POINT SPREAD FUNCTION REPORT

Gibbs thru ~~SC~~ SC-14

16 August 68

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1.0 SCOPE

This is an interim report describing the Point Spread Function (PSF) measurements made on the Slide Viewing System (SVS) and the data reduced to date (8/2/68). This includes the following seven "data points":

Data Point	Target Pinhole Field Position	Zoom	Anamorphic Lens
#1	On Axis	M	1:1
#2	On Axis	M	1.7:1
#3	Half field horizontal	M	1:1
#4	Full field horizontal	M	1:1
#5	Full field vertical	M	1:1
#6	Half field vertical	M	1:1
#7	On Axis	M	Removed

1.1 Introduction

A point spread function of an optical system is the distribution of energy at the image plane of the system when a "point source" is placed in the object plane. In practice, it is impossible to obtain a "point source", so a subresolution pinhole that is uniformly illuminated is usually substituted.

The data that is presented here consists of the intensity value of the PSF at selected points. These points lie on a cross with a vertical and horizontal components each containing 11 points (one of which is the center and is the same for both sets of points). (According to document number 344-68-063).

2.0 APPLICABLE DOCUMENTS

2.1 344-68-063 - Test Plan

2.2 344-68-063/B - Addendum I, Test Plan

2.3 344-68-414 - Status Report - July 18, 1968

2.4 Itek file X15, Addendum A - Specifications

3.0 TEST DESCRIPTION

3.1 Physical Setup

Figure 1 is a schematic drawing of all the major components used in the PSF measurements. Detailed discussions follow.

3.1.1 Source

The light source consisted of a G.E. 18 amp ribbon filament bulb (18A-T10-2P) mounted in a three-way stage. The bulb was supplied by a Nobatron DCR 40-35A calibrated power supply and drew 22 amps yielding a tungsten spectrum with a color temperature of about 3400°K.

3.1.2 Condenser Lenses

The ribbon filament was focused on the pinhole using two 2.5" diameter pyrex condenser lenses. The filament magnification was approximately one to one.

3.1.3 Target Pinhole

The pinhole used was an Ealing precision 10μ diameter pinhole which was etched in a piece of plate nickel 10μ thick. This was then mounted in an aluminum fixture which was in turn mounted on the two-way target stage. Photographs of the pinhole were taken.

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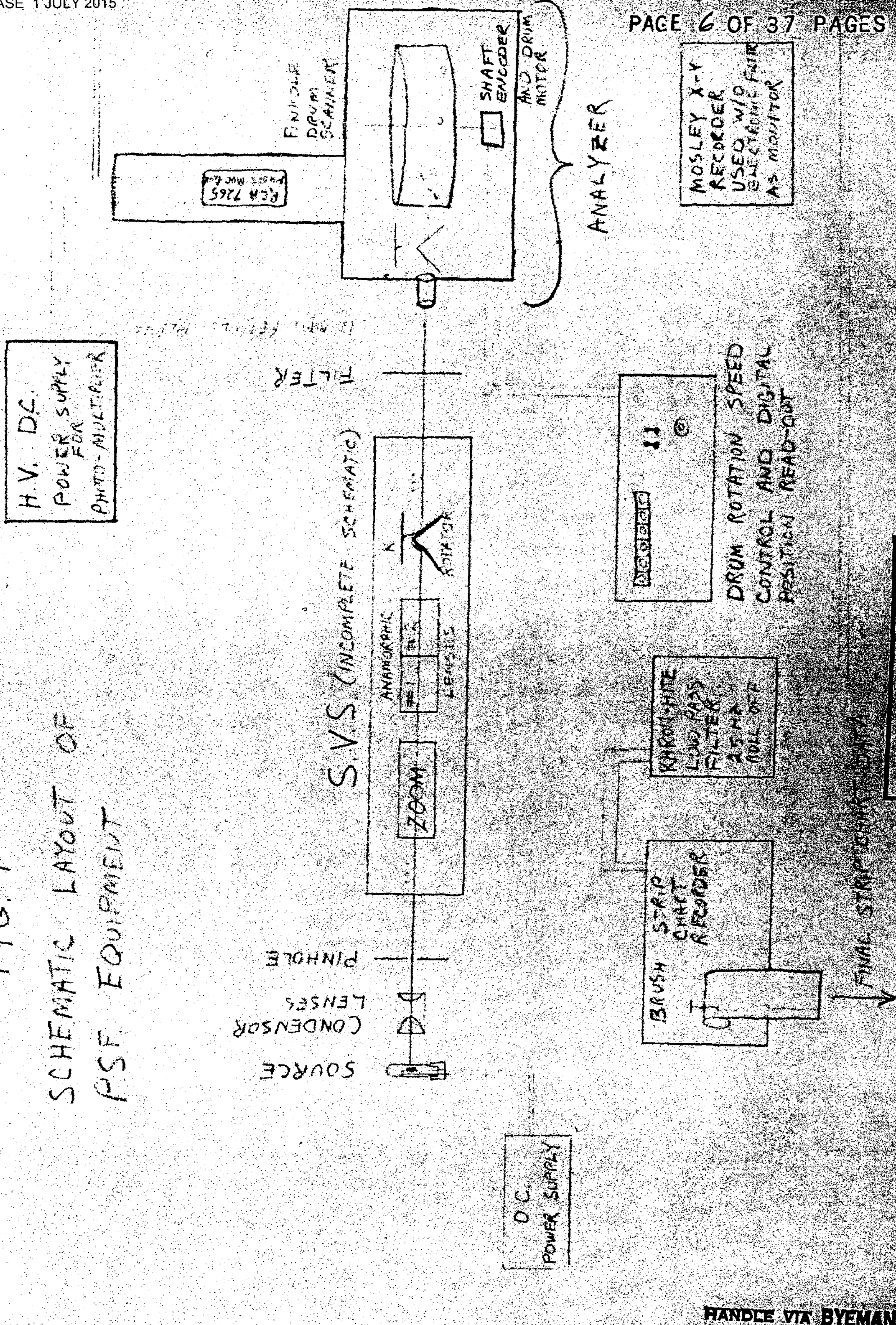

FIG. 1
SCHEMATIC LAYOUT OF PSF EQUIPMENT

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3.1.4 Filter

The photo-multiplier tube used to measure the PSF has an S-20 response. The correction filter used during the test was a multi-layer visible pass filter and a plate glass microscope slide. which eliminated sensitivity outside the visible band. (See Figure 2.) Note: The filters were mounted in front of the analyzer as that was the only place that they could be mounted to give minimum interference. They could not be mounted near the source due to the heat and they would not fit inside the analyzer.

3.1.5 Analyzer

The analyzer consists of an objective to image and magnify the point spread function, (objective magnification : 4.9X) a K-rotator, a series of 33 pinholes mounted on a drum at sequential heights with the drum placed so that the pinholes pass across the imaged point spread function as the drum rotates. Behind the pinholes is an RCA 7265, 14 stage photo-multiplier. (See Figure 3) The height separation of the pinholes is 0.002" and the pinholes are 0.0005" in diameter. A photograph of the analyzer is contained in the Appendix.

3.1.6 Analyzer Support Equipment

3.1.6.1 A d.c. high voltage power supply was used to supply 1900 volts to the RCA 7265 photo-multiplier tube through the network contained in a "Pacific Instruments" 7265 photo-multiplier housing.

3.1.6.2 The output of the photo-multiplier tube was fed into a solid state current amplifier and then to a calibrated Kron-Hite filter, employed in the "low pass" mode with a roll off of 24db per octave at 25HZ. The filtered signal

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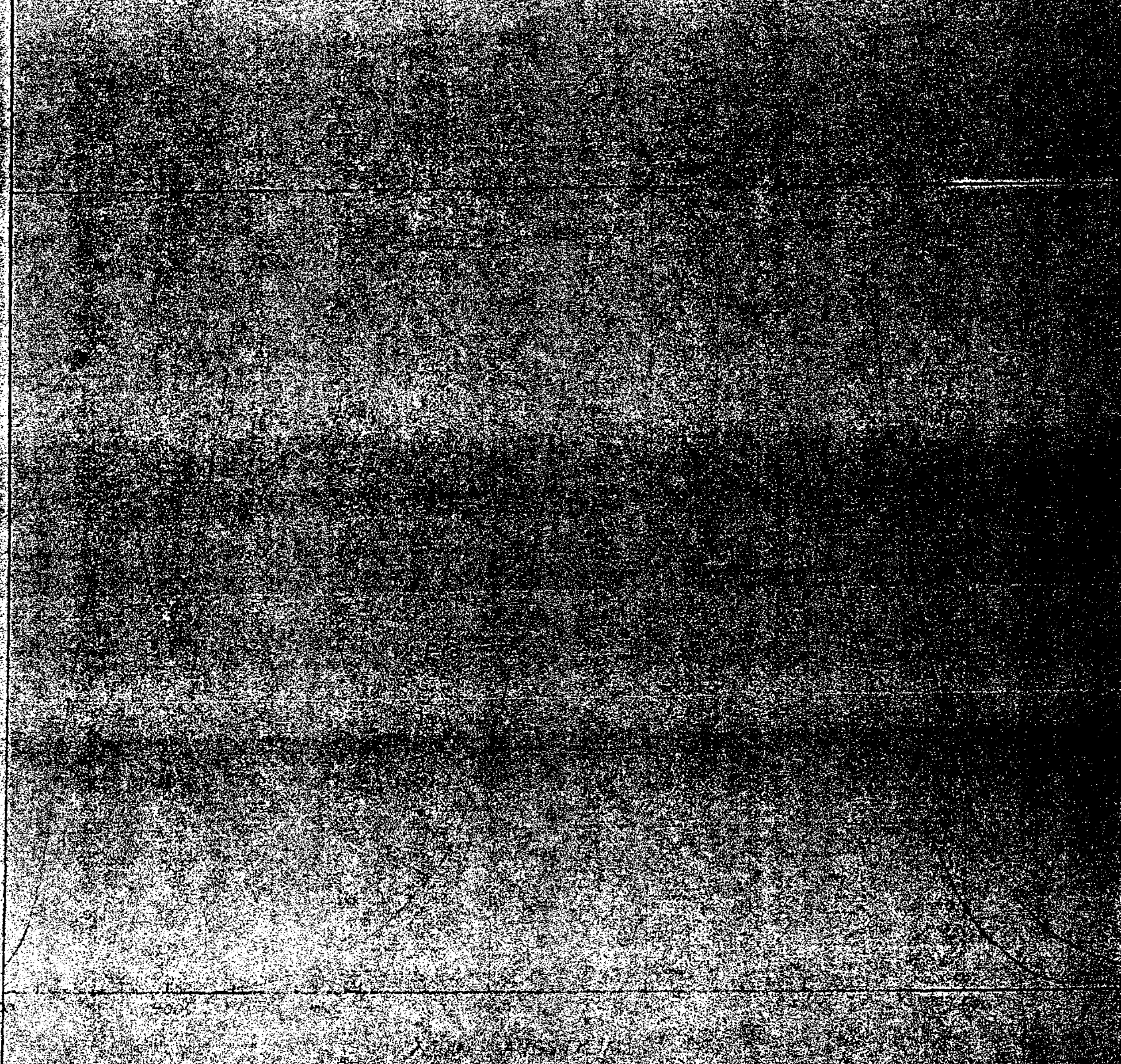

FIG. 2

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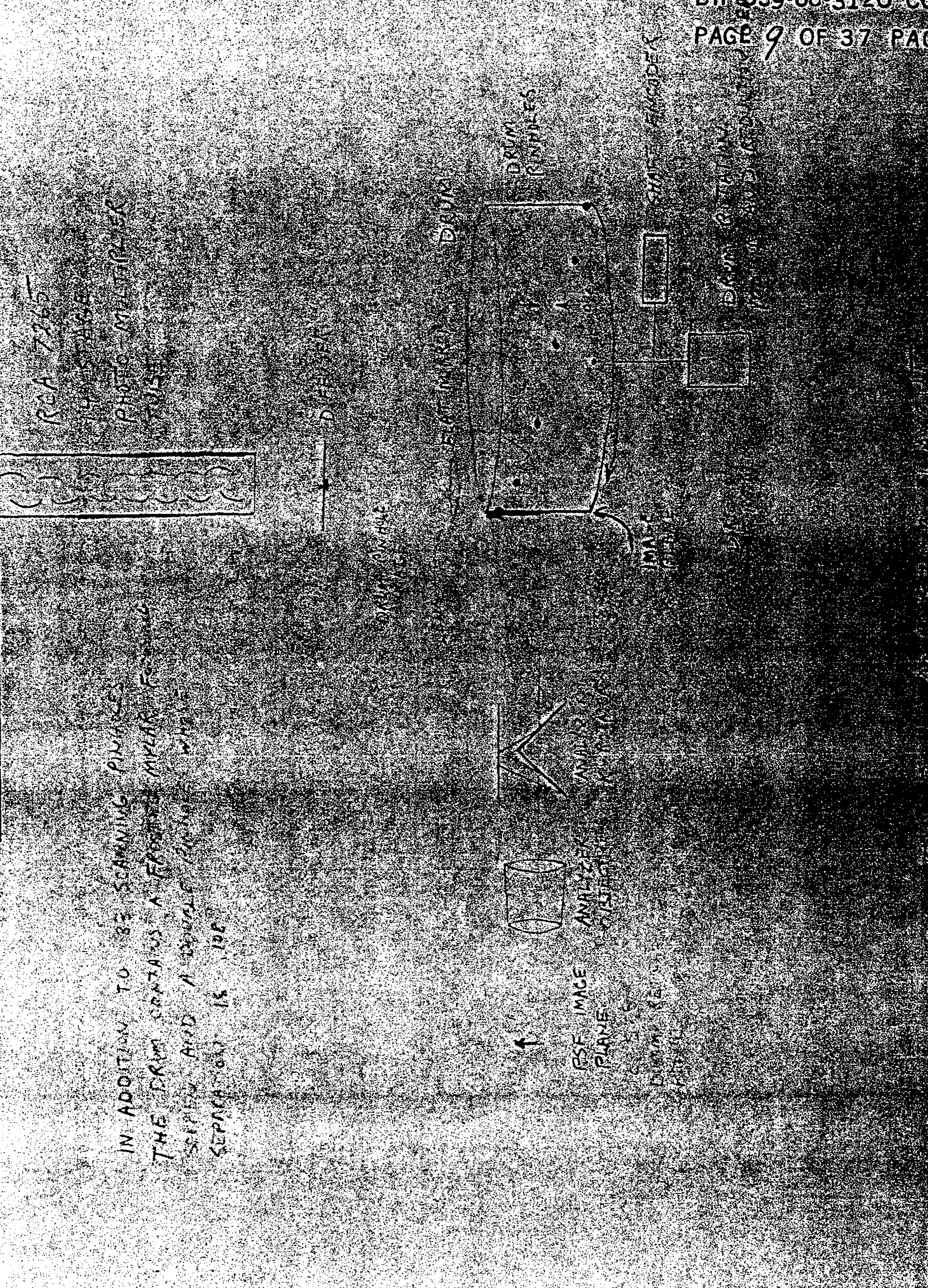

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was then fed to a 4" channel on a 3 channel Brush Strip Chart Recorder. The unfiltered signal was monitored on a Mosley X-Y recorder.

3.1.6.3 The drum rotation motor was run from another supply with a continuously adjustable potentiometer to regulate the speed. There were also fixed resistor settings that could be switched in for calibrated rotation speeds. The position of the drum was presented on a digital display which operated off a shaft encoder attached to the drum yielding some 1780 counts per revolution. Every tenth encoder count was displayed on a vacant channel on the strip chart.

3.2 Procedure Used in Taking Data

Following is the general sequence of steps used to take each data point.

3.2.1 Pinhole Adjustment

Pinhole adjusted to proper field position by first centering the pinhole with the pointer centered microscope and then in the case of the off axis data points, turning the adjustment screws of the stage on which the pinhole was mounted, until the proper displacement was registered on the appropriate micrometer.

Note: Half field at "M" zoom is 0.200" from the center -- full field is 0.400" -- system magnification at "M" zoom is 1.63. The full field points were checked to make sure the pinhole was entirely within the field. Vertical displacements were up, horizontal displacements were to the right.

3.2.2 Light Adjustment

Light source and condensers were shifted to properly illuminate pinhole in the new position.

3.2.3 System Adjustment

Zoom setting and aperture were checked. (The zoom setting was "M" for all data points and the aperture was 3.2.

3.2.4 Analyzer Adjustment

Analyzer was moved horizontally and rotated until the principle ray entered the analyzer objective at normal incidence. Then the image was focused at the drum pinhole plane by moving the entire analyzer along the ways of the bench and looking through a microscope at the image on a piece of frosted mylar inserted in the drum pinhole plane. Note that in the case of the two vertical field displacement data points, The SVS K-rotator was used to bring the image back to a horizontal displacement in the image plane. This was done because changing the analyzer height was considerably more difficult than changing its lateral displacement. Thus, for those data points the apparent field point was horizontal through the relay part of the SVS, i.e. from the K-rotator to the simulated eyepiece.

3.2.5 Lamp Operations

Analyzer head replaced and light source turned up to 22 amps -- allowed to stabilize 10 minutes.

3.2.6 Centering Trace Made to Isolate Peak Pinhole

One run through all 33 drum pinholes was made and from this trace (referred to as "centering trace") the highest peak was chosen, taking into account the pinhole correction factors.

3.2.7 Lamp Drift Observed

The peak pinhole was set to give maximum photo-multiplier output and observed over several minutes to detect any lamp drift.

3.2.8 PSF Data Recorded

The drum was rotated until the pinhole was clear of the image and then 10 sweeps across the image in the same direction were recorded. Note that the strip chart amplitude scale is linear. (See sample sweep in Appendix.)

3.2.9 Records Kept

Test conditions and other information were recorded on the strip chart.

3.2.10 Proceeding from Horizontal to Vertical Sweep Setup

The analyzer K-rotator was then employed to rotate the image 90°CCW for the vertical sweep. The image was checked again with the microscope on the ground glass and steps 3.2.5 through 3.2.9 were repeated.

3.2.11 Calibration of the Chart Paper to Image at Dummy Reticle

To calibrate the chart paper analog image with the actual image at the dummy reticle, two measurements were made. First, since the actual image was magnified by an objective and refocused on the drum pinholes, the magnification had to be measured. This was done by placing a slit at the object plane of the objective (i.e. in the dummy reticle plane of the SVS) and then traversing the entire analyzer laterally until the slit image moved from one of a pair of pinholes on the drum, whose separation was known, to the other. The traverse distance was compared with the pinhole separation and the magnification was found to be 4.9.

Then, to calibrate the drum speed and the chart speed, the double pinhole was driven past the slit image at the speed that was used during data taking. The peaks were recorded on the strip chart, at the same speed that was used during data taking. These two measurements yielded the scale factor that 1mm on the strip chart is 3.81μ in the actual image. This figure is reproducibly accurate to within 1 %.

3.3 Method Used to Reduce Data

3.3.1 Rolls Assembled

The strip charts were assembled in rolls with 10 corresponding sweeps on a roll.

3.3.2 Peaks Marked

The 10 sweeps on each roll were compared and a peak reference point was selected and marked in the same spot on each sweep. These points were positioned with reference to several prominent features on the various sweeps. (See "Peak Ref" on sample strip chart sweep in the Appendix.)

3.3.3 Baselines Marked

In a similar manner a baseline was drawn along the bottom of the trace. Due to the noise levels, the baselines vary from one roll to the next but they are the same on all the sweeps on any particular roll. (See "Baseline" on sample strip chart sweep in the Appendix.)

3.3.4 Sweeps Digitized

The charts were digitized at millimeter intervals (3.8μ in the actual image) on a Gerber GDDRS-6B comparator. Each sweep was read to a full width of 150mm. The heights were read from the top of the baseline to the top of the trace line. The accuracy of the readings were within 0.005". The output was in the form of 15 points per punch card.

3.3.5 Data Analyzed

The cards were analyzed by Itek's FRAP program. This program averaged the 10 sweeps into one trace and then normalized and plotted the trace.

3.3.6 Data Assembled

This data was reviewed and the every 15th point was extracted to yield the final format of the data, per Test Plan - 344-68-063.

4.0 TEST RESULTS

4.1 Format of the Data

The reduced data is displayed in the Appendix on computer output sheets with the reduced information from one strip chart on each sheet. (Thus there are 14 sheets, two for each data point, i.e. one component of a cross on each sheet.)

The first line on each sheet contains the identification information including field position, zoom setting, anamorphic lens settings, and whether it is the vertical or horizontal component of the cross.

Below this are two columns of data, one labeled X, the other labeled F(X). The X column indicates the displacement (in the actual image at the dummy reticle) of the measurement from the peak in millimeters (+ is left and - is right for the horizontal sweeps and + is down and - is up for the vertical sweeps).

Opposite the displacement is the (averaged, normalized) height of the sweep at that point. This represents the intensity of the image at that point. This appears in the form of a seven place number and the base 10 exponent to which it must be raised. (i.e. $2.039007E-02 = 2.039007 \cdot 10^{-02} = 0.02039007$)

Note also that the order of presentation is: peak, nearest positive displacement measurement, second nearest positive displacement.....

The sweeps displayed have been normalized with the peak measurement centered and set equal to one. The negative extreme has been set to 0.

Sample Format:

	Field Position	Zoom Setting	Anamorph Lens Setting	Sweep Direction
C	HALF X,	M ZOOM,	ANA. 1-1,	VERTICAL SWEEP

displacement in mm X	height F(X)
0	1.000000 E 00
0.05700	9.026234E-02
-0.05700	3.499333E-01

4.2 Confidence -Errors

The errors in the final data arise from two origins. These are: 1) Noise in the signal and the equipment accuracy, and 2) evaluation accuracy. Since they lend themselves to a separate discussion, that format will be followed here:

4.2.1 Noise in the Signal and Equipment Accuracy

The equipment used to measure the PSF was modified from configuration that was used to measure MTF at considerably higher light levels. This led to problems with noise levels. J. Bala and Dr. Peter Ford of Itek who are familiar with the equipment being used, investigated the situation and wrote a report (344-68-452) concerning the noise levels that could be expected at the output. Those levels are on the order of 2% at best for the full signal from the brightest data points and as poor at 10% on others. The signal to noise degrades in the "tails" of the trace.

4.2.2 Evaluation Accuracy

The digitization was accurate to within 0.015% of full signal heights and the baselines were drawn uniformly within 1% of full signal height. The peak reference point was marked at the same spot on each sweep to within 0.1% of full width.

To estimate the overall correlation, the standard deviation of all the points on one roll was computed. The results were that the peak standard deviation was about 6%, and the tail standard deviation was about 50%. The roll used in the standard deviation calculation was selected at random. A later subjective evaluation of this chart showed that it was in fact one of the poorest in signal to noise. A spot check of some of the other charts showed noticeably better values for the standard deviation. Some as good as 2% of full signal height. Thus, all things being considered, the averaged PSF are probably good to better than 4% of full peak height.

4.3 Subjective Observations

4.3.1 Visual Correlation

During the data taking the results were observed and several things of interest were noted. For each data point the Point Spread Function was observed visually through a microscope placed in the analyzer drum. In each case the rough features of the PSF were estimated. There was extremely good correlation in the sense that the more prominent features did show up as predicted.

4.3.2 Centering Trace Correlations

Another check made to verify the shape of the PSF's was to examine the "centering traces" described in 3.2.6. The vertical centering trace profile of a particular data point should look like the horizontal sweeps of that data point. In order to get complete information the centering traces had to be corrected to account for drum pinhole size differences. This second check did in fact show a very strong correlation which tends to lend credibility to the rather odd shapes of some of the PSF's.

4.3.3 Chromatic Separation in the Visual Image

The Point Spread Image does contain some chromatic separation. An attempt to photograph them on Polarcolor film was made. However, the necessary exposure time of five minutes caused chromatic alterations in the photographic image which in general, altered the appearance of the images so that they did not resemble the visual Point Spread Image enough to be of any use.

4.3.4 Effects of Chromatic Separation on PSF

The chromatic separation was such that the blue (which does not appear very bright to the eye) was spread out more than the green or red. The filtered S-20 response was still more sensitive to blue than to green or red. Now, the blue in the image tends to fall in a horizontal streak, so if the sweep made happened to fall along the streak the appearance would be that of an extremely elliptical PSF.

4.3.5 Pinhole Comparisons

In addition to the seven data points, several strip charts were run in a comparison between 5, 10 and 25μ pinholes for the same data point. Experimental conditions were controlled such that the pinholes were centered at the same point and the analyzer was not touched during the pinhole change.

Filter-No-Filter Comparisons

Further, in addition to the pinhole comparisons, several duplicate runs were made with and without optical filters. In this case an additional problem was the fact that withdrawing the filter, slightly defocused the image. Any attempt to change the focus caused enough of a disturbance to alter the analyzer position enough to shift the pinhole track lines across the image.

Results

An evaluation of these strip charts revealed that as expected, in the case of the filter, there was a greater intensity without the filter as opposed to with the filter. There is also a detectable change in shape. This is due most likely to the red and blue aberration in the system which would show up better through an unfiltered S-20. The 5-10 -25μ comparison also turned out as expected. Peak half width ratios were proper and the detail increased from 25μ to 5μ pinhole. This data was evaluated from the chart only. No digitizing or averaging was done.

4.3.6 Additional Data Available

The data reported is in the form of 11 measurements across the field in each direction. More detail is evident when more points are used and in fact 15 times the resolution of the 11 measurements is available.

5.0 DATA

C ON AXIS, M ZOOM, ANA.1-1, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	1.893055E-01
-0.05700	1.850031E-01
.11400	1.349109E-01
-0.11400	6.760910E-02
.17100	8.082360E-02
-0.17100	2.827289E-02
.22800	2.458513E-02
-0.22800	1.290719E-02
.28500	8.297480E-03
-0.28500	

PAGE 0

C ON AXIS, M ZOOM, ANA.1-1, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1,000000E 00
,05700	1,678899E-01
-0,05700	9,174312E-02
,11400	3,073394E-02
-0,11400	2,293578E-02
,17100	1,146789E-02
-0,17100	1,100917E-02
,22800	3,669725E-03
-0,22800	6,422018E-03
,28500	9,174312E-04
-0,28500	0

PAGE

C ON AXIS, M ZOOM, ANA. 1.7-1, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	2.633833E-01
-0.05700	1.486081E-01
.11400	2.419700E-01
-0.11400	1.584582E-02
.17100	-1.027837E-02
-0.17100	-8.565310E-04
.22800	-1.541756E-02
-0.22800	-2.226981E-02
.28500	-1.327623E-02
-0.28500	0

PAGE

C ON AXIS, M ZOOM, ANA, 1.7-1, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1,000000E 00
,05700	7,147531E-01
-0,05700	5,356930E-01
,11400	4,646044E-01
-0,11400	6,543724E-02
,17100	1,445568E-01
-0,17100	1,844140E-02
,22800	3,004164E-02
-0,22800	-2,082094E-03
,28500	9,220702E-03
-0,28500	0

PAGE

C HALF X , M ZOOM, ANA. 1-1, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1,000000E 00
,05700	5,197435E-02
-0,05700	4,893689E-02
,11400	1.923726E-02
-0,11400	1,248734E-02
,17100	1,248734E-02
-0,17100	5,737428E-03
,22800	4,387445E-03
-0,22800	2,699966E-03
,28500	3,037462E-03
-0,28500	0

PAGE

C HALF X , M ZOOM, ANA. 1-1, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
,05700	5.174793E-02
-0,05700	7.198712E-02
,11400	1.566937E-02
-0,11400	1.310948E-02
,17100	5.519779E-03
-0,17100	8.049678E-03
,22800	2.299908E-03
-0,22800	3.449862E-03
,28500	1.839926E-03
-0,28500	0

PAGE

C FULL X , M ZOOM, ANA. 1-1, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1,000000E 00
,05700	5,771277E-01
-0,05700	2,925532E-02
,11400	9,219858E-02
-0,11400	2,039007E-02
,17100	7,358156E-02
-0,17100	1,241135E-02
,22800	3,546099E-02
-0,22800	1,595745E-02
,28500	2,659574E-02
-0,28500	

PAGE 0

C FULL X, M ZOOM, ANA.1-1, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	9.026234E-02
-0.05700	3.499333E-01
.11400	2.712317E-02
-0.11400	2.045353E-02
.17100	8.448199E-03
-0.17100	4.001779E-03
.22800	4.891063E-03
-0.22800	3.112494E-03
.28500	4.446421E-03
-0.28500	0

PAGE

C FULL Y , M ZOOM, ANA. 1-1, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	2.222222E-02
-0.05700	6.206349E-01
.11400	1.269841E-02
-0.11400	3.321429E-01
.17100	5.952381E-03
-0.17100	1.563492E-01
.22800	3.174603E-03
-0.22800	7.936508E-03
.28500	1.587302E-03
-0.28500	0

PAGE

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C FULL Y , M ZOOM, ANA. 1-1, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1,000000E 00
,05700	1,601281E-01
-0,05700	1,733387E-01
,11400	2,401922E-02
-0,11400	4,683747E-02
,17100	1,000801E-02
-0,17100	1,441153E-02
,22800	8,807046E-03
-0,22800	8,406725E-03
,28500	4,803843E-03
-0,28500	0

PAGE

C HALF Y , M ZOOM, ANA. 1-1, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	1.389360E-02
-0.05700	7.024737E-01
.11400	5.760759E-03
-0.11400	3.652999E-01
.17100	3.727550E-03
-0.17100	1.877330E-01
.22800	3.388682E-04
-0.22800	1.145374E-01
.28500	1.355473E-03
-0.28500	0

PAGE

C HALF Y , M ZOOM, ANA. 1-1, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	2.810914E-01
-0.05700	3.242386E-01
.11400	4.822335E-02
-0.11400	4.949239E-02
.17100	1.713198E-02
-0.17100	1.903553E-02
.22800	8.248731E-03
-0.22800	1.459391E-02
.28500	6.345178E-03
-0.28500	0

PAGE

D-SECRET

C ONAXIS, M ZOOM, ANA. REMOVED, HORIZONTAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	3.984820E-02
-0.05700	6.641366E-02
.11400	1.463811E-02
-0.11400	2.656546E-02
.17100	7.047980E-03
-0.17100	1.192735E-02
.22800	8.132285E-04
-0.22800	7.047980E-03
.28500	-5.421523E-04
-0.28500	0

PAGE

D-SECRET

HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY

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C ONAXIS, M ZOOM, ANA. REMOVED, VERTICAL SWEEP

PRINT OUT LINE

LINE

X	F(X)
0	1.000000E 00
.05700	7.964072E-02
-0.05700	3.115768E-01
.11400	3.013972E-02
-0.11400	5.888224E-02
.17100	1.477046E-02
-0.17100	2.794411E-02
.22800	9.980040E-03
-0.22800	1.996008E-02
.28500	8.982036E-03
-0.28500	

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Appendix

1. Sample Strip Chart
2. Two photographs

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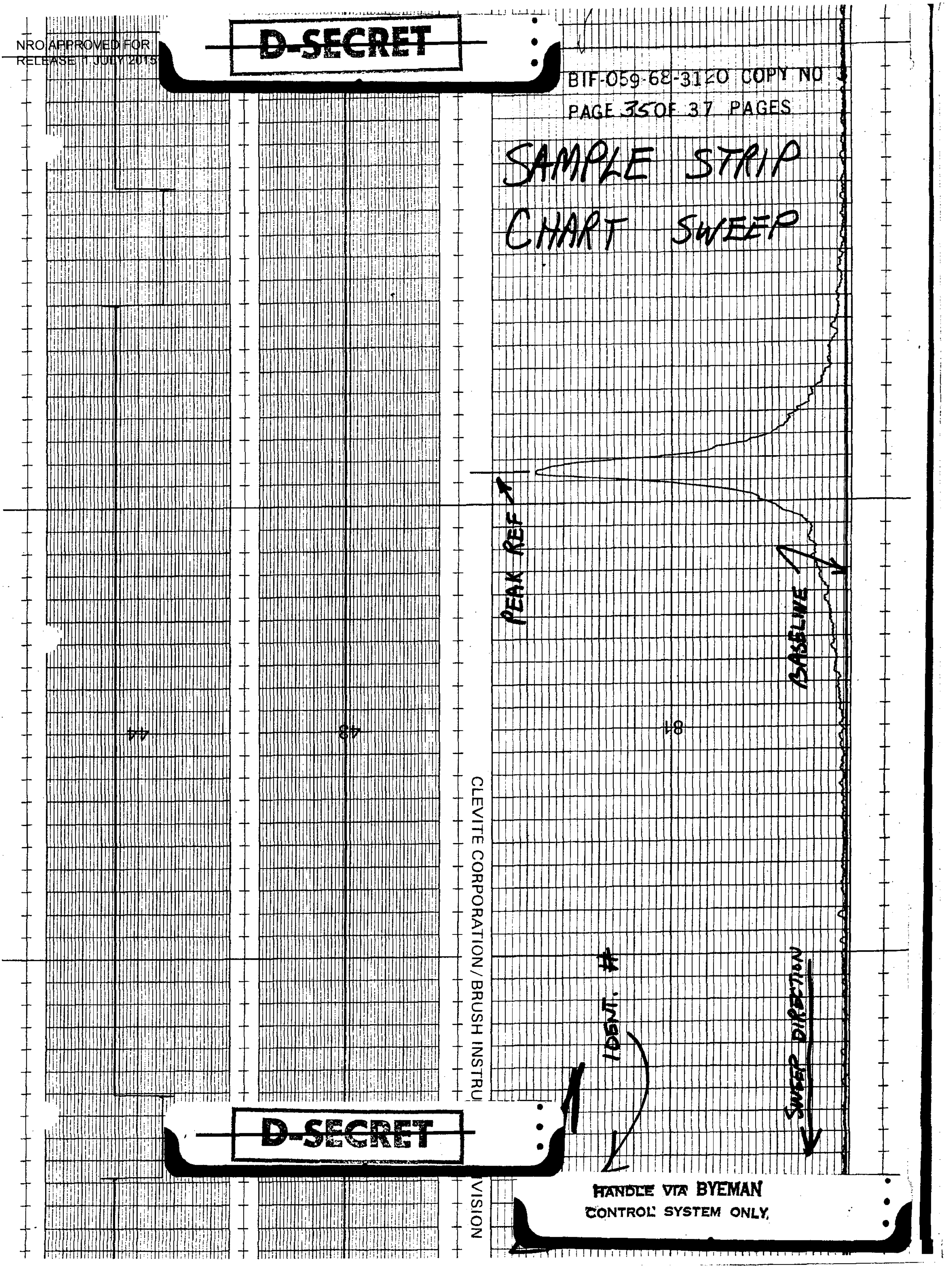
SAMPLE STRIP CHART SWEEP



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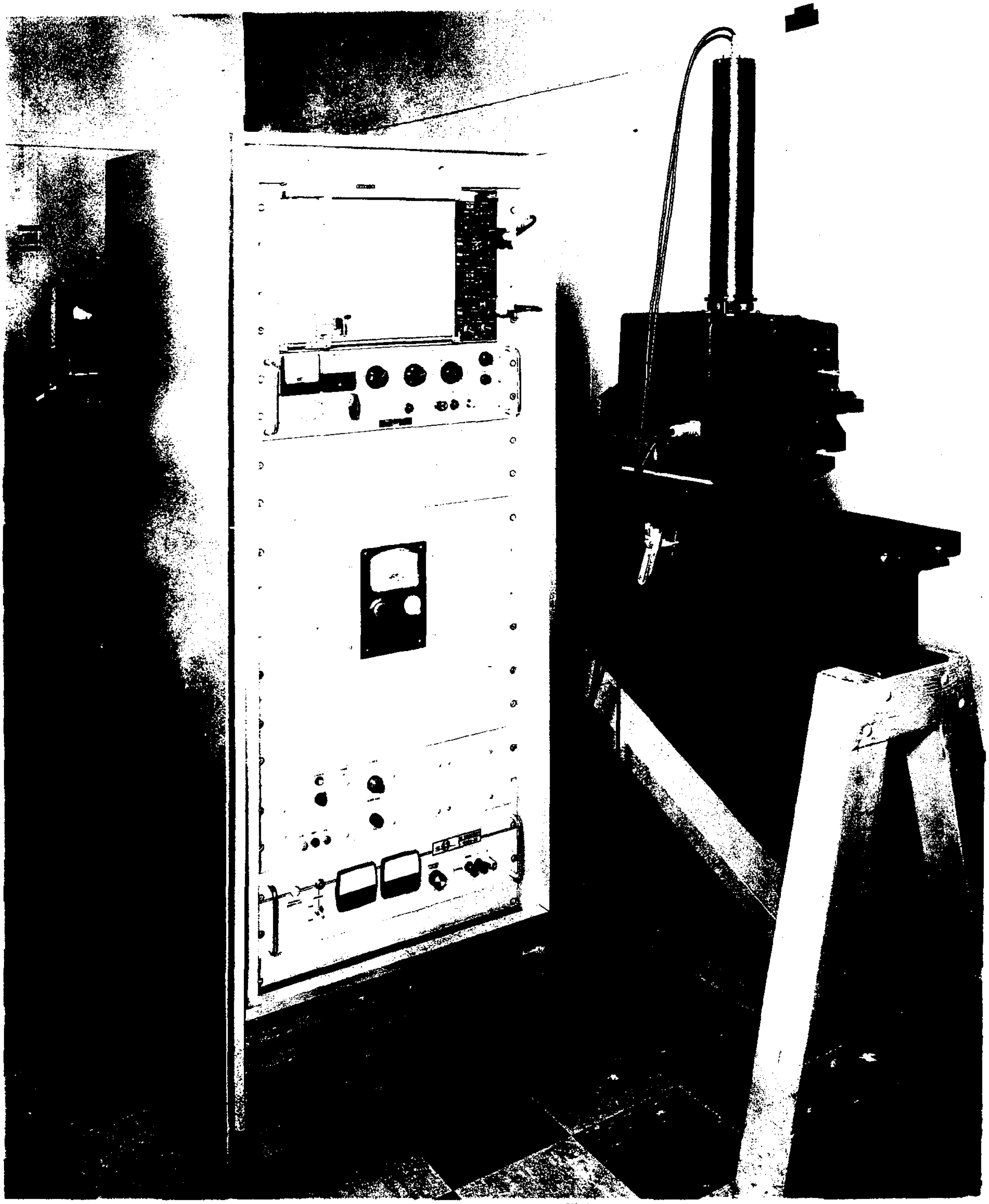
HANDLE VIA BYEMAN
CONTROL SYSTEM ONLY



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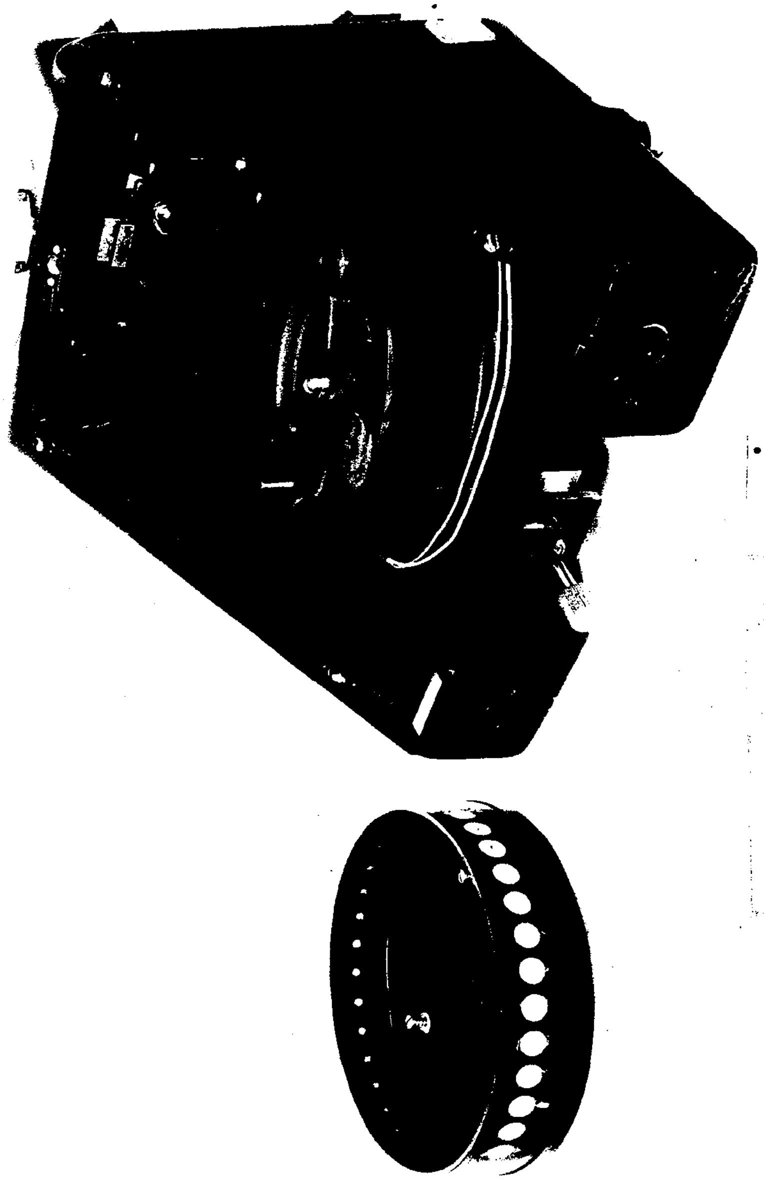

13696

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CONTROL SYSTEM ONLY