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CRT IMAGE RECORDING

EVALUATION

Final Report

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EVALUATION

Final Report

Contract NAS5-21392

November 19, 1971

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1.0 INTRODUCTION

This document is the final report of a study on cathode ray tube image recording systems under contract number NAS5-21392. The objectives of this program were to evaluate and quantitatively define the performance capabilities and limitations of a fiber optic coupled line scan CRT image recording system. The test program evaluated the following components:

A. P31 phosphor CRT with EMA faceplate
B. P31 phosphor CRT with clear clad faceplate
C. Type 7743 semi-gloss dry process positive print paper
D. Type 777 flat finish dry process positive print paper
E. Type 7842 dry process positive film
F. Type 1971 semi-gloss wet process positive print paper

The test program was divided into two parts. In the first part, all of the salient performance characteristics of the CRT alone were investigated. In the second part, the system performance was investigated with all combinations of CRT's and photographic materials. This approach enabled the system performance to be compared with the expected performance based on the CRT tests and also isolated the component responsible for each performance limitation.

Section 2 presents the detailed test procedures used in each test.

Section 3 provides a description of each test, the test data, and an analysis of the results.

Section 4 sumarizes the results of the test program.

Appendix I presents the original test plan that was submitted prior to the start of the test program.

Appendix 2 provides a specification of the EMR Video Information Process used for this evaluation program.

2.0 DETAILED TEST PROCEDURES

2.1 Preliminary Set-Up

2.1.1 Turn on the photorecorder and all test equipment and allow 1/2 hour warm-up.

2.1.2 Measure the output of the +20 reference supply, the +20 V supply, the +15 V supply, the +5 V supply, and the -15 V supply. All supplies are to measure within $\pm 1\%$ of ratings with a maximum of 10 millivolts peak-to-peak noise.

2.1.3 Measure the output of the high voltage supply. Measurement is to be 15 KV $\pm 1\%$ with a peak-to-peak ripple of less than 5 volts.

2.1.4 Set up the horizontal sweep circuit for a normal scan. A normal scan is a $\pm$ 4-inch deflection on the faceplate with a 250 millisecond horizontal sync pulse period with a 10% retrace period.

2.1.5 Set up the CRT beam DC bias for zero beam current with the horizontal sync removed and the sweep protection circuit temporarily disabled.

2.1.6 Set the reference CRT black level by setting the video input to zero volts and adjusting the Black Level Set Control for 5.0 microamperes beam current.

2.1.7 Check the S/N ratio of the video electronics by applying a DC video input one half way between the reference black level and CRT beam cutoff and measuring the noise at the output of the modulator. All sources of random and coherent noise are to be greater than 40 db below the DC video level.

2.1.8 Check the bandwidth of the video electronics by applying a sine wave and measuring the output of the demodulator on the oscilloscope. At the normal scan (4 HZ), the video 3 db bandwidth is to be greater than 30 KHZ. Note: The bandwidth at other sweep speed to be tested as specified in Section 3.

2.1.9 Verify that the dynamic focus correction is set to the theoretical optimum waveform by measuring the output of each segment amplifier with 7.5 volts at the input of the Dynamic Focus Board.

Segment Amplifier Number	Output Voltage
2	2.74 V $\pm$ 2%
3	2.12 V $\pm$ 2%
4	1.59 V $\pm$ 2%
5	0.99 V $\pm$ 2%
6	0.55 V $\pm$ 2%

2.1.10 Adjust the static and dynamic focus for minimum line width with the spot analyzer microscope.

2.2 Spot Size vs. Beam Position

2.2.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.2.2 Remove the horizontal sweep card to find the center point of the horizontal deflection and mark off one inch intervals across the face of the CRT. Replace sweep card.

2.2.3 Remove the video card to disable the video carrier.

2.2.4 Install a .02 μf disc capacitor on the output of the spot analyzer to filter out high frequency noise.

2.2.5 Remove the dynamic focus waveform generator and connect the precision power supply to the base of Q3 in the dynamic focus driver.

2.2.6 Check and record the calibration of the spot analyzer with the test lamp and the 1 to 3 mil slits installed.

2.2.7 Set the beam current for 1.0 microamperes.

2.2.8 Measure and record the spot size in the center with 0 V on the dynamic focus coil and static focus optimized.

2.2.9 Repeat the measurement at one inch intervals. At each point, adjust the dynamic focus DC voltage for minimum spot size without changing static focus.

2.2.10 Repeat the measurements at one inch intervals with the dynamic focus removed.

2.2.11 Repeat entire test with the P31 clear clad tube.

2.3 Spot Size vs. Beam Current

2.3.1 Perform steps 2.2.1, 2.2.3, 2.2.4, and 2.2.6 as in test 2.2.

2.3.2 Check the calibration of the anode current detector by feeding 1.0 V from the precision power supply through a 1 megohm 5% resistor into the input. Output should measure 0.1 V ±5 mv.

2.3.3 Set the beam current for 0.5 μa by adjusting the G1 DC bias control.

2.3.4 Set the static focus at the center and the dynamic focus at the corner for minimum spot size.

2.3.5 Measure and record the spot size at the center and corner of the faceplate.

2.3.6 Repeat measurements at 1, 1.5, 2, 3, 4, 5, and 7 μa.

2.3.7 Repeat the entire test with the P31 clear clad tube.

2.4 CRT Signal-to-Noise Ratio

2.4.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.4.2 Remove the video card to disable the video carrier.

2.4.3 Check and record the calibration of the spot analyzer with the test lamp and the 1.4 to 12 mil slit installed.

2.4.4 Adjust static focus for a 2 mil spot at a beam current of 0.2 μa.

2.4.5 Remove slit and focus the spot analyzer for maximum signal output at the center fo the faceplate.

2.4.6 Measure and record the S/N ratio as the peak signal to peak-to-peak noise.

2.4.7 Repeat the above measurement at beam currents of 1 μa and 5 μa. If the photomultiplier tube starts to saturate, install neutral density filters between the faceplate and the spot analyzer.

2.4.8 Repeat steps 2.4.4, 2.4.5, 2.4.6, and 2.4.7 with a 4 mil spot size.

2.4.9 Repeat steps 2.4.4, 2.4.5, 2.4.6, and 2.4.7 with a 6 mil spot size.

2.4.10 Insert the video card and repeat the above measurements with a 2 mil spot size and beam currents of 0.2 μa, 1 μa, and 5 μa.

2.4.11 Repeat the entire test with the P31 clear clad tube.

2.5 CRT Intensity Non-Uniformity

2.5.1 Perform preliminary set-up procedure in Section 2.1 with P31 EMA tube installed.

2.5.2 Disconnect the output of the horizontal sweep integrator stage.

2.5.3 Remove horizontal linearity card.

2.5.4 Connect a precision power supply to the input of the horizontal driver IC1.

2.5.5 Disconnect the center tap of the vertical position control.

2.5.6 Connect a second precision power supply on the vertical driver Q1 and Q2.

2.5.7 Connect the 0.5 ms one shot on the test board to the horizontal sync output of the calibrator.

2.5.8 Connect the output of the one shot to the video input to pulse on the sweep 0.5 ms out of the 250 ms period.

2.5.9 Turn on high voltage and adjust the beam current for a peak value of 0.2 μa.

2.5.10 Set the bandwidth of the anode current detector at 2 KHZ by connecting a 75 pf capacitor across the 1 meg feedback resistor.

2.5.11 Adjust the horizontal precision power supply to divide the horizontal sweep range into 30 positions by using $\pm$0.5 volt steps.

2.5.12 At each step, adjust the static focus for a minimum spot size as viewed through the microscope of the spot analyzer.

2.5.13 Remove the slit plate from the spot analyzer.

2.5.14 At each horizontal position, make 7 measurements by varying the vertical position of the beam by using 1 volt steps with the precision power supply.

2.5.15 At each beam position, position the spot analyzer to set the spot at approximately the center of the field of view of the spot analyzer.

2.5.16 Focus the spot analyzer for a maximum output at each position.

2.5.17 Measure and record the peak output at each beam position. Check that the anode current is maintained at 0.2 μa for each measurement.

2.5.18 Repeat above procedure with the P31 clear clad tube installed.

2.6 CRT Dynamic Range

2.6.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.6.2 Remove card No. 5 to remove the modulation and focus for a 2 mil spot with the 1.4 to 12 mil slit plate.

2.6.3 Re-install Card 5 and connect the calibrator modulator.

2.6.4 Set up the calibrator for square wave modulation with a 1 line per inch pattern and a 1 HZ sweep period.

2.6.5 Remove the slit plate, center and focus the spot analyzer at the center of a dark region in the line scan.

2.6.6 Adjust and measure the beam current at the point of minimum discernable signal at the output of the spot analyzer.

2.6.7 Center the spot analyzer in the center of a bright region in the line scan.

2.6.8 Measure the output of the spot analyzer with sufficient neutral density filter between the spot analyzer and the CRT to prevent saturation of the photomultiplier tube.

2.6.9 Repeat the above procedure at sweep speeds of 10 HZ, 100 HZ, and 1000 HZ with a 1 line/inch line pattern.

2.6.10 Repeat the above procedure with the spot adjusted for 4 mils and 6 mils.

2.6.11 Repeat the above procedure with the P31 clear clad tube installed.

2.7 CRT MTF

2.7.1 Perform preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.7.2 Connect the sine wave oscillator to the 15 line/inch input on the calibrator through the buffer stage on the test board.

2.7.3 Adjust the oscillator for a 60 HZ output with a 5 V peak output.

2.7.4 Adjust the horizontal sweep for a full width trace with approximately a 10% retrace period.

2.7.5 Measure and record the time period of the portion of the sweep waveform used to deflect the beam across the CRT.

2.7.6 Connect the sine wave oscillator before the buffer to the video input.

2.7.7 Adjust the waveform at the output of the 2 MHZ video modulator for approximately 10% modulation.

2.7.8 Measure and record the peak-to-peak amplitude of the modulator.

2.7.9 Turn on high voltage and adjust the static focus at the center and dynamic focus at the corner for minimum spot size with the microscope on the spot analyzer.

2.7.10 Adjust the CRT G1 bias for approximately 1 μa beam current.

2.7.11 Mask one of the two slits in the 1 to 3 mil slit plate and install in spot analyzer.

2.7.12 Position spot analyzer near the center of the trace and focus the analyzer for maximum output.

2.7.13 Slowly move the spot analyzer parallel to the faceplate and measure and record 5 maximum and 5 minimum outputs.

2.7.14 Move the sine wave oscillator to the inputs in the table below and set the frequency as indicated. Check the output of the modulator to insure that there is no change in the percentage of modulation at each step.

Table I

Input	Frequency			
	1 HZ Sweep	10HZ Sweep	100HZ Sweep	1 KHZ Sweep
15 lines/inch	60 HZ	600 HZ	6 KHZ	60 KHZ
30 lines/inch	120 HZ	1200 HZ	12 KHZ	120 KHZ
60 lines/inch	240 HZ	2400 HZ	24 KHZ	240 KHZ
120 lines/inch	480 HZ	4800 HZ	48 KHZ	480 KHZ
240 lines/inch	960 HZ	9600 HZ	96 KHZ	960 KHZ
480 lines/inch	1920 HZ	19200 HZ	192 KHZ	
960 lines/inch	3840 HZ	38400 HZ	384 KHZ	

2.7.15 Repeat the entire procedure for a 10 HZ, 100 HZ, and 1 KHZ sweep using the frequencies in Table I.

2.7.16 Repeat the entire test with the P31 clear clad tube installed.

2.8 CRT Light Output

2.8.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.8.2 Adjust the beam current for 7 μa with no modulation.

2.8.3 Adjust the sweep for a one inch trace at a sweep rate of 0.1 HZ.

2.8.4 Adjust the static focus for minimum spot size.

2.8.5 Position the thermopile approximately one half inch from the face-plate in the middle of the scan.

2.8.6 Connect the output of the thermopile amplifier to the oscilloscope and measure the peak deflection.

2.8.7 Repeat above procedure with the P31 clear clad tube installed.

2.9 Material Non-Uniformity

2.9.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA installed.

2.9.2 Set the horizontal sweep for 4 HZ and adjust the paper speed control for 8 mils/sec to produce a flat field with approximately zero overlap.

2.9.3 Ground the input of the video amplifier to produce a uniform CRT trace.

2.9.4 Develop samples of each of the photographic materials with beam currents of 0.1, 1, 3, 5, and 10 microamperes.

2.9.5 For each of the heat processed materials, set the heater bar for the following approximate temperatures.

Material	
7743	250°F
777	270°F
7842	260°F

2.9.6 Develop additional samples of each material with the heater bar set approximately 10 degrees above and below the above temperatures.

2.9.7 Develop the wet process materials by immersing the samples for several seconds in the A10 Activator, wash with water, and immerse in the S30 Stabilizer.

2.9.8 Run additional samples at the beam currents in 2.9.4 and develop on the model 17 ADS external heater using type 7743 paper.

2.9.9 Repeat the above tests with the P31 clear clad tube.

2.10 System MTF

2.10.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.10.2 Perform steps 2.7.1 through 2.7.9.

2.10.3 Develop samples of each of the four materials using the beam currents and development parameters that produced a gray scale in the middle of the range from the non-uniformity tests.

2.10.4 With each material, develop samples at the required inputs for a 1 HZ sweep and a 10 HZ sweep as indicated in Table I of test 2.7.

2.10.5 At each sweep speed, set the paper speed to advance 2 mils/sweep.

2.10.6 With the 7743 material, develop samples at sweep speeds of 1 HZ, 10HZ, 100 HZ, and 1000HZ at the inputs given in Table I.

2.10.7 Repeat the entire test with the P31 clear clad tube installed.

2.11 Horizontal Linearity

2.11.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.11.2 Connect 7.50 volts to the input (pin) of the linearity corrector card.

2.11.3 Adjust the breakpoints and gains of each segment amplifier for the following outputs:

Segment	Break Point	Output
1		
2	1.886	1.552
3	3.268	1.491
4	4.525	1.170
5	5.540	0.734
6	6.545	0.409

2.11.4 Connect the 3.75 lines/inch output of the calibrator to the one shot on the test board.

2.11.5 Connect the output of the one shot to the video input.

2.11.6 Adjust the period of the one shot for the smallest perceptible dot on the faceplate.

2.11.7 With the spot analyzer microscope and the micrometer stage, measure the separation between dots at the center, the two ends, and half way between.

2.12 Vertical Linearity

2.12.1 Perform the preliminary set-up in Section 2.1 with the P31 EMA tube installed.

2.12.2 Set the output of the calibrator for 1 HZ sweep.

2.12.3 Set the paper speed for 250 pps to advance the paper approximately 1/4 inch per trace.

2.12.4 Develop a two-foot strip of 7743 paper with the heat set for a line at the maximum density.

2.12.5 Repeat the above procedure using the HP 202A generator set for 0.08 HZ for horizontal sync and the paper speed set for 20 pps.

3.0 TEST RESULTS

3.1 CRT

The two tubes used in this program were a P31 phosphor line scan tube with an EMA faceplate and a P31 with a clear clad faceplate. The EMA tube was manufactured by Litton Industries and the clear clad tube by Westinghouse. The letters EMA mean extramural absorbing material and signify a manufacturing process where black glass was placed around each hexagonal bundle in the faceplate. These tubes were primarily designed for a single line scan and had an 8-inch by 0.2 inch faceplate made of glass fibers with a 0.66 numerical aperature. Both tubes used the same type of deflection coils and focus coils and were completely enclosed in an electromagnetic shield. The EMA tube had an additional aperature electrode, G3, that was internally connected to the anode. The maximum beam current for the EMA tube was 10 microamperes and was over 100 microamperes for the clear clad tube.

3.2 CRT Spot Size

The best possible spot size at a beam current of 1 microampere was 1.5 mils for the EMA tube and 2 mils for the clear clad tube. The anode aperaturing in the EMA tube produced a smaller spot size at the expense of maximum beam current. These measurements were the width of the CRT spot one half power points as determined by the Celco Model 1726-5 spot analyzer. Figure 1 shows copies of Polaroid prints of the spot analyzer output with a 15 second time exposure. The dimensions of the two slits in the spot analyzer provided a calibration of 4 mils per centimeter when the peaks were adjusted for 6 centimeters on the oscilloscope.

3.2.1 Spot Size vs. Beam Current

Spot size increases with beam current. High resolution tubes inherently have a relatively long beam path length between the gun aperture and the focusing coils to demagnify the spot image at the faceplate. Due to the natural repulsion between electrons in the beam bundle, the repulsion will increase with beam current especially in the region between the fun aperture and the center of focus.

The measured data of spot size vs. beam current is shown in Table 2. With a change in beam current between 1 to 7 microamperes, the EMA tube spot grew 21.4%, and the clear clad tube spot grew 30% when the spot was not at optimum focus. However, when the spot was focused at or near the minimum value, there was no measurable spot growth in this current range. With the clear clad tube, a current change of 1 to 20 microamperes was required to produce a 20% change in spot size and between 20 and 100 microamperes, the spot growth was only an additional 20 percent. This test was not repeated with the EMA tube since this tube cannot produce 20 microamperes of beam current.

It was observed that it was preferable to adjust focus at maximum beam current. With the spot focused at large values of beam current, the degree of change in spot size was less than when the spot was initially focused at a low value of beam current. The focus adjustment is more critical at higher values of beam current.

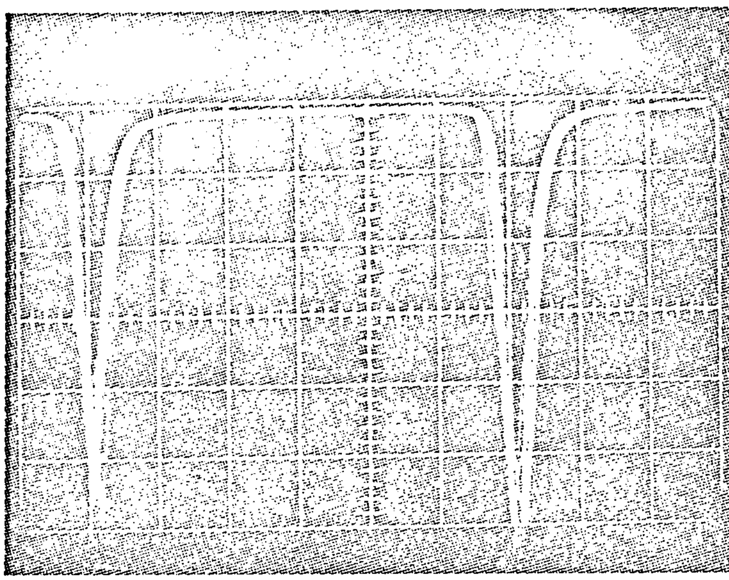
The resultant data indicates that the magnitude of beam current does affect the ultimate resolution but that the magnitude of change is small since large changes in beam current only defocused the spot by 20 percent.

3.2.2 Spot Size vs. Beam Position

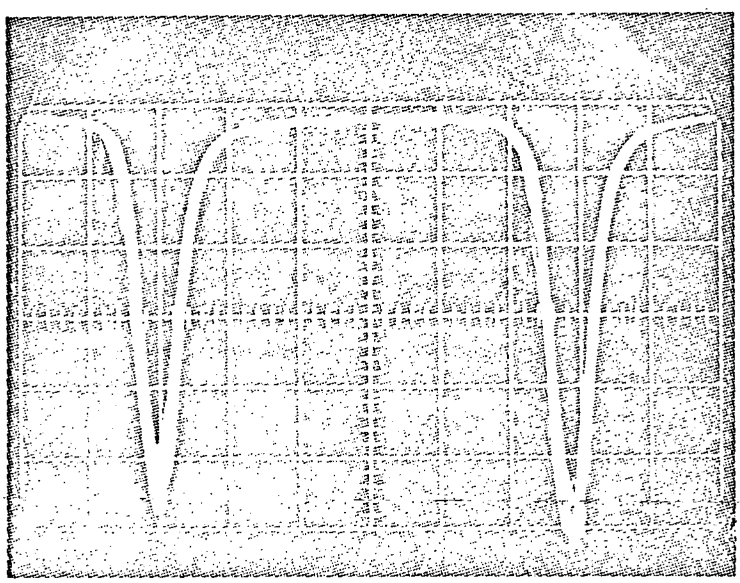
Due to the change in electron beam path length, dynamic focusing must be used to maintain minimum spot size across the faceplate. The correct focus waveform is usually approximated by using the first two terms in a binary expansion of the algebraic expression for the beam path length. This results in a parabolic waveform. EMR synthesizes the secant waveform of the deflection angle by piecewise linear approximation because this matches the theoretical waveform better than the parabolic function.

In this test, the experimentally measured dynamic focus current for best possible focus was compared with the segment of the secent function that was the best fit to the experimental data. The test data is shown in Table 3. Plots of these curves are shown in Figure 2. These curves indicate that the secent function was a good fit of the required focus function. The greatest errors occurred at small deflection angles. At small angles, the possible measurement error was large since the amount of defocusing was small for small deflection angles.

EMA TUBE



CLEAR CLAD TUBE



CRT SPOT SIZE

FIGURE I

Table 2

Spot Size vs. Beam Current

P31 EMA Clad Tube

	Beam Current	Spot Size	Position
	.5 ua	2.8 mils	Center
	1 ua	2.8 mils	Center
	1.5 ua	3.2 mils	Center
	2 ua	3.2 mils	Center
	3 ua	3.2 mils	Center
	4 ua	3.2 mils	Center
	5 ua	3.4 mils	Center
	7 ua	3.4 mils	Center
↑	.5 ua	2 mils	Right Corner
	1 ua	2 mils	Right Corner
	1.5 ua	2 mils	Right Corner
Note 1	2 ua	2 mils	Right Corner
	3 ua	2 mils	Right Corner
	4 ua	2 mils	Right Corner
	5 ua	2 mils	Right Corner
↓	7 ua	2 mils	Right Corner

Note 1: Spot refocused for minimum spot size.

Table 2

P31 Clear Clad Tube

	Beam Current	Spot Size	Position
	.5 ua	4 mils	Center
	1 ua	4 mils	Center
	1.5 ua	4 mils	Center
	2 ua	4 mils	Center
	3 ua	4.4 mils	Center
	4 ua	4.8 mils	Center
	5 ua	4.8 mils	Center
	7 ua	5.2 mils	Center
	.5 ua	3.2 mils	Right Corner
	1 ua	3.2 mils	Right Corner
	1.5 ua	3.2 mils	Right Corner
	2 ua	3.2 mils	Right Corner
	3 ua	3.2 mils	Right Corner
	4 ua	3.2 mils	Right Corner
	5 ua	3.2 mils	Right Corner
	7 ua	3.2 mils	Right Corner
	1 ua	2 mils	Center
	7 ua	2 mils	Center
	20 ua	2.4 mils	Center
	40 ua	2.4 mils	Center
	60 ua	2.4 mils	Center
Note 1	100 ua	2.4 mils	Center
	1 ua	2 mils	Right Corner
	7 ua	2 mils	Right Corner
	20 ua	2.4 mils	Right Corner
	40 ua	2.8 mils	Right Corner
	60 ua	2.8 mils	Right Corner
	100 ua	2.8 mils	Right Corner

Note 1: Spot refocused for minimum spot size.

Table 3

Spot Size vs. Beam Position

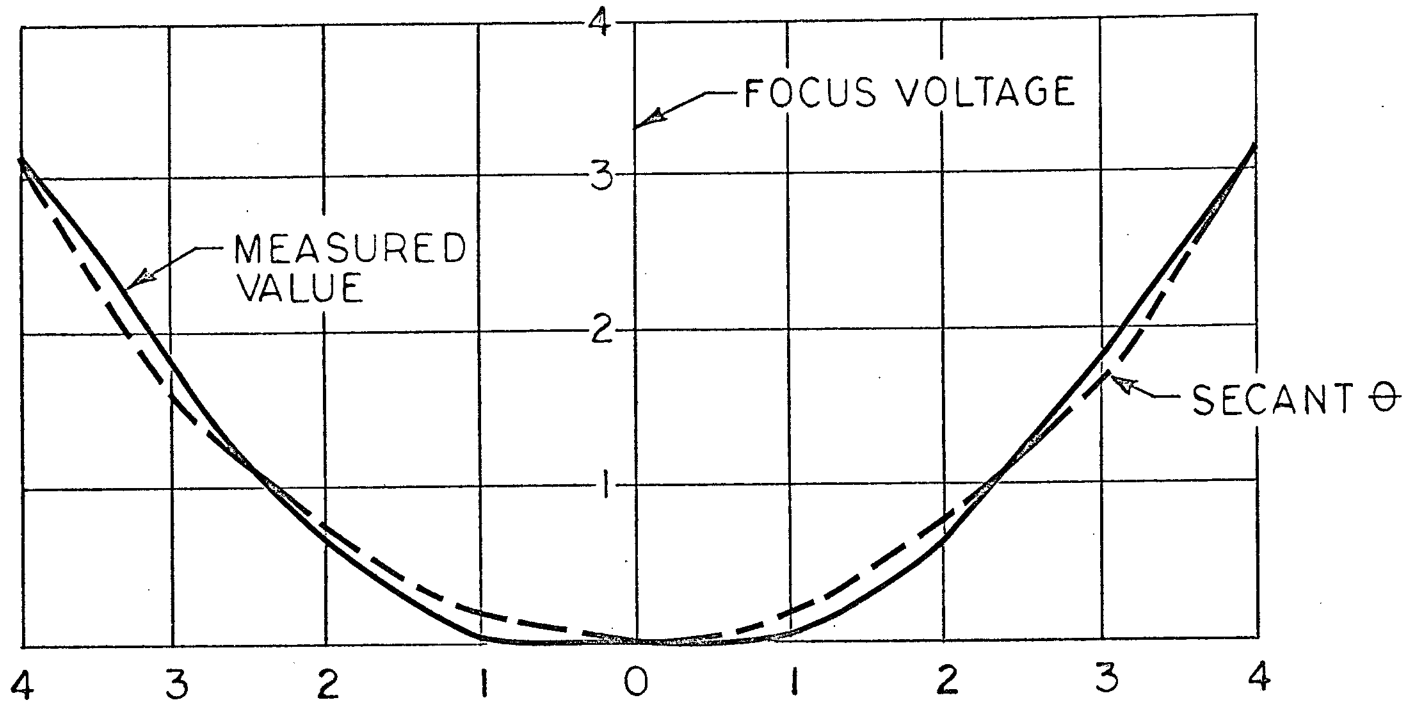
P31 EMA Clad Tube

Spot Size	Spot Position	Dynamic Focus
1.5 mils	Center	0 V
1.5 mils	1 in. right	0 V
1.5 mils	2 in. right	.591 V
1.5 mils	3 in. right	1.844 V
2.0 mils	4 in. right	3.108 V
1.5 mils	1 in. left	0 V
1.5 mils	2 in. left	.652 V
1.5 mils	3 in. left	1.840 V
2.0 mils	4 in. left	3.108 V

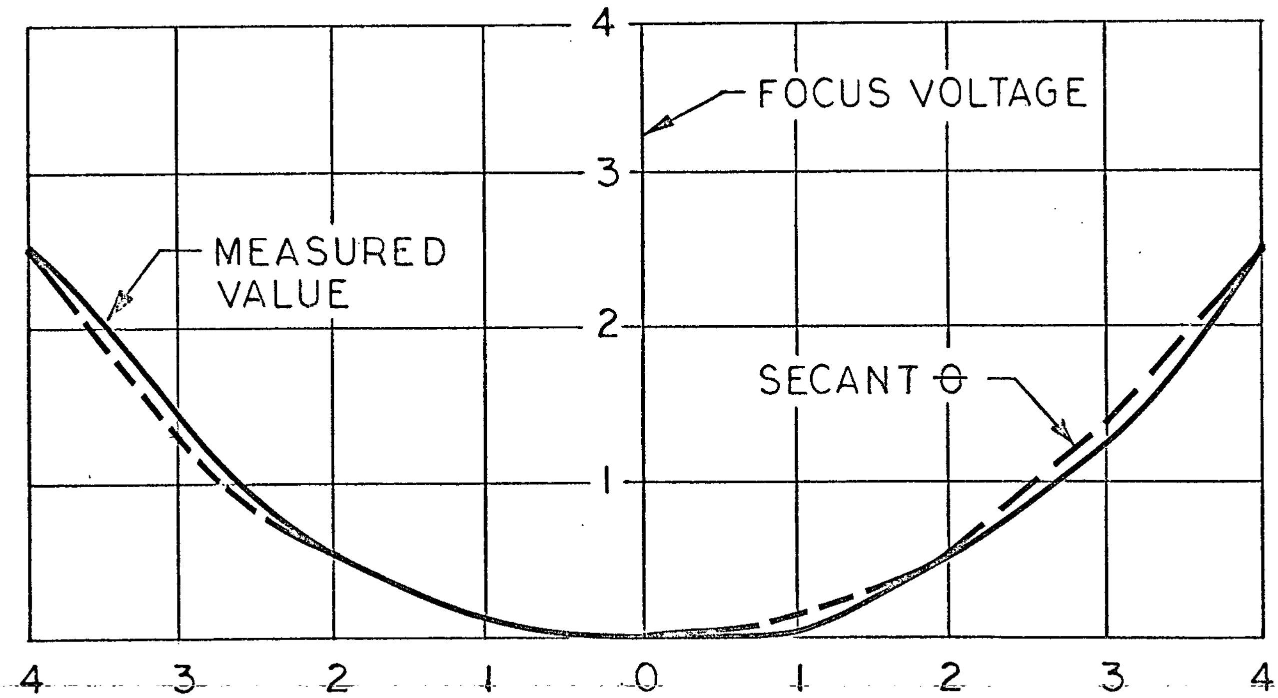
Table 3

P31 Clear Clad Tube

Spot Size	Spot Position	Dynamic Focus
2.0 mils	Center	0 V
2.0 mils	1 in.right	0 V
2.5 mils	2 in.right	.586 V
2.5 mils	3 in.right	1.20 V
3.75 mils	4 in.right	2.457 V
2.0 mils	1 in.left	.120 V
2.5 mils	2 in.left	.585 V
2.5 mils	3 in.left	1.452 V
3.0 mils	4 in.left	2.455 V



P31 EMA BEAM POSITION INCHES



P31 CLEAR CLAD BEAM POSITION INCHES

DYNAMIC FOCUS CURVES

FIGURE 2

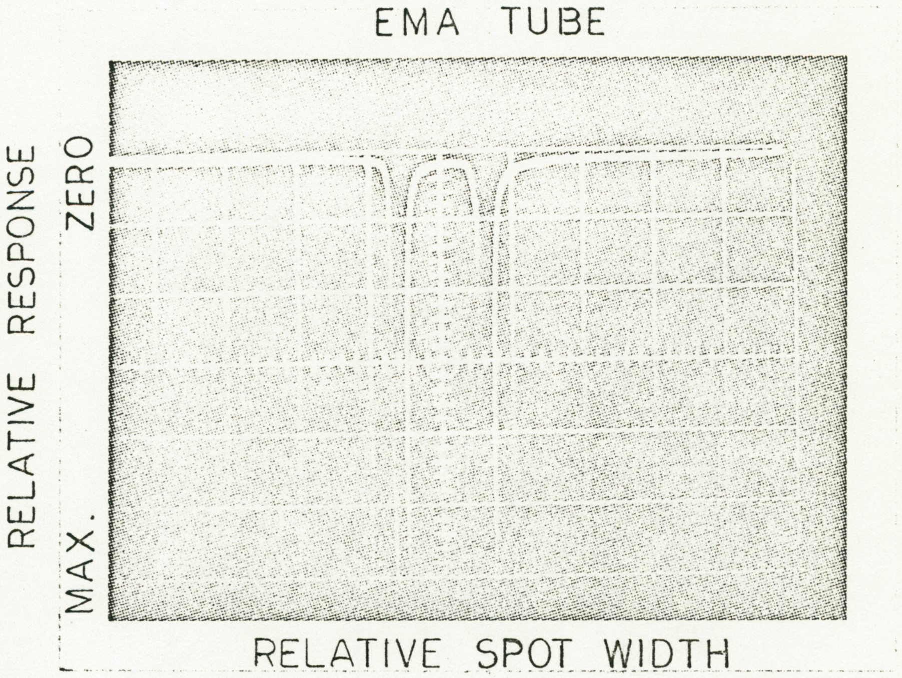
3.2.3 Spot Light Distribution

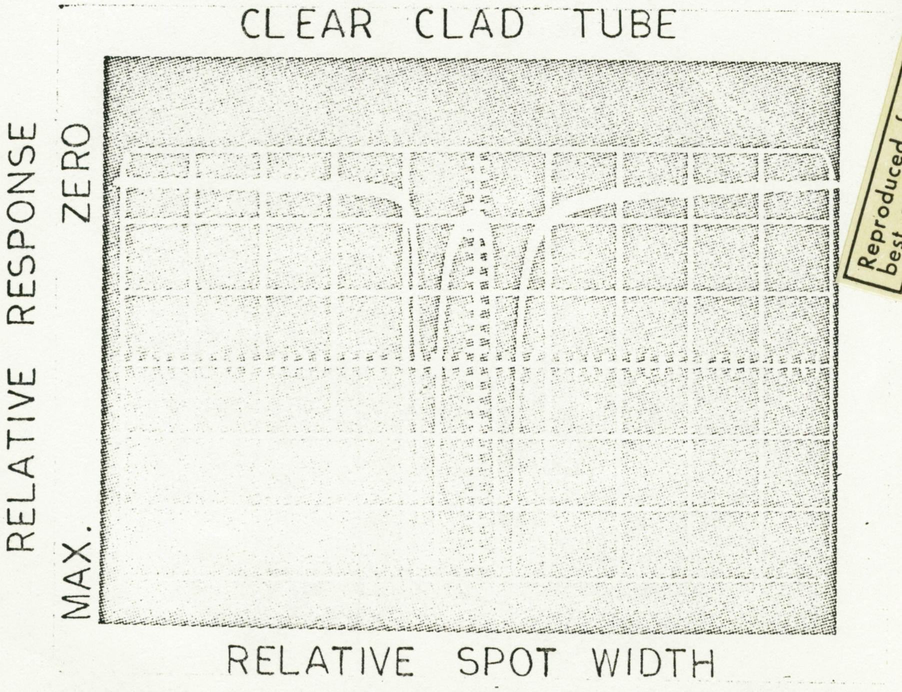
An investigation was made into the differences in light distribution of the CRT spot in the EMA and clear clad faceplates. Due to the random nature of the beam electron collisions with the phosphor, the theoretical light distribution is Gaussian. However, the fiber optic faceplate modifies the light distribution at the surface of the faceplate. Figure 3 shows copies of Polaroid prints of the output of the spot analyzer for the two tubes. In these figures, the waveform has been expanded to observe the detail at the baseline of the waveforms. Both pictures were made at the same peak light output and the same oscilloscope settings. With this particular geometry, the ratio of the peak light to the light when the spot was focused between two slits 3 mils wide separated by 120 mils was approximately 60 to 1 for the clear clad faceplate and 200 to 1 for the EMA faceplate. This difference was due almost entirely to the greater crosstalk caused by light leakage between bundles in the clear clad faceplate.

This crosstalk was also observed by measuring the spot size with the spot analyzer positioned off axis. Figure 4 shows the spot analyzer output for these two tubes with the spot analyzer positioned at an angle of 30 degrees above the faceplate with an identical set-up. With the EMA faceplate, the spot intensity at 30 degrees was approximately 10% of the normal value whereas the spot intensity was essentially the same with the clear clad faceplate. Both tubes are specified with glass fibers with a numerical aperture of 0.66 so the intensity difference at 30 degrees was due to the difference in crosstalk.

3.2.4 Spot Astigmatism

The CRT spot was observed with a 60 power microscope at several points across the faceplate. In the center of the faceplate, the cross section of the spot was circular in both tubes. Varying the static focus only changed the diameter of the spot without introducing any type of observable astigmatism in the spot. At the corners of the faceplate, varying the dynamic focus rotated the spot and transformed it from a near circle to an ellipse. Dynamic focus in both tubes was capable of reducing the size of the spot to approximately the same size as the spot in the center of the tube. The cross section of the spot in the corners could not however be adjusted to a perfect circular cross section as in the center. This was the only observable astigmatism in the two tubes.

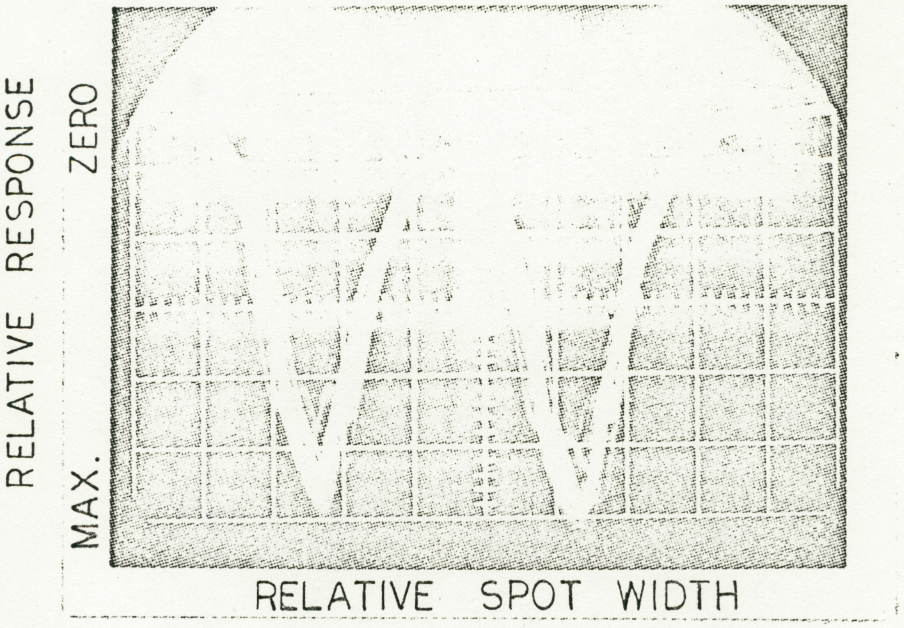




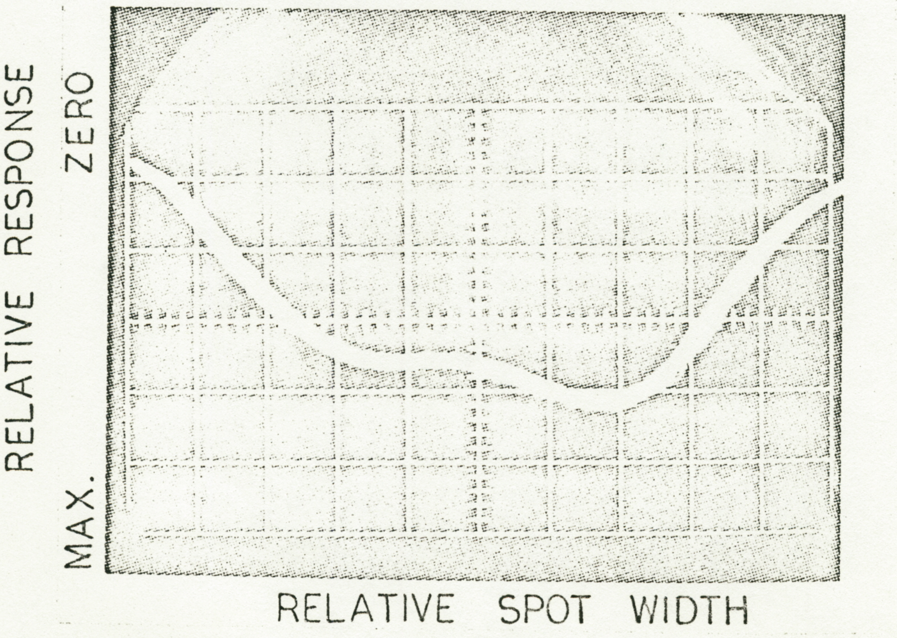
SPOT LIGHT DISTRIBUTION
NORMAL TO FACEPLATE

FIGURE 3

EMA TUBE



CLEAR CLAD TUBE



SPOT LIGHT DISTRIBUTION
30 DEGREES ABOVE FACEPLATE

FIGURE 4

3-11A

3.3 CRT Signal/Noise Ratio

The various types of noise associated with the CRT trace were investigated by using the spot analyzer photomultiplier tube as a photo detector with the slits removed. This data was taken at various spot sizes and beam currents to study the effect of spot size and beam current on the S/N ratio. The resultant data is shown in Table 4. These readings are relative measurements to determine S/N ratio and have no relationship between different rows.

With both tubes, the S/N ratio was inversely proportional to the spot size because the spot behaves as a spatial filter with an effective bandwidth inversely proportional to the spot size. The S/N ratio also increased with beam current due to the increased light output. The noise in each case consisted of two components; a 10 KHZ component and a random component.

The 10 KHZ component was caused by the 10 KHZ oscillator in the high voltage power supply. This signal appeared to intensity modulate the beam. The two most obvious reasons for this interference were 10 KHZ ripple in the Gl power supply or a change in amplitude or phase of the -15 KV power supply ripple between Gl and the cathode. Since both Gl and the cathode were biased around -15 KV, it was not feasible to monitor these waveforms. A circuit analysis of the system did not indicate how this problem could exist.

The peak signal to peak 10 KHZ noise ratio varied between 6.8 to 100 for the EMA tube and between 8.3 to 33 for the clear clad tube. This coherent noise is not a problem in a system with a video bandwidth lower than the power supply oscillator frequency. In a wide band system, this interference can produce various Moire type interference problems. In addition, this interference is more severe with high sensitivity photographic materials due to the lower S/N ratio at low beam currents. This problem is a circuit limitation and not an inherent system limitation and will be corrected when the high voltage power supply is redesigned.

The random noise component was a combination of phosphor particle noise and electron beam shot noise. The peak signal to peak random noise varied between 34 to 120 for the EMA tube and between 50 to 200 for the clear clad tube with a 2 mil spot. At larger spot sizes, the random noise component was negligible.

The ratio of signal to random noise was sufficiently high to prevent any limitations with most print papers due to the limited dynamic range of most of these materials. This noise could, however, degrade system performance when used with a wide dynamic range film.

Table 4

CRT Signal-to-Noise Ratio

P31 EMA Clad Tube

Beam Current	Spot Size	Peak Signal	P-P Noise Supply	P-P Noise Random
.2 ua	2 mils	17	5	1
1 ua	2 mils	24	5	.5
5 ua	2 mils	12	2	.2
.2 ua	4 mils	23	3	Approx. 0
1 ua	4 mils	20	2	Approx. 0
5 ua	4 mils	7	.2	Approx. 0
.2 ua	6 mils	25	2	Approx. 0
1 ua	6 mils	25	1	Approx. 0
5 ua	6 mils	25	.5	Approx. 0

Table 4

P31 Clear Clad Tube

Beam Current	Spot Size	Peak Signal	P-P Noise Supply	P-P Noise Random
.2 ua	2 mils	25	6	1
1 ua	2 mils	25	5	.5
5 ua	2 mils	25	3	.2
.2 ua	4 mils	25	2	Approx. 0
1 ua	4 mils	25	2	Approx. 0
5 ua	4 mils	25	2	Approx. 0
.2 ua	6 mils	25	2	Approx. 0
1 ua	6 mils	25	2	Approx. 0
5 ua	6 mils	25	1.5	Approx. 0

3.4 CRT Non-Uniformity

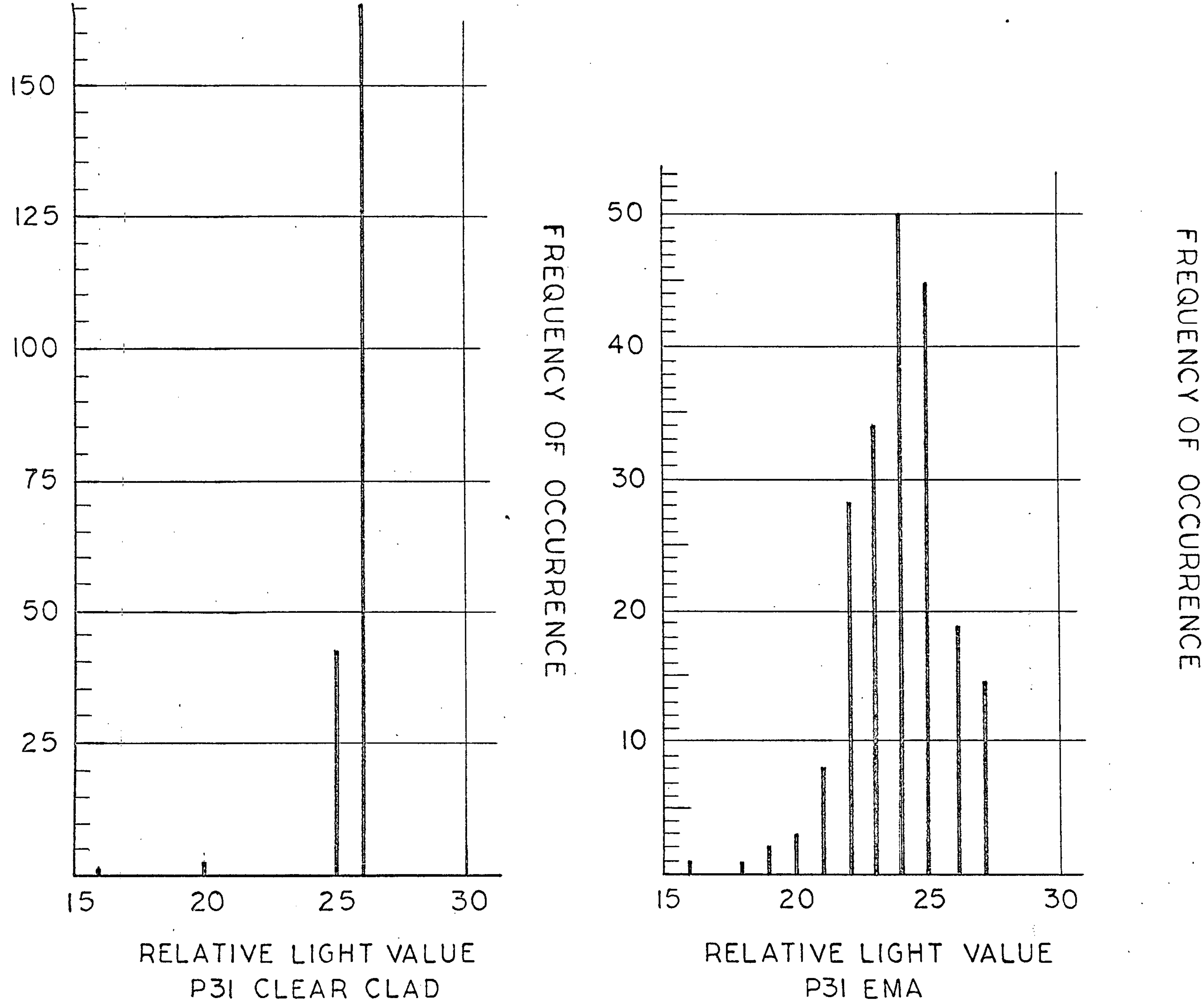
The light energy of the beam at any point on the faceplate will depend upon the beam current, the accelerating potential, the spot focus, the writing speed, the phosphor conversion efficiency, and the fiber optic transmission. In this test, the variation in light due to the phosphor and the faceplate was measured.

Due to the short light path, the light attenuation through a normal fiber optic is negligible. However, severe light losses can result from manufacturing imperfections. Some of the primary losses result from impurities, absorbed gas bubbles, variations in fiber diameter, and surface imperfections. In addition, the black glass and the crushed fibers at the boundries between bundles partially mask the beam.

The CRT light non-uniformity was measured by sampling 210 random points across the faceplate. At each point, the beam was held stationary and focused for the smallest spot size with a constant beam current. The resultant intensity distribution for the two tubes are shown in the histograms in Figure 5.

The principal reason for the smaller dispersion in the clear clad tube is attributed to the greater crosstalk in the clear clad faceplate. A single trace in the center of this faceplate causes a background illumination over the entire faceplate. This effect can be visibly seen when the faceplate is viewed with a bright trace and near zero ambient light.

The points with readings below a magnitude of 20 were examined with a 5 power microscope. In most cases, a visible flaw could be seen in the faceplate.



CRT NON-UNIFORMITY

FIGURE 5

3.5 CRT Dynamic Range

The dynamic range of a CRT is the ratio of the peak intensity to the intensity with the beam near cutoff. With a fiber optic CRT, the internally reflected light is negligible. Also, the ambient light is negligible since the faceplate is housed in a light tight enclosure to protect the photographic material. For these reasons, the dynamic range is far greater than a conventional display type CRT.

The test performed was designed to measure the dynamic range of both the electronics and the CRT. The relative light in the blanked and unblanked segments of a 1 line per inch square wave modulated trace were measured with the spot analyzer. In each case, the G1 bias was adjusted to produce the minimum detectable signal in the blanked segments. The results are shown below:

Spot Size	Beam Current	Spot Analyzer Output	
		Min.	Max.
	EMA Tube		
2 mils	5.8 μa peak	2 mv	20 v
4 mils	5.8 μa peak	2 mv	30 v
6 mils	5.8 μa peak	2 mv	40 v
	Clear Clad Tube		
2 mils	11 μa peak	2 mv	13 v
4 mils	11 μa peak	2 mv	20 v
6 mils	11 μa peak	2 mv	30 v

The dynamic range was also tested at sweep speeds of 1 HZ, 10 HZ, 100 HZ, and 1000 HZ by the same procedure. There was no discernable change in dynamic range in this sweep speed range.

The dynamic range increased with increased spot size with a constant beam current. This effect is caused by a reduction in the P31 phosphor conversion efficiency when the CRT beam bundle is tightly packed. A P31 phosphor, in comparison with other suitable phosphors, is a highly efficient phosphor but it has a greater tendency to saturate at high current densities.

The worst case dynamic range in this test was 10,000 to 1. Of the four photographic materials tested, the type 7842 has the greatest dynamic range with a maximum to minimum density ratio of 100. The exposure ratio for this density range with a gamma around 1 is 200 to 1. Therefore, the photographic material is the limiting factor in dynamic range.

3.6 CRT MTF

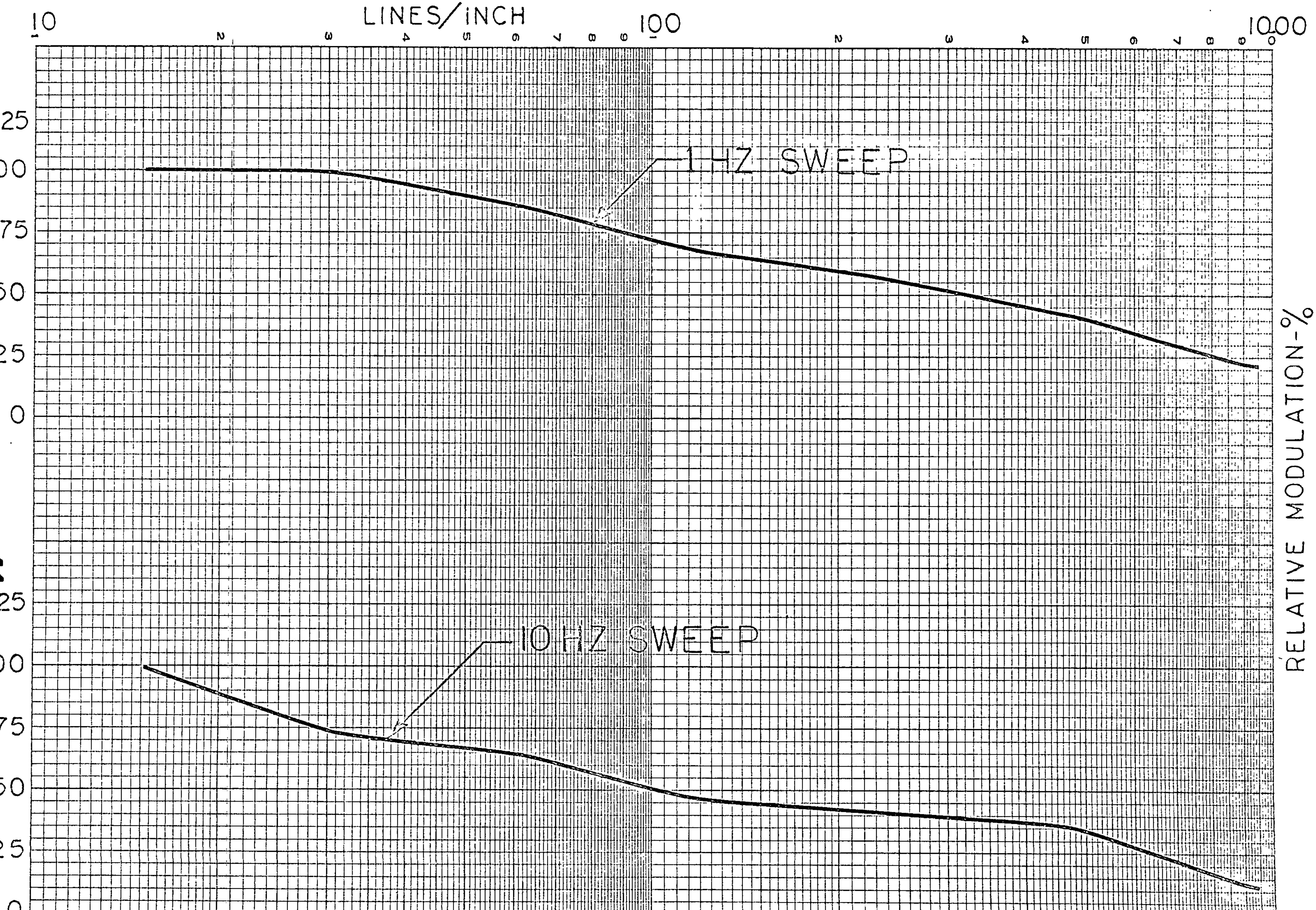
The modulation transfer function is a fairly universal method of defining the resolution because in a linear system the overall resolution is simply the product of each component MTF. With the two tubes tested, the phosphor particle size is in the order of 2 to 10 microns and the size of the fibers in the faceplates 6 to 12 microns. Thus the CRT resolution is determined by the spot size and the degree of crosstalk.

The MTF of the CRT was measured to compare the results with the hard copy imagery MTF as measured with a microdensitometer. These measurements were performed by sine wave modulating the beam with a constant 10% modulated video signal and an average beam current of 1 microampere. The relative maximum and minimum light along the CRT trace was measured through one slit of the spot analyzer. Since the slit width was 2 mils and the lens magnification was 5, the effective measuring aperature size was 0.4 mils. Plots of the MTF's for both tubes at sweep speeds of 1 HZ, 10 HZ, 100 HZ, and 1000 HZ are shown in Figures 6 through 9. In each case, the 15 lines per inch modulation was normalized to 100% and the higher frequency line patterns were compared to the 15 lines per inch reference. At each line pattern, five maximum and five minimum measurements were taken and averaged to compute the percentage of modulation.

In all MTF measurements, the normal modulator with a 100 KHZ carrier was replaced with a breadboard unit with a 2 MHZ carrier. An amplitude modulated video signal was required to transformer couple the video to the grid because the grid was biased at -15080 volts. Theoretically, the full wave demodulator in the grid circuit should be capable of passing a 2 MHZ video bandwidth. Due to circuit limitations, the actual bandwidth was 1 MHZ. With this bandwidth, MTF measurements were made up to 240 lines/inch at a 1 KHZ sweep because the required bandwidth was 960 KHZ.

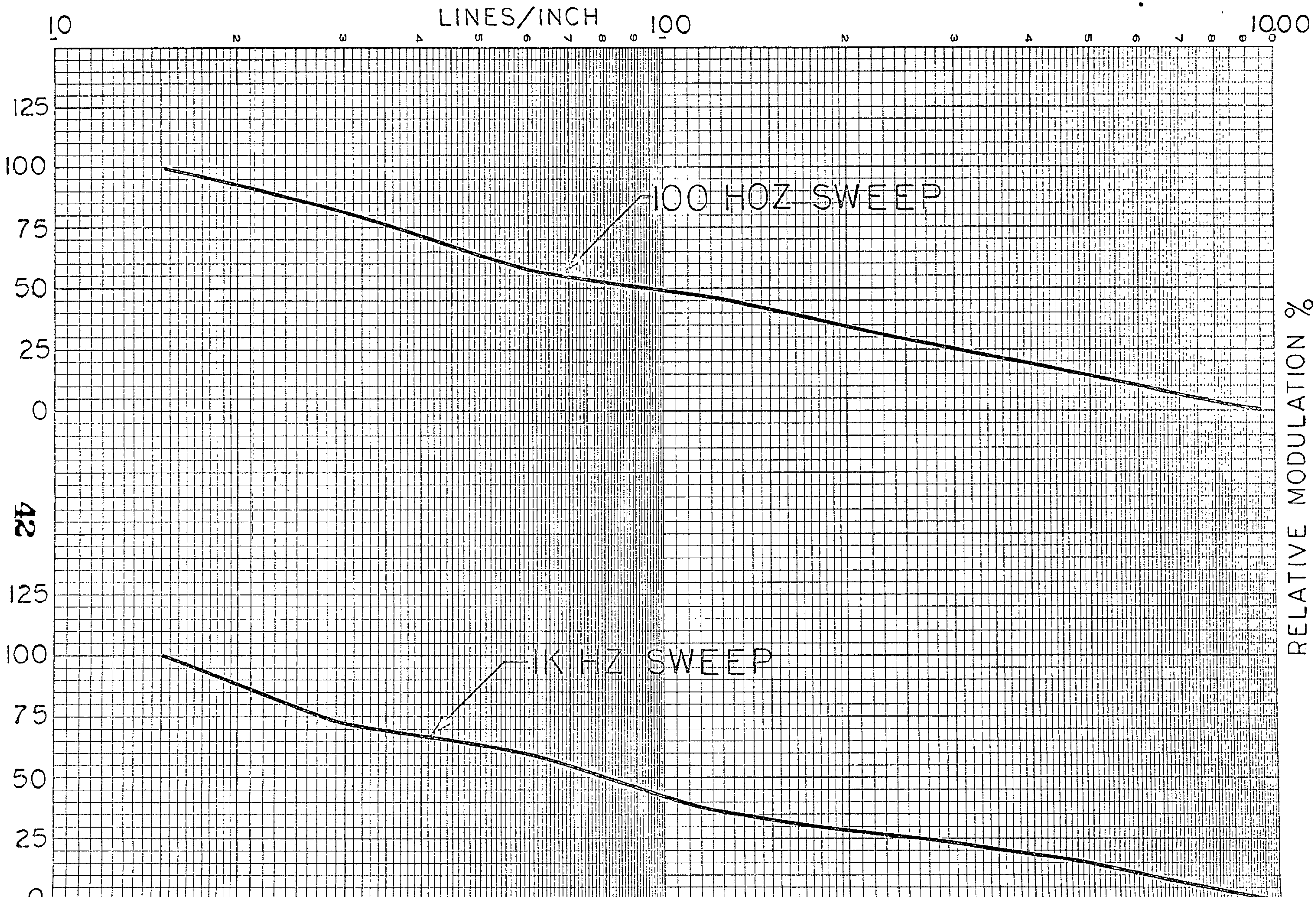
A comparison of the low sweep speed MTF plots indicates a limiting resolu tion of approximately 1300 lines/inch for the EMA tube and 1000 lines/inch for the clear clad tube. The theoretical limiting resolution is equal to one half of the spot size. With spot sizes of 1.5 mils and 2 mils for the EMA and clear clad tubes respectively, the theoretical limiting resolution is 1300 lines/inch and 1000 lines/inch. Thus, the measured results agree quite well with the theoretical results. The excessive crosstalk in the clear clad tube had little effect on the measured MTF of the tubes because the light level due to crosstalk was significantly less than the light level due to the sine wave modulation.

Another trend that can be noticed was that the MTF was reduced as the sweep frequency was increased. This reduction was not due to a bandwidth limitation in the video or measurement circuits. Part of this change was due to the reduction in light output with increased sweep speeds because of the finite rise time in the phosphor. This change in light output changed the transfer characteristic between beam current and CRT light output. The transfer characteristic was non-linear in the range of beam currents used in this test.



P31 EMA CRT MTF

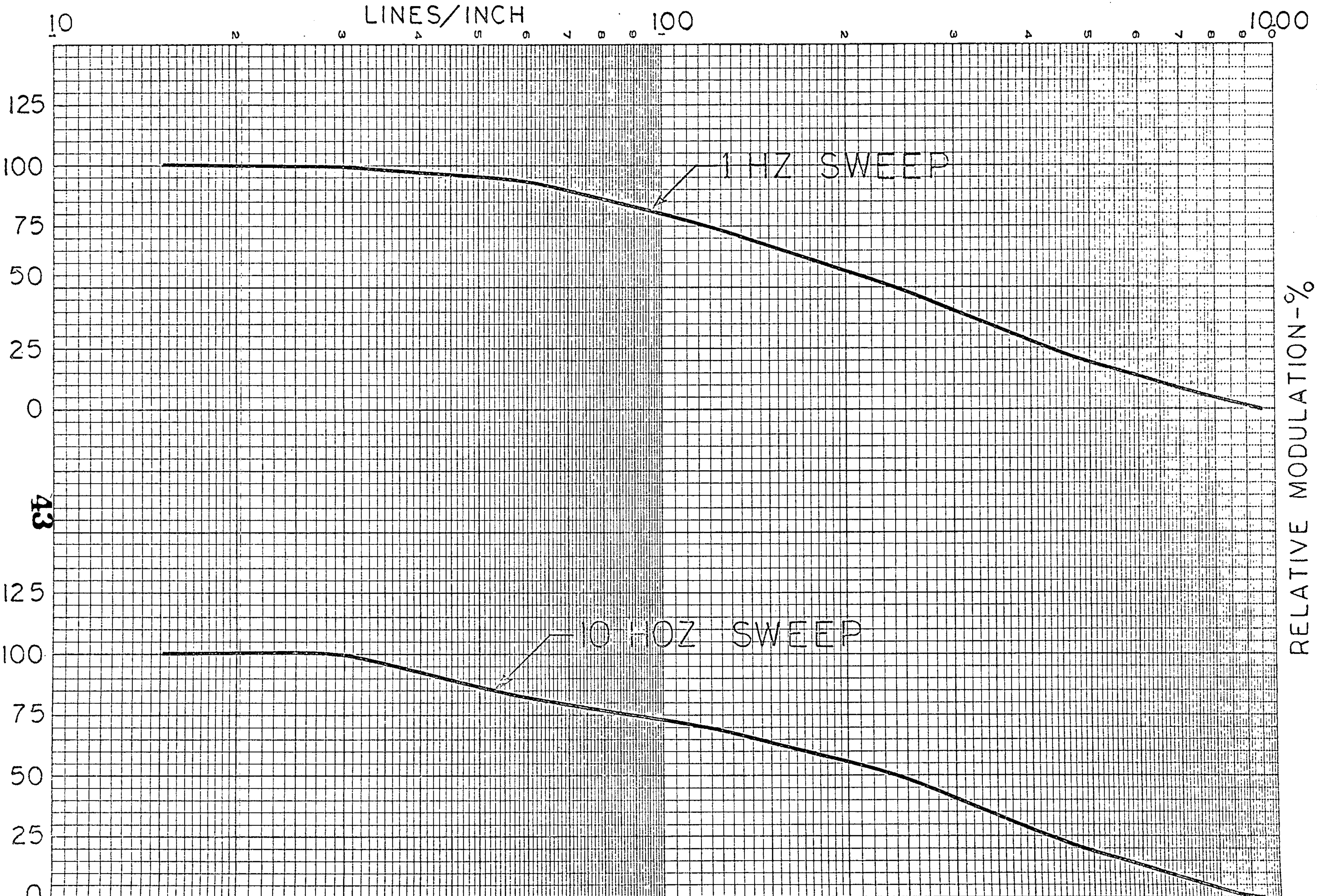
FIGURE 6



3-21-A

P31 EMA CRT MTF

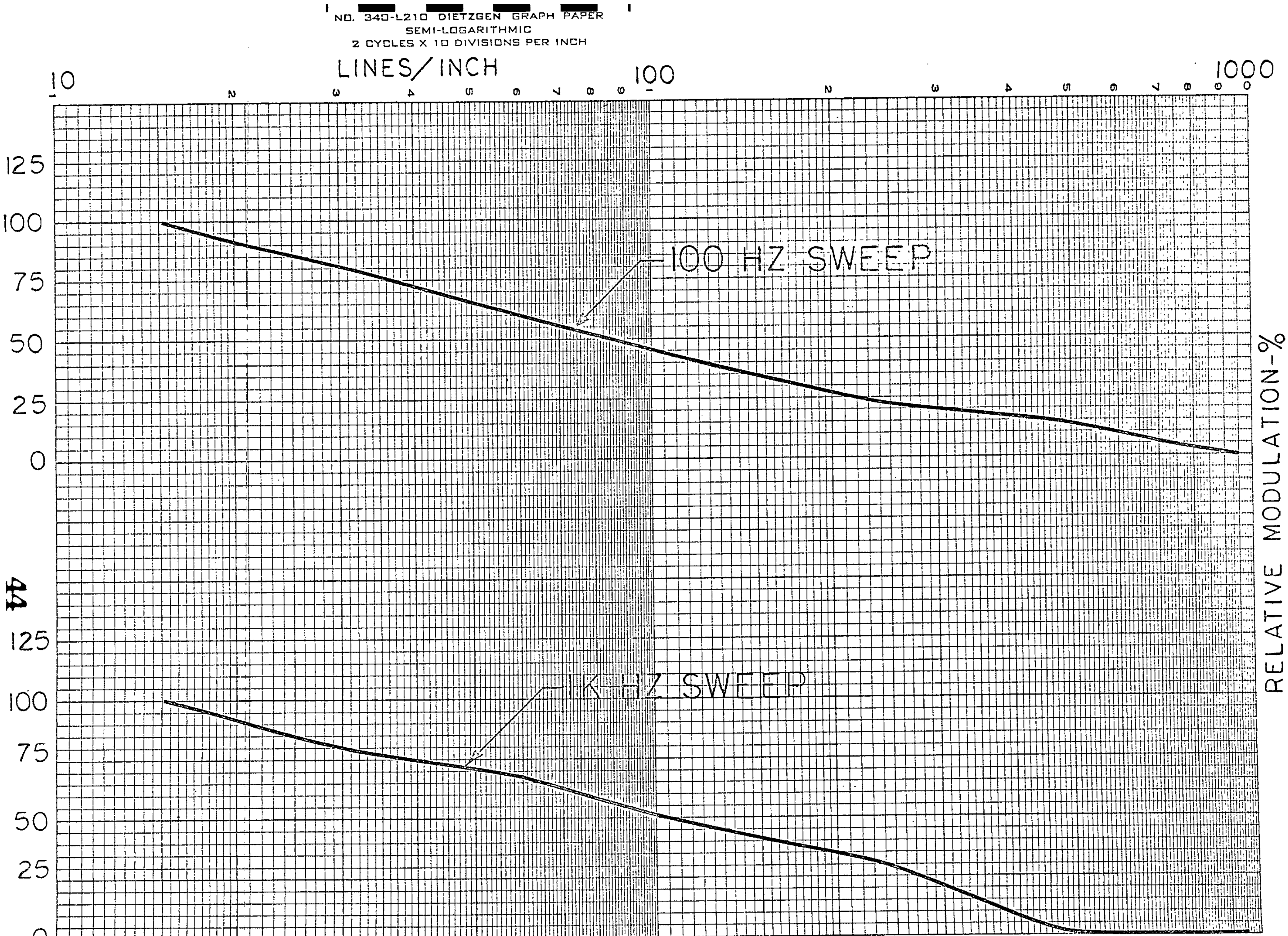
FIGURE 7



P31 CLEAR CRT MTF

FIGURE 8

3-21-B



3-21-C

P31 CLEAR CRT MTF

FIGURE 9

3.7 CRT Light Output

All of the light measurements made with the spot analyzer were relative light measurements. In this section, the absolute power density in radiometric units was measured. With this data, it is possible to calculate the performance of the CRT with any photographic material.

The CRT spot intensity was measured with a Hewlett Packard model 8334A radiation thermopile. The radiant intensity was measured as the fundamental unit since the CRT trace is actually a moving point source of light. A field stop aperature in the thermopile detector limited the solid angle to 0.1 steradians. The CRT sweep was deflected at 0.1 inch per second to prevent the 0.7 second time constant of the thin film detector from limiting the response. The resultant intensity with 7 microamperes beam current and smallest possible spot size was J = 12 microwatts per steradian for the EMA tube and J = 22 microwatts per steradian for the clear clad tube.

The differences in spot intensity are due to the difference in spot size and the difference in effective beam current. As the beam is concentrated into a smaller area, the phosphor conversion efficiency decreases from saturation effects. When the EMA clad tube was severely defocused, the spot intensity increased by a factor of 6. In addition, the anode aperaturing in the EMA tubes prevents a portion of the beam electrons from striking the phosphor. Since G3 and the anode are internally connected, the percentage of electrons captured by G3 cannot be determined.

To determine the resultant exposure, the irradiance in meter candles was calculated since the material D log E curves are expressed in meter-candle-seconds. The source radiance N for an equivalent constant intensity 2 mil spot in the EMA tube is:

$$N = J/A = 12 \times 10^{-6}/\pi \times 6.45 \times 10^{-10} = 5.9 \times 10^{3} \text{ watts/sq. m.}$$

3-21-d

Since the photographic material is against the faceplate, the emitted irradiance H is:

$$H = \pi N = 18.7 \times 10^{3} \text{ watts/ sq.m.}$$

To convert the irradiance to photometric units, this irradiance is multiplied by 680 lumens/watt times the matching factor between P31 phosphor and the standard visibility function.

$$H = 680 \times 18.7 \times 10^{3} \times .626 = 7.96 \times 10^{6} \text{ lumens/sq.m.}$$

This result was compared with the irradiance calculated from the exposure requirements of 7743 paper. With this paper, the maximum sweep speed is around 10 HZ at 7 microamperes beam current for the EMA tube. The exposure time is the dwell time of the spot and the effect of phosphor persistence on exposure. For P31 phosphor, the persistence to the 10 percent value is 40 microseconds and is approximately 2 time constants. The total effect of the persistence is equivalent to the peak value for 1 time constant. The dwell time is the time the spot occupies its diameter and is 25 microseconds for a 10 HZ sweep. The total exposure time is therefore 45 microseconds. The exposure for maximum density is 500 meter candle seconds. Therefore, the required irradiance is:

$$H = 500/\ 45 \times 10^{-6} = 11 \times 10^{6} \text{ lumens/sq.m.}$$

This result correlates well with the irradiance of 7.96×10^{6} calculated from the measured intensity.

3.7.1 Relative Light Output .

To establish the range of light output as a function of beam current, sweep speed, and spot focus, the spot analyzer was used to measure the relative light output of each tube. Since both tubes have the same spectral characteristics, this was a legitimate method of comparison. Neutral density filters were used in these measurements to insure that the photomultiplier tube was operating in a linear region. These measurements are tabulated below:

Tube	Sweep	Beam Current	Spot Size	Spot Analyzer Output
EMA	10 HZ	7 μa	1.5 mil	10 V
EMA	10 HZ	7 μa	>20.0 mil	60 V
EMA	40 HZ	7 μa	1.5 mil	7 V
Clear	10 HZ	40 μa	2.0 mil	90 V
Clear	10 HZ	40 μa	>20.0 mil	360 V
Clear	40 HZ	40 μa	2.0 mil	60 V

In this table, 10 volts corresponds to the measurements of 12 μw/steradian in Section 3.7. At 40 HZ, the spot intensity was down 3 db so the approximate rise time of the P31 phosphor was 5 microseconds since the dwell time was 5 microseconds. The beam currents in this table were the current levels that produced the maximum possible light with minimum spot size.

3.8 Photographic Materials

Four types of photographic materials were used in this evaluation; 3 dry process and 2 wet process. The three dry process materials were type 7743 print paper, type 777 print paper and type 7842 positive film all manufactured by the 3 M Company. The wet process material was Linagraph 1971 print paper manufactured by Kodak.

Type 7743 is a semi-gloss finish dry silver print paper with the following properties:

Paper thickness	7 mils nominal
Peak spectral response	510 nanometers
Maximum density	greater than 1.7
Background density	0.2 maximum
Resolution	80 cycles/mm

This paper is normally developed in 3 to 20 seconds in contact with a heater at a temperature between 250 to 280 degrees F. Nominal exposure for maximum density is 500 meter candle seconds with maximum development to stay within the specified background density.

Type 777 is a matte finish dry silver print paper with the following properties:

Paper thickness	3 mils nominal
Peak spectral response	510 nanometers
Maximum density	Greater than 1.4
Background density	0.2 maximum
Resolution	50 cycles/mm

This paper is normally developed in 3 to 30 seconds in contact with a heater at a temperature between 260 to 285 degrees F. Nominal exposure for maximum density is 70 meter candle seconds with maximum development to stay within the specified background density.

Type 7842 is a dry silver positive film with the following properties:

Film thickness	3 mils nominal
Peak spectral response	510 nanometers
Maximum density	greater than 2.0
Background density	0.15 maximum
Resolution	500 cycles/mm

This film is normally developed in 3 to 30 seconds in contact with a heater at a temperature between 260 to 270 degrees F. The heater cannot make contact with the emulsion side of the film. Nominal exposure for maximum density is 10,000 meter candle seconds with maximum development to stay within the specified background density.

Linograph 1971 is a semi-gloss stabilization process print paper. This is now a standard product that was referred to as experimental paper number 43781A on the GFE sample. The basic properties of this wet process material are as follows:

Paper thickness	6 mils nominal
Peak spectral response	420 nanometers
Maximum density	greater than 1.8
Background density	0.15 maximum

Stabilization process materials have development agents incorporated in the paper emulsion. Development is achieved by applying an activator solution and then a stabilizer solution to convert the remaining silver halide particles to relatively stable compounds. These prints can be processed in about 15 seconds and are normally stable for a period of a few months. With conventional fix and wash methods, these prints can be made sufficiently stable for archiaval storage. Nominal exposure for maximum density is 10 meter candle seconds.

3.9 System Non-Uniformity

Non-uniformity in the developed photomaterials can stem from several sources. Some types of non-uniformity are independent of the material such as variations in CRT intensity and heater bar temperature variations. The three most prevalent types of CRT intensity variations are changes in spot size across the faceplate, variations in fiber optic transmission, and instantaneous changes in sweep velocity across the faceplate. The other types of non-uniformity are either inherent in the material or depend upon both the material and the development.

The system non-uniformity was measured by developing samples of a flat field with the 7743, 7842, 777, and 1971 materials using both the EMA and the clear clad tube. All flat field samples were taken around the center of the gray scale range to produce worst case non-uniformity conditions. The above dry process materials were developed on the heater bar inside of the equipment. In addition, flat fields were developed on both the internal heater bar and an external heater with the 7743 material.

The non-uniformity measurements were performed by scanning the flat field samples with a transmitting and reflecting microdensitometer. In most cases, two measurements were performed on each sample with apertures of 2.7 by 140 microns and 7 by 1100 microns to compare fine grain noise with larger area noise. The microdensitometer did not have provisions to measure the absolute density so the calibration used was made from recordings of a gray scale evaluator made by Ansco. This calibration was made with the 0.5 and 3 density wedges available with the microdensitometer. On each microdensitometer recording, the change in density was 0.025 for each 0.2 inch (1 major division) with the 0.5 density wedge.

3.9.1 Material Non-Uniformity

Figures 16 through 20 show plots of the four materials made with the microdensitometer scanning normal to the CRT trace and parallel to the direction of paper motion. By scanning in this direction, non-uniformities associated with the CRT and the heater bar are eliminated. Thus the remaining non-uniformities are those inherent in the material and the material development process. These measurements were made with a 5 to 1 arm ratio with 5 inches of the graph equal to 1 inch of the sample. From these graphs, the maximum density variations of each material were derived and are listed below:

Material	Sampling Aperture	Density Variation
7842	2.7 by 140 microns	0.11
7842	7 by 1100 microns	0.06
7743	2.7 by 140 microns	0.20
7743	7 by 1100 microns	0.14
777	2.7 by 140 microns	0.32
777	7 by 1100 microns	0.29
1971	2.7 by 140 microns	0.12
1971	7 by 1100 microns	0.08

The four materials have been listed in the order of ascending photographic speed. For the dry process materials, it can be seen that there was a direct trade-off between speed and uniformity. The uniformity of the wet process was about the same as the slowest dry process material tested.

3.9.2 Non-Uniformity from Faceplate

Figures 21 and 22 show the non-uniformity of the 7743 material with a microdensitometer scan parallel to the CRT trace. These figures show the additional variations caused by the faceplates. A fiber optic faceplate is constructed of bundles of glass fibers that are fused into a solid plate. In the EMA tube, rods of black glass are dispersed around each bundle to absorb stray light. The average width of these bundles is 0.047 mils. With the 5 to 1 arm, this is approximately equal to 6 small divisions in these figures. In these graphs, there is an average density change for increments of 6 divisions of 0.09 for the EMA tube and 0.04 for the clear clad tube. Since this variation is a fixed pattern interference, the EMA tube variation appears as vertical banding that is quite apparent in a flat field. Due to the crosstalk in the clear clad tube, this banding is not visible on a flat field.

3.9.3 Large Area Density Variations

Figures 21 and 23 show large area density variations in the 777 and 7743 papers with the heater bar built in the processor. On both of these papers, a mottled effect was produced that results in dark spots from 0.1 square inch to continuous streaks. This effect appears to be due to non-uniform development from pockets of moisture in the paper. When these papers have been stored for extended periods or when the roll of paper in the cassette has not been used for several days, this type of variation is more pronounced. This type of variation results in peak densities up to 0.3 above the average density. This effect is always present with the 777 paper and occasionally appears with the 7743 paper. Due to this effect, the 777 paper does not produce high quality imagery with a continuous motion heat process development. This type of non-uniformity was not observed in the 7842 film or the 1971 paper.

3.9.4 Comparison of Developers

Figures 24 and 25 show microdensitometer graphs of flat field on 7743 paper developed on the internal equipment heater and on a model 17ADS external heater. These graphs indicate that there was not any significant difference between these heaters. Thus the internal heater performed as well as a commercial heater that was designed to develop this paper.

3.10 System MTF

The system MTF was determined by recording sine wave modulation patterns on each of the four photographic materials. Each recording was made with line patterns between 15 to 960 lines per inch in binary multiples. A constant beam current and a constant video modulation was used in each recording. Each of the four materials were tested at a sweep speed of 10 HZ or less with both tubes to compare the materials and the tubes. In addition, recordings were made at 1, 10, 100, and 1,000 HZ with the EMA tube and the 7743 paper to measure the effect of sweep speed on MTF. Figures 26 through 36 show the microdensitometer plots of these recordings. A plotting arm ratio of 20 to 1 and the 3 D wedge were used at the start of each measurement. In some cases, the arm ratio was changed to 50 to 1 and the 0.5 D wedge was substituted to reveal more detail in the plots. An aperture of 7 by 1100 microns was used on these plots.

The system MTF was calculated from the microdensitometer plots by taking the amplitude at 15 lines per inch as 100% modulation and calculating the remaining modulation percentage from this reference frequency. These results are shown in Figures 10 through 15.

A comparison of the MTF between the EMA and the clear clad tubes indicated a significant difference with all four materials. At 240 lines per inch, the MTF measured on the two tubes alone was approximately equal whereas there was at least a two to one improvement in MTF with the EMA tube used with all four materials. This difference results from the fact that the photographic material has an appreciable time to integrate the light from the low level crosstalk. The width of the faceplate was 0.2 inches and at low sweep speeds the material was in contact with the faceplate for a period of 10 to 100 seconds depending on paper speed.

A comparison of the four materials indicates significant difference in the system MTF with the same CRT. All four of these materials have published resolution specifications indicating resolutions well above the limiting resolution in the MTF tests. The 777 material has the lowest specified resolution but this is greater than 2500 lines per inch. Therefore, the materials tested were not the limiting factor for resolution.

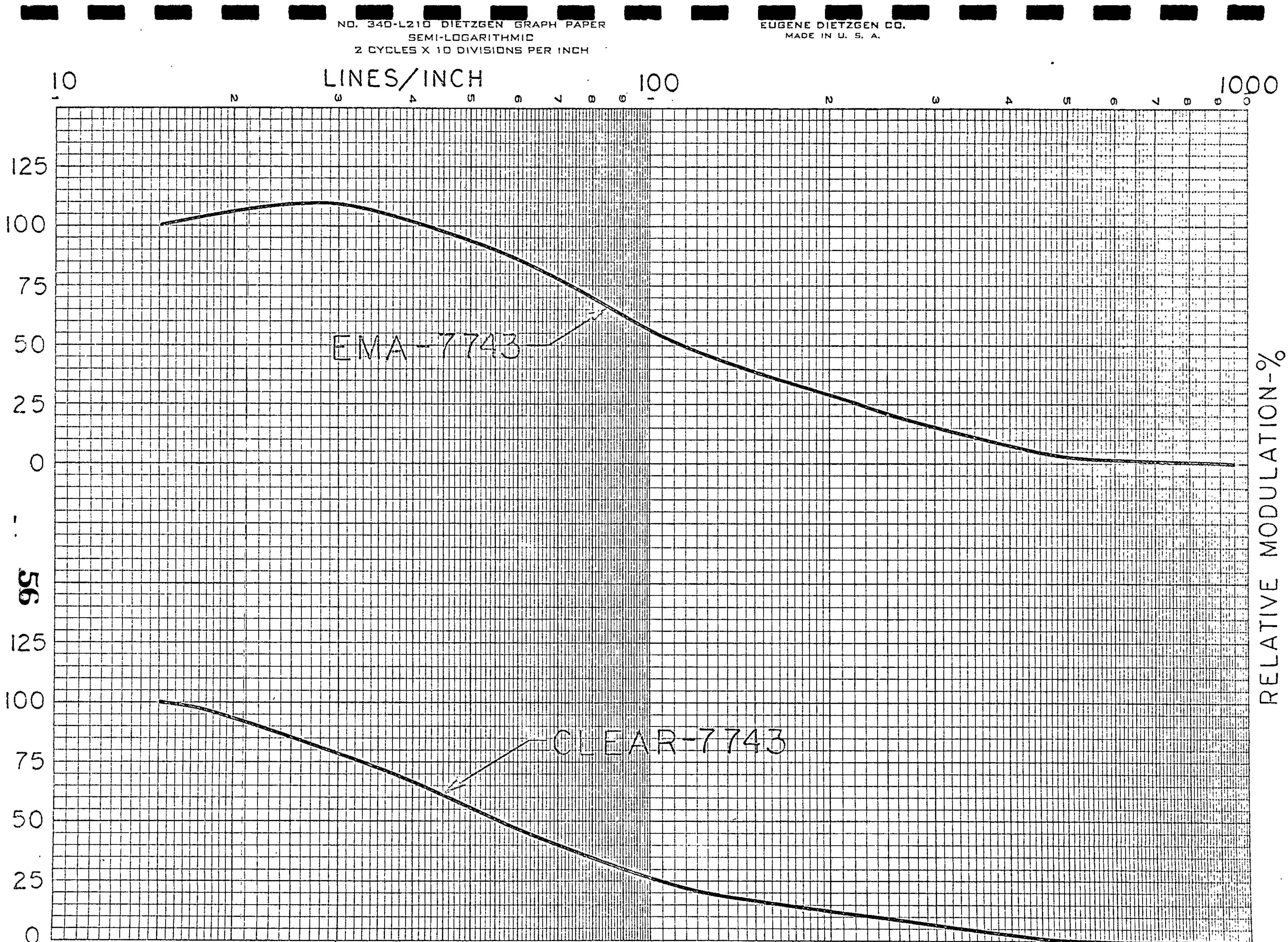
The EMA tube had a spot size of 1.5 mils so the theoretical limiting resolution is one half the spot size or approximately 1300 lines per inch. Two of the materials tested, 1971 and 7842, indicated a limiting resolution quite close to the theoretical maximum. Also, the similarity in MTF for these two materials confirms the measurements on spot growth with beam current. The 7842 material was recorded with a peak beam current of 5 microamperes and the peak beam current for the 1971 material was less than 0.5 microamperes. In spite of the 10 to 1 difference in beam current, the MTF measured with the 7842 material was better than the 1971 material.

The 777 and 7743 materials fell short of the theoretical resolution limit because of the excessive granularity in the emulsion. In both of these materials, silver particles are randomly developed in unexposed regions. Some of these grains have been observed up to a size of 4 mils with a microscope. As the development time and temperature are increased, the density of these particles increases but they are present even when the paper is developed at gammas less than one. Due to the presence of these grains, the measurement of MTF above 250 lines per inch was difficult with the microdensitometer. In the other two materials, the maximum grain size was considerably less than the resolution being measured.

The measurement of MTF as a function of sweep speed did not indicate any degradation in MTF with sweep speed. These plots are shown in Figures 28, 34, 35, and 36. At 250 lines per inch, the MTF was 23% at 1 HZ, 18% at 10HZ, 15% at 100 HZ, and 22% at a 1 KHZ sweep.

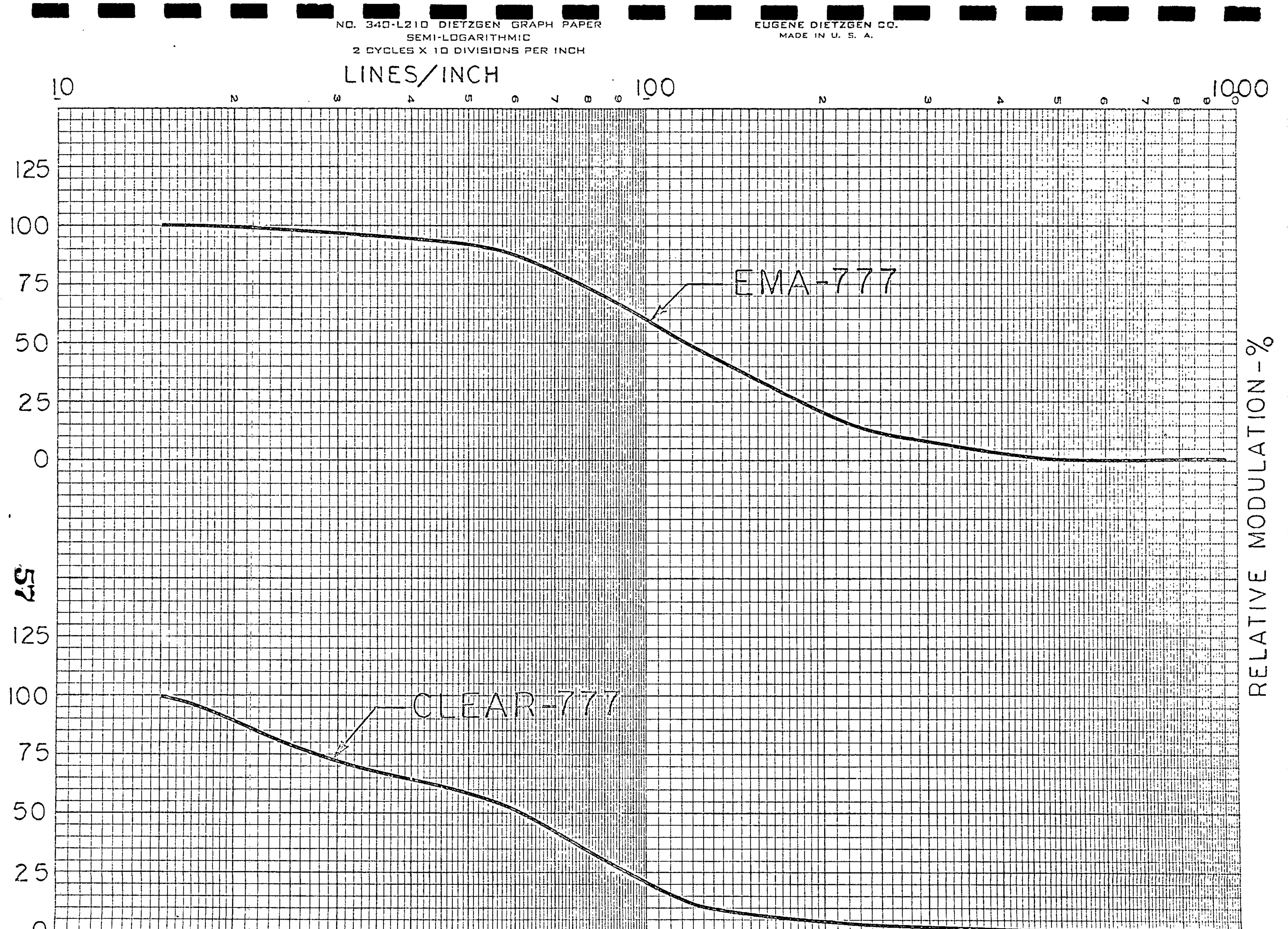
3.10.1 Square Wave Modulation

Figure 37 shows mocrodensitometer plots of a square wave modulated signal at the same test frequencies used in the MTF measurements. This data is from a sample of 7743 paper with a 10 HZ sweep frequency. Since the beam is overmodulated in this sample, the degradation due to material granularity was less pronounced than in the MTF tests.



SYSTEM MTF
FIGURE 10

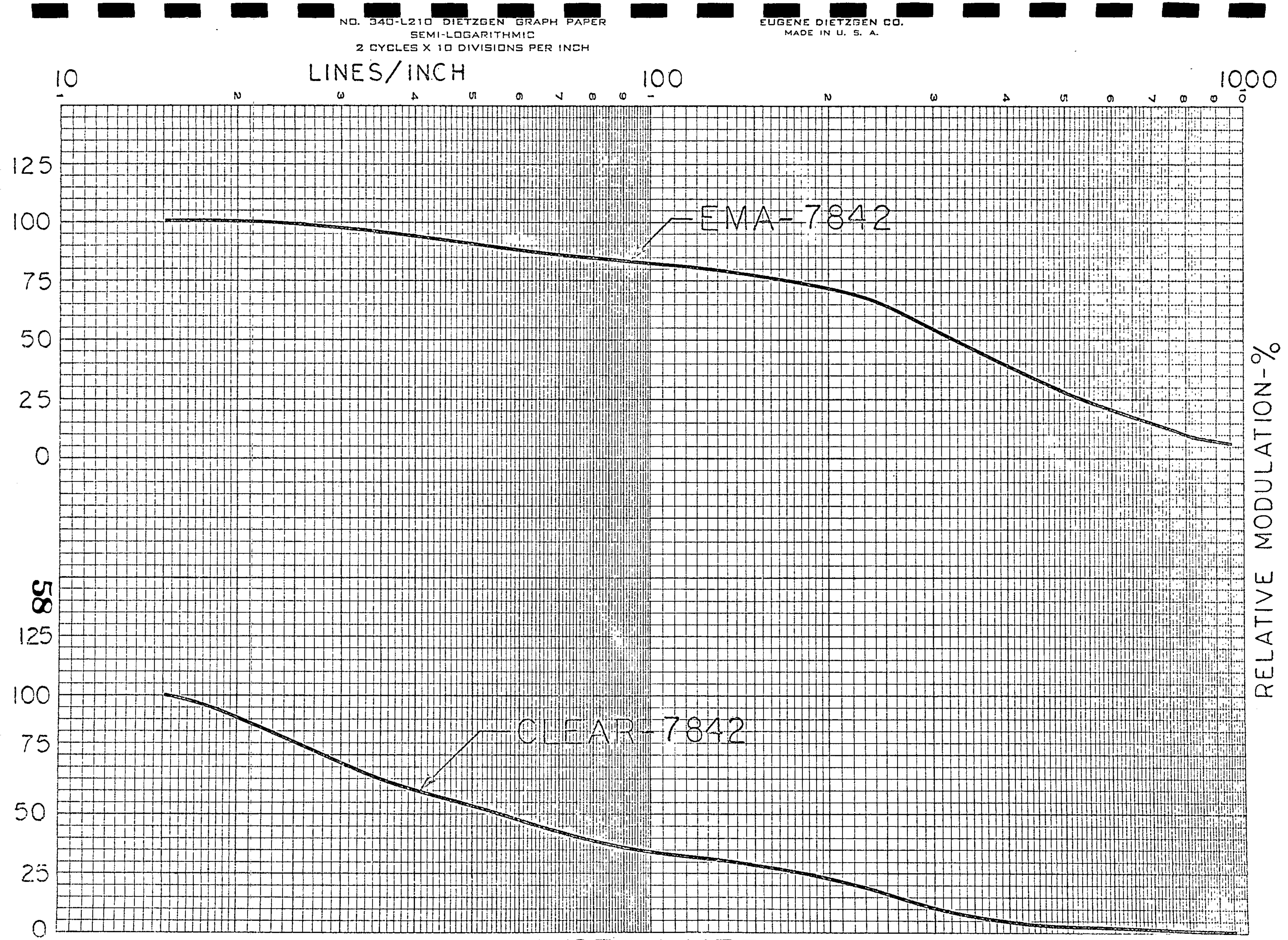
3-32-A



3- 32- B

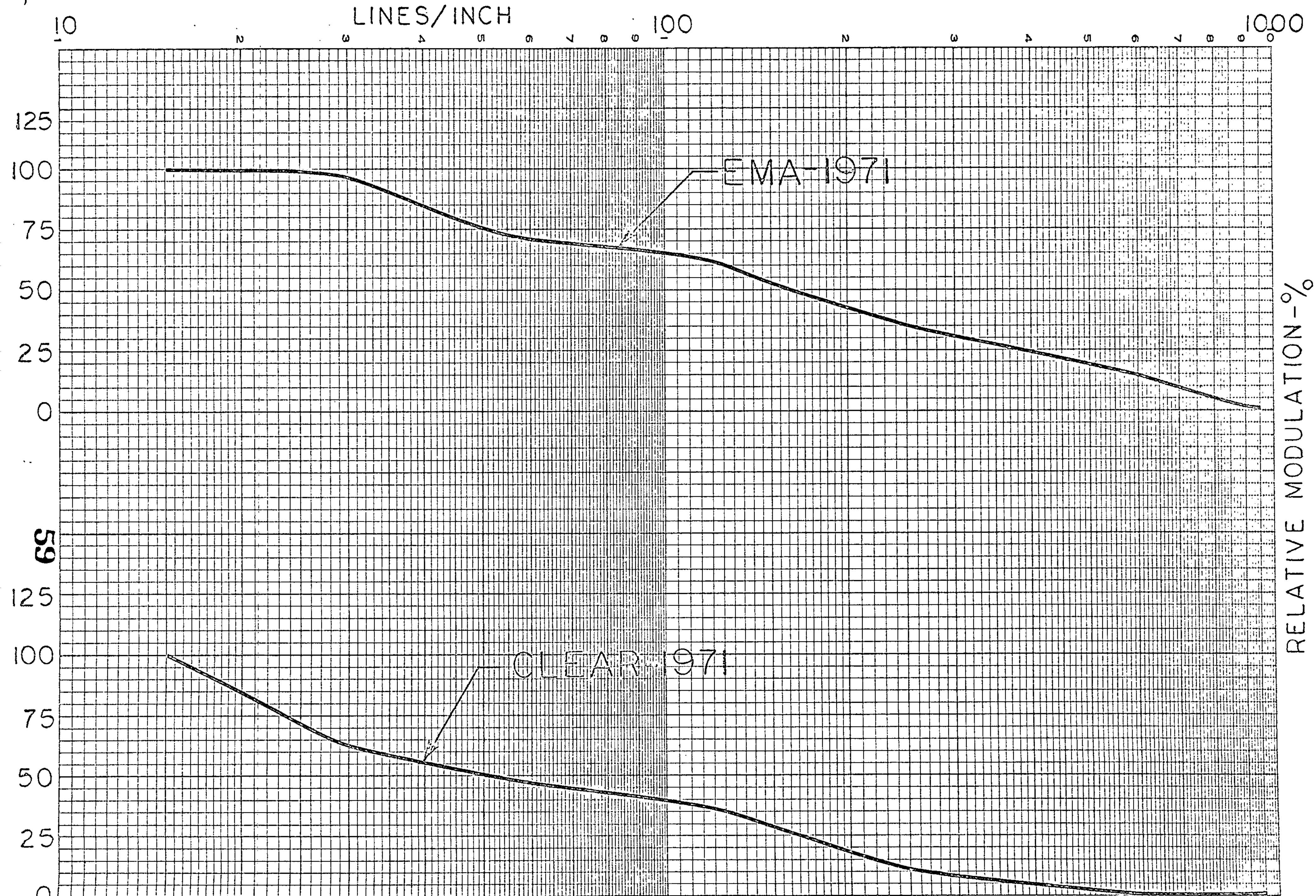
SYSTEM MTF

FIGURE 11



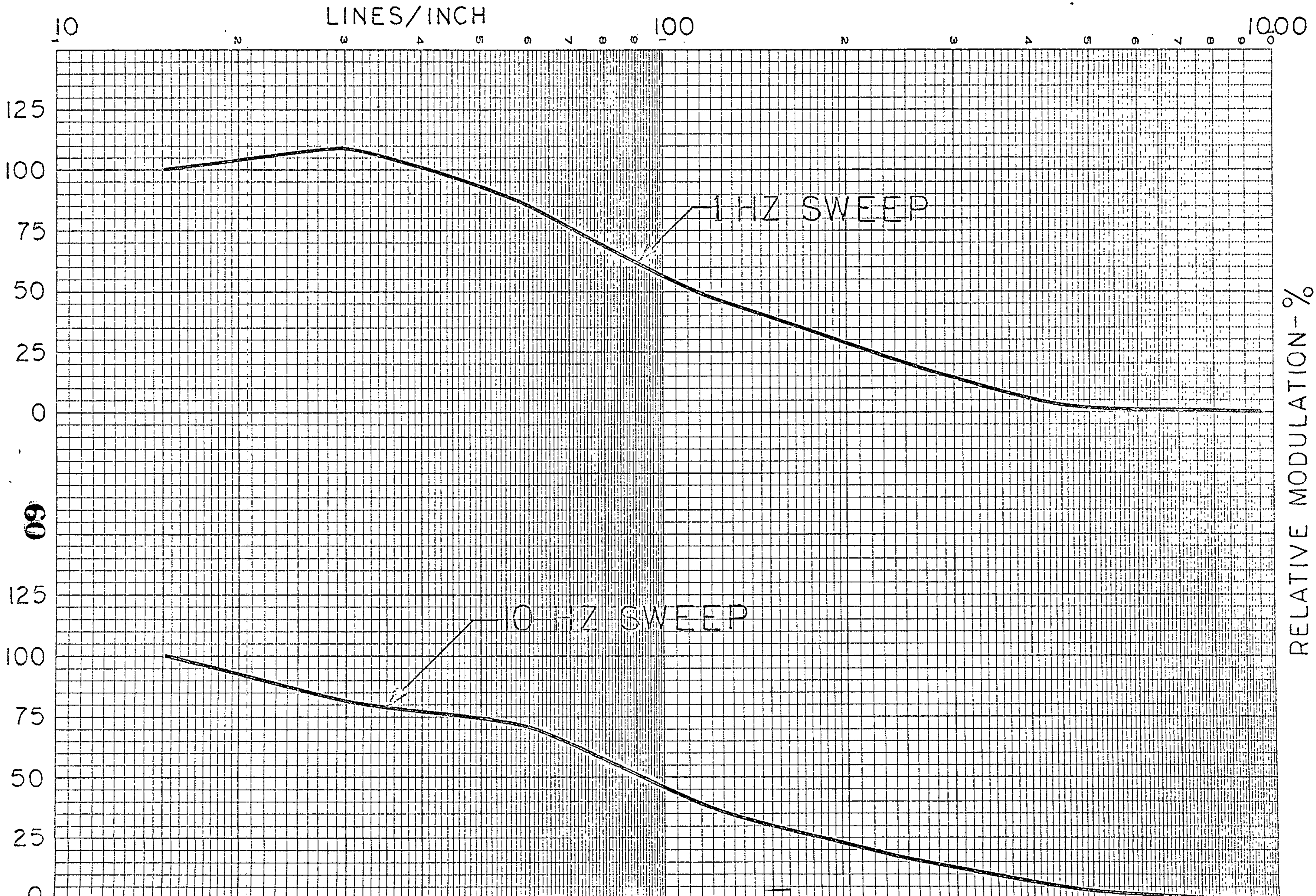
3.32-c

SYSTEM MTF
FIGURE 12



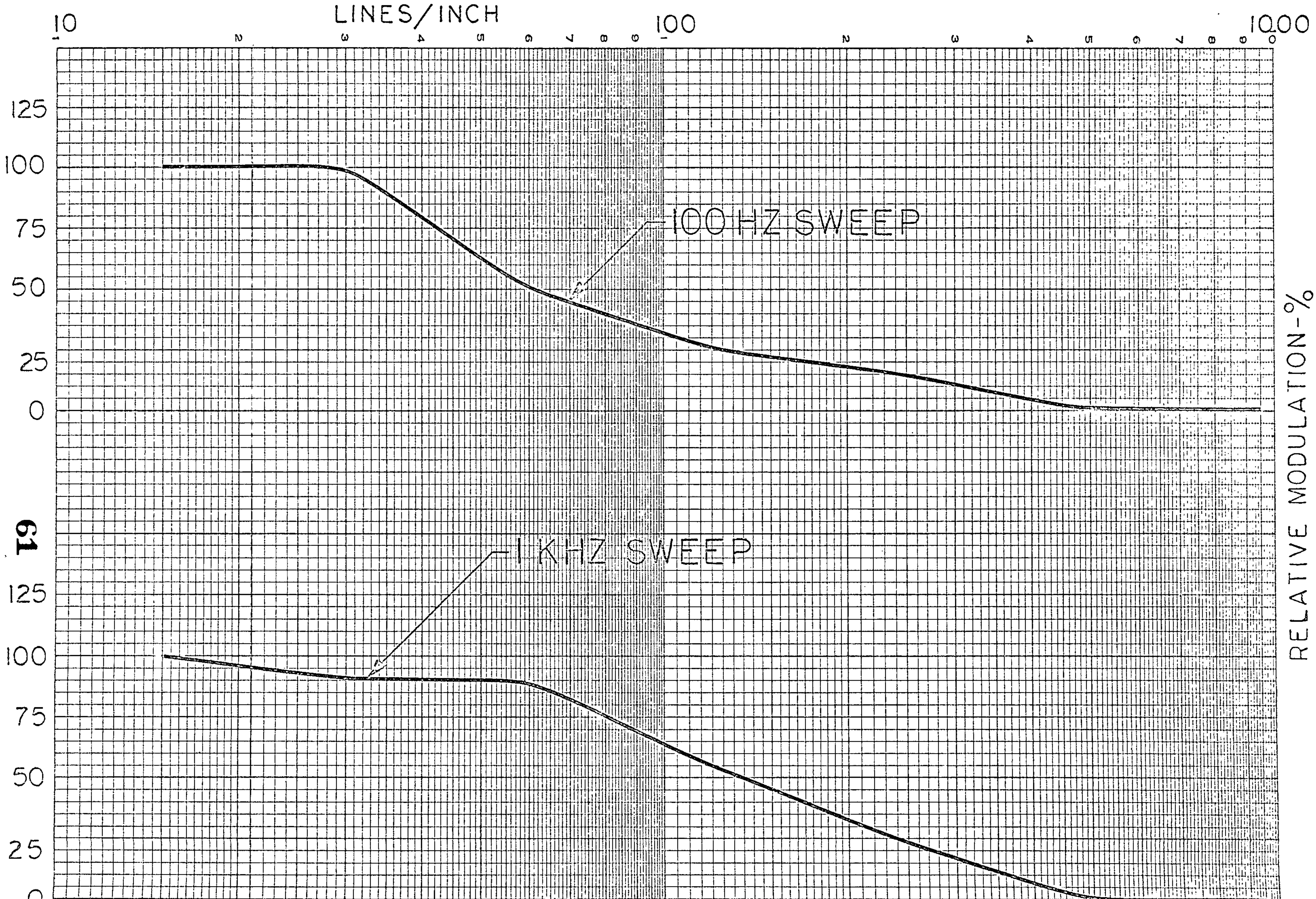
3-32-d

SYSTEM MTF
FIGURE E-13



P31 EMA SYSTEM MTF
FIGURE 14

3-32-2



P31 EMA SYSTEM MTF
FIGURE # 15

3-32-f

3.11 Writing Speed

The writing speed is the absolute maximum beam velocity that is capable of recording the maximum density for a particular material under proper development conditions. Due to the many parameters involved, it is not a simple matter to quantitively state the maximum writing speed. As the development parameters of time and temperature are increased, the exposure necessary to achieve maximum density is reduced. However, the resultant higher gamma increases the background density and degrades the gray scale in the imagery. Also, the spot size must be specified since for a given beam current the available light increases with spot size. In addition, as the spot size is increased, more beam current can be utilized before the light output saturates. The paper speed must be specified since any separation between traces will reduce the effective density. Line width or vertical astigmatism is an effective technique for filling in the vacant area between traces at low writing speeds but it is ineffective near the maximum writing speed. Since the spot dwell time on each incremental area is inversely proportional to the area between lines, the maximum writing speed for separated lines is reduced. The presence of any background illumination in the faceplate will increase the maximum writing speed since the photographic material can be effectively prefogged up to the knee of the D log E curve.

The maximum writing speed for each material was determined by measuring the maximum sweep speed that would achieve the maximum density with minimum spot size. As the sweep speed was varied, the paper speed was varied to maintain zero overlap with a 2 mil spot. Also, the development parameters were set as high as possible without increasing the background density. For the heat processed materials, this results in a gamma around 2 or 3. In the stabilization process material, the development parameters are essentially fixed over moderate ranges of time and temperature.

The measured writing speed for the four materials and the two tubes are tabulated below. These results are subject to some error because the measurement of background density, maximum density, and development parameters were a matter of judgment. The last three readings were indicated as greater than 8000 since the maximum sweep speed used was 1 KHZ.

Material		
7842	EMA	10 in/second
7842	Clear	200 in/second
7743	EMA	100 in/second
7743	Clear	4000 in/second
777	EMA	1000 in/second
777	Clear	>8000 in/second
1971	EMA	>8000 in/second
1971	Clear	>8000 in/second

A comparison of writing speeds between the two tubes for the same material indicated a ratio up to 40 to 1. Previous measurements of the CRT light output indicated a maximum difference of around 9 to 1. This difference was due to the increased exposure from the crosstalk in the faceplate.

3.12 Horizontal Linearity

Since the faceplate of the CRT is flat, a linear sweep waveform would result in approximately 11% distortion in the corners. To correct for this distortion, a correction waveform is generated that is related to the sine and the tangent of the deflection angle. Both functions are required because the faceplate deflection is a function of the tangent of the deflection angle and the required deflection current is a function of the sine of the deflection angle.

The corrected sweep waveform is generated by a piecewise linear approximation of 12 linear segments. This waveform can be adjusted to within 0.1% of the theoretical waveform. However, this waveform must be normalized with the deflection sensitivity and the deflection angle of the CRT. The exact deflection angle is not known since it is specified only to a nominal angle of 55 degrees. Also, there is a static position error in the CRT. With the correction waveform set up for an assumed deflection angle of 55 degrees, the linearity error in the corners was a maximum of 1.5 percent.

The test was next performed by independently adjusting the amount of correction applied to the linear sweep for the left and right corners. The resultant data is shown in Table 5.

With this technique, the horizontal linearity across the paper can be adjusted down to an accuracy of 0.2 percent. The degree of accuracy depends upon the precision used in setting up the correction waveform. Also, the linearity was independent of the sweep speed up to the bandwidth limitations of the circuit. At a 1 KHZ sweep, the measurements were performed 1/2 inch in from the corner because of ringing in the start of the sweep waveform.

Table 5

Horizontal Linearity

1 HZ Sweep Frequency

Position	Measurement	Percent Error
Left Corner	276.5 mils	.54%
Left Center	276.5 mils	.54%
Center	278.0 mils	
Right Center	276.0 mils	.72%
Right Corner	277.0 mils	.36%

10 HZ Sweep Frequency

Left Corner	281.5 mils	0%
Left Center	282.0 mils	.18%
Center	281.5 mils	
Right Center	281.5 mils	0%
Right Corner	282.0 mils	.18%

100 HZ Sweep Frequency

Left Corner	293.5 mils	.51%
Left Center	292.0 mils	0%
Center	292.0 mils	
Right Center	291.0 mils	.34%
Right Corner	291.0 mils	.34%

1 KHZ Sweep Frequency

Left Corner	340 mils	.29%
Left Center	339.5 mils	.15%
Center	339.0 mils	
Right Center	340.0 mils	.29%
Right Corner	340.5 mils	.44%

3.13 Vertical Linearity

In this equipment, vertical linearity does not have the same significance as horizontal linearity because it is a continuous process and does not have a fundamental period. Therefore, in this test vertical linearity was interpreted as the absolute variation in paper displacement as a function of time with constant ambient conditions.

The vertical linearity was tested by preparing samples of 7743 paper with adjacent scan lines separated by 1/4 inch. Samples were prepared with the stepping motor operating at a low rate of 20 pps and at 250 pps which is near the upper frequency limit. A series of measurements were made at both ends of 2 foot samples. The resultant data is shown below:

Sample 1

Separation between lines in mils

Top of Sample	Bottom of Sample
211	211
210	211
211	211
211	212
211	211

Sample 2

Separation between lines in mils

Top of Sample	Bottom of Sample
72	72
72	72
72	71.5
72	72
72	72

The maximum error between adjacent readings was 1 mil or less. This error is within the range of deviation attributed to the stepping motor since each pulse advances the paper approximately 1 mil. This variation is possible because the stepping motor oscillator and the horizontal sync oscillator were independent frequencies.

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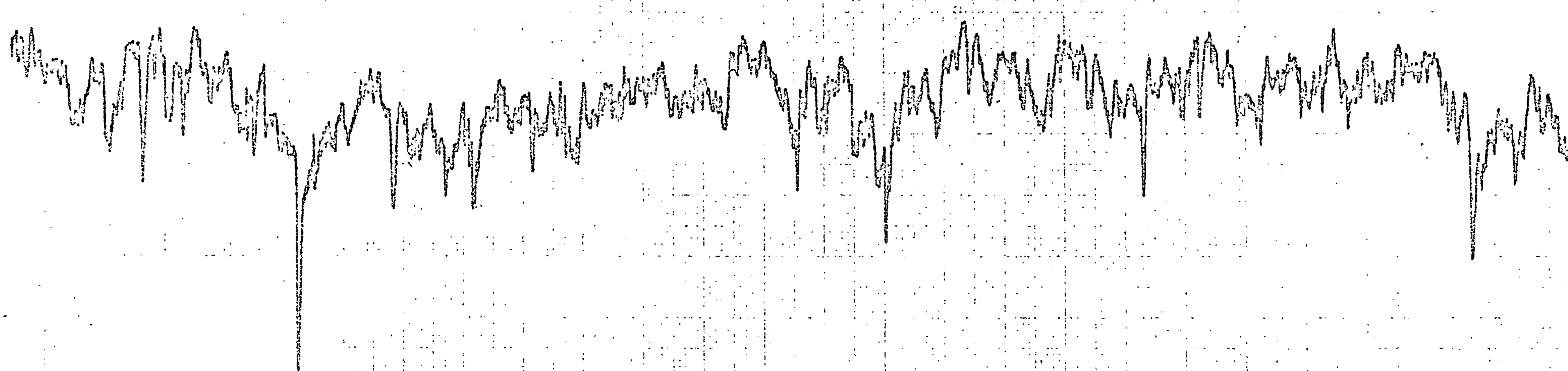
ΔW 1/2

$\frac{120-60}{40} \times 1/2''$



NOT REPRODUCIBLE

FLAT FIELD 7842

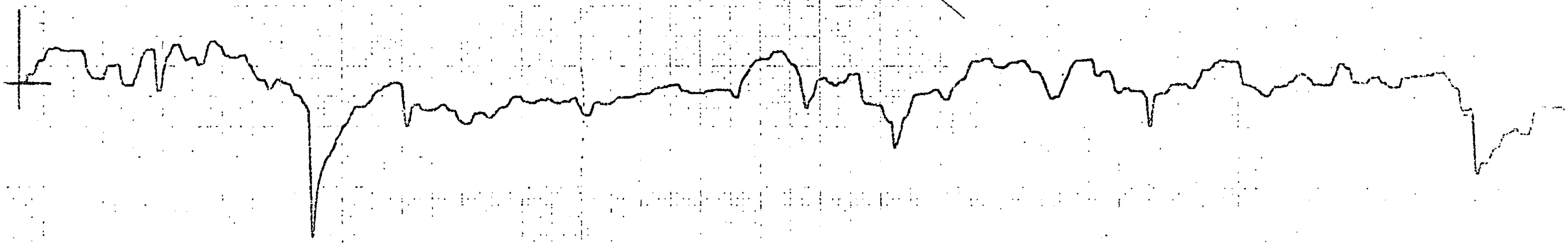
FIGURE 16

3-37

27 oct 71

DW 1/2

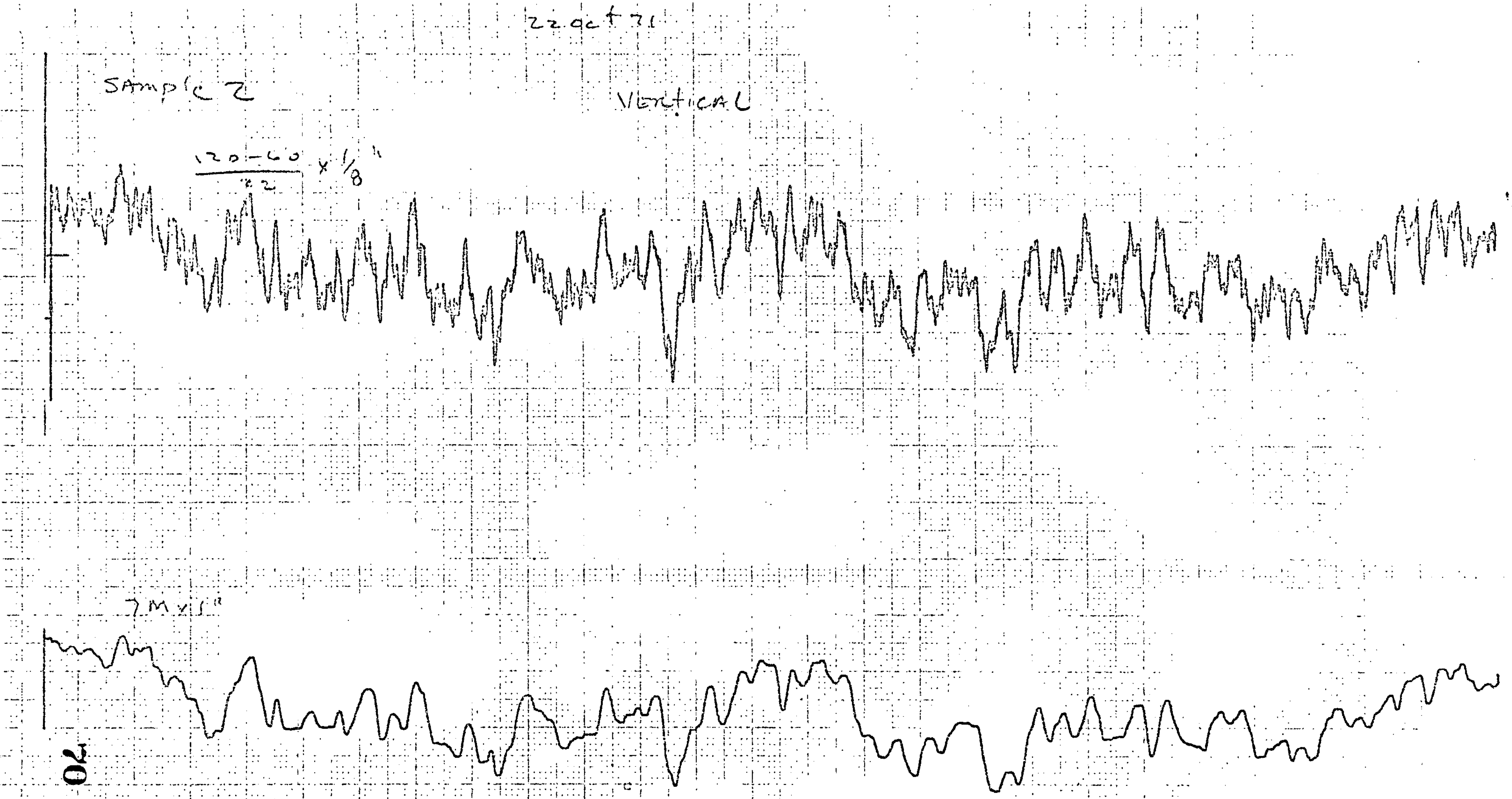
$\frac{4060-60}{10}$, 1/2"



FLAT FIELD 7842

FIGURE 17

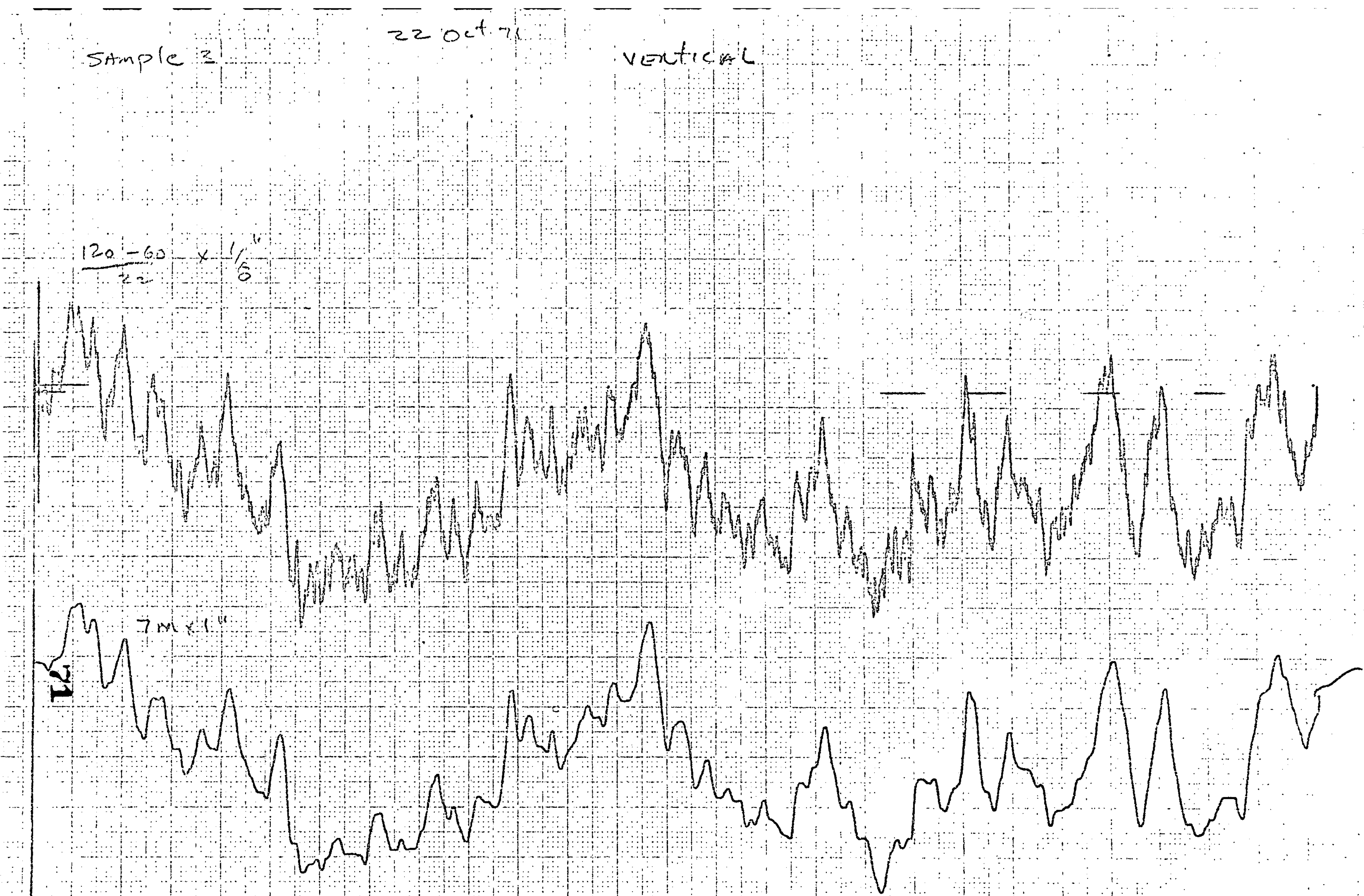
3-37-A



FLAT FIELD 7743

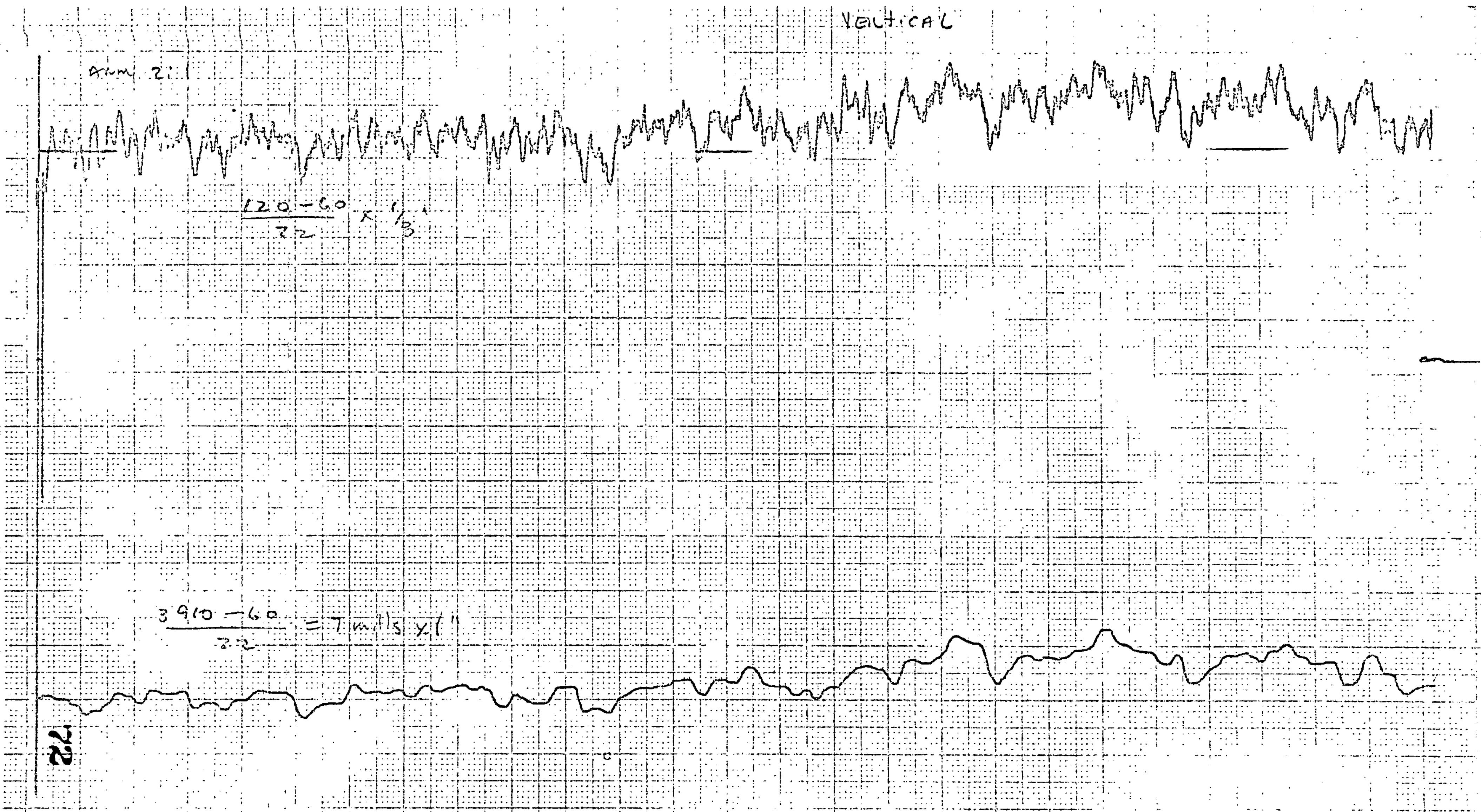
FIGURE 18

3-37-B



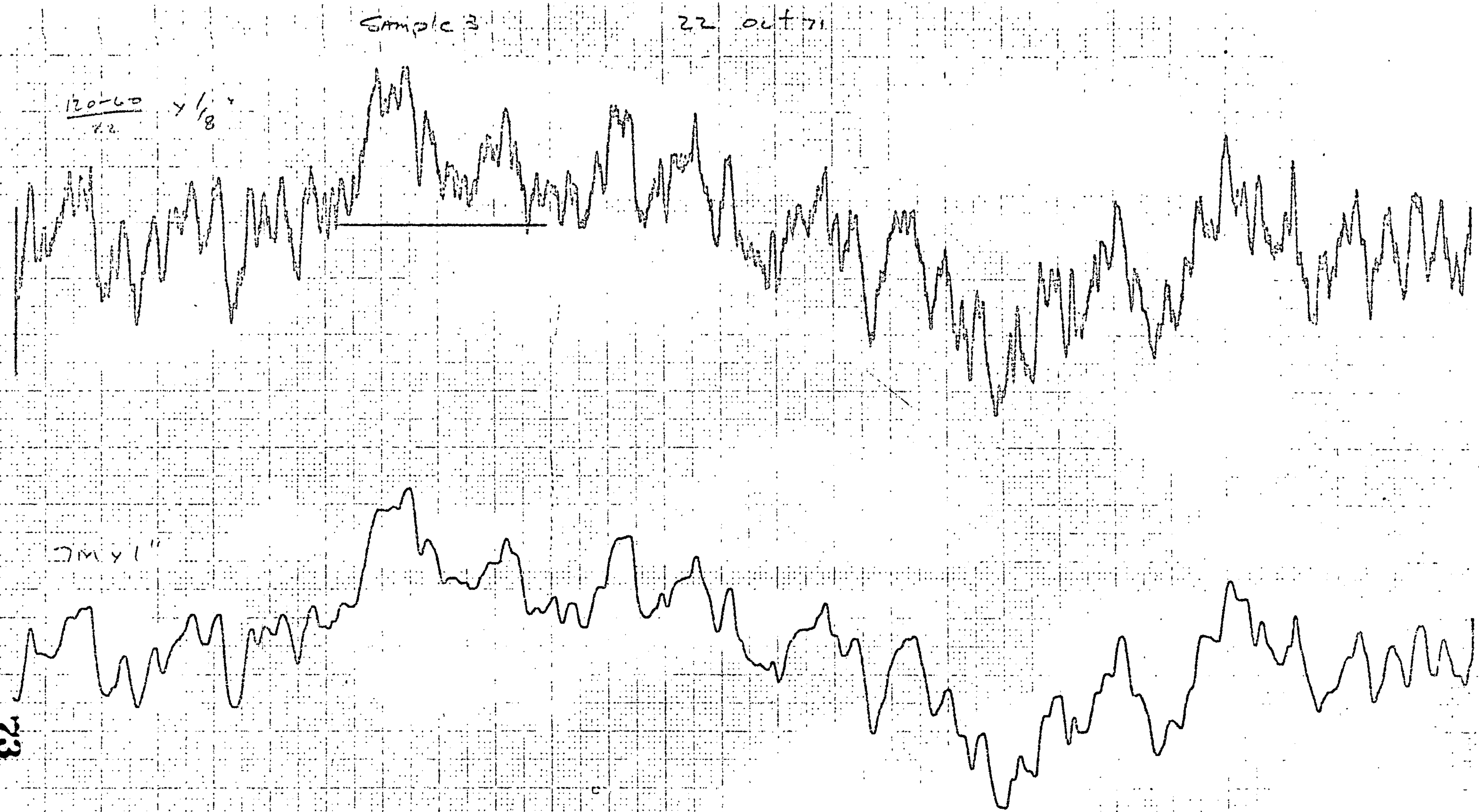
FLAT FIELD 777

FIGURE 19



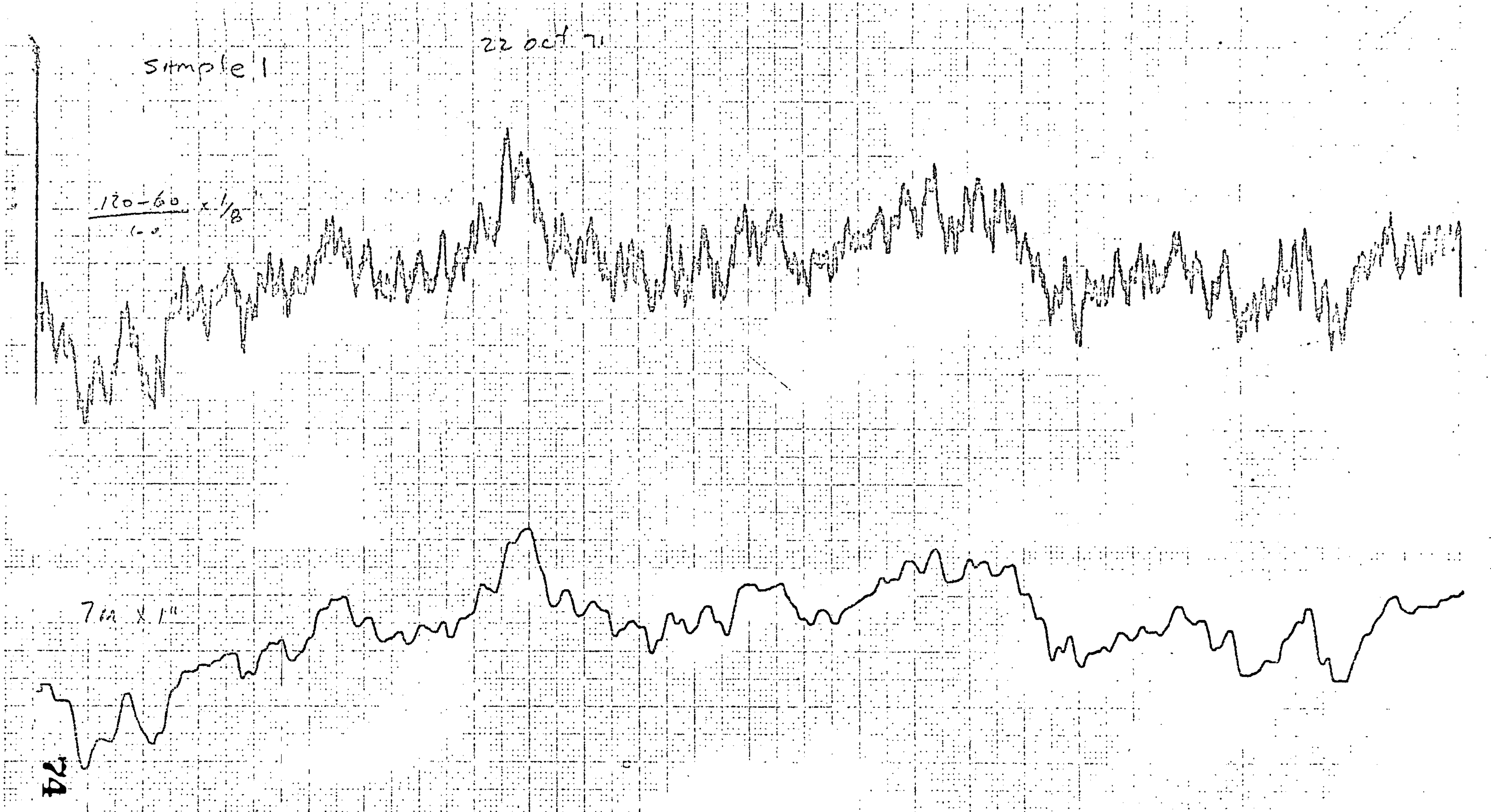
FLAT FIELD 1971

FIGURE 20



FLAT FIELD 7743 EMA

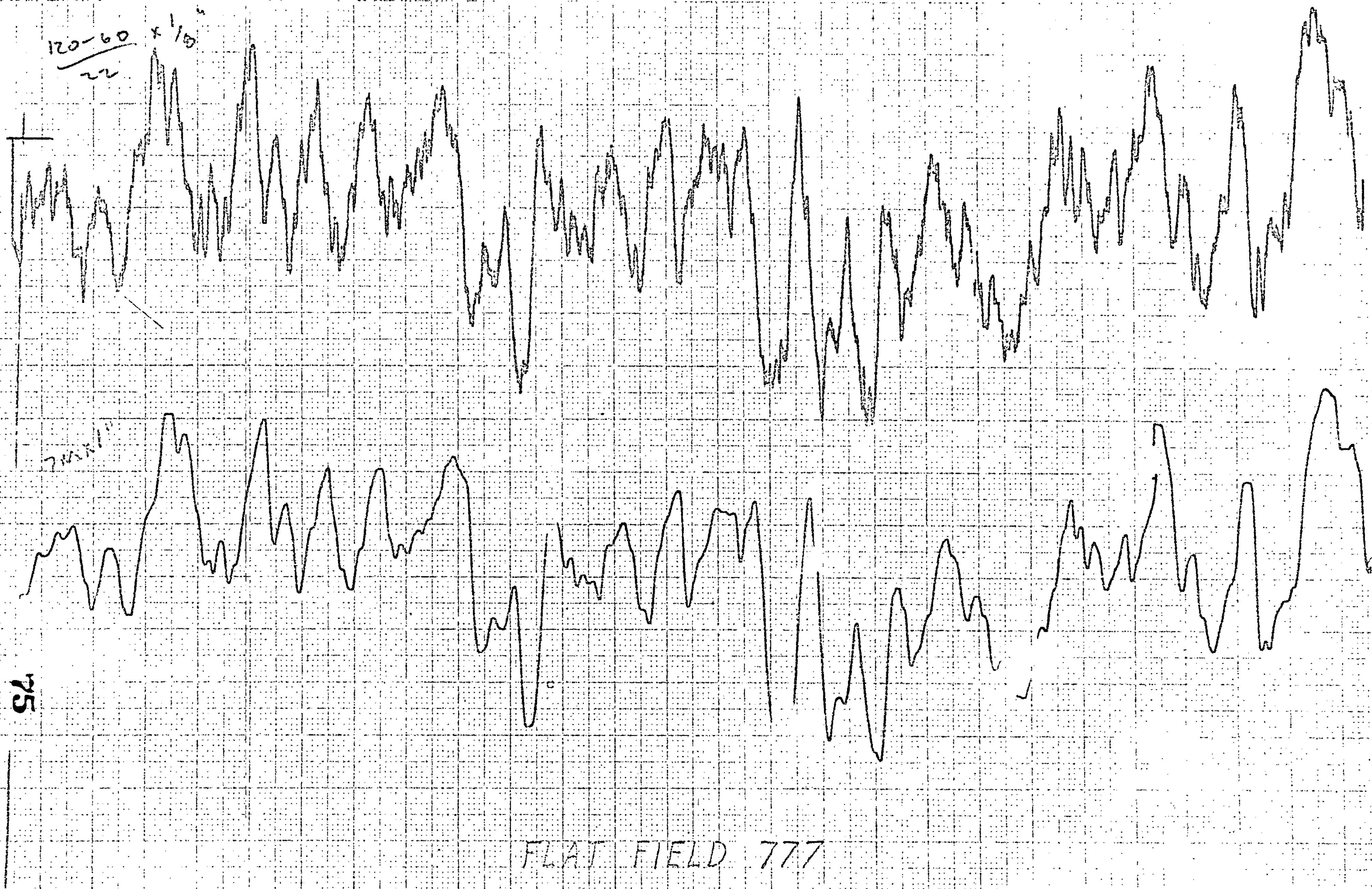
FIGURE 21



FLAT FIELD 7743 CLEAR

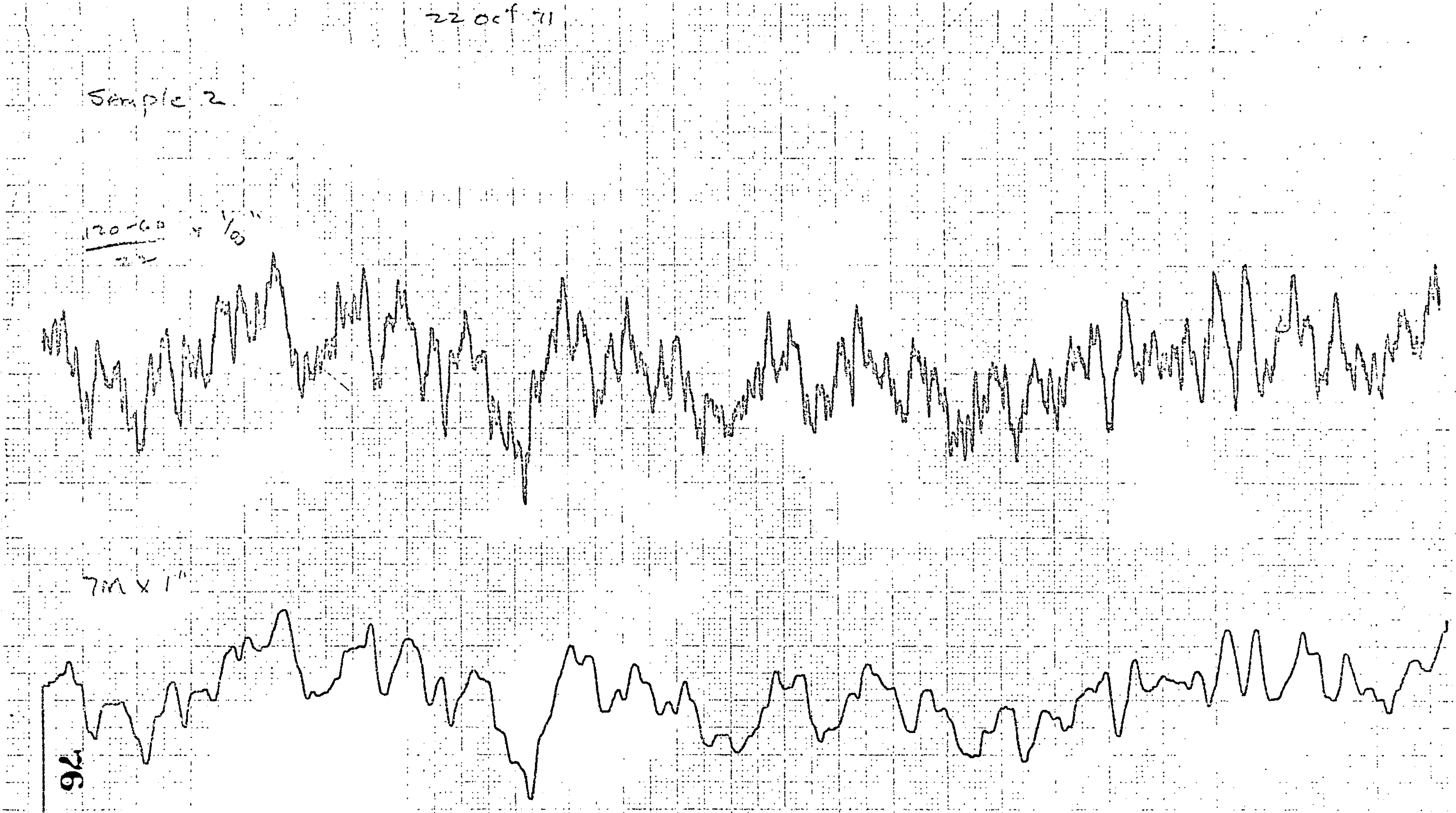
FIGURE 22

5-57-4



FLAT FIELD 777

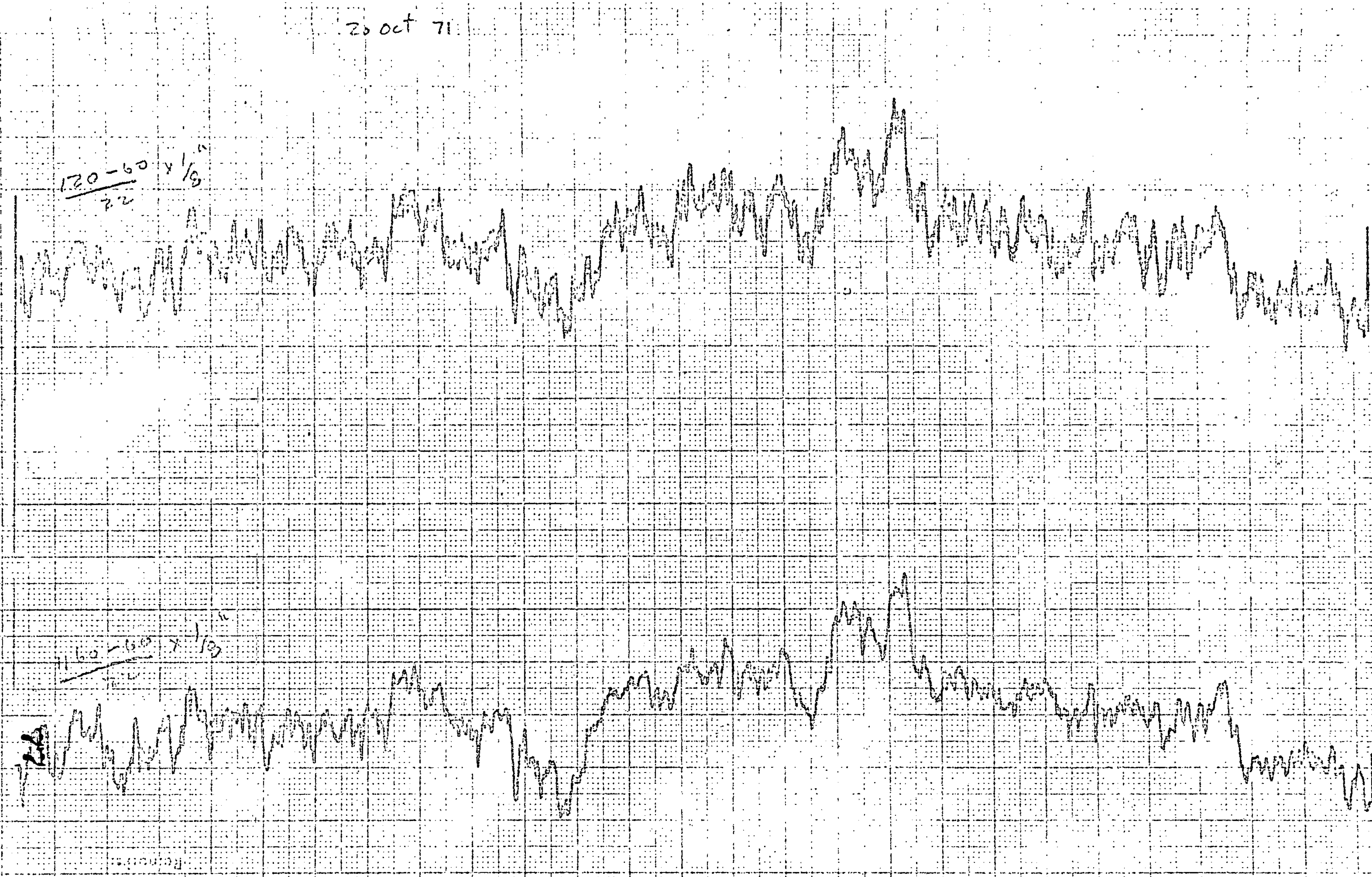
FIGURE 23



FLAT FIELD 7743 INTERNAL HEATER

FIGURE 24

3-3-72



FLAT FIELD 7743 EXTERNAL HEATER

FIGURE 25

3-37

15

DW 3

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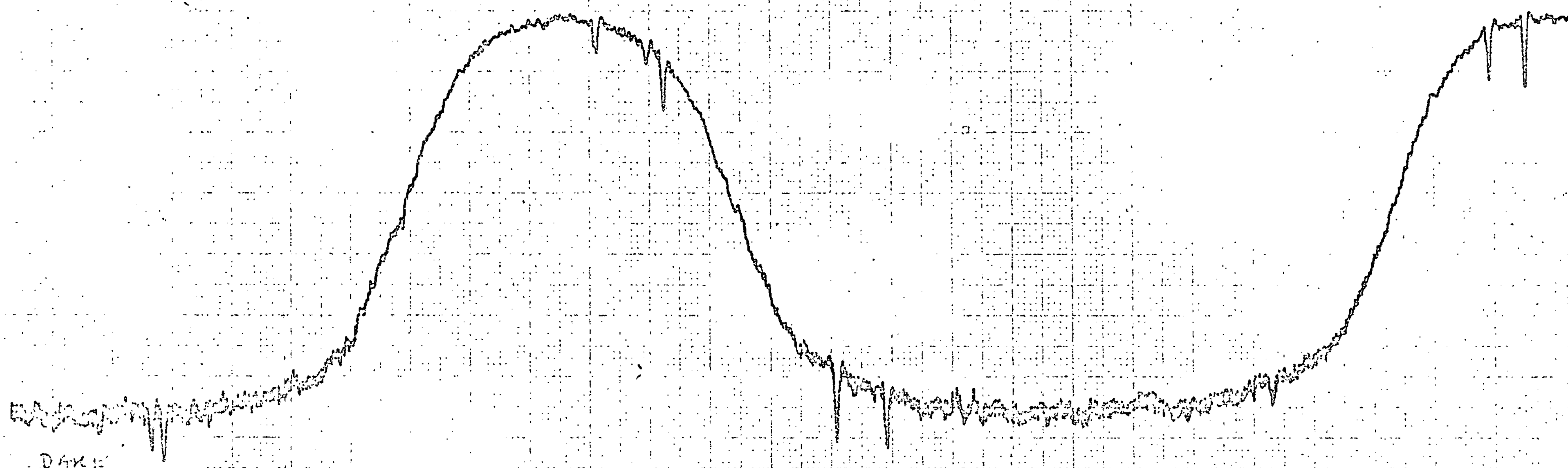
$\frac{120-60}{40} \times 1/2"$



28

SYSTEM MTF 7842 EMA

FIGURE 26-1 15 LN./IN.

3.377

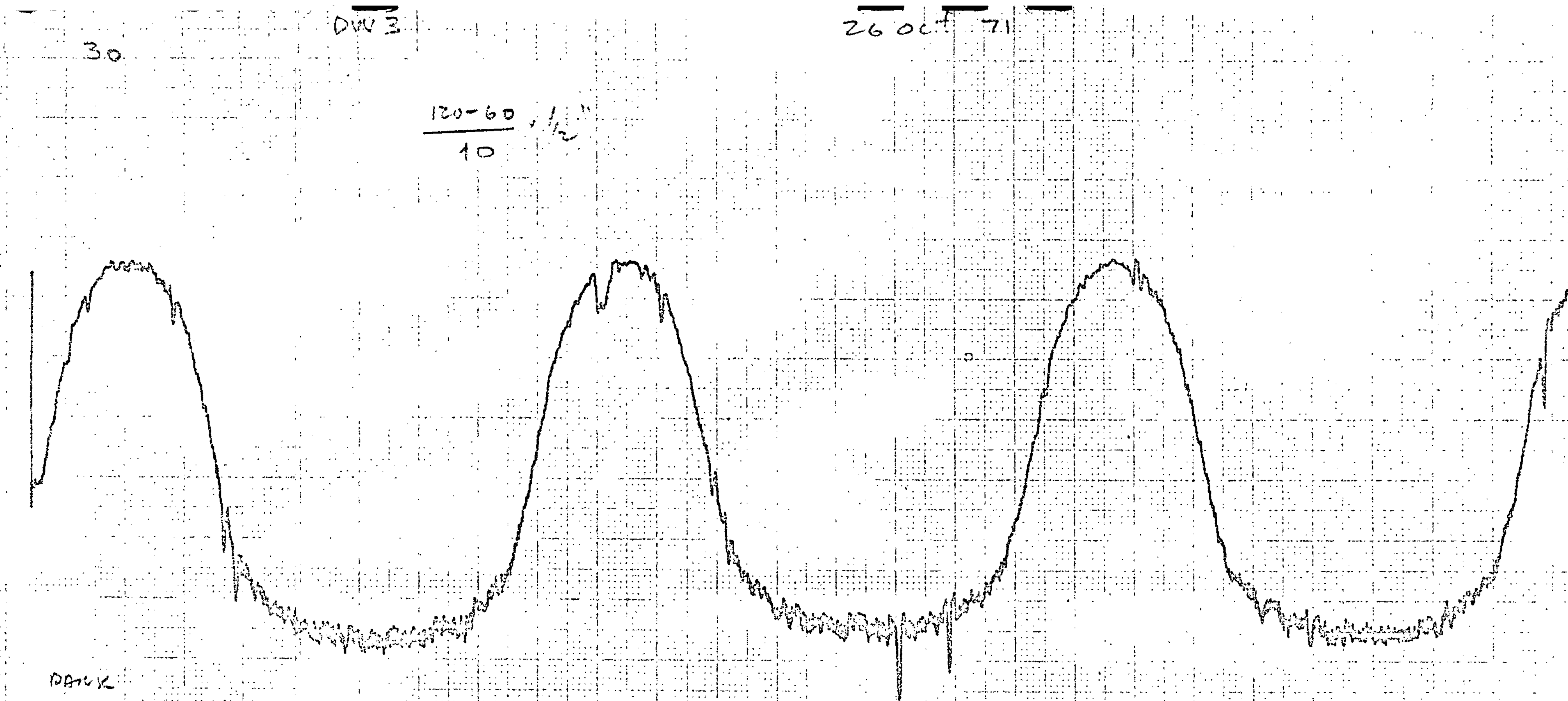


FIGURE 26-2 30 LN./IN.

62

3-77k

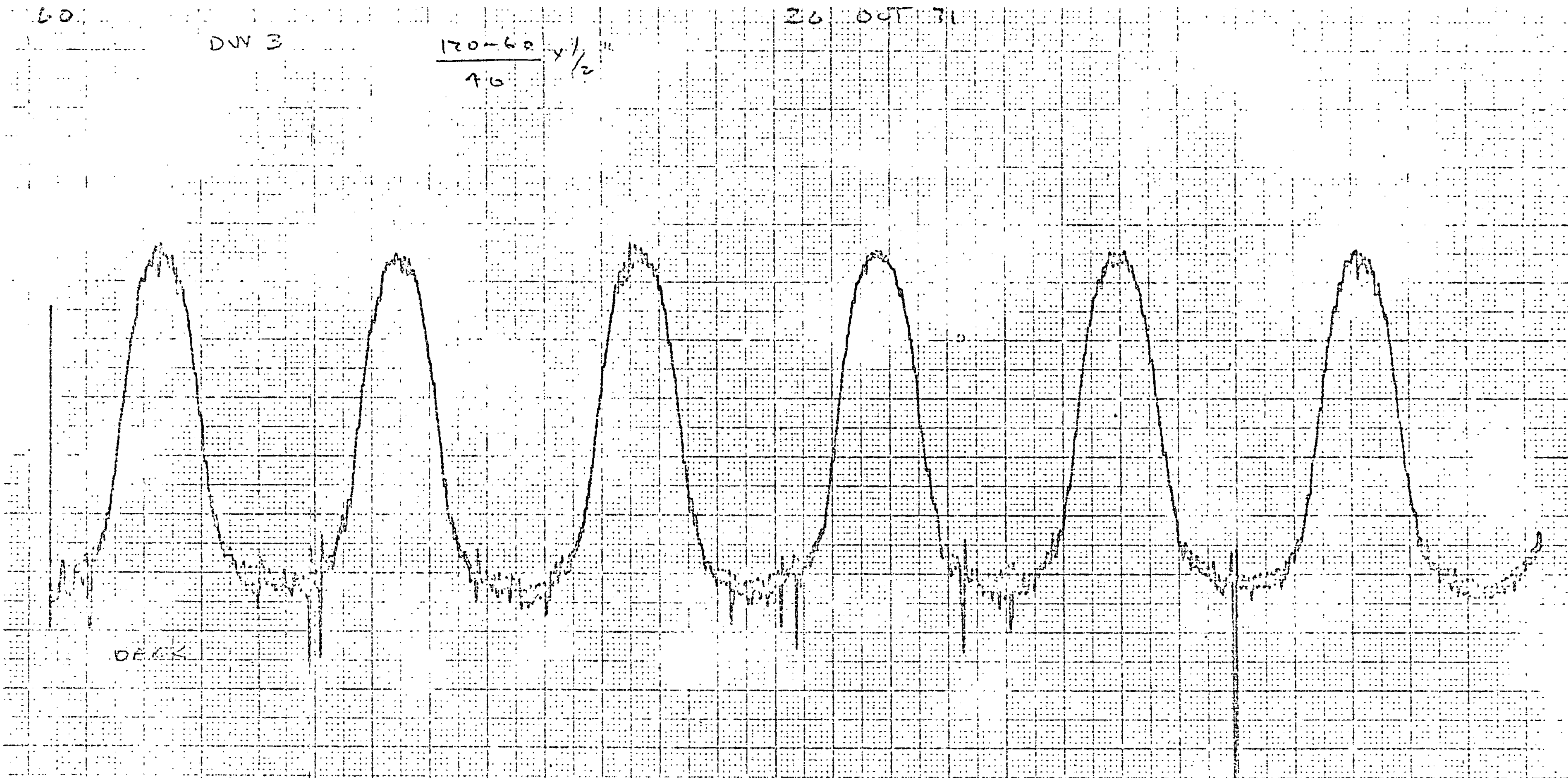


FIGURE 26-3 60 LN./IN.

80

120

DW3

$\frac{120-60}{40} \times 1/2"$

26 oct 71

81

FIGURE 26-4 120 LN/IN.

3-37-2m

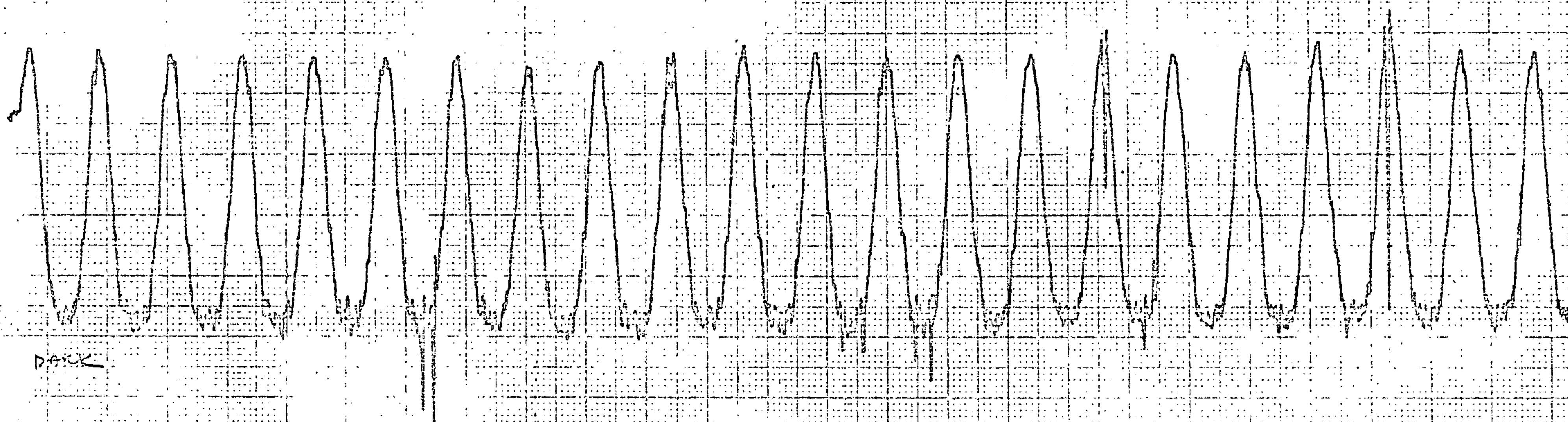


FIGURE 26-5 240 LN./IN.

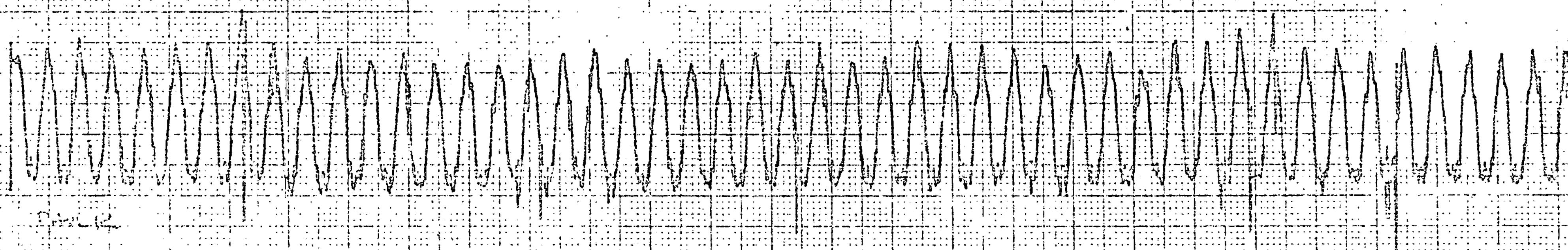
3-37

480

DW3

26 Oct 71

$\frac{120-60}{45} \times \frac{1}{2}$



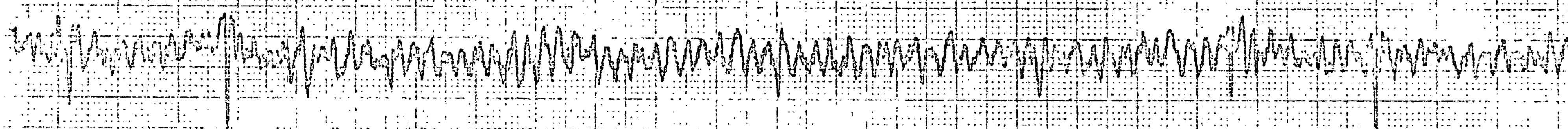
83

FIGURE 26-6 480 LL/IN

3-37-d

960 NW 3 26 OCT 71

$\frac{120-60}{40} \times 1/6''$

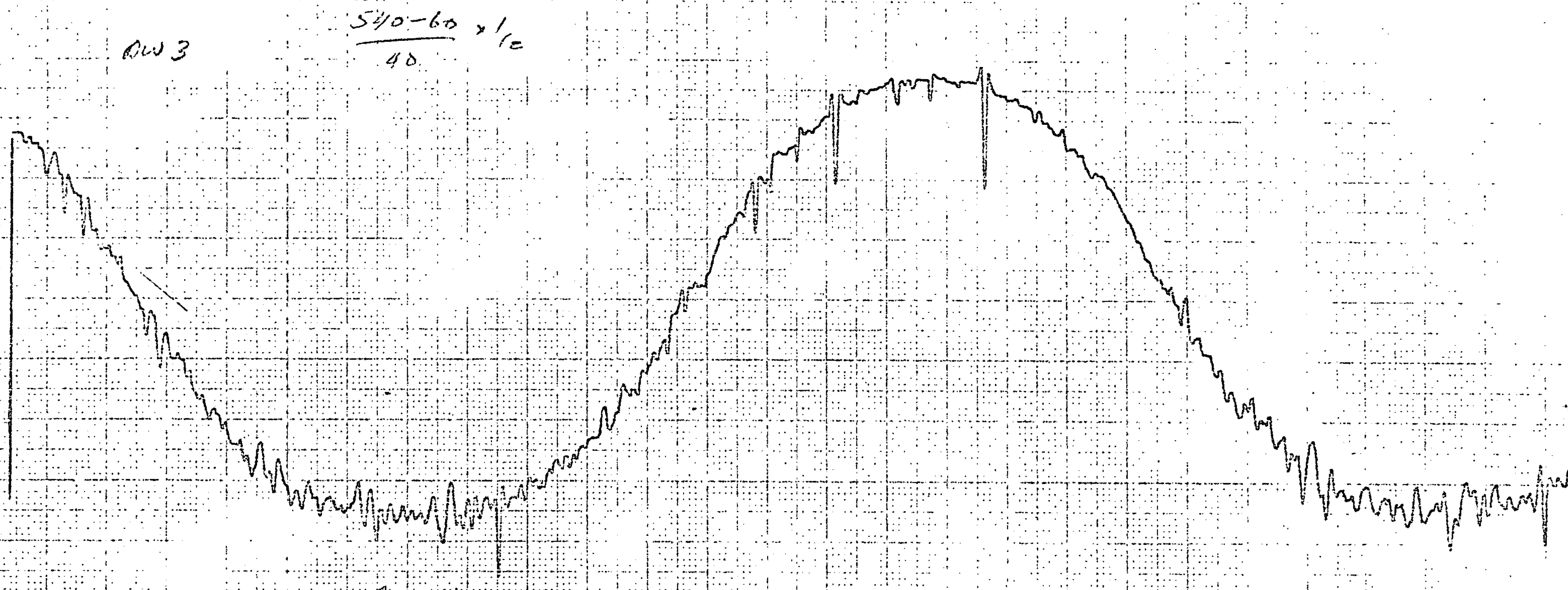


DARK

84

FIGURE 26-7 960 LN/IN

3-37 p



SYSTEM MTF 7842 CLEAR

FIGURE 27-1 15 LN./IN.

85

3-31-

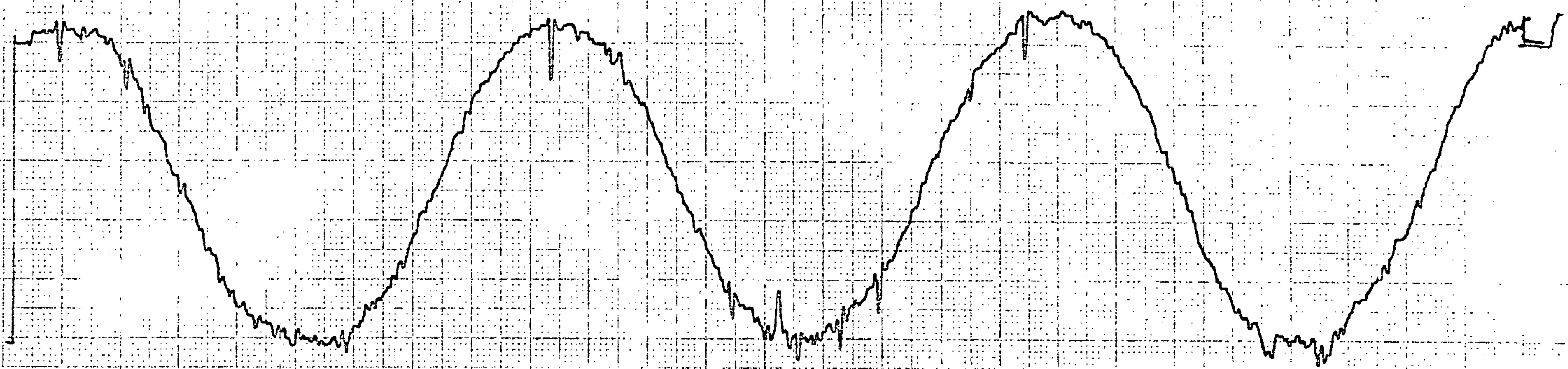
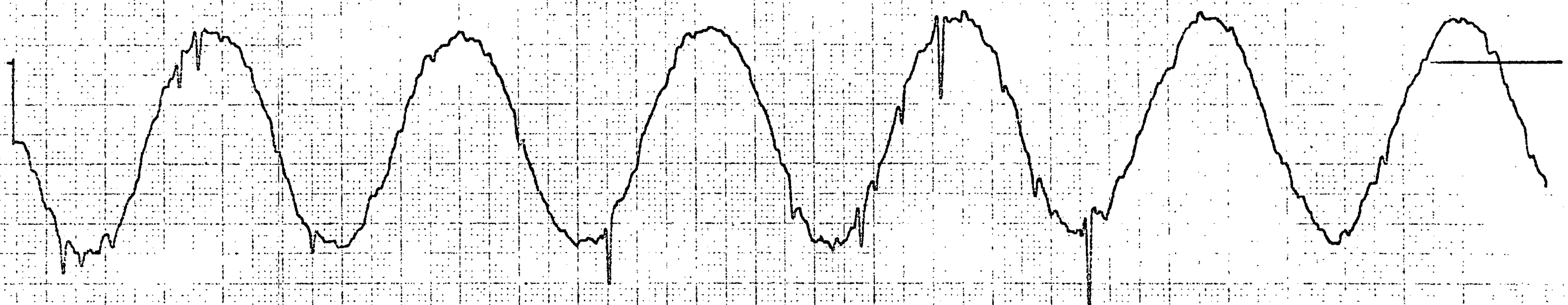


FIGURE 27-2 30 LN./IN.

60

$\frac{540-60}{40} \times 1/12"$

DW 3



28

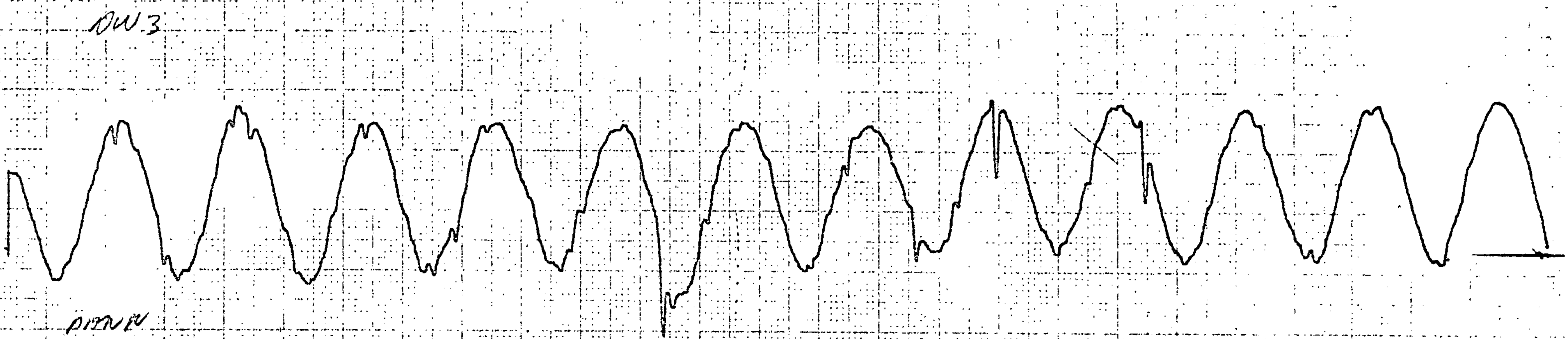
FIGURE 27-3 60 LN./IN.

3-37-5

120

27 oct 76

$\frac{540-60}{10} \times 1/2$"



88

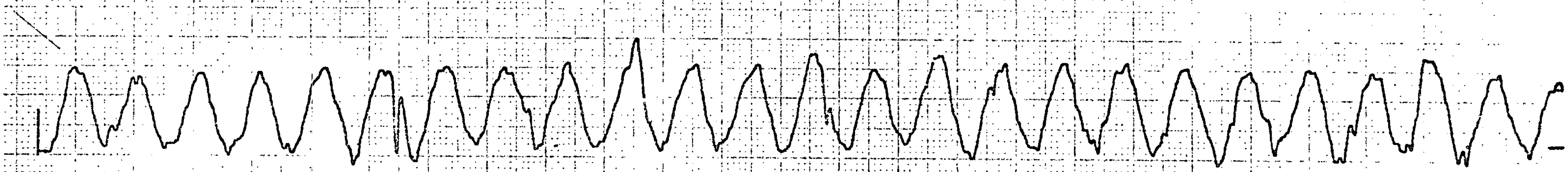
FIGURE 27-4 120 LN./IN.

3-37

240

27 oct 71

$\frac{540-60}{40} \times \frac{1}{10}$



68

FIGURE 27-5 240 LN/IN

3-37-4

480

[redacted] 27 OCT [redacted] 71 [redacted]

$\frac{540-60}{40} \times 1/2''$

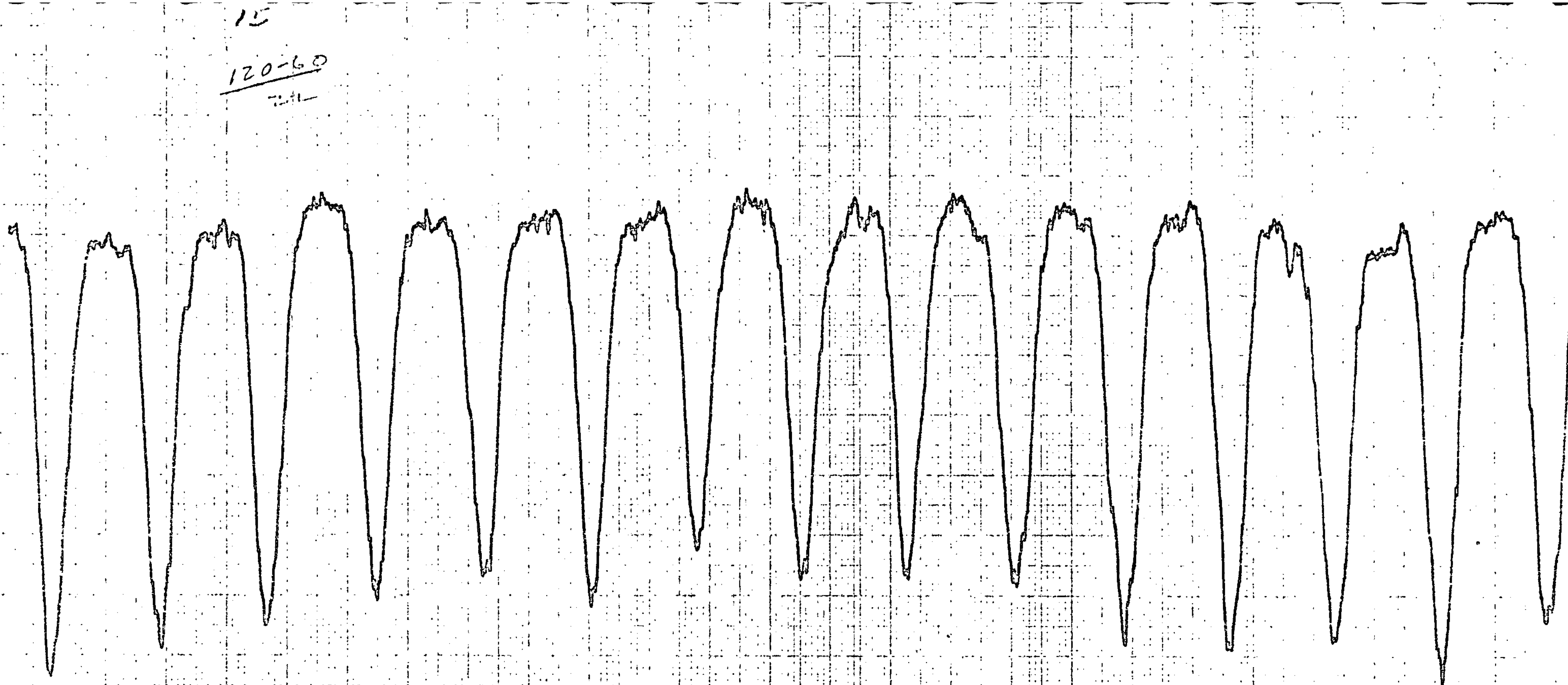
DW3

DARK

90

FIGURE 27-6 480 LN./IN.

3-37 ✓



SYSTEM MTF 7743 EMA
FIGURE 28-1 15 LN./IN.

3-37-w

30

120 - 60

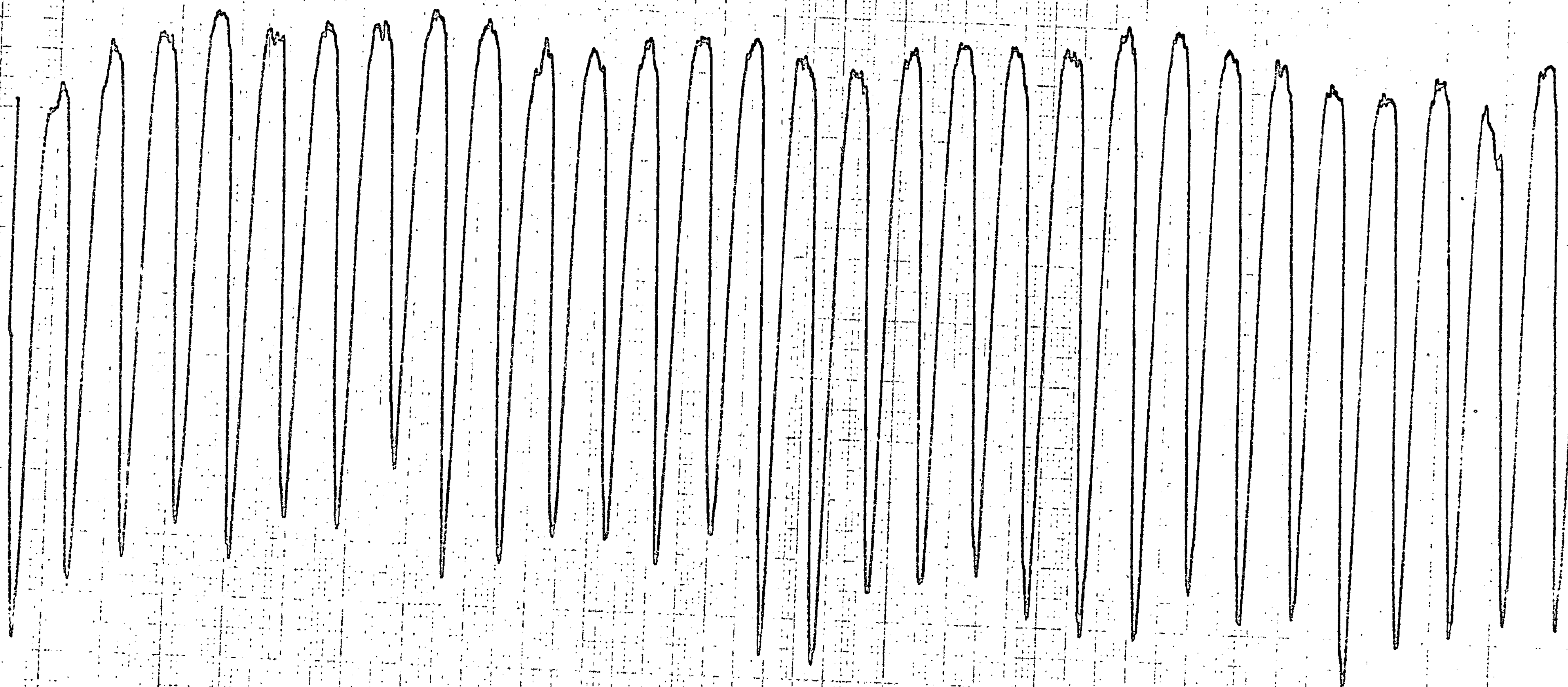


FIGURE 28-2 30 LN/IN

3-37-t

120-60
22

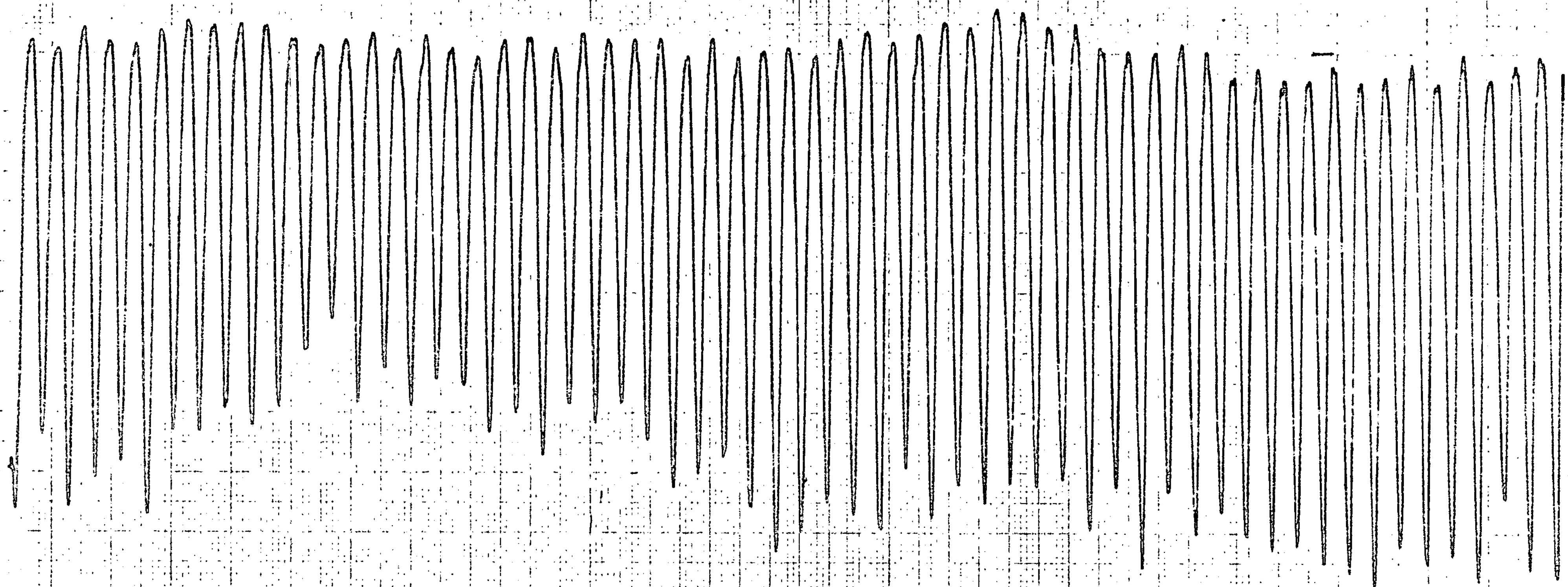


FIGURE 28-3 60 LN./IN.

93

3-37-4

120-60
72

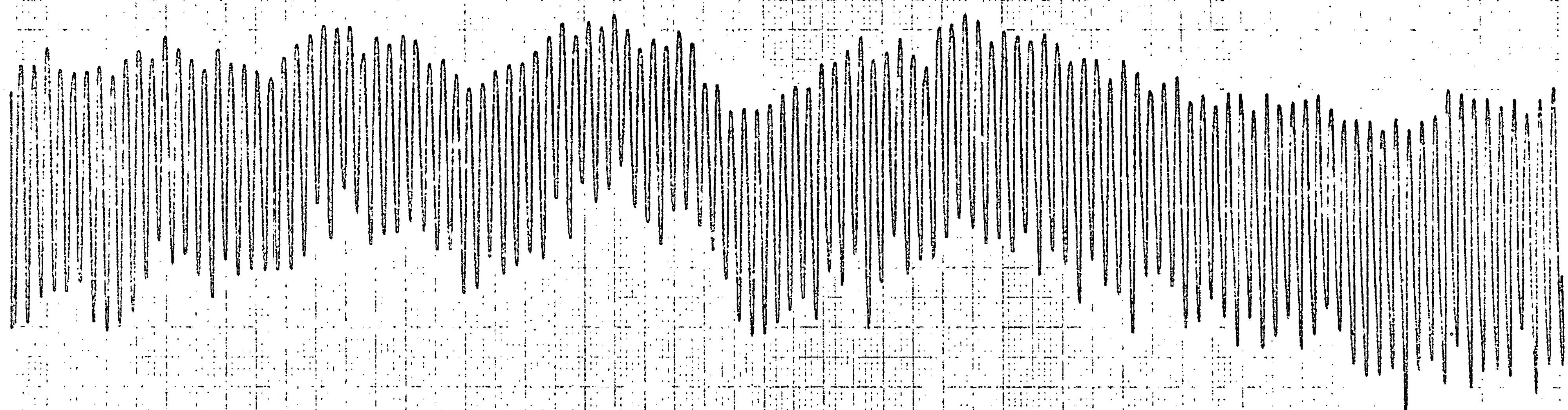


FIGURE 28-4A 120 LN/IN

3.37-2

120-60

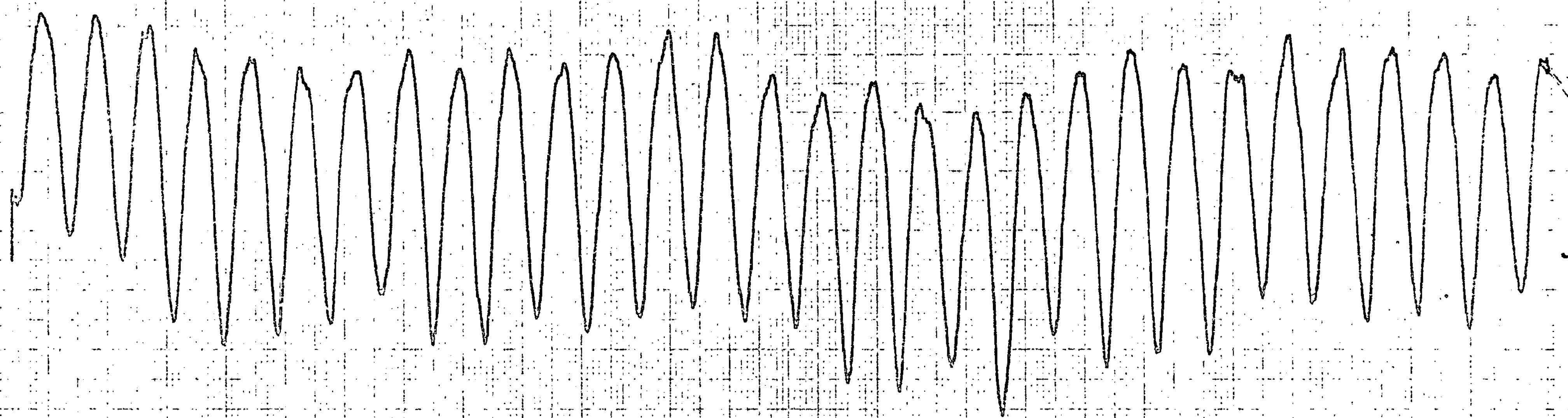


FIGURE 28-4B 120 LN/IN

95

3-37-1

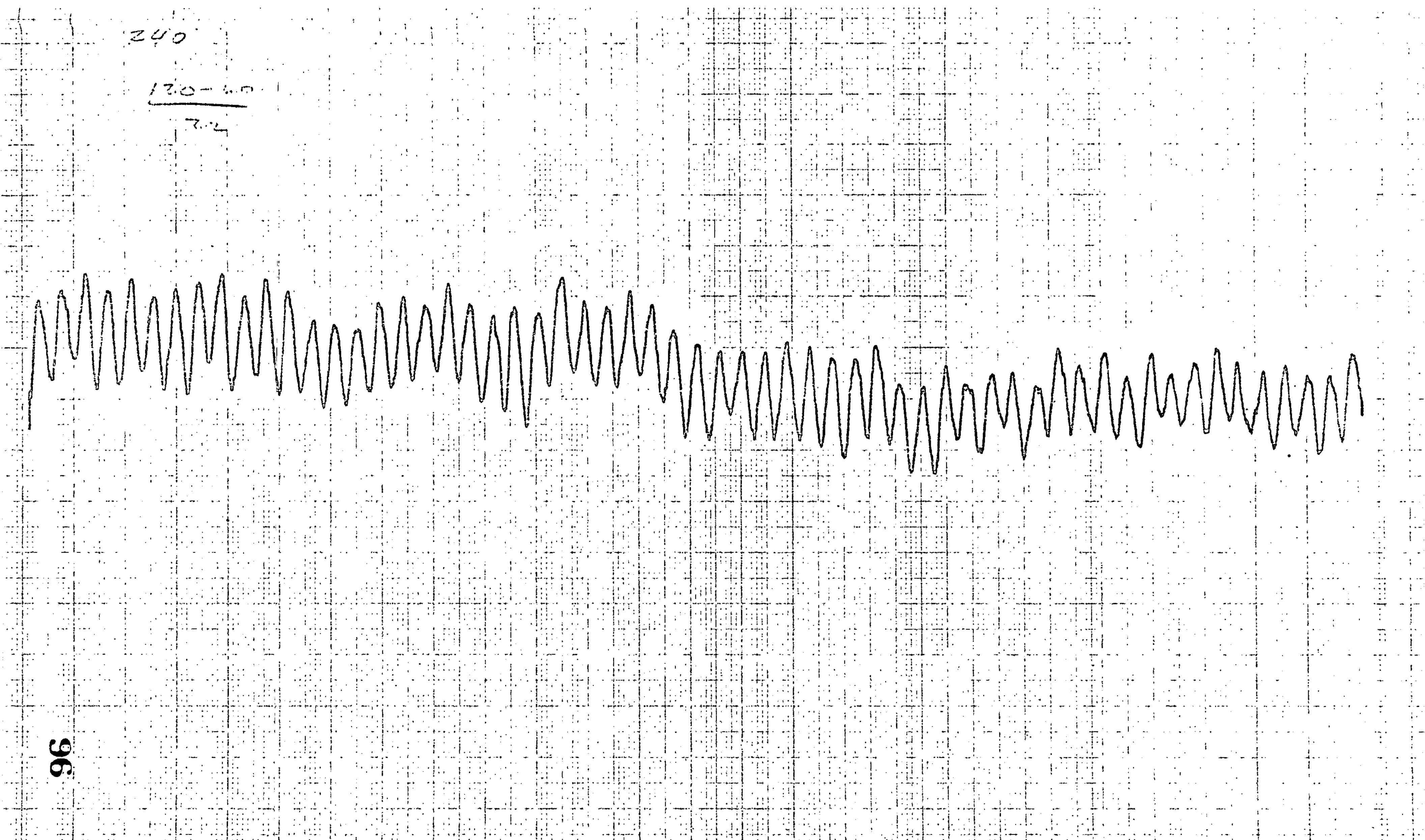


FIGURE 28-5 240 LN/IN

3-37.2

480

120 - 60

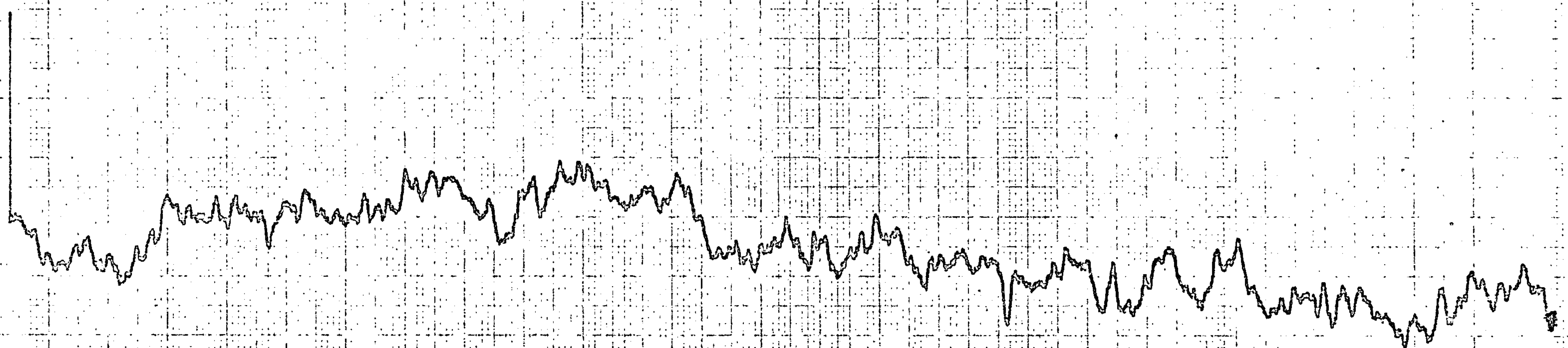
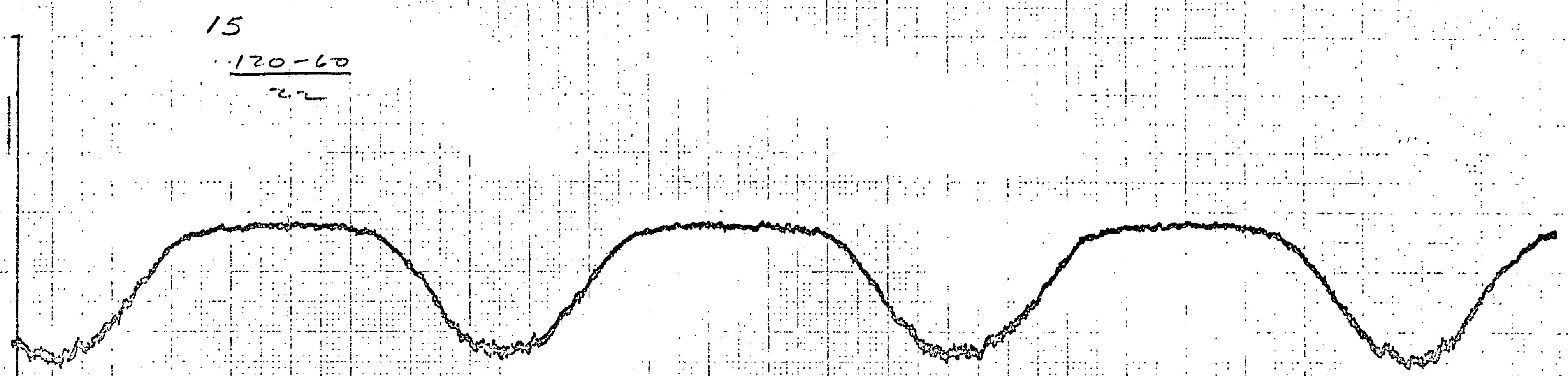


FIGURE 28-6 480 LN/IN

3-37-3



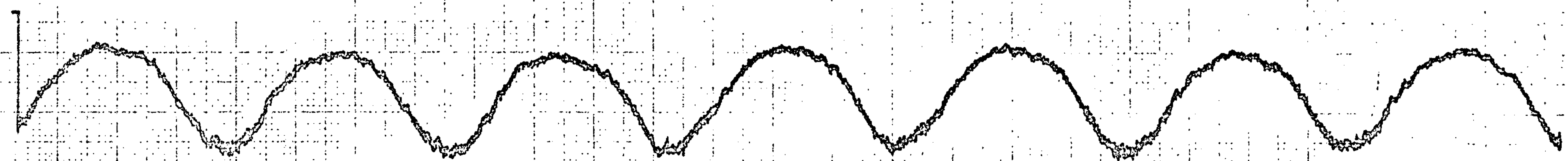
SYSTEM MTF 7743 CLEAR

FIGURE 29-1 15 LN./IN.

3-37-4

30

120 – 60
22



66

FIGURE 29-2A 30 LN./IN.

3-37-5

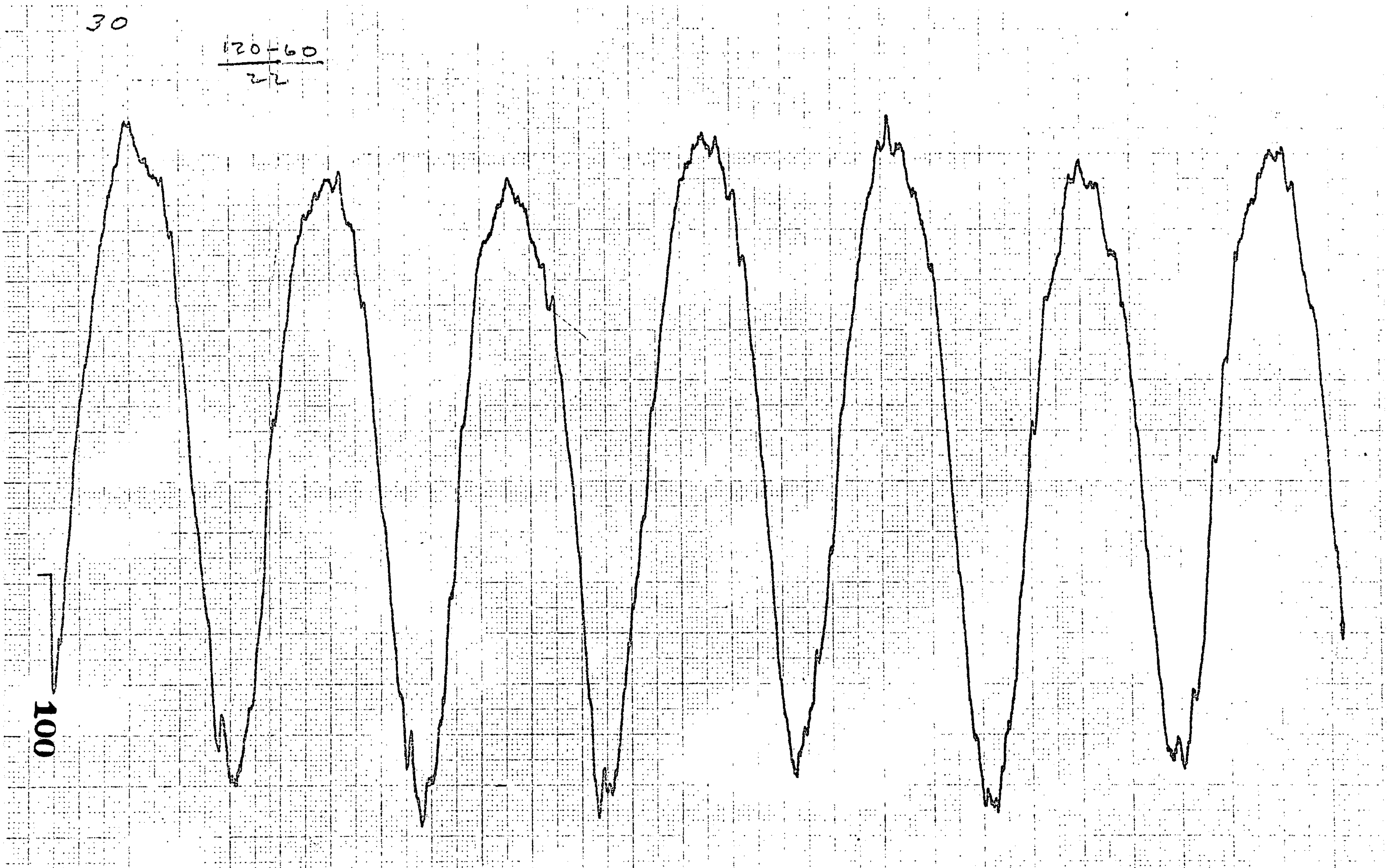


FIGURE 29-2B 30 LN./IN.

60

120 − 60 / 7.2

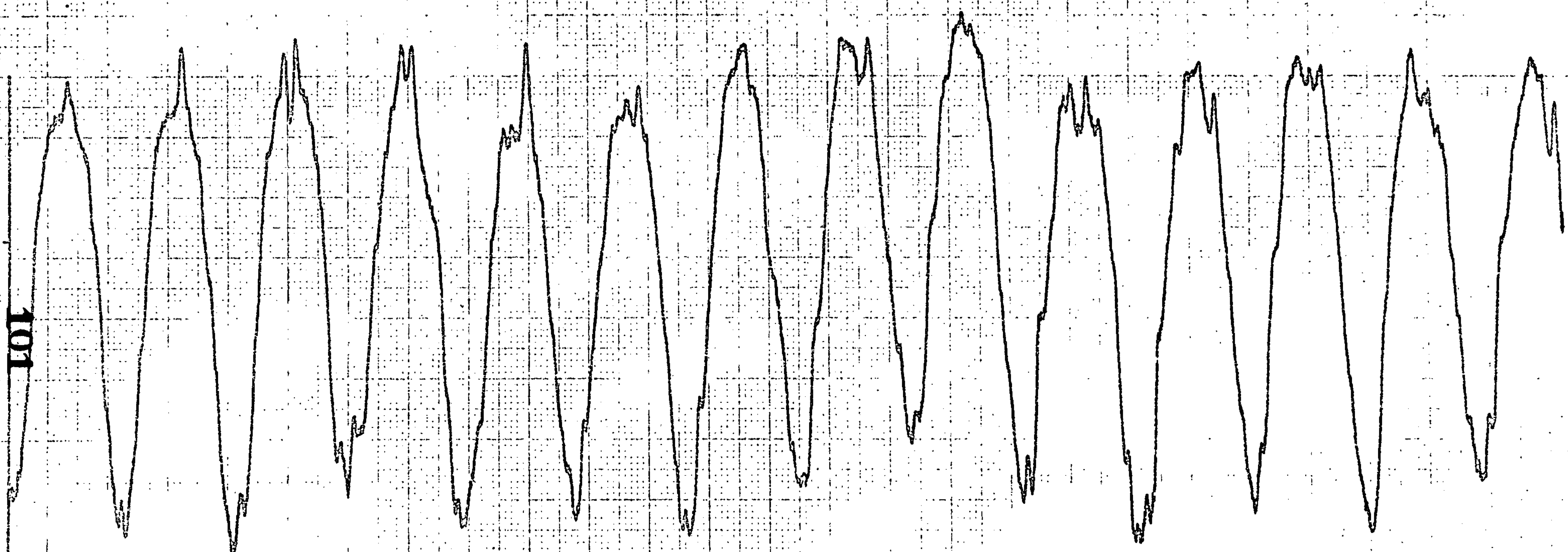


FIGURE 29-3 60 LN/IN

101

39

120

120 – 60 / 22

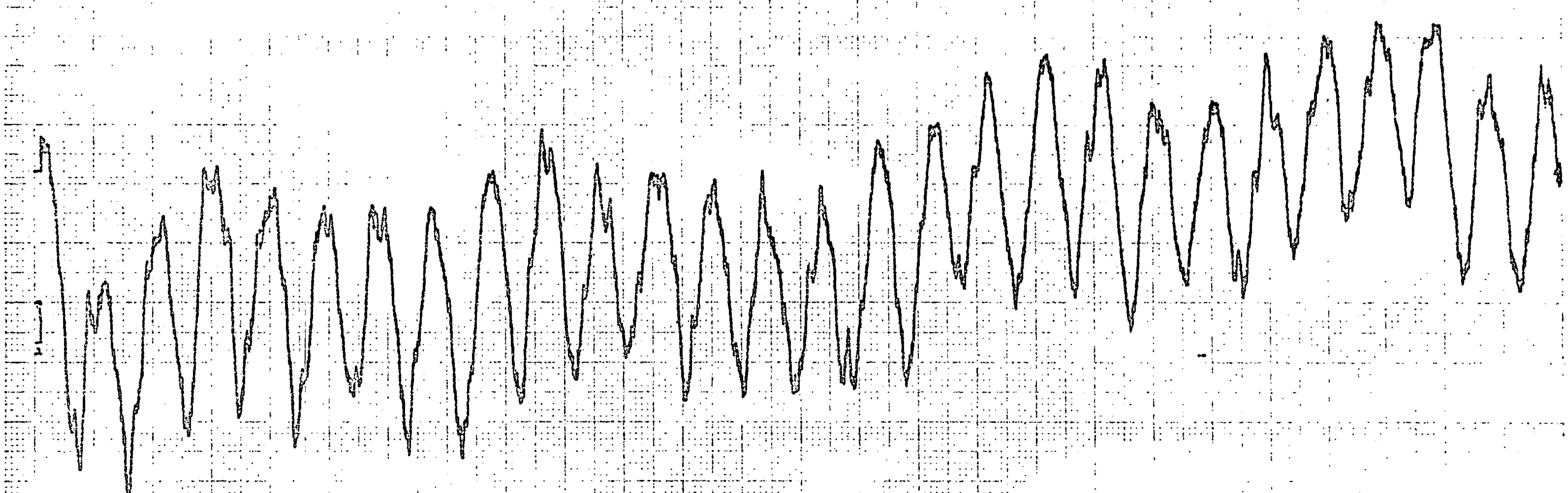


FIGURE 29-4 120 LN/IN

240

120-60
2-2

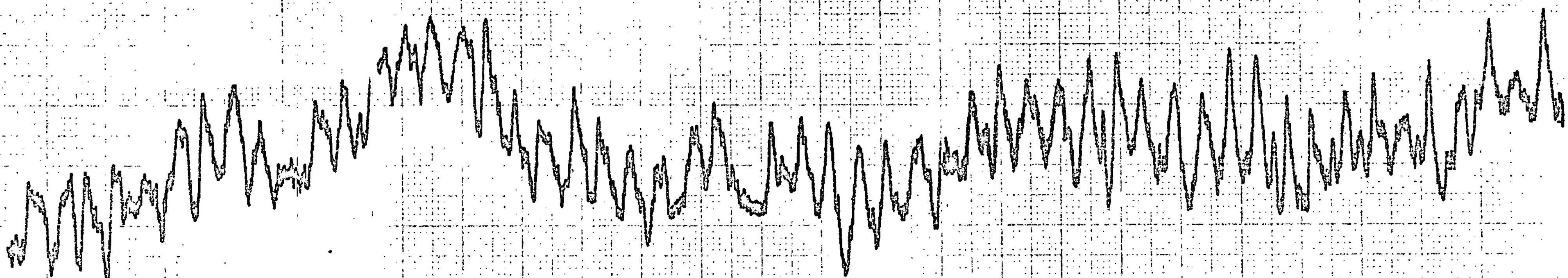


FIGURE 29-5 240 LN/IN.

480

$\frac{120-60}{22}$

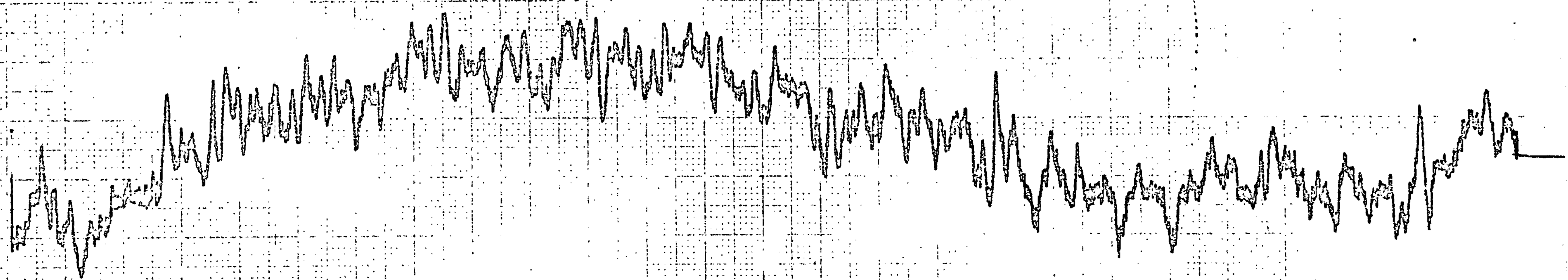
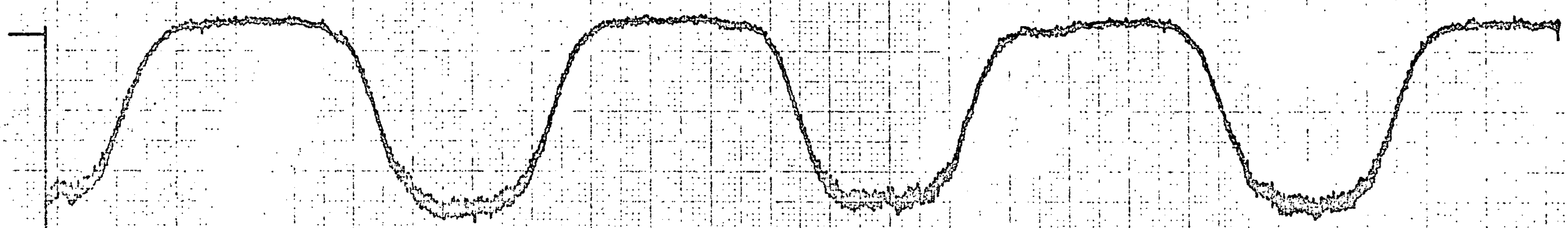


FIGURE 29-6 480 LN/IN

42



SYSTEM MTF 777 EMA
FIGURE 30-1 15 LN/IN

[redacted] 30 [redacted]
120-6.0

FIGURE 30-2 30 LN/IN

[redacted] 60

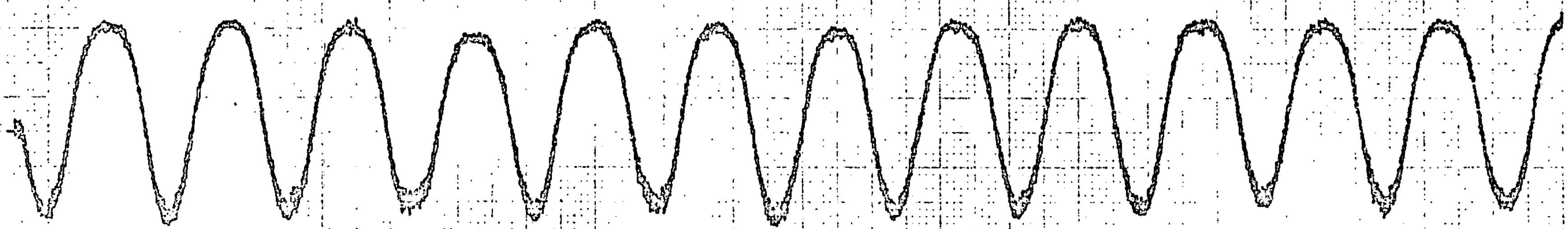


FIGURE 30-3 60 LN/IN

120

120 - 60

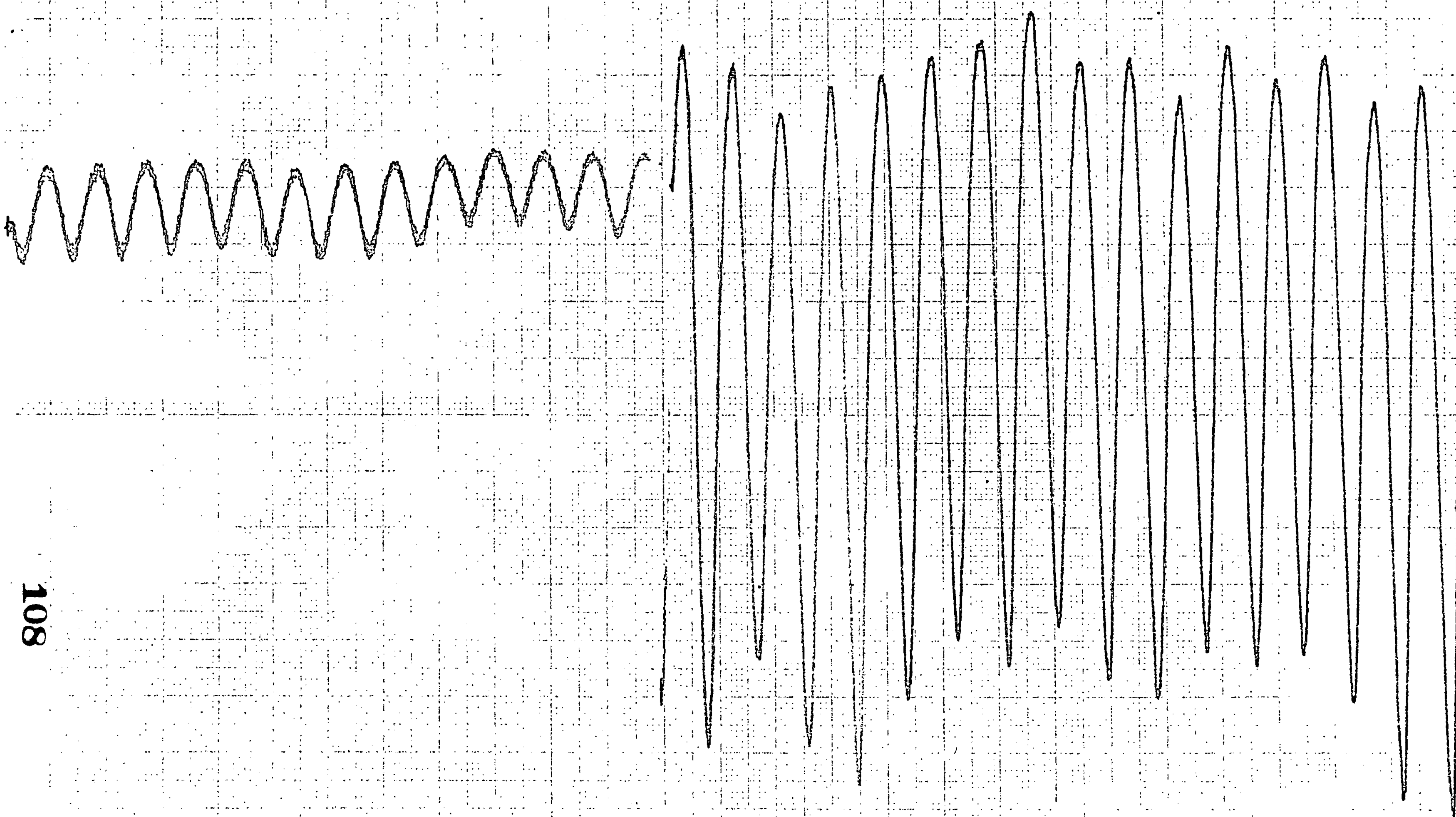


FIGURE 30-4 120 LN/IN

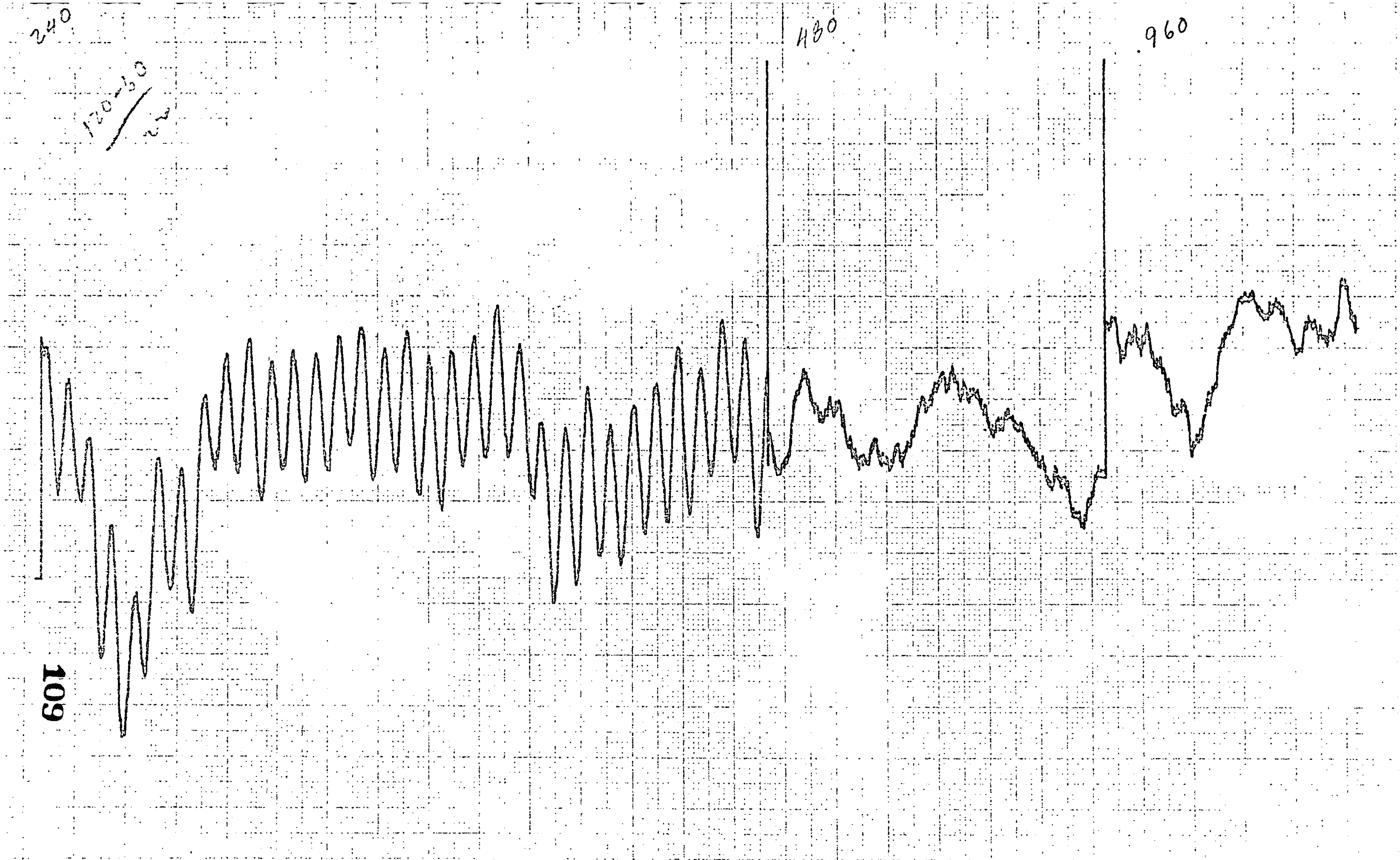
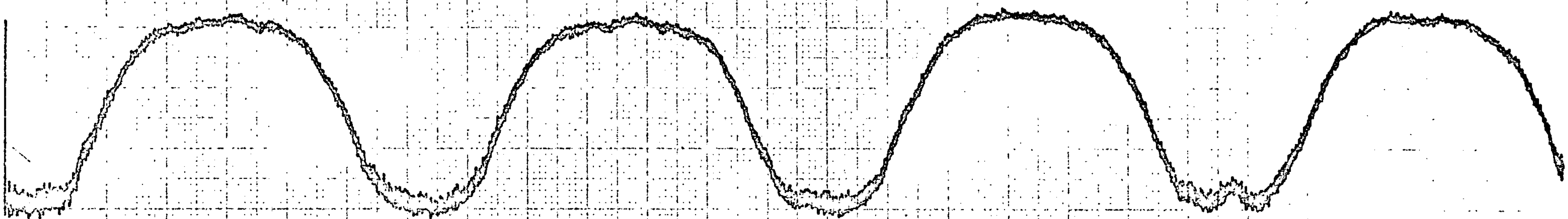


FIGURE 30-5 240 AND 480 LN/IN

15



SYSTEM MTF 777 CLEAR
FIGURE 31-1 15 LN/IN

30

FIGURE 31-2A 30 LN/IN

111

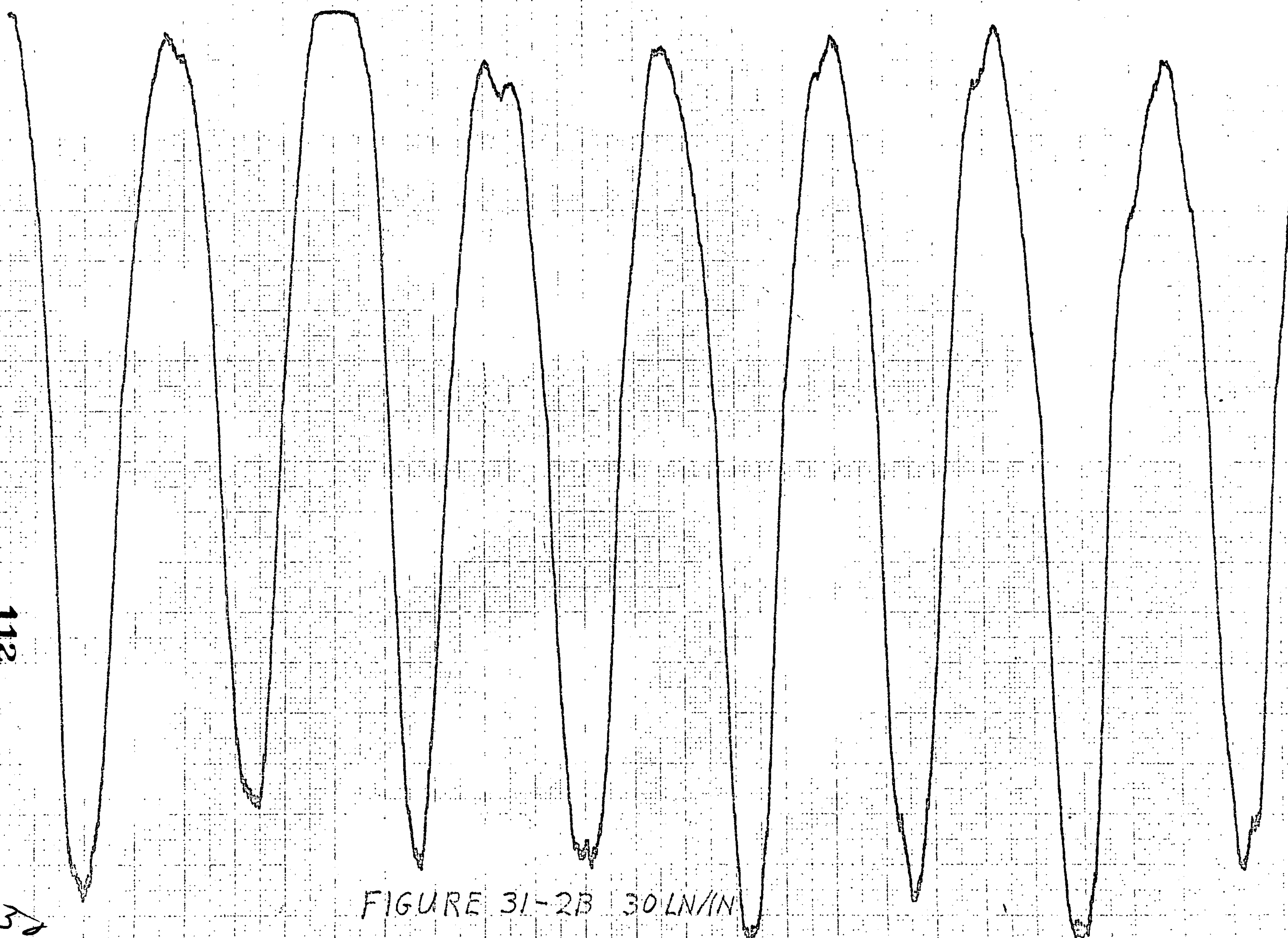


FIGURE 31-2B 30 LN/IN

[redacted] 60 [redacted]

113

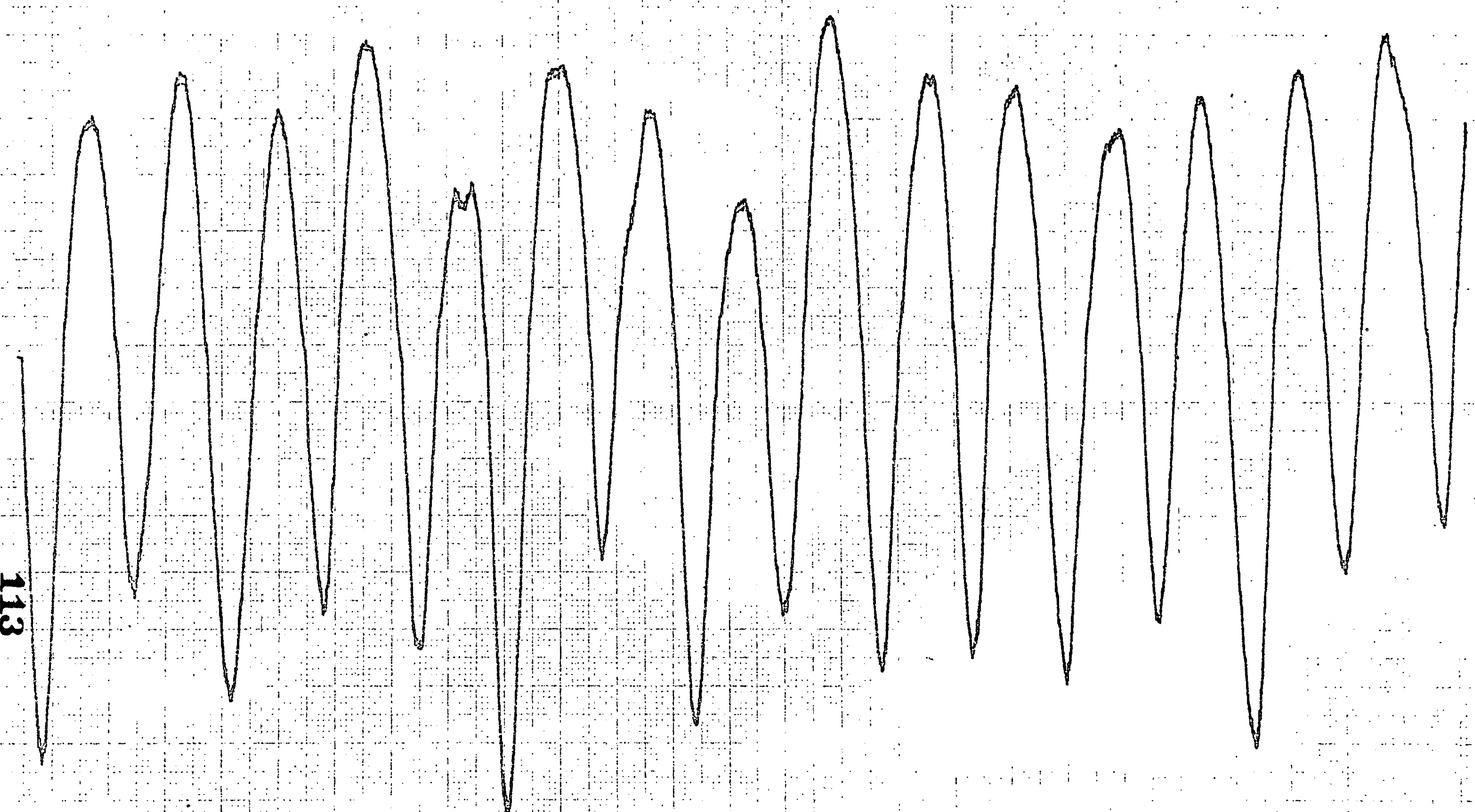


FIGURE 31-3 60 LN/IN

51

120

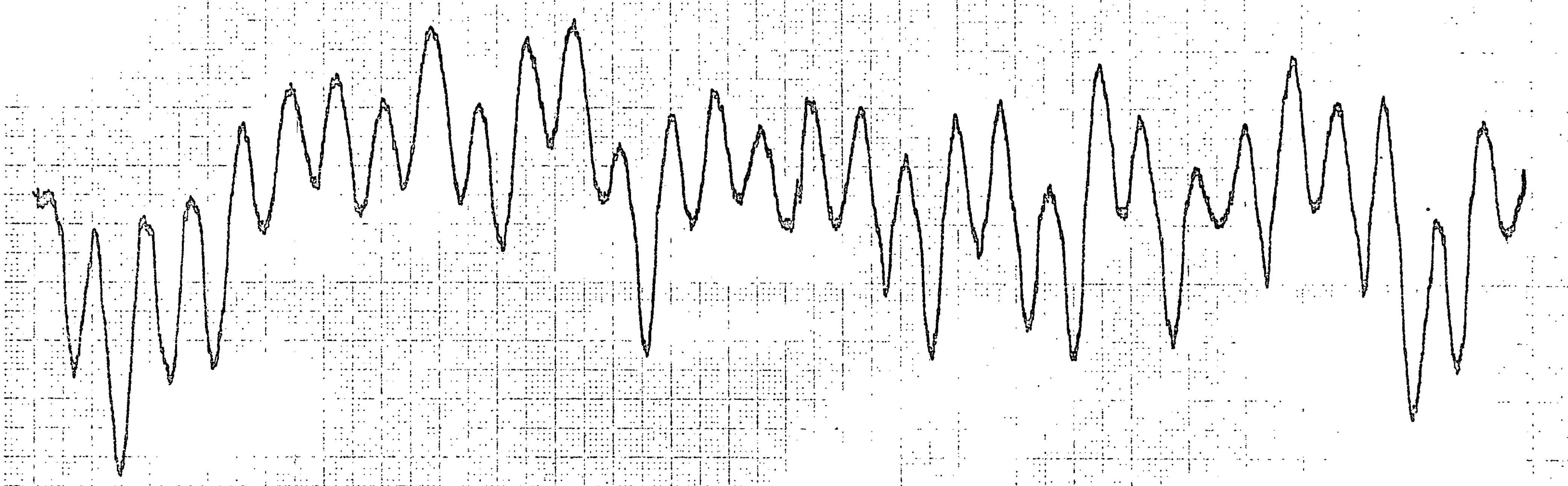
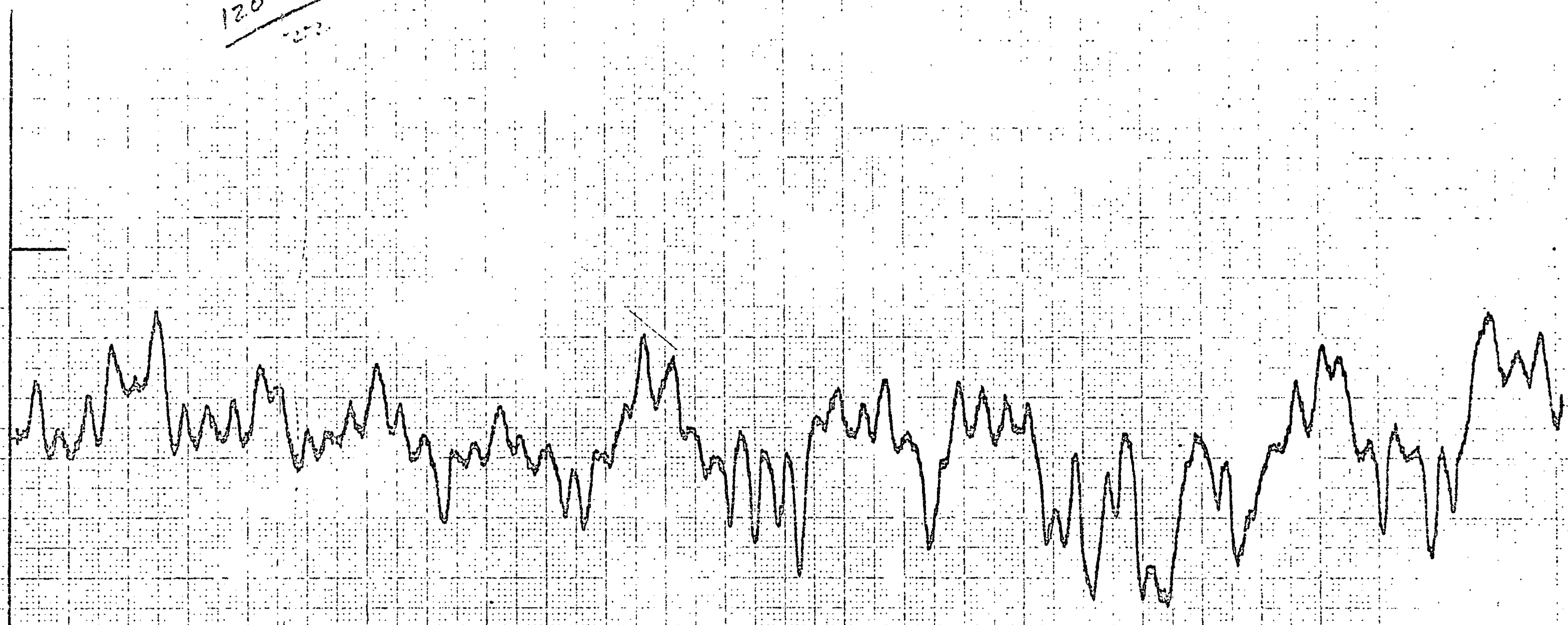


FIGURE 31-4 120 LN/IN

240

120-60



115

FIGURE 31-5 240 LN/IN

53

480

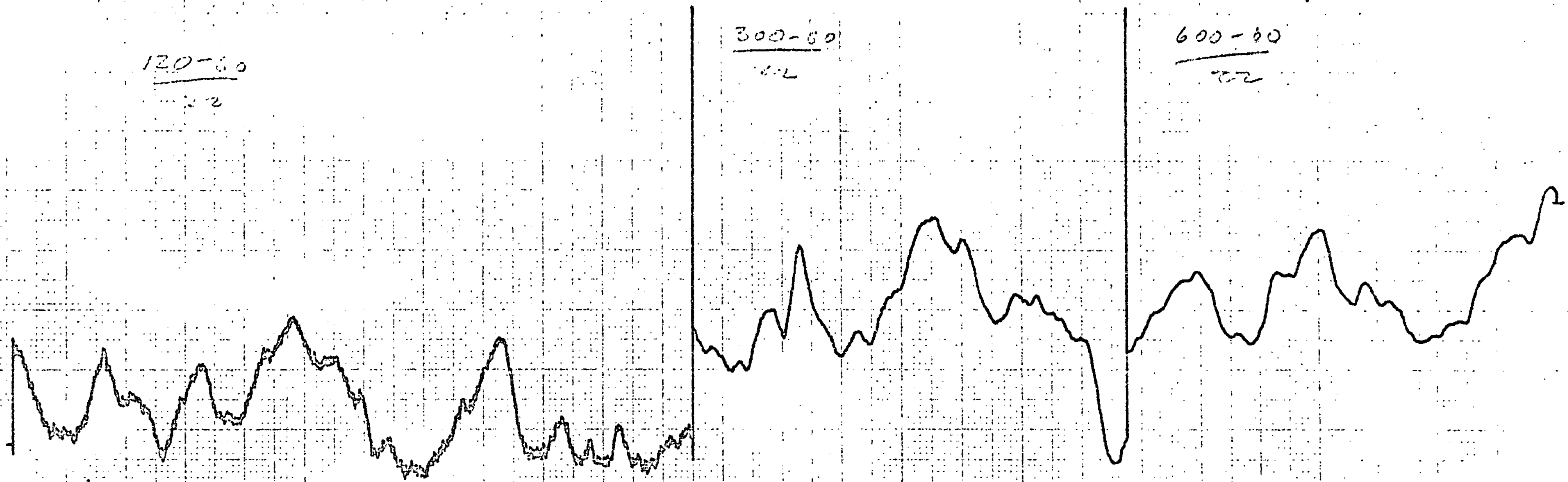
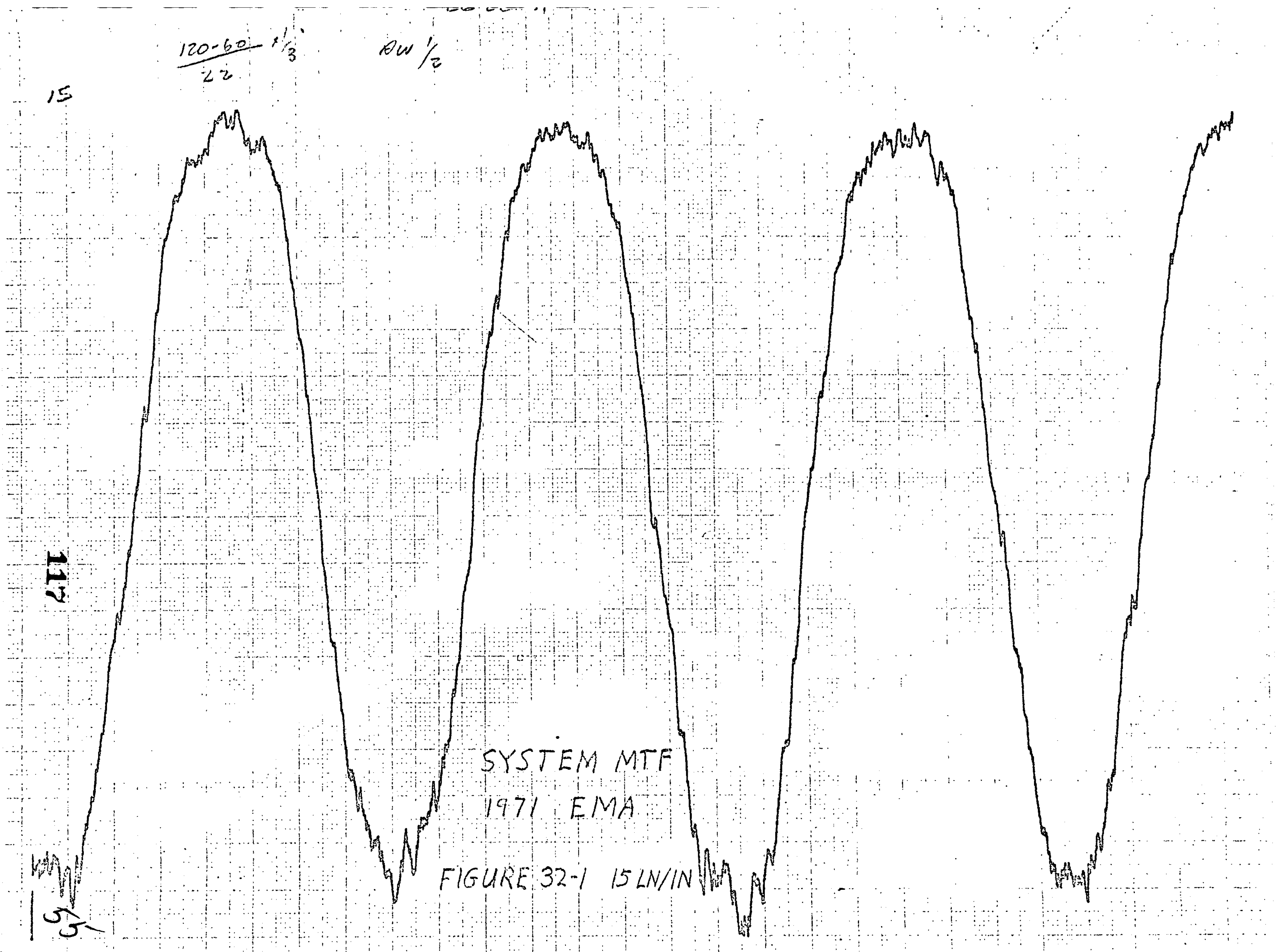


FIGURE 31-6 480 LN/IN



SYSTEM MTF
1971 EMA

FIGURE 32-1 15 LN/IN

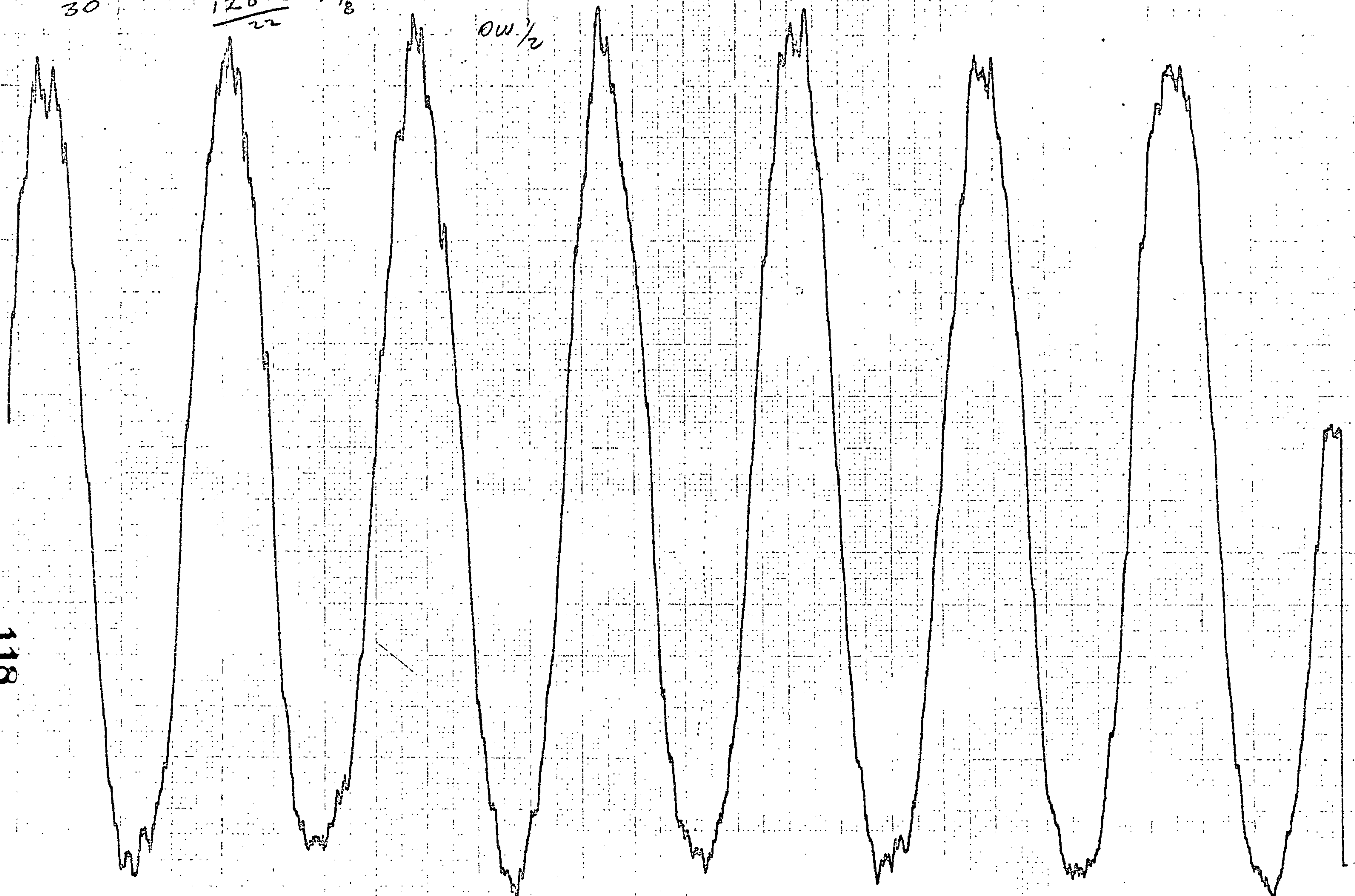


FIGURE 32-2 30 LN/IN

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60 $\frac{120-60}{22} \times 1/8"$ DW 1/2

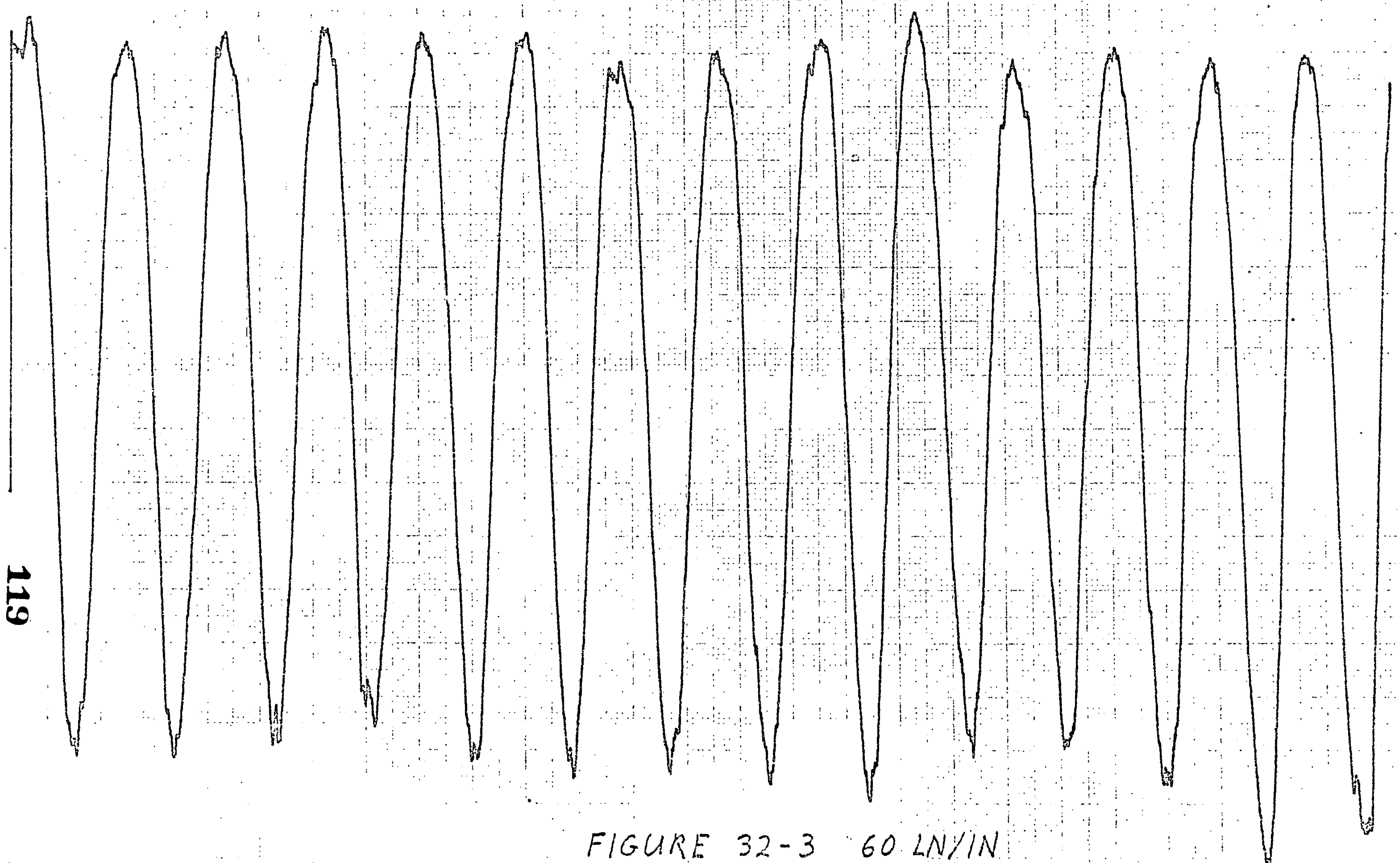

FIGURE 32-3 60 LN/IN

120

120 - 60, 1/10"

26 Oct 71

DW 1/2

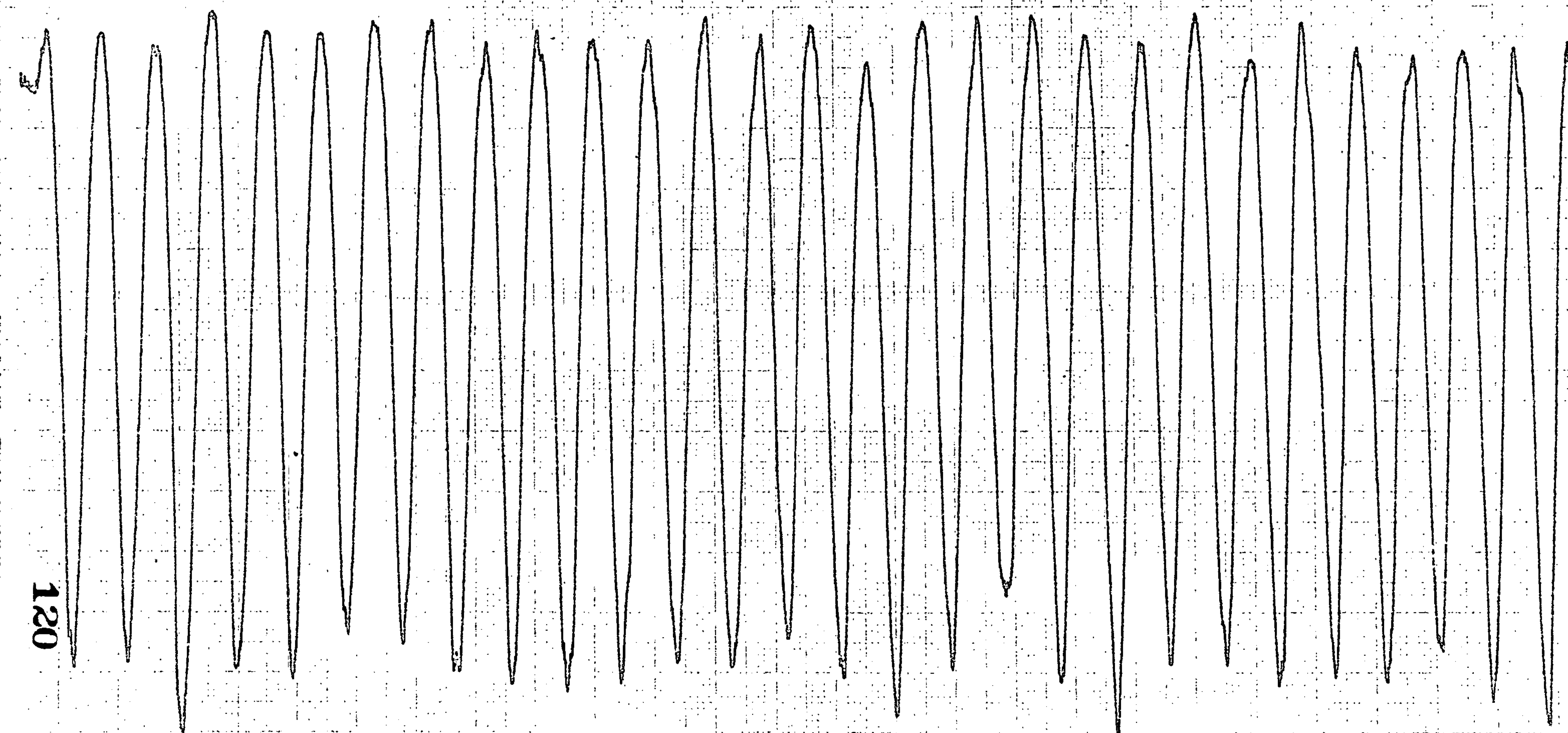

FIGURE 32-4 120 LN/IN

26 Oct 71

240

$\frac{120-60}{22} + 1/10"$

DW 1/2

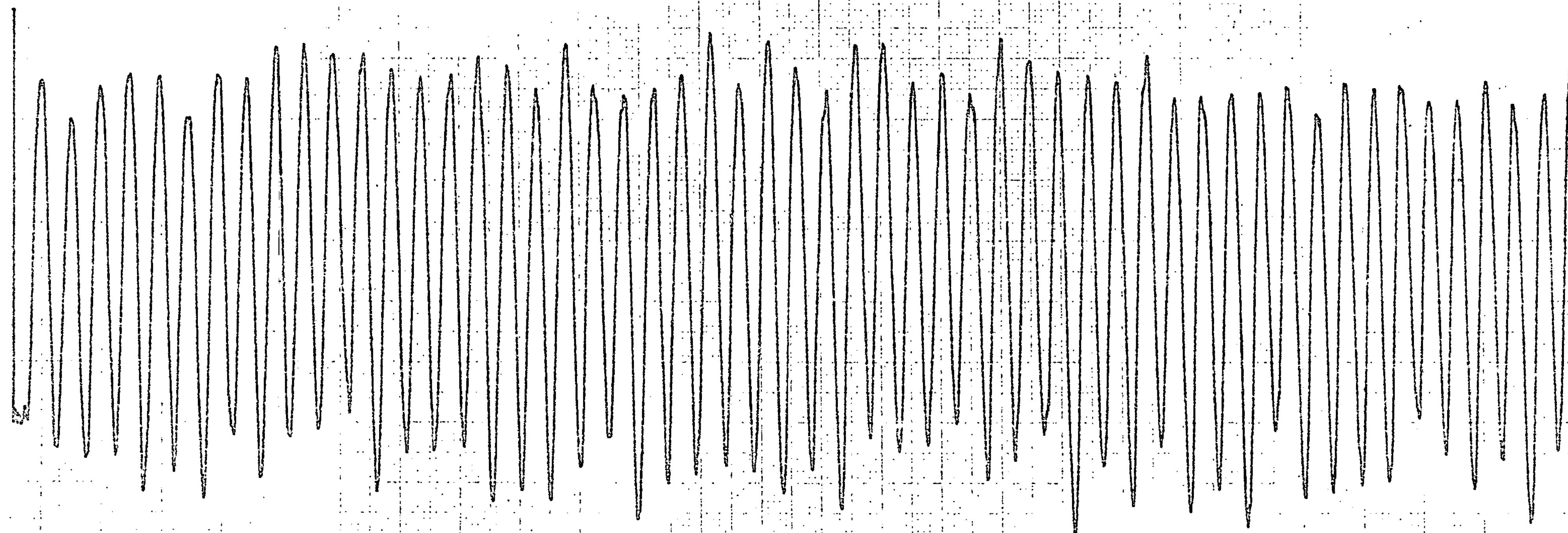

FIGURE 32-5 240 LN/IN

121

59

480

$\frac{120-60}{.22} \times \frac{1}{8}"$

DW ½

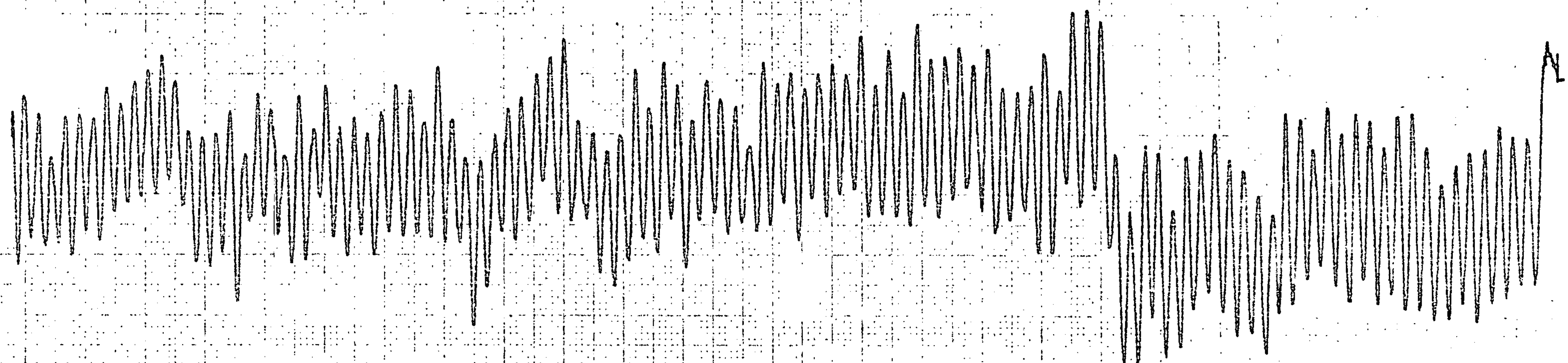

FIGURE 32-6A 480 LN/IN

60

1180

$\frac{120-60}{22} \times 1/8$"

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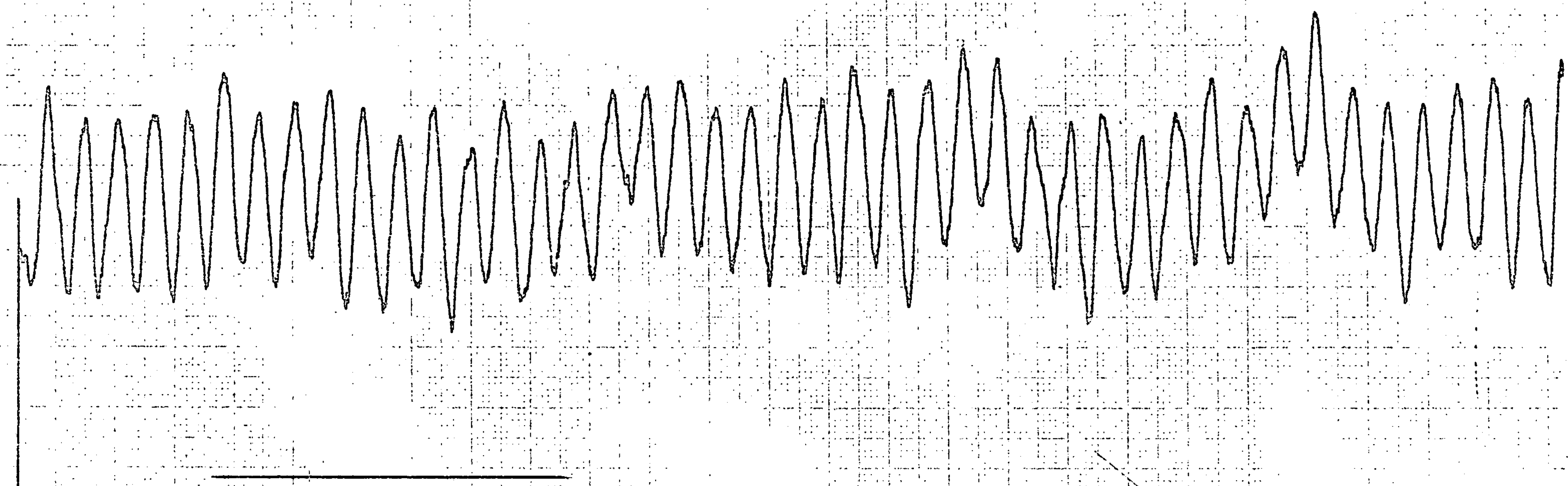
BW 1/2

Gain 50:1



123

FIGURE 32-6B 480 LN/IN

67

960 AICM 50:1

$\frac{120-60}{22} \times 1/18$

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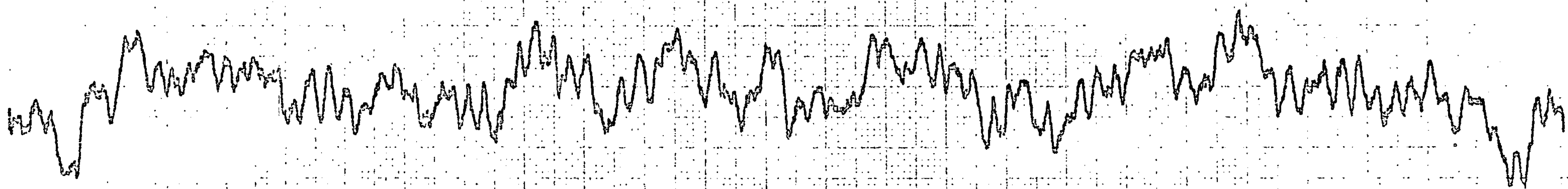
DW 1/2



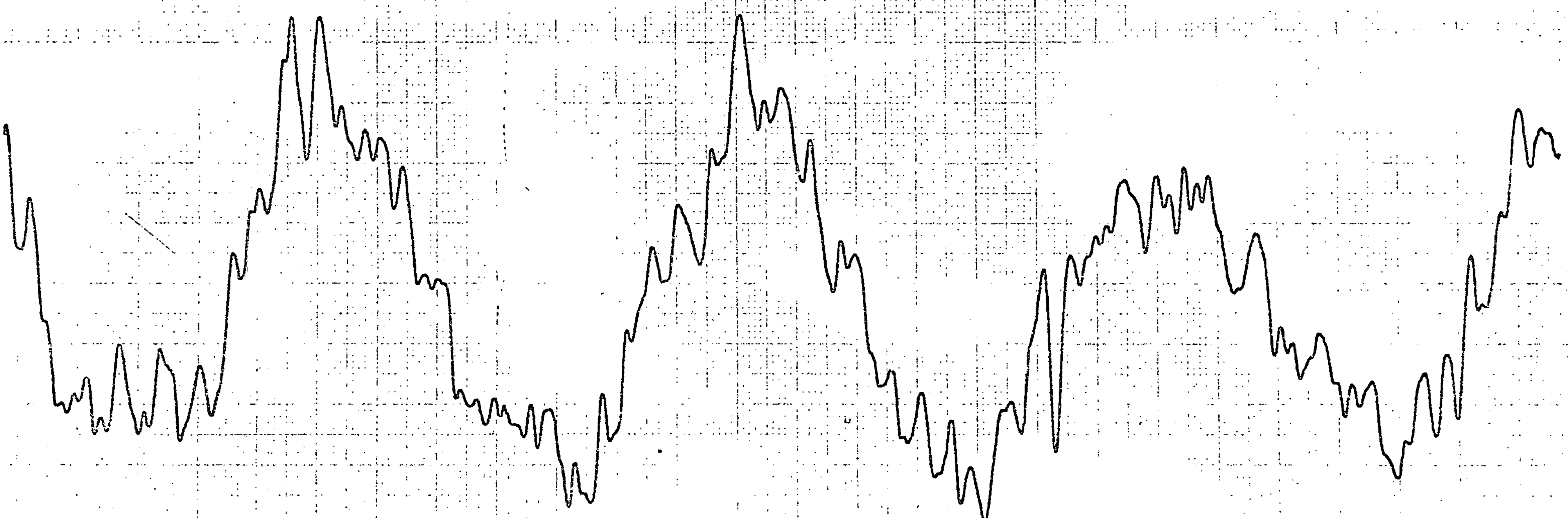
1

FIGURE 32-7 960 LN/IN

124

62

1160-60
22



SYSTEM MTF 1971 CLEAR

FIGURE 33-1 15 LN/IN

63

30 21 oct 71

11 60-60
22

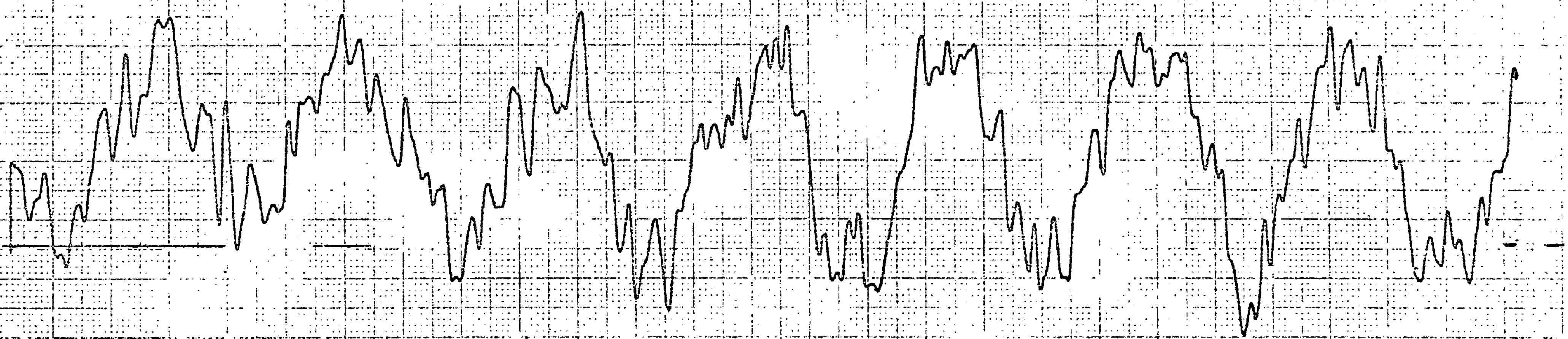
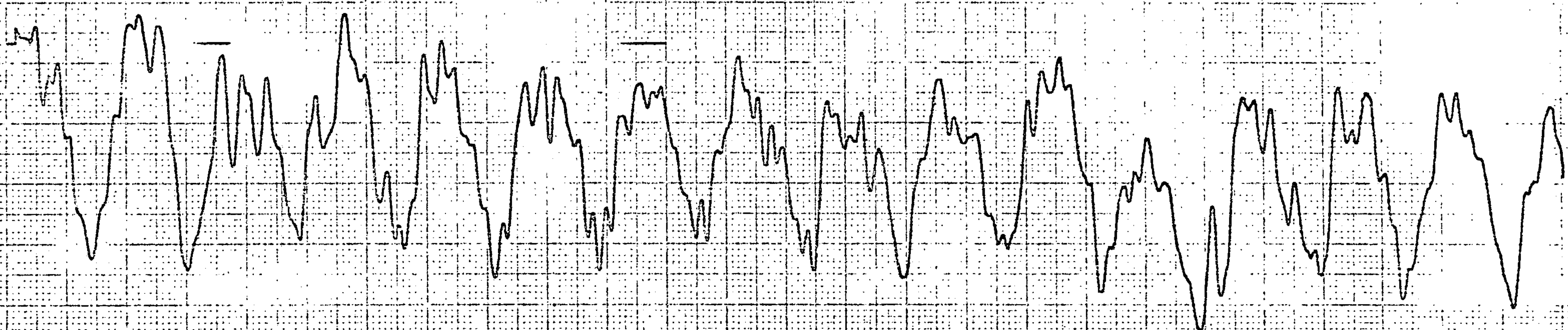


FIGURE 33-2 30 LN/IN

60

21 Oct 71

1160-60 / 22



127

FIGURE 33-3 60 LN/IN

1160-60
22

21 Oct 71

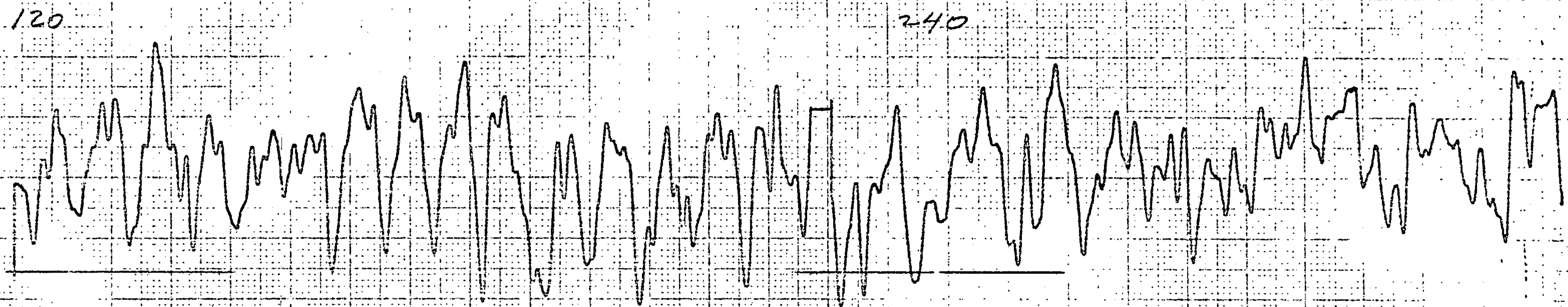


FIGURE 33-4 120 AND 240 LN/IN

128

65

1160-60
22

21 Oct 71

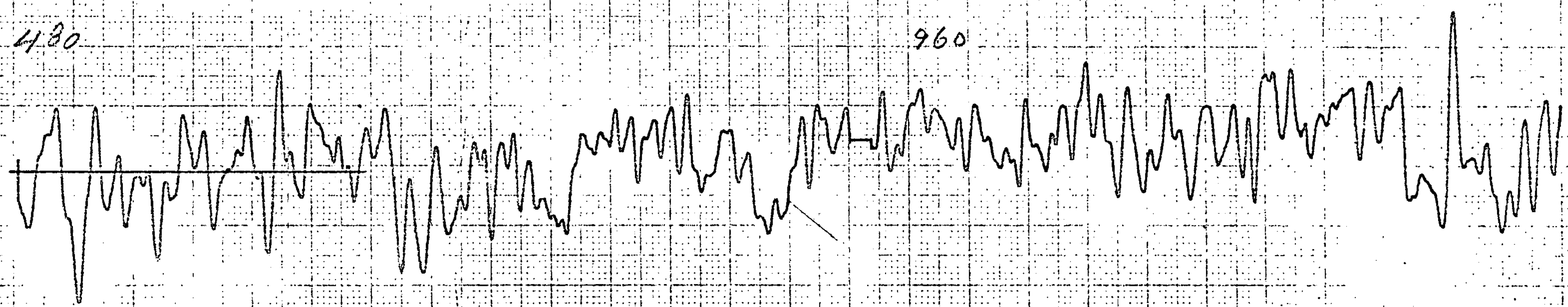
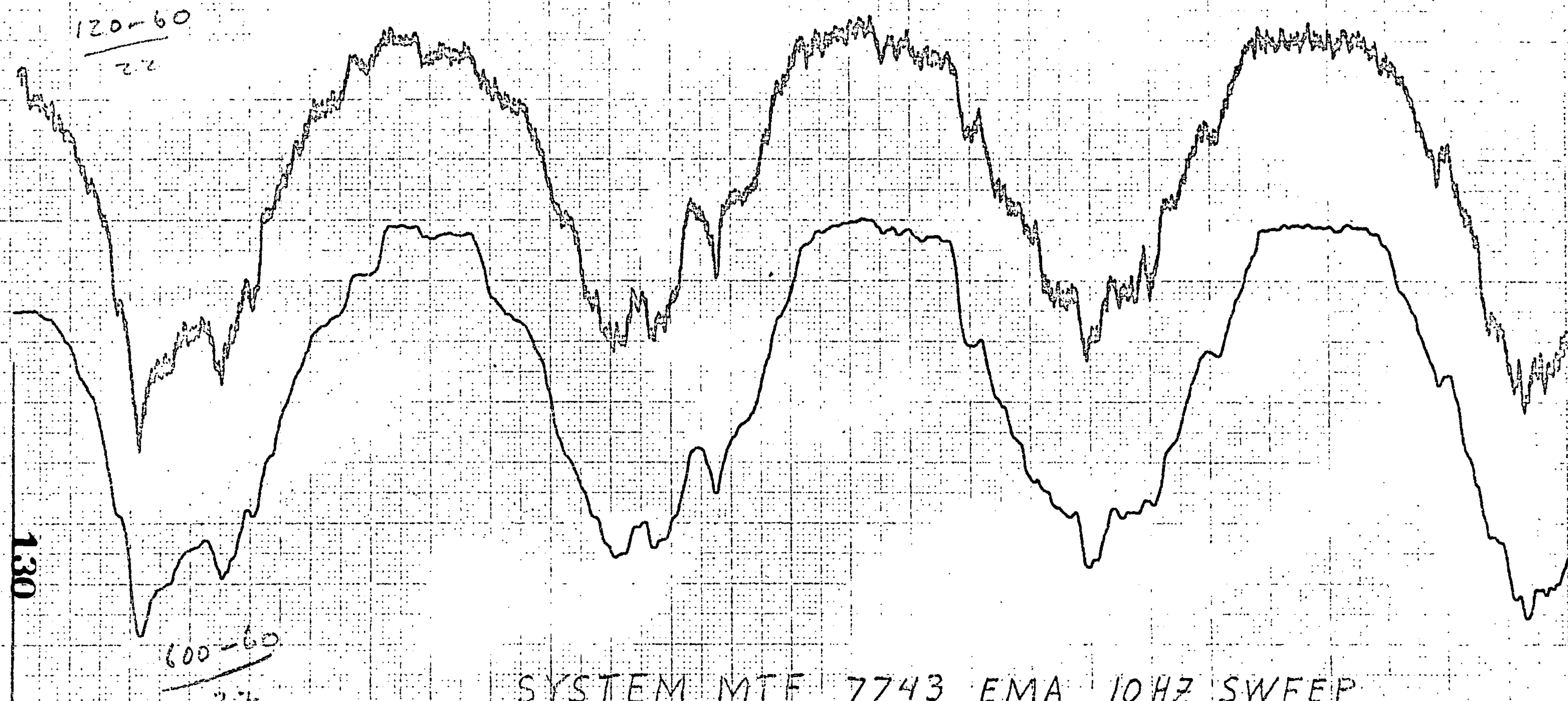


FIGURE 33-5 480 LN/IN

15

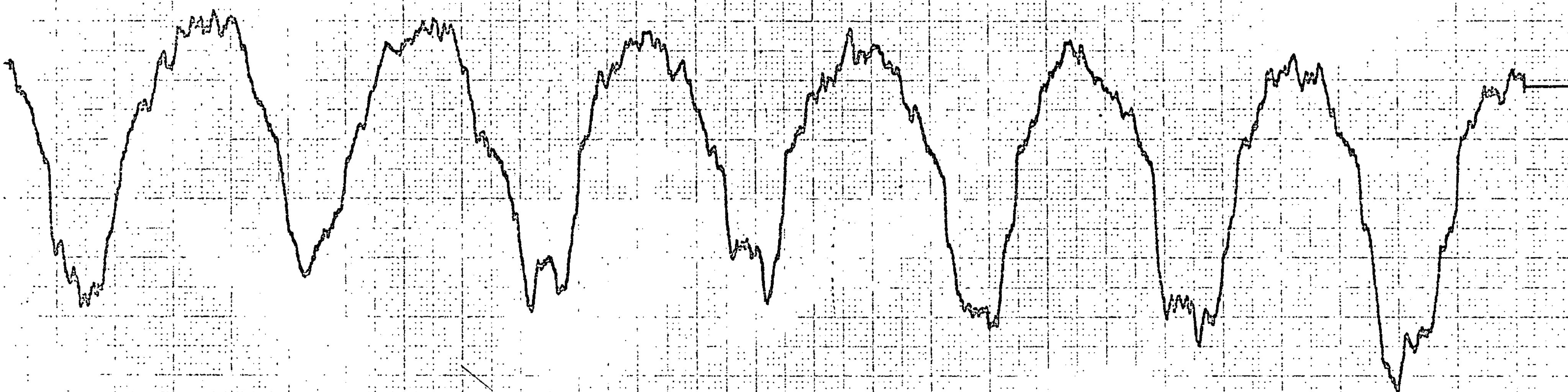


SYSTEM MTF 7743 EMA 10HZ SWEEP

FIGURE 34-1 15 LN/IN

30

120-60 / 22



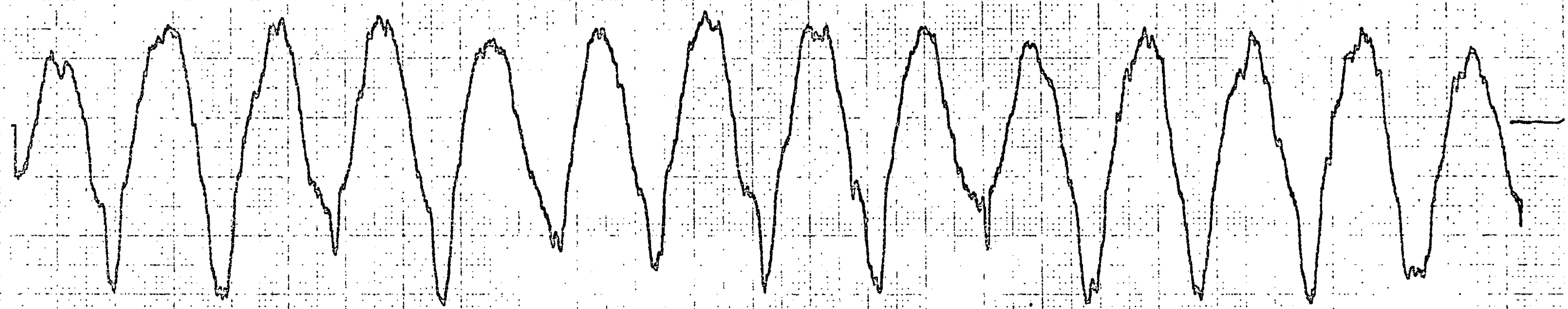
131

FIGURE 34-2 30 LN/IN

69

60

120-60



132

FIGURE 34-3 60 LN/IN

20

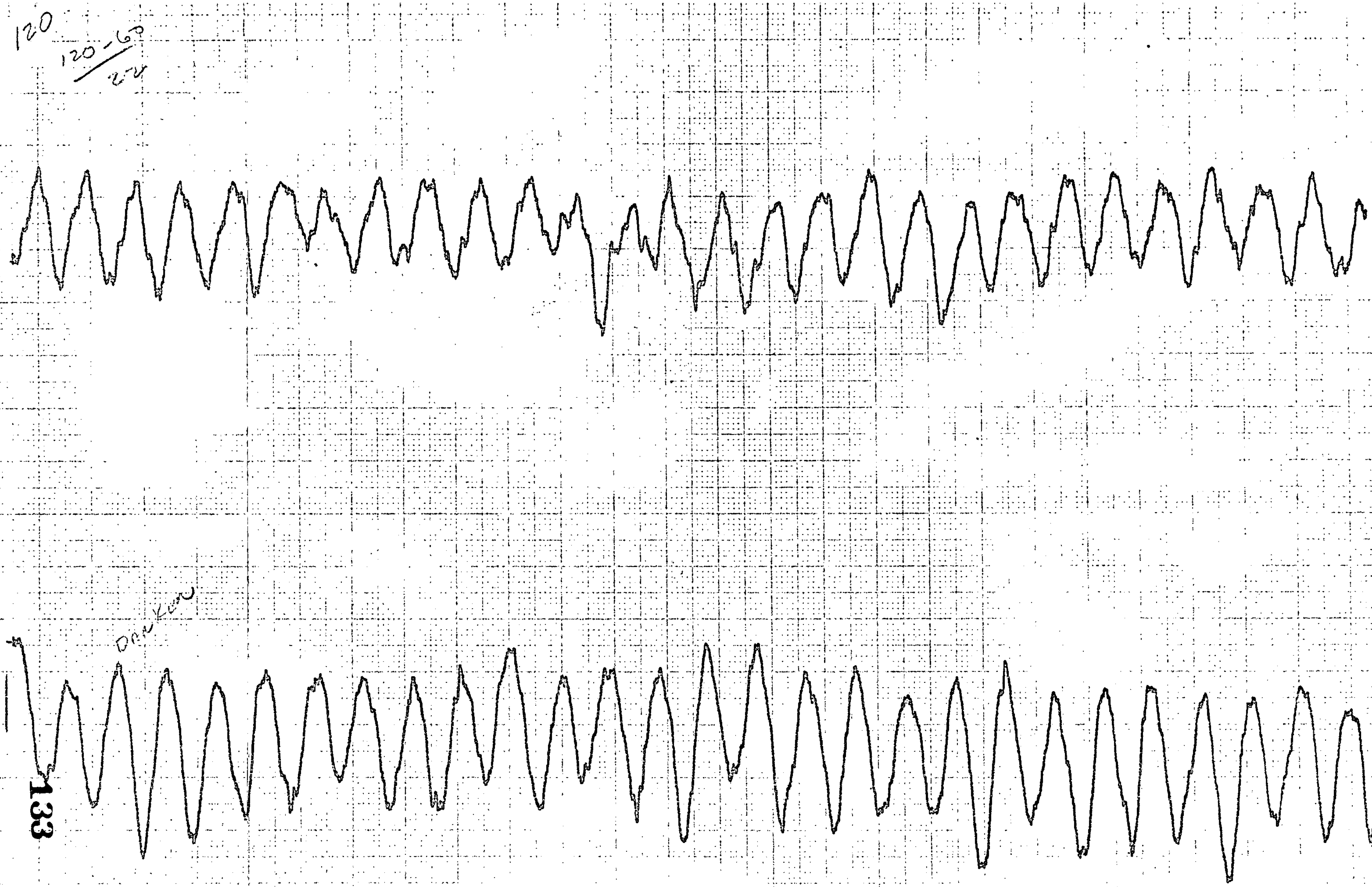


FIGURE 34-4 120 LN/IN

9/

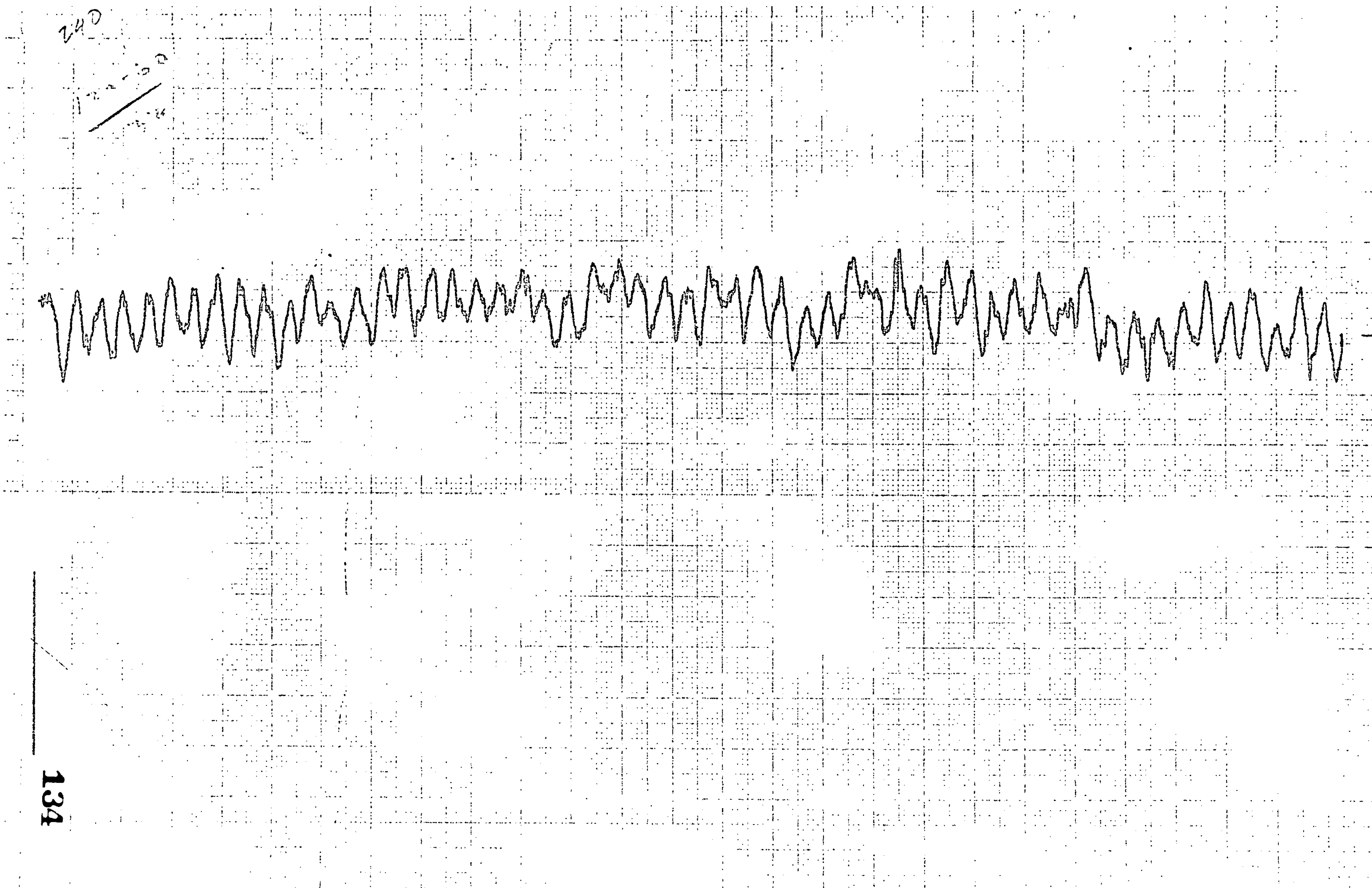


FIGURE 34-5 240 LN/IN

120-60 / 22

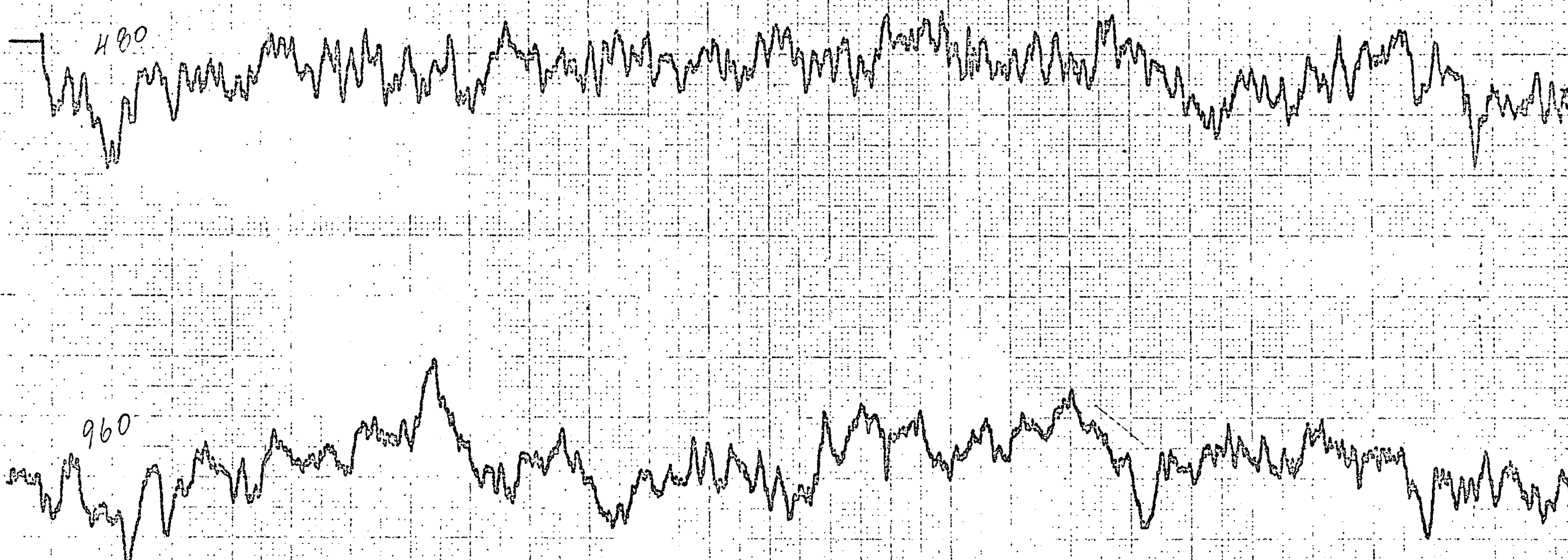
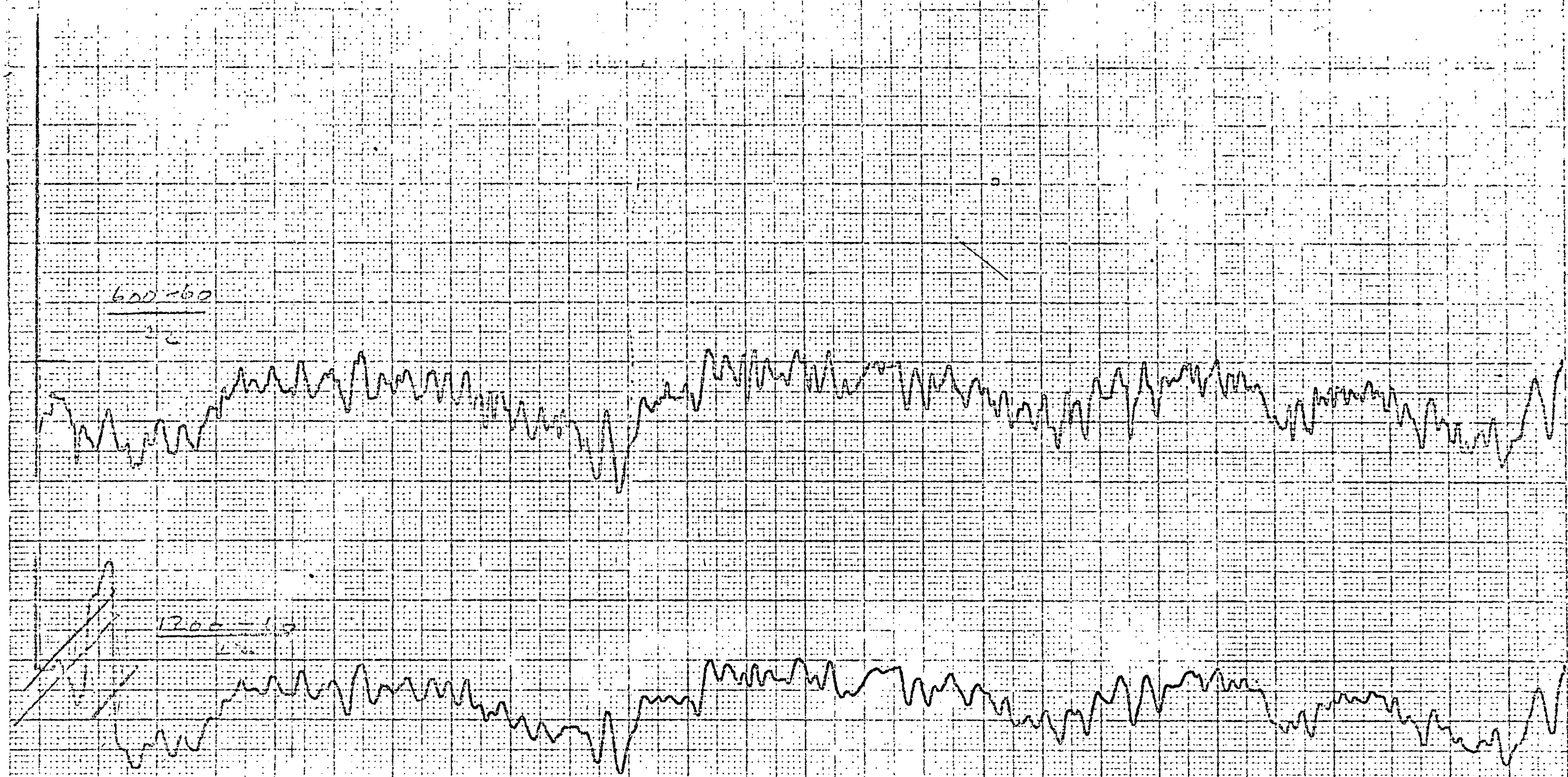


FIGURE 34-6 480 AND 960 LN/IN



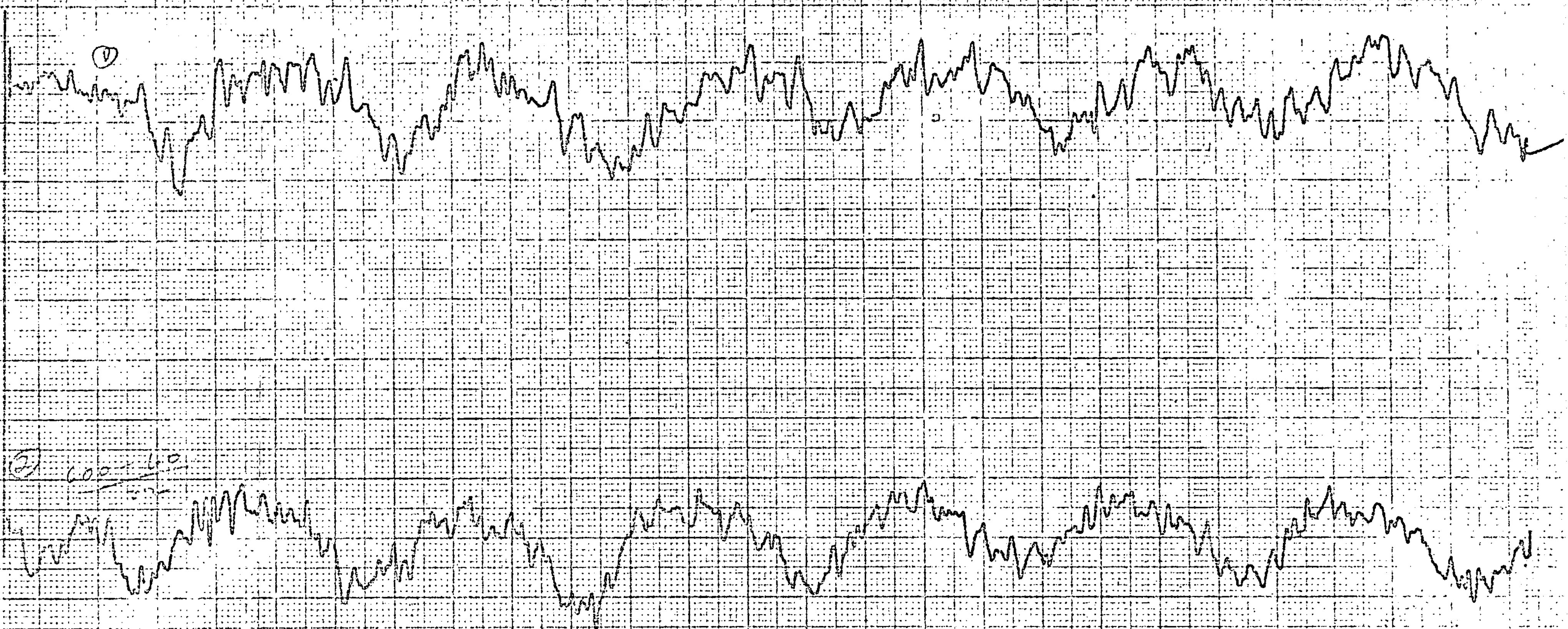
SYSTEM MTF 7743 EMA 100 HZ SWEEP

FIGURE 35-1 15 LN/IN

30

20 Oct 71

600-60



137

FIGURE B5-2 30 LN/IN

75

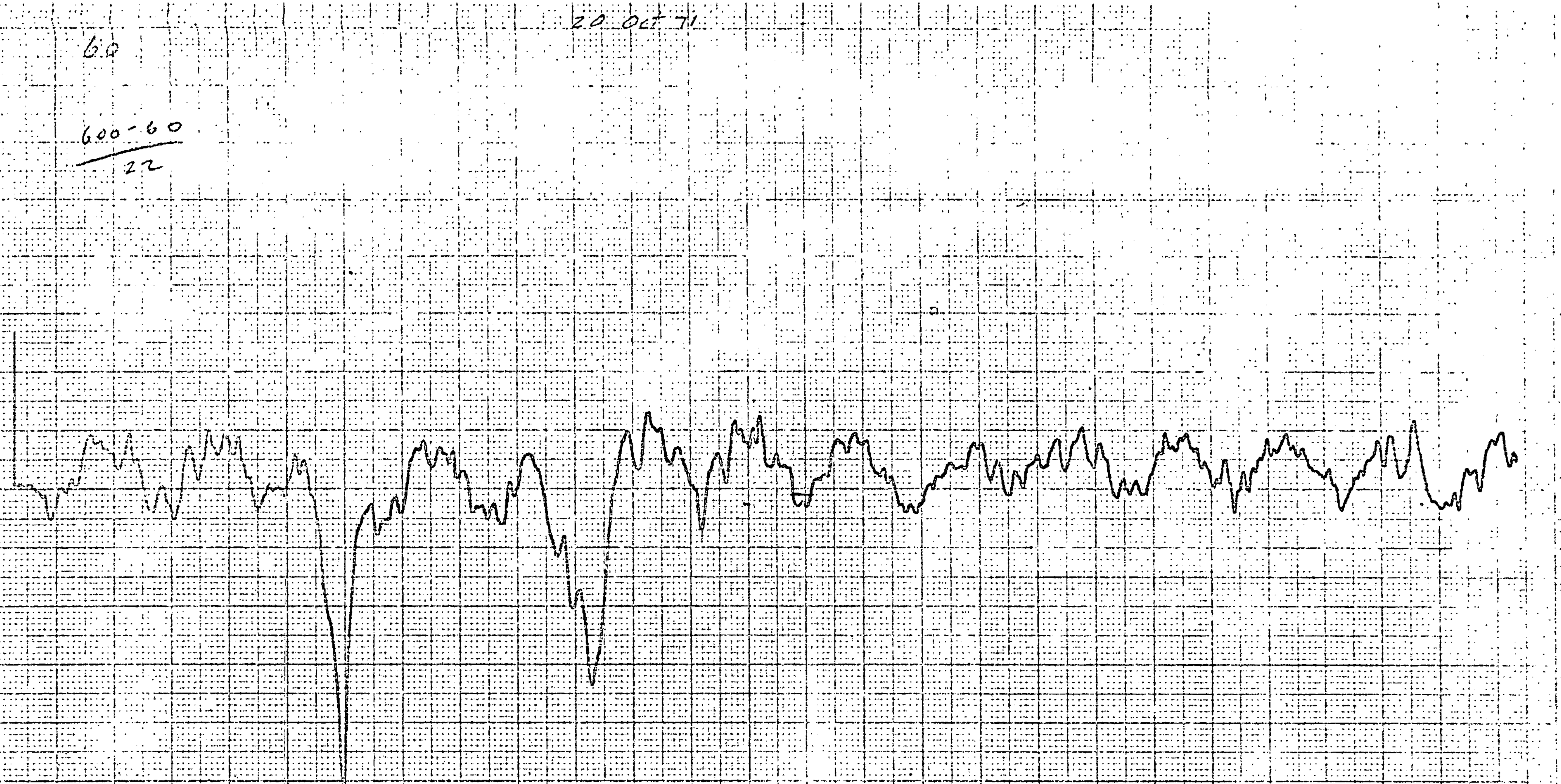


FIGURE 35-3 60 LN/IN

20 oct 71

600-60

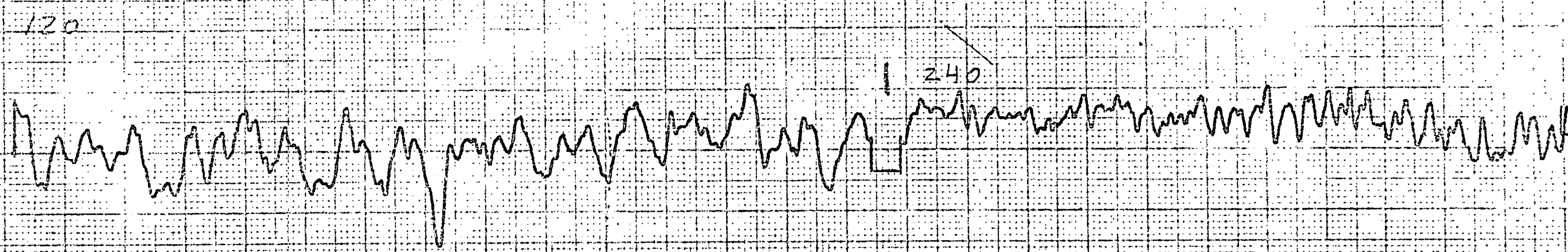


FIGURE 35-4 120 AND 240 LN/IN

139

20 Oct 71

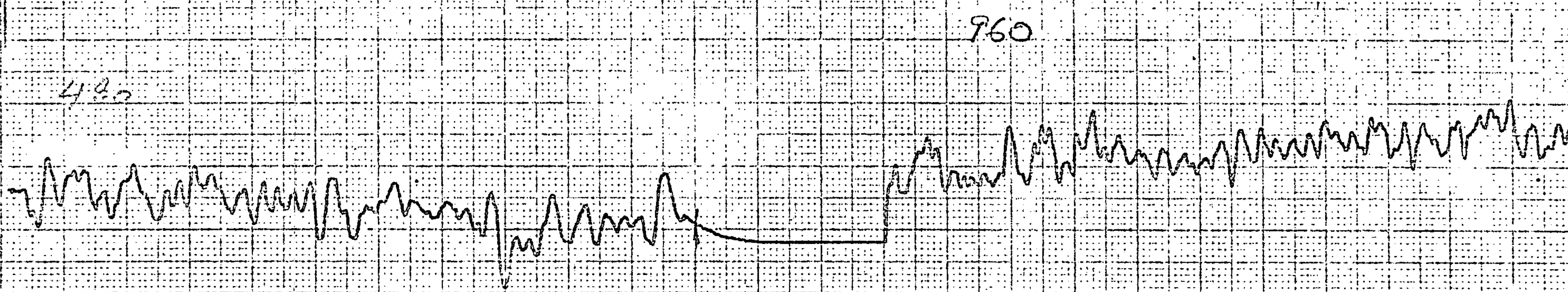
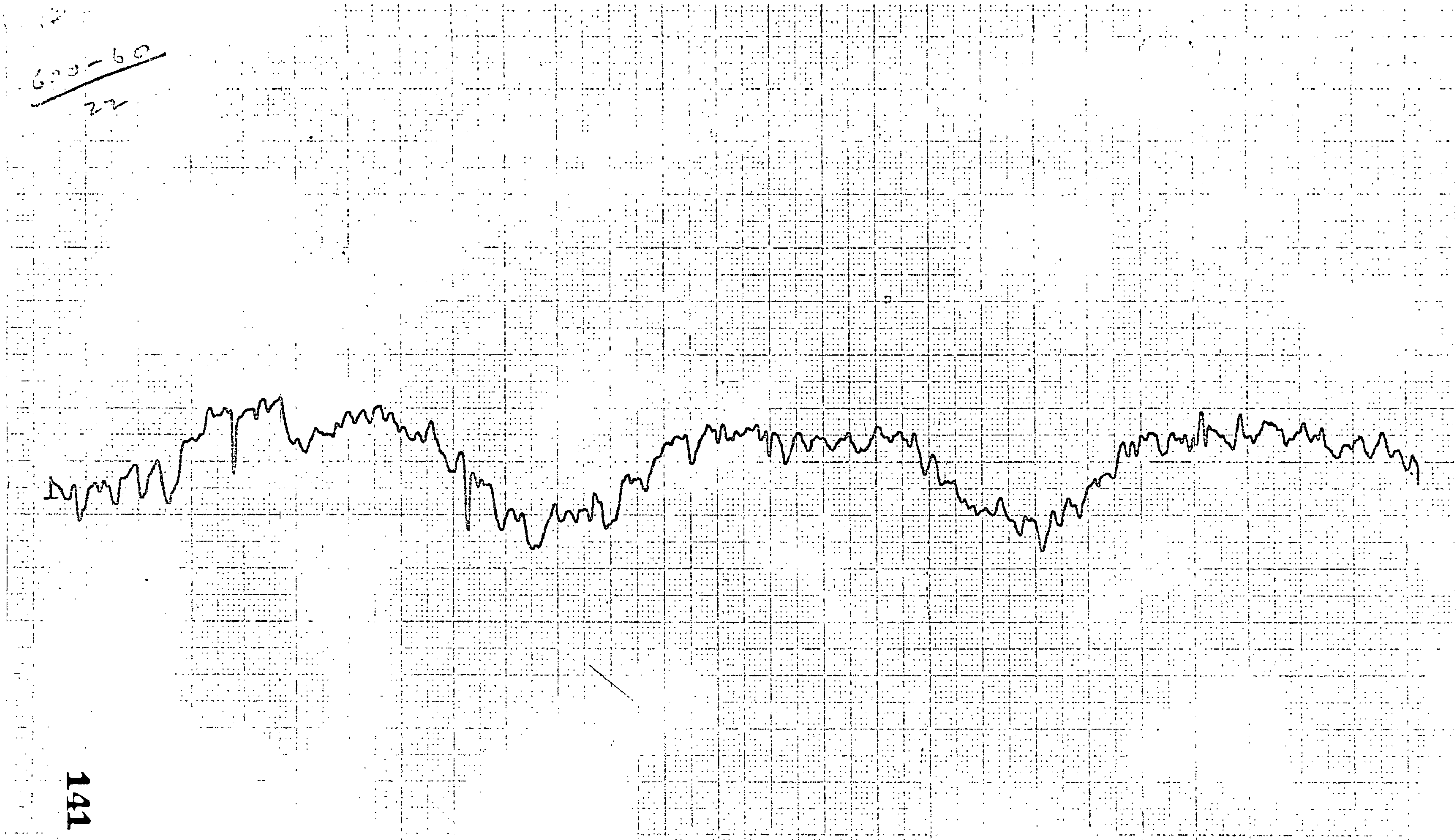


FIGURE 35-5 480 AND 960 LNY IN



SYSTEM MTF 7743 EMA 1000 HZ SWEEP

FIGURE 36-1 15 LN/IN

[redacted]

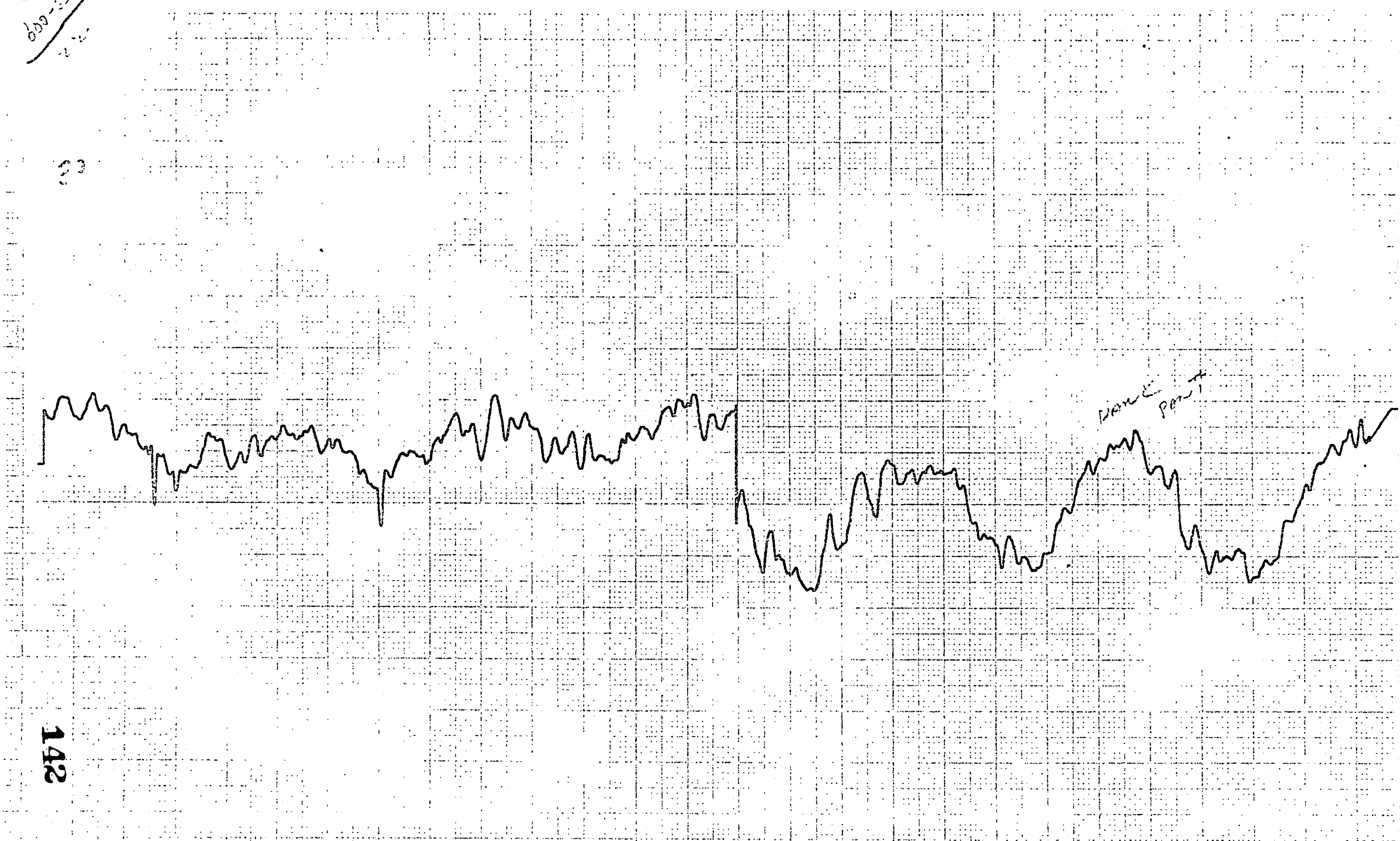


FIGURE 36-2 30 LN/IN

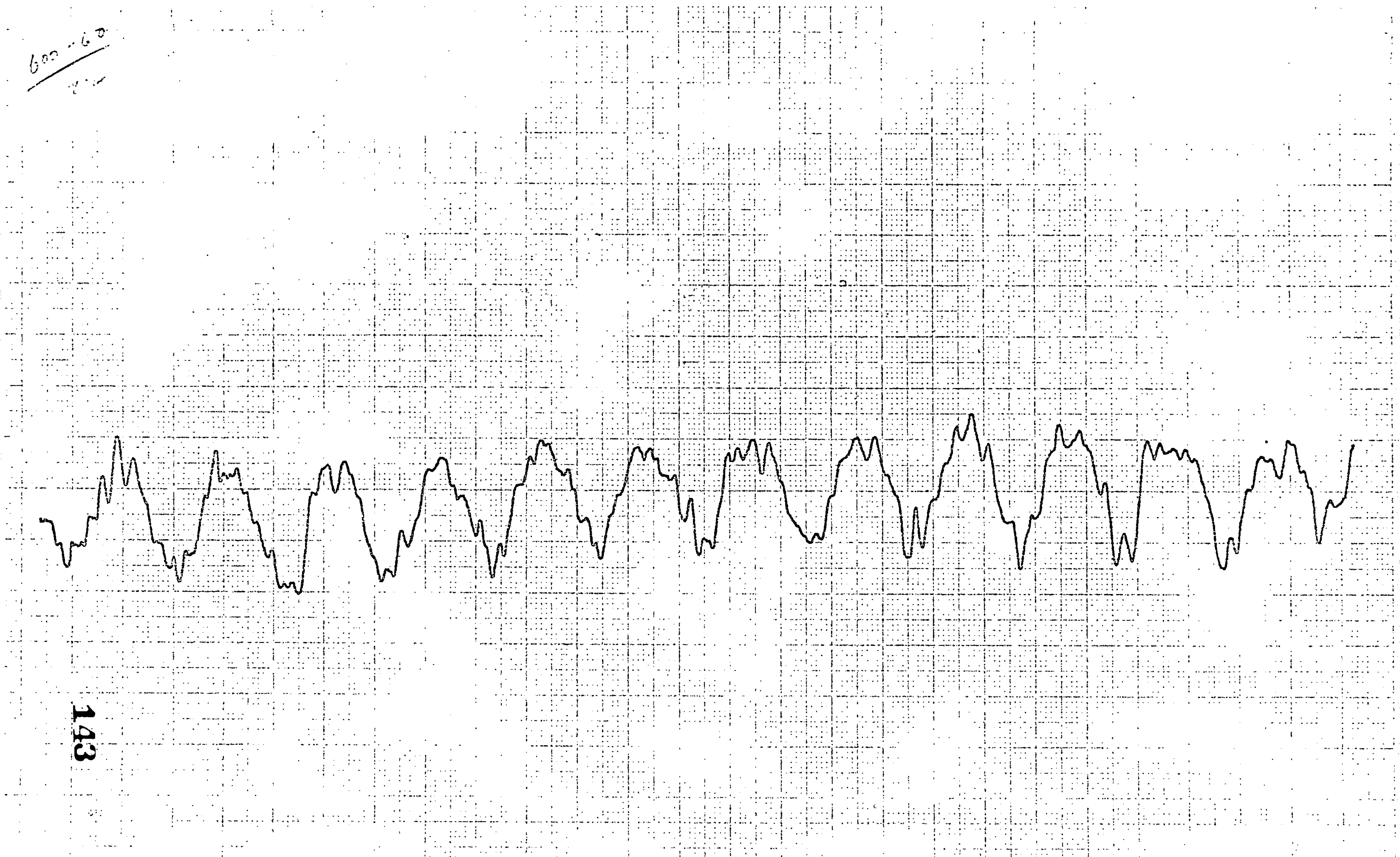


FIGURE 36-3 60 LN/IN

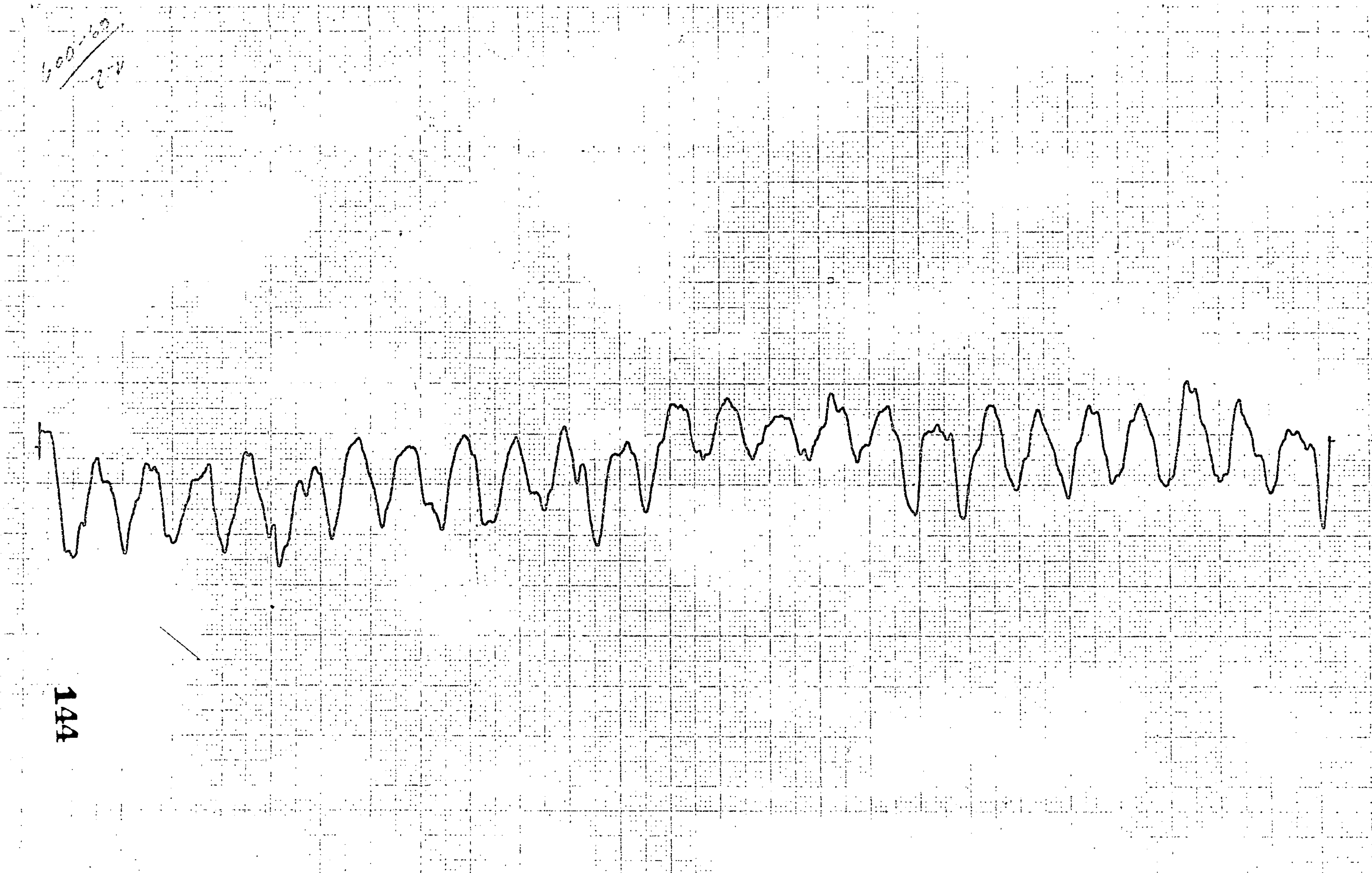


FIGURE 36-4 120 LN/IN

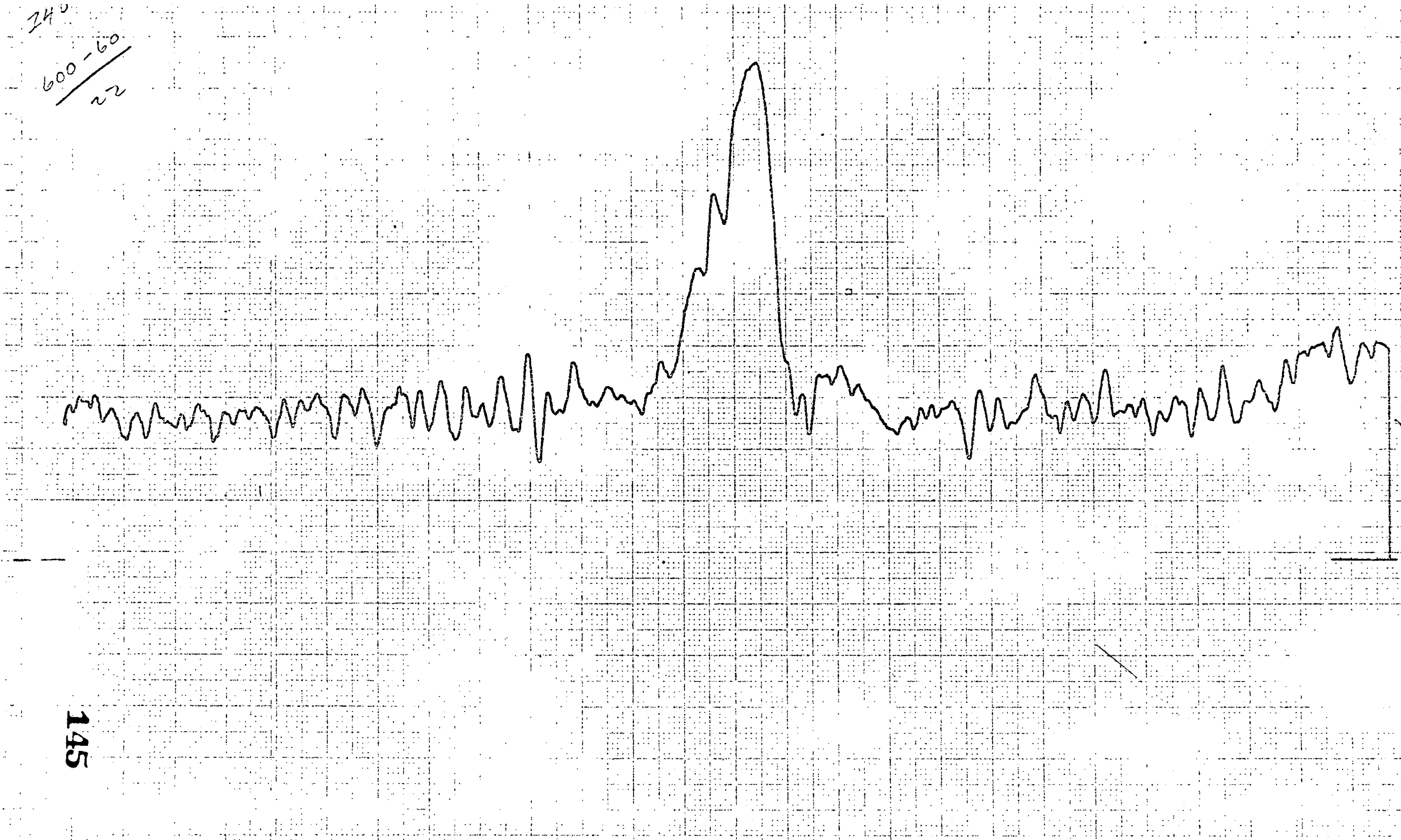
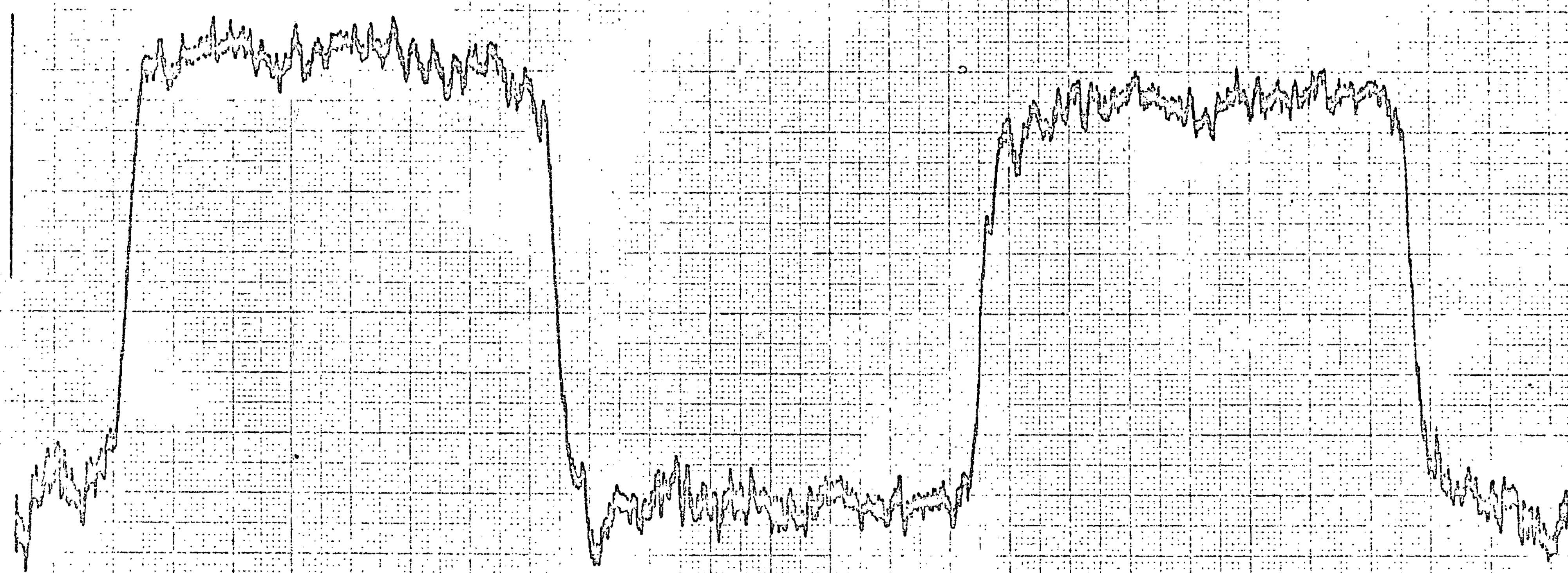


FIGURE 36-5 240 LN/IN

83

7.5 20 Oct 71

120-60



SQUARE WAVE MODULATION

FIGURE 37-1 7.5 LN/IN

15

120-60 / 22

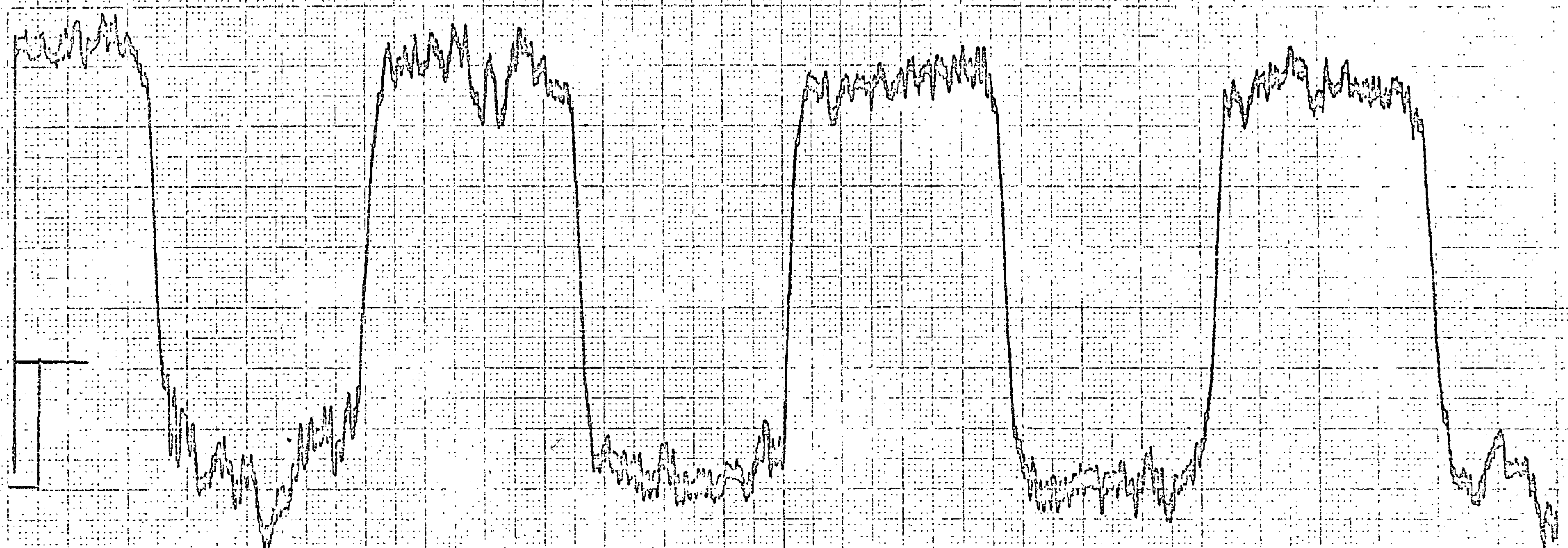


FIGURE 37-2 15 LN/IN

147

85

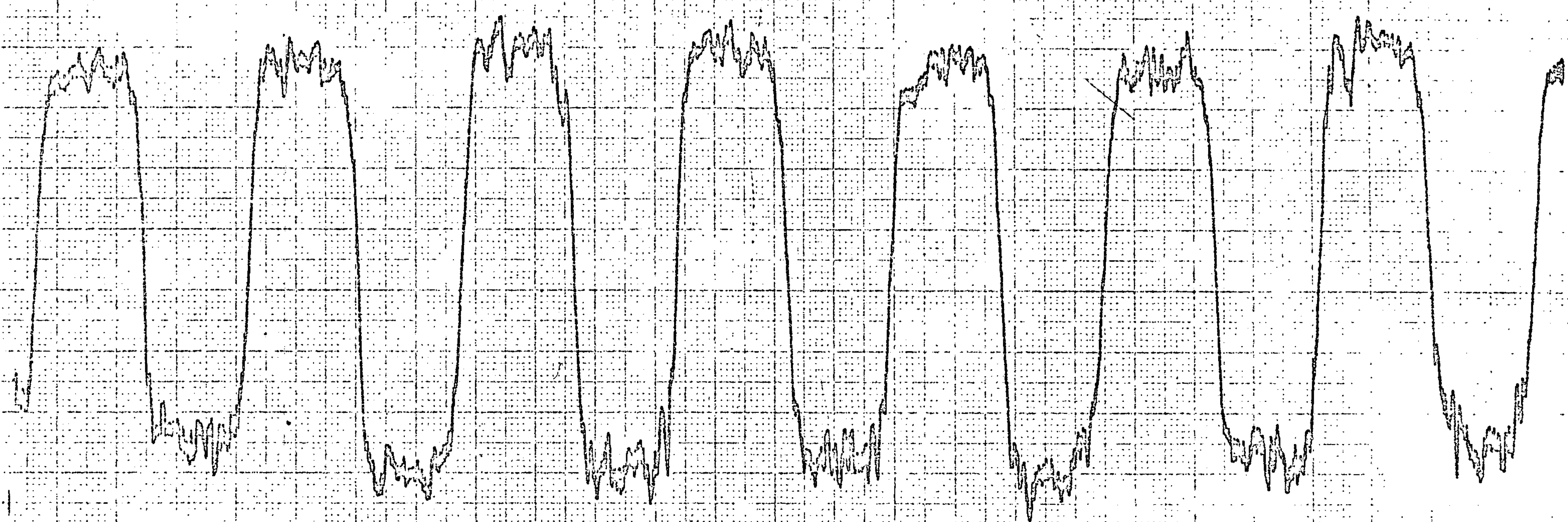


FIGURE 37-3 30 LN/IN

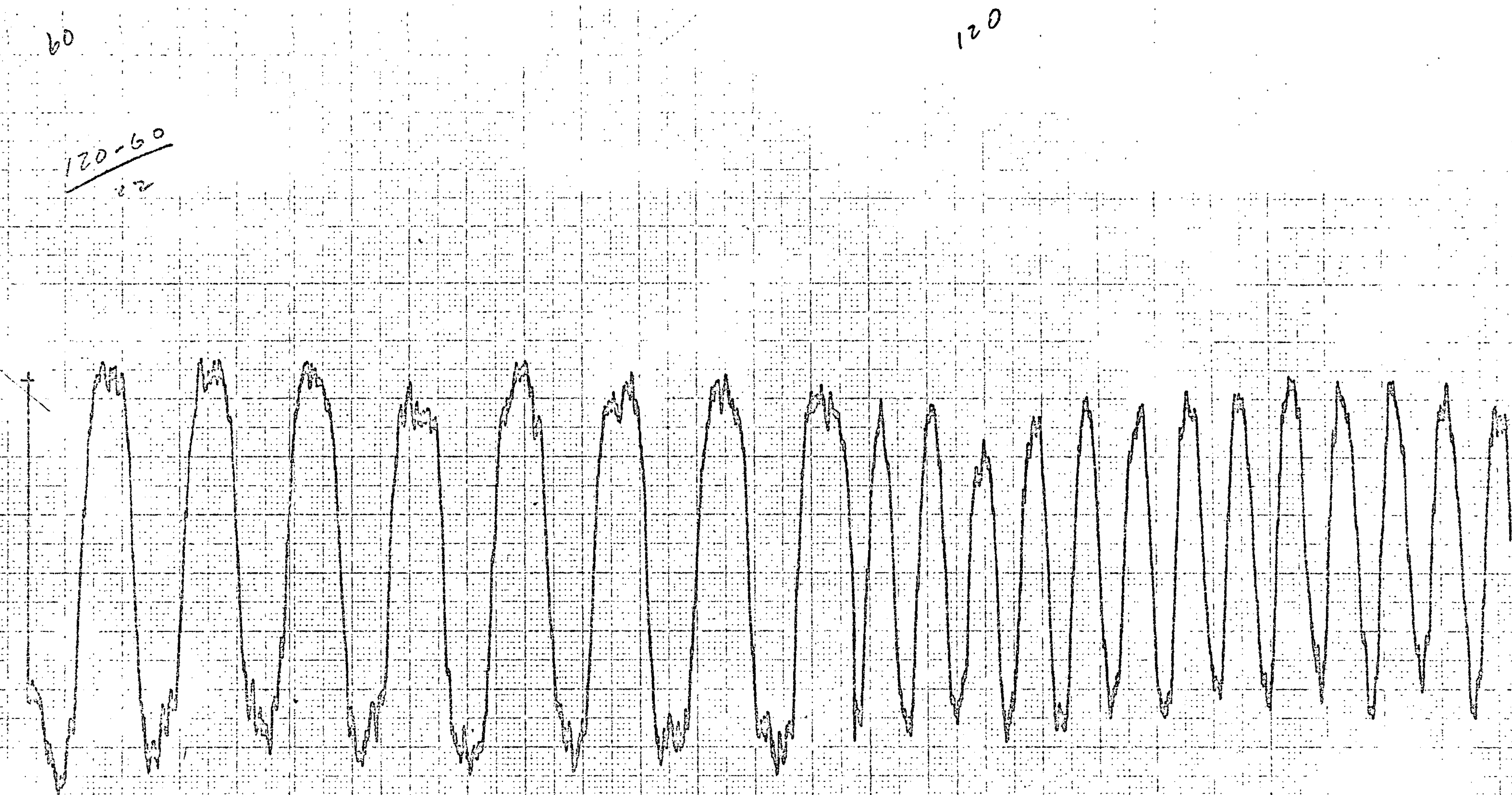


FIGURE 37-4 60 AND 120 LN/IN

240

480

120-60 / 22

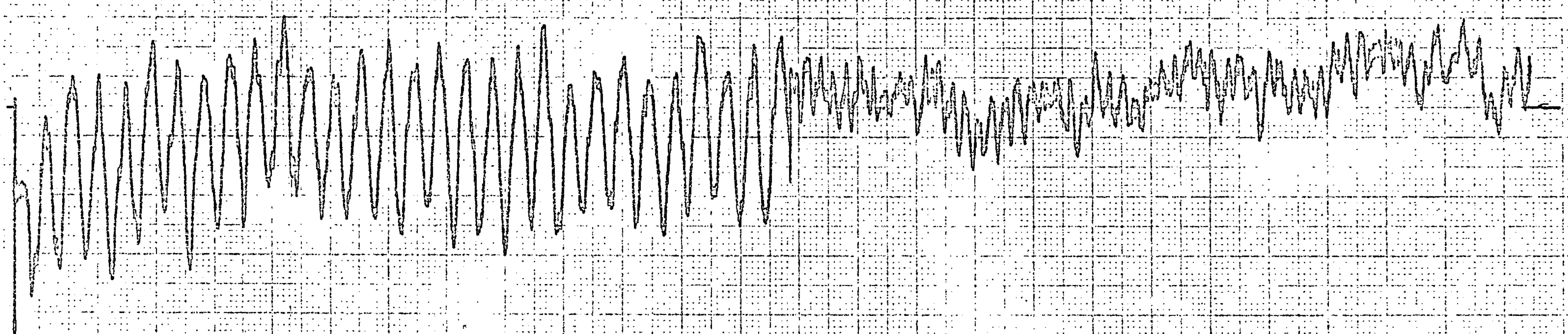


FIGURE 37-5 240 AND 480 LN/IN

4.0 SUMMARY

In the selection of a CRT for a photorecorder application, the two most important specifications are spot size and light output. With the tubes tested, there was a trade-off in these parameters. The anode aperturing in the EMA tube reduced the spot size by 25 percent but there was a 9 to 1 reduction in light output. With a CRT that is capable of supplying a large amount of beam current, not all of the beam current is usable. At a spot size of 2 mils, the P31 phosphor completely saturated with 40 microamperes of beam current. The rate of change of spot growth with beam current was typically a 20 percent increase in spot size for a 10 to 1 increase in beam current. For most applications, all of the other CRT characteristics such as S/N ratio, spot astigmatism, horizontal linearity, dynamic range, and dynamic focus accuracy were not limiting factors in the tubes supplied by two different manufacturers.

A comparison of the two types of faceplates indicated that the EMA was definitely superior for most applications. At 240 lines per inch, the system MTF was better than 3 times higher due to the reduced crosstalk. However, the EMA faceplate produced density variations 2.25 times larger than the clear clad faceplate. This non-uniformity resulted in a fixed pattern banding noise on the photomaterial that was quite apparent in a flat field but was barely perceptible in most imagery. Due to the superior uniformity, the clear clad faceplate would be better in low resolution applications requiring resolution below 100 lines per inch. Non-uniformity in the CRT due to sweep speed variations and variations in focus produced density variations less than the density variations inherent in the development of the paper.

The three dry processed materials tested produced most of the system limitations. The 7842 material had good uniformity with a density variation of 0.11. Also, the granularity did not degrade resolution since the system resolution was as good as the CRT capability. Limiting resolution was approximately 1000 lines per inch with the EMR CRT. However, this material was extremely insensitive so a fiber optic CRT could normally only be used at writing speeds below 100 inches per second.

The 777 material was the fastest dry process material tested but the density variations were over 0.3. This large density variation limits the use of this paper to applications requiring medium quality imagery. Limiting resolution was approximately 450 lines per inch with the EMA CRT.

The 7743 material was a compromise between the three dry process materials with a normal density variation of 0.2. However, this material occasionally produced peak density variations up to 0.3. Limiting resolution was approximately 650 lines per inch with the EMA CRT.

Due to the granularity and the non-uniformity in the 777 and 7743 materials, a CRT with a spot size of 3 mils would be adequate when used with these materials. The theoretical limiting resolution would be around 650 lines per inch but these materials would reduce the limiting resolution to 500 lines per inch or less.

The 1971 material was capable of recordings with resolution as good as the CRT at relatively high writing speeds. This material required an exposure 500 times less than 7743. Thus a CRT with a spot below 1 mil could be used since the required beam current could be within the capability of the CRT at writing speeds around 8000 inches per second. The density variations in this material was 0.12. Limiting resolution was approximately 900 lines per inch with the EMA CRT. Development of a simple two-chemical wet processor would make this unit ideal for real time use with video bandwidths up to 5 MHZ.

APPENDIX 1

TEST PLAN

POA 2041

TEST PLAN

EVALUATION OF A FIBER-OPTIC COUPLED LINE SCAN CRT IMAGE RECORDING SYSTEM

CONTRACT NAS5-21392

Prepared By:

EMR-Aerospace Sciences
EMR Division
Weston Instruments, Inc.
College Park, Maryland

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TEST PLAN

1.0 SCOPE

This test plan defines the tests to evaluate the performance capabilities of a fiber optic coupled line scan cathode ray tube image recording system. The primary objective is to quantitatively establish the performance limitations of the photorecorder with the following components:

A. P31 phosphor CRT with EMA faceplate

B. P1 phosphor CRT with EMA faceplate

C. P31 phosphor CRT with clear clad faceplate

D. Type 774 semi-glossy positive print paper

E. Type 777 flat finish positive print paper

F. Type 784 negative film

Section 2 describes the test equipment to be used and the calibration to be performed prior to the start of the test program. Also, the start-up procedure and the primary operational data to be measured are covered in this section.

Section 3 presents a detailed description of each test to be performed. This description also covers the objectives of each test.

Section 4 provides the detailed test procedures to conduct each test listed in Section 3.

Section 5 lists the raw data and reduced data that will be submitted for each test.

2.0 CALIBRATION AND SET-UP

2.1 Test Equipment

The test instruments to be used in this test program are listed below.

A. Celco model No. 1726-5, Two-Slit Spot Analyzer, S/N 9072

B. Joyce and Lobel Reflecting and Transmitting Micro-densitometer (owned by and to be used at GSFC)

C. Eppley model No. 6767 Bismuth Silver 12 Junction Radiation Thermopile

D. Tektronix model 535 oscilloscope, EMR S/N 0084 with model 1A1 vertical plug-in, EMR S/N 0119

E. Hewlett Packard model 5512A, Period/Frequency Counter, EMR S/N 0081.

F. Hewlett Packard model 3440A, Digital Voltmeter, EMR S/N 0109 with model 3442A Range Selector, EMR S/N 0034.

G. Power Designs model 2005, Precision Power Supply, EMR S/N 0159.

H. Hewlett Packard model 425 AR, Micro Volt-Ammeter, EMR S/N 0186

I. Hewlett Packard model 202A, Low Frequency Function Generator, EMR S/N 0100

J. Hewlett Packard model 650A, Test Oscillator, EMR S/N 0010

K. Bausch and Lomb model BVB-73, Thirty Power Micro-scope, EMR S/N 0059

L. Leeds and Northrup model 8692, Thermocouple Temperature Potentiometer, EMR S/N 0123.

2.2 Test Equipment Calibration

The calibration for each type of test equipment is listed on the following page.

2.2.1 The Celco Spot Analyzer does not require a special calibration for spot size measurements since the slit dimensions are fixed. The initial spot size measurement will be made with two separate slit plates to assure the dimensional integrity of these slits.

The stability of the photomultiplier tube will be checked prior to all tests utilizing the Spot Analyzer. This will be performed by measuring the response with a test incandescent lamp operating at 50% of the rated voltage with a voltage accuracy of 0.05%.

2.2.2 The microdensitometer is the property of GSFC and will not be calibrated by EMR. EMR will use any calibration data supplied in preparing the test data results.

2.2.3 The calibration data supplied by the Eppley Laboratory, Inc. will be used in this test program. This data provides the emf developed at three different intensities from a standard lamp calibrated by NBS under specified atmospheric pressure, ambient temperature, and relative humidity.

2.2.4 Items D through J on the test equipment list will be calibrated by the Quality Control Department of EMR. EMR-Aerospace Sciences maintains a quality program as defined in the Quality Control and Assurance Manual Document 990-002. This program is in compliance with NASA 200-3 and MIL-Q-9858A and is directly compatible with the requirements of NASA NHB 5300.4 (1B). The calibration provisions meet MIL-C-45662.

2.2.5 Item K does not require any specific calibration. This unit is periodically inspected and cleaned by the manufacture's representative.

2.2.6 Item L will be calibrated by the Quality Control Department of EMR-Photoelectric in Princeton, New Jersey. Their calibration provisions are also in accordance with MIL-C-45662.

2.3 Set-Up Procedure

The following procedure will be performed prior to all tests to verify the operation of the photorecorder and insure repeatibility in all tests. This procedure is a preliminary set-up procedure to be followed prior to the set-up procedures for each test in Section 4.

2.3.1 Turn on the photorecorder and all test equipment and allow 1/2 hour warm-up.

2.3.2 Measure the output of the +20 reference supply, the +20 V supply, the +15 V supply, the +5 V supply, and the -15 V supply. All supplies are to measure within ± 1 % of ratings with a maximum of 10 millivolts peak-to-peak noise.

2.3.3 Measure the output of the high voltage supply. Measurement is to be 15 KV ± 1 % with a peak-to-peak ripple of less than 15 volts.

2.3.4 Set up the horizontal sweep circuit for a normal scan. A normal scan is a ± 4 - inch deflection on the faceplate with a 100 millisecond horizontal sync pulse period and a 10% retrace period.

2.3.5 Verify that the horizontal linearity correction is set to the theoretical optimum waveform by measuring the output of the Linearity Correction Board with the following inputs.

Linearity Correction Input		Linearity Correction Output	
±2.5 V	±0.2%	V	± 2%
±5.0 V	±0.2%	V	± 2%
±7.5 V	±0.2%	V	± 2%

Note: This test to be performed only at the start of the test program and prior to the Horizontal Linearity Test

2.3.6 Set up the CRT beam DC bias for zero beam current with the horizontal sync removed and the sweep protection circuit temporarily disabled.

2.3.7 Set the reference CRT black level by setting the video input to zero volts and adjusting the Black Level Set Control for 5.0 microamperes beam current.

2.3.8 Check the S/N ratio of the video electronics by applying a DC video input one half way between the reference black level and CRT beam cutoff and measuring the noise at the output of the modulator. All sources of random and coherent noise to be greater than 40 db below the DC video level.

2.3.9 Check the bandwidth of the video electronics by applying a sine wave and measuring the output of the demodulator on the oscilloscope. At the normal scan (10 HZ), the video 3 db bandwidth to be greater than 30 KHZ.
Note: The bandwidth at other sweep speeds to be tested as specified in Section 4.

2.3.10 Verify that the dynamic focus correction is set to the theoretical optimum waveform by measuring the output of each segment amplifier with 7.5 volts at the input of the Dynamic Focus Board.

Segment Amplifier Number	Output Voltage
2	V ± 2%
3	V ± 2%
4	V ± 2%
5	V ± 2%
6	V ± 2%

2.3.11 Check the accuracy of the paper drive by setting the paper drive oscillator to a fixed frequency and measuring the length between markers on a 1 minute run of paper.

Paper Oscillator Frequency	Length Between Marks
HZ ± 0.1%	in ± 1%

Note: This test to be performed only once during the test program with all three photographic materials.

2.3.12 Check the accuracy of the development heater bar by measuring the surface temperature at the center of the heater bar at three temperature control settings. Allow 5 minutes for temperature stabilization at each setting.

Temperature Control Setting	Measured Temperature
	$^{o}F \pm 1\%$
	$^{o}F \pm 1\%$
	$^{o}F \pm 1\%$

3.0 TEST DESCRIPTION

3.1 Spot Size

3.1.1 Spot Size vs Beam Position

The spot size will be measured with a double slit spot analyzer calibrated to provide a direct measure of the spot size from the oscilloscope display of the photomultiplier output signal. The spot size will be measured at one inch intervals across the 8-inch faceplate of the CRT. All measurements will be made with a normal scan at a sweep rate of 1 HZ to insure that the CRT persistence does not affect the measurement. For each measurement, the valve of the static and dynamic focus current will be measured and recorded. These measurements will indicate the correlation between the theoretical and actual optimum dynamic focus waveform. These measurements will be repeated with all three test tubes to measure the variation in spot size and focus currents for different yoke assemblies. In addition, the spot size will be measured with the static focus optimized and the dynamic focus removed to indicate the degree of improvement with dynamic focusing.

3.1.2 Spot Size vs Beam Current

The spot size will be measured over the usable range of beam currents. This measurement will be performed at 10 equal increments of beam current between the limits where the beam is just visually perceptable to a magnitude just below the phosphor burn level. This test will indicate the rate of spot growth with beam current. These measurements will be performed at the center and the limit of the line scan to measure the variation in spot size with beam current density. In addition, these measurements will be performed on a P1 and a P31 EMA clad CRT to determine the spot growth due to a long and a short persistence phosphor.

3.1.3 Spot Astigmatism

The deviation of the spot from a theoretical circular cross section will be measured as a function of beam current and beam position. The CRT beam will be modulated with a square wave synchronous with the scan rate. The frequency will be adjusted to provide spots with center-to-center separation equal to the vertical dimension of the spots at the center of the scan. The relative horizontal and vertical dimensions of the spots will be measured with a 30 power microscope at one-inch intervals at the beam current levels used in Section 3.1.2.

3.2 Writing Speed

3.2.1 CRT MTF vs Exposure

The writing speed limitations of the CRT will be determined by measuring the modulation transfer function at the faceplate as a function of sweep speed and exposure. This measurement will be performed at sweep speeds of 1 HZ, 10 HZ, 100 HZ, and 1 KHZ. For each sweep speed, the exposure (beam intensity per element dwell time) necessary to obtain the maximum density for 774 paper will be experimentally measured. The spot analyzer will be used to provide a measure of each exposure by electronically integrating the waveform from the spot analyzer.

The MTF for the reference exposure will be measured by modulating the CRT beam with a series of sine wave frequencies at binary multiples of the sweep frequency. At each video frequency, the maximum and minimum beam intensity will be measured with the spot analyzer. A plot of the CRT MTF will be prepared from the ratio of high frequency to low frequency modulation percentage. At each sweep speed, the MTF will be measured at 10% and 50% of the reference exposure. The above set of measurements will be performed with all three tubes to evaluate the effects of phosphor and faceplate types on writing speed.

3.2.2 System MTF vs Exposure

The system MTF will be tested using the same procedure used in Section 3.2.1. The main difference is that the microdensitometer with a one mill aperature will be used to measure the sine wave modulation on the photosensitive materials. At each sweep speed, the paper speed will be set for zero overlap by assuming a 2 mill trace width. The development time and temperature will be fixed at one optimum setting for all measurements. Each modulation measurement will be repeated at 5 different positions to minimize the density variations introduced from paper and heater nonuniformity. These tests will be performed with types 374, 377, and 384 materials with a P31 EMA clad tube to compare the performance for each type of photographic material.

3.3 Dynamic Range

3.3.1 CRT Light Output

The dynamic range of the CRT will be determined by measuring the light intensity at the faceplate with spot sizes of 2 mills, 4 mills, and 6 mills. With each spot size, light measurements will be performed at sweep speeds of 1 HZ, 10 HZ, 100 HZ, and 1 KHZ. In each test, the beam current will be set as high as possible consistent with the spot size requirements. These measurements will determine the upper light level limit over a wide range of resolution limits and sweep speeds. The intensity of the beam in watts/steradian will be measured with a radiation thermopile. A thermopile provides a stable detector that does not require spectral sensitivity correction factors. In each test, the scan will be unblanked for a time period sufficient to provide a point source of light equal to the spot size. Thus each measurement will indicate the total energy or exposure of a fundamental resolution element. The above tests will be performed on all three tubes to study the effects of phosphor conversion efficiency and persistence on dynamic range.

3.3.2 Photographic Material Dynamic Range

The dynamic range of the 774 and 777 positive print paper and the 784 negative transparency film will not be measured since the manufacturer publishes D Log E curves for each material. These data sheets indicate the range of gamma and the dynamic range for various combinations of development time and temperature.

3.3.3 System Dynamic Range

The system dynamic range will be determined by exposing strips of the photographic material to all of the combinations of spot sizes and sweep speeds used in Section 3.3.1. Each strip will be developed at the specified time and temperature that provides the maximum density range with a gamma close to unity. The reflecting microdensitometer with an aperature of 100 mills will be used to measure the density of each strip. The maximum density measured to the density of the unexposed portion of each strip indicates the system dynamic range for each test. This test will indicate whether the paper or the CRT is the limiting factor because a measured density equal to the maximum paper density indicates the dynamic range is set by the paper. This test will be performed with all three tubes and all three materials to compare the dynamic range with different phosphors and different emulsions.

3.4 <u>Image Non-Uniformity</u>

3.4.1 CRT Intensity Non-Uniformity

The non-uniformity of the CRT beam intensity will be determined by making relative light intensity measurements with the spot analyzer. The CRT beam will be statically positioned at 200 random positions and the beam will be gated on for approximately the same duty cycle as a normal scan. A static position will be used for each measurement to eliminate intensity variations caused by noise and non-linearity in the sweep waveform. The output of the spot analyzer will be sent through a narrow band DC amplifier to accurately measure the small differences in beam intensity. The resultant data will be used to plot the density distribution of CRT intensity. This test will be performed with all three tubes to investigate the variations with phosphors and fiber optic faceplates.

3.4.2 Photographic Material Non-Uniformity

The density variations in the photographic materials will be measured by examining long strips of a flat field image with the microdensitometer. Each of the three photographic materials will be exposed with the P31 EMA tube with a normal scan. Approximately 10 feet of each material will be developed to a density half way between the upper and lower density limits. On each strip, the density will be measured along a 1/8 inch vertical strip near the center of the scan. The density measurements will be made in this narrow strip to minimize density variations caused by sweep distortion, sweep noise, fiber optic non-uniformity, and heater development non-uniformity. The density will be measured at 100 random points throughout the entire length of each strip. This measurement will be repeated with aperture settings of 1, 10, and 100 mills for each of the three materials. This data will be used to construct a series of plots of density distribution as a function of aperature or sample size for each material.

3.4.3 Non-Uniformity vs Beam Focus

The significance of beam focus on density will be investigated by defocusing the beam and measuring the change in average density. With a normal scan, one spot position near the center of the scan will be selected and the beam will be focused for a 2, 4, and 6 mill spot with the same beam current.

The paper speed will be fixed for all three tests at a zero overlap for a 4 mill spot. Thus the paper will be exposed with both a dense circular spot without overlap and a diffused circular spot with overlap. For each spot size, 20 density measurements will be made over a vertical strip of 774 material with the microdensitometer set at a 100 mill aperature. The change in average reading for each group of readings will indicate the effect of focus on the reproduced image density.

3.5 Signal-to-Noise Ratio

3.5.1 CRT Signal-to-Noise Ratio

The S/N ratio of the CRT beam will be made with the spot analyzer with the slits removed. With a normal scan and a DC video signal, the S/N ratio will be measured from an oscilloscope display of the photomultiplier output signal. This measurement will be made with 2, 4, and 6 mill spot sizes and with 3 levels of beam current for each spot size. These measurements will be performed with a P1 and P31 EMA tubes to compare the phosphor noise.

3.5.2 System Signal-to-Noise Ratio

No specific tests of system S/N ratio will be made since all significant sources of system noise have been covered in other portions of this test plan.

3.6 Linearity

3.6.1 Horizontal Linearity

The horizontal linearity will be investigated by comparing the differences in the theoretical positions of marker pulses with the measured position with the spot analyzer. A binary counter will provide the horizontal sync pulse and 20 equally spaced marker pulses over the entire sweep period. The actual position of each marker pulse will be measured with the spot analyzer mounted on a micrometer adjustable stage. The distance measurements between the marker pulses will indicate the non-linearity of the CRT trace. This test will be repeated at scan speeds of 1, 10, 100, and 100 HZ to measure the change in linearity with sweep speed.

3.6.2 Vertical Linearity

The vertical linearity will be investigated by measuring the vertical separation between adjacent scan lines on a strip of 774 paper. This measurement will be made at paper speeds of 1 inch / minute and 20 inches/minute. At each paper speed, the horizontal sweep will be adjusted to a frequency sufficiently low to produce approximately a 1/2 inch separation between adjacent lines. These separations will be measured with a microscope with a reticle over a 10-inch interval to indicate the system vertical non-linearity.

APPENDIX 2

VIDEO INFORMATION PROCESSOR SPECIFICATION

EMR AEROSPACE SCIENCES
5012 COLLEGE AVENUE, COLLEGE PARK, MARYLAND 20740
TELEPHONE 301-864-6340

PRELIMINARY SPECIFICATIONS
VIDEO INFORMATION PROCESSOR
EMR MODEL NO. 200

Description

EMR has developed a Video Information Processor which produces high quality photographs from a received video signal. A high resolution CRT exposes the photographic paper or film directly through a fiber optic faceplate. The high efficiency of this fiber optic coupling of light energy from the CRT phosphor to photographic surface makes possible the direct recording of photographic paper at low CRT beam currents. The CRT scans the photographic paper in the horizontal direction as a precision paper drive moves the photographic paper past the CRT in the vertical direction producing a two dimensional picture or graph. The standard paper processor which is part of the film drive mechanism is designed to use the 3M type dry silver paper which is developed thermally. The use of this paper and development process produces a photographic picture of excellent quality within seconds of exposure. To enhance the inherent features of the Video Information Processor, EMR has available a full line of interface modules which readily adapts the Recorder to a variety of applications. These include sweep roll correction and tangential sweep and intensity correction modules which are used when the recorder provides real time readout for various scanners aboard aircraft. Also, available are modules which synchronize the Processor to various Meteorological and earth resource satellite picture transmission formats. These include APT, DRIR, VHRR and "Spin Scan" modules which operate either real time from the video output signal of a receiver connected to a tracking antenna or from a delayed tape playback. Accessory modules are also available which are used to display pictures transmitted in standard facsimile formats.

Photographic Specification

1. Recording Medium

Paper Type:	Glossy, single weight, heat processed, positive, photographic paper (3M type 7743).
Paper Size:	9-1/2 inches wide, up to 500 feet long roll.
Paper Development:	Performed by passing the photographic paper over a thermostatically controlled heater bar. No chemicals are required.

2. Image Characteristics

Image Size:	8.0 inches maximum width. Length up to 500 feet.
Limiting Resolution:	Over 500 lines per inch at 50% points over 8 inch width. Dynamic focusing is used to retain optimum spot size over the complete trace width.
Dynamic Range:	11 gray shades in $\sqrt{2}$ steps as measured with a microdensitometer. A 4 step gamma correction circuit is included in the intensity modulator circuitry to provide adjustment for a linear dynamic transfer function.
Horizontal Linearity:	Better than $\pm 1\%$ over the full 8 inch width. Linearity correction circuitry is part of the sweep generator electronics. $\pm 0.3\%$ linearity can be provided on special order.
Vertical Paper Drive Accuracy:	Better than $\pm 0.2\%$.

Electrical Characteristics

Video Input:	0 to 1 volts (0=black, 1 volts=white) ±15 volts can be applied without damage to the recorder. Reverse polarity signals can be accommodated on special order.
Video Bandwidth:	0 to 100 KHz standard 0 to 1 mHz special order.
Synchronization:	+5 volt pulse with less than 0.1 microsecond risetime.
Scan Speed:	0.5 sweeps/sec to 200 sweeps per second.
Retrace Time:	Less than 100 microseconds.
Vertical Paper Drive Rate:	0.5 inches per minute to 30 inches per minute.
Gamma Correction:	Internal circuitry is used to match the gamma response of the CRT to that of the recording paper.
Control External:	Power Switch Standby / Operate Level Set, 10 turn control Contrast, 10 turn control Paper drive rate switch Heater bar temperature, 10 turn control Sweep Rate Switch
Control Internal:	Static Focus Sweep Linearity Dynamic Focus Vertical Centering Horizontal adjustments permit the horizontal line to be expanded and positioned to display any portion of the video signal desired.
Indicators:	High voltage meter.
Input Power:	115/230 volts, 50-400 Hz, 600 watts maximum.
CRT Protection:	Built-in protection for filament supply failure, sweep circuit failure, and G1 bias failure.

Mechanical Specifications

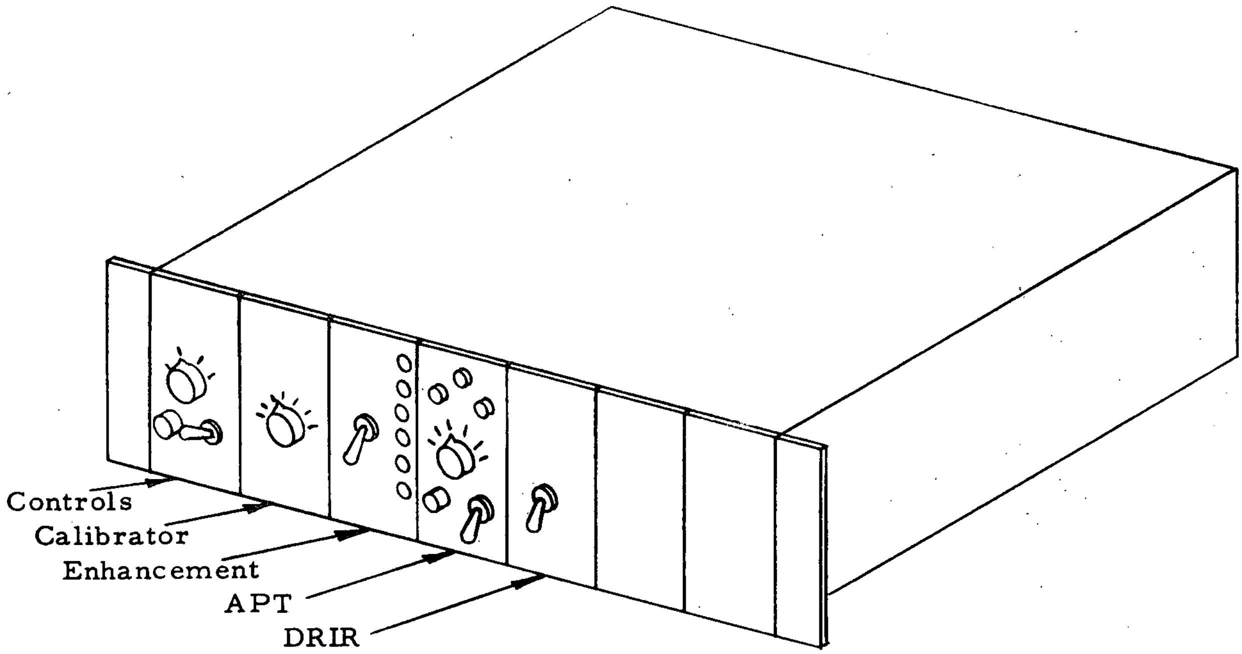
Size:	17-1/2 x 19 x 23 inches. 19 inch rack mountable.
Weight:	130 pounds with a full roll of paper.

Environmental Specification

Temperature:	
Operating:	$40^{\circ}F$ to $100^{\circ}F$
Storage:	$-40^{\circ}F$ to $130^{\circ}F$ (without film)
Relative Humidity:	Operating or in storage to 90 percent.
Altitude:	Operates to an altitude of 15, 000 feet. Non-operating altitude to 35, 000 feet.
Vibration:	0. 08 inches double amplitude to 27 Hz and 3 g from 27 to 500 Hz.

Accessories

A 5-1/4 inch rack mount chassis is available to hold up to 7 plug-in modules. Modules are available for performing signal enhancement, FM signal recording and playback, and adaption to various facsimile and spacecraft formats.


Controls
Calibrator
Enhancement
APT
DRIR