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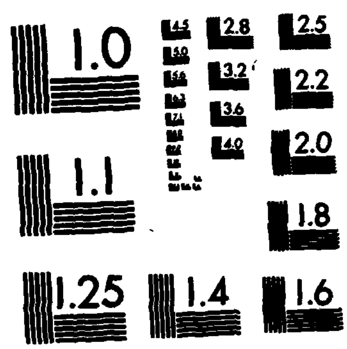
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COMPUTER TECHNIQUE FOR THEORETICAL ANALYSIS OF BEAMFORMERS AND ARRAYS

BY EDWARD J. ROTH

UNDERWATER SYSTEMS DEPARTMENT

SEPTEMBER 1982

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NAVAL SURFACE WEAPONS CENTER

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This report documents a computer program which simulates the beamforming process of a planar array. It uses the physical characteristics, electrical shading characteristics and other factors to obtain detailed information of theoretical beam structures. Amplitude and phase coefficients can be varied to study main and side lobe structures for steered/unsteered and/or spread/unspread beam patterns.

FOREWORD

This report documents a computer program which simulates the beamforming process of a planar array.

The program uses the physical characteristics, electrical shading characteristics, medium sound speed and vehicle motion to obtain detailed information of beam structures. Amplitude and phase coefficients can be varied to study main and side lobe structures for any combination of steered or unsteered and spread or unspread beam patterns.

The computer program documented in this report represents the first phase of a beamforming package, and is used to determine the theoretical limits of a beamformer. Work is currently under way on the second phase of this study, where the effects of parameter variation during production will be examined. A third phase of this study will deal with determining beamformer performance in a counter-measure environment.

Approved by:

JACK E. GOELLER, Head
System Engineering Division

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INTRODUCTION

The computer program THRYPLT is a simulation of the response of a desired transducer array. It is currently compatible with the DEC VAX-11/780 computer, using VAX-11 FORTRAN code. The program may be used to generate data for both transmit and receive beam patterns. Calculations are made relative to spherical coordinates, using necessary coordinate transformations as required. Amplitude (in decibels) and phase angle (in degrees) data are generated for a beam over any desired section of a sphere. The input data created for this report and sample outputs are included in Appendices A and B, respectively.

In developing the program, several assumptions were made. The module directivity was assumed to be independent of frequency, depth and location in the array. The program included in this report is currently set up for planar arrays, and uses the assumption that there will be no variance in the "Z" direction of the array (see Figure 1). That is, the face of the array will be smooth across its entirety. Mutual coupling for the array is set to zero. Finally, voltage levels below -50 decibels (db) are considered to be noise, and a lower boundary is set at that level.

The program has a set of run options available. The user may specify that his data be calculated relative to the main response axis (MRA), to the "Z" axis, or to any other axis he chooses (see Figure 1). Once this has been chosen, the user may obtain data for a variety of regions. The user may specify that his data be calculated for a specific roll or pitch plane, or input a range of pitch and azimuthal angles. This is discussed in detail later. With respect to module directivity, the user must insert into the program the directivity pattern he chooses, or may set a flag to run an omnidirectional pattern. The response levels may be normalized to the value of the pattern at the MRA, to the sum of the amplitude shading coefficients, or to any other value the user feels is needed.

Calculations are included in the program for equivalent beam patterns and the directivity index. The equivalent beam patterns are calculated assuming identical transmit and receive beam patterns, and should be viewed as a special case.

THEORY

The coordinate system used in this development is a left-handed spherical system, as shown in Figure 1. This system was chosen to allow calculations to be made relative to the standard azimuth and pitch angles. Note is made that the angles theta (θ) and phi (ϕ) are not the usual spherical coordinates as found in most text books.

The major calculations made in the program yield a voltage response (which is later converted to decibels) and a phase angle. The program assumes that waves incident on the array are planar. This assumption is valid providing that the array-to-target distance is much greater than the module spacings in the array.

A plane wave may be represented, using complex notation, as

$$\psi = A*EXP[i*(wt+B(l,m)+T(l,m))]$$

where

A = amplitude

w = $2*\pi*$frequency

t = time

B(l,m) = phase of the wave at the (l,m) element relative to the array center

T(l,m) = electronic phase delay of the (l,m) element

The use of "EXP(x)" in the equations in this report is equivalent to the natural exponential function of x. The term "i" in the equations is equal to the square root of negative one.

Using a maximum amplitude of one, and letting the individual module responses lie between zero and one, the response of the (l,m) element may be written as

$$V(l,m) = H(l,m)*R(l,m)*EXP[i*(wt+B(l,m)+T(l,m))]$$

where R(l,m) and H(l,m) are the electrical attenuation and module directivity, respectively, of the (l,m) element (both are normalized to one). A discussion of module directivity is included later in this report. Neglecting the time dependence of the wave, the response may be written as

$$V(l,m) = H(l,m)*R(l,m)*EXP[i*(B(l,m)+T(l,m))]$$

The first phase term, B(l,m), is simply the difference in phase at which the wave arrives at element (l,m) with respect to the array center. If the phase term B(l,m) has a positive value, it is said to be a phase lead, while a negative value of B(l,m) is defined as a phase lag. This phase delay relates directly to the perpendicular distance between the plane wave front and the element being looked at when the wave front is at the array center. This distance (phase delay) can be seen by examining Figures 2 and 3.

Figure 2 is a sketch of a plane wave front incident on an array, perpendicular to the direction given by theta and phi. The wave front is represented by the broken line. Module 1 is located at the center of the unprimed axes, while module 2 is located at the center of the primed axes. The origin (0,0,0) of the unprimed axes will be taken as the reference point for the derivation that follows. The line segments from module 1 to point A, point A to point B, and point B to module 2 represent the distances X(k), Y(k), and Z(k), respectively. The origin of the primed axes is located at the point (X(k),Y(k),Z(k)). The vector S represents the total perpendicular distance to the wave front from module 2.

To find the total distance to the wave from module 2, the modules will first be looked at as if they were both in the X-Z plane, with module 1 being located at (0,0,0) and module 2 being located at (X(k),0,Z(k)). The contribution due to a difference in the Y positions will then be added.

To start, let the plane wave be incident on the modules in the direction $(\theta,0)$, i.e., where $\theta=\theta$ and $\phi=0$. This is shown in Figure 3(a). As shown in Figure 3(a), the value of X(k) is positive, while Z(k) is negative. The value of theta as shown is also negative. With these conditions, the total distance to the wave front from module 2 is

$$S1 = X(k)*\sin(\theta) + Z(k)*\cos(\theta)$$

Moving to figure 3(b), there is still no Y separation, but the wave is now incident in the direction (θ,ϕ). The view in Figure 3(b) is taken looking down the wave front at a vertical plane. With the wave now incident in the direction (θ,ϕ), the total distance to the wave front from module 2 becomes

$$S2 = S1*\cos(\phi) = [X(k)*\sin(\theta) + Z(k)*\cos(\theta)]*\cos(\phi)$$

Figure 3(c) shows the representation of the addition of a Y separation for the modules. The view is the same as that used in Figure 3(b). In this figure, module 2 has been moved a distance Y(k) below module 1 (i.e., Y(k) has a negative value), and the wave is again incident in the direction (Θ,Ø). Modules 1 and 2 are now located at the positions (0,0,0) and (X(k),Y(k),Z(k)), respectively. The total distance to the wave front from module 2 is then

$$S = X(k)*\sin(\Theta)*\cos(\emptyset) + Y(k)*\sin(\emptyset) + Z(k)*\cos(\Theta)*\cos(\emptyset)$$

In the equation representing V(l,m), B(l,m) is in fact directly related to this distance S. Adding a normalizing term (to convert S to a phase) and letting the subscript "k" become "l,m", B(l,m) may be written as

$$\begin{aligned} B(l,m) &= (2\pi/\lambda)*[X(l,m)*\sin(\Theta)*\cos(\emptyset) \\ &\quad +Y(l,m)*\sin(\emptyset)+Z(l,m)*\cos(\Theta)*\cos(\emptyset)] \\ &= (2\pi f/c)*[X(l,m)*\sin(\Theta)*\cos(\emptyset) \\ &\quad +Y(l,m)*\sin(\emptyset)+Z(l,m)*\cos(\Theta)*\cos(\emptyset)] \end{aligned}$$

where

X(l,m) = X location of (l,m) element relative to (0,0,0)

Y(l,m) = Y location of (l,m) element relative to (0,0,0)

Z(l,m) = Z location of (l,m) element relative to (0,0,0)

λ = wavelength

c = speed of wave in medium

f = frequency

The second phase term, T(l,m), is the steer/spread coefficient. The program will calculate these coefficients for a steered beam, but not for a spread beam, using the equation

$$\begin{aligned} T(l,m) = -W*[&X(l,m)*\sin(\Theta(MRA))*\cos(\emptyset(MRA)) \\ &+Y(l,m)*\sin(\emptyset(MRA))+Z(l,m)*\cos(\Theta(MRA))*\cos(\emptyset(MRA))] \end{aligned}$$

where (Θ(MRA)) and (Ø(MRA)) are the values of theta and phi at the MRA. The term W above is equal to 2πf/c, the normalization term. Phase coefficients containing spread information must be calculated by the user before running the program. The Z(l,m) terms have been omitted in this simulation, using the assumption that the face of a planar array will be smooth across its entirety. If the user foresees a Z dependence in his system, it should be put into the equations in the program. The frequency used in these equations may be adjusted for motion using the common Doppler shift equation, as found in texts on general physics. The equation is included in the program and may be flagged as desired.

Using Euler's theorem, and letting $\varepsilon(l,m) = T(l,m)+B(l,m)$, the response may be written as

$$V(l,m) = H(l,m)*R(l,m)*EXP[i*(\varepsilon(l,m))]$$

$$= H(l,m)*R(l,m)*[\cos(\varepsilon(l,m))+i*\sin(\varepsilon(l,m))]$$

To get the total response of the array, the individual transducer responses are summed up. This total response is

$$V = \sum_{\ell=1}^{Ny} \sum_{m=1}^{Nx} H(l,m)*R(l,m)*[\cos(\varepsilon(l,m))+i*\sin(\varepsilon(l,m))]$$

where Nx and Ny are the number of columns and rows, respectively.

Taking the modulus of the complex term above, the response becomes

$$V = ([\sum_{\ell=1}^{Ny} \sum_{m=1}^{Nx} H(l,m)*R(l,m)*\cos(\varepsilon(l,m))]^2$$

$$+[\sum_{\ell=1}^{Ny} \sum_{m=1}^{Nx} H(l,m)*R(l,m)*\sin(\varepsilon(l,m))]^2)^{1/2}$$

The assumption is now made that the term H(l,m) will be the same for every element; this is discussed later in this section. Using this assumption, and letting all H(l,m) be equal to H, the response may be written as

$$V = H*([\sum_{\ell=1}^{Ny} \sum_{m=1}^{Nx} R(l,m)*\cos(\varepsilon(l,m))]^2$$

$$+[\sum_{\ell=1}^{Ny} \sum_{m=1}^{Nx} R(l,m)*\sin(\varepsilon(l,m))]^2)^{1/2}$$

The phase of the total response, in the complex system, is given by the vector sum of the individual phases. Specifically, the phase is equal to

$$\varepsilon = \arctan[Im/Re]$$

where

ε = phase of the total response

Im = sum of the imaginary terms

Re = sum of the real terms

The assumption was made earlier that the module directivity will be the same for all elements. This assumption has been shown through hardware testing to be a reasonable one for the systems looked at thus far. For values of theta and phi out to ± 60 degrees, differences in directivity between elements were negligible. Caution is given here that this assumption may not be valid for other arrays of interest. It is left to the user to test his system to see if the assumption holds, and to make program modifications if necessary.

PROGRAM DESCRIPTION

The main section of the program is controlled by two nested loops. The limits for these loops are based on the spherical coordinates theta (Θ) and phi (Ø), as shown in Figure 1. The inner loop runs over the desired range of theta, while the outer loop runs over the desired range of phi. Both loops must be run with a constant increment.

The user may run the program relative to any position he chooses. Usual positions to run relative to are the Z axis (theta = phi = 0) or the main response axis (MRA). When running relative to an axis other than the Z axis, adjustments are made to theta and phi, through the use of offsets.

When running the program, the user must specify the set of angles he is interested in. He may do this directly, or may specify a roll plane and range of angles relative to the roll axis. The roll axis is the ray about which the plane is rotated. The roll angle is to be given between -90 and 90 degrees (e.g., specify -70 instead of 110). In Figure C-1 (in Appendix C), the Z axis is the roll axis. When the user specifies a roll plane to be calculated, the program converts back to real-space theta and phi. The angle on the roll plane, relative to the roll axis, will be designated here as theta prime (Θ'), while the roll angle itself will be designated gamma (γ). The following relations are used for the conversion from the roll plane to real-space coordinates:

$$\Theta = \arctan[\tan(\Theta') * \cos(\gamma)] + \text{theta offset}$$

$$\emptyset = \arcsin[\sin(\Theta') * \sin(\gamma)] + \text{phi offset}$$

A derivation and diagram of these relations is included in Appendix C (see Figure C-1).

The total response is normalized to a value requested by the user. While any value may be chosen, the most common and useful choices are either to the total system or to the individual beam itself (i.e., to the response at the MRA). System and self-normalizations can be calculated in the program by setting the flag appropriately; any other choice for normalization must be input by the user.

When the total normalized response and phase have been calculated, minor adjustments are made. The response is converted to a decibel level, with a lower limit set to -50 db. The phase angle is calculated using a four-quadrant arctangent function, and will have a value between ± 180 degrees.

As mentioned earlier, the program will take into account shaping of the beam due to module directivity. The equation for this shaping must be put into the program by the user, and should be normalized to one. The variable representing this factor is designated "H", and is found in both the normalization and main sections of the program.

The shaping factor is employed as a multiplier on the voltage response levels. The shaping factor currently in the model is

$$H=[.6+\cos(\theta)\cos(\emptyset)]^2/2.56$$

The equation above is an approximation to a cardioid pattern and will have a value between zero and one. Figure 4 shows a polar plot of this pattern. This directivity pattern is symmetric about the Z axis, and is shown in Figure 4 in the X-Z plane. It is not to be considered accurate in the region directly behind the face of the array. When running the program, a flag may be set to default to an omnidirectional pattern (i.e., H=1 over the entire space).

Additional calculations are performed in the program to give levels for the directivity index and equivalent beam patterns for use in reverberation calculations. The equivalent beam patterns here are calculated assuming identical transmit and receive beams. This should be taken into account when examining the output. Additionally, these values will only be valid when the program is run over the entire necessary space. For example, to get a good value for the directivity index, the total sphere should be run. Running over the entire sphere, however, requires knowledge of the beam pattern and module directivity for that entire region. A hemispherical run using θ and Ø between ± 90 degrees has in general proven to be satisfactory for a planar array, since contributions from behind the array are usually quite small. The angular resolution is left up to the user.

The following integrals are included in the program:

$$DI = 10*\log(4\pi) - 10*\log[\int_{\theta(1)}^{\theta(2)} \int_{\phi(1)}^{\phi(2)} b(\theta,\emptyset)*\cos(\emptyset)d\emptyset d\theta]$$

$$EBPVOL = 10*\log[\int_{\theta(1)}^{\theta(2)} \int_{\phi(1)}^{\phi(2)} b(\theta,\emptyset)*b'(\theta,\emptyset)*\cos(\emptyset)d\emptyset d\theta]$$

$$EBPSB = 10*\log[\int_{\theta(1)}^{\theta(2)} b(\theta,\emptyset(MRA))*b'(\theta,\emptyset(MRA))d\theta]$$

where DI is the directivity index and EBPVOL and EBPSB are the volume and surface/bottom equivalent beam patterns, respectively. The transmit and receive patterns are given by b'(Θ,Ø) and b(Θ,Ø), respectively. The program currently automatically sets the value of phi for the surface integration to the value of phi at the MRA. The limits on the integrals are set by the user. Theoretically, the limits should cover the entire sphere. However, as mentioned earlier, a hemisphere has generally been found to be satisfactory.

The integrations in the program are done numerically, using a rectangular integration method. A discussion of the method is included in Appendix D. As an example of the method's accuracy, the directivity index was calculated by the program for an omnidirectional voltage response and a cos(Θ)*cos(Ø) voltage reponse. Direct integrations were also done for these same integrals, and the resultant errors were calculated. The results are given below in Table 1.

TABLE 1. COMPARISON OF DIRECTIVITY INDEX (DI) CALCULATIONS

	Omnidirectional	cos(Θ)*cos(Ø)
Computer Calculation	0.0003 db	4.7713 db
Direct Integration	0.0000 db	4.7712 db

The error in the omnidirectional response is approximately .0003 db, while the cos(Θ)*cos(Ø) response has an error of approximately .0001 db. The integrations on the computer were done using a resolution of one degree in each direction. The error may be attributed to resolution error, and for most applications is negligible.

Table 2 below contains four sample calculations of equivalent beam patterns. All four patterns were calculated using the same receive beam (b(Θ,Ø) - see Appendix A for inputs), while the transmit pattern (b'(Θ,Ø)) was varied. For cases 3 and 4, the transmit patterns are cone shaped; within the cone specified, the pattern has the form of a zero decibel omnidirectional beam, while outside the cone it is assumed to have a negligible level.

TABLE 2. SAMPLE EQUIVALENT BEAM PATTERN (EBP) CALCULATIONS

1. b'(Θ,Ø) = b(Θ,Ø)
   a. EBPVOL = -14.7485 db
   b. EBPSB = -7.3586 db

2. $b'(\theta,\phi)$ = zero db omnidirectional
   a. EBPVOL = -11.7097 db
   b. EBPSB = -5.8553 db

3. $b'(\theta,\phi)$ = zero db omnidirectional out to receive pattern's -10 db points
   a. EBPVOL = -12.1470 db
   b. EBPSB = -6.0466 db

4. $b'(\theta,\phi)$ = zero db omnidirectional out to receive pattern's -3 db points
   a. EBPVOL = -13.6843 db
   b. EBPSB = -6.8339 db

Case 3 above approximates a constant transmit source level within the 10 db receive band width with the transmit beam falling off below -50 db outside. The result given in case 3 above is a good representation of the real-world system, since transmit beams will usually be shaped somewhere between a shaded beam and an omnidirectional beam. By comparing cases 1 through 3, it is reasonable to assume that when the source level is constant over the 10 db receive band width, the real-world equivalent volume beam pattern will be 2.6 db to 3 db higher than the program's calculation, while the equivalent surface/bottom beam pattern will be 1.3 db to 1.5 db higher than the program's calculation. Case 4 points out that using the receive pattern's -3 db points as a guide will give rise to an appreciable difference, and, depending on requirements, may or may not be an acceptable approximation.

SUMMARY

The computer program documented in this report is useful for determining the response of planar arrays. It may be used as an aid in determining the combination of amplitude and phase shading coefficients which will produce a desired beam pattern. The program will also prove useful in determining the effects of variations in frequency and wave propagation speed.

The results from the program will represent the theoretical limits of an array. Actual performance will most likely be somewhat degraded in production units, particularly in side lobe structures.

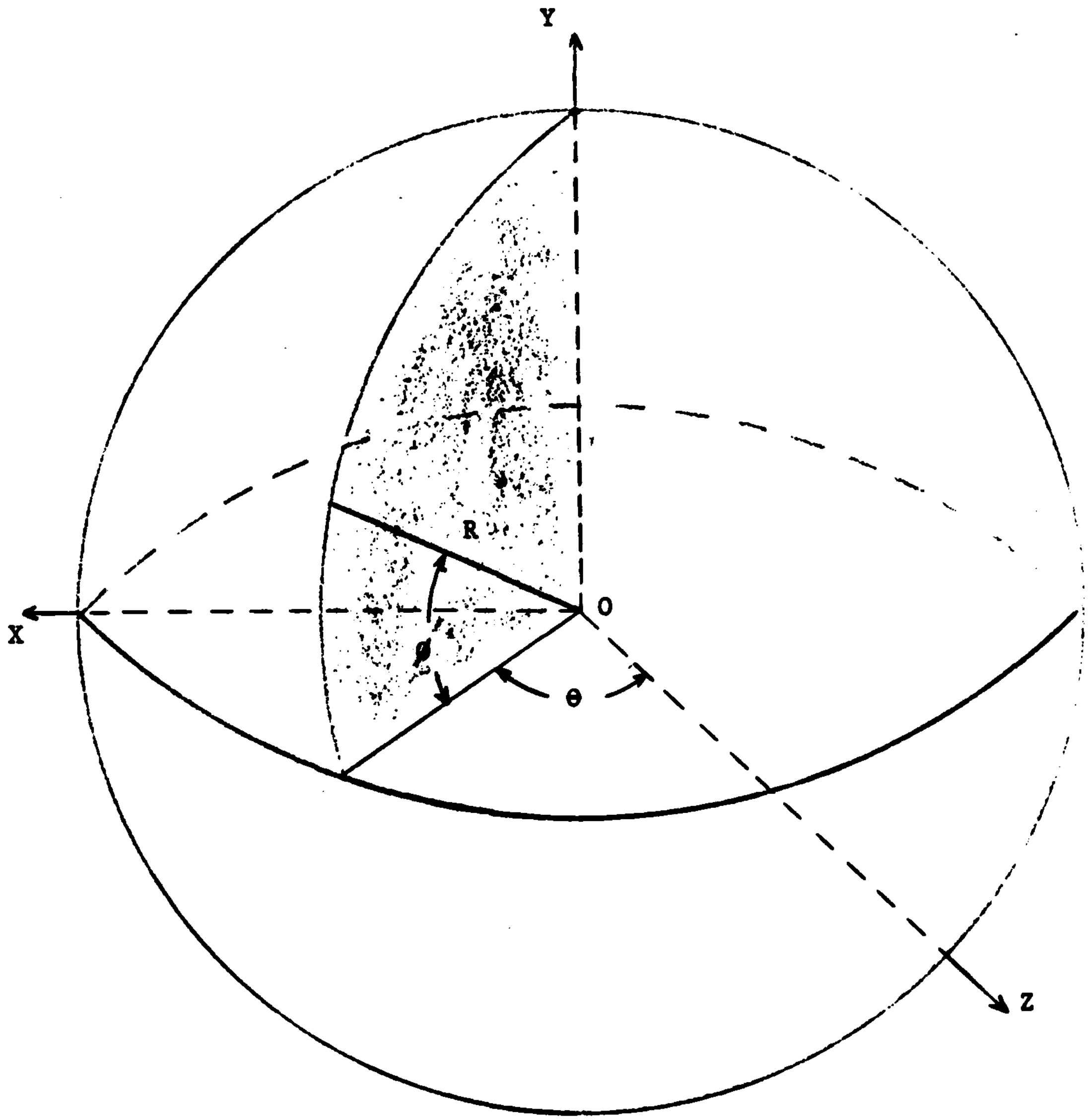

FIGURE 1. COORDINATE SYSTEM USED IN SIMULATION

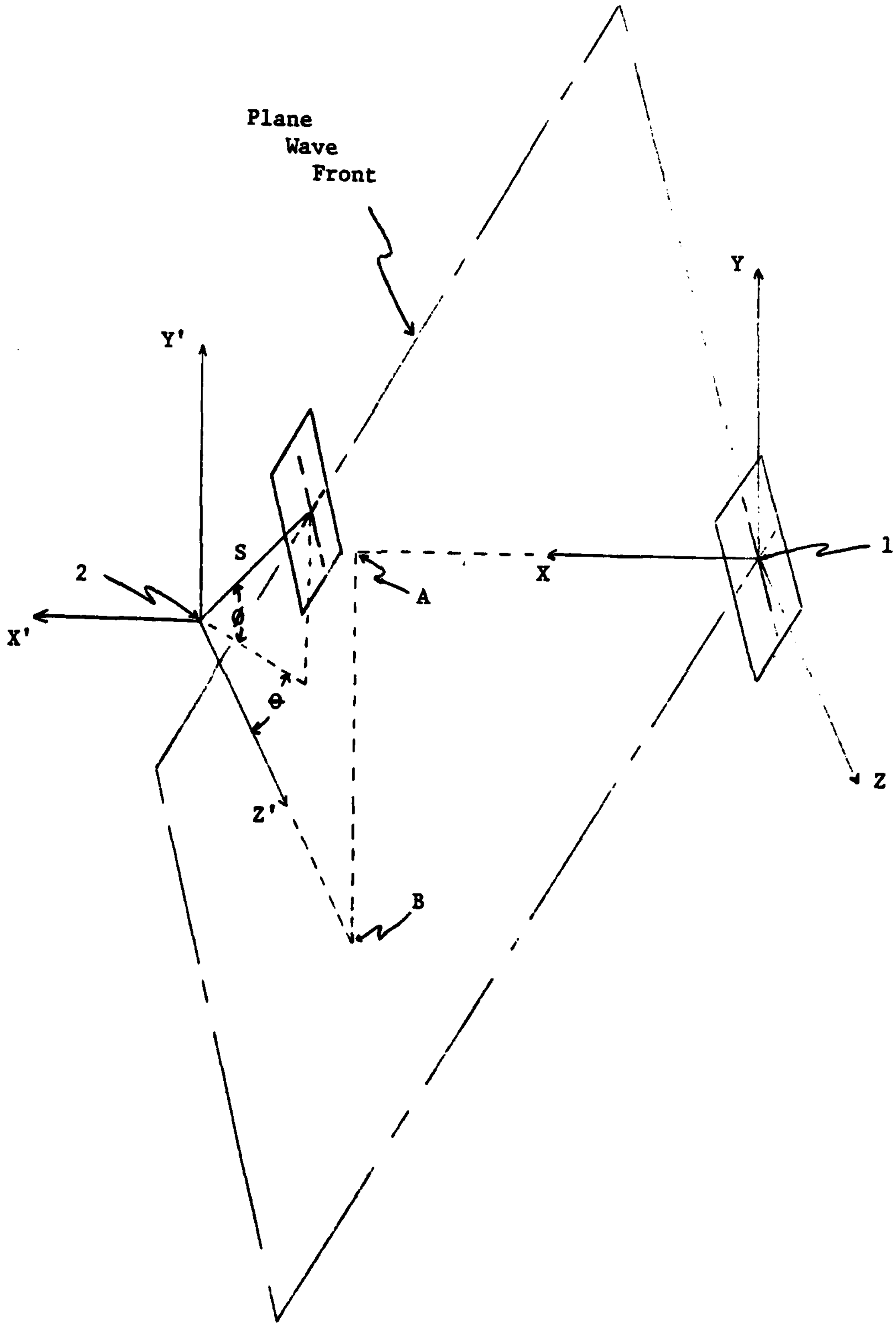

FIGURE 2. INCIDENT PLANE WAVE IN THREE DIMENSIONS

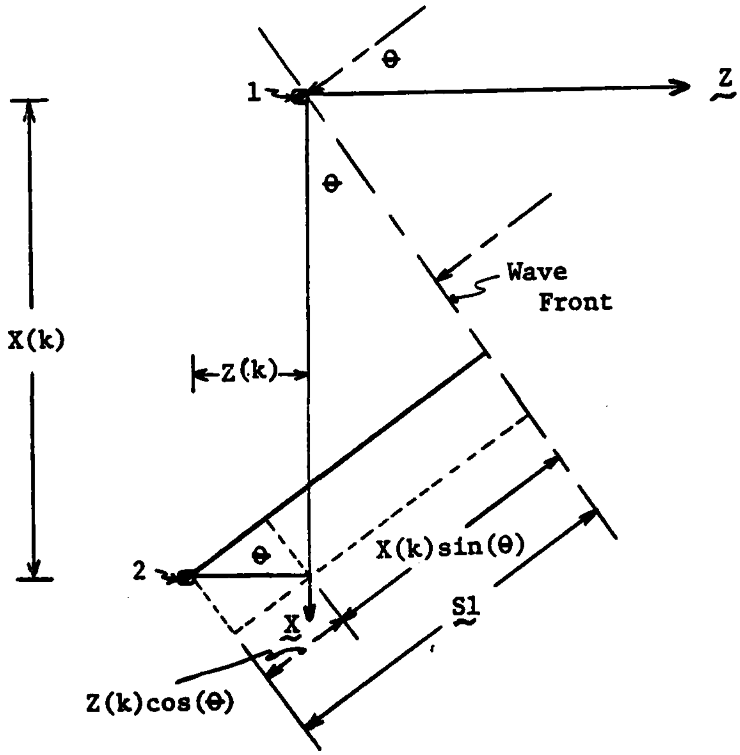

FIGURE 3(a). TWO MODULES LOCATED AT (0,0,0) AND (X(k),0,Z(k)) - PLANE WAVE INCIDENT IN DIRECTION OF (θ,0)

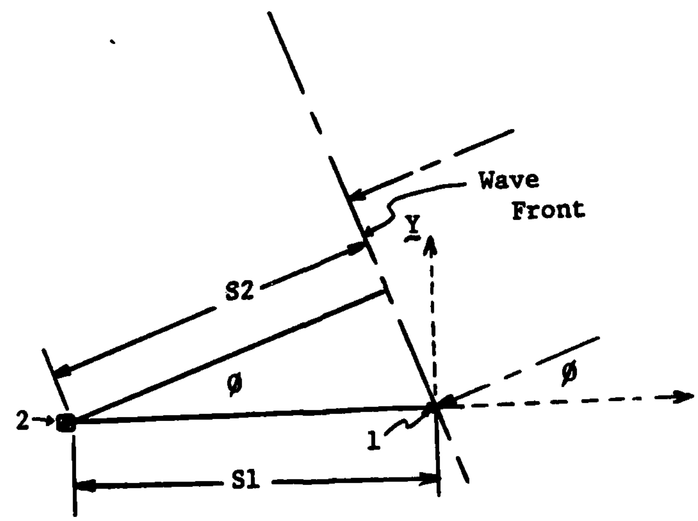

FIGURE 3(b). TWO MODULES LOCATED AT (0,0,0) AND (X(k),0,Z(k)) - PLANE WAVE INCIDENT IN DIRECTION OF (θ,Ø)

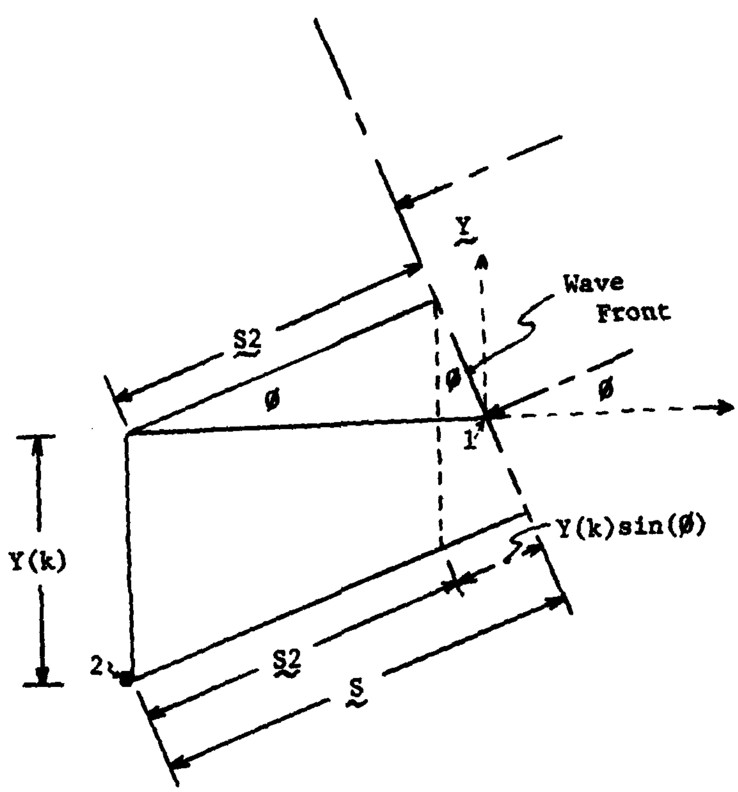

FIGURE 3(c). TWO MODULES LOCATED AT (0,0,0) AND (X(k),Y(k),Z(k)) - PLANE WAVE INCIDENT IN DIRECTION OF (θ,ø)

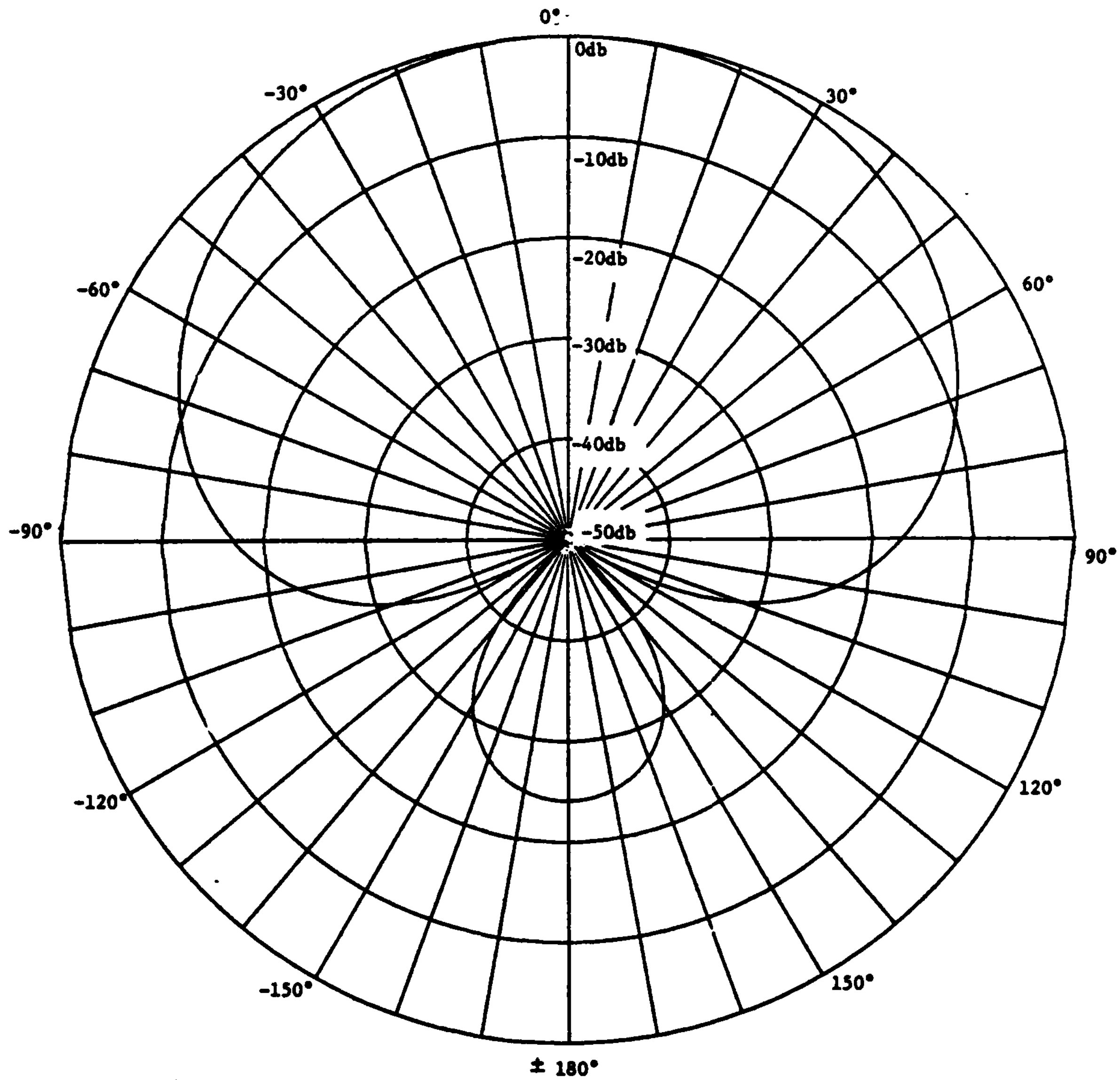

FIGURE 4. CARDIOID DIRECTIVITY PATTERN IN POLAR COORDINATES

APPENDIX A

INPUT VARIABLES

Inputs to the program are to be put into a data file called THRYPLT. The program references this file for all of its inputs, excluding matrices. The program uses four matrices which must be created by the user: X and Y positions, amplitude shading and phase shading. The X and Y position matrices give module locations, in inches, relative to the array center. The amplitude shading coefficients are given relative to a maximum value of one, and the phase shading coefficients are given in degrees. A Z position matrix will be required if the user foresees any Z dependence in the array. The input data file and matrices used to generate this report's output data are given in Figure A-1. Below is a list of the input variables and their definitions. Numbers to the left of the variable names correspond to the lines of data under INPUT DATA FILE in Figure A-1. Input numbers 2, 3, 4 and 6 are input with a character format. All of the other inputs use a free format, and decimal points are not required for real variables.

1. Phaseplot	Controls which plots will be made 0 = db vs. angle 1 = db vs. angle and phase vs. angle 2 = phase vs. angle 3 = no plots made
2. Filx	Name of the X position matrix
3. Fily	Name of the Y position matrix
4. Filr	Name of the amplitude shading matrix
5. Tscalc	Controls if phase matrix is to be input or calculated by the program 0 = input a matrix name 1 = program will calculate steering coefficients
6. Filt	Name of the phase shading matrix - present only if #5 is a 0
7. Loop Control	
a. La1	Input a 1
b. La2	Number of phi angles to be run
c. Inca	Input a 1
d. Lb1	Input a 1
e. Lb2	Number of theta angles to be run
f. Incb	Input a 1
g. Aresol	Resolution for phi loop (in degrees)
h. Bresol	Resolution for theta loop (in degrees)

	i. Astart	Starting position for phi (in degrees)
	j. Bstart	Starting position for theta (in degrees)

Note: Some loop control variables are used in the output sections of the program. The default values above should be used to insure correct output formats.

8.	a. F	Frequency of the wave (in kHz)
	b. C	Speed of wave in medium (in ft/sec)
	c. Nx	Number of columns in the array
	d. Ny	Number of rows in the array
9.	a. Vweap	Velocity of the weapon (in knots)
	b. Amainr	Value of phi (in degrees) at the MRA
	c. Bmainr	Value of theta (in degrees) at the MRA
	d. Norml	Normalization flag 0 = normalization is equal to the sum of the amplitude shading coefficients 1 = normalize to the beam itself 2 = normalize to an input value
	e. Freqfl	Controls if angular doppler shift is to be added into the frequency 0 = no 1 = yes
10.	Anorml	Normalization value (in decibels) - present only if #9-d is a 2
11.	Offlag	Controls if beam is to be offset to the MRA 0 = no 1 = yes
12.	Froll	Controls if a roll plane calculation is requested 0 = no 1 = yes
13.	Roll	Roll plane angle (in degrees) - present only if #12 is a 1
14.	Hflag	Controls the type of directivity shaping present 0 = the equation in the program is used 1 = an omnidirectional pattern is used
15.	FD,CD	Design frequency (kHz) and wave speed (ft/sec). Need to be present only if #5 is a 1.

```
INPUT DATA FILE

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
1 1 1 1 1e1 1 1 1 0 -90
50 5000 5 5
0 0 0 1 0
0
[illegible]
0

"X" ELEMENT LOCATION IN INCHES

2  1  0 -1 -2
2  1  0 -1 -2
2  1  0 -1 -2
2  1  0 -1 -2
2  1  0 -1 -2

"Y" ELEMENT LOCATION IN INCHES

 2  2  2  2  2
 1  1  1  1  1
 0  0  0  0  0
-1 -1 -1 -1 -1
-2 -2 -2 -2 -2

ELEMENT AMPLITUDE SHADING (RELATIVE)

0.25 0.50 0.75 0.50 0.25
0.50 0.75 1.00 0.75 0.50
0.75 1.00 1.00 1.00 0.75
0.50 0.75 1.00 0.75 0.50
0.25 0.50 0.75 0.50 0.25


ELEMENT PHASE DELAY IN DEGREES

0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
```

FIGURE A-1. PROGRAM INPUTS

APPENDIX B

OUTPUT FILES

The user has the option of selecting his outputs from the following list:

1. A formatted file combining an input list and selective outputs such as the directivity index.
   This file is found under FOR003.DAT (see Figure B-1).
2. A sequential file of decibel and phase data, sequenced according to the phi and theta loops.
   This file is found under FOR013.DAT.
3. A formatted file divided into two sections:
   a. decibel values vs. angle (see Figure B-2)
   b. phase angles vs. angle (see Figure B-3)
   These are found under FOR002.DAT.
4. A file containing plots of the output data:
   a. decibel values vs. angle (see Figure B-4)
   b. phase angles vs. angle (see Figure B-5)
   These plots are found under PLOTDAT.DAT

The angles used in the tables of output number 3 are for a specific plane requested by the user. For example, if the user specifies a pitch plane, the angles represent the values of θ. If a roll plane is requested, the angles in the tables represent values of θ'. Output number 3 should be used in conjunction with number 4 if the accuracy of the plots is insufficient. When no plots are requested (i.e., input number one is set to 3), the FOR002.DAT file has a slightly different format than above. It will contain all of the decibel and sign data generated by the program, and will have the pitch angles labeled at the top. However, this file will contain only the decibel level and sign of the real part of the voltage response. It will not contain the actual phase angle data in this mode (see Figure B-6). When using the program to generate plots, the FOR002.DAT file will contain the last set of decibel and phase data, as seen in Figures B-2 and B-3.

To use the plot routines in the program, the user must have access to a Digital DECwriter III or similar hardcopy terminal. In addition, the user must create a data file named PLOTDAT, having an available record length of at least 200. This is to be done using a file create routine from the computer, or in the OPEN statement for that file in the program. The attached program code currently uses a file created by a file create routine. To print the plots out, the following settings must be made on the terminal:

1. Horizontal print control is set to 16 characters/inch.
2. Vertical print control is set to 8 lines/inch.
3. Page size is set to 88 lines/page.

The required form size is approximately 15 inches wide by 11 inches long. The user must also set the terminal width to 200. On the VAX 11/780, the command which will set this is

'SET TERMINAL/WIDTH=200'.

The above settings should also be used if the user desires that the file FOR002.DAT fit into a standard 8-1/2 by 11 inch notebook. Reductions are necessary for the plots to fit into these same books.

When using the data plots, note should be taken of the degree of accuracy inherent in a computer; i.e., there is a finite limit. When using the phase vs. angle plot, it is seen that the values of the phase are between ±180 degrees. In terms of phase, -180 and 180 degrees are the same. However, the computer's finite limit in accuracy may cause the phasor to oscillate around this point, and be plotted at two different values.

When using the sign vs. angle plot (located under the db vs. angle plot), the "sign" term represents the sign of the real part of the total voltage response, i.e., whether it is positive or negative. This tells the user which quadrant set (1-4 or 2-3) the phasor is located in for a given angle. The points having a value of 0 for sign are artificially set to that value to tell the user that the value (in decibels) has gone below -50 db.

If the user requests the program to calculate the phase steering matrix, it will be output to a file named FOR020.DAT. The user should rename this file to reflect its contents. For example, if the file contains phase steering data for a (10,10) steer, the file might be renamed to T1010.DAT to remind the user that the file contains "T" data for a "(10,10)" steer angle.

```
LA1=   1    LA2= 181    INCA=   1    ARESOL= 1.00   ASTART= -90.00
LB1=   1    LB2= 181    INCB=   1    BRESOL= 1.00   BSTART= -90.00

ROLL FLAG=   0.     ROLL ANGLE=    0.00  DEGREES

FREQ.(KHZ)=  50.000     SND. SPD.(F/S)=5000.     NX=   5     NY=   5

AMAINR=     0.00   BMAINR=     0.00   VWEAP (KNOTS)=     0.00

PLOTTING FLAG=   1.     FREQFL=   0.

NORML=  1     NORMALIZATION FACTOR (DB)=   24.0824

DIRECTIVITY INDEX=   22.7025

A OFFSET=    0.00     B OFFSET=    0.00    HFLAG=   0.     TSCALC=   0.

EQ BEAM PATTERN-VOL=  -14.7486     EQ BEAM PATTERN-S,B=   -7.3586
$
```

FIGURE B-1. INPUT/OUTPUT SUMMARY FILE

ANGLE	DB	SIGN	ANGLE	DB	SIGN	ANGLE	DB	SIGN	ANGLE	DB	SIGN	ANGLE	DB	SIGN
-90.0	-25.9	1.	-89.0	-25.4	1.	-88.0	-25.0	1.	-87.0	-24.6	1.	-86.0	-24.3	1.
-85.0	-24.0	1.	-84.0	-23.8	1.	-83.0	-23.6	1.	-82.0	-23.4	1.	-81.0	-23.3	1.
-80.0	-23.3	1.	-79.0	-23.4	1.	-78.0	-23.5	1.	-77.0	-23.6	1.	-76.0	-23.9	1.
-75.0	-24.3	1.	-74.0	-24.7	1.	-73.0	-25.3	1.	-72.0	-26.0	1.	-71.0	-26.9	1.
-70.0	-28.0	1.	-69.0	-29.5	1.	-68.0	-31.3	1.	-67.0	-33.8	1.	-66.0	-37.5	1.
-65.0	-44.2	1.	-64.0	-50.0	0.	-63.0	-41.5	-1.	-62.0	-36.2	-1.	-61.0	-33.1	-1.
-60.0	-31.0	-1.	-59.0	-29.4	-1.	-58.0	-28.3	-1.	-57.0	-27.5	-1.	-56.0	-27.0	-1.
-55.0	-26.8	-1.	-54.0	-26.9	-1.	-53.0	-27.2	-1.	-52.0	-27.9	-1.	-51.0	-29.0	-1.
-50.0	-30.7	-1.	-49.0	-33.5	-1.	-48.0	-38.5	-1.	-47.0	-50.0	0.	-46.0	-40.1	1.
-45.0	-33.2	1.	-44.0	-29.3	1.	-43.0	-26.6	1.	-42.0	-24.7	1.	-41.0	-23.2	1.
-40.0	-22.1	1.	-39.0	-21.2	1.	-38.0	-20.7	1.	-37.0	-20.4	1.	-36.0	-20.4	1.
-35.0	-20.6	1.	-34.0	-21.2	1.	-33.0	-22.1	1.	-32.0	-23.5	1.	-31.0	-25.6	1.
-30.0	-28.9	1.	-29.0	-34.9	1.	-28.0	-50.0	0.	-27.0	-34.1	-1.	-26.0	-28.5	-1.
-25.0	-25.4	-1.	-24.0	-23.6	-1.	-23.0	-22.6	-1.	-22.0	-22.2	-1.	-21.0	-22.6	-1.
-20.0	-23.9	-1.	-19.0	-26.9	-1.	-18.0	-34.8	-1.	-17.0	-35.2	1.	-16.0	-24.2	1.
-15.0	-18.3	1.	-14.0	-15.2	1.	-13.0	-12.3	1.	-12.0	-10.0	1.	-11.0	-8.1	1.
-10.0	-6.5	1.	-9.0	-5.2	1.	-8.0	-4.0	1.	-7.0	-3.0	1.	-6.0	-2.2	1.
-5.0	-1.5	1.	-4.0	-0.9	1.	-3.0	-0.5	1.	-2.0	-0.2	1.	-1.0	-0.1	1.
0.0	0.0	1.	1.0	-0.1	1.	2.0	-0.2	1.	3.0	-0.5	1.	4.0	-0.9	1.
5.0	-1.5	1.	6.0	-2.2	1.	7.0	-3.0	1.	8.0	-4.0	1.	9.0	-5.2	1.
10.0	-6.5	1.	11.0	-8.1	1.	12.0	-10.0	1.	13.0	-12.3	1.	14.0	-15.2	1.
15.0	-18.3	1.	16.0	-24.2	1.	17.0	-35.2	1.	18.0	-34.8	-1.	19.0	-26.9	-1.
20.0	-23.9	-1.	21.0	-22.6	-1.	22.0	-22.2	-1.	23.0	-22.6	-1.	24.0	-23.6	-1.
25.0	-25.4	-1.	26.0	-28.5	-1.	27.0	-34.1	-1.	28.0	-50.0	0.	29.0	-34.9	1.
30.0	-28.9	1.	31.0	-25.6	1.	32.0	-23.5	1.	33.0	-22.1	1.	34.0	-21.2	1.
35.0	-20.6	1.	36.0	-20.4	1.	37.0	-20.4	1.	38.0	-20.7	1.	39.0	-21.2	1.
40.0	-22.1	1.	41.0	-23.2	1.	42.0	-24.7	1.	43.0	-26.6	1.	44.0	-29.3	1.
45.0	-33.2	1.	46.0	-40.1	1.	47.0	-50.0	0.	48.0	-38.5	-1.	49.0	-33.5	-1.
50.0	-30.7	-1.	51.0	-29.0	-1.	52.0	-27.9	-1.	53.0	-27.2	-1.	54.0	-26.9	-1.
55.0	-26.8	-1.	56.0	-27.0	-1.	57.0	-27.5	-1.	58.0	-28.3	-1.	59.0	-29.4	-1.
60.0	-31.0	-1.	61.0	-33.1	-1.	62.0	-36.2	-1.	63.0	-41.5	-1.	64.0	-50.0	0.
65.0	-44.2	1.	66.0	-37.5	1.	67.0	-33.8	1.	68.0	-31.3	1.	69.0	-29.5	1.
70.0	-28.0	1.	71.0	-26.9	1.	72.0	-26.0	1.	73.0	-25.3	1.	74.0	-24.7	1.
75.0	-24.3	1.	76.0	-23.9	1.	77.0	-23.6	1.	78.0	-23.5	1.	79.0	-23.4	1.
80.0	-23.3	1.	81.0	-23.3	1.	82.0	-23.4	1.	83.0	-23.6	1.	84.0	-23.8	1.
85.0	-24.0	1.	86.0	-24.3	1.	87.0	-24.6	1.	88.0	-25.0	1.	89.0	-25.4	1.
90.0	-25.9	1.	0.0	0.0	0.	0.0	0.0	0.	0.0	0.0	0.	0.0	0.0	0.

FIGURE B-2. DECIBEL VS. ANGLE FILE

ANGLE	PHASE	ANGLE	PHASE	ANGLE	PHASE	ANGLE	PHASE	ANGLE	PHASE
-90.0	0.0	-89.0	0.0	-88.0	0.0	-87.0	0.0	-86.0	0.0
-85.0	0.0	-84.0	0.0	-83.0	0.0	-82.0	0.0	-81.0	0.0
-80.0	0.0	-79.0	0.0	-78.0	0.0	-77.0	0.0	-76.0	0.0
-75.0	0.0	-74.0	0.0	-73.0	0.0	-72.0	0.0	-71.0	0.0
-70.0	0.0	-69.0	0.0	-68.0	0.0	-67.0	0.0	-66.0	0.0
-65.0	0.0	-64.0	180.0	-63.0	180.0	-62.0	-180.0	-61.0	180.0
-60.0	180.0	-59.0	-180.0	-58.0	180.0	-57.0	180.0	-56.0	180.0
-55.0	180.0	-54.0	180.0	-53.0	180.0	-52.0	180.0	-51.0	180.0
-50.0	180.0	-49.0	180.0	-48.0	180.0	-47.0	180.0	-46.0	0.0
-45.0	0.0	-44.0	0.0	-43.0	0.0	-42.0	0.0	-41.0	0.0
-40.0	0.0	-39.0	0.0	-38.0	0.0	-37.0	0.0	-36.0	0.0
-35.0	0.0	-34.0	0.0	-33.0	0.0	-32.0	0.0	-31.0	0.0
-30.0	0.0	-29.0	0.0	-28.0	180.0	-27.0	180.0	-26.0	180.0
-25.0	180.0	-24.0	180.0	-23.0	180.0	-22.0	-180.0	-21.0	-180.0
-20.0	-180.0	-19.0	-180.0	-18.0	-180.0	-17.0	0.0	-16.0	0.0
-15.0	0.0	-14.0	0.0	-13.0	0.0	-12.0	0.0	-11.0	0.0
-10.0	0.0	-9.0	0.0	-8.0	0.0	-7.0	0.0	-6.0	0.0
-5.0	0.0	-4.0	0.0	-3.0	0.0	-2.0	0.0	-1.0	0.0
0.0	0.0	1.0	0.0	2.0	0.0	3.0	0.0	4.0	0.0
5.0	0.0	6.0	0.0	7.0	0.0	8.0	0.0	9.0	0.0
10.0	0.0	11.0	0.0	12.0	0.0	13.0	0.0	14.0	0.0
15.0	0.0	16.0	0.0	17.0	0.0	18.0	180.0	19.0	180.0
20.0	180.0	21.0	180.0	22.0	180.0	23.0	180.0	24.0	180.0
25.0	180.0	26.0	180.0	27.0	180.0	28.0	180.0	29.0	0.0
30.0	0.0	31.0	0.0	32.0	0.0	33.0	0.0	34.0	0.0
35.0	0.0	36.0	0.0	37.0	0.0	38.0	0.0	39.0	0.0
40.0	0.0	41.0	0.0	42.0	0.0	43.0	0.0	44.0	0.0
45.0	0.0	46.0	0.0	47.0	180.0	48.0	180.0	49.0	180.0
50.0	180.0	51.0	180.0	52.0	180.0	53.0	180.0	54.0	180.0
55.0	-180.0	56.0	180.0	57.0	-180.0	58.0	-180.0	59.0	180.0
60.0	-180.0	61.0	180.0	62.0	180.0	63.0	-180.0	64.0	-180.0
65.0	0.0	66.0	0.0	67.0	0.0	68.0	0.0	69.0	0.0
70.0	0.0	71.0	0.0	72.0	0.0	73.0	0.0	74.0	0.0
75.0	0.0	76.0	0.0	77.0	0.0	78.0	0.0	79.0	0.0
80.0	0.0	81.0	0.0	82.0	0.0	83.0	0.0	84.0	0.0
85.0	0.0	86.0	0.0	87.0	0.0	88.0	0.0	89.0	0.0
90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

FIGURE B-3. PHASE VS. ANGLE FILE

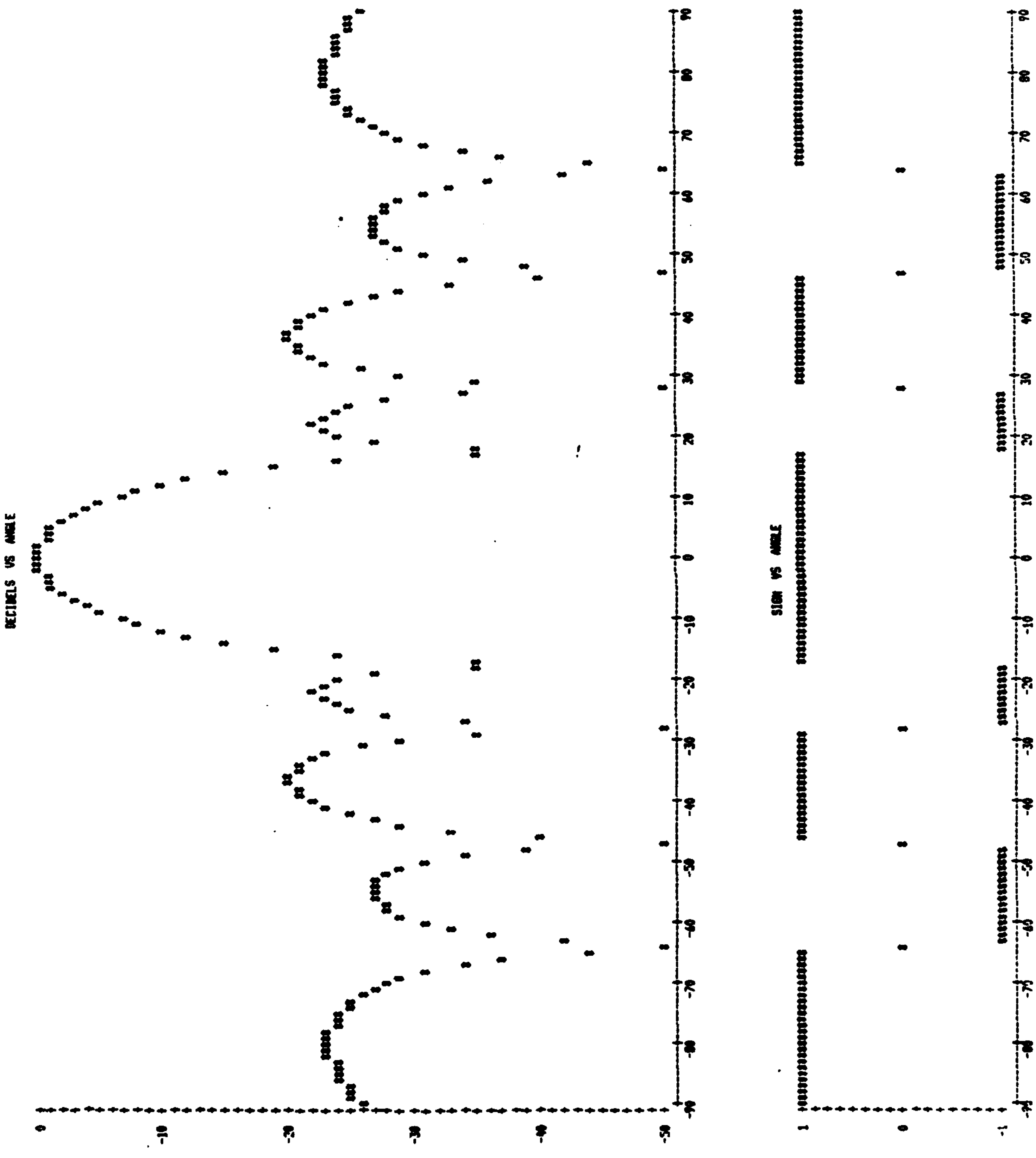

FIGURE B-4. DECIBEL VS. ANGLE PLOT

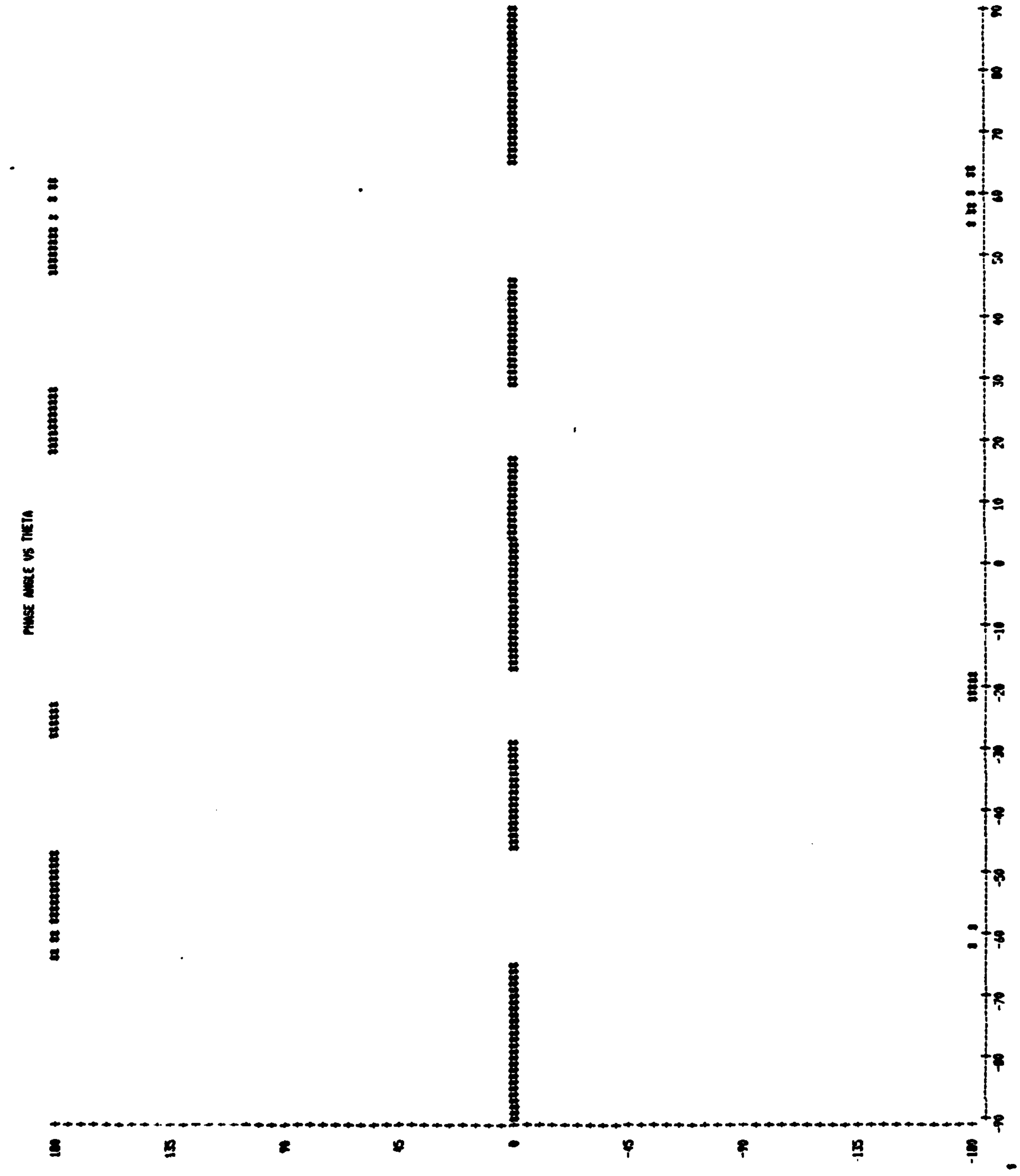

FIGURE B-5. PHASE VS. ANGLE PLOT

PITCH	-2.00		-1.00		0.00		1.00		2.00	
AZ	DB	+/-	DB	+/-	DB	+/-	DB	+/-	DB	+/-
-20.00	-23.9	-1.	-23.9	-1.	-23.9	-1.	-23.9	-1.	-23.9	-1.
-19.00	-26.8	-1.	-26.9	-1.	-26.9	-1.	-26.9	-1.	-26.8	-1.
-18.00	-34.3	-1.	-34.7	-1.	-34.8	-1.	-34.7	-1.	-34.3	-1.
-17.00	-36.3	1.	-35.5	1.	-35.2	1.	-35.5	1.	-36.3	1.
-16.00	-24.6	1.	-24.3	1.	-24.2	1.	-24.3	1.	-24.6	1.
-15.00	-19.2	1.	-18.9	1.	-18.8	1.	-18.9	1.	-19.2	1.
-14.00	-15.5	1.	-15.2	1.	-15.2	1.	-15.2	1.	-15.5	1.
-13.00	-12.6	1.	-12.4	1.	-12.3	1.	-12.4	1.	-12.6	1.
-12.00	-10.3	1.	-10.1	1.	-10.0	1.	-10.1	1.	-10.3	1.
-11.00	-8.4	1.	-8.2	1.	-8.1	1.	-8.2	1.	-8.4	1.
-10.00	-6.8	1.	-6.6	1.	-6.5	1.	-6.6	1.	-6.8	1.
-9.00	-5.4	1.	-5.2	1.	-5.2	1.	-5.2	1.	-5.4	1.
-8.00	-4.2	1.	-4.1	1.	-4.0	1.	-4.1	1.	-4.2	1.
-7.00	-3.2	1.	-3.1	1.	-3.0	1.	-3.1	1.	-3.2	1.
-6.00	-2.4	1.	-2.2	1.	-2.2	1.	-2.2	1.	-2.4	1.
-5.00	-1.7	1.	-1.6	1.	-1.5	1.	-1.6	1.	-1.7	1.
-4.00	-1.2	1.	-1.0	1.	-0.9	1.	-1.0	1.	-1.2	1.
-3.00	-0.8	1.	-0.6	1.	-0.5	1.	-0.6	1.	-0.8	1.
-2.00	-0.5	1.	-0.3	1.	-0.2	1.	-0.3	1.	-0.5	1.
-1.00	-0.3	1.	-0.1	1.	-0.1	1.	-0.1	1.	-0.3	1.
0.00	-0.2	1.	-0.1	1.	0.0	1.	-0.1	1.	-0.2	1.
1.00	-0.3	1.	-0.1	1.	-0.1	1.	-0.1	1.	-0.3	1.
2.00	-0.5	1.	-0.3	1.	-0.2	1.	-0.3	1.	-0.5	1.
3.00	-0.8	1.	-0.6	1.	-0.5	1.	-0.6	1.	-0.8	1.
4.00	-1.2	1.	-1.0	1.	-0.9	1.	-1.0	1.	-1.2	1.
5.00	-1.7	1.	-1.6	1.	-1.5	1.	-1.6	1.	-1.7	1.
6.00	-2.4	1.	-2.2	1.	-2.2	1.	-2.2	1.	-2.4	1.
7.00	-3.2	1.	-3.1	1.	-3.0	1.	-3.1	1.	-3.2	1.
8.00	-4.2	1.	-4.1	1.	-4.0	1.	-4.1	1.	-4.2	1.
9.00	-5.4	1.	-5.2	1.	-5.2	1.	-5.2	1.	-5.4	1.
10.00	-6.8	1.	-6.6	1.	-6.5	1.	-6.6	1.	-6.8	1.
11.00	-8.4	1.	-8.2	1.	-8.1	1.	-8.2	1.	-8.4	1.
12.00	-10.3	1.	-10.1	1.	-10.0	1.	-10.1	1.	-10.3	1.
13.00	-12.6	1.	-12.4	1.	-12.3	1.	-12.4	1.	-12.6	1.
14.00	-15.5	1.	-15.2	1.	-15.2	1.	-15.2	1.	-15.5	1.
15.00	-19.2	1.	-18.9	1.	-18.8	1.	-18.9	1.	-19.2	1.
16.00	-24.6	1.	-24.3	1.	-24.2	1.	-24.3	1.	-24.6	1.
17.00	-36.3	1.	-35.5	1.	-35.2	1.	-35.5	1.	-36.3	1.
18.00	-34.3	-1.	-34.7	-1.	-34.8	-1.	-34.7	-1.	-34.3	-1.
19.00	-26.8	-1.	-26.9	-1.	-26.9	-1.	-26.9	-1.	-26.8	-1.
20.00	-23.9	-1.	-23.9	-1.	-23.9	-1.	-23.9	-1.	-23.9	-1.

$

FIGURE B-6. DECIBEL VS. ANGLE FILE/NO PLOTS REQUESTED

APPENDIX C

CONVERSION FROM ROLL PLANE TO REAL-SPACE COORDINATES

Following is a development of the equations used to convert from a given roll angle and theta prime to the real-space coordinates theta (Θ) and phi (Ø). The angles theta and phi are as noted earlier.

In Figure C-1, the angle gamma (γ) is the roll plane angle and theta prime (Θ') is the angle from the axis on that roll plane.

Using Figure C-1, the following relationships may be written down for the four angles mentioned above:

i) tan(Θ) = S/R
ii) sin(Θ) = S/P
iii) cos(Θ) = R/P
iv) tan(Ø) = W/P
v) sin(Ø) = W/Q
vi) cos(Ø) = P/Q
vii) tan(γ) = W/S
viii) sin(γ) = W/T
ix) cos(γ) = S/T
x) tan(Θ') = T/R
xi) sin(Θ') = T/Q
xii) cos(Θ') = R/Q

where the letters P, Q, R, S, T and W are the lengths designated in Figure C-1.

Combining equations (i), (ix) and (x), the following relation may be seen:

$$\cos(\gamma)*\tan(\Theta') = S/T*T/R = S/R = \tan(\Theta)$$

which leads to the relation

$$\Theta = \arctan(\tan(\Theta')*\cos(\gamma))$$

Combining equations (v),(viii) and (xi), the following relation may be seen:

$$\sin(\gamma)*\sin(\Theta') = W/T*T/Q = W/Q = \sin(\emptyset)$$

which gives

$$\phi = \arcsin(\sin(\theta')*\sin(\gamma))$$

These equations are then used in the program to make the necessary transformations. Theta and phi offsets are added to the theta and phi equations, respectively, to change the location of the roll axis.

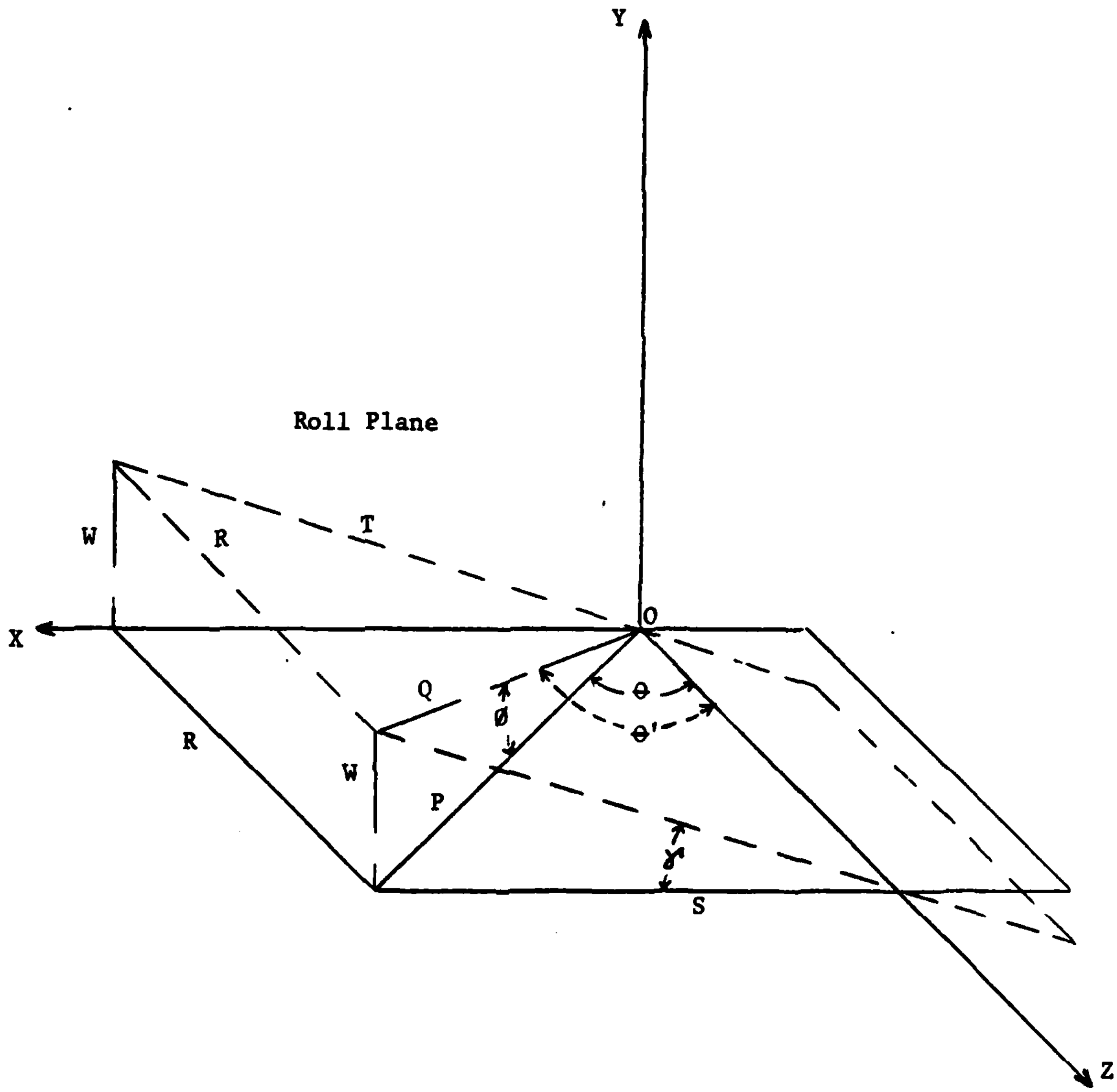

FIGURE C-1. REPRESENTATION OF ROLL PLANE IN SPACE COORDINATES

APPENDIX D

INTEGRATION TECHNIQUE

The integrations done in the program are done in spherical coordinates, using integrals of the form

$$I = \int_{\theta(1)}^{\theta(2)} \int_{\phi(1)}^{\phi(2)} F*\cos(\phi)d\phi d\theta$$

where F represents a beam pattern (or product of beam patterns) and $\theta(1)$, $\theta(2)$, $\phi(1)$ and $\phi(2)$ are the integration limits.

The computer program performs the integrations numerically using the Newton-Cotes method of degree zero. A resolution of one degree has normally been used, along with the mid-point rule. Any other resolution may be chosen; thus far, one degree has been found to be satisfactory.

The degree zero Newton-Cotes method sets the entire interval used to the value at the interval's mid-point. The accuracy of this method depends directly on the second derivative (f'') of the curve over the intervals. This may also be thought of as the derivative of the slope over each interval. If the slope over an interval is constant (f''=0), the error for that interval will approach zero, while a large change in the slope over the interval will result in a large error for that interval. For the two beams analyzed in Table 1 (see page 9), the slopes were mainly slow changing, and the one-degree resolution gave a very small error.

For the sonar beam created for this report, a large value of f'' was found at the null points. However, the levels at these points are so depressed that the resulting relative error is very small. For this beam (see the inputs in Appendix A), two separate directivity index integrations were run: the first was over the entire hemisphere, while the second used only those points contained in the main lobe (θ and ϕ between $\pm$17 degrees). The result for the hemispherical run was 22.7025 db, while the main lobe integration yielded a value of 23.0245 db. For this beam, then, the side lobe contribution was less than .33 db. While this is one discrete case, it is seen that eliminating all of the null points and side lobes did not drastically change the result. The user is cautioned to check his beams as he creates them to see that his values for f'' are small over his range of interest. To increase the degree of accuracy, the user may reduce the interval size. However, a decrease in the interval size will result in an increase in run time. For example, decreasing the interval size from one degree to one half of a degree in each direction will result in an increase in run time of almost four times.

Figure D-1 is a representation of the interval used in the integrations. The delta area is centered at (Θ,Ø). R represents the intensity of the beam at (Θ,Ø). The area can be approximated as a rectangle, whose sides are the segments labeled 2 and 3. For small values of dΘ and dØ, arc lengths can be approximated by their corresponding chord lengths. Then as shown in Figure D-1, segment 3 is equal to dØ, while segment 2 is approximately equal to segment 1 times the cosine of Ø, namely cos(Ø)dΘ. Multiplying segments 2 and 3 gives a value for the delta area of cos(Ø)dØdΘ. For small values of dØ, surface 2 will vary less than .01 percent from (Ø-(dØ/2)) to (Ø+(dØ/2)), making the approximation used quite reasonable.

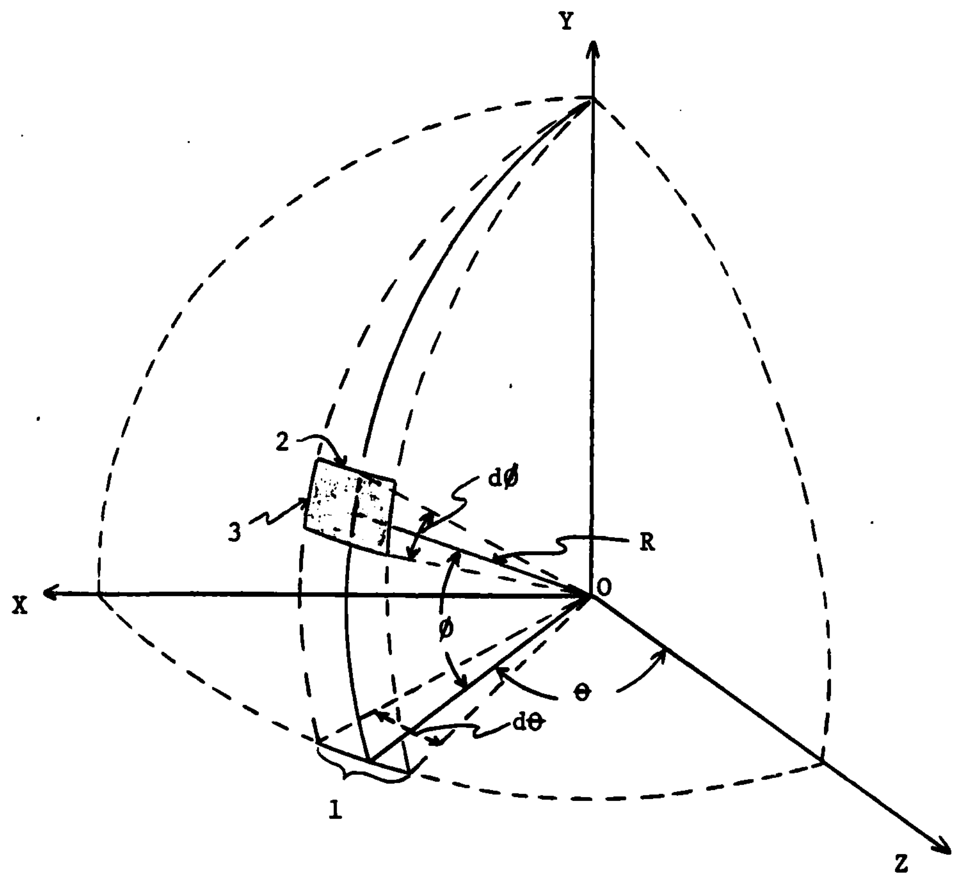

FIGURE D-1. DIFFERENTIAL AREA USED FOR INTEGRATIONS

APPENDIX E

PROGRAM LISTING

```
C     PROGRAM BPATRN(INPUT,OUTPUT,TAPE2,TAPE3,TAPE9,TAPE10,TAPE11,
C     TAPE5,TAPE12)
      DIMENSION X(8,8),T(8,8),Y(8,8),R(8,8)
      DIMENSION A(365),B(365)
      DIMENSION V1(365),V2(365),V3(365),V4(365),V5(365),
     *SS1(365),SS2(365),SS3(365),SS4(365),SS5(365)
      DOUBLE PRECISION TB(10),TC(10)
      INTEGER AA,BB
      REAL*8 FILX
      REAL*8 FILY
      REAL*8 FILR
      REAL*8 FILT
C
C     THE ARRAYS MAY BE DIMENSIONED TO HANDLE ANY REASONABLE
C  NUMBER OF ANGLES.  TB AND TC ARE ARRAYS USED FOR PRINTING
C  OUT DATA.
C     FOR INPUT,USUALLY LET LA1=LB1=INCA=INCB=1.  LA2=NUMBER
C  OF PITCH ANGLES AND LB2=NUMBER OF HORIZONTAL ANGLES REQUESTED.
C  ARESOL AND BRESOL ARE THE RESOLUTIONS FOR PITCH AND HORIZ.
C  ANGLES, RESPECTIVELY.  ASTART AND BSTART ARE THE STARTING POINTS
C  OF SAME.
C     NX IS THE NUMBER OF ROWS OF MODULES AND NY IS THE NUMBER
C  OF COLUMNS.
C     NORML IS THE FLAG FOR NORMALIZATION.
C     ROLL IS THE ROLL ANGLE TO BE PLOTTED.  VWEAP IS THE
C  WEAPON'S VELOCITY(IN KNOTS), AND AMAINR AND BMAINR DESIGNATE
C  THE MAIN RESPONSE AXIS(PITCH AND HORIZ. ANGLES, RESPECTIVELY).
C
      OPEN(UNIT=25,TYPE='OLD',NAME='PLOTDAT')
      OPEN(UNIT=45,TYPE='OLD',NAME='THRYPLT')
      AOFSET=0.
      BOFSET=0.
      ANORML=0.
      DI=-777.
      ROLL=0.
      PI=3.14159
      DTR=.0174533
      OFFLAG=0.
      READ(45,*)PHASEPLOT
      READ(45,950)FILX
      OPEN(UNIT=9,TYPE='OLD',NAME=FILX)
      READ(45,950)FILY
```

```
      OPEN(UNIT=10,TYPE='OLD',NAME=FILY)
      READ(45,950)FILR
      OPEN(UNIT=11,TYPE='OLD',NAME=FILR)
      READ(45,*)TSCALC
      IF(TSCALC.EQ.1.)GO TO 75
      READ(45,950)FILT
      OPEN(UNIT=12,TYPE='OLD',NAME=FILT)
  950 FORMAT(A)
   75  CONTINUE
      READ(45,*)LA1,LA2,INCA,LB1,LB2,INCB,ARESOL,BRESOL,ASTART,BSTART
      READ(45,*)F,C,NX,NY
C
C  FLAGS ARE TO BE ENTERED AS FOLLOWS:  A #1# MEANS GO, AND
C  ANYTHING ELSE WILL BE TAKEN TO MEAN NO GO.
C
      READ(45,*)VWEAP,AMAINR,BMAINR,NORML,FREQFL
      PCHEBP=AMAINR
      IF(NORML.NE.2)GO TO 70
      READ(45,*)ANORML
      ANORML=10**(ANORML/20)
   70 CONTINUE
      READ(45,*)OFFLAG
      IF(OFFLAG.NE.1)GO TO 78
      AOFSET=AMAINR
      BOFSET=BMAINR
   78 CONTINUE
      READ(45,*)FROLL
      IF(FROLL.NE.1)GO TO 71
      READ(45,*)ROLL
   71 CONTINUE
      READ(45,*)HFLAG
      READ (9,*)((X(I,J),J=1,NX),I=1,NY)
      READ (10,*)((Y(I,J),J=1,NX),I=1,NY)
      READ (11,*)((R(I,J),J=1,NX),I=1,NY)
      IF(TSCALC.EQ.0)GO TO 72
      CALL PHASTR(X,Y,R,T,NX,NY,AMAINR,BMAINR,PI,DTR)
      GO TO 73
   72 CONTINUE
      READ (12,*)((T(I,J),J=1,NX),I=1,NY)
   73 CONTINUE
C  CHANGE VWEAP FROM KNOTS TO FT/SEC
      VWEAP=VWEAP*1.689
C  COMPUTE NUMBER OF ENABLED ARRAYS
      RT=0
      DO 5 I=1,NY
      DO 4 J=1,NX
      RT=RT+R(I,J)
    4 CONTINUE
    5 CONTINUE
C  SUMIN1 AND SUMIN2 ARE THE VOLUME AND SURFACE(BOTTOM) EQUIV.
C  BEAM PATTERNS.  INTEGRATIONS ARE DONE BY SIMPLY SUMMING UP
C  OVER THE VOLUME OR SURFACE IN INCREMENTS OF THE APPROPRIATE
C  RESOLUTION(S).  THE VOLUME INTEGRAL MUST BE DONE OVER THE EN-
```

```
C   TIRE VOLUME TO HAVE ANY MEANING, AND THE SURFACE(BOTTOM) IN-
C   TEGRAL IS TAKEN AT THE LARGEST POINT, USUALLY 0 DEGREE PITCH.
       SUMIN1=0
       SUMIN2=0
       DIINT=0
       W=(2*PI*F*(C+VWEAP)*1000)/(C*12*(C-VWEAP))
       IF(NORML.NE.1)GO TO 1
C   CALCULATE THE NORMALIZATION VALUE (ANORML)
       IF(FROLL.EQ.0)GO TO 74
       IF(FROLL.EQ.1)AMAINR=(ASIN(SIN(ROLL*DTR)*SIN(BMAINR*DTR)))/DTR
       IF(FROLL.EQ.1)BMAINR=(ATAN(TAN(BMAINR*DTR)*COS(ROLL*DTR)))/DTR
       IF(FROLL.EQ.1.AND.OFFLAG.NE.1)GO TO 74
       AMAINR=AOFSET
       BMAINR=BOFSET
    74 CAMR=COS(AMAINR*DTR)
       SAMR=SIN(AMAINR*DTR)
       CBMR=COS(BMAINR*DTR)
       SBMR=SIN(BMAINR*DTR)
       E=1
       H=((.6+CAMR*CBMR)**2)/2.56
       IF(HFLAG.EQ.1)H=1
       IF(H.LT.0.)H=-H
       RRT=0
       AIIT=0
       DO 611 I=1,NY
       DO 612 J=1,NX
       DDD=(W*(X(I,J)*SBMR*CAMR+Y(I,J)*SAMR)+T(I,J)*DTR)
       RR=R(I,J)*COS(DDD)
       AII=R(I,J)*SIN(DDD)
       RRT=RRT+RR
       AIIT=AIIT+AII
   612 CONTINUE
   611 CONTINUE
       ANORML=H*SQRT(RRT**2 + AIIT**2)
       IF(ANORML.LT.0.00001)ANORML=0.00001
       GO TO 2
     1 IF(NORML.EQ.0)ANORML=RT
C
     2 CONTINUE
C
C   START THE MAIN CALCULATIONS.  THE AA LOOP RUNS THROUGH THE
C   PITCH ANGLES; THE BB LOOP THROUGH THE HORIZ. ANGLES.  DB VALUES
C   LOWER THAN -50 ARE SET TO -50.
C
       DO 50 AA=LA1,LA2,INCA
       A(AA)=ASTART+(AA-1)*ARESOL
       PHY=(A(AA) + AOFSET)*DTR
       CA=COS(PHY)
       SA=SIN(PHY)
       DO 60 BB=LB1,LB2,INCB
       B(BB)=BSTART+(BB-1)*BRESOL
       TSI=(B(BB) + BOFSET)*DTR
       SB=SIN(TSI)
```

```
      CB=COS(TSI)
C  MODULE EFFICIENCY
C  CHECK FOR ROLL ANGLE DATA
      IF(FROLL.EQ.0)GO TO 10
      PHY=ASIN(SIN(ROLL*DTR) * SIN(B(BB)*DTR))
      TSI=ATAN(TAN(B(BB)*DTR) * COS(ROLL*DTR))
      IF(B(BB).LE.-90.OR.B(BB).GE.90)TSI=TSI+180*DTR
      IF(ROLL.EQ.90.OR.ROLL.EQ.-90)TSI=0
      PHY=PHY + AOFSET*DTR
      TSI=TSI + BOFSET*DTR
      SB=SIN(TSI)
      CB=COS(TSI)
      SA=SIN(PHY)
      CA=COS(PHY)
   10 CONTINUE
      E=1
      H=((.6+CA*CB)**2)/2.56
      IF(HFLAG.EQ.1)H=1
      IF(H.LT.0.)H=-H
      RRT=0
      AIIT=0
C  ADJUST FOR FREQUENCY ANGLE DEPENDENCE IF REQUIRED
      IF(FREQFL.NE.1)GO TO 76
      VWTEMP=VWEAP*CA*CB
      W=(2*PI*F*(C+VWTEMP)*1000)/(C*12*(C-VWTEMP))
C  CALCULATE AND SUM THE CONTRIBUTIONS OF THE INDIVIDUAL ELEMENTS.
C  THIS SECTION USES EULER"S THEOREM TO ADD IN THE PHASE SHADING.
   76 DO 61 I=1,NY
      DO 62 J=1,NX
      DD=(W*(X(I,J)*SB*CA+Y(I,J)*SA)+T(I,J)*DTR)
      RR=R(I,J)*COS(DD)
      AII=R(I,J)*SIN(DD)
      RRT=RRT+RR
      AIIT=AIIT+AII
  62  CONTINUE
  61  CONTINUE
C  TAKE THE MODULUS OF THE COMPLEX VALUE (COS(X) + ISIN(X))
      AMOD=H*SQRT(RRT*RRT + AIIT*AIIT)
      IF(AMOD.LT.0.00001)AMOD=0.00001
      VV=20*ALOG10(AMOD/ANORML)
      IF(VV.LT.-50)VV=-50
      IF(AIIT.EQ.0)GO TO 761
      ROVERI=ABS(RRT/AIIT)
      GO TO 762
  761 ROVERI=100.
C  DETERMINE THE SIGN
  762 S=1
      IF(ROVERI.GT.0.1.AND.ROVERI.LT.10)S=2
      IF(ROVERI.LE.0.1)S=3
      IF(RRT.LT.0)S=-S
      IF(VV.LE.-50)S=0
      PHANG=ATAN2(AIIT,RRT)/DTR
C  THIS GIVES THE INTENSITY RELATIVE TO THE NORMALIZATION FACTOR
```

```
      AINTEN=(AMOD/ANORML)**2
      DIINT=DIINT+CA*AINTEN
      SUMIN1=SUMIN1+CA*AINTEN**2
      IF((PHY/DTR).EQ.PCHEBP)SUMIN2=SUMIN2+AINTEN**2
C  WRITE DBS AND SIGNS TO A STORAGE FILE FOR USE IN PRINTING
C  AND PLOTTING THE DATA AT A LATER TIME IN THE PROGRAM.
  600 WRITE(13,*) VV,S,PHANG
  60  CONTINUE
  50  CONTINUE
      SUMIN1=SUMIN1*ARESOL*BRESOL*DTR*DTR
      SUMIN2=SUMIN2*BRESOL*DTR
      DIINT=DIINT*ARESOL*BRESOL*DTR*DTR
      IF(SUMIN2.LT..00001)SUMIN2=.00001
      IF(SUMIN1.LT..00001)SUMIN1=.00001
      IF(DIINT.LT..00001)DIINT=.00001
      DI=10.9921 - 10*ALOG10(DIINT)
      SUMIN1=10*ALOG10(SUMIN1)
      SUMIN2=10*ALOG10(SUMIN2)
   25 REWIND 13
      K1=LB1
      K2=LB2
      Q=LA2
      P=LA1
      IF(PHASEPLOT.NE.3)GO TO 40
C  READ DATA FROM TAPE13 AND WRITE IT OUT TO TAPE2.  THIS TAPE2
C  WILL CONTAIN THE DATA IN AN EASY-TO-READ FORM.
      WRITE(2,110)
  163 IV=(LB2-LB1)/INCB
      IF (IV.LT.0.) GO TO 170
      IF (IV.LE.45.) GO TO 125
      LB2=LB1+45*INCB
  125 L=((LA2-LA1)/INCA)
      IL=0
      IF (L.LT.0.) GO TO 160
      IF (L.LE.4.) GO TO 140
      IL=1
      LA2=LA1+4*INCA
  140 WRITE(2,93)(A(AA),AA=LA1,LA2,INCA)
      WRITE(2,97)
      WRITE(2,97)
      MINC=(LA2-LA1)/INCA+1
      DO 145 M=1,MINC
      TB(M)=8HDB    +/-
  145 CONTINUE
      WRITE(2,109)(TB(M),M=1,MINC)
      WRITE(2,97)
      READ(13,*,END=17) (V1(BB),SS1(BB),XXX,BB=K1,K2,INCB)
      READ(13,*,END=512) (V2(BB),SS2(BB),XXX,BB=K1,K2,INCB)
      GO TO 513
  512 DO 21 BB=K1,K2,INCB
      WRITE(2,95) B(BB),V1(BB),SS1(BB)
   21 CONTINUE
      GO TO 17
```

```
513 READ(13,*,END=514) (V3(BB),SS3(BB),XXX,BB=K1,K2,INCB)
    GO TO 515
514 DO 22 BB=K1,K2,INCB
    WRITE(2,95) B(BB),V1(BB),SS1(BB),V2(BB),SS2(BB)
 22 CONTINUE
    GO TO 17
515 READ(13,*,END=516) (V4(BB),SS4(BB),XXX,BB=K1,K2,INCB)
    GO TO 517
516 DO 23 BB=K1,K2,INCB
    WRITE(2,95) B(BB),V1(BB),SS1(BB),V2(BB),SS2(BB),V3(BB),SS3(BB)
 23 CONTINUE
    GO TO 17
517 READ(13,*,END=518) (V5(BB),SS5(BB),XXX,BB=K1,K2,INCB)
    GO TO 519
518 DO 24 BB=K1,K2,INCB
    WRITE(2,95) B(BB),V1(BB),SS1(BB),V2(BB),SS2(BB),V3(BB),SS3(BB),
   *V4(BB),SS4(BB)
 24 CONTINUE
    GO TO 17
519 DO 16 BB=K1,K2,INCB
    WRITE(2,95) B(BB),V1(BB),SS1(BB),V2(BB),SS2(BB),V3(BB),SS3(BB),
   *V4(BB),SS4(BB),V5(BB),SS5(BB)
16  CONTINUE
 17 CONTINUE
    LA1=LA2+INCA
    LA2=Q
    IF(LA1.GT.LA2)GO TO 170
    IF (IL.EQ.1.) WRITE(2,110)
    GO TO 125
160 LA1=P
165 WRITE(2,110)
    LB1=LB2+INCB
    LB2=K2
    GO TO 163
 26 REWIND 13
170 LB1=K1
    LB2=K2
    LA1=P
    LA2=Q
 40 CONTINUE
C
C  CHANGE VWEAP BACK TO KNOTS
    VWEAP=VWEAP/1.689
C
C  WRITE INPUT DATA TO TAPE3
C
    ANORML=20*ALOG10(ANORML)
    WRITE(3,110)
    WRITE(3,98)(LA1,LA2,INCA,ARESOL,ASTART)
    WRITE(3,99)(K1,K2,INCB,BRESOL,BSTART)
    WRITE(3,91)FROLL,ROLL
    WRITE(3,114)(F,C,NX,NY)
    WRITE(3,104)AMAINR,BMAINR,VWEAP
```

```
      WRITE(3,123)PHASEPLOT,FREQFL
      WRITE(3,106)NORML,ANORML
  106 FORMAT(1H0,'NORML=  ',I1,5X,'NORMALIZATION FACTOR (DB)=',F10.4)
      WRITE(3,107)DI
  107 FORMAT(1H0,'DIRECTIVITY INDEX=',F10.4)
      WRITE(3,108)AOFSET,BOFSET,HFLAG,TSCALC
  108 FORMAT(1H0,'A OFFSET=',F8.2,5X,'B OFFSET=',F8.2,5X,'HFLAG=',
     *F5.0,5X,'TSCALC=',F5.0)
      WRITE(3,105)SUMIN1,SUMIN2
  104 FORMAT(1H0,'AMAINR=  ',F7.2,3X,'BMAINR=  ',F7.2,3X,
     *'VWEAP (KNOTS)=  ',F7.2)
  105 FORMAT(1H0,'EQ BEAM PATTERN-VOL=',F10.4,5X,
     *'EQ BEAM PATTERN-S,B=',F10.4)
  622 FORMAT(1H )
  623 FORMAT(1H ,9(F10.3,3X))
  45  FORMAT(1X,6I6,4(2X,F7.2))
  91  FORMAT(1H0,'ROLL FLAG=  ',F3.0,5X,'ROLL ANGLE=',F8.2,
     *2X,'DEGREES')
  93  FORMAT(1X,'     PITCH ',4X,8(F6.2,9X))
  95  FORMAT(1H ,5X,F6.2,3X,8(F5.1,3X,F3.0,4X))
  97  FORMAT(1H )
  123 FORMAT(1H0,'PLOTTING FLAG=  ',F3.0,5X,'FREQFL=  ',F3.0)
  98  FORMAT(1X,'LA1=',I4,4X,'LA2=',I4,4X,'INCA=',I4,4X,'ARESOL=',
     *F5.2,3X,'ASTART=',F7.2)
  99  FORMAT(1X,'LB1=',I4,4X,'LB2=',I4,4X,'INCB=',I4,4X,'BRESOL=',
     *F5.2,3X,'BSTART=',F7.2)
  109 FORMAT(1X,2X,'     AZ ',4X,8(2X,A8,5X))
  110 FORMAT(1H1)
  114 FORMAT(1H0,'FREQ.(KHZ)=',F8.3,5X,'SND. SPD.(F/S)=',F5.0,5X,
     1'NX=',I4,5X,'NY=',I4,5X)
      IF(PHASEPLOT.EQ.0.OR.PHASEPLOT.EQ.1)CALL PLOTDB
      IF(PHASEPLOT.EQ.1.OR.PHASEPLOT.EQ.2)CALL PLOTPHANG
      CLOSE(UNIT=9,DISPOSE='SAVE')
      CLOSE(UNIT=10,DISPOSE='SAVE')
      CLOSE(UNIT=11,DISPOSE='SAVE')
      CLOSE(UNIT=12,DISPOSE='SAVE')
      CLOSE(UNIT=25,DISPOSE='SAVE')
      STOP
      END
C
C
      SUBROUTINE PHASTR(X,Y,R,T,NX,NY,AMAINR,BMAINR,PI,DTR)
      DIMENSION X(8,8),Y(8,8),R(8,8),T(8,8)
      READ(45,*)FD,CD
      SA=SIN(AMAINR*DTR)
      SB=SIN(BMAINR*DTR)
      CA=COS(AMAINR*DTR)
      CB=COS(BMAINR*DTR)
      W=(2*PI*FD*1000)/(CD*12)
      DO 10 I=1,NY
      DO 20 J=1,NX
      T(I,J)=-(W*(X(I,J)*CA*SB + Y(I,J)*SA))/DTR
      IF(R(I,J).EQ.0)T(I,J)=0
```

```
   20 CONTINUE
   10 CONTINUE
      DO 30 I=1,NX
      WRITE(20,50)(T(I,J),J=1,NY)
   50 FORMAT(1X,9(F8.3,1X))
   30 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE PLOTS(V1,SS1)
      DIMENSION V1(365),SS1(365)
      COMMON/DBSIGN/DBDAT(51,181),SDAT(3,181)
      DO 10 N=1,181
      I=IABS(INT(V1(N)-.5)) + 1
      S=0
      IF(SS1(N).GT.0)S=1
      IF(SS1(N).LT.0)S=-1
      K=S+2
      DBDAT(I,N)=1H*
      SDAT(K,N)=1H*
   10 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE PLOTDB
      COMMON/DBSIGN/DBDAT(51,181),SDAT(3,181),V1(365),SS1(365),B(365)
      DO 680 J=1,181
      DO 681 I=1,51
      DBDAT(I,J)=1H
  681 CONTINUE
      DO 682 K=1,3
      SDAT(K,J)=1H
  682 CONTINUE
  680 CONTINUE
      REWIND 13
      DO 1 I=1,181
      B(I)=I-91
    1 CONTINUE
      WRITE(2,377)
      WRITE(2,622)
  377 FORMAT(1H1,8X,5(' ANGLE     DB  SIGN',5X))
  622 FORMAT(1H )
      READ(13,*,END=515)(V1(BB),SS1(BB),XX,BB=1,181)
  515 CONTINUE
      CALL PLOTS(V1,SS1)
      IMM=181/5
      MM=IMM+1
      DO 517 I=1,MM
      WRITE(2,516)(B(5*(I-1)+J),V1(5*(I-1)+J),SS1(5*(I-1)+J),J=1,5)
  517 CONTINUE
  516 FORMAT(1H ,8X,5(F6.1,3X,F5.1,2X,F3.0,5X))
```

```
 26 REWIND 13
    WRITE(25,650)
650 FORMAT(1H1,87X,'DECIBELS  VS  ANGLE')
    WRITE(25,622)
    WRITE(25,651)(DBDAT(1,J),J=1,181)
    DO 671 I=2,10
    WRITE(25,652)(DBDAT(I,J),J=1,181)
671 CONTINUE
651 FORMAT(1H ,2X,'  0',2X,'+',181(A1))
652 FORMAT(1H ,7X,'+',181(A1))
    WRITE(25,653)(DBDAT(11,J),J=1,181)
653 FORMAT(1H ,2X,'-10',2X,'+',181(A1))
    DO 672 I=12,20
    WRITE(25,652)(DBDAT(I,J),J=1,181)
672 CONTINUE
    WRITE(25,654)(DBDAT(21,J),J=1,181)
654 FORMAT(1H ,2X,'-20',2X,'+',181(A1))
    DO 673 I=22,30
    WRITE(25,652)(DBDAT(I,J),J=1,181)
673 CONTINUE
    WRITE(25,655)(DBDAT(31,J),J=1,181)
655 FORMAT(1H ,2X,'-30',2X,'+',181(A1))
    DO 674 I=32,40
    WRITE(25,652)(DBDAT(I,J),J=1,181)
674 CONTINUE
    WRITE(25,656)(DBDAT(41,J),J=1,181)
656 FORMAT(1H ,2X,'-40',2X,'+',181(A1))
    DO 675 I=42,50
    WRITE(25,652)(DBDAT(I,J),J=1,181)
675 CONTINUE
    WRITE(25,657)(DBDAT(51,J),J=1,181)
657 FORMAT(1H ,2X,'-50',2X,'+',181(A1))
    WRITE(25,658)
658 FORMAT(1H ,8X,18('+---------'),'+')
    WRITE(25,659)
659 FORMAT(1H ,6X,'-90',7X,'-80',7X,'-70',7X,'-60',7X,'-50',7X,
   *'-40',7X,'-30',7X,'-20',7X,'-10',9X,'0',8X,'10',8X,'20',
   *8X,'30',8X,'40',8X,'50',8X,'60',8X,'70',8X,'80',8X,'90')
    WRITE(25,679)
679 FORMAT(1H ,/////)
    WRITE(25,660)
660 FORMAT(1H ,89X,'SIGN  VS  ANGLE')
    WRITE(25,622)
    WRITE(25,661)(SDAT(3,J),J=1,181)
661 FORMAT(1H ,3X,' 1',2X,'+',181(A1))
    DO 676 I=1,7
    WRITE(25,662)
676 CONTINUE
662 FORMAT(1H ,7X,'+')
    WRITE(25,663)(SDAT(2,J),J=1,181)
    DO 677 I=1,7
    WRITE(25,662)
677 CONTINUE
```

```
  663 FORMAT(1H ,3X,' 0',2X,'+',181(A1))
      WRITE(25,664)(SDAT(1,J),J=1,181)
  664 FORMAT(1H ,3X,'-1',2X,'+',181(A1))
      WRITE(25,658)
      WRITE(25,659)
      END
C
      SUBROUTINE PLOTPHANG
      DIMENSION SS1(365),DBPHASE(73,181),B(365)
      REWIND 13
      READ(13,*,END=515)(X,Y,SS1(I),I=1,181)
 515     CONTINUE
      DO 1 I=1,181
      B(I)=I-91
 1       CONTINUE
      DO 2 J=1,181
      DO 2 I=1,73
      DBPHASE(I,J)=1H
  2      CONTINUE
 781     DO 10 N=1,181
      I=INT((-SS1(N)/5.)+37.5)
      IF(I.GT.73)I=73
      IF(I.LT.1)I=1
      DBPHASE(I,N)=1H*
 10      CONTINUE
C   WRITE OUT NICE EASILY READ DATA SET
      WRITE(2,377)
 377     FORMAT(1H1,8X,5(' ANGLE    PHASE',9X))
      IMM=181/5
      MM=IMM+1
         DO 517 I=1,MM
      WRITE(2,516)(B(5*(I-1)+J),SS1(5*(I-1)+J),J=1,5)
 516     FORMAT(1H ,8X,5(F6.1,3X,F6.1,9X))
 517 CONTINUE
      WRITE(25,650)
 650 FORMAT(1H1,87X,'PHASE ANGLE VS THETA')
      WRITE(25,622)
 622 FORMAT(1H )
      WRITE(25,651)(DBPHASE(1,J),J=1,181)
      DO 671 I=2,9
      WRITE(25,652)(DBPHASE(I,J),J=1,181)
  671 CONTINUE
  651 FORMAT(1H ,2X,'180',2X,'+',181(A1))
  652 FORMAT(1H ,7X,'+',181(A1))
      WRITE(25,653)(DBPHASE(10,J),J=1,181)
  653 FORMAT(1H ,2X,'135',2X,'+',181(A1))
      DO 672 I=11,18
      WRITE(25,652)(DBPHASE(I,J),J=1,181)
  672 CONTINUE
      WRITE(25,654)(DBPHASE(19,J),J=1,181)
  654 FORMAT(1H ,2X,' 90',2X,'+',181(A1))
      DO 673 I=20,27
      WRITE(25,652)(DBPHASE(I,J),J=1,181)
```

```
 673 CONTINUE
     WRITE(25,655)(DBPHASE(28,J),J=1,181)
 655 FORMAT(1H ,2X,' 45',2X,'+',181(A1))
     DO 674 I=29,36
     WRITE(25,652)(DBPHASE(I,J),J=1,181)
 674 CONTINUE
     WRITE(25,656)(DBPHASE(37,J),J=1,181)
 656 FORMAT(1H ,2X,'  0',2X,'+',181(A1))
     DO 675 I=38,45
     WRITE(25,652)(DBPHASE(I,J),J=1,181)
 675 CONTINUE
     WRITE(25,657)(DBPHASE(46,J),J=1,181)
 657 FORMAT(1H ,2X,'-45',2X,'+',181(A1))
    DO 845 I=47,54
    WRITE(25,652)(DBPHASE(I,J),J=1,181)
845 CONTINUE
    WRITE(25,847)(DBPHASE(55,J),J=1,181)
847    FORMAT(1H ,2X,'-90',2X,'+',181(A1))
    DO 848 I=56,63
    WRITE(25,652)(DBPHASE(I,J),J=1,181)
848 CONTINUE
       WRITE(25,849)(DBPHASE(64,J),J=1,181)
849 FORMAT(1H ,1X,'-135',2X,'+',181(A1))
       DO 850 I=65,72
    WRITE(25,652)(DBPHASE(I,J),J=1,181)
850    CONTINUE
    WRITE(25,851)(DBPHASE(73,J),J=1,181)
851 FORMAT(1H ,1X,'-180',2X,'+',181(A1))
     WRITE(25,658)
 658 FORMAT(1H ,8X,18('+---------'),'+')
     WRITE(25,659)
 659 FORMAT(1H ,6X,'-90',7X,'-80',7X,'-70',7X,'-60',7X,'-50',7X,
    *'-40',7X,'-30',7X,'-20',7X,'-10',9X,'0',8X,'10',8X,'20',
    *8X,'30',8X,'40',8X,'50',8X,'60',8X,'70',8X,'80',8X,'90')
1000   FORMAT(1H ,I3)
    RETURN
    END
```

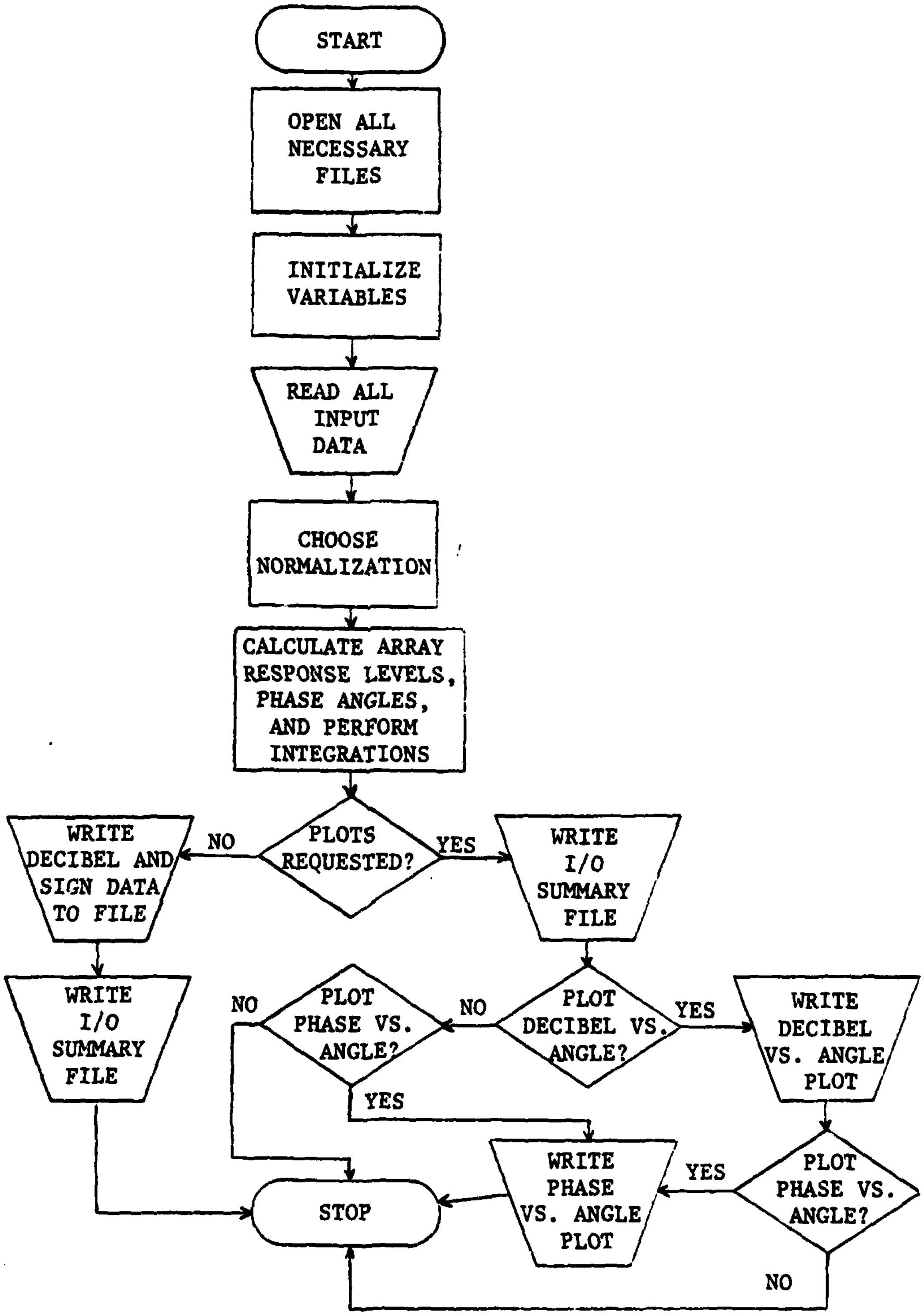

FIGURE E-1. PROGRAM FLOW CHART

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END