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A SIMULATION ANALYSIS OF SPACE-BASED AND AIRBORNE MOVING PLATFORM RADARS IN LOOK-DOWN CLUTTER

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A simulation technique has been developed to provide the radar engineer with a tool for comparative examination of radar systems and target detection in the presence of look-down clutter. Using a plotting interface such as the Dedicated User Interface System (DUIS), an engineer can evaluate proposed radar designs against one another for target detection performance in a precise graphical format.

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The user is able to select an antenna function from either measured data or derived data under the existing Parametric Antenna Analysis Software (PAAS). The antenna platform may be at any designated altitude and velocity with respect to ground clutter scatterers. Entry of an exoatmospheric altitude automatically computes the proper circular satellite orbit velocity and introduces Earth rotation. Target radar echoes at specified ground locations are compared to clutter echoes in the sidelobes as well as the radar mainbeam. Analysis of output data serves as a measure of moving target minimum detectable velocity (MDV) for the total radar system.

Written for analysts with some technical doppler radar and clutter understanding this report leads the engineer through the theory and equations which develop the simulation computer program. Example cases and analyses are given to show program utility and output results.

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INTRODUCTION

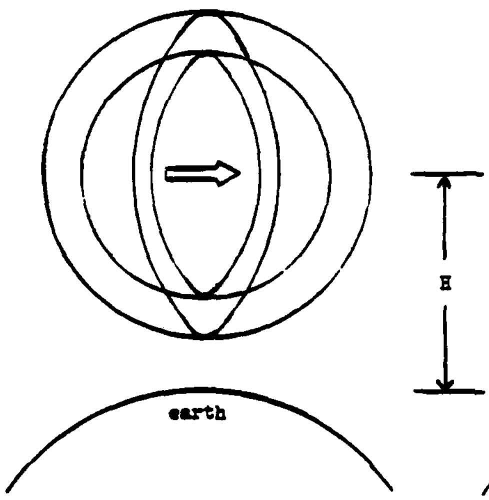
Analysis of radar detection performance in moving platforms, either in a satellite or aircraft, is a continuing area of interest. The need to detect smaller targets in look-down geometries, plus the expected difficulty of achieving deterministic low sidelobe patterns in space deployable antennas and for conformal antennas on various airframes has dictated a relook at the moving target detection design for such radar systems.

This report describes a simulation analysis computer program which examines the target detection performance of space based and airborne surveillance radars in look-down clutter. The computer model samples ground clutter with specified radar cross section and grazing angle effect and analyzes clutter signal power intensity as an effective area in range and range-rate (doppler) space. With included targets and antenna parameter data, a computed target to clutter ratio plotted for some range over all range-rates is shown as a means of measuring target minimum detectable velocity. A 3-D plot of clutter intensity as program output indicates how antenna systems may be compared with one another in terms of target detectability. The program is capable of plotting in 3-D format the clutter intensity or clutter to target ratio over all range and doppler which is visible to the antenna. The 3-D plots at a glance indicate the relative merit of given radar antenna systems.

General program parameters are developed with geometric consideration of both a non-rotating and a more complex rotating earth model. Current program limitations are discussed as well as continuing and future improvement efforts. Although this program is applicable to any set of monostatic antenna and platform parameters, a specific example is given as an illustrative example.

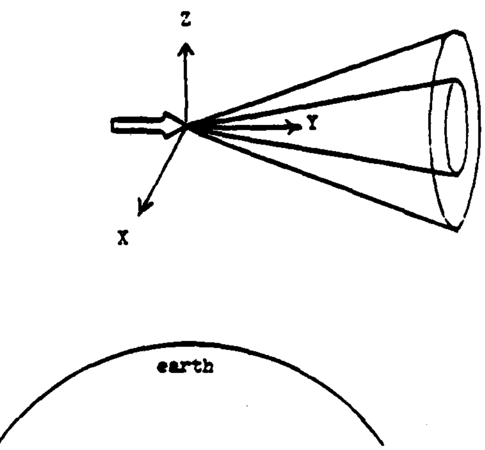
RANGE-DOPPLER CELLS

The problem of computing range-doppler sample data from a moving platform is outlined in figures 1a and 1b. A range gated doppler radar analyzes the returned signal in both time (range) and frequency (doppler). The signal is processed by first dividing it into a number of intervals in time (range gates) and then analyzed by passing it through a set of doppler frequency filters. The locus of points of equal range from a monostatic radar antenna which intersects the earth is called an isorange and is a circle centered about the platform subpoint. All such sampled ranges produce a series of concentric circles on the earth (figure 2a).



EQUAL RANGE CONTOURS
FROM AN ELEVATED PLATFORM

Figure 1a.



EQUAL DOPPLER CONTOURS
FROM AN ELEVATED MOVING PLATFORM

Figure 1b.

Unfortunately, the locus of equal range-rates intersecting the earth is not as easy to characterize. Relative to a moving platform the locus of points in space of equal doppler shift is a cone whose vertex is at the antenna, and whose axis coincides with the velocity vector of the platform. Intersection with the spherical earth results in a distorted conic section called an isodop. The maximum doppler component of ground clutter is thus the platform velocity relative to the earth multiplied by the cosine of the minimum cone angle which intersects the earth (figure 1b). The zero doppler component will be at all range points which lie orthogonal to the velocity vector (neglecting rotating earth effects).

The intersection of isoranges and isodops for a radar system with contiguous range gates and doppler filters is sketched in figure 2a. To limit the processing required, the radar clutter returns may be sampled at a finite number of ranges equally spaced from the minimum to the maximum expected range. The doppler data may also be sampled by a finite number of doppler filters equally spaced between maximum and zero doppler. The minimum width of the range gates may be taken down to the range resolution limit of the radar system. Similarly, the doppler filter bandwidth minimum limit depends on the radar system characteristics. The intersection of N isoranges with M isodops and their respective resolution widths define NxM range-doppler cells (see figure 2b). It is from these cells that the simulation clutter data is sampled and computed.

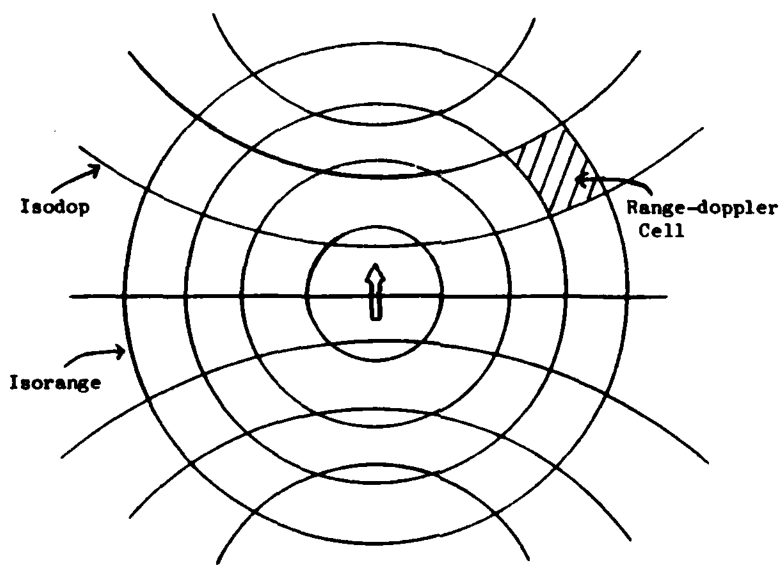


Figure 2a. Equal Range and Equal Doppler Map on Earth's Surface

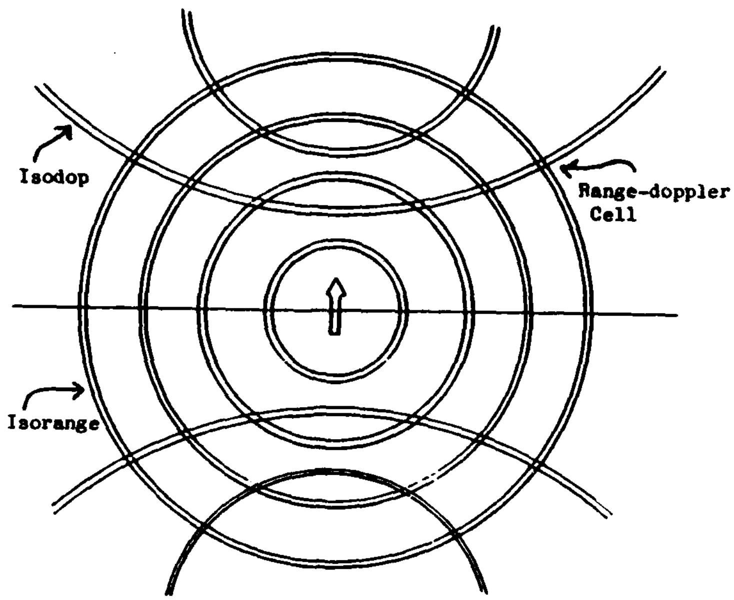


Figure 2b. Sampled Resolution Limited Map

GEOMETRIC ANALYSIS

Figure 3 shows a moving platform radar antenna at a distance H above the earth's surface in a right hand coordinate system. A geometric analysis of figure 3 yields the equations necessary to calculate the range-doppler cells and their effective clutter contribution to the radar echo.

Any point in the far field of an antenna can be represented by a pair of direction cosines T_x and T_y, where the relationship with spherical coordinate angles is:

$$T_x = \cos(A_x) = \sin(\theta)\cos(\phi)$$
$$T_y = \cos(A_y) = \sin(\theta)\sin(\phi)$$

It is convenient to place the moving antenna platform at the center of the coordinate system with the velocity vector $\bar{V}$ coinciding with the

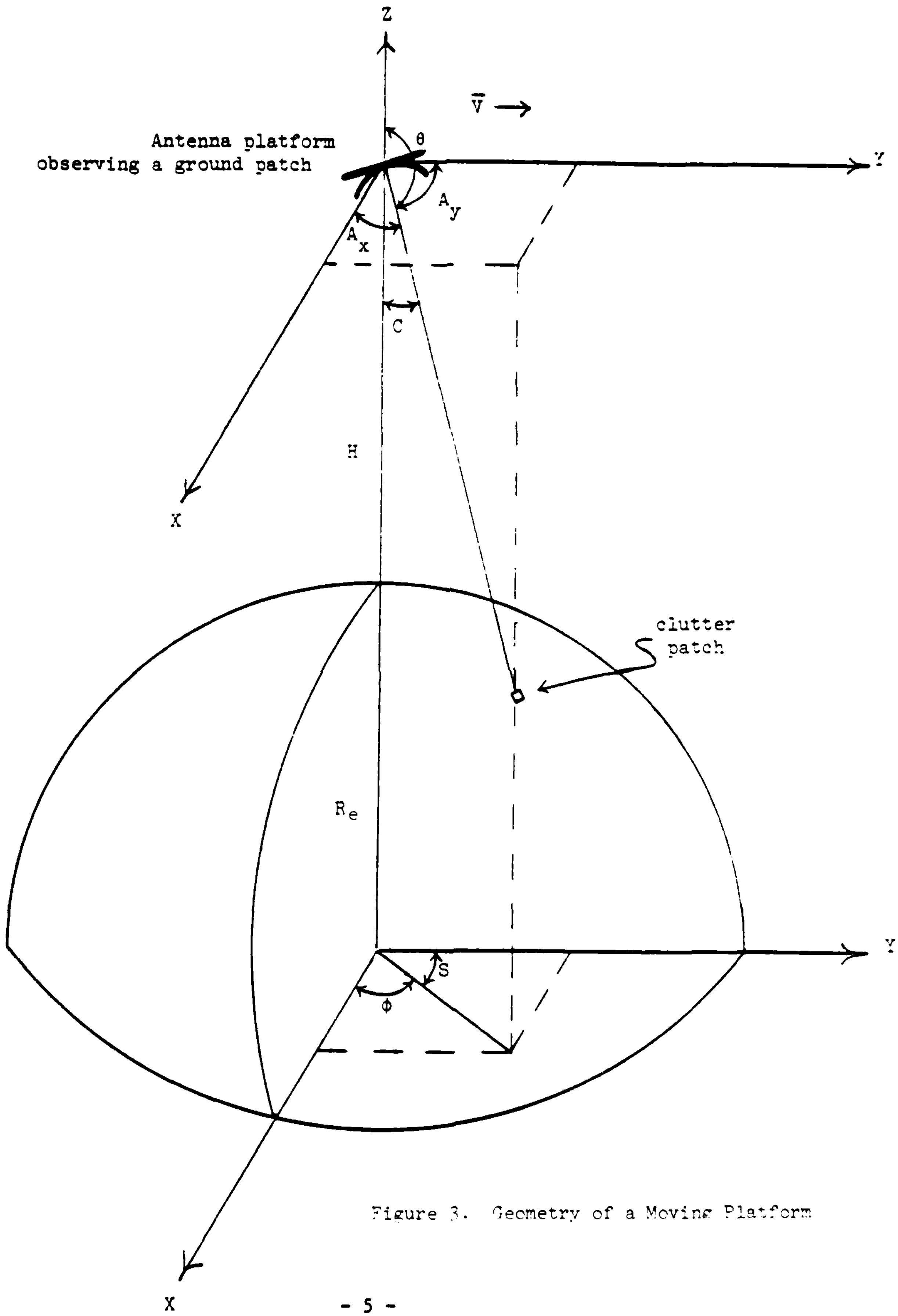


Figure 3. Geometry of a Moving Platform

Y axis and the Z axis pointing up. The reference to a point on the ground may be given in terms of a vertical elevation angle C and an azimuthal scan angle S measured from $\bar{V}$. The direction cosines are simply related by:

$$T_x = \sin(C)\sin(S)$$
$$T_y = \sin(C)\cos(S)$$

From figure 4a the elevation angle of the horizon, which is the complement of the minimum horizon cone angle A_{ymin}, and the range to the visible horizon R_{max} are:

$$\sin(C_{max}) = \cos(A_{ymin}) = Re/(Re+H)$$

$$R_{max} = ((Re+H)^2 - Re^2)^{\frac{1}{2}}$$

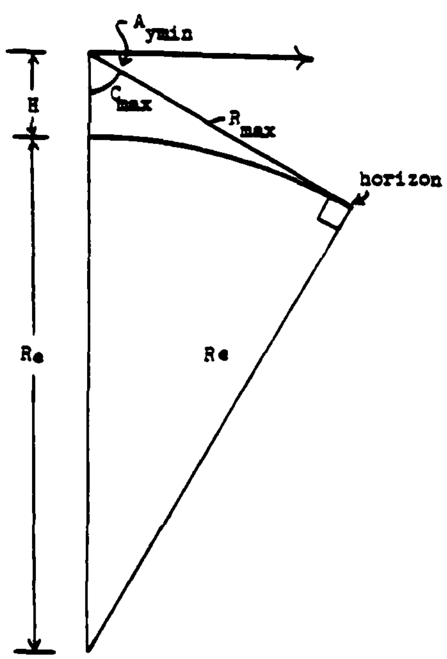


Figure 4a.
Geometry at the Horizon

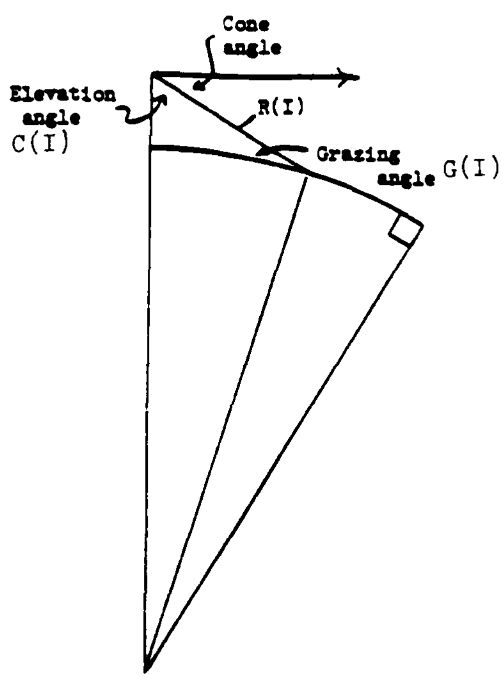


Figure 4b.
Geometry at Intermediate Ranges

Similarly, for any given range R(I) corresponding to some range bin I, figure 4b and the law of cosines results in the elevation angle C(I):

$$C(I) = \arccos\left[\frac{R^2(I) + (R_e+H)^2 - R_e^2}{2R(I)(R_e+H)}\right]$$

The grazing angle G(I) at a particular range R(I) is given by figure 4b and the law of sines:

$$G(I) = \arccos\left[\frac{R_e+H}{R_e}\sin(C(I))\right]$$

Consider now the equally spaced sampled range and doppler bins of figure 2b. The distance between the N range bins is determined by dividing the total range difference by the number of range gates less one:

$$D_r = (R_{max} - H)/(N-1)$$

The range of the I^{th} (I=1 to N) bin is calculated from:

$$R(I) = (I-1)D_r + H$$

where the nadir is at R(1)=H and the horizon is at $R(I=N)=R_{max}$.

To avoid the problems of clutter cell area on the horizon, for the purposes of the simulation the range difference is divided by N instead of N-1. This has the effect of decreasing D_r slightly and placing the last range bin R(N) a small distance back from the horizon. If the range resolution of the radar is Δr, from figure 4b the effective ground range coverage for small Δr is $\Delta r/\cos(G(I))$. Of course N must be chosen so that D_r is significantly larger than this value to prevent range overlapping in the range bins of interest.

The M equally spaced doppler bins are equivalently computed from the radial velocity components, since the two way radar doppler shift is proportional to the radial velocity seen at the antenna platform and the wavelength of the radar operating frequency:

$$F_d = 2V_r/\lambda$$

where the radial velocity component is related to the platform velocity (for a stationary earth):

$$V_r = V_p \cos(A_y)$$

Then the frequency difference between the M equally spaced doppler filters, and the cone angles which yield the M isodops are:

$$D_f = 2V_p \cos(A_{ymin})/M\lambda$$

$$A_y(J) = \arccos(JD_f \lambda/2V_p) \qquad J=1 \text{ to } M$$

If the doppler filter width is Δf, then the angles which yield the N isodops of width Δf are between $A_y(J)$ and:

$$A_{yd}(J) = \arccos((JD_f+\Delta f)\lambda/2V_p)$$

A critical factor arises at this point in the calculations. Since a cosine function has its most rapid change at large angles, most of the equally spaced doppler bins will be crowded at cone angles greater than 45 degrees away from the velocity vector. By the same reasoning, the ground coverage due to these angles is larger for smaller cone angles (i.e. close to the plane of motion near the horizon). In effect the area of the range-doppler bins of figure 2b becomes larger as the plane of motion is approached.

Now the clutter intensity in the radar echo will be a function of the area of the range-doppler cells in figure 2b. From here on a simplifying assumption must be made concerning the shape of the range-doppler cells. As long as the resolution width of the range bins and doppler bins is small compared to the distance between them, each cell can be approximated as a rectangular area. The radial component is a simple function dependent on the grazing angle and range resolution, but the lateral component requires a somewhat more complicated geometric analysis of the vectors which define the isodops and their equivalent resolution widths at each range.

CLUTTER INTENSITY DIAGRAM

Consider the case of continuous scatterers uniformly distributed on the earth's surface and a radar with infinitely fine resolution. If the radar is unambiguous in both range and doppler, the clutter scatter signal strength $C(r,\dot{r})$ will be a function of at least four components. First is the $1/R^4$ two way path loss attenuation factor from the radar range equation. Second is the radar cross section σ_0, of the ground scatterers. Several models are available which describe ground RCS as a function of terrain type and grazing angle. The third component is the two way relative antenna gain as a function of directional cosines T_x and T_y. The directional cosines correspond to those angles which yield r and $\dot{r}$ at the earth's surface. Finally, the area of the range-doppler cells must be computed which will determine the number of discrete scattering centers, providing the integrated clutter signal power.

Presuming for the moment an omnidirectional antenna with unity gain and uniformly distributed range-doppler scatterers, the clutter intensity diagram takes on the smoothly shaded appearance of figure 5a. Range R is plotted along the ordinate axis and the direction cosine angle A_y is plotted on the abscissa. Dark shading represents regions of high clutter echo intensity (integrated radar return signal power).

The distinctive "U" shape of the expected clutter return of figure 5a is strictly a function of platform altitude and earth radius. Outside this shaded area is a clutter free region where no combination of range and cone angle intersect the earth's surface and in this region a target would not compete with surface clutter. Directly beneath the antenna platform corresponds to a zero degree elevation angle and 90 degree cone angle, with range equal to platform altitude (figure 1b). Progressing outward in range one reaches the radio horizon, which is the range of the visible horizon from the elevated antenna platform. Greater ranges would correspond to range-doppler cells which do not intersect the earth. Range excursion along the central vertical of figure 5a at a constant 90 degree cone angle is a vertical scan in elevation orthogonal to the plane of motion, while travel along the "U" edge is a vertical scan in the plane of motion. A depiction of the relationship between a pencil beam antenna footprint and the clutter intensity diagram is shown in figure 5b. Notice that near the edge, close to the plane of motion, the intensity rises due to the increased area size of the range-doppler cells. Since the cell area is larger, effectively more point scatterers are covered per cell resulting in a greater power intensity.

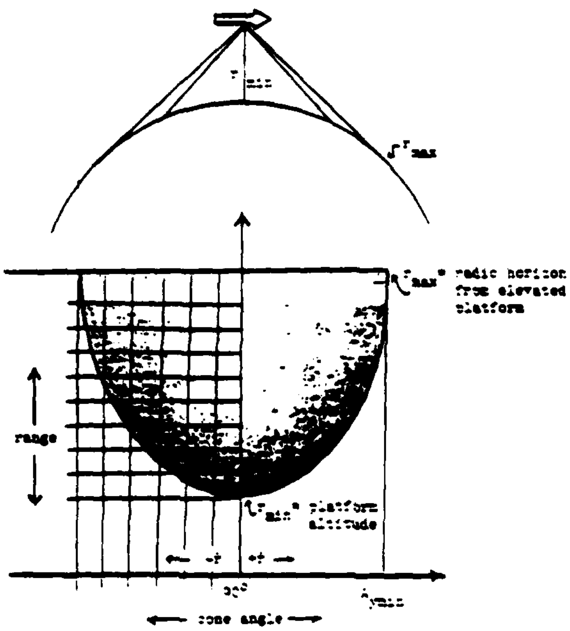


Figure 5a.

Clutter Intensity Diagram $C(r,\dot{r})$

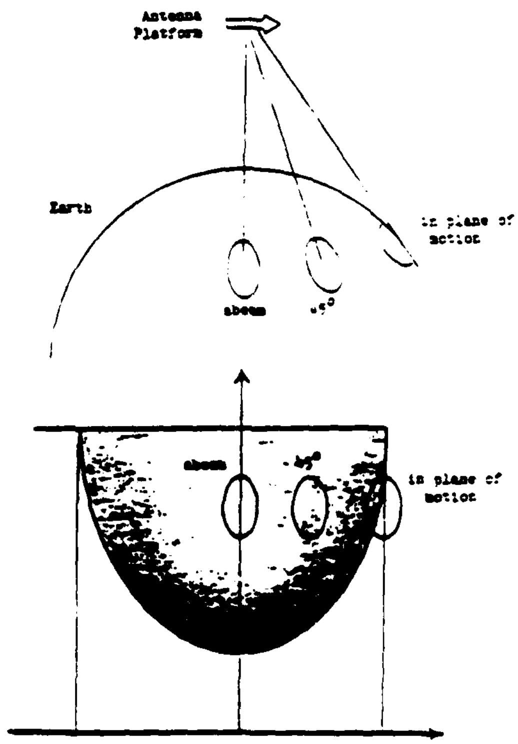


Figure 5b.

Relationship Between a Pencil Beam Antenna Footprint and the Clutter Intensity Diagram

Now consider a somewhat more realistic antenna with finite range resolution Δr and finite doppler resolution $\Delta \dot{r}$ corresponding to discrete noncontiguous range-doppler cell scatterers. The clutter scatter function for each cell is depicted in figure 6. This discrete characterization of the distributed returns $C(\Delta r, \Delta \dot{r})$ for the I^{th} specific range bin and the J^{th} specific doppler bin is used in the computer program simulation. The clutter scatter function of each cell is an integral over the range and doppler cell widths.

$$C_{i,j}(\Delta r, \Delta \dot{r}) = \int_{r_i - \Delta r/2}^{r_i + \Delta r/2} \int_{\dot{r}_j - \Delta \dot{r}/2}^{\dot{r}_j + \Delta \dot{r}/2} C(r_i, \dot{r}_j)\, dr_i\, d\dot{r}_j$$

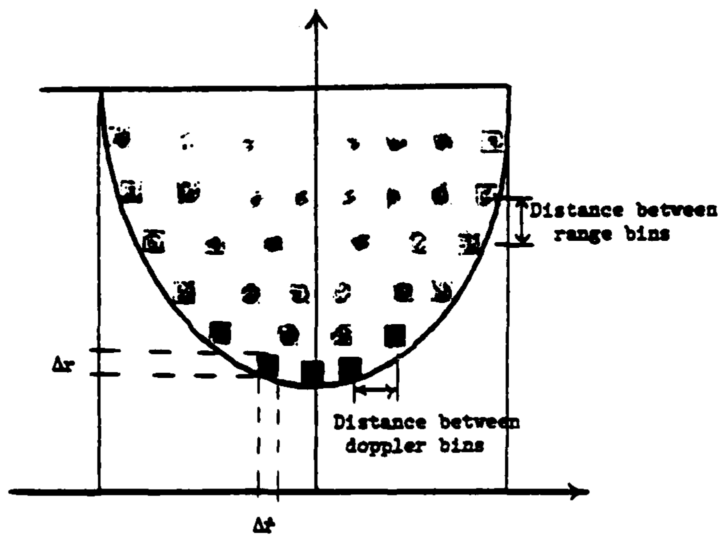


Figure 6.
Clutter Intensity Diagram
Discrete Scatterer Case $C(\Delta r, \Delta \dot{r})$

For an unambiguous range gated pulse doppler radar with a known far field antenna pattern weighting (including sidelobes) as a function of directional cosines, one only needs to multiply the discrete clutter by the weighting function $ANT(T_x, T_y)$ to obtain the clutter intensity function of the antenna.

DIRECTING THE ANTENNA

The question of directing the antenna main beam toward some specified point on the earth's surface must be addressed. In a phased array this is accomplished by electronic beam steering, which simply redefines the weighting function $ANT(T_x, T_y)$. Alternatively, the antenna platform may be mechanically steered in roll, pitch, and yaw as defined in the right hand coordinate system of figure 7.

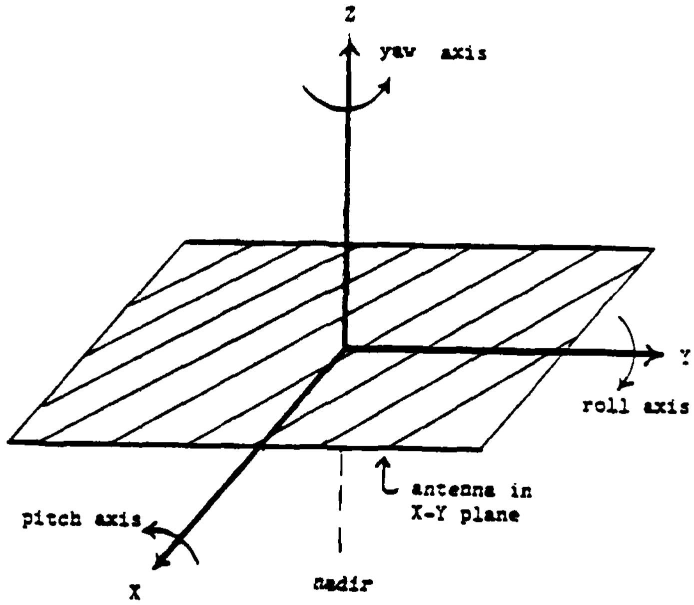


Figure 7.
Coordinate Transformation Axes

Mechanical steering is accomplished by applying the Jacobian matrix:

$$\begin{bmatrix} T'_x \\ T'_y \end{bmatrix} = \begin{bmatrix} \cos(pit)\cos(yaw) & -\cos(pit)\sin(yaw) \\ \sin(rol)\sin(pit)\cos(yaw) + \cos(rol)\sin(yaw) & -\sin(rol)\sin(pit)\sin(yaw) + \cos(rol)\cos(yaw) \end{bmatrix} \begin{bmatrix} T_x \\ T_y \end{bmatrix}$$

(From Mathematical Handbook for Scientists and Engineers, Korn and Korn, 2nd ed., McGraw Hill, 1968) where the primed coordinates are in the steered frame of reference. These new directional cosines are input to the modified weighting function ANT(T_x',T_y'). The antenna has been effectively steered toward the specified patch of earth.

ROTATING EARTH MODEL

Up to this point the effects of the rotating earth have been neglected. This assumption is valid for airborne antenna platforms which are in a rotating earth frame of reference, but the motion of space based radar platforms is independent of earth rotation and the earth will provide a component of doppler velocity. Consider a platform stationary in space with the earth rotating beneath as sketched in figure 8.

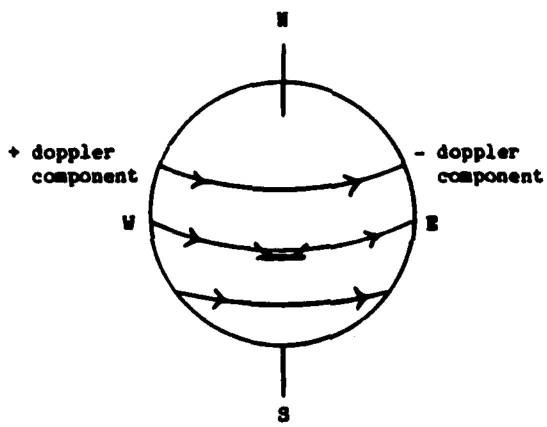


Figure 8.
Rotating Earth Doppler Components

Clearly for an orbiting platform, the earth's doppler velocity component will be negative when looking in the eastern hemisphere, positive in the western hemisphere, and zero along the central meridian. Of course, to the earth component radial velocity must be added the radial component due to the orbital velocity of the satellite. Note that the line of zero total doppler velocity will no longer be precisely orthogonal to the velocity vector (except in an equatorial orbit). In general for a moving platform in circular orbit, the radial doppler velocity component depends on altitude, orbit inclination, and the grazing angle of the ground clutter patch. In the simulation of a range-doppler cell radar system the total radial velocity component from each of the individual cells is given by:

$$V_r(I,J) = V_p\cos(A_y) - V_e\cos(G)\cos(lat)\cos(scan)$$

$$scan = \arccos(\cos(A_y)/\sin(C)) - \arccos(\cos(inc)/\cos(lat))$$

where A_y is a function of I and J; G and C are functions of I; "inc" is orbital inclination; "lat" is instantaneous satellite sub-latitude; and V_e is the equatorial rotational velocity of the earth. The term "scan" is essentially the azimuthal scan angle measured from the satellite's instantaneous velocity vector.

The maximum total doppler velocity component will be at the horizon in the plane of motion. (Actually, depending on the position of the velocity vector, the rotating earth may change this maximum component direction, but for circular orbits up to geosynchronous altitudes the effect is small.)

$$V_{rmax} = V_p\cos(A_{ymin}) - V_e\cos(inc)$$

The velocity differential between each of the M equally spaced doppler bins is thus:

$$V_{diff} = V_{rmax}/M$$

and the doppler velocity of the J^{th} doppler bin is:

$$JV_{rmax}/M = V_r(I,J)$$

Solving for the cone angles $A_y(I,J)$ which yield the desired equally spaced doppler bins results in a considerably more complex function than for the nonrotating earth model because of the combined I,J dependence.

$$\cos(A_y(I,J)) = \frac{DV1 \cdot DV2 \pm DV3 \cdot SQV \cdot \sin(C(I))}{DV2^2 + DV3^2}$$

where:

$$DV1 = (V_p \cos(A_{ymin}) - V_e \cos(inc))J/M$$

$$DV2 = V_p - V_e \cos(inc)/\cos(A_{ymin})$$

$$DV3 = (\cos^2(lat) - \cos^2(inc))^{\frac{1}{2}} V_e/\cos(A_{ymin})$$

$$SQV = \left[DV2^2 + DV3^2 - DV1^2/\sin^2(C(I))\right]^{\frac{1}{2}}$$

If the doppler filter bandwidth is Δf, then the angles which yield the N isodops of width Δf are between $A_y(I,J)$ and:

$$A_{yd}(I,J) = A_y(I,J)\Big|_{DV1=DV1 + \Delta f\lambda/2}$$

Care must be exercised when applying these equations to take into account the direction of orbit and whether the antenna is pointed toward the northern or southern hemisphere. For the nonrotating earth case (V_e=0), or for the satellite subpoint over a pole (inc=90, lat=90) the equations reduce to the simpler form previously derived.

THE CLUTTER SIMULATION PROGRAM

The program CLUTR is designed for either a space based radar antenna in circular orbit or for an airborne platform in level flight. The antenna far field weighting input data resides in a file which either has been previously generated from PAAS (Parametric Antenna Analysis Software) or from an actual antenna data tape.

The inputs for a circular orbiting space based moving platform radar are:

(1) The altitude above the earth's surface.
(2) The range and doppler bin resolution size.
(3) The radar operating frequency.
(4) The orbit inclination and platform sub-latitude.
(5) The direction of orbit, east or west.
(6) The main beam pointing quadrant, north or south.

(7) The antenna roll, pitch, and yaw pointing angles.

(8) The target radar cross section.

(9) The far field antenna weighting values $ANT(T_x,T_y)$.

Inputs for an airborne platform are the same except items (4), (5), and (6) are omitted and an input ground speed is required. Figure 9 is a block diagram of the basic components of the program.

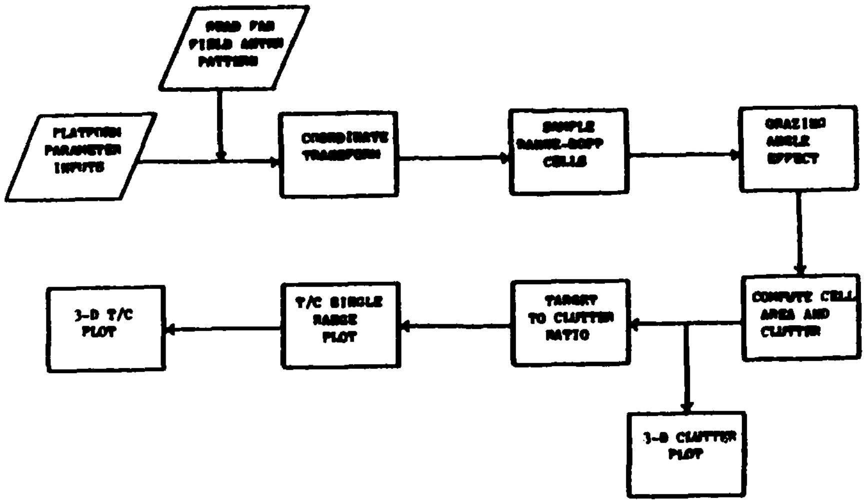


Figure 9.

Program CLUTR Block Diagram

The data from two auxiliary programs are required for inputs to the main program CLUTR. This is to insure that the radar main beam falls within one of the sampled range-doppler cells. Program RANGE provides a listing of range bin numbers with range R(I), elevation angle C(I), and grazing angle G(I) for each range bin I. Given a desired grazing angle, for example, the range bin number yielding the nearest grazing angle is selected. This grazing angle and corresponding elevation angle value must be entered i⌞⌞o CLUTR and will center the main beam in range I. Program SCAN provides a listing of azimuthal scan angle S(I,J) and cone angle $A_y(I,J)$ for each doppler bin J at the range I. The value S(I,J) centers the main beam in doppler bin J.

EXAMPLE CLUTTER PROGRAM RUN

The utility of the simulation is best demonstrated with an example case. Consider first an omnidirectional antenna (i.e. all T_x and T_y antenna weighting values are unity) with the antenna platform in a 4000 nautical mile high circular orbit. Samples of 128 range bins and 128 doppler bins are taken, resulting in 128 range-doppler cells. The 3-D sampled clutter intensity diagram output is shown in figure 10. Notice that figure 10 is just one half of figure 6, with the inter-cell spaces compressed. The ragged edge is an artifact of the sampling process, as no samples are taken exactly in the plane of motion, but the distinctive "U" shape is clearly evident.

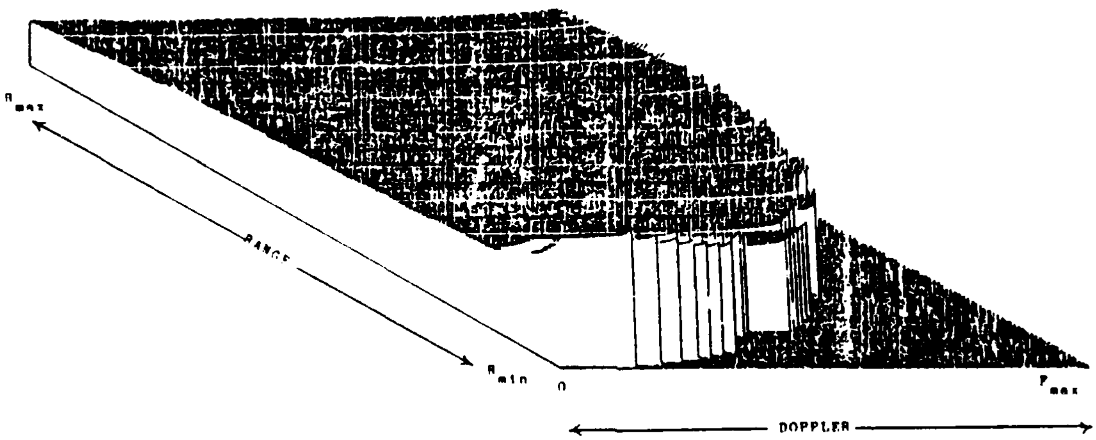


Figure 10.

3-D Omnidirectional Antenna Clutter Intensity

Next consider PAAS generated far field weighting for the following hypothetical antenna system:

Diameter - 35m circular

Weighting - 40dB Taylor

Blockage - None

Wavelength - L Band

Range Resolution - 100m

Doppler Filter Bandwidth - 50Hz

Element Grid Spacing - .5λ

The central portion of the far field antenna pattern is shown in figure 11.

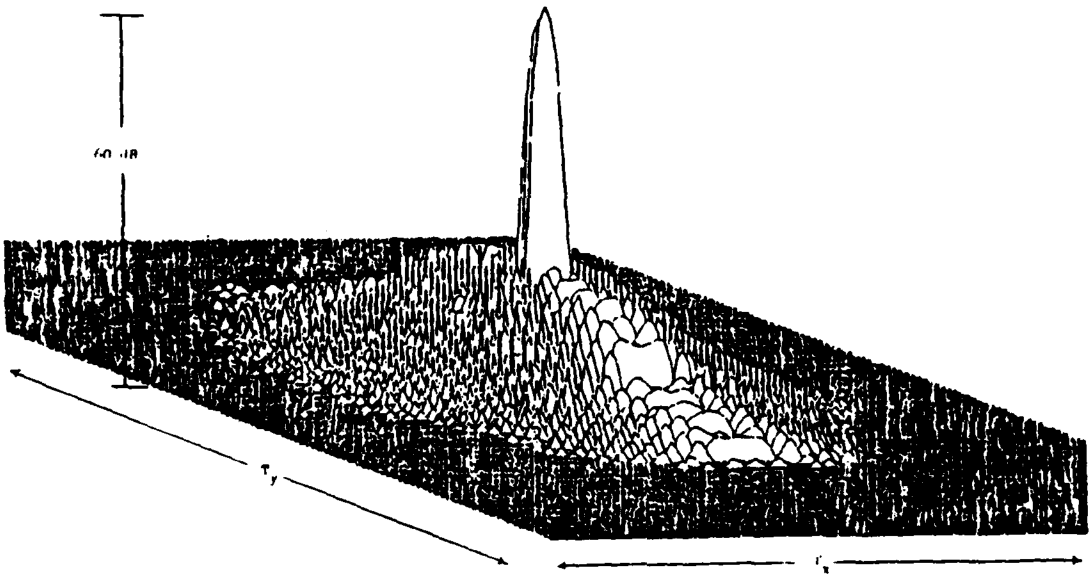


Figure 11.

40 dB Taylor Far Field Antenna Pattern

Now place the antenna aboard an orbiting platform with the following observation characteristics:

Altitude - 4000 nautical miles

Inclination - 60 degrees

Sub-latitude Point - 20 degrees

Main Beam Scan - True north (000 degrees true)

Desired Main Beam Grazing Angles - 5 degrees and 30 degrees

Target RCS - 20dBsm

From the auxiliary program output RANGE, the grazing angle closest to 30° is 30.049°, corresponding to an elevation angle of 23.59° at range bin number 55. Similarly from the same output listing, a grazing angle of 4.84° is in range bin number 115 with an elevation of 27.43°. The antenna is steered by providing the elevation angle as a roll or pitch angle.

```
FRN RANGE

INPUT THE ALTITUDE IN NM
=4000.

ALTITUDE =  0.74080000E 07    METERS
RMAX     =  0.12217659E 08    METERS
CEEMAX   =  0.27540163E 02    DEGREES

 I         RANGE(I)          CEE(I)            GRAZ(I)

110    1.1503725E 07  27.3402605E 00  66.3459975E-01
111    1.1541301E 07  27.3613958E 00  62.7339971E-01
112    1.1578876E 07  27.3812790E 00  59.1364515E-01
113    1.1616452E 07  27.3999195E 00  55.5539829E-01
114    1.1654027E 07  27.4173350E 00  51.9357126E-01
115    1.1691603E 07  27.4335396E 00  48.4312826E-01
116    1.1729178E 07  27.4485452E 00  44.8907173E-01
117    1.1766754E 07  27.4623659E 00  41.3635564E-01
118    1.1904329E 07  27.4750142E 00  37.8495097E-01
119    1.1841905E 07  27.4865022E 00  34.3486792E-01
120    1.1879480E 07  27.4968429E 00  30.8604759E-01
```

Sample Output Program RANGE

5° Grazing Angle Case

At this point in the orbit, the velocity vector heading relative to true north is:

$$HDG = \arcsin(\cos(inc)/\cos(lat))$$

$$= 32.15 \text{ degrees}$$

Thus to scan to a true heading of 000 degrees a steering yaw of 32.15° is required. From the auxiliary program output SCAN, the nearest scan angle for the 55th range bin is 32.718° in the 103rd doppler bin; for the 115th range bin it is 32.232° in the 119th doppler bin.

```
 FRN SCAN

INPUT THE ALTITUDE IN NM
=4000.

ALTITUDE  =  0.40000000E 04  NM
ORBITAL VELOCITY  =  0.53814546E 04  M/S
ORBITAL VELOCITY  =  0.10460711E 05 KNOTS

INPUT SATELLITE INCLINATION ANGLE
AND INSTANTANEOUS LATITUDE
=60.,20.
IF FLYING EAST ENTER E
IF FLYING WEST ENTER W
=E
IF LOOKING IN NORTH QUADRANT ENTER N
IF LOOKING IN SOUTH QUADRANT ENTER S
=N
ENTER THE RANGE BIN NUMBER
TO SEE ALL DOPPLER COMPONENTS AT THAT RANGE
=115

VECTOR HEADING  =  0.32146700E 02   DEGREES

  J        ALPHA(I,J)        SCAN(I,J)        VDOP  KTS

114    58.5241127E 00   37.3780093E 00   3.9066537E 03
115    58.2395792E 00   36.4217615E 00   3.9409225E 03
116    57.9515810E 00   35.4333115E 00   3.9751914E 03
117    57.6597738E 00   34.4088478E 00   4.0094603E 03
118    57.3637439E 00   33.3437486E 00   4.0437292E 03
119    57.0629845E 00   32.2323437E 00   4.0779980E 03
120    56.7569665E 00   31.0675187E 00   4.1122670E 03
121    56.4445915E 00   29.8401928E 00   4.1465358E 03
122    56.1251125E 00   28.5383661E 00   4.1808047E 03
123    55.7970142E 00   27.1457679E 00   4.2150737E 03
124    55.4582968E 00   25.6392056F 00   4.2493425E 03
```

Sample Output Program SCAN

5° Grazing Angle Case

Figure 12 is a 3-D plot of the antenna pattern weighted clutter intensity diagram for the 5° grazing angle case. The main beam clutter region is clearly defined (centered at range bin number 115 and doppler bin number 119), although it is smeared in range near the horizon. At low grazing angles such as this, even if the main beam has relatively narrow angular beamwidth, it will cover many range clutter cells due to the curvature of the earth. Again the "U" shape similar to figures 5a and 10 is apparent, with most of the clutter along the doppler edge. Even though the main beam is pointed well out in range and the sidelobes are very low, there is some close in clutter do to (1) the $1/R^4$ factor

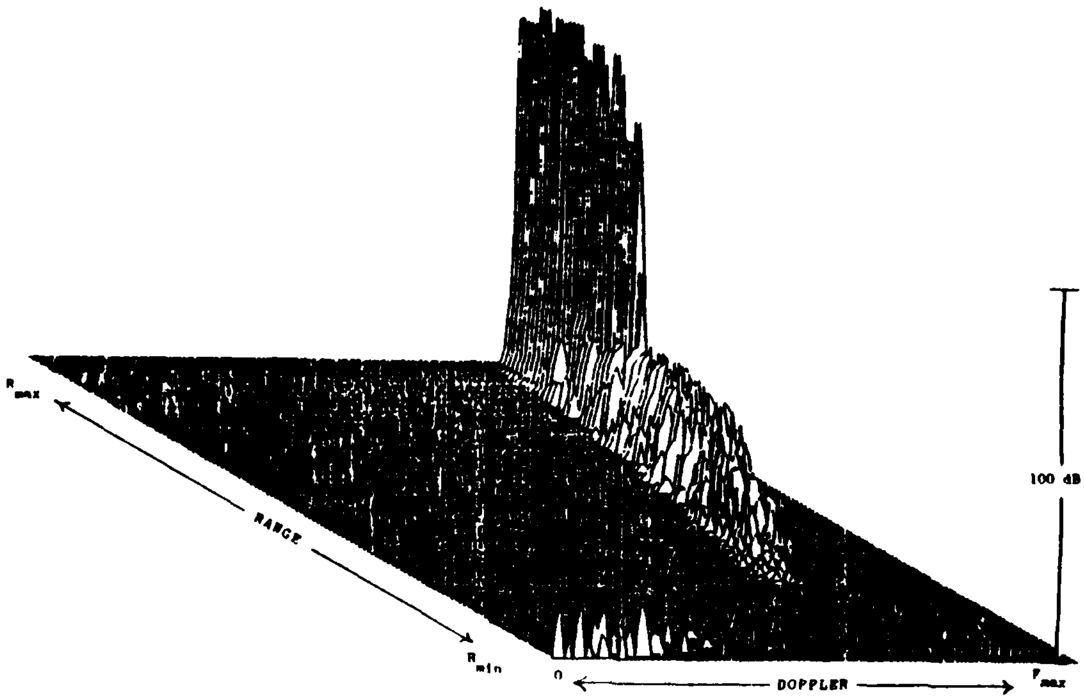


Figure 12.

3-D Clutter Intensity Plot
5° Grazing Angle

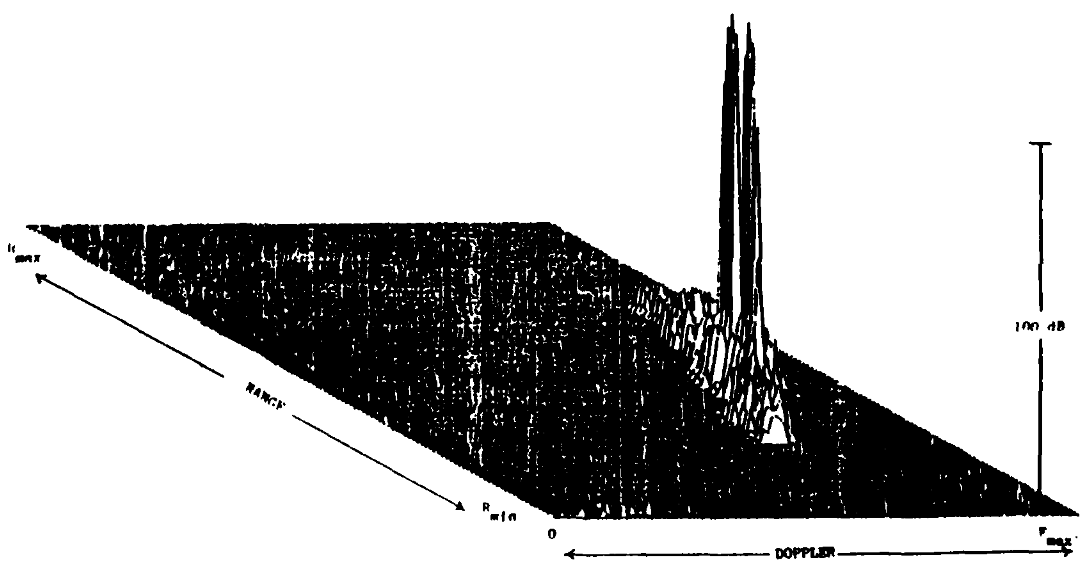


Figure 13.

3-D Clutter Intensity Plot
30° Grazing Angle

which has much less effect for small R, and (2) the grazing angle effect which increases the ground patch clutter RCS for near ranges.

A similar plot in figure 13 is for the 30° grazing angle case. Here the beamwidth on the ground is relatively narrow and the sidelobes still contribute to the near range clutter, although performance is better because there is not such a large difference between the range of the main beam clutter and the nadir.

ANTENNA WITH BLOCKAGE

Consider the same PAAS generated antenna pattern, only this time with a 5% central blockage. The far field pattern is shown in figure 14. Notice that the blockage has significantly degraded the sidelobe structure so that this antenna would be expected to have degraded off axis clutter suppression.

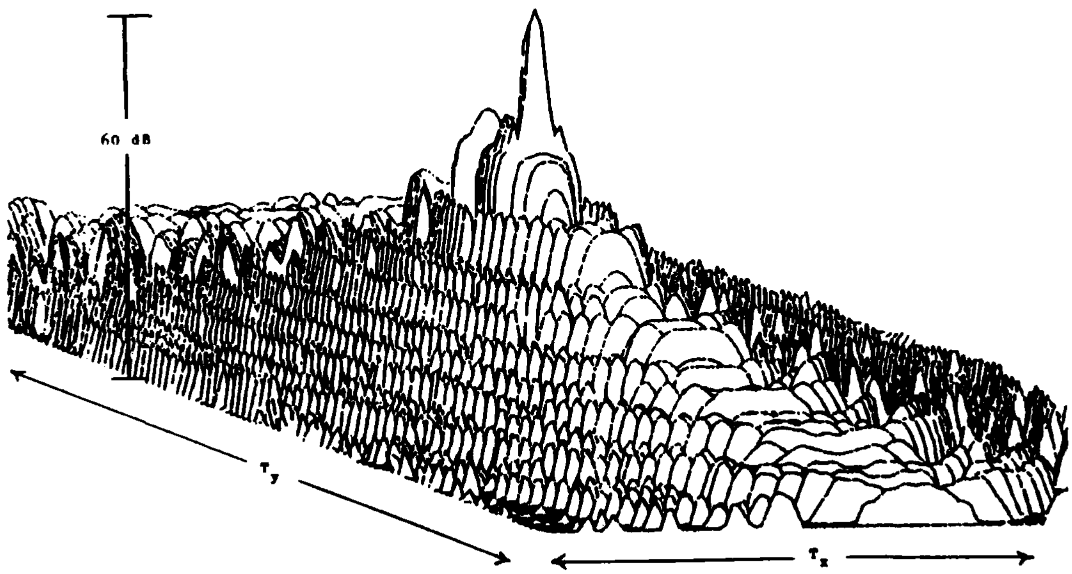


Figure 14.
40 dB Taylor Far Field Antenna Pattern
With 5% Central Blockage

Figure 15 is a 3-D plot of the clutter intensity diagram for the 5° grazing angle case with the blockage antenna. The general form is, as expected, the same as figure 12 but a considerable amount of sidelobe clutter has been introduced. Figure 16 is similarly a degraded version of figure 13.

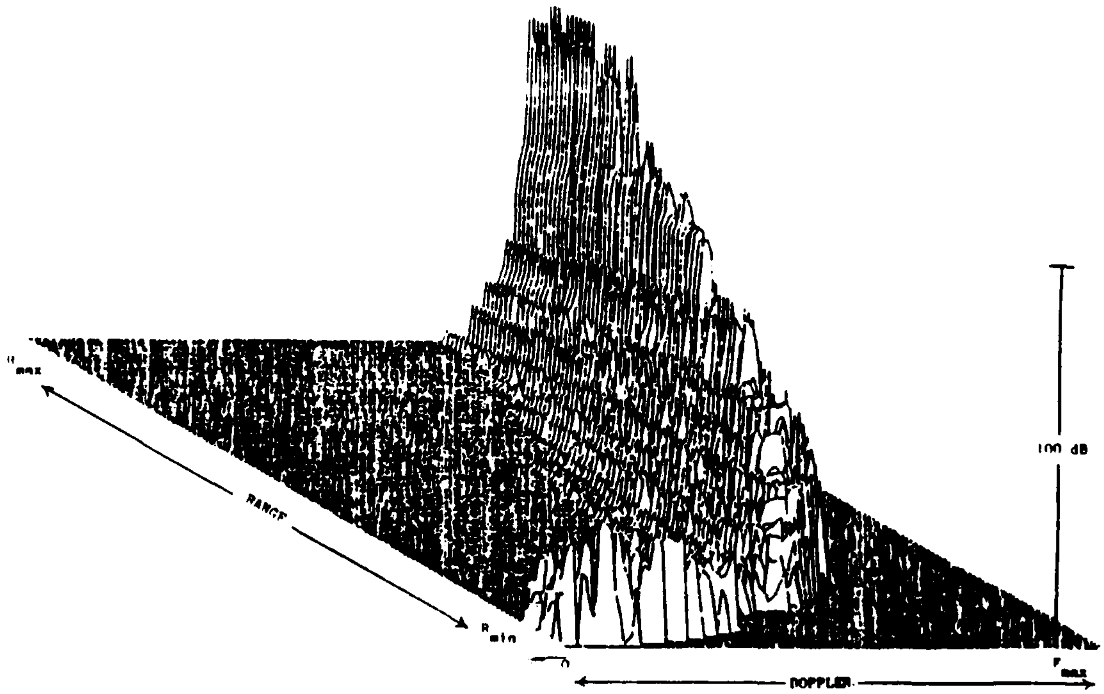


Figure 15.

3-D Clutter Intensity Plot With Blockage
5° Grazing Angle

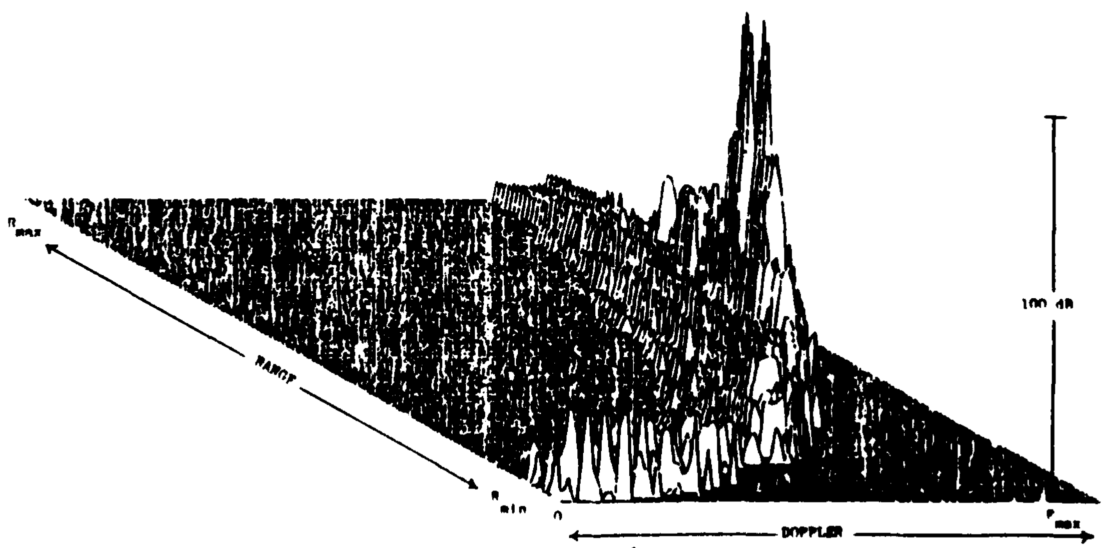


Figure 16.

30° Grazing Angle

MINIMUM DETECTABLE VELOCITY

The target to clutter ratio output of CLUTR for the 55th range bin over all doppler bins is plotted in figure 17a and expanded in figure 17b. Output for the 115th range bin is plotted in figures 18a and 18b.

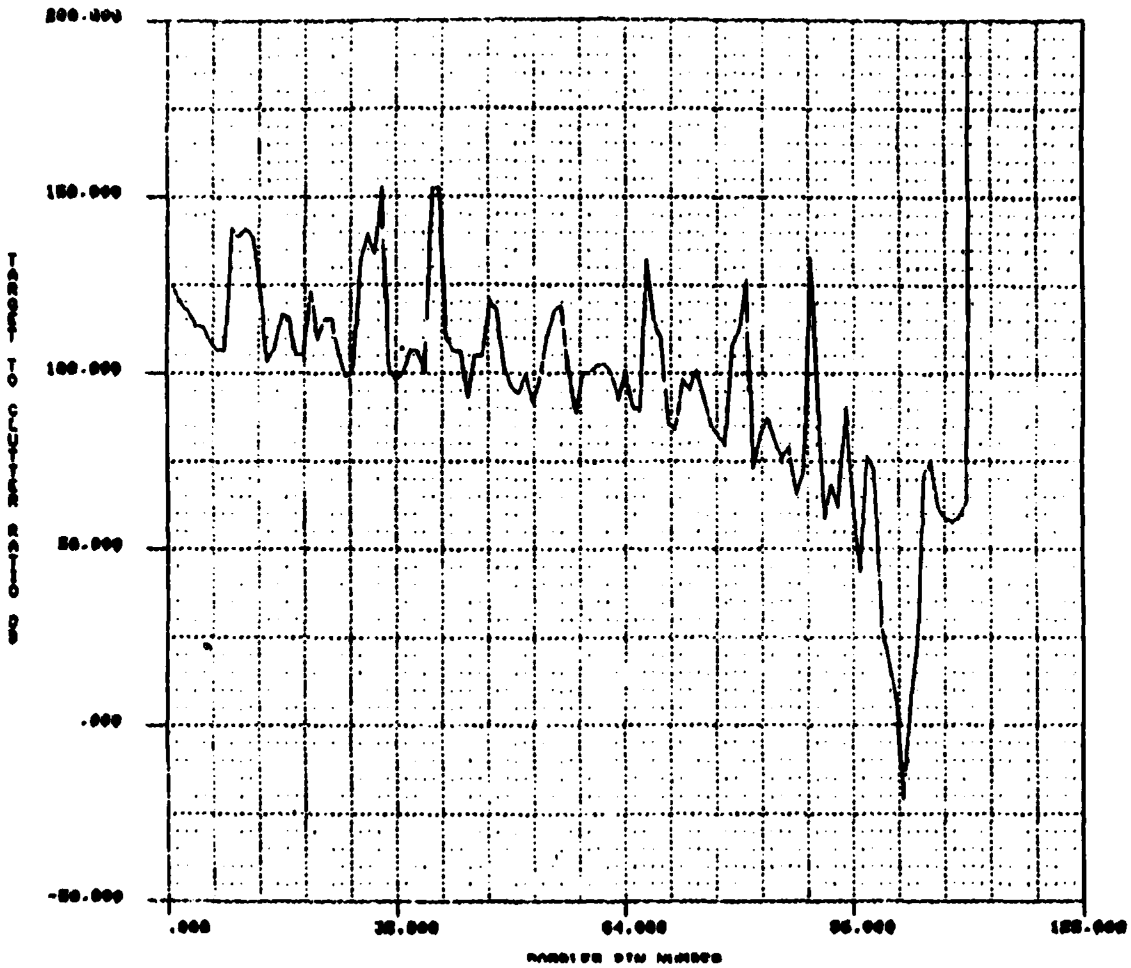


Figure 17a.

Target to Clutter Ratio Versus Doppler Bin
30° Grazing Angle
Range Bin 55

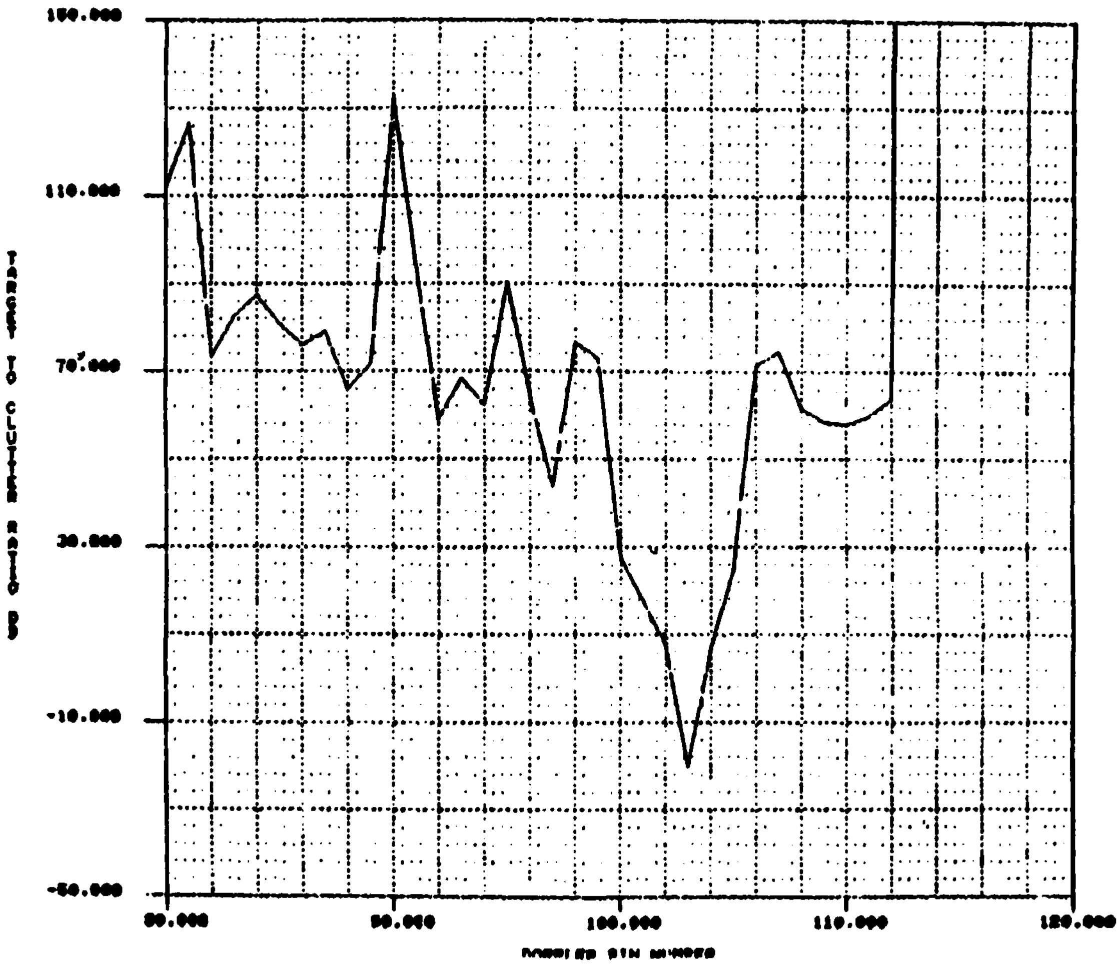


Figure 17b.

Target to Clutter Ratio Versus Doppler Bin
30° Grazing Angle
Range Bin 55

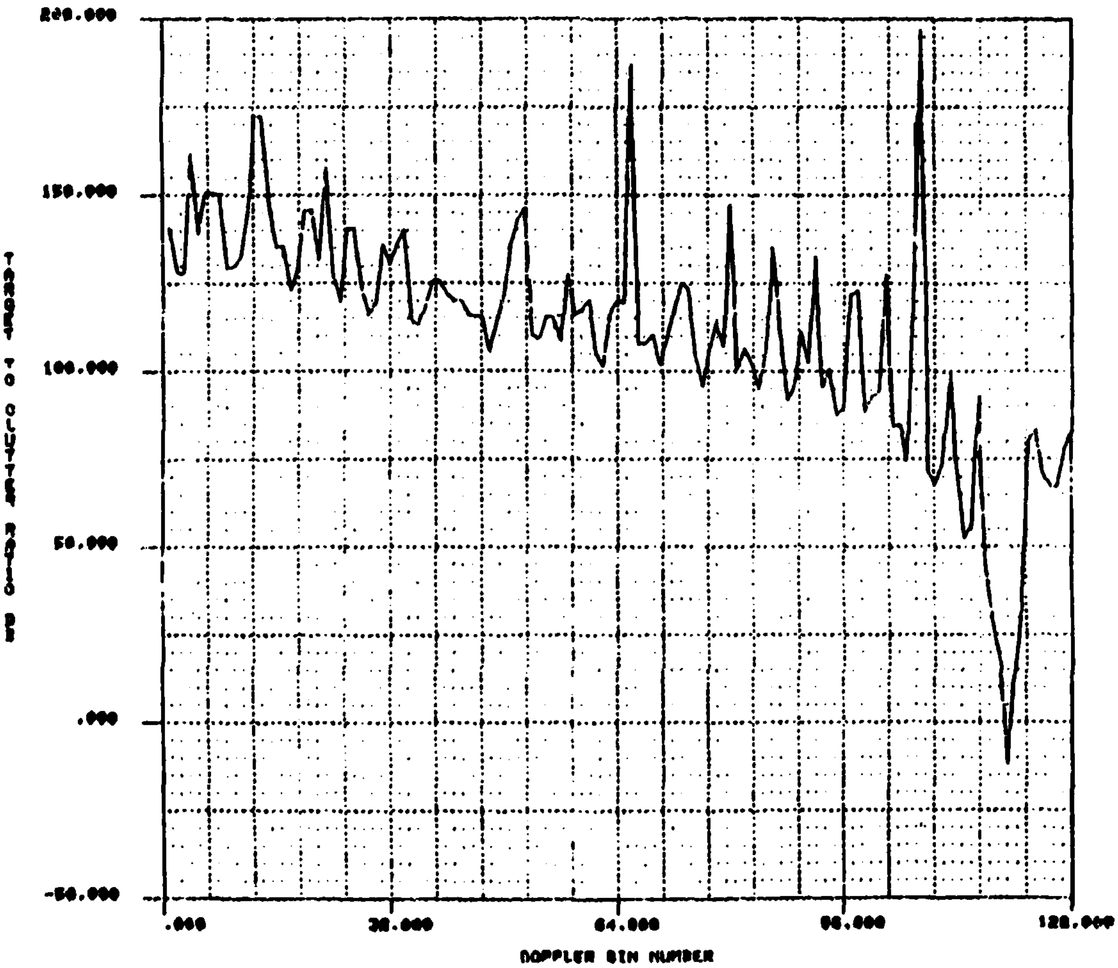


Figure 18a.

Target to Clutter Ratio Versus Doppler Bin
5° Grazing Angle
Range Bin 115

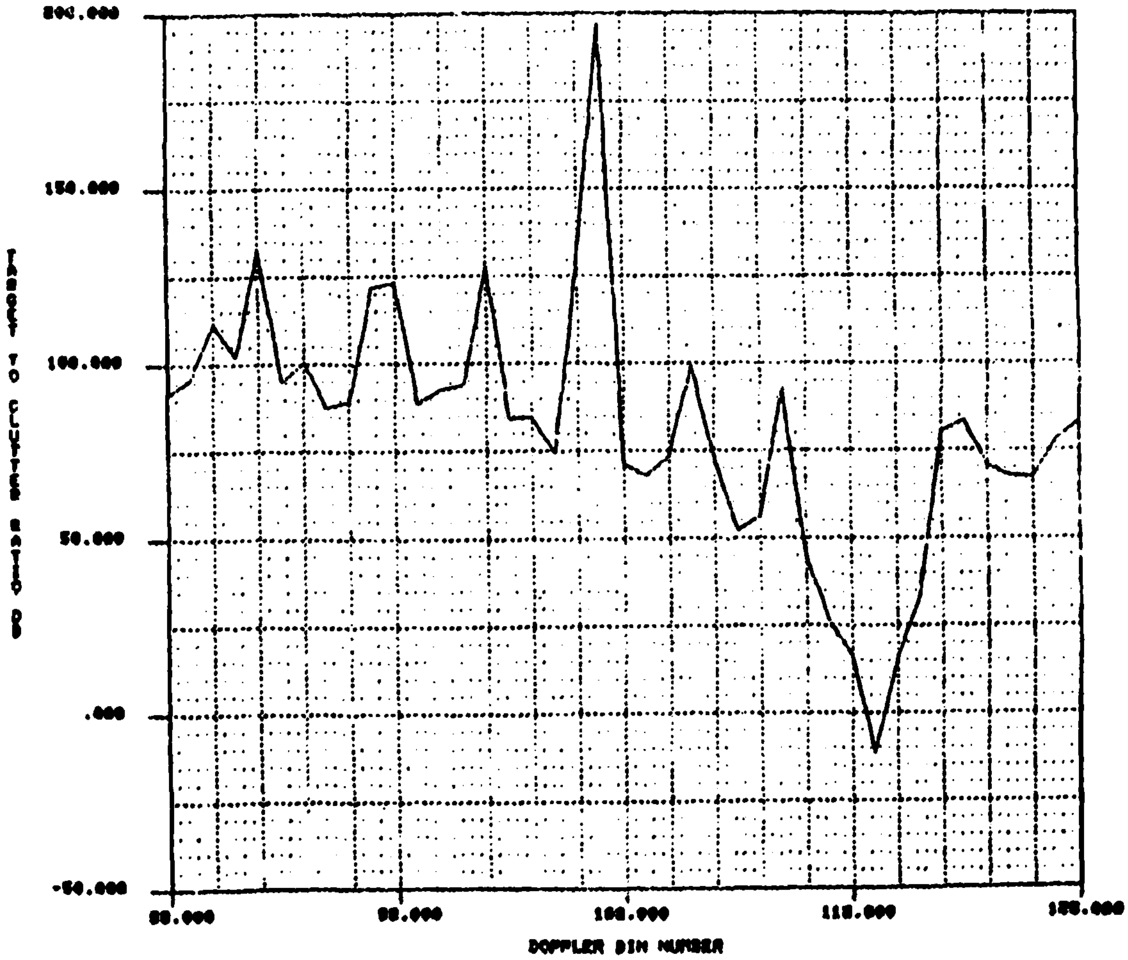


Figure 18b.

Target to Clutter Ratio Versus Doppler Bin
5° Grazing Angle
Range Bin 115

Notice that the minimum plot value falls in the 103rd doppler bin for the 55th range bin of figure 17b. This doppler bin corresponds to the radar return of a target which is stationary with respect to the earth. The rise to an infinite target to clutter ratio at doppler bin 112 corresponds to cone angle (target doppler) and elevation angle combinations which do not intersect the earth and hence the target does not compete with any clutter (clutter free region). Similarly, in figure 18b the stationary target minimum value falls in doppler bin 119.

The fixed clutter echoes with which the desired target signal must compete are those included within the same radar resolution cell as the target, or those which enter the receiver via the antenna sidelobes. To interpret the above plots in terms of minimum detectable velocity, note that the minimum value of the target to clutter ratio corresponds to a stationary target (relative to the earth) located in the same range-doppler cell as the clutter patch that the main beam is pointed to. This cell location is set to zero relative velocity between ground and target. Thus, in order to detect a stationary target a hypothetical receiver would require a detectability of better than -20dB at a 30° grazing angle and better than -12dB at a 5° grazing angle. However as the target's radial velocity increases, detectability performance increases markedly. Each doppler bin number is equivalent to a radial velocity difference of 34.3 knots (another output of SCAN), which is constant over all range bins. At a 30° grazing angle, with a target velocity of +64.6 knots (two doppler bins) the receiver detectability requirement jumps to a more reasonable value of 25dB. Similarly at a 5° grazing angle, a target velocity of +64.6 knots increases the requirement to 32dB.

A composite of all 128 target to clutter ratio range bins produces the 3-D clutter to target ratios of figures 19 and 20. As clutter is the dominant factor and the target RCS is nonfluctuating, the 3-D clutter to target ratio plots are near copies of their respective 3-D clutter plots.

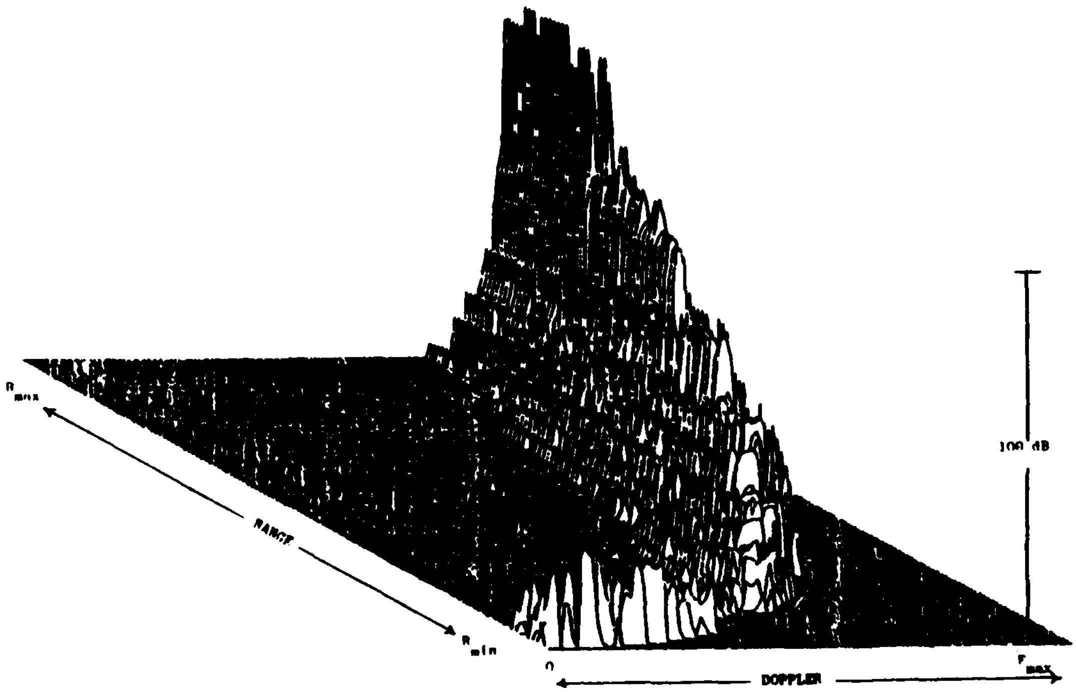


Figure 19.

3-D Clutter to Target Ratio
5° Grazing Angle

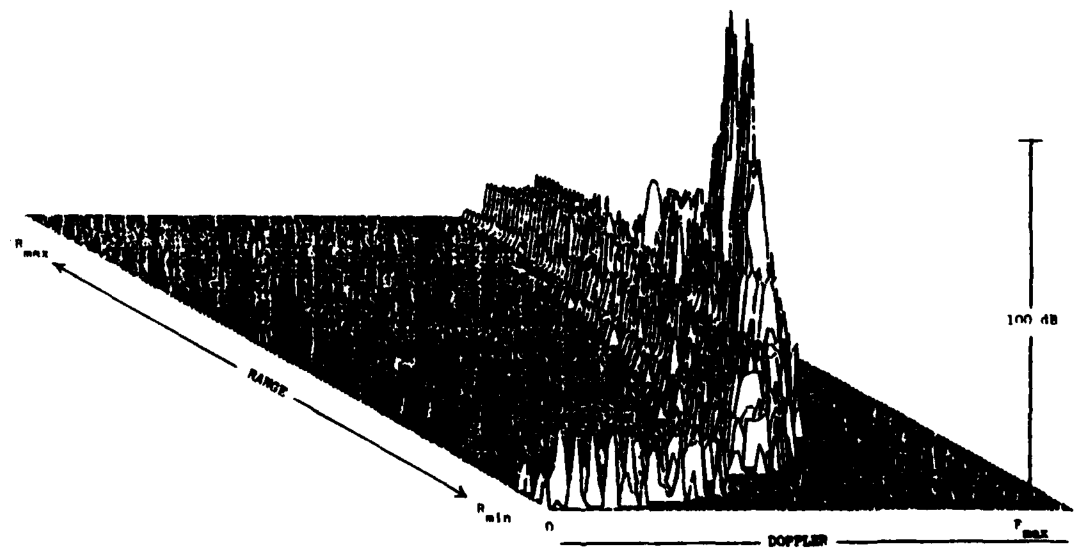


Figure 20.

3-D Clutter to Target Ratio
30° Grazing Angle

LIMITATIONS

The waveform characteristics are not included in the simulation model. There are two consequences of this limitation. First, the total energy transmitted in the radar range equation is unknown and as a result there can be no absolute level set on probability of detection of any given radar system; only the ratio of target to clutter return signal. Second, the particular shape of the waveform determines the resolution size (above that already determined by the physical antenna parameters) and the ambiguity function. The true radar return signal will be the convolution of the clutter intensity diagram and the ambiguity function.

The minimum detectable velocity is computed radial to the antenna platform, and as such the actual velocity of the target over the ground may be much larger in specific cases. This is especially true for large grazing angles where the target is illuminated from overhead. Dividing by the cosine of the grazing angle will in some sense result in a minimum ground speed in the radial plane.

The simulation presumes a "snapshot" radar image, and then only at designated sampled range-doppler cell positions. The intersection of the beam with the ground for a moving platform is a dynamic process (even more so for a moving target) which in a real system must be considered over an interval of time. Additionally, the target RCS is assumed nonfluctuating and independent of aspect angle.

The simulation program orbit is presumed circular. Many surveillance space radar applications, however, are in highly elliptical orbits. A minor program modification will handle elliptical orbits if the orbit's radial and tangential velocities are known.

To completely describe the far field antenna pattern of a radar system requires an enormous amount of computer memory space. The pattern can only be sampled at a finite number of discrete points in T space. The quality of the program results depends to a large extent on the fidelity of the far field pattern and the extent to which the sidelobe structure is detailed.

FUTURE DEVELOPMENT EFFORTS

The program CLUTR is in a continuous state of change and improvement. Current goals lead to inclusion of the radar waveform and eventual convolution with the ambiguity function. This will result in a true target to clutter ratio prediction for a given radar platform and will allow quantitative analysis of the system. The present program is only applicable to monostatic radars with no ambiguities, but the increasing importance and development of bistatic radar systems will dictate program expansion to bistatics capabilities as well. Ongoing future developments seek to expand the utility of the simulation with greater accuracy and a wider range of applications.

CONCLUSION

A major problem in designing a radar system with look-down capability is determining target detectability in the presence of ground clutter. The simulation analysis program is useful for the designer of a range gated pulse doppler to determine the clutter levels with which a target in a given cell must compete for detection. The results, while only a model and subject to certain limitations, should be most useful for comparing various candidate radar systems in the early concept stages. Considerable engineering savings in time and cost may be realized by the early elimination of inferior candidate antenna/platform system designs. The procedure described in this report should lead to more efficient radar system tradeoff analyses for the design engineer.

APPENDIX - I

Listing of Program CLUTR

*
*
*   LISTH CLUTR

04/06/83   13.60

```
C      A SIMULATION ANALYSIS OF SPACE-BASED AND AIRBORNE MOVING
C      PLATFORM RADARS IN LOOK-DOWN CLUTTER
C
C      TO RUN, ATTACH PLOTD.F FILE
C
C      VARIABLES:
C
C       RE = RADIUS OF THE EARTH
C       HGT = ALTITUDE
C       VEL = VELOCITY OF THE PLATFORM
C       VE = EARTH ROTATIONAL VELOCITY
C       XLAM = WAVELENGTH
C       RMAX = MAXIMUM RANGE
C       DELR = DISTANCE BETWEEN RANGE BINS
C       DELTAR = RANGE BIN WIDTH
C       DELF = DISTANCE BETWEEN DOPPLER BINS
C       DELTF = DOPPLER BIN WIDTH
C       ALPHA = ANGLE B/N VELOCITY VECTOR AND VECTOR TO POINT ON GROUND
C       ALPHAM = MINIMUM ANGLE ALPHA
C       ANT = ANTENNA PATTERN FACTOR
C       SF = SCALE FACTOR
C       CEE = ANGLE MEASURED FROM NADIR
C       LPJ, LRK = MAXIMUM NUMBER OF RECORD LENGTHS ACROSS TX AND TY
C       JWIDE, KWIDE = NUMBER OF DISCRETE VALUES IN TX AND TY
C       XLAT = SUBLATITUDE POINT OF SATELLITE
C       XINC = ORBITAL INCLINATION ANGLE
C       QUAD = NORTH OR SOUTH LOOKING QUADRANT
C       DIRE = EAST OR WEST ORBIT DIRECTION
C       TMAXX,TMINX = MAX AND MIN VALUES OF TX IN T PLANE
C       TMAXY,TMINY = MAX AND MIN VALUES OF TY IN T PLANE
C
C
C*********************************************************************
C    I N P U T   S E C T I O N
C
C
       DIMENSION ANT(256)
       COMMON/ANTRANS/A11,A12,A13,A21,A22,A23,A11P,A12P
       COMMON/ANTENX/ANTX(256,256),NBMAX,CTRWT
       COMMON/TRIG/SINC,COSAZ
       COMMON/TPLANE/TMAXX,TMINX,TMAXY,TMINY
       COMMON/RANGE/LPJ,JWIDE,KWIDE,RANGEX,RANGEY
       COMMON/CLUTTER/CRRDOT(128),TCRATIO(128)
       COMMON/CONE/ALPHA,ALPHAD,ICR
       COMMON/ANGLE/R(128),CEE(128),SIGMA(128),GRAZ(128)
       [illegible] DV2,DV3,VV[illegible]
       [illegible] XINC,DELTF,[illegible]
       [illegible]
       [illegible] SP,N,S
       [illegible] P,E,W
       [illegible] P,Y,N

       [illegible] /,RE/6371000./,HGT/[redacted]/,VEL/[redacted]/,
```

```
      XLAM/.21/,DELTAR/75./,DELTF/20./,SF/1.0E30/,LRJ/16/,LRK/16/,
      TMAXX/.20758/,TMINX/-.20921/,TMAXY/.20921/,TMINY/-.20758/
      DATA Y/1HY/,N/1HN/,S/1HS/,E/1HE/,W/1HW/
C
 1000 FORMAT(V)
C
C    ATTACH OUTPUT DATA FILE FOR RTI AND 3-D PLOTTING
      CALL ATTACH(27,"BHICLANCY/DATA.R;",3,0,ISTAT, )
      CALL RANSIZ(27,128)
C
C
C    SET UP ANTENNA PATTERN FORMAT
      NBMAX = LRJ*LRK
      JWIDE = LRJ*16
      KWIDE = LRK*16
      RANGEX = TMAXX-TMINX
      RANGEY = TMAXY-TMINY
C
      WRITE(06,1000)" "
      WRITE(06,1000)"INSURE THAT MAX ANTENNA VALUES"
      WRITE(06,1000)"AND LIMITS ARE SET"
C
      WRITE(06,1000)" "
      ALTI=HGT/1852.0
      WRITE(06,1000)"ALTITUDE  =",ALTI,"  NM"
C
      WRITE(06,1000)"DO YOU WISH TO CHANGE THE CIRCULAR ORBIT ALTITUDE ?"
      WRITE(06,1000)"ENTER Y OR N"
      READ(05,1000)RESP3
C
C    SET SPACE/AIR TRANSITION ALTITUDE
      HNM=91.
      IF(RESP3.EQ.N) GO TO 14
C
      WRITE(06,1000)"INPUT THE NEW ALTITUDE IN NM"
      READ(05,1000)HNM
      HGT=HNM*1852.0
      VEL=1.9976E07*SQRT(1/(HGT+RE))
C
C    FOR ALTITUDES LESS THAN 90 NM, ASSUME AIRBORNE PLATFORM
      IF(HNM.GT.90.0) GO TO 81
      WRITE(06,1000)"INPUT AIRCRAFT'S GROUND SPEED IN KNOTS"
      READ(05,1000) GS
      QUAD=0.0
      DIRE=0.0
      XLAT=0.0
      XINC=0.0
      VEL=GS*0.5144444
C
      WRITE(06,1000)"GROUND SPEED =",VEL,"  M/S"
      GO TO 14
   81 WRITE(06,1000)"ALTITUDE  =",HGT,"  METERS"
      WRITE(06,1000)"ORBITAL VELOCITY  =",VEL,"  M/S"
C
   14 CONTINUE
      WRITE(06,1000)" "
C
C    INPUT SATELLITE ORBIT DATA
C     BYPASS SATELLITE DATA IF AIRBORNE PLATFORM
      IF(HNM.LT.90.0) GO TO 89
      WRITE(06,1000)"INPUT SATELLITE INCLINATION ANGLE"
      WRITE(06,1000)"AND INSTANTANEOUS LATITUDE"
      READ(05,1000)XINC,XLAT
      XINC=XINC*PI/180.0
```

```
      XLAT=XLAT*PI/180.0
      CINC=COS(XINC)
      CLAT=COS(XLAT)
      CD=ARCOS(CINC/CLAT)
C
      WRITE(06,1000)"IF FLYING EAST ENTER E"
      WRITE(06,1000)"IF FLYING WEST ENTER W"
      READ(05,1000)RESP
      IF(RESP.EQ.W)DIRE=-1.0
      IF(RESP.EQ.E)DIRE=1.0
C
      WRITE(06,1000)"IF LOOKING IN NORTH QUADRANT ENTER N"
      WRITE(06,1000)"IF LOOKING IN SOUTH QUADRANT ENTER S"
      READ(05,1000)RESP2
      IF(RESP2.EQ.N) QUAD=-1.0
      IF(RESP2.EQ.S) QUAD=1.0
      IF(XINC.LT.0.0) QUAD=-QUAD
 89   UD=QUAD*DIRE
C
      WRITE(06,1000) "INPUT TARGET RCS (M**2)"
      READ(05,1000) TRCS
C
C   SET FLAGS FOR DESIRED PLOTTING
      WRITE(06,1000)"ENTER 0 FOR 3-D CLUTTER, 1 FOR C/T 3-D PLOT"
      READ(05 1000)ICT
      WRITE(06,1000)"ENTER -1 FOR 3-D ONLY"
      READ(05 1000) ITD
      IF(ITD.EQ.-1) GO TO 413
C
      WRITE(06,1000)"INPUT 3 RANGE BINS TO BE PLOTTED"
      READ(05,1000)NR1,NR2,NR3
C
 413  CONTINUE
C
      COMMON/GEOM/PI,RE,HGT,VEL,XLAM,DELTAR,DELTF,SF
      COMMON/ANTENNA/ANTX,LRJ,LRK,TMAXX,TMINX,TMAXY,TMINY
      COMMON/CLUTTER/CRRDOT,ALPHA,CEE
C
C
         CALL COORD
C
         CALL ANTEN
C
C
C****************************************************************************
C
C  P R O G R A M   S E C T I O N
C
C   COMPUTE THE MINIMUM CONE ANGLE WHICH INTERSECTS THE EARTH
C    AND THE RANGE TO THE HORIZON
C
      ALPHAM=(PI/2.)-ARSIN(RE/(RE+HGT))
      CAM=COS(ALPHAM)
C
C
C   COMPUTE EQUATORIAL ROTATIONAL VELOCITY
      VE=2.0*PI*DIRE*RE/86400.0
C
C   CALCULATE CONSTANTS FOR LATER USE
      DV2 =VEL/2.*CINC/CAM
      DV3=(VE**2*(CLAT**2-CINC**2))/CAM**2
      DV3=SQRT(DV3/2)
      DV1J=(VEL*CAM-VE*CINC)/120.0
      VV2=DV2**2/D/350
```

```
C
C
      CALL GRZ(HGT,RE)
C
C
C
C  CALCULATE C(R,RDOT) FOR EACH RANGE/DOPPLER BIN
C    I = RANGE LOOP
C    J = DOPPLER LOOP
C
C   ENTER RANGE LOOP
      DO 72 I=1,128
           RI4=R(I)**4
           RI4SF=SF/RI4
           SINC=SIN(CEE(I))
           COSAZ=COS(CEE(I))
C
C         SET CLUTTER FLAG
           ICR=1
           IX=I
C
C         COMPUTE TARGET TO CLUTTER RATIO
           TPWR=TRCS*RI4SF
C
C       ENTER DOPPLER LOOP
C
           DO 70 J=1,128
               JX=J
C
C              BYPASS CLUTTER AT NADIR
               IF(I.EQ.1) GO TO 717
C
C
               CALL ROTEAR(SINC,COSAX,$717)
C
C
               CALL AREA(RI4SF,CRRDOT,IX,JX,DELTAR,$717)
C
C
                GO TO 719
C
C              ZERO CLUTTER FLAG
  717           ICR=0
C
C
  719     CALL CWEIGHT(ALPHA,COSAX,TPWR,ICR,ICT,IX,JX,$621)
C
C
                GO TO 633
C
C              SET ZERO CLUTTER
  621           CRRDOT(J)=0.0
                TCRATIO(J)=0.0
C
C              RESET CLUTTER FLAG
  633           ICR=1
C
   70     CONTINUE
C
C        END OF DOPPLER LOOP
C
      WRITE(27'I) CRRDOT
      IF(IID.EQ.-1) GO TO 72
      IF((I.NE.NR1).AND.(I.NE.NR2).AND.(I.NE.NR3))GO TO 72
```

```
4444  CALL PLOTD(TCRATIO,120.1.0.1.0..1.0)
      WRITE(06,1000) ' zzp'
      READ 1000,ISTAT
      IF(ISTAT.EQ.1) GO TO 4444
      PRINT, ' Type CR When Ready'
      READ 1000,RPLY
 72   CONTINUE
C
871  CALL DETACH(27,ISTAT, )
     CALL DETACH(29,ISTAT, )
C
     IF((ICT.NE.1).AND.(ICT.NE.0)) GO TO 142
     WRITE(06,1000) "TYPE CTRL F BEFORE 3-D PLOTTING"
     WRITE(06,1000) "NEXT RUN CONVER.F"
     IF(ICT.NE.0) GO TO 141
     WRITE(06,1000) "THEN RUN DBCONVER"
 141 WRITE(06,1000) "FOLLOWED BY PAAS.TEM"
 142 STOP
     END
C
C
C*********************************************************************
C
     SUBROUTINE COORD
C
     ROUTINE TO TRANSFORM DIRECTIONAL COSINES COSAX AND COSAY
      FROM HORIZONTAL COORDINATES TO ARBITRARY COORDINATES OF
      KNOWN ROLL, PITCH, AND YAW
C
      VELOCITY VECTOR ALONG Y AXIS
      NADIR ALONG -Z AXIS
C
     COMMON/ANTRANS/A11,A12,A13,A21,A22,A23,A11P,A12P
      DATA PI/3.1415927/
1000  FORMAT(V)
C
C
     INPUT ANTENNA DIRECTIONAL PARAMETERS
     WRITE(06,1000)"INPUT ROLL, PITCH, YAW  IN DEGREES"
     READ(05,1000)ROL,PIT,YAW
C
     WRITE(06,1000)"INPUT ANTENNA ROTATION ANGLE (CCW=+)"
     READ(05,1000) ANTROT
C
C
     ROL = ROL*PI/180.
     PIT = PIT*PI/180.
     YAW = YAW*PI/180.
     ANTROT = ANTROT*PI/180.
C
     COMPUTE COORDINATE TRANSFORMATION MATRIX VALUES
     A11 = COS(PIT)*COS(YAW)
     A12 = -COS(PIT)*SIN(YAW)
     A13 = SIN(PIT)
     A21 = SIN(ROL)*SIN(PIT)*COS(YAW)+COS(ROL)*SIN(YAW)
     A22 = -SIN(ROL)*SIN(PIT)*SIN(YAW)+COS(ROL)*COS(YAW)
     A23 = -SIN(ROL)*COS(PIT)
     A11P = COS(ANTROT)
     A12P = SIN(ANTROT)
C
     RETURN
     END
C
C*********************************************************************
```

```
C
      SUBROUTINE ANTEN
C
C      READ ANTENNA PATTERN FROM INPUT FILE AND PLACE INTO
C       2-DIMENSIONAL LOOK-UP TABLE ANT(IX,JX)
C
       COMMON/ANTENX/ANTX(256,256),NBMAX,CTRWT
       DIMENSION ANT(256)
       COMPLEX ANT
C
       CALL ATTACH(29,"FF1ANTONIK/ANT;",3,0,ISTAT, )
       CALL RANSIZ(29,512)
C
           DO 400 IX=1,NBMAX
              READ(29'IX+1)ANT
                DO 300 JX=1,256
                   ANTX(IX,JX) = CABS(ANT(JX))
  300           CONTINUE
  400      CONTINUE
C
C      FIND THE ANTENNA WEIGHTING MAXIMUM VALUE
       CTRWT=ANTX(137,1)**4
C
       RETURN
       END
C***************************************************************************
C
     SUBROUTINE GRZ(HGT,RE)
C
C     CALCULATE ELEVATION ANGLE CEE FOR EACH RANGE INCREMENT
C      AND GRAZING ANGLE GRAZ
C
       COMMON/ANGLE/R(128),CEE(128),SIGMA(128),GRAZ(128)
       DATA PI/3.1415927/
C
C      COMPUTE RANGE BIN SPACING SUCH THAT THE LAST BIN IS PRIOR TO
C       THE HORIZON
         RESQ=RE**2
         RHTSQ=(RE+HGT)**2
         RMAX=SQRT(RHTSQ-RESQ)
         DELR=(RMAX-HGT)/128.
C
C     THE FIRST ELEVATION ANGLE IS NORMAL TO THE EARTH
        CEE(1)=0.0
C
        DO 50 I=1,128
            R(I)=HGT+(FLOAT(I-1)*DELR)
C
            IF(I.EQ.1) GO TO 53
            CEE(I)=ARCOS((-RESQ+(R(I)*R(I))+RHTSQ)/(2.*R(I)*(RE+HGT)))
C
C          COMPUTE THE GRAZING ANGLE
   53       GRAZ(I)=ARCOS(((RE+HGT)/RE)*SIN(CEE(I)))
            GRAZDEG=GRAZ(I)*180.0/PI
C
C          GRAZING ANGLE EFFECT
C
            IF(GRAZDEG.GT.15.0) GO TO 111
            SIGMADB=0.067*GRAZDEG-32.0
            GO TO 333
C
  111       IF(GRAZDEG.GT.60.0) GO TO 222
            SIGMADB=0.156*GRAZDEG-24.33
```

```
            GO TO 333
C
  222       IF(GRAZDEG.GT.80.0) GO TO 40
            SIGMADB=1.5*GRAZDEG-105.0
            GO TO 333
C
   40       SIGMA(I)=31.62
            GO TO 50
  333       SIGMA(I)=10.0**(SIGMADB/10.0)
   50  CONTINUE
      RETURN
      END
C**************************************************************************
C
      SUBROUTINE ROTEAR(SINC,COSAX,*)
C
       COMPUTE ANGLES CORRESPONDING TO DOPPLER BINS
C
       COMMON/ROTATE/DV1J,DV2,DV3,VV2,J
       COMMON/CONE/ALPHA,ALPHAD,ICR
       COMMON/CONST/XLAM,XINC,DELTF,QD
C
        COMPUTE FRACTIONAL DOPPLER VELOCITY
          DV1=FLOAT(J)*DV1J
          SQVSQ=VV2-(DV1/SINC)**2
C
        TEST FOR INVALID ANGLE OFF EARTH
          IF(SQVSQ.LT.0.0) GO TO 91
          SQV=SQRT(SQVSQ)*QD
          XNUME=DV1*DV2+DV3*SINC*SQV
C
        COMPUTE CONE ANGLE ALPHA
          ALPHA=ARCOS(XNUME/VV2)
C
        COMPUTE SCAN ANGLE AND RELATIVE SCAN ANGLE
          SCAN=ARCOS(COS(ALPHA)/SINC)
          RSCAN=QD*SCAN
C
        COMPUTE X DIRECTION COSINE
          COSAX=SIN(RSCAN)*SINC
C
        NEGATIVE INCLINATION TEST
          IF(XINC.LT.0.0) COSAX=-COSAX
C
        COMPUTE DIFFERENTIAL ANGLE ALPHAD
          DV1D=DV1-DELTF*XLAM/2.0
          SQVSQD=VV2-(DV1D/SINC)**2
          SQVD=SQRT(SQVSQD)*QD
          XNUMED=DV1D*DV2+DV3*SINC*SQVD
          ALPHAD=ARCOS(XNUMED/VV2)
          RETURN
   91     RETURN1
          END
C
C**************************************************************************
C
      SUBROUTINE AREA(RI45F,CRRDOT,I,J,DELTAR,*)
C
       COMPUTE RANGE-DOPPLER CELL AREAS
       AND THE CLUTTER INTENSITY CRRDOT
C
       COMMON/CONE/ALPHA,ALPHAD,ICR
       COMMON/ANGLE/R(128),CEE(128),SIGMA(128),GRAZ(128)
```

```
      DIMENSION CRRDOT(128)
C
C
       A=R(I)*SIN(CEE(I))
       SCL=0.
       XNUMB=0.
   62  CONTINUE
       B=R(I)*COS(ALPHA)
       C=A
       D=R(I)*COS(ALPHAD-(SCL*XNUMB))
       IF (C .GE. D) GO TO 69
       IF (A .LT. B) GO TO 71
       SCL=(ALPHAD-ALPHA)/10.
       XNUMB=XNUMB+1.
       GO TO 62
   69  IF (A .LT. B) GO TO 71
       SIX=SQRT((A*A)-(B*B))
       SIY=B
       SIZ=R(I)*COS(CEE(I))
       S2X=SQRT((C*C)-(D*D))
       S2Y=D
       S2Z=SIZ
       EX=(SIX-S2X)*(SIX-S2X)
       EY=(SIY-S2Y)*(SIY-S2Y)
       EZ=(SIZ-S2Z)*(SIZ-S2Z)
       CRRDOT(J)=(SQRT(EX+EY+EZ)*DELTAR/COS(GRAZ(I)))*SIGMA(I)
       CRRDOT(J)=CRRDOT(J)*RI4SF
       RETURN
   71  RETURN1
       END
C
C*******************************************************************
C
      SUBROUTINE CWEIGHT(ALPHA,COSAX,TPWR,ICR,ICT,I,J,*)
C
C     ROUTINE TO WEIGHT CRRDOT BY COMPUTED ANTENNA PATTERN FROM
C     KNOWN VELOCITY VECTOR ANGLE ALPHA AND NADIR ANGLE CEE(I)
C
       COMMON/TPLANE/TMAXX,TMINX,TMAXY,TMINY
       COMMON/TRIG/SINC,COSAZ
       COMMON/RANGE/LRJ,JWIDE,KWIDE,RANGEX,RANGEY
       COMMON/CLUTTER/CRRDOT(128),TCRATIO(128)
       COMMON/ANTRANS/A11,A12,A13,A21,A22,A23,A11P,A12P
       COMMON/ANTENX/ANTX(256,256),NBMAX,CTRWT
C
      IF(ICR.EQ.0)GO TO 66
C
C          DIGITIZE COSINE ANGLE INTO COLUMNS AND ROWS, ROUNDING OFF
C          IXCOL, IYROW = COLUMN, ROW NUMBER OF TX AND TY VALUE
C          LRECJ = LOGICAL RECORD NUMBER ACROSS TX
C          LRECK = LOGICAL RECORD NUMBER DOWN TY
C          LREC = ABSOLUTE LOGICAL RECORD NUMBER IN ANTENNA PATTERN
C
C          CONVERT FROM NADIR ANGLE CEE TO ANTENNA ANGLE ALPHAX
C          CONVERT FROM VEL VECTOR ANGLE ALPHA TO ANTENNA ANGLE ALPHAY
           COSAY = COS(ALPHA)
C
C        COMPUTE TRANSFORMED DIRECTION COSINES
           TCAX = A21*COSAY+A22*COSAX-A23*COSAZ
           TCAY = A11*COSAY+A12*COSAX-A13*COSAZ
           TCAX = A12P*TCAY+A11P*TCAX
           TCAY = A11P*TCAY-A12P*TCAX
           IAX = ARCOS(TCAX)
           IAY = ARCOS(TCAY)
```

```
      ALPHAX = TAX
      ALPHAY = TAY

     CHECK FOR LOOK ANGLES BEYOND AVAILABLE DATA COVERAGE AREA
      TESTX=TCAX-TMINX
      TESTY=TMAXY-TCAY
      IF((TCAX.GT.TMAXX).OR.(TCAX.LT.TMINX)) GO TO 522
      IF((TCAY.GT.TMAXY).OR.(TCAY.LT.TMINY)) GO TO 522
      XCOL = TESTX*(FLOAT(JWIDE)-1.)/RANGEX+1.5
      IXCOL = XCOL
      YROW = TESTY*(FLOAT(KWIDE)-1.)/RANGEY+1.5
      IYROW = YROW


     FIND THE LOGICAL RECORD LOCATION OF THE LOOK ANGLE
      LRECJ = INT((FLOAT(IXCOL)-1.)/16.)+1
      LRECK = INT((FLOAT(IYROW)-1.)/16.)+1
      LREC = LRECJ+LRJ*(LRECK-1)

      IACOLJ, IAROWK = COLUMN, ROW IN EACH LOGICAL RECORD
      IACOLJ = MOD(IXCOL,16)
      IAROWK = MOD(IYROW,16)
      IF (IACOLJ .EQ. 0) IACOLJ=16
      IF (IAROWK .EQ. 0) IAROWK=16
      IA = ABSOLUTE POSITION WITHIN EACH LOGICAL RECORD
      IA = IACOLJ+(IAROWK-1)*16

     DETERMINE MULTIPLYING FACTOR FROM LOGICAL RECORD
      CRRDOT(J) = ANTX(LREC,IA)**4*CRRDOT(J)

     SET TARGET TO CLUTTER RATIO TO INFINITY FOR ZERO CLUTTER
      TCRATIO(J)=10.*ALOG10(TPWR*CTRWT/CRRDOT(J))
      GO TO 93
56    TCRATIO(J)=999.0
      CRRDOT(J)=0.0
      ICR=0
93    IF(ICT.NE.1) GO TO 792
      CRRDOT(J)=-TCRATIO(J)+300.0
      IF (ICR.EQ.0) CRRDOT(J)=0.0
792   CONTINUE
      RETURN
522   RETURN
      END
```

APPENDIX - II

Listing of Program RANGE

- LISTN RANGE

04/06/83 09.08

```
C     PROGRAM TO DIVIDE THE EARTH INTO EQUALLY SPACED
C      RANGE BINS AS SEEN FROM AN ELEVATED PLATFORM
C
C
C     VARIABLES:
C
C      RE = RADIUS OF THE EARTH
C      HGT = ALTITUDE OF THE PLATFORM ABOVE THE EARTH'S SURFACE
C      RMAX = MAXIMUM RANGE (HORIZON)
C      DELR = DISTANCE BETWEEN RANGE BINS
C      CEE = ELEVATION ANGLE
C      GRAZ = GRAZING ANGLE
C
C
C*************************************************************************
C  D A T A   S E C T I O N
C
C
      DIMENSION CEE(128),R(128),GRAZ(128)
      DATA PI/3.1415927/,RE/6371000./,HGT/[redacted]/
C
        CHARACTER*3 RESP3,Y,N
        DATA N/1HN/,Y/1HY/
C
        WRITE(06,1000)" "
        ALTI=HGT/1852.0
        WRITE(06,1000)"ALTITUDE  =",ALTI,"  NM"
        WRITE(06,1000)" "
C
        WRITE(06,1000)"DO YOU WISH TO CHANGE THE
        WRITE(06,1000)" CIRCULAR ORBIT ALTITUDE ?"
        WRITE(06,1000)" "
        WRITE(06,1000)"ENTER Y OR N"
        READ(05,1000)RESP3
        IF(RESP3.EQ.N) GO TO 14
        WRITE(06,1000)" "
C
        WRITE(06,1000)"INPUT THE NEW ALTITUDE IN NM"
        READ(05,1000)HNM
        HGT=HNM*1852.0
 14     CONTINUE
C
C
C*************************************************************************
C  P R O G R A M   S E C T I O N
C
C
       RESQ=RE**2
       RHTSQ=(RE+HGT)**2
       RMAX=SQRT(RHTSQ-RESQ)
       CEEMAX=ARSIN(RE/(RE+HGT))
       CEEMAXDEG=CEEMAX*180.0/PI
C
C    COMPUTE SPACINGS SUCH THAT THE LAST RANGE BIN IS NOT AT THE HORIZON
       DELR=(RMAX-HGT)/128.0
C
C     SET UP OUTPUT LABELS
```

```
C
      WRITE(06.1000)" "
      WRITE(06.1000)"ALTITUDE =".HGT."    METERS"
      WRITE(06.1000)"RMAX     =".RMAX."    METERS"
      WRITE(06.1000)"CEEMAX   =".CEMAXDEG."    DEGREES"
      WRITE(06.1000)" "
      PRINT 1009
      WRITE(06.1000)" "
C
 1000 FORMAT(V)
 1009 FORMAT(3X."I".7X."RANGE(I)".9X."CEE(I)".10X."GRAZ(I)")
 1010 FORMAT(I4.2X.1P1E16.7.2P2E16.7)
C
C   CALCULATE ELEVATION ANGLE CEE FOR EACH RANGE INCREMENT
C    AND GRAZING ANGLE GRAZ
C
C     THE FIRST ELEVATION ANGLE IS NORMAL TO THE EARTH
      CEE(1)=0.0
C
      DO 50 I=1.128
          R(I)=HGT+(FLOAT(I-1)*DELR)
C
          IF(I.EQ.1) GO TO 53
          CEE(I)=ARCOS((-RESQ+(R(I)*R(I))+RHTSQ)/
     & (2.*R(I)*(RE+HGT)))
C
C          COMPUTE THE GRAZING ANGLE
 53       GRAZ(I)=ARCOS(((RE+HGT)/RE)*SIN(CEE(I)))
          GRAZDEG=GRAZ(I)*180.0/PI
          CEEDEG=CEE(I)*180.0/PI
          WRITE(06.1010)I.R(I).CEEDEG.GRAZDEG
 50   CONTINUE
      STOP
      END
```

APPENDIX - III

Listing of Program SCAN

LISTH SCAN

04/06/83 09.09

```
C      PROGRAM TO COMPUTE SCAN ANGLES OF EQUALLY SPACED
C       DOPPLER BINS AS SEEN FROM A MOVING PLATFORM
C
C
C      VARIABLES:
C
C       RE = RADIUS OF THE EARTH
C       HGT = ALTITUDE
C       VEL = VELOCITY
C       XLAM = WAVELENGTH
C       RMAX = MAXIMUM RANGE
C       DELR = DISTANCE BETWEEN RANGE BINS
C       DELTAR = RANGE BIN WIDTH
C       DELF = DISTANCE BETWEEN DOPPLER BINS
C       DELTF = DOPPLER BIN WIDTH
C       ALPHA = ANGLE B/N VELOCITY VECTOR AND VECTOR TO POINT ON GROUND
C       ALPHAM = MINIMUM ANGLE ALPHA
C       SF = SCALE FACTOR
C       CEE = ANGLE MEASURED FORM NADIR
C       XLAT = SUBLATITUDE POINT OF SATELLITE
C       XINC = ORBITAL INCLINATION ANGLE
C       QUAD = NORTH OR SOUTH LOOKING QUADRANT
C       DIRE = EAST OR WEST ORBIT DIRECTION
C
C
C*************************************************************************
C  D A T A   S E C T I O N
C
C
       DIMENSION  VDOP(128,128),VDE(128,128),VDS(128,128)
       DIMENSION CEE(128),ALPHA(128,128),R(128),GRAZ(128)
       DATA PI/3.1415927/,RE/[redacted]/,HGT/[redacted]/,VEL/[redacted]/,
       XLAM/.24/,DELTAR/78./,DELTF/20./,SF/1.0E30/
C
         CHARACTER*3 RESP,N,S
         CHARACTER*3 RESP2,E,W
         CHARACTER*3 RESP3,Y,N
         DATA N/1HN/,Y/1HY/,S/1HS/,E/1HE/,W/1HW/
C
       WRITE(06,1000)" "
       ALTI=HGT/1852.0
       WRITE(06,1000)"ALTITUDE  =",ALTI,"  NM"
C
       WRITE(06,1000)"DO YOU WISH TO CHANGE THE CIRCULAR ORBIT ALTITUDE ?"
       WRITE(06,1000)"ENTER Y OR N"
       READ(05,1000)RESP3
C
C     SET SPACE/AIR TRANSITION ALTITUDE
       HNM=[illegible]
       IF(RESP3.EQ.N) GO TO 14
C
       WRITE(06,1000)"INPUT THE NEW ALTITUDE IN NM"
       READ(05,1000)HNM
```

```
      HGT=HNM*1852.0
      VEL=1.9976E07*SQRT(1/(HGT+RE))
C
C     FOR ALTITUDES LESS THAN 90 NM. ASSUME AIRBORNE PLATFORM
      IF(HNM.GT.90.0) GO TO 81
      WRITE(06,1000)"INPUT AIRCRAFT'S GROUND SPEED IN KNOTS"
      READ(05,1000) GS
      QUAD=0.0
      DIRE=0.0
      XLAT=0.0
      XINC=0.0
      VEL=GS*0.5144444
C
      WRITE(06,1000)"GROUND SPEED =".VEL."  M/S"
      GO TO 14
   81 WRITE(06,1000)"ALTITUDE  =".HGT."  METERS"
      WRITE(06,1000)"ORBITAL VELOCITY  =".VEL."  M/S"
C
   14 CONTINUE
      WRITE(06,1000)" "
C
C    INPUT SATELLITE ORBIT DATA
C     BYPASS SATELLITE DATA IF AIRBORNE PLATFORM
      IF(HNM.LT.90.0) GO TO 89
      WRITE(06,1000)"INPUT SATELLITE INCLINATION ANGLE"
      WRITE(06,1000)"AND INSTANTANEOUS LATITUDE"
      READ(05,1000)XINC,XLAT
      XINC=XINC*PI/180.0
      XLAT=XLAT*PI/180.0
      CINC=COS(XINC)
      CLAT=COS(XLAT)
      CD=ARCOS(CINC/CLAT)
C
      WRITE(06,1000)"IF FLYING EAST ENTER E"
      WRITE(06,1000)"IF FLYING WEST ENTER W"
      READ(05,1000)RESP
      IF(RESP.EQ.W)DIRE=-1.0
      IF(RESP.EQ.E)DIRE=1.0
C
      WRITE(06,1000)"IF LOOKING IN NORTH QUADRANT ENTER N"
      WRITE(06,1000)"IF LOOKING IN SOUTH QUADRANT ENTER S"
      READ(05,1000)RESP2
      IF(RESP2.EQ.N) QUAD=-1.0
      IF(RESP2.EQ.S) QUAD=1.0
      IF(XINC.LT.0.0) QUAD=-QUAD
   89 QD=QUAD*DIRE
C
C
C*********************************************************************
C  P R O G R A M   S E C T I O N
C
 1000 FORMAT(V)
      RESQ=RE*RE
      RHTSQ=(RE+HGT)*(RE+HGT)
      R[illegible]=SQRT(RHTSQ-RESQ)
      DE[illegible]=(RMAX-HGT)/128.
C
      ALPHA(1+[illegible])/[illegible]=ARSIN(RE/(RE+HGT))
      DEL[illegible]=((2.*VEL/VLAM)/128.)*COS(ALPHAN)
C
C
C    CALCULATE POLAR ANGLE C FOR EACH RANGE INCREMENT
C     AND FACING ANGLE
      DO 10 I=1,128
```

```
      R(I)=HGT+(FLOAT(I-1)*DELR)
      IF(I.EQ.1) GO TO 36
      CEE(I)=ARCOS((-RESQ+(R(I)*R(I))+RHTSQ)/(2.*R(I)*(RE+HGT)))
 36   CEE(1)=0.0
      BETA=ARSIN(((RE+HGT)/RE)*SIN(CEE(I)))
      GRAZ(I)=-BETA+(PI/2.0)
C
 50 CONTINUE
C
C
    WRITE(06.1000)"ENTER THE RANGE BIN NUMBER"
    WRITE(06.1000)"TO SEE ALL DOPPLER COMPONENTS AT THAT RANGE"
    READ(05.1000)NRAN
C
C  COMPUTE EQUATORIAL ROTATIONAL VELOCITY
C   AND ASSOCIATED CONSTANTS
C
     VE=2.0*PI*DIRE*RE/86400.0
     CINC=COS(XINC)
     CLAT=COS(XLAT)
     CD=ARCOS(CINC/CLAT)
     CAM=COS(ALPHAM)
     DV2=VEL-VE*CINC/CAM
     DV3SQ=VE**2*(CLAT**2-CINC**2)/CAM**2
     DV3=SQRT(DV3SQ)
     VV2=DV2**2+DV3SQ
C
C   COMPUTE THE MAX DOPPLER BIN
     XJMAX=128.0*SIN(CEE(NRAN))/(VEL*CAM-VE*CINC)
     XJMAX=XJMAX*SQRT((DV2**2+DV3SQ))
     JMAX=INT(XJMAX)
     IF(JMAX.GT.128) JMAX=128
C
     HDG=ARSIN(CINC/CLAT)
     HDGDEG=HDG*180./PI
C
C   ALPHA LOOP
         IV=NRAN
         GR=COS(GRAZ(IV))
         SINC=SIN(CEE(IV))
C
        DO 150 JV=1,128
C          DONT COMPUTE FIRST RANGE BIN
           IF(IV.EQ.1) ALPHA(IV,JV)=PI/2.0
           IF(IV.EQ.1) GO TO 450
C
C          COMPUTE FRACTIONAL DOPPLER VELOCITY
           DV1=FLOAT(JV)*(VEL*CAM-VE*CINC)/128.0
           RT=(DV2**2+DV3SQ)-(DV1/SINC)**2
C
C          TEST FOR INVALID ANGLE OFF EARTH
           IF(RT.LT.0.0) GO TO 450
           SQTV=SQRT(RT)*QD
           XNUME=DV1*DV2+DV3*SINC*SQTV
           ALPHA(IV,JV)=ARCOS(XNUME/VV2)
C
C          COMPUTE SCAN ANGLE
           SCAN=ARCOS(COS(ALPHA(IV,JV))/SINC)
           ALPHADEG=ALPHA(IV,JV)*180.0/PI
C
C          COMPUTE SATELLITE DOPPLER COMPONENT
           VOS(IV,JV)=VEL*COS(ALPHA(IV,JV))
C
C          COMPUTE EARTH DOPPLER COMPONENT
```

```
                 VDE(IV,JV)=VE*GR*COS(SCAN-CD*QUAD)*CLAT
C
                COMPUTE TOTAL DOPPLER COMPONENT
                 VDOP(IV,JV)=VDS(IV,JV)-VDE(IV,JV)
C
  450       CONTINUE
C
C
C***********************************************************************
C   O U T P U T   S E C T I O N
C
C
      WRITE(06,1000)" "
      WRITE(06,1000)"VECTOR HEADING  =",HDGDEG,"   DEGREES"
      WRITE(06,1000)" "
      PRINT 1004
 1004 FORMAT(3X,"J",7X,"ALPHA(I,J)",7X,"SCAN(I,J)",7X,"VDOP  KTS")
      WRITE(06,1000)" "
C
         DO 452 JP=1,JMAX
            ALPHADEG=ALPHA(NRAN,JP)*180.0/PI
            VDE(NRAN,JP)=-VDE(NRAN,JP)
            SCANR=ARCOS(COS(ALPHA(NRAN,JP))/SINC)
            SCAN=SCANR*180.0/PI
            VKTS=VDOP(NRAN,JP)*1.9438445
            WRITE(06,1003)JP,ALPHADEG,SCAN,VKTS
 1003       FORMAT(I4,2X,2P2E16.7,1P1E16.7)
C
  452    CONTINUE
C
C
      GRAZDEG=GRAZ(NRAN)*180.0/PI
      CEDEG=CEE(NRAN)*180.0/PI
      VDMAX=VEL*CAM-VE*COS(XINC)
      WRITE(06,1000)" "
      WRITE(06,1000)" "
      WRITE(06,1000)" "
      WRITE(06,1000)"                  I      GRAZDEG          CEDEG
     &     VDMAX"
C
      WRITE(06,1000)" "
      WRITE(06,1000)NRAN,GRAZDEG,CEDEG,VDMAX
      WRITE(06,1000)" "
      WRITE(06,1000)" "
      SQTVZ=SQRT((DV2**2+DV3SQ))*QD
      XNUMEZ=DV3*SINC*SQTVZ
      ALPHAZ=ARCOS(XNUMEZ/(DV2**2+DV3SQ))
      SCANZ=ARCOS(COS(ALPHAZ)/SINC)
      ALPHADEZ=ALPHAZ*180./PI
      SCANDEZ=SCANZ*180./PI
C
      WRITE(06,1000)" "
      WRITE(06,1000)"                        ALPHA(J=0)       SCAN(J=0)"
      WRITE(06,1000)" "
      WRITE(06,1000)"                 ",ALPHADEZ,SCANDEZ
      STOP
      END
```

APPENDIX - IV

Glossary

$ANT(T_x, T_y)$ Antenna pattern weighting function.

A_x Polar angle from X axis.

A_y Polar angle from Y axis.

A_{yd} Polar angle from Y axis with doppler increment included.

A_{ymin} Minimum Y axis angle which intersects the horizon.

$C(I)$ Elevation angle as a function of range.

C_{max} Maximum elevation angle which intersects the Earth.

$C(r,\dot{r})$ Clutter intensity scatter function, dependent on range and doppler.

D_f Frequency separation of consecutive doppler bins.

D_r Range separation of consecutive range bins.

F_d Two way doppler shift of radar echo.

$G(I)$ Grazing angle as a function of range.

H Height of radar platform above the Earth's surface.

inc Satellite orbit inclination angle.

Isodop Locus of equal doppler points on the Earth's surface.

Isorange Locus of equal range points on the Earth's surface.

lat Instantaneous satellite subpoint latitude.

$R(I)$ Range as a function of range bin number.

R_e Radius of the Earth.

R_{max} Range of the most distant range bin.

T_x Directional cosine from X axis.

T_y Directional cosine from Y axis.

V_{diff} Velocity differential between successive doppler bins

V_e Equatorial velocity of the rotating Earth.

V_r Radial velocity component of a target.

V_{rmax} Maximum relative radial velocity of the Earth's surface.

V_p Radar platform air/orbital velocity.

Δf Doppler filter bandwidth.

Δr Range cell resolution width.

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