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DEVELOPMENT OF A GROUND SIGNAL PROCESSOR FOR DIGITAL SYNTHETIC ARRAY RADAR DATA

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I. INTRODUCTION

The optically processed images from a SLAR are useful to investigators in the field of remote sensing to the degree that the wavelength and polarization response of terrain and water areas can be quantitatively determined. Since the radar video is recorded on photographic film with its inherent limitation in dynamic range, it is desirable to consider converting the video to digitally recorded data on magnetic tape, for subsequent correlation to radar maps and analysis of the resolution cell contents. The video data collected by the radar are thus preserved intact and the subsequent operations to recover the images may be closely controlled on a high speed digital computer and high resolution electronic display system with controllable dynamic range. The photographic processing, through an analog recording system and an analog optical film processor, suffers from the aforementioned limitation in film dynamic range (on the order of 23 dB) and correlation errors, which result in loss of precision in the photographic images produced. In addition to these errors, which may occur during the correlation process or film exposure, tight controls are required on film processing to generate a satisfactory photograph.

With properly digitized data, the precision of the operations can be controlled to the level represented by the digital equipment used in recovering the data, and the characteristics of the electronic display system used. Additionally, the data may be made available on magnetic tape records for analysis by users in the field of earth resources. Photographs of the display may be used qualitatively to identify areas of interest for detailed evaluation of magnetic tape data.

The NASA Lyndon B. Johnson Space Center (NASA/JSC) operates an APQ-102 modified SLAR radar on an RB-57 aircraft test bed, normally flying at about 60,000 ft, to simulate orbiting vehicle geometries and to
gather wide coverage camera data. The work described in this report involved the design, fabrication, and installation of a video sampling and recording system on board the aircraft, and the processor development to generate digital radar imagery. The work was performed by ARL:UT under contracts with NASA/JSC.
II. RADAR AND DIGITAL SAMPLING SYSTEMS

The modified APQ-102 generates two pulse compressed video signals, one from a co-polarized antenna with nominal 3 dB beamwidth of 1.3°, and one from a cross-polarized antenna. The radar uses a linear frequency modulated pulse with 15 MHz bandwidth at an X-band operating wavelength of 3.125 cm. The compressed 3 dB pulse width is about 60 nsec. The radar prf is locked to the aircraft ground speed with a sample rate of two per foot. The transmitter can be switched to either the horizontally or vertically polarized antenna, both of which are gimbaled to provide motion compensation and to keep the boresite direction normal to the velocity vector at nadir angles of 33 or 54°. Figure 1 illustrates the antenna installation.

The digital data recording system (DDRS) was designed to digitize the raw (pulse compressed) video signals from the radar and various parameters from the radar operating environment, such as the inertial platform signals and aircraft operating parameters. These are necessary in reconstituting the radar video into synthetic aperture maps and, subsequently, in analyzing the recorded data.

The DDRS is installed in the instrumentation pallet which is carried in the center section of the RB-57 aircraft test bed. Figure 2 is a photograph of the electronics pallet which houses the APQ-102 photographic data recorder as well as the DDRS.

A. Characteristics

The DDRS receives the analog video signals generated by the APQ-102 and normally used to modulate the two axes of two cathode ray tubes in the photographic recording system. Buffer amplifiers supply both horizontally and vertically polarized, synchronously detected, and range pulse compressed signals to the DDRS. The operator can adjust the gain of these signals to the DDRS and the photo recorder. In addition,
FIGURE 2
INSTRUMENTATION PALLET
the operator can select the radar mode, which essentially selects the depression angle of the antenna system (or the nadir angle) to change the swath of terrain imaged for a nominal operating altitude of 55,000 to 60,000 ft MSL. The system also digitizes and records various operating parameters of the radar and its platform, the power supply status for various power supply voltages, and operating environment temperatures. This permits evaluation of the digitizing and recording subsystem in conjunction with each data gathering exercise.

The details of the DDRS subsystem and its interface with the APQ-102 radar are documented in ARL-TM-80-14, an operating and maintenance manual produced under NASA Contract NAS9-15217. Figure 3 illustrates the relationships among the various components.

B. Parameter Options Available

The principal option available to the system operator is the sampling rate of the DDRS which permits selection of sampling intervals by the high speed analog-to-digital (A/D) converters of 40-150 nsec in 10 nsec steps. The system operation at the 40 nsec interval is critical and requires careful setup of the timing pulses for satisfactory performance. Coupled with the selection of sampling rate is the precision of the data recorded, i.e., 1-, 2-, 4-, or 7-bit levels of digital data for each sample, which may also be selected by the operator. Certain combinations of mode (there are two modes or operating geometries), sample interval (SI), and data precision (DP) are invalid and are so identified in the recorded data. Finally, the start of sampling is set by the delay selected, 2-99 μsec.

The PRF of the radar system is determined by the ground speed, so that two pulses per foot of travel along its velocity vector are generated by the radar. This parameter is not adjustable, nor is the range resolution, which is set by the analog pulse compression system
FIGURE 3

DATA REDUCTION AND DISPLAY SYSTEM
of the APQ-102. It has a time bandwidth product of \(1.2 \mu\text{sec})(15 \text{ MHz})\), or a compression ratio of 18:1, with a compressed pulse width of about 60 nsec or 30 ft in slant range. The DDRS can thus oversample at the 40 and 50 nsec SI selections, or undersample at the higher rates with respect to the nominal 3 dB range resolution of the radar.

The azimuth resolution of a sidelaying SAR is limited theoretically to half the antenna dimension for the focused processing situation; for the APQ-102 it is the antenna azimuth plane dimension of 120 cm/2, or 60 cm, roughly 2 ft.

Practically speaking, the resolution in azimuth is limited to about 30 ft by errors introduced in motion compensation of the video. The antenna is designed to minimize Doppler ambiguities, i.e., act as a spatial filter to eliminate echoes from scatterers with modulo 2\(\pi\) radian phase shifts identical to phase shifts from other (different) scatterers in the main beam. This real beamwidth, coupled with the prf, determines the number of time samples that can be obtained from any given scatterer for processing in a synthetic aperture. The real beamwidth therefore sets the maximum length of a synthetic aperture and the resolution or main lobe width of the synthetic aperture.

The main lobe width of the APQ-102 in azimuth is a nominal 1.3° (22.7 mrad) at the 3 dB points. At the nominal slant ranges for operation in modes 1 and 2 at the center of an imaged swath, the alongtrack ground coverages are 1710 and 2478 ft, respectively, so at 2 samples/ft, a large number can be processed. To keep the sample grid spacing approximately the same in azimuth and range, a much smaller number of pulses should be processed in a synthetic array. The choice of array length will determine the need for applying a quadratic phase correction or focus correction to the recorded data prior to processing the synthetic array.
An additional option for the processor is the selection of a weighting function, or window, to optimize the tradeoff between width of the main lobe in the Doppler spectrum and the suppression of sidelobes. The processor developed by ARL:UT provides either Taylor, cosine on a pedestal (Hamming), or Hanning weights for the pulses in the arrays. Other weighting routines, such as Kaiser, Chebyshev, etc., may be employed by providing the additional algorithms to the software.

Finally, the choice of display parameters must be made in the postprocessor, based on the statistics of the image calculated by the program from the overlaid outputs of the Doppler filters or pixel values. The operator must also choose the threshold of the displayed data, dynamic range, and logarithmic or linear data options, as well as the size of the displayed coverage. The latter is fixed in the ARL:UT processor at 360 azimuth lines by 384 range sample intervals.

In essence, therefore, one set of parameters is chosen at the equipment, and another set in processing the raw data. Table I provides a breakdown of these choices.
TABLE I
SYSTEM SELECTABLE PARAMETERS

Operator Selectable Parameters

<table>
<thead>
<tr>
<th>DDRS</th>
<th>Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRMIN - Delay time to start of sampling</td>
<td>Mode (1 or 2)</td>
</tr>
<tr>
<td>SI - Sampling interval for A/D</td>
<td>Gain (H or V video)</td>
</tr>
<tr>
<td>DP - Data Precision (1,2,4,7 bit)</td>
<td>Transmitted Polarization</td>
</tr>
</tbody>
</table>

Note: The DDRS design incorporates logic to flag incompatible or invalid combinations of the above parameters. Valid settings are listed in Table C-1 of ARL-TM-80-14 for various combinations of mode, delay, SI, and DP. Nevertheless, data can still be recorded, despite invalid control settings.

Processor Selectable Parameters

Co-polarized or Cross-polarized Data
Area to be Imaged: Starting Range Sample + 384 Range Bins
Starting Frame Number + 360 Azimuth Elements
Azimuth Resolution - Fixed by the Software to be the Same as Range Resolution at the Map Center
Array Weighting and Beam Broadening Factor
Range Bin Used as the Map Center
Range Bin Used as the First Range Bin on the Image

Postprocessor/Display Parameters

Log or Linear Data
dB/Gray Shade or Number of Filter Magnitudes/Gray Shade Assignment
Brightness, Contrast Settings
III. RECORDED DATA

The DDRS was designed to record the digital data, video, and radar parameters on a 14-track wideband tape recorder in Miller code. The format was designed to be compatible with the DRIE equipment used at ARL:UT.

A. Formatting and Track Assignments

Details of the data formats and the track assignments on the Mincom (in-flight) tape recorder may be found in ARL-TM-80-14. Unfortunately, the track assignment utilized by the NASA/JSC contractor does not agree with that prescribed, requiring some cabling adjustments in the ARL:UT playback equipment for compatibility with the reformatting hardware.

B. Decoding and Reformatting Requirements

The video data and the radar parameter environment (RPE) data are recorded on the wideband tape after being Miller encoded. The Miller code has certain advantages over the NRZ (non-return-to-zero) code in recording efficiency and S/N ratio. Miller decoders are required for the 8 tracks of video (4 horizontal and 4 vertical polarization) and 1 track of RPE data. So-called NERDAS (NASA Earth Resources Data Acquisition System) data and time codes are recorded directly in NRZ code. The digital video and RPE data, after decoding, are processed through the DRIE to an IBM computer-compatible format and rerecorded on a Hewlett-Packard 7970B tape drive unit. Figure 4 illustrates the process. The DRIE reformats the data as described in the technical report ARL-TR-76-42. The wideband tape formats are described in the technical manual ARL-TM-80-14.
FIGURE 4
DIGITAL DATA TRANSFORMER
C. **DRIE - Functions and Characteristics**

The DRIE equipment was designed for the FLAMR radar system, and hence its application to the APQ-102/DDRS is not very efficient. It duplicates a realtime airborne processor, and the function of converting the data, illustrated in Fig. 4, is not implemented adequately for this purpose. Depending on the bit precision of the data recorded, a maximum of 128 range bin samples may be reduced at one pass through the selected frame numbers (FN) on the wideband tape. This is true for the 4-, 2-, and 1-bit data. With 7-bit data, however, only 16 range samples can be processed at a time; consequently, 24 passes are required through the wideband tape records to convert 384 range samples of data. Usually, 8-12 9-track, 800 bpi computer tapes are required for a full image set of raw data.

The DRIE contains bit parity error detecting circuitry which permits monitoring the source and rate of bit error generation, a feature of considerable value in evaluating the performance of the DDRS and wideband tape recording equipment. It also indicates error sources in the re-encoding process, such as the Hewlett-Packard tape drive buffer memory and tape recorder operation. Various addresses for the RPE data may also be displayed, with their bit contents, to evaluate the data as decoded from the instrumentation (wideband) tape.
IV. PROCESSING REQUIREMENTS

The video data are recorded in continuous strips. The range swath beginning and width are determined by the DRMIN variable (the selected delay following the STC trigger in the APQ-102), the sampling interval, bit precision, and mode (see Performance Specifications, pp. 20-21, ARL-TM-80-141). The range coverage is thus determined by the number of samples to be displayed and the sample interval. Likewise, the displayed azimuth coverage is determined by the Doppler filter separation or spatial frequency corresponding to spectral frequency, and the number of unique filters, after overlay. The ground signal processor (GSP), in its delivered configuration, makes the azimuth interval equal the range interval at the center of the image.

A. Physical Limitation on Parameter Selection

The GSP options are limited by the previously selected values of the DDRS and APQ-102 parameters, and by certain design parameters of the radar system. The most important of the latter is the fixed relationship between the platform ground speed and the radar prf of 2 pulses/ft, which sets the maximum synthetic beamwidth of the system and the fixed slant range resolution capability of the radar (about 30 ft). Sampling in range can be varied from a 1.5 oversampling ratio at the 40 nsec rate to 0.4 undersampling at the 150 nsec rate. Once the DDRS parameters are set by the airborne operator, the GSP characteristics are fixed, except those that determine the azimuth resolution and at the same time, the sampling ratio, since the sampling rate is fixed by the platform velocity. Second, the GSP operator must select the portion of the sampled radar data to be processed, depending on the number of display elements available.
The smallest number of range samples recorded (at 7-bit precision) is 512, and this is larger than, for example, the number of display elements (pixels) on the ARL:UT High Resolution Display System. The number of azimuth elements is usually of the same order as the range elements on most CRT displays. Thus, the displayed area should be small enough to accept (digitally) a legend containing a description of the scene, its dimensions, and data concerning the flight parameters.

Finally, the GSP operator must select the postprocessing display parameters such as the dynamic range represented, number of bits, intensity resolution, etc. This selection can be made after examining the statistics of the linear data for the radar image, i.e., the mean, standard deviation, and maximum and minimum values generated after array processing and overlaying. The characteristics of a display will determine this selection, i.e., number of gray shades, availability of color, etc. The ARL:UT display is limited to 16 gray shades, and the dynamic range is determined by the assignment of dB/gray shade. Usually, 2 dB/gray shade is used, with a dynamic range of 32 dB.

B. Processor Organization

Figure 5 is a flow diagram of the processor, which is organized into a Doppler processor and a postprocessor. Table II lists the routines included in the GSP.

The first step is to reformat the DRIE data records. Program REFORMPI reads the DRIE records, decodes them, and then outputs them to a scratch disk file. REFORMPI also has the option of checking the DRIE records for errors; each DRIE record contains parameters which alert the operator to possible errors in the radar, DDRS, and DRIE hardware and its tape output unit. The first file generated by REFORMPI contains recorded radar parameters. The rest of the generated files contain
FIGURE 5
GROUND SIGNAL PROCESSOR
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<th>PROGRAMS AND SUBROUTINES INCLUDED IN THE GROUND SIGNAL PROCESSOR</th>
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<tr>
<td>GSP Main program, performs Doppler processing and filter overlay</td>
</tr>
<tr>
<td>REFORMP Program, decodes DRIE records and formats them into range bin records</td>
</tr>
<tr>
<td>REFORMD Program, uses output of REFORMP and creates files of samples by range bin</td>
</tr>
<tr>
<td>RDECOD Subroutine used by REFORMP to decode the RIOT parameters from DRIE formatted records</td>
</tr>
<tr>
<td>RSACLE Subroutine used by REFORMP to interpret the decoded RIOT parameters from part of the output of RDECOD</td>
</tr>
<tr>
<td>HVDECOD Subroutine which recovers the video data samples from DRIE formatted records</td>
</tr>
<tr>
<td>IBCDTD Function, converts BCD to binary format, used by RSACLE</td>
</tr>
<tr>
<td>APWT Subroutine used to calculate an array of weights for different aperture weighting functions</td>
</tr>
<tr>
<td>TAYLOR Subroutine used by APWT to calculate an array of weighting coefficients for the Taylor weighting function</td>
</tr>
<tr>
<td>PULSES Subroutine, it skips and recovers video pulses from the input data file into an array for use by GSP</td>
</tr>
<tr>
<td>LIGHTF Function which checks the status of pseudo-sense switches set by the operator before program execution</td>
</tr>
<tr>
<td>LUNPOS Subroutine that positions data files</td>
</tr>
<tr>
<td>FFTCC Subroutine, computes fast Fourier transform of a complex sequence; from the International Mathematical and Statistical Library</td>
</tr>
<tr>
<td>MAPSTAT Program which reads all or part of GSP output files of filter magnitude values and compiles statistics on the data</td>
</tr>
<tr>
<td>DSTATR Subroutine which compiles and computes statistics, used by MAPSTAT</td>
</tr>
<tr>
<td>PIMAGE Program, performs the postprocessing on filter magnitude data in files generated by GSP, then outputs the data in records formatted for input to the ARL:UT high resolution display software</td>
</tr>
<tr>
<td>DRTA Subroutine, reformats azimuth lines of 384 range samples into records compatible with the ARL:UT high resolution display software, used by PIMAGE</td>
</tr>
</tbody>
</table>
1024-word records of sampled video data at different range bins. Program REFORMD is run next to reorganize the records into files containing the sampled video at individual range bins. At the start of the reformatting process, the operator must choose to decode either the co-polarized or the cross-polarized data.

The output file from REFORMD is used as input to the main program, GSP. GSP requires the operator to select parameters such as the aperture weighting function, shading factor and, in particular, the range bin of the map center, an important parameter in the processor algorithms.

Certain default values are provided in the programs. For example, the Taylor aperture weighting function with 30 dB peak sidelobes is the default for the window function, and 1.27 (BBF) is the 3 dB width of the resulting Doppler filters. If a different weighting function is chosen, the BBF must be calculated or obtained, and entered into the program as a change.

The selection of synthetic array length is governed by the range sampling interval originally selected and the operating mode and patch center, which determine the nadir angle to the patch center. Referring to the GSP program listing, the Doppler spectrum line spacing is set equal to the projection of the slant range sample spacing on the horizontal or image plane. This is fixed in the software, but could be changed by making FILTSPC equal any arbitrary spacing.

In using digital SAR data to provide radar images for remote sensing applications, achieving maximum resolution in azimuth was not considered important. In addition, by keeping the array length shorter, focusing requirements are less stringent, although focusing (quadratic phase) corrections are included.
Following establishment of the window weights, the focus weights are obtained and placed in a complex array \( FOC \). The correction to the \( i \)th pulse in the array is

\[
\text{DPHI} = \frac{4 \times \pi}{\text{WL}} \left( \sqrt{\text{RANGE}^2 + D^2} - \text{RANGE} \right),
\]

where \( D \) is the distance from the \( i \)th pulse to the center pulse in the synthetic array. The phase angles are converted to in-phase and quadrature components and combined with the aperture weights.

Since the ground coverage of the synthetic arrays is a function of range, the corresponding filters from arrays at different range bins may not represent the same azimuth components. To maintain the integrity of the image, the difference in the azimuth coverage at the current range bin versus the coverage at an initial reference range bin is computed. This reference range bin is input as parameter IRBFMAP. If processing is to begin with range bin one, then IRBFMAP=1. The azimuth component represented by the first filter from the first available synthetic array of range bin IRBFMAP is then the azimuth coordinate of the start of the map. To have the first filter of following range bins represent the same azimuth coordinate, the difference in the coverage is converted into pulses and these pulses (data samples) are skipped before Doppler processing begins.

Subroutine PULSES skips data samples in a file and recovers data into array \( \text{VIDATA} \). The data for one array are then weighted with the proper weight from array \( FOC \) and placed in a complex array \( HV \). The array is processed by a complex FFT and the resultant filters are obtained by summing the square of the real and imaginary components out of the FFT. The corresponding filters from consecutive arrays are summed (overlaid), and the number of overlays at each azimuth coordinate is kept in array \( \text{RNORM} \) so that the filters may be normalized for the number of summations they contain.
C. **Image Formation**

Referring to Attachment I for the algorithms, Attachment II for numerical values associated with the images shown in Section V, Table III for a list of GSP variables, and Fig. 6 for the flowchart,

\[
RESR = \frac{CL \times SISR}{2 \times \sin(XNAPC)} = \frac{(0.2998 \times 10^9)(1.006 \times 10^{-7})}{2 \sin(0.70973 \frac{\pi}{180})} \text{ .}
\]

\[RESR = 23.14 \text{ m and FILTSPC is set to this value.}\]

Each input file into GSP contains the samples from one range bin. The coverage and filter spacing of the synthetic arrays are a function of range. Based on a desired filter spacing on the ground of FILTSPC, the size of the synthetic arrays is calculated,

\[NP \text{ (at range } R) = \frac{WL \times R}{FILTSPC} + 1 \text{ .}\]

Since \(NP\) is an integer, the filter spacing out of the synthetic arrays is actually given by FILTSP,

\[FILTSP = \frac{WL \times R}{NP - 1} \text{ .}\]

This number is calculated and printed for reference; however, for the parameters encountered in this system, FILTSP and FILTSPC are nearly equal and FILTSPC is assumed to be the filter spacing.

The 3 dB resolution of the synthetic filters is also calculated and given for reference,

\[RESA = 0.4429 \times BBF \times WL \times \text{RANGE} \div (NP-1) \times 0.5 \text{ ft} \text{ .}\]

Next, the pulse weights for the input aperture weighting function are calculated in APWT.
BEGIN GSP

INITIALIZE CONSTANTS AND DEFAULT VALUES

INPUT PARAMETER CHANGES (OPTIONAL):
NRBF
IRBFMAP
KWTPTNA, SHADFAC
BBF
INPUT FILE POSITIONS FOR:
RNGBIN
FILMAG
NRBFILS - NUMBER RANGE BINS

READ RIOT PARAMETERS OFF HEADER RECORD

COMPUTE:
IRBF, RNGFMAP
RESR, FITSPC

ENTRY 1

CLEAR OUTPUT ARRAYS, RMAP, RNORM
RESET POINTERS
COMPUTE: RANGE, NP, NF

COMPUTE AMPLITUDE WEIGHTING COEFFICIENTS AND FOCUSING FACTORS

COMPUTE NPLMAP, SKIP NPLMAP PULSES

A

FIGURE 6
FUNCTIONAL FLOW OF PROGRAM GSP
FIGURE 6 (Cont'd)
FUNCTIONAL FLOW OF PROGRAM GSP
### TABLE III
**VARIABLES AND CONSTANTS USED BY PROGRAM GSP**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>The value of $\pi$</td>
</tr>
<tr>
<td>TPI</td>
<td>Twice the value of $\pi$</td>
</tr>
<tr>
<td>PIH</td>
<td>Half the value of $\pi$</td>
</tr>
<tr>
<td>RTD</td>
<td>Degrees/radian, conversion factor</td>
</tr>
<tr>
<td>DTR</td>
<td>Radians/degree, conversion factor</td>
</tr>
<tr>
<td>FPM</td>
<td>Feet/meter, conversion factor</td>
</tr>
<tr>
<td>CL</td>
<td>Velocity of light, $2.997925 \times 10^8$</td>
</tr>
<tr>
<td>WL</td>
<td>Operating wavelength of radar, $0.031228$ m</td>
</tr>
<tr>
<td>BBF</td>
<td>Beam broadening factor, default=$1.27$</td>
</tr>
<tr>
<td>KWTFTNA</td>
<td>Name of weighting function in H format, default=&quot;TAYLOR&quot;</td>
</tr>
<tr>
<td>SHADFAC</td>
<td>Scale factor for the weighting function; for Taylor weighting, it is the peak sidelobe ratio (in dB), default=30</td>
</tr>
<tr>
<td>NRBPC</td>
<td>Number of range bins to be used as the map center, default=$1/2$ of the number of range samples per pulse taken by the DDRS</td>
</tr>
<tr>
<td>IRBFMAP</td>
<td>Number of range bins to be used to set the azimuth coordinate of the start of the image, default=range bin of the first file processed</td>
</tr>
<tr>
<td>DRMIN</td>
<td>Delay (sec) from the STC trigger to the start of sampling by the DDRS</td>
</tr>
<tr>
<td>SISR</td>
<td>Slant range sample interval of DDRS</td>
</tr>
<tr>
<td>NBIT</td>
<td>Bit precision of the sampled video data</td>
</tr>
<tr>
<td>NRB</td>
<td>Number of digitized samples or range bins, per pulse</td>
</tr>
<tr>
<td>RMIN</td>
<td>Slant range distance (m) from the radar to start of DDRS sampling</td>
</tr>
<tr>
<td>RPC</td>
<td>Range to the map center, m</td>
</tr>
<tr>
<td>XNAPC</td>
<td>Nadir angle to the map center</td>
</tr>
<tr>
<td>IRBF</td>
<td>Range bin of first data file processed</td>
</tr>
</tbody>
</table>
TABLE III (Cont'd)
VARIABLES AND CONSTANTS USED BY PROGRAM GSP

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNGFMAP</td>
<td>Slant range distance, m, from radar to the range bin IRBFMAP</td>
</tr>
<tr>
<td>RESR</td>
<td>Ground spacing, m, between range samples at the map center</td>
</tr>
<tr>
<td>FILTSPC</td>
<td>Desired spacing (ft) of output azimuth filters</td>
</tr>
<tr>
<td>NPT</td>
<td>Counter to keep track of total number of pulses used during processing of each range bin file</td>
</tr>
<tr>
<td>IAZLINE</td>
<td>Counter pointing to the azimuth line with which the first filter out of the current array is overlaid</td>
</tr>
<tr>
<td>NRBPROC</td>
<td>Range bin currently being processed</td>
</tr>
<tr>
<td>RANGE</td>
<td>Slant range (m) to the range bin currently being processed</td>
</tr>
<tr>
<td>XNP</td>
<td>Number of pulses to process per array, real variable</td>
</tr>
<tr>
<td>NP</td>
<td>Round of XNP</td>
</tr>
<tr>
<td>NF</td>
<td>Number of filters recovered per synthetic array</td>
</tr>
<tr>
<td>FILTSP</td>
<td>Actual filter spacing (ft) of the current arrays</td>
</tr>
<tr>
<td>RESA</td>
<td>The 3 dB resolution of the Doppler filters of the current arrays</td>
</tr>
<tr>
<td>WT</td>
<td>Array containing the amplitude weight for each pulse in a synthetic array</td>
</tr>
<tr>
<td>GI</td>
<td>Inverse gain factor of the weighting array, from APWT</td>
</tr>
<tr>
<td>DPHI</td>
<td>Quadratic phase correction angle</td>
</tr>
<tr>
<td>FOC</td>
<td>Array containing the focusing corrections and amplitude weights for each pulse</td>
</tr>
<tr>
<td>NPLMAP</td>
<td>Number of pulses to skip on the current range bin file so the first filter out of the first synthetic array represents the azimuth coordinate of the left edge of the map</td>
</tr>
<tr>
<td>VIDATA</td>
<td>Array containing the video data samples of one synthetic array</td>
</tr>
<tr>
<td>HV</td>
<td>Complex array used for input and output to the FFT routine</td>
</tr>
<tr>
<td>IWK</td>
<td>Integer scratch array for FFTCC</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>WK</td>
<td>Scratch array for FFTCC</td>
</tr>
<tr>
<td>RMAP</td>
<td>Array containing the processed overlaid filter magnitude values for a range bin</td>
</tr>
<tr>
<td>RNORM</td>
<td>Array containing the number of overlays at each azimuth line</td>
</tr>
<tr>
<td>DFLOWN</td>
<td>Distance (ft) the radar has moved since the start of azimuth processing</td>
</tr>
<tr>
<td>NPSkip</td>
<td>Number of pulses to skip before forming the next synthetic array</td>
</tr>
</tbody>
</table>
Based on the principle of keeping the Doppler filters aligned from one array to the next, it is necessary to discard some of the pulse samples. The distance flown (in feet) is computed as equal to half the total number of pulses, NPT, reached at the last pulse of the last array processed, based on two pulses/ft. Next, the residual fraction of a filter spacing in azimuth is calculated by dividing DFLOWN by FILTSPC and discarding the integer part of the quotient. The fractional part, FLEFT, is subtracted from a filter spacing and the remainder is converted to an integer number of pulses to be skipped by doubling, adding 0.5, and truncating.

\[
NPSkip = 2(RESAEF - FLEFT) + 0.5
\]

The next pulse (after skipping) becomes the first in the next array. Finally, the overlaid filter magnitude values in RMAP are normalized, using RNORM, the number of overlays. These data are buffered out onto tape or disc file.

The user must control the processing by interacting with the processor to provide various parameter or data selections.

The principal operations consist of the following.

1. Select the desired frame numbers (octal) to start and stop the map. The start FN is usually the first one on the file.
2. Indicate the tape number and select the file to be processed, which usually contains a strip of 16 or 32 range samples.
3. Select the polarization you wish to process.
4. Select the aperture weighting function and shading factor. Default is Taylor weighting, 30 dB PSLR.
5. Select patch (map) center range bin.
6. Select beam broadening factor. For Taylor 30 dB weighting, it is 1.27. Cosine\(^2\) and Hanning must be determined after establishing shading factor.
The main processor program GSP, listed in Table II, is supported by a number of subroutines and library functions. The most important ones are HVDECOD, which decodes the horizontal or vertically polarized video signals; RDECOD, which decodes and makes available necessary radar system operating parameters; and a complex Fourier transform routine FFTCC from International Mathematical and Statistical Library. Others include APWT, the calculation of synthetic aperture pulse weighting values; PULSES and RECOVRY, used in organizing and obtaining the data from tape and disc; and LIGHTF, a means for checking a pseudo-sense switch. Program MAPSTAT compiles statistics, i.e., minimum and maximum values, mean and standard deviation. MAPSTAT may be run on the entire map or any desired section. Figure 6 is a flow diagram of GSP.

D. Synthetic Array Coverage

Consider a digital time series of $N_p$ samples of video data in a synthetic array. The sample rate is the PRF of the radar so that $PRF/2$ is the highest recoverable frequency in the series and $\Delta f = PRF/(N_p - 1)$ is the spacing between resultant filters of a Fourier transform performed on the series.

The two-way Doppler shift associated with a target is given by

$$\Delta f_d = \frac{2V_r}{\lambda} = \frac{2V \sin \theta}{\lambda},$$

where $V_r$ is the radial velocity, $\lambda$ is the operating wavelength of the radar, and $\theta$ is the angle from the normal to the target. Figure 7 illustrates the geometry of the ground coverage of a synthetic array; for typical values of $R$, i.e., slant range from radar to ground, $\approx 3^\circ$ so that $\sin \theta \approx \pi x/R$. As stated above, the maximum recoverable frequency is PRF/2 so that

$$\Delta f_d = \frac{PRF}{2} = \frac{2V \sin \theta}{\lambda} = \frac{2V x}{R \lambda}.$$
FIGURE 7
SYNTHETIC ARRAY COVERAGE GEOMETRY
Now, two pulses per foot are emitted by the radar, so PRF=2V if PRF is in hertz and V in ft/sec, and \( x = Ra/2 \) if \( R, \lambda \) are in feet.

Thus the coverage for any synthetic array formed is a function of the range represented by the data samples of the array. The radar is mounted on the left side of the plane so the image is made from left to right as the synthetic arrays are formed. To start the coverage of the arrays at the same azimuth coordinate, the difference in coverage, \( \Delta \), at \( R \) and \( R_0 \) (RNGFMAP in program GSP) is computed. Then \( \Delta \) ft x 2 pulses/ft is the number of pulses to skip before processing the range bin at \( R \).

The spacing between the resultant FFT filters, \( d_f \), represented on the ground is

\[
d_f = \frac{\lambda R}{(N_p - 1)} \quad \text{R in ft}
\]

Thus, once a value for the filter spacing is obtained (in GSP it is arbitrarily taken to be the spacing between range samples at the patch center), the number of pulses, \( N_p \), necessary to obtain that spacing is fixed. In this way the spacing between azimuth filters remains the same at different ranges. Since \( N_p \) must be an integer, one can only get close to the desired spacing; however, with the parameters and geometry encountered in this system, actual spacings within 1% of the desired spacing are realized.

Finally, the 3 dB resolution of the formed synthetic beams (filters) is given by

\[
\rho_a = \frac{0.4429 \lambda K_a R}{(N_p - 1)0.5 \text{ ft/pulse}}
\]
where $K_a$ is the beam broadening factor resulting from nonuniform weighting of the synthetic arrays. Note that $\rho_a = 0.886 K_a d_f$; thus for Taylor weighting ($K_a = 1.27$) the 3 dB resolution of the synthetic beams is approximately $1.12 d_f$. The only variables which affect the accuracy of the calculation for filter spacing are $\lambda$, $R$, and the accuracy of PRF versus ground speed, i.e., how accurate is the assumption of two pulses per foot emitted by the radar. Inaccurate determination of $d_f$ results in improper overlay, which has the effect of degrading the azimuth resolution of the image.
V. POSTPROCESSING AND DISPLAY

Attachment III is a listing of the short program which generates the image display tape. In generating the tape, the operator should refer to the (optional) printout of statistics of the filter magnitude values. This will provide insight to the gray shade resolution, noise threshold, and dynamic range of data to be displayed.

A. Display Parameter Options

There are three display parameter options:

(1) Logarithmic or linear data. Logarithmic data are most representative since the human eye functions in a logarithmic manner, and dynamic range is compressed on the display.

(2) Gray shade level assignments. The gray shade resolution may be adjusted by selection of the levels per gray shade, DBGS assignment. A default value of 2 is provided in the software.

Note: Dynamic range is set by (2) above. The ARL:UT high resolution display has 16 gray shade levels, so DBGS x 15 is the dynamic range.

(3) Threshold. A noise cutoff threshold is set by the assignment of a selected level to the top gray shade (number 15 out of 0-15), and then subtracting the dynamic range.

Once the data are displayed, the characteristics of the display itself must be considered. In particular, the brightness and contrast controls will affect the quality of the displayed radar image.
B. **Image Quality Considerations**

In providing maximum image quality, a most important consideration is resolution. In this case, the sampling rate of the DDRS sets the resolution of the image. Comparisons of digitally and photographically processed images reveal the effects of undersampling. Figures 8 and 9 illustrate the evolution of high quality digital imagery.

1. **Radar/DDRS Parameter Selection Options** - Selection of the longer SI (sampling intervals) on the DDRS increases the range swath recorded, but results in undersampling in both range and azimuth (although the latter could be changed in the GSP). The choice of bit precision also affects the quality of the image, since the lower bit precision values result in decreased data resolution compared with 7-bit data. Mode selection affects ground resolution versus slant range resolution, since in mode 2 the cosecant of the nadir angle is less than in mode 1.

2. **Processing Options** - Since the factors above are set, once the data are recorded, only the selection of polarization channel to be processed and those factors discussed previously (such as the weighting function), can be adjusted. In particular, the display options in Section V.A become effective. Figures 8 and 9 illustrate, to some degree, variations in gray shade assignment, focusing of the data in a relatively short array, and overlaying of arrays. These variations affect the displayed image quality in varying degrees. Although the processor does not generate images with maximum azimuth resolution, the saving in processing time was considered the overriding factor. If maximum length arrays were processed, then the focus function would become very important, whereas improvement over the unfocused image for the relatively short arrays is almost indiscernible.
(a) 50% Overlay of Patches
12 Arrays Procesed
6 Arrays in Map, 50 ft
Azimuth Resolution

(b) 75% Overlay of Patches
24 Arrays Processed
6 Arrays in Map, 76 ft
Azimuth Resolution

(c) 100% Overlay of Patches
48 Arrays Processed
6 Arrays in Map, 76 ft
Azimuth Resolution

FIGURE 8
DISPLAY IMAGE PHOTOGRAPHS, PROCESSOR DEVELOPMENT
FIGURE 9
DISPLAY IMAGE PHOTOGRAPHS, VARIATION IN GRAY SHADE ASSIGNMENT

All images were processed with the GSP in its final form.
Azimuth filter spacing is 76 ft with 85 ft azimuth resolution.
C. Algorithm Details

Program PIMAGE is the postprocessing program which requires the inputs listed in Section V.A. After entry of DBGS and T15, (power level assigned to the top gray shade) a threshold is set, THOLD = 10 log(T15)-16 DBGS. Then an integer value from 0-15(IGS) is assigned to each pixel power level (Pi) output from GSP,

\[ IGS = \frac{10 \log(Pi) - THOLD}{DBGS} \]

If IGS<0, then IGS=0; or if IGS>15, then IGS=15.

Next, subroutine DRTA is called to output the display values IGS in a format compatible with the ARL:UT high resolution display software. Following the same procedure, values could be assigned based on any number of gray shades and output in formats compatible with other displays.
ATTACHMENT I
LISTING OF PROGRAM GSP
PROGRAM GSP

C

--- INITIALIZE ------------------------------------------

C

COMMON/CON/ PI,PI1,PI2,H10,H1M,CL
COMMON/JO1/ II,I1,I1DLX,ALT,ALT,HDG,UNIFT,ROLL,PITCH,GPU,
VACC,XISS,KF1,URMIN,SISH,NB11,NRBC1,RP0,ANPC,MU0,MV,AUX(16)
DIMENSION WI(512),WK(322),WI(322),MNORM(360),KATCH(y),
1 RMAP(360),VIUTA(1024)

C

COMPLEX FOC(512),MV(62)
EQUIVALENCE (WK(1),WI(1))

C

C********************************************************************

C GSP - GROUND SIGNAL PHASESUN, INPUT/ DATA FROM FILE= RNGBIN
C IS FORMATTED BY RANGE MIN AND INPUT I0 THE MAIN PROGRAM VIA
C SUBROUTINE PULSES, THE FIND FILE ON FILE RNGBIN, HOWEVER,
C CONTAINS BOTH DATA AND I1 IS INPUT IN THE PHASESUN, AZIMUTH
C COVERAGE IS SET AT 300 LINE FROM COVERAGE IS VARIABLE UP TO
C THE EXTENT OF AVAILABLE DATA, BECAUSE OF SURFACE CONSIDERATIONS
C NMAX IS THE MAXIMUM NUMBER OF PULSES THAT CAN BE PROCESSED
C IN ONE SYNTHETIC ARRAY.
C********************************************************************

C

NMAX=512

C

CALL RECOVERY
PI=3.141592653589
TPI=2.4PI
PI=PI/2.
RT0=100./P1
DIR=1./RT0
CL=2.997925E+9
FPH=3.288399
BBF=1.27288
WL=0.31228
KWTNAP=TAYLOR
SHADFAC=300.
NRBC=0.
IRBFMAP=0.
40 C ---- KBRANCH -----------------------------------------------
C
20 PRINT *,# INPUT KBRANCH#
READ *,KBRANCH
IF (EOF(SINPUT),NE.,0.) STOP
45 IF (KBRANCH.EQ.#CMGRBPC#) GO TO 70
IF (KBRANCH.EQ.#CMGRBMP#) GO TO 80
IF (KBRANCH.EQ.#CMGAPW#) GO TO 100
IF (KBRANCH.EQ.#CMGBFF#) GO TO 110
IF (KBRANCH.EQ.#PHUCSS#) GO TO 120
50 GO TO 20
C
C**** CMGRBPC - CHANGE RANGE BIN USED TO COMPUTE THE DISTANCE TO THE
C**** PATCH CENTER TO BE PROCESSED. DEFAULT IS 0.
C**** USE CENTER RANGE BIN OF THE ENTIRE SAMPLED PULSE IF
C**** NRBPC=0 (1E, 208 PUN 7-BIT DATA, 512 PUN 8-BIT DATA,
C**** 1924 PUN 2-MI! DATA, AND 2048 PUN 1-BIT)
C
70 CONTINUE
PRINT *,# INPUT NRBPC#
60 READ *,NRBPC
PRINT *,PATCH CENTER RANGE BIN CHANGED TO #,NRBPC
GO TO 20
C
C**** CMGRBMP - CHANGE RANGE BIN USED FOR ALIGNMENT OF LEFT EDGE OF
C**** MAP, DEFAULT IS VALUE OF FIRST RANGE BIN DESIGNATED
C**** IN HIUOT MEASURE.
C
C
80 CONTINUE
PRINT #,INPUT IRBFMAP#
70 READ #,IRBFMAP
PRINT #,FIRST RANGE BIN USED AS LEFT EDGE OF IMAGE - #,IRBFMAP
GO TO 20
C
C**** CMGAPW - CHANGE APERTURE WEIGHT FUNCTION, DEFAULT IS TAYLOR
C**** AT 30 DB.
C**** KWFINA= APERTURE WEIGHT FUNCTION (HGU), EITHER -
C**** HANNING, COSINE**, OR TAYLOR.
C**** SHADFAC= SHADING FACTOR -
PROGRAM GSP

C***** MANNING = PERCENT OF APERTURE WITH COSINE TAPER
C***** CUSINE**2 = VALUE OF ARGUMENT AT APERTURE END-
C***** POINT* DEGREES*
C***** TAYLOR = PEAK DIURGLOBE RATIO (UB)
C
C 100 CONTINUE
C PRINT *, # INPUT KWITNA#SHA UPAC#
C READ *, KWITNA#SHAUPAC#
C PRINT *, #APERTURE SHADING CHANGE IU #,KWITNA#, FACTOR #,SHAUPA#
C IC
C GO TO 20
C
C***** CHGBBF = CHANGE BEAM BROADENING FACTUM, DEFAULT IS 1.27.
C***** BBF= BEAM BROADENING FACTUM,
C
C 110 CONTINUE
C PRINT *, # INPUT BBF#
C READ *, BBF#
C PRINT *, #BEAM BROADENING FACTUR CHANGED TO #,BBF#
C IC
C GO TO 2
C
C***** PROCESS = PROCESS INPUT VOPPLE# VIDEO INTO DISPLAY VIDEO.
C***** IFILL= INPUT FILE NO.
C***** IFILO= OUTPUT FILE NO.
C***** NRBFFILS= NUMBER OF INPUT FILES (RANGE HINS) TO PROCESS
C
C 120 CONTINUE
C LUNI=6,LANGBIN
C LUNO=6,LFILMAO
C PRINT *, # INPUT IFILL+,IFILU+ NRBFFILS#
C READ *, IFILL+,IFILU+,NRBFFILS#
C PRINT *, #INPUT FILE+, OUTPUT FILE+, NUMBER FILES (RANGE HINS) TO
C PROCESS #,IFILL+,IFILU+,NRBFFILS#
C IPROCESS #,IFILL+,IFILU+,NRBFFILS#
C CALL LUNPOS (LUNI+,IFILL+)
C CALL LUNPOS (LUNO+,IFILU+)
C
C 115 C *** READ HIT MELOM FROM FIRST FILE OF LUNI, ********
C ** BUFFER IN (LUNI,1) (1TIME,AUX(16))

C
PROGRAM GSP 73/171 UPT=1

IF (UNIT(LUNI)) 150,140,130
130 PRINT *,#PE, ON LUNI - MEAUX #
STOP #PE ON LUNI#
140 PRINT *,#EOF ON LUNI - MEAUX #
STOP #EOF ON LUNI#
150 BUFFER IN (LUNI+1) (KATCH(1):KATCH(9))
IF (UNIT(LUNI)) 190,140,130

160 CONTINUE

C
--- INITIALIZE VARIABLES COMMON TO ALL RANGE BINS. ---------------

 IF (NRBP_NR_0) NRC=MIN(NRBPC*SRHCL/2,
 IF (NRBP_NR_0) NAPC=ACUS(AL)/FPMX/FM)
 IF (KATCH(I))
 IF (NBIT,EQ.4) IRBF=IRBF*2
 IF (NBIT,EQ.2) IRBF=IRBF*4
 IF (NBIT,EQ.1) IRBF=IRBF*8
135 IF (IRBFMAP,EQ.0) IRBFMAP=IHBF
 PRINT *,#Range Bin #,IRBFMAP # USED TO LINE UP LEFT EDGE OF IMAGE#
 PRINT *,# #
 RNBFMAP=RMIN*RHBFMAP*SRHCL/2.
 RESR=CL/SIR/2/SIN(AAPL)
 FILTPC=RESR/FPM

C
--- PROCESS NRBFLS RANGE BINS. -------------------------------------

140 DO 380 IRBFIL=1,NRBFLS

C
**** INITIALIZE VARIABLES FOR START OF PROCESSING OF ONE RANGE BIN.

 C
 CALL SKIPER(LUNI,1,0,9,LINBUFFER)
 CALL SETO(RMAP(1),RMAP(360)-1)
 CALL SET(RANR1,1,RANR1(360)-1)
 NPT=0
 IA1LINE=1
 IFIRST=1
150 NRPPROC=IRBF*IRBFIL-1
 RANGE=RMIN+NRBPCL*SRHCL/2,
PROGRAM GSP

73/171 UPT*1

XNP=WL*FPM*RANGE*FPM/FIL*SPC*1.0
NP=XNP+.5
NF=NP/2-1
FILTSP=WL*FPM*RANGE*FPM/(NP-1)
RESA=.4429*UHF*WL*FPM*RANGE*FPM/(.5*NP-1)
CALL APWT(W1+NF,WT+1+NA+SHA+AC+1)
DO 260 IP=1,IP
260 WT(IP)=T(IP)*IP/IP
PRINT *,#NHPHUC,NP,RESA
FILPIC=FILISH
IF (NP.LE.NPMAK) GOTO 260
PRINT *,#NUMBER OF PULSES NEEDED FOR SYNTHEIC ARRAYS GREATER
1THAN NPMAK #
STOP
265 CONTINUE

C***** COMPUTE ARRAY OF VALUES FOR FOCUSING THE SYNTHETIC ARRAYS.
C
175 DO 270 J=1,NP
   D=(ABS(FLOAT(J)-FLOAT(NP/2.))*S+5)/FPM
   DPHI=4.*PI/WL*SQRT((RANGE*RANGE+D*0)-RANGE)
   FOC(J)=CMPLX(COS(DPHI)+SIN(DPHI))
   FOC(J)=FOC(J)*T(I)
270 CONTINUE
C
C***** SKIP PULSES SO THAT THE STATIONARY MAP COINCIDES WITH THE
C***** START OF THE MAP AT RANGE = 1HPMAK .
C
185 NPLMAP=WL*(RANGE*NHPMAK/2.*HPMAK/FPM+.5
CALL PULSES(LUNI,VIDATA,NPLMAP,0,IFIRST)
IFIRST=0
C
C***** RECOVER NP PULSES.
C
190 CONTINUE
CALL PULSES(LUNI,VIDATA,0,NP,0)
NP=NP+NP
C
C***** APPLY FOCUSING AND WEIGHTING, FOURIER PROCESS, OVERLAY.
PROGRAM GSP

DO 310 IP=1,NP
   HV(IP)=VIDATA(IP)*FUC(IP)
   CALL FFTCC(HV,NP,1,WK,WK)
  310 CONTINUE

CALL IAIZLINE*NP+1
IF(IJEND.GT.360) JEND=360
K=3
DO 330 J=IAIZLINE,JEND
   RMAP(J)=(REAL(HV(K))**2.*AIMAG(HV(K))**2.*RMAP(J)
  330 CONTINUE

DO 350 J=IAIZLINE,JEND
   RNRBNM(J)=RNRM(J)+1
  350 CONTINUE

C**** DETERMINE VALUES FOR PHORDER ARRAY POSITIONING AND FILTER OVERLAY.

DFLOWW=NPT+5,
IAIZLINE=DFLOWW/FRILP+1
FLEFT=AMOD(DFLOWW/FRILP)
NPSKP=MOD(DFLOWW/FRILP)*2+5
IF (NPSKP+LT,NP) IAIZLINE=IAIZLINE+1
IF (NPSKP+GT,NP) NPSKP=0
C**** NORMALIZE SUMS OF FILTER MAGNITUDES.

DO 360 J=1,360
   RMAP(J)=RMAP(J)/RNRM(J)
  360 CONTINUE

C**** OUTPUT AMPLITUDE DATA.

BUFFER OUT (LUNO+1) (RMAP(J)+RMAP(360))
IF (UNIT(LUNO).GT.0.) GO TO 390
ENDFILE LUNO
ATTACHMENT II
PRINTOUT OF DRIE DATA FOR GALVESTON ISLAND
ATTACHMENT III
LISTING OF PROGRAM PIMAGE
PROGRAM PIMAGE(FILMAP=0,IMAGE=0,INPUT=OUTPUT):
C*******************************************************************************
C PINAGE -- PCFHUMA  PUSI PPROCSSING UP DATA FPUH THE USP. EACN
C**** INPUT FILE IN FILE FILMAP LMTAINS 360 VALUES (ONE
C**** RANGE BIN), BECAUSE OF STORAGE CONSIDERATIONS ONLY
C**** 48 FILES MAY BE PROCESSED AT A TIME.
C*******************************************************************************
C
10 REAL RMAP(360,48)
INTEGER IA2(384)
LUNI=6,LFILMAP
LUNO=5,SLIMAGE
C
15 PRINT *,#NO OF FILES #,
READ *,#FILES
IF (FILES.EQ.0) STOP
PRINT *,#ENTER DB/GRAY SHADE T1#,#
READ *,#DB05+!T1)
C
20 THCLD#10,#ALG DB(115)-16.,#DB05
C
25 DO 30 K=1,#FILES
BUFFER IN (LUNI,1) (RMAP(I,K),RMAP(360,K))
IF (UNIT(LUNI)) 20,30,40
30 PRINT *,#EOF ON LUNI#
STOP
40 PRINT *,#PARITY ERROR ON LUNI#
STOP
20 CALL SKIPER(LUNI,1,0,9,WINBUFFER)
C
30 PROCESS INTO 4-BIT IMAGE DATA ANY OUTPUT TO SUBROUTINE
---- DATA IN AZIMUTH LINES. ---------------
C
35 CALL SETO (IA2(1),IA2(384),0)
DO 60 IF=1,360
DO 50 IRB=1,FILES
SS=RMAP(IF=1)
IF (SS.LE.4.0) SS=1.0E-100
DO 60
60 CONTINUE
C
C
PROGRAM PIMAGE  73/171  UPI#1

        40  IGS=(10.*ALOG10(55)-THUL)/UMUS
        IF (IGS.LE.0)  IGS=0
        IF (IGS.GT.15)  IGS=15
        50  IA2(IPA)*IGS
        CALL UDATA (I+IA2+1+LUNO)

        45  CONTINUE
            END FILE LUNO
            GOTO 10

        C
            END
REFERENCES
