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COMPUTER MODELING OF A WIDESWATH SAR CONCEPT EMPLOYING MULTIPLE ANTENNA BEAM FORMATION TECHNIQUES

Final Technical Report under Contract NAS9-16437

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HOUSTON, TX 77058

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A technique for wideswath synthetic aperture radar coverage, developed at the Texas A&M's Remote Sensing Center, was implemented into the ARL:UT OSS (orbital sar simulation) computer programs. This report describes the OSS modifications, and the implementation and simulation of the concept. The wideswath technique uses formed multiple antenna beams.

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I. INTRODUCTION

Under NASA Contracts NAS9-15401 and NAS9-15217, Subtask 1, Applied Research Laboratories, The University of Texas at Austin (ARL:UT), developed a computer simulation of an orbiting synthetic aperture radar (SAR). The simulation is a computer model of a terrain to be imaged, an antenna pattern to be used in the imaging, and the complete specification of a satellite orbit along with radar system parameters (e.g., range pulse compression codes and length, radar orientation with respect to a defined planet, SAR image patch centers and offsets, pulse repetition frequency (PRF), etc). The simulation uses these inputs and "flies" the terrain model placed on a planet (of user specified mass, size, and shape). Synthetic in-phase/quadrature (I/Q) video data are generated, just as in a real system. These data are then processed through a SAR processor and an image of the terrain model is created for analysis. The set of computer programs written and documented[1] under the abovementioned contracts are known collectively as the orbital SAR simulation (OSS). The OSS provides a powerful tool for analysis of proposed orbital SAR concepts as well as parametric SAR studies, etc.

This report under Contract NAS9-16437 describes the effort undertaken by ARL:UT to verify a concept for an orbital SAR. The concept was developed at the Remote Sensing Center, Texas A&M University (TAMU/RSC), and makes use of simultaneously formed antenna beams along the surface of a cone intersected by the ground plane. The technique, known as multibeam formation, has been documented.[2] The OSS was adapted to incorporate the basic ideas of this technique; then the model was executed to verify the feasibility of the concept.

II. MULTIBEAM CONCEPT

The multibeam technique allows wideswath SAR image coverage at a constant angle of incidence (but not aspect). By properly combining the phased and weighted outputs of multiple receiving antenna elements in an array antenna, multiple simultaneous beams may be created; see Fig. 1.[3] These beams are formed along a cone of half-angle θ_0. One of the antenna array elements acts as a transmitter which transmits a real beam of angle ψ in the image plane and has a narrow beamwidth in the elevation plane β_e. In addition to the wideswath coverage, the narrow elevation beamwidth permits the use of a high PRF (due to the short unambiguous slant range interval), thus reducing transmitter peak power and providing reduced ambiguity levels in the Doppler dimension because of the increased Doppler sampling rate, i.e., the PRF.

The multiple beams are created by combining the outputs of the receiving antennas with proper phase shifts applied to each element. Referring to Fig. 2,[4] the phase shift α_i between each element required to point the ith beam in the θ_i direction is

$$\alpha_i = \frac{2\pi d_h \sin\theta_0 \sin(\phi_i - \phi_0)}{\lambda} ,$$

where d_h is the spacing between the antenna elements and λ is the transmitted wavelength.[5] Thus the basic operation required to generate the ith beam is to implement the following sum over the N antenna receiving elements

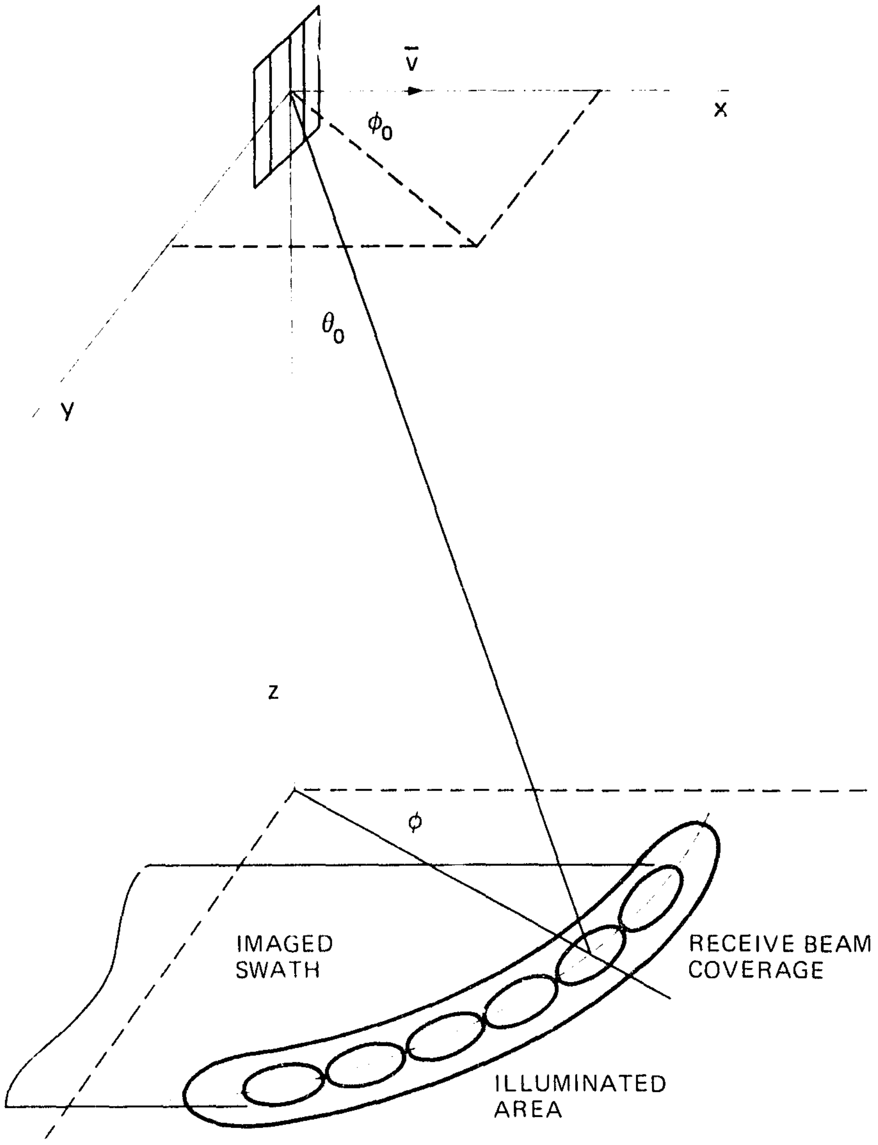


FIGURE 1
THE GEOMETRY OF THE MULTIPLE BEAM SAR

ARL:UT
AE-81-137
CRG - GA
9 - 16 - 81

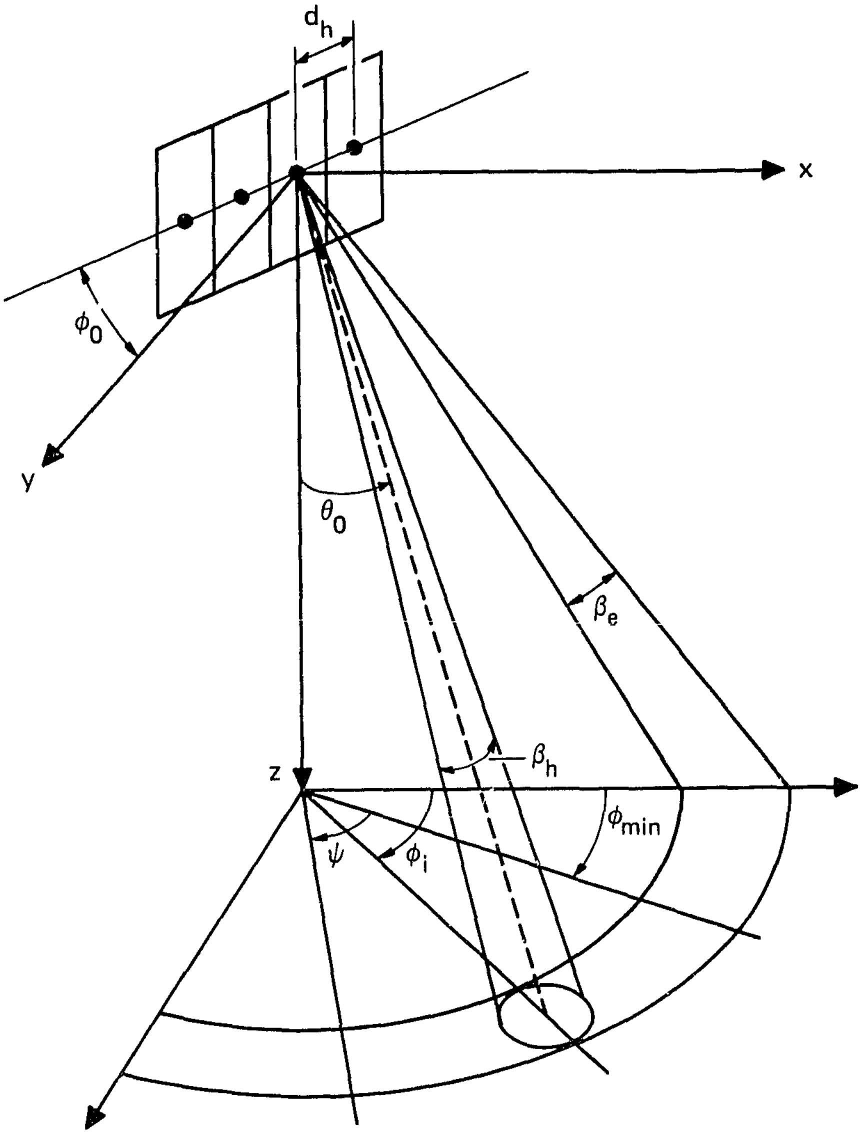


FIGURE 2
MULTIBEAM FORMATION GEOMETRY

ARL:UT
AS-82-1481
JME - GA
9-10-82

$$E_i = \sum_{n=0}^{N-1} E_n \, e^{-jn\alpha_i} \quad .$$

where E_n is the sampled output of the signal of the nth receiving element.[6] Finally, the first-null beamwidth of the formed beam is[7]

$$\beta_h \text{ (1st null)} = \arcsin\left[\sin(\phi_i-\phi_o) + \frac{\lambda}{Nd_h \sin\theta_o}\right] - \arcsin\left[\sin(\phi_i-\phi_o) - \frac{\lambda}{Nd_h \sin\theta_o}\right] \quad .$$

III. IMPLEMENTATION OF A MULTIBEAM COMPUTER SIMULATION

A. Strategy for the Verification of the Multibeam Concept

Due to limitations in the flexibility of the OSS and limited time and computer resources, a full simulation of the multibeam concept utilizing the outputs of all the formed beams for full wideswath coverage was impractical. The approach taken was to create a squint mode model with specified parameters (such as the antenna 3 dB beamwidth) which correspond to those of one beam formed from a multibeam model. In this way the maximum compatability with the current OSS configuration was achieved.

The OSS calculates the PRF and some of the other parameters based on the specifications of one of the multibeams to be formed. When the simulation is executed, the phase centers of the antenna elements making up the antenna array for multibeam processing are specified. Synthetic I/Q video is created from each receiving element; one of the elements is also used to transmit a real beam antenna pattern with the beamwidth necessary to encompass all the possible formed beams. Since the OSS-multibeam model is specified with an antenna beamwidth less than that used when the I/Q data are formed, processing of the I/Q data from any one of the elements (without multibeam formation) should produce an image containing ambiguities; these ambiguities can be suppressed by processing the I/Q data resulting from the multibeam formation between all the antenna elements. It is possible to process the I/Q data from one antenna element and from one of the formed beams to demonstrate the amount of ambiguity suppression.

To minimize the amount of computer time necessary to execute the multibeam simulation, an OSS feature is used to locate the points in a terrain model (given the planet, orbit, radar, and synthetic array formation specifications) which will map ambiguously into the patch center of the created image if not suppressed by the proper antenna pattern.[8] Placing scatterers around these points makes full use of the point scatterers' terrain positions and minimizes the number of scatterers needed in a terrain model to demonstrate suppression by the multibeam technique. The computer time required to execute a simulation is proportional to the number of scatterers in the terrain model.

While the approach taken does not fully test the multibeam concept as it would be implemented in a real system, it does demonstrate some of the advantages and disadvantages associated with the radar, orbit, and antenna pattern specifications for multibeam formation. Aside from the use of a single beam instead of all the possible beams, the greatest departure of the multibeam simulation from a real implementation is in the signal processing and image formation process. The OSS processes the I/Q data into an imaged patch perpendicular to the line of sight (LOS) of the antenna boresight (or formed beam), thus not taking full advantage of the simplicities of the multibeam geometry; however, this does not detract from the verification of the multibeam formation technique.

B. Limitations of the Orbital SAR Simulation's Adaptability to the Multibeam Technique

The current implementation of the OSS terrain modeling and image formation procedures place some severe restrictions on possible multibeam implementations. An OSS terrain model is created by specifying two-dimensional coordinate positions at which point scatterers are specified along with a relative scattering intensity. The coordinate system is defined such that (0,0) is the center of the terrain model and it will be the patch center of the imaged area. This presents no problem for creating I/Q data for the multibeam simulation; however, it makes it difficult to process images from beams not formed about the patch center. For this reason, we concentrated on forming and imaging only one arbitrary beam, whose coordinates are chosen prior to the start of OSS execution. Simultaneous imaging of more than one beam would require major changes to the signal processing routines and would add little to the demonstration of the multibeam technique, i.e., the problem of beam formation and imaging of each beam is separated from the task of combining all the beam's images into one wideswath image.

Program ECHO is the OSS routine which computes the slant ranges and echo strength levels from the point scatterers. The distance to each scatterer at each orbit position at which a pulse is transmitted must be determined along with the angle to the scatterer from the antenna boresight. Input to ECHO consists of the terrain model, antenna model, and SARCON data created by the controller program, SARTREK. ECHO places the terrain model on the planet; currently this is done by placing the terrain origin center (0,0) at a user selected planet latitude and computing the longitude at which the antenna boresight will intersect the selected latitude.[9] The terrain plane is rotated so that its x axis is perpendicular to the LOS from the radar at some user specified squint and nadir angles. The plane is then radially projected onto the planet's surface. As the radar "flies" the array the distance to the patch center at each transmitted pulse is recorded and the received echo is automatically range gated such that the center sample of the echo always contains the patch center, thus eliminating the need for range walk corrections. The slant range data are used later in the focus operation. To process more than one beam per multibeam simulation run would thus require revision of this procedure and changes to the focus routines. It should be pointed out that all the multiple beams from one model could be generated by repeated runs with changing patch center locations. Again, these restrictions do not detract from the demonstration of the multibeam technique.

C. Procedure for Execution of the Multibeam Simulation

The procedure for execution of a multibeam simulation is similar to that used for execution of the general OSS. OSS programs TERAIN, ANTENA, and SARTREK are run to set up the terrain and antenna models, and to specify the general theoretical parameters for a simulation. A program developed for the multibeam simulation, MECHO, replaces the OSS program ECHO. The output file of slant range/echo strength data generated by MECHO is then reorganized into several files, each one identical to the output file that program ECHO creates. There is one echo strength data file for each antenna element in the multibeam antenna array. These files are then processed one at a time into files of synthetic video I/Q samples by OSS program SAMPLE. If range pulse compression processing is selected, then OSS program COMPRES is executed next on each of the I/Q video data files. Program MBEAM, the beamforming processor, is executed next; MBEAM combines the I/Q data files to form a multibeam at some specified squint angle. Program MBEAM creates a file of I/Q data which is identical in format to the files produced by OSS program SAMPLE. The I/Q video data file for the formed beam is then processed through the remainder of the OSS programs: FOCUS FILTER, and POST. The output of program POST is sent to the ARL [illegible] high resolution image display system for analysis and, optionally, to be photographed.

IV. COMPUTER PROGRAMS

A. Overview of Program Additions for the OSS

The OSS program ECHO has been modified (into program MECHO) to calculate and output the slant range/echo strength data for all the antenna elements in the real antenna array. The multibeam simulation could have been constructed by using one set of SARCON data (output from the controller program SARTREK) and running program ECHO one time for each antenna element specifying the proper phase center for that element (i.e., specifying the position of the element in the real antenna array in orbiter coordinates). However, for a modest size terrain model, ECHO is the most expensive program in the simulation (in terms of computer time), and executing it separately for each antenna element would be very costly. Program MECHO makes use of the redundant coordinate transformations which comprise the greatest expense in the execution of program ECHO.

The output file of MECHO is reorganized into files which are processed by the program SAMPLE (and COMPRES if required) into I/Q video data. Program MBEAM was written to perform the multibeam formation. MBEAM uses the squint and nadir angles stored in the SARCON data recorded on the I/Q video data files. The squint and nadir angles are in the direction of image formation used by the OSS, so MBEAM forms the multibeam in the direction specified by these angles.

Routines were also developed to convert the I/Q floating point data files to files of I/Q data which contain scaled integer values of arbitrary bit precision. A program is available to transfer 32-bit I/Q integer data to computer compatible tape for transfer to other computers. These routines were used to transport data to TAMU/RSC for beam formation and image processing.

B. Program MECHO

A listing of program MECHO is available in Appendix A. It is identical to the OSS program ECHO with the following additions. A file, ANTPOS, has been added for additional input to define the phase center positions of the antenna elements. The positions are defined in the body axis coordinate system of the orbiter.[10] The file is a standard text file and has the structure listed below.

Line No.	Description
1	Number of elements in the antenna
2	X position of element 1, Y position of element 1, Z position of element 1
3	X position of element 2, Y position of element 2, Z position of element 2
N+1	X position of element N, Y position of element N, Z position of element N

In program ECHO the variables PHCPBX, PHCPBY, and PHCPBZ contain the x, y, and z phase center coordinates, and variables X, Y, and Z contain the phase center coordinates transformed into the Greenwich TOD (true-of-date) coordinate system. In program MECHO, these variables have been made into arrays which contain the element coordinates. These arrays are currently dimensioned at 16 so that an antenna with up to 16 elements may be specified.

In the ECHO programs, all the scatterers are placed on the planet and then transformed into the Greenwich TOD system. After the positions of the orbiter at the pulse transmission locations are computed and transformed into the Greenwich TOD system, the orbiter-to-scatterer distances and echo strength levels are computed. In MECHO, the array

SREL, which stores the computed slant ranges and echo levels, was dimensioned to accommodate all the element positions, whereas this dimension in ECHO was for a single element.

MECHO outputs data sequentially first by pulse, then by element, so that all the data for each element at one pulse position is output, and then all the data for each element at the next pulse position is output, etc. The output file must then be reorganized by the antenna element so that each element's echo data can be input to the next routine, OSS program SAMPLE. This is accomplished by program MEREORG, which reorders the MECHO output file into ECHO-compatible data files, one file for each element.

C. Program MBEAM

A listing of program MBEAM is included in Appendix B. Program MBEAM uses as input the video I/Q data files generated for the elements of the array antenna along with some interactive input and then produces an I/Q data file for one of the possible multibeams. The interactive input required is specification of the squint angle of the array antenna ϕ_0 and the inter-element spacing of the antenna in meters.

The program reads the SARCON data record from the first I/Q data file, then the SARCON records on the rest of the I/Q data files are skipped positioning the files at the start of the first video data records. The SARCON record is copied to the I/Q data output file. Using the squint angle, nadir angle, and radar wavelength specified in the SARCON data along with entered antenna array squint and element spacing, MBEAM calculates the phase shift to be applied to the video I/Q data from each element of the antenna array according to the equation given in Section II. One record is read from each I/Q data input file; the phase shift for each I/Q data record is applied to every I/Q data point in the record. Next, the corresponding I/Q data points from each record are summed and the resulting data record, the I/Q data of a formed multibeam, is written to the video I/Q data output file. This process is repeated for each set of I/Q data input records.

D. Data Exchange Programs

Programs were written to allow interchange of video I/Q data with TAMU/RSC. ARL:UT and TAMU/RSC jointly agreed on a format for exchange. Since the ARL:UT computer, a Control Data Corporation CYBER, and the TAMU/RSC computer, a Digital Equipment Corporation VAX, do not have the same internal number representation, it was decided that exchange of integer data would be the easiest approach. The programs first calculate statistics on the I/Q data generated by OSS program SAMPLE; these statistics are used to appropriately scale the I/Q data, and then they are converted to 32-bit integer format.

After conversion from the one's complement format (used by the CYBER) to the two's complement format (used by the VAX) the I/Q data are output. One record is output for each received pulse. Each record contains the I/Q data from all the antenna elements, the data for element 1 followed by element 2, etc. Each element's data consist of 256 I/Q samples; if less than 256 samples per element per pulse were synthesized, then each element's data are padded with zeroes to make up the 256 samples.

V. MULTIBEAM SIMULATION RESULTS

A. First Model

The model parameters were jointly specified by ARL:UT and TAMU/RSC with TAMU/RSC supplying the antenna pattern used for the transmitting and receiving elements and the multibeam locations in the ground plane. The rest of the model's parameters closely correspond to the SEASAT-A based parameters used in the test model documented in Ref. 1; thus the non-multibeam simulation's results described are of some use in interpreting the results of the multibeam simulation.

Figure 3 contains the antenna beam patterns used by the transmitting element and the receiving elements of the antenna array. The multibeam parameters are (referring to Figs. 1 and 2)

$$d_h = 1 \text{ m} \quad ,$$

$$\phi_o = 30^o$$

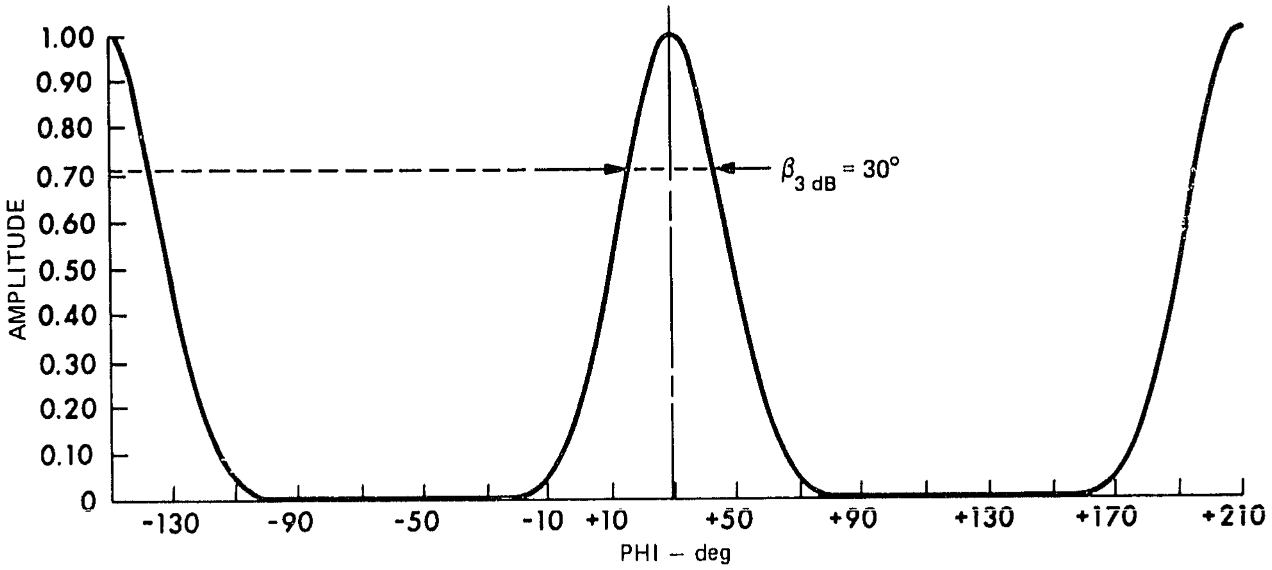
$$\phi \text{ of beams} = 18^o, 26^o, 34^o, 42^o \quad ,$$

$$\theta_o = 20^o \quad ,$$

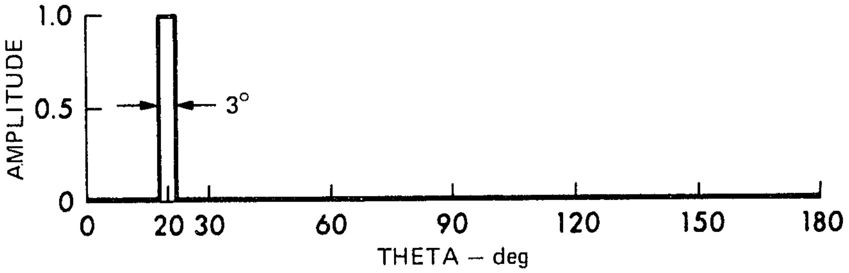
$$SW \approx 150 \text{ km} \quad .$$

The antenna array contained four elements with phase center positions:

$$(0, 0, 0) \quad ,$$
$$(-0.5, 0.866, 0) \quad ,$$
$$(-1, 1.732, 0) \quad ,$$



(a) AZIMUTH PATTERN



(b) ELEVATION PATTERN

FIGURE 3
ONE-WAY ANTENNA BEAM PATTERNS
OF AN ANTENNA ELEMENT

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JME - GA
9-10-82

and

$$(-1.5,\ 2.598,\ 0) \quad .$$

The beamwidth in the x-y plane of a formed beam is 8^0. For the simulation execution described herein, only the beam at $\theta=34^0$ was created and processed.

Figure 4 is a listing of the SARCON data which contains the OSS parameters for the first model. Figure 5 is an OSS produced plot of the ambiguity locations which map into the patch center based on the SARCON data of Fig. 4; imposed on the plot is the radar platform's ground projected location, the platform's velocity vector, and the 3 dB beamwidth of the array antenna's elements (30^0). The points which approximately define a circle are azimuth ambiguities (i.e., points at the same slant range as the patch center whose Doppler frequencies will alias into the Doppler frequency of the patch center) while the points lying approximately on a line are range ambiguities (i.e.,points which differ in slant range to the radar platform by an amount equal to the distance light travels between two successive radar pulses). Figure 6 contains plots of the scatterer positions for the terrain model used in the first simulation model. The fields were placed at azimuth ambiguity locations so that they would be imaged about the patch center if not suppressed by the beam pattern of the multibeam to be formed. The OSS calculated the SARCON data assuming that a beam pattern of 8^0 beamwidth was to be used in imaging; however, the 30^0 real beam pattern was used so that ambiguities will be introduced if the multibeam formation is not performed.

The multibeam simulation was then executed to the point of obtaining I/Q data for each element. The I/Q data from element 1 was processed into an image; since no multibeam processing was performed, we expect to see ambiguities in the image. The I/Q data from all the elements were also processed through the beam formation processor. The results of these simulations are shown in Fig. 7. The suppression of the imaged ambiguities is contrasted in Figs. 7(a) and 7(c);

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                  * * * * * * * * * *   P L A N E T   S P E C I F I C A T I O N   * * * * * * * * * *
PLANET NAME  **                           EARTH            EQUATORIAL RADIUS (KM)  **                         .63781670000E+04
ECCENTRICITY  **                          .81820179996E-01 GRAVITATIONAL CONSTANT (KM3/SEC2)  ** .39860100000E+06
ROTATIONAL RATE (DEG/S)  **               .41780745995E-02 TIME OF PRIME MERIDIAN PASSAGE (S) **0.

                  * * * * * * * * * *   O R B I T   S P E C I F I C A T I O N   * * * * * * * * * *
ORBIT I.D.  **                            794CIRCULR       SEMI-MAJOR AXIS (KM)  **                           .71865400000E+04
ECCENTRICITY  **                          .20000000000E-02 INCLINATION (DEG)  **                              .10800000000E+03
LONG OF ASCENDING NODE (DEG)  **        0.                 ARGUMENT OF PERIGEE (DEG)  **                    0.
TIME OF PERIGEE PASSAGE (S)  **         0.                 ROTATIONAL RATE (DEG/S)  **                        .59376152657E-01
ORBITER INITIALIZATION TIME(S)  **     -.10000000000E-03

                  * * * * * * * * * *   R A D A R   S P E C I F I C A T I O N   * * * * * * * * * *
RADAR I.D.  **                            SEASAT-A         OPERATING WAVELENGTH (M)  **                       .23500000000E+00
RECIEVER/TRANSMITTER BW (MHZ)  **         .77972901347E+01 RANGE TIME-BANDWIDTH PRODUCT  **                   .10000000000E+01
SIGNAL-TO-NOISE RATIO (DB)  **            .10000000000E+03 A/D SAMPLE RATE (MHZ)  **                          .15594580269E+02
SAMPLE LENGTH OF RANGE CORRELATION **                    1 SAMPLE LENGTH ACROSS PHASE INTERVAL *                             1
BINARY PHASE CODE  **                     R                BINARY PHASE CODE SEQUENCE  **                     RANDOM
GROUND RANGE RESOLUTION (M)  **           .50000000000E+02 AZIMUTH RESOLUTION (M)  **                         .50000000000E+02
RANGE SAMPLING RATIO (M)  **              .20000000000E+01 AZIMUTH SAMPLING RATIO (M)  **                     .20000000000E+01
RANGE IMPULSE RESPONSE FUNCTION  **       COSINE**2        APERTURE WEIGHT FUNCTION  **                       TAYLOR
PATCH-TO-PATCH OFFSET, RNG (M)  **      0.                 PATCH-TO-PATCH OFFSET, AZ (M)  **                0.
RANGE SWATH WIDTH (KM)  **                .63750000000E+01 NO OF PATCHES  **                                                 1
MAP START LATITUDE (DEG)  **              .45000000000E+02

                  * * * * * * * * * *   A N T E N N A   S P E C I F I C A T I O N   * * * * * * * * * *
ANTENNA I.D.  **                          MULTI-BEAM       BORESIGHT NADIR AT TO (DEG)  **                    .20000000000E+02
BORESIGHT SQUINT AT TO (DEG)  **          .34000000000E+02 AZIMUTH ANGULAR COVERAGE (DEG)  **                 .80000000000E+01
ELEVATION ANGULAR COVERAGE (DEG)  **      .30000000000E+01 PHASE CENTER, BODY AXIS X (M)  **                0.
PHASE CENTER, BODY AXIS Y (M)  **       0.                 PHASE CENTER, BODY AXIS Z (M)  **                0.
COORD SYS, BODY AXIS ROLL, (DEG)  **    0.                 COORD SYS, BODY AXIS PITCH, (DEG) **              -.70000000000E+02
COORD SYS, BODY AXIS YAW, (DEG)  **       .34000000000E+02 PLAT ROLL RATE (DEG/S)  **                       0.
PLAT PITCH RATE (DEG/S)  **             0.                 PLAT YAW RATE (DEG/S)  **                        0.

                  * * * * * * * * * *   T E R R A I N   S P E C I F I C A T I O N   * * * * * * * * * *
TERRAIN I.D.  **                          MULTI-TST1       NO OF DISCRETES  **                                              52
NO OF FIELDS  **                                         2 TOTAL NO OF SCATTERERS  **                                      126
X-AXIS COVERAGE (KM)  **                  .26605000000E+03 Y-AXIS COVERAGE (KM)  **                           .54950000000E+02
TERRAIN CENTER, R (KM)  **                .63675192370E+04 TERRAIN CENTER, LAT (DEG)  **                      .45000000000E+02
TERRAIN CENTER, LONG (DEG)  **            .34020958470E+03

                      * * * * * * *   S Y N T H E T I C   A R R A Y   P A R A M E T E R S   * * * * * * *
SYNTHETIC ARRAY NO  **                                   1 TRANSMISSION START TIME (S)  **                    .75706892121E+03
ARRAY LENGTH (M)  **                      .23997304242E+04 ARRAY INCLINATION (DEG)  **                        .81088631361E-01
ARRAY FORMATION TIME (MS)  **             .32176541097E+03 PLATFORM VELOCITY (KM/S)  **                       .74580106359E+01
NO OF PULSES  **                                      1758 PRF (HZ)  **                                       .54629996835E+04
NO OF RANGE SAMPLES  **                                255 NO. OF AZIMUTH FILTERS  **                                      255
PATCH CENTER RANGE SAMPLE NO.  **                      128 SLANT RANGE SWATH WIDTH (KM)  **                   .24510624417E+01
SLANT RANGE RESOLUTION (M)  **            .19224146775E+02 SLANT RANGE SAMPLE INTERVAL (M)  **                .96120733877E+01
START RANGE (KM)  **                      .86659032998E+03 RANGE PATCH CENTER (KM)  **                        .86781106330E+03
SQ.INT ANGLE PATCH CENTER (DEG)  **       .34125168252E+02 NADIR ANGLE PATCH CENTER (DEG)  **                 .19946775461E+02
LOS AZIMUTH AT PATCH CENTER (DEG) **     -.17017585118E+03 LOS INCIDENCE AT PATCH CENTER (DEG)**              .22611644021E+02
PATCH CENTER, R (KM)  **                  .63675192370E+04 ORBITER MASS CENTER, R (KM)  **                    .71763842359E+04
PATCH CENTER, LAT (DEG)  **               .45000000000E+02 ORBITER MASS CENTER, LAT (DEG)  **                 .42372508999E+02
PATCH CENTER, LONG (DEG)  **              .34020958470E+03 ORBITER MASS CENTER, LONG (DEG)  **                .33959432948E+03
```

FIGURE 4

SARCON DATA - MULTIBEAM MODEL 1

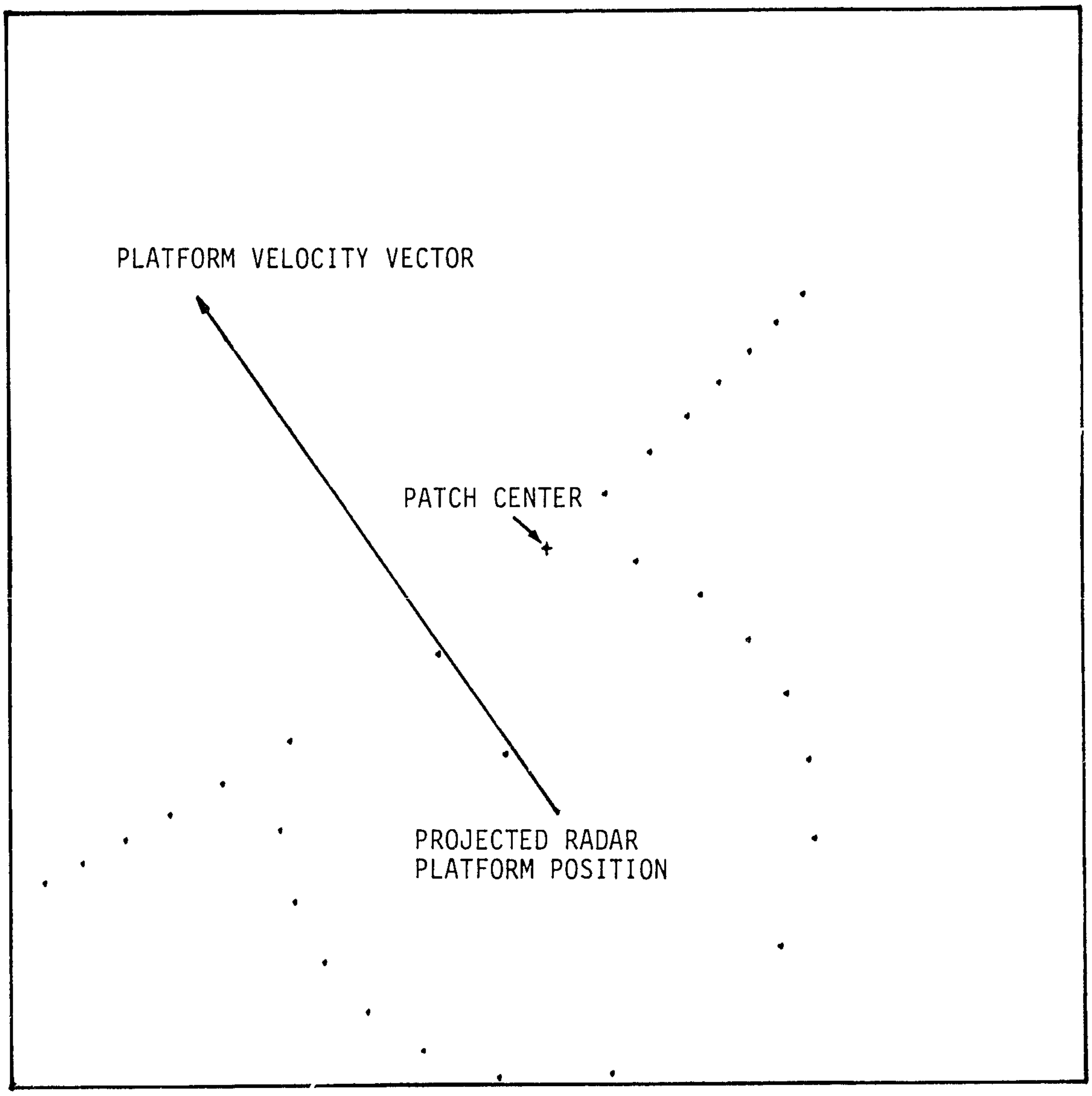
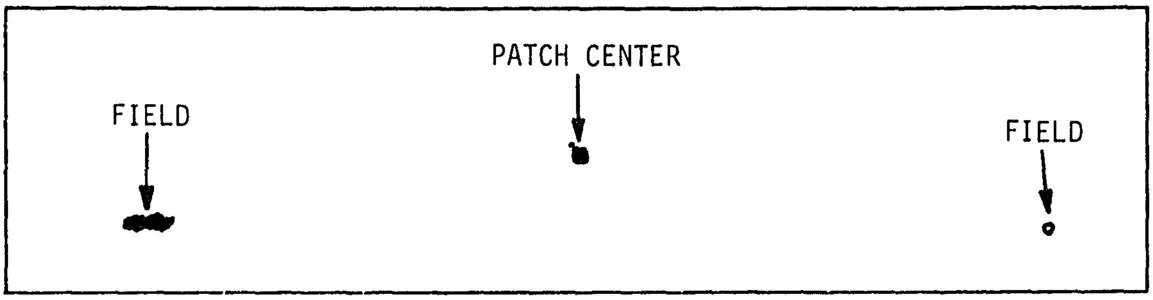
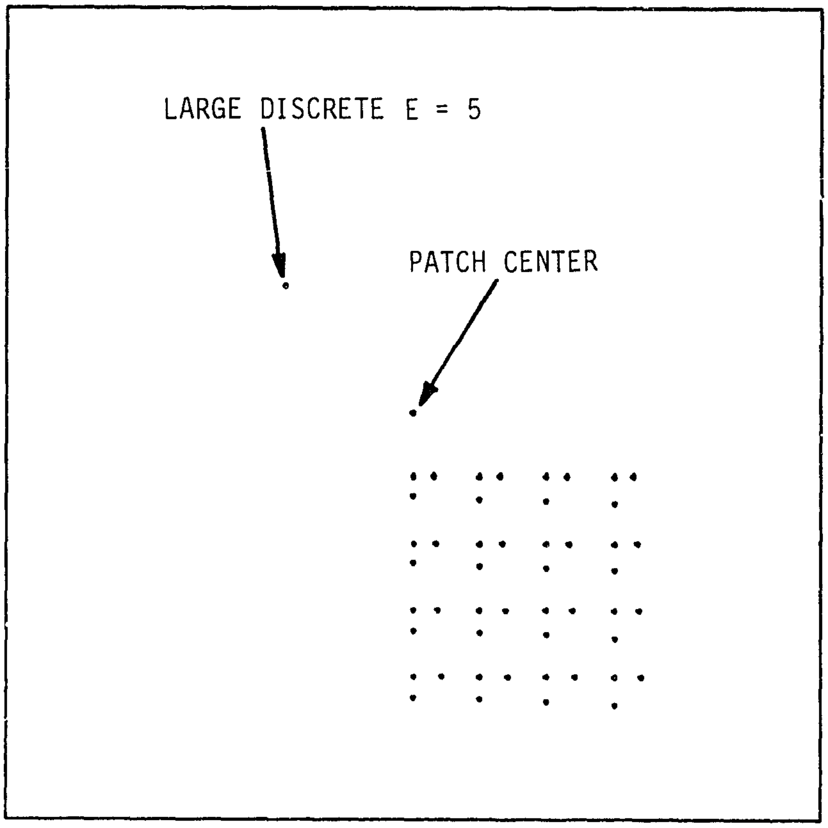


FIGURE 5

TERRAIN PLOT OF THE AMBIGUITY LOCATIONS FOR THE MULTIBEAM MODEL

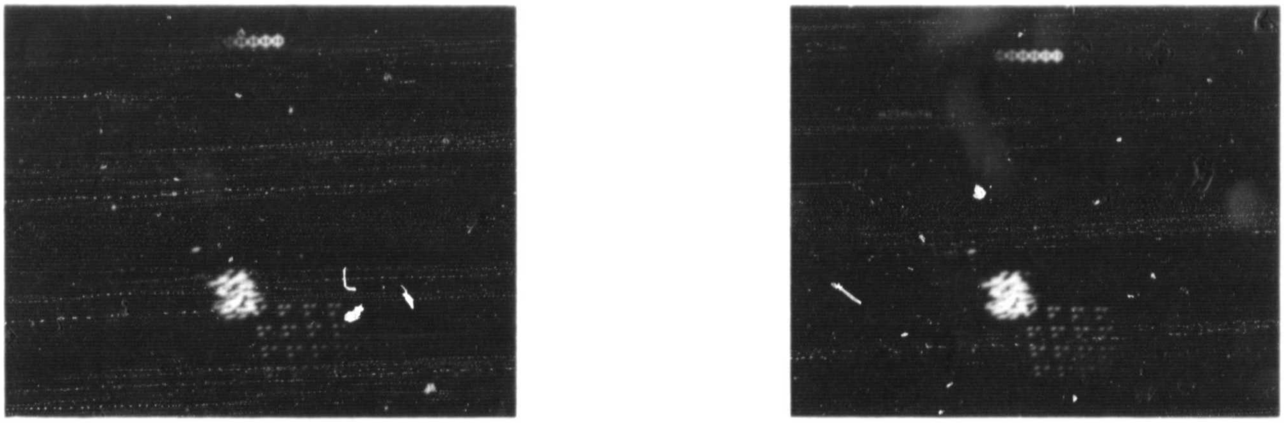


(a) COMPLETE TERRAIN MODEL (240 km x 60 km)
Field at right: E=2 All other scatterers: E=1



(b) AREA OF THE TERRAIN MODEL TO BE IMAGED
(6.375 km x 6.375 km)

FIGURE 6
TERRAIN MODEL FOR THE FIRST MULTIBEAM SIMULATION

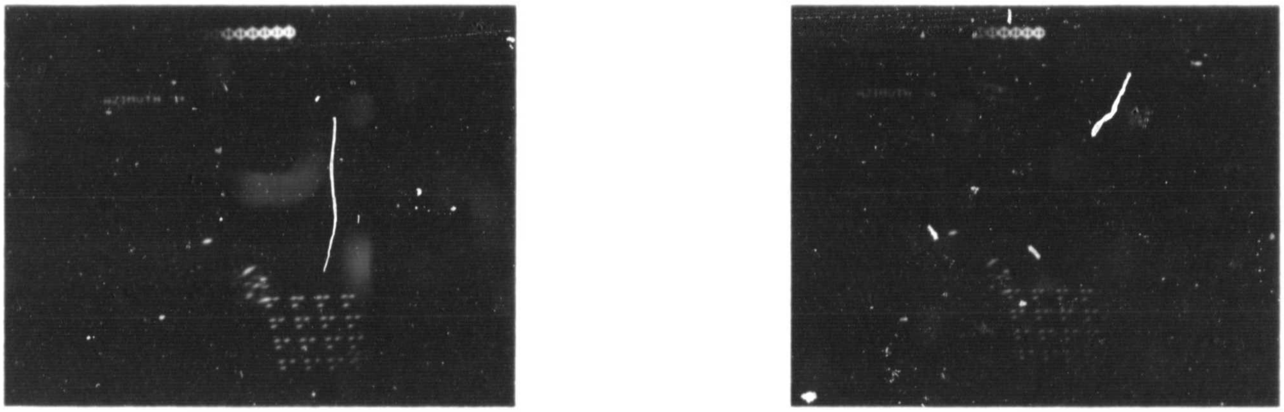


(a)

NO MULTIBEAM PROCESSING
2 dB/GRAY SCALE - 16 SCALES

(b)

NO MULTIBEAM PROCESSING
2 dB/GRAY SCALE - TOP 6 SCALES



(c)

MULTIBEAM PROCESSING
2 dB/GRAY SCALE - 16 SCALES

(d)

MULTIBEAM PROCESSING
2 dB/GRAY SCALE - TOP 6 SCALES

FIGURE 7

IMAGES FROM THE FIRST MULTIBEAM SIMULATION

Figs. 7(b) and 7(d) show only the top 12 dB of the images and demonstrate more clearly the significance of multibeam processing. The beam formation processing was not shaded, and so sidelobes of approximately 13 dB are expected (application of a weighting or shading function to the antenna element outputs should reduce this level); as illustrated in Fig. 7 the level of the imaged ambiguities from the multibeam processing are approximately 13 dB below the level of the imaged ambiguities with no multibeam processing.

The images are observed to be slightly "skewed" in azimuth, a result of the squint mode geometry and OSS image processing. If a line is drawn through the range ambiguity points of Fig. 5 (including the patch center), then all the points on this line have the same Doppler frequency as the patch center. The OSS currently processes all the range bins of one patch (synthetic array) with the same focus and filtering functions and lines up all the azimuth filters into vertical lines. Therefore, the azimuth filters are shifted in the range bins about the range bin containing the patch center. Program POST removed some of the skewing by shifting the azimuth lines based on their position relative to the center range bin.

B. Second Model

Except for the terrain model, the second simulation's parameters are identical to the first simulation discussed above. The section of the terrain model to be imaged is shown in Fig. 8. Fields were placed at the locations shown in Fig. 6, but they consisted of many more scatterers; a total of 933 scatterers were used in the second terrain model compared to only 126 for the first model. Figure 9 contains the SARCON data generated for this simulation.

The resultant images of the simulation are shown in Fig. 10. The photographs show that the multibeam processing suppresses the imaged ambiguity fields by over 12 dB; the fields would probably be less pronounced if the area being imaged contained a background reflectance

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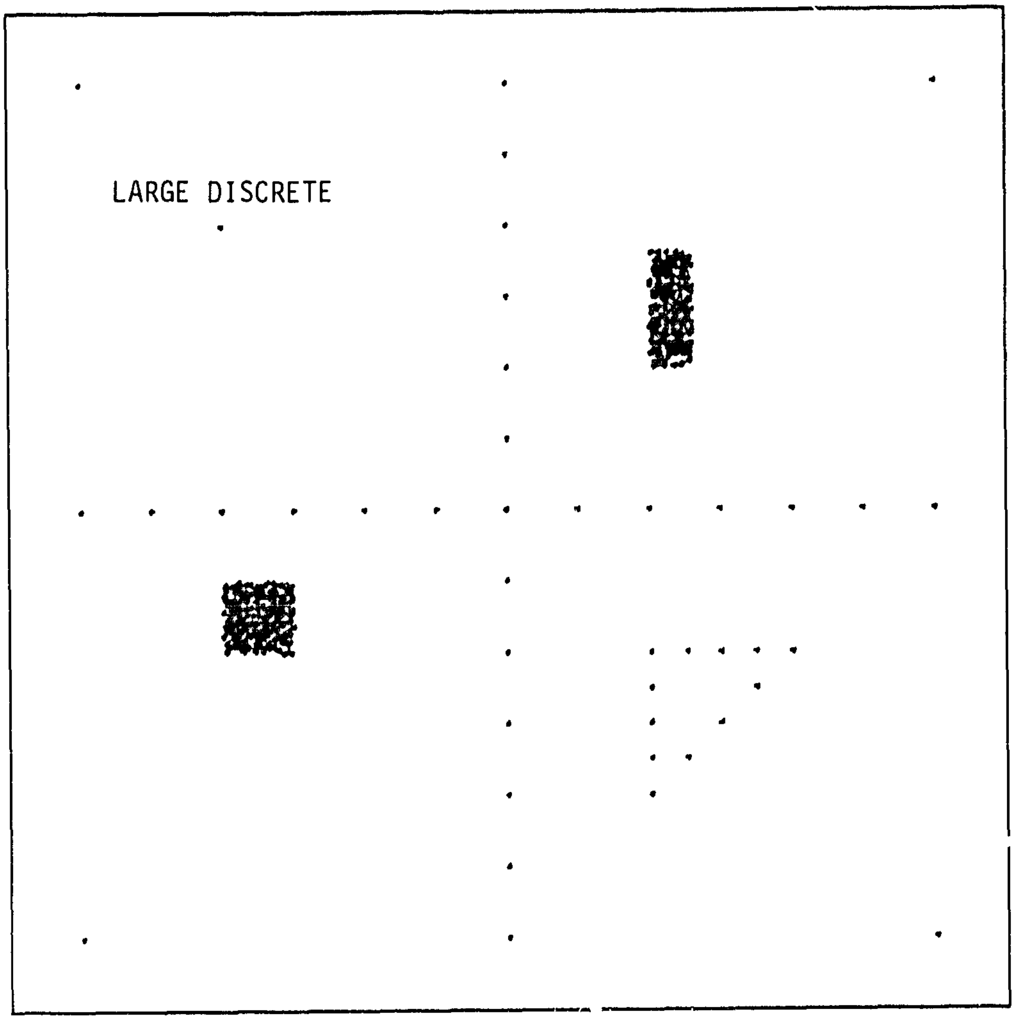

FIGURE 8

TERRAIN MODEL FOR THE SECOND MULTIBEAM SIMULATION

AREA OF THE TERRAIN MODEL TO BE IMAGED
(6.375 km x 6.375 km)

Large Discrete: E=20
Field at lower left: E=0.2 Field at upper right: E=0.5
All other scatterers, including the ambiguity scatterers not shown on the plot: E=1

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          * * * * * * * * * *   P L A N E T   S P E C I F I C A T I O N   * * * * * * * * * *
PLANET NAME  **                              EARTH             EQUATORIAL RADIUS (KM)  **                  .63781670000E+04
ECCENTRICITY  **                             .81820179996E-01 GRAVITATIONAL CONSTANT (KM3/SEC2)  ** .39860100000E+06
ROTATIONAL RATE (DEG/S)  **                  .41780745995E-02 TIME OF PRIME MERIDIAN PASSAGE (S) **0.

          * * * * * * * * * *   O R B I T   S P E C I F I C A T I O N   * * * * * * * * * *
ORBIT I.D.  **                               794CIRCULR        SEMI-MAJOR AXIS (KM)  **                    .71865400000E+04
ECCENTRICITY  **                             .20000000000E-02 INCLINATION (DEG)  **                        .10800000000E+03
LONG OF ASCENDING NODE (DEG)  **      0.                       ARGUMENT OF PERIGEE (DEG)  **           0.
TIME OF PERIGEE PASSAGE (S)  **       0.                       ROTATIONAL RATE (DEG/S)  **                 .59376152657E-01
ORBITER INITIALIZATION TIME(S)  **   -.10000000000E-03

          * * * * * * * * * *   R A D A R   S P E C I F I C A T I O N   * * * * * * * * * *
RADAR I.D.  **                               SEASAT-A          OPERATING WAVELENGTH (M)  **                .23500000000E+00
RECIEVER/TRANSMITTER BW (MHZ)  **            .77972901347E+01 RANGE TIME-BANDWIDTH PRODUCT  **            .10000000000E+01
SIGNAL-TO-NOISE RATIO (DB)  **               .10000000000E+03 A/D SAMPLE RATE (MHZ)  **                   .15594580269E+02
SAMPLE LENGTH OF RANGE CORRELATION **                       1 SAMPLE LENGTH ACROSS PHASE INTERVAL *                   1
BINARY PHASE CODE  **                        B                 BINARY PHASE CODE SEQUENCE  **             RANDOM
GROUND RANGE RESOLUTION (M)  **              .50000000000E+02 AZIMUTH RESOLUTION (M)  **                  .50000000000E+02
RANGE SAMPLING RATIO (M)  **                 .20000000000E+01 AZIMUTH SAMPLING RATIO (M)  **              .20000000000E+01
RANGE IMPULSE RESPONSE FUNCTION  **          COSINE**2         APERTURE WEIGHT FUNCTION  **               TAYLOR
PATCH-TO-PATCH OFFSET, RNG (M)  **    0.                       PATCH-TO-PATCH OFFSET, AZ (M)  **       0.
RANGE SWATH WIDTH (KM)  **                   .63750000000E+01 NO OF PATCHES  **                                       1
MAP START LATITUDE (DEG)  **                 .45000000000E+02

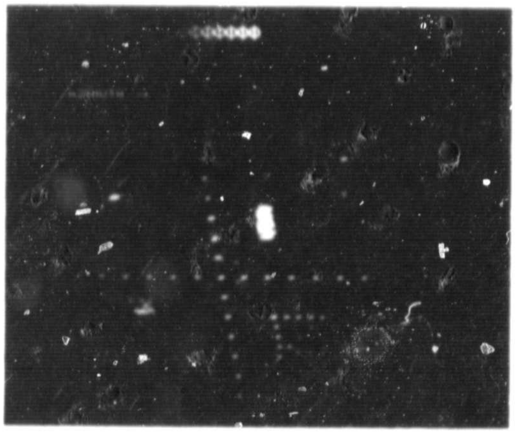
          * * * * * * * * *   A N T E N N A   S P E C I F I C A T I O N   * * * * * * * * *
ANTENNA I.D.  **                             MULTI-BEAM        BORESIGHT NADIR AT TO (DEG)  **            .20000000000E+02
BORESIGHT SQUINT AT TO (DEG)  **             .34000000000E+02 AZIMUTH ANGULAR COVERAGE (DEG)  **          .80000000000E+01
ELEVATION ANGULAR COVERAGE (DEG)  **         .30000000000E+01 PHASE CENTER, BODY AXIS X (M)  **        0.
PHASE CENTER, BODY AXIS Y (M)  **     0.                       PHASE CENTER, BODY AXIS Z (M)  **        0.
COORD SYS, BODY AXIS ROLL, (DEG)  ** 0.                        COORD SYS, BODY AXIS PITCH, (DEG) ** -.70000000000E+02
COORD SYS, BODY AXIS YAW, (DEG)  **          .34000000008E+02 PLAT ROLL RATE (DEG/S)  **               0.
PLAT PITCH RATE (DEG/S)  **           0.                       PLAT YAW RATE (DEG/S)  **                0.

          * * * * * * * * *   T E R R A I N   S P E C I F I C A T I O N   * * * * * * * * *
TERRAIN I.D.  **                             MULTI-1           NO OF DISCRETES  **                                     43
NO OF FIELDS  **                                            4 TOTAL NO OF SCATTERERS  **                            933
X-AXIS COVERAGE (KM)  **                     .19984500008E+03 Y-AXIS COVERAGE (KM)  **                    .21300000000E+02
TERRAIN CENTER, R (KM)  **                   .63675192370E+04 TERRAIN CENTER, LAT (DEG)  **               .45000000000E+02
TERRAIN CENTER, LONG (DEG)  **               .34020958470E+03

          * * * * * *   S Y N T H E T I C   A R R A Y   P A R A M E T E R S   * * * * * *
SYNTHETIC ARRAY NO  **                                      1 TRANSMISSION START TIME (S)  **             .75706892121E+03
ARRAY LENGTH (M)  **                         .23997304242E+04 ARRAY INCLINATION (DEG)  **                 .81088631361E-01
ARRAY FORMATION TIME (MS)  **                .32176541097E+03 PLATFORM VELOCITY (KM/S)  **                .74580106359E+01
NO OF PULSES  **                                         1758 PRF (HZ)  **                                .54629996835E+04
NO OF RANGE SAMPLES  **                                   255 NO. OF AZIMUTH FILTERS  **                             255
PATCH CENTER RANGE SAMPLE NO.  **                         128 SLANT RANGE SWATH WIDTH (KM)  **            .24510624417E+01
SLANT RANGE RESOLUTION (M)  **               .19224146775E+02 SLANT RANGE SAMPLE INTERVAL (M)  **         .96120733877E+01
START RANGE (KM)  **                         .86659032998E+03 RANGE PATCH CENTER (KM)  **                 .86781106330E+03
SQ INT ANGLE PATCH CENTER (DEG)  **          .34135168252E+02 NADIR ANGLE PATCH CENTER (DEG)  **          .19946775461E+02
LOS AZIMUTH AT PATCH CENTER (DEG) ** -.17017585118E+03 LOS INCIDENCE AT PATCH CENTER (DEG)** .22611644021E+02
PATCH CENTER, R (KM)  **                     .63675192370E+04 ORBITER MASS CENTER, R (KM)  **             .71763842359E+04
PATCH CENTER, LAT (DEG)  **                  .45000000000E+02 ORBITER MASS CENTER, LAT (DEG)  **          .42372508999E+02
PATCH CENTER, LONG (DEG)  **                 .34020958470E+03 ORBITER MASS CENTER, LONG (DEG)  **         .33959432948E+03
```

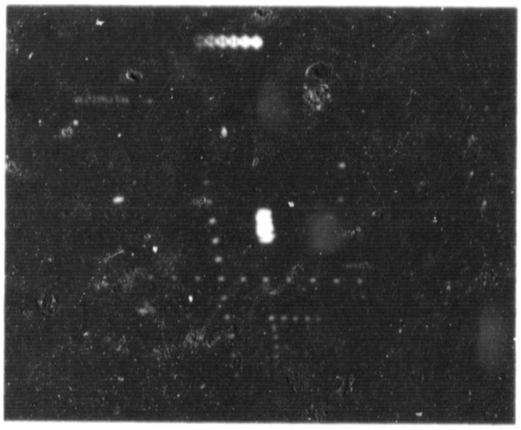
FIGURE 9

SARCON DATA - MULTIBEAM MODEL 2



(a)

2 dB/GRAY SCALE - 16 SCALES



(b)

2 dB/GRAY SCALE - TOP 6 SCALES

FIGURE 10

IMAGES FROM THE SECOND MULTIBEAM SIMULATION

AS-82-1489

instead of being composed strictly of point scatterers. The skewing in the azimuth direction discussed above for the first model is more evident in this model. The skewing also caused the scatterers in the extreme left top and bottom right of the terrain model to be pushed off the image, and they do not appear in the photographs of Fig. 10. Reference 1 includes photographs (see Ref. 1, p. 11/2) of images produced under the test simulation which that document describes. That test simulation and the simulations described in this report contain some identical parameters, i.e., wavelength, orbit specification, and planet specification. The multibeam simulations were squint mode simulations (as opposed to sidelooking) and the synthetic array formation parameters are different for the models. The images shown on page 11/2 of Ref. 1 contains a scatterer of amplitude 26 dB above the calibration target just as the second multibeam simulation model does. However, the test simulation shows the large discrete target to have much higher sidelobes than the multibeam models; the higher PRF and multibeam processing appear to suppress the sidelobes even though the same azimuth weighting functions are used.

VI. CONCLUSIONS

While some concessions had to be made in adapting the OSS to implement the wideswath multibeam SAR technique, the basic concept was successfully incorporated into the OSS for verification. Overall, the OSS proved to be versatile and, in particular, was completely (and efficiently) adapted to the task of generating synthetic I/Q video data from a multiple antenna element orbital SAR model.

The multibeam technique for generating wideswath SAR images has been verified. No serious design problems were encountered in the implementation of the multibeam technique. However, the advantages of the technique compared to conventional SAR image techniques are still not completely clear. The multibeam technique allows for higher PRF's, implying lower transmitter peak power and greater Doppler ambiguity suppression, but the possible advantages in wideswath image formation and registration are still not clear. A study of signal processing and image formation algorithms and the development of a Doppler processor incorporating multiple beams and the multibeam geometry would be necessary to adequately address the possible advantages. Also a study of the effects of antenna array and platform errors on the formation of multibeams (using the OSS-multibeam simulation) would prove useful.

APPENDIX A
LISTING OF PROGRAM MECHO

```
      PROGRAM MECHO(SARCON=0,TDATA=0,ADATA=0,ANTPOS=0,EDATA=0,PLOT,      MECHO
     1INPUT,OUTPUT,TAPE25=0)                                             MECHO
      COMMON SARCON1,PI,TPI,PIH,RTD,DTR,CL                               MECHO
      COMMON KPLNT,PRE,PE,PGC,PRR,PTM                                    MECHO
      COMMON KORB,OSMA,OE,OINC,OLON,OPERI,OTP,ORB,TINIT,XEC              MECHO
      COMMON KRADR,WL,THW,SNR,LRC,LPT,KPC,KPCS,RESR,RESA,SRP,SRA,        MECHO
     .KRETNR,KWTETNA,SHADFAC,PCOFFR,PCOFFA,SW,NA,STLAT                   MECHO
      COMMON KANT,SNAC,SQUINT,ABW,EBW,PHCPH(3),AGRPY(3),PORPY(3)         MECHO
      COMMON KSNC,NDISC,NFLDS,NSCATS,EMEAN,DISTX,DISTY,TCP,TCLAT,        MECHO
     .TCLONG                                                             MECHO
      COMMON IO,PRF,PREMCD,NP,NF,NRB,RMIN,SRSW,RESSR,SISR,IPRPC          MECHO
      COMMON IA,ATO,AL,AT,PLATP(3),PPMAG,PLATV(3),PVMAG,SRPC,XSWPC,      MECHO
     .XNAPC,GAMMA,XAZPC,XIAPC,APC,PCR,PCLAT,PCLONG,SR,SLAT,SLONG         MECHO
      COMMON PHCP(3),F,HS,SARCON2                                        MECHO
      COMMON/ANTPAT/KANTP,MIDAZ,DAZ,ANTAZ(1001),MIDEL,DEL,ANTEL(1001)    MECHO
      COMMON/THEAD/KSNOX,NDISCX,NFLDSX,NSCATSX,EMEANX,DISTXX,            MECHO
     .DISTYX,NRECS                                                       MECHO
      DIMENSION SREL(2,256,16),TERAIN(4,256),A(3),ANTD(2007),LBL(2)      MECHO
      DIMENSION PHCPBX(16),PHCPBY(16),PHCPBZ(16),X(16),Y(16),Z(16)       MECHO
      EQUIVALENCE (KANTP,ANTD(1))                                        MECHO
C*****************************************************************MECHO
C***** ECHO -- COMPUTES SLANT RANGE AND ECHO LEVEL OF EACH SCATTERER     MECHO
C***** FOR EACH PULSE FOR EACH ANTENNA ON THE ORBITER AND STORES IN      MECHO
C***** PULSE SEQUENCE, ALL SCATTERERS EACH PULSE, AT 256 SCATTERERS OR   MECHO
C***** LESS PER RECORD, NA ARRAYS PER FILE.                              MECHO
C*****        SARCON- SARCON DATA, INPUT.                                MECHO
C*****        TDATA- TERRAIN DATA, INPUT.                                MECHO
C*****        ADATA- ANTENNA PATTERN DATA, INPUT.                        MECHO
C*****        ANTPOS- ANTENNA POSITION DATA, INPUT.                      MECHO
C*****        EDATA- SLANT RANGE, ECHO STRENGTH DATA, OUTPUT.            MECHO
C*****        TAPE25- TERRAIN DATA, TEMPORARY.                           MECHO
C*****************************************************************MECHO
      ITERX=0                                                            MECHO
    1 PRINT 1110  $  IPULSE=IFLG1=IFLG3=IFLG4=IPONLY=0                   MECHO
      NASKP=NPSKP=0                                                      MECHO
      ITERX=ITERX+1  $  IF(ITERX.GT.1)GOTO 10                            MECHO
      PRINT *,≠----------- PROGRAM MECHO IN EXECUTION ----------≠        MECHO
   10 IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT KBRANCH≠                         MECHO
      READ *, KBRANCH                                                    MECHO
```

```
      IF(EOF(5LINPUT).NE.0.0)GOTO 1000                                  MECHO      40
      IF(KBRANCH.EQ.≠SARDATA≠)GOTO 100                                  MECHO      41
      IF(KBRANCH.EQ.≠TERDATA≠)GOTO 200                                  MECHO      42
      IF(KBRANCH.EQ.≠PLOT≠)GOTO 250                                     MECHO      43
      IF(KBRANCH.EQ.≠ANIDATA≠)GOTO 300                                  MECHO      44
      IF(KBRANCH.EQ.≠PROCESS≠)GOTO 400                                  MECHO      45
      IF(KBRANCH.EQ.≠AECOVERAGE≠)GOTO 320                               MECHO      46
      IF(KBRANCH.EQ.≠PDHPY≠)GOTO 360                                    MECHO      47
      IF(KBRANCH.EQ.≠PREMAN≠)GOTO 380                                   MECHO      48
      IF(KBRANCH.EQ.≠APPEND≠)GOTO 390                                   MECHO      49
      GOTO 10                                                           MECHO      50
C**** SARDATA -- IDENTIFY SARCON DATA FILE NO.                          MECHO      51
C****           IFILS- FILE NO.                                         MECHO      52
  100 CONTINUE                                                          MECHO      53
      LUNSR=≠SARCON≠  $  LUNS=6LSARCON                                  MECHO      54
      IF(LIGHTF(5).EQ.0)PRINT *,≠ INPUT IFILS≠                          MECHO      55
      READ *,IFILS                                                      MECHO      56
      PRINT 1010,LUNSR,IFILS                                            MECHO      57
      IRECS=0                                                           MECHO      58
      CALL LUNPOS(LUNS,IFILS)                                           MECHO      59
      GOTO 10                                                           MECHO      60
C**** TERDATA -- IDENTIFY TERRAIN DATA FILE NO.                          MECHO      61
C****           IFILT- FILE NO.                                          MECHO      62
C****           XYZSCAL- SCALE FACTOR APPLIED TO TERRAIN DATA (KM).      MECHO      63
  200 CONTINUE                                                          MECHO      64
      LUNTR=≠TDATA≠  $  LUNT=5LTDATA                                    MECHO      65
      IF(LIGHTF(5).EQ.0)PRINT *,≠ INPUT IFILT,XYZSCAL≠                  MECHO      66
      READ *, IFILT,XYZSCAL                                             MECHO      67
      PRINT 1020,LUNTR,IFILT                                            MECHO      68
      PRINT *,XYZSCAL,≠ KM SCALE FACTOR APPLIED TO TERRAIN DATA.≠       MECHO      69
      IRECT=0                                                           MECHO      70
      CALL LUNPOS(LUNT,IFILT)                                           MECHO      71
      GOTO 10                                                           MECHO      72
C**** PLOT -- PLOT SLANT RANGE, ECHO LEVEL DATA.                         MECHO      73
C****        IPULSE- PULSE NO.                                           MECHO      74
C****        IARAY- ARRAY NO.                                            MECHO      75
C****        IPONLY- PLOT ONLY FLAG IF = 1. OTHERWISE NORMAL ECHO DATA  MECHO      76
C****                OUTPUT FILE WRITTEN.                                MECHO      77
  250 CONTINUE                                                          MECHO      78
```

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      IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT IPULSE,IARAY,IPONLY≠              MECHO          79
      READ *,IPULSE,IARAY,IPONLY                                          MECHO          80
      PRINT 1070,IPULSE,IARAY                                             MECHO          81
      IF(IPONLY.EQ.1)PRINT *,≠PLOT ONLY. NO OTHER OUTPUT.≠                MECHO          82
      IF(LFN.EQ.4LPLOT)GOTO 260                                           MECHO          83
      LFN=4LPLOT  $  CALL PLTLFN(LFN,≠K GRAF≠)                            MECHO          84
  260 CALL PLTORG(2.,4.)                                                  MECHO          85
      GOTO 10                                                             MECHO          86
C**** ANTDATA -- IDENTIFY ANTENNA PATTERN DATA FILE NO.                    MECHO          87
C****                IFILA- FILE NO.                                      MECHO          88
  300 CONTINUE                                                            MECHO          89
      LUNAB=≠ADATA≠  $  LUNA=5LADATA                                      MECHO          90
      IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT IFILA≠                            MECHO          91
      READ *,IFILA                                                        MECHO          92
      PRINT 1030,LUNAB,IFILA                                              MECHO          93
      IRECA=0                                                             MECHO          94
      CALL LUNPOS(LUNA,IFILA)                                             MECHO          95
      GOTO 10                                                             MECHO          96
C**** AECOVERAGE -- CHANGE ANTENNA COVERAGE IN AZIMUTH AND ELEVATION.      MECHO          97
C**** SARCON WORDS ABW,EBW.                                                MECHO          98
  320 CONTINUE                                                            MECHO          99
      IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT ABW,EBW (DEG)≠                    MECHO         100
      READ *,ABWX,EBWX                                                    MECHO         101
      PRINT 1080,ABWX,EBWX                                                MECHO         102
      IFLG1=1  $  GOTO 10                                                 MECHO         103
C**** PDRPY -- CHANGE PLATFORM RATES OF ROLL,PITCH,YAW.                    MECHO         104
C**** SARCON ARRAY PDRPY.                                                  MECHO         105
  350 CONTINUE                                                            MECHO         106
      IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT PDRPY(3) (DEG/S)≠                 MECHO         107
      READ *,PDRPYR,PDRPYP,PDRPYY                                         MECHO         108
      PRINT 1100,PDRPYR,PDRPYP,PDRPYY                                     MECHO         109
      IFLG3=1  $  GOTO 10                                                 MECHO         110
C**** PRFMAN -- MANUAL PRF INPUT.  SARCON WORD PRF.                        MECHO         111
  380 CONTINUE                                                            MECHO         112
      IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT PRF≠                              MECHO         113
      READ *,PRFMAN                                                       MECHO         114
      PRINT *,≠PRF CHANGED TO ≠,PRFMAN                                    MECHO         115
      IFLG4=1  $  GOTO 10                                                 MECHO         116
C**** APPEND -- APPEND PROCESSING.                                         MECHO         117
```

```
      C*****           NASKP- NO. OF ARRAYS TO SKIP ON FILES SARCON AND       MECHO      118
      C*****                  EDATA.                                          MECHO      119
      C*****           NPSKP- NO. OF PULSES TO SKIP ON FILE EDATA.            MECHO      120
        390 CONTINUE                                                          MECHO      121
            IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT NASKP,NPSKP≠                    MECHO      122
            READ *,NASKP,NPSKP                                                MECHO      123
            PRINT *,≠APPEND PROCESSING. SKIP ≠,NASKP,≠ ARRAYS, THEN ≠,        MECHO      124
           .NPSKP,≠ PULSES.≠                                                  MECHO      125
            GOTO 10                                                           MECHO      126
      C***** PROCESS -- GENERATE OUTPUT FILE OF SLANT RANGE, ECHO LEVEL DATA  MECHO      127
      C***** FOR EACH SCATTERER, FOR EACH PULSE, FOR EACH ARRAY.              MECHO      128
      C*****                IFILSRE- FILE NO.                                 MECHO      129
        400 CONTINUE                                                          MECHO      130
            LUNSREB=≠EDATA≠  $  LUNSRE=5LEDATA                                MECHO      131
            IF(LIGHIF(5).EQ.0)PRINT *,≠ INPUT IFILSRE≠                        MECHO      132
            READ *,IFILSRE                                                    MECHO      133
            PRINT 1040,LUNSREB,IFILSRE                                        MECHO      134
            IRECSRE=0 $ CALL LUNPOS(LUNSRE,IFILSRE)                           MECHO      135
            IPSARCN=3                                                         MECHO      136
      C***** READ AND STORE ANTENNA PATTERN DATA.                             MECHO      137
            IRECA=IRECA+1                                                     MECHO      138
            BUFFER IN(LUNA,1)(ANTD(1),ANTD(2007))                             MECHO      139
            IF(UNIT(LUNA))410,408,406                                         MECHO      140
        406 STOP ≠P.F. ON LUNA≠                                               MECHO      141
        408 PRINT 1050,LUNAB,IRECA  $  GOTO 10                                MECHO      142
      C***** ARRAY LOOP START. READ SARCON DATA.                              MECHO      143
        410 CONTINUE                                                          MECHO      144
            IRECS=IRECS+1                                                     MECHO      145
            BUFFER IN(LUNS,1)(SARCON1,SARCON2)                                MECHO      146
            IF(UNIT(LUNS))416,415,414                                         MECHO      147
        414 STOP ≠P.F. ON LUNS≠                                               MECHO      148
        415 PRINT 1050,LUNSB,IRECS  $  GOTO 10                                MECHO      149
        416 CONTINUE                                                          MECHO      150
      C***** UPDATE SARCON DATA.                                              MECHO      151
            KANT=KANTP                                                        MECHO      152
            IF(IFLG1.EQ.0)GOTO 417                                            MECHO      153
            ABW=ABWX*DTR $ EBW=EBWX*DTR $ CALL PRESLCT(0.)                    MECHO      154
      C***** INPUT ANTENNA PHASE CENTER POSITIONS FROM FILE - ANTPOS .        MECHO      155
        417 CONTINUE                                                          MECHO      156
```

```
      LUNAPOS=6LANTPOS
      READ(LUNAPOS,*) NANTS
      DO 2417 JL=1,NANTS
 2417 READ(LUNAPOS,*) PHCPBX(JL),PHCPBY(JL),PHCPBZ(JL)
      REWIND LUNAPOS
  418 IF(IFLG3.EQ.0)GOTO 419
      PDRPY(1)=PDRPYR*DTR $ PDRPY(2)=PDRPYP*DTR
      PDRPY(3)=PDRPYY*DTR
  419 IF(IFLG4.EQ.0)GOTO 409
      CALL PRESLCT(PREMAN)
C**** READ TERRAIN DATA ON FIRST ARRAY. RESCALE, ROTATE FROM ENU,
C**** CONVERT TO GREENWICH TOD, RESTORE.
  409 IF(IA.EQ.1)420,440
  420 IRECT=IRECT+1
      BUFFER IN(LUNT,1)(KSNOY,NRECS)
      IF(UNIT(LUNT))423,422,421
  421 STOP ≠P.F. ON LUNT≠
  422 PRINT 1050, LUNTR,IRECT  $  GOTO 10
  423 TCPX=PCR  $  TCLATX=PCLAT  $  TCLONGX=PCLONG
      DISTXX=DISTXX*XYZSCAL  $  DISTYX=DISTYX*XYZSCAL
      NSCATR=128
      DO 430 IRECS=1,NRECS
      IF(IRECS.EQ.NRECS)NSCATR=NSCATSX-(NRECS-1)*NSCATR
      NWDS=NSCATR*4
      IRECT=IRECT+1
      BUFFER IN(LUNT,1)(TERAIN(1),TERAIN(NWDS))
      IF(UNIT(LUNT))426,425,424
  424 STOP ≠P.F. ON LUNT≠
  425 PRINT 1050, LUNTR,IRECT  $  GOTO 10
  426 CONTINUE
      DO 428 ISCATR=1,NSCATR
      DO 427 I=1,3
  427 A(I)=TERAIN(I,ISCATR)*XYZSCAL
      CALL ROTZ(A,XAZPC-PI)
      A(3)=A(3)+TCRX
      CALL ROTX(A,TCLATX-PIH)
      CALL ROTZ(A,-PIH-TCLONGX)
      CALL XYZTSPH(A,A)  $  A(1)=PRADIUS(A(2))  $  CALL SPHTXYZ(A,A)
      DO 428 I=1,3
```

```
  428 TERAIN(1,ISCATR)=A(I)                                                 MECHO    196
      BUFFER OUT(25,1)(TERAIN(1),TERAIN(NWDS))                              MECHO    197
      IF(UNIT(25))430,429,429                                               MECHO    198
  429 STOP ≠P.F. ON 25≠                                                     MECHO    199
  430 CONTINUE                                                              MECHO    200
      ENDFILE 25                                                            MECHO    201
      CALL AMHTL(UAILA,UAILF)                                               MECHO    202
      IF(IPULSE.EQ.0)GOTO 440                                               MECHO    203
      XNRB=NRB  $  DELTA=1.0                                                MECHO    204
      OFST=4./(XNRB-1.)  $  I1=NRB/2                                        MECHO    205
      LBL(1)=≠ECHO LEVEL≠                                                   MECHO    206
      CALL PLTAXIS(-OFST,0.,1.,90.,0.,1.,1.,LBL,10,1.,.04,.08)              MECHO    207
      LBL(1)=≠RANGE SAMP≠  $  LBL(2)=≠LE≠                                   MECHO    208
      CALL PLTAXIS(0.,0.,4.,0.,1.,XNRB,DELTA,LBL,-12,I1,.04,.08)            MECHO    209
  440 CONTINUE                                                              MECHO    210
      KSNO=KSNOX  $  NDISC=NDISCX  $  NFLDS=NFLDSX  $  NSCATS=NSCATSX       MECHO    211
      EMEAN=EMEANX  $  DISTX=DISTXX  $  DISTY=DISTYX                        MECHO    212
      TCR=TCRX  $  TCLAT=TCLATX  $  TCLONG=TCLONGX                          MECHO    213
C**** WRITE SARCON DATA.                                                    MECHO    214
      IF(NASKP.GE.IA)435,436                                                MECHO    215
  435 NRSKP=NP*(NRECS+1)/2+1  $  CALL SKIPER(LUNSRE,0,NRSKP)                MECHO    216
      IRECSRE=IRECSRE+NRSKP  $  GOTO 475                                    MECHO    217
  436 IF(IPONLY.EQ.1)GOTO 442  $  IF(NPSKP.GT.0)GOTO 442                    MECHO    218
      DO 2442 JL=1,NANTS                                                    MECHO    219
      PHCPR(1)=PHCPBX(JL) $  PHCPB(2)=PHCPBY(JL) $  PHCPR(3)=PHCP3Z(JL) MECHO    220
      IF(LIGHIF(6).EQ.0)CALL PSARCON(IPSARCN)                               MECHO    221
      IRECSRE=IRECSRE+1                                                     MECHO    222
      BUFFER OUT(LUNSRE,1)(SARCON1,SARCON2)                                 MECHO    223
      IF(UNIT(LUNSRE))2442,441,441                                          MECHO    224
  441 STOP ≠P.F. ON LUNSRE≠                                                 MECHO    225
 2442 CONTINUE                                                              MECHO    226
  442 CONTINUE                                                              MECHO    227
      IPSARCN=2                                                             MECHO    228
C**** PULSE LOOP START.                                                     MECHO    229
      XIPP=1.0/PRF  $  T=ATO  $  IP1=1                                      MECHO    230
      IF(NPSKP.EQ.0)GOTO 433                                                MECHO    231
      NRSKP=NPSKP*(NRECS+1)/2+1  $  T=T+NPSKP*XIPP  $  IP1=IP1+NPSKP        MECHO    232
      CALL SKIPER(LUNSRE,0,NRSKP)  $  NPSKP=0                               MECHO    233
      IRECSRE=IRECSRE+NRSKP                                                 MECHO    234
```

```
  433 DO 470 IP=IP1,NP                                                     MECHO      235
      REWIND 25                                                            MECHO      236
      DO 434 JL=1,NANTS                                                    MECHO      237
      PHCPB(1)=PHCPBX(JL) $  PHCPB(2)=PHCPBY(JL) $  PHCPB(3)=PHCPBZ(JL)    MECHO      238
      CALL PHCMOTN(T)                                                      MECHO      239
      X(JL)=PHCP(1)  $  Y(JL)=PHCP(2)  $  Z(JL)=PHCP(3)                    MECHO      240
  434 CONTINUE                                                             MECHO      241
      IF(LIGHTF(2).NE.1)GOTO 443                                           MECHO      242
      IF(IA.NE.1)GOTO 443                                                  MECHO      243
      IF(IP.EQ.1)PRINT 1110                                                MECHO      244
      IF(IP.LE.4)PRINT *,≠IA,IP,T,PHCP(3) ≠,IA,IP,T,X,Y,Z                  MECHO      245
  443 NSCATR=128  $  JSCATR=0                                              MECHO      246
      DO 460 IRECS=1,NRECS                                                 MECHO      247
      IOE=AND(IRECS,1)                                                     MECHO      248
      IF(IRECS.EQ.NRECS)NSCATR=NSCATS-(NRECS-1)*NSCATR                     MECHO      249
      NWDS=NSCATR*4                                                        MECHO      250
      IF(IOE.EQ.1)K2=0  $  K1=K2+1  $ K2=K1-1+NWDS                         MECHO      251
      BUFFER IN(25,1)(TERAIN(K1),TERAIN(K2))                               MECHO      252
      IF(UNIT(25))446,445,444                                              MECHO      253
  444 STOP ≠P.F. ON 25≠                                                    MECHO      254
  445 STOP ≠EOF ON 25≠                                                     MECHO      255
  446 JSCATR=JSCATR+NSCATR                                                 MECHO      256
      IF(IRECS.NE.1)GOTO 449                                               MECHO      257
      TERAIN(1)=PCR  $  TERAIN(2)=PCLAT  $  TERAIN(3)=PCLONG               MECHO      258
      CALL SPHTXYZ(TERAIN,TERAIN)                                          MECHO      259
  449 IF(IRECS.EQ.NRECS)GOTO 447                                           MECHO      260
      IF(IOE.EQ.1)GOTO 460                                                 MECHO      261
  447 DO 450 JL=1,NANTS                                                    MECHO      262
      DO 450 ISCATR=1,JSCATR                                               MECHO      263
      RX=TERAIN(1,ISCATR)-X(JL)  $  RY=TERAIN(2,ISCATR)-Y(JL)              MECHO      264
      RZ=TERAIN(3,ISCATR)-Z(JL)                                            MECHO      265
  450 SREL(1,ISCATR,JL)=SQRT(RX*RX+RY*RY+RZ*RZ)                            MECHO      266
      CALL ANTWT(TERAIN,SREL,JSCATR,T)                                     MECHO      267
      DO 2450 JL=2,NANTS                                                   MECHO      268
      DO 2450 ISCATR=1,JSCATR                                              MECHO      269
 2450 SREL(2,ISCATR,JL)=SREL(2,ISCATR,1)                                   MECHO      270
      IF(LIGHTF(2).NE.1)GOTO 451                                           MECHO      271
      IF(IA.EQ.1.AND.IP.LE.4.AND.IRECS.LE.2)PRINT *,≠ISCATR,≠,             MECHO      272
     .≠SREL,TERAIN ≠,(K,(SREL(I,K),I=1,2),(TERAIN(I,K),I=1,3),K=1,10)      MECHO      273
```

```
C**** CHECK FOR DATA PLOT
  451 IF(IP.NE.IPULSE)GOTO 452
      IF(IA.EQ.IARAY)GOTO 500
  452 NWDS=JSCATR*2  $  JSCATR=0  $  IF(IPONLY.EQ.1)GOTO 460
      NWDSH=NWDS/2
      DO 2460 JL=1,NANTS
      IRECSRE=IRECSRE+1
      BUFFER OUT(LUNSRE,1)(SREL(1,1,JL),SREL(2,NWDSH,JL))
      IF(UNIT(LUNSRE))2460,455,455
  455 STOP ≠P.F. ON LUNSRE≠
 2460 CONTINUE
  460 CONTINUE
  470 T=T+XIPP
  475 IF(IA.NE.NA)GOTO 410
      ENDFILE LUNSRE  $  PRINT 1060,LUNSREB,IRECSRE
  480 IF(IPULSE.NE.0) CALL PLTEND(0.0)
      GOTO 1
C**** PLOT SLANT RANGE, ECHO LEVEL DATA.
  500 CONTINUE
      DENOM=(NRB-1)*SISH/1000.
      K=0  $  IF(IRECS.LE.2)RO=SREL(1,1)
  502 K=K+1  $  IF(K.GT.JSCATR)GOTO 510
      XX=(SREL(1,K)-RO)*4./DENOM+2.
      YY=SREL(2,K)
      IF(XX.LT.0..OR.XX.GT.4.)GOTO 505
      CALL PLT(XX,0.,3)  $  CALL PLT(XX,YY,2)
  505 K=K+1  $  IF(K.GT.JSCATR)GOTO 510
      XX=(SREL(1,K)-RO)*4./DENOM+2.  $  YY=SREL(2,K)
      IF(XX.LT.0..OR.XX.GT.4.)GOTO 502
      CALL PLT(XX,YY,3)  $  CALL PLT(XX,0.,2)  $  GOTO 502
  510 CONTINUE
      IF(IRECS.EQ.NRECS.AND.IPONLY.EQ.1)GOTO 480
      GOTO 452
 1000 CONTINUE
 1010 FORMAT(* SARCON DATA ON *A10*, FILE*I3*.*)
 1020 FORMAT(* TERRAIN DATA ON *A10*, FILE*I3*.*)
 1030 FORMAT(* ANTENNA PATTERN DATA ON *A10*, FILE*I3*.*)
 1040 FORMAT(* OUTPUT SLANT RANGE, ECHO LEVEL DATA TO BE WRITTEN ON *
     1A10*, FILE*I3*.*)
```

```
      PROGRAM MECHO       73/171   OPT=2                        FTN 4.8+528       82/09/07. 16.06.42

              1050 FORMAT(* FOF SENSED ON *A10*, RECORD*I5*.*)                        MECHO       313
              1060 FORMAT(*)  FOF WRITTEN ON *A10*, AFTER RECORD*I5*.*)               MECHO       314
  31E         1070 FORMAT(* PLOT SR-EL DATA OF PULSE*I3*, ARRAY*I3*.*)                MECHO       315
              1080 FORMAT(* ANTENNA COVERAGE ABW,FRW CHANGED TO (DEG) -*              MECHO       316
                  12(1XE14.7))                                                        MECHO       317
              1100 FORMAT(* PLATFORM ATTITUDE RATE[illegible] PDRPY(3), CHANGED TO*   MECHO       318
                  1* (DEG/S) -*3(1XE14.7))                                            MECHO       319
  32C         1110 FORMAT(*1*)                                                        MECHO       320
                   END                                                                MECHO       321
```

APPENDIX B
LISTING OF PROGRAM MBEAM

```
 1              PROGRAM WBEAM(INPUT,OUTPUT,IQDATA=0,IQDAT1=0,IQDAT2=0,
               1               IQDAT3=0,IQDAT4=0)
                COMMON SARCON1,PI,TPI,PIH,RTD,DTR,CL
                COMMON KPLAT,PRE,PE,PGC,PRR,PTM
 5              COMMON KORB,OSMA,OE,OINC,OLON,OPERI,OTP,ORB,TINIT,XEC
                COMMON KRADR,WL,TBW,SNR,LPC,LPI,KPC,KPCS,RESR,RESA,SPR,SHA,
               .KREFNR,KWTFTNA,SHADFAC,PCOFFR,PCOFFA,SW,NA,STLAT
                COMMON KANT,SNAC,SQUINT,ABW,ERW,PHCPH(3),ABRPY(3),PDRPY(3)
                COMMON KSNC,NDISC,NFLDS,NSCATS,EMEAN,DISTX,DISTY,TCR,TCLAT,
10             .TCLONG
                COMMON IO,PRF,PRFMOD,NP,NF,NRB,RMIN,SHSW,RESSH,SISR,IPHPC
                COMMON IA,ATO,AL,AT,PLATP(3),PPMAG,PLATV(3),PVMAG,SRPC,XSWPC,
               .XNAPC,GAMMA,XA7PC,XIAPC,APC,PCR,PCLAT,PCLONG,SR,SLAT,SLONG
                COMMON PHCP(3),F,HS,SARCON2
15        C
          C*************************************************************************
          C*****        PROGRAM TO FORM A BEAM (SET OF I/Q DATA) IN THE DIRECTION
          C***** OF THE SQUINT AND NADIR ANGLES SPECIFIED IN THE SARCON DATA.
          C***** THERE ARE  NANTS  SETS OF INPUT DATA.  EACH SET CONSISTING OF
20        C***** THE I/Q DATA COLLECTED FROM ONE ELEMENT IN THE ARRAY.  IN LINE
          C***** 49, NANTS IS SET EQUAL TO 4, TO RUN A SIMULATION WITH A DIFFERENT
          C***** VALUE CHANGE THE VALUE OF NANTS AND THE PROGRAM STATEMENT ACCORD-
          C***** INGLY.  ALSO THE ARRAY DIMENSIONS NEED TO BE CHANGED FOR SIMULA-
          C***** TIONS IN WHICH NRB IS GREATER THAN 255 AND/OR (NRB+1)*NANTS IS
25        C***** GREATER THAN 1024.
          C*****        EACH INPUT RECORD OF I/Q DATA IS OF LENGTH (NRB+1)*2 ; EACH
          C***** RANGE BIN CONTAINS 2 SAMPLES - I AND Q DATA, THE  2*NRB+1  TH
          C***** LOCATION CONTAINS THE DISTANCE FROM THE ANTENNA ELEMENT PHASE
          C***** CENTER TO THE PATCH CENTER (SO THERE ARE NANTS DISTANCES FOR EACH
30        C***** RECEIVED RADAR PULSE) AND IS USED FOR FOCUSING THE DATA IN ANOTHER
          C***** PROGRAM.  THE PHASE SHIFTS CALCULATED TO FORM THE BEAM ARE REFER-
          C***** ENCED TO THE FIRST ANTENNA ELEMENT (WHICH ALSO SERVED AS THE TRANS-
          C***** MITTING ANTENNA), THEREFORE THE THE FIRST ELEMENT PHASE CENTER IS
          C***** THE PHASE CENTER OF THE FORMED BEAM AND THE DISTANCES FROM THE
35        C***** FIRST ANTENNA ELEMENT TO THE PATCH CENTER ARE PUT IN THE OUTPUT
          C***** RECORDS OF THE BEAM-FORMED I/Q DATA FOR USE IN THE FOCUSING
          C***** ROUTINES.  ALSO THE SARCON RECORD FROM THE FIRST ELEMENTS DATA
          C***** IS PLACED WITH THE BEAM-FORMED DATA.
          C*****        THE ANGLE OF THE ARRAY BROADSIDE WITH RESPECT TO THE VELOCITY
```

```
PROGRAM MBEAM       73/171   OPT=2                        FTN 4.8+528        82/09/07. 16.17.0

C***** VECTOR (PHI0) AND THE INTER ELEMENT SPACING MUST BE ENTERED INTO
C***** THE PROGRAM INTERACTIVLY
C***************************************************************************
C
      INTEGER LUNI(4)
      REAL XIQ(2048),XIQBEAM(512)
      COMPLEX CMPLXJ,PSHIFT(4),EN(1024),EI(256)
      EQUIVALENCE (XIQ(1),EN(1)),(XIQBEAM(1),EI(1))
C
      NANTS=4
      LUNI(1)=6LIQDAT1         $      LUNI(2)=6LIQDAT2
      LUNI(3)=6LIQDAT3         $      LUNI(4)=6LIQDAT4
      LUNO=6LIQDATA
      CMPLXJ=CMPLX(0.,1.)
C
C***** READ THE SARCON RECORD OFF IQDAT1 AND SKIP THE ONES ON THE
C***** OTHER DATA SETS.  THEN WRITE THE SARCON DATA UNTO
C***** OUTPUT FILE. IQDATA.
C
      LUNIS=LUNI(1)
      BUFFER IN (LUNIS,1) (SARCON1,SARCON2)
      IF (UNIT(LUNIS)) 30,20,10
   10 STOP ≠P.E. ON LUNI1≠
   20 STOP ≠EOF ON SARCON INPUT≠
   30 CONTINUE
      DO 31 JL=2,NANTS
      LUNIS=LUNI(JL)
      CALL SKIPER(LUNIS,0,1,9LBINBUFFER)
   31 CONTINUE
      BUFFER OUT (LUNO,1) (SARCON1,SARCON2)
      IF (UNIT(LUNO)) 37,33,33
   33 PRINT *,≠P.E. ON LUNO - SARCON RECORD≠
      STOP ≠P.E. ON LUNO - SARCON RECORD≠
   37 CONTINUE
C
      PRINT *,≠ENTER ANTENNA ELEMENT SPACING (M), PHI-0 (DEG) ≠,
      READ *,DH,PHI0
      PHI0=PHI0*DTR
C
```

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```
C***** CALCULATE THE PHASE SHIFT TO BE APPLIED TO EACH ELEMENT TO
C***** STEER THE BEAM IN THE DIRECTION SPECIFIED BY THE SARCON
C***** DATA - SQUINT, SNAC.
C
      ALPHA=TPI*DH*SIN(SNAC)*SIN(SQUINT-PHI0)/WL
      DO 35 JL=1,NANTS
      PSHIFT(JL)=CEXP(-CMPLXJ*(JL-1)*ALPHA)
   35 CONTINUE
C
C
C***** READ, PERFORM BEAM FORMATION AND OUTPUT THE IQDATA FOR
C***** THE FORMED BEAM.
C
      IQWDS=(NRB+1)*2
C
      DO 110 IP=1,NP
      CALL SET(XIQBEAM(1),XIQBEAM(IQWDS),0.)
      DO 60 JL=1,NANTS
      LUNIS=LUNI(JL)
      IND1=(JL-1)*IQWDS+1
      IND2=(IND1-1)+IQWDS
      BUFFER IN (LUNIS,1) (XIQ(1),XIQ(512))
      IF (UNIT(LUNIS)) 60,50,40
   40 STOP ≠P.E. ON INPUT - IQDATA≠
   50 STOP ≠EOF ON INPUT - IQDATA≠
   60 CONTINUE
C
      DO 100 IRB=1,NRB
C***** CALCULATE AN I/Q VALUE BY SUMMING THE PHASE SHIFTED I/Q
C***** DATA FROM EACH OF THE ELEMENTS ACROSS THE ARRAY.
      DO 100 IO=1,NANTS
      INDEX=IRB+(IO-1)*(NRB+1)
      EI(IRB)=EI(IRB)+EN(INDEX)*PSHIFT(IO)
  100 CONTINUE
      EI(NRB+1)=EN(NRB+1)
C
      BUFFER OUT (LUNO,1) (XIQBEAM(1),XIQBEAM(IQWDS))
      IF (UNIT(LUNO)) 110,105,105
  105 PRINT *,≠P.E. ON LUNO - NP=≠,NP
```

```
PROGRAM MHEAM        73/171  OPT=2                  FTN 4.8+528        82/09/07. 16.17.05

              STOP ≠PE ON LUNO≠
          110 CONTINUE
C
C
              STOP
              END
```

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