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LANDSAT-4 THEMATIC MAPPER
MODULATION TRANSFER FUNCTION (MTF) EVALUATION

Progress Report
June 15 - September 15, 1983

submitted to

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September 16, 1983

Original photography may be purchased from EROS Data Center
Sioux Falls, SD 57198

Introduction

In the previous progress report (dated June 13, 1983) we described a procedure for comparing the image quality of forward and backward TM scans using a spatial frequency power spectrum (PS) analysis. We have, during this contract quarter, applied this power spectrum analysis technique to comparison of TM A and P-tape data for the Washington DC scene of 11/02/82 (ID#4020915140).

We have modified slightly our data indentification code from that given in the previous progress report to include a code for the TM band processed as follows:

characters 1,2 - Thematic Mapper (TM)
" 3 - Tape type (A or P)
" 4 - Scene ID (1:ID#4020915140)
" 5 - Area within the scene (1,2,etc)
" 6 - TM band (1-7)
" 7,8 - Odd/even scan shift in pixels (A-tape only)

Three areas from scene #1 were used in the A-P data comparison. Two of them are different from those used in the odd/even scan comparison (Table 1).

TABLE 1

Study areas in scene #1 for A and P-data comparison

Designation	Pixel #1	Line #1	# pixels	# lines
TMP124	3961	1079	512	512
TMP144	4786	1		
TMP154	5266	1132		
TMA12447	3391	1200		
TMA14447	4126	180		
TMA15447	4651	1249		

The A and P-tape extracts correspond approximately to the same ground region, e.g. TMP124 and TMA12447.

Procedures for A and P-data Comparison

The first step is registration of the two extracted files. A number of control points were visually-located in each image and a standard least squares quadratic polynomial distortion model was used to warp the A-data to the P-data. Nearest-neighbor resampling was used in all cases to minimize image alteration of the A-data. A summary of the warping algorithm parameters is given in Table 2.

TABLE 2

A to P-data Registration Summary

area	# CPs	ave CP error (pixels)	max CP error (pixels)
2	12	0.26	0.5
4	12	0.27	0.41
5	13	0.23	0.37

In all three cases the A-data, after registration to the P-data, exhibited small unfilled regions on the left and right sides. This could have been avoided by using original A-data areas larger than 512 x 512, but that would have complicated the control point and geometric processing. To avoid subsequent artifacts in the power spectrum analysis, both the P-data and the registered A-data were trimmed on the left and right edges (yielding 483 pixels/line) and expanded in the x-direction only to 512 pixels/line. Again nearest-neighbor resampling was used, and because the scale change was the same for both the A and P-data, there should be no effect on the power spectrum analysis. There is, however, a six percent scale change in the x-direction, compared to the y-direction, and a corresponding change in spatial frequency scale that must be accounted for in comparing results from the two directions.

The next step in the analysis was calculation of the FFT of each image line (x-direction) and each image column (y-direction), calculation of the corresponding PS (squared modulus of the FFT), and the average PS over lines (x) and average PS over columns (y). No spatial window was used to provide additional smoothing. As described in the earlier progress report, the effective MTF between the P and A-data is then given by

$$MTF_x = \sqrt{PS_x^P / PS_x^A}$$

$$MTF_y = \sqrt{PS_y^P / PS_y^A}$$

As in the earlier analysis, the resulting MTFs exhibit some noise, and a least squares polynomial fit (even terms only to 8th order) is used to represent the final curves.

Results and Discussion

An example of the calculated MTF and corresponding polynomial representation is show in Fig. 1. The fit is quite good and all three areas and both directions exhibited similar characteristics.

The MTFs in the x and y directions for the three areas are shown in Figs. 2 and 3 respectively. Note the results from the three areas agree well. In Fig. 4, the MTFs in the x and y directions are compared for area #2. We believe the apparent lower MTF in the y direction is an artifact caused by residual scan-to-scan (16 lines) misregistration in the A-data. Our correction for this problem was a simple constant shift of 46 or 47 pixels between scans. Visual examination of the A-data reveals residual misregistration that varies from scan-to-scan. This misregistration creates artificial edges in the horizontal direction, and therefore artificially higher frequency content in the vertical (y) direction. Thus the ratio of PS_y^P to PS_y^A is lower than expected. Our philosophy is that this artifact, as long as it is understood, should remain in the data because further correction of the A-data would be simply another step to rederivation of the P-data! Therefore it is an indication of true difference between the A and P-data.

Summary

We have applied the PS analysis technique to three different areas in scene #1, and in two orthogonal directions, along-scan and along-track. The resulting effective MTFs between the A and P-data are repeatable from area to area and consistent with theoretical expectations, as seen in Fig. 5. In Fig. 5 the average x-direction (along-scan) MTF calculated with the PS techniques is compared to the MTF of the cubic convolution resampling function used to create P-data from A-data. The two curves are nearly identical, indicating that the major factor affecting the image quality of P-data relative to A-data is the cubic convolution resampling, as expected. This experimental verification gives us confidence in the PS technique, and we plan to apply it to registered sets of TM imagery and simultaneous underflight imagery from the recently acquired TM test scene over San Francisco to estimate the TM system MTF.

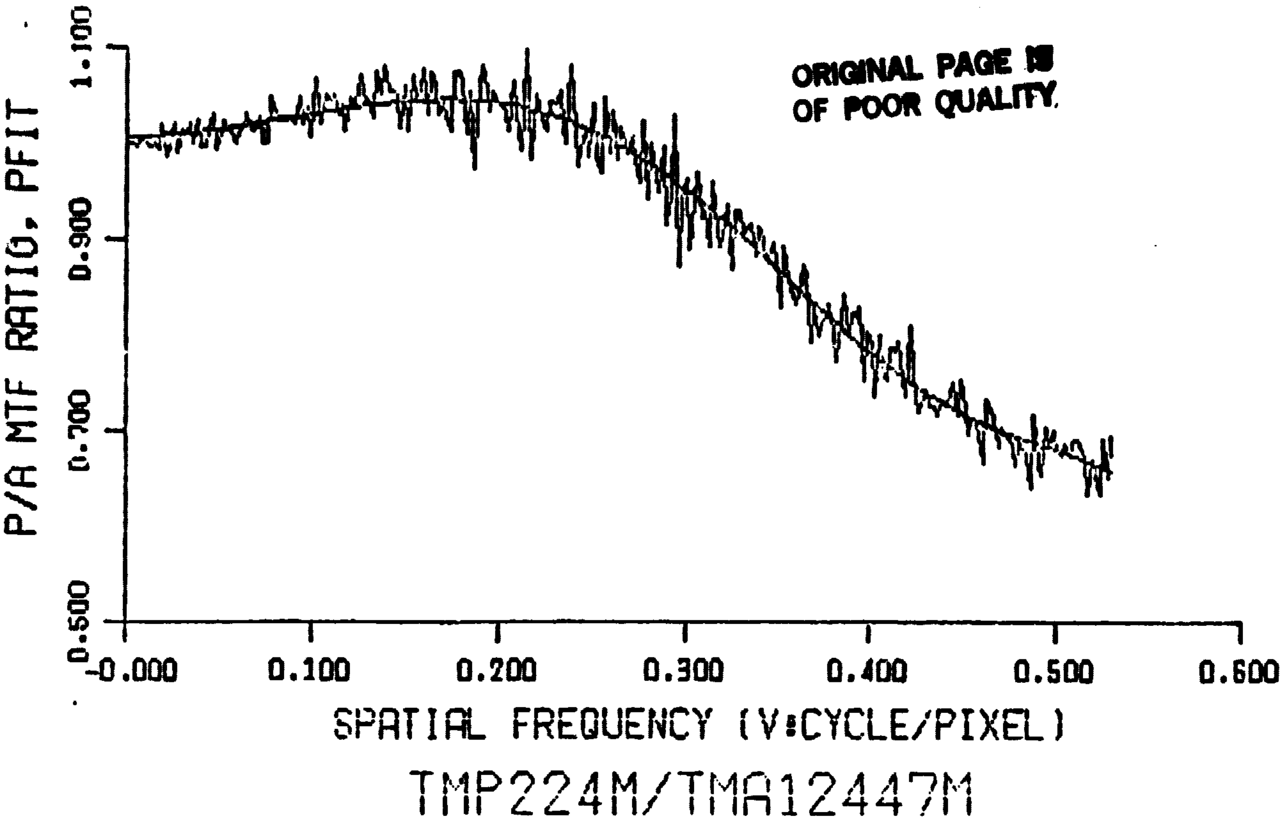

FIGURE 1. Example 8th order polynomial fit to P/A data MTF

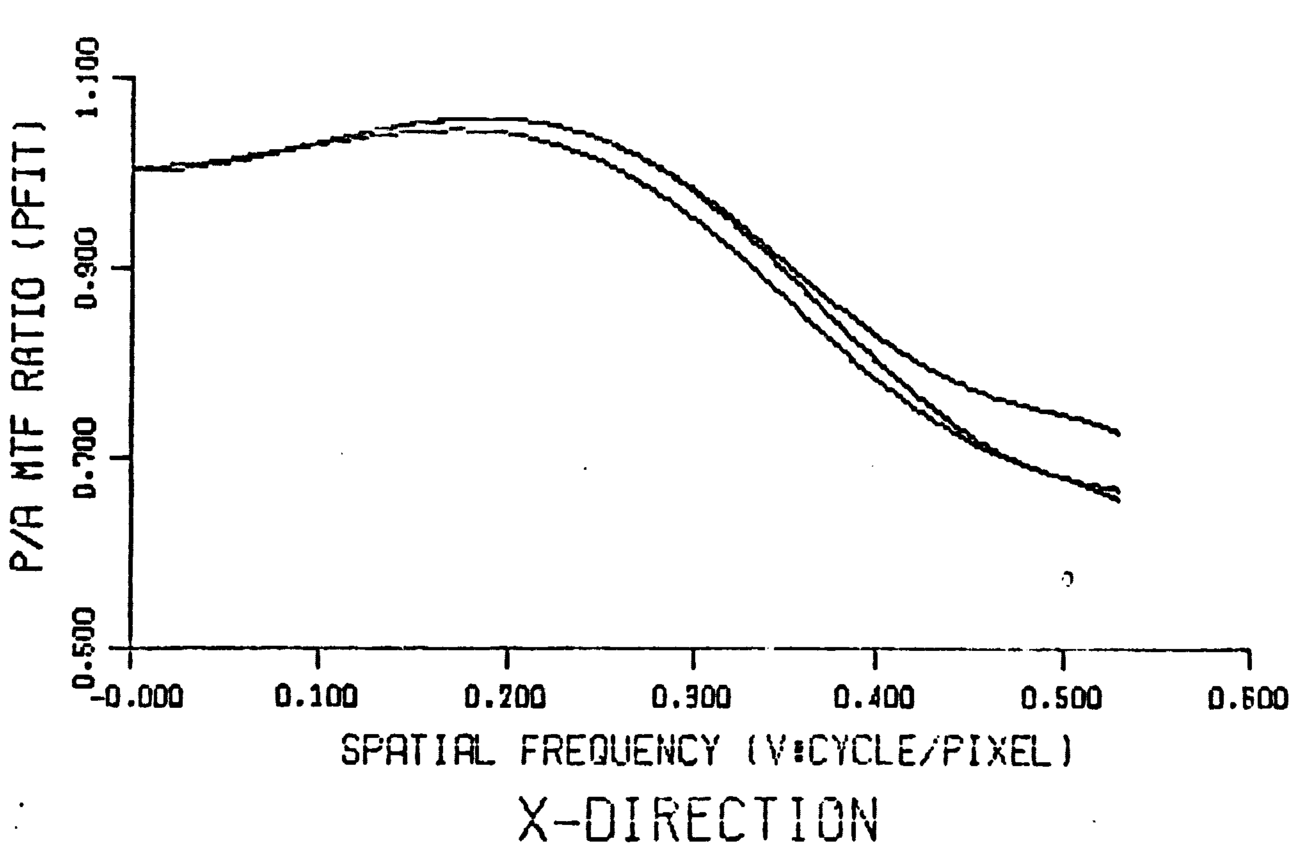

FIGURE 2. Along-scan MTFs between P and A-data for 3 areas

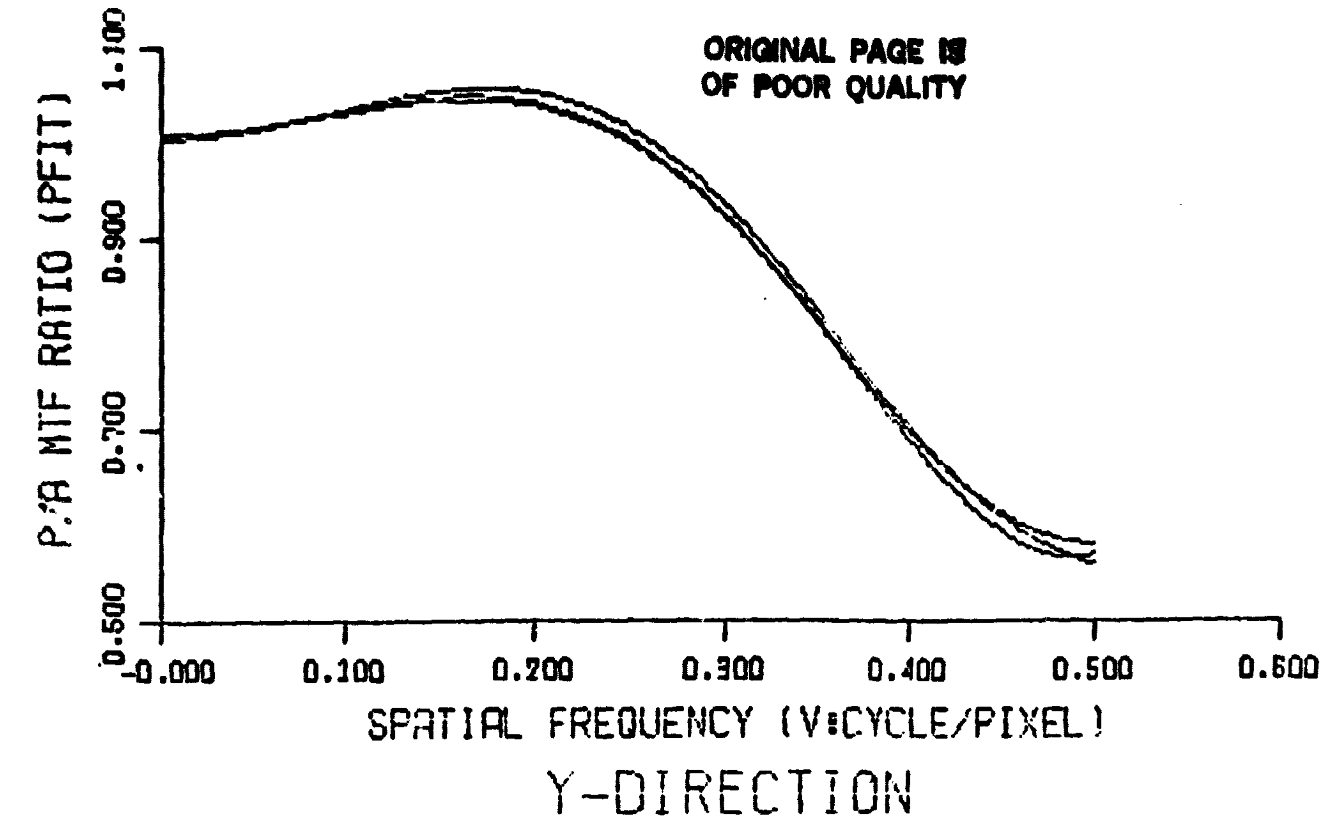

FIGURE 3. Along-track MTFs between P and A-data for 3 areas

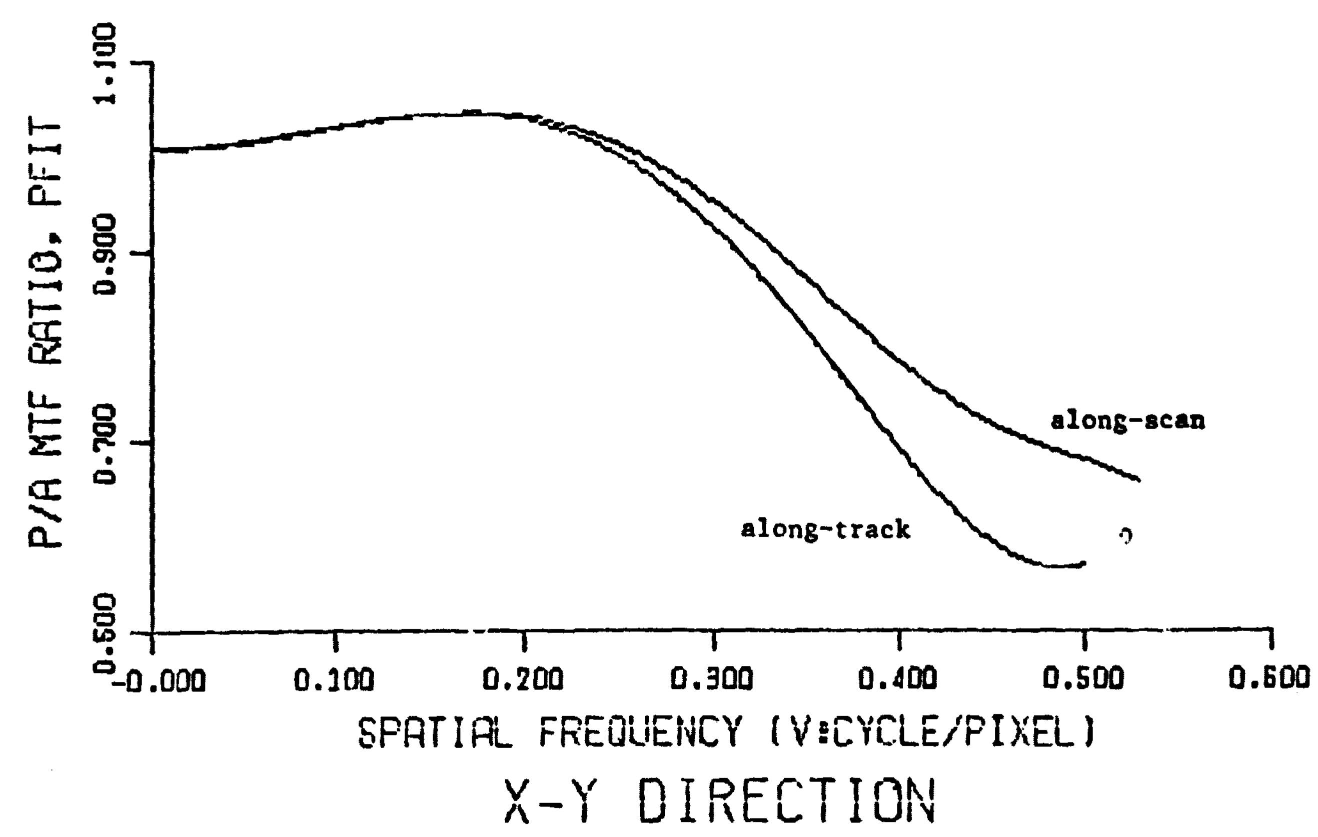

FIGURE 4. Along-scan and along-track MTF comparison, area #2

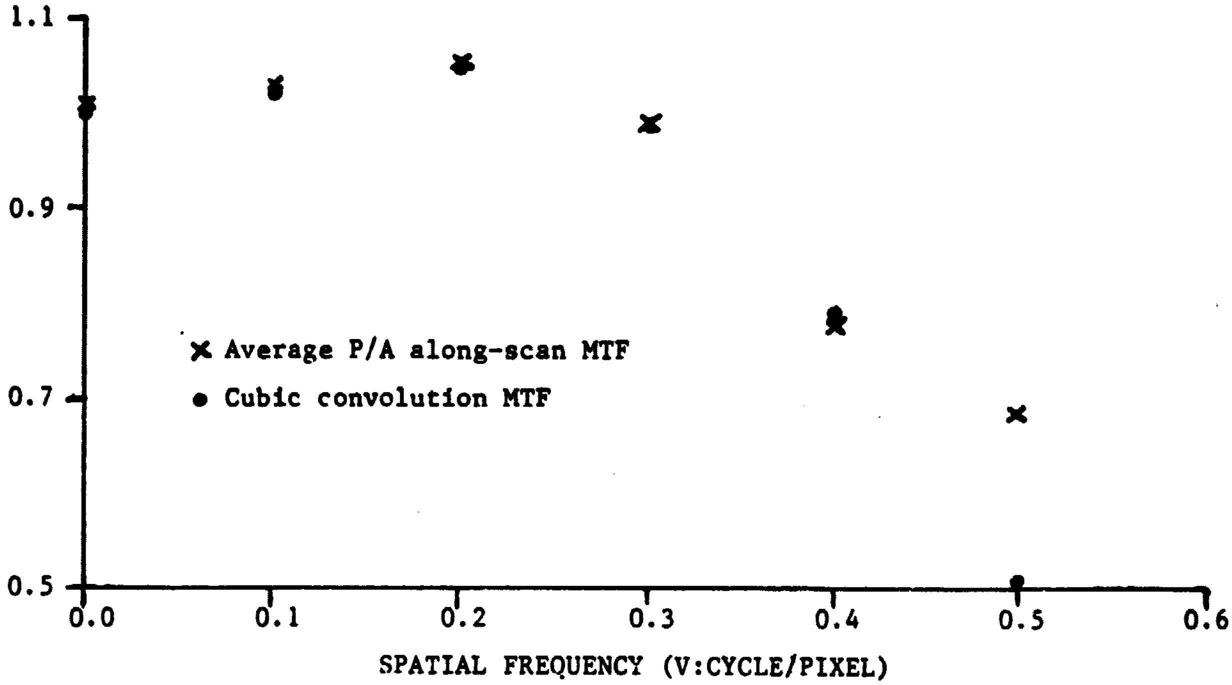

FIGURE 5. Comparison of average P/A MTF along-scan to the MTF for cubic convolution resampling

5a

INVESTIGATION OF SEVERAL ASPECTS OF LANDSAT-4 DATA QUALITY

ROBERT C. WRIGLEY, PRINCIPLE INVESTIGATOR

QUARTERLY PROGRESS REPORT #3

SEPTEMBER 20, 1983

Analysis of interdetector variations and periodic noise has continued with the A-tape from the Washington, DC TM scene of November 2, 1982. A 256x256 pixel window was selected from water areas in Chesapeake Bay which appeared to be uniform. All seven bands of the window were subjected to Fourier transform analysis. In the frequency domain, several noise components were revealed very clearly. Aside from the striping due to interdetector variations among the 16 detectors in each band which was more or less expected, unexpected noise components existed in the primary focal plane detectors, i. e. TM bands 1-4. These noise components do not exist in bands 5-7, leading to the suspicion that they are electronic and not related to the scene content. If they are electronic, presumably they could be eliminated by design changes or conductor placement.

To be specific, all four bands exhibit noise at a spatial frequency of approximately 1/3.2 cycles per pixel in roughly equal amounts in the along-scan direction. Given a pixel sampling time of 9.611 microseconds, this spatial frequency corresponds to 32 kHz electronic noise. A discussion of this result with J. Hsieh of General Electric at the recent International Geoscience and Remote Sensing Symposium in San Francisco revealed that the payload correction data (PCD) has a similar frequency. We suspect the PCD is modulating the video data in TM bands 1-4. One dimensional Fourier transforms of individual lines in each band revealed that in some bands particular detectors were more affected than others. In band 3 detectors numbered 1, 9 and 13 (when numbered starting from the top of the scan sweep) were the noisiest while the even-numbered detectors had little noise at this frequency. In band 4, detectors 9, 13 and 16 were noisy. Bands 1 and 2 had the 32 kHz noise distributed fairly evenly in all detectors. Smaller components of noise exist in all four primary focal plane bands at a spatial frequency of 1/17.5 cycles per pixel or 5.9 kHz. Band 3 has an additional, and large, noise component at a spatial frequency of 1/13.5 cycles per pixel or 7.7 kHz which seem to be most prominent in detectors 16 and 14. Curiously, the 7.7 kHz noise in detector 16 seemed to be much greater in the forward scan direction compared to the back scan direction.

The Fourier transform image of band 3 was notch filtered for the specific noise frequencies mentioned above and

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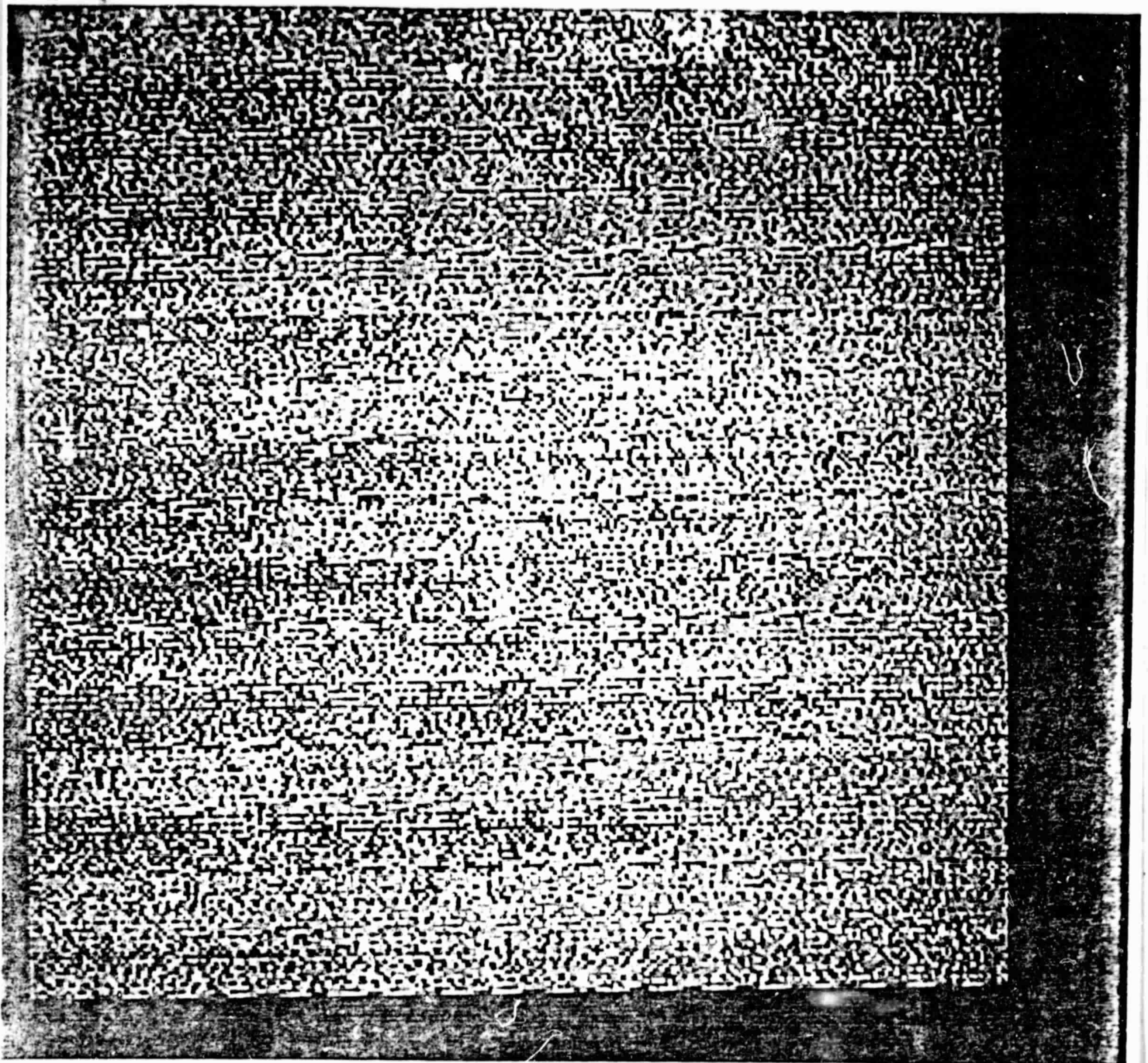
the inverse Fourier transforms were calculated for each component. The resulting noise images were used in two ways: 1) to display the noise components as they are normally perceived and 2) to subtract the noise components from the original image. Both approaches yielded a better understanding of the noise and the effects on the imagery. The noise-corrected image revealed information not apparent in the original data: suspended sediment patterns as well as the forward/backward scan offsets of approximately 50 pixels. Therefore, the noise components degrade low contrast data at least. A set of copies of the periodic noise portion of the poster paper presented at the International Geoscience and Remote Sensing Symposium entitled "Thematic Mapper Image Quality: Preliminary Results" by Wrigley et al. is enclosed for further detail.

We had the good fortune to have one of our test areas covered during the recent TDRSS/TM test. In conjunction with this test (which worked and yielded useable data) we acquired a suite of other data sets: 1) Daedalus TM simulator imagery of portions of the San Francisco, Sacramento and Susanville scenes with a 25 meter IFOV from the ER-2 at 65,000 ft, 2) Daedalus DEI-1260 scanner imagery of 18 small, high contrast targets in the San Francisco scene with a 6.5 meter IFOV coupled with CIR imagery from an RC-8 camera with a 6" lens both from 8,500 ft, and 3) several sets of field data gathered by individuals in the field but mostly concerned with crop type. The two sets of concurrent underflight imagery will be used in the MTF analysis in conjunction with Schowengerdt at the University of Arizona. Preliminary examination of the underflight imagery showed some problems with image quality (gyro stability, sunglint, missed targets, scan angle effects, etc.) but there should be a wealth of good data for MTF analysis.

Schowengerdt has essentially completed the analysis of the Washington, DC scene A-tape/P-tape pair to determine the effects of the geometric correction processing on MTF. His progress report for the period June 15 to September 15, 1983 is attached to provide full detail but a brief summary of the work will be given here. He used his spatial frequency power spectrum analysis on three registered sub-scenes (512x512) of the A-tape/P-tape pair to generate effective MTFs between the two data sets in both the along-scan and across-scan directions. He found these effective MTFs were repeatable from area to area and consistent with theoretical expectations in that the effective MTFs were nearly identical with the MTF of the cubic convolution function used to create P-data from A-data. This result indicates that the major factor affecting image quality of P-data relative to A-data is the cubic convolution resampling, as expected.

6-28-82



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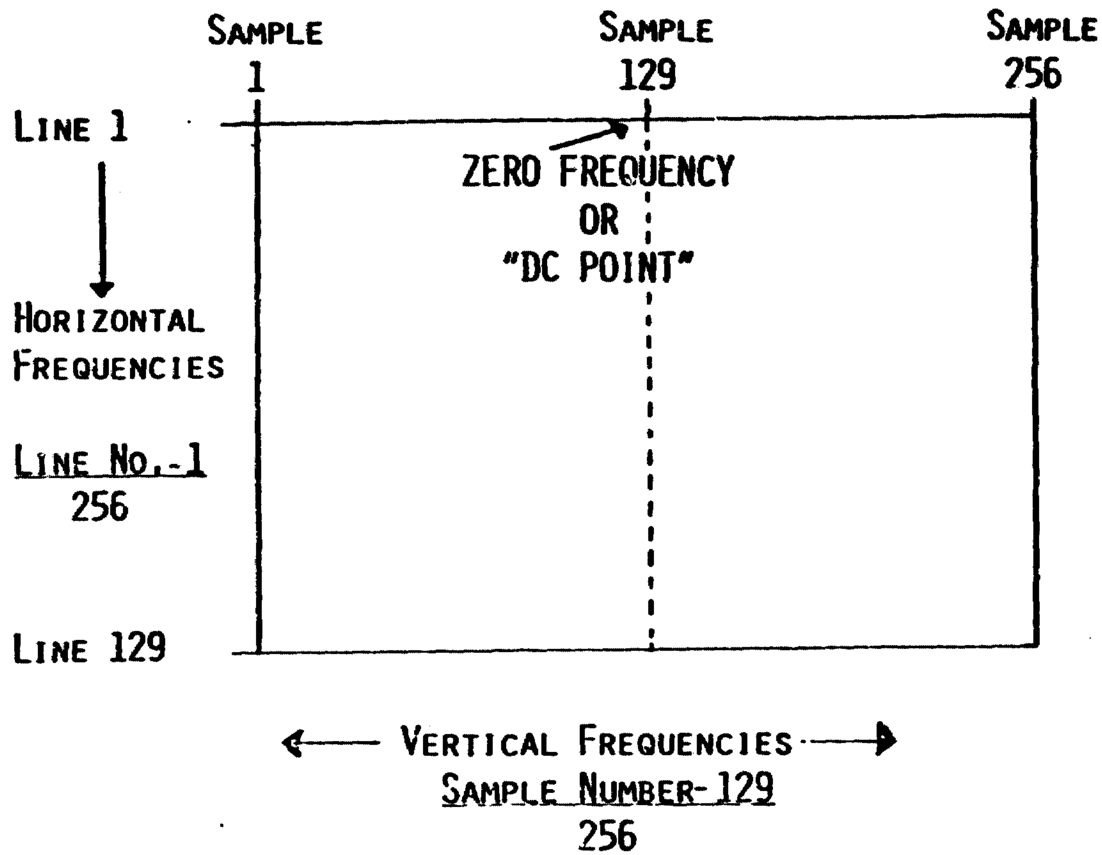
RAW DATA.

PERIODIC NOISE STUDY SITE FROM WASHINGTON, D.C. THEMATIC MAPPER A-TAPE

THE ABOVE 256 x 256 PIXEL WINDOW WAS EXTRACTED FROM THE THEMATIC MAPPER'S BAND 3 (RED) IN THE WASHINGTON, D.C. SCENE ACQUIRED NOVEMBER 2, 1982 (ID #40291540). THIS WINDOW IS AN IMAGE OF A CENTRAL PORTION OF CHESAPEAKE BAY, AN AREA CHOSEN TO PROVIDE CONSTANT RESPONSE IN THE SENSOR. THE IMAGE IS FROM AN A-TAPE WHICH HAD NO GEOMETRIC CORRECTIONS OR RE-SAMPLING APPLIED TO IT SO THAT EVERY 16TH LINE IS FROM THE SAME DETECTOR (OR EVERY 4TH LINE FOR THE THERMAL BAND). THE A-TAPES HAVE VARIABLE OFFSETS OF APPROXIMATELY 50 PIXELS BETWEEN 16 LINE GROUPS REPRESENTING THE DATA FROM THE FORWARD AND BACKWARD SCANS, BUT THE OFFSETS ARE NOT APPARENT IN THIS IMAGE OF WATER. THE DATA CONTRAST IN THE BAND 3 IMAGE HAS BEEN ENHANCED FOR DETAIL; THE RANGE OF GREYTONE VALUES IS ONLY 6 COUNTS.

KEY TO FOURIER TRANSFORM IMAGES

THE FOURIER TRANSFORM OF A 256 X 256 PIXEL IMAGE RESULTS IN ANOTHER 256 X 256 PIXEL IMAGE HAVING COMPLEX VALUES AT EACH POINT. THE MAGNITUDE, OR REAL PART, OF THE FOURIER TRANSFORM REPRESENTS THE MAGNITUDES OF ALL THE SPATIAL FREQUENCIES PRESENT IN THE ORIGINAL IMAGE. THE IMAGINARY PART OF THE FOURIER TRANSFORM IMAGE REPRESENTS THE PHASES OF ALL THE SPATIAL FREQUENCIES PRESENT; THE IMAGINARY PART WAS NOT USED IN THIS ANALYSIS. THE FOURIER TRANSFORM IMAGES DISPLAYED HERE ARE ONLY THE LOWER HALF IF THE FULL 256 X 256 PIXEL IMAGE BECAUSE THEY ARE SYMMETRIC ABOUT THE CENTRAL LINE OR ROW. BECAUSE THE FOURIER TRANSFORM ALGORITHM TRANSPOSES THE LINE AND SAMPLE DIRECTIONS, THE FOLLOWING DIAGRAM MAKES EXPLICIT THE LOCATIONS OF THE VARIOUS FREQUENCY COMPONENTS.



THUS, LINE 1 CONTAINS ONLY INFORMATION HAVING VERTICAL FREQUENCY COMPONENTS WITH NO HORIZONTAL COMPONENTS; THIS COULD BE CONSIDERED STRIPING WITH VERTICAL VARIATIONS. ANOTHER LINE, SAY LINE NUMBER 81, WOULD CONTAIN INFORMATION PERTAINING TO ALL VERTICAL FREQUENCIES AT THE PARTICULAR HORIZONTAL FREQUENCY OF

$$\frac{81-1}{256} = \frac{80}{256} = \frac{1}{3.2} = 0.312\ \frac{\text{CYCLES}}{\text{PIXEL}} = 32{,}000\ Hz$$

SUCH NOISE COMPONENTS EXIST ON BANDS 1-4 OF THE THEMATIC MAPPER AND ARE REFERRED TO AS HIGH FREQUENCY NOISE. OTHER NOISE

THUS, LINE 1 CONTAINS ONLY INFORMATION HAVING VERTICAL FREQUENCY COMPONENTS WITH NO HORIZONTAL COMPONENTS; THIS COULD BE CONSIDERED STRIPING WITH VERTICAL VARIATIONS. ANOTHER LINE, SAY LINE NUMBER 81, WOULD CONTAIN INFORMATION PERTAINING TO ALL VERTICAL FREQUENCIES AT THE PARTICULAR HORIZONTAL FREQUENCY OF

$$\frac{81-1}{256} = \frac{80}{256} = \frac{1}{3.2} = 0.312 \ \frac{\text{CYCLES}}{\text{PIXEL}} = 32{,}000 \text{ Hz}$$

SUCH NOISE COMPONENTS EXIST ON BANDS 1-4 OF THE THEMATIC MAPPER AND ARE REFERRED TO AS HIGH FREQUENCY NOISE. OTHER NOISE COMPONENTS ARE APPARENT AT LINES 20 AND 15-16 CORRESPONDING TO HORIZONTAL FREQUENCIES OF

$$\frac{20-1}{256} = \frac{19}{256} = \frac{1}{13.5} = 0.074 \ \frac{\text{CYCLES}}{\text{PIXEL}} = 7{,}700 \text{ Hz}$$

$$\frac{15.5}{256} = \frac{14.5}{256} = \frac{1}{17.5} = 0.057 \ \frac{\text{CYCLES}}{\text{PIXEL}} = 5{,}900 \text{ Hz}$$

THESE COMPONENTS ARE REFERRED TO AS LOW FREQUENCY NOISE.

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FOURIER TRANSFORMS OF PERIODIC NOISE STUDY SITES

THE FOURIER TRANSFORMS OF EACH OF THE SEVEN BANDS OF THE SAMPLE WINDOW REVEAL CHARACTERISTICS OF THE PERIODIC NOISE IN EACH BAND. THE IMAGES SHOWN HERE ARE THE MAGNITUDES OF THE FOURIER TRANSFORMS; THEY WERE ENHANCED FOR VISUAL ANALYSIS BY THE EQUATION I =LOG (20MAG+1). INTERDETECTOR NOISE (STRIPING) IS REVEALED AS SPIKES IN THE ACROSS-SCAN DIRECTION (THE FIRST LINE OF THE FOURIER TRANSFORM IMAGE), AT SPATIAL FREQUENCIES OF 1/16 CYCLES PER PIXEL AND THEIR HARMONICS (1/4 CYCLES PER PIXEL FOR BAND 6). SUCH SPIKES ALSO APPEAR AT HALF FREQUENCIES, AN EFFECT OF THE DIFFERENCES BETWEEN FORWARD AND BACKWARD SCANS.

ADDITIONAL NOISE IS APPARENT IN THEMATIC MAPPER BANDS 1-4, THE VISIBLE AND NEAR-INFRARED BANDS, BUT IT IS CONSPICUOUSLY ABSENT FROM THEMATIC MAPPER BANDS 5-7, THE MIDDLE AND THERMAL INFRARED BANDS. THIS NOISE OCCURS AT APPROXIMATE FREQUENCIES OF 1/17.5 AND 1/3.2 CYCLES PER PIXEL IN THE ALONG-SCAN DIRECTION. BAND 3 ALSO HAS NOISE COMPONENTS AT 1/13.5 CYCLES PER PIXEL. THESE NOISE COMPONENTS ARE MODULATED BY PERIODOCITIES IN THE ALONG-TRACK DIRECTION, INDICATING VARIATIONS IN THE AMPLITUDES OF THE NOISE WITH INDIVIDUAL DETECTORS. THE FOURIER TRANSFORM OF BAND 6 (THERMAL INFRARED) SHOWS ALIASING DUE TO THE REPETITION OF PIXELS FROM 4 DETECTORS AT A RESOLUTION OF 120 METERS IN ORDER TO OBTAIN A DATA SET OF THE SAME SIZE AS THE OTHER BANDS WITH 16 DETECTORS AND A RESOLUTION OF 30 METERS.

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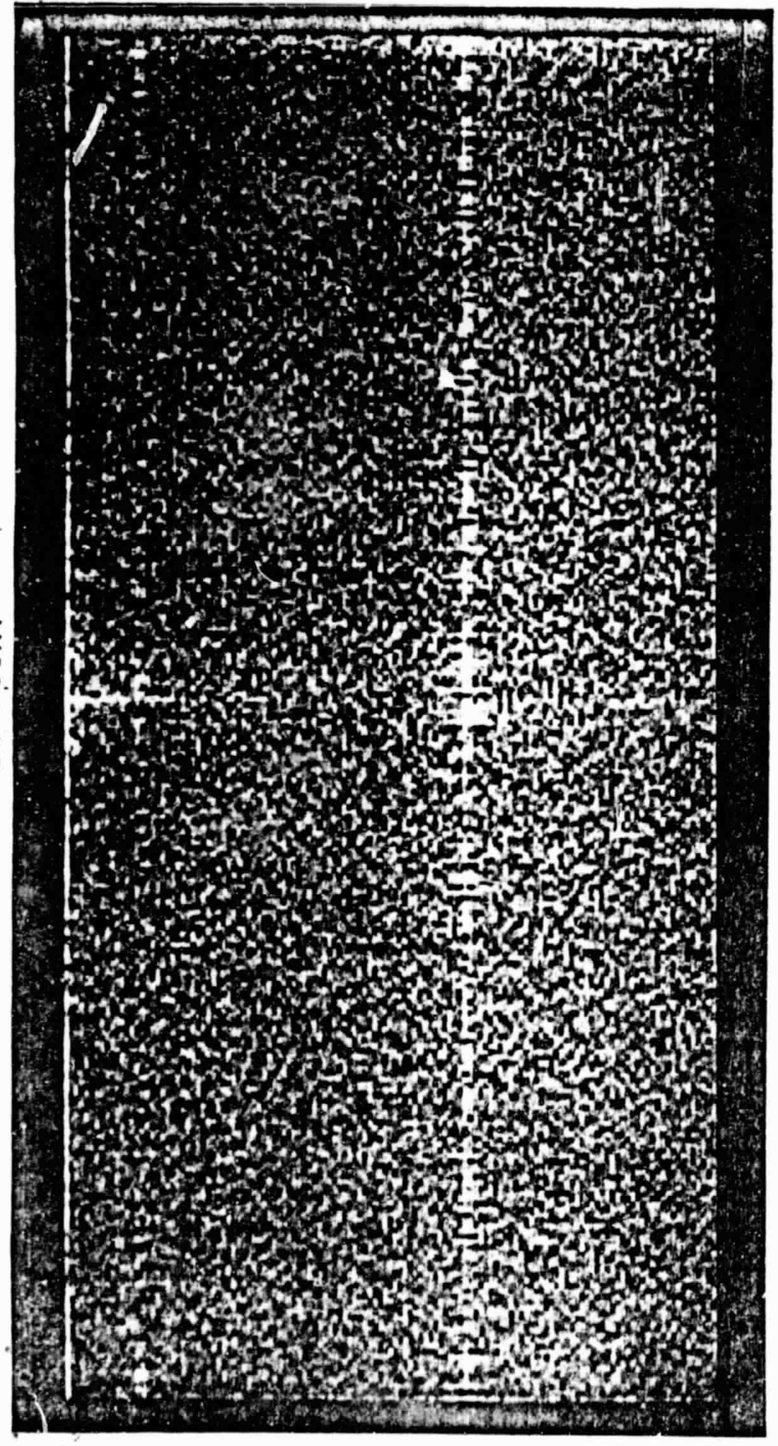
DC POINT



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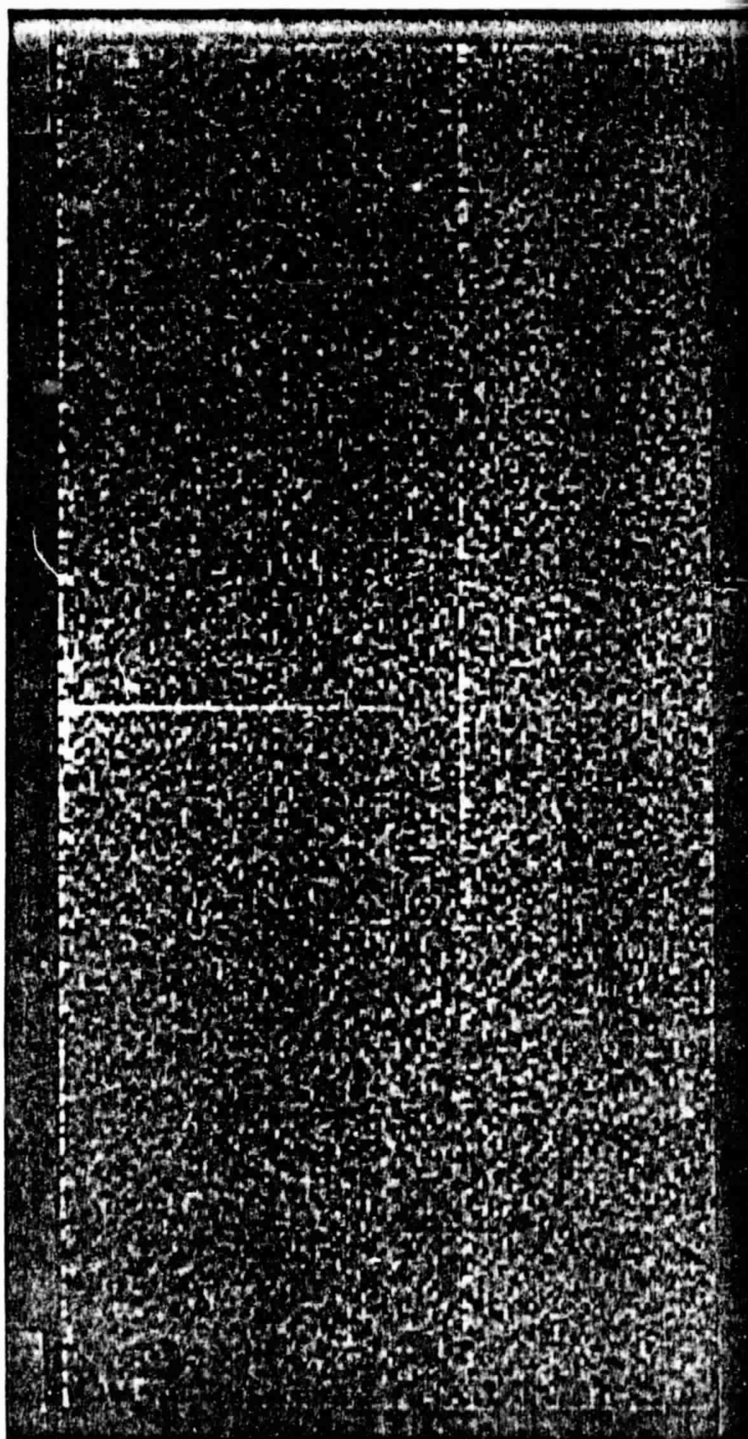
BAND 1



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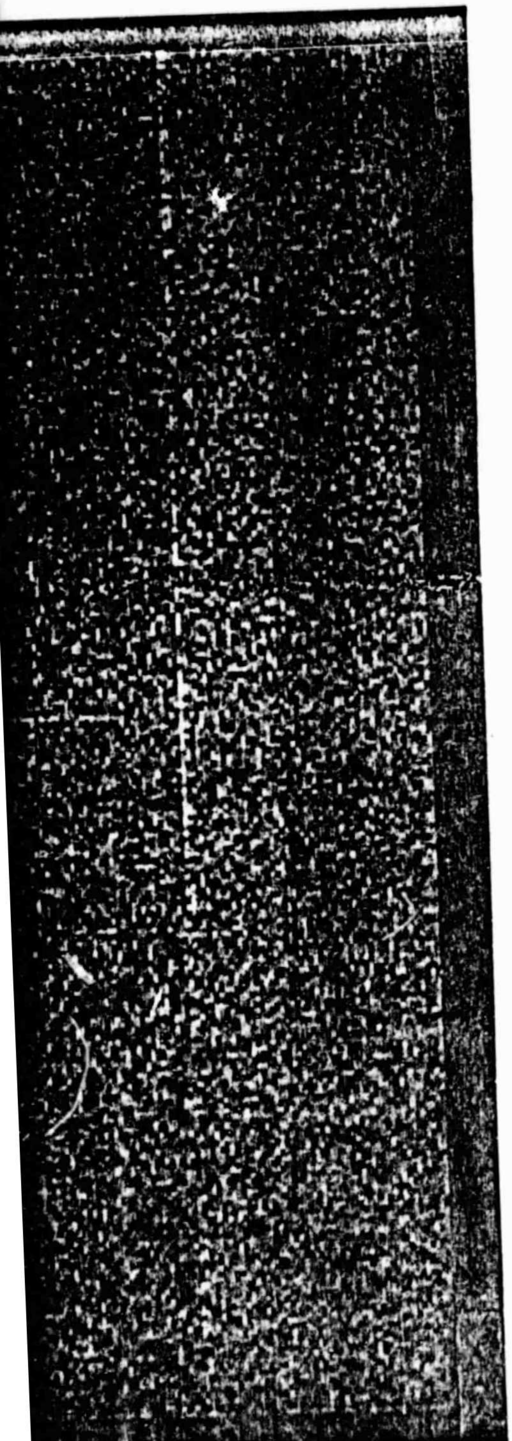

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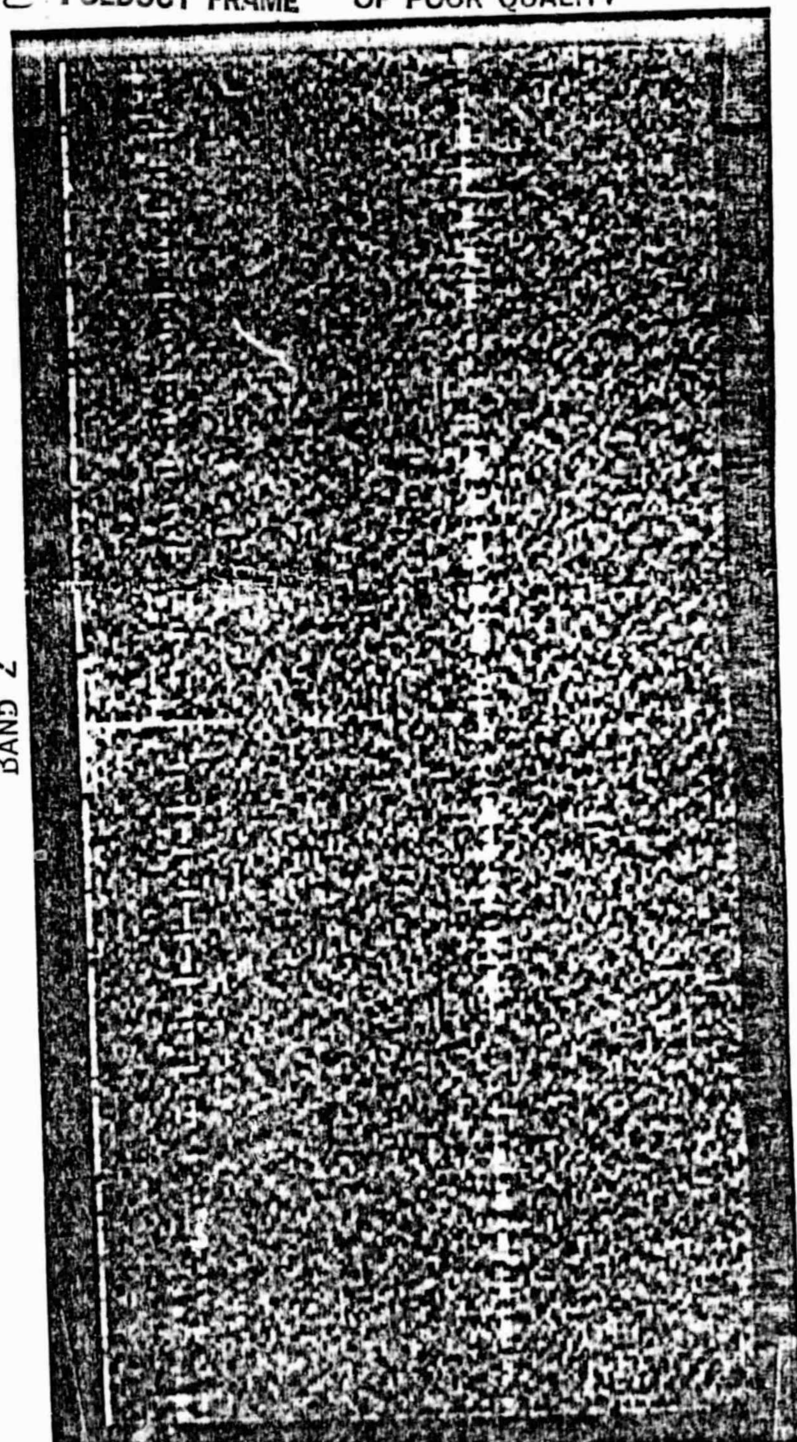
BAND 2



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BAND 3

DC POINT

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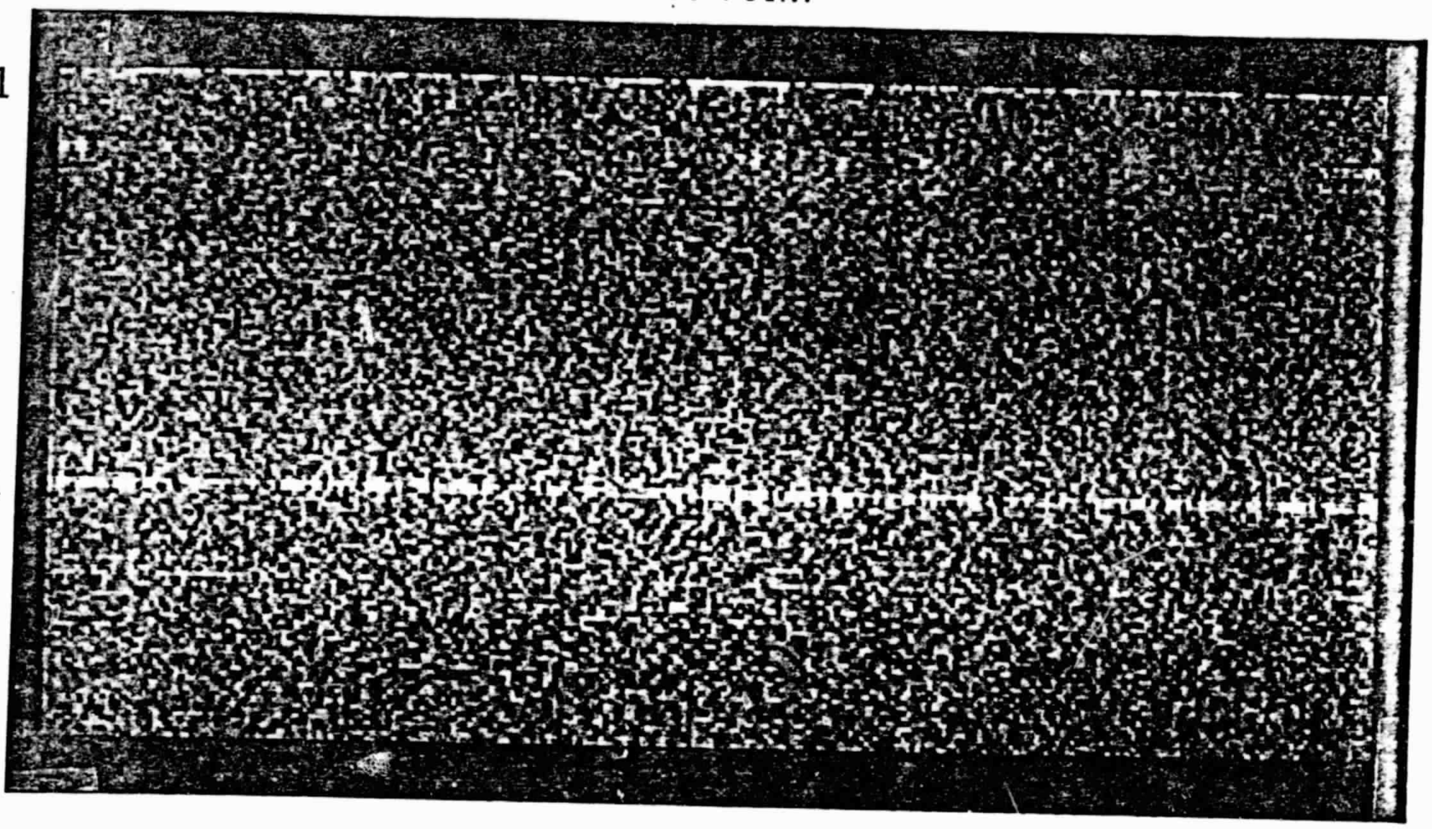

BAND 4

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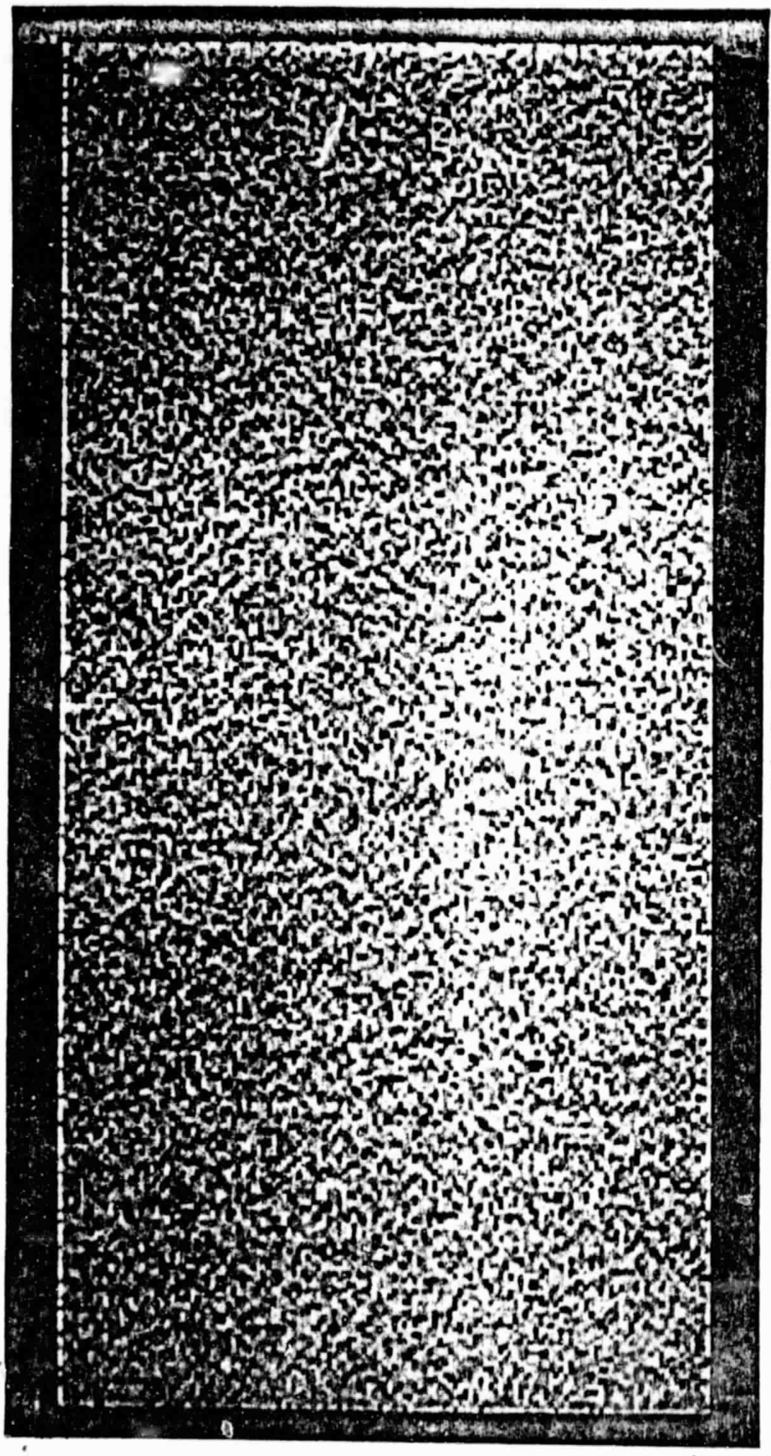

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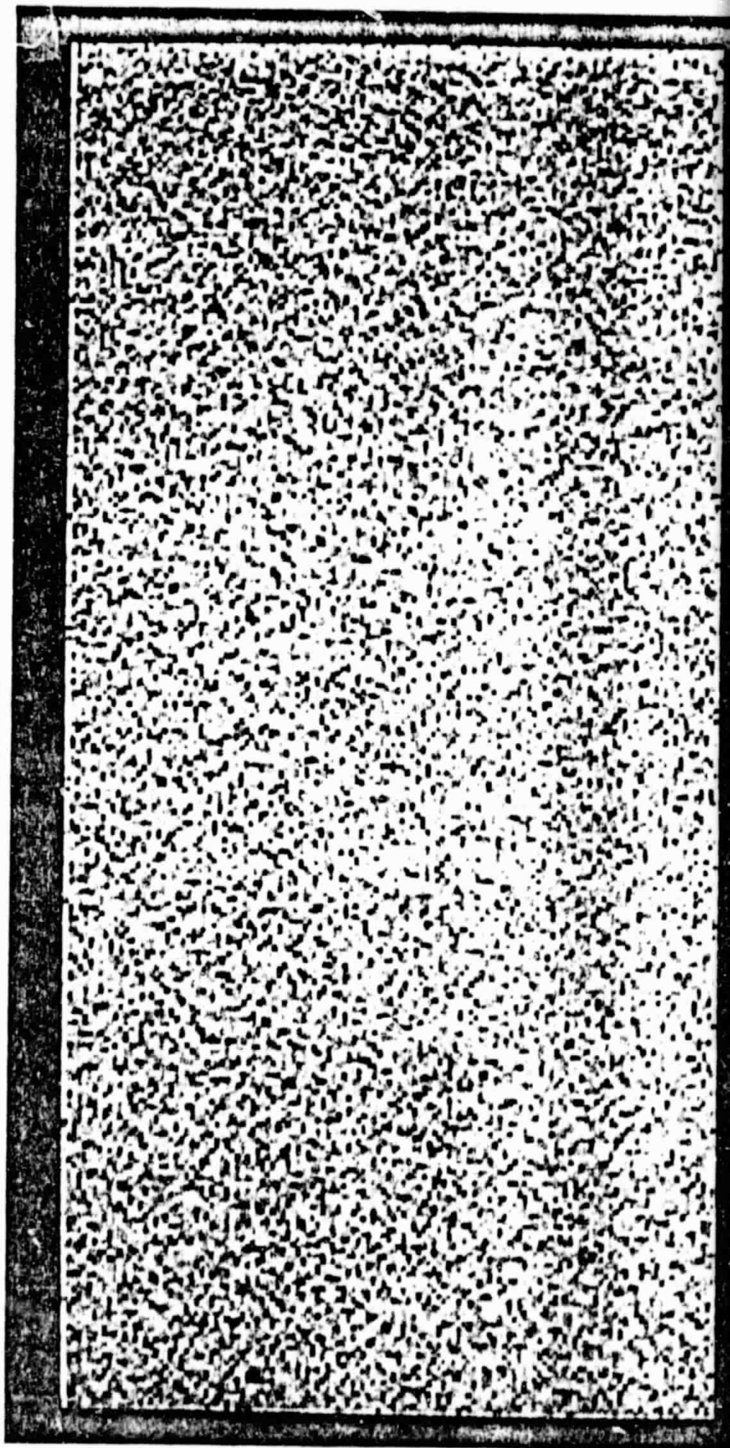
BAND 5



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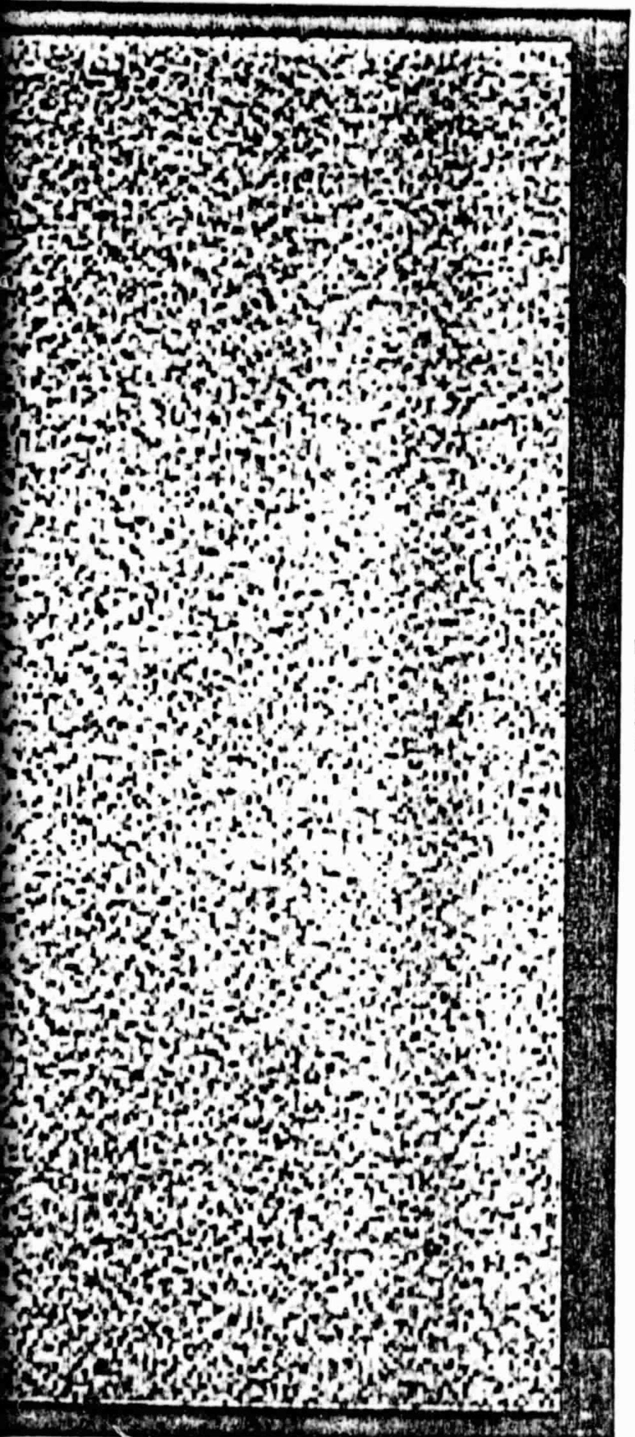

BAND 7

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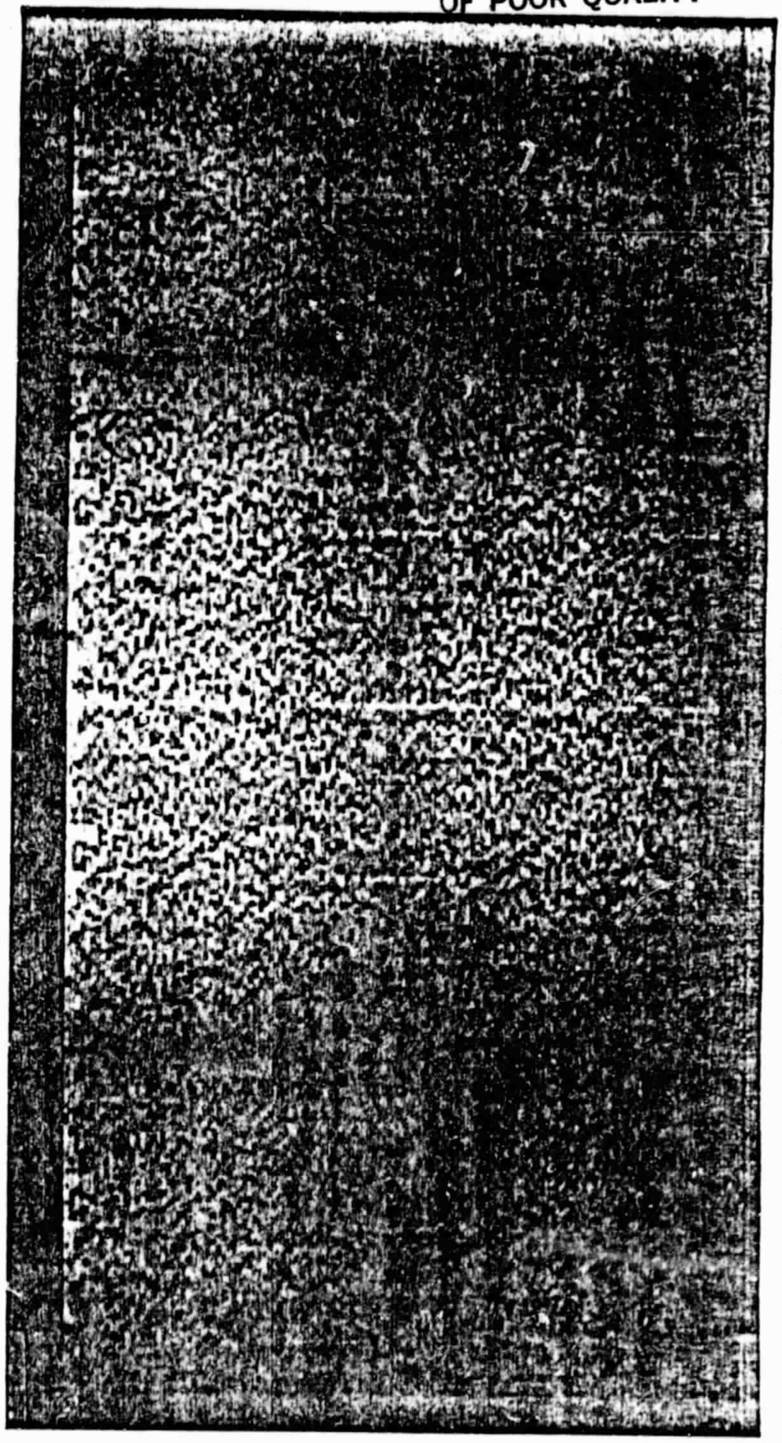

BAND 5

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PERIODIC NOISE COMPONENTS

THE PERIODIC NOISE COMPONENTS PRESENT IN BAND 3 (RED) DATA OF THE 256 x 256 WINDOW IN CHESAPEAKE BAY WATER FROM THE WASHINGTON, D.C. THEMATIC MAPPER SCENE WERE ISOLATED BY NOTCH FILTERING THEM FROM THE FOURIER TRANSFORM IMAGE (IGNORING SCENE CONTENT WHICH IS ASSUMED CONSTANT) AND PERFORMING THE INVERSE FOURIER TRANSFORM ON THE RESULTS. EACH NOISE COMPONENT IMAGE IS THE INVERSE FOURIER TRANSFORM OF SEVERAL LINES OF THE FOURIER TRANSFORM IMAGE. THE STRIPING IMAGE RESULTED FROM THE INVERSE FOURIER TRANSFORM OF THE (SINGLE) FIRST LINE OF THE FOURIER TRANSFORM IMAGE REPRESENTING THE ACROSS-SCAN COMPONENTS. THE LOW FREQUENCY NOISE IMAGE IS THE RESULT OF THE INVERSE FOURIER TRANSFORM OF THE 1/17.5 AND 1/13.5 CYCLES PER PIXEL FREQUENCY COMPONENTS TOGETHER. THE HIGH FREQUENCY NOISE IMAGE IS THE RESULT OF THE INVERSE FOURIER TRANSFORM OF THE 1/3.2 CYCLES PER PIXEL COMPONENT. THESE THREE NOISE COMPONENT IMAGES HAVE BEEN CONTRAST ENHANCED TO SHOW GRAPHICALLY THE NOISE PRESENT

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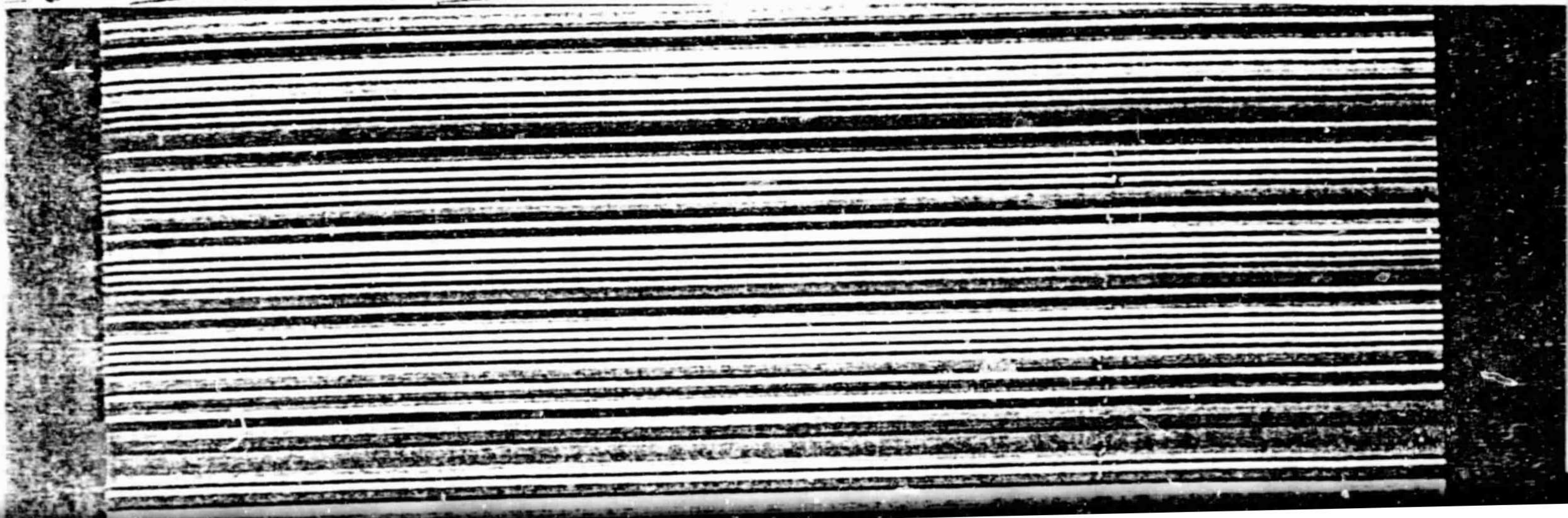

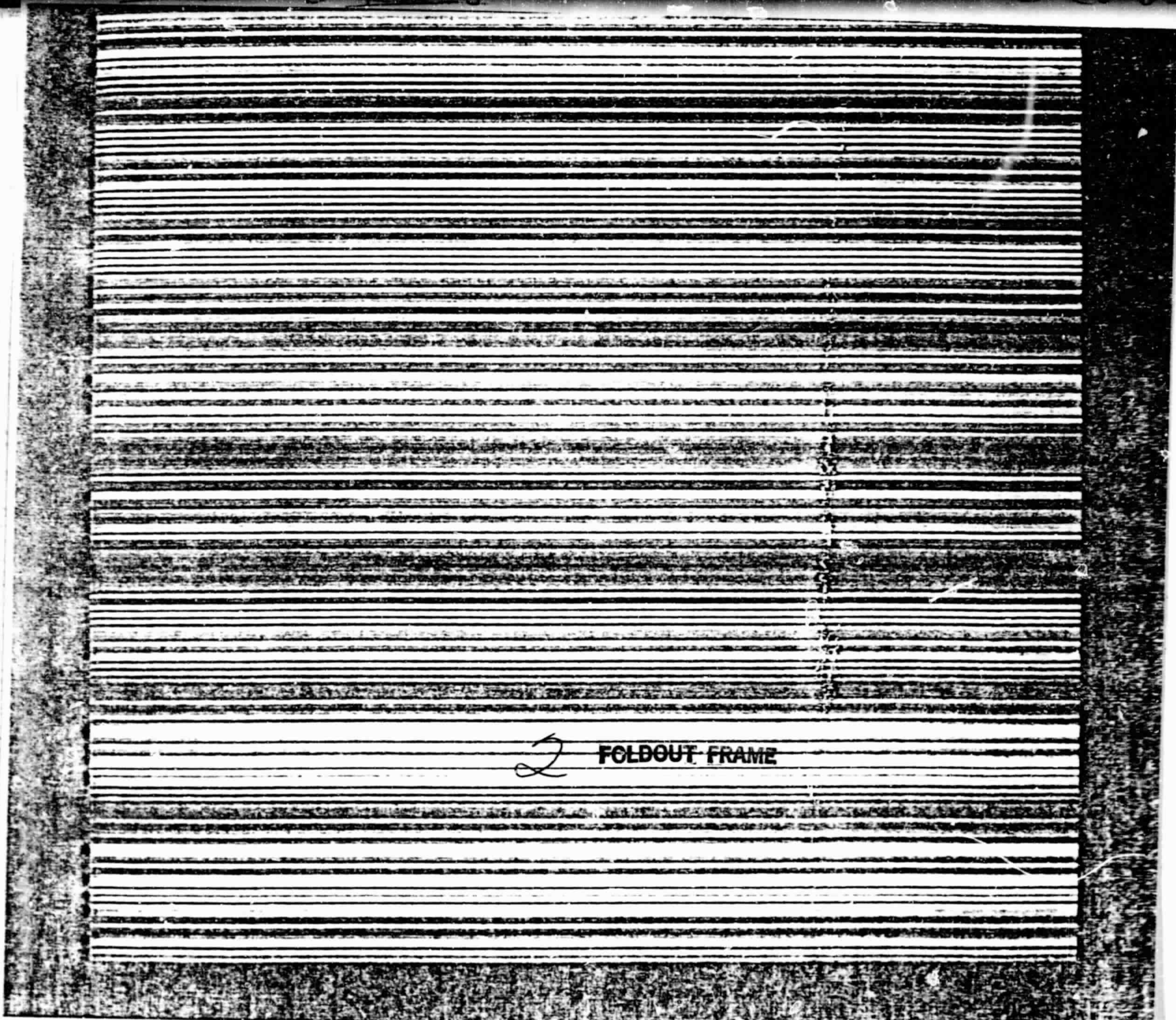

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Spatial frequencies represented by line 1 of Fourier Transform

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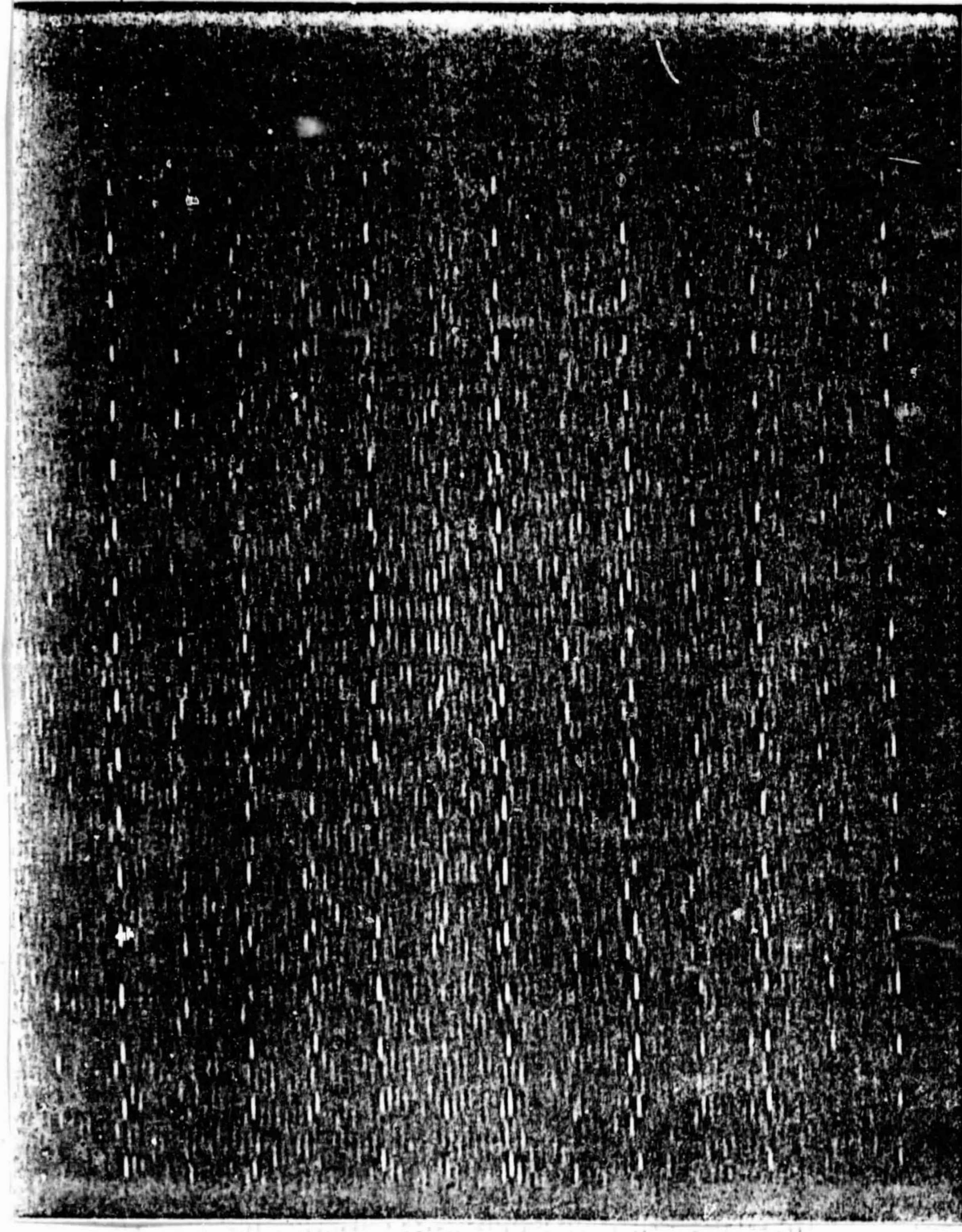

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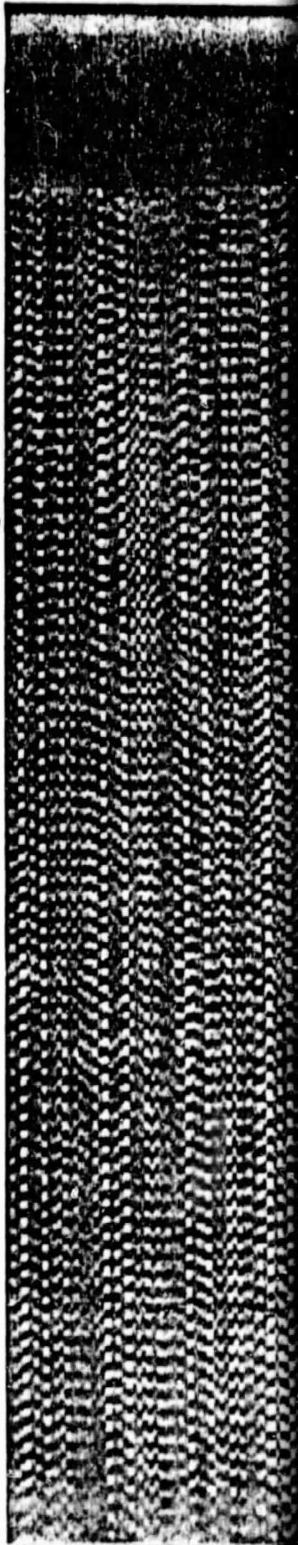
Spatial frequency is represented
by lines 13-24 of FFT



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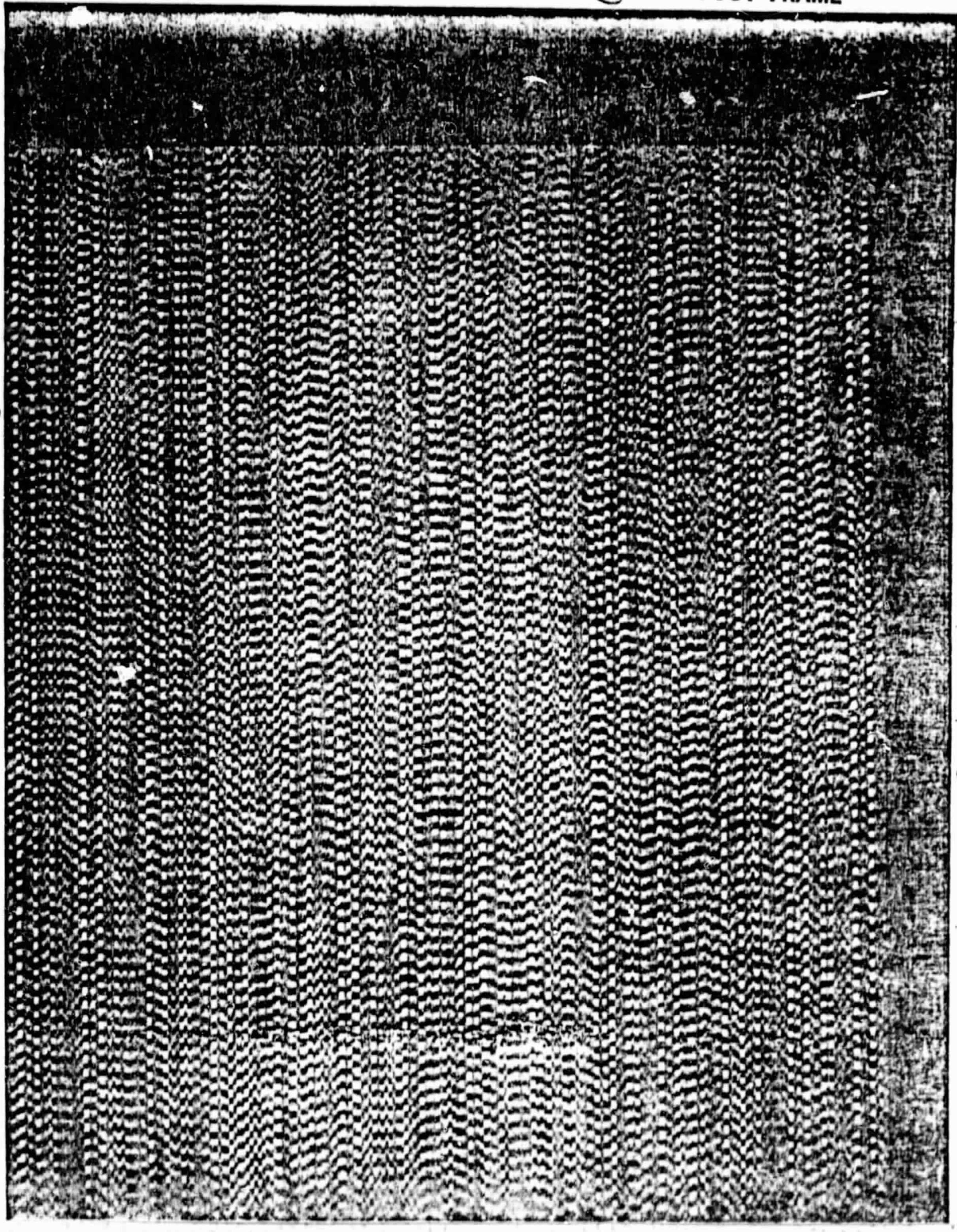
-5.7 4350 256 256)

Spatial frequencies represented
by lines 13-22 of FFT



Spatial frequencies represented by lines 78-83

5.7 4350 256 256)

CONCLUSIONS OF THE PERIODIC NOISE ANALYSIS

SOME STRIPING, OR INTERDETECTOR NOISE, IS OBSERVED IN ALL BANDS IN THE SAMPLE WINDOW FROM THE WASHINGTON, D.C. A-TAPE. SOME OF THE DETECTORS IN THE PRIMARY FOCAL PLANE (BANDS 1-4) HAVE ADDITIONAL NOISE AT APPROXIMATE SPATIAL FREQUENCIES OF 1/17.5, 1/13.5 AND 1/3.2 CYCLES PER PIXEL. THIS ADDITIONAL NOISE IS NOT PRESENT IN BANDS FROM THE COOLED FOCAL PLANE (BANDS 5-7). IN BAND 3, THE NOISE AT 1/3.2 CYCLES/PIXEL IS PRESENT ONLY IN DETECTORS 1, 9, AND 13 (WHEN NUMBERING FROM THE TOP OF THE IMAGE) WHILE THE NOISE AT 1/13.5 CYCLES/PIXEL IS CONFINED TO DETECTORS 16 AND 14.