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APPROACHES TO ON-BOARD GRIDDING OF APT PICTURES

EDITED BY

ROBERT P. BARTLETT

ARACON GEOPHYSICS COMPANY

VIRGINIA ROAD

CONCORD, MASSACHUSETTS

MARCH 1965

SUMMARY REPORT

PHASE I

UNDER

CONTRACT NO. NAS 5-9012

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

AERONOMY AND METEOROLOGY DIVISION

GREENBELT, MARYLAND

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ABSTRACT

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Cloud-cover pictures taken with the Automatic Picture Transmission system designed for the Nimbus satellite and experimentally tested on a TIROS satellite, do not pass through a central processing station. These pictures are received directly by the ultimate user from the satellite. Any geographic referencing of the data in the pictures (latitude-longitude grid) must be accomplished by the receiver (user) of the data or must be added to the video picture in the satellite. This report contains the results of a study of the various methods by which the latitude-longitude grid can be added to the video picture on board the satellite. Both analog and digital approaches to onboard gridding were considered. Several digital approaches were found feasible. These approaches call for computer computation of the picture grids on the ground, transmission of the grid line data to the satellite for storage, and logic circuitry to withdraw the data from memory and electronically mix grid line marks into the video during the picture scan. The approaches judged feasible are: (1) straight-line method where the curved grid lines are approximated with straight line segments whose slope, length and initial coordinates are transmitted to the satellite, (2) coordinate method where the individual image plane coordinates of each mark are transmitted, (3) slope-coordinate method where starting coordinates and a slope range are specified to reduce the information necessary to obtain the image plane coordinates of each mark. On the basis of preliminary designs, the flight system weight and power requirement is approximately 7-8 pounds and less than 2 watts respectively.

Author

FOREWORD

This report is a condensation of the Phase I Final Report covering work performed under Contract NAS 5-9012. Phase I of this contract was a study to determine and compare the most practical approaches to on-board gridding. For a more complete treatment of the results of the study, the reader is referred to the unabridged Final Report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENT

This report contains contributions from several individuals and companies. Contributors to the report are listed below:

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- Mr. Robert P. Bartlett
- Mr. Robert F. Smiley
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- Mr. Samuel Goldman
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ADCOM, Inc.
- Dr. Steven Sussman

SECTION 1

INTRODUCTION

1.1 GENERAL

The Automatic Picture Transmission (APT) system is designed to permit meteorological activities to obtain promptly, satellite cloud pictures over a substantial area. A simple and inexpensive ground station, located in the meteorological office, can receive pictures taken within a radius of over 1,000 miles. This direct satellite readout avoids the problems of re-transmission of pictures, elaborate communication equipment, degradation of pictorial content, and "aging" of perishable meteorological data in a complex communication and data handling network.

The APT camera takes a snapshot, the image being retained on the screen of a long persistence vidicon. The television scan of this fixed image is very slow, the 800 line picture being scanned in 200 seconds. A continuous broadcast of the video signal is made from the satellite. This broadcast can be received by anyone, within acquisition range, equipped with the appropriate receiving equipment.

Geographic referencing (gridding) is now carried out by superposition of a transparent overlay map on the picture.* Correct location of the overlay on the picture requires accurate calculation of the satellite position at picture time, using appropriate ephemeris data.

This report summarizes studies made of an "on-board" gridding facility. Briefly, the grids are computed in advance at a central facility for pictures to be taken at programmed times. The grid parameters are coded in suitable form and are transmitted from a command and data acquisition facility to the spacecraft, where they are retained in a suitable memory. During the scanning and transmission of each APT picture, a small special purpose computer on the spacecraft expands the grid parameters to a suitable form for gridding. The on-board computer generates "blips" at appropriate times which are superposed on the transmitted signal. When the picture is formed on the ground, the blips form a superposed latitude-longitude grid.

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* Reference is made to the "APT Users' Guide", AFCRL-63-655, June 1963 for a detailed description of APT gridding and antenna programming procedures.

Manual gridding and antenna tracking procedures currently in use for APT were developed by ARACON. In use, they have proved to be effective and fairly accurate. However, significant errors (as large as 100 miles) can occur due to (1) the deliberately introduced error in the map projection (necessary to reduce the number of overlay maps to a manageable file), (2) difficulties in obtaining an accurate picture time, (3) the inability of station operators to cope with attitude variations as effectively as a CDA computer-operation.

Additionally, a significant amount of operator time is required to plot the satellite track, derive the antenna program, determine satellite subpoint at picture time, determine picture azimuth, find and superpose the proper map overlay on the picture, adjust for apparent yaw error, and finally trace the grid. While we have not conducted time and motion studies, it would appear that the operator has time for little besides a cup of coffee between passes, so that for a 3-pass day he may be tied up for some 250 minutes or over four hours.

If the operator can be released by on-board gridding for other weather station duties during this period, a significant manpower economy is possible. Multiplied by the potential number of APT stations in the world, which we will conservatively take at 200, a two hour saving becomes 400 hours per day. At U.S. direct labor rates, this approaches $500,000 annually. More importantly, it may make the critical difference in establishing the economic feasibility of APT in marginal situations. A modicum of automation in antenna control could then reduce the requirement for operator intercession to an attractive minimum.

If nighttime DRIR (Direct readout high resolution infrared system) is added to the APT capability, an on-board gridding system would more than double the labor saving mentioned above. Manual IR gridding has proved to be extremely laborious, largely because of the nature of the projection arising from the circular scan of the HRIR instrument. A fixed IR grid can be used with the resulting projection only if the recipients of the data are willing to accept a completely arbitrary set of values for the geographic grid lines. This would considerably complicate the task of cross-referencing the IR data with video data and earth geography.

There are other reasons to supplant manual methods of gridding at the receiving station. The APT stations are not able to receive telemetry data from the satellites. As a result they are unable to correct for the effects of attitude error in the geographic referencing of the picture data. An on-board gridding system can make corrections in the picture grid for roll and pitch errors determined from attitude sensor outputs at the time of picture taking. Further, the ground operator seldom has a good fix on picture time.

ERRATA SHEET

FOR

APPROACHES TO ON-BOARD GRIDDING OF APT PICTURES

SUMMARY REPORT

PHASE I

MARCH 1965

Page 4-1, Paragraph 1

Replace with: "Analog approaches have been eliminated from consideration. Of the digital methods, four approaches show sufficient promise to warrant a detailed comparison. These are:"

Page A-1, Line 8

Change "or" to "of"

Although at present a station operator must carefully set antenna drive controls as a function of time, the satellite tracking procedure can be considerably simplified. Indeed, the capability for line drawing and annotation of an on-board gridding system in itself offers a method of simplifying the tracking procedures. Tracking data for tomorrow's orbits can be included in today's APT pictures (see Appendix A). The combination of an on-board gridding system and simplified tracking procedures will make the automatic picture transmission system a truly "automatic" system. This would be especially beneficial to military or commercial users of the APT data who have little or no knowledge of satellite tracking and data reduction procedures.

If the APT system is to take its proper place in the weather station as an operational tool providing weather data with as little attention required of the man in the station as demanded by the weather facsimile devices, the manual procedures now mandatory must be eliminated. An onboard gridding system will eliminate the greater percentage of time consuming and error inherent procedures now needed.

A variety of methods can be potentially applied to the task of on-board gridding; this report is a condensed study of advantages and disadvantages of each method.

1.2 SYSTEM REQUIREMENTS

The on-board gridding system, if practical, will be flown on future APT satellites. However, such a system is potentially useful on board any cloud cover observing satellite. In studying the possible approaches to on-board gridding, all constraints common to the meteorological satellites now in use or in active planning were considered. The range of height for the meteorological satellites was fixed between 400 and 800 nautical miles. Although it is presumed that the satellite orbits will be circular, consideration was given to the effects of elliptical orbits. The study assumed the use of the present APT camera system, the 107° diagonal angular aperture forming the primary constraint for this system. The following APT system parameters were assumed.

1.	Pictures per orbit	10 to 15, dependent on height
2.	Field of view	107° diagonal
3.	Number of lines per frame	800
4.	Number of elements per line	784

5. Frame rate — 208 seconds
6. Frame scanning time — 200 seconds
7. Line rate — 250 milliseconds/line
8. Exposure time — 40 milliseconds

The latitude-longitude lines may be represented by discontinuous grid marks. Maximum spacing between grid marks called for in the original specification is one percent of the side dimension in either X or Y displacement on the picture plane. The shape of the grid marks was specified as two black followed by three white picture elements, one line thick. Some form of annotation is to be included in the picture to allow the data user to readily identify the grid lines. The grid spacing as initially specified is as follows:

<u>Latitude spacing on picture</u>

a. 2^o from $0-70^o$ latitude north and south.
b. 4^o from $>70^o$ latitude north and south.

<u>Longitude spacing on picture</u>

a. 2^o from $0-40^o$ latitude north and south.
b. 4^o from $40-70^o$ latitude north and south.
c. 8^o from $70-82^o$ latitude north and south.
d. 40^o from $>82^o$ latitude north and south.

The maximum error of grid marks is to be no greater than one percent. The error is defined:

$$e = \frac{P_t - P_a}{s} \quad (100)$$

where

e - percent error
P_t - true grid point
P_a - actual grid mark
s - side dimension of picture

It is assumed that the time of picture taking is known in advance. It is also assumed that the approximate satellite attitude for the time of picture taking will be known. In particular for Nimbus, which is actively controlled in all three of its axes, the attitude should be constant. However, the remaining error may be sufficient to cause some error in APT picture location. Consequently, an on-board gridding system should be capable of including the possibility of grid corrections from on-board attitude sensors.

Computers are available in the ground stations for computation of the picture grids. However, an important constraint is that the computational time be short to avoid interfering with the station operations normally assigned to these computers.

Since a possibility of using the existing command channel of the Nimbus satellite exists, the capabilities of the command channel form a part of the specifications. Command receiver specifications are:

Frequency	149 Mc
Bandwidth	40 kc, i. f.
S/N ratio	17 dB at 20 kc bandwidth of reciver output, worst case

Finally, the cost of an on-board gridding system is a constraint; it must be commensurate with the advantages gained.

1.3 APPROACHES CONSIDERED

A number of analog schemes were studied. These included systems which optically add the grid to the video picture and systems in which the grid, stored on board the satellite, is scanned and mixed with the signal during transmission. Some of the forms of grid storage considered were:

1. Storage of the picture grid on continuously advancing film strips.
2. Storage of the picture grid on a cylinder.
3. Storage of the picture grid on a sphere.

Digital approaches to on-board gridding are:

1. Ellipse Method - In the ellipse method the coefficients of the ellipses can be transmitted and stored in the satellite. At the time of transmission of the picture, the coordinates of the ellipse section can be computed from the stored coefficient and mixed with the picture.

2. Straight Line Method - In the ground station computer the latitude-longitude lines can be fitted with straight line segments restricted to the specified maximum error. The picture plane can be represented by 800 Y coordinates representing the scan lines and 800 X coordinates representing the elements of the

scan lines. The initial coordinates and the slope of the line segments are then transmitted and stored. The information for a particular section is then extracted from the main memory and compared with the scanning of the picture to mix in grid marks at the proper locations as the picture is scanned for transmission. The ΔX of the slope is added to the previous mark coordinate to locate the next mark. The initial Y coordinate of the following line segment can be used to terminate the previous line segment. This method will allow many coordinates to be plotted with only moderate memory since the initial coordinates plus the slope will only take as much memory as two sets of coordinates but may plot out many points.

3. Coordinate Method - All the coordinates of the points of the grid lines can be transmitted and stored. On picture transmission the points are mixed with the picture. Storing all the points would take a rather large memory; however, by reducing the number of possible coordinates, within the restriction of the given maximum error, the memory may be reduced to a feasible size while not degrading the grid lines excessively.

A block diagram showing the basic elements common to all the digital approaches appears in Figure 1-1.

1.4 SCOPE OF EFFORT

At the beginning of the study, all of the approaches listed above were briefly analyzed to permit dropping those approaches which were obviously impractical. Rough designs were done for those approaches which showed any promise. Two of the digital approaches, the straight line method and the coordinate method, appeared to be practical. Fairly detailed system designs were completed for each of these methods to allow the determination of the following parameters.

a. Storage requirements.
b. Error tolerance and system reliability.
c. Instantaneous and average power requirements.
d. Weight and volume.
e. Interface requirements.
f. Communications channel requirements.
g. CDA station computer requirements.

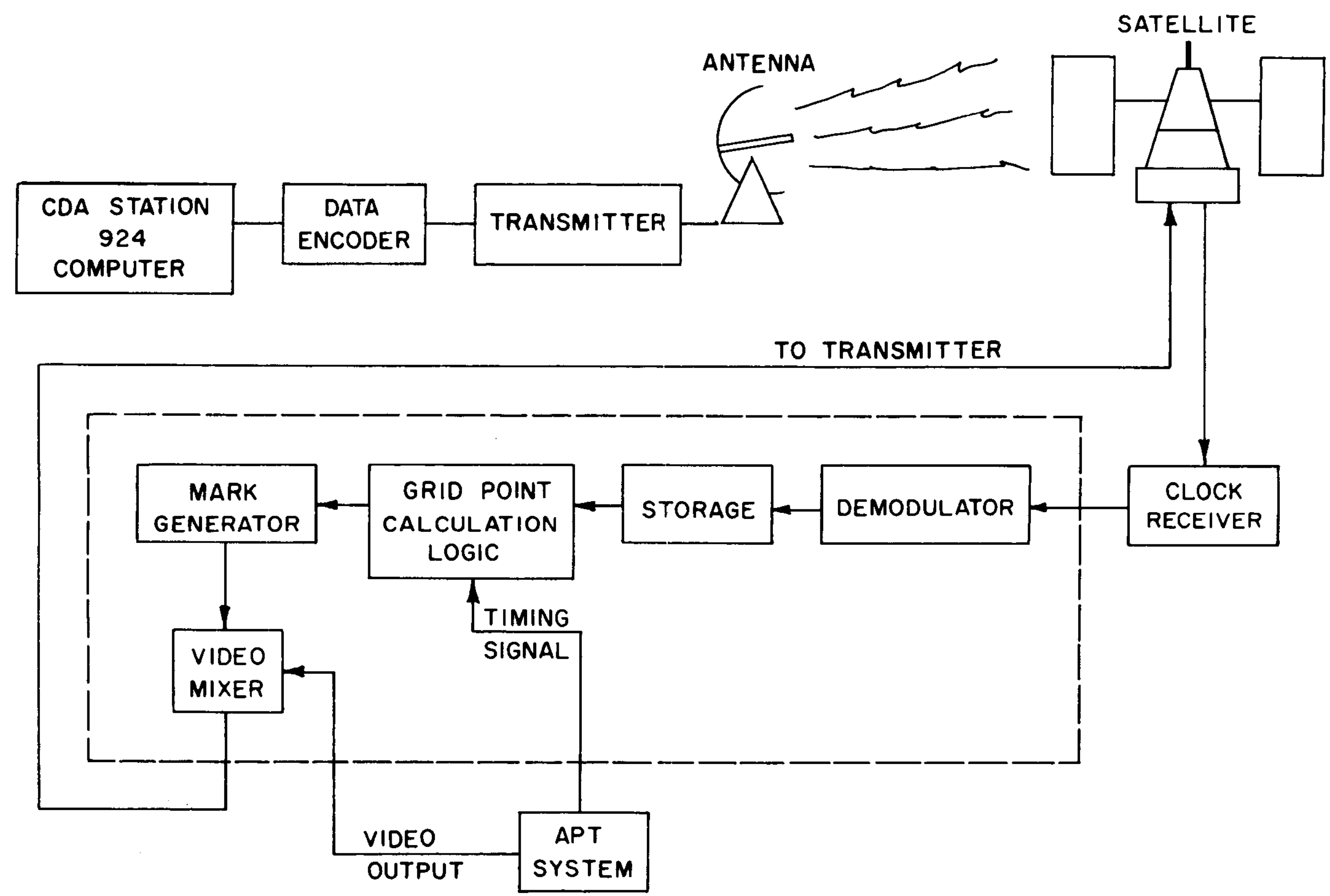


Fig. 1-1 Block Diagram - On-Board Grid System

1.5 REPORT TERMINOLOGY

Some of the nomenclature used in this report is often ambiguous; e.g., line is commonly used for a television sweep and is easily confused with grid line. Hence, the following terms are defined as they will be used in this report.

1. Coordinate - refers to the location of an element on the 800 x 800 element picture.

2. Mesh - the set of points of a particular defined coordinate subsystem. More specifically, a set of points lying on an array of perpendicular equally spaced lines. The horizontal lines of the mesh are parallel to the APT horizontal sweeps. The mesh line spacing is specified by n, which is the number of picture elements between mesh lines.

3. Picture element - conventional definition in common use for television. For the APT system there are 800 x 800 picture elements in a single picture.

4. Sweep - as in conventional television terminology.

5. Grid - the set of meridian and parallels to be superimposed on a particular APT picture.

6. Mark (grid mark) - a pattern consisting of five coded adjacent elements on a single sweep, specified to be three black followed by two white picture elements, one line thick.

7. Line - a set of marks approximating a meridian, parallel, arrow, or alphanumeric character in the APT pictures.

8. K - the number of picture elements between successive marks of a mode 0 line or the number of sweeps separating marks of a mode 1 line.

9. Mode 0 line - a grid line which makes an intersection angle θ with a sweep such that $0^\circ \leqq \theta < 45^\circ$.

10. Mode 1 line - a grid line which makes an intersection angle θ with a sweep such that $45^\circ \leqq \theta \leqq 90^\circ$.

11. Mesh interval - a distance along a mesh line of n picture elements. The mesh intervals are a set of allowable mark locations.

12. Zone - an equalized group of contiguous horizontal sweeps in a picture which divides the picture for purposes of frequent resynchronization in case of errors.

1.6 SUMMARY AND RECOMMENDATIONS

None of the analog approaches to on-board gridding are considered practical relative to the digital approaches for the following reasons.

1. A flexible analog system contains most of the elements of any of the digital systems - data channel (demodulator, synchronizer, error detection circuitry), memory (storage of data for correction of orbit and picture parameter errors), and logic circuitry to compensate for attitude, orbit and APT parameter errors. The additional equipment needed for the analog systems - lens or scanner, grid storage medium, servo controls - places the analog system at a severe weight disadvantage when compared to the digital approaches.

2. The reliability of the electromechanical analog approaches is inherently lower.

3. The spacecraft on which an on-board gridding system is useful (Nimbus-TIROS) are sensitive to internal motions. The motion compensation required complicates design and produces further weight penalties.

4. Optical mixing approaches require modification of the mechanical (and preferably the optical) portions of the APT system. The extremely wide angular coverage of the APT lens (107^{o}) complicates the optical design for introducing the picture grid into the camera focal plane.

5. Annotation (for grid line referencing) is difficult to accomplish unless an annotated grid of the entire earth is stored. Digital approaches which draw grid lines can produce alphanumeric characters with relative ease.

Consideration was given to the use of the Nimbus PCM recorder (stored-A) for the storage of the grid data. This would permit a substantial savings in weight. However, this approach was dropped due to the nature of the interface and the loss of the ability to produce a "standard package" useful on any meteorological satellite.

Several approaches to on-board gridding appear promising. These are the straight line method, the coordinate method and a modification of the coordinate method which utilizes slope prediction and storage to reduce the amount of data necessary to specify the locations of the individual grid marks.

All of the approaches judged promising can be accomplished with a flight system weight in the 6.5 to 9 lb range and an average power requirement of less than 2 watts. These estimates were obtained by preparing fairly detailed preliminary designs for each method. The final choice of the system design is dependent on grid appearance and anticipated updata communications channel errors as summarized in Section 4. A simulated grid, characteristic of the coordinate method, appears in Figure 1-2.

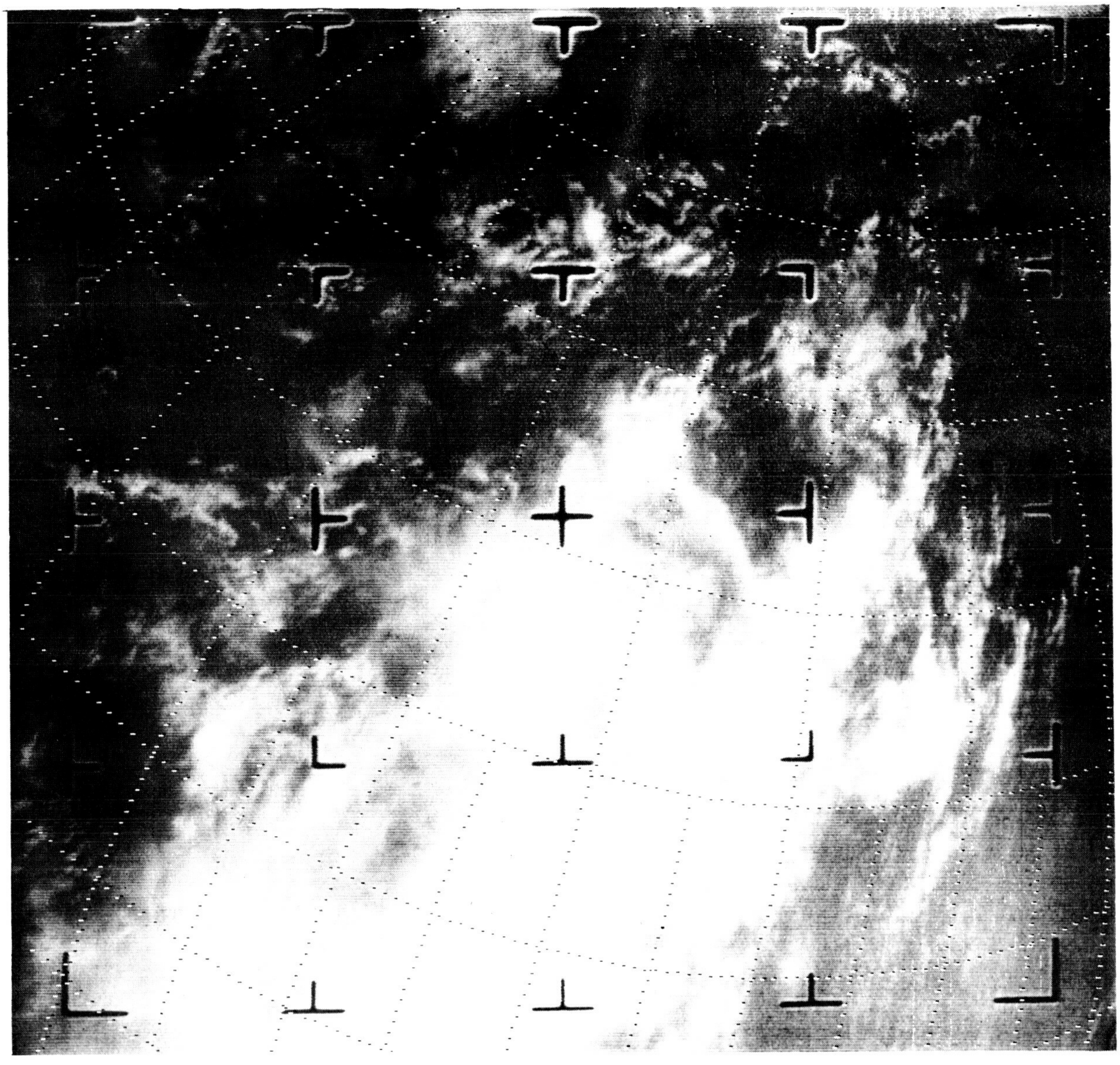


Fig. 1-2 Simulated Grid K = 8

The digital methods require that picture times be predictable. Although timing problems have been experienced with TIROS satellites in the past, this problem will certainly not persist as there are no fundamental obstacles to obtaining predictable shutter times. As a safeguard, the individual picture grids, stored in the satellite memory, could very well be tagged with the times for which they were computed. These times could be compared to an external or grid-system-contained clock to insure that a grid is superimposed on a picture only if the shutter is tripped at the predicted time.

SECTION 2

GRIDDING REQUIREMENTS

2.1 GRID LINE SPACING

The initial specification for grid line spacing is as follows:

Latitude spacing on picture

a. 2° from $0-70^{\circ}$ latitude, north and south
b. 4° from $>70^{\circ}$ north and south

Longitude spacing on picture

a. 2° from $0-40^{\circ}$ latitude, north and south
b. 4° from $40-70^{\circ}$ latitude, north and south
c. 8° from $70-82^{\circ}$ latitude, north and south
d. 40° from $>82^{\circ}$ latitude, north and south.

If this spacing were maintained for the complete height range of the satellites (400-800 nm.), pictures taken at the higher altitudes would be virtually obscured by the grid lines. Figure 2-1 shows a picture grid with a basic 2° interval as suggested above for a height of 800 nm. It is obvious that the grid line spacing must be either a function of altitude or if it is to remain constant, it must be made larger than specified above.

The problem of grid line spacing has been previously examined in some detail. Picture data from the APT system will often be manually transferred to a base map. Widger and Glaser have shown that these base maps are almost universally graduated in 5° intervals,* making the transfer from a 2° gridded picture to a standard map extremely laborious. For these reasons we suggest the following grid spacing:

Latitude: 5° throughout

Longitude: 5° - equator to 60° latitude
10° - 60° to 75° latitude

* Widger, W.K., Jr., and A.H. Glaser, 1963: A Rationale for Geographic Referencing of Meteorological Satellite Data, Technical Report No. 1, Contract No. NAS 5-1204, ARACON Geophysics Company.

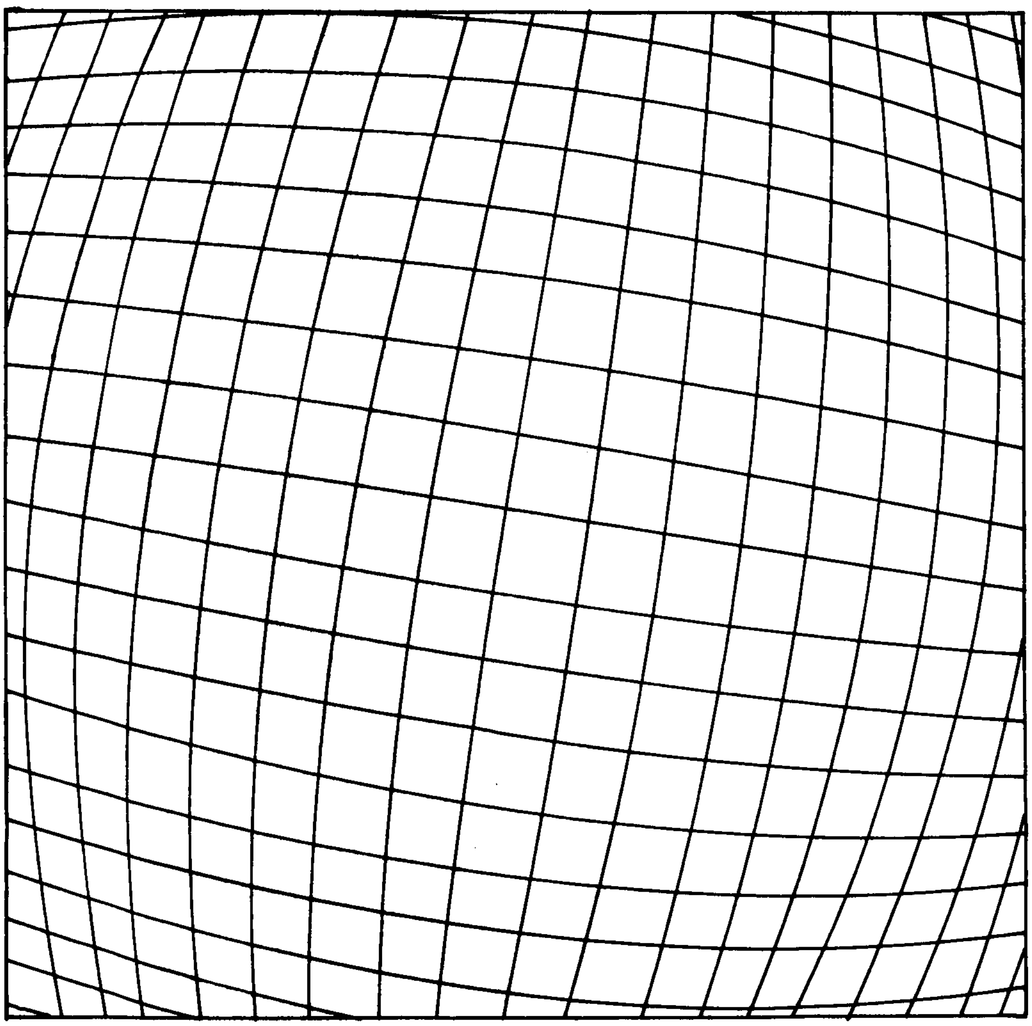


Fig. 2-1 Grid With 2° Spacing for 800 NM Orbit

20° - 75° to 85° latitude
40° - 85° latitude to pole.

This has the additional advantage of maintaining a uniform spacing throughout the vast majority of the habitable regions of the world.

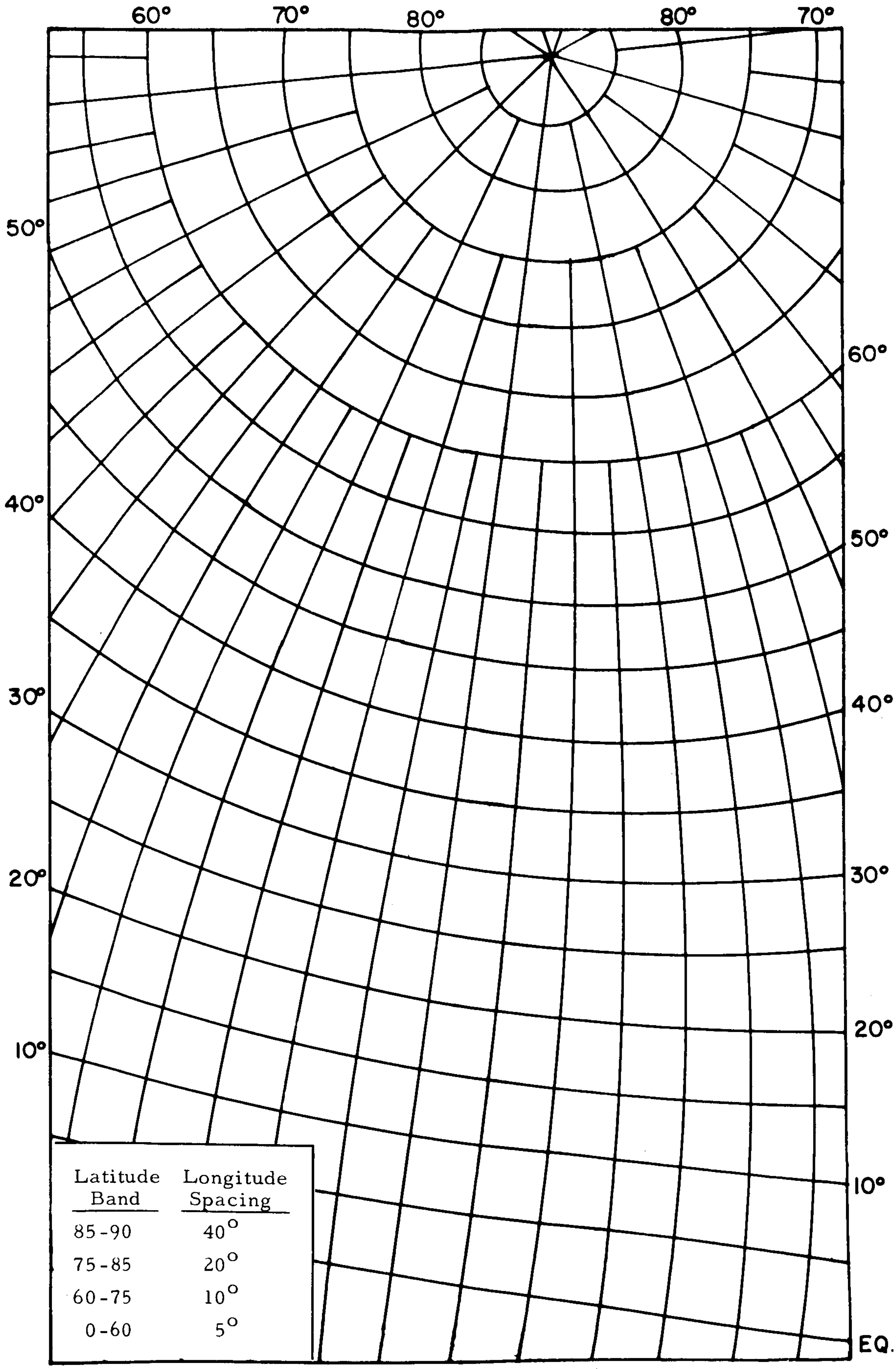
An appreciation for the appearance of the grid lines as they would appear in the pictures as a function of altitude can be attained by superimposing the camera apertures shown in Figure 2-3 onto the OEC map of Figure 2-2. (The apertures are contained in the pocket attached to the rear of this report.)

It is our recommendation that the 5° grid be universally used regardless of altitude. Should strong objections to the 5° grid interval occur for pictures taken at low altitudes, we would recommend that the basic 5° grid be maintained but that 2 $1/2^{\circ}$ lines, identifiable as such, be added between 5° lines in the picture. This will still permit correlation of the grid and base map lines to be obtained easily. If the 2 $1/2^{\circ}$ grid is used, it is recommended that it be reserved for altitudes of <500 nm.

2.2 GRID LINE REFERENCING

The grid lines appearing in the picture must be somehow referenced to enable the latitude and longitude identification of the lines. In the past, it has been common to place a north arrow at one of the grid line intersections whose latitude, longitude coordinates are sent with the picture. It would certainly be desirable to maintain this method of grid line referencing for the on board system. Alphanumeric characters must be superimposed upon the pictures along with the grid lines to identify the coordinates of the north arrow. With the basic 5° grid proposed, at least two latitude or longitude lines are visible in the pictures even at an altitude of 400 nm. Thus, the north arrow could always be placed at a latitude or longitude line which is an integral multiple of 10°. This enables the lines to be identified with four alphanumeric characters. N or S (+ or -) and one decimal character will suffice to identify the latitude of the north arrow and two decimal characters will identify the east or west longitude of the north arrow.

The ease with which the alphanumeric characters can be generated in an on-board gridding system is highly dependent upon the type of system chosen. For this reason, a second alternate scheme of grid line referencing is proposed. North arrows can be placed at fixed latitude and longitude intersections. At least one north arrow must be visible in any picture which might be taken. The arrangement of the north arrows on a global map must be such that a data analyst cannot confuse two sections



Latitude Band	Longitude Spacing
85-90	40°
75-85	20°
60-75	10°
0-60	5°

Fig. 2-2 OEC Map With Proposed 5° Grid

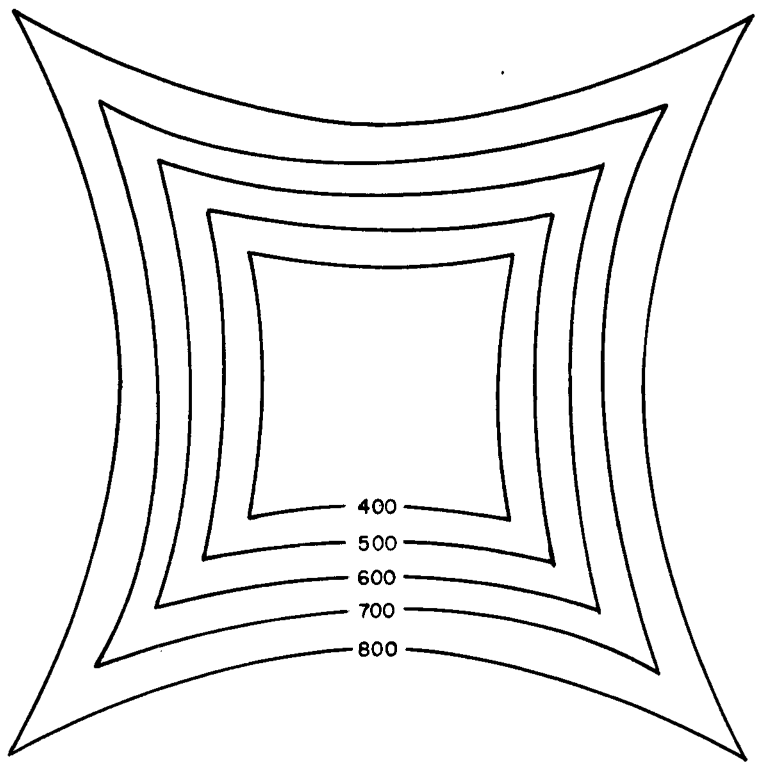


Fig. 2-3 OEC Map Coverage as a Function of Satellite Height

of the globe over a wide enough band of latitude and longitude to preclude error. Preferably a single fixed catalog of arrows would be employed for all altitudes. A suggested arrangement of north arrows is shown in Figure 2-4. With the arrangement of arrows depicted in Figure 2-4 an analyst must make an error of 10° in both latitude and longitude or 20° in one of the coordinates in order to incorrectly identify the lines. Since any receiver of the APT data must have a fairly accurate estimate of the satellite orbit in order to operate the ground station (track the satellite) it is extremely unlikely that he can make this large an error. His most likely error is an incorrect latitude guess. Latitude of the pictures is primarily a function of time. To make a 10° error in latitude, the estimate of picture time must be almost three minutes in error. Since it is unlikely that this large an error in picture time will be made, the fixed catalog of north arrows shown in Figure 2-4 should suffice to enable error-free grid-line identification.

The identification of grid lines through superimposed alphanumeric annotation is certainly superior to identification of grid lines through a fixed catalog of north arrows. The alphanumeric picture annotation provides a permanent record of the grid line coordinates. However, the relative cost and reliability of the two approaches will be the deciding factors.

2.3 NUMBER OF PICTURES PER ORBIT

The number of pictures which must be gridded during a single orbit is a function of satellite altitude. (The 208 second prepare-expose-scan cycle is the factor limiting the number of pictures.) The third column of Table 2-1 lists the maximum possible number of pictures per orbit. The fourth column lists the number of pictures which would be taken if picture overlap is minimized. The fifth column gives the number of pictures per orbit which might be taken to avoid excessive picture overlap.

The last column of Table 2-1 is the product of pictures/orbit x earth angular coverage. This product indicates the relative number of grid lines or grid line marks which must be superimposed on the APT pictures.

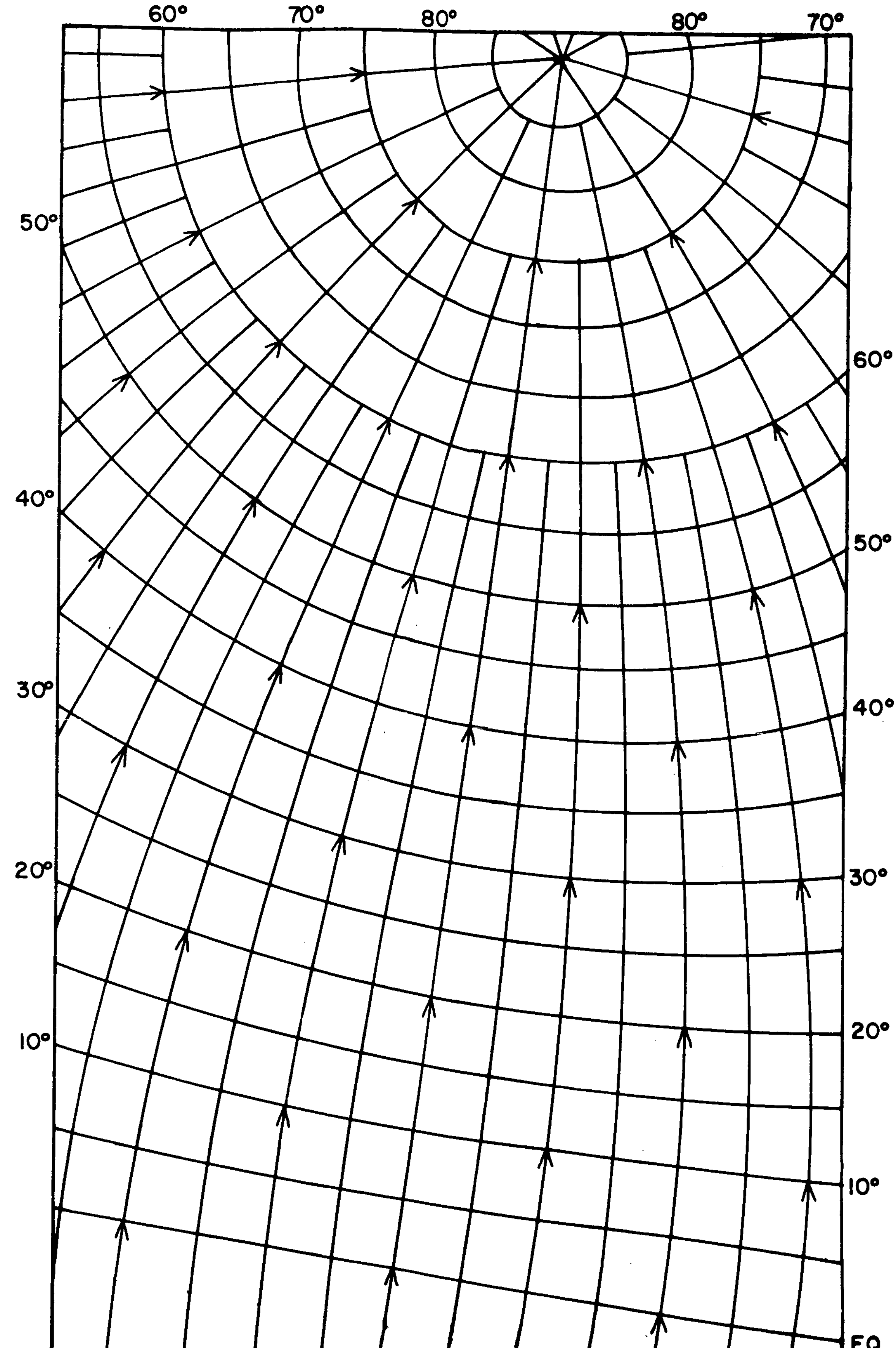


Fig.2-4 Suggested Locations of Fixed North Arrows
for Grid Line Referencing

Table 2-1

Number of Pictures as a Function of Satellite Altitude

Satellite Altitude (nm.)	Earth * Angular Coverage (degrees)	Maximum Possible No. Pictures/Orbit	Number Pictures/Orbit No Overlap	Estimated Number Pictures/Orbit	Est. Number Pictures/Orbit X Earth Angular Coverage
400	13.5	14.3	13.3	14	189
500	19.2	14.9	10.5	15	288
600	21.1	15.5	8.5	14	295
700	25.1	16.1	7.2	12	301
800	29.4	16.6	6.1	10	294

* Great circle arc through the picture principal point and bisecting the picture sides.

SECTION 3

DIGITAL APPROACHES TO ON-BOARD GRIDDING

3.1 STRAIGHT LINE METHOD

The straight line methods approximate the curved lines of the geographic grid by a sequence of straight lines. In general the line segments should be made as long as possible, subject to the limitation of a maximum one percent error, to minimize the number of line segments and hence the required data transmission to the satellite. Each line segment can be characterized by its initial starting coordinates and a slope. If we are to have the longest possible line segments, the tolerable one percent error should represent primarily the deviation of the curved true grid line from the straight line. To obtain this condition the initial coordinates and slope of the line should be represented with the highest precision with which it is possible to plot the points in the picture. A single picture element is considered to be the smallest resolvable distance in the APT picture. Thus the initial X, Y coordinates for the start of a line segment are specified with ten bit precision. If the slope of a line were characterized by the number of picture elements along a sweep (ΔX), the range of slope encountered would be $\frac{1}{800}$ (nearly horizontal line) to 800 (nearly vertical line). In a fixed point notation system, a total of 20 bits would be required to achieve this range of slope. An alternate manner of specifying slope is depicted in Figure 3-1. Lines which make an intersection with the TV sweep of $<45^{\circ}$ (mode 0) are characterized by the increment in Y for $\Delta X = K$ (mark spacing). Lines which make an angle of intersection with the TV sweep which is $>45^{\circ}$(mode 1) are characterized by the ΔX corresponding to a ΔY of K sweeps. If we ignore the perfect 45° line, the slope of any line can then be specified with a total of 12 bits, one for the mode, one for the slope (positive sloping lines have a ΔX component in the sweep direction for increasing Y), and 10 for the ΔX or ΔY.

The most promising straight line system (SL-2), employs two separate fixed meshes, one for each line mode. For mode 0 lines the vertical lines of the mesh are spaced apart K picture elements. The horizontal lines of the mesh are spaced apart a single picture element (sweep). See Figure 3-2a. The horizontal mesh spacing permits the mode 0 line segment words to be cycled through the calculation logic in a time interval corresponding to K picture elements. Points for mode 1 lines see Figure 3-2b) are plotted on a mesh whose vertical lines are spaced apart a single

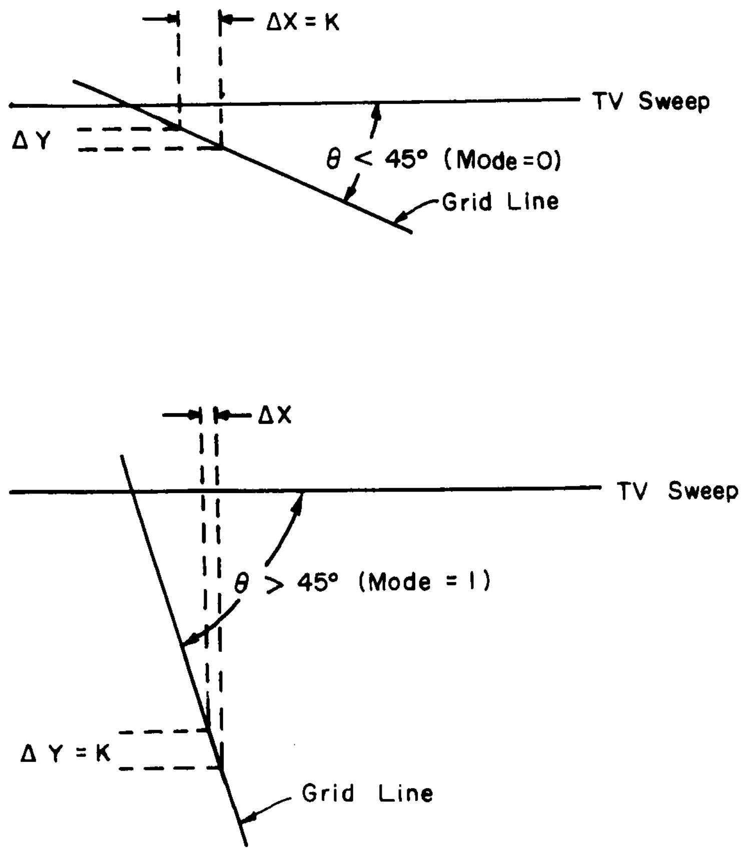
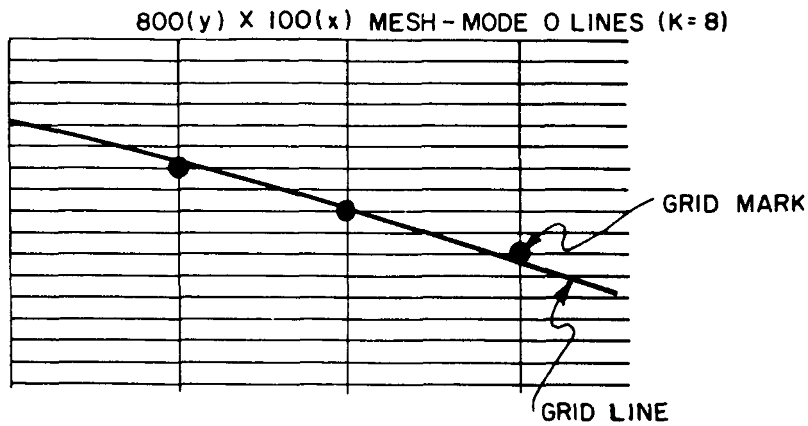
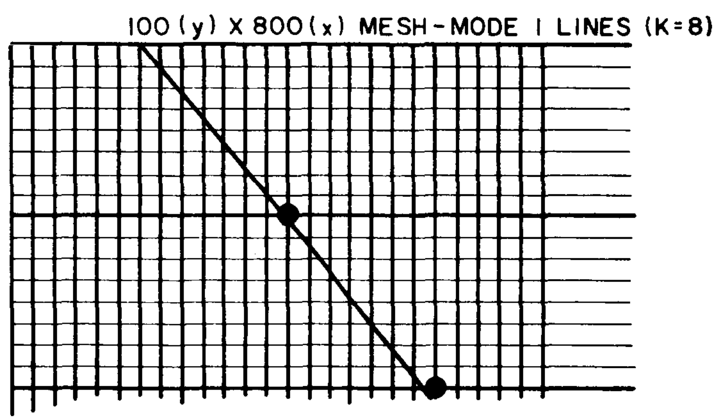


Fig. 3-1 Slope Specification



(a)



(b)

Fig. 3-2 Allowable Locations of Grid Mark SL-2 picture element, and whose horizontal lines are spaced apart K sweeps. The use of these fixed meshes for plotting allows any line to be marked at intervals of K picture elements. The direction in which the mark spacing (horizontal or vertical) equals K is determined by the mode. The use of these meshes also permit marks to be plotted with single picture element precision as can be seen from examining the marks for the grid lines of Figure 3-2.

A block diagram of the system appears in Figure 3-3. The grid line data transmitted from the CDA station is stored in a thin film or magnetic core memory. When the picture taking sequence is initiated, the Y portion of the word for the first line segment is compared to a line counter. When the APT sweep reaches the value of the Y-coordinate of the starting point of the line segment, the word is transferred from the main storage to a circulating delay line storage. The delay line storage will contain all the line segment data in process at any given time. The delay line cycles at a rate sufficient to present all the line segment words to the calculation logic in the time interval which corresponds to the distance between mesh lines (allowable grid mark locations). Each line segment word is examined by the calculation logic to determine if a mark should be made before each new mesh intersection is reached.

The maximum number of line segments which must be handled by the buffer at any one time (number of line segments intersected by a single sweep) is 17 for the most dense grid corresponding to an 800 nm. altitude. If we include the possibility of north arrow annotation, this number is increased to 23. This results in a storage requirement for the delay line of approximately 900 bits, to be cycled every 2 1/2 milliseconds for K = 8. This figure is entirely practical for present day aerospace qualified delay lines.

3.2 COORDINATE METHODS

3.2.1 Full X-Address System CM-1A

The coordinate method requires new information for each mark plotted to approximate a grid line. Consequently, the coordinate approach is not economical of storage. However, it can offer sufficient decrease in logic complexity for mark calculation to offset the increased storage requirement.

The number of marks needed to produce the grid lines in the APT pictures is dependent on the mark spacing, the method of picture annotation, and the spacing of the latitude longitude lines. We will assume that the 5° grid spacing recommended

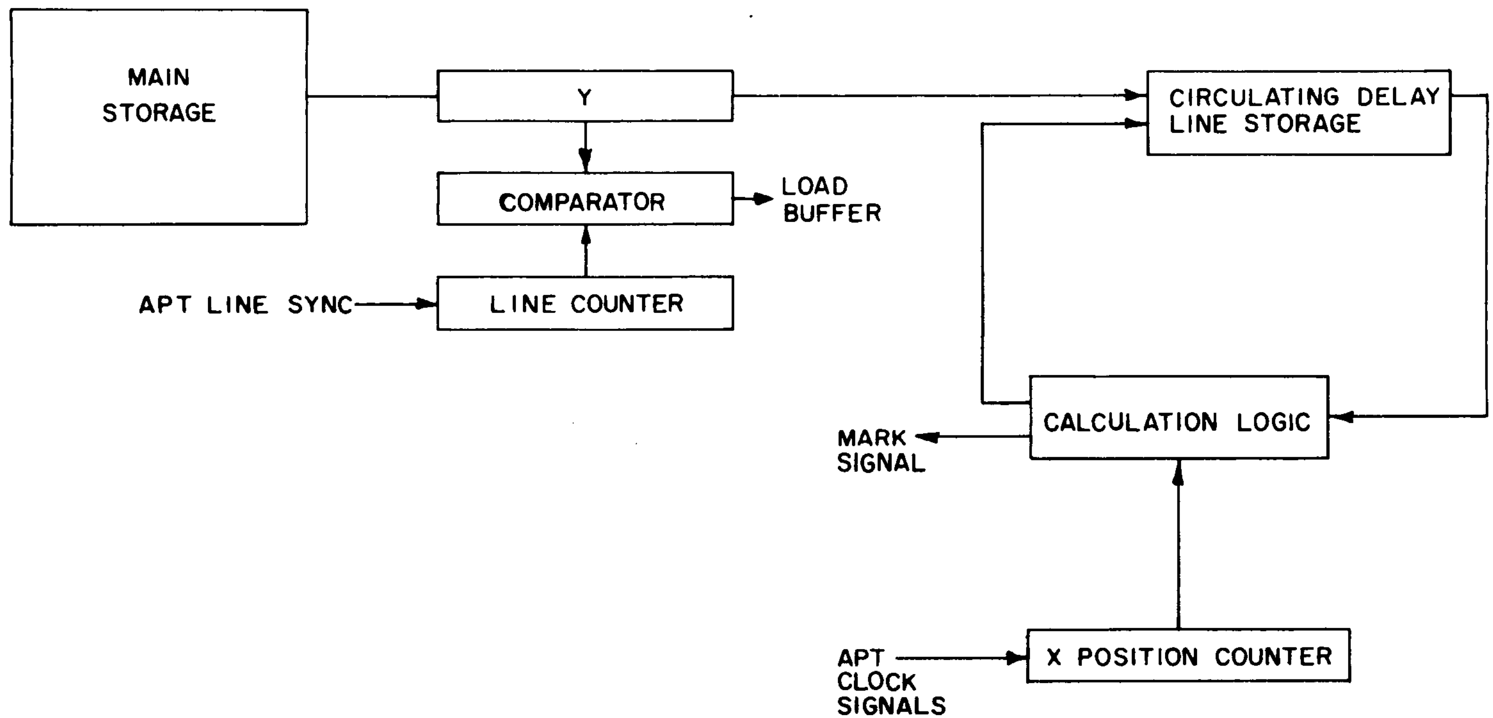


Fig. 3-3 SL-2 Block Diagram

for the straight line system is adopted for the coordinate method. In drawing the grid lines for the 5^{o} grid for an 800 nm., 10 picture orbit, the equivalent of 156 straight,horizontal or vertical lines completely crossing the picture, is produced. The equivalent of two more complete lines is required to produce the north arrows in the picture. If we assume that the mark density of the north arrow lines is twice that of the grid lines, the equivalent of four additional complete lines is required, for a total of 160 lines.

In one promising coordinate system approach (CM-1A), the horizontal (X-coordinate) address of each grid mark is transmitted to the satellite. The word length for each horizontal address is 8 bits if marks are restricted to a mesh specified by n = 4. To plot a total of 160 lines with a mark spacing (K) of 16 picture elements, approximately 80,000 bits must be stored in the satellite. The addresses are separated by mesh line (allowable sweep line) through detecting a decrease in the X-coordinate values. The horizontal coordinate values for each new mark increase until a new line is begun. For those cases in which this condition is violated, a "false" end of line mark is added to the sequence of addresses.

The logic circuitry needed for the CM-1A approach is very straightforward. Words are sequentially withdrawn from memory and compared to a horizontal beam position counter. Each time equality is detected, a mark command is generated and a new word is withdrawn from memory.

3.2.2 Mark Plotting through a Combination of Slope and Coordinate Specification

To minimize the amount of data transmission to the satellite, we should try to send only that part of a mark coordinate specification which represents new information, and add some memory capability to the gridding system so that critical parts of the data for past events can be retained. An implementation of this approach might consist in having the data for the marks on a new TV line consist only of the changes in the coordinate of the grid lines currently being mixed into the pictures. Consider the potential points at which a mark of a grid line can be placed relative to the last mark for the grid line. For a mark spacing of 16 picture elements (horizontal or vertical -- depending on the slope) and a mesh n = 4, the potential points at which a new mark can occur are shown in Figure 3-4a. The number of allowable new positions is 16. With a four-bit code we can then specify the next mark position for the grid line if we modify the last mark coordinates in accordance with the code. If we

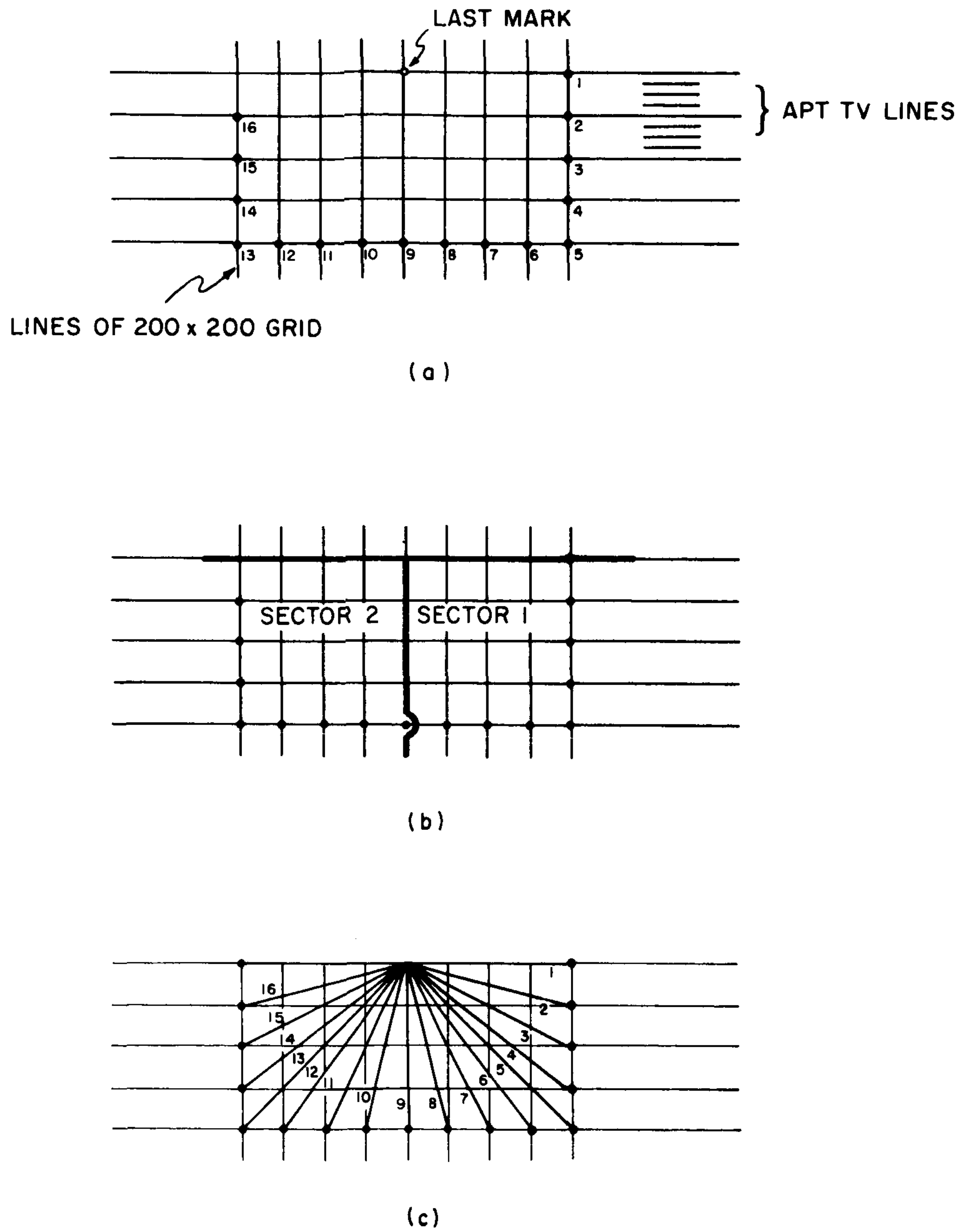


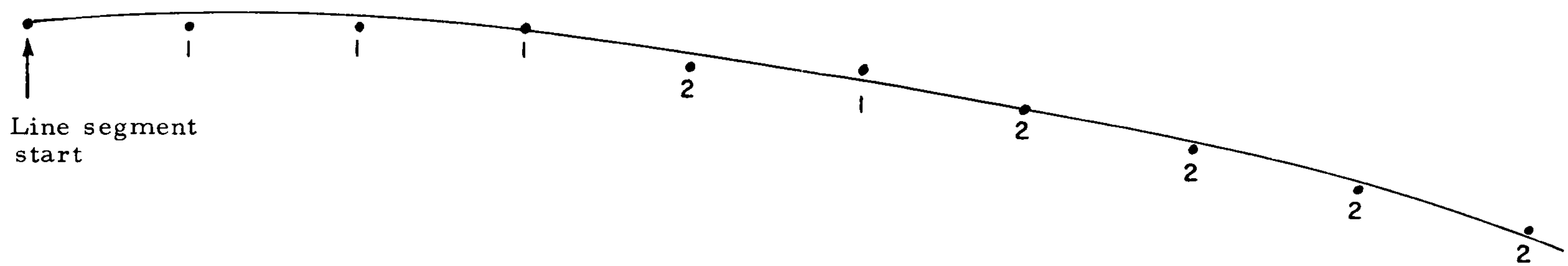
Fig. 3-4 Potential Locations of New Marks

maintain mark position registers, one for each line in process, we can then specify the changes in the mark positions from a store of 32,000 bits (8,000 marks). However, in making our choice of the next coordinate for a grid line in this manner, we have not utilized any information about the line other than the coordinates of the last mark laid down. Grid lines are quite regular and predictable. We could then, divide the grid lines into two broad categories, as shown in Figure 3-4b, and rarely would we be required to change categories in the course of drawing out the grid line on the picture. Taking advantage of the regularity of the lines has thus reduced each new mark word to 3 bits (while retaining an additional bit for each line in a buffer memory). Carrying this technique to its ultimate, we divide the 16 potential new mark positions into 16 categories or sectors of 10^{o} average (Fig. 3-4c) and end up requiring a single bit for each new mark position for a grid line, since only two potential mark positions are allowed for a given sector.

A sector actually defines a slope band. The grid lines must be broken into segments, where each segment is contained in one of the slope bands. Examine the drawing at the top of Figure 3- 5 , and consider a line segment whose slope starts at 0^{o} and ends at 14^{o}. This segment will be plotted by a sequence of marks occupying position 1 (Fig. 3- 5) relative to the preceding mark where the slope of the segment is zero. As the slope increases, the new mark position will oscillate between points 1 and 2, and when the segment slope approaches 14^{o} the new mark positions will occur at point 2 relative to each preceding mark. The basic logic and the data required for this method of marking is listed in Figure 3-5. We can see that 10 marks can be plotted with a data requirement averaging 3 bits per mark.

To ascertain the practicality of this approach, the number of sector changes experienced in drawing grid lines was approximately determined for the 800 nm. orbit. For the recommended basic 5^{o} grid interval, the number of sector changes is in the vicinity of 300. Since this figure does not appear to impose any serious limitation, we shall pursue the total storage requirement for this technique.

Note that Figure 3- 4 c includes point 17, even though this position cannot be marked unless computed prior to the vidicon's sweep circuits arriving at the previous mark position. A four bit sector code can be used for the marks on a line segment, in combination with the individual mark words, until the slope of the line changes enough to move the line marks into a new sector. We then have the lines divided into segments, as in the straight line system, but the line segments are not required to be straight. The initial coordinates of each segment must be specified



A. Plot initial mark when vidicon beam position equals segment starting coordinates X_o Y_o .

B. From sector code and 1 bit mark word determine next mark position relative to first.

C. When vidicon beam position reaches coordinates of second mark, make the mark and determine coordinates of third mark from sector code and 1 bit mark word, etc.

REQUIRED DATA

Y_o	X_o	Sector Code	9 Single bit mark words	
8 bits	8 bits	4 bits	9 bits	⟶ TOTAL = 29 bits for 10 marks

Figure 3-5 . Line Marking From Combined Slope - Coordinate Specification along with the sector code. The sector code is 4 bits long and a fifth (erase) bit is needed to terminate lines in mid-picture. This yields a total of 21 bits to start or end (mid-picture) a line segment.

For an 800 nm. - 10 picture orbit, approximately 250 line starts, 54 terminations, and 278 sector changes occur for a bit total of 12,306. Adding to this the 8,000 bits for the 1 bit mark words, the total memory requirement for the grid lines is approximately 21,300 bits.

The CM-2 approach appears to offer a much lower storage requirement than the straight coordinate methods, while producing better looking lines with simpler logic when compared to the straight-line method.

A drawback to the slope-coordinate method is the requirement for dissimilar word lengths (1 bit mark words and 21 bit segment words). This requirement will increase susceptibility to error.

Two versions of a slope-coordinate (CM-2) approach were investigated. CM-2L operates with a low calculation speed (less than 5 kc and employs a core buffer). CM-2H is a high speed design employing an equipment configuration similar to SL-2.

3.3 ANCILLARY FUNCTIONS

3.3.1 Numeral Generation

The generation of numerals on the picture to identify selected latitude and longitude grid lines can require the use of additional logic which is separate from the calculation logic used for generating marks for the grid lines. In the coordinate method, the annotation data are included with the grid data, but numeral marks will appear only on mesh sweeps unless more equipment is added. Extra storage is needed to make marks along the sweeps between meshes if it is desired to produce more attractive numerals. Examples of both types of numerals are given in Figure 3-6.

3.3.2 Satellite Orientation Corrections

3.3.2.1 Coordinate Methods, Orientation Correction

In the CM-1A approach, the corrections for pitch and roll are made rather easily. The detection of a roll error indicates that the mark locations along a mesh sweep are incorrect. The roll error is sampled at the time the picture is taken.

(a) (b)

(a) Numeral with marks along every fourth sweep

(b) Numeral with marks along every sweep

FROM DI/AN CONTROLS, INC. DRWG 2177-4010

Fig. 3-6 Numeral Appearance

For the case of the full address coordinate method, the correction must be added to each address word. This can be implemented by the insertion of a full adder just following the output of the memory, which is activated each time an address word is selected.

An alternate roll correction method is to shift the time axis by presetting (up or down) the X mesh interval counter.

Both methods, although in many ways easy to operate, allow a whole class of points that cannot be put on the picture to reach the calculation logic, and a comparison must be made to allow the memory to advance to the proper location as each sweep is changed.

Correction for pitch can be made similarly by delaying or advancing the count of the Y interval counter. The consequences of this situation are not as severe as that for the mesh interval roll correction as sweeps which are shifted off the picture due to a forward pitch are covered by the methods already described, that is, they are rejected. Sweeps that are shifted off the picture by backwards pitch would not be plotted since they would not leave memory until after the vertical sweep had been terminated. Sweeps that may be "left over" in the memory following a pitch corrected picture would be wiped out when the synchronizing system automatically seeks the start of the next picture.

In the slope-coordinate system, portions of line segments cannot be dropped without upsetting the operation of matching mark words to segments. This situation can be remedied by prohibiting grid line marks within 3.5% of the picture borders. For this condition, marks would not move out of the borders for a 3^{o} roll or pitch error. The corrections for pitch can be made by adding to or subtracting from the Y counter. Roll corrections can be made by presetting the X counter for each sweep.

3.3.2.2 Straight Line Orientation Corrections

The compensation technique for pitch and roll in the straight line methods is similar to the technique outlined for the CM-1 methods. However, the timing is somewhat more complicated because of the more complex word structure. With use of an adder at the memory output, pitch and roll correction can be obtained by adding fixed numbers to the origin X and Y address. ("Origin" means the point at which a straight line segment begins.)

3.3.3 Updata Transmission System

3.3.3.1 Modulation Form

The data transmission system may use the basic OGO FSK/AM and Command Data Link built for the Nimbus system. The binary data are put in NRZ form and used to establish "zero" and "one" audio frequencies. Since the NRZ form does not yield positive sync, the basic bit rate is superimposed by AM on the FSK signal. The composite signal is amplitude modulated on an RF carrier and sent to the satellite. In the satellite, an FSK demodulator and an envelope detector recover data and bit sync from the signal. The APT Gridding System should use a separate FSK demodulator from the command demodulator already on board the satellite because:

a. The APT Gridding bit transmission rate is one or two orders of magnitude faster than the command data rate, and would be too fast for the narrow band FSK demodulator already on board. The FSK command demodulator would have to be modified (thus reducing the noise margin in the command link) to recover the wide band data transmission.

b. It is desirable that existing satellite systems be modified as little as possible.

3.3.3.2 New Commands

For Nimbus use, "GRID DATA START" and "GRID DATA END" commands should be added to the Nimbus vocabulary. In addition, "GRID DATA HOLD' should be added if it is desired to have the capability to interrupt and later to resume grid data transmission. The FSK APT data demodulator supplies to the APT gridding subsystem the data obtained from the ground along with a bit synchronization pulse train. Word sync is contained in the data in appropriate codes and is inserted at pre-planned times.

The APT gridding demodulator would be turned on and off by the new commands described above, via the existing command decoder.

3.4 ELECTRICAL AND PHYSICAL PARAMETERS

3.4.1 Subsystem Parameters

The weight and power goals for the gridding systems were informally specified to be 5 pounds and 4 watts. The study performed here kept these limitations in mind, but optimum designs to minimize a weighted combination of these parameters were not evolved.

In previous sections, the logical methods for performing the required tasks were outlined. From this information and a consideration of the number of logic elements required for each function, the following parameters were calculated for each subsystem, and are shown in Tables 3-1 through 3-8 for the various system implementations.

a. Module Count

b. Power: Average per Orbit and Peak

c. Weight

d. Volume

e. Cost

f. Reliability

Tables 3-1 through 3-3 show estimates for CM-1 type systems. Table 3-1 assumes the use of core transistor logic (CTL) elements, Table 3-2 integrated circuit logic elements, and Table 3-3 a combination of the two element types each used to best advantage. Table 3-4 is an estimate for the straight line (SL-2) system using integrated circuitry. The module estimates of these four tables are based on the designs previously described.

For the CM-2 system, an extrapolation of the estimates for CM-1 and SL-2 has been performed. The estimate for CM-2H is assumed to be virtually identical to that of SL-2 (Table 3-4). The estimate for CM-2L shown in Table 3-5 is based on the assumption that the CM-2L calculation logic is approximately 2/3 of that needed for SL-2.

The tables include information for two possible additions:

a. Numeral annotation.

b. Analog-to-digital conversion in case the roll and pitch errors cannot be made available to the gridding system in digital form.

Table 3-1

CM-1 CTL Logic Implementation
Per Unit Parameter Estimates

Unit	Module Power	Peak † Power	Avg. Power/ † Orbit	Wt(lbs.)	Vol(in^3)
Calculation	35	250*	6	.63	14
Sync and Error	60	420**	7	1.1	24
Annotation	48	5*	0	.89	20.6
Roll and Pitch	43	10*	0	.76	17.5
FSK Detector, Demod.	25	250	10	.45	10
Interfaces	30	150*	60	.54	12
Memory, 100 KB	1	100*	100	3.5	140
TOTALS	242	845	183	7.9	238

* Power drains that can occur simultaneously

** Error detection power drain approximately 20% of total.

† Milliwatts

Table 3-2

CM-1 Integrated Logic Implementation

Per Unit Parameter Estimates

Unit	Module Power	Peak Power	Avg. Power/ Orbit	Wt(lbs.)	Vol(in^3)
Calculation	60	470*	360	.63	14
Sync and Error	58	980**	17	.35	11.6
Annotation	53	600*	35	.29	10
Roll and Pitch	34	290*	215	.19	6.3
FSK Detector, Demod.	25	250	10	.45	10
Interfaces	30	150*	60	.54	12
Memory, 100 KB	1	100*	100	3.5	140
TOTALS	261	1510	797	5.95	205

* Power drains that can occur simultaneously

** Error detection power drain approximately 20% of total.

Table 3- 3

CM-1 Hybrid Logic Implementation
Per Unit Parameter Estimates

Unit	Module Power	Peak Power	Avg. Power/ Orbit	Wt(lbs.)	Vol(in^3)
Calculation CTL	35	250*	6	.63	14
Sync and Error CTL	17	110**	2	.31	6.8
Annotation CTL	15	95*	4	.27	6
Roll and Pitch CTL	18	0	0	.33	7.2
FSK Detector, Demod.	25	250	10	.45	10
Interfaces	40	200*	80	.70	16
Memory, 100 KB	1	100*	100	3.5	140
Sync (Int.)	11	96**	5	.09	2.1
Annotation	6	65*	3	.03	4.5
Roll and Pitch	20	160*	8	.15	3.8
TOTALS	188	788	218	6.46	212

* Power drains that can occur simultaneously

** Error detection power drain approximately 20% of total.

Table 3-4

SL-2 (CM-2H) Integrated Logic Implementation
Per Unit Parameter Estimates

Unit	Module Count	Peak Power	Avg. Power/ Orbit	Wt(lbs.)	Vol(in^3)
Calculation	175	1600	1200	1.3	43
Sync and Error	58	980	16	.35	11.6
Annotation	60	600	38	.31	11
Roll and Pitch	34	290	15	.19	6.3
FSK Detector, Demod.	25	250	10	.45	10
Interfaces	30	150	60	.54	12
Memory, 25 KB	1	75	75	2.5	100
Delay Line	1	120	84	.65	20
TOTALS	384	2000	1500	6.29	204

Table 3-5

CM-2L Integrated Logic Implementation

Per Unit Parameter Estimates

Unit	Module Count	Peak Power	Avg. Power/ Orbit	Wt(lbs.)	Vol(in^3)
Calculation	120	1100	830	.90	30
Sync and Error	58	980	16	.35	11.6
Annotation	60	660	33	.31	11
Roll and Pitch	34	290	15	.19	6.3
FSK Detector, Demod.	25	250	10	.45	10
Interfaces	30	150	60	.54	12
Memory, 25 KB	1	75	75	2.50	100
Core Buffer, 2 KB	1	200	8	1.10	50
TOTALS	329	2000	1047	6.34	230.9

Table 3-6

Estimate of Design Parameters for APT Gridding Subsystem

Logical Method	Number of Modules	Peak Power (MW)	Average Power/Orbit (MW)	Weight (lbs.)	Volume (in^3)	Flight Unit $ Cost	Engineering $ Cost
CM-1, CTL (1)	290	1000	200	8.8	260	72 K	210 K
CM-1, Integrated (2)	310	1790	935	6.5	215	71 K	260 K
CM-1, Hybrid (3)	230	925	240	7.1	230	64 K	180 K
SL-2, CM-2H, Integrated (4)	460	2500	1800	7.1	225	74 K	370 K
CM-2L, Ingegrated (5)	400	2500	1230	7.1	255	74 K	330 K

(1) Pico-Bit CTL, DI/AN Controls, Inc.

(2), (4), (5) Milliwat Micrologic, Fairchild Semiconductor Corp.

(3) CTL, and MOS of General Microelectronics, Inc.

(4) Magnetostrictive Delay Line, Computer Control Company.

(1), (2), (3) 80,000 Bit Serial Memory, DI/AN Controls or UNIVAC.

(4), (5) 25,000 Bit Serial Memory, DI/AN Controls or UNIVAC.

(5) 2,000 Bit Serial Buffer, DI/AN Controls.

Assumptions:

For CM-1 and CM-2, K = 16 and n = 4.

For SL-2, K = 8.

Table 3- 6 summarizes some of the flight system parameters represented in Tables 3-8 through 3-12. A 20% across the board increase in module count, weight, volume, and power over the actual estimates appears in Table 3-6 to offset increases which often occur in translating paper designs to hardware. An exception is taken for the memory estimates where it is assumed the vendor has already inserted this safety factor.

For these estimates it was assumed: 1) that the first flight system is to be delivered in 1966, 2) that the system would be procured in lots of four. Only those components now in production or close to production states were considered in the preliminary design leading to the estimates.

3.4.2 Module Parameters

Logic modules assumed in the system estimates are the Fairchild Milliwatt Micrologic flat-pack and the DI/AN CTL Pico-Bit as discussed in Appendix D. Table 3-7 summarizes the per-module parameters of interest.

The values for package weight and volume of logical modules were obtained from actual aerospace and microminiature digital equipments built by DI/AN and others. In the case of CTL Pico-Bit modules, most of the data were obtained on the larger CTL-LSQ module; but it is felt that a fair scaling of parameters has been performed.

3.4.3 Reliability of APT On-Board Gridding System

Based on the module count data presented in the previous sections of this report, one-year reliability figures and MTBF values have been calculated. Table 3-8 is a summary of results.

Table 3-7

Per-Module Parameters

Item	Average Power(mw)	Packaged Wt. (lbs.)	Packaged Vol. (in^3)	Cost, Lots of 1000
913 Flip-Flop	12	0.0057	0.19	$ 18.55
912 Half Adder	8	0.0057	0.19	10.31
910 Dual Gate	4	0.0057	0.19	7.92
909 Buffer	10	0.0057	0.19	9.07
911 Four Input Gate	4	0.0057	0.19	7.92
CTL-100-24-PB	$7x10^{-8}$ joules per "one" shift	0.018	0.40	40.00

Table 3-8

Reliability Estimates

Method	MTBF(Hours)	Reliability (1 year)
CM-1, CTL	36,300	.78
CM-1, Integrated Ckts.	69,300	.88
CM-1, Hybrid	50,600	.84
SL-2, Integrated Ckts.	52,400	.85

The supporting data for Table 3-8 is listed in Tables 3-9 through 3-12.

Table 3- 9

CM-1, CTL Reliability Estimate

Logic	Module Count	Failure Rate %/1000 Hours	Total Failure Rate %/1000 Hours
Pico Bit CTL	223	.007	1.561
Integrated Ckt. Flat-Packs	67	.001	.067
Memory (Univac 80,000 Bits)	1	1.13	1.13
TOTAL CM-1, CTL Failure Rate =			2.758

$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{2.758 \times 10^{-5}} = 36,300 \text{ Hours}$$

R = .78

Table 3- 10

CM-1 Integrated Circuits Reliability Estimate

Logic	Module Count	Failure Rate %/1000 Hours	Total Failure Rate %/1000 Hours
Integrated Ckts.	312	.001	.312
Memory (Univac 80K bit)	1	1.13	1.13

TOTAL CM-1 Integrated Ckt. Failure Rate =1.442

$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{1.442 \times 10^{-5}} = 69,300 \text{ Hours}$$

R = .88

Table 3-11

CM-1 Hybrid Reliability Estimate

Logic	Module Count	Failure Rate %/1000 Hours	Total Failure Rate %/1000 Hours
Pico Bit CTL	103	.007	.721
Integrated Ckts.	123	.001	.123
Memory (Univac 80K bits)	1	1.13	1.13
TOTAL CM-1 Hybrid Failure Rate =			1.974

$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{1.974 \times 10^{-5}} = 50,600 \text{ Hours}$$

$$R = .84$$

Table 3-12

SL-2 Integrated Ckt. Reliability Estimate

Logic	Module Count	Failure Rate %/1000 Hours	Total Failure Rate %/1000 Hours
Integrated Ckts.	459	.001	.459
Delay Line	1	.585	.585
Memory (Univac 40K bits)	1	.86	.86
TOTAL SL-2 Integrated Ckt. Failure Rate=			1.904

$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{1.319 \times 10^{-5}} = 52,400 \text{ Hours}$$

$$R = .85$$

SECTION 4

COMPARISON OF APPROACHES TO ON-BOARD GRIDDING

4.1 INTRODUCTION

Analog approaches have eliminated from consideration of the digital methods, four approaches which show sufficient promise to warrant a detailed comparison. These are:

1. straight-line method SL-2
2. coordinate method CM-1
3. coordinate method CM-2L
4. coordinate method CM-2H

The ground computation of the picture grid should not provide a limitation on any of the three methods although the straight-line method is certainly the easiest to implement. Hence, this factor can be eliminated in comparing the relative performance and feasibility of the three systems.

The differences in the flight-system weights are small and although the power differences are appreciable, all are small (less than 2 watts).

The system parameters which are most dependent on the particular approach are:

1. appearance of the picture grid
2. storage requirements
3. error susceptibility

4.2 APPEARANCE OF THE PICTURE GRID

Two characteristics of the superimposed grid line significantly affect system design— mark spacing and smoothness of change in slope. With regard to the latter property, examine the appearance of the grid lines appearing in Figure 4-1 (simulated grid representative of the straight-line method). Although the marks deviate a maximum of 1% from the true grid line, the large slope changes between segments are disturbing (in the opinion of the writer). One solution to this problem is an increase in the number of line segments. The storage requirement for a single orbit with the SL-2 system is 20,000 bits maximum for grid and annotation

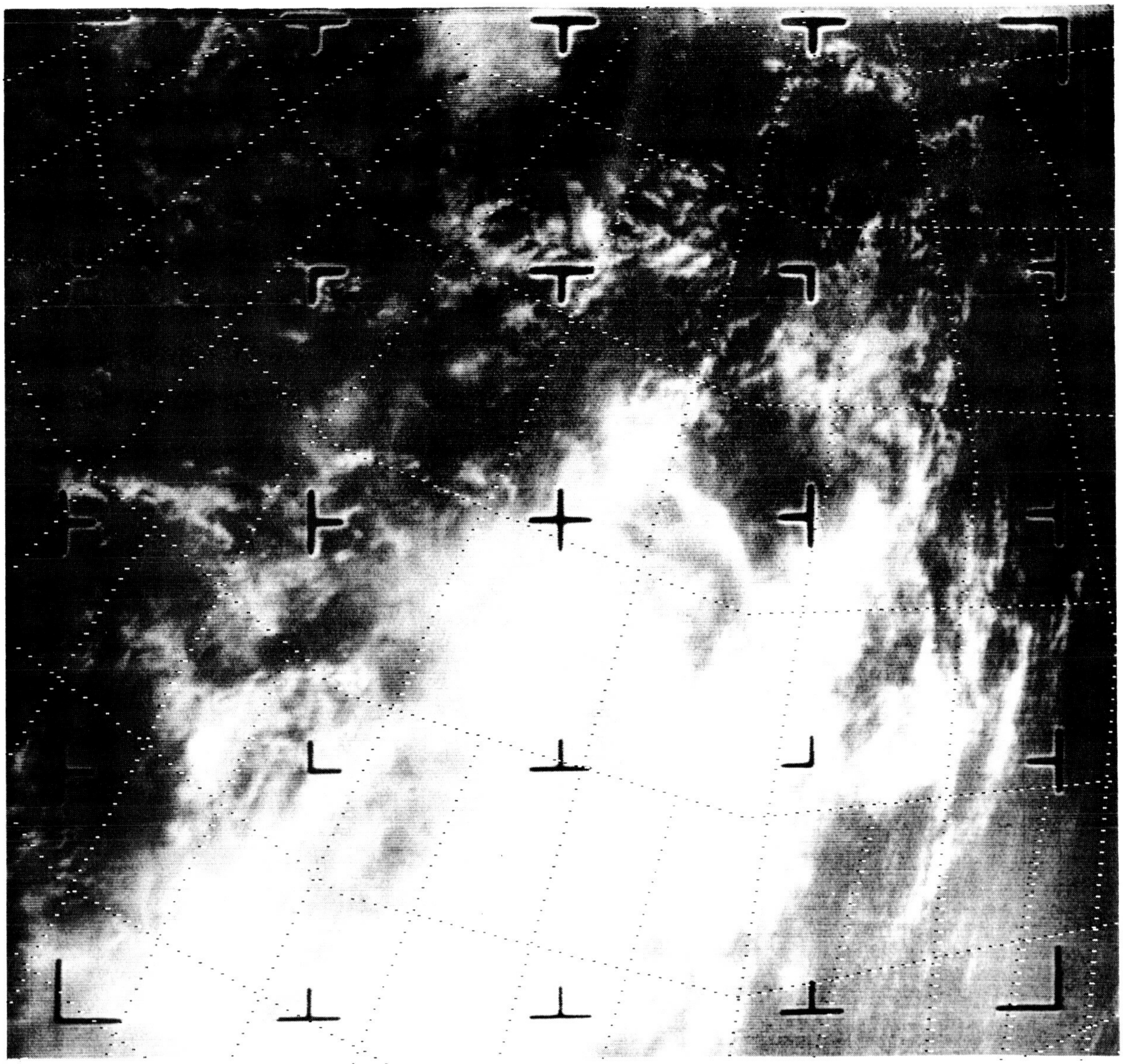


Fig. 4-1 Simulated Grid SL-2

(assuming the more efficient annotation scheme is employed). However, any reasonable increase would bring the storage requirement past that of CM-2H. CM-2H has the additional advantage of a lower logic speed since only one bit is added to Y or X rather than the 10 bit slope added for SL-2. If the appearance of the lines in Figure 4-1 is judged objectionable (compared to the lines typical of a coordinate system, shown in Figures 4-2 to 4-10), the choice between SL-2 and CM-2H is certainly the latter.

With regard to mark spacing, a spacing of eight picture elements provides a very pleasing well-defined line. However, a larger spacing may be adequate. Simulated grids representative of any of the coordinate system approaches with a mesh spacing of two picture elements appear in Figures 4-2 through 4-10.* In these figures, grid lines are simulated with mark spacings of 8 (Fig. 4-2, 4-5, 4-8), 12 (Fig. 4-3, 4-6, 4-9), and 16 (Fig. 4-4, 4-7, 4-10) picture elements. Each grid is superimposed on three different cloud pictures to provide a firm basis for evaluation of a satisfactory spacing. Although the mark spacing has no effect on the design of the straight line system, it affects the storage requirement of the coordinate methods. A decrease in mark spacing from 16 to 8 in the CM-1 approach almost doubles the size of the memory. For CM-2 the corresponding increase in memory size is approximately 33%.

4.3 SUSCEPTIBILITY TO ERROR

An estimate of the signal-to-noise ratio likely to be experienced in the ground station-to-satellite communications channel indicates that thermal noise will not be an important factor contributing to gridding-system errors. The more important considerations are operation with low S/N ratios when operating near antenna pattern nulls and the effects of interference from other spacecraft or ground sources. These factors can only be assessed through experience gained from similar communications channels now in existence.

If interference is judged to be a very serious problem, the CM-1 approach having the lowest error susceptibility is probably the best approach and CM-2L the worst.

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* Contained in pocket attached to rear cover.

Table 4-1

Comparison of Digital Approaches to On-Board Gridding

Method	Straight-Line SL-2	Coordinate CM-1	Coordinate CM-2L	Coordinate CM-2H
K = 8	Main Store* 20,000 bits Buffer 1,000 bits Weight 7 lbs. Power** 1.8 W	Main Store 160,000 bits Weight 8-9 lbs. Power 1/4 - 1 W	Main Store 40,000 bits Buffer 2,000 bits Weight 7 1/4 lbs. Power 1.3 W	Main Store 34,000 bits Buffer 1,300 bits Weight 7 1/2 lbs. Power 1.8 W
K = 12	Same as above	Main Store 120,000 bits Weight 7-8 lbs. Power 1/4 - 1 W	Main Store 35,000 bits Buffer 2,000 bits Weight 7-7 1/4 lbs. Power 1.3W	Main Store 30,000 bits Buffer 1,300 bits Weight 7-71/2 lbs. Power 1.8 W
K = 16	Same as above	Main Store 80,000 bits Weight 6.5 - 7 lbs. Power 1/4 - 1 W	Main Store 30,000 bits Buffer 2,000 bits Weight 7 lbs. Power 1.3 W	Main Store 25,000 bits Buffer 1,300 bits Weight 7 lbs. Power 1.8 W
Comments	1. Poor grid appearance 2. Most complex logic	1. Minimum logic 2. Least vulnerable to error. 3. Largest Memory	1. Most vulnerable to loss of portion of picture grid as a result of bit error.	1. Pleasing grid appearance — Good compromise on all other counts.

* Storage estimates are for 1 orbit.

* average

4.4 CONCLUSIONS

Table 4-1 summarizes the storage, weight and power requirements for the four approaches along with comments on characteristics peculiar to the individual approach. Although no severe weight penalty results from the large memory requirement of CM-1, the ability to grid multiple orbits and eventually direct-readout infrared (DRIR) is impaired. The multi-orbit/function capability makes the SL-2 and CM-2H approaches attractive. However, the final choice hinges on an assessment of the grid-appearance requirements and the error probability expected in the updata communications channel of the satellite.

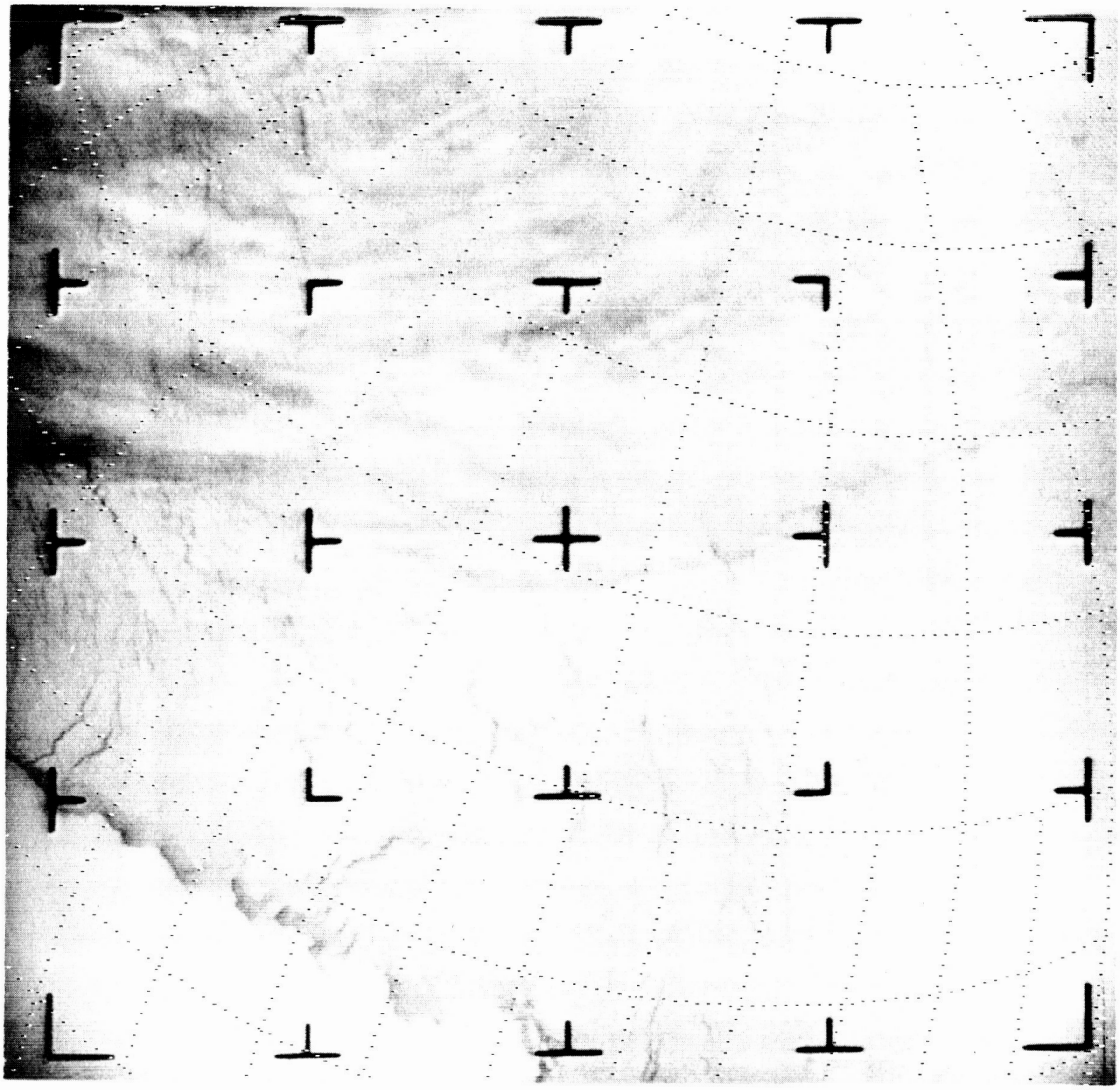

Fig. 4-2 Simulated Grid K = 8

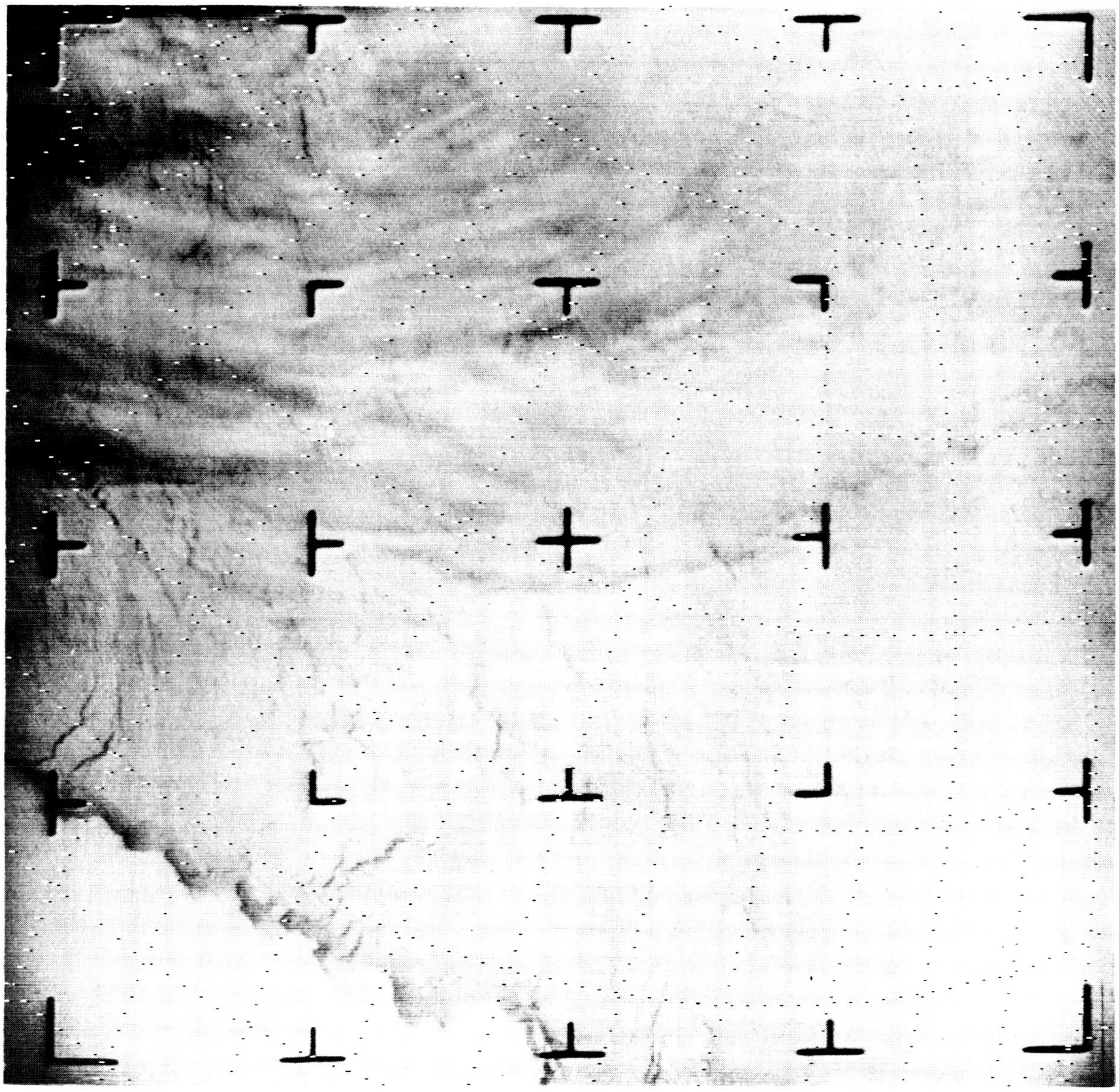

Fig. 4-3 Simulated Grid K = 12

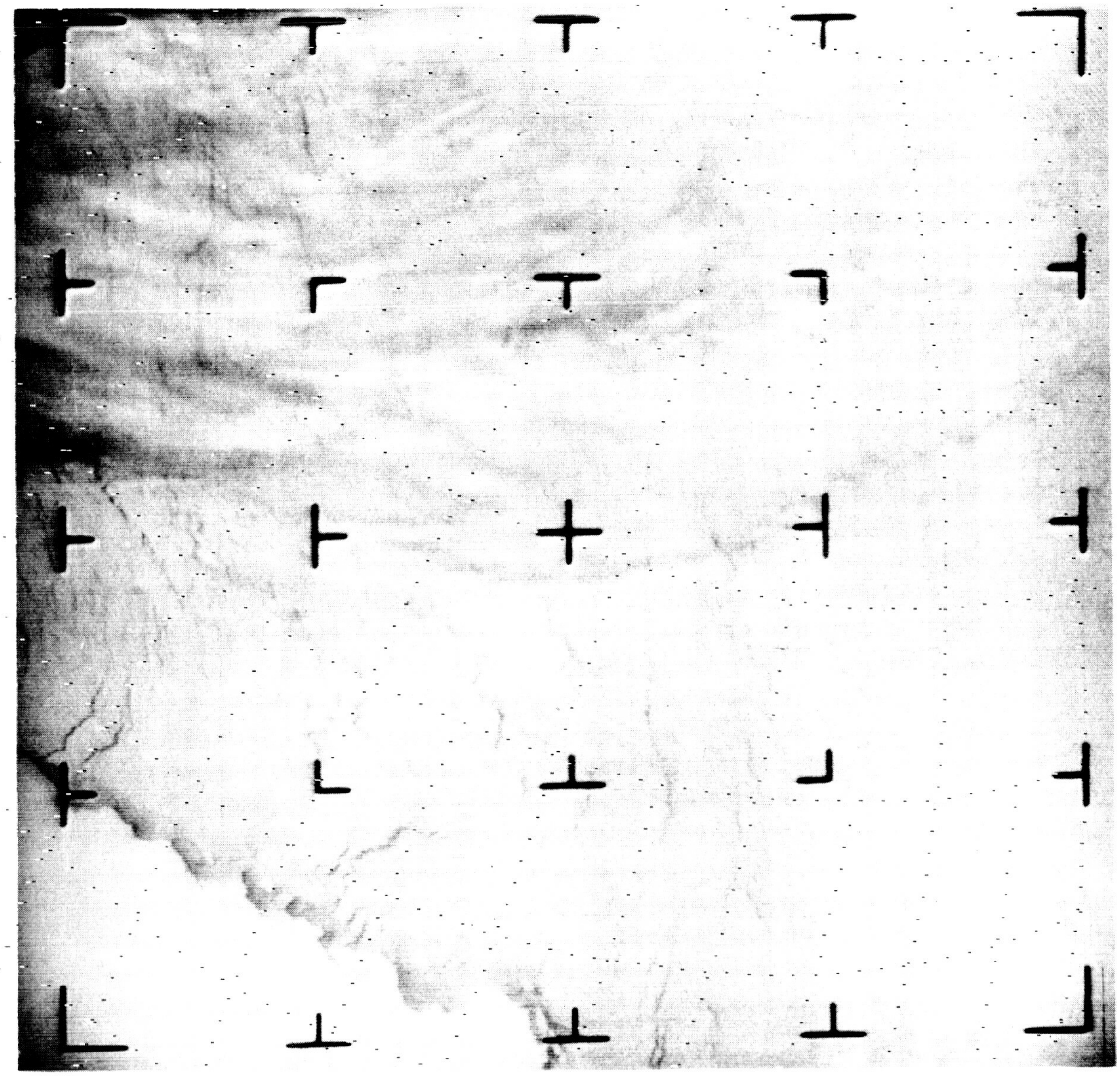

Fig. 4-4 Simulated Grid K = 16

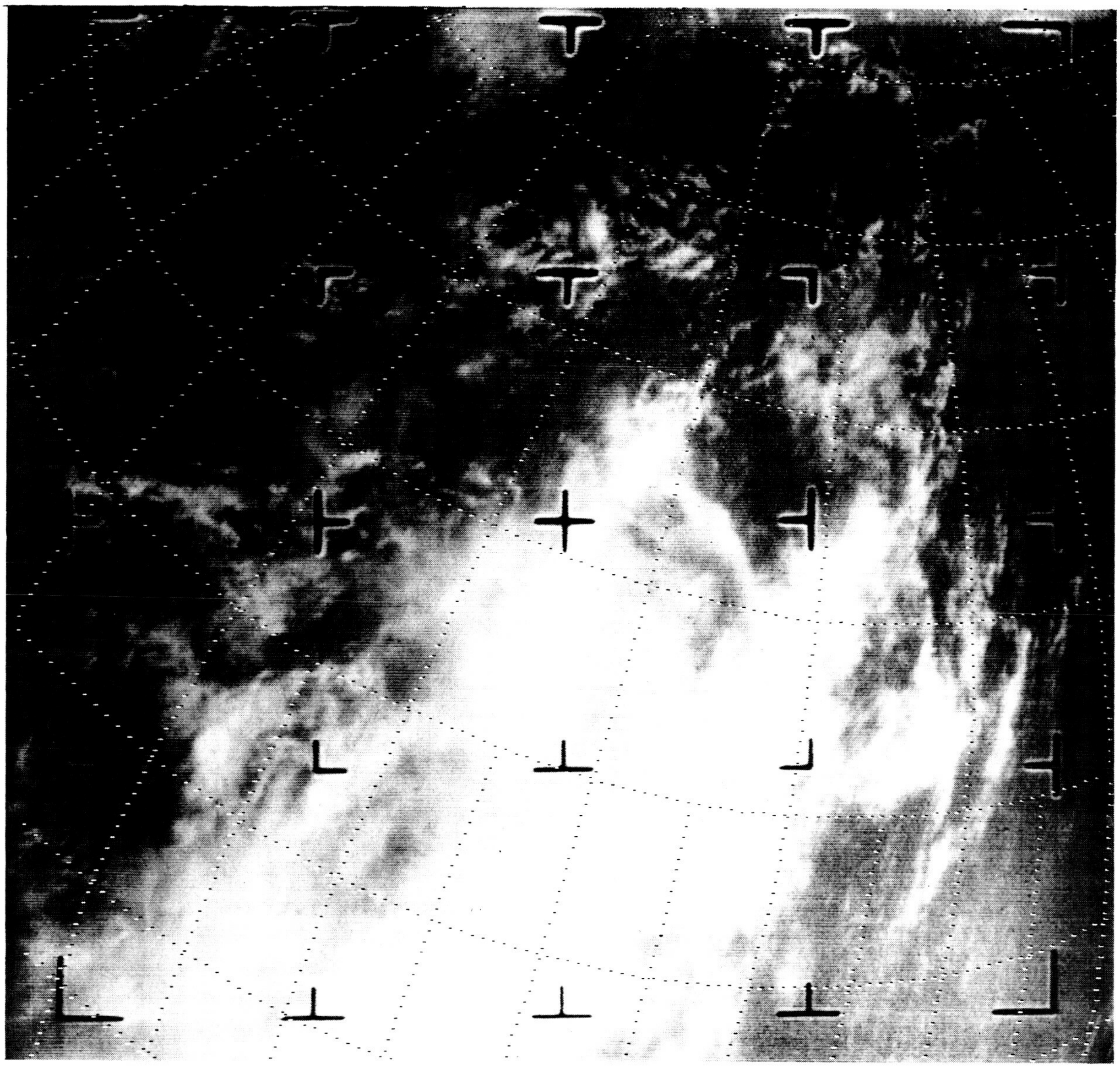

Fig. 4-5 Simulated Grid K = 8

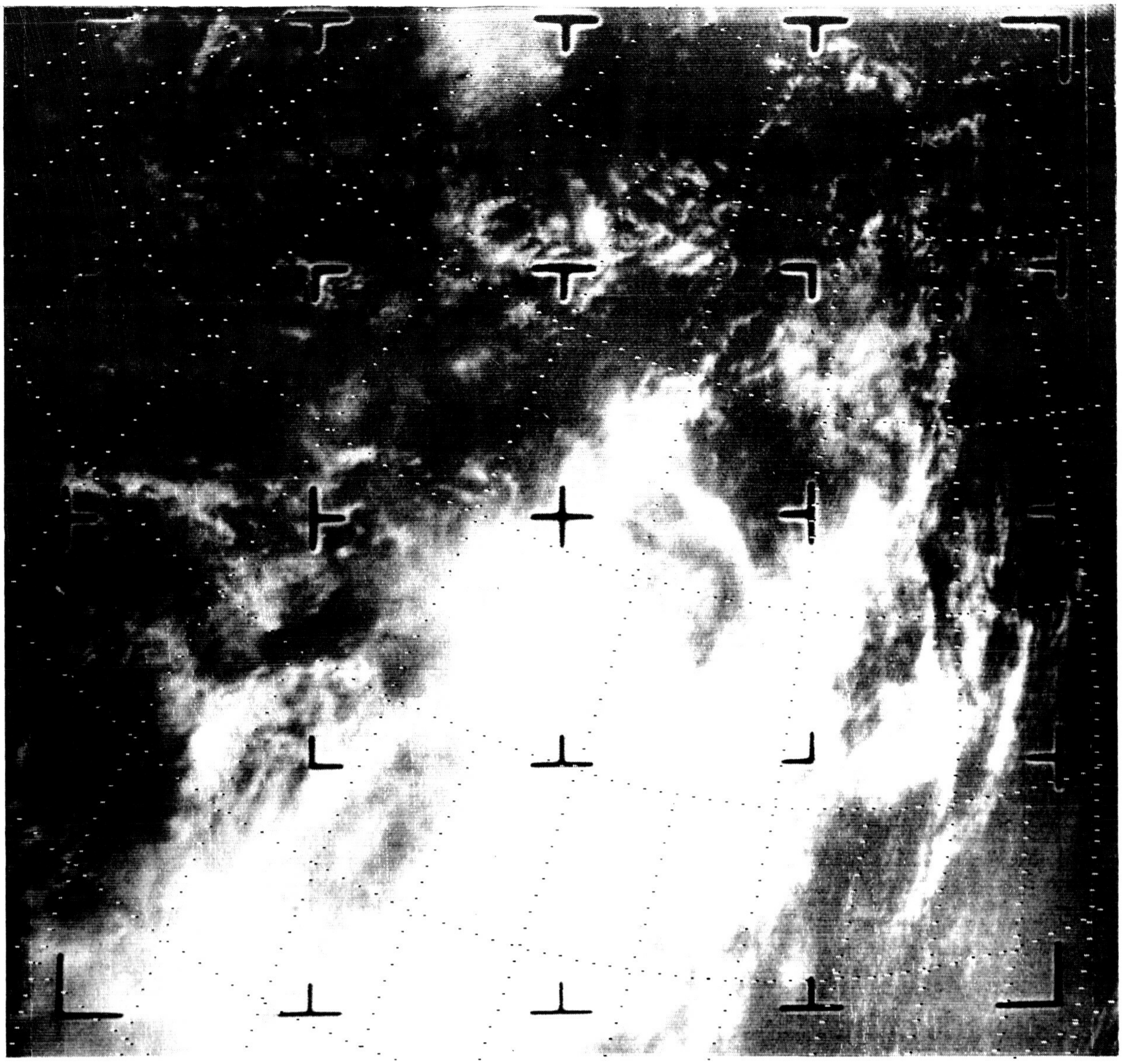

Fig. 4-6 Simulated Grid K = 12

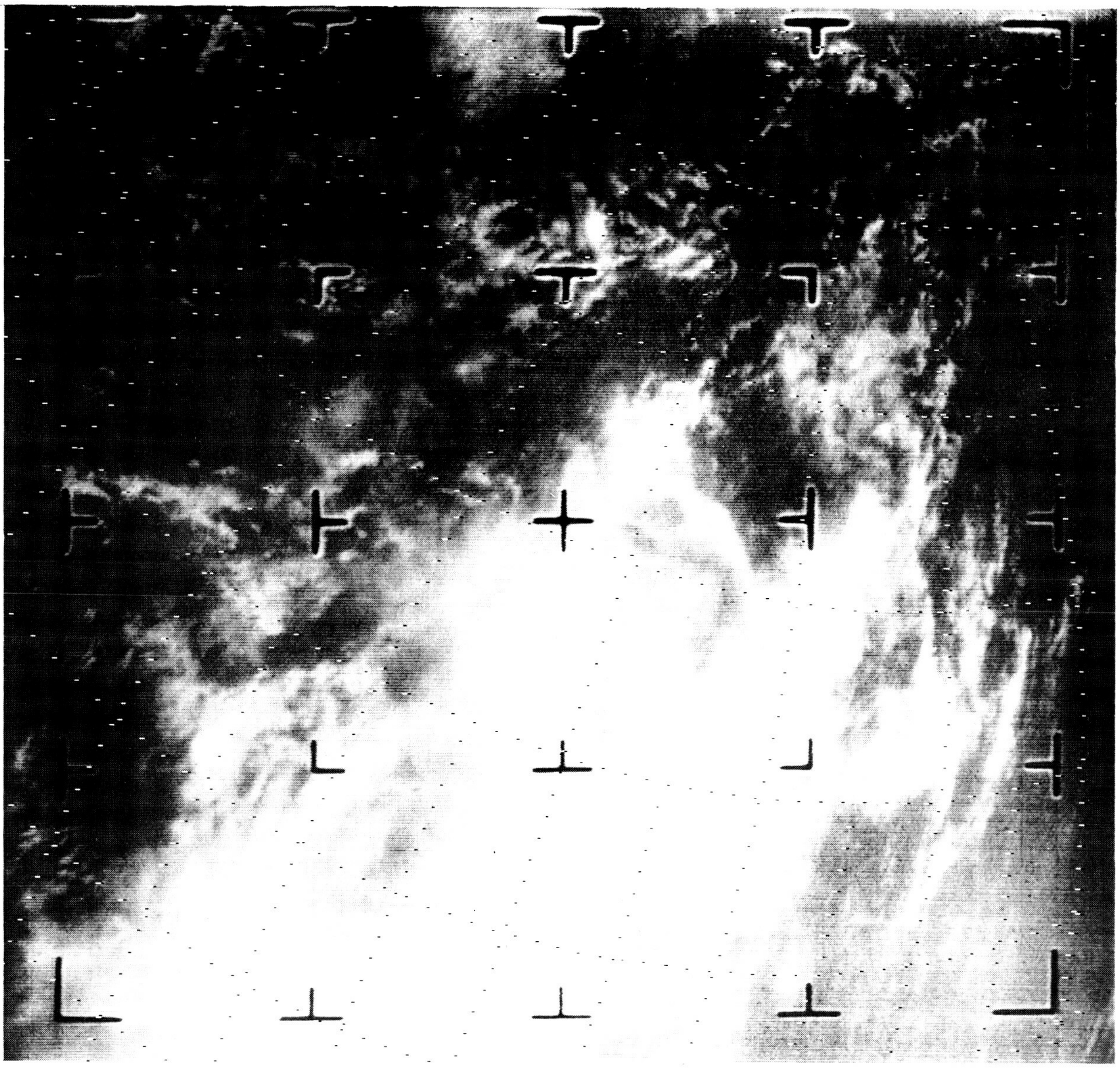

Fig. 4-7 Simulated Grid K = 16

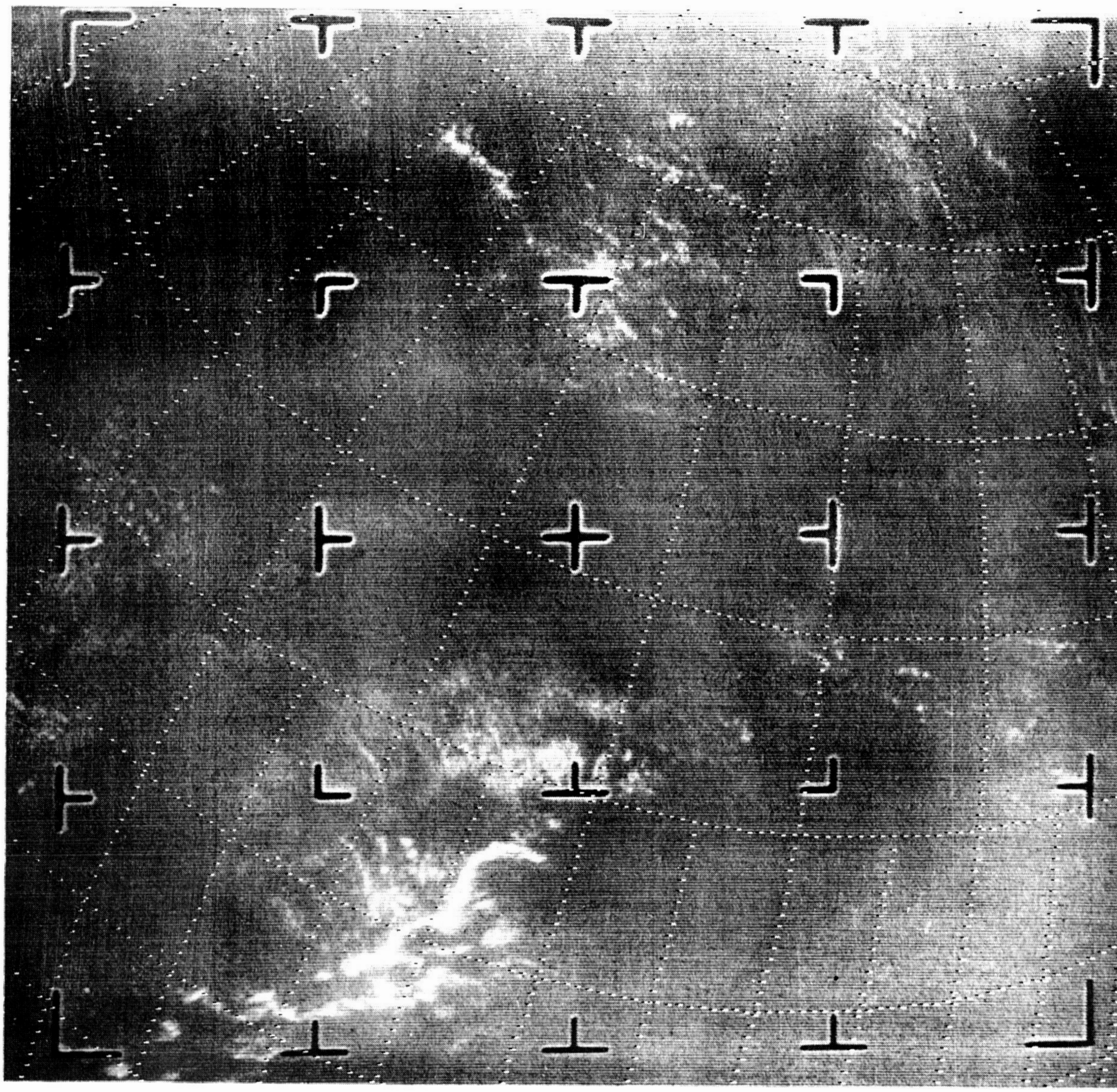

Fig. 4-8 Simulated Grid K = 8

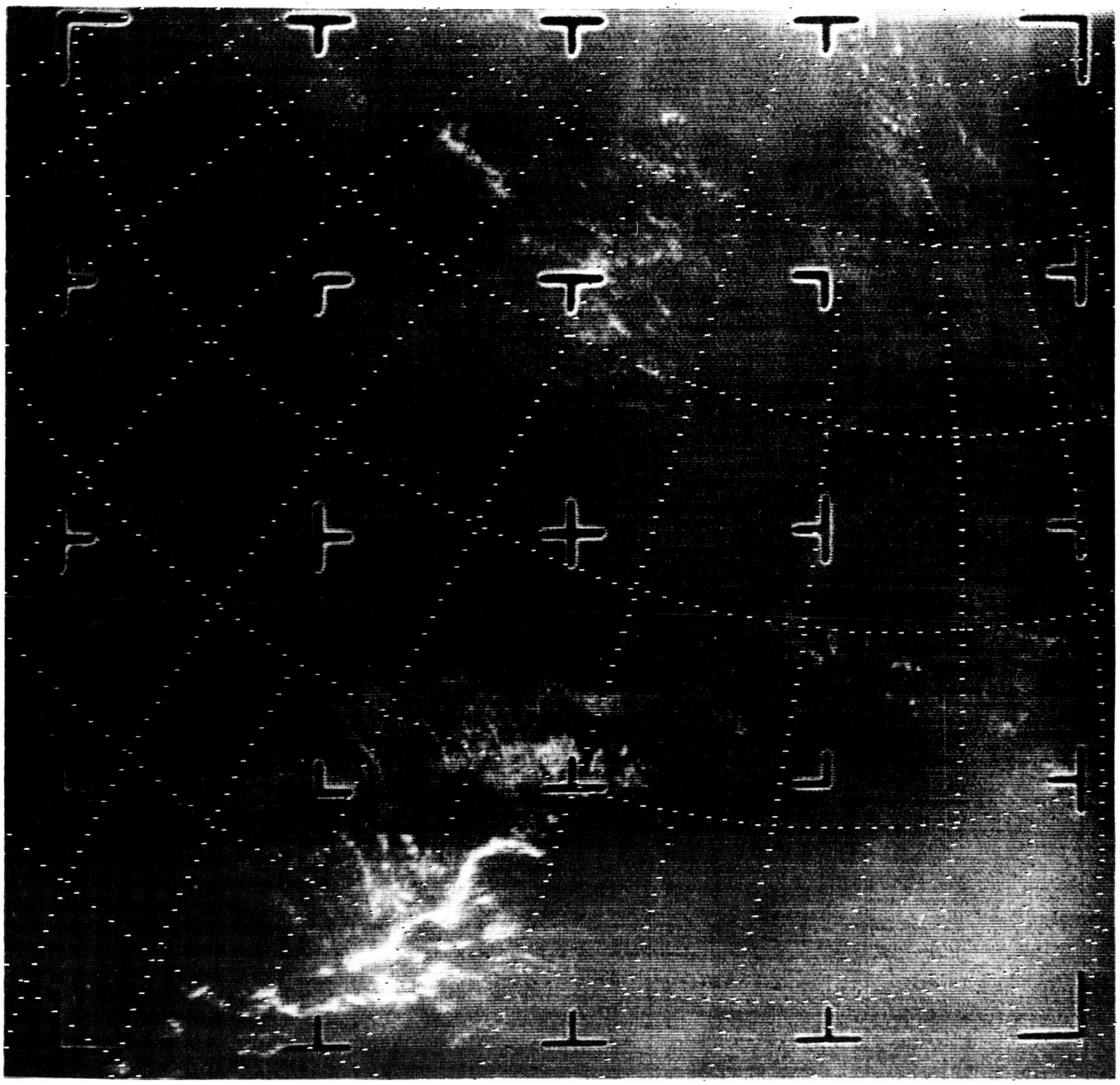

Fig. 4-9 Simulated Grid K = 12

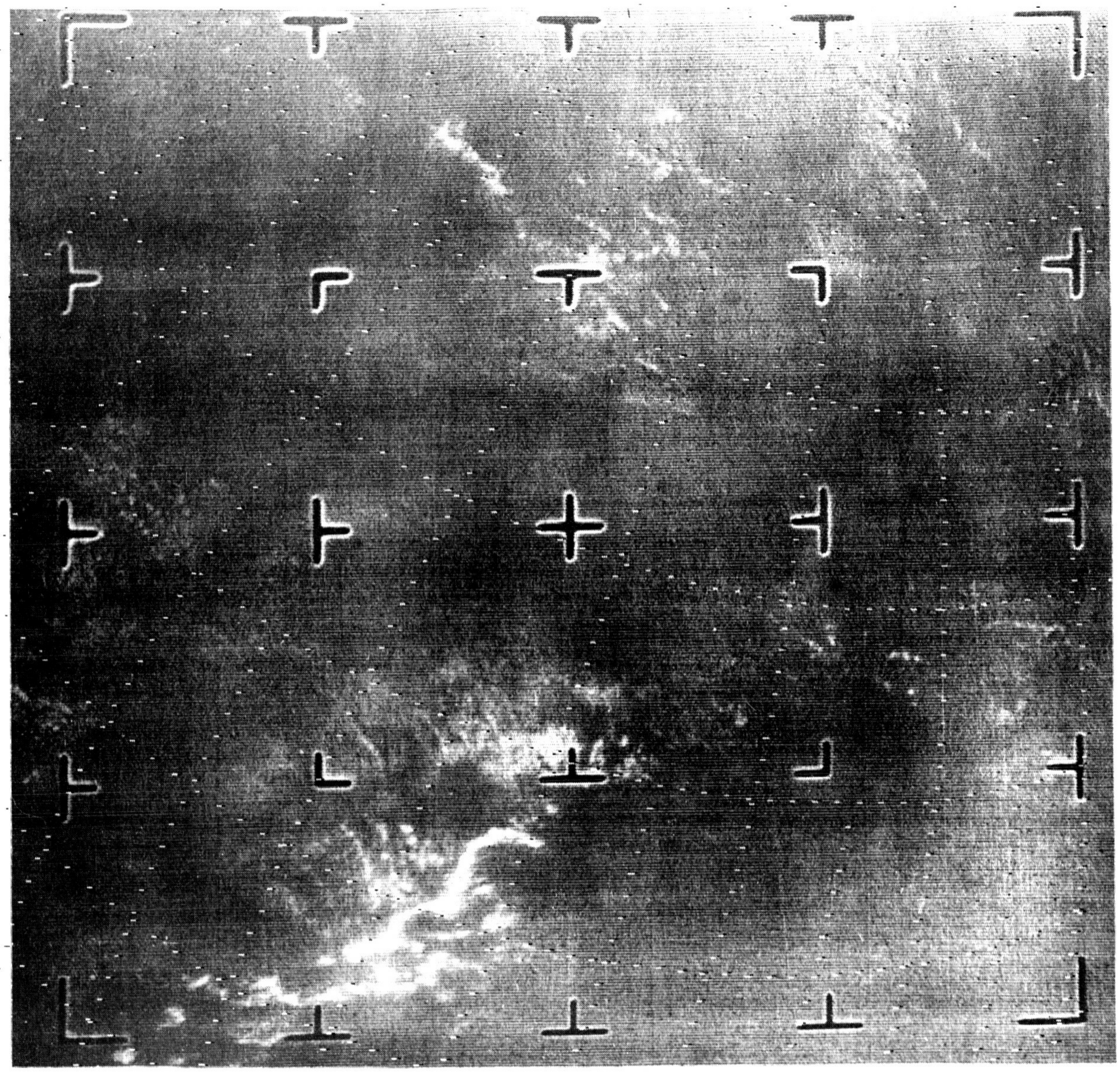

Fig. 4-10 Simulated Grid K = 16

APPENDIX A

ANTENNA PROGRAMMING

The on-board gridding system can be used to facilitate antenna programming at the remote receiving stations. This can be of great importance to military stations cut off from effective communication with NASA or other sources of orbital information. While present techniques permit a resourceful and properly trained individual to construct training programs indefinitely once he has available basic orbital elements and has succeeded in acquiring one or two passes, the requisite talents may not be universally available.

Antenna programming can be simplified by placing the sub-point track or an orbit about 24 hours later on each picture. The track would be marked at 1 or 1/2 minute intervals by grid-type marks. At least one per picture of these should be identified with the actual minute. At a 1/2 minute interval, about 10 dots would cross the picture. It might be necessary to repeat the dots over two or three sweeps to make them conspicuous.

Determination of tomorrow's antenna programs would then be achieved by placing the pictures under an overlay which would be similar to the present gridding overlay with an azimuth-elevation diagram added. In practice, this would be two overlays stapled together to properly locate the azimuth-elevation diagram. The operator need only approximately match latitude-longitude grid lines on picture and overlay. He can then read off required azimuths and elevations against time, giving tomorrow's programs directly.

Accuracy is completely adequate for all current and contemplated APT antennas. Because the overlay height does not correspond exactly to satellite height, some elevation angle error is possible. It goes to zero in the vicinity of the station, where it is most important because of its relation to azimuth slewing.

The addition of this antenna programming feature would vastly simplify ground operations under field conditions.