Evaluation of ERTS-1 Image Sensor Spatial Resolution in Photographic Form

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Type I

Progress Report 9

Prepared for

NASA/ERTS Contract Number NAS 5-21849

Proposal Number 618

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April 1974

Introduction

This report describes progress on this contract during the period 1 January 1974 to 1 March 1974. OTF analysis for imagery from 11/29/72 is reported. The first steps in the two-dimensional OTF analysis of 4/4/73 imagery, both photographic and digital (CCT), is also presented.

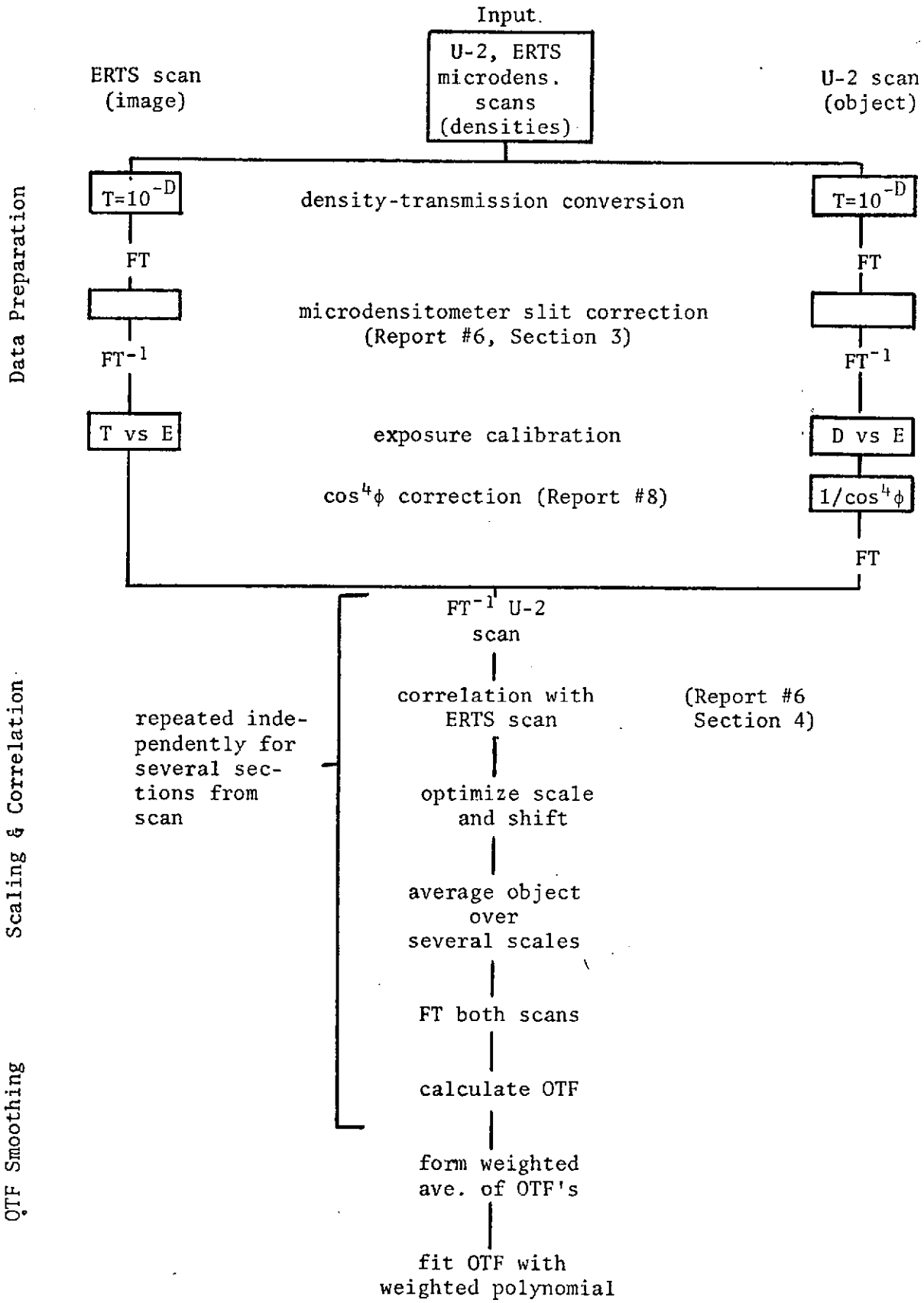
Discussion

OTF analysis of the microdensitometer scans of ERTS image #1129-18181 (taken 11/29/72) is essentially complete. Indicated variations between bands 4, 5, and 6 are considerable, but must await further verification by analysis of the other imagery sets. Some refinements in the analysis are expected but the complete basic OTF calculation procedure is programmed (and discussed below) and analysis of the 1/4/73 and 6/15/73 imagery will be accomplished relatively rapidly.

The two-dimensional OTF study of 4/4/73 imagery is in progress. As discussed in the Data Analysis Plan, only ERTS band 5 will be compared in 70-mm photographic and digital CCT form. A CCT read program for the CDC 6400 machine was recently acquired from the Office of Arid Lands at the University of Arizona.

Outline of One-Dimensional OTF Analysis

The procedure, as programmed, is as follows, (FT and FT^{-1} indicate forward and inverse Fourier transform respectively).


Input
U-2, ERTS microdens. scans (densities)
ERTS scan (image)
U-2 scan (object)
Data Preparation
$T=10^{-D}$
density-transmission conversion
$T=10^{-D}$
FT
FT
microdensitometer slit correction (Report #6, Section 3)
FT^{-1}
FT^{-1}
T vs E
exposure calibration
D vs E
$\cos^4\phi$ correction (Report #8)
$1/\cos^4\phi$
FT
FT^{-1} U-2 scan
Scaling & Correlation
correlation with ERTS scan
(Report #6 Section 4)
repeated independently for several sections from scan
optimize scale and shift
average object over several scales
FT both scans
OTF Smoothing
calculate OTF
form weighted ave. of OTF's
fit OTF with weighted polynomial

The data preparation steps were discussed sufficiently in earlier reports. Scaling and correlation is done as described in Report #6 with the addition of the object scene averaging over a range of scales (currently set at the range giving a ±2% change in correlation). This is to provide some smoothing in the object spectrum. Figures 1 and 2 show the average object spectra obtained in this way for scans 1 and 2 of the 11/29/72 imagery. Even after the smoothing there is considerable oscillation across the frequency scale.

Generally, 3 sections of data are analyzed from each scan, to allow for changes in scale across the U2 image format. An OTF is calculated for each section and then weighted by the object modulus at each frequency to form a final average OTF. The reasoning is that the higher the strength of the object at a given frequency, the better will be the measurement of the OTF at that frequency. The mathematical representation is,

$$\bar{\tau}(f) = \frac{\sum_i |O_i(f)|\tau_i(f)}{\sum_i |O_i(f)|}, \quad i \equiv \text{data section.}$$

Finally the OTF is fitted with a weighted polynomial of the form,

$$\text{MTF} \qquad |\tau(f)| = A + Cf^2 + Ef^4$$

$$\text{Phase TF} \qquad P(f) = Bf + Df^3 + Ff^5.$$

The OTF weighting goes as $|O(f)|^2$ assuming the variance in $\tau(f)$ depends on $O(f)$ in that form. Currently this is done on an intuitive basis and has not been verified experimentally.

Figures 3 and 4 give the MTF and PTF for ERTS image #1129-18181. Two scans and two sets of data are represented. The sets of data differ in that the ERTS image was scanned with two different length slits, set 1 giving a scale (with the U-2 slit) of 6.3 and set 2 a scale of 8. The same U-2 scan data were used in both cases. Figures 5 and 6 depict a final fit of ERTS band 5 data to the U-2 scan for each set. Set 2 shows a better match and higher scale. Independent scale measurements gave a scale of about 7.2. Since the scale range was bracketed by the slit lengths, the resulting OTF's are averaged for the two sets and shown in Fig. 7. The differences between bands may not be significant compared to the differences between scan 1 and scan 2, which is purely an experimental error. The variations between bands for $|O(f)|$ shown in Figs. 1 and 2 do not seem to be significant enough to cause a bias in the weighting procedure for calculating the OTF.

Analysis of imagery from 1/4/73 and 6/14/73 (being scanned) is progressing and should indicate whether these first results are true trends or not. The data from 4/4/73 will undergo two-dimensional scaling and OTF calculation, including a comparison with CCT imagery for band 5, and is discussed below.

Preliminary Two-Dimensional Analysis

Figures 8 and 9 are gray level computer printer outputs of the microdensitometer array scans for the U-2 and ERTS band 5 imagery from 4/4/73. Operator alignment was nearly perfect but the actual overlapping

region is indicated. A similar array will be extracted from the ERTS CCT for comparison.

A 2 to 3 month effort to locate a computer program to read the ERTS CCT's on the CDC 6400 computer recently ended when a program was developed (from an existing IBM 360 program) at the Office of Arid Lands, University of Arizona. The image tapes necessary for our work have been acquired and appear to be the correct CCT's.

Effect of Spectral Mismatch between U2 and ERTS MSS

An interesting trend appears in the OTF analysis for 11/29/72 imagery. The average mean squared difference between optimally matched U2 and ERTS images was tabulated and is given in Table 1. Band 5 shows a consistent tendency for poorer matching between the aircraft-spacecraft data. The most interesting explanation is that this is caused by the greater discrepancy between the sensor spectral sensitivities for this band shown in Report #3, Fig. 9. Scan misalignment (perpendicular to scan direction) could also cause this trend, however. Again, analysis of other imagery is necessary to verify any trends.

TABLE 1

AVERAGE M-S DIFFERENCE

BETWEEN OBJECT AND IMAGE

11/29/72 Imagery

	Band		
	4	5	6
set 1, scan 1	.0124	.0270	.0146
set 1, scan 2	.0136	.0282	.0129
set 2, scan 1	.0132	.0182	.0167
set 2, scan 2	.0139	.0251	.0188

Current Status of Acquired Imagery

Set	Flight Date	Aircraft (A/C) Vinten	Aircraft (A/C) Scanner	ERTS-1 MSS	Microdensitometer Scans	OTF Analysis
1	8/22/72 8/23/72 Arizona	✓	NA	✓	-	-
2	11/29/72 San Francisco	✓	✓*	✓	✓	✓
3	1/4/73 San Francisco	✓**	✓*	✓	✓	in progress
4	4/4/73 San Francisco	✓	✓*	✓	✓	in progress
5	6/15/73 San Francisco	✓	✓	✓***	in progress	-
6	Requested for 10/73	on order	not requested	-	-	-

* Scanner data not suitable for analysis because of severe geometric distortion arising from the lack of a gyrostabilized platform on the A/C.

** Band 001 (green) malfunction, no imagery.

***ERTS-1 imagery of San Francisco was not acquired on 6/15/73. Therefore imagery from the previous (5/28/73) and following (7/3/73) cycles and from the adjacent 6/14/73 pass have been acquired.

Acknowledgements

Mead Technology Laboratories (Dayton, Ohio), an Industrial Associate of the Optical Sciences Center, is performing the microdensitometer scanning for this contract. The Office of Arid Lands, University of Arizona, supplied a CCT tape reading program.

ERTS Frames Studied

Data Set	Frame #'s	Bands
11/29/72	1129-18181	4, 5, 6
4/04/73	1255-18183	5

jmr

12-184

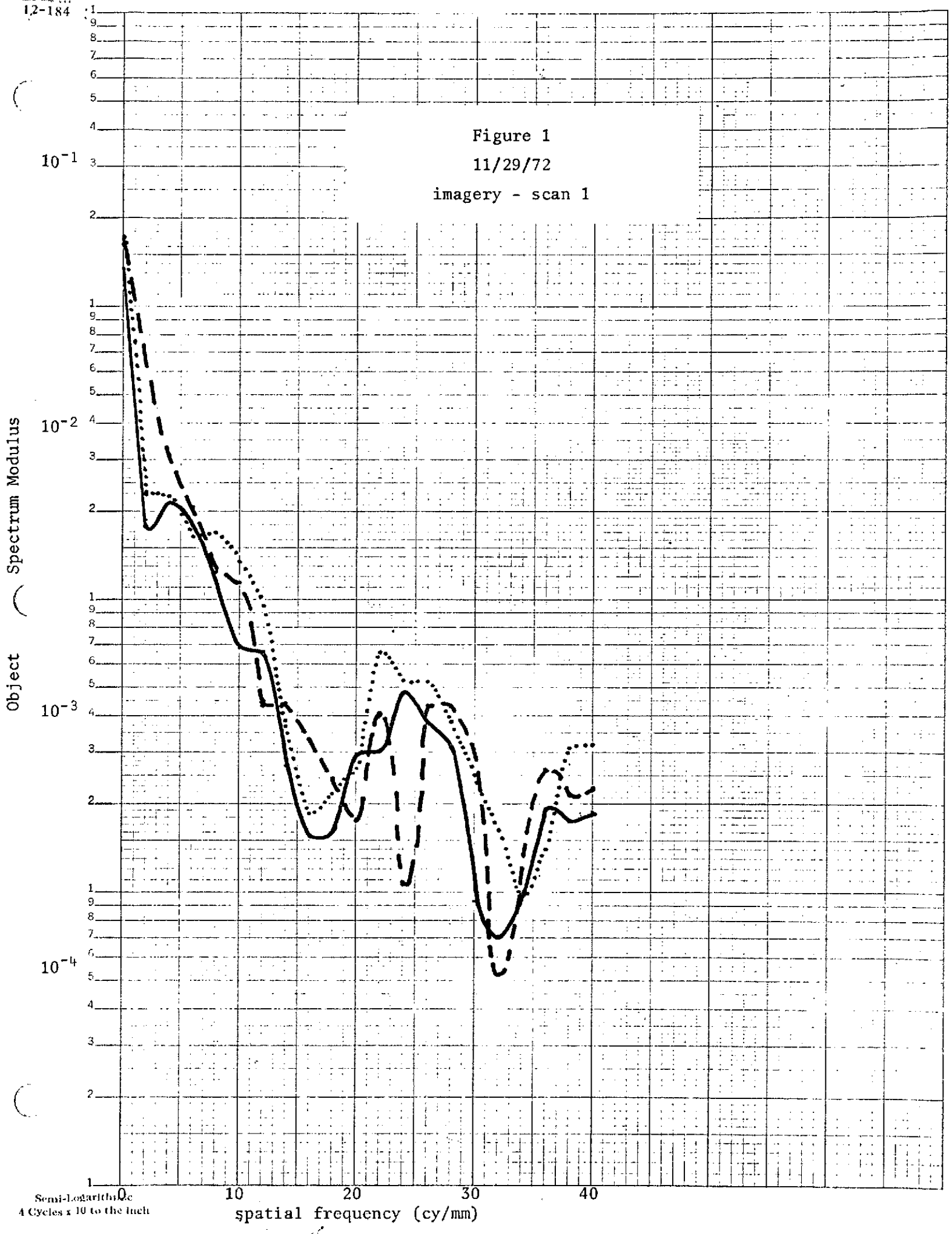
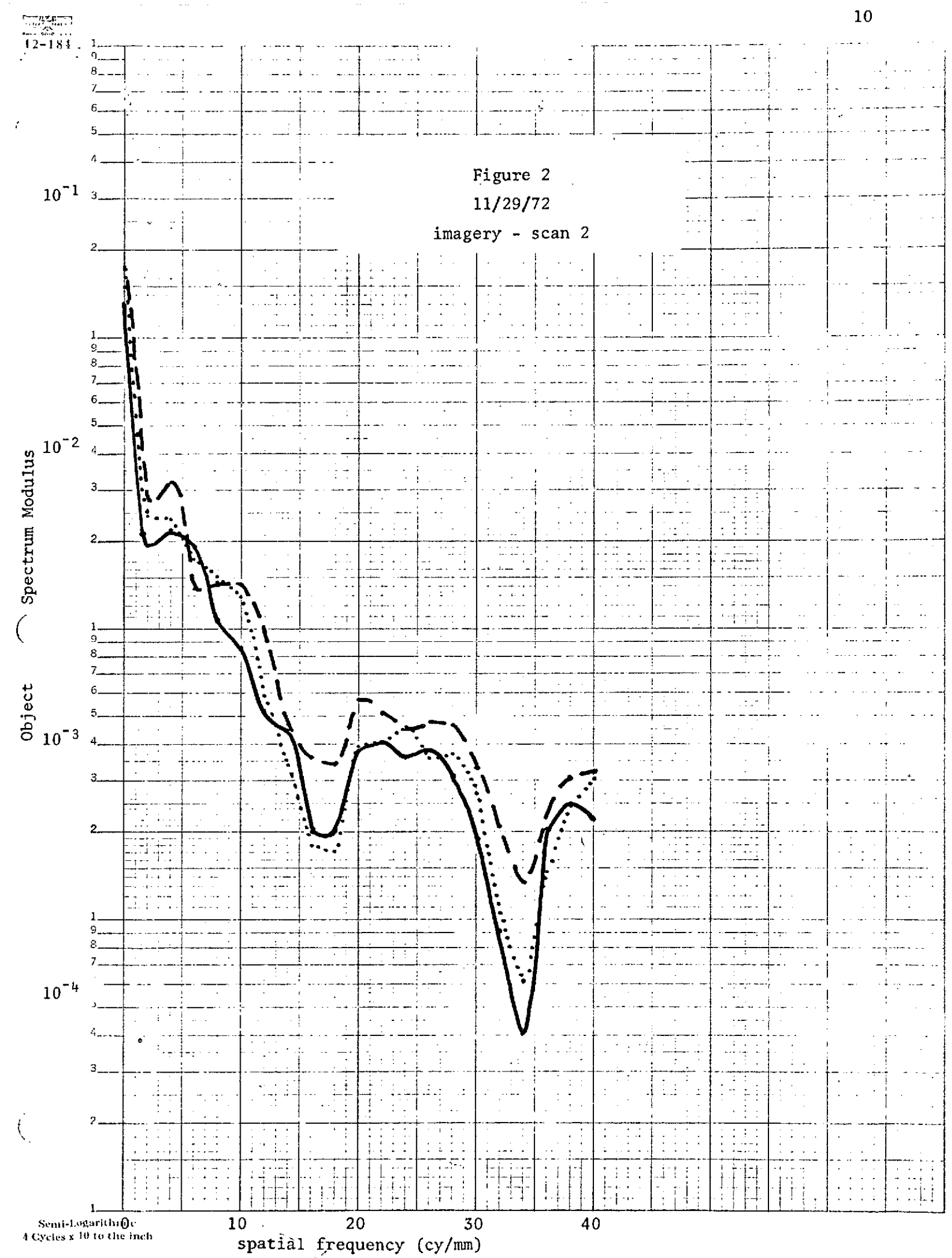


Figure 1
11/29/72
imagery - scan 1
Object Spectrum Modulus
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
10
20
30
40
spatial frequency (cy/mm)
Semi-Logarithmic
4 Cycles x 10 to the Inch

Figure 2

11/29/72

imagery - scan 2



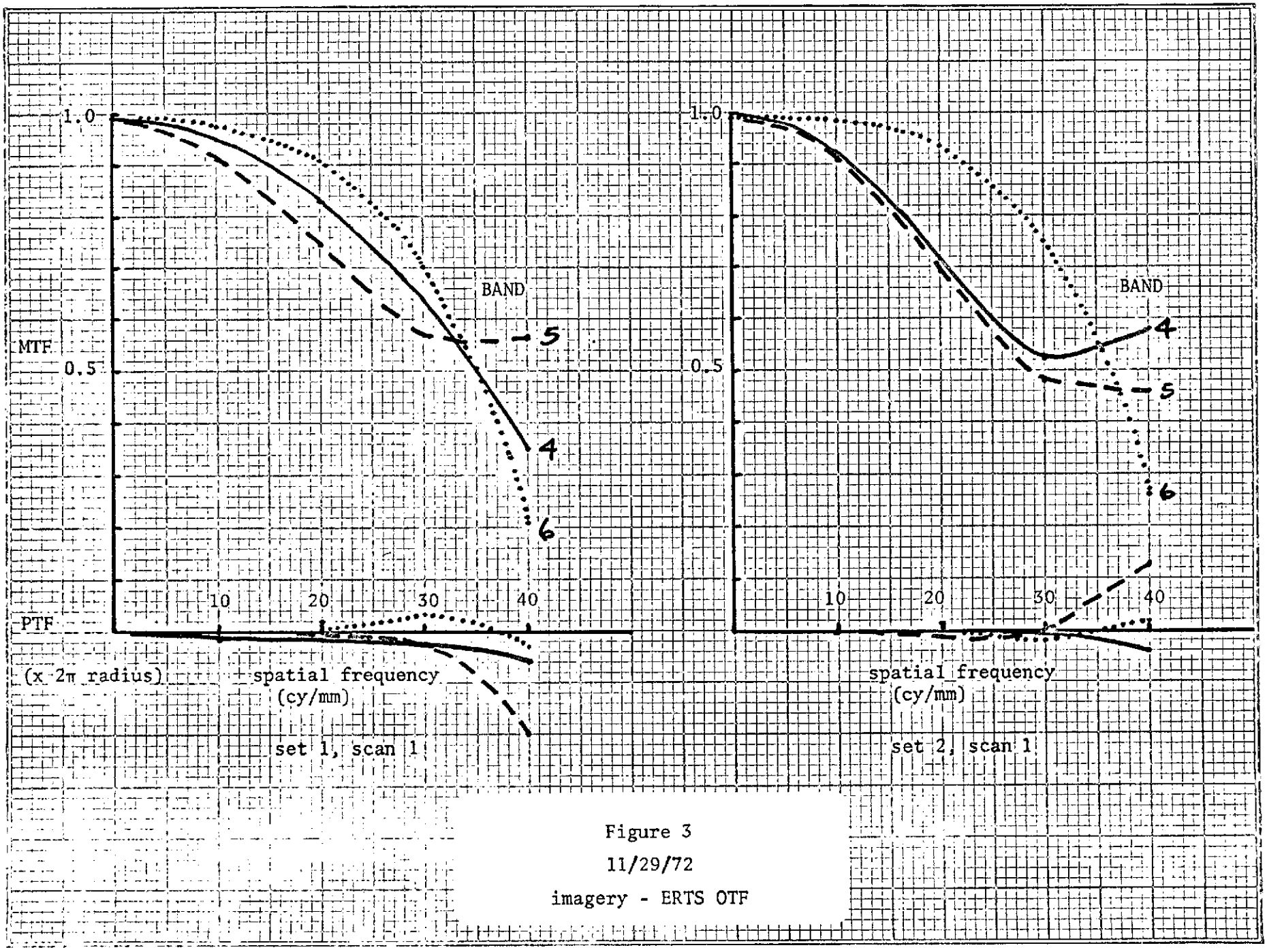


Figure 3

11/29/72

imagery - ERTS OTF

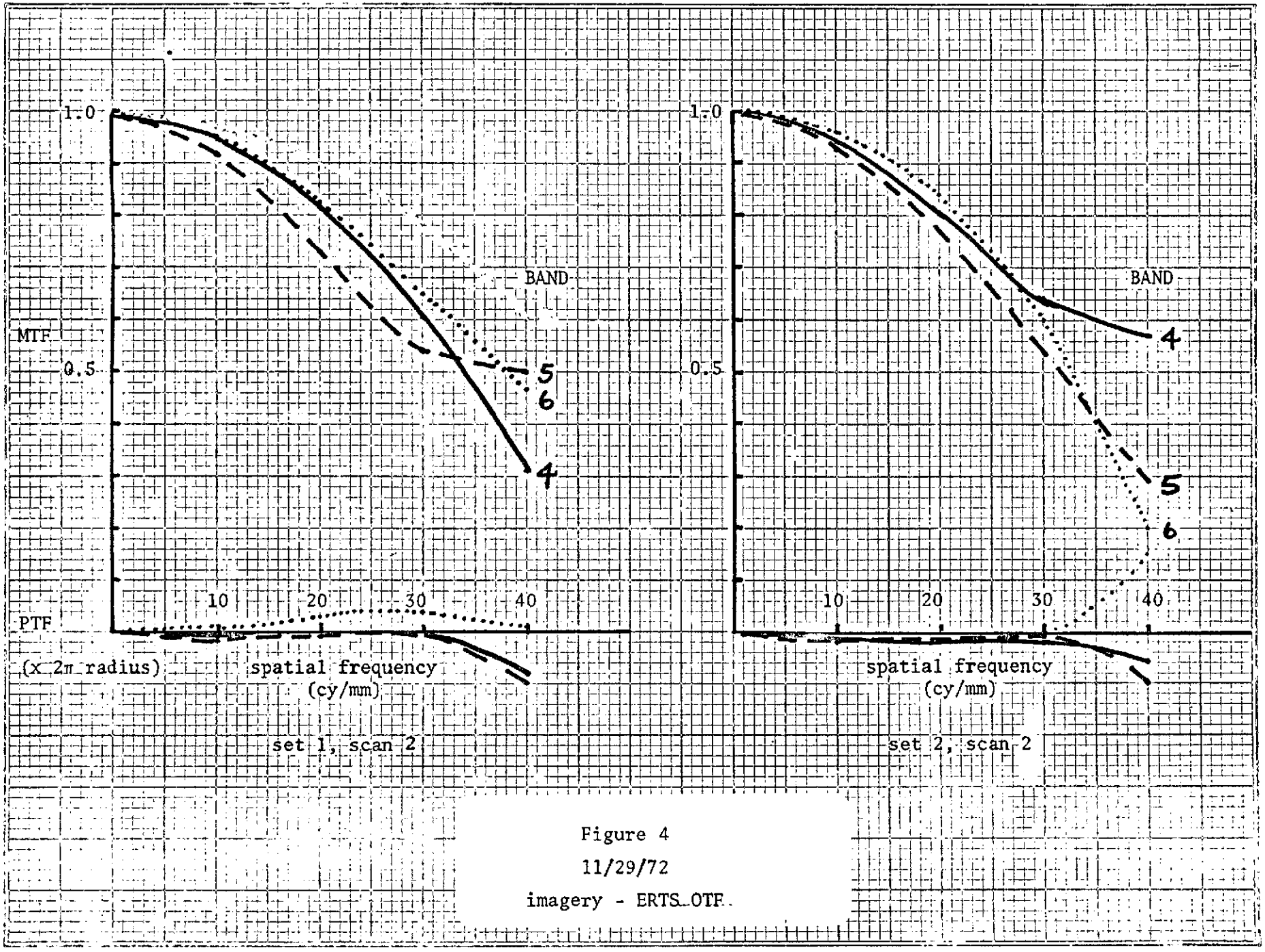
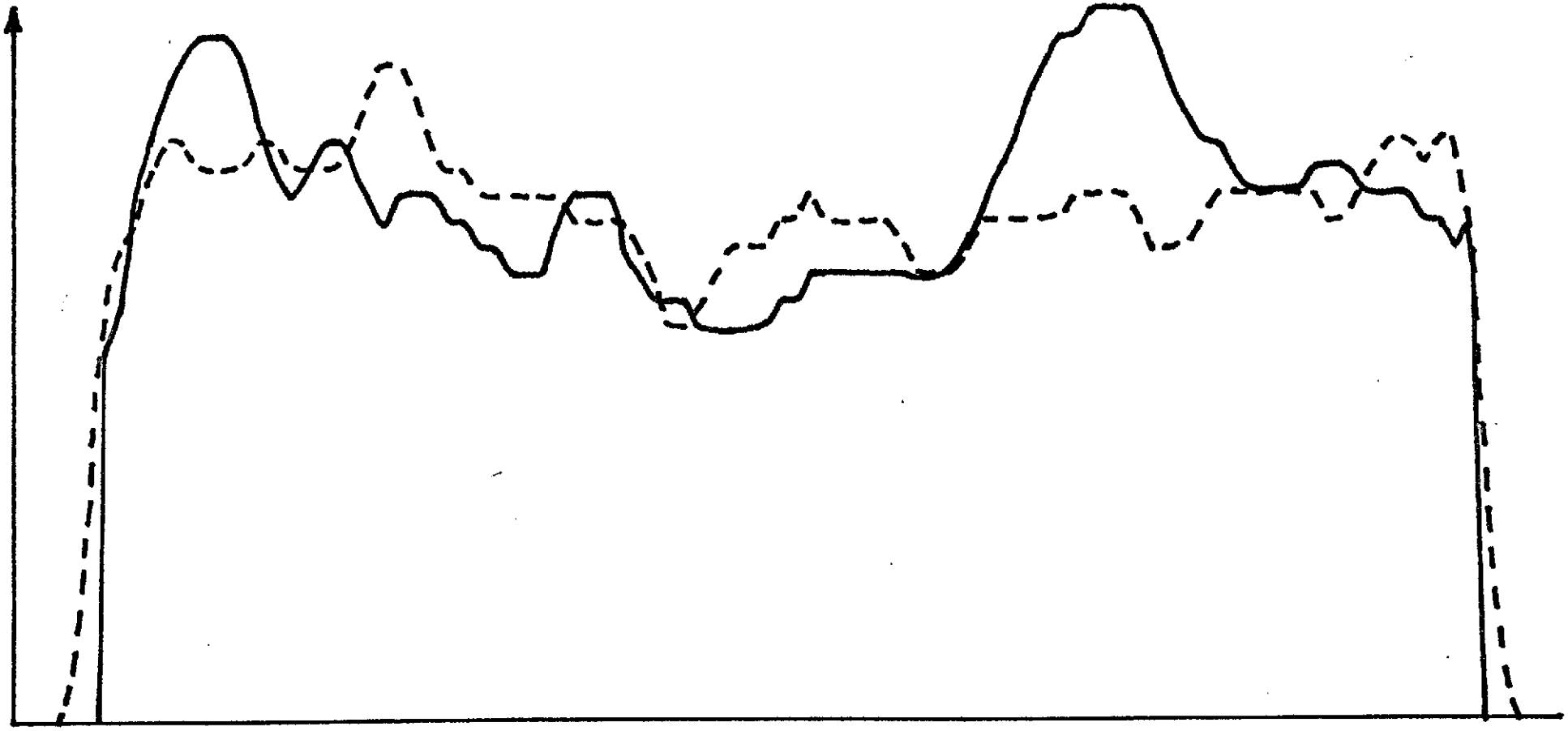


Figure 4

11/29/72

imagery - ERTS OTF



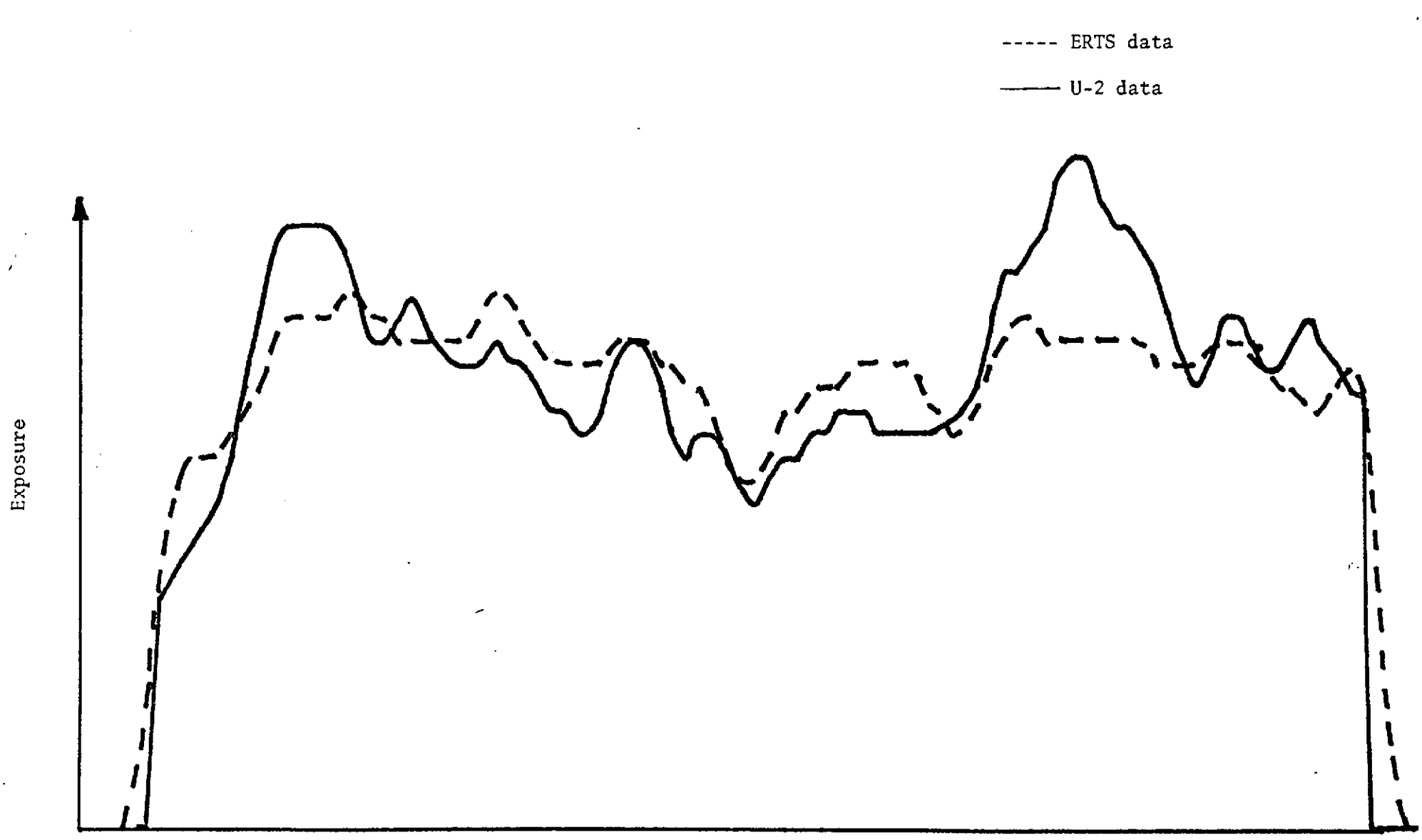
spatial coordinate

set 1, scan 1

Figure 5

11/29/72

imagery - Band 5



set 2, scan 1

Figure 6

11/29/72

imagery - Band 5

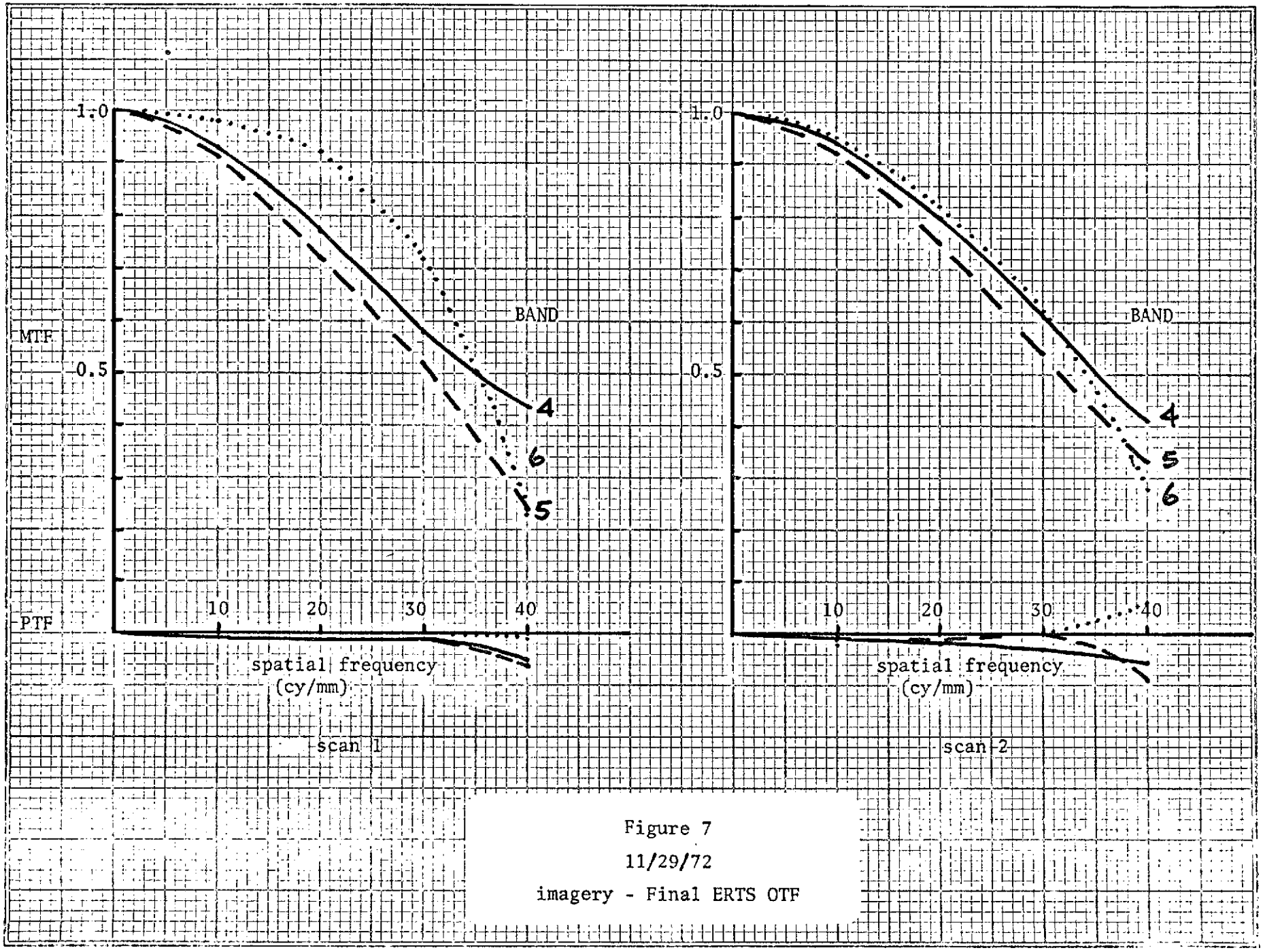
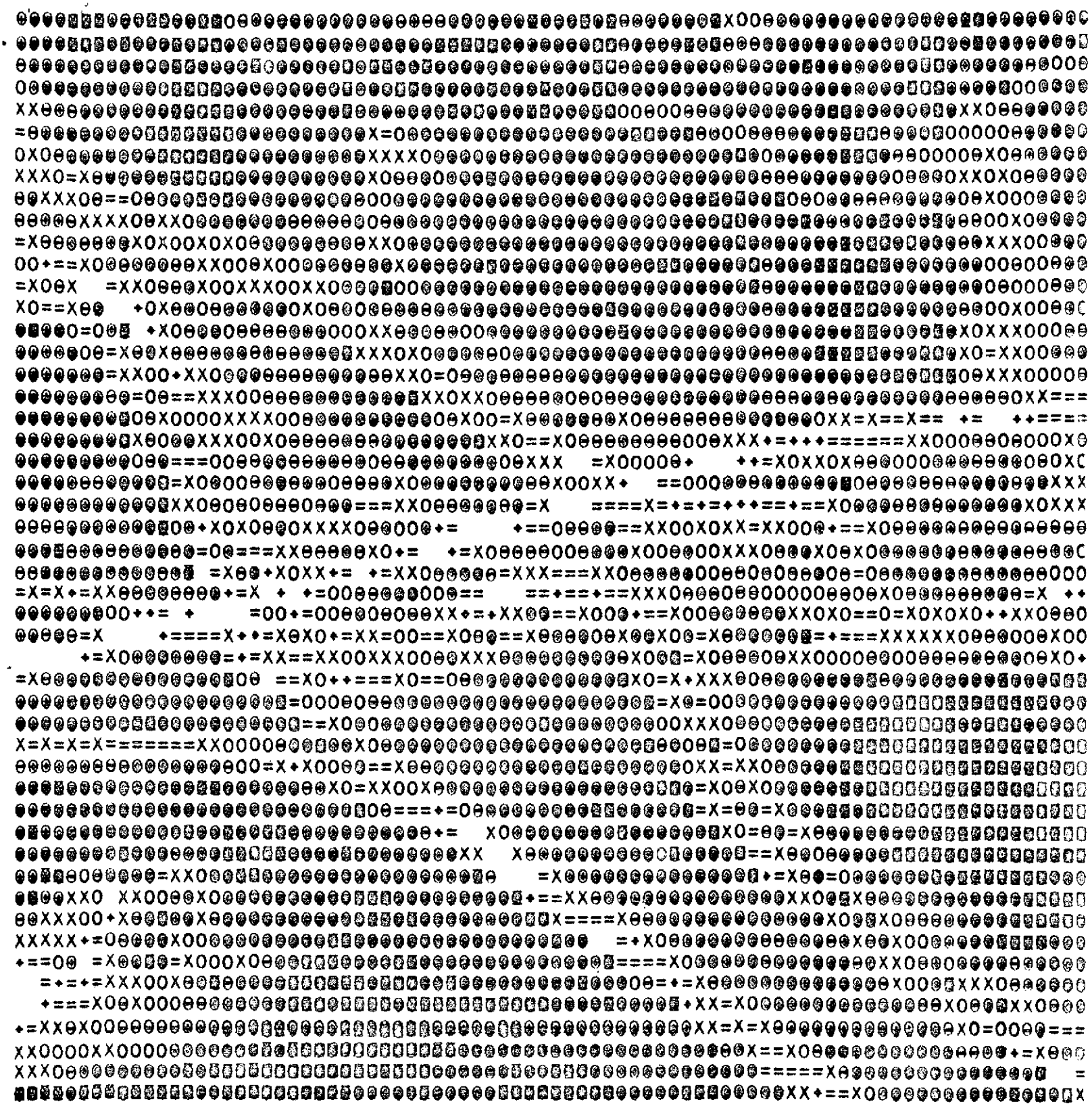


Figure 7

11/29/72

imagery - Final ERTS OTF



MAX VALUE : 155 MIN VALUE : 112

Figure 8

Gray level picture of microdensitometer scan of U-2 imagery from 04/04/73

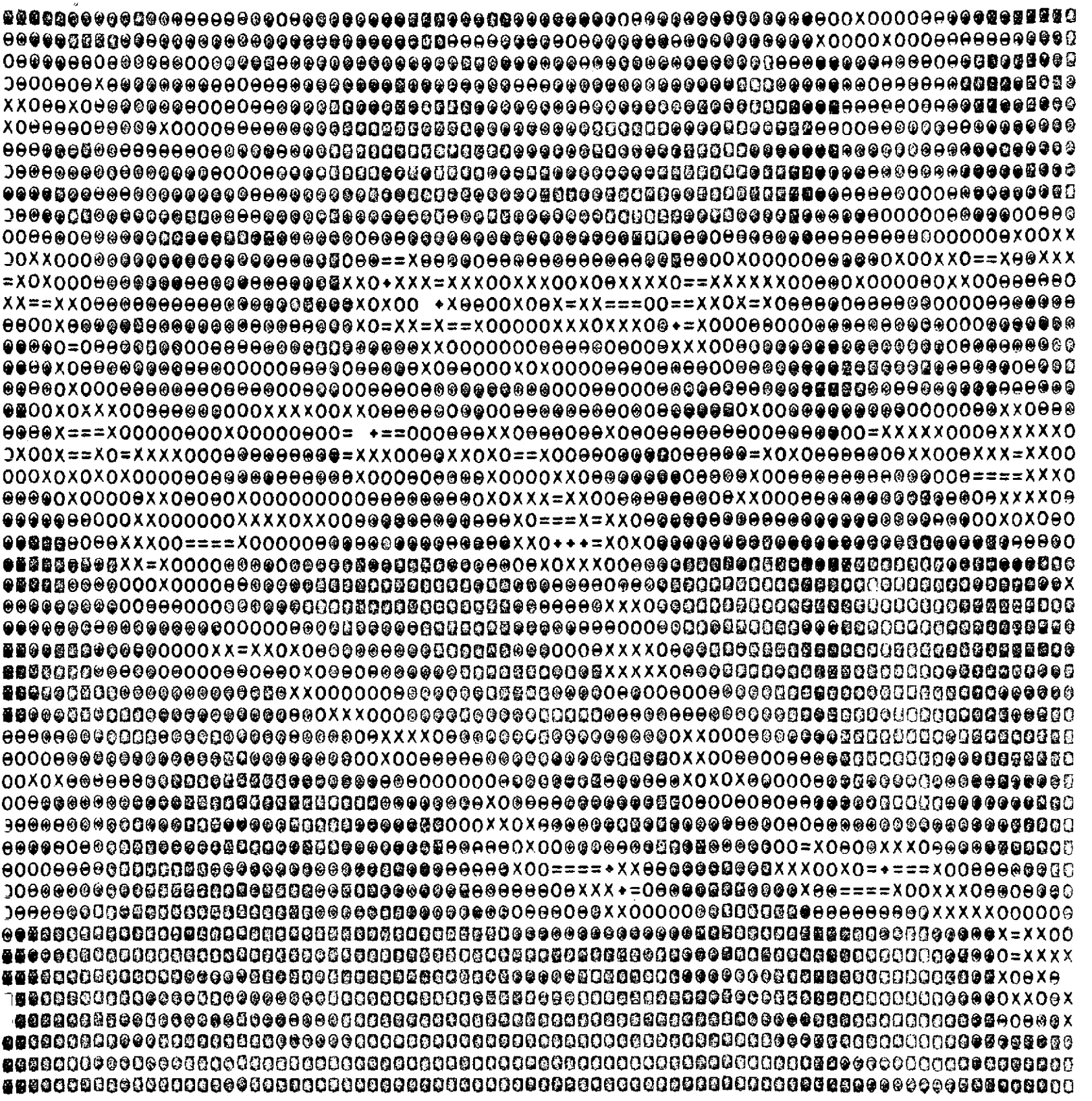


Figure 9

Gray level picture of microdensitometer scan of ERTS imagery from 04/04/73

REPORT SUMMARY

Evaluation of ERTS-1 Image Sensor Spatial Resolution in Photographic Form

Type I Report # 9

Category 9a - Sensor Technology

This report describes progress on contract number NAS 5-21849, during the period 1/1/74 - 3/1/74. A flow chart depicting the complete OTF analysis procedure and OTF's from ERTS image # 1129-18181 are given. The first steps in the two-dimensional analysis of ERTS image # 1255-18183 are also described.