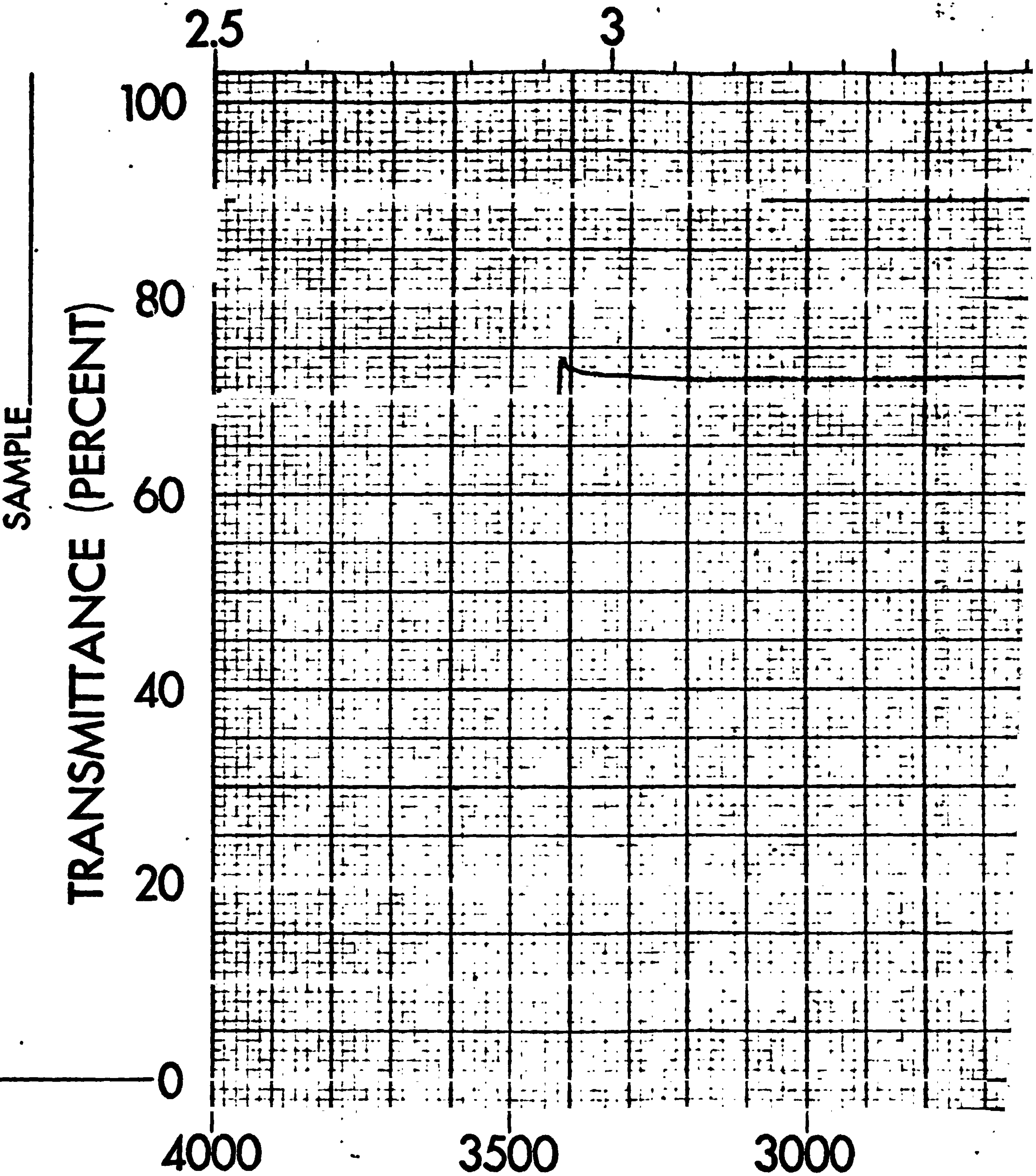
SUPPRESSION

SCALE EXPANSION 1X

SOURCE CURRENT

NO. 221-1607

127



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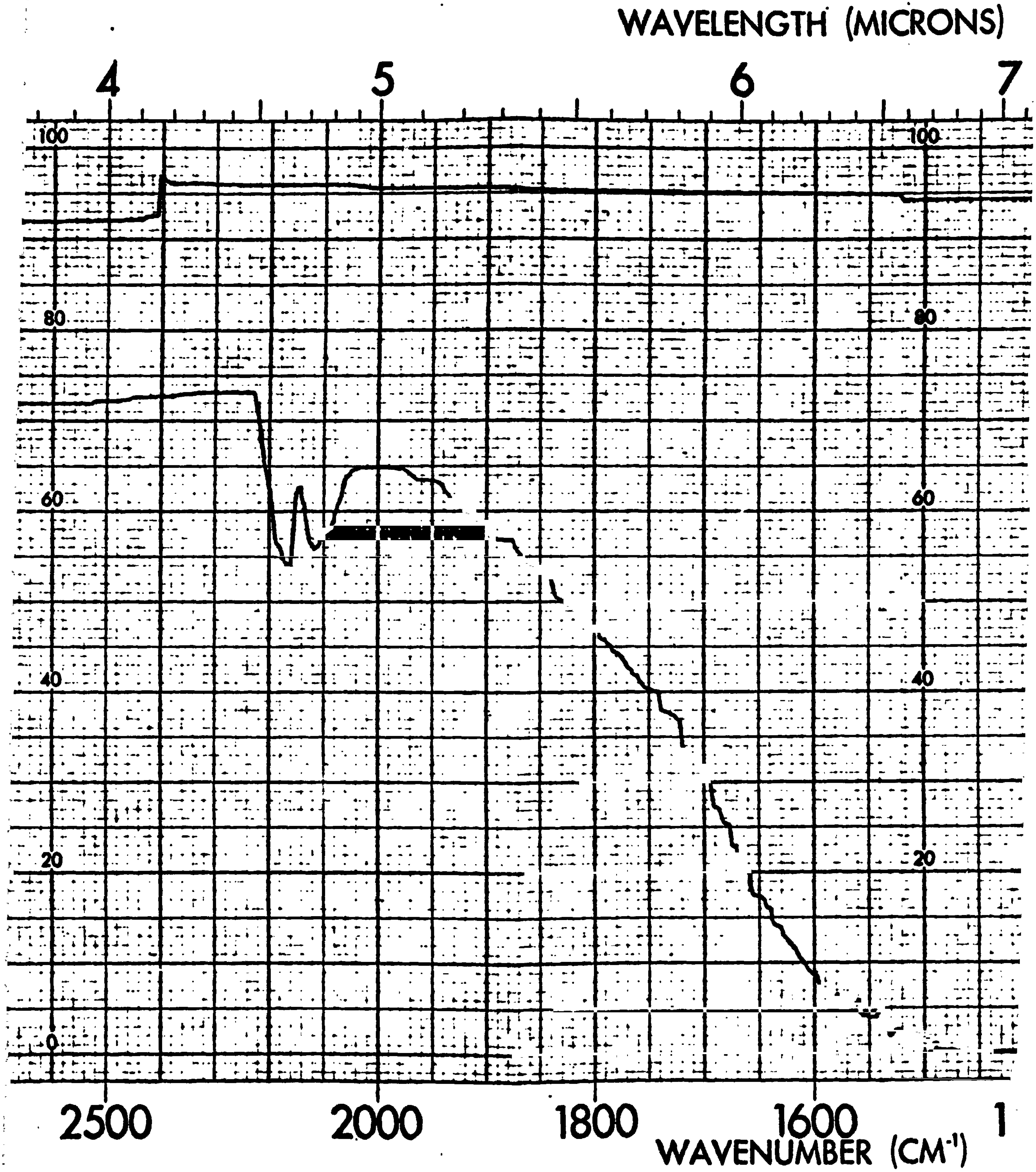
WAVELENGTH (MICRONS)
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WAVENUMBER (CM-1)

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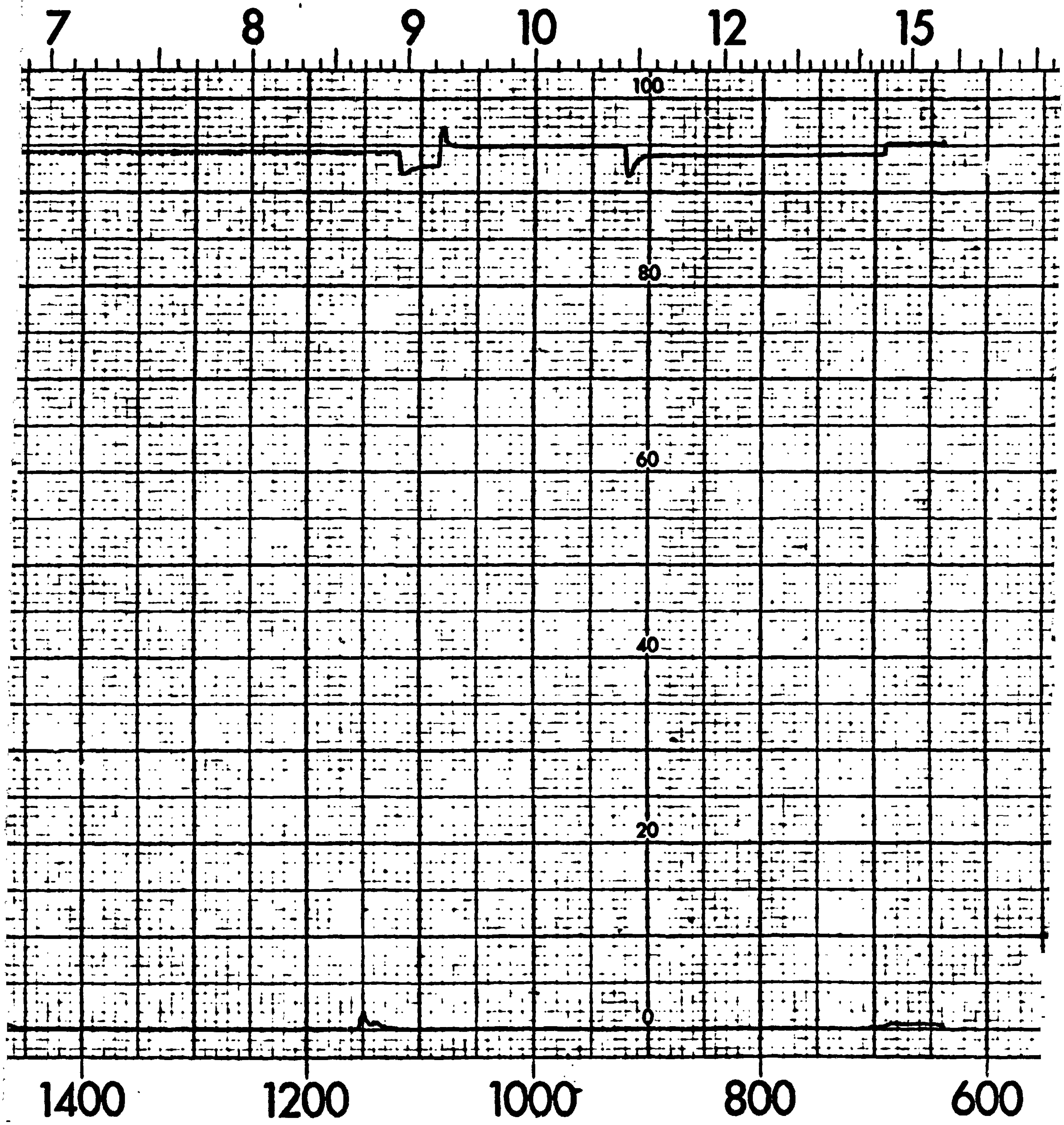
S)



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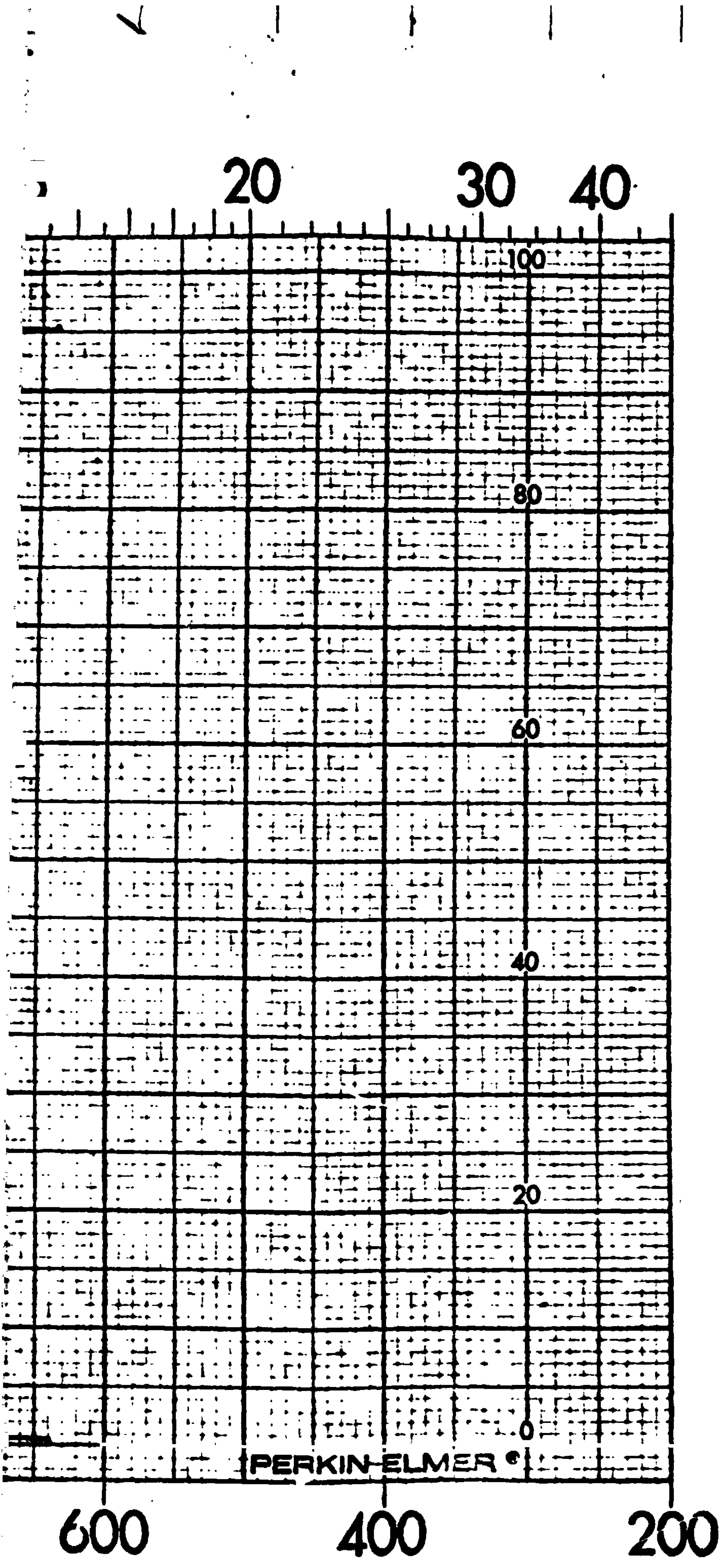


SPECTRUM NO. B-0327

SAMPLE GAS CELL S/N 108

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 6/9/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

SUPPRESSION

SCALE EXPANSION

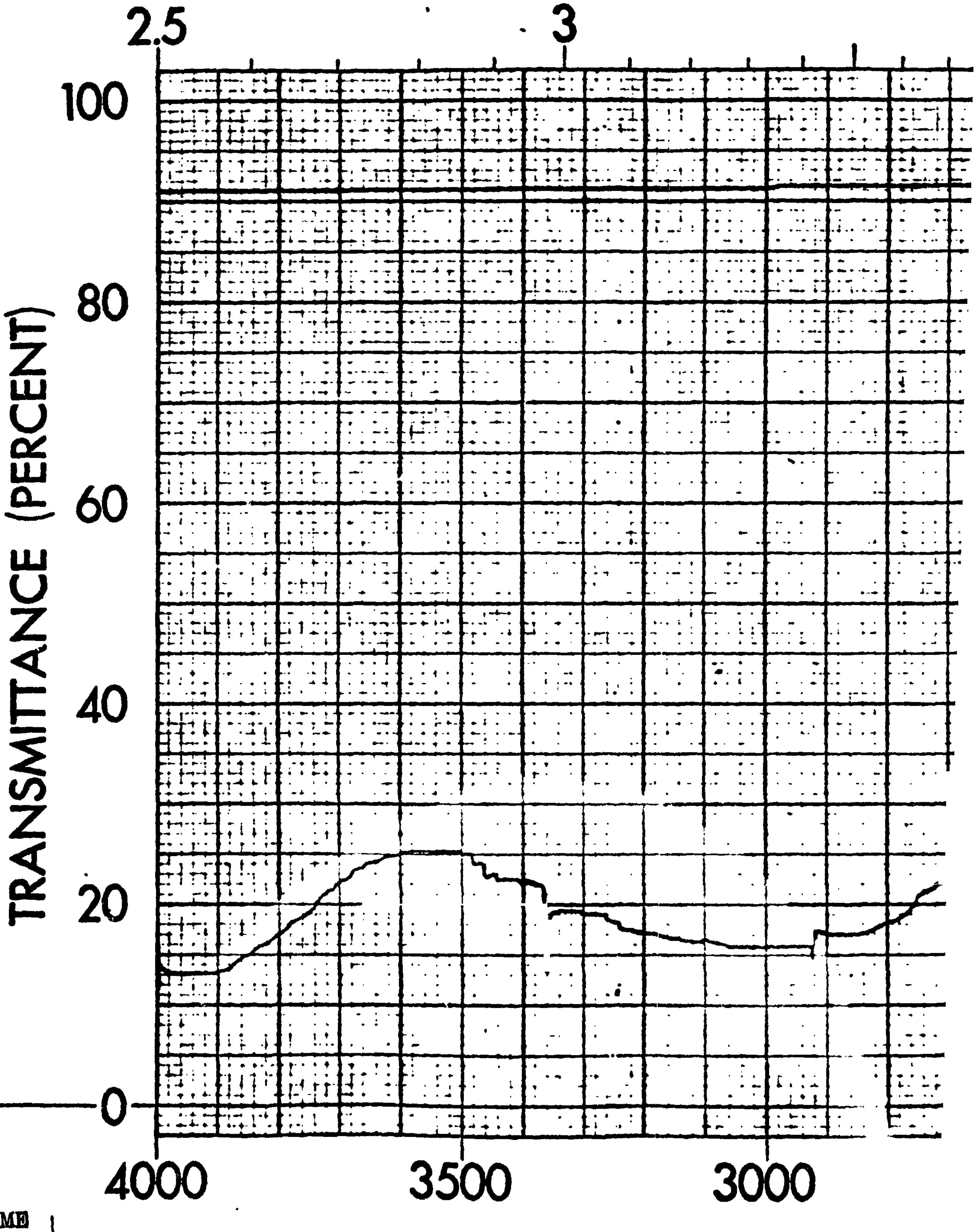
SOURCE CURRENT

NO. 221-1607

FOLDOUT FRAME 4

#22

SAMPLE



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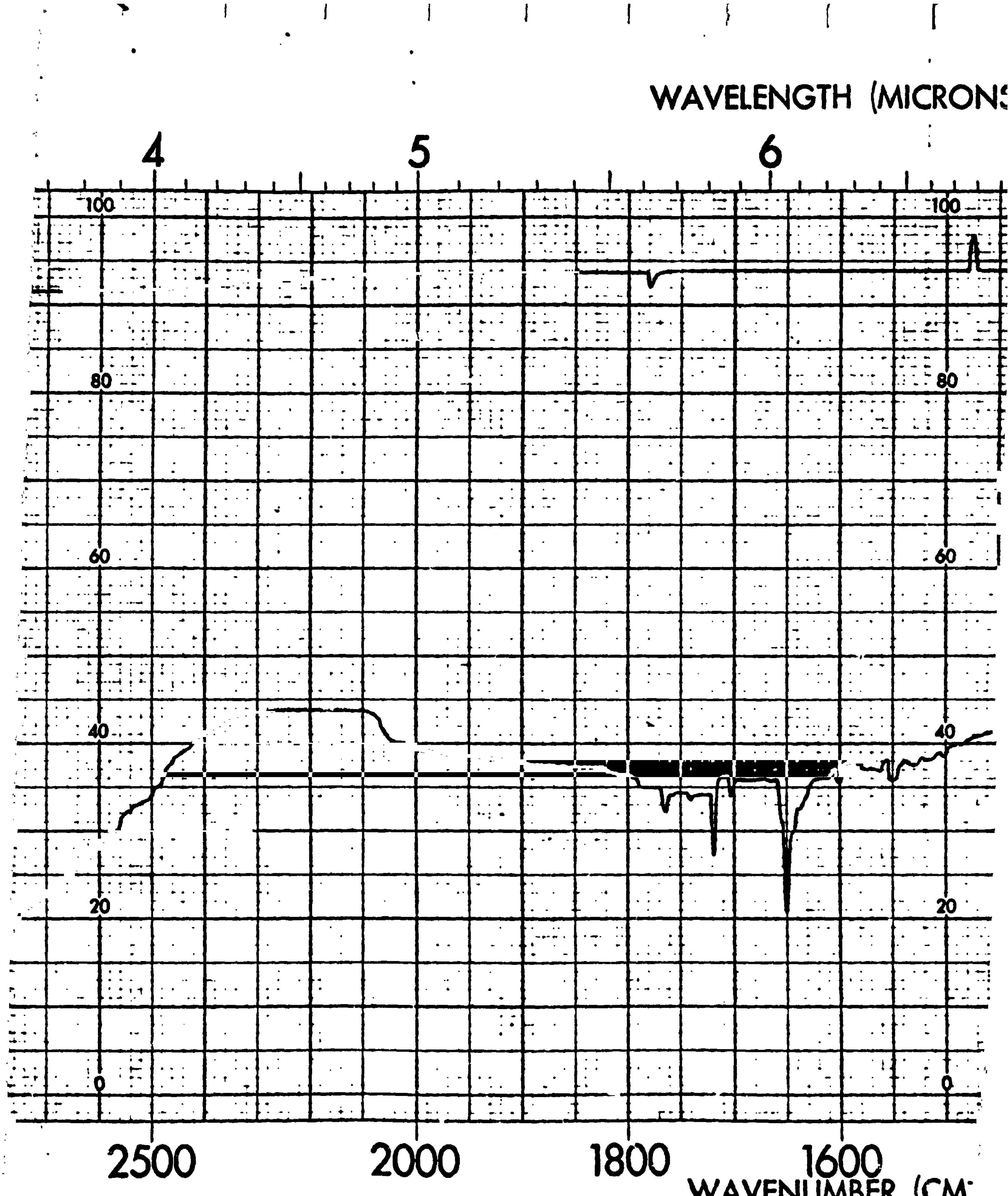

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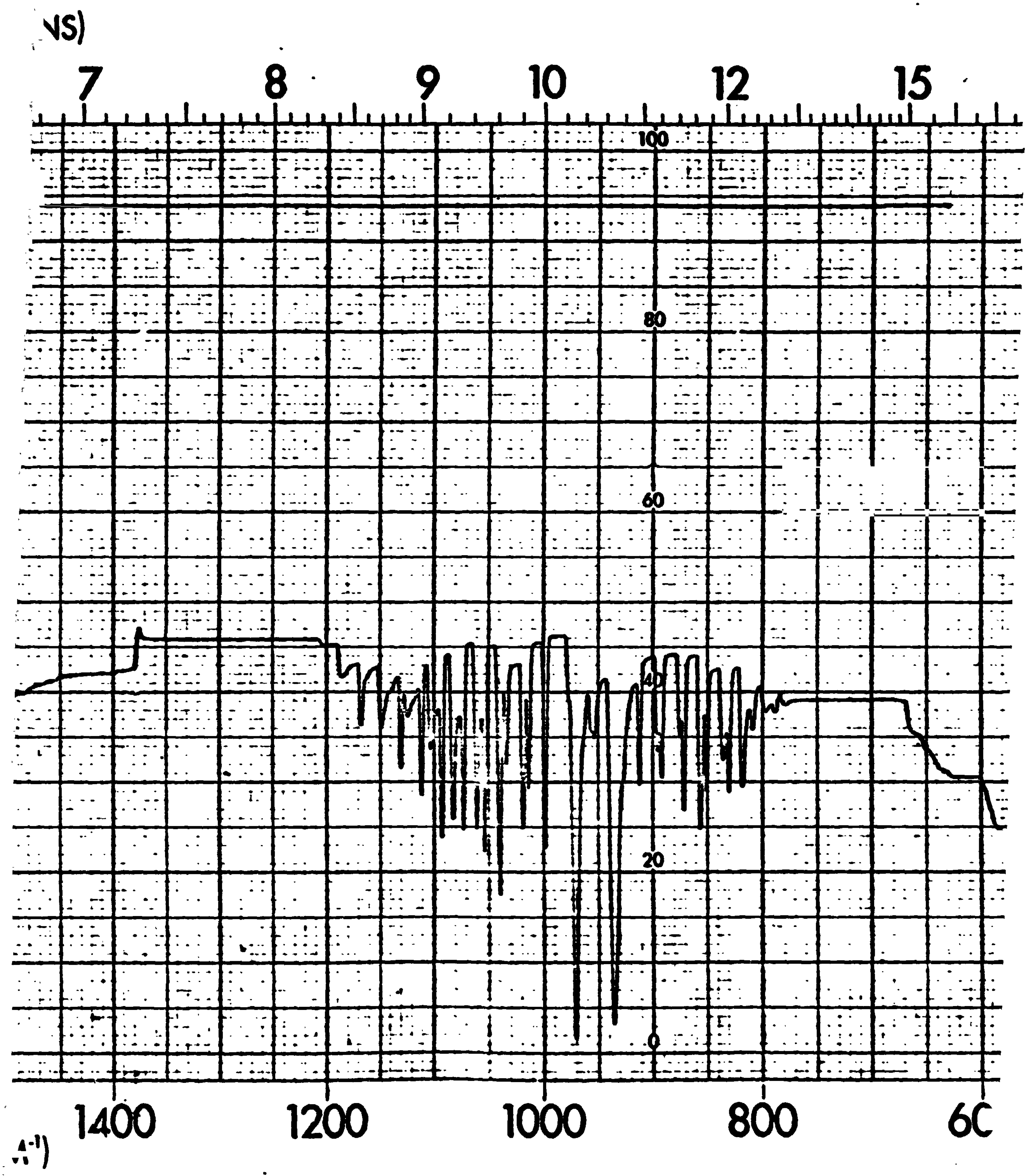

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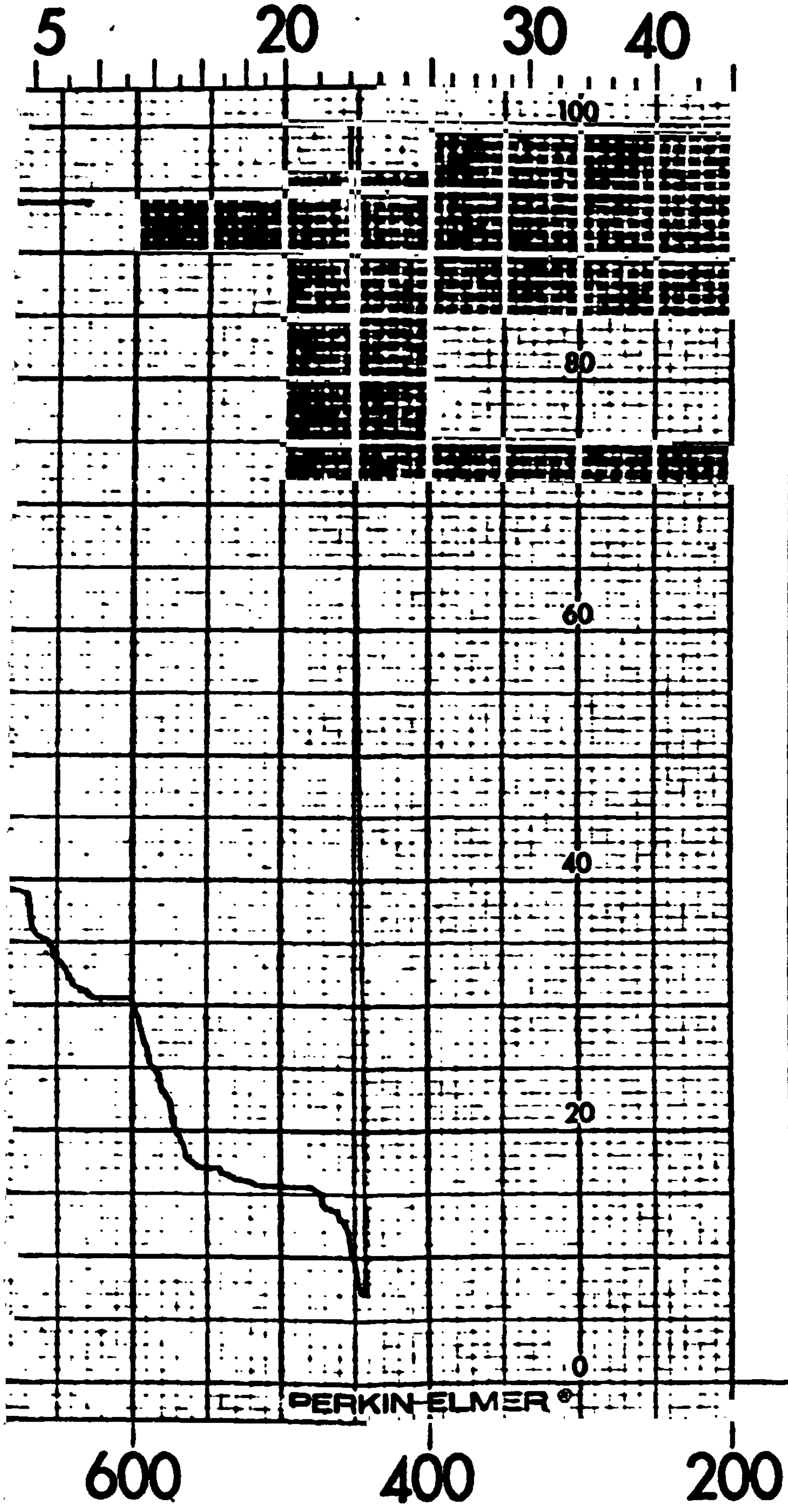


SPECTRUM NO. B-03274

SAMPLE Gas Cell S/N 109

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 6/9/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

SUPPRESSION

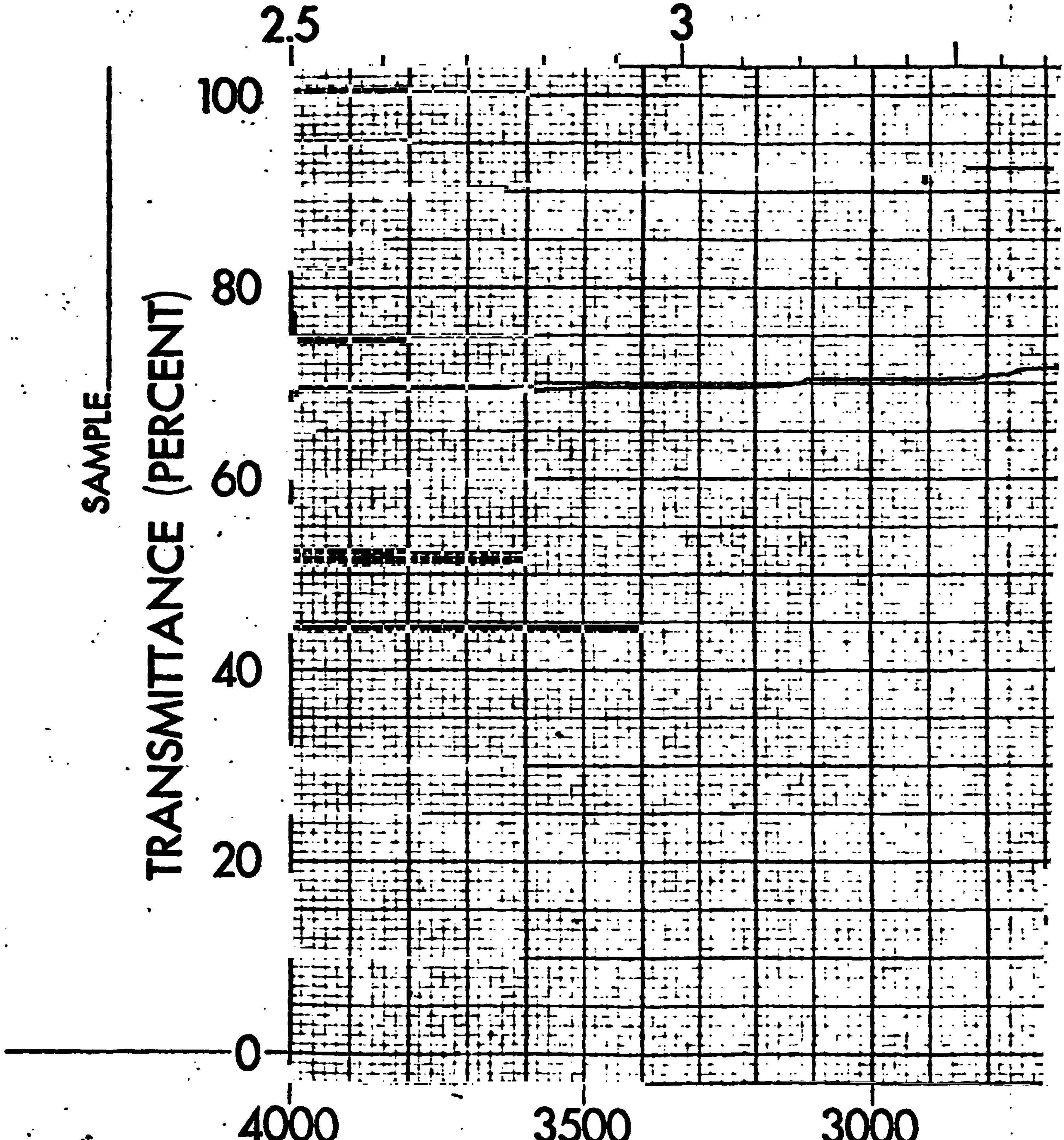
SCALE EXPANSION

SOURCE CURRENT

NO. 221-1607

FOLDOUT FRAME 4

#23



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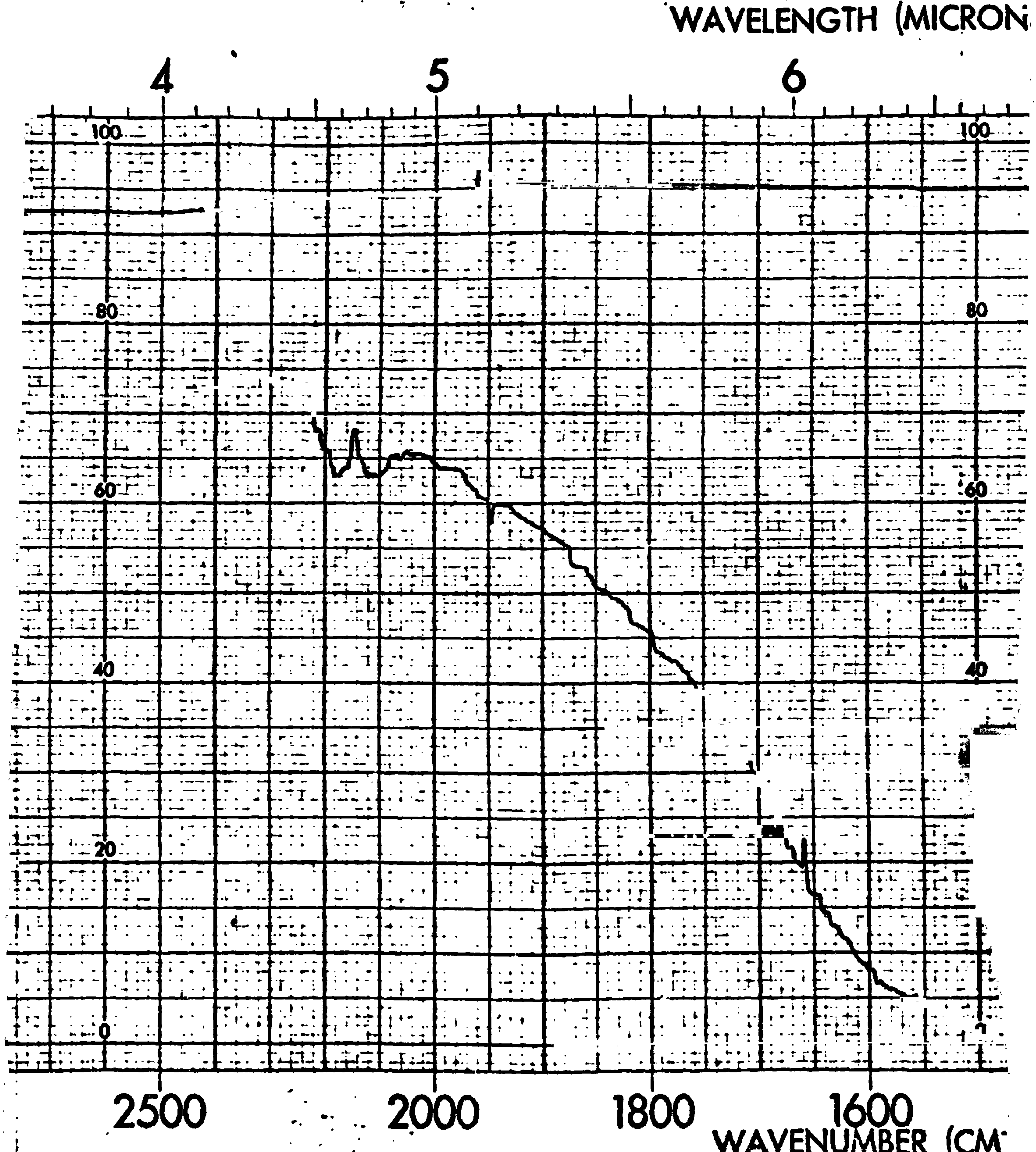

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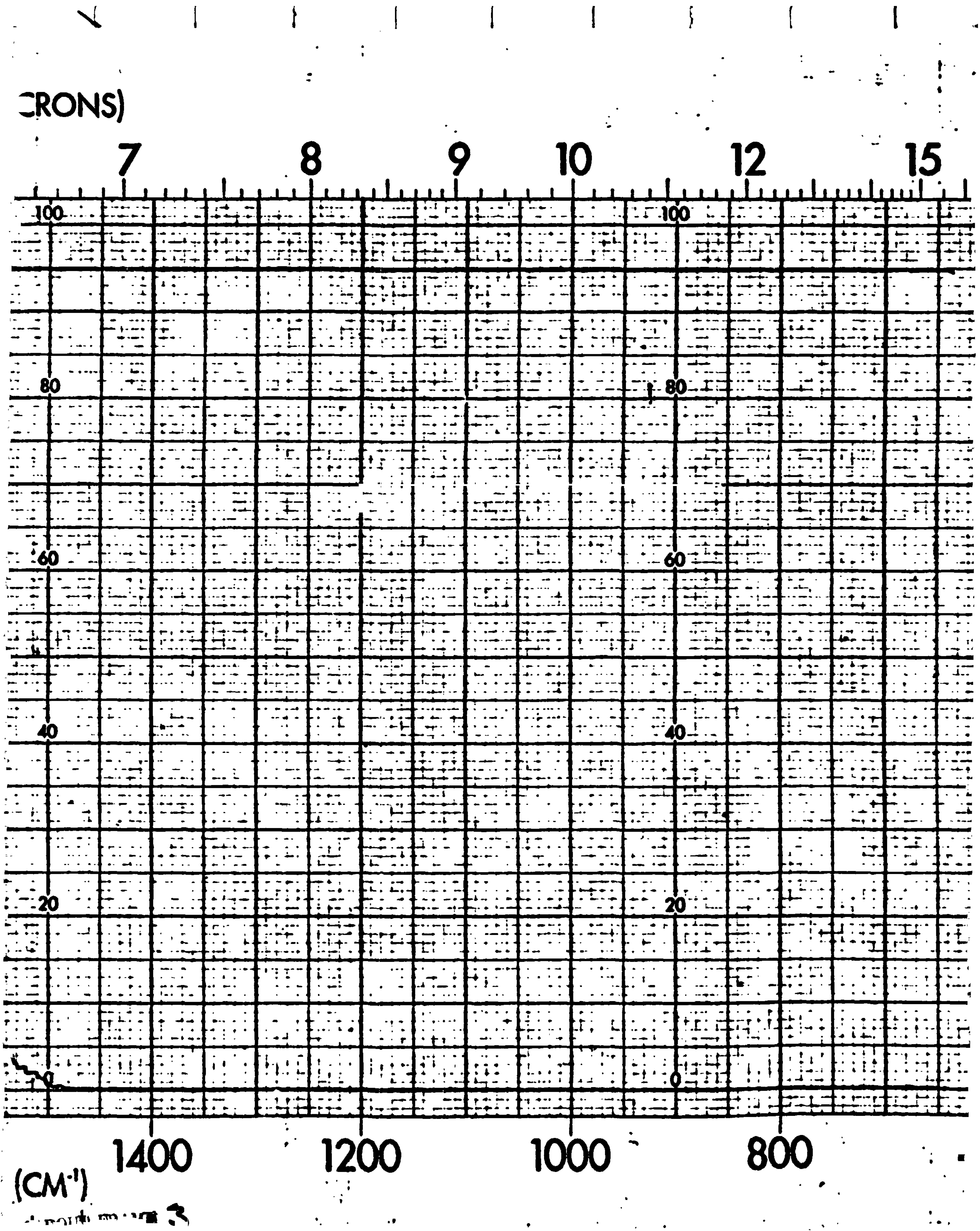
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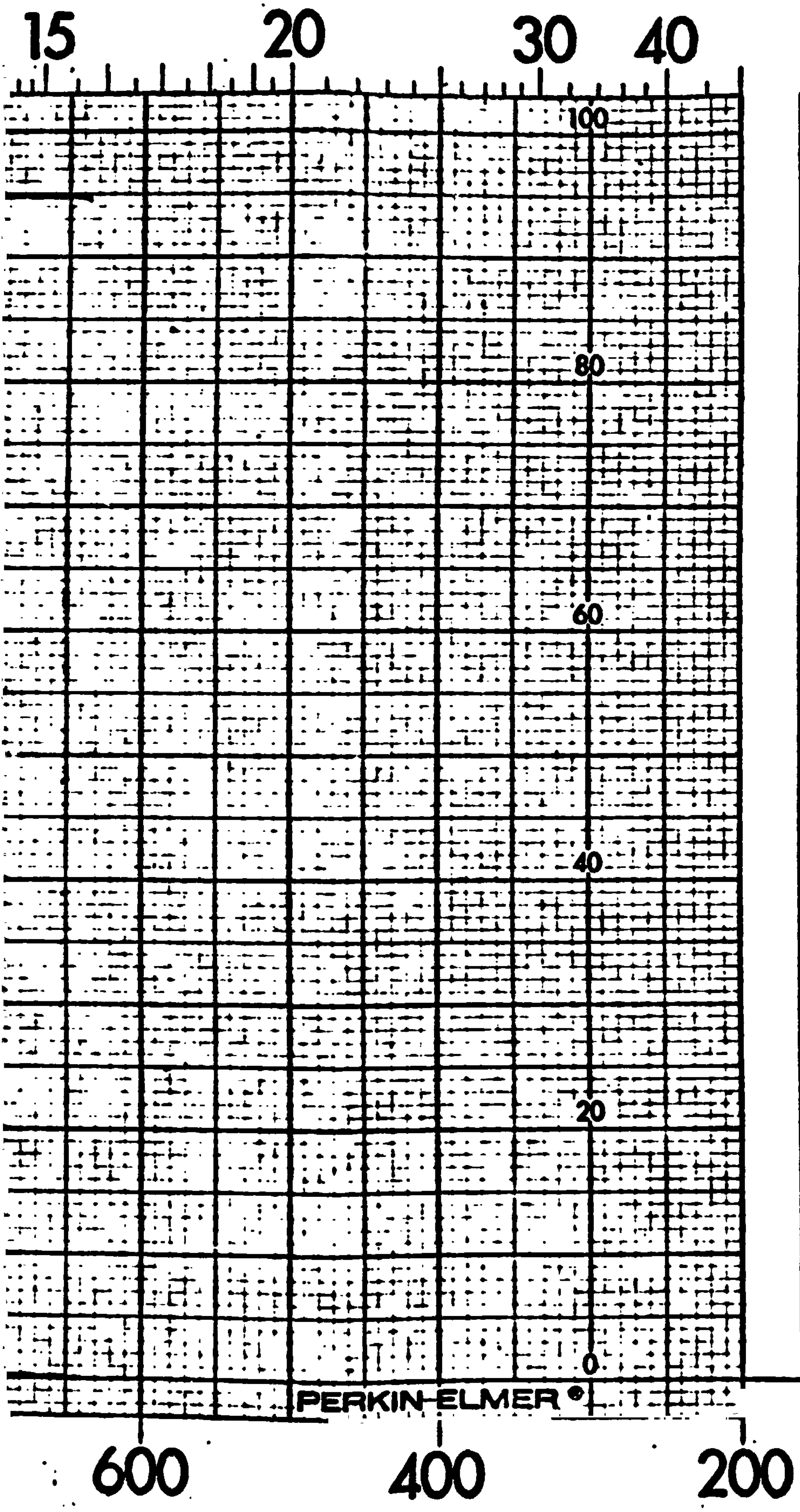


SPECTRUM NO. B-O 3275

SAMPLE Gas Cell S/N 110

ORIGIN

PURITY

PHASE

THICKNESS

1.

2.

3.

DATE 6/9/76

OPERATOR KENNEDY

REMARKS

MODEL 521 2:1 SCALE CHANGE

SLIT PROGRAM

GAIN

ATTENUATOR SPEED

SCAN TIME

SUPPRESSION

SCALE EXPANSION

SOURCE CURRENT

NO. 221-1607

APPENDIX J

INSTRUCTION MANUAL FOR
GROUND SUPPORT UNIT (G.S.U.)

INSTRUCTION MANUAL
FOR GROUND SUPPORT UNIT (G.S.U.)

PREPARED BY
BARRINGER RESEARCH LIMITED
304 CARLINGVIEW DRIVE
REXDALE, ONTARIO, CANADA

PREPARED FOR
T.R.W. SYSTEMS INC.
ONE SPACE PARK
LOS ANGELES, CALIFORNIA

OUR REF: TR75-255 OCTOBER 1975

CONTENTS

GSU OPERATING INSTRUCTIONS

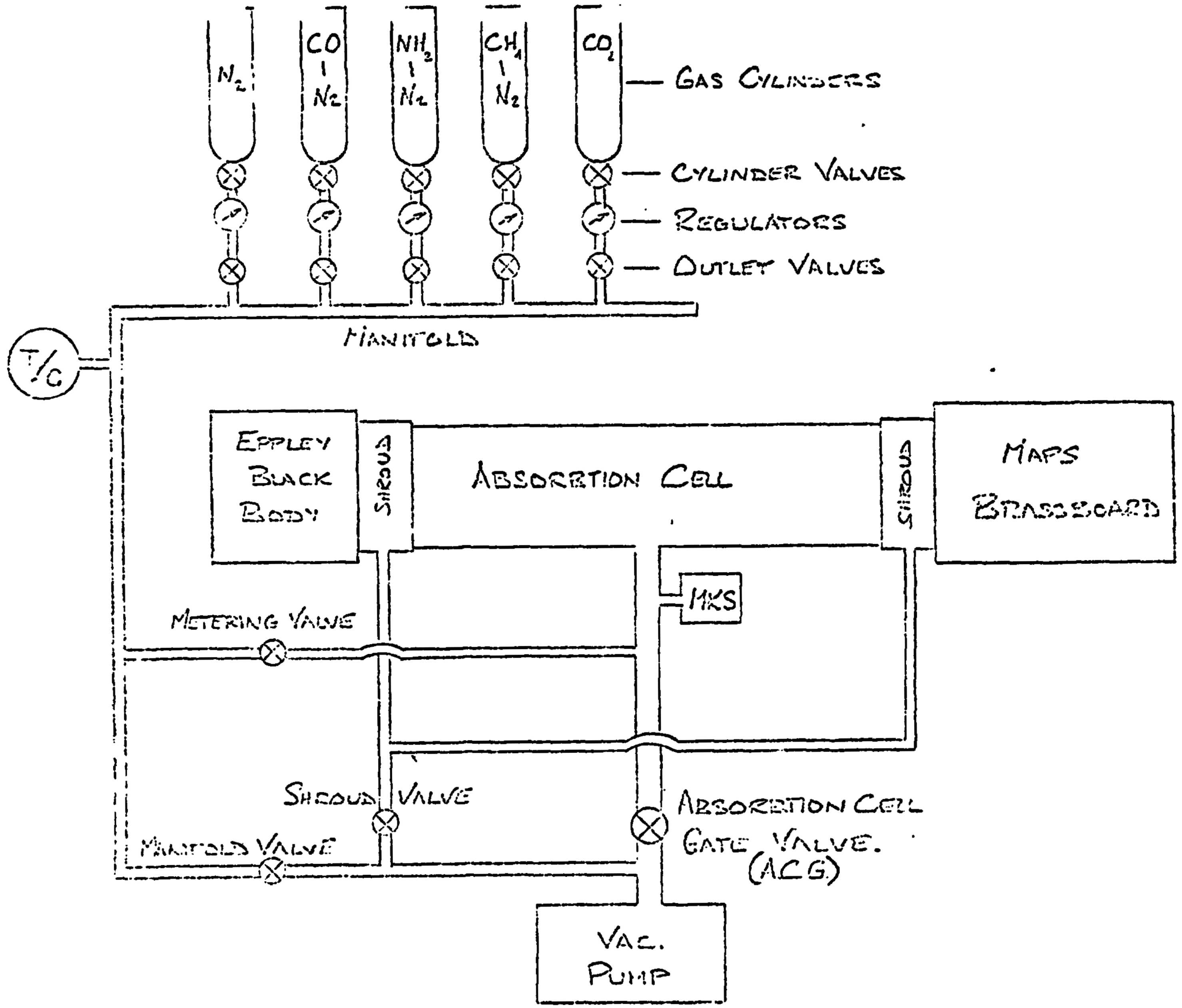
Starting Conditions

Valve or Switch	Position		Location
Absorption cell gate valve	Closed	Fully C.W.	1
Manifold gate valve	Closed	Fully C.W.	2
Shroud gate valve	Closed	Fully C.W.	3
Air admittance valves	Closed	Fully C.W.	4
Metering valve	Closed	Fully C.W.	5
Manifold outlet valves (5)	Closed	Fully C.W.	6
MKS Electronic module	Power On	X 1	7
MKS Digital Readout	Auto	X 1,000	8
Temptronic TE Controller	Power Off		10
Doric Pt. Res. Thermometer	Power On		12
Cell Temp. Readout	Power On	Position No.5	14
Vac pump Circuit breaker	ON		15
Cooler 1 Circuit breaker	ON		16
Cooler 2 Circuit breaker	ON		17
Electronics Circuit breaker	OFF		18
Heater Circuit breaker	ON		19
Vac pump Powerswitch	OFF		above 15
Cooler 1 Powerswitch	OFF		above 16
Cooler 2 Powerswitch	OFF		above 17
NRC 801 T/C Pressure gauge	Power On	Cell Position	22
Cell temp control	Power Off		23
Lauda K-2R Thermal Control	Compressor ON Line ON Thermometer set to -20°C Circulator pump off		Bottom inside Hammond cabinet

Start up of GSU

POWER Connect power cords to three 115V, 15 amp. receptacles.

PUMP DOWN Switch On pump power switch (20). Switch on electronics circuit breaker and pump out the cell and manifold (open 1 and 2). The pump out should take approximately one hour. (Refer to pump down curve Figure 1). The pressure is monitored on the MKS digital readout in the 760-2 Torr range and on the NRC 801 in the 2 Torr to 1μ range. (Refer to the MKS and NRC instructions for detailed operation of these systems).



G.S.U. SCHEMATIC

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CELL TEMPERATURE

Set the Cell Temperature Control dial at the desired cell temperature and switch on the C.T.C. power (23). If this temperature is below ambient, switch on cooler ~~1~~ 2 (21). Monitor the cell temperature on the cell temperature readout thermocouple number 5. For the lowest temperature -27°C the system requires about 10 hours to stabilize, for the highest temperature about 1 hour is required.

BLACKBODY TEMPERATURE

Switch on cooler number ~~2~~ 1 (17). After one hour turn on the circulation pump. (Lever on side of cooler). If a low temperature (below -20°C) setting is desired, allow the coolant to circulate for two hours through the blackbody before switching on the Temptronic T.E. Controller. For temperature higher than ambient the T.E. Controller may be switched on as soon as the circulating pump is switched on. Set the T.E. Controller using the calibration sheet supplied in the Eppley Instructions. Prior to switching on the T.E. control, set the Temptronic on high range if the desired temperature is greater than the temperature of the base plate and on the low range if the temperature is lower.

PURGING REGULATORS

Allow absorption 11 to evacuate to between 1 and 30μ. Close the absorption cell gate valve (AGC). Open the test gas outlet valve and manifold gate valve. Allow the manifold to evacuate to between 1 and 2 x 10^{-1} Torr on the Varian thermocouple pressure gauge and then close the test gas outlet valve. Open the test gas cylinder valve and adjust the pressure to between 0* and +5 P.S.I. Open the test gas outlet valve and flow test gas at >2 Torr for about 5 minutes. Shut off test gas outlet valve. Repeat the above regulator pump out procedure with all other test gases. Pump down the manifold to less than 60μ.

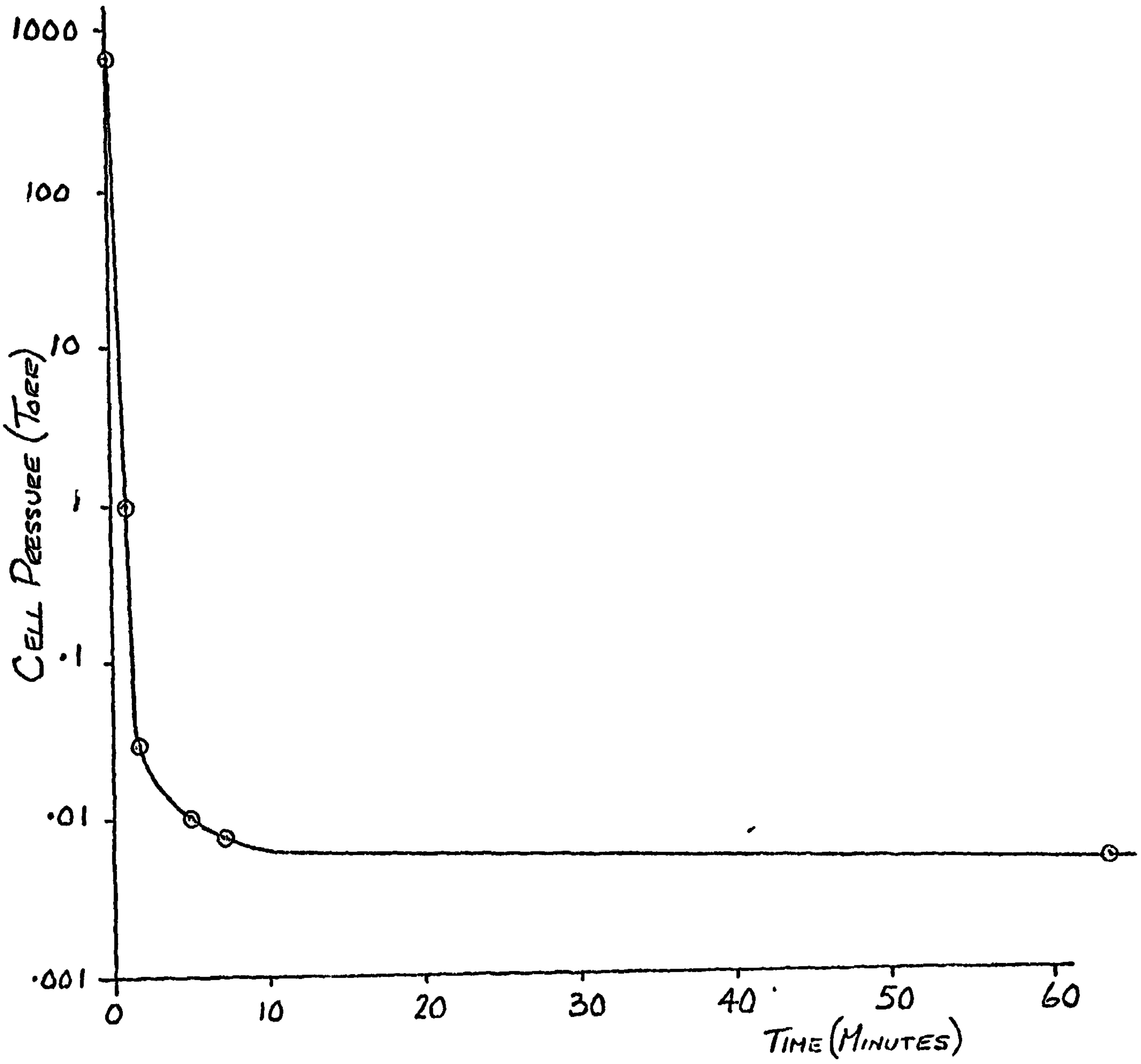
FILLING CELL WITH TEST GAS

Open the test gas outlet valve ½ turn ccw. Open the metering valve until the change in pressure observed on the MKS pressure gauge readout corresponds to the amount of gas required. Pump out the manifold and add a second gas using the same procedure

---

* 1 Atmosphere

FIGURE 1



GSU Cell
Pump Down Tests (MKS Guage)
July 25th 1975

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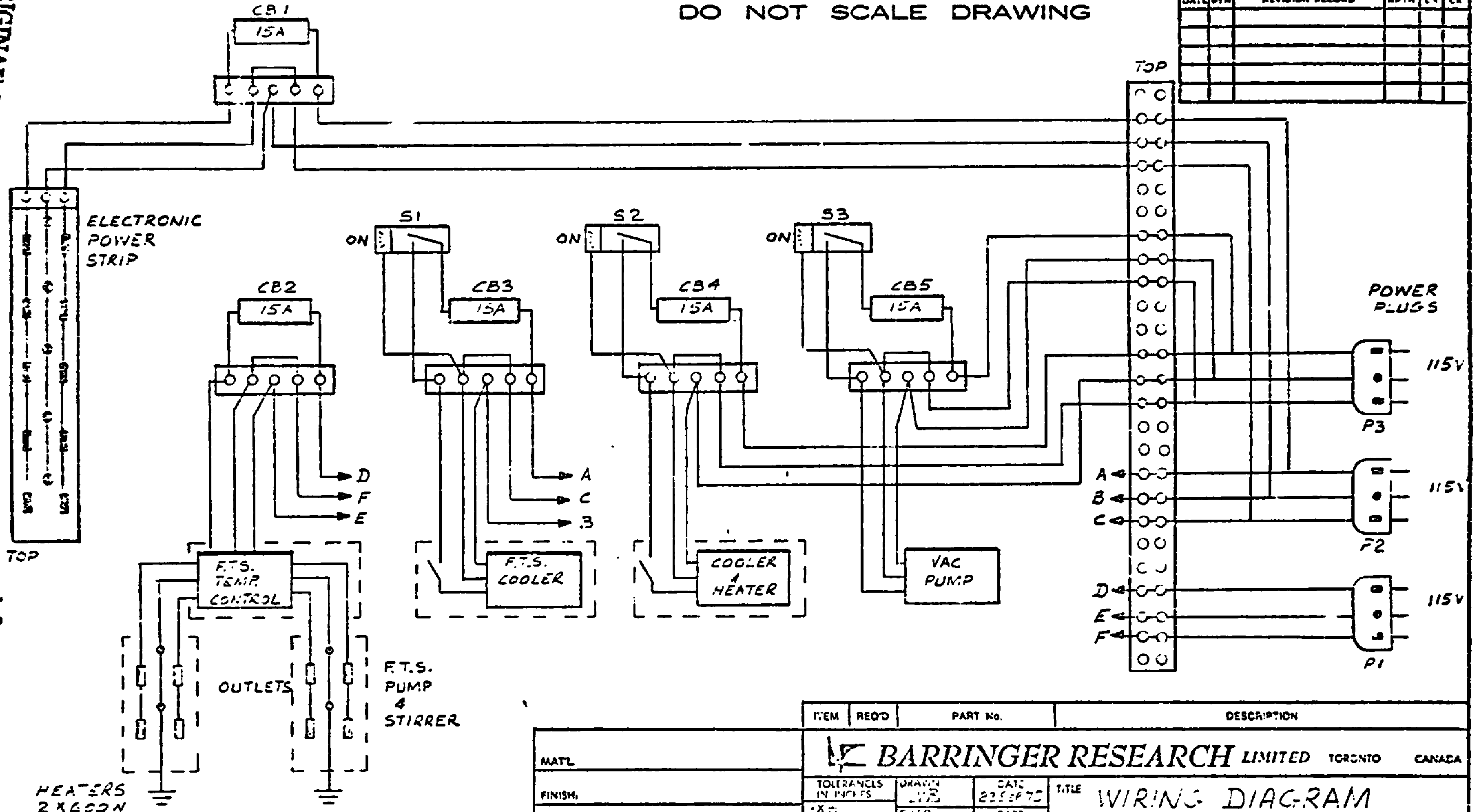

DATE	SYM	REVISION RECORD	AUTH	EN	CK

ITEM	REQ'D	PART No.	DESCRIPTION

MAT'L.

FINISH:

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·XX ±
·XXX ±
X° ±
$\frac{x}{y}$ ±
UNLESS OTHERWISE NOTED

DRAWN [illegible] DATE [illegible]
CHK'D. WM DATE 7 [illegible] 75
APP'D. [illegible] DATE [illegible]
APP'D. DATE
NEXT ASS'Y. ASS'Y.

TITLE WIRING DIAGRAM
CIRCUIT BREAKER PANEL

SCALE ——

DRAWING No. 2105294 SHT. 1 OF 1

REV.

DRAWING NO.

196 EXP 084

NOTES:
1. REMOVE BURRS & BREAK ALL SHARP EDGES.
2. ALL WIRING 3 x 14SJ

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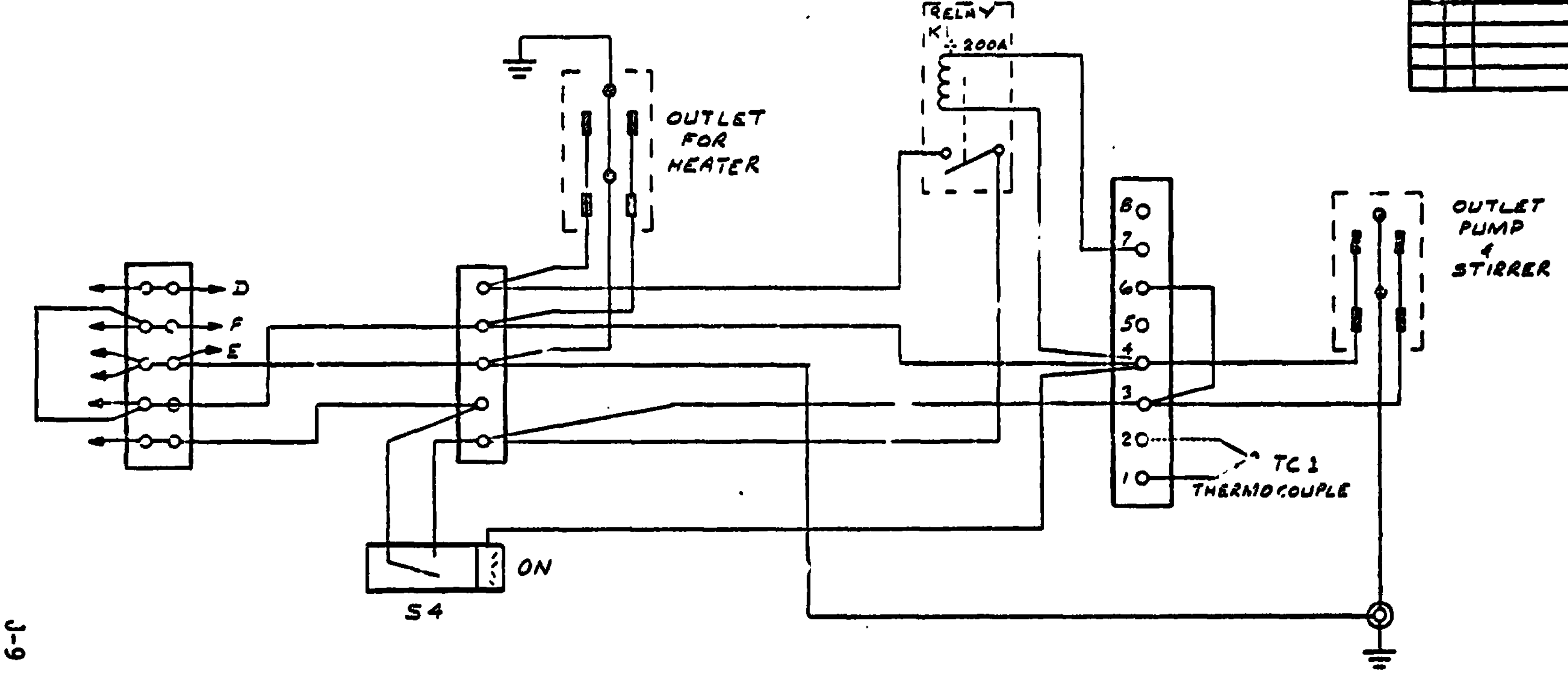
DO NOT SCALE DRAWING

DATE	SYM	REVISION RECORD			



NOTES:
1. REMOVE BURRS & BREAK ALL SHARP EDGES.
2. ALL WIRING 3 x 14 S3

ITEM	REQ'D	PART No.	DESCRIPTION

MAT'L

FINISH

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.XX ±
.XXX ±
X° ±
UNLESS OTHERWISE NOTED

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APPD.
NEXT ASSY.
DATE
DATE
DATE
DATE
ASSY.

TITLE WIRING DIAGRAM
F.T.S. TEMP. CONTROL

SCALE —
DRAWING No. 2105895
SHT. 1 OF 1
REV.

196 EXP 085

DRAWING NO.

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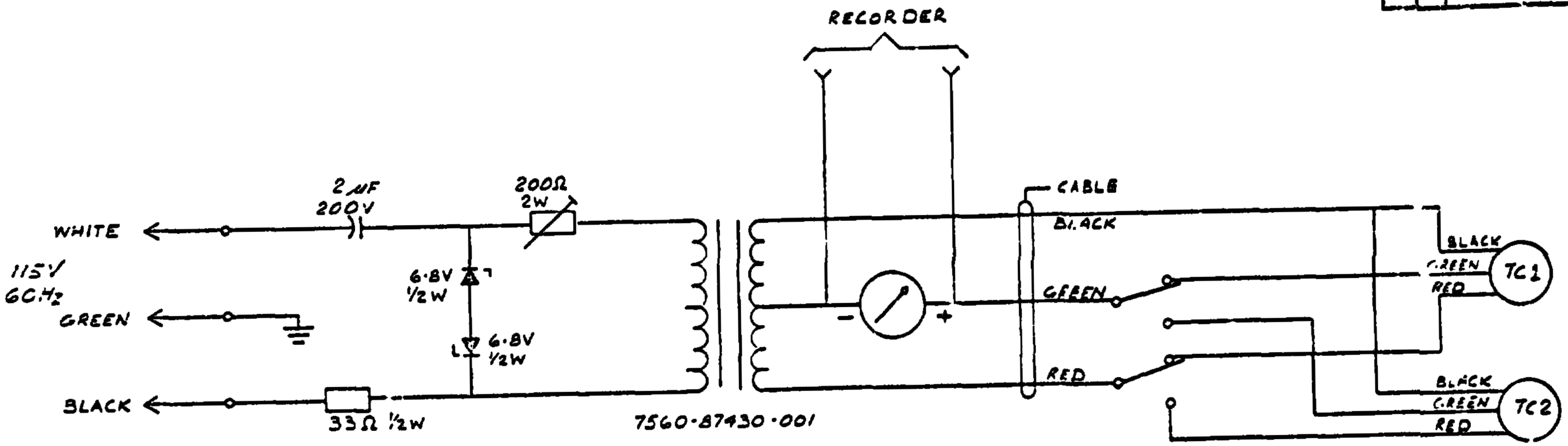

NOTES:

1. REMOVE BURRS & BREAK ALL SHARP EDGES.

2.

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THE BENEFIT OF OTHERS
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MAT'L.

FINISH.

ITEM	REQ'D	PART No.	DESCRIPTION

BARRINGER RESEARCH LIMITED TORONTO CANADA

TITLE SCHEMATIC THERMOCOUPLE CONTROL

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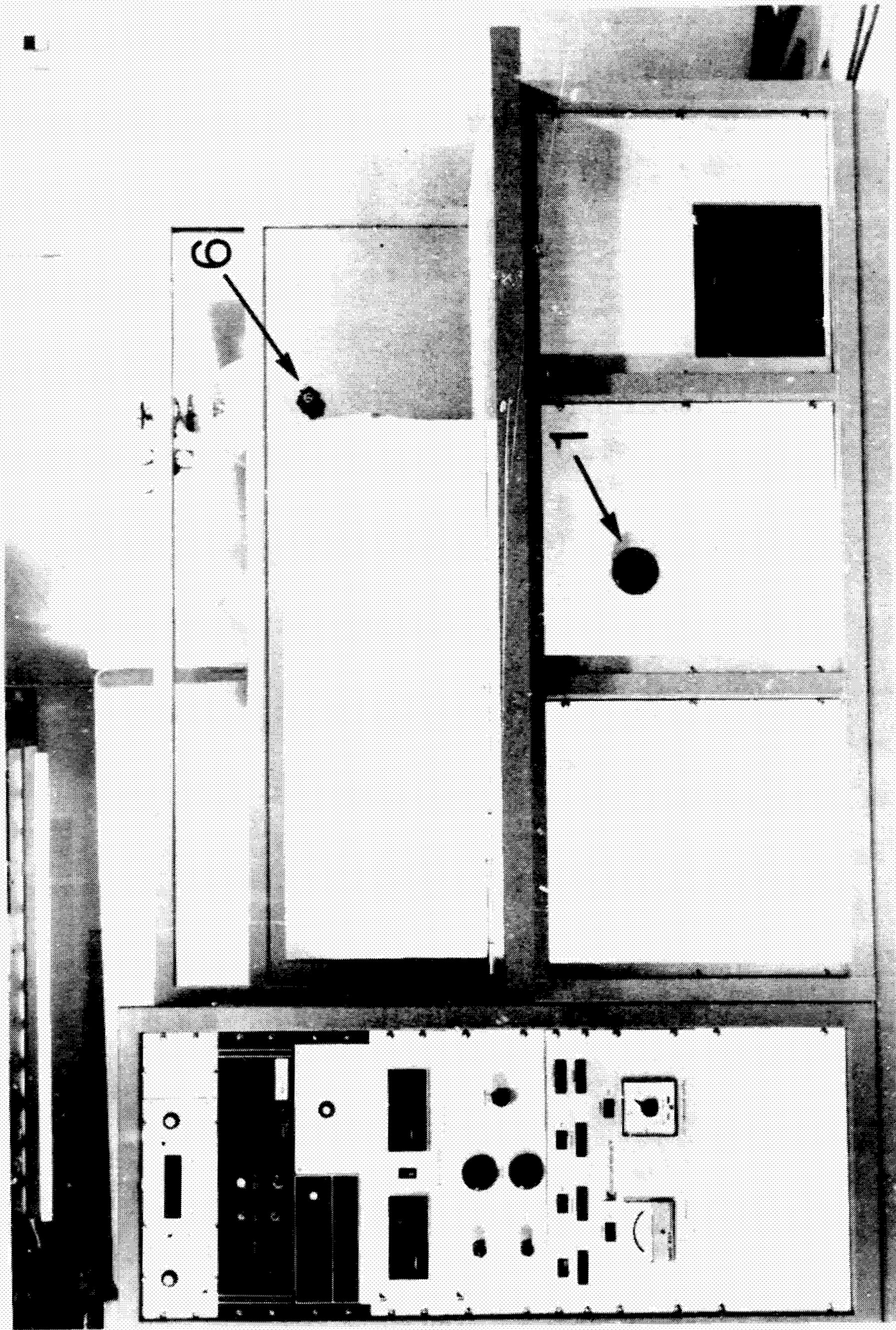
CHK'D WM DATE [illegible]
APP'D [illegible] DATE [illegible]
APP'D. DATE
NEXT ASS'Y. ASSY.
SCALE —
DRAWING No. 210 5803 SHT. 1 OF 1
REV.

DRAWING NO.

196 EXP 003

GSU INCOMING POWER DISTRIBUTION

Block #	Instruments	Current in Amps	Remarks
(see circuit diagram)	F.T.S. Heaters	10.2 A	2 x 600 W
I	F.T.S. Circulation Pump	0.8 A	
	F.T.S. Stirrer	0.8 A	
		TOTAL 11.8 A	
II	F.T.S Refrigeration	10.5 A	up to 14A Startir current
	Electronics plug strip	2.8 A	
III	Black Body Cooler	9 A	typ. 4-5 amps
	Vacuum pump	5.5 A	6 A starting current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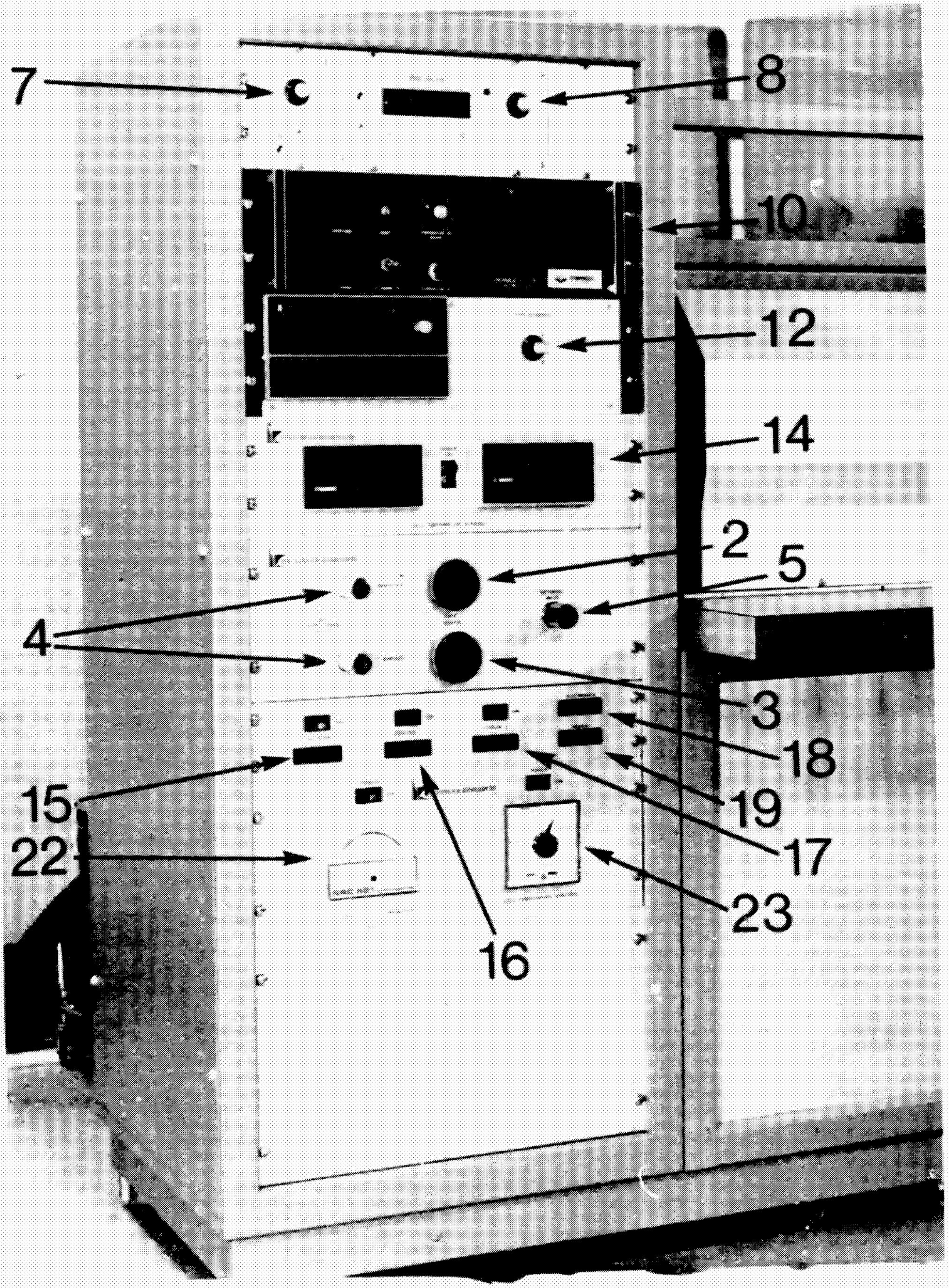

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NRC 801 THERMOCOUPLE GAUGE CONTROL

INSTALLATION, CALIBRATION AND OPERATING INSTRUCTIONS

The NRC 801 thermocouple gauge control is a compact, self-contained instrument, designed primarily for panel mounting. It is supplied with a 6 ft line cord and a 10 ft thermocouple gauge cable. The instrument is line voltage regulated, and a temperature sensitive element to compensate for temperature drift in thermocouple gauges is built into the thermocouple cable socket. The indicator dial, which covers the pressure range from 1 to 1000 microns (1 micron is 1/1000 of 1 mm of mercury, or 1/1000 of 1 torr) is calibrated for an NRC 521 thermocouple gauge in dry air. The mechanical zero adjust is located on the front of the instrument. The pressure calibration can be reached through a hole in the rear cover (Fig. 1a and 1d). The meter voltage (0 - 11 mv) is available at two solder terminals at the rear for operating remote indicators whose input resistance should be 200 ohms or more.

Installation

A panel cutout, as shown in Fig. 1a, is required for the installation of the NRC 801 thermocouple gauge control. The instrument is mounted from the front and fastened with three nuts supplied (Figs 1b, 1c).

Calibration

1. Adjust the mechanical meter zero until the needle reads OFF.
2. Connect an NRC 521 thermocouple gauge to a vacuum system capable of maintaining a pressure of less than 1.0 micron.
3. Pump down the system to less than 1.0 micron.
4. Connect the thermocouple cable of the NR 801 control to the NRC 521 thermocouple gauge.
5. Plug the line cord into a 115V 50/60 cycle outlet.
6. Turn calibration control in the rear of the instrument until the meter registers Zero microns.
7. Allow the system to stabilize for approximately 15 minutes, and readjust the zero if necessary.

NOTE: If so desired, the gauge can be calibrated against an NRC Alphatron(R) or a McLeod gauge.

Maintenance

Due to aging and/or contamination of the thermocouple gauge, recalibration may be necessary from time to time. The above procedure should then be followed. As the temperature compensation for the TC gauge is built into the TC cord socket, it is not advisable to cut the plug off the TC cord. If the cable is too long, it should be coiled.

Disassembly of Control

The NRC 801 should give years of trouble-free service but, if repairs are necessary, the following procedure of dismantling should be followed.

1. Unplug line cord.
2. Remove the two screws that hold the rear cover and terminals.
3. Slip cover as far back as the cable allow.
4. Unscrew the two spacers.
5. Remove printed circuit card from meter.

NOTE: If, after assembly, the meter reads backwards, turn printed circuit card one-half turn.

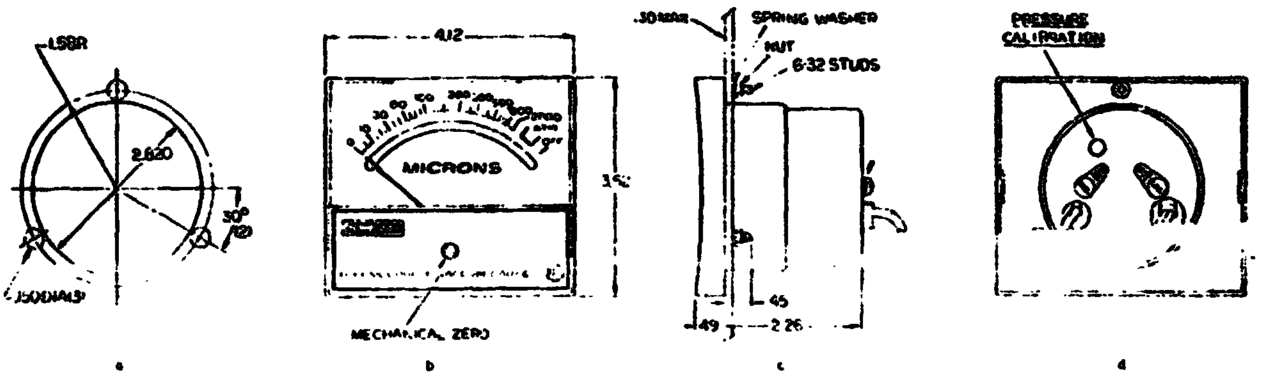

Fig. 1

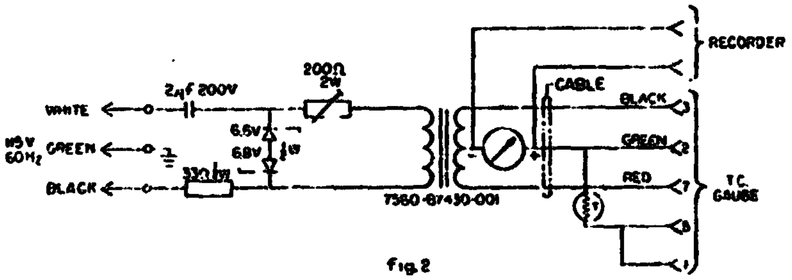

fig.2

OPERATING INSTRUCTIONS #132-B

LAUDA/BRINKMANN CIRCULATOR

All Models In The K-2/R Series

(Please read the notes on this page)

CAUTION: 1. This circulator is designed for normally supervised laboratory use. If unattended or over-night operation is required, a suitable back-up safety system should be used in order to prevent possible secondary damage due to leakage or uncontrolled heating. BRINKMANN INSTRUMENTS cannot assume liability for damage to the circulator or the laboratory in which it is located, beyond the replacement, within the warranty period, of defective components as specified in paragraph II.

2. In order to avoid damage to the compressor and eliminate an excessive starting current which may result in a blown fuse, the compressor should not be turned on for at least 15 minutes after having been turned off. This time interval will permit the Freon to reach the pressure which is needed for a proper start-up.

(a)

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PLEASE NOTE: This manual covers models K-2/R and Super K-2/R. The term "K-2/R" as used in the text refers to both models. Differences in specifications and spare parts are indicated wherever applicable.

I. UNPACKING

Please check the packing material carefully to be sure that all components have been received and that nothing is accidentally discarded. The following items must be received:

- identifying numbers refer to Fig. 1, page 2 -

(1)	Bath housing with built-in pump and controls
(1)	Thermoregulator (contact thermometer) -5 to +105 °C — (1) with Metal sleeve for above — (2) and Rotating magnet in plastic housing — (3)
(1)	Control (reading) thermometer with tapered joint connection — (4)
(1)	Piece of hose for temperatures to 150 °C (not illustrated)
(1)	Cover for access opening (mounted) — (5)

Any shortage or damage must be reported to your supplier within 7 (seven) days after receipt — see paragraph II.

II. WARRANTY

In lieu of other warranties, either expressed or implied, all LAUDA constant -temperature circulators are unconditionally guaranteed for repair or replacement of all parts (except tubes and thermometers) which become defective due to manufacturing defects or faulty materials, for a period of one year from date of delivery. This warranty is effective only if the instrument is returned to our plant at Westbury, N.Y. for examination and repairs, and becomes void if the equipment has been tampered with unless specifically authorized by us. Damage resulting from misuse of the equipment is not covered by this guarantee, neither will we be responsible for secondary damage due to continued unsupervised use of equipment which has become partially defective. Damage incurred during shipment must be reported to the carrier immediately since an inspection is essential to the settlement of any claim. All packing materials must be retained until their disposal is authorized by the carrier or his representative.

III. OPERATING INSTRUCTIONS

A. Fill in water to maintain level approximately 1 inch below top of bath. In order to remove the bath cover its handle should be rotated 45 ° in either direction until it clicks into place in a diagonal position. The cover can then be removed and the circulating liquid should be poured

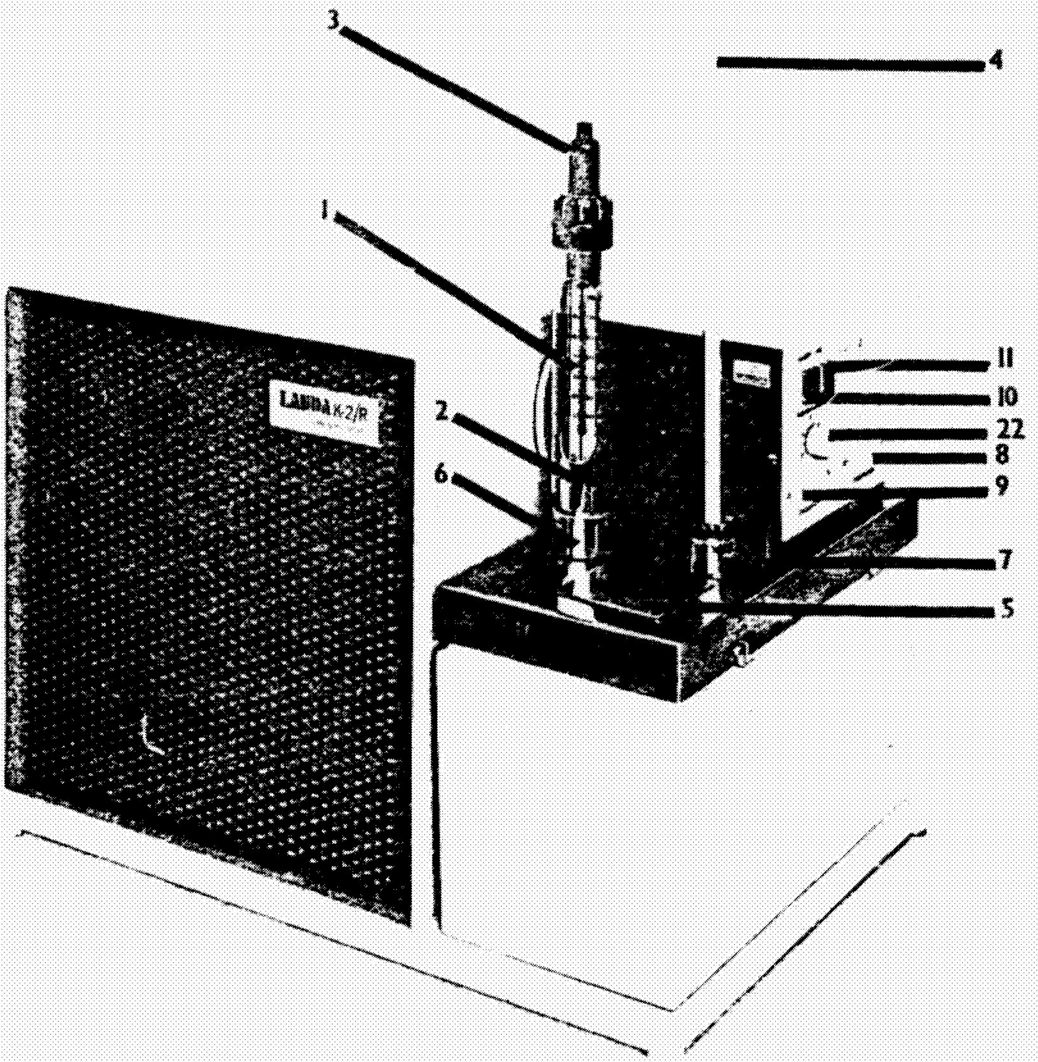

Illustration No. 1

K-2/R Front/Side View

1 - Contact thermometer (thermoregulator)
2 - Sleeve
3 - Rotating magnet
4 - Control thermometer (reading thermometer)
5 - Bath cover
6 - Opening for metal sleeve
7 - Tapered opening for control thermometer
8 - Sliding switch (compressor)
9 - Sliding switch (circulator)
10 - Heater indicating light
11 - Power indicating light
22 - Proportioning Control

into the reservoir within one inch of the top. Since a certain amount of liquid will be required for the external circulating system, the level should be checked after the first few minutes of operation. The cover should then be replaced and locked by rotating the handle 45° in either direction.

B. For external circulation connect circuit hoses to OUT nozzle (20) and IN nozzle (21). After the instrument has been turned ON and liquid has been circulated through the external system, the internal level should be checked and additional liquid should be added as may be required (see A. above). The K-2/R is designed for external circulation through a closed system only. It is not recommended that this circulator be used for circulation through an open bath or reservoir although this is possible if the external bath level is sufficiently above that of the K-2/R in order to permit a continuous gravity return. In this case, the control valve (14) must be adjusted in such a way that the pumping rate will not exceed the gravity return rate.

C. Without external circulation — Connect a short piece of hose across nozzles 20 and 21. This connection is necessary because the amount of internal agitation is directly related to the flow rate through the above-mentioned nozzles as controlled by lever 14.

D. Supplementary Instructions for K-2 Series Circulators which are equipped with Duplex Pumps (K-2/D and K-2/RD).

Duplex pumps consist of separate pressure and suction sections which are connected to one and the same motor. The suction section operates continuously at its maximum flow rate. The rate of liquid which is pumped out by the pressure section is continuously regulated by a float-operated valve which will increase or decrease the output in order to maintain a constant level within the internal reservoir. For additional information on the operation and performance of Duplex pumps, please read the following paragraphs:

a. This pump can be used both for circulating in a "closed" circuit, through an external, jacketed appliance, or for circulating through a "broken" circuit such as an open water bath. In the latter case, the open ends of the two hoses from the circulating nozzles are merely immersed in the liquid of the open bath; return to the circulator is accomplished by the suction state of the pump. To balance possible variations between the pressure and suction stages, the pump is equipped with a floating valve regulator which controls the amount of liquid flowing out of the circulator; thus maintaining a constant niveau (level) in the circulator within an accuracy of ±1 mm. The external (open) bath may be mounted 1 meter higher or lower than the circulator without disturbing this relationship.

b. When first placing the system in operation, fill the external bath to the desired height. The circulator maintains its own level and the external bath must be filled accordingly.

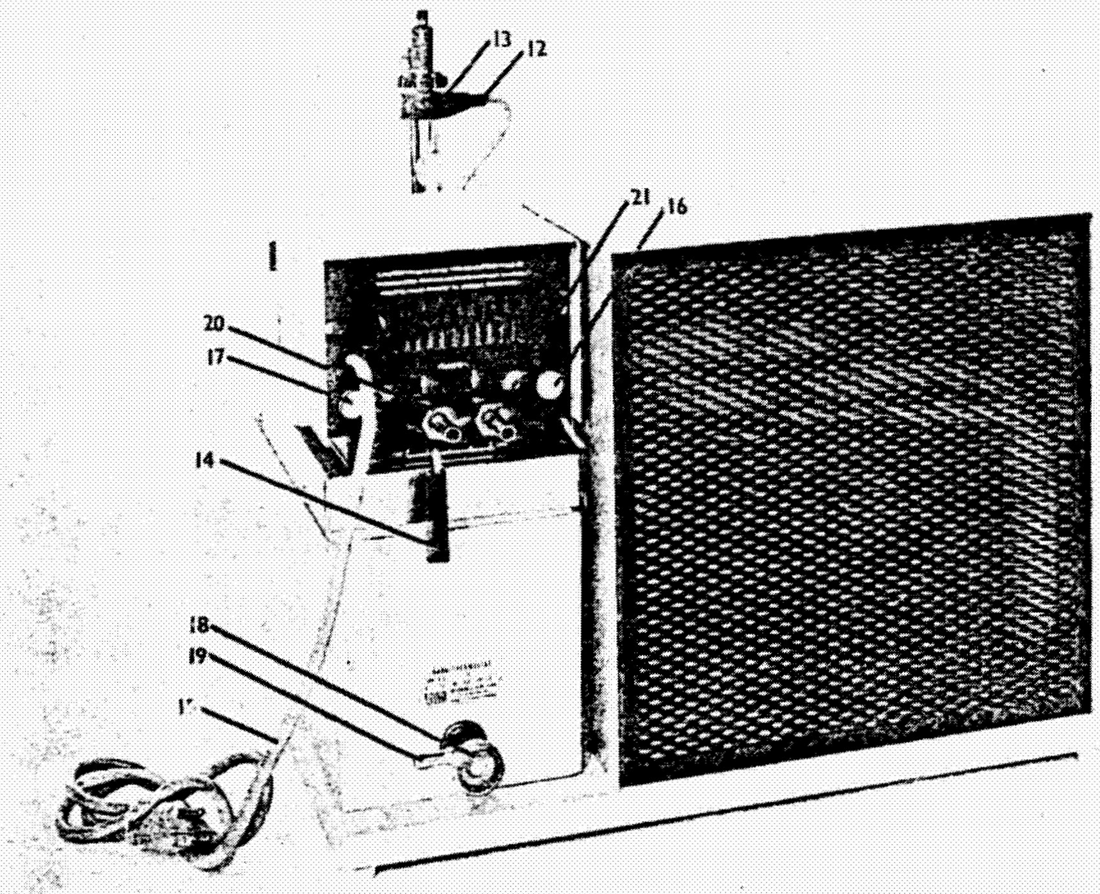

Illustration No. 2

K-2/R Rear View

12 - Female plug of connecting cable
13 - Male receptacle on contact thermometer
14 - Control valve lever
15 - Line cord
16)
17) - Locking screws for upper housing
18 - Drain valve knob
19 - Drain valve nozzle
20 - Circulating pump nozzle OUT
21 - Circulating pump nozzle IN

c. The front nozzle of the pump is the pressure side and the rear nozzle is the suction side. If an open bath is tempered by simply immersing the open ends of the hose in the external bath, it is advisable to cut the hose end at a slant (diagonal cut) to eliminate any possibility of the suction hose attaching itself to the inside of the tank wall (by suction) and cutting off the return flow of liquid.

d. Trouble-free circulating operation can only be guaranteed if the circulated liquid does not have a viscosity higher than 50 cP at 20 °C.

e. The flow-control valve is not as effective on the Duplex pump as on the Simplex version because of varying forces in the pressure and suction side and because of the floating valve. Therefore, with the Duplex pump, this valve should normally be open (pushed to the front) or closed (pushed to the rear). Generally, this is not a disadvantage because even when circulating through a small external system (capacity 1 liter), there is no evidence of a violent reaction (waves) in the external bath.

f. If a system with a Duplex pump is used for circulating through a closed circuit (refractometer, spectrophotometer, viscometer, etc.,) the liquid in the circulator must be filled within 30 mm (1-1/2") of the top. Otherwise, the rate of circulation may be restricted by the floating valve in the pressure side. This valve closes as the bath level falls. If the liquid level is insufficient, it will continue to stay closed in an effort to suck liquid out of the other side of the circuit. Do not forget that liquid fills the hose circuit which may require that some refilling of the bath is necessary. Ideally, for closed circuit operation, the floater of the pump in the bath should be as close as possible to the top of the circulator tank.

E. Adjust lever 14 for the rate of flow which is required. Flow rate is zero when the lever is on the extreme right; do not select maximum flow rate until circulator has been turned on.

F. Install metal sleeve (2) for thermoregulator in opening (6) provided and push down firmly. End of sleeve closest to center of cut-out for scale must be at top.

G. Install thermoregulator (1) by gently but firmly pushing it into sleeve. Push down as far as it will go. Then connect two-prong plug on line from left side of circulator to connectors on thermoregulator. Now, mount rotating magnet in housing (3) on top of thermoregulator and adjust temperature setting on scale by rotating magnet (see para. IV.).

H. Install reading thermometer (4) into tapered opening (7).

I. Connect three-prong plug attached to end of line cord (15) to a 115 V A.C., 60 cycle outlet, fused for a minimum of 10 amps.

J. The circulator can now be turned "ON" by sliding switch (9) towards the right. In this position a red dot on the left side of the switch will be exposed; the right-hand pilot light (11) will light up at full intensity. For operation above 40 °C the compressor switch (8) should be in the OFF position. At all temperatures below 40 °C this switch should be ON.

K. The K-2/R is equipped with a solid state triac controlled electronic relay which also includes a wattage proportioning control (22) and a noise suppression circuit. The proportioning control can be set for 20-100% of the maximum rated output (750 Watts). For initial heat-up or maximum heating, the proportioning control should be set to 10 (100%). When the circulator cycles at its operating temperature, as indicated by the heater light (10), the control accuracy can be increased by reducing the proportioning control to a setting at which the ratio of heating vs. non-heating cycles is approx. 1:2. If the proportioning control is set too low, the heater will stay on continuously because the wattage output will not be high enough to overcome the cooling effect of the refrigeration system which is operating at all times. Very brief and infrequent heating pulses are indicative of a proportioning setting which is too high, and thus, results in excessive temperature variations.

IV. USE OF THERMOREGULATORS

A. Setting the Temperature (control point) — Proceed as follows:

1. After loosening the locking screw on the magnet housing, place the magnet on top of the contact thermometer.

2. On the upper (exposed) scale of the thermoregulator there is a small horizontal black bar which moves up or down on a spindle depending on the direction in which the magnet is rotated.

3. Rotate the magnet in the desired direction until the top of the moving bar is approximately level with the desired temperature on the scale. Clockwise rotation increases the set point; counter-clockwise rotation lowers the temperature. One complete turn on the standard -35/+105 °C thermometer is equal to a change of approximately 0.5 °C. Then lock the magnet with screw.

4. After putting the bath in operation, the temperature will stabilize near the set point. However, some adjustment is usually necessary since the operating temperature may be 1 °C above or below the desired temperature. To assist the user, each magnet housing is calibrated and the change in temperature, per division of rota-

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tion, can be determined with the particular thermoregulator being used. On the thermoregulator -35 /+105°C one division on the magnet scale represents a temperature change of approximately 0.05°C. In adjusting the thermoregulator, the switching point (point at which the operating temperature exactly equals the set temperature) can be determined visually with the aid of the signal lamp (10). When heating is required, this lamp is ON.

5. For operation at temperatures above 100°C we now deliver only the longer stem thermoregulators which must be used with the long metal support sleeve. This was done because experience has shown that if the scale is left in the bath liquid at high temperatures, the mercury may be distilled only to condense again at a higher, cooler location. This shortens the mercury column of the thermoregulator (breaking contact) which causes the system to call for heat while the actual temperature climbs steadily beyond the control point. By mounting the scale above the bath liquid, this problem has been eliminated on our baths.

6. <u>When not in daily use, always set the thermoregulator above room temperature (if possible).</u> This prevents continuous contact between the contact wire and the mercury column.

B. Trouble Shooting the Thermoregulator

It is possible that due to shock encountered in transportation, the mercury column in the thermoregulator has separated. To remedy this, proceed as follows:

1. Rotate the magnet until the reading bar on the face of the thermoregulator is above the scale.

2. Carefully heat the mercury bulb of the thermometer over a small flame until the mercury column rises into the excess temperature collector, between upper and lower scales, where it will rejoin.

3. Cool thermometer slowly. If mercury does not rejoin, it may be necessary to heat again until it collects in the neck between the two scales. Then tap bulb of thermometer on a soft padded surface and shake out manually.

C. Testing Defective Thermoregulator

If the circulator does not function correctly — heater does not begin to operate and system does not maintain temperature — the thermoregulator may be defective. To test, proceed as follows:

1. Disconnect cable and plug (12) from receptacle on thermoregulator.

2. Short-circuit the connecting plug (12) by inserting a piece of wire. The signal lamp (10) must go off. If it does not go off and does not disengage the heater, the defect must be in the control circuit.

V. OPERATION IN VARIOUS TEMPERATURE RANGES

A. The K-2/R is equipped with contact and control thermometers which cover a range of -35 to +105°C. If this circulator is to be used at temperatures above or below the above-mentioned range it will be necessary to obtain additional thermometers which are listed in the LAUDA catalog. PLEASE NOTE that adjacent to each contact thermometer we list the length of the metal protecting sleeve with which it must be used. The K-2/R comes equipped with a short sleeve; it follows that, if one purchases a thermometer which requires a long sleeve, such a sleeve should be purchased at the same time. In lieu of additional thermometers it may be more convenient to use a platinum resistance thermometer with the R-20 temperature controller.

B. Below +1°C — We recommend a 50:50 Methanol/water mixture. Please use distilled water only. Switches (8) and (9) must be in the ON position. For external circulation we would recommend the use of our foam -rubber insulated silicone hose. Cat. No. 27 59 200-7.

C. From +1 to +40°C — We recommend the use of distilled water. Operation is the same as listed under "B" above.

D. From +40 to +95°C — We suggest the use of distilled water. The compressor switch (8) must be in the OFF position. For external circulation we recommend our perbunan hose, Cat. No. 27 59 100-1.

E. From +95 to +150°C — We recommend the use of special liquids as listed in paragraph VI. The compressor switch (8) must be left in the OFF position at all times. For external circulation use perbunan hose. Cat. No. 27 59 100-1.

VI. RECOMMENDED CIRCULATING LIQUIDS

A. Distilled water (+1 to +95°C)

B. Methanol (-70 to +50°C) — Although Methanol is toxic, we do recommend its use if it is handled with reasonable care. For operation from -10°C to ambient, it may be diluted with water on a 50/50 basis.

C. Ultra-Therm 250W (+20 to +250°C) — Cat. No. 27 57 010-1 — Our own mixture. A hydrocarbon oil which is water soluble for easy exchange. It is not transparent and has a distinct brown/green color.

D. Silicone Oils (-30 to +150°C) — a phenyl-methyl silicone oil but one having a very low viscosity of 5 cST at 20°C.

1. Type SK Frigor (-60 to +120°C) — Cat. No. 27 57 100-0.

2. Type SK Super-Frigor (-60°C to +120°C)— Cat. No. 27 57 110-7.

VII. SUGGESTED HOSES FOR EXTERNAL CIRCULATION AND MISC. ACCESSORIES

A. Foam-rubber insulated silicone hose, 8 mm i.d., 30 mm o.d., Cat. No. 27 59 200-7

B. Silicone hose, 8 mm i.d., for use to -55°C, not insulated. Cat. No. 27 59 180-9.

C. Perbunan hose, 9 mm i.d., for use to +150°C, Cat. No. 27 59 100-1.

D. Test tube holder for 5 (five) test tubes. Cat. No. 27 53 890-0.

VIII. PERFORMANCE DATA

Operating Range	:	-10 to +150°C — K-2/R -20 to +100°C — Super K-2/R
Sensitivity	:	±0.01°C
Control Accuracy	:	±0.01 to 0.02°C (measured with distilled water as circulating liquid)
Cooling Performance (*) (without load)	:	Net available cooling capacity at -10°C approximately 200 BTU/h — K-2/R approximately 150 BTU/h — Super K-2/R
Heating Wattage	:	750 Watts
Reservoir Liquid Required	:	Approximately 1 (one) gallon
Pumping Capacity	:	2-1/2 gal/min.

(*) If compressor has not been used for 24 hours or longer the cooling performance will reach this level only after several hours of compressor operation.

IX. PARTS LIST

Cat. No.	Parts Description
	Thermometers
27 59 980-0	Contact thermometer type 215F (fork-type) -35 to +105°C
27 59 690-8	Control (reading) thermometer type 125, -35 to +105°C
27 53 400-7	Short protective sleeve for contact thermometer
27 53 420-1	Rotating magnet drum
	Compressor
27 57 940-0	Compressor (condensing system) Tecumseh type AE6H (K-2/R)
27 56 060-1	Compressor (condensing system) Tecumseh type AE5I (Super K-2/R)

X. SERVICE

A. Refrigeration

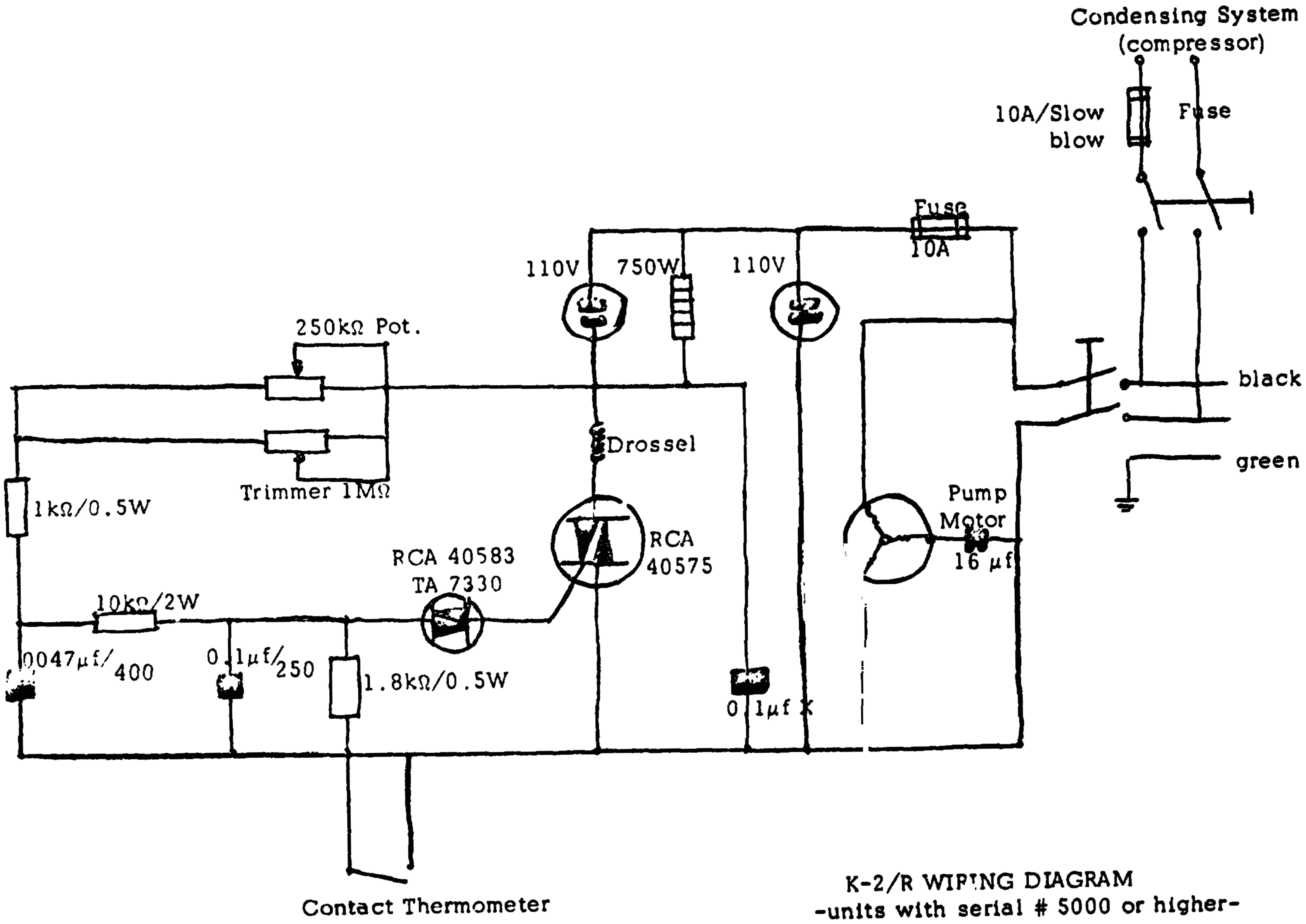
	K-2/R	Super K-2/R
Compressor:	Tecumseh AE 6 H	Tecumseh AE 5 L
Refrigerant:	Freon 12 - approx. 5 oz.	Freon 12 - approx. 8 oz.
Suction pressure:	10 psi after 15 min. running time	5 psi after 15 min. running time

B. General

Any Lauda constant-temperature circulator, or component thereof, may be returned to our shops in New York for service, overhaul or replacement of parts.

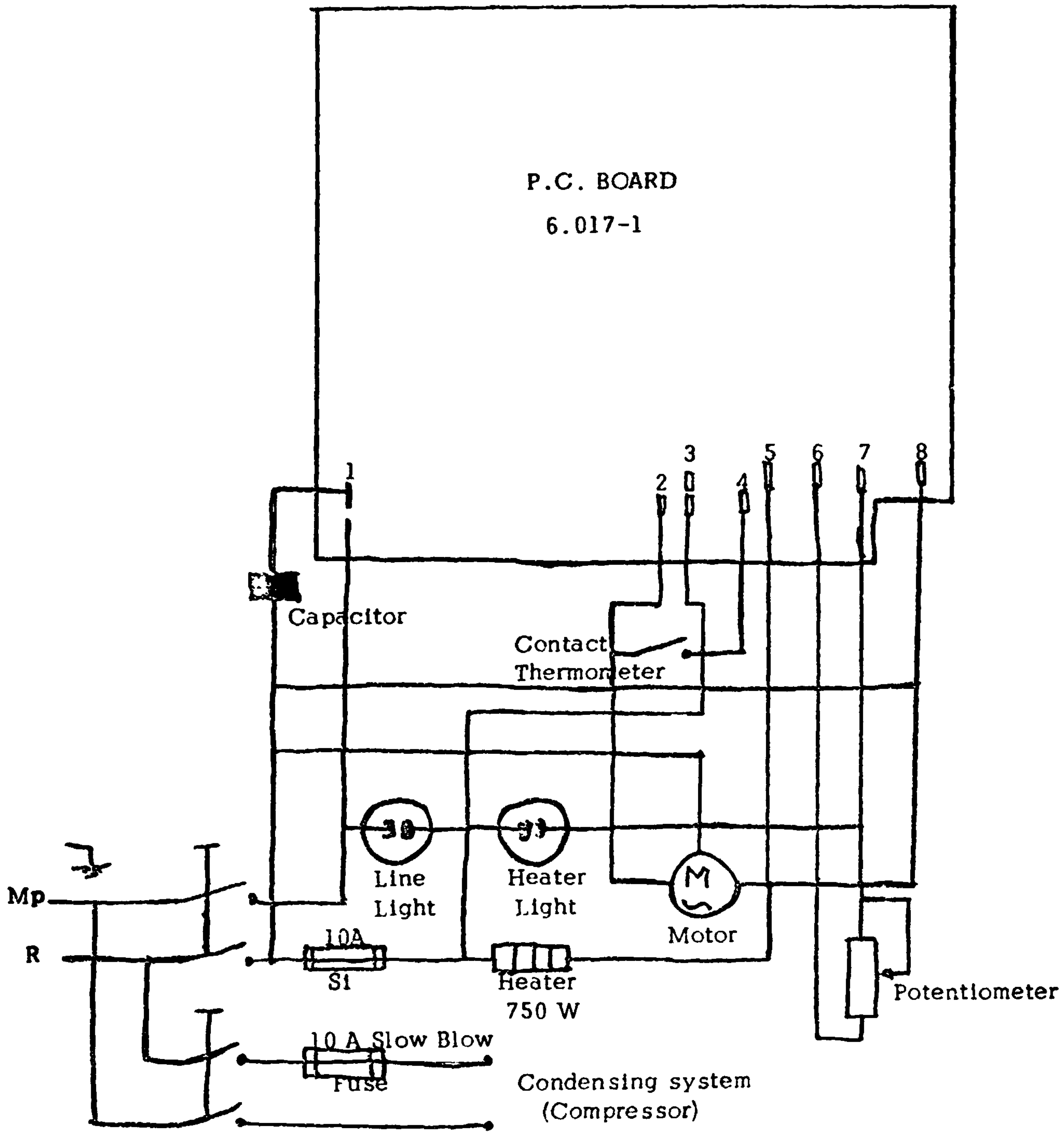
For information, contact:

LAUDA INSTRUMENTS DIVISION
BRINKMANN INSTRUMENTS INC.
Westbury, New York 11590
Phone (516) 334-7500
TWX 510 222 8254



K-2/R WIRING DIAGRAM
-units with serial # 5000 or higher-

-Fig. 3-



K-2/R CIRCUIT CONNECTIONS

-units with serial # 5000 or higher-

-Fig. 4-